1.1 General

The term 'mooring' refers to the system for securing a ship to a terminal. The most common terminals for tankers are piers and sea islands. However, other shipboard operations such as mooring at Single Point Moorings (SPMs), Multi-Buoy Moorings (MBMs), Floating Production, Storage and Offloading vessels (FPSOs) and offshore loading facilities, emergency towing, tug handling, barge mooring, canal transit, ship-to-ship transfer and anchoring may fall into the broad category of mooring and so require specialised fittings or equipment. Anchoring equipment is covered by Classification Society rules and is therefore not included in these guidelines.

Figure 1.1 shows a typical mooring pattern at a tanker terminal.

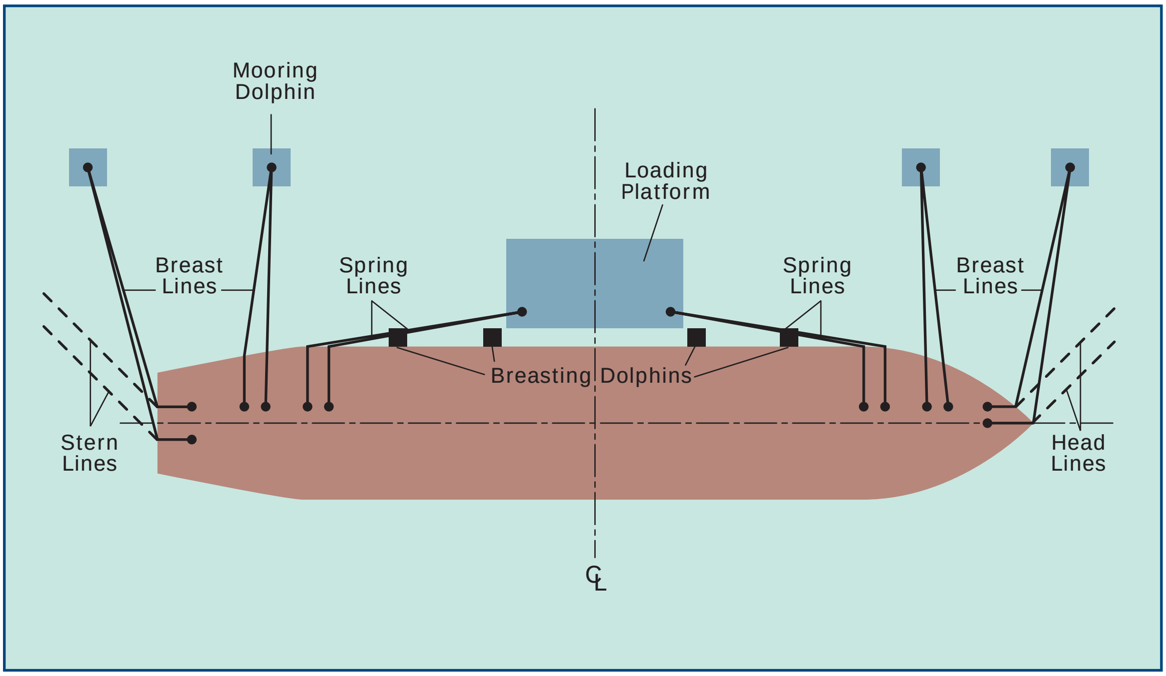


Figure 1.1: Typical Mooring Pattern

The use of an efficient mooring system is essential for the safety of the ship, her crew, the terminal and the environment. The problem of how to optimise the moorings to resist the various forces will be dealt with by answering the following questions:

- What are the forces applied on the ship?
- What general principles determine how the applied forces are distributed to the mooring lines?
- How can the above principles be applied in establishing a good mooring arrangement?

Since no mooring arrangement has unlimited capability, to address these questions it will be necessary to understand precisely what the moorings of a ship are expected to achieve.

1.2 Forces Acting on the Ship

The moorings of a ship must resist the forces due to some, or possibly all, of the following factors:

- Wind
- current
- tides
- surges from passing ships
- waves/swell/seiche
- ice
- changes in draft, trim or list.

This Section deals mainly with the development of a mooring system to resist wind, current and tidal forces on a ship at a conventional berth. Normally, if the mooring arrangement is designed to accommodate maximum wind and current forces, reserve strength will be sufficient to resist other moderate forces that may arise. However, if appreciable surge, waves or ice conditions exist at a terminal, considerable loads can be developed in the ship's moorings. These forces are difficult to analyse except through model testing, field measurements or dynamic computer programs. Ships calling at such terminals should be made aware that the standard environmental condition may be exceeded and appropriate measures will need to be implemented in advance.

Forces in the moorings due to changes in ship elevation from either tidal fluctuations or loading or discharging operations must be compensated by proper line tending.

1.2.1 Wind and Current Drag Forces

The procedures for calculating these forces are covered in Section 2 and Appendix A. Although the initial calculations were based on large ships, additional testing conducted for smaller ships has shown that the wind and current drag coefficients are not significantly different for most cases. Consequently, the large ship drag coefficients in Appendix A may be used for bridge-aft ships with similar geometry, down to 16,000 DWT in size.

Figure 1.2 demonstrates how the resultant wind force on a ship varies with wind velocity and direction. For simplicity, wind forces on a ship can be broken down into two components: a longitudinal force acting parallel to the longitudinal axis of the ship and a transverse force acting perpendicular to the longitudinal axis. The resultant force initiates a yawing moment.

Wind force on the ship also varies with the exposed area of the ship. Since a head wind only strikes a small portion of the total exposed area of the ship, the longitudinal force is relatively small. A beam wind, on the other hand, exerts a very large transverse force on the exposed side area of the ship. For a given wind velocity the maximum transverse wind force on a VLCC is about five times as great as the maximum longitudinal wind force. For a 50 knot wind on a light 250,000 DWT tanker, the maximum transverse forces are about 300 tonnes (2,943 kN), whereas the ahead longitudinal forces are about 60 tonnes (589 kN).

Mean Draft metres	Astern tonnes	Ahead tonnes	Transverse tonnes
6	47.8	68	303
7	47.2	66.7	283
8	46.7	65.3	263
9	46.1	63.9	244

Table 1.1: Maximum Longitudinal and Transverse Wind Forces on a 250,000 DWT Tanker, 5 m Trim, 50 Knot Wind

If the wind hits the ship from any quartering direction between the beam and ahead (or astern), it will exert both a transverse and longitudinal force, since it is striking both the bow (or stern) and the side of the ship. For any given wind velocity, both the transverse and longitudinal force components of a quartering wind will be smaller than the corresponding forces caused by the same wind blowing abeam or head on.

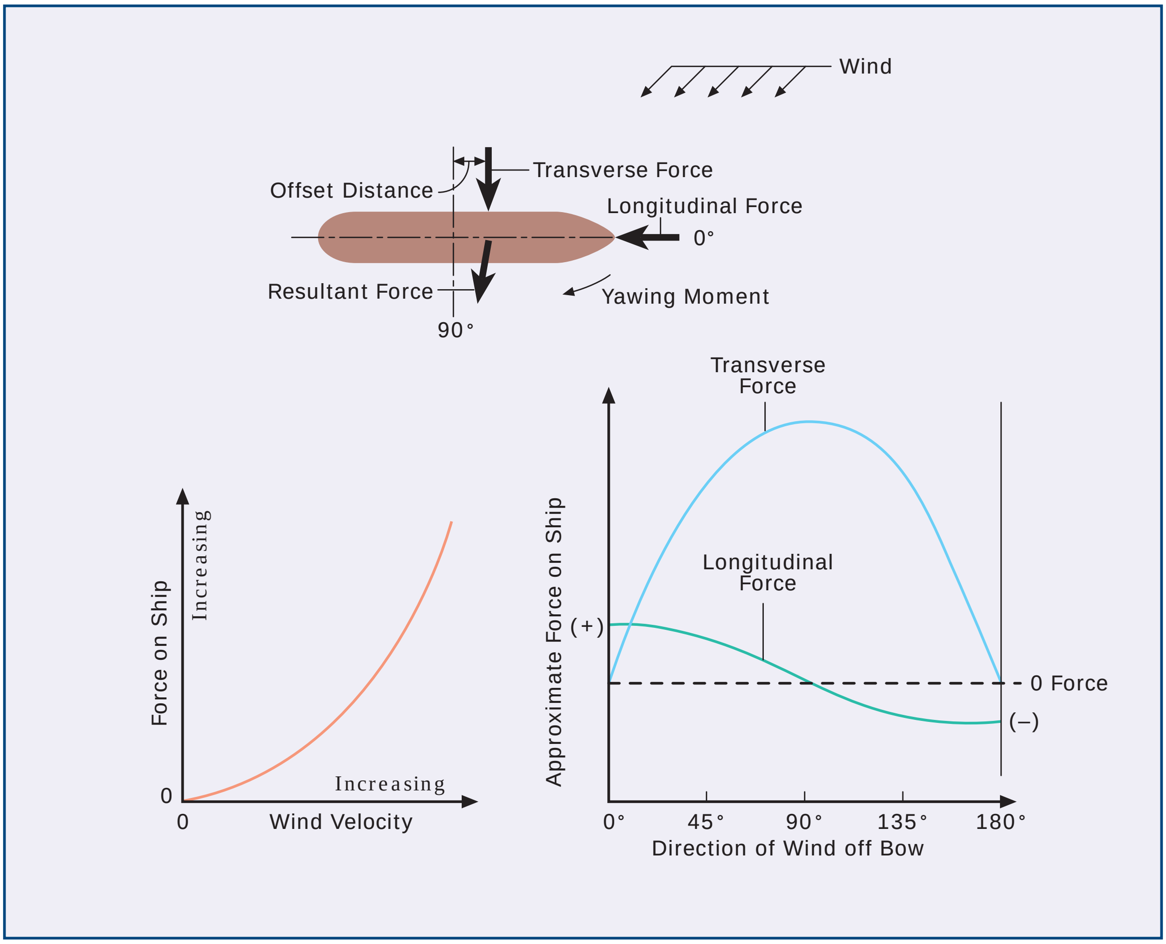


Figure 1.2: Wind Forces on a Ship

With the exception of wind that is dead ahead or astern or dead abeam, the resultant wind force does not have the same angular direction as the wind. For example, for a 250,000 DWT tanker, a wind 45° off the bow leads to a resultant wind force of about 80° off the bow. In this case, the point of application of the force is forward of the transverse centre line producing a yawing moment on the ship.

It should be noted that the sign conventions used in this Section relate to the normal interpretation used by mariners, whereby a force from right ahead is considered to be from 0° and the compass angles proceed in a clockwise direction. This is different to the sign convention used by the scientific community, such as research establishments and designers, where a force from right astern is considered to be from 0° and the compass angles proceed in an anti-clockwise direction. This latter convention is adopted in Section 2 and Appendix A when discussing wind and current forces.

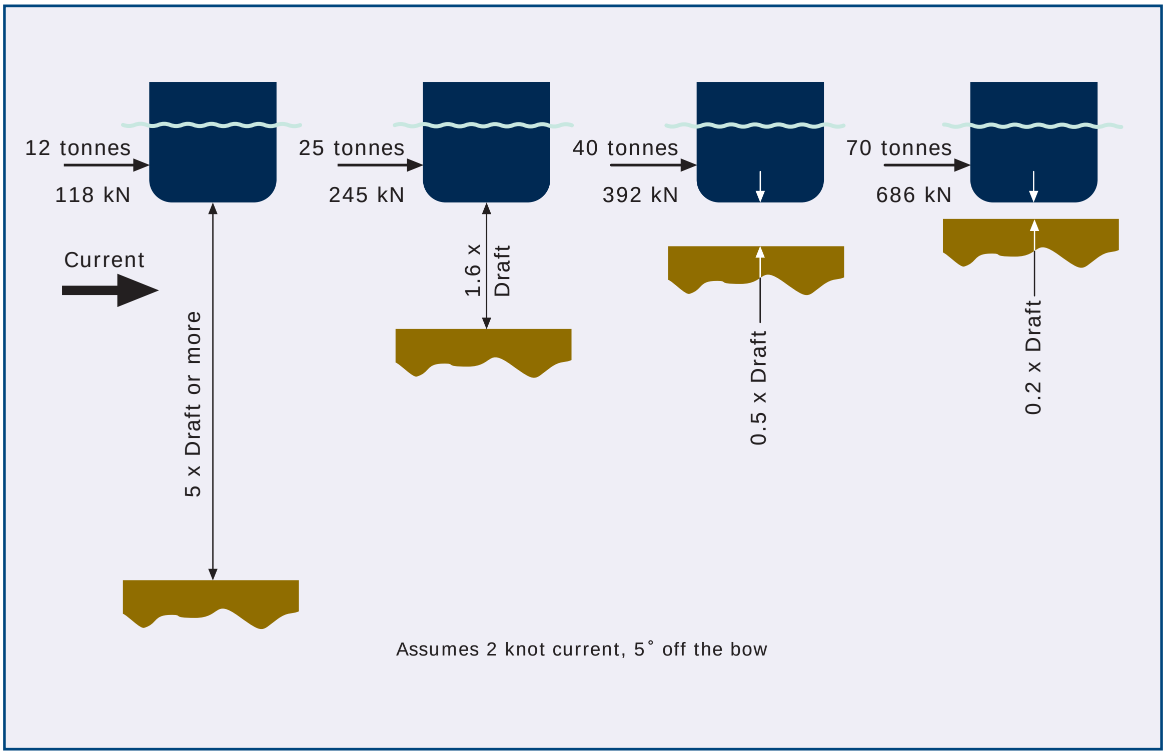


Figure 1.3: Effect of Underkeel Clearance on Current Force

Current forces on the ship must be added to the wind forces when evaluating a mooring arrangement. In general, the variability of current forces on a ship due to current velocity and direction follows a pattern similar to that for wind forces. Current forces are further complicated by the significant effect of clearance beneath the keel. Figure 1.3 shows the increase in force due to reduced underkeel clearance. The majority of terminals are oriented more or less parallel to the current thereby minimising current forces. Nevertheless, even a current with a small angle (such as 5°) off the ship's longitudinal axis can create a large transverse force and must be taken into consideration.

Model tests indicate that the current force created by a 1 knot head current on a loaded 250,000 DWT tanker with a 2 m underkeel clearance is about 5 tonnes (49 kN), whereas the load developed by a 1 knot beam current for the same underkeel clearance is about 230 tonnes (2,256 kN). For a 2 knot current, the force created would be about 14 tonnes (137 kN) when from ahead and 990 tonnes (9,712 kN) when on the beam.

1.3 Mooring Pattern

The term 'mooring pattern' refers to the geometric arrangement of mooring lines between the ship and the berth. It should be noted that the industry has previously standardised on the concept of a generic mooring layout (see Figure 2.1), taking into account standard environmental criteria. The generic mooring layout is mainly applicable to a 'multi-directional' environment and to the design of ship's mooring equipment. 'Multi-directional' is where no single direction dominates or where any of the environmental forces become a dominant factor.

For terminals with a 'directional environment', i.e. one with a high current, wind or swell waves, a site-specific layout such as one including head and stern lines and/or extra breast and spring lines may be more efficient. For ships regularly trading to these terminals, consideration may be given to the provision of additional or higher capacity mooring equipment.

The most efficient line 'lead' for resisting any given environmental load is a line orientated in the same direction as the load. This would imply that, theoretically, mooring lines should all be oriented in the direction of the environmental forces and be attached at such a longitudinal location on the ship that the resultant load and restraint act through one and the same location. Such a system would be impractical since it has no flexibility to accommodate the different environmental load directions and mooring point locations encountered at various terminals. For general applications, the mooring pattern must be able to cope with environmental forces from any direction. This can best be approached by splitting these forces into a longitudinal and a transverse component and then calculating how to most effectively resist them. It follows that some lines should be in a longitudinal direction (spring lines) and some lines in a transverse direction (breast lines). This is the guiding principle for an effective mooring pattern for general application, although locations of the actual fittings at the terminal will not always allow it to be put into practice. The decrease in efficiency caused by deviating from the optimum line lead is shown in Figures 1.4. and 1.5 (compare Cases 1 and 3 in Figures 1.4, where the maximum line load increases from 57 (559 kN) to 88 tonnes (863 kN)).

However, it should be noted that for a 60 knot head wind the highest loaded line for the generic layout is 39.5 tonnes, whereas it is 28.6 tonnes for the specific layout. Therefore, for terminals located where the environment is directional, the specific layout is actually more efficient. Refer to Sections 1.5, 1.6, 1.7, 2.4 and 2.5 for further details.

There is a basic difference in the function of spring and breast lines, which must be understood by designers and operators alike. Spring lines restrain the ship in two directions (forward and aft); breast lines essentially deployed perpendicular to the ship restrain in only one direction (off the berth), restraint in the on-berth direction being provided by the fenders and breasting dolphins. Whereas all breast lines will be stressed under an off-berth environmental force, only the aft or the forward spring lines will generally be stressed. For this reason the method of line-tending differs between spring and breast lines (as explained in Section 1.8.1). It is important to recognise that, if spring lines are pre-tensioned, the effective longitudinal restraint is provided by only the difference between the tension in the opposing spring lines. Therefore, too high a pre-tension can significantly reduce the efficiency of the mooring system. Likewise, differences in vertical angles between forward and aft springs can lead to ship surge along the jetty.

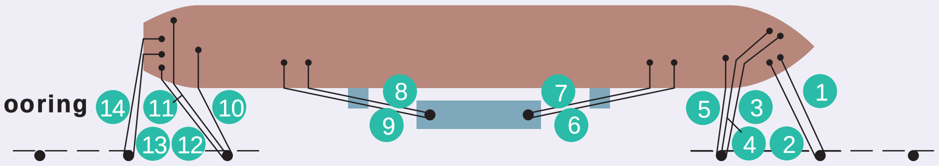
Mooring patterns for a directional environment may incorporate head and stern lines that are orientated between a longitudinal and transverse direction. This optimises restraint for the longitudinal direction where the dominant environmental force acts, while maintaining some lateral restraint for the less dominant lateral environmental directions.

Another option for mooring layouts with dominant longitudinal forces is to add more spring lines.

Furthermore, the effectiveness of a mooring line is influenced by two angles, the vertical angle the line forms with the pier deck and the horizontal angle the line forms with the parallel side of the ship. The steeper the orientation of a line, the less effective it is in resisting horizontal loads. As an example, a line orientated at a vertical angle of 45° is only 75% as effective in restraining the ship as a line orientated at a 20° vertical angle. Similarly, the larger the horizontal angle between the parallel side of the ship and the line, the less effective the line is in resisting a longitudinal force.

All loads are in tonnes

CASE 1 Generic All Wire Mooring



All lines 42 mm
MBL 115 tonnes

Line number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
60 knot head wind	8.6	11.3	0	0	0	0	0	39.0	39.5	0	0	0	0	0
60 knot wind 45° off bow	56.7	57.1	34.5	34.9	39.0	5.9	5.9	10.9	11.3	25.9	25.4	34.0	24.9	23.6
60 knot beam wind	56.7	56.7	39.5	39.9	44.9	13.2	13.2	6.3	6.3	43.5	42.6	57.1	51.2	47.6

CASE 2 Generic Mixed Moorings
Not Recommended

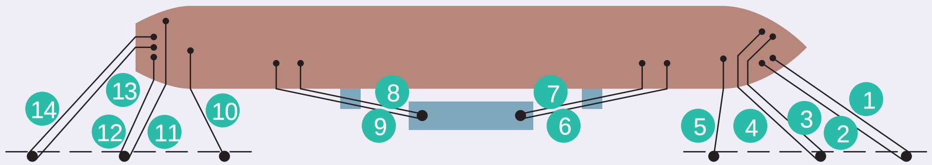
Illustrates lack of contribution of fibre lines to overall mooring strength

Mooring arrangements as above except that lines 2, 4, 11 and 13 are polypropylene

Line number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
60 knot head wind	15.9	5.0	0	4.1	0	0	0	39.4	39.4	0	3.6	0	2.7	0
60 knot wind 45° off bow	91.6	6.8	54.4	5.9	62.6	7.7	7.3	14.5	15.0	37.6	5.4	50.3	5.4	33.6
60 knot beam wind	91.2	6.8	61.2	5.9	69.8	17.2	16.8	9.5	9.5	67.1	5.9	88.0	6.3	73.0

CASE 3 Site-specific
All Wire Mooring

Showing effect on line tensions as consequence of non-ideal leads



Line number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
60 knot head wind	10.4	11.8	5.4	8.2	0	0	0	28.6	28.6	0.9	0	0	0	0
60 knot wind 45° off bow	52.6	49.9	48.5	43.5	83.9	19.5	19.0	5.0	5.0	36.7	30.4	40.8	24.9	24.0
60 knot beam wind	56.2	54.0	53.1	48.1	88.4	17.7	17.2	11.8	12.2	70.3	49.9	70.3	46.3	45.8

Note: Computer Program assumes line does not yield or break. Examples are based on ballasted 250,000 dwt ship. Loads are for conditions shown. Should the wind shift, lines without loads, as shown above, would assume some loadings, so all lines should be tended at all times

Figure 1.4: Mooring Pattern Analysis

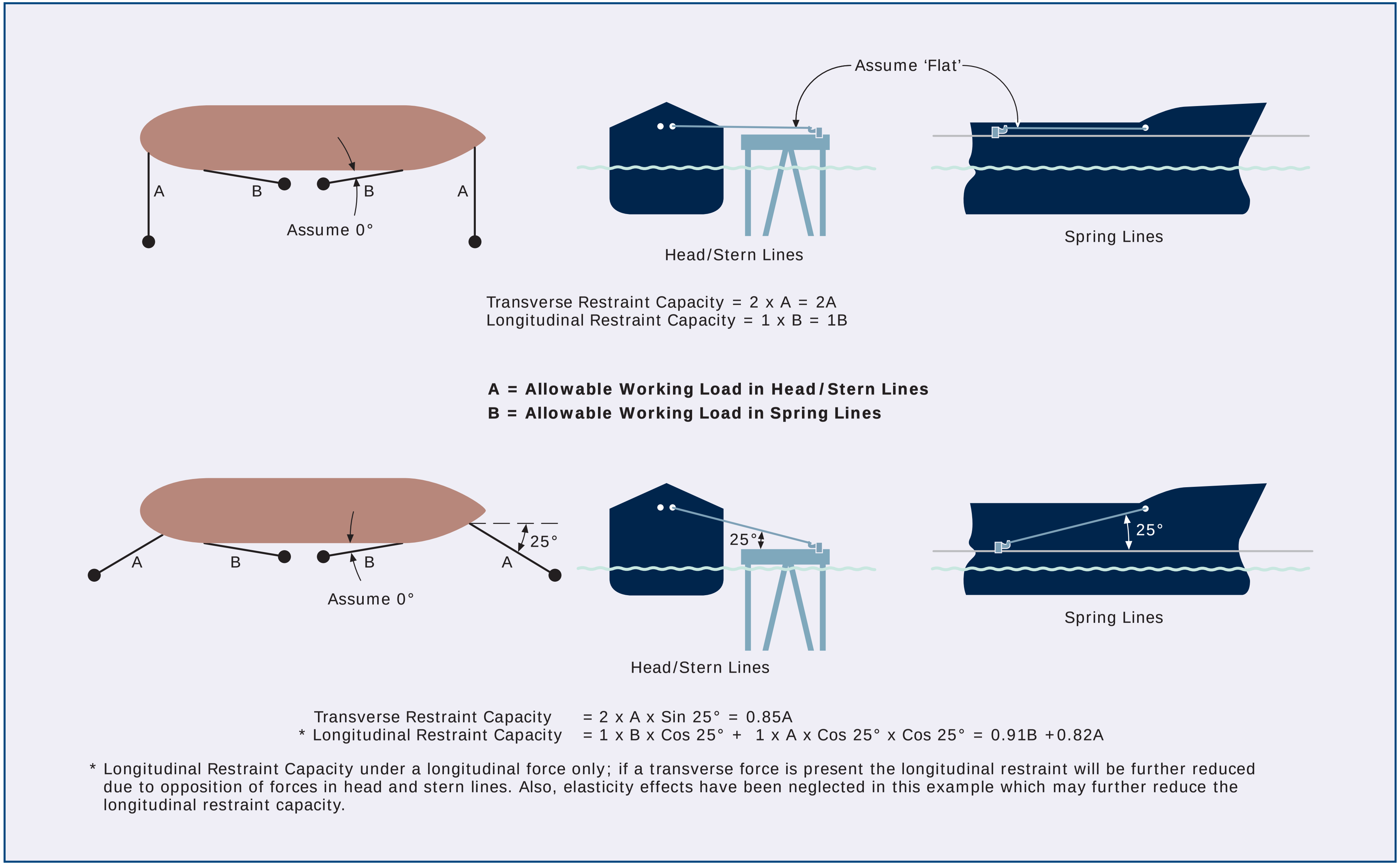


Figure 1.5: Effect of Hawser Orientation on Restraint Capacity

1.4 Elasticity of Lines

The elasticity of a mooring line is a measure of its ability to stretch under load. Under a given load, an elastic line will stretch more than a stiff line. Elasticity plays an important role in the mooring system for several reasons:

- High elasticity can absorb higher dynamic loads. For this reason, high elasticity is desirable for ship-to-ship transfer operations, or at terminals subject to waves or swell
- high elasticity also means that the ship will move further in her berth and this could cause problems with loading arms or hoses. Such movement also creates additional kinetic energy in the mooring system
- a third and most important aspect is the effect of elasticity on the distribution of forces among several mooring lines. The simple four-line mooring pattern shown in the upper portion of Figure 1.5 is insensitive to the elasticity of the lines but is suitable only for tugs, small barges and very small ships such as coasters. Larger ships require more lines resulting in load sharing and interaction between lines. This becomes more complicated as the number of mooring lines increases. Optimum restraint is generally accomplished if all lines, except spring lines, are stressed to the same percentage of their breaking strength. Good load-sharing can be accomplished if the following principles are understood.

The general principle is that if two lines of different elasticity are connected to a ship at the same point, the stiffer one will always assume a greater portion of the load (assuming the winch brake is set) even if the orientation is the same. The reason for this is that both lines must stretch an equal amount and, in doing so, the stiffer line assumes a greater portion of the load. The relative difference between the loads will depend upon the difference between the elasticities, and can be very large.

The elasticity of a mooring line primarily depends upon the following factors:

- Material and construction
- length
- diameter.

Figure 1.6 demonstrates the significance of each of the above factors on load distribution. The most important points to note are the appreciable difference in elasticity between wire lines and fibre ropes and the effect of line length on elasticity. Case A shows an acceptable mooring where lines of the same size and material are used. Case B indicates the sharing of loads between lines of the same material but of different size and each line is stressed to approximately the same percentage of its breaking strength. However, Cases C and D are examples of mooring arrangements that should be avoided.

Wire mooring lines are very stiff. The elongation for a 6 x 37 construction wire line at a load where the material begins to be permanently deformed is about 1% of wire length. Under an equivalent load a polypropylene rope may stretch 10 times as much as a wire. Therefore, if a wire is run out parallel to a conventional fibre line, the wire will carry almost the entire load while the fibre line carries practically none. Elasticity also varies between different types of fibre lines and, although the difference is generally not as significant as that between fibre line and wire, the difference will affect load distribution. High modulus polyethylene or aramid fibre lines, for example, have much less elasticity than other synthetic fibre lines and would carry the majority of the load if run out parallel to conventional synthetic lines.

The effect of material on load distribution is critical and the use of mixed moorings for similar service, e.g. forward springs, is to be avoided. In some cases the fibre lines may carry almost no load, while at the same time some of the wires are heavily loaded, possibly beyond their breaking strength. The same could be true of mixed fibre lines of varying elasticity although the differences would generally not be as great unless the moorings also include high modulus synthetic ropes.

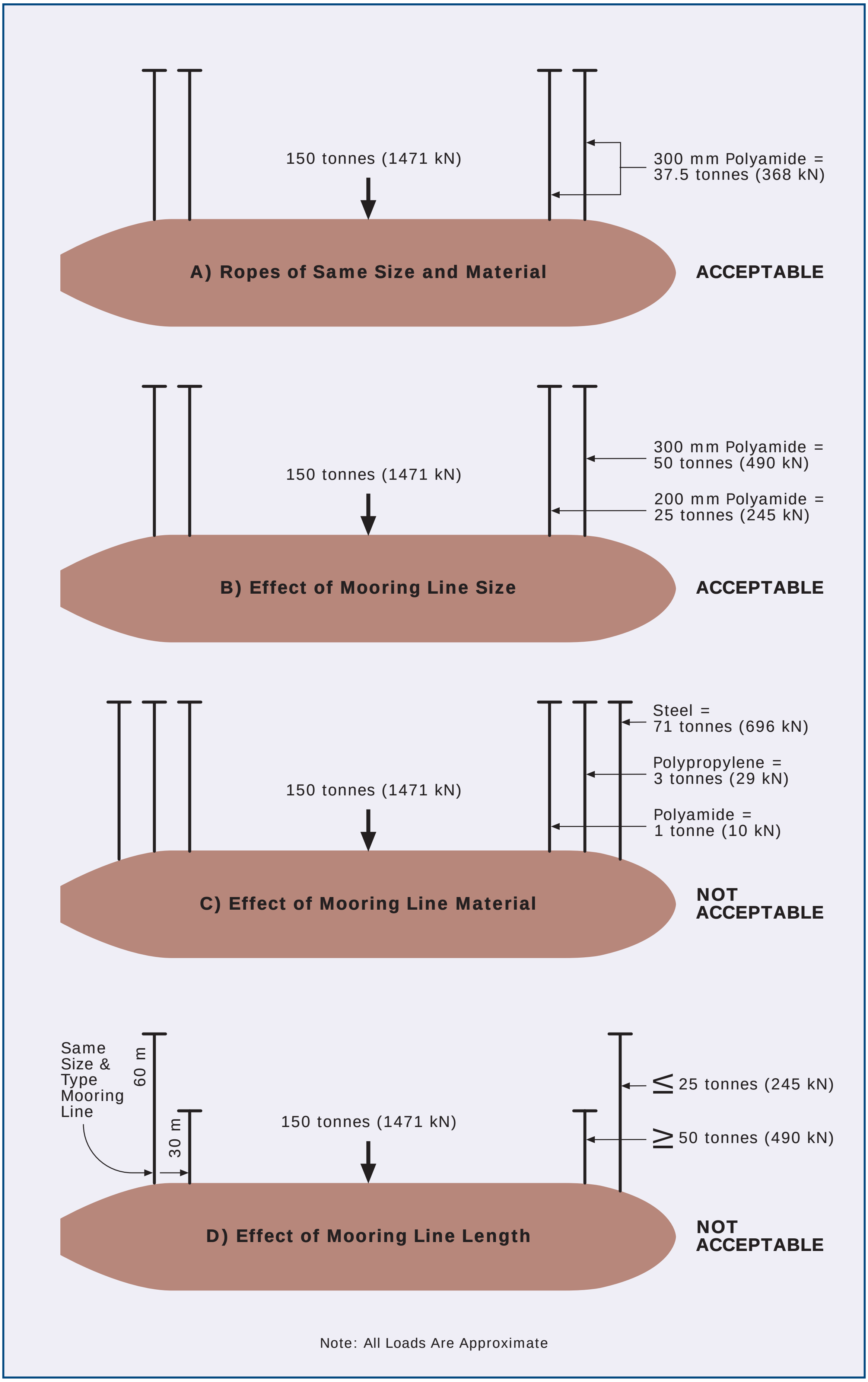


Figure 1.6: Effect of Mooring Elasticity on Restraint Capacity

The effects of mixing wire and synthetic fibre lines are shown in Figure 1.4, by comparison of Cases 1 and 2. (Note the low loads in fibre lines 2, 4, 11 and 13 and the increase in wire loads from a maximum of 57 tonnes (559 kN) to a maximum of 88 tonnes (863 kN)).

The effect of line length (from securing point on board to shore bollard) on load distribution must also be considered. Line elasticity varies directly with line length and has a significant effect on line load. A wire line 60 m long will assume only about half the load of a 30 m parallel and adjacent line of the same size, construction and material.

Elasticity of a given type of line also varies with its diameter, construction and age. Usually this factor is not an important consideration since the load relative to a line's strength is the governing factor rather than the absolute load. Conventional fibre ropes lose some elasticity with age.

1.5 General Mooring Guidelines

Consideration of the principles of load distribution in Figure 1.4 leads to the following mooring guidelines. These assume that the moored ship may be exposed to strong winds or current from any direction.

- Mooring lines should be arranged as symmetrically as possible about the midship point of the ship. (A symmetrical arrangement is more likely to ensure a good load distribution than an asymmetrical arrangement)
- breast lines should be orientated as perpendicular as possible to the longitudinal centre line of the ship and as far aft and forward as possible
- spring lines should be orientated as parallel as possible to the longitudinal centre line of the ship.

Head and stern lines are normally not efficient in restraining a ship in its berth. Mooring facilities with good breast and spring lines allow a ship to be moored most efficiently, virtually 'within its own length'. The use of head and stern lines requires two additional mooring dolphins and decreases the overall restraining efficiency of a mooring pattern when the number of available lines is limited. This is due to their long length and consequent higher elasticity and poor orientation. They should only be used where required for manoeuvring purposes or where necessitated by local pier geometry, surge forces or weather conditions. Small ships berthed in facilities designed properly for larger ships may have head and stern lines because of the berth geometry.

- The vertical angle of the mooring lines should be kept to a minimum.

The 'flatter' the mooring angle, the more efficient the line will be in resisting horizontally-applied loads on the ship.

A comparison of Cases 1 and 3 in Figure 1.4 demonstrates that a ship can usually be moored more efficiently within its own length. Although the same number of lines is used in each situation, Case 1 results in a better load distribution, minimising the load in any single line.

- Generally, mooring lines of the same size and type (material) should be used for all leads. If this is not possible, all lines in the same service, ie breast lines, spring lines, head lines, etc. should be the same size and type. For example, all spring lines could be wire and all breast lines synthetic.

'First lines ashore' are sometimes provided on very large ships to assist in the initial approach and positioning of the ship alongside. These lines often have high elasticity and are unlikely to add to the final restraining capacity of the system unless all lines in that group are of the same material.

Synthetic tails are often used on the ends of wire lines to permit easier handling and to increase line elasticity. Tails may also be used to increase the elasticity of low stretch ropes made from high modulus polyetheylene or Aramid fibres (see Section 6.5).

- If tails are used, the same size and type of tail should be used on all lines run out in the same service.

The effect of attaching 11 metre long tails, made from both polyester and polyamide, to steel wire and HMPE mooring lines is shown in the following graph. It should be noted that longer tails will have a significant impact on the assemblies' elasticity.

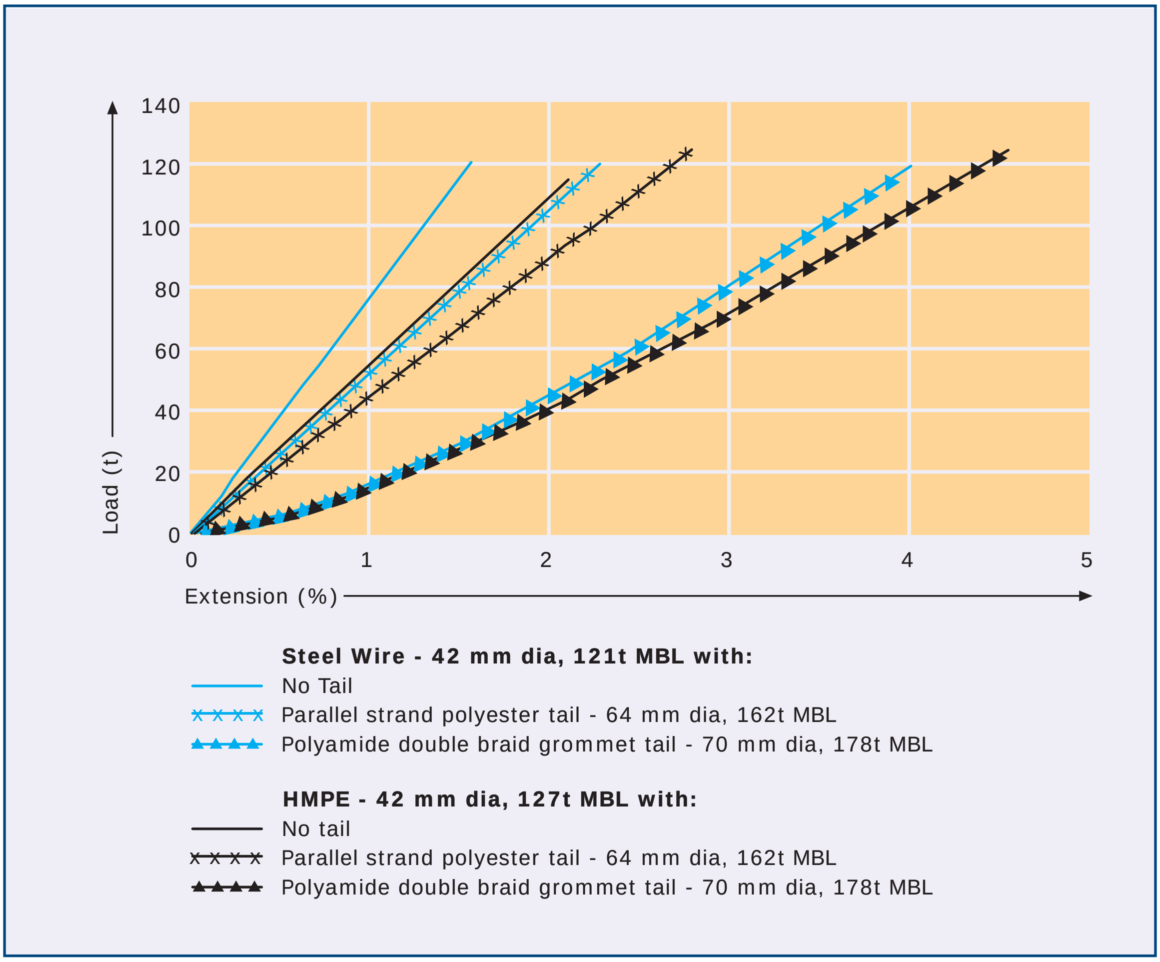


Figure 1.7: Comparison of Steel Wire versus HMPE Mooring Lines with and without 11 Metre Tails

(References 8 and 9)

- Mooring lines should be arranged so that all lines in the same service are about the same length between the ship's winch and the shore bollard. Line elasticity varies directly with line length and shorter lines will assume more load.

1.6 Operational Considerations

The mooring guidelines in Section 1.5 were developed to optimise load distribution to the moorings. In practice, final selection of the mooring pattern for a given berth must also take into account local operational and weather conditions, pier geometry and ship design. Some pilots, for example, desire head and stern lines to assist ships moving into, along, or out of a berth, while others may use spring lines for this purpose. Head and stern lines would be advantageous at berths where the mooring points are too close to the ship and good breast lines cannot be provided, or where the bollards are located so that the lines will have an excessive vertical angle in the light condition. These excessive angles would result in considerably reduced restraint capability.

High winds and currents from certain directions might make it desirable to have an asymmetrical mooring arrangement. This could mean placing more mooring lines or breast lines at one end of the ship.

The other factor to consider is the optimum length of mooring lines. It would be desirable to keep all lines at a vertical angle of less than 25°. For example, if the ship's chock location is 25 m above the shore mooring point, the mooring point should be at least 50 m horizontally from the chock.

Long lines are advantageous both from a standpoint of load efficiency and line-tending. However, where conventional fibre ropes are used, the increased elasticity can be a disadvantage by permitting the ship to move excessively thereby endangering loading arms. Figure 1.8 illustrates the effects of line lengths on line-tending requirements.

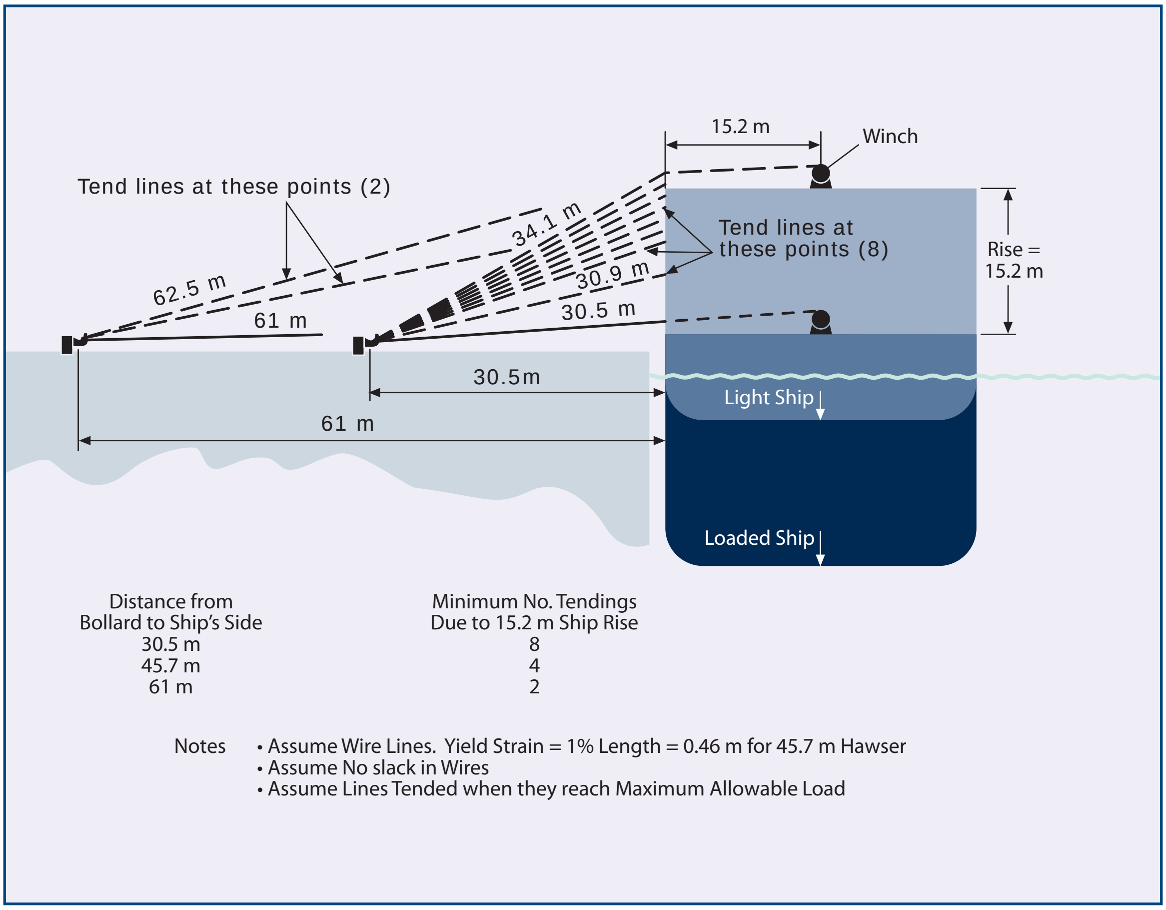


Figure 1.8 : Effect of Line Length on Tending Requirements

1.7 Terminal Mooring System Management

Good mooring management requires the application of sound principles, well maintained equipment, trained personnel and, most importantly, proper co-ordination and interaction between ship and shore.

Terminals are responsible for the provision of mooring equipment on their berths that is appropriate, in both size and number, for the full range of ship sizes and types using the berths. Mooring bollards, mooring hooks or rollers/pulleys should be positioned and sized for the ships being handled. The optimum arrangement and SWL of mooring equipment should be based on the output of engineering analysis using site-specific environmental data (see Section 2.5).

While the safety of the ship and its proper mooring is the prime responsibility of the Master, the terminal, because of its knowledge of the operating environment at its site and its equipment, should be in the best position to advise the Master regarding mooring line layout and operating limitations. The mooring analysis should be used to provide information on recommended mooring arrangements for the range of ships using each berth. Based on this information, the terminal should produce standard mooring diagrams for each generic ship size depicting the recommended number, size, and service of moorings. The information should also include details of operating limitations (see Section 1.7.2).

The responsibilities and arrangements for the mutual checking of moorings, cargo transfer and other aspects of the ship/shore interface should be addressed under the provisions of the Ship/Shore Safety Check-List.

The mooring equipment of existing ships varies widely, ranging from synthetic mooring ropes, mixed moorings (synthetic ropes and wire lines), all wire moorings (with and without synthetic tails) to systems using high modulus synthetic fibre ropes. Rated brake capacities, winch and fairlead locations can vary significantly from ship to ship. Ship crews will have varying degrees of expertise in mooring matters and varying philosophies concerning maintenance and/or replacement of critical items of mooring equipment.

The terminal can utilise a number of concepts in modern mooring management to reduce the possibility of ship break-out. These are:

- To run computer analysis of the mooring with site-specific environment to establish the optimum pattern, vessel movement, fender and mooring line loads

- based on this analysis, develop guidelines for the safe mooring of ships for the operating environment existing at the terminal together with recommended mooring plans
- to ensure that terminal mooring equipment is positioned and sized for the range of ships being handled, is properly maintained and clearly marked with its SWL
- to obtain information about the ship's mooring equipment prior to its arrival
- to examine the ship's mooring equipment after berthing to determine what modification, if any, must be made to standard guidelines in view of the state of maintenance, training of crew, etc.
- to check on the effectiveness of line tending periodically, either visually or by the instrumentation of mooring hooks
- to take whatever action is deemed appropriate to ensure stoppage of cargo transfer, disconnection of loading arms or transfer hoses and removal of the ship from the berth should the ship fail to take appropriate measures to ensure safety of mooring or should environmental conditions reach or exceed the operating limits as agreed and documented in the Ship/Shore Safety Check-List.

1.7.1 Operating Limits

Another important aspect in restraining the ship at its berth is the movement of the ship. No simple formula can be offered for the ship movement, although this is generally included in the output of computer calculations. Movement of the ship due to environmental loads can exceed loading arm or transfer hose operating limits before the strength limits in the mooring lines are reached. Similarly, limits and requirements may apply to gangways, particularly shore-based equipment incorporating a tower or a long span from the jetty to the ship. This is especially true for synthetic line systems. Under worsening environmental conditions, the loading arms and gangways may therefore have to be disconnected at lesser wind and current conditions than those used as a design basis for the mooring system.

Environmental operating limits should be established for each berth and should be detailed on the Ship/Shore Safety Check-List. In addition, ship's staff should be advised of any limitations on ship movement due to the operating envelopes of shore equipment such as hard arms, hoses, fenders (compression limits) and gangways, and the actions to be taken should these be reached.

The concept of 'manageable escalating events' is applied when establishing environmental limits and the following illustrates this principle:

- The loading arms may typically be drained and purged if necessary and disconnected when the wind reaches 30 knots (15 metres/second) and preparations made to leave the berth
- tugs may be requested to hold the ship alongside up to wind speeds of 35 knots (18 metres/second)
- the gangway will be stowed and the ship will be ready to leave the berth at the Master's judgement when the wind reaches 35 knots (18 metres/second)
- the ship's mooring lines should be able to hold the ship in position with wind speeds of 60 knots (31 metres/second) and the maximum tension in any one line should not exceed 55% of the MBL (wires), 50% MBL (synthetic ropes) or 45% MBL (polyamide). However, this may exceed the limits of the terminal's mooring system and a lesser wind speed may be appropriate when establishing environmental limits
- at wind speeds above 60 knots (31 metres/second), line tensions will exceed 60-65% MBL and winch brakes will start to render (see Section 7.4). The ship will be in a potentially dangerous situation.

For ships moored at an SPM, the practical safety limitation may well be related to physical ability of the crew to handle hoses and work safely rather than either ship movement or mooring loadings.

1.7.2 Operating Guidelines/Mooring Limits

In the past, operating guidelines and mooring limits have generally been developed empirically. With the advent of computers and the ready availability of specialised programs, in combination with the development of more accurate wind and current drag coefficients, guidelines can be developed systematically that can provide the limits for various classes of ships with varying mooring capabilities. It is recommended that mooring analyses are undertaken for facilities to validate recommended mooring arrangements and plans.

The following tables depict how data from a mooring analysis may be presented to assist ship and terminal staff understand and implement operating guidelines. In the examples shown in Tables 1.2 and 1.3, the maximum line and fender load, and ship surge and sway at the manifold, is given for an oil tanker and a very large LNG carrier. Where mooring loads exceed the 50% of MBL (synthetic) and 55% of MBL (steel wire) limitations, additional shore lines or very small reductions in weather criteria may bring the mooring under the tension limit. Conditions shown as 'not safe' would require a very large reduction in weather criteria and would probably result in unacceptable increases in downtime.

The information generated can be used for a number of purposes:

- To decide whether a given ship can be moored at a given berth under the expected weather conditions
- to determine when to discontinue cargo transfer and to disconnect loading arms
- to advise the ship when it would be desirable to take on ballast to reduce its freeboard
- to advise the ship when it would be desirable to have tugs available to assist in maintaining the ship's position at the jetty while preparations are made to vacate the berth.

Three significant wave heights are considered in the examples shown in the tables to establish the sensitivity to line tension and ship excursion over the range 1.0 m, 1.5 m and 2.0 m. These wave heights cover the typical range that would be experienced up to the practical limit of 2.0 m. It can be seen that at the higher wave heights the 11 m tails are inadequate and that longer 22 m tails are required. Conversely, at lower wave heights the 11 m tails are adequate. Another very important factor is the elasticity of the tail where the high stretch polyamide provides lower tensions than the lower stretch polpropylene/polyester and 100% polyester tails.

It should be noted that, when tail length is doubled, surge and sway does not increase by the same amount. As an example, for the large LNG carrier in Table 1.3, the HMPE mooring with 11 m tail, 2 m significant wave height and offshore wind, produces 0.6 m aft surge and 0.3 m sway out from the jetty. With a 100% increase in tail length to 22 m, there is no increase in sway and only a 50% increase in surge. For the tanker in Table 1.2, there is no change in surge and sway, even though the tail length has doubled.

3.4 Requirements for Emergency Towing, Escorting and Pull-Back

Regulation Ch V/15-1 (Ch II-1/3-4 from 1/7/98) of SOLAS adopted by IMO in 1994, contains the following provisions:

- All ´tankers`of 20,000 DWT and above are to be provided with an emergency towing arrangement at both ends
- the term ´tankers` includes oil tankers, chemical tankers and gas carriers
- the minimum components for an emergency towing arrangement are to comprise of the following:

Component	Forward	Aft
Towing pennant	Optional	Required
Pick-up gear	Optional	Required
Chafing gear	Required	Dependent on design
Fairlead	Required	Required
Strong point	Required	Required
Roller pedestal lead	Required	Dependent on design

- the forward arrangement of strong point, fairlead, chafing gear and roller pedestal lead reflects the guidance previously contained in IMO Assembly Resolution A.535(13), which on many oil tankers may be accommodated by the fittings recommended to facilitate mooring at SPMs (see Appendix E)
- the arrangement aft contains a major new provision introduced since IMO Assembly Resolution A.535 (13) was developed, i.e. the requirement for the ship to carry a pre-rigged towing pennant incorporating pick-up gear. The pick-up gear must be capable of being deployed manually by one person and the pennant must be demonstrated to be capable of full deployment within 15 minutes under harbour conditions.

For tankers over 20,000 DWT but under 50,000 DWT, the fairlead (chock) arrangement should have a minimum SWL of 1,000 kN. The strong point arrangement, with suitable reinforcement, should also have a minimum SWL of 1,000 kN when used with a single eye towing line or grommet.

For tankers of 50,000 DWT and above, the fairlead (chock) arrangement, with suitable reinforcement, should have a minimum SWL of 2,000 kN. The strong point arrangement, with suitable reinforcement, should also have a minimum SWL of 2,000 kN when used with a single eye towing line or grommet.

Fittings should be marked with their SWL expressed in tonnes (t).

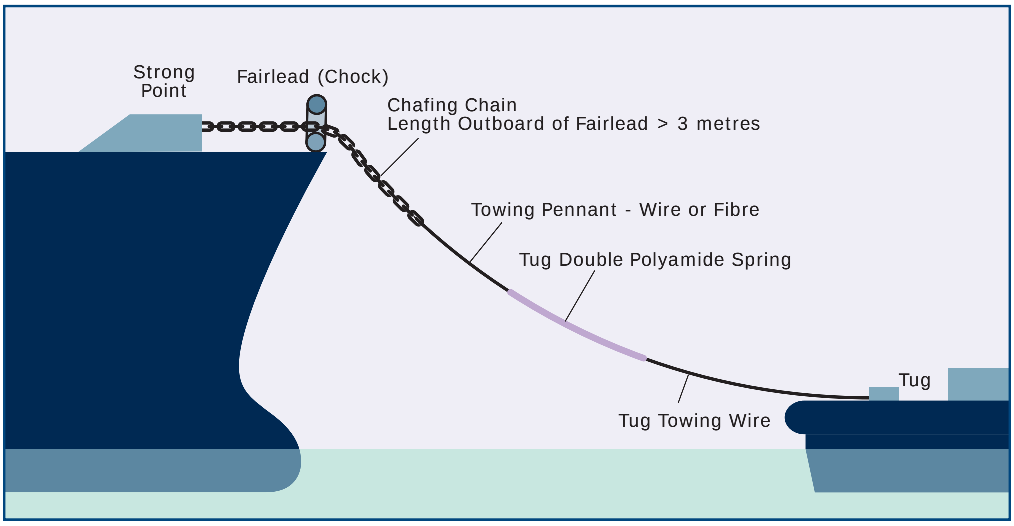


Figure 3.8: Typical Emergency Towing Arrangement at Forward End

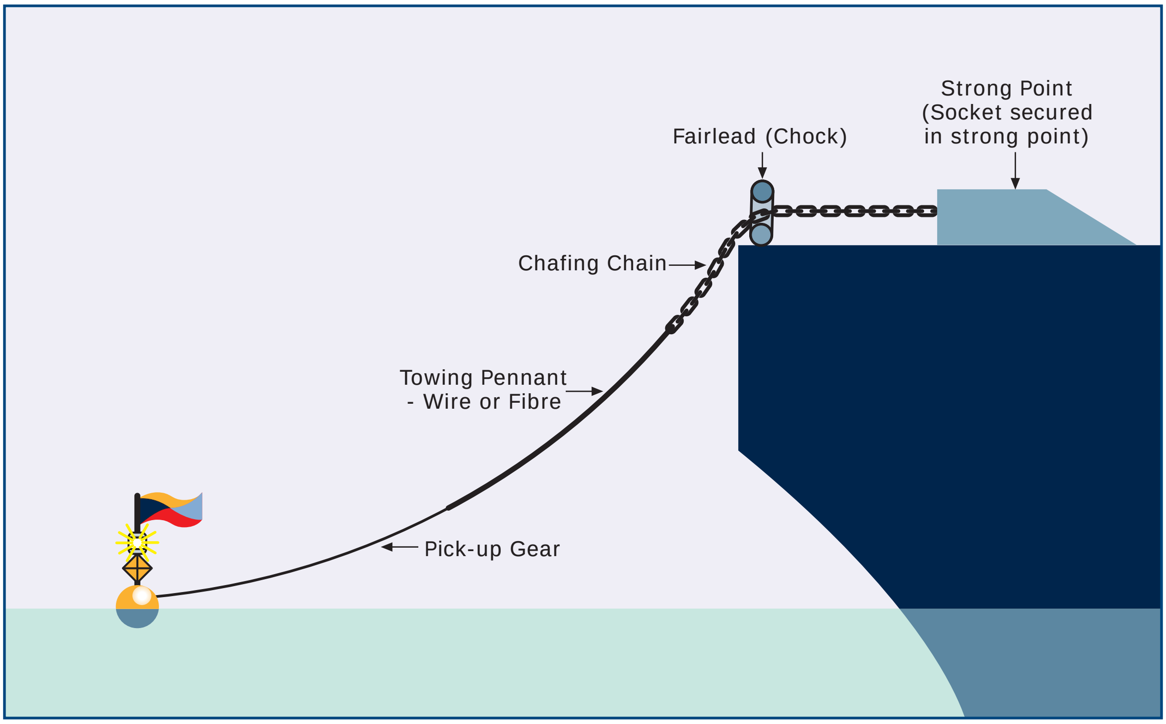


Figure 3.9: Typical Emergency Towing Arrangement at Aft End

3.4.1 Fittings for Tug Escort and Pull-Back

On many ships the emergency towing arrangements required by SOLAS may also be suitable for escort/pull-back requirements provided that such use does not in any way compromise the deployment and use of the emergency towing arrangements for their SOLAS purpose. For new installations it is recommended that consideration is given to designing the emergency towing arrangement to provide this dual purpose capability. The following recommendations apply where separate strongpoints and chocks are provided specifically for tug escort and pull-back duties. In such cases:

- The major components and supporting structure should be designed for a load that is a minimum of 2 times the SWL rating
- towing arrangements should be adequate for towing line angles up to 90° from the ship's centreline to both starboard and port in the horizontal plane and to 30° below horizontal in the vertical plane
- the fairlead (chock) should be located on the stern as close as possible to the centreline of the ship. (If the emergency towing arrangement is used, the strong point should be located so as to facilitate towing from either side of the stern and to minimise the stress on the towing system - see Resolution MSC.35(63))
- the fairlead (chock) opening should be oval or to have well-rounded corners
- the towing or connection point should be aligned longitudinally with the fairlead (chock) and clear of all obstructions
- the fairlead (chock) should have a minimum diameter of 600 mm and a minimum height of 300 mm
- the minimum distance from strong point to fairlead (chock) should be 4.0 metres. It is recognised that this may be difficult to achieve on ships of less than 50,000 DWT, but it is aimed at ensuring that the eye splice of the towing line sits inboard of the fairlead (chock). If the distance from strong point to fairlead (chock) is less than 4.0 metres, the tug should be advised. (This recommendation does not apply if the emergency towing arrangement is used as, in that case, the chafing gear will lie in the chock)
- each fitting should be clearly marked by bead weld outline with its SWL. The SWL should be expressed in tonnes (letter 't') to avoid any confusion
- fixed gear such as strong points, fairleads (chocks), foundations and associated supporting structure should be demonstrated as adequate for the loads imposed. The ship should hold a copy of the manufacturer's type test certificate for the fittings or a certificate confirming that the fittings are constructed in strict compliance with a recognised standard that specifies design load, safety factor and load application. The ship should also hold a certificate attesting to the strength of the strong

points, fairleads (chocks), foundations and associated supporting structure substantiated by detailed engineering analysis or calculations and an inspection of the installation. Both certificates should be issued by an independent authority (such as a Classification Society)

- the equipment should be subject to periodic survey and maintained in good order
- means should be provided for safely letting go the tug in the worst case environmental conditions likely to be experienced while the tug is attached. When letting go, the towline should be slacked back to the chock in a controlled manner, using a messenger line if necessary, to avoid whiplash
- the equipment to be used for the guidance and connection of the tug's towing line should be clearly marked as such and preferably painted a distinctive colour.

The recommended dimensions for the fairlead (chock) (600 mm x 300 mm) take into account the increased use of high modulus synthetic fibre ropes as towing lines for escort duties. The minimum bending diameter for such ropes is typically 10 times the rope diameter for plaited lines and 8 times the rope diameter for braided lines. The diameter for a plaited grommet with a Minimum Breaking Load (MBL) of 480 tonnes is typically 68 mm. This gives a minimum bending diameter of 680 mm and leads to the conclusion that a minimum diameter of 600 mm is appropriate for an escort/pull-back service with an MBL of 400 tonnes. The recommended height of 300 mm is sufficient to accommodate the towing line/grommet with possible protection against chafing.

High modulus synthetic fibre ropes are susceptible to damage by cutting and abrasion. Fittings that are also used with wires may have gouges and sharp edges that could damage such ropes unless steps are taken to protect them. It is recommended that chocks and strong points are kept fair on the contact surfaces to avoid undue abrasion of tow lines.

Certification of equipment to demonstrate adequacy for the anticipated loads is regarded as a 'one-off' exercise. Assuming there are no changes to the fittings or their supporting structure, re-certification should not be necessary.

3.6 Requirements for Harbour Towing

Provisions for tug handling consist of properly placed closed chocks and associated bitts for the guidance and attachment of the tug's towing line. Some high freeboard ships, such as large gas carriers, may be provided with recessed bitts on the ship's side shell as an alternative to sets of bitts and chocks. In addition, means for hauling the tug's line aboard with a ship's heaving line should be provided. These consist of suitable pedestal fairleads, guide posts or bitts to lead the heaving line onto the warping head of a mooring winch or, on some larger ships, the provision of dedicated capstans in way of the bitts.

In determining chock locations, the following points should be considered:

- Adequate separation of chocks should be provided to allow manoeuvring space for tugs. For large tugs, handling VLCCs or ULCCs, this separation should be about 50 to 60 metres
- chock locations should be in the same transverse plane as tug-pushing locations as tugs may alternately push or pull from the same location to check the ship's motion. The forward and aft chocks should be placed so that maximum leverage is provided for turning the ship, but not be so far towards the ends of the ship that the flare of the hull endangers the tug during pushing operations. It should also be noted that the tug push (and consequently chock) location is normally near a transverse bulkhead or web frame, as determined and marked by the shipyard or, in the case of retrofitting, by naval architect's design analysis
- an alternate neutral pull or push location is required midships to allow checking the lateral motion without applying a turning moment. The chock is generally located just aft of the cargo manifold hose support rail
- towing arrangements should be adequate to accommodate a 180° range of tow line angles in the horizontal plane and a 0° to 90° downward range in the vertical plane outboard of the chock.

For VLCCs and ULCCs these requirements generally result in five push/pull locations on each side of the ship. For smaller ships, where adequate separation of five tugs cannot be provided, three locations on each side will suffice.

A method of safely letting go the tug should be provided. When letting go, the towline should be slacked back to the chock in a controlled manner using a messenger line, if necessary, to avoid whiplash.

Bitts and chocks used for guiding and attaching tug's lines using a single eye towing line or grommet should have minimum SWLs in accordance with the following table:

Ship Size	**Maximum Rope Loading in tonnes - Attached with Eye** *(Figure-of-Eight Belayed)*	Nominal Size of Bitt (D) in mm
20,000 - 49,999 DWT	**64** *(32)*	400
50,000 DWT and above	**92** *(46)*	500
Note: (1) ´Figure-of-Eight` values are the values recommended to be marked on the fitting as the SWL		

Each fitting that is intended for use with tugs should be clearly marked by bead weld outline with its SWL. The SWL should be expressed in tonnes (letter 't') to avoid any confusion.

The SWL marked on the bitts should be the maximum permissible when using a wire or a rope belayed in a figure of eight near the base of the bitts (see Section 4.4.1). When using a single eye, this SWL can be doubled, i.e. the permissible SWL using a single eye is then twice the SWL marked on the bitts (see Section 4.4.1).

The SWL of ship's equipment used for connecting emergency towing-off pennants (fire wires) should be brought to the attention of the terminal representative when completing the Ship/Shore Safety Check-List.

Fixed gear such as strong points, chocks, foundations and associated supporting structure should be demonstrated as being adequate for the potential loads. The ship should hold a copy of the manufacturer's type test certificate for the fittings or a certificate confirming that the fittings are constructed in strict compliance with a recognised standard that specifies design load, safety factor and load application. The ship should also hold a certificate attesting to the strength of the strong points, chocks, foundations and associated supporting structure substantiated by detailed engineering analysis or calculations and an inspection of the installation. Both certificates should be issued by an independent authority (such as a Classification Society).

Certification of equipment to demonstrate adequacy for the anticipated loads is regarded as a 'one-off' exercise. Assuming there are no changes to the fittings or their support structure, re-certification should not be necessary.

4.1 General

These guidelines are intended to assist ship operators, designers and equipment suppliers in outfitting ships with mooring equipment designed to accommodate the expected loads safely.

´Mooring equipment` means the items of equipment mounted onboard a ship to handle the loads needed to secure the ship temporarily in a berth, or to another ship. Mooring equipment includes bitts, mooring winches, chain stoppers, fairleads, chocks and capstans. Anchoring equipment is not included in these guidelines as its specification is adequately covered in Classification Society rules.

To determine the required design strength of a particular fitting or piece of mooring equipment, the following information is needed:

- The magnitude of the greatest possible tension in the line that can contact the fitting. In these guidelines, the design value of this line tension is defined by, and shall be equal to, the Minimum Breaking Load (MBL) of the line. The Safe Working Load (SWL) that will be marked on the fitting is then normally equal to the MBL
- the magnitude, position and direction of application of the most severe load that can be applied to the fitting in service. The force given by this calculation is called the Design Basis Load (DBL). Its calculation takes account of the location and geometry of the line as it contacts the fitting and is based on a force in the line equal to the MBL. For example, a line led 180° around (wrap or wrap angle, see Section 4.4) a bollard subjects the fitting to a force (equal to twice the rope MBL) that acts on the bollard midway between the two legs of rope, while a line attached to a bollard near the top of the barrel produces a higher stress than one attached close to the base
- the safety factor recommended by these guidelines. This is specified on the stresses caused in the fitting by the DBL. It provides a margin of safety against the permanent deformation (yield) of any part of the fitting or its attachments to the ship.

It is worth repeating that, in these guidelines, the SWL is defined by the MBL of the line and not by the force exerted on the fitting by the line. Further, it is the SWL of the fitting rather than a safe working load for the line. At the SWL of a fitting, the line is at its MBL. As defined, the SWL is approximately twice the maximum force in the line in normal service (see the line safety factors in Section 6.1.2). It is a tension that will only be reached in rare and extraordinary circumstances. In everyday service the line tension is unlikely to be more than 20% of MBL.

Safety factors generally account for uncertainties such as additional dynamic loads, normal wear or corrosion of fittings or equipment, small material or welding defects, locked-in weld stress, and for uncertainties in the design calculation model used. The value of the safety factor is also influenced by the consequences of a failure. As an example from another area, very high safety factors are used on lifting gear, particularly if it is used to hoist personnel. However, safety factors generally are also influenced by the probability of the design event occurring, with rare events requiring lower safety factors than everyday occurrences. It is noted here that the probability of a given fitting experiencing the forces associated with line breakage once during the life of a ship is small. This low probability suggests that the possibility that some localised yield might occur in the fitting (for example, because actual rope strength exceeds the MBL, particularly early in the life of HMPE ropes) during this design event should be acceptable.

As a significant change from the previous edition of these guidelines, the safety factor no longer incorporates an allowance for any geometric effects that are a factor on the service tension in the line in calculating the force applied to a fitting, e.g. the factor of 2 on the line tension that arises in calculating the force applied to a bollard carrying a 180° wrap. Instead, a separate geometric factor is specified. This change brings these guidelines into line with the practice in many other design codes.

The ´Design Basis Load` of the fitting is then given by the product of the Minimum Breaking Load and the geometric factor. The dimensions of the fitting should be chosen by the designer so that the stresses caused by the Design Basis Load acting on the fitting nowhere exceed a percentage, in most cases 85%, of the Specified Minimum Yield Stress (SMYS) of the material. Thus, the safety margin against yield is the reciprocal of 0.85, i.e.1.18.

4.2 Basic Strength Philosophy

Since a wire rope, synthetic rope or chain with a specific minimum breaking strength is used as the link between the ship and the berth, it is very desirable to relate the required strength of equipment and fittings to the strength of the associated lines or chains.

Industry practice has not been consistent in this respect. Some designers have based the strength of fittings and equipment on the maximum line tension anticipated for certain weather criteria; others base the ultimate (breaking) strength of fittings and equipment on the minimum breaking load of the mooring line. Neither of these possible strength criteria is appropriate if damage to the fitting and equipment is to be avoided, simply because under heavy loads it would be possible for the fitting to become damaged while the mooring line was still intact.

The consequences of damage to fittings and equipment are usually more serious and costly than those of damaging or breaking a line.

The recommended design basis for mooring fittings and equipment is therefore that the fitting or piece of equipment and its components should be able to withstand, without permanent deformation, the Design Basis Load (DBL) given by multiplying the mooring line manufacturer's Minimum Break Load (MBL) by the geometric factor specified in these guidelines. The magnitude, point, and line of application of this load on the fitting should take due regard of the line geometry. ´Permanent deformation` is to be avoided by limiting the calculated stresses caused by the DBL to a percentage, in most cases 85%, of the Specified Minimum Yield Stress of the material.

This general requirement should be modified if it is possible that more than one line may be deployed on a fitting. For example, it may be possible to pass two lines through a single fairlead. If, in this case, the effects of the two lines are cumulative, the Design Basis Load must be increased to allow for this possibility.

It is specifically recommended that winch brake rendering (slippage) in a mooring should not be used to reduce the DBL below the value given above. Brake rendering at specific loads cannot be guaranteed, as brake settings are not precise and winches may inadvertently be left engaged in gear. Rather, brake rendering is considered to be an additional safety mechanism in protecting the integrity of the mooring system against unexpected failure when the ship is moored at a terminal.

It is further noted that rope over-strength, including the modest excess of strength in new ropes above their MBL and the increase in pure tensile strength in HMPE ropes in the early part of their working lives, need not be considered in calculating the DBL (refer to Appendix B).

4.3 Existing Standards and Requirements

Numerous national standards for mooring fittings exist, but often they do not provide sufficient information to establish the actual strength. In some cases, an 'SWL' is stated, but no safety factor indicated; in others an 'applicable line' is listed, but no information as to how the line stress relates to fitting stress is given. In yet other cases, the line position, direction or quantity may be missing. In comparing two fittings designed to different standards, it is possible that the obviously weaker design lists a higher rated 'load'. Listed 'load' variations between two fittings of equal size may be as much as a ratio of 1 to 10, most of which can be due to different definitions of 'load', safety factors and load application.

Mooring fittings are also often specified in nominal sizes, such as 300 mm or 400 mm diameter bitts. Fittings with the same nominal size manufactured to different standards may have very different actual strength capabilities and safety factors.

When the applicable mooring line size is determined from the existing standards, it is recommended to check the allowable MBL of the rope, if specified, along with the specified applicable rope size, because the rope breaking strengths may be different among standards and dependent on the grade. It should be noted that rope manufacturers catalogue minimum breaking strengths using different methods. For example, ISO shows MBL as unspliced strength while USA manufacturer's standards use spliced strength. In addition, some manufacturers catalogue average minimum break strength while others use 2 standard deviations below lowest actual break strength. This can result in significant variations above catalogue strengths when new. **For the purposes of these guidelines, the ISO definition of MBL is considered applicable.**

As a general point, it is not recommended that any design proceeds on the basis of selecting a mixture of clauses and factors from different standards.

More positively, IMO MSC Circular 1175 and IACS UR A2 include mandatory minimum requirements for mooring fittings and supporting hull structure, and reference international standards in force. The recommendations in this Section are intended to match or exceed these mandatory requirements. In addition, the principle that the supporting deck structure should be at least as strong as the fitting has been recognised.

As one example, Table 4.1 compares the recommendations given in Section 4.4 of these guidelines with the requirements of IMO MSC Circular 1175.

	Rope MBL (tonnes)	Fitting SWL (tonnes)	Design Load at Geometric Factor of 1.0 (tonnes)	Max. Fitting Stress at SWL (% of yield)	Max. Supporting Hull Structure Stress at SWL (% of yield)
Section 4.4	100	100	100	85%	80% of SMYS (see Section 5)
MSC Circ 1175	100	100	125	References industry standards	80% (i.e. 100% at design load)

Table 4.1: Comparison Between Section 4.4 and MSC Circ. 1175

4.4 Recommended Design Criteria

Until accepted international standards are developed for all mooring equipment, safety factors, and DBL and SWL values should be set as given in this Section. These recommendations are based on the basic strength criteria mentioned above and allow for wear and tear or corrosion in service, residual stresses or construction defects during manufacture and a degree of dynamic loading of the fitting.

If fittings are being regularly exposed to dynamic loadings, then dynamic analysis should be used to identify the true peak loading. A separate consideration of fatigue damage may then be necessary.

If fittings are to be exposed to low air temperatures in service, then steel with appropriate low temperature properties should be employed for the fittings and their supporting structures.

As indicated in Section 4.2, the basic recommendation for any fitting is that the fitting or equipment should not suffer any permanent deformation when the associated line is tensioned to its MBL. This requirement is achieved by ensuring that the stresses in the fitting do not exceed a percentage, in most cases 85%, of yield when the fitting is subjected to an applied Design Basis Load (DBL) given by rope MBL times the appropriate geometric factor provided later in this Section. In a Finite Element Analysis, the calculated stresses may often exceed yield in some localised hot-spots due to abrupt geometrical changes, constraints and load introductions. Such local areas of high stress should be accepted for ductile materials where stresses will re-distribute without affecting the safety of the structure. The SWL marked on the fitting should equal the MBL.

The general requirement of the previous paragraph is modified if it is possible that more than one line may be deployed on a fitting. For example, it may be possible to pass two lines through a single fairlead. If, in this case, the effects of the two lines are cumulative, the Design Basis Load must be increased to allow for this possibility. Otherwise, the worst loading applied by either of the two lines separately should be considered. The marked SWL should be the MBL of one line and the acceptability of more than one line on the fitting should be indicated on the mooring layout plan described in Section 4.6.

When selecting mooring equipment for new ships or conversions, it is recommended that the strength criteria listed in this Section be specified in addition to the usual information on size and materials. Reference to another specific standard should only be made if all strength details are published and are in general agreement with the recommendations in this Section. Standard fittings of unknown strength may be specified with the proviso that the standards are to be used as a guide to overall dimensions, materials and design concept, but that actual scantlings should be modified, if necessary, to meet the strength recommendations in this Section. In this case, compliance with the criteria should be substantiated with detailed calculations and a load test for each generic type of fitting.

The capacity of the foundations and supporting deck structure to any fitting must be specifically considered when rating the capacity of any fitting. As a basic principle, the strength of the supporting structure and the connection of the fitting to it should be greater than the marked SWL of the fitting itself, so that any fitting failure does not result in damage to the structure of the ship (see Section 5).

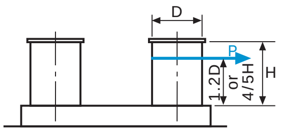
In the guidance that follows, the geometric factors, which as indicated in Section 4.1 allow for the geometry of the contact between line and fitting, can in principle be directly related to the angle through which the line is deflected in its passage through or over the fitting. If this ´wrap angle` is defined as θ, then the theoretical geometric factor (GF) is:

$$GF = 2\sin(\theta / 2) \quad \ldots \text{(Equation 4.1)}$$

For a wrap angle of 180°, a geometric factor of 2.0 is produced. Other wrap angles permit a smaller factor, including values less than 1.0 for small wrap angles. Hence θ may be taken conservatively as 180°, but this will adversely affect economy for small values of θ. On the other hand, if equation 4.1 is employed, it is absolutely essential that the value of θ used should be the largest deflection angle that can occur at that fitting, having due regard to all possible present and future rigging arrangements on the ship, and combining vertical and horizontal deflection angles. In practice, designers may conclude that the conservative value, 2.0, should be generally employed.

For the benefit of designers familiar with the 1997 (2nd) edition of OCIMF *Mooring Equipment Guidelines*, it is noted that the safety factor of 2.36 that was referenced in several Sections combined a geometric factor of 2.00 and a safety factor on yield of 85%, expressed as its reciprocal, 1.18, resulting in the product of those two factors, namely, 2.36.

4.4.1 Bitts (Double Bollards)

Fitting	Diagram	Geometric Factor	Load Position (P)	Marked SWL of Fitting	Design Basis Load	Stress Limit (see 4.4.11)	Test Load
Bitts (Double Bollard)		GF= 2.00	1.2D above base of a bitt of diameter 'D'	MBL	DBL= MBL x GF	85% of SMYS	DBL

As an example, if the rope MBL is 100 tonnes, the DBL is given by:

DBL = 100 x 2.00 = 200 tonnes

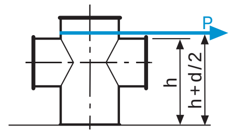
and the stresses caused by this DBL should be ≤ 85% of the Specified Minimum Yield Stress (SMYS).

It is essential to understand that bitts belayed in figure-of-eight style can subject either of the two posts (barrels) to a force at least twice as large as that in the mooring line. If for any reason there is a low friction coefficient between line and bitts due, for example, to the presence of paint, grease or icing, the force on an individual post could be more than twice the line load. For these reasons, Section 8 of these Guidelines (see Figure 8.1) recommends that the line is taken one full turn around the leading post before the figure-of-eight belay is taken, a procedure that reduces the loading on the most heavily loaded post. HMPE fibre ropes have a very low coefficient of friction on steel and two turns may be necessary to prevent overloading. However, the recommendation in 4.4.1 above recognises that it would be unsafe to rely on the single or double turn always being taken around the leading post.

If bitts designed to Section 4.4.1 are used with a rope eye dropped over one of the posts, without taking any turn around the other, then that rope could safely have twice the MBL assumed in the calculations here (see Table 8.1).

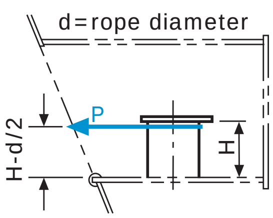
For bitts (double bollards) with a figure-of-eight belay, given the relative weakness of the baseplate as compared with the bitts themselves, the supporting hull structure should be designed to an applied load of 2 x MBL. The hull will then also be strong enough to cope with the loads from the rope eye described in the previous paragraph.

4.4.2 Single Cruciform Bollard (Single Bitt)

Fitting	Diagram	Geometric Factor	Load Position (P)	Marked SWL of Fitting	Design Basis Load	Stress Limit (see 4.4.11)	Test Load
Cruciform Bollard	d=rope diameter 	GF= 1.00	Cross bar height + 0.5 rope diameter	MBL	DBL= MBL x GF	85% of SMYS	DBL

With a single cruciform bollard (single bitt), the load multiplication effect noted for double bollards in Section 4.4.1 is absent, provided the line is secured on the single cruciform bollard itself.

4.4.3 Recessed Bitt

Fitting	Diagram	Geometric Factor	Load Position (P)	Marked SWL of Fitting	Design Basis Load	Stress Limit (see 4.4.11)	Test Load
Recessed Bitt		GF= 1.00	Top of Bitt – 0.5 rope diameter	MBL	DBL= MBL x GF	85% of SMYS	DBL

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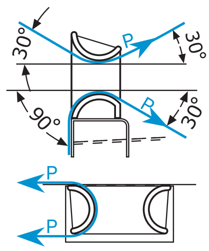
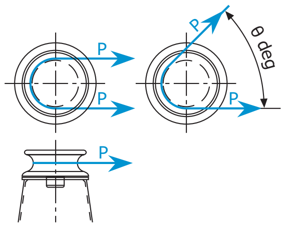
4.4.4 Closed Chock (Fairlead)

Fitting	Diagram	Geometric Factor	Load Position (P)	Marked SWL of Fitting	Design Basis Load	Stress Limit (see 4.4.11)	Test Load
Closed Chock		GF= see Eqn.4.1 (max = 2.00)	See Note	MBL	DBL= MBL x GF	85% of SMYS	DBL

Load position: Outboard, horizontal ± 90°, vertical up 30°, down 90°
Inboard, horizontal ±90°, vertical ±30°

Because the loading arrangement shown in the diagram includes the possibility that a line may be deflected through 180°, it is again necessary to understand that this produces a load on the chock twice as large as the line load. The possibility of more than one line being passed through a given chock should also be borne in mind. In this case, the method recommended in the introduction to Section 4.4 should be employed.

4.4.5 Pedestal Fairlead and Rollers of Button-Roller Chocks

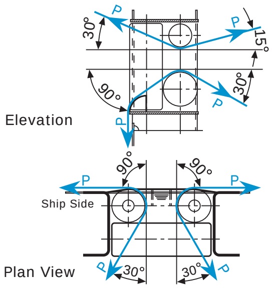
Fitting	Diagram	Geometric Factor	Load Position (P)	Marked SWL of Fitting	Design Basis Load	Stress Limit (see 4.4.11)	Test Load
Pedestal Fairlead		GF= 2.00 See Note	See Note	MBL	DBL= MBL x GF	85% of SMYS	DBL

Load position: 180° wrap: at upper end of cylinder or conical part of throat
(at centre of roller if radiused throat).

For rollers with a typical D/d (Diameter of roller 'D' : Diameter of line 'd') ratio of 8, Figure 6.4 indicates a strength reduction of some 15% on the MBL for wire ropes. The DBL may be reduced accordingly.

For a single line, the geometric factor may safely be taken as 2.00, or the value given by equation 4.1 may be used if physical measures are put in place to limit the wrap angle.

4.4.6 Universal Fairlead (4 Roller Type)

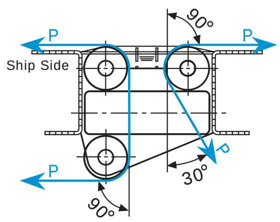
Fitting	Diagram	Geometric Factor	Load Position (P)	Marked SWL of Fitting	Design Basis Load	Stress Limit (see 4.4.11)	Test Load
Universal Fairlead		GF = see Eqn 4.1 and Notes below	See Note	MBL	DBL= MBL x GF	85% of SMYS	DBL

Load position: Outboard: Horizontal: ±90º, Vertical up: 30°down: 90°
Inboard: Horizontal: ±30º, Vertical up: 15° down: 30°

For rollers with a typical D/d ratio of 8, Figure 6.4 indicates a strength reduction of some 15% on the MBL for wire ropes. The DBL may be reduced accordingly.

For a single line, the geometric factor may safely be taken as 2.00, or the value given by equation 4.1 may be used.

4.4.7 Universal Fairlead (5 Roller Type)

Fitting	Diagram	Geometric Factor	Load Position (P)	Marked SWL of Fitting	Design Basis Load	Stress Limit (see 4.4.11)	Test Load
Universal Fairlead		GF = see Eqn 4.1 and Notes below	See Note	MBL	DBL= MBL x GF	85% of SMYS	DBL

Load position: Outboard: Horizontal: ±90°, Vertical up: 30°, down: 90°
Inboard: Horizontal: 30°/ 90°, Vertical up: 15°, down: 30°

For rollers with a typical D/d ratio of 8, Figure 6.4 indicates a strength reduction of some 15% on the MBL for wire ropes. The DBL may be reduced accordingly.

For a single line, the geometric factor may safely be taken as 2.00, or the value given by equation 4.1 may be used.

4.6 Marking of Mooring Fittings

Mooring fittings should be marked in order to provide ship operators with information on the strength of fittings.

Each fitting should be clearly marked by weld bead outline with its SWL, as listed in Section 4.4, in addition to any markings required by other applicable standards. The SWL should be expressed in tonnes (letter 't') and be located so that it is not obscured during operation of the fitting.

For safety, the marked SWL should correspond to the load in the associated line or chain. Therefore, the marked SWL will normally be the mooring line's MBL. It will not be the resultant load on the fitting which may be higher, e.g. on a set of bitts. It should also be noted that the unit 't' is recommended rather than the technically correct 'kN', since some operators may not be fully familiar with the metric system and a fitting may be dangerously overloaded if 'kN' is confused with 't'.

Since the SWL does not provide information on safety factor, test load or geometry of line (or lines) application, and marking of all data would be impractical, the ship should be provided with all additional relevant information. This should include actual test load applied, geometry of load application, bitt strength when belayed by eye and higher up on the barrel, maximum size and MBL of applicable line or chain, test certificates, standard drawings, etc. Where twin lines may be deployed on a fitting, the SWL of each single line should be marked and the acceptability of more than one line on the fitting should be indicated on the mooring layout plan.

Such information should be incorporated in a mooring layout plan available, or preferably displayed, on the ship.

6.1 General

A major decision should be made at the ship design stage regarding the type of mooring line to be used. The type of line will influence issues such as winch drum size, type and bend radius of chocks and fairleads and required deck space.

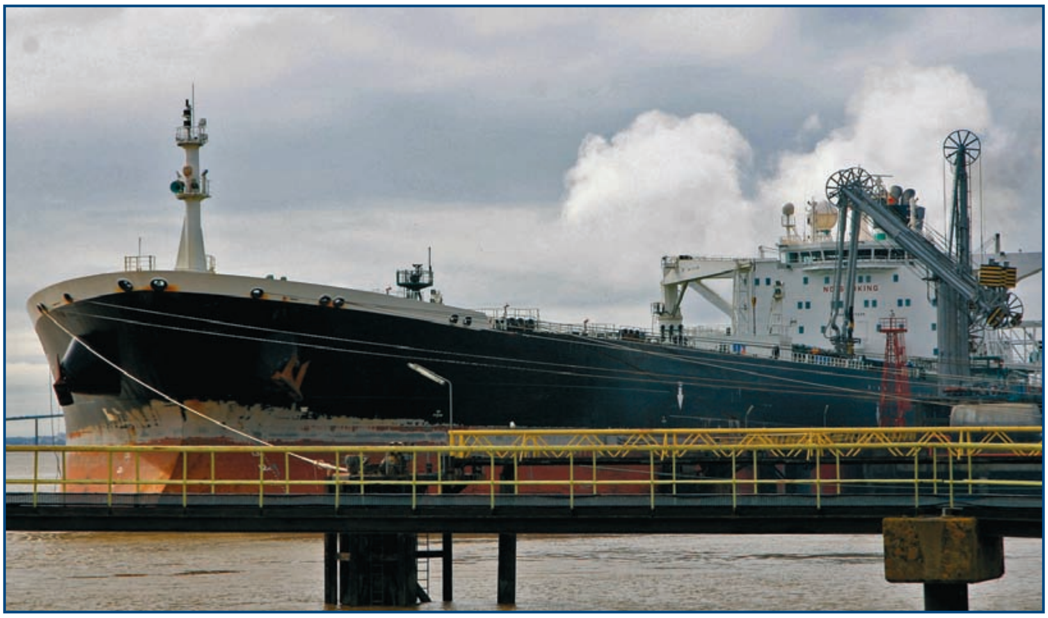
Low stretch ropes made from steel wire or synthetic materials such as High Modulus Polyethylene (HMPE) or Aramid fibres are advantageous where close limits are placed on ship movement such as at berths with hard arm equipment and where low dynamic loads are expected. These ropes are therefore recommended on large ships. If high dynamic loads are expected, a number of solutions are possible such as the fitting of longer tails or higher stretch tails or the provision of more elastic mooring lines.

Synthetic lines having greater elasticity may be more appropriate for use on small ships where ease of handling, flexibility of moorings and lower line tension are important criteria.

Other factors that may influence the choice of material include cost and the type of outfitting customarily used within a particular trade.

A mixed system utilising low stretch spring lines and more elastic breast lines, as found on some ships, has certain theoretical advantages. It reduces the fore and aft excursion of the ship while moored. This in turn reduces shifting of loads from one breast line to another and limits the motion of loading arms or hoses. Nonetheless, it is recommended that all lines be of the same size and material (see Section 1).

The properties and performance of steel wire and high modulus synthetic ropes are described in Sections 6.2 and 6.4, while those of the other, more elastic, conventional fibre ropes are covered in Section 6.3.



6.1.1 General Safety Hazards

All mooring lines can pose a great danger to personnel if not properly used. Handling of mooring lines has a higher potential accident risk than most other shipboard activities.

A significant danger is snap-back, the sudden release of the energy stored in the tensioned mooring line when it breaks.

When a line is loaded it stretches. Energy is stored in the line in proportion to the load and the stretch. When the line breaks, this energy is suddenly released. The ends of the line snap back striking anything in its path with significant force.

Snap-back is common to all lines. Even long wire lines under tension can stretch enough to snap back with considerable energy. Synthetic lines are more elastic and thus the danger of snap-back is more severe.

Line handlers must stand well clear of the potential path of snap-back, which extends to the sides of and far beyond the ends of the tensioned line. Figure 6.1 illustrates potential snap-back danger zones.

A broken line will snap back beyond the point at which it is secured, possibly to a distance almost as far as its own length. If the line passes around a fairlead, then its snap-back path may not follow the original path of the line. When it breaks behind the fairlead, the end of the line will fly around and beyond the fairlead.

It is not possible to predict all the potential danger zones from snap-back. When in doubt, personnel should be kept well away from any line under tension.

When it is necessary to pass near a line under tension, it should be done as quickly as possible. If it is a mooring line and the ship is moving about, passage should be timed for the period during which the line is under little or no tension. If possible, personnel should not stand or pass near a line while it is being tensioned or while the ship is being moved along the pier.

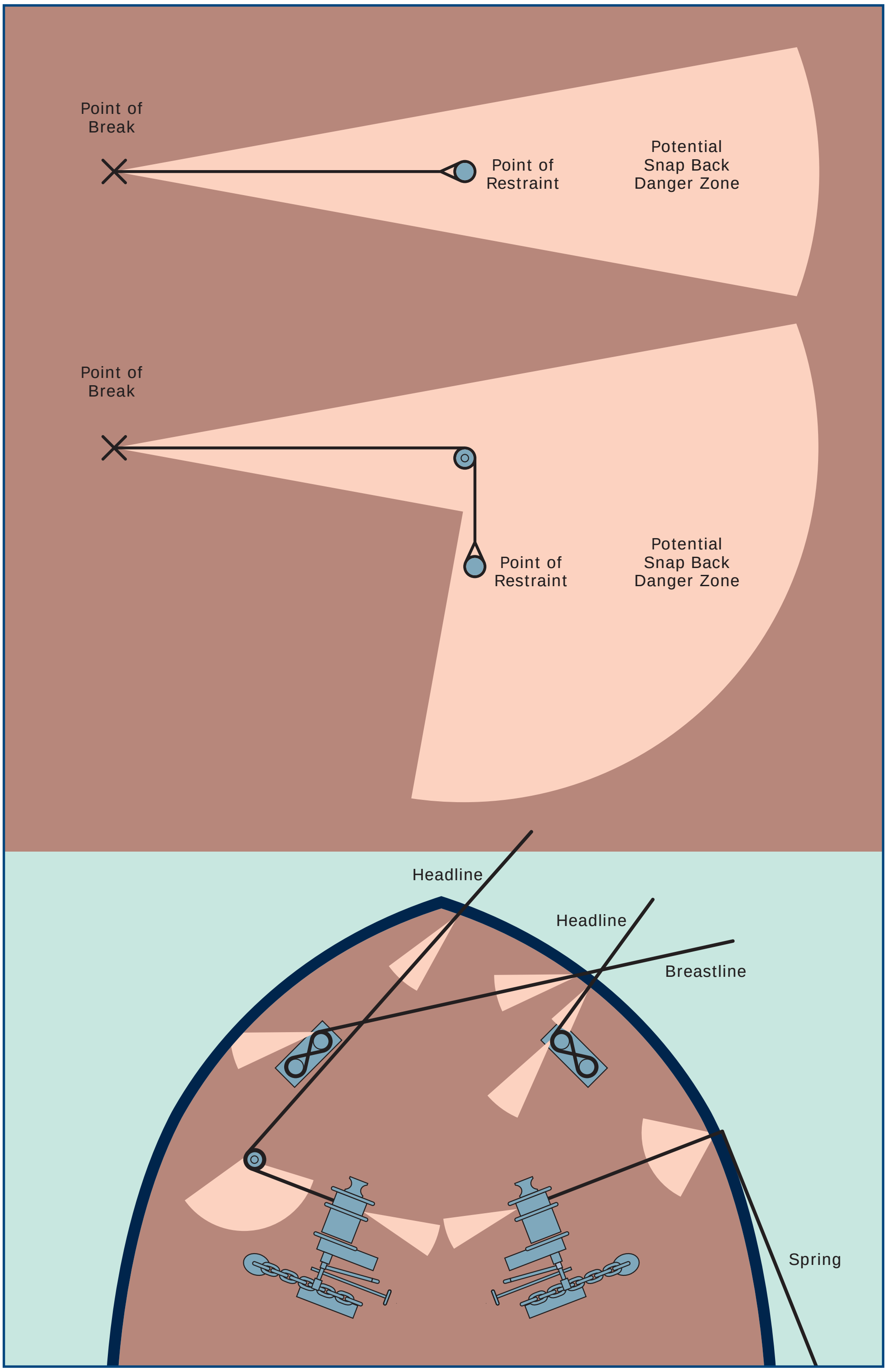


Figure 6.1: Examples of Potential Snap-Back Danger Zones

If work must be undertaken near a line under tension, it should be done quickly and the danger zone should be vacated as soon as possible. The activity should be planned before approaching the line and the number of personnel near the line should be kept to a minimum. If the activity involves line handling, it should be ensured that there are enough personnel to perform it in an expedient and safe manner.

High modulus synthetic fibre ropes have similar breaking characteristics to wire ropes. However, snap-back from these ropes will generally be along the length of the line and not in a snaking manner as found with wire ropes.

6.1.2 Strength Criteria

Ship designers will normally have determined the mooring restraint requirements for large ships under Standard Environmental Criteria assuming all mooring lines are steel wire ropes.

Before fitting wire ropes or high modulus synthetic fibre mooring ropes, ship operators should conduct a mooring analysis to determine and demonstrate the adequacy of the mooring arrangement.

More vessels are being outfitted from new with HMPE ropes. The higher Safety Factor (SF) of 2.0 for HMPE (see Table 6.1 below) may result in larger deck equipment being required than for equivalent wires (SF 1.82) particularly where fittings are on the borderline of that size range.

When retrofitting with HMPE lines, caution should applied as the application of a higher SF in combination with the potential for 'over-strength' (see Appendix B) could result in the HMPE mooring having a significantly higher MBL than the previously specified steel wire rope. This could create a situation where strength margins between deck fittings and mooring lines is reduced.

Current practice has been to replace steel wire ropes with HMPE lines having the same MBL where operating limits and experience has been found to be adequate. In these cases, the implied SF of the HMPE line is 1.82 assuming that the vessel is moored in the same environmental conditions as when equipped with steel wire ropes.

The rope manufacturing industry advocates a higher SF for HMPE than for steel wire since they have to apply it to a wide range of materials and constructions. The higher SF is also believed to result in a longer service life and higher residual strength at end of life.

Recommended minimum SFs for steel, polyamide and other synthetic mooring ropes are provided in Table 6.1 below.

Fitting	SWL	SF = MBL/SWL	% MBL	Test Load
Mooring Lines	Highest load calculated for adopted standard environmental criteria	Steel: 1.82 Polyamide (2): 2.22 Other Synth: 2.00	55% 45% 50%	Test sample to destruction to confirm MBL (3)
Tails (1) for Wire Mooring Lines	As above	Polyamide (2): 2.50 Other Synth: 2.28		As above
Tails (1) for Synthetic Mooring Lines	As above	Polyamide (2): 2.75 Other Synth: 2.50		As above
Joining Shackles	Equal to or greater than mooring lines to which attached	2.00		Proof Load

Table 6.1: Strength Criteria

Notes: 1) Tails will have a higher breaking strength than mooring lines (steel and synthetic) since they will take most of the fatigue and are subject to more abrasion.

2) For polyamide, the SF is higher due to allowance for the strength loss when wet.

3) MBL is defined as the minimum load that a new rope will sustain before breaking when tested to destruction. Ref ISO 3108 (steel wire ropes) and ISO 2307 (fibre ropes).

6.1.3 Elasticity

Figure 6.2 shows the typical broken-in load extension characteristics for steel wire, conventional synthetic fibre and high modulus synthetic fibre ropes. The broken-in characteristics are determined by cycling the ropes ten times to 50% of their rated strength following procedures recommended in the OCIMF *Guidelines for the Purchasing and Testing of SPM Hawsers* (Reference 7). This accelerated test procedure approximates the change in elasticity that might occur over many more cycles under lower tensions in typical service.

Conventional synthetic ropes such as polyamide, polyester and polypropylene are considerably more elastic than high modulus synthetic fibre ropes. High modulus synthetic fibre ropes are marginally more elastic than steel wire ropes. However, the ratio of extension is significantly closer to that of steel wire than conventional synthetic ropes.

Accepted mooring practice requires all lines in the same service, i.e. breast lines, spring lines, etc., to be of the same size and type. While the load extension characteristics of high modulus synthetic fibre ropes approach those of steel wire ropes, the use of different materials in the same service should be avoided.

Steel wire ropes should not be led through the same chocks as soft ropes as it may cause chafing damage (see also Section 6.4.7.2).

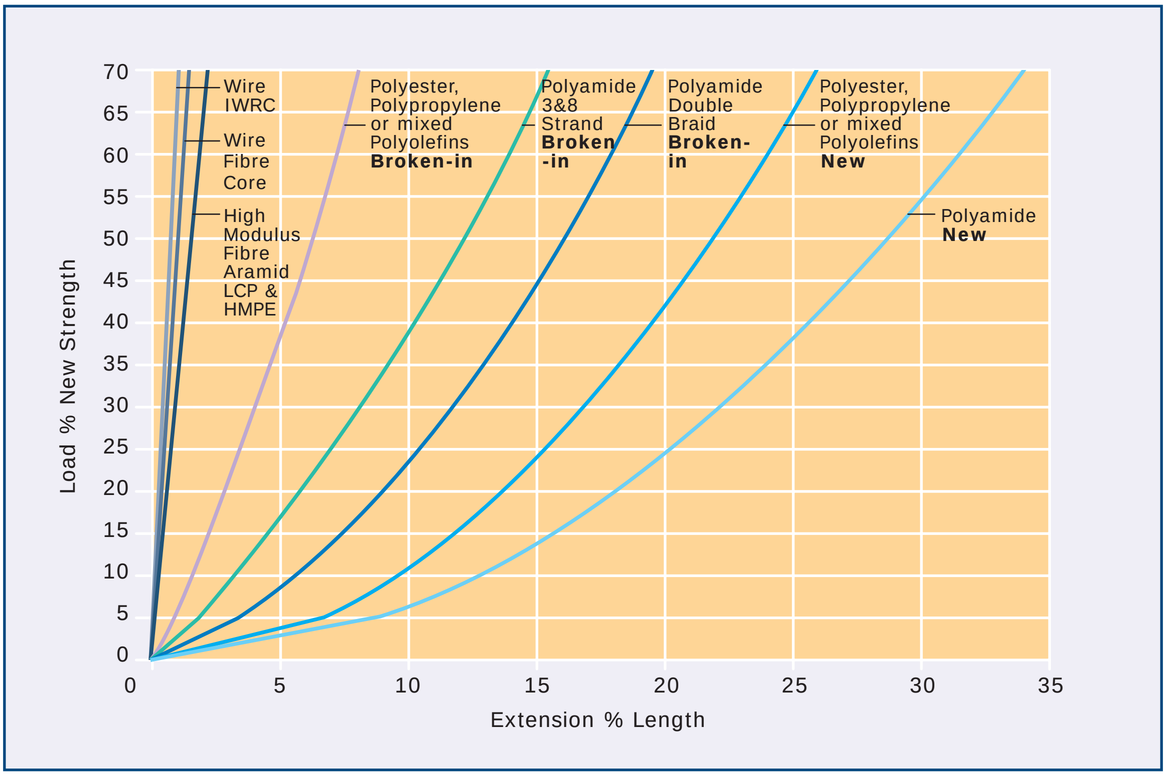


Figure 6.2: Load-Extension Characteristics

Wire and Fibre Ropes, New and Broken-In

(Reference 8 and 9)

The synthetic fibre rope test data used in developing the load-extension characteristics were determined from tests conducted using OCIMF's hawser test procedures (Reference 7). For example, the broken-in characteristics are measured on the tenth cycle to 50% strength. Most ropes will approach these characteristics within a few cycles and will not change significantly even after many more cycles. These load extension curves apply to a loading rate of over a minute or more rather than typical wave loading periods of 10 seconds. This will apply to most sheltered mooring situations.

If the same ropes had been tested by some other procedure, the resulting load-extension characteristics might appear to be considerably different. Some of the variables that affect rope load-extension characteristics are the number of cycles, cyclic load range, relaxation time, rate of loading and whether the rope is wet or dry.

For exposed moorings when vessel wave induced motions may be present, constant cyclic loading will occur and a significantly stiffer curve will result, especially at higher mean loads.

6.1.4 Record Keeping

All mooring ropes, wires and tails should be received with either individual certificates or, if part of a batch, a certificate of conformity.

These certificates should be retained and will typically contain the following information:

- Manufacturer
- date
- Minimum Breaking Load (MBL)
- description of rope, including:
  - type
  - reference number in mm per diameter, weight per metre
  - length
  - material
  - rope construction (e.g. laid, braided, number of strands)
  - jacketing information (material and construction)
  - end terminations.

It is recommended that, on receipt, all ropes, wires and tails be permanently marked so that positive identification with their corresponding certificate can be made.

Records should be kept of date placed in use, inspections and any maintenance.

7.1 Function and Type of Mooring Winches

Mooring winches perform a multitude of functions. They secure the shipboard end of mooring lines, provide for adjustment of the mooring line length to suit the mooring pattern in each port and compensate for changes in draft and tide. They serve to store the mooring line when not in use and to haul the ship into position against environmental or inertia forces. They also act as a safety device that releases the line load in a controlled manner once the force in the line increases to pre-set levels. General requirements for shipboard mooring winches are dealt with in ISO Standards 3730 and 7825.

Winches can be categorised by their control type (automatic or manual tensioning), drive type (hydraulic, electric or steam), by the number of drums associated with each drive (single drum, double drum, triple drum), by the type of drums (split, undivided) and by their brake type and brake application (band, disc, mechanical screw, spring applied). Each of these features influences the mooring winch function and will be briefly discussed below.

Although winch drives serving double drums are common on many ships, caution is advised when considering the fitting of triple drums owing to the potential impact of a failure of a single drive on overall mooring capabilities.

7.1.1 Automatic Tension Winches

Automatic tension winches are designed to automatically heave-in whenever the line tension falls below a pre-set value. Likewise, they will pay out if the line tension exceeds a pre-set value. Because of the possibility of tension winches operating in an uncontrolled manner resulting in ships being 'walked' along the pier, they should never be operated in the automatic mode when the ship is connected to the shore cargo manifold. Moorings should be secured with the winch drum held on the manual brake and with the winch out of gear.

7.2 Winch Drums

Winch drums may be either split or undivided. The split drum is composed of a tension section and a line storage section. It has the advantage that it can maintain a constant brake holding capacity and heaving force due to the fact that the mooring line is always run off the first layer of the tension drum. For this reason, split drum winches are preferred by most operators. The disadvantage of the split drum is the more difficult operation, a factor which can be overcome with proper instructions and operator experience. Another reason for their use is that ISO Standard 3730, Annex A, recommends that synthetic ropes under tension should not be wound on a drum in more than one layer or a shorter life span will result. This can normally only be achieved by using split drums.

For either type of drum, the minimum drum diameter should be 16 times the design wire rope's diameter. For conventional and high modulus fibre ropes, the manufacturer should be consulted for information on the acceptable minimum bend radius for specific applications.

Split drums should be wide enough to allow for 10 turns of the design wire rope on the tension section. A minimum of 10 turns is also required when using low friction unjacketed high modulus synthetic fibre ropes. For high friction jacketed high modulus ropes and conventional fibre ropes, a minimum of 5 or 6 turns should be allowed for. When specifying the number of turns on the tension section, due account must be given to ensuring proper spooling.

While most operators prefer the split drum type, the undivided drum has its proponents also. The following discusses the pros and cons for each type and also discusses the effects that the number of layers of mooring line on the tension or working drum has on each.

7.2.1 Split Drums

As shown in Figures 7.1 and 7.2, the split drum winch is a common drum divided by a notched flange into a storage section and a tension section (see Figures 6.6b and c). It is operated with only one layer of mooring line on the tension section and theoretically can maintain a constant, high brake holding power.

The split drum winch was designed as a solution to the spooling problem encountered with undivided drum winches. When mooring lines are handled directly off drums, the final turns of the outer layer when under tension tend to bite into the lower layers. This could result in damage and difficulties when releasing the line. Also, the mechanical spooling devices that were used on undivided drums were found to be susceptible to damage.

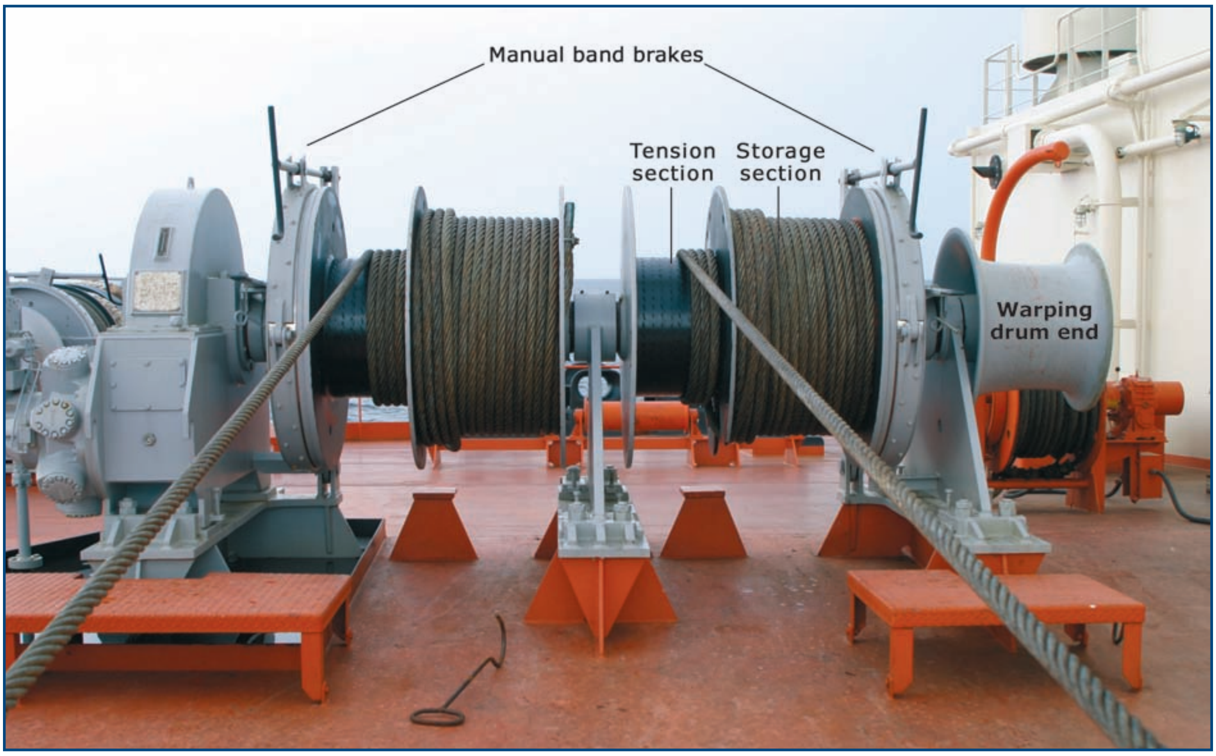


Figure 7.1: The Split Drum Winch

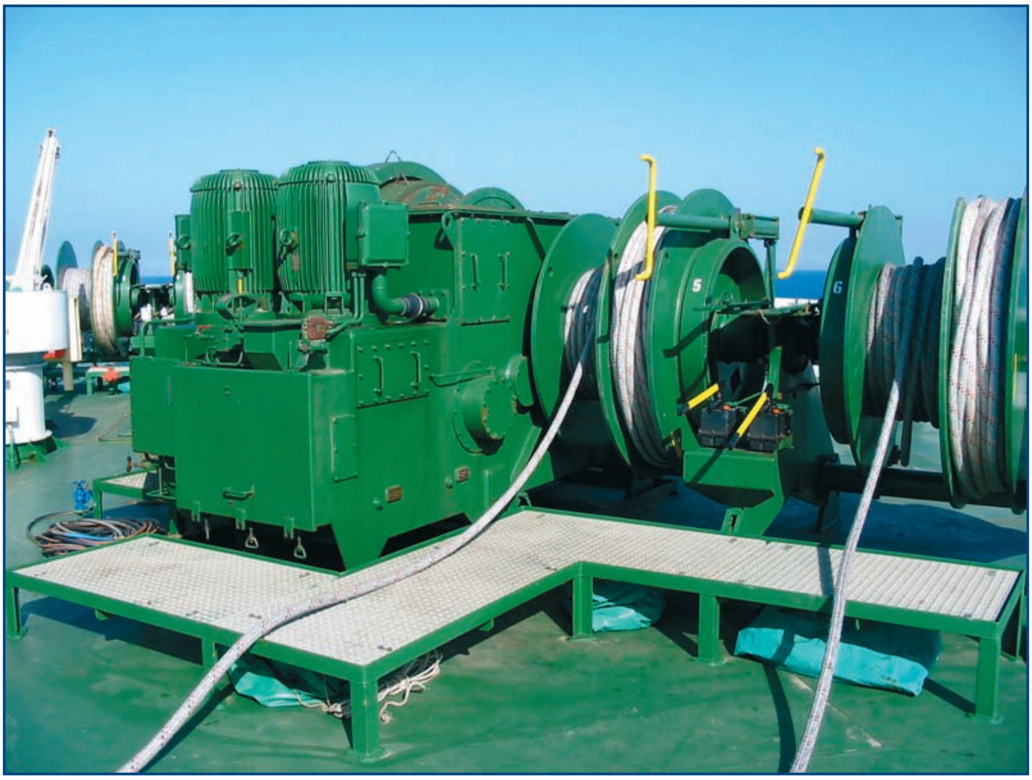


Figure 7.2: Jacketed High Modulus Fibre Moorings on Split Drum Winches

In operation, the mooring line from the split drum winch is sent ashore, either directly from the storage section or first from the working section and then from the storage section. As the line is recovered, it is wound directly on the storage section until that time when only sufficient slack is available to provide a sufficient number of turns on the tension section to: (1) hold the tension of the line on the tension section only and (2) provide extra turns to allow for adjustments of the line throughout cargo transfer. At that time the mooring line is fed through the slot from the storage section to the tension section.

The transfer of the mooring line from the storage section to the tension section is difficult to judge, particularly when long drifts of line are used such as at MBMs. Care must also be exercised to prevent tension coming on the line during the transfer at the time when it passes through the slot. If this is not done, such tension could cause damage to the line or injury to personnel involved in the transfer. There is also concern that the mooring operations could take longer, especially when excessive layers develop on the tension section. The delay occurs because steps must be taken prior to completion of mooring to correct the number of turns on the tension section.

7.2.2 Undivided Drums

The undivided drum winch is commonly found on smaller ships and is preferred by some shipyards, mainly in Japan, for VLCCs. The undivided drum avoids the need to transfer the mooring line from section to section as is required for a split-drum winch when a poor estimate has been made of the spooling requirements. The undivided drum eliminates the potential for line damage and personnel injury that exists at the time of transfer on a split drum.

However, if this type of drum is selected, the operator should be aware that it is often difficult to spool and stow the mooring line on the drum satisfactorily. If the line is not spooled properly it can be damaged when tension is applied to the system. To reduce this problem, care should be exercised in the location of the winch. It should be placed a sufficient distance from the fairlead to ensure that the mooring line can be properly spooled. Reference should also be made to Section 3.15.

7.2.3 Handling of SPM Pick-up Ropes

Ships likely to trade to SPMs should be equipped to safely handle SPM pick-up ropes taking into consideration safety and protection from risk of snap-back injury to mooring personnel. (Refer also to Appendix E).

Wherever possible, winch storage drums used to recover the pick-up ropes should be positioned to enable a direct straight lead with the bow fairlead and bow chain stopper without the use of pedestal rollers. This relative positioning of the tanker SPM mooring equipment in a direct straight lead is considered the safest and most efficient arrangement for handling the pick-up ropes. However, recognising that not all mooring arrangement designs will permit a direct straight lead to a winch storage drum, pedestal rollers may need to be utilised.

Personnel safety considerations should take priority when determining the number and position of pedestal rollers. It is essential that the pedestal roller(s) are correctly positioned relative to the winch drum and the centre of the bow chain stopper to enable a direct lead from the centre of the bow fairlead to the centre of the bow chain stopper and to allow the pick-up rope to be stowed evenly on the storage drum. There should be at least 3.0 m distance between the aft side of the bow chain stopper and the closest pedestal roller to allow for the pick-up rope eye, connecting shackle, shipboard end oblong plate and a number of chafe chain links. The number of pedestal rollers used for each bow chain stopper should not exceed 2 and the angle of change of direction of the pick-up rope lead should be minimised.

Winch storage drums used to stow the pick-up rope should be capable of lifting at least 15 tonnes and be of sufficient size to accommodate 150 metres of 80 mm diameter rope. Use of winch drum ends (warping ends) to handle pick-up ropes is considered unsafe and should be avoided.

8.1 Introduction

Many national, shipyard and vendor standards exist for mooring fittings. However, one difficulty in establishing the general acceptability of a particular fitting is the inconsistency in load and design parameters between various standards. This can be partially compensated for by the continuing adoption of ISO Standards as the basis of national or vendor specifications. Unfortunately, the ISO Standards do not cover all mooring fittings, nor do they always provide the detail included in some national standards. Moreover, some ISO and national standards have not been updated to keep pace with industry progress adding further difficulty in knowing which strength criteria are relevant to a fitting. It is therefore recommended that the criteria detailed in Section 4.4 are adopted.

Any fitting with undocumented or incomplete strength characteristics should be verified for compliance with the strength criteria recommended in Section 4.4 using detailed calculations and formal type-approval processes.

The following guidance highlights some of the critical elements associated with the selection and installation of acceptable deck mooring fittings.

8.2 Mooring Bitts

ISO 3913 contains standards for bitts (double bollards) with diameters from 100 mm to 800 mm.

The bitts should penetrate the baseplate rather than just being welded to its top. Strengthening rib plates should be fitted in the base.

The tabulated 'single rope maximum loading' quoted in the ISO Standard is the SWL when the rope is belayed in a figure-of-eight fashion. According to the ISO Standard, two ropes of this value may be applied in figure-of-eight fashion near the base, or alternatively a single rope of twice the load may be applied, as a loop, at heights up to 1.2 times the bitt nominal diameter.

The reason that the SWL depends on the method of rope belaying is that certain belaying methods tend to pull the two posts together inducing a higher stress in each barrel than that produced by an eye laid around a single post. With figure-of-eight belaying, the loading in each post corresponds to the sum of all forces in the successive rope layers, which can be higher than the maximum rope load (see Section 4.4.1). Experienced mariners are aware of this phenomenon and have devised methods that effectively distribute the external load over the two posts (for instance, by taking one or two turns around the first post before starting to belay in figure-of-eight fashion). Figure 8.1 illustrates the two methods of belaying a rope around bitts.

When belaying unjacketed high modulus lines around bitts, for example, when making fast a tug's line, two turns should be taken around the leading post prior to turning the line up in a figure-of-eight fashion.

Nominal Size of Bitt (D) in mm	**Total Maximum** Rope Loading in Tonnes if Load is Applied at 1.2 D above Base, or Lower	
	Figure-of-Eight Belayed	Attached With Eye
100	3	6
125	4	8
160	5	10
200	8	16
250	12	24
315	20	40
400	32	64
500	46	92
630	70	140
710	82	164
800	100	200

Notes:
1) Scantlings per ISO 3913
2) The ´figure-of-eight` values correspond to the ´single rope maximum loading` in ISO 3913 and are the values recommended to be marked on the fitting as SWL

Table 8.1: Maximum Permissible Rope Loading of Bitts

8.3 Cruciform Bollards

ISO 3913, Addendum 1, covers bollards with a barrel diameter from 70 mm to 400 mm.

In a similar manner to bitts (double bollards), the tabulated 'single rope maximum loading' value quoted in ISO for double cruciform bollards is the SWL when the rope is applied in figure-of-eight fashion. Since a single cruciform bollard cannot be overstressed by this type of belaying method (see Section 4.4.2), its SWL is twice that of a double bollard. No information on height of rope application is given in the Standard. However, since the scantlings are the same, it is assumed to be the same as for bitts.

Cruciform bollards, or single bits, are fitted in the vicinity of tanker manifolds. These fittings typically have a SWL suited for hose-handling operations and they may not be suitable for use for mooring applications.

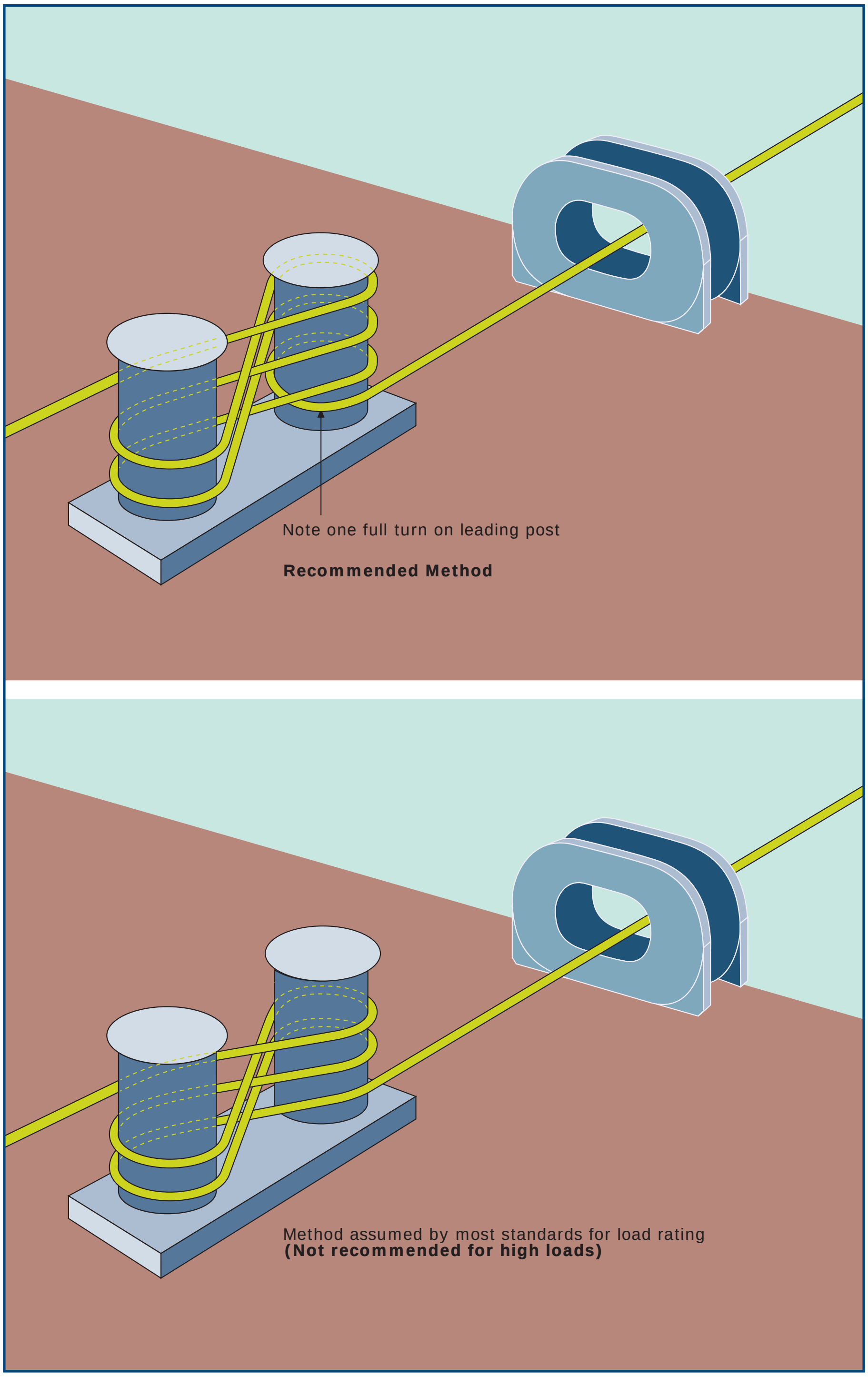


Figure 8.1: Methods of Belaying a Rope on Bitts

8.4 Closed and Panama-Type Chocks

Although the terms 'closed chock' and 'Panama chock' (and fairlead) are often used interchangeably, not all closed chocks are 'Panama chocks'. Panama chocks must comply with Panama Canal regulations, the stipulations for which include a minimum surface radius (178 mm), a minimum throat opening (300 x 250 mm for single, 350 x 250 mm for double type) and a safe working load (32 t for single, 64 t for double type (314 kN or 628 kN).

Closed chocks or Panama-type chocks are either deck mounted or bulwark mounted. The strength of these fittings does not appear to be a problem due to their substantial design. Nevertheless, the method of attachment to the deck or bulwark is important and it is recommended that the criteria listed in Section 4.4.4 be applied.

Some standards quote 'enlarged' type closed chocks or fairleads. These are usually large throat opening size and large radius fittings. They are especially useful with large diameter wires where the effects of bend radius are significant. Where soft rope tails are used, the size of the throat opening may have to be of the enlarged type to allow for connector shackles.

When closed chocks are used in conjunction with HMPE mooring lines, consideration must be given to ensuring that contact surfaces are smooth and free from chafe points (see Section 6.4.7.2).

Specific requirements are in place for closed chocks, or fairleads, that are used in conjunction with the emergency towing equipment required under Regulation Ch V/15-1 (Ch II-1/3-4 from 1/7/98) of SOLAS, details of which are provided in Section 3.4.

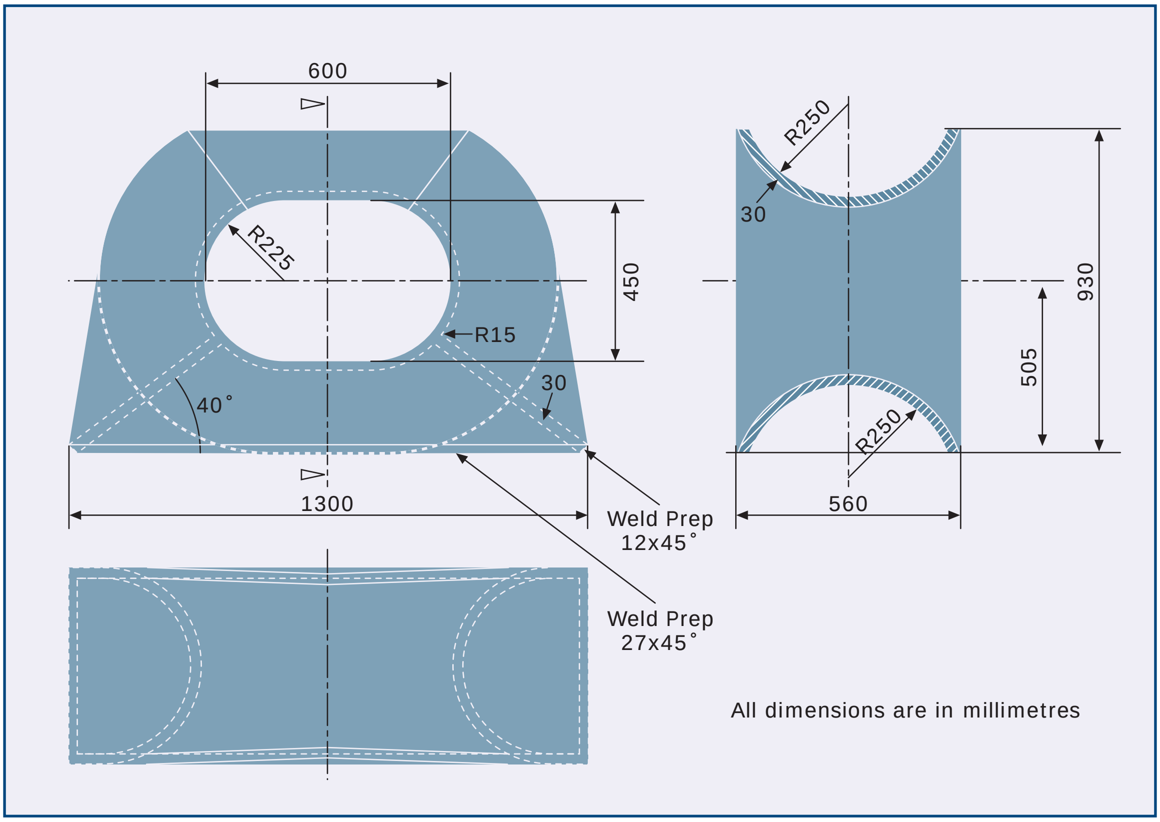


Figure 8.2: Closed Chock

8.5 Roller Fairleads and Pedestal Fairleads

The rollers resemble sheaves and may be mounted near the edge of the deck to serve as mooring fairleads or they may be mounted upon a pedestal elsewhere on the deck to provide a fair lead to a winch drum or warping drum. Deckside roller fairleads may be of the open or closed type. In the case of the open type, the roller pin is a cantilever attached at the base only. Almost all pedestal fairleads are of the cantilever pin type. Experience has shown that the cantilever pin and its attachment are very critical. Pin failure has been the cause of serious accidents. Pedestal fairleads have also failed at the pedestal-to-deck connection due to improper design or workmanship.

Roller fairleads and pedestal fairleads should be designed to meet the strength requirements contained in Section 4.4 and undergo a formal type-approval process.

8.6 Universal Roller Fairleads

Universal roller fairleads consist of several cylindrical rollers, or a combination of rollers and curved surfaces. Possible arrangements are shown in Figures 8.3, 8.4 and 8.5

The basic four-roller type may have to be modified to suit extreme inboard or outboard line angles. Sometimes the inboard lead to the winch or bitts requires an additional vertical roller or, in rare cases, two additional vertical rollers as shown in Figure 8.5. Extreme outboard angles can be accommodated with chafe plates as shown in Figure 8.4.

Some line angles are impractical and seldom occur. For example, the inboard lead seldom runs in an upward direction and the outboard angle is upward only at terminals with a large difference in tide or when moored in canal locks. In this case, the Type C shown in Figure 8.2 would be adequate and result in a lower overall height of the fairlead.

Care should be taken when installing fairleads on sloping bulwarks, such as those in the bow area, to avoid line chafing at the upper outboard edge of the frame. Type A-2 or A-3 of Figure 8.4 would be suitable for this case.

Apart from line leads, the following considerations apply when selecting universal fairleads:

- **Roller diameter** A small diameter will reduce the strength of the line (refer to Section 6.2.4). For use with wire rope with independent wire rope core, the roller diameter should be about 12 times the rope diameter. For synthetic ropes, including HMPE, advice should be sought from the rope manufacturer
- **Opening size (dimensions W1 and W2 in Figure 8.3)** The minimum size is determined by the space required to pass the eye of the line or end fittings (such as those required for tails) through the fairlead. The following minimum dimensions are recommended:

  Width = 7 x d (wire and HMPE)
  4 x d (conventional synthetic fibre)

  Depth = 6 x d (wire and HMPE)
  2 x d (conventional synthetic fibre)

- **Strength** should be the main criterion. The recommended strength criteria are shown in Section 4.4.6 and 4.4.7. Many existing designs do not comply with these criteria. Often the frame is not strong enough to resist longitudinal forces such as those applied to spring lines. Adequate frame strength, in the areas indicated by the letter 'K' in Figure 8.3, should therefore be provided by the designer to ensure that the fitting is suitable for such applications
- **Installation/material** As mentioned in Section 5, the type of frame construction can seriously affect the ease of installation. Designs with a closed base member effectively connecting the end posts are preferable. Also, if the frame is made of steel of higher strength than the adjoining hull structure, elaborate hull reinforcements will be required.

All rollers should have lubrication-free bearings or bush bearings provided with grease nipples and provisions for turning.

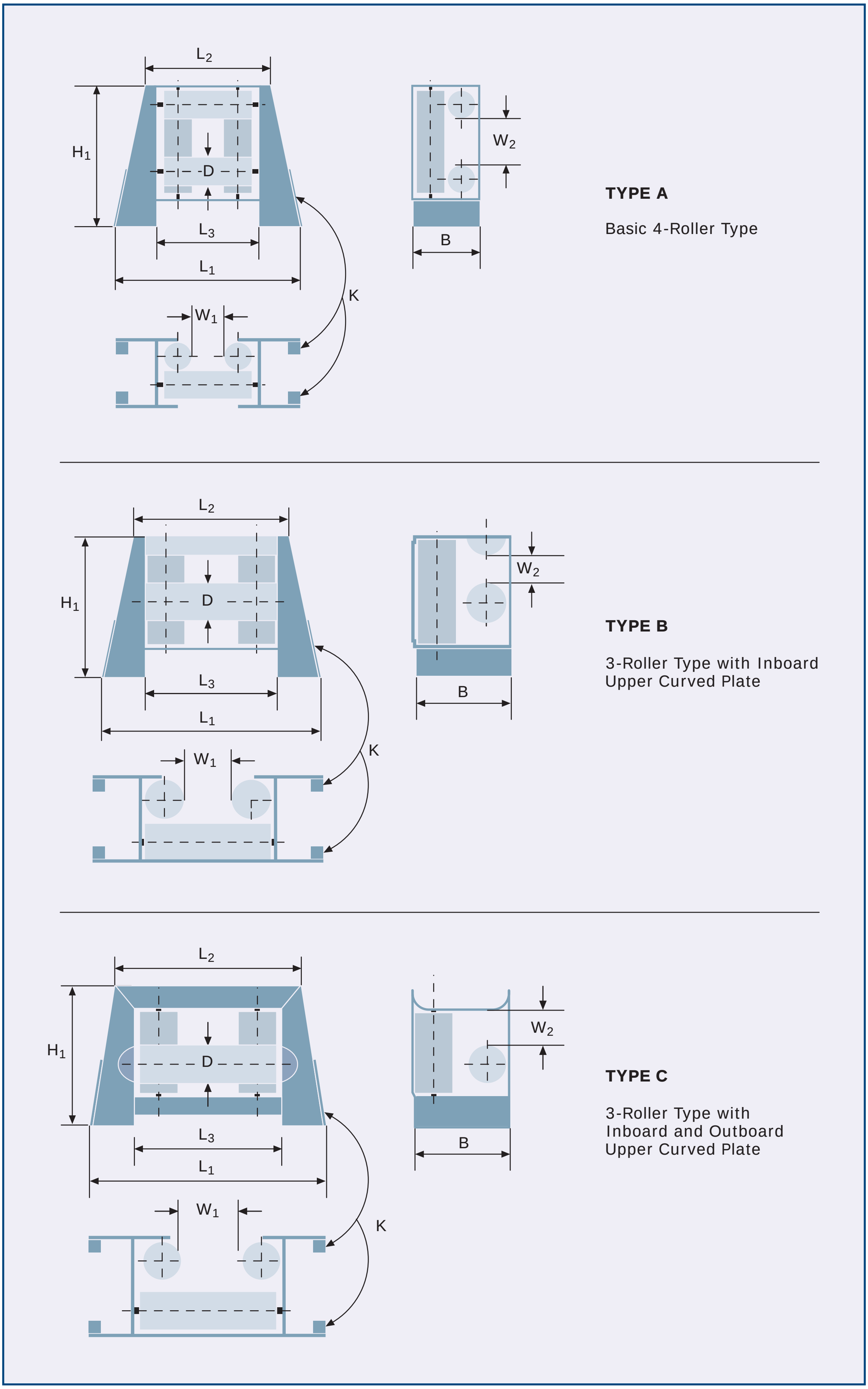


Figure 8.3 : Types of Universal Roller Fairleads

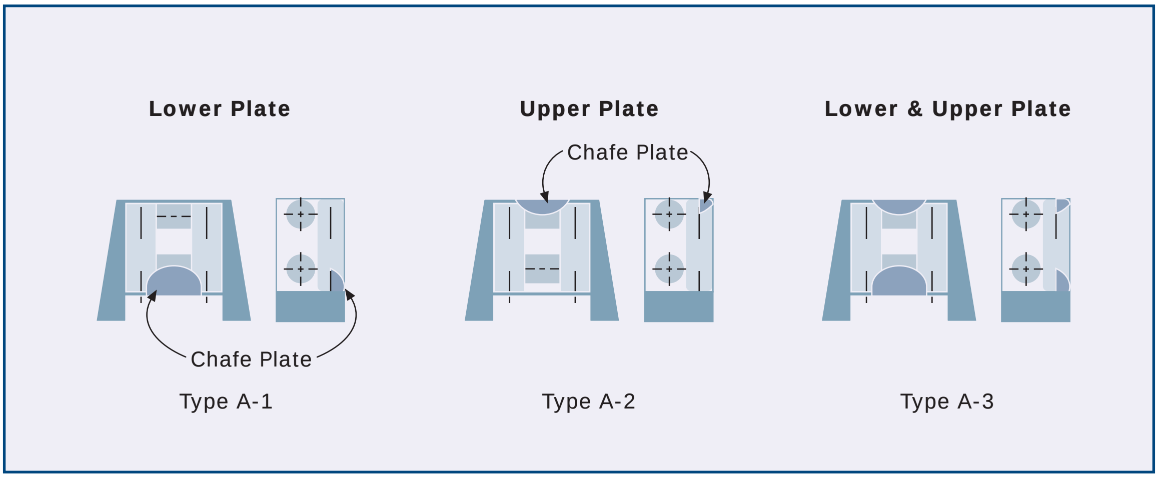


Figure 8.4 : Additional Chafe Plates for Type A Fairleads

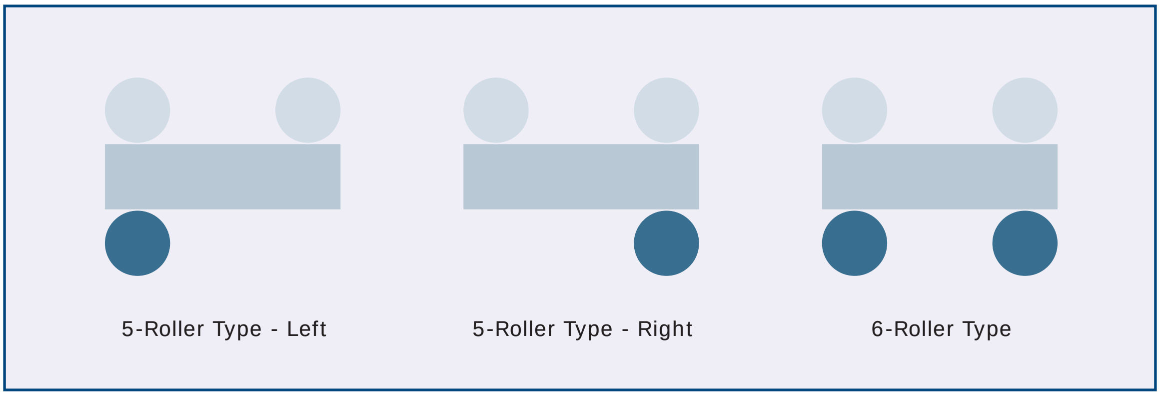


Figure 8.5 : Universal Fairleads with Additional Inboard Rollers

8.7 Selection of Fitting Type

At the ship design stage, a decision should be taken regarding the types of fairleads employed at the shipside for use with mooring lines. Roller-type chocks result in less line wear and improve the winch hauling capacity because they reduce friction between line and chock. On the other hand, roller-type fittings require more maintenance and can be very large if the rollers are of proper size for the intended service. A large bend radius is much easier to realise in Panama-type chocks and for this reason they are often used in combination with winch-mounted wire ropes.

Winch-mounted conventional fibre lines should ideally be used with properly maintained roller-type fairleads, since the friction created by the fixed fairleads can lead to rapid line damage. However, it has been shown that HMPE ropes, due to their low coefficient of friction, may not turn the roller leads, even if well maintained. In such situations, rapid line wear may result.

B.1 Introduction

This Appendix has been prepared as background to the treatment of rope over-strength in this 3rd edition of *Mooring Equipment Guidelines*. It was prompted by concern about the fact that HMPE ropes show an increase in strength above MBL during the early part of their service life. This over-strength could typically be apparent for many months on a mooring line designed for a service life of 10 to 15 years.

This Appendix considers the implications of this over-strength for fitting design for new ships and for fittings when wire ropes are to be replaced by HMPE on an existing ship. For original equipment, it is possible to increase the size of fittings to carry the maximum strength of the rope rather than its MBL, but for replacement ropes this is rarely an option. The guiding principle of Section 4 is that fittings should be able to carry rope breaking load without permanent deformation. It is considered essential to maintain this principle even when over-strength ropes are in use. It is therefore necessary to make an informed choice between simply accepting rope over-strength in the existing recommendations or amending them by adding a factor to recommend extra strength in fittings carrying potentially over-strength ropes.

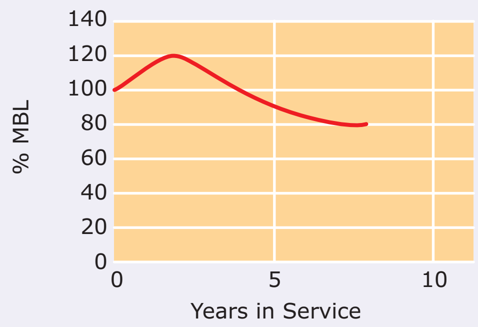


Figure B1 : Depiction of HMPE Mooring Line Residual Strength

There are two aspects to this problem, one being the loading applied by the rope and the other the strength or resistance of the fitting. Both of these are subject to statistical variations of various types. The loading, based as it is on rope breaking load, is also time dependent.

It should also be noted that rope manufacturers catalogue minimum breaking strengths using different methods. For example, ISO shows MBL as unspliced strength whereas USA manufacturers use spliced strength. In addition, some manufacturers catalogue average minimum break strength whereas others use 2 standard deviations below lowest actual break strength. This can result in variations of up to 20% above catalogue strengths when new. For the purposes of these guidelines, the ISO definition has been adopted.

B.2 Loading

The breaking of a mooring rope on a fitting is a rare event. The objective of *Mooring Equipment Guidelines* is to provide guidance on how to ensure that fitting failure is very rare. A given fitting on a given ship has a very small chance of experiencing a rope failure during the life of a ship. Because the odds against experiencing more than one rope failure on a given fitting during a ship's life are so high, a large safety margin against permanent deformation of a fitting is not necessary even though the consequences of fitting failure may be very serious.

The actual load needed to break a rope is influenced by a number of factors:

- MBL for a new rope is the minimum guaranteed value in a population of breaking load values with a mean value greater than the MBL and a standard deviation about the mean
- **Rope Type** Steel wire has less variability (smaller standard deviation) than fibre rope
- **Age** The strength of all rope types eventually declines with age. The HMPE problem is that there is an initial increase of strength of around 20% as the rope works in from new
- strength in an in-line tensile test is higher than that obtained in a test over a curved surface, where strength reductions of 15% can occur at D/d ratios of 8 or less, and such ratios occur in a number of fitting types. Even on a winch, with a more benign D/d ratio, strength reductions are known to occur.

B.3 Resistance

The calculated ability of a fitting to withstand, without permanent deformation, the force exerted on it by a breaking rope is influenced by:

- The refinement of the calculation model employed
- the fact that the actual yield strength is larger than the specified minimum yield stress (SMYS). The SMYS is, in fact, the minimum of a population of yield stress values with a mean value, by definition, larger than the minimum and a standard deviation about the mean. For steels, the variability can be quite large, particularly in thin sections and plate
- the use of 85% of SMYS as the limit on the stresses caused by the load on the fitting. This concentration on linear elasticity and avoidance of yield overlooks all the benefits of the well-known ductility of steel. Reaching yield stress at hot spots (as long as it is not done repeatedly) does not mean that there is no strength reserve available. For example, if a rather thick-walled tube in bending (e.g. a bollard) reaches surface yield at a bending moment of, say, 100 kNm, it will continue to accept increasing bending moments up to about 130 kNm before the entire cross-section has reached yield and a ´plastic hinge` forms with deformation growing at constant moment. Even then strain hardening provides further reserves of strength. The ratio of 1.3 rises to 1.5 for solid rectangular cross-sections although it is smaller for structural I-sections. In terms of bending moment, the ratio of 1.3 to 0.85 is close to 1.5, so that the real reserve against noticeable permanent deformation at 85% of yield is not a factor of 1.18 but one of 1.5. Values close to 1.5 apply for shear loading, although for pure tension the factor of 1.18 would be more appropriate. Fortunately pure tension does not often occur in typical fittings
- in passing, there is no such thing as a welded structure where yield is not present from day one. Any deposit of weld metal is brought into tensile yield as it cools. Some of these stresses may be shaken out by service loads on the structure.

This all suggests that it would not be surprising if test results for fittings designed to the 85% of yield criterion in Section 4 showed reserves of strength of 50% or more above the design load before permanent deformation was noted and even greater reserves before fracture occurred.

B.4 Comparison of Resistance and Loading

The preceding remarks above show that loading and resistance are statistical distributions with loading having time dependence as the rope ages. The objective is to minimise the overlap between the upper tail of the loading distribution and the lower tail of the resistance distribution. In minimising rather than eliminating, expensive over-design of fittings is avoided.

The worst case scenario seems to involve an HMPE rope breaking at that point in its life when it has maximum over-strength. In round figures, this point is 1.2 MBL reduced by a minimum of 10% for curved surfaces. The designed resistance factor is 1.18 on yield and up to 1.5 allowing for spread of plasticity short of permanent deformation. Even comparing 1.2 MBL (with some reduction due to the curved surface effect) and 1.18 on yield, there does not seem to be a real problem for an event that occurs so rarely on any given fitting. With ductility considered and the fact that the over-strength persists for only a fraction of the rope service life, it seems extremely unlikely that fitting failure will ever precede rope failure, even if HMPE ropes are used to replace original equipment of a similar rating at some stage in the life of a ship. There appears to be a more than adequate reserve to cope with the worst case where a stronger than expected rope is placed on a fitting whose steel is only just up to the specified minimum yield stress.

It is also worth noting that fitting failure has apparently been a very rare occurrence in the experience of operators in recent years, much rarer than the already rare rope failures. This would suggest that the safety criteria of the 2nd edition of *Mooring Equipment Guidelines* have given good service and can be carried forward to the 3rd edition, following careful review, with some confidence.

B.5 Conclusion

In the light of the discussion presented above, it was concluded that it was not necessary to add a specific factor in the revision of Section 4 to cope with rope over-strength in the early service life of HMPE ropes.