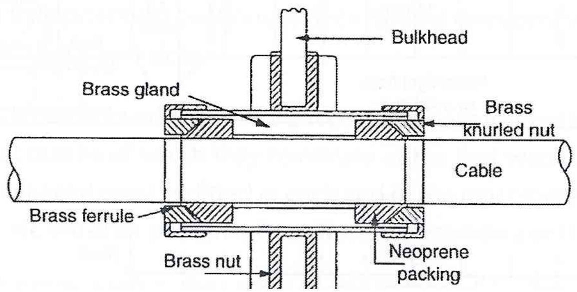
the bulkhead is to be designed to withstand such a force, it may be expected that the plating on the lower part of the bulkhead is thicker than that at the top. The bulkheads are supported by vertical stiffeners spaced 760 mm apart. Any variation in this spacing results in variations in size of stiffeners and thickness of plating. The ends of the stiffeners are usually bracketed to the tank top and deck although in some cases the brackets are omitted, resulting in heavier stiffeners.

The stiffeners are in the form of either bulb plates or toe welded angles. It is of interest to note that since a welded bulkhead is less liable to leak under load, or alternatively it may deflect further without leakage, the strength of the stiffeners may be reduced by 15%. It may be necessary to increase the strength of a stiffener which is attached to a longitudinal deck girder in order to carry the pillar load.

The May 2010 revision of IACS rules requires that bulkheads are tested for watertightness by the application of a hydrostatic test. If this is not possible, then hydropneumatic testing can be used. This is where a tank is part filled with water and then pressurised with the use of compressed air. If neither of these methods are feasible, then they can be tested using water pressure of 200 kN/m^2 from a hoes with a nozzle of at least 12 mm diameter applied from a distance of no more than 1.5 metres.

The hose test is carried out from the side on which the stiffeners are attached. It is essential that the structure should be maintained in a watertight condition. If it is found necessary to penetrate the bulkhead, precautions must be taken to ensure that the bulkhead remains watertight. If the after engine room bulkhead is penetrated by the main shaft, which passes through a watertight gland, and by an opening leading to the shaft tunnel, then this opening must be fitted with a sliding watertight door.

When pipes or electric cables pass through a bulkhead, the integrity of the bulkhead must be maintained. Figure 6.2 shows a bulkhead fitting in the form of a watertight gland for an electric cable.



In many insulated ships, ducts are fitted to provide efficient circulation of cooled air to the cargo spaces. The majority of such ships are designed so that the ducts from the hold spaces pass vertically through the deck into a fan room, separate rooms being constructed for each hold. In these ships it is not necessary to penetrate any transverse bulkhead with a duct. In some cases, however, it is necessary to penetrate the bulkhead in which case a sliding watertight shutter must be fitted.

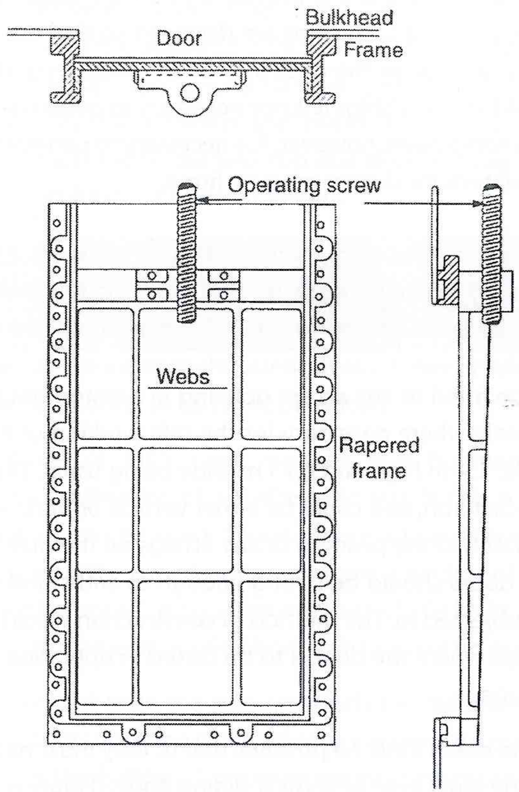
Watertight Doors

A watertight door will be fitted to any access opening in a watertight bulkhead. Such openings must be cut only where necessary for the safe working of the ship and are kept as small as possible, 1.4 m high and 0.75 m wide being usual. The doors may be mild steel, cast steel or cast iron, and could be either vertical or horizontal sliding, the choice being usually related to the position of any fittings on the bulkhead. The latest class rules are that the doors should be strong enough to withstand the pressure of water that it could be subjected to. The method of construction would be a matter for the designer but on ships where the door is to be closed in operation at sea the door must be of the sliding type.

The means of closing the doors must be positive, that is, they must not rely on gravity or a dropping weight. The older type of vertical sliding doors (Figure 6.3) are closed by means of a vertical screw thread which turns in a gunmetal nut secured to the door. The screw is turned by a spindle which extends above the bulkhead deck, fitted with a crank handle allowing complete circular motion. A similar crank must be fitted at the door. The door runs in vertical grooves which are tapered towards the bottom, the door having similar taper, so that a tight bearing fit is obtained when the door is closed. Brass facing strips are fitted to both the door and the frame. There must be no groove at the bottom of the door to collect dirt which would prevent the door fully closing. An indicator must be fitted at the control position above the bulkhead deck, showing whether the door is open or closed.

A horizontal sliding door is shown in Figure 6.4. It could be operated by means of an electric motor 'A' which turns a vertical shaft 'B'. However, the more usual arrangement is by using a hydraulic system.

Near the top and bottom of the door, horizontal screw shafts 'C' are turned by the vertical shaft through the bevel gears 'D'. The door nut 'E' moves along the screw shaft

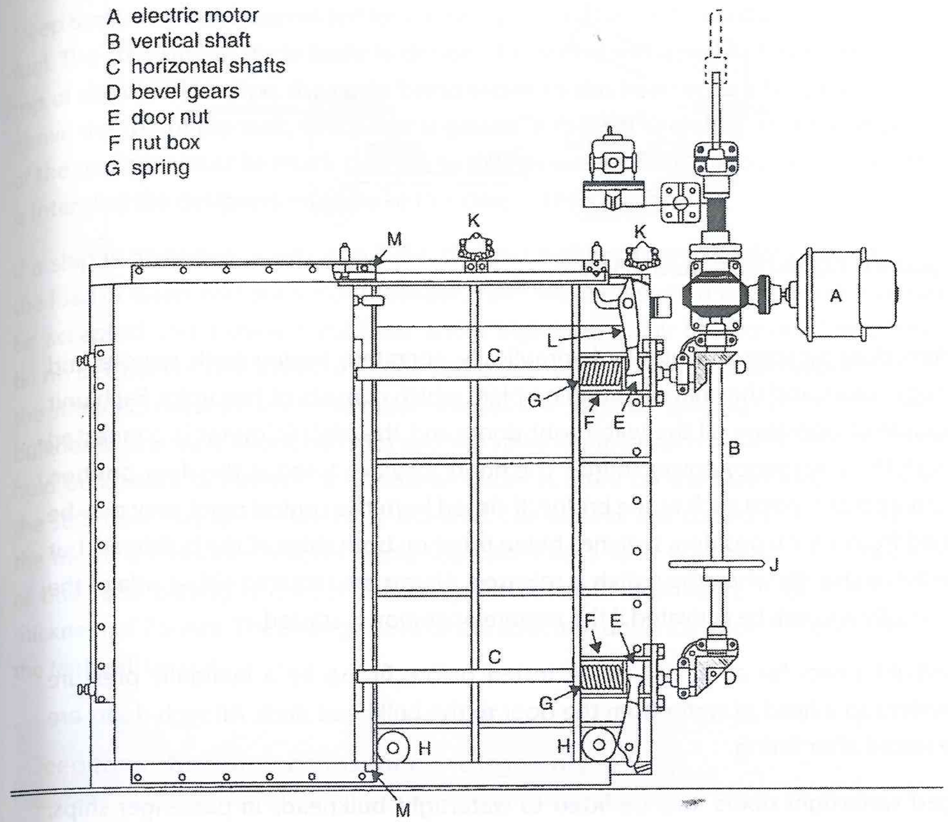


▲ **Figure 6.3** *Vertical sliding watertight door*

The door may be opened or closed manually at the bulkhead position by means of a handwheel J, the motor being automatically disengaged during this operation. An alarm bell gives a warning 10 s before the door is to close and while it is being closed. Opening and closing limit switches K are built into the system to prevent overloading of the motors.

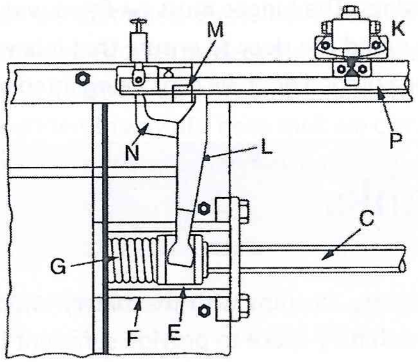
A de-wedging device (Figure 6.5) may be fitted to release the door from the wedge frame and to avoid overloading the power unit if the door meets an obstruction. As the door-operating shaft turns, the spring-loaded nut E engages a lever L which comes into contact with a block M on the door frame. As the nut continues to move along the shaft, a force is exerted by the lever on the block, easing the door out of the wedge. Should a solid obstruction be met, the striker N lifts a switch bar P and cuts

A electric motor
B vertical shaft
C horizontal shafts
D bevel gears
E door nut
F nut box
G spring

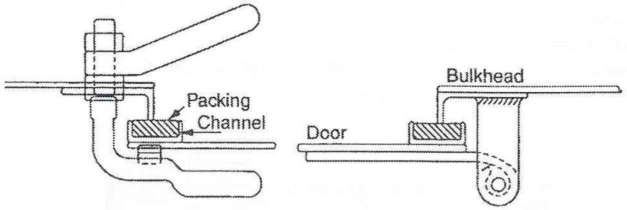


▲ **Figure 6.4** *Horizontal sliding watertight door*

H rollers
J handwheel
K limit switches
L de-wedging lever
M de-wedging block
N striker•
P swtich bar



▲ **Figure 6.5** *De-wedging device*



▲ **Figure 6.6** *Clip and hinge watertight door*

Modern door systems are usually hydraulically operated, having both remote and local operation, and they have a pumping plant which consists of two units. Each unit is capable of operating all the watertight doors and the electric motor is connected through the emergency power source. The doors may be closed at the door position or from a control point such as the bridge. If closed from the control point they may be opened from a local position, switches being fitted on both sides of the bulkhead, but close automatically when the switch is released. Alarms are required either side of the door locally and will be activated if the remote operation is started.

Watertight doors for all ships can be tested before fitting by a hydraulic pressure equivalent to a head of water from the door to the bulkhead deck. All such doors are hose tested after fitting.

Hinged watertight doors may be fitted to watertight bulkheads in passenger ships, above decks which are 2.2 m or more above the load waterline. Similar doors are fitted in cargo ships to weather deck openings which are required to be watertight. The doors are secured by clips which may be fitted to the door or to the frame. The clips are forced against brass wedges. The hinges must be fitted with gunmetal pins. Some suitable packing is fitted round the door to ensure that it is watertight. Figure 6.6 shows the hinge and clip for a hinged door, six clips being fitted to the frame.

Deep Tanks

It might be necessary, in ships with machinery amidships, to arrange a deep tank forward of the machinery space to provide sufficient ballast capacity in order to help trim the vessel correctly. This deep tank might also be designed to allow dry cargo to be carried and some ships may carry vegetable oil or oil fuel as cargo; however no

Deep tanks may also be provided for the carriage of oil fuel to be used as a ship's bunker fuel. The structure in these tanks is designed to withstand a head of water up to the top of the overflow pipe, the tanks being tested to this head or to a height of 2.44 m above the top of the tank, whichever is greater. It follows, therefore, that the strength of the structure must be much superior to that required for dry cargo holds. Where this is intended the designers must make this clear in their plans.

If a ship is damaged in way of a hold, the end bulkheads are required to withstand the load of water without serious leakage. Permanent deflection of the bulkhead may be accepted under these conditions and a high stress may be allowed. There must be no permanent deflection of a tank bulkhead, however, and the allowable stress in the stiffeners must therefore be much smaller. The stiffener spacing on the transverse bulkheads is usually about 600 mm and the stiffeners are much heavier than those on hold bulkheads. If, however a horizontal girder is fitted on the bulkhead, the size of the stiffeners may be considerably reduced. The ends of the stiffeners are bracketed, the toe of the bottom bracket being supported by a solid floor plate. The thickness of bulkhead plating is greater than required for hold bulkheads, with a minimum thickness of 7.5 mm. The arrangement of the structure depends upon the use to which the tank will be put.

Deep tanks for water ballast or dry cargo only

A water ballast tank should be either completely full or empty while at sea and therefore there should be no movement of water. The side frames are increased in strength by 15% unless horizontal stringers are fitted, when the frames are reduced. If such stringers are fitted, they must be continued across bulkheads to form a ring. These girders are substantial, with stiffened edges. The deck forming the top of a deep tank may be required to be increased in thickness because of the increased load due to water pressure. The beams and deck girders in way of a deep tank are calculated in the same way as the bulkhead stiffeners and girders and therefore depend upon the head to which they are subject.

Deep tanks for oil fuel, oil cargo or fresh water

A partially full deep tank carrying oil or water will have a free surface and will therefore be subjected to dynamic forces. In the case of an oil fuel or fresh water bunker tank the tank may cause damage to the structure. To reduce this surging it is necessary to fit divisions or deep swashes to minimise the dynamic stresses caused by this arrangement.

These divisions may be intact, in which case they must be as strong as the boundary bulkheads, or perforated, when the stiffeners may be considerably reduced. The perforations must be between 5% and 10% of the area of the bulkhead. Any smaller area would allow a build-up of pressure on one side, for which the bulkhead is not designed, while a greater area would not reduce surging to any marked extent.

Sparring must be fitted to the cargo side of a bulkhead which is a partition between a bunker and a hold. If a settling tank is heated and is adjacent to a compartment which may carry coal or cargo, the structure outside the tank must be insulated. Figure 6.7 shows the structural arrangement of a deep tank which may be used for oil or dry cargo.

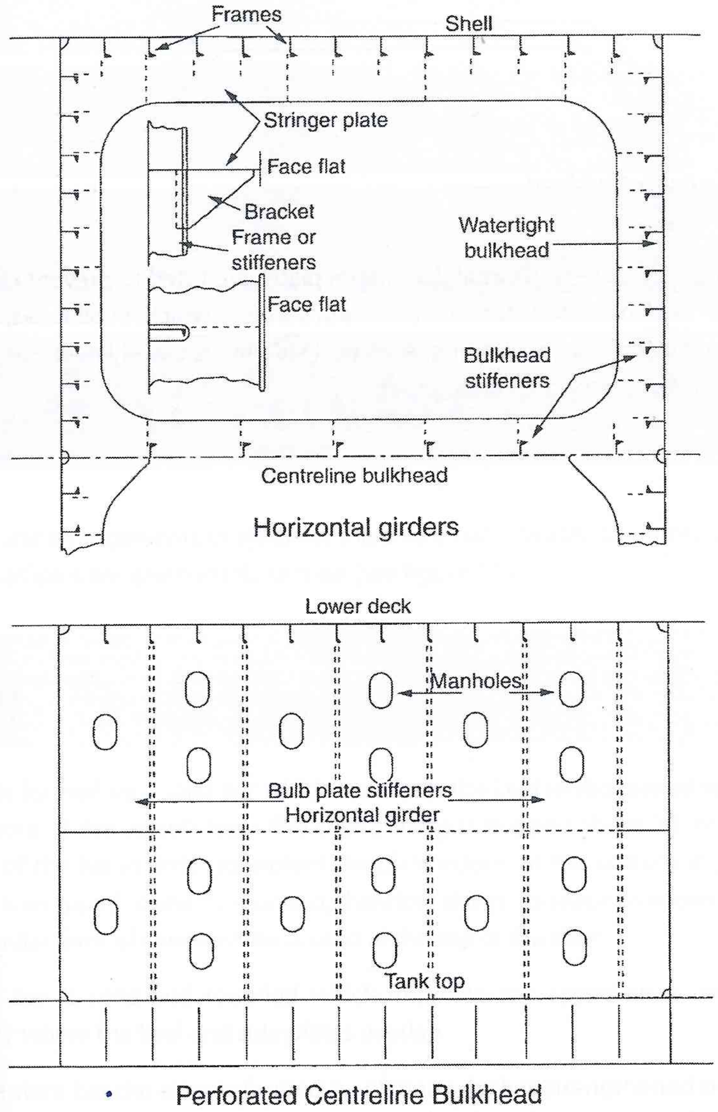
If dry cargo is to be carried in a deep tank, one or two large watertight hatches are required in the deck as described in Chapter 5.

Non-watertight Bulkheads

Any bulkhead which does not form part of a tank or part of the watertight subdivision of the ship may be non-watertight. Many of these bulkheads are fitted in a ship, forming engine casings and partitions in accommodation. 'Tween deck bulkheads fitted above the freeboard deck may be of non-watertight construction, while many ships are fitted with partial centreline bulkheads if grain is to be carried. Centreline bulkheads and many deck-house bulkheads act as pillars supporting beams and deck girders, in which case the stiffeners are designed to carry the load. The remaining bulkheads are lightly stiffened by angle bars or welded flats.

Corrugated Bulkheads

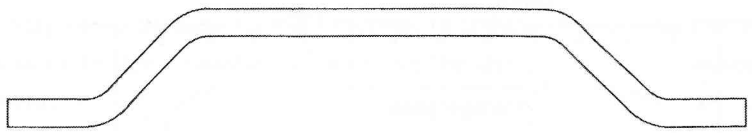
A corrugated plate is stronger than a flat plate if subjected to a bending moment or pillar load along the corrugations. This principle may be used in bulkhead construction, when the corrugations may be used to dispense with the stiffeners (Figure 6.8), resulting in a considerable saving in weight. The troughs are vertical on transverse



▲ **Figure 6.7** *Horizontal girders and perforated centreline bulkhead*

with adequate support to avoid stress concentrations. They should be supported by floors or girders with the stiffening members providing additional support if necessary.

A load acting across the corrugations will tend to cause the bulkheads to fold in concertina fashion. It is usual, therefore, on transverse bulkheads to fit a stiffened flat



▲ Figure 6.8 *Corrugated bulkhead*

of the shell is considerable. Horizontal diaphragm plates are fitted to prevent collapse of the troughs. These bulkheads form very smooth surfaces which, in oil tanks, allows improved drainage and ease of cleaning. A vertical stiffener is usually necessary if the bulkhead is required to support a deck girder.

7 FORE END ARRANGEMENTS

The structural arrangements of different ships vary considerably, therefore typical and general examples are given in this section (see figure 7.1).

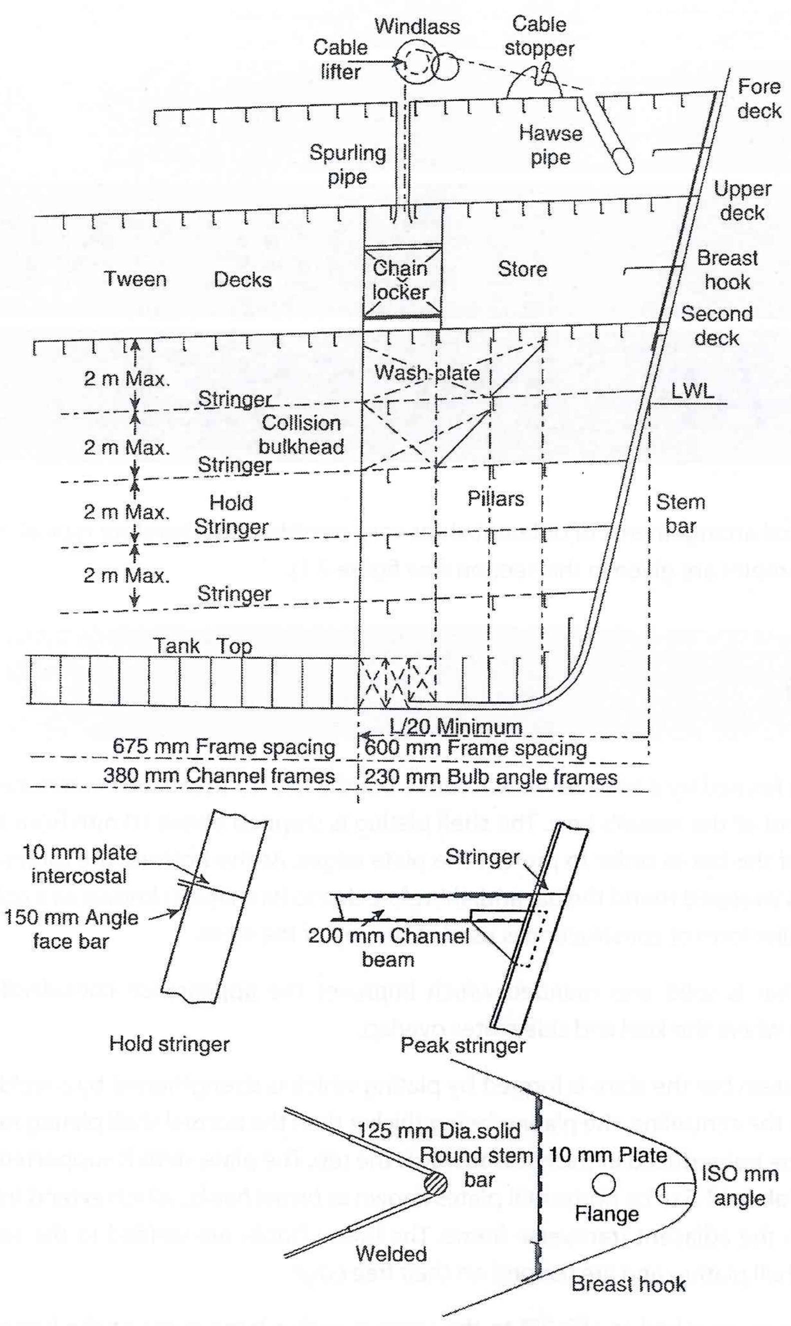
Stem

The stem is formed by a solid bar which runs from the keel to the loaded waterline at the very front of the vessel's bow. The shell plating is stopped about 10 mm from the fore edge of the bar in order to protect the plate edges. At the bottom, the foremost keel plate is wrapped round the bar and, therefore due to its shape, is known as a *coffin plate*. A similar form of construction is used at the top of the stem.

The 'stem' bar is solid and rounded which improves the appearance considerably, particularly where the keel and side plates overlap.

Above the stem bar the stem is formed by plating which is strengthened by a welded stiffener on the centreline, the plating being thicker than the normal shell plating near the waterline but reduced in thickness towards the top. The plate stem is supported at intervals of about 1.5 m by horizontal plates known as *breast hooks*, which extend from the stem to the adjacent transverse frame. The breast hooks are welded to the stem plate and shell plating and are flanged on their free edge.

Modern stems are raked at 15°–25° to the vertical, with a large curve at the bottom, running into the line of the keel. Above the waterline some stems curve forward of the



▲ **Figure 7.1** *Fore end construction*

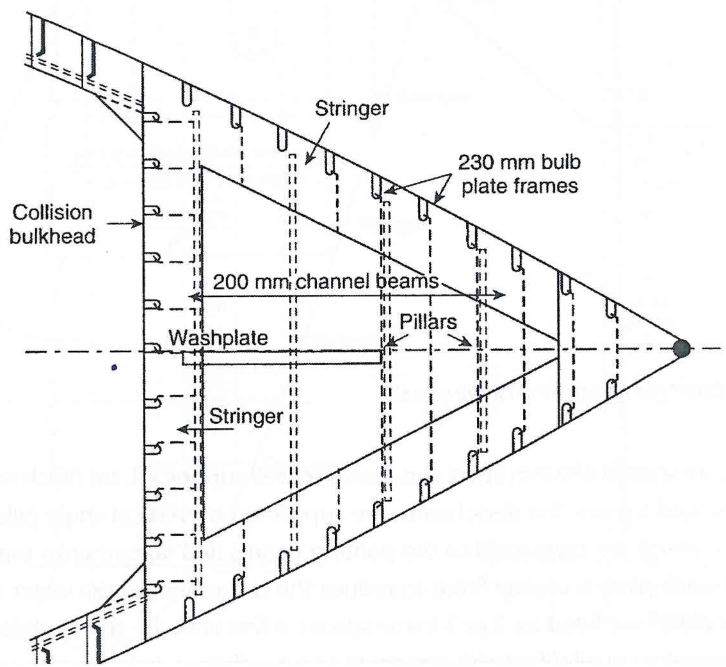
pitching motion of the ship. This increase in area in turn increases the ship's buoyancy thus helping to resist the pitching, and the additional forces must be taken into account when calculating the maximum bending moment caused by wave action. The downside of this arrangement is the added possibility of damage due to pounding.

Studies into a condition known as 'parametric rolling' have found that it comes about due to this fluctuating change in the transverse stability which in turn is encouraged by the changes in the waterplane area due to the vessel pitching.

Arrangements to Resist Panting

The structure of the ship is strengthened to resist the effects of panting from 15% of the ship's length from forward to the stem and aft of the after peak bulkhead.

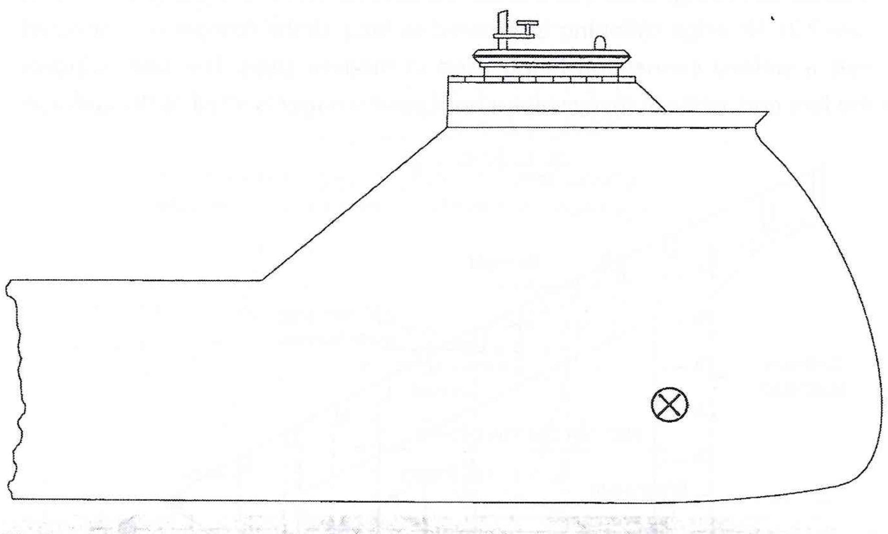
In the fore peak, side stringers are fitted to the shell at intervals of 2 m below the lowest deck (Figure 7.2). No edge stiffening is required as long as the stringer is connected to the shell, a welded connection being used in modern ships. The side stringers meet at the fore end, while in many ships a horizontal stringer is fitted to the collision



bulkhead in line with each shell stringer. This forms a ring round the tank and supports the bulkhead stiffeners. Channel beams are fitted at alternate frames in line with the stringers, and connected to the frames by brackets. The intermediate frames are bracketed to the stringer. The free edge of the bulkhead stringer may be stiffened by one of the beams. In fine ships it is common practice to plate over the beams, lightening holes being punched in the plate.

The tank top is not carried into the peak, but solid floors are fitted at each frame. These floors are slightly thicker than those in the double bottom space and are flanged on their free edge.

An interesting development is the X-BOW (see Figure 7.3) design that is being used on offshore vessels. The design gives the vessel an increasing underwater volume as the vessel pitches, similar to the flare in the bow of a conventional ship. This reduces the motion of the vessel due to wave action.

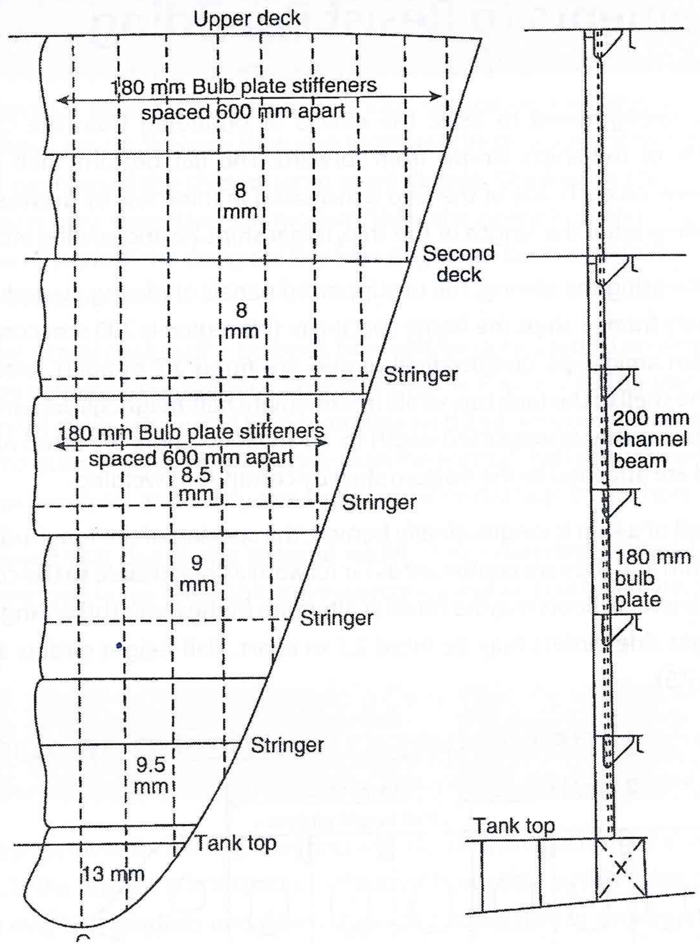


▲ **Figure 7.3** *X-Bow type design for offshore vessels*

The side frames are spaced 610 mm apart and, being so well supported, are much smaller than the normal hold frames. The deck beams are supported by vertical angle pillars on alternate frames, which are connected to the panting beams and lapped onto the solid floors. A partial wash-plate is usually fitted to reduce the movement of the water in the tank. Intercostal plates are fitted for 2 or 3 frame spaces in line with the centre girder. The lower part of the peak is usually filled with cement to ensure efficient drainage of the space

spacing of the frames from the collision bulkhead to 20% of the length from forward must be 700 mm. Light side stringers are fitted in the panting area in line with those in the peak. These stringers consist of intercostal plates connected to the shell and to a continuous face angle running along the toes of the frames. These stringers may be dispensed with if the shell plating is increased in thickness by 15%. This proves uneconomical when considering the weight but reduces the obstructions to cargo stowage in the hold. The peak is usually used as a tank and therefore such obstructions are of no importance.

The collision bulkhead is stiffened by vertical bulb plates spaced about 600 mm apart inside the peak. It is usual to fit horizontal plating because of the excessive taper on the plates which would occur with vertical plating. Figure 7.4 shows the construction of a collision bulkhead.



The structure in the after peak is similar in principle to that in the fore peak, although the stringers and beams may be fitted 2.5 m apart. The floors should extend above the stern tube or the frames above the tube must be stiffened by flanged tie plates to reduce the possibility of vibration. The latter arrangement is shown in Figure 8.8 in Chapter 8.

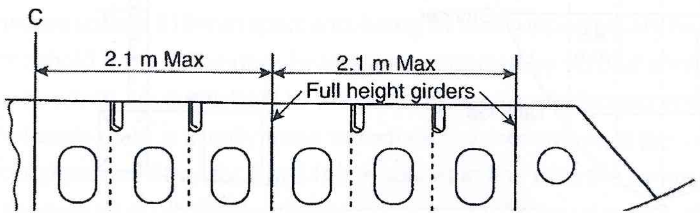
It is recommended that the bow of an ice breaking vessel is constructed without a bulbous bow. However, a vessel with limited ice breaking capacity should be constructed with added strength as detailed in the new 'polar code' that has recently been developed by the International Maritime Organization (IMO).

Arrangements to Resist Pounding

The structure is strengthened to resist the effects of pounding from the collision bulkhead to 25% of the ship's length from forward. The flat bottom shell plating adjacent to the keel on each side of the ship is increased in thickness by between 15% and 30% depending upon the length of the ship, larger ships having smaller increases.

In addition to increasing the plating, the unsupported panels of plating are reduced in size. In transversely framed ships the frame spacing in this region is 700 mm compared with 750–900 mm amidships. Longitudinal girders are fitted 2.2 m apart, extending vertically from the shell to the tank top, while intermediate half-height girders are fitted to the shell, reducing the unsupported width to 1.1 m. Solid floors are fitted at every frame space and are attached to the bottom shell by continuous welding.

If the bottom shell of a ship is longitudinally framed, the spacing of the longitudinals is reduced to 700 mm and they are continued as far forward as practicable to the collision bulkhead. The transverse floors may be fitted at alternate frames with this arrangement and the full-height side girders may be fitted 2.1 m apart. Half-height girders are not required (Figure 7.5).



Bulbous Bow

One of the most important tasks facing the designers of ships is to optimise hull performance. There are two aspects to this activity: the first is to reduce hull resistance and the second is to reduce the effect of 'wave drag'.

The act of pushing the vessel through the water will create a bow wave. If a sphere is immersed just below the surface of the water and at the bow of the ship the wave from the sphere interferes with the normal bow wave created by the vessel and results in a smaller bow wave. Thus the force required to produce the bow wave is reduced.

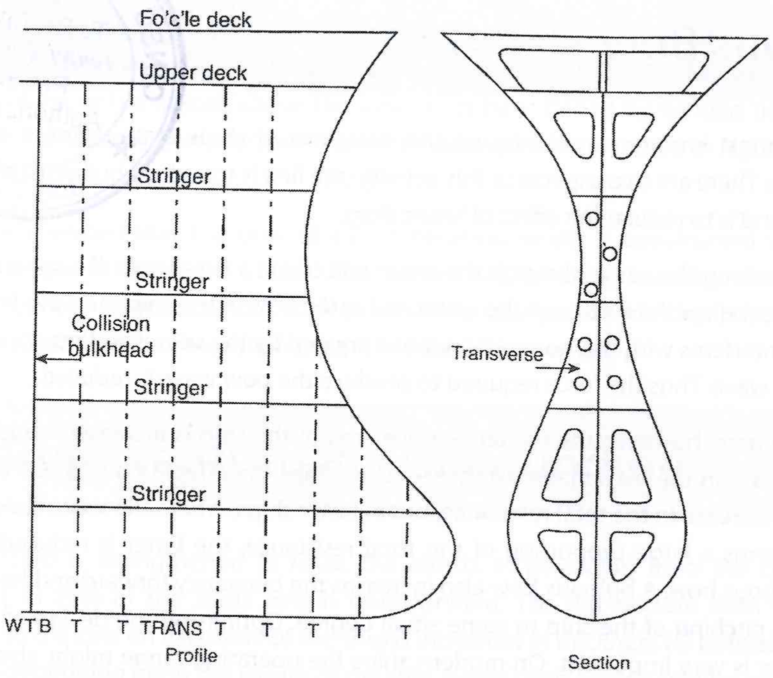
At the same time, however, the wetted surface area of the ship is increased, causing a slight increase in the frictional resistance. In slow ships the effect of a bulbous bow could be an increase in the total resistance, but in faster ships, where the wave making resistance forms a large proportion of the total resistance, the latter is reduced by fitting a bulbous bow. A bulbous bow also increases the buoyancy forward and hence reduces the pitching of the ship to some small degree. Optimising the design of the bulbous bow is very important. On modern ships the operating range might also be increased and therefore the design of the bow might not be as straight forward as first thought by the designers.

Although the actual design of a bulbous bow will be optimised to an actual vessel a typical construction of the bulbous bow is shown in Figure 7.6. The stem plating is formed by steel plates supported by a centreline web and horizontal diaphragm plates 1 m apart. The outer bulb plating is thicker than the normal shell plating, partly because of high water pressures and partly due to the possible damage by anchors and cables.

It is often found that due to the reduced width at the waterline caused by the bulb, horizontal stringers in the fore peak prove uneconomical and complete perforated flats are fitted.

Anchor and Cable Arrangements

A typical arrangement for raising, lowering and stowing the anchors of a ship is shown in Figure 7.1. The anchor is attached to a heavy chain cable which is led through the *hawse pipe* over the windlass and down through a *chain pipe* or *spurling pipe* into the



▲ **Figure 7.6** *Bulbous bow*

The hawse pipes may be constructed of mild steel tubes with castings at the deck and shell, or cast in one complete unit for each side of the ship. There must be ample clearance for the anchor stock to prevent jamming and they must be strong enough to withstand the hammering which they receive from the cable and the anchor. The shell plating is increased in thickness in way of each hawse pipe and adjacent plate edges are fitted with mouldings to prevent damage. A chafing piece is fitted to the top of each hawse pipe, while a sliding cover is arranged to guard the opening.

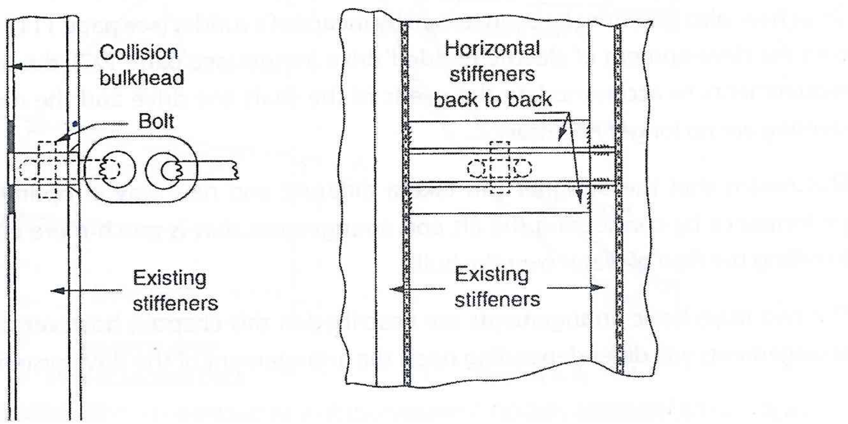
The *cable stopper* is a casting with a hinged lever, which may be used to lock the cable in any desired position and thus relieve the load from the windlass either when the anchor is out or when it is stowed.

The drums of the windlass are shaped to suit the cable and are known as *cable lifters*. The cable lifters are arranged over the spurling pipes to ensure a direct lead for the cables into the lockers. The windlass may be either steam or electric in common with the other deck auxiliaries. Warping ends are fitted to assist in handling the mooring ropes. The windlass must rest on solid supports with pillars and runners in way of the

The chain pipes are of mild steel, bell mouthed at the bottom. The bells may be of cast iron, well rounded to avoid chafing. The pipes are fitted as near as possible to the centre of the chain locker for ease of stowage.

The chain locker may be fitted between the upper and second decks, below the second deck or in the forecastle. It must be of sufficient volume to allow adequate headroom when the anchors are in the stowed position. The locker is usually situated forward of the collision bulkhead, using this bulkhead as the after locker bulkhead. The locker is not normally carried out to the ship side. The stiffeners are preferably fitted outside the locker to prevent damage from the chains. If the locker is fitted in the forecastle, the bulkheads may be used to support the windlass. A centreline division is fitted to separate the two chains and is carried above the stowed level of the chain but is not taken up to the deck. It is stiffened by means of solid half round bars while the top edge is protected by a split pipe. Foot holds are cut in to allow access from one side to the other. A hinged door is fitted in the forward bulkhead, giving access to the locker from the store space. Many lockers are fitted with false floors to allow drainage of water and mud, which is cleared by a drain plug in the forward bulkhead, leading into a drain hat from where it is discharged by means of a hand pump. The end of the cable must be connected to the deck or bulkhead in the chain locker. A typical arrangement is shown in Figure 7.7.

With this method, use is made of the existing stiffeners fitted to the fore side of the collision bulkhead. Two similar sections are fitted horizontally back to back, riveted to the bulkhead and welded to the adjacent stiffeners. A space is allowed between the horizontal bars to allow the end link of the cable to slide in and be secured by a bolt.



8 AFTER END ARRANGEMENTS

Continuing with the task of optimising hull performance the after end arrangement has been the subject of considerable focus in recent years. This is because so much of the aft end depends upon the requirements of the steering and propulsion machinery.

Traditionally ships have one or two propellers, being driven by shafts that need to project out through the hull via a seal, called the stern tube seal. The strength of the after end arrangement will be determined by:

- weight of the propeller;
- the dynamic loading; and
- the vibration analysis (including excessive conditions due to the loss of a blade).

Ships have also traditionally been turned by means of a rudder (see page 111). However with the development of electric 'podded' drive motors (see page 127), the traditional requirements to accommodate the needs of the shaft line drive and the rudders for steering are no longer necessary.

This means that the designer can take a different and new way in optimising hull performance by considering the aft end arrangement that is much more efficient at handling the flow of water over the hull.

The two main basic arrangements are described in this chapter; however the actual arrangements will differ depending upon the arrangement of the drive system.

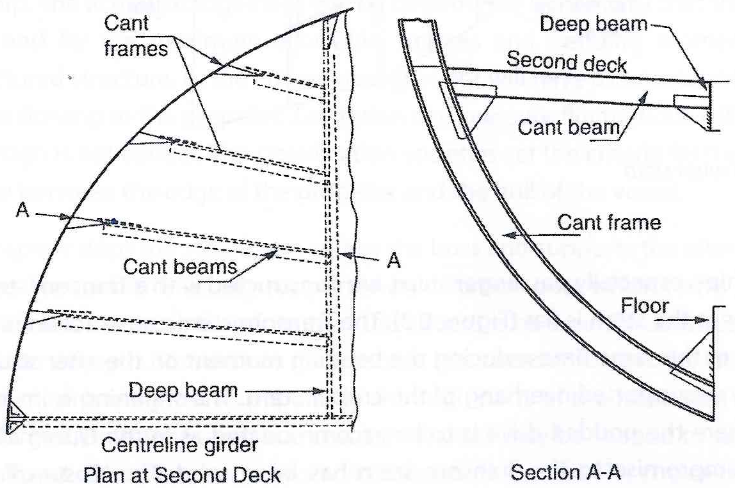
Cruiser Stern

The cruiser stern forms a continuation of the hull of the ship above the sternframe and improves the appearance of the ship. It increases the buoyancy at the after end and improves the inflow of water to the propeller disk.

This arrangement is however very susceptible to slamming and must therefore be heavily stiffened. Class rules require that the framing should be similar to that of the after peak with web frames fitted where necessary, while solid floors must be fitted, together with a centreline girder. In practice the structure is arranged in two main forms:

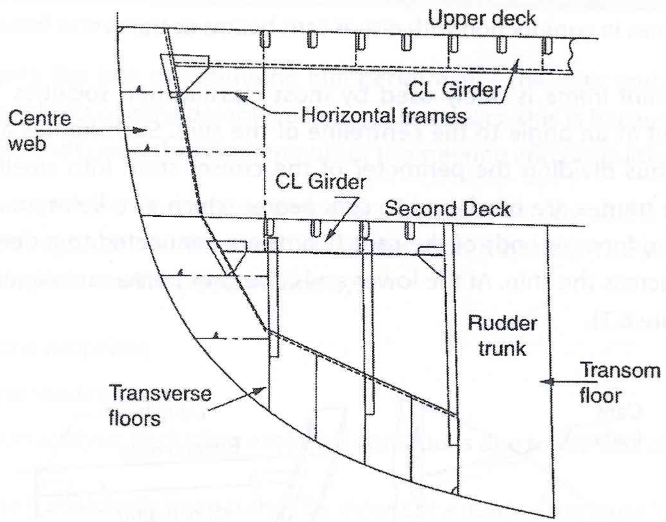
1. Cant frames in conjunction with cant beams
2. Horizontal frames in conjunction with either cant beams or transverse beams

The description *cant frame* is rarely used by most classification societies but it is a frame that is set at an angle to the centreline of the ship. Such frames are fitted 610 mm apart, thus dividing the perimeter of the cruiser stern into small panels. At the top, these frames are bracketed to *cant beams* which also lie at an angle to the centreline. The forward ends of the cant beams are connected to a deep beam extending right across the ship. At the lower ends, the cant frames are connected to a solid floor (Figure 8.1).



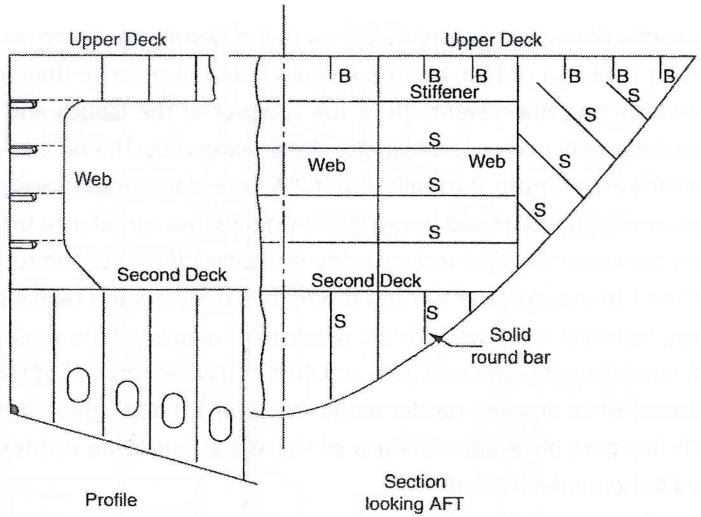
The alternative method of construction has proved very successful, particularly with prefabricated structures. The horizontal frames are fitted at intervals of about 750 mm and are connected at their forward ends to a heavier transverse frame. They are supported at the centreline by a deep web which is also required with the cant frame system. If cant beams are fitted, the end brackets are carried down to the adjacent horizontal frame.

The structure at the fore end of the cruiser stern consists of solid floors attached to vertical side frames with transverse beams extending across the decks. A watertight rudder trunk is fitted enclosing part of the rudder stock. A typical centreline view of a cruiser stern with horizontal framing is shown in Figure 8.2.



▲ **Figure 8.2** *Cruiser stern*

Many larger ships, especially passenger ships, are constructed with a Transom stern. In this arrangement the stern is flat (Figure 8.3). The Transom stern construction is more cost effective, at the same time reducing the bending moment on the after structure caused by the unsupported overhang of the cruiser stern. The stiffening is invariably horizontal. Where the podded drive is to be accommodated as in the *Queen Mary II*, a 'rounded' compromise to the Transom stern has been used. The 'Costanzi' stern improves the sea keeping ability of the ship while retaining the need for a flat underside



▲ **Figure 8.3** *Transom stern*

Sternframe and Rudder

The sternframe forms the termination of the lower part of the shell at the after end of the ship. The actual arrangement will be determined by the way that the propeller is sited and by the maximum allowable stresses and bending moments for the manufactured structure, as the aft end arrangement will have a considerable effect on the water flowing to the propeller. Cavitation and pressure fluctuations will be caused if this design is not correct. The classification societies set the criteria for the minimum clearance between the edge of the propeller and the hull of the vessel.

In single screw ships the sternframe carries the boss and supports the after end of the sterntube. The rudder is usually supported by a vertical post which forms part of the sternframe. It is essential, therefore, that the structure be soundly constructed and of tremendous strength. Sternframes may be cast, fabricated or forged, the latter method of construction having lost its popularity although parts of the fabricated sternframe may be forged. Both fabricated and cast sternframes may be shaped to suit the form of the hull and streamlined to reduce turbulence of the water. The choice of casting or fabrication in the construction of a sternframe depends upon the personal preference

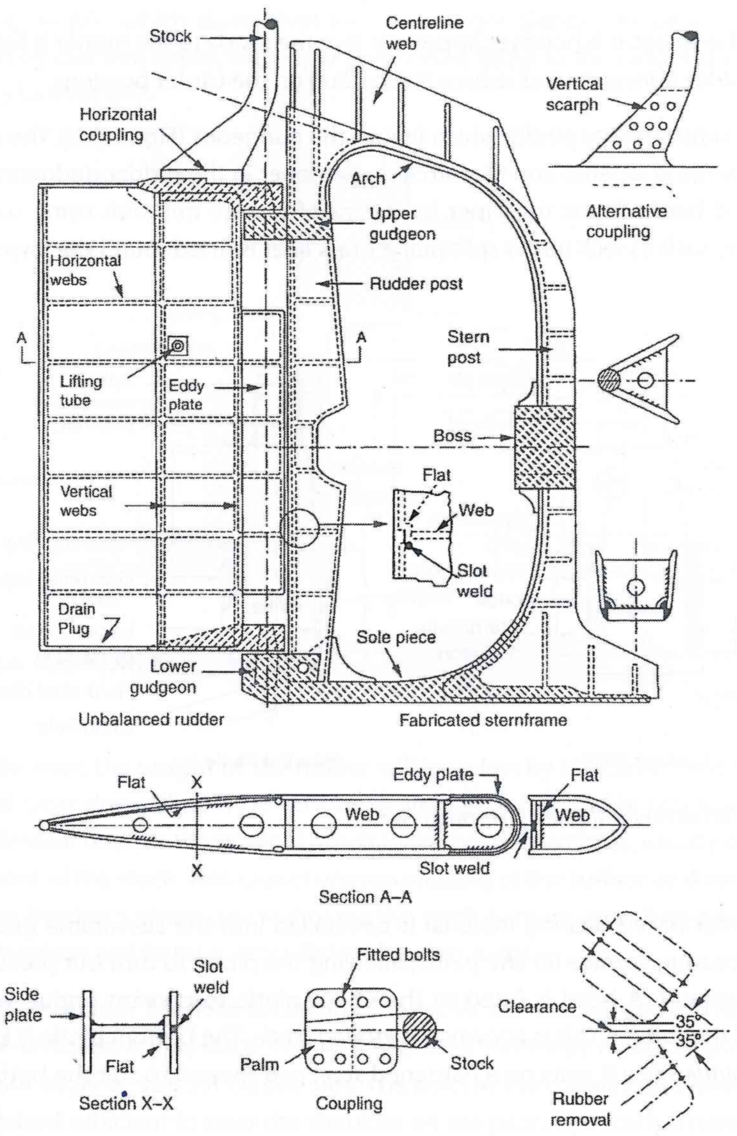
It is useful to consider the rudder in conjunction with the sternframe. There are no fixed regulations for the area of a rudder, but it has been found in practice that an area of between one-sixtieth and one-seventieth of the product of the length and draught of the ship provides ample manoeuvrability for deep sea vessels. The ratio of depth to width, known as the aspect ratio, is usually about 2. Single plate rudders were used for many years but are now seldom used because of the increased turbulence they create. Modern rudders are streamlined to reduce eddy resistance. If part of the rudder area lies forward of the turning axis, the turning moment is reduced and hence a smaller rudder stock may be fitted. A rudder with the whole of its area aft of the stock is said to be *unbalanced*. A rudder with between 20% and 40% of its area forward of the stock is said to be *balanced*, since at some rudder angle there will be no torque on the stock. A rudder which has part of its area forward of the stock, but at no rudder angle is balanced, is said to be *semi-balanced*.

Fabricated sternframe with unbalanced rudder

Figure 8.4 shows a fabricated sternframe used to support an unbalanced rudder. The *sole piece* is a forging which is carried aft to form the *lower gudgeon* supporting the bearing pintle, and forward to scarph to the aftermost keel plate which used to be known as a *coffin plate* because of its shape. The sternpost is formed by a solid round bar to which heavy plates, 25–40 mm thick, are welded, the boss being positioned to suit the height of the shaft. Thick web plates are fitted horizontally to tie the two sides of the sternframe rigidly. The side shell plates are riveted or welded to the plates forming the sternframe. This form of construction is continued to form the *arch* which joins the sternpost to the rudderpost. Vertical webs are used in this position to secure the sternframe to the floor plates, while a thick centreline web is fitted to ensure rigidity of the arch.

The rudderpost is similar in construction to the sternpost, a thick web plate being fitted at the after side, while one or more gudgeons are fitted as required to support the rudder. The web plate is continued inside the ship at the top of the rudder post and attached to a thick transom floor which is watertight.

The rudder is formed by two plates about 10–20 mm thick, connected at the top and bottom to forgings which are extended to form the upper and lower gudgeons. The upper forging is opened into a palm, forming part of the horizontal coupling. This palm is stepped to provide a shoulder which reduces the possibility of shearing the

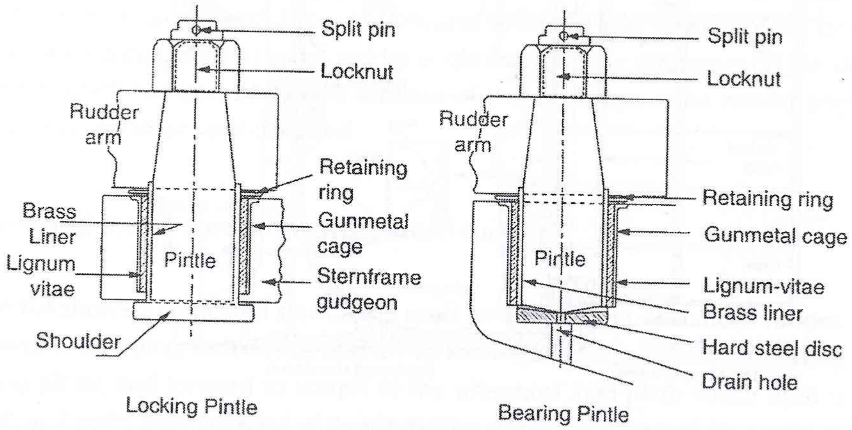


▲ **Figure 8.4** *A Fabricated Sternframe*

structure is difficult to weld due to its inaccessibility. An efficient attachment may be made by fitting a flat bar to the edge of the horizontal webs and slot welding.

One disadvantage of double plate rudders is the possibility of internal corrosion and dry-docking the vessel. It is however important that the inside to the rudder is kept dry to give the rudder buoyancy and reduce the loading on the carrier bearings.

The rudder is supported by *pintles* which fit into the gudgeons (Figure 8.5). The upper part of each pintle is tapered and fits into a similar taper in the rudder gudgeons. The pintle is pulled hard against the taper by means of a large nut with some suitable locking device, such as lock nut or split pin. A brass liner is fitted round the lower part of the pintle.



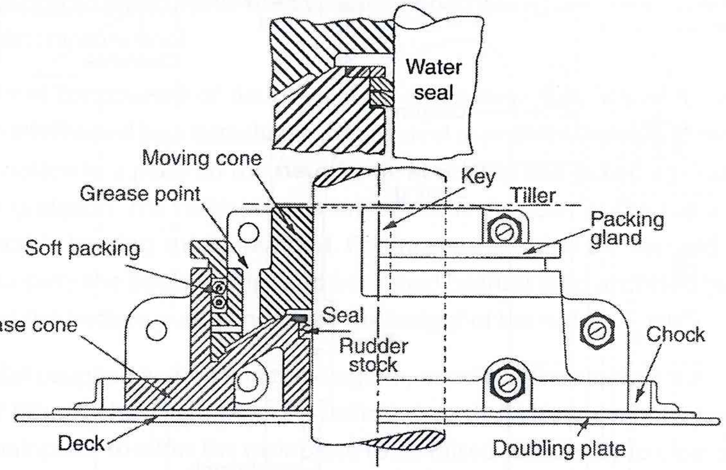
▲ **Figure 8.5** *(a) Locking pintle and (b) bearing pintle*

Modern polymer based bearing material is dovetailed into the sternframe gudgeon to provide a bearing surface for the pintle, allowing the pintle to turn but preventing any side movement. A head is fitted to the upper pintle to prevent undue vertical movement of the rudder. This is known as a *locking pintle*. The bottom pintle is known as a *bearing pintle* since it rests on a hardened steel pad shaped to suit the bottom of the pintle.

With the emphasis on environmentally friendly ships this is an important area for consideration, and the lubrication of the rudder bearings could mean that oil or grease has the potential to escape into the sea/river. Biodegradable lubricants should be used where self-lubricating polymer material is not being fitted.

The rudder is turned by means of a stock which is of forged steel, opened out into a palm at its lower end. The stock is carried through the rudder trunk and keyed to the

carriers (Figure 8.6), which themselves form watertight glands. The bearing surfaces are formed by cast iron cones, the upper cone being fitted to the rudder stock. As the bearing surfaces of the



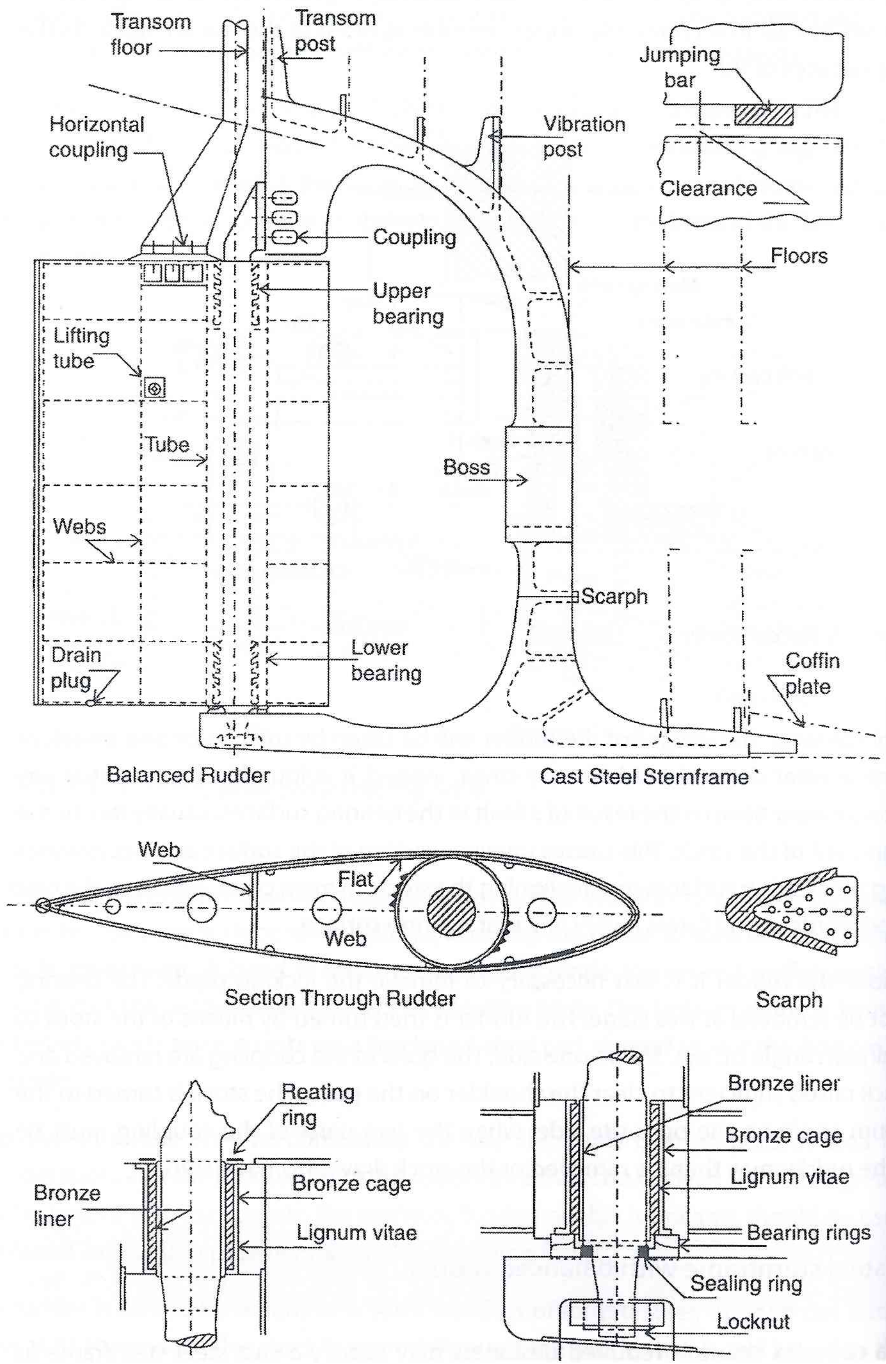
▲ **Figure 8.6** *Rudder carrier*

lower pintle wear, the weight of the rudder will be taken by the carrier, and therefore the vertical wear down should be very small. Indeed, it is found in practice that any appreciable wear down is the result of a fault in the bearing surfaces, usually due to the misalignment of the stock. This causes uneven wasting of the surface and necessitates refacing the bearing surfaces and realigning the stock. In most cases, however, the cast iron work hardens and forms a very efficient bearing surface.

To remove the rudder it is first necessary to remove the locking pintle. The bearing may not be removed at this stage. The rudder is then turned by means of the stock to its maximum angle of, say, 35° on one side. The bolts in the coupling are removed and the stock raised sufficient to clear the shoulder on the palm. The stock is turned to the maximum angle on the opposite side, when the two parts of the coupling must be clear. The rudder may then be removed or the stock drawn from the ship.

Cast steel sternframe with balanced rudder

When a complex shape is required designers may specify a cast steel sternframe as



the aftermost keel plate, while the after end forms the lower gudgeon. The sternpost is carried up inside the ship and opened to form a palm which is connected to a floor plate. This is known is a vibration post. The casting is continued aft at the top of the propeller aperture to form the arch and the upper rudder support. At the extreme after end the casting is carried inside the ship and opened into a palm which is connected to a watertight transom floor.

The rudder is constructed of double plates, with a large tube down the centre. The rudder post is formed by a detachable forged steel mainpiece which is carried through the tube, bolted to a palm on the stern frame at the top and pulled against a taper in the lower gudgeon. The main piece is increased in diameter at the top and bottom where suitable bearing strips are fitted. Castings are fitted at the top and bottom of the tube to carry the bearing strips and hard steel bearing rings are fitted between the rudder and the bottom gudgeon to take the weight of the rudder.

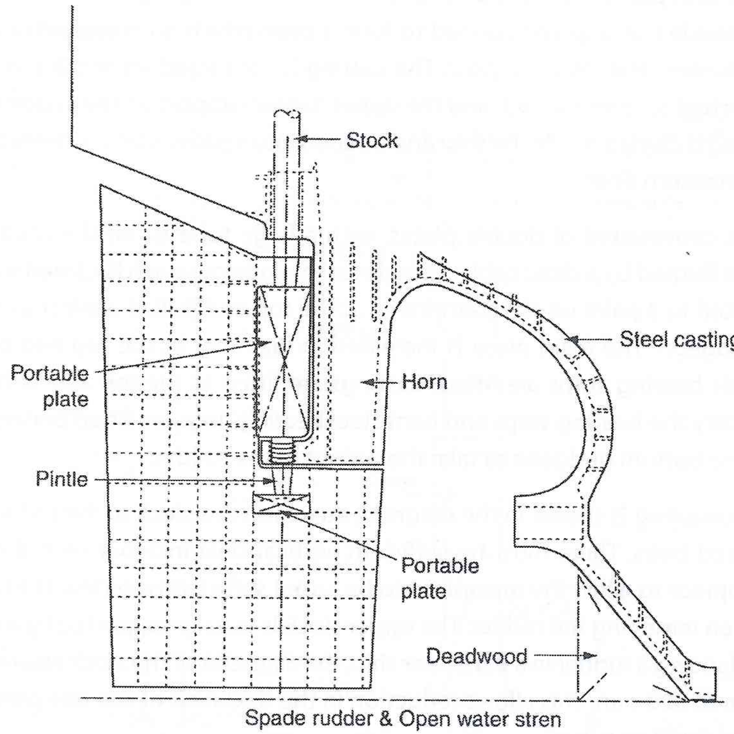
A horizontal coupling is shown in the diagram, attaching the stock to the rudder with the aid of fitted bolts. There must be sufficient vertical clearance between the stock and the mainpiece to allow the mainpiece to be raised sufficiently to clear the bottom gudgeon when removing the rudder. The upper stock is usually supported by a rudder carrier. By balancing a rudder in a particular ship, the diameter of the stock was reduced from 460 mm to 320 mm. This allows reduction in the thickness of the side plates and the size of the steering gear.

A flat bar is welded to the bottom of the horn to restrict the lift of the rudder. The clearance between the rudder and the flat should be less than the cross-head clearance. Any vertical force on the rudder will hence be transmitted to the sternframe and not to the steering gear.

Open water stern with spade rudder

Many modern large ships are fitted with spade-type rudders (Figure 8.8). The rudder is supported by means of a gudgeon on a large rudder horn and by the lower end of the stock, the latter being carried straight into the rudder and is either of a keyed or keyless design.

The lower part of the ship at the after end is known as the *deadwood* since it was seen in wooden ships to serve no useful purpose. However, as we now know the arrangement of the hull in this area can have a significant effect on hull performance.



▲ **Figure 8.8** *(a) Spade rudder and (b) open water stern*

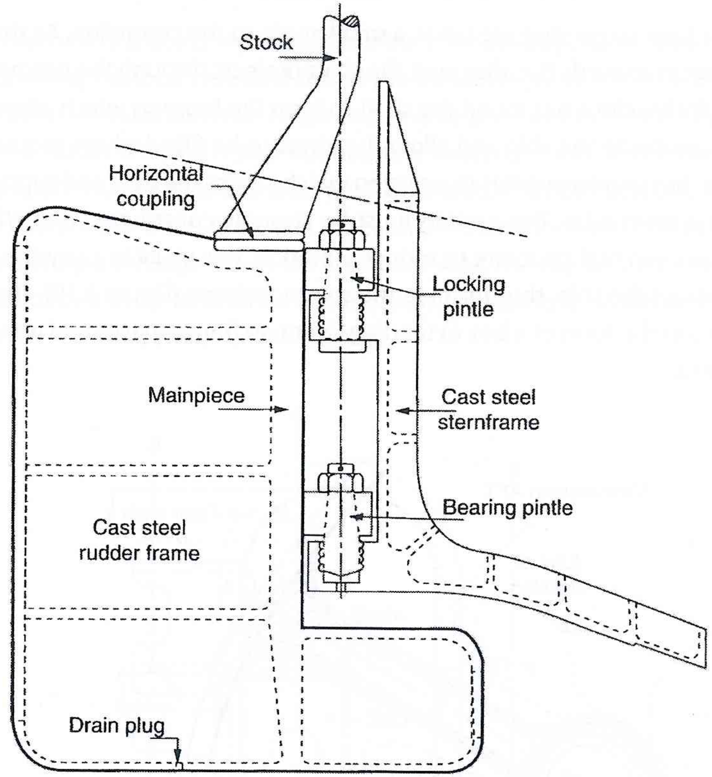
propeller. In addition, the distance of the rudder from the propeller may be adjusted to improve the efficiency of the rudder and in practice considerable reductions have been made, both in the diameter of the turning circle and in the vibration when turning. A recent design, from Rolls Royce, extends the boss of the propeller to meet a similarly formed section on the rudder. This design drastically reduces the propeller boos vortices and improves fuel consumption.

The rudder horn and the sternframe may be cast or fabricated depending upon the complexity of the final shape required and the calculated stresses involved.

Rudder and sternframe for twin screw ship

In a twin screw ship the propellers are fitted off the centreline of the ship and therefore

use of this space by carrying the lower part of the rudder forward of the centreline of stock. Figure 8.9 shows a typical arrangement.



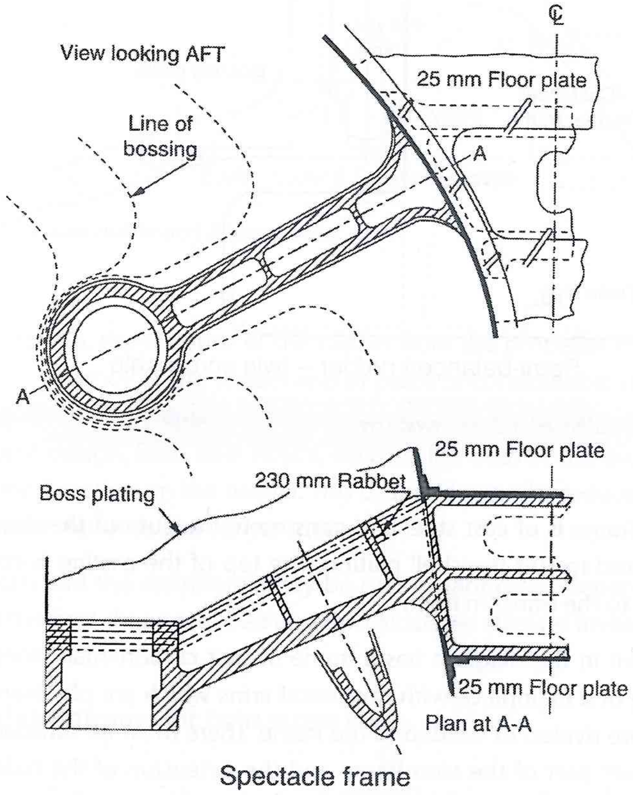
▲ **Figure 8.9** *Semi-balanced rudder – twin screw ship*

Where the sternframe is of cast steel and constructed to cut out the deadwood, it is notched or rebated to suit the shell plating. The top of the casting is connected by means of a palm to the transom floor.

The rudder shown in the diagram has a frame of cast carbon–manganese steel, the frame consisting of a mainpiece with horizontal arms which are of streamlined form. The side plates are riveted or welded to the frame. There must be sufficient clearance between the lower part of the sternframe and the extension of the rudder to allow the rudder to be lifted clear of the bearing pintle. The mainpiece must be particularly

Bossings and spectacle frame for twin screw ship

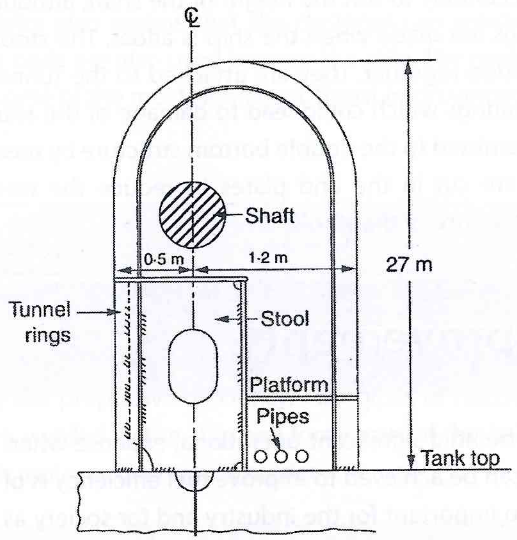
The shafts of a twin screw ship are set at a small angle to the centreline. As the width of the ship reduces towards the after end, the shaft projects through the normal line of the shell. The shell widens out round the shaft to form the *bossings* which allow access to the shaft from inside the ship and allows bearings to be fitted where required. The after end of the bossing terminates in a casting which carries the boss and supports the after end of the stern tube. This casting must be strongly constructed and efficiently attached to the main hull structure to reduce vibration. It is usual to carry the casting in one piece across the ship, thus forming the *spectacle frame* (Figure 8.10). The centre of the casting is in the form of a box extending over two frame spaces and attached to thick floor plates.



▲ Figure 8.10 *(a) View looking aft and (b) spectacle frame*

Shaft Tunnel

When the machinery space is separated from the after peak by one or more cargo holds, the main shafting must be carried through the holds. A tunnel is then built round the shaft to prevent contact with the cargo and to give access to the shaft at all times for maintenance, inspection and repair. The tunnel is watertight and extends from the after machinery space bulkhead to the after peak bulkhead. It is not necessary to provide a passage on both sides of the shaft, and the tunnel is therefore built off the centreline of the ship, allowing a passage down the starboard side. The top of the tunnel is usually circular except in a deep tank when it is more convenient to fit a flat top. Figure 8.11 shows a cross-section through a shaft tunnel.



▲ **Figure 8.11** *Shaft tunnel*

The tunnel stiffeners or *rings* are fitted inside the tunnel although in insulated ships and in tunnels which pass through deep tanks, the rings are fitted outside the tunnel. The rings may be welded to the tank top or connected by angle lugs. The plating is attached to the tank top by welding or by a boundary angle fitted on the opposite side of the plating to the stiffeners. The stiffeners and plating must be strong enough to withstand a water pressure without appreciable leakage in the event of flooding. The scantlings side plates is arranged so that it may easily be removed, together with the stiffeners, to allow the main shafting to be unshipped.

A watertight door is fitted in the machinery space bulkhead giving access to the shaft tunnel from the machinery space (see Chapter 6). At the after end of the tunnel, a watertight escape trunk is fitted and extends to the deck above the load waterline. At the after end of the tunnel, the ship is so fine that there is very little useful cargo space at each side of the tunnel. The tunnel top is then carried right across the ship to form a *tunnel recess*. The additional space on the port side of this recess is usually used to store the spare tail shaft.

The shaft tunnel can be used as a pipe tunnel, the pipes being carried along the tank top with a light metal walking platform fitted about 0.5 m from the tank top. The shaft is supported at intervals by bearings which are fitted on shaft stools. The tops of the stools are lined up accurately to suit the height of the shaft, although adjustments to the height of bearings are made when the ship is afloat. The stools are constructed of 12 mm plates welded together. They are attached to the tunnel rings to prevent movement of the bearings which could lead to damage of the shaft. The loads from the bearings are transmitted to the double bottom structure by means of longitudinal brackets. Manholes are cut in the end plates to reduce the weight and to allow inspection and maintenance of the stools.

Thrust Improvement

With the cost of fuel being a significant operational expense when running a fleet of ships, anything that can be achieved to improve fuel efficiency is of great importance to the owner. It is also important for the industry and for society as a whole as better fuel efficiency means less damage to the environment.

Research into the causes of cavitation and propulsion induced vibration have produced some significant information. For example, just 40 years ago it was thought that vibration from the propeller was due to a resonating frequency that was due to a function of the number of blades and the propeller turning at certain revolutions.

Modern research shows that there are several forms of cavitation and uneven inflow of water to the propeller that are causing the vibration. If the circle scribed by the propeller is considered, students will be able to realise that the water flowing into the circle or disc at the [...]

come around the hull whereas the water at the bottom just runs straight across the bottom of the ship. This flow of water from around the hull is called the 'wake field' and a poor wake field gives rise to poor propeller efficiency. (See Chapter 11 for more details.)

This causes a pressure differential at different places around the propeller disc. The fluctuating pressure is happening each revolution (up to twice per second) and it is this pressure differential – together with the varying forms of cavitation – that is the designers focus when looking for efficiency gains.

One of the major developments in this area has been with the design of the 'podded drive'. This feature has enabled the designer to smooth out the inflow of water to the propeller disc and thus improve efficiency. Further gains are made as the pods are arranged to 'pull' rather than to 'push'.

The Azimuthing ability also means that the designer can remove the rudder from the equation as the pods are also used to steer the ship. The next few pages contain information about some of the most significant 'thrust improvement' devices currently in use on ships.

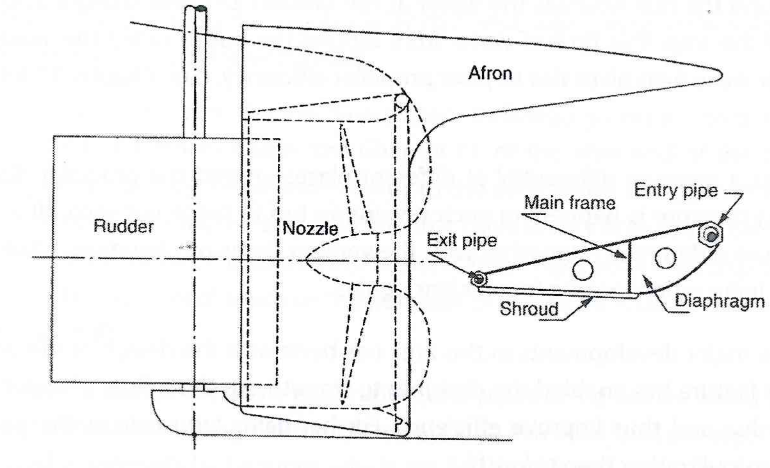
Kort Nozzle

The Kort nozzle is a form of hollow truncated cone which is fitted around the propeller in order to increase the propulsive efficiency. Two types of nozzles are available: the fixed nozzle which is welded to the ship and forms part of the hull structure; and the nozzle rudder which replaces the normal rudder.

Fixed nozzle

Figure 8.12 shows the arrangement of a nozzle which is fixed and joined together by plates which form aerofoil cross-section. At the bottom the nozzle is welded to the sole piece of the sternframe, while at the top it is faired into the shell plating. Diaphragm plates are fitted at intervals to support the structure.

The nozzle directs the water into the propeller disc in lines parallel to the shaft, causing a possible increase in thrust of about 20–50%. This may be used in several ways. The



▲ **Figure 8.12** *(a) Fixed Kort nozzle and (b) section through nozzle*

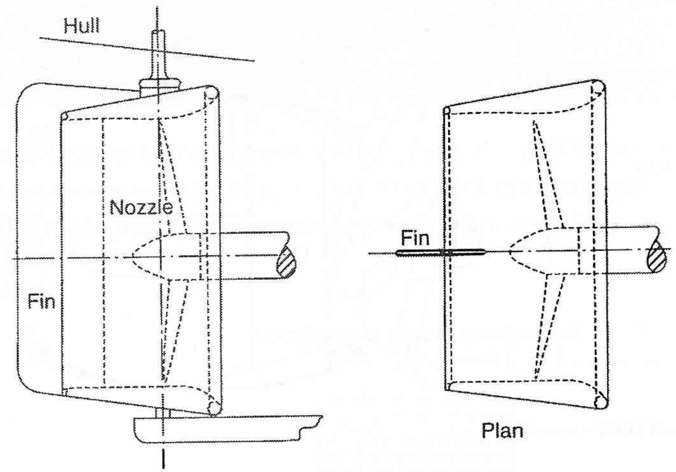
force may be accepted for the same power. It is also found that, in rough water, the effect of pitching on the propulsive efficiency is greatly reduced, since the water is still directed into the propeller disc.

In all rotating machinery the clearance between the rotating element and the casing should preferably be constant, maximum efficiency being obtained when the clearance is in the order of one-thousandth of the diameter. The Kort nozzle permits a constant clearance, although this is in the order of one-hundredth of the diameter. One of the troubles with conventional type sternframes is the fluctuation in stress on the propeller blades as they pass close to the structure. If the tip clearance is too small, these fluctuations cause vibration of the propeller blades. Such vibration is avoided entirely with the constant tip clearance of the Kort nozzle.

The nozzle also acts as a guard for the propeller, protecting it from loose ropes and floating debris. If, however, ropes do become entangled with the propeller, they are much more difficult to remove than with the open propeller. Such nozzles are fitted mainly to tugs and trawlers, where the increased pull may be utilised directly in service.

Nozzle rudder

form of rudder (Figure 8.13). The water is then projected at an angle to the centreline, causing the ship to turn. The centreline of the stock must be in line with the propeller in order to allow the nozzle to turn and yet maintain small tip clearance.



▲ **Figure 8.13** *Kort nozzle rudder*

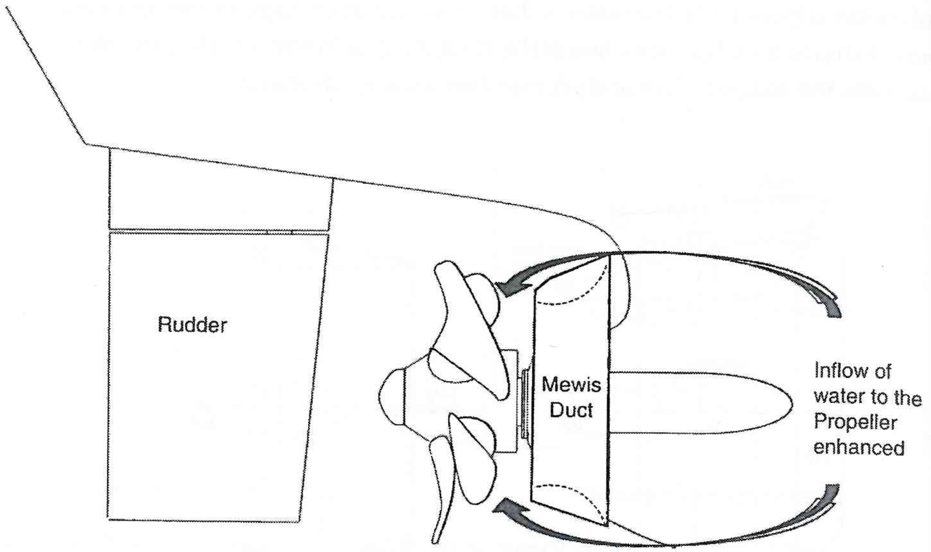
The support of the shaft at the extreme after end may prove rather difficult with this form of construction. The bossing may be increased and extended, or the boss may be supported by brackets fitted to the stern.

Both types of nozzle may be fitted to existing ships, although the rudder type requires greater alteration to the structure.

Mewis Duct

A reason for poor propeller performance was given earlier in this section as a reason for poor propeller performance. The Mewis Duct is designed to smooth out the wake field thus reducing the pressure fluctuations around the propeller disc (Figure 8.14).

The duct is a similar shape to the Kort nozzle, but it is placed ahead of the propeller and acts a funnel for the water flowing into the propeller. The flow is further 'improved' by fins arranged to impart a rotational effect on the water entering the propeller which is opposite to the propellers direction and thus generates more thrust. The fins



▲ **Figure 8.14** *Mewis Duct*

Tail Flaps and Rotating Cylinders

It was stated earlier in this chapter that the rudder angle is usually limited to about 35° on each side of the centreline. It is found that if this angle is exceeded, the diameter of the turning circle is increased, largely due to the separation of the flow of water behind the rudder. In vessels where high manoeuvrability is essential this limit is a disadvantage.

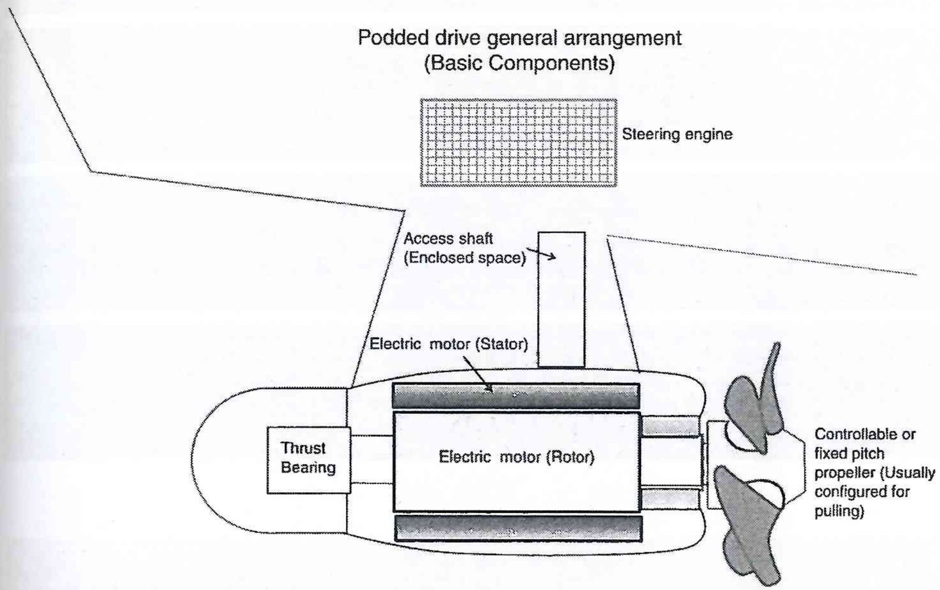
One method of improving the rudder performance is to fit a tail flap which moves automatically to a larger angle as the rudder is turned, in a similar manner to a fin stabiliser (see Chapter 11). Experiments have shown excellent results although the cost of manufacture and maintenance has proved prohibitive until recently. The 'Becker Flap' is now finding a market in this time when efficiency gains result in significant fuel savings.

An alternative method which has been tested is to fit a rotating cylinder at the fore end of the rudder. This cylinder controls the boundary layer of water and reduces the separation of the water behind the rudder, producing a positive thrust at larger rudder

1 m diameter rotating at about 350 rev/min and requiring about 400 kW. Although positive thrust is achieved at a rudder angle of 90°, practical considerations would limit the rudder angle to about 70° and even this would require a redesign of steering gears.

Podded Drive

As mentioned earlier in this volume and in others, the podded drive is a significant development for the industry (Figure 8.15). As of 2016 the two major manufacturers in the world for the highest powered pods are Rolls Royce and ABB.



▲ **Figure 8.15** *Podded drive*

They vary slightly in design but the basic concept is the same. Both are variable speed electric motors driving a fixed pitch propeller. The largest of the pods are pulling units of around 20 MW power. Large cruise ships might have up to 4 of these units. They could be arranged so that some are fixed and others provide the steering capability.

The significance of the design is not only in being able to optimise hull efficiency but also in the arrangement of the electrical generators. Free from the constraints of the

Cruise ships also require significant power for passenger lighting, galley and air conditioning. Therefore, the 'power station' concept is ideal for matching to the podded drive. See Volume 8, 'General Engineering for Marine Engineers', for more information about this subject.

9 OIL TANKERS, BULK CARRIERS, LIQUEFIED GAS CARRIERS AND CONTAINER SHIPS

Introduction

The International Association of Classification Societies (IACS) has re-examined their rules for the construction of oil tankers and bulk carriers (BCs). Their group of technical experts found considerable overlap and therefore the Common Structural Rules for Bulk Carriers and Oil Tankers has, from 1 July 2015, replaced the existing Common Structural Rules for Double Hull Oil Tankers and the Common Structural Rules for Bulk Carriers.

Oil Tankers

There has been a tremendous growth in the size of tankers since the end of the 1940s. The deadweight of these vessels has increased from about 13 000 tonne in 1946 to the present very large crude carriers (VLCCs) of 150 000–250 000 tonne and the ultra large crude carriers (ULCCs) of over 300 000 tonne, with the largest built to date (2016) being just over 560 000 tonne deadweight. The most significant development in recent years has been the introduction of the 'double hulled' tanker design which was introduced in response to environmental damage that came about due to oil escaping from tankers that had run aground.

The design of the basic oil tanker structure has also progressed quite significantly, once the inherent faults in welded vessels had been overcome by using a continuous, welded structure with well-rounded corners. At the same time improved quality steel, known as *extra-notch tough steel*, has been introduced which is less susceptible to the formation of cracks and will also resist the spread of cracks.

Following on from the basic 'single hulled' tankers there were variations such as the double bottom design, the double sided version and now the full double hulled design. However, the first significant development was in the way that the cargo tanks were cleaned ready for the next load.

Originally it was common practice to wash the tanks in crude oil carriers with water, pump the oily residue into the sea and fill the same tanks with water 'ballast'. Upon arrival at the loading port, and sometimes before arrival, the ballast was pumped out into the sea. The water washing was done using powerful jets; however following serious explosions it was found that the water jet was generating static electricity which in turn generated sparks initiating an explosion as the tank still contained a volatile atmosphere.

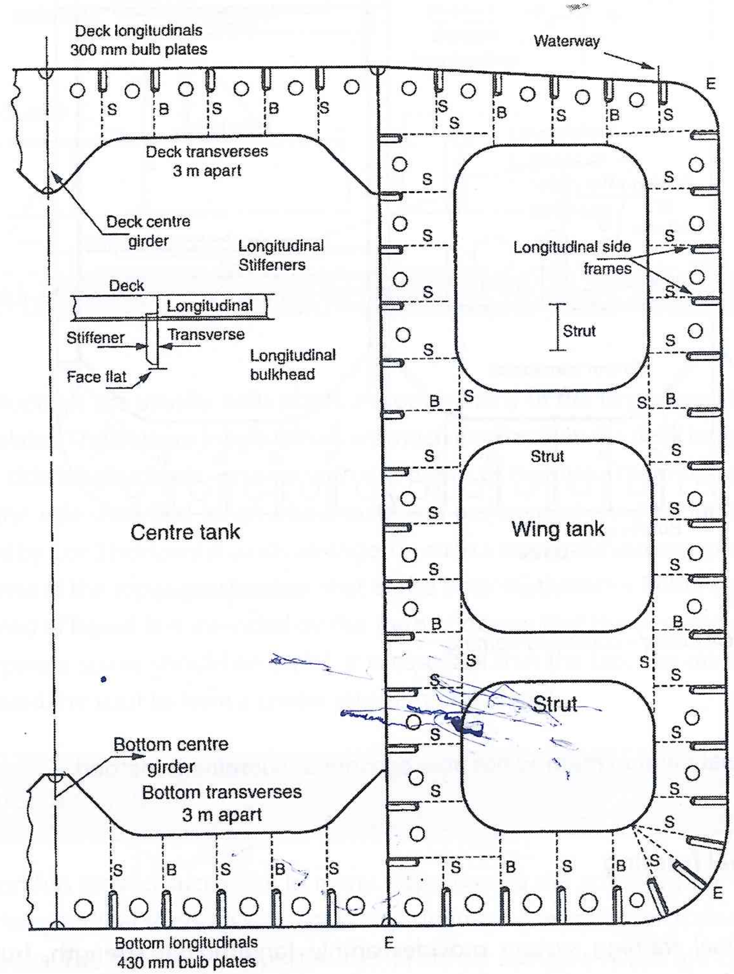
Two developments happened subsequently; the first was the introduction of inert gas in the space above the cargo and the second was the development of 'crude oil washing' (COW).

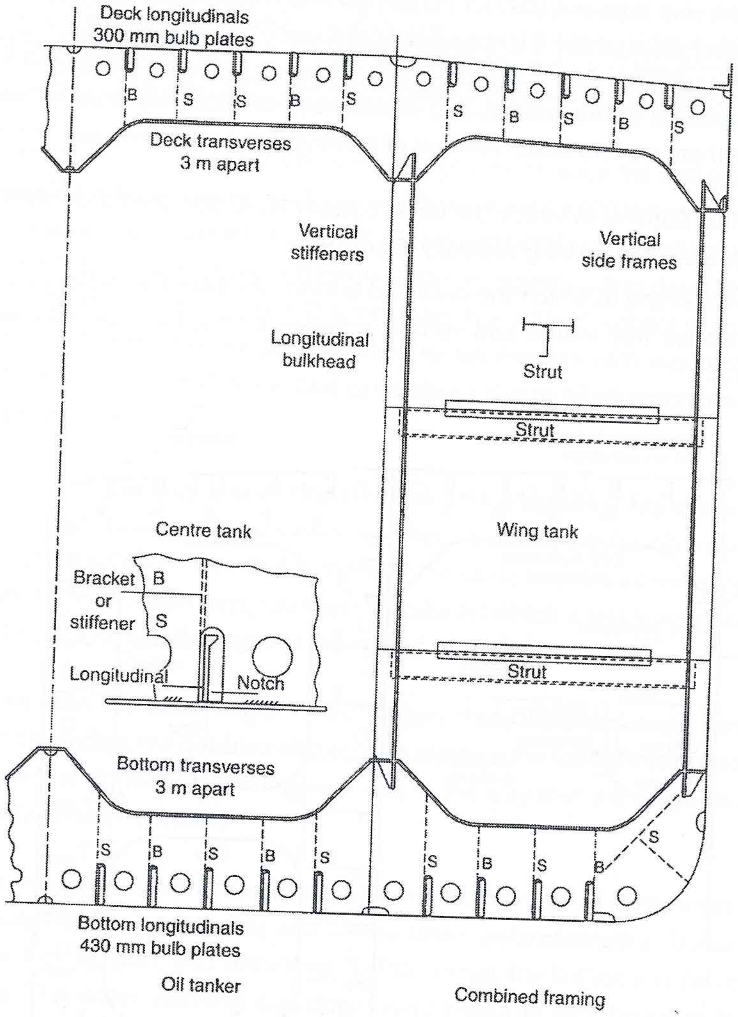
Tankers were then required to have segregated ballast systems so that the oil cargo was always separated from the ballast water. The latest vessels are required to have a full double hull as well

ensure that the ship does not transfer marine life which is common to one part of the world to another place where it is not a native species.

The basic structural arrangements and details vary considerably from shipyard to shipyard, but there are two basic methods of framing that have been used. These are:

1. Longitudinal framing in which the deck, bottom shell, side shell and longitudinal bulkheads are stiffened longitudinally (Figure 9.1).
2. Combined framing in which the deck and bottom shell are framed longitudinally, with transverse side frames and vertical stiffeners on the longitudinal bulkheads (Figure 9.2).





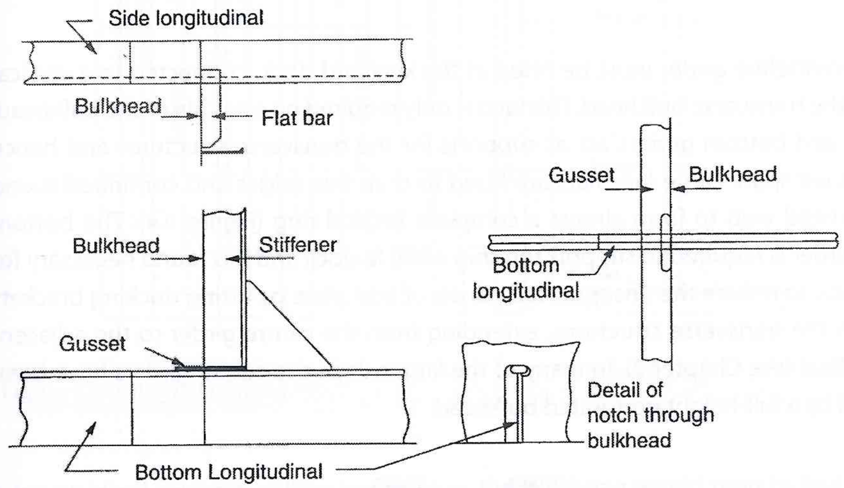
▲ **Figure 9.2** *Oil tanker – combined framing*

The longitudinal framing method has now become the dominant method.

Longitudinal framing

The longitudinal framing system provides ample longitudinal strength, but the horizontal side frames and longitudinal bulkhead stiff...

of 3–6 m and to which they are attached by flat bars or brackets. At the transverse bulkheads, the structure must be carefully designed to give maximum continuity of strength. Figure 9.3 shows typical attachments of bottom and side longitudinals at the transverse bulkhead.



▲ **Figure 9.3** *End connections of longitudinal*

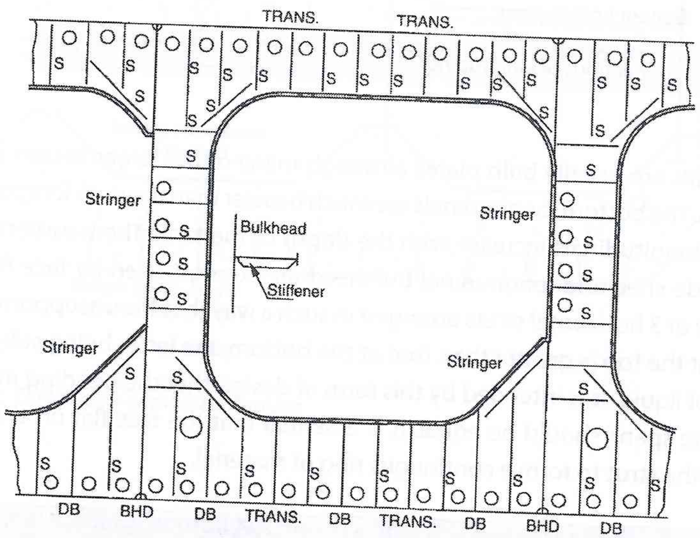
The longitudinals are usually bulb plates although many of the larger vessels employ large flat plates. The bottom longitudinals are much heavier than the deck longitudinals, while the side longitudinals increase with the depth of the tank. The transverse webs fitted to the side shell and longitudinal bulkhead are strengthened by face flats and supported by 2 or 3 horizontal struts arranged in such a way that the unsupported span of transverse at the top is greater than that at the bottom, the latter being subject to a greater head of liquid. It is intended by this form of design that the bending moments on the separate spans should be equal. It is essential that the face flat on the web is carried round the strut to form a continuous ring of material.

Combined framing

This system has proved successful in many ships, having the advantage of providing sufficient longitudinal strength with good tank drainage due to the vertical side frames and stiffeners. The latter are supported by horizontal stringers which are continuous are heavier than the upper stringers. Where the length of the tanker exceeds 200 m Lloyd's require longitudinal framing to be used.

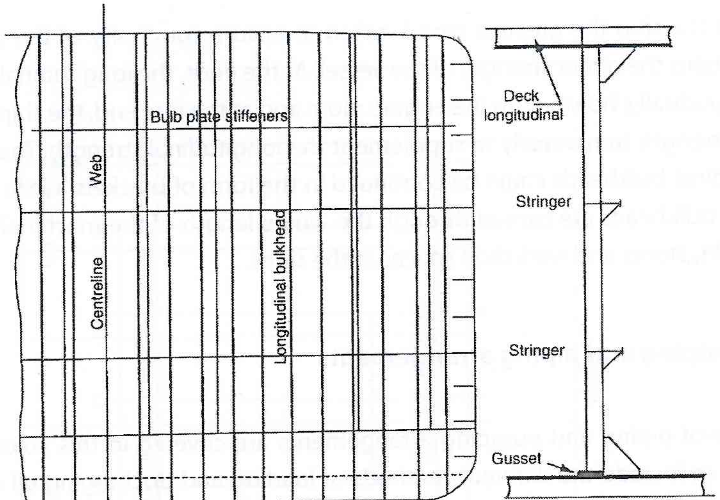
General structure

A deep centreline girder must be fitted at the keel and deck, connected to a vertical web on the transverse bulkhead. This web is only required on one side of the bulkhead. The top and bottom girders act as supports for the transverse structures and hence reduce their span. Large face flats are fitted to their free edges and continued round the bulkhead web to form almost a complete vertical ring (Figure 9.4). The bottom centre girder is required to support the ship while in dock and it is found necessary for this reason to reduce the unsupported panels of keel plate by fitting docking brackets between the transverse structures, extending from the centre girder to the adjacent longitudinal (see Chapter 2). In many of the larger ships the centre girders have been replaced by a full-height perforated bulkhead.



▲ **Figure 9.4** *Centreline web*

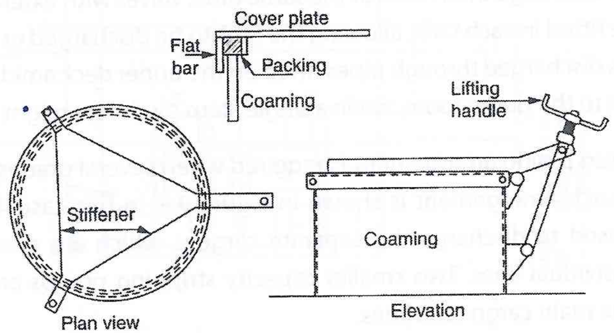
The transverse bulkheads are usually stiffened vertically, the stiffeners being bracketed at their ends and supported by horizontal stringers (Figure 9.5). Corrugated bulkheads are often fitted, the corrugations being vertical, and have the advantages of improving



▲ **Figure 9.5** *Oil tight bulkhead*

the longitudinal strength will be impaired as the bulkhead would tend to fold like a concertina as the ship hogs and sags.

The thickness of the deck plating depends on the maximum bending moment to which the ship is liable to be subject, and is given in the form of a cross-sectional area of material in way of openings. These openings consist of oil tight hatches and tank measuring equipment and/or openings through which deep-well pumps could be inserted (Figure 9.6).



▲ **Figure 9.6** *Oil tight hatch*

Throughout the ship the greatest care is taken to ensure continuity of the structure which maintains the girder strength of the vessel. At the ends, the longitudinals reduce in number gradually, however, in the engine room and at the fore end, the ship is given additional strength transversely to supplement the longitudinal strength. The ends of the longitudinal bulkheads could be continued in the form of brackets, while in some designs the bulkheads are carried through the whole length of the machinery space, forming tanks, stores and workshop spaces at the sides.

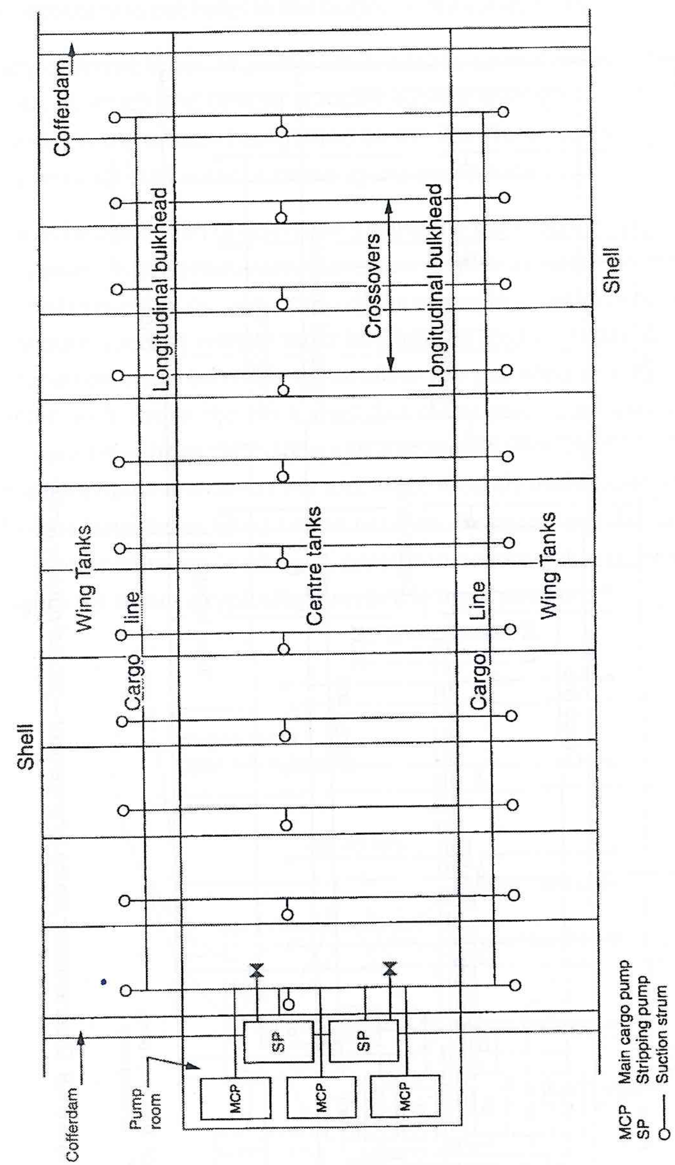
Cargo pumping and piping arrangements

An overview of piping and pumping arrangements are covered in this volume as it is necessary to include the different methods of loading and discharging oil cargoes. Traditionally a cargo pump room is arranged at the after end of the cargo tank range, containing 3 or 4 large capacity centrifugal pumps together with between 2 and 4 smaller capacity stripping pumps. These pumps are used to clear the tanks of oil when the main cargo pumps lose suction. In addition, two ballast pumps may be provided, especially where segregated ballast systems are used.

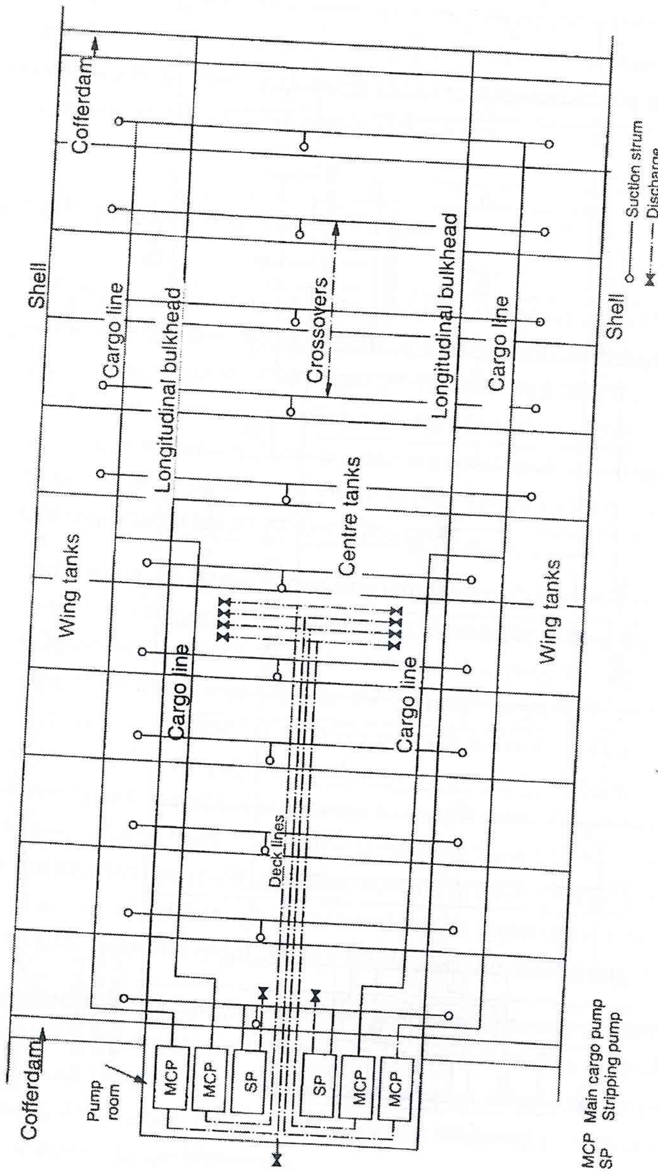
Several systems of piping are in use, depending largely on whether it is intended to carry single grade or multi-grade cargo. A simple piping arrangement may be used for single grade cargo as shown in Figure 9.7. This is known as a ring main system and consists of a continuous pipe from the pump room to the forward cargo tank and back into the pump room, with cross-over pipes in each centre tank extending into the wing tanks. This system may be used in conjunction with 2 or 3 pumps, the centre pump assisting one or both of the outside pumps. It is possible to carry 2 different grades of cargo with this system and to discharge them both at the same time. Valves with extended spindles up to the deck are fitted in each tank, allowing the tank to be discharged or by-passed as required. The oil is discharged through pipes fitted on the upper deck amidships and led aft along the deck to the pump room, while a single stern discharge might be arranged.

A more complicated piping arrangement is required when several grades of cargo are carried and one such arrangement is shown in Figure 9.8. In this case 4 main cargo pumps may be used to discharge the separate cargoes which are drawn from the tanks through individual lines. Two smaller capacity stripping pumps are fitted with connections to the main cargo tank lines.

A more modern arrangement has been developed in which the oil is allowed to flow through hydraulically operated sluice valves into a common suction strum



▲ Figure 9.7 *Diagrammatic piping arrangement – crude oil tanker*

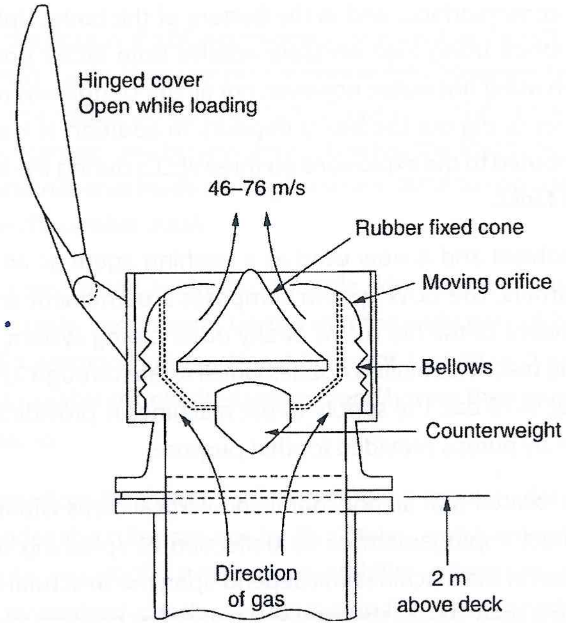


▲ **Figure 9.8** *Diagrammatic piping arrangement – general purpose tanker*

Many oils must be heated before discharging and therefore heating coils are fitted to all tanks. The coils are of cast iron with large heating surfaces which are heated by means of steam. It is essential that these coils be close to the bottom of the tank, and it is therefore necessary to cut holes in the bottom transverses to allow the coils to be fitted.

While many different types of pump are available, several ships make use of vertical drive pumps in which the driving spindles extend through an oil tight flat into the machinery space, the motors being fitted on the flat. This ensures regular maintenance by the engine room staff without entering the pump room.

When cargo is being loaded or discharged using the high capacity pumps, the structure is subject to an increase or reduction in pressure. Similar variations in pressure occur due to the thermal expansion or contraction of the cargo. To avoid structural damage, some form of pressure/vacuum release must be fitted to accommodate these variations. In addition, provision must be made to ventilate the gas-filled space, ensuring that the gas is ejected well above the deck level. For many years the latter was achieved by running vapour lines from the hatches to a common vent pipe running up the mast and fitted with a flame arrester at the top. More recently individual high velocity vents on stand pipes have been fitted to the hatches. By restricting the orifice, a high gas velocity is produced when loading. A pressure/vacuum valve is incorporated in the system. Figure 9.9 shows a typical system in the open position.



In order to reduce the possibility of explosion in the cargo tanks the oxygen content is reduced by means of an inert gas system. It is essential that the tank space above the liquid is inerted at all times, which means, when the tanks are full, empty or partially filled and particularly during the tank cleaning operation.

Deepwell pumping systems

With this, the most modern of systems, each tank has its own 'deepwell' pump which replaces the large centralised cargo pumps. The electric motor is arranged at the top of each pump at the deck level. Each motor sits above the pump head which is working at the bottom of the tank and is connected via a long drive shaft.

The pumps also have variable speed electric motors, as standard or retrofitted, making them particularly efficient and suited for this purpose.

Crude oil washing (COW)

Once cargo has been discharged it is necessary to clean the tanks of the sludge which accumulates on horizontal surfaces and in the bottom of the tanks. Until recently the tanks were water washed using high pressure nozzles from either portable or fixed machines. Even when using hot water, however, not all the sludge was removed and it was necessary at times to dig out the heavy deposits. In addition, it is suspected that water washing contributed to the explosions on three VLCCs during the ballast passage while washing cargo tanks.

Crude oil is itself a solvent and is now used as a washing agent as an alternative to water in crude oil carriers. The COW system comprises a permanent arrangement of steel piping, independent of the fire mains or any other piping system, connected to high capacity washing machines having nozzles which rotate through 120° and project the crude oil at about 9–10 bar. The supply to the machines is provided either by the main cargo pumps or by pumps provided for that purpose.

The machines are so located that all horizontal and vertical areas within the tank are washed either by direct impingement or by deflection or splashing of the jet. The number and disposition of the machines will depend upon the structural arrangements within the tank, but less than 10% of the total surface of the structure...

It is essential that an efficient inert gas system is used in conjunction with the COW system. It is also a requirement that only trained personnel carry out the work and a comprehensive operations and equipment manual is required on each ship.

There were some advantages over the water washing system, however modern environmental considerations dictate that this is now the only practice as all tankers and gas carriers must not discharge any oil into the sea water.

Tanker vetting (Chemical Distribution Institute – Marine) and their Ship Inspection, Reporting System (SIRE): This an inspection scheme used to ensure that tankers that are being chartered conform to all the necessary rules and regulations that are in-force at the time. This means that 'charters' can be sure that they are hiring a robust vessel.

Bulk Carriers

Originally the majority of bulk cargoes were carried by general cargo ships which were not designed specifically for such cargoes. This was inefficient and led to the development of the specialised BC. The rate of loading in bulk at some terminals is tremendous, 4000–5000 tonne/hour being regarded as normal.

It used to be that the design of a BC depended a great deal on the type of cargo that is to be carried and which tanks, if any, were to remain empty. However, high density cargos such as iron ore will require a high strength vessel since the ore is heavy for a given volume and other cargoes will be less dense. This led the Maritime Safety Committee (MSC85) of the International Maritime Organization (IMO) to consider the definition of a BC in November/December 2008.

The BC could be constructed as single or double skin ships with double bottoms and have hopper side tanks and topside tanks. From the early part of 2015 BCs had to be built to the IACS 'Common Constructional Rules for Tankers and Bulk Carriers'. These rules apply to BCs capable of unlimited voyages and having their engine rooms situated aft of the cargo tanks.

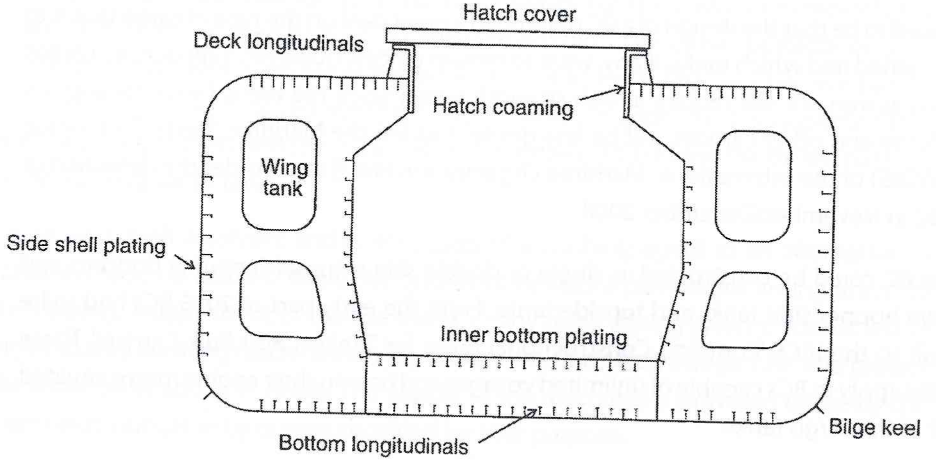
The general assumptions for the IACS rules are that the ships are designed, constructed and operated under the rules set out by flag states and a recognised classification society. The safety, watertight subdivisions, stability criteria and fire protection all conform to the recognised standards. The design life and strength of the vessel are

However, as stated, the design of a bulk carrier must be of high strength due to the high-density cargos it is required to carry. For example, ore is heavy for a given volume and therefore a deep double bottom is fitted in the vessel that carries it.

A deep double bottom is fitted, together with longitudinal bulkheads which restrict the ore and maintain a high centre of gravity consistent with comfortable rolling. A ship designed to carry bauxite, however, requires twice the volume of space for cargo and will therefore have a normal height of double bottom although longitudinal bulkheads may be used to restrict the ore space.

A bulk 'tramp' if one can coin a term, that is, one which may be required to carry any type of bulk cargo, must have restricted volume for an iron ore cargo and at the same time must have sufficient cargo capacity to carry its full deadweight of light grain which requires 3 times the volume of the ore. One method of overcoming this difficulty is to design the ship to load ore in alternate holds.

It may readily be seen, therefore, that the design of BCs will vary considerably. However, the practice of operating a bulk ore carrier (OBO) vessel (Figure 9.10) has died out. The figure shows a cross-section of an OBO which may carry an alternative cargo of oil in the wings and double bottom.

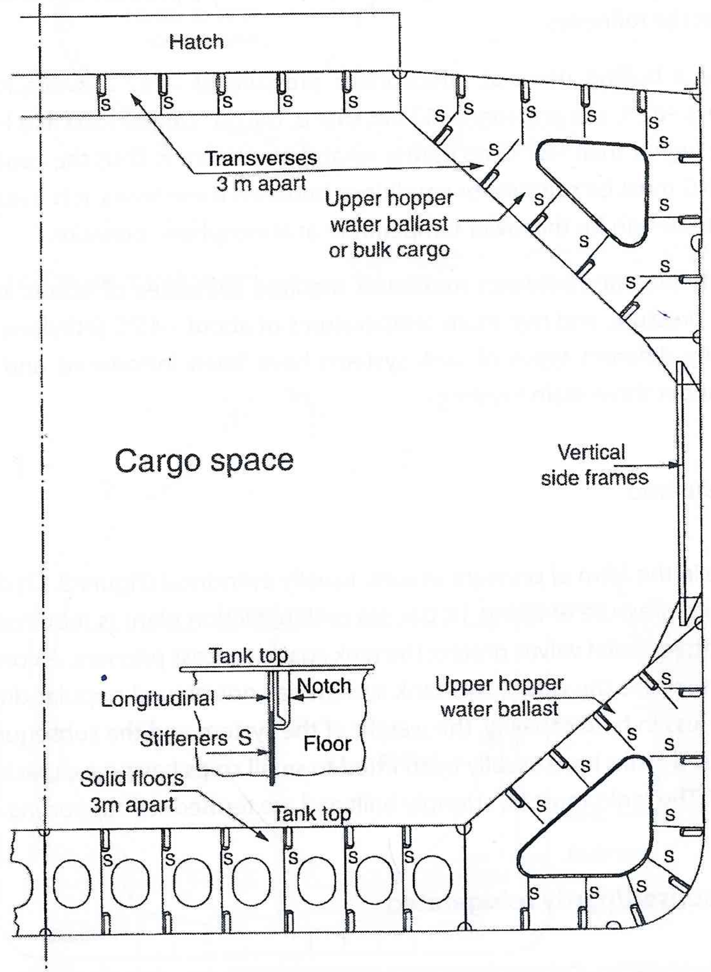


▲ **Figure 9.10** *OreCarrier-mid-section*

The structure is similar to that required for oil tankers having longitudinal f...

possible, fitted in the tanks rather than the ore space, to facilitate discharge of cargo using grabs. For the same reason it is common practice to increase the thickness of the tank top beyond that required by the classification societies.

The structural arrangement of a BC is shown in Figure 9.11. The arrangement of the stiffening members is once again similar to the oil tanker, although the layout of the cargo space is entirely different from that shown in Figure 9.10. In this design the double bottom, lower hopper and upper hopper spaces are available for water ballast, the upper tanks raising the centre of gravity of the ship and hence reducing the stiffness of roll. A large cargo capacity is provided by the main cargo holds and, if necessary, the upper hopper tanks.



Liquefied Gas Carriers

It is now becoming much more popular to carry natural gas and petroleum gas in liquefied form rather than as a vapour, the volume of the liquid being one-three hundredth to one-six hundredth of the volume of the vapour. Several gases are transported in this way, such as methane, propane, butane and anhydrous ammonia. The gases are divided into *liquefied natural gas* (LNG), which consists mainly of methane, and *liquefied petroleum gas* (LPG), mainly propane, propylene, butane and butylene. The latter are derived from the refining of the LNG or as a by-product of the distillation of crude oil at the refineries.

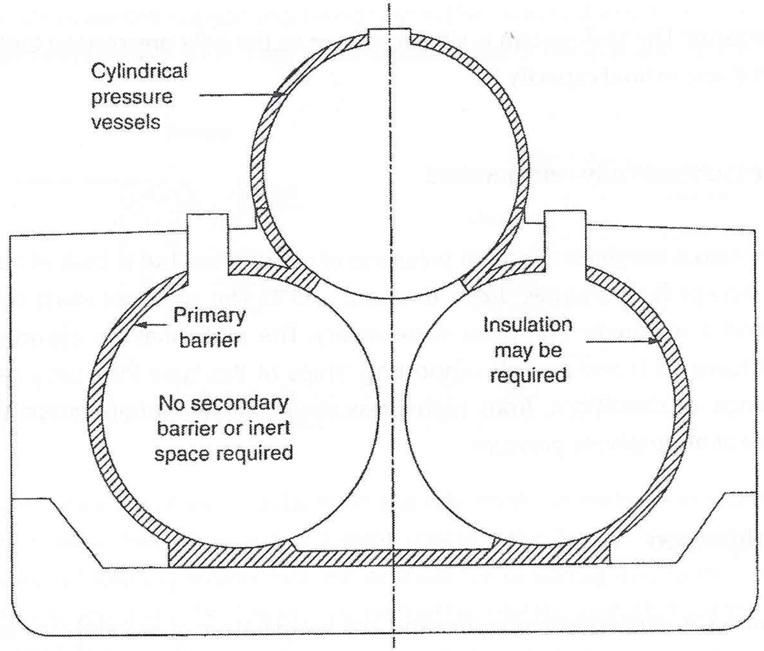
Methane has a boiling point at atmospheric pressure of −162°C, while its critical temperature is −82°C at a pressure of 47 bar, that is, the gas cannot exist as a liquid at a temperature higher than −82°C, no matter what the pressure is. Thus the containment system for LNG must be suitable for conditions between these limits. It is usually more economical to design for the lower temperature at atmospheric pressure.

LPG requirements vary between maximum required pressures of about 18 bar to atmospheric pressure, and minimum temperatures of about −45°C (ethylene −104°C) to −5°C. Many different types of tank systems have been introduced and may be considered under three main headings.

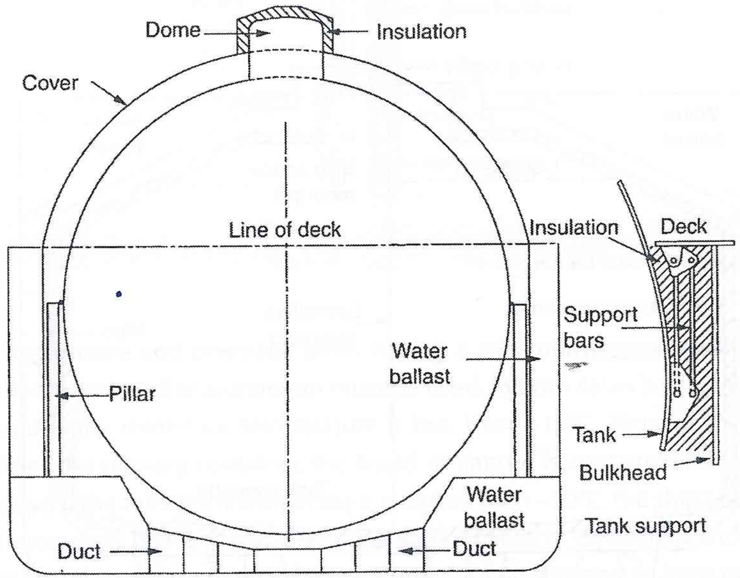
Fully pressurised

The tanks are in the form of pressure vessels, usually cylindrical (Figure 9.12) designed for a maximum pressure of about 18 bar. No re-liquefaction plant is required and no insulation is fitted. Relief valves protect the tank against excess pressure. A compressor is fitted to pressurise the cargo. This tank system has not proved popular due to the considerable loss in hold capacity, the weight of the system and the subsequent cost. Fully pressurised tanks have usually been fitted to small ships having a capacity of less than 2000 m³. The tanks must be strongly built and are termed *self-supporting*.

Semi-pressurised/partly refrigerated



▲ **Figure 9.12** *Cylindrical tank system*



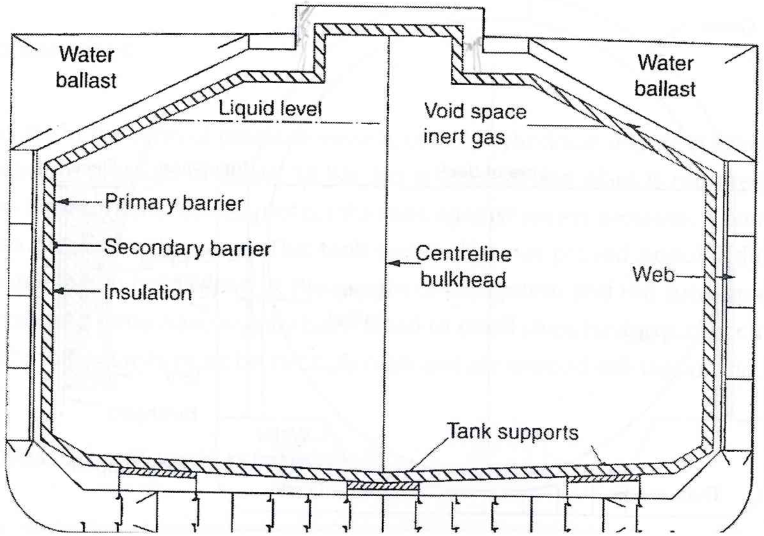
5000 m^3 capacity. The tank system is similar in form to the fully pressurised tanks and has the same loss in hold capacity.

Semi-pressurised/fully refrigerated

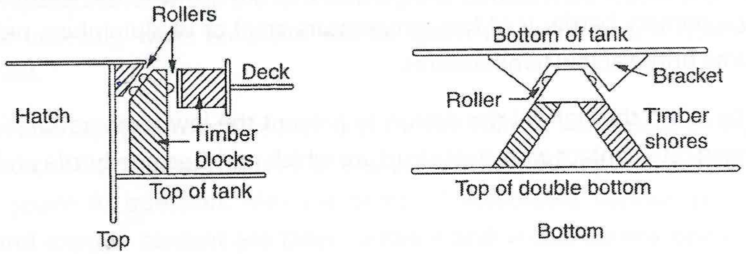
This tank system is designed to accept pressures of about 8 bar, but is built of material which will accept temperatures down to about −45°C. The structure must be well-insulated and a re-liquefaction plant is necessary. The tanks may be cylindrical or spherical (Figure 9.13) and are self-supporting. Ships of this type may carry cargoes under a range of conditions, from high pressure at ambient temperature to low temperature at atmospheric pressure.

Fully refrigerated

Cargo is carried at atmospheric pressure and at a temperature at or below the boiling point. The system is particularly suitable for the carriage of LNG but is also used extensively for LPG and ammonia. Vessels designed for LNG do not usually carry a re-liquefaction plant but LPG and ammonia vessels may gain from its use. The tank structure may be of prismatic form (Figure 9.14) or of membrane construction.

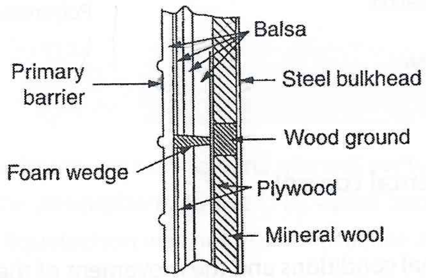


Prismatic tanks are self-supporting, being tied to the main hull structure by a system of chocks and keys (Figure 9.15). They make excellent use of the available space.



▲ **Figure 9.15** *Tank chocks*

Membrane tanks are of rectangular form and rely on the main hull structure for their strength. A very thin lining (0.5–1.2 mm) contains the liquid. This lining must be constructed of low expansion material or must be of corrugated form to allow for changes in temperature. The lining is supported by insulation which must therefore be load-bearing (Figure 9.16).

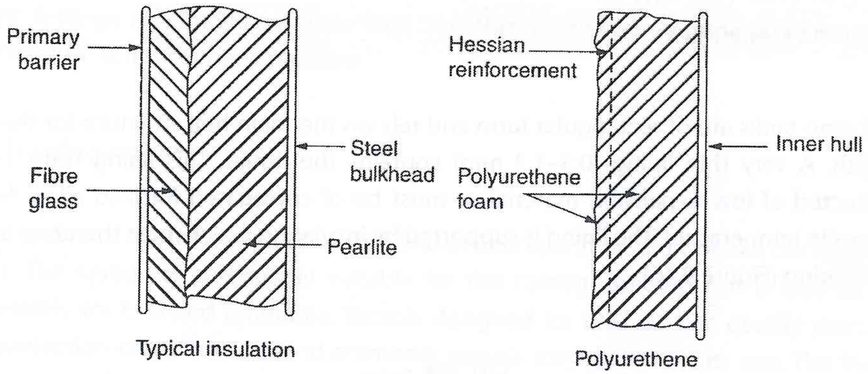


▲ **Figure 9.16** *Membrane system*

For both membrane and prismatic tanks having a minimum temperature less than −50°C either nickel steel or aluminium must be used. In both cases secondary barriers are required if the minimum temperature is less than −10°C. Thus, in the event of leakage from the primary container, the liquid or vapour is contained for a period of up to 15 days. If the minimum temperature is higher than −50°C, the ship's hull may be used as a secondary barrier if constructed of Arctic D steel or equivalent. Independent secondary barriers may be of nickel steel, aluminium or plywood as long as they can

Several types of insulation are acceptable, such as balsa wood, polyurethane, pearlite, glass wool and foam glass (Figure 9.17). Indeed, the primary barrier itself may be constructed of polyurethane which will both contain and insulate the cargo. Usually, however, the primary barrier is of low-temperature steel or of aluminium, neither of which become brittle at low temperatures.

Care must be taken throughout the design to prevent the low-temperature liquid or vapour coming into contact with steel structure which may become brittle and hence fracture.



▲ **Figure 9.17** *Tank insulation*

Safety and environmental control

Due to variations in external conditions and the movement of the ship the liquid cargo will boil and release gas. This gas must be removed from the tank to avoid increased pressure. If the gas is lighter than air it may be vented to the atmosphere, vertically from the ship and away from the accommodation. Many authorities are concerned about the increased pollution and alternatives are encouraged (see 'Boil-off').

The cargo piping system is designed for easy gas freeing and purging, with gas sampling points for each tank. The spaces between the barriers and between the secondary barrier and the ship side are either constantly inserted or sufficient inert gas is made available if required.

Each tank is fitted with means of indicating the level of the liquid, the pressure within

High and low pressure alarms are fitted within the tanks and in the inter-barrier space if that space is not open to the atmosphere. A temperature measuring device is fitted near the top and at the bottom of each tank with an indicator showing the lowest temperature for which the tank is designed. Temperature readings are recorded at regular intervals, while an alarm will be given if the minimum temperature is approached.

Gas detection equipment is fitted in inter-barrier spaces, void spaces, cargo pump rooms and control rooms. The type of equipment depends upon the type of cargo and the space in question. Measurements of flammable vapour, toxic vapour, vapour and oxygen content are taken, audible and visible alarms being actuated if dangerous levels are recorded. Measurements for toxic gas are recorded every 4 h except when personnel are in the compartment, when 30 min samples are taken and analysed.

In the event of a fire, it is essential that the fire pumps are capable of supplying two jets or sprays which can reach all parts of the deck over the cargo tanks. The main fire pumps or a special spray pump may be used for protecting the cargo area. The sprays may also be used to reduce the deck temperature during the voyage and hence reduce the heat gain by the cargo. If the cargo is flammable, then a fixed dry chemical fire extinguishing system is fitted.

Boil-off

In the early stage of LNG design, excess methane gas was vented astern of the ship and burned as it exited to the atmosphere. As the LNG vessel became more popular and sophisticated and as re-liquefaction was not economical, the exhaust gas was used as fuel for the main engine.

This is still common practice and in motor vessels normal injection equipment is used, together with a hydraulically operated gas injection valve in the cylinder head, blowing in the 'boil-off' gas at about 3 bar into the incoming scavenge air. The gas line from the tanks is fitted with a relief valve. Under normal running conditions the gas is used as the fuel. Should the gas pressure fall, however, liquid fuel is injected, a 10% drop in pressure resulting in automatic oil supply, while if the gas pressure falls by 15% the gas flow is stopped. Oil fuel must be used when starting or manoeuvring.

In steam ships the firing equipment is capable of burning oil fuel and methane gas simultaneously. The oil flame must be present at all times and an alarm system is fitted gas or steam before and after use. As with motor ships oil fuel is used when starting or manoeuvring.

Currently any excess gas in LNG ships is used in the main engine or re-liquefied by passing it through a cooling system and returning it to the tanks in liquid form. Methane is a highly potent 'greenhouse' warming gas and it is highly undesirable, and against all international regulations, to release it into the atmosphere unless it is an emergency.

Operating procedures

Drying

Water in any part of the cargo handling system will impair its operation, by freezing, reducing the purity of the cargo or in some cases changing its nature. The system must be cleared of water or water vapour by purging with a dry gas or by the use of a drying agent.

Inerting

If the oxygen content in a tank is too high a flammable mixture may be produced or the oxygen may be absorbed by the cargo producing a chemical change. It is essential, therefore, to reduce the oxygen content by the introduction of inert gas to a maximum content of 5% for hydrocarbons, 12% for ammonia and 0.5% for ethylene. The most suitable and common inert gases are nitrogen and carbon dioxide and in some cases helium, argon and neon are used but these are expensive. Inert gas generated by the ship-board plant usually consists of about 84% nitrogen and 12%–15% carbon dioxide with an oxygen content of about 0.2%. The inert gas, in turn, must be purged from the system by the cargo gas vapour. An inert gas barrier must also be used when discharging cargo and allowing air into the tanks.

Pre-cooling

Classification societies require that the maximum temperature difference between the cargo and the tank should not exceed 28°C. Before loading, the tank may be at ambient temperature. It is then cooled by spraying liquefied gas into the tank. The gas then vaporises and cools down the tank. The vapour produced in this way is either vented or re-liquefied. The cooling rate must be controlled to prevent undue thermal stresses and excess vapour and a rate of between 3°C and 6°C per hour

Loading and discharging

The cargo pipeline must first be cooled before loading commences. The rate of loading depends largely on the rate at which the cargo vapour can be vented or re-liquefied. Thus a ship designed for a particular run should have a re-liquefaction plant compatible with the loading facilities.

When the cargo is discharged it must be in a condition suitable for the shore-based tanks. Thus, if the shore tanks are at atmospheric pressure, the cargo in the ship's tanks should be brought to about the same pressure before discharging commences.

Sufficient net positive suction head must be provided for the pumps to work the cargo without cavitation. In pressure vessels the ship's compressor may pressurise the vapour from an adjoining tank to maintain a positive thrust at the impeller. In refrigerated ships the impeller is fitted at the bottom of the tank, the liquid head producing the pressure required. In the event of pump failure, the cargo may be removed by the injection of inert gas. Booster pumps are usually fitted to overcome any individual pump problem and ensure a continuous rate of discharge.

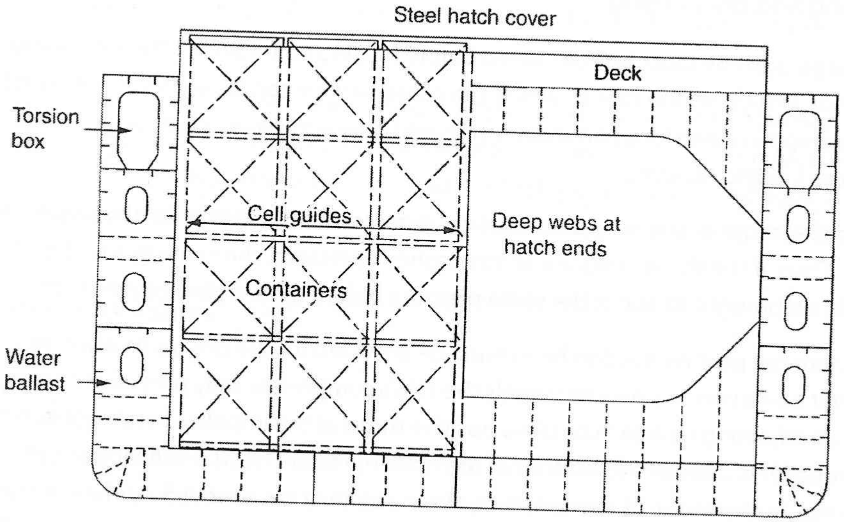
Container Ships

Container ships are designed to carry large numbers of standard containers. When first introduced the ships were designed for high speeds between specific terminal ports and they required a fast turn round at those ports.

The containers are of international standard either 20 ft or 40 ft in length, 8 ft in width and 8 ft 6 in in height. There is a less popular 'Hi-Cube' container which is of a standard size but 9 ft 6 in high. These can be straight containers or they can be refrigerated.

Containers are strong enough to be stacked six high. There are two basic types of refrigerated containers available, one which carries its own refrigeration plant, either fixed or clipped on, and one which relies on air from brine coolers in the ship which is ducted to the container. The refrigerated container with the 'clip-on' unit is not the most popular as it can easily be transported across 'intermodal' transport systems (Figure 9.18).

The containers are loaded into the ship vertically, fitting into the top of the container underneath or sliding into cell guides which are chamfered out at the top to provide a lead-in. Pads are fitted to the tank top at the bottom of the guides in line with the corner



▲ **Figure 9.18** *Container ship*

therefore, to have long, wide hatches to take a maximum number of containers. The spaces at the sides of the hatch are used for access and water ballast. The hatch coamings and covers are designed to carry tiers of containers as deck cargo. Since the vessels mostly work between well-equipped ports, they do not usually carry their own cargo handling equipment.

Due to the wide hatches the deck plating must be thick, and higher tensile steel is often used. The deck, side shell and longitudinal bulkheads are longitudinally framed in addition to the double bottom. The hatch coamings may be continuous and therefore improve the longitudinal strength. Problems may arise in these vessels due to the lack of torsional strength caused by the large hatches. The girder strength is boosted by fitting additional scantlings which act as *torsion boxes* on each side of the ship. These boxes are formed by the upper deck, top part of the longitudinal bulkhead, sheerstrake and upper platform, all of which are of thick material. The boxes are supported inside by transverses and wash bulkheads in addition to the longitudinal framing.

These transverse boxes are only effective if they are efficiently secured at their ends. At the after end they extend into the engine room and are tied to deep transverse webs. Similarly at the fore end, they are carried as far forward as the form of the ship will allow and are welded to transverse webs. The longitudinal bulkheads below the box may have to be stepped in-board to suit the shape of the ship...

At the ends of the hatches deep box webs are fitted to increase the transverse and torsional strength of the ship. These webs are fitted at tank top and deck levels. Care is taken in the structural design at the hatch corners to avoid excessive stresses.

The double bottom structure beneath the cell guides is subject to impact loading as the containers are put on board. Side girders are usually fitted under the container seats with additional transverse local stiffening to distribute the load. Unlike normal cargo ships in which the cargo is distributed over the tank top, the inner bottom of a container ship is subject to point loading. The double bottom must be deep enough to support the upthrust from the water when the ship is deeply loaded, without distortion between the containers.

The 'liner' trade is now dominated by container ships and the size is generally measured in their ability to carry containers. The 20 ft container is used as a measuring scale (20 ft equivalent Twenty Foot Equivalent Unit – TEU) and ships or 20,000 teu are now being planned.

10

THE LOAD LINE REGULATIONS

The general introduction to this book explains how International Shipping has become increasingly guided by the decisions made within the maritime department (the International Maritime Organization (IMO) of the United Nations (UN).

The International Convention on Load Lines was adopted by the IMO in 1968. Previously, the rules for the construction and loading of ships was left to the individual flag administrations. The updated version that entered into force in February 2000 harmonised the convention with Safety Of Life At Sea (SOLAS) and MARPOL (the convention for the prevention of maritime pollution). This chapter gives a brief introduction to the important features of the convention that help to keep ships safe and fit for purpose.

Freeboard

Originally associated with 'the Plimsoll line' *freeboard* is the distance from the waterline to the top of the deck plating at the side of the freeboard deck amidships. The *freeboard deck* is the uppermost continuous deck that has the necessary equipment to close all openings to the outside weather.

The *minimum freeboard* is based on providing the vessel with a volume of reserve buoyancy which cannot be loaded with cargo and therefore may be regarded as making the ship safe and ensuring that the ship proceeds to sea in a stable condition.

However, the exact level of 'reserve buoyancy' required depends upon

- the conditions of service of the ship;
- type of vessel;
- the stability of the vessel in still water;
- the degree of subdivision after suffering 'prescribed damage';
- the safety of the ship's staff when out on deck;
- the ability of the vessel to protect the weather deck from taking on water; and
- the fixtures and fittings used to allow any 'shipped' water to be removed.

In deep sea ships, for example, sufficient reserve buoyancy must be provided to enable the vessel to rise up again when shipping the heavy seas that could be encountered in the oceans of the world, small vessels on the inland waterways will not encounter such conditions and therefore are allowed to sail with a different level of 'reserve buoyancy'.

Vessels conforming to the Load Line Rules are assigned a freeboard according to a table of values, and it is therefore termed the *tabular freeboard*. The initial table used depends upon the type of ship and its length and is based on a standard vessel having a block coefficient of 0.68, length ÷ depth of 15 and a standard sheer curve.

Corrections are then made to this value for any variation from the standard, together with deductions for the reserve buoyancy provided by weather tight superstructures on the freeboard deck. One further point to consider is the likelihood of water coming onto the fore deck. This is largely a function of the distance of the fore end of the deck from the waterline and for this reason a *minimum bow height* is stipulated.

The bow height required depends upon the length of the ship and the block coefficient and may be measured to the forecastle deck if the forecastle is 7% or more of the ship's length. Should the bow height be less than the minimum then either the freeboard is increased or the deck raised by increasing the sheer or fitting a forecastle. The function of the forecastle has been brought into sharp focus recently as some bulk carriers suffered weather damage to the fwd hatch coaming due to the lack of protection offered by the inadequate forecastle.

There are two sets of tables A and B and students who are familiar with looking at loaded ships will know that, for example, an oil tanker fully loaded will look much lower in the water than will a car carrier.

The type *A ships* are designed to carry only liquid cargoes and hence have a high cause flooding of the cargo space or the accommodation. As a result, these vessels are allowed to load to a comparatively deep draught than the type B ships.

While these ships have a high standard of watertight deck, they have a comparatively small volume of reserve buoyancy and may therefore be less safe if damaged. It is necessary, therefore, in all such vessels over 150 m in length, to investigate the effect of damaging the underwater part of the cargo space and, in longer ships, the engine room. Under such conditions the vessel must remain afloat without excessive heel and have positive stability.

Type B ships cover the remaining types of vessels and are assumed to be fitted with steel hatch covers. In older ships having wood covers the freeboard is increased.

Should the hatch covers in Type B ships be sealed with efficient securing arrangements, then their improved water tight integrity is rewarded by a reduction in freeboard of up to 60% of the difference between the Type A and Type B tabular freeboards.

If, in addition, the vessel satisfies the remaining conditions for a Type A ship (e.g. flooding of cargo spaces and engine room), 100% of the difference is allowed and the vessel may be regarded as a Type A ship.

The tabular freeboards for Types A and B ships are given in the Rules for lengths of ship varying between 24 m and 365 m.

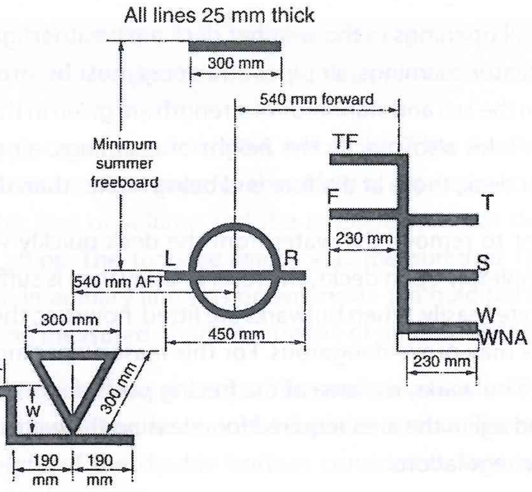
Typical values are as follows:

Length of ship	Type A	Type B	Difference
m	Freeboard in mm		
24	200	200	–
100	1135	1271	136
200	2612	3264	652
300	3262	4630	1368
365	3433	5303	1870

The freeboard, calculated from the tabular freeboard and corrected, is termed the Summer Freeboard and corresponds with a Summer Load Line S. In the tropics the weather is usually favourable and therefore a deduction of $\frac{1}{48}$ the Summer draught

The above freeboards are based on the assumption that the ship floats in sea water of 1025 kg/m³. If the vessel floats in fresh water with the same displacement, then it will lie at a deeper draught. The *Fresh Water Allowance is* $\frac{4}{41}$ mm where displacement is the measurement taken in sea water at the Summer draught and T is the tonne per cm at the same draught. F represents the fresh water line in the Summer zone and TF the equivalent mark in the Tropical zone.

The freeboard markings (Figure 10.1) are cut into the shell plating with the centre of the circle at midships. The letters LR on the circle indicate that the load line has been assigned by Lloyd's Register of Shipping. If the vessel has a radiused gunwale, the deck line is cut at a convenient distance below the correct position and this distance is then deducted from the freeboard stated on the Load Line Certificate.



▲ **Figure 10.1** *Freeboard markings and tonnage mark*

Special provision is made in the Rules for vessels carrying timber as a deck cargo. The timber increases the reserve buoyancy and hence the vessels are allowed to float at deeper draughts. An additional set of freeboard markings is cut in aft of midships with the normal letters prefixed by L (lumber).

Conditions of assignment

The Load Line Rules are based on the very reasonable assumption that the ship is seaworthy condition. Although the legal definition of seaworthiness is quite subjective and could be open to interpretation in a court of law

Until recently the Rules laid down the standard of longitudinal and transverse strength. The classification societies usually found it necessary to increase these standards although in some designs the Rules were considered excessive. It is now felt that the structural strength of the ship is more properly the function of the classification societies who may well be the Assigning Authority.

Standards of stability are given in the Rules for both small and large angles of heel. Details of the information required to be carried on a ship are stated, together with typical calculations. All the information is based on an inclining experiment carried out on the completed ship in the presence of a Flag surveyor.

It is essential that all openings in the weather deck are weathertight. Hatch coamings, hatch covers, ventilator coamings, air pipes and doors must be strong enough to resist the pounding from the sea and standards of strength are given in the Flag/Classification society rules. The Rules also specify the height of coamings, air pipes and door sills above the weather deck, those at the fore end being higher than the remainder.

It is also important to remove the water from the deck quickly when a heavy sea is shipped. With completely open decks, the reserve buoyancy is sufficient to lift the ship and remove the water easily. When bulwarks are fitted, however, they tend to hold back the water and this may prove dangerous. For this reason openings known as freeing ports are cut in the bulwarks, the area of the freeing ports depending upon the length of the bulwark, and again the area required for releasing the water from the deck is set out in the load line regulations.

If the freeing ports are wide, grids must be fitted to prevent crew being washed overboard. In addition, scuppers are fitted to remove the surplus water from the deck. The scuppers on the weather deck are led overboard while those on intermediate decks may be led to the bilges or, if automatic non-return valves are fitted, may be led overboard.

Type A ships, with their smaller freeboard, are more likely to have water on the deck and it is a condition of assignment that open rails be fitted instead of bulwarks.

On the older ships with the accommodation midships, a longitudinal gangway was fitted to allow passage between the after end and midships and between the for'd end and midships, without setting foot on the weather deck. In larger ships it is necessary to

Load line surveys

To ensure that the vessel is maintained at the same standard of safety, annual surveys are made by the Assigning Authority. An inspection is made of all those items which affect the freeboard of the ship and are included in the Conditions of Assignment. The accuracy of the freeboard marks is checked and a note made of any alterations to the ship which could affect the assigned freeboard.

Tonnage

Early rules

Gross registered tonnage came about in 1854, but in 1967 the Tonnage Rules were completely revised in an attempt to improve the safety of dry cargo ships. *A registered ton* represents 100 cubic feet of volume and the *tonnage deck* was the second deck except in single deck ships. The *tonnage length* was measured at the level of the tonnage deck where an imaginary line was drawn inside the hold frames or sparring, the tonnage length being measured on the centreline of the ship to this line.

Tonnage depths were measured from the top of the tank or ceiling to the underside of the tonnage deck at the centreline, less one-third of the camber. There was, however, a limitation on the height of the double bottom considered. *Tonnage breadths* are measured to the inside of the hold frames or sparring.

The tonnage length was divided into a number of parts. At each cross-section the tonnage depth is similarly divided and tonnage breadths measured. The breadths are put through Simpson's Rule to give cross-sectional areas. The cross-sectional areas were then put through the Simpson's Rule to give a volume. This volume, divided by 100, is the *Underdeck Tonnage*.

The *Gross Tonnage* was found by adding to the Underdeck Tonnage, the tonnage of all enclosed spaces between the upper deck and the second deck, the tonnage of all enclosed spaces above the upper deck together with any portion of hatchways exceeding $\frac{1}{2}$% of the gross tonnage.

The *Net Tonnage* or *Register Tonnage* was then obtained by deducting from the Gross Tonnage, the tonnage of spaces which are required for the safe working of the ship:

- master's accommodation;
- crew accommodation and an allowance for provision stores;
- wheelhouse, chartroom, radio room and navigation aids room;
- chain locker, steering gear space, anchor gear and capstan space;
- space for safety equipment and batteries;
- workshops and storerooms for pumpmen, electricians, carpenter, boatswains and the lamp room;
- auxiliary/emergency diesel engine and/or auxiliary boiler space if outside the engine room;
- pump room if outside the engine room;
- in sailing ships, the storage space required for the sails, with an upper limit of $2\frac{1}{2}$% of the gross tonnage;
- water ballast spaces if used only for that purpose (the total deduction for water ballast, including double bottom spaces, may not exceed 19% of the gross tonnage); and
- *Propelling Power Allowance* – This forms the largest deduction and is calculated as follows:

If the Machinery Space Tonnage is between 13% and 20% of the Gross Tonnage, the Propelling Power Allowance is 32% of the Gross Tonnage. If the Machinery Space Tonnage is less than 13% of the Gross Tonnage, the Propelling Power Allowance is a proportion of 32% of the Gross Tonnage.

Modified tonnage

Many ships are designed to run in service at a loaded draught which is much less than that allowed by the Load Line Rules. If the freeboard of a vessel is greater than that which would be assigned taking the second deck as the freeboard deck, then reduced Gross and Net Tonnages used to be allowed. In this case the tonnage of the space between the upper deck and the second deck is not added to the Underdeck Tonnage and is therefore not included in the Gross Tonnage or Net Tonnage, both of which are consequently considerably reduced. As an indication that this *modified tonnage* has been allocated to the ship, a *tonnage mark* must be cut in each side of the ship in line

Alternative tonnage

The owner may, if he wishes, have assigned to any ship reduced Gross and Net Tonnages calculated by the method given above. This is an *alternative* to the normal tonnages and is penalised by a reduction in the maximum draught. A *tonnage mark* must be cut in each side of the ship at a distance below the second deck depending upon the ratio of the tonnage length to the depth of the second deck. If the ship floats at a draught at or below the apex of the triangle, then the reduced tonnages may be used. If, however, the tonnage mark is submerged, then the normal tonnages must be used.

The principle behind the modified and alternative tonnages is that reduced tonnages were previously assigned if a tonnage hatch were fitted. This hatch seriously impaired the safety of the ship. Thus by omitting the hatch the ship is more seaworthy and no tonnage penalty is incurred. The tonnage mark suitable for alternative tonnage is shown in Figure 10.1. The distance W is $\frac{1}{4B}$ × the moulded draught to the tonnage mark.

Current rules

The 1967 and earlier Tonnage Rules influenced the design of ships and introduced features which were not necessarily consistent with the safety and efficiency of the ship. In 1969 an International Convention on Tonnage Measurement of ships was held and new Tonnage Rules were produced. These Rules came into force in 1982 for new ships, although the 1967 Rules could still be applied to existing ships until 1994.

The principle behind the new Rules was to produce similar values to the previous rules for gross and net tonnage using a simplified method which reflected more closely the actual size of the ship and its earning capacity without influencing the design and safety of the ship.

The gross tonnage is calculated from the formula

$$\text{Gross tonnage (GT)} = K_1 V,$$

where V = total volume of all enclosed spaces in the ship in m^3 and $K_1 = 0.2 + 0.02 \log_{10} V$. Thus the gross tonnage depends upon the total volume of the ship and therefore represents the size of the ship.

Enclosed spaces represent all those spaces which are bounded by the ship's hull, by fixed or portable partitions or bulkheads and by decks or coverings other than awnings.

Spaces excluded from measurement are those at the sides and ends of erections which cannot be closed to the weather and are not fitted with shelves or other cargo fitments.

The net tonnage is calculated from the formula

$$\text{Net tonnage (NT)} = K_2 V_C \left(\frac{4d}{3D}\right)^2 + K_3 \left(N_1 + \frac{N_2}{10}\right)$$

where V_C = total volume of cargo spaces in m³,

$K_2 = 0.2 + 0.02 \log_{10} V_C$,

$K_3 = 1.25\left(\frac{GT + 10\,000}{10\,000}\right)$,

D = moulded depth amidships in m,

d = moulded draught amidships in m,

N_1 = number of passengers in cabins with not more than 8 berths, and

N_2 = number of other passengers.

When a ship is designed to carry less than 13 passengers, the second term in the equation is ignored and the net tonnage is then based directly on the cargo capacity.

There are three further conditions:

The term $\left(\frac{4d}{3D}\right)$ is not to be taken as greater than unity.

The term $K_2 V_C \left(\frac{4d}{3D}\right)^2$ is not to be taken as less than 0.25 GT.

The net tonnage is not to be taken as less than 0.30 GT.

Hence ships which carry no passengers and little or no cargo will have a net tonnage of 30% of the gross tonnage. All cargo spaces are certified by permanent markings CC (cargo compartment).

The result of these rules saw the Shelter Deck Vessels carrying dual tonnage and the Tonnage Mark disappear from the scene. A unified system of measurement is now used by all nations with no variations in interpretation. Net tonnage is used to determine canal dues, light dues, some pilotage dues, some harbour dues and national 'tonnage taxes'.

Gross tonnage is used to determine manning levels, safety requirements such as fire

Life-Saving Appliances

The life-saving equipment carried on board a ship depends upon the number of persons carried and the normal service of the ship. A Transatlantic passenger liner would carry considerably more equipment than a coastal cargo vessel. The following notes are based on the requirements for a deep-sea cargo ship.

There must be sufficient lifeboat accommodation on *each* side of the ship for the whole of the ship's complement. The lifeboats must be at least 7.3 m long and may be constructed of wood, steel, aluminium or fibreglass. They carry rations for several days, together with survival and signalling equipment such as fishing lines, first-aid equipment, compass, lights, distress rockets and smoke flares. One lifeboat on each side must be motor-driven.

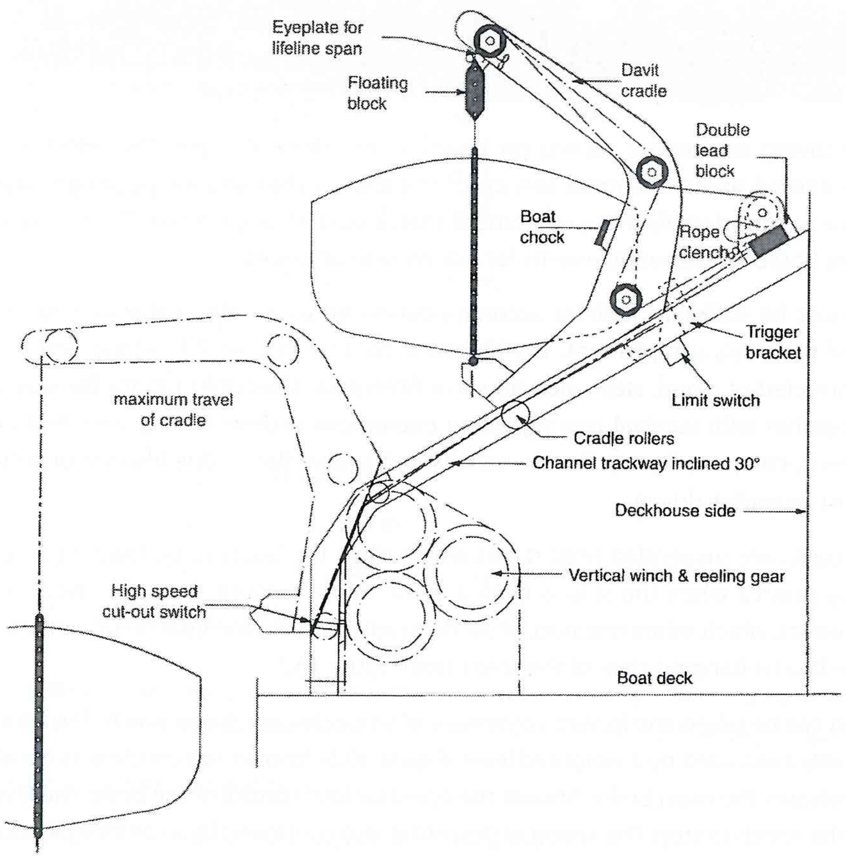
The lifeboats are suspended from davits which allow the boats to be lowered to the water by gravity, when the ship is heeled to 15°. Most modern ships are fitted with gravity davits, which, when released, allow the cradle carrying the boat to run outboard until the boat is hanging clear of the ship's side (Figure 10.2).

The boat can be raised and lowered by means of an electrically driven winch. The winch is manually controlled by a weighted lever (Figure 10.3), known as a *dead man's handle* which releases the main brake. Should the operator lose control of the brake the lever causes the winch to stop. The speed of descent is also controlled by a centrifugal brake which limits the speed to a maximum of 36 m/min. Both the centrifugal brake and the main brake drum remain stationary during the hoisting operation. If the power fails while raising the boat, the main brake will hold the boat.

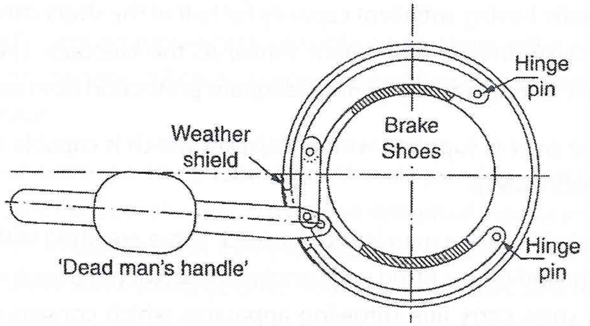
Ships also carry liferafts having sufficient capacity for half of the ship's crew. The liferafts are inflatable and carry survival equipment similar to the lifeboats. They have been found extremely efficient in practice, giving adequate protection from exposure.

Each member of the crew is supplied with a lifejacket which is capable of supporting an unconscious person safely.

Lifebuoys are provided in case a man falls overboard. Some are fitted with self-igniting lights for use at night and others fitted with smoke signals for pin-pointing the position during the day. All ships carry line throwing apparatus which consists of a light line to which a rocket is attached. The rocket is fired from a pistol and must be capable of carrying 230 m. This enables contact to be made between the ship and the shore or



▲ **Figure 10.2** *Gravity davit*



▲ **Figure 10.3** *Main brake*

the ship either directly or through a block, allowing persons to be transferred or vessels to be towed.

With the introduction of Totally Enclosed Lifeboats came the need to use on-load release gear which was activated from inside an enclosed boat. These devices need very special attention as the original designs did not 'fail safe'. However, after January 2015 all ships must be fitted with a new 'fail safe' design, at the first available dry-dock.

The recent development of Free fall life boats has been applied to smaller vessels where the drop to the water is limited. Some manufacturers state that these boats can be built to fall from up to 40 m, however each boat will come with a certificate from the manufacturers stating the 'Greatest Launching Height'.

Under strict control a limited number of vessels are fitted with Maritime Escape Systems. These are inflatable slides or cylindrical shoots usually fitted to a limited number of passenger ferries. They are designed to evacuate a large number of passengers to inflatable liferafts.

Fire Protection

Definitions

A non-combustible material is one which neither burns nor gives off flammable vapours in sufficient quantity for self-ignition when heated to 750°C.

A *standard fire test* is carried out on a stiffened panel of material 4.65 m^2 in area, 2.44 m high with one joint. One side of the panel is exposed in a test furnace to a series of temperatures, 538°C, 704°C, 843°C and 927°C at the end of 5, 10, 30 and 60 min periods, respectively.

An *A-class division* must be made of steel or equivalent material capable of preventing the passage of smoke and flame to the end of the 60-min standard fire test. The average temperature on the unexposed surface of the panel must not rise more than 139°C after a given time and it may be necessary to insulate the material. The time intervals are 0, 15, 30 and 60 min and the divisions classed to indicate this interval, that is, A-0; A-60.

A *B-class division* need not be made of steel but must be of non-combustible material and must prevent the passage of smoke and flame to the end of the first 30 min of the

A *C-class division* must be of non-combustible material.

Control stations refer to spaces containing main navigation or radio equipment, central fire-recording system or the emergency generator.

Fire potential is the likelihood of fire starting or spreading in a compartment. If the fire potential is high, then a high standard of insulation is required. Thus bulkheads separating accommodation from machinery spaces would be required to be A-60 while those dividing accommodation from sanitary spaces could be B-0 or even C.

There are three basic principles of fire protection:

1. The separation of accommodation spaces from the rest of the ship by thermal and structural boundaries.
2. The containment, automatic extinction or detection of fire in the space of origin, together with a fire alarm system.
3. The protection of a means of escape.

Passenger ships

Passenger ships are divided into main vertical zones by A-class divisions not more than 40 m apart. These divisions are carried through the main hull, superstructure and deckhouses. If it is necessary to step the bulkhead, then the deck within the step must also be A-class.

The remainder of the bulkheads and decks within the main vertical zones are A, B or C class depending upon the fire potential and relative importance of the adjacent compartments. Thus bulkheads between control stations or machinery spaces and accommodation will be A-60 while those between accommodation and sanitary spaces will be B-0.

The containment of fire vertically is extremely important and the standard of protection afforded by the decks is similar to that of the bulkheads. If a sprinkler system is fitted the standard of the division may be reduced, typically from A-60 to A-15.

All compartments in the accommodation, service spaces and control stations are fitted with automatic fire alarm and detection systems.

vertical zone bulkheads are fitted with dampers capable of being operated from both sides of the bulkheads.

Fire resisting doors may be fitted in the A-class bulkheads forming the main vertical zone and those enclosing the stairways. They are usually held in the open position but close automatically when released from a control station or at the door position even if the ship is heeled ±3.5°.

Vehicle spaces in ships having drive-on/drive-off facilities present particular problems because of their high fire potential and the difficulty of fitting A-class divisions. A high standard of fire extinguishing is provided by means of a *drencher* system. This comprises a series of full-bore nozzles giving an even distribution of water of between 3.5 and 5.0 l/m^2min over the full area of the vehicle deck. Separate pumps are provided for the system.

Dry cargo ships

In ships over 4000 tonnes gross all the corridor bulkheads in the accommodation are of steel or B-class. The deck coverings inside accommodation which lies above machinery or cargo spaces must not readily ignite. Interior stairways and crew lift trunks are of steel as are bulkheads of the emergency generator room and bulkheads separating the galley, paint store, lamp room or bosun's store from accommodation.

Oil tankers

In tankers of over 500 tonnes gross, the machinery space must lie aft of the cargo space and must be separated from it by a cofferdam or pumproom. Similarly all accommodation must lie aft of the cofferdam. The parts of the exterior of the superstructure facing the cargo tanks and for 3 m aft must be A-60 standard. Any bulkhead or deck separating the accommodation from a pump room or machinery space must also be of A-60 standard.

Within the accommodation the partition bulkheads must be of at least C standard. Interior stairways and lift trunks are of steel, within an enclosure of A-0 material.

To keep deck spills away from the accommodation and service area a permanent continuous coaming 150 mm high is welded to the deck forward of the superstructure.

It is important to prevent gas entering the accommodation and engine room. In the first non-opening ports may be fitted but are required to have internal steel covers. Above the first tier non-opening windows may be fitted in the house front with internal steel covers.

Classification of Ships

A classification society is an organisation whose function is to ensure that a ship is built to match its rules of construction and that the standard of construction is maintained. The ship is then classified according to the standard of construction and equipment. The cost of insurance of both ship and cargo depends to a great extent upon this classification, and it is therefore to the advantage of the shipowner to have a high class ship. It should be noted, however, that the classification societies are independent of the insurance companies.

There are a number of large societies, each being responsible for the classification of the majority of ships built in at least one country, although in most cases it is left to the shipowner to choose the society. Some of the major organisations are as follows:

Lloyd's Register of Shipping	United Kingdom
American Bureau of Shipping	USA
Bureau Veritas	France
Det Norske Veritas	Norway
Registro Italiano	Italy
Teikoku Kaiji Kyokai	Japan
Germanischer Lloyds	Germany

Each of these societies has its own rules which may be used to determine the design, composition and therefore the ultimate strength of the structural members. The following notes are based on Lloyd's Rules. Steel ships which are built in accordance with the Society's Rules, or are regarded by Lloyds as equivalent in strength, are assigned a class in the Register Book. This class applies as long as the ships are found under survey to be in a fit and efficient condition. Class 100A is assigned to ships which are built in accordance with the rules or are of equivalent strength.

is, when a surveyor is in attendance and examines the ship during all stages of construction. Thus a ship classed as ✠ 100A 1 is built to the highest standard assigned by Lloyds. Additional notations are added to suit particular types of ship such as 100A 1 oil tanker or 100A 1 ore carrier.

When the machinery is constructed and installed in accordance with Lloyd's Rules a notation LMC is assigned, indicating that the ship has Lloyd's Machinery Certificate.

In order to claim the 100A 1 class, the materials used in the construction of the ship must be of good quality and free from defects. To ensure that this quality is obtained, samples of material are tested at regular intervals by Lloyd's Surveyors.

To ensure that the ship remains worthy of its classification, annual and special surveys are carried out by the surveyors. The special surveys are carried out at intervals of 4–5 years.

In an annual survey the ship is examined externally and, if considered necessary, internally. All parts liable to corrosion and chafing are examined, together with the hatchways, closing devices and ventilators to ensure that the standards required for the Load Line Regulations are maintained. The steering gear, windlass, anchors and cables are inspected.

A more thorough examination is required at the special surveys. The shell plating, sternframe and rudder are inspected, the rudder being lifted if considered necessary. The holds, peaks, deep tanks and double bottom tanks are cleared, examined and the tanks tested. The bilges, limbers and tank top are inspected, part of the tank top ceiling being removed to examine the plating. In way of any corroded parts, the thickness of the plating must be determined by ultrasonic testing.

The scantlings of the structure are based on theory, but because a ship is a very complex structure, a 'factor of experience' is introduced. Lloyds receives reports of all faults and failures in ships which carry their class, and on the basis of these reports, consistent faults in any particular type of ship may be studied in detail and amendments made to the rules.

For example, structural damage in some ships did lead to the introduction of longitudinal framing in the double bottom. Reports of brittle fracture have resulted in amendments to the design rules for the shell and deck of some types of ships. It is important to note that Lloyds have the power to require owners to alter the structure of an existing ship if they consider that the structure is weak. An example of this in the past was the fitting of butt straps to some welded tankers to act as crack arrestors, the

In order for a ship to receive Lloyd's highest classification, scantling plans are drawn. On these plans the thicknesses of all plating, sizes of beams and girders and the method of construction are shown. The scantlings are obtained from Lloyd's Rules and depend upon the length, breadth, draught, depth and frame spacing of the ship and the span of the members. Variations may occur due to special design characteristics such as the size and position of the machinery space. Shipowners are at liberty to increase any of the scantlings and many do so, particularly where such increases lead to reduced repair costs. An increase in diameter of rudder stock by 10% above rule is a popular owners' extra. Shipbuilders may also submit alternative arrangements to those given in the rules and Lloyds may allow their use if they are equivalent in strength. The scantling plans are submitted to Lloyds for their approval before detailed plans are drawn and the material ordered.

The number of Deep Water Berths is on the increase as the size of oil tankers, bulk carriers and container ships continues to grow. This has led to an increase of the system of hull survey while the vessel is afloat. The in-water survey (IWS) is used to check those parts of a ship which are usually surveyed in dry dock. It includes visual examination of the hull, rudder, propeller, sea inlets and so on, and the measurement of wear down of rudder bearings and stern bush.

There are several requirements to be met before IWS is allowed. High resolution colour photographs are taken of all parts which are likely to be inspected, before the ship is launched. The rudder and sternframe are designed for easy access to bearings. The ship must be less than 10 years old, have a high resistance coating on the underwater hull and be fitted with an impressed current cathodic protection system.

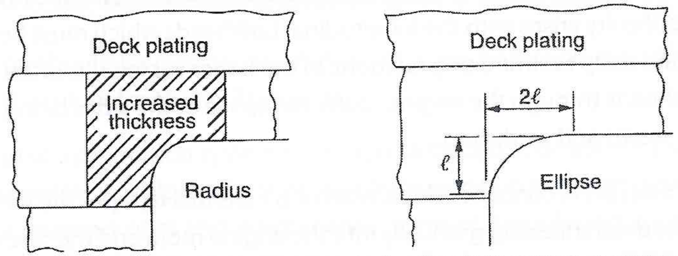
At the time of the inspection the hull is cleaned by one of the many brush systems available. The water must be clear and the draught less than 10 m. The inspection may be made by an underwater closed-circuit television camera. The camera may be hand-held by a diver or carried by a hydraulically propelled camera vehicle, remotely controlled from a surface monitoring station. The use of remotely operated unmanned vehicles is transforming this area of ship inspection/maintenance.

Discontinuities

A ship is a structure in which discontinuities are impossible to avoid. It is also subject to fluctuations or even reversals of stress when passing through waves. The ship must be designed to reduce such discontinuities to a minimum, while great care must be taken in the design of structural detail in way of any remaining changes in section.

The most highly stressed part of the ship structure is usually that within 40%–50% of its length amidships. Within this region every effort must be made to maintain a continuous flow of material.

Difficulties occur at hatch corners (Figure 10.4). Square corners must be avoided and the corners should be radiused or elliptical. With radiused corners the plating at the corners must be thicker than the remaining deck plating. Elliptical corners are more efficient in reducing the corner stress and no increase in thickness is required.



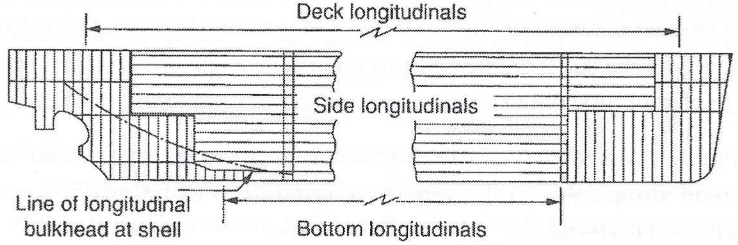
▲ **Figure 10.4** *Hatch corners*

Similarly openings for doors, windows, access hatches, ladderways and so on in all parts of the ship must have rounded corners with the free edges dressed smooth.

If a bridge structure is fitted over more than 15% of the ship's length, the bridge side plating must be tapered or curved down to the level of the upper deck. The sheerstrake is increased in thickness by 50% and the upper deck stringer plate by 25% at the ends of the bridge. Four 'tween deck frames are carried through the upper deck into the bridge space at each end of the bridge to ensure that the ends are securely tied to the remaining structure.

In bulk carriers, where a large proportion of the deck area is cut away to form hatches, the hatch coamings should preferably be continuous and tapered down to the deck level at the ends of the ship.

Longitudinal framing must be continued as far as possible into the ends of the ship and scarphed gradually into a transverse framing system (Figure 10.5). This problem



▲ **Figure 10.5** *Extent of longitudinal framing oil tanker*

longitudinals through to the collision bulkhead, with transverse framing in the fore deep tank up to the tank top level and in the fore peak up to the upper deck. Similarly at the after end the side and deck longitudinals are carried aft as far as they will conveniently go. A particular difficulty arises with the longitudinal bulkheads which must be tapered off into the forward deep tank and engine room. In the larger vessels it is often possible to carry the bulkheads through the engine room, the space at the sides being used for auxiliary spaces, stores and workshops.

A similar problem occurs in container ships, when it is essential to taper the torsion box and similar longitudinal stiffening gradually into the engine room and the fore end. The fine lines of these ships cause complications which are not found in the fuller vessels. In these faster vessels the importance of tying the main hull structure efficiently into the engine room structure cannot be sufficiently emphasised.

11

SHIP DYNAMICS

Propellers

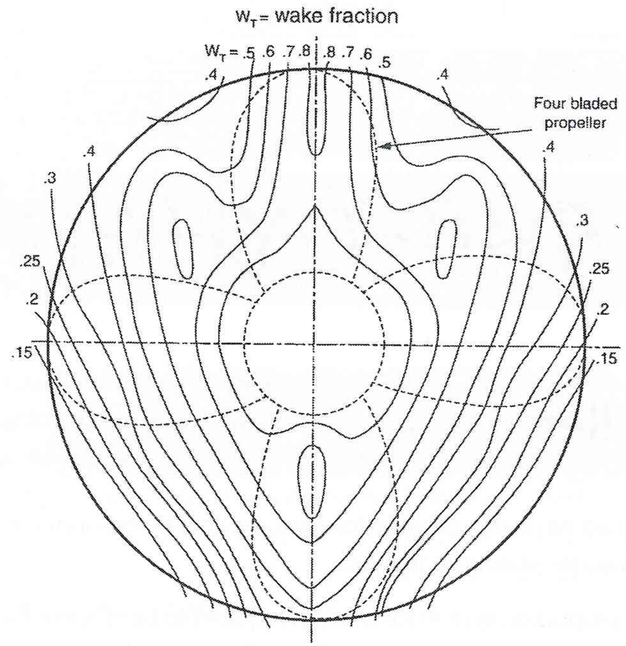
This section should be read in conjunction with the chapter on propellers in Volume 4, 'Naval Architecture for Marine Engineers'.

The design of a propulsion system for a ship is required to be efficient for the ship in its intended service, reliable in operation, free from vibration and cavitation, economical in initial cost, running costs and maintenance. Some of these factors conflict with others and, as with many areas of engineering, the final system is a compromise. Various options are open to the shipowner including the number of blades, the number of propellers, the type and design of propellers and shaft line or electric drive.

Propellers work in an adverse environment created by the varying wake field produced by the after end of the ship at the propeller disc. Figure 11.1 shows a typical wake distribution for a single screw ship. The localised calculation of the wake fraction W_T is determined by wake speed ÷ ship speed.

High wake fractions indicate that the water is being carried along at almost the same speed as the ship. Thus the propeller is working in almost *dead* water. The lower fractions indicate that the water is almost stationary and therefore has a high speed relative to the propeller. As the propeller blade passes through these different regions it is subject to a fluctuating load. These variations in loading cause several problems.

For example, consider a four-bladed propeller turning in the wake field shown in Figure 11.1, two of the blades are lightly loaded and two heavily loaded when the blades are in the position shown in the figure. When the propeller turns through 90°

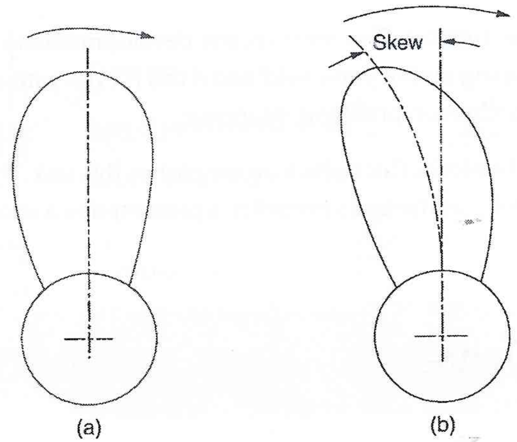


▲ **Figure 11.1** *Typical wake distribution – single screw ship*

The fluctuating loads might be reduced by changing the number of the blades or cleaning up the wake field. A three-bladed propeller, for example, will have only one blade fully loaded or lightly loaded at any one time, while five, six and seven blades produce more gradual changes in thrust and torque per blade and hence reduce the possibility of vibration due to this cause.

An alternative method of reducing the variation in blade loading is to fit a *skewed* propeller (Figure 11.2) in which the centreline of each blade is curved to spread the distribution of the blade area over a greater range of wake contours. In these propellers there is also less cavitation produced and under some conditions there are efficiency gains as well as a reduction in vibration.

Fluctuating Forces Caused by the Propeller Wake Field



▲ **Figure 11.2** *(a) Normal blade and (b) skewed blade*

the wake field moving past the hull and therefore it accelerates water which is already moving. The disturbed water moving toward the blade will create a fluctuating pressure entering the propeller disc as it rotates (Figure 11.1). The fluctuating pressure will set up vibration and also differencing effectiveness in the thrust produced across the propeller blade.

A propeller which is off the centreline lies only partly within the wake field and therefore has a wider variation in pressure differential to contend with as some of the blade is working in slower moving water which is outside of the influence of the hull. For this reason, single screw ships can be slightly more efficient than twin screw ships for similar conditions.

The main advantages of twin screw ships are their increased manoeuvrability and the duplication of propulsion systems leading to improved safety. Set against this is the considerable increase in the cost of the construction of the after end, whether the shaft support is by A-frames or by spectacle frames and bossings, compared with the sternframe of a single screw ship.

In a single screw ship, the rudder is also more effective since it lies directly in the outflow from the propeller and hence the velocity of water at the rudder is increased producing increased rudder force. Conversely, many twin screw ships are fitted with twin rudders in line with the propellers, further increasing their manoeuvrability at the expense of increased cost of steering gear. The variation in wake in a twin screw ship can be less than with a single screw ship, due to the propellers working in smoother water, and the deflection of the support. The most recent developments in ship design have concentrated on cleaning up the 'wake field' and if this is even with much less pressure differentials then the vibration problems disappear.

Page 126 describes the Mewis Duct which accomplishes this task. The development of podded drives also helps as the pod's propeller is presented to a relatively undisturbed wake field.

Podded Drive

With the developments in diesel electric propulsion systems (Chapter 9 in Volume 12, 'Motor Engineering Knowledge' of the Reeds Marine Engineering series), the efficiency of the propeller has taken a jump forward.

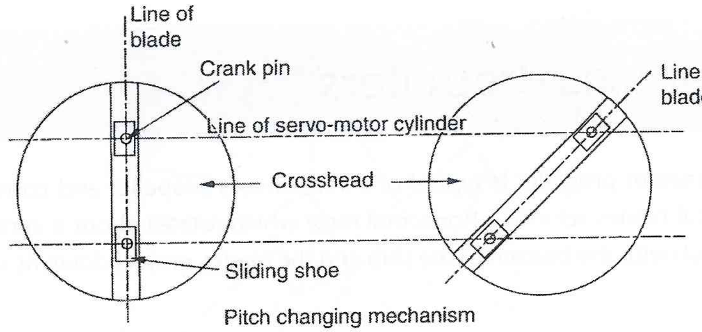
The major reason for this is that the pods can be placed in the most beneficial place under the hull. The pods usually face forward taking advantage of the less disturbed water in this position.

Vessels fitted with pods do not need rudders or stern thrusters, as the units are arranged so that they are able to turn 360°, which makes the design of the aft end of the vessel much cleaner and the hull presents much less resistance to movement resulting in a much more efficient arrangement overall.

Controllable Pitch Propellers

A controllable pitch propeller is one that always rotates in the same direction but the pitch of the blades may be altered by remote control. The blades are separately mounted onto bearing rings in the propeller hub. A valve rod is fitted within the hollow main shaft and this actuates a servo-motor cylinder. Longitudinal movement of this cylinder transmits a load through a crank pin and sliding shoe to rotate the propeller blade (Figure 11.3).

The propeller pitch is controlled directly from the bridge and hence closer and quicker control of the ship speed is obtained. This is of particular importance when manoeuvring in confined waters when the ship speed may be changed and indeed



▲ **Figure 11.3** *Pitch changing mechanism*

The initial cost of a c.p. propeller is considerably greater than that of a fixed pitch installation. On the other hand a simpler non-reversing main engine may be used or a reversing gear box is not required, and since the engine speed may be maintained at all times the c.p. installation lends itself to the fitting of shaft-driven auxiliaries such as a shaft alternator. The efficiency of a c. p. propeller is less than that of a fixed pitch propeller for optimum conditions, due to the larger diameter of boss required, but at different speeds the c.p. propeller has the advantage. The cost of repair and maintenance is high compared with a fixed pitch propeller although it might be possible to repair or replace a single blade of the c.p. arrangement.

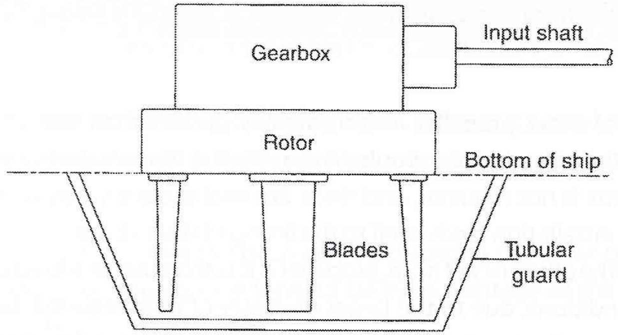
Contra-rotating Propellers

This system consists of two propellers in line, but turning in opposite directions. The after propeller is driven by a normal solid shaft. The forward propeller is driven by a short hollow shaft which encloses the solid shaft. The forward propeller is usually larger and has a different number of blades from the after propeller to reduce the possibility of vibration due to blade interference.

Research has shown that the system may increase the propulsion efficiency by 10%–12% by cancelling out the rotational losses imparted to the stream of water passing through the propeller disc. Contra-rotating propellers are extremely costly and are suitable only for highly loaded propellers and large single screw tankers, particularly when the draught is limited. The increased surface area of the combined system reduces the possibility of cavitation but the longitudinal displacement of the

Vertical Axis Propellers

The Voith–Schneider propeller is typical of a vertical axis propeller and consists of a series of vertical blades set into a horizontal rotor which rotates about a vertical axis. The rotor is flush with the bottom of the ship and the blades project down as shown in Figure 11.4.



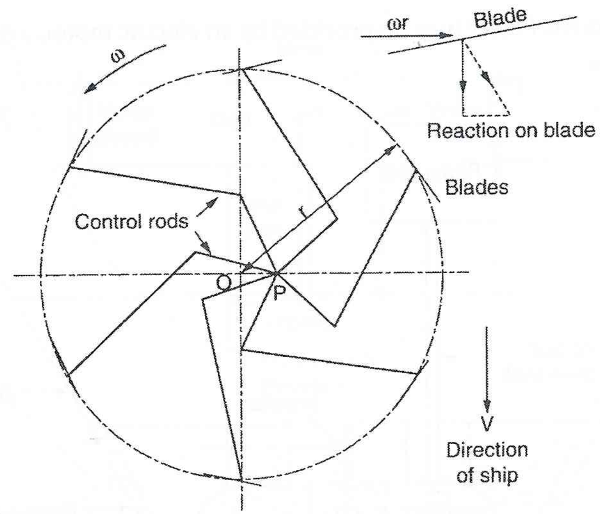
▲ **Figure 11.4** *Voith Schneider Drive*

The blades are linked to a control point P by cranked control rods (Figure 11.5). When P is in the centre of the disc, the blades rotate without producing a thrust. When P is moved away from the centre in any direction, the blades turn in the rotor out of line with the blade orbit and a thrust is produced. The direction and magnitude of the thrust depends upon the position of P. Since P can move in any direction within its inner circle, the ship may be driven in any direction and at varying speeds.

Thus the Voith–Schneider propeller may propel and manoeuvre a ship without the use of a rudder.

The efficiency of a Voith–Schneider propeller is relatively low but it has the advantage of high manoeuvrability and is useful in harbour craft and ferries. Two or more installations may be fitted and in special vessels (e.g. firefloats) can move the ship sideways or rotate it in its own length.

Replacement of damaged blades is simple although they are fairly susceptible to damage. A tubular guard is usually fitted to protect the blades. The propeller may be



▲ **Figure 11.5** *Blade positions*

Tunnel Thrusters (Bow and Stern Thrusters)

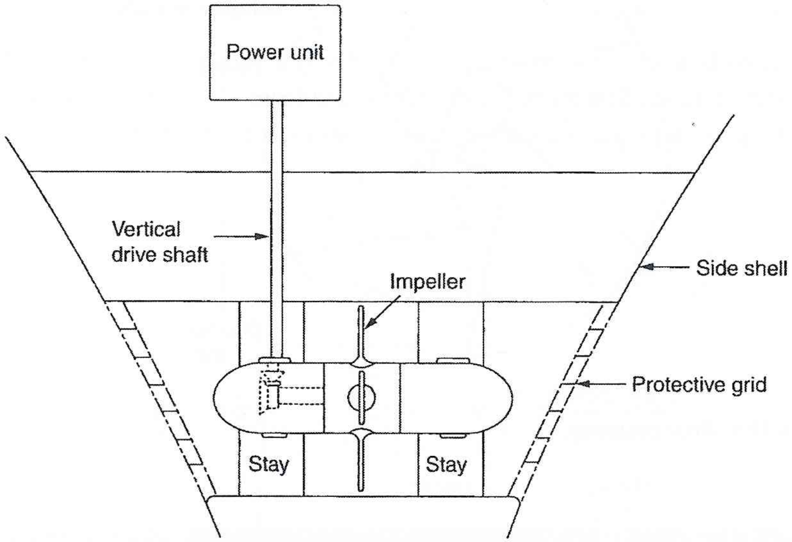
Many ships are fitted with bow thrust units to improve their manoeuvrability (Figure 11.6). They are an obvious feature in ships working within, or constantly in and out of harbour where close control is obtained without the use of tugs. They have also proved to be of considerable benefit to larger vessels such as oil tankers and bulk carriers, where the tug requirement has been reduced.

Several types of tunnel thrusters are available, each having its own advantages and disadvantages.

In all cases the necessity to penetrate the hull forward causes an increase in ship resistance and hence in fuel costs, although the increase is small and with the podded drives the tunnel thrusters at the stern of the vessel are not required.

A popular arrangement is to have a cylindrical duct passing through the ship from side to side, in which is fitted an impeller that can produce a thrust to port or to starboard. The complete duct must lie below the waterline at all draughts, the impeller acting best when subject to a reasonable head of water and thus reducing the possibility of cavitation.

constant-speed drive. Power may be provided by an electric motor, a diesel engine or a hydraulic motor.



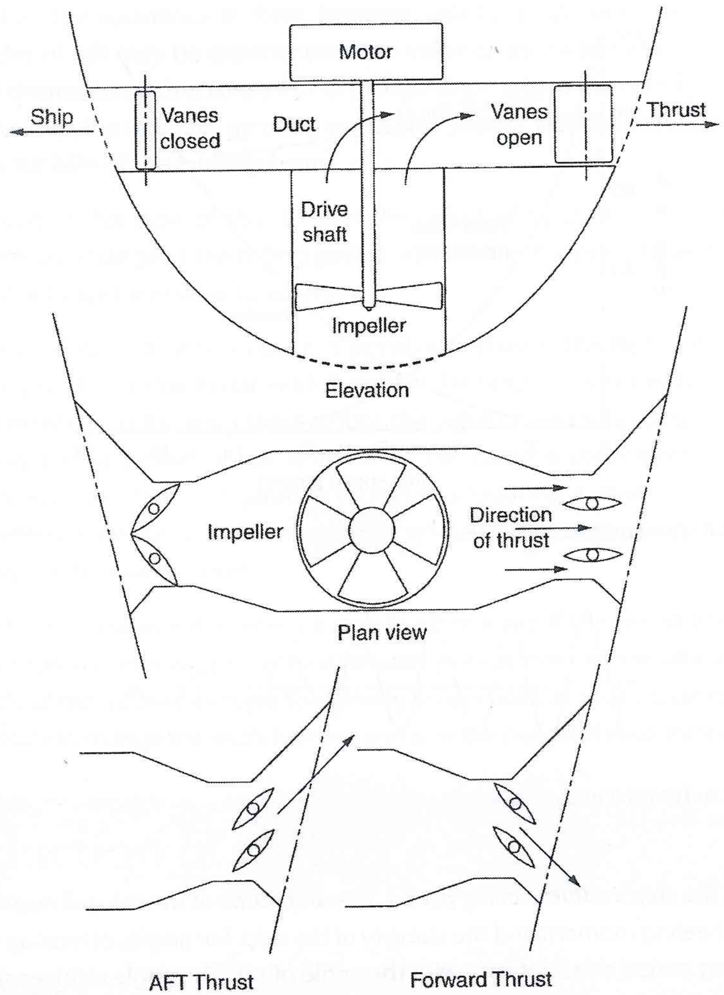
▲ **Figure 11.6** *Controllable pitch bow thrusters*

Some vessels are fitted with Voith–Schneider propellers within the ducts to produce the transverse thrust.

As an alternative the water may be drawn from below the ship and projected port or starboard through a horizontal duct which may lie above or below the waterline. A unidirectional horizontal impeller is fitted in a vertical duct below the waterline. The lower end of the duct is open to the sea, while the upper end leads into the horizontal duct which has outlets in the side shell port and starboard.

Within this duct two hydraulically operated vertical vanes are fitted to each side (Figure 11.7). Water is drawn from the bottom of the ship into the horizontal duct. By varying the position of the vanes the water jet is deflected either port or starboard, producing a thrust and creating a reaction which pushes the bow in the opposite direction.

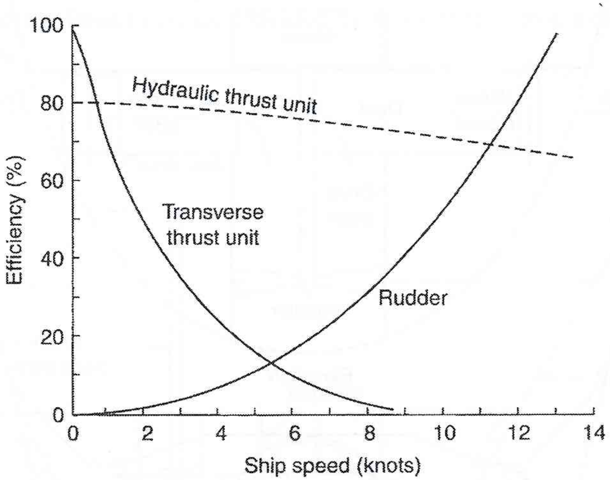
This system has an advantage that by turning all vanes 45° either forward or aft an additional thrust forward or aft can be produced. A forward thrust would act as a retarding force while an aft thrust would increase the speed of the ship. These actions



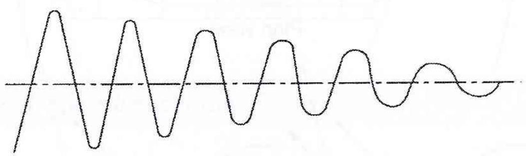
▲ **Figure 11.7** *Hydraulic thrust unit*

relatively ineffective at low speeds. The water jet unit appears to maintain its efficiency at all speeds, although neither type of thrust unit would normally be used at speed. Figure 11.8 does indicate the usefulness of thrust units when moving and docking compared with the use of the rudder.

Rolling and Stabilisation



▲ **Figure 11.8** *Comparison of efficiencies*



▲ **Figure 11.9** *Typical damping curve*

is known as the ship's *natural rolling period*. The *amplitude* of the roll will depend upon the applied heeling moment and the stability of the ship. For angles of heel up to about 15° the rolling period does not vary with the angle of roll. The angle reduces slightly at the end of each swing and will eventually dampen out completely. This dampening is caused by the frictional resistance between the hull and the water, which causes a mass of *entrained water* to move with the ship (Figure 11.9).

The natural rolling period of a ship may be estimated by the formula:

$$\text{Rolling period } P = \frac{2\pi k}{\sqrt{g\ \text{GM}}} \text{ seconds,}$$

where GM is the metacentric height, and k is the radius of gyration of the loaded ship about a longitudinal polar axis.

Thus a large metacentric height will produce a small period of roll although the

of the ship. The resistance to heel, however, will be small and consequently large amplitudes of roll may be experienced. The value of the radius of gyration will vary with the disposition of the cargo. For dry cargo ships, where the cargo is stowed right across the ship, the radius of gyration varies only slightly with the condition of loading and is about 35% of the midship beam.

It is difficult in this type of ship to alter the radius of gyration sufficiently to cause any significant change in the rolling period. Variation in the period due to changes in metacentric height are easier to achieve.

In tankers and bulk carriers vessels it is possible to change the radius of gyration and not as easy to change the metacentric height. If the cargo is concentrated in the centre compartments, with the wing tanks empty, the value of the radius of gyration is small, producing a small period of roll. If, however, the cargo is concentrated in the wing compartments, the radius of gyration increases, producing a slow rolling period. This phenomenon is similar to a skater spinning on ice; as the arms are outstretched the spin is seen to be much slower.

Problems may occur in a ship which travels in a beam sea, if the period of encounter of the waves synchronises with the natural frequency of roll. Even with small wave forces the amplitude of the roll may increase to alarming proportions. In such circumstances it may be necessary to change the ship's heading and alter the period of encounter of the waves.

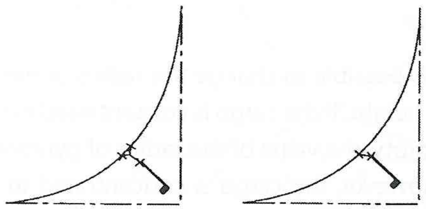
Reduction of Roll

Bilge keels

This plating projects from the hull and are arranged at the bilge to lie above the line of the bottom shell and within the breadth of the ship, thus being partially protected against damage. The depth of the bilge keels depends to some extent on the size of the ship, but there are two main factors to be considered:

1. The web must be deep enough to penetrate the boundary layer of water travelling with the ship.
2. If the web is too deep, the force of water when rolling may cause damage.

be continuous and are tapered gradually at the ends with the ends terminated on an internal stiffening member. Some forms of bilge keel are shown in Figure 11.10 and they are usually fitted in two parts, the connection to the shell plating being stronger than the connection between the two parts. In this way it is more likely, in the event of damage, that the web will be torn from the connecting angle rather than the connecting angle from the shell plating.

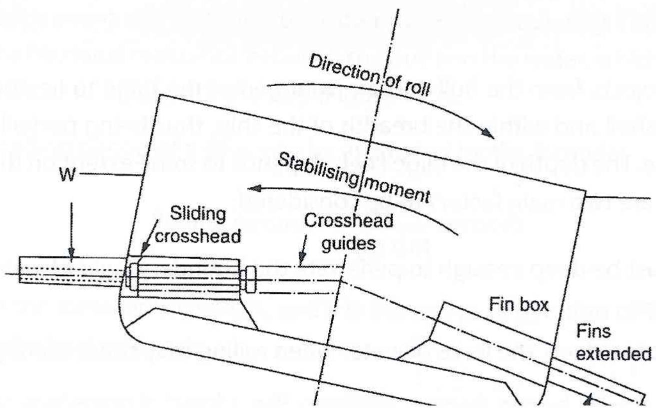


▲ **Figure 11.10** *Bilge keels*

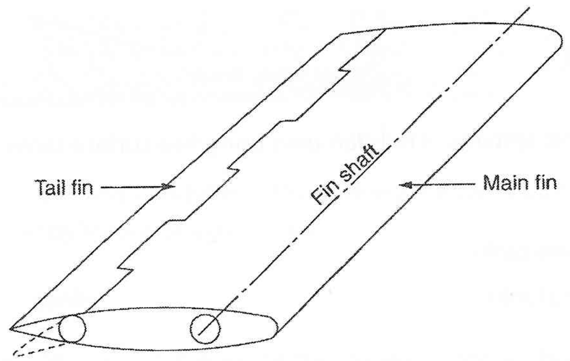
The bilge keels reduce the initial amplitude of roll as well as subsequent movements.

Active fin stabilisers

Two fins extend from the ship side at about bilge level. They are turned in opposite directions as the ship rolls. The forward motion of the ship creates a force on each fin and hence produces a moment opposing the roll. When the fin is turned down, the water exerts an upward force. When the fin is turned up, the water exerts a downward force (Figure 11.11).

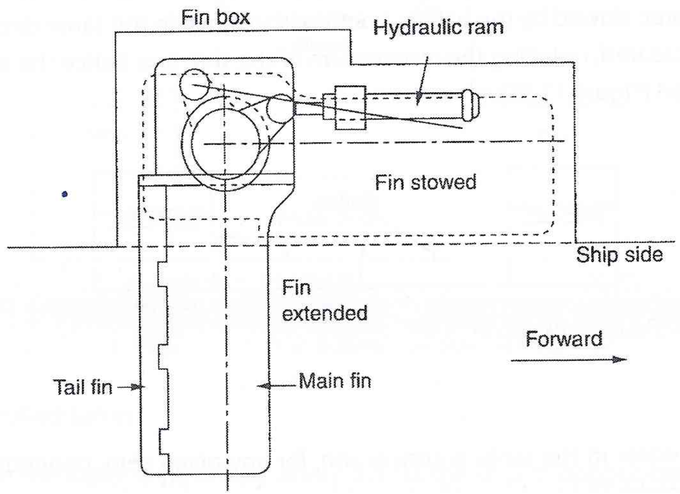


The fins are usually rectangular, having aerofoil cross-section (Figure 11.12) and turn through about 20°. Many are fitted with tail fins which turn relative to the main fin through a further 10°. The fins are turned by means of an electric motor driving a variable delivery pump, delivering oil under pressure to the fin tilting gear. The oil actuates rams coupled through a lever to the fin shaft.



▲ **Figure 11.12** *Stabiliser fin*

Most fins are retractable, either sliding into fin boxes transversely or hinged into the ship. Hinged fins are used when there is a restriction on the width of ship, which may be allocated, such as in a container ship (Figure 11.13).



The equipment is controlled by means of two gyroscopes, one measuring the angle roll and the other the velocity of roll. The movements of the gyroscopes actuate relays which control the angle and direction through which the fins are turned. It should be noted that no movement of stabiliser can take place until there is an initial roll of the ship and that the fins require a forward movement of the ship to produce a righting moment.

Tank stabilisers

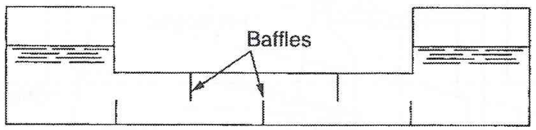
There are three basic systems of roll-damping using free surface tanks:

1. Passive tanks
2. Controlled passive tanks
3. Active controlled tanks

These systems do not depend upon the forward movement of the ship and are therefore suitable for vessels such as drill ships. In introducing a free surface to the ship, however, there is a reduction in stability which must be considered when loading the ship.

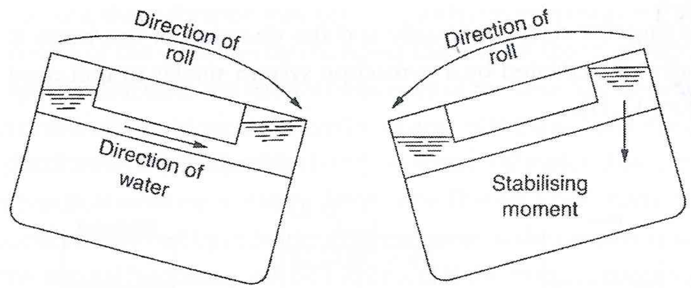
Passive tanks

Two wing tanks are connected by a duct having a system of baffles (Figure 11.14). The tanks are partly filled with water. When the ship rolls, the water moves across the system in the direction of the roll. As the ship reaches its maximum angle and commences to return, the water, slowed by the baffles, continues to move in the same direction. Thus a moment is created, reducing the momentum of the ship and hence the angle of the subsequent roll (Figure 11.15).



▲ **Figure 11.14** *Passive tank system*

The depth of water in the tanks is critical and, for any given ship, depends upon the



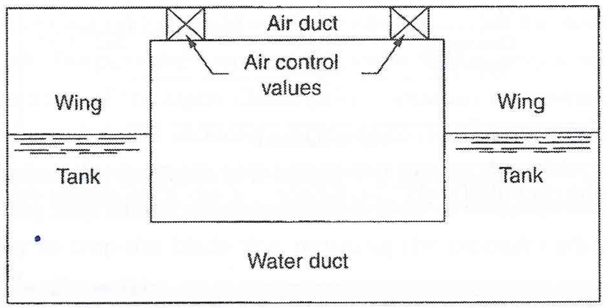
▲ **Figure 11.15** *Passive tank system in action*

and create dangerous rolling conditions. Alternatively the cross-sectional area of the duct may be adjusted by means of a gate valve.

Controlled passive tanks

The principle of action is the same as for the previous system, but the transverse movement of the water is controlled by valves operated by a control system similar to that used in the fin stabiliser. The valves may be used to restrict the flow of water in a U-tube system, or the flow of air in a fully enclosed system (Figure 11.16).

The mass of water required in the system is about 2–2$\frac{1}{2}$% of the displacement of the ship.

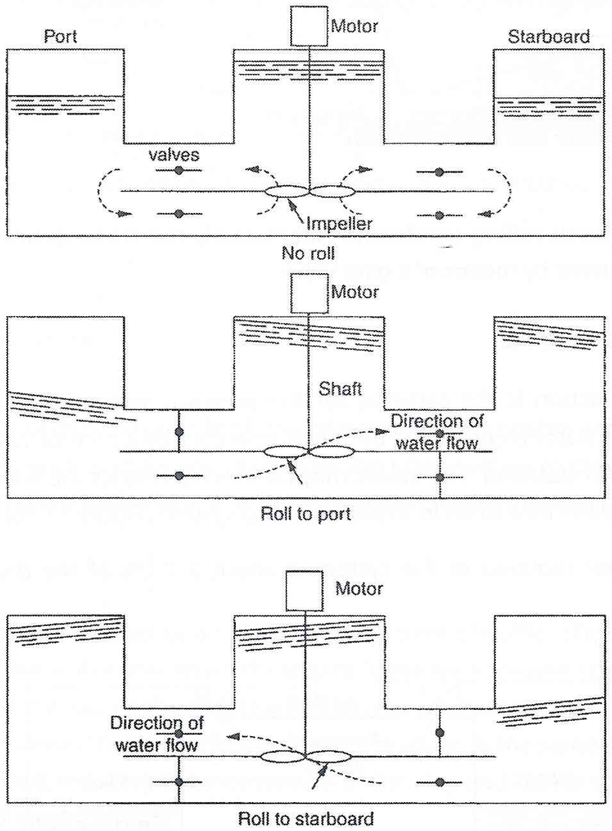


▲ **Figure 11.16** *Controlled passive tank*

Active controlled tanks

In this system the water is positively driven across the ship in opposition to the roll.

of valves. The impeller runs continually and the direction of the water is controlled by valves which are activated by a gyroscope system similar to that used for the fin stabiliser (Figure 11.17).



▲ **Figure 11.17** *Active controlled tank*

Vibration

Ship vibration is the periodic movement of the structure and may occur vertically, horizontally or torsionally.

of the hull structure, then vibration may occur. In such circumstances it is usually easier to alter the source of the vibration by changing the engine speed or fitting dampers, than to change the structure. The natural frequency of the structure depends upon the length, mass distribution and second moment of area of the structural material. For any given mass distribution a considerable change in structural material would be required to cause any practical variation in natural frequency. There is a possibility of altering the natural frequency of the hull by redistributing the cargo. If the cargo is concentrated at the nodes, the natural frequency will be increased. If the cargo is concentrated at the anti-nodes, the natural frequency and the deflection will be reduced. Such changes in cargo distribution may only be possible in vessels such as oil tankers or bulk carriers in the ballast condition.

Similarly vibration may occur in a machinery space due to unbalanced forces from the main or auxiliary machinery or as a result of uneven power distribution in the main engine. This vibration may be transmitted through the main structure to the superstructure, causing extreme discomfort to the personnel.

As explained earlier the variation in blade loading due to the wake may create vibration of the after end, which may be reduced by changing the number of blades. The turbulence of the water caused by the shape of the after end is also a source of vibration which may be severe. It is possible to design the after end of the ship to reduce this turbulence resulting in a smoother flow of water into the propeller disc.

Severe vibration of the after end of some ships is caused by insufficient propeller tip clearance. As the blade tip passes the top of the aperture it attempts to compress the water. This creates a force on the blade which causes bending of the blade and increased torque in the shaft. The periodic nature of this force, that is, revs × number of blades, produces the vibration of the stern. Classification societies recommend minimum tip clearances to reduce propeller-induced vibrations to reasonable levels. Should the tip clearance be constant, for example, with a propeller nozzle, then this problem does not occur. If an existing ship suffers an unacceptable level of vibration from this source, it may be necessary to crop the blade tips, reducing the propeller efficiency, or to fit a propeller of smaller diameter.

A damaged propeller blade will create out-of-balance moments due to the unequal weight distribution and the uneven loading on the blades. Little may be done to relieve the resultant vibration except to repair or replace the propeller.

Wave induced vibrations may occur in ships due to pitching, heaving, slamming or the passage of waves along the ship. In smaller vessels pitching and slamming are the main cases the vibration has been caused by the periodic increase and decrease in buoyancy with regular waves much shorter than the ship, while in other cases, with non-uniform waves, the internal energy of the wave is considered to be the source. Such vibrations are dampened by a combination of the hull structure, the cargo, the water friction and the generation of waves by the ship.

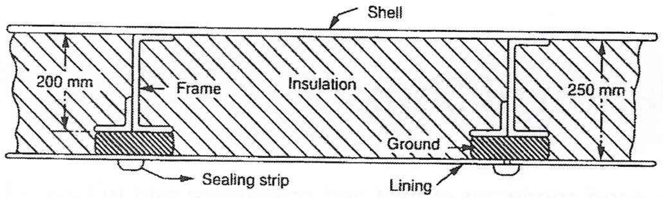
12 MISCELLANEOUS

Insulation of Ships

Steelwork is a good conductor of heat and is therefore said to have a high thermal conductivity. It will therefore be appreciated that some form of insulation, having low thermal conductivity, must be fitted to the inner face of the steelwork in refrigerated compartments to reduce the transfer of heat. The ideal form of insulation is a vacuum although good results may be obtained using air pockets. Most insulants are composed of materials having entrapped air cells, such as cork, glass fibre and foam plastic. Cork may be supplied in slab or granulated form, glass fibre in slab form or as loose fill, while foam plastic may either be supplied as slabs or the plastic may be foamed into position. Granulated cork and loose glass fibre depend to a large extent for their efficiency on the labour force, while in service they tend to settle, leaving voids at the top of the compartment. These voids allow increased heat transfer and plugs are fitted to allow the spaces to be repacked. Horizontal stoppers are arranged to reduce settlement. Glass fibre has the advantages of being fire resistant and vermin-proof and will not absorb moisture. Since it is also lighter than most other insulants it has proved very popular in modern vessels. Foam plastic has recently been introduced, however, and when foamed in position, entirely fills the cavity even if it is of awkward shape.

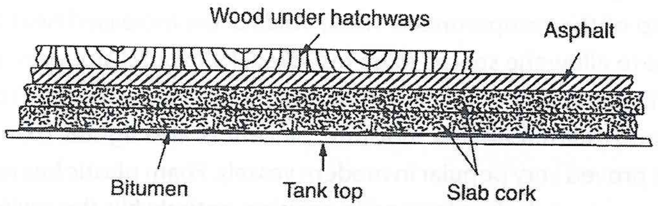
The depth of insulation in any compartment depends upon the temperature required to maintain the cargo in good condition, the insulating material and the depth to which any part of the structure penetrates the insulant. It is usually found that the depths of frames and beams govern the thickness of insulation at the shell and decks, 25–50 mm of insulation projecting past the toe of the section. It therefore proves economical in insulated ships to use frame and reverse as shown in Figure 3.7 in Chapter 3 and thus

The internal linings required to retain and protect the insulation may be of galvanised iron, stainless steel or aluminium alloy. The linings are screwed to timber grounds which are, in turn, connected to the steel structure. The linings are made airtight by coating the overlaps with a composition such as white lead and fitting sealing strips. This prevents heat transfer due to a circulation of air and prevents moisture entering the insulation. Cargo battens are fitted to all the exposed surfaces to prevent contact between the cargo and the linings and to improve the circulation of air round the cargo. Figure 12.1 shows a typical arrangement of insulation at the ship side.



▲ **Figure 12.1** *Shell insulation*

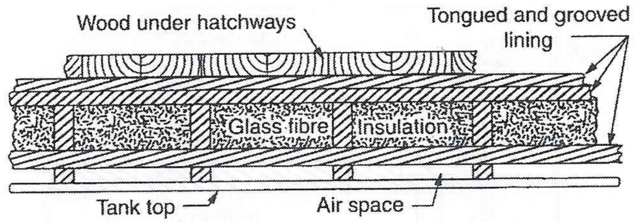
At the tank top an additional difficulty arises – that of providing support for the cargo. Much depends upon the load bearing qualities of the insulant. Slab cork, for instance, is much superior in this respect to glass fibre, and may be expected to carry some part of the cargo load. The tank top arrangement in such a case would be as shown in Figure 12.2.



▲ **Figure 12.2** *Cork insulation of tank top*

Slab cork 150–200 mm thick is laid on hot bitumen. The material is protected on its upper surface by a layer of asphalt 50 mm thick which is reinforced by steel mesh. Wood ceiling is fitted under the hatchways where damage is most likely to occur.

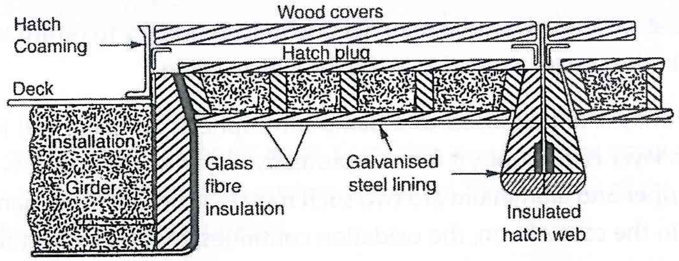
Figure 12.3 shows the arrangement where glass fibre is used. The cargo is supported on



▲ **Figure 12.3** *Glass fibre insulation of tank top*

the bearers. If oil fuel is carried in the double bottom in way of an insulated space, it is usual to leave an air gap between the tank top and the insulation. This ensures that any leakage of oil will not affect the insulation.

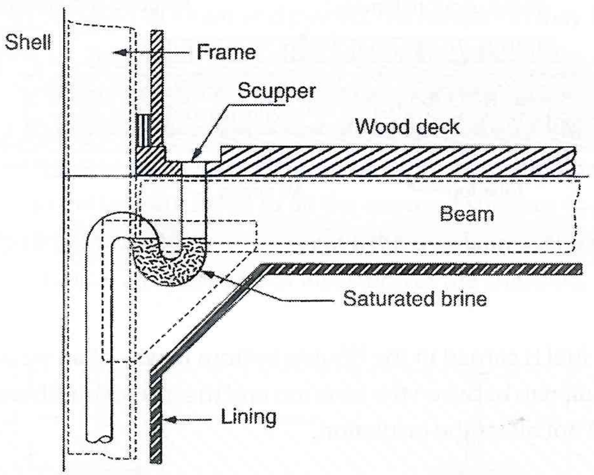
Particular care must be taken to design the hatchways to avoid heat transfer. The normal hatch beams are fitted with tapered wood which is covered with galvanised sheet. A similar type of arrangement is made at the ends of the hatch. Insulated plugs with opposing taper are wedged into the spaces. The normal hatch boards are fitted at the top of the hatch as shown in Figure 12.4. Steel hatch covers may be filled with some suitable insulation and do not then require separate plugs.



▲ **Figure 12.4** *Insulated hatch plug*

Similar types of plug are fitted at the bilge to allow inspection and maintenance, and in way of tank top manholes.

Drainage of insulated spaces is rather difficult. Normal forms of scupper would lead to increase in temperature. It becomes necessary, therefore, to fit brine traps to all 'tween deck and hold spaces. After defrosting the compartments and removing the cargo the traps must be refilled with saturated brine, thus forming an air seal which will not freeze. Figure 12.5 shows a typical brine trap fitted in the 'tween decks.



▲ **Figure 12.5** *Tween deck scupper*

Corrosion

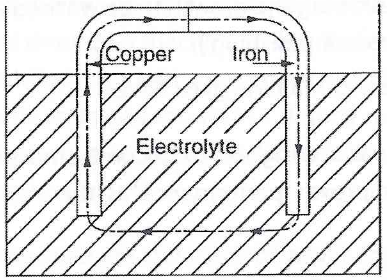
Corrosion is the wasting away of a material due to its tendency to return to its natural state, which, in the case of a metal, is in the form of an oxide.

If a metal or alloy is left exposed to a damp atmosphere, an oxide will form on the surface. If this layer is insoluble, it forms a protective layer which prevents any further corrosion. Copper and aluminium are two such metals. If, on the other hand, the layer is soluble, as in the case of iron, the oxidation continues, together with the erosion of the material.

When two dissimilar metals or alloys are immersed in an electrolyte, an electric current flows through the liquid from one metal to the other and back through the metal pathway. The direction in which the current flows depends upon the relative position of the metals in the electrochemical series. For common metals in use in ships, this series is in the following order of electrode potential:

The current flows from the anode to the cathode which is higher in the Periodic table, or more electro-positive. Thus, if copper and iron are joined together and immersed in an electrolyte, a current will flow through the electrolyte from the iron to the copper

Positive copper	+
Lead	
Tin	
Iron	
Chromium	
Zinc	
Aluminium	
Negative magnesium	−



▲ **Figure 12.6** *Corrosion cell*

the same material. Steel plate, for instance, is not perfectly homogeneous and will therefore have anodic and cathodic areas. Corrosion may therefore occur when such a plate is immersed in an electrolyte such as sea water. The majority of the corrosion of ships is due to this electrolytic process.

Hull Coatings – for Efficiency and for the Prevention of Corrosion

When metal is subjected to moisture and oxygen the original parent metal starts to degrade in a chemical process known as corrosion. The corrosion of metal may be prevented by coating the metallic surface with a substance which prevents contact with moisture and/or oxygen. This does seem like a simple principle to achieve; in practice, however it is proved difficult to maintain such a coating, particularly on ships

When a vessel is travelling across the ocean the hull might come into contact with floating or submerged objects that could cause damage. While arriving at or leaving the berth the hull could be subjected to damage by coming into contact with the quay and while the ship is stationary, either at anchor or alongside, the various marine organisms like to attach themselves to the hull.

Therefore, a modern hull coating has to accomplish two major objectives, which are to stop the hull corroding and to stop the hull becoming fouled with marine growth.

Anti-fouling can be accomplished by using a:

- coating containing a biocide that kills the marine growth;
- 'low adhesion' coating, allowing the growth to be washed away by the moving ship (sometimes referred to as 'self-polishing');
- very hard coating possibly containing glass flakes.

Some coating systems are also designed to become smoother as the vessel moves through the water. This improves performance as the vessel progresses from one docking to the next.

Surface preparation

New building

Steel plates supplied to shipbuilders have patches of a black oxide known as *mill scale* adhering to the surface. This scale is insoluble and, if maintained over the whole surface, would reduce corrosion. It is, however, very brittle and does not expand either mechanically or thermally at the same rate as the steel plate. Unless this mill scale is removed before coating, the covered scale will drop off in service, leaving bare steel plate which will corrode rapidly. Unfortunately mill scale is difficult to remove completely.

If the plate is left exposed to the atmosphere, rust will form behind the mill scale. On wire brushing, the majority of the scale will be removed. This is known as *weathering*. In modern times a good flow of material through the shipyard is essential and therefore the time allowed for weathering must be severely limited. In addition, it is found in practice that much of the mill scale is not removed by this process.

plate must be hosed down with fresh water on removal from the tank, to remove all traces of the acid. It is then allowed to dry before painting. One disadvantage with this method is that during the drying period a light coating of rust is formed on the plate and must be removed before painting.

Flame cleaning of a ship's structure came into use some time ago. An oxy-acetylene torch, having several jets, is used to brush the surface. It burns any dirt and grease, loosens the surface rust and, due to the differential expansion between the steel and the mill scale, loosens the latter. The surface is immediately wire brushed and the priming coat applied while the plate is still warm. This method is not usually used on a large scale any more.

The most effective method of removing the mill scale to date is the use of *shot blasting*. The steel plates are passed through a machine in which steel shot is projected at the plate, removing the mill scale together with any surface rust, dirt and grease. This system removes 95–100% of the mill scale and results in a slightly rough surface which allows adequate adhesion of the paint. In modern installations, the plate is spray painted on emerging from the shot blasting machine.

These methods of preparing steel are still used; however the ship builder will require the steel to be supplied in this 'pre-prepared' condition. The steel will arrive with the mill scale removed and the steel coated with a thin coat of primer. This 'shop primer' gives temporary protection from the atmospheric conditions while it is transported and stored ready for use.

Surface preparation during dry-docking

One of the primary reasons for docking a ship is to inspect the hull for any damage to the structure, to repair the damage and to reinstate the hull coating.

Surface preparation is crucial to the performance of any coating system. It is desirable but sometimes not cost effective to take the surface back to bare metal. This is termed Sa 2½ which comes from the Swedish Standards for the cleanliness of the metal surface. Sa 3 is totally bare metal with Sa 2½ being a practical approximation to Sa 3.

If changing from one coating system to another, then the hull should be shot/sand blasted to Sa 2½ before the new system is applied. A second reason for paying attention

Some owners will only allow the hull to be prepared in areas where there is corrosion visible. This is known as 'spot blasting', and the rest of the hull is cleaned of oil, dirt and other contaminants by pressure washing with water and detergent.

The problem with the second method is that it leaves an uneven surface as the old coating is removed in patches and there is a small step change at the point where the blasting occurs. Within the industry studies have shown significant savings in fuel when the hull is prepared to Sa 2½ as opposed to spot blasting. As the IMO require year on year efficiency savings and cost of fuel then full preparation to Sa 2½ might work out to be cost effective in some cases.

Coating systems

The careful attention to surface preparation is wasted unless backed up by a high quality coating system that is correctly applied. The priming coat is very important as it must adhere to the metal surface. It must be capable of withstanding the wear and tear of everyday working and be easy to apply with airless spray equipment. The substrate is usually an epoxy resin and the pigment is usually grey. The primer must be compatible with the hard wearing, watertight topcoat. The coatings must be applied on clean, dry surfaces with some of the most modern 'self-polishing' coatings having the ability to make their top surface smother by evening out the imperfections in the hull's surface.

Cathodic protection

If three dissimilar metals are immersed in an electrolyte, the metal lowest on the electro chemical scale becomes the anode, the remaining two being cathodes. Thus if copper and iron are immersed in sea water, they may be protected by a block of zinc which is then known as a *sacrificial anode*, since it is allowed to corrode in preference to the copper and iron. Thus zinc or magnesium anodes may be used to protect the propeller and stern frame assembly of a ship, and will, at the same time, reduce corrosion of the hull due to differences in the steel.

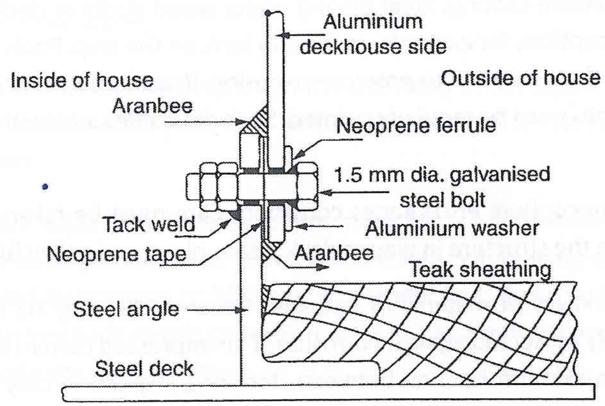
Water ballast tanks may also be protected by sacrificial anodes. It is first essential to remove any rust or scale from the surface and to form a film on the plates which prevents any further corrosion. Both of these functions are performed by booster anodes which have large surface area compared with their volume (e.g. flat discs).

are designed to last about 3 years. Protection is only afforded to the whole tank if the electrolyte is in contact with the whole tank. Thus it is necessary when carrying water ballast to press the tank up.

Electrolytic action may occur when two dissimilar metals are in contact above the waterline. Great care must be taken, for instance, when joining an aluminium alloy deckhouse to a steel deck. The traditional method, such as with some of the great ocean liners, was for the steel bar forming the attachment to be galvanised and steel or iron rivets being used through the steel deck, with aluminium rivets to the deckhouse. A coating of barium chromate between the surfaces forms a measure of protection.

The method used on M.S. *Bergensfjord* was most effective, although perhaps costly. Contact between the two materials was prevented by fitting 'neoprene' tape in the joint (Figure 12.7). Galvanised steel bolts were used, but 'neoprene' ferrules were fitted in the bolt holes, opening out to form a washer at the bolt head. The nut was fitted in the inside of the house, and tack welded to the boundary angle to allow the joint to be tightened without removal of the internal lining. The top and bottom of the joints were then filled with a compound known as 'Aranbee' to form a watertight seal.

The modern method is with the use of a welded aluminium/steel structural transition joint. An explosion welding technique is used and as the metals join a natural layer of aluminium oxide forms which in the completed process acts to prevent the galvanic corrosion.



▲ **Figure 12.7** *Connection of aluminium deckhouse to steel deck*

Impressed current system

A more sophisticated method of corrosion control of the outer shell may be achieved by the use of an impressed current. A number of zinc reference anodes are fitted to the hull but insulated from it. It is found that the potential difference between the anode and a fully protected steel hull is about 250 mV. If the measured difference at the electrode exceeds this value, an electric current is passed through a number of long lead–silver alloy anodes attached to, but insulated from, the hull. The protection afforded is more positive than with sacrificial anodes, and it is found that the lead–silver anodes do not erode. A current of 7–350 mA/m^2 is required depending upon the surface protection and the degree to which the protection has broken down.

Design and maintenance

Corrosion of ships may be considerably reduced if careful attention is paid to the design of the structure. Smooth, clean surfaces are easy to maintain and therefore careful attention should be paid to the welding of ships. If parts of the structure are difficult to inspect, then it is unlikely that these parts will be properly maintained. Efficient drainage of all compartments should be ensured.

Those parts of the structure which are most liable to corrosion should be heavily covered with a suitable coating. Steel plating under wood decks or deck composition is particularly susceptible, for example, as is every tank on the ship. Pools of water lying in plate edges on the deck tend to promote corrosion. If such pools cannot be avoided then the plate edges must be regularly painted. Such difficulties arise with joggled deck plating.

A warm, damp atmosphere encourages corrosion. Care must be taken, therefore, to regularly maintain the structure in way of deck steam pipes and galley funnels.

Reductions in thickness of material of between 5% and 10% may be allowed if the structure is suitably protected against corrosion. If an impressed current system is used for the hull, the maximum interval between dockings/inspection may be increased from 2 to $2\frac{1}{2}$ years.

Fouling

The resistance exerted by the water on a ship will be considerably increased if the hull is badly fouled by marine growth. It is found that marine growth will adhere to the ship if the speed is less than about 4 knots. Once attached, however, the growth will continue and will be difficult to remove despite the speed. The type of fouling depends upon the nature of the plant and animal life in the water.

It is essential to reduce fouling, since the increase in resistance in severe cases may be in the order of 30–40%. This is reflected in an increase in fuel consumption to maintain the same speed, or a reduction in speed for the same power.

The main 'anti-fouling' system used to be made up of toxic coatings – usually mercury based. The coating exudes a biocide poison which inhibits the marine growth. Unfortunately, the poison works at all times and poison is being released into the water.

A recent development in the anti-fouling campaign is the introduction of self-polishing copolymers (spc). This is a paint in which the binder and toxins are chemically combined. Water in contact with the hull causes a chemical and physical change on the surface of the coating. When water flows across the surface, the local turbulence removes or *polishes* this top layer. With the introduction of MARPOL V the anti-fouling coatings are no longer allowed to contain toxins and therefore a low adhesion coating is used and any marine growth is washed off when the ship starts to travel through the water.

In addition to the anti-fouling properties, the polishing of the layers produces a very smooth surface and hence considerably reduces the frictional resistance and hence the fuel consumption.

Fouling of the sea inlets may cause problems in engine cooling, while explosions have been caused by such growths in air pipes. When a ship is in graving dock, hull fouling must be removed by scrapers or high pressure water jets. These water jets, with the addition of abrasives such as grit, prove very effective in removing marine growth and may be used while the vessel is afloat.

One method of removing growth is by means of explosive cord. The cord is formed into a diamond-shaped mesh which is hung down from the ship side, attached to a floating line.

growth and loose paint. By energising the net in sequential layers, the hull is cleaned quickly but without the excessive energy which would result from a single charge.

Examination in Dry Dock – Class

Dry-docking a ship is a necessary part of ownership. Traditionally this was the only way that the parts of the vessel usually covered by water could be examined thoroughly. Recently however in-water surveys have gained popularity as the equipment becomes more sophisticated and more companies are offering an approved service.

In many companies it is the responsibility of the marine engineers and/or superintendents to make an official inspection of the hull of the ship after entering a graving or floating dry dock, while in other companies it is the responsibility of the deck officers. It is essential on such occasions to make a thorough examination to ensure that all necessary work is carried out bearing in mind that whoever is making the inspection is doing so on behalf of the owner.

The shell plating should be hosed with fresh water and brushed down immediately to remove the salt before the sea water dries. The plating must be carefully checked for distortion, buckling, roughness, corrosion and defective welding. The welded seams and butt joints should also be inspected for cracks.

Until recently inspections of this nature to the sides of the vessel would have to wait until scaffolding or other suitable equipment could be erected so that people could work at a height safely.

The use of cameras mounted on small unmanned flying vehicles or drones is starting to prove extremely cost-effective in this area of work. The initial survey is undertaken quickly and identifies areas that require closer inspection.

For example, the side shell may be slightly damaged due to rubbing against quays, jetties etc. After inspection and repair the plating should be wire brushed or shot blasted and painted. Any sacrificial anodes must be checked and replaced if necessary, taking care not to paint over the surface.

The ship side valves and cocks are examined, glands repacked and greased where

be built up with welding or replaced. The shell boxes are wire brushed and painted with a suitable coating.

If the double bottom tanks are to be cleaned, the tanks are drained by unscrewing the plugs fitted at the after end of the tank. This allows complete drainage since the ship lies at a slight trim by the stern. It is essential that these plugs should be replaced before undocking and new jointing should always be fitted.

The after end must be examined with particular care. If at any time the ship has grounded, the sternframe may be damaged. It should be carefully inspected for cracks, paying particular attention to the sole piece. In twin screw ships the spectacle frame must be thoroughly examined. The drain plug at the bottom of the rudder is removed to determine whether any water has entered the rudder.

Corrosion on the external surface may be the result of complete wastage of the plate from the inside. The 'wear-down' of the rudder bearing is measured either at the tiller or at the upper gudgeon. Little or no wear-down should be seen if the rudder is supported by a carrier, but if there are measurable differences the bearing surfaces of the carrier should be examined. If no carrier is fitted, appreciable wear-down may necessitate replacing the hard steel bearing pad in the lower gudgeon. The bearing material in the gudgeons must be examined to see that the pintles are not too slack, a clearance of 5 mm being regarded as a maximum. The pintle nuts, together with any form of locking device, must be checked to ensure that they are tight.

Careful examination of the propeller is essential. Pitting may occur near the tips on the driving face and on the whole of the 'low pressure' side due to cavitation. Propeller blades are sometimes damaged by floating debris which is drawn into the propeller stream. Such damage must be made good as it reduces the propeller efficiency, while the performance is improved by polishing the blade surface. If a built propeller is fitted, it is necessary to ensure that the blades are tight and the pitch should be checked at the same time. If appropriate, the stern gland should be carefully repacked and the propeller nut examined for movement. On vessels with a more traditional arrangement, the wear of the tail-shaft should be measured by inserting a wedge between the shaft and the packing. If measurement exceeds about 8 mm the bearing material should be renewed, 10 mm being regarded as an absolute maximum. There should be little or no wear in the more modern 'oil lubricated' stern tube systems. The wear in this type of tail shaft is usually measured by means of a special gauge as the sealing ring does not allow the insertion of a 'wear-down' wedge. The efficiency and safety of the ship depend to a great extent on the care taken in carrying out such an inspection. The classification society is usually present at the dry docking. Their surveyors are there to help and give

Emergency Repairs to Structure

During a ship's life faults may occur in the structure. Some of these faults are of little importance and are inconvenient rather than dangerous. Other faults, although apparently small, may be the source of major damage. It is essential that a guided judgement be made of the relative importance of the fault before undertaking repairs.

In Chapter 2 it was explained that the highest longitudinal bending moments usually occur in the section of the ship between about 25% forward and aft of midships. Continuous longitudinal material is provided to maintain the stresses at an acceptable level. If there is a serious reduction in cross-sectional area of this material, then the ship could split in two. Damage to the plating at the fore end or the stern is of less importance, although flooding could occur, while a crack in a rudder plate is inconvenient.

If a plate is damaged, several options are available, such as:

1. Replacing the plate
2. Cutting out and welding any cracks
3. Filling in any pits with welding
4. Fitting a welded patch over the fault
5. Cutting off any loose plating

The best solution in all cases is to replace the plate or damaged section. However, this may require docking the ship and in an emergency or on a short-term basis, the other options could be considered, including a temporary 'patch' repair. In the past this 'patch' had been a cement box but in recent times more up-to-date materials have been used.

If a crack occurs in a plate, then a hole should be drilled at each end of the crack to prevent its propagation. If the plate is in the midship part of the ship, then great care must be taken. Any welding must be carried out by authorised personnel in the presence of a classification society surveyor, to ensure that all the class rules are applied.

The correct weld preparation and welding sequence must be followed. If the plating is of high tensile steel the correct welding rods must be used. Greater damage may be caused by an untrained welder than leaving the crack untreated.

Pitting in a plate may be filled

A crack in a rudder plate may be patched once the crack has been stopped. Water in a rudder may increase the load on the rudder carrier and steering gear but has little other effect.

Damage to the fore end usually results in distortion of the structure and leakage. It may be possible to partially remove the distortion with the aid of hydraulic jacks, in which case the plating may be patched. Otherwise it is probably necessary to fit some sort of containment such as a cement box.

Damage to a bilge keel may prove serious. In this case it is better to cut off any loose material and to taper the material on each side of the damage, taking care to buff off any projecting material or welding in way of the damage. A replacement bilge keel must be fitted in the presence of a classification society surveyor.

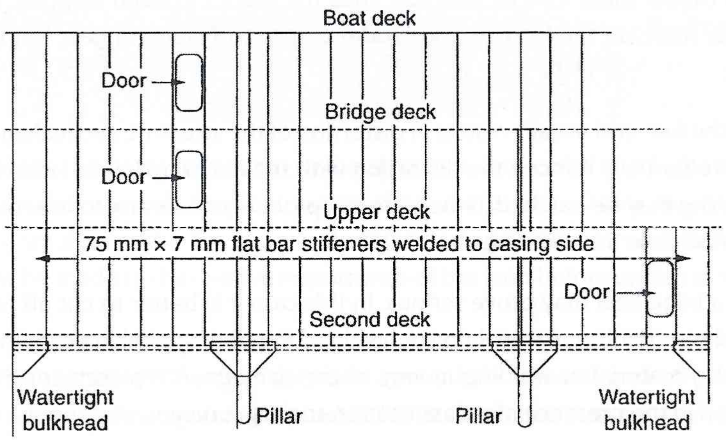
Engine Casing

The main part of the machinery space in a ship lies between the double bottom and the lowest deck. Above this deck is a large vertical trunk known as the engine casing, which extends to the weather deck. In the majority of ships this casing is surrounded by accommodation. An access door is fitted in each side of the casing, leading into the accommodation. In the case of Unmanned Machinery Spaces this door must carry suitable warnings about the entry into such spaces.

At the top of the trunk the funnel and engine room skylight could be fitted. In the older ships these skylights supplied natural light to the engine room; however modern designs cannot contain glass and casings are used as a supplement to the ventilation, with the whole casing then acting as an air trunk.

The volume taken up by the casings is kept as small as possible since, apart from the light and air space, they serve no useful purpose. It is essential, however, that the minimum width and length should be sufficient to allow for removal of the machinery. The whole of the machinery casing is however protected by a class 1 fire bulkhead.

The casings are constructed of relatively thin plating with small vertical angle stiffeners about 750 mm apart. Flat bars may be used or the plating may be swedged. The stiffeners are fitted inside the casing and are therefore continuous (Figure 12.8). Pillars or deep cantilevers are fitted to support the casing sides. Cantilevers are fitted in many ships to dispense with the pillars which interfere with the layout of machinery. The



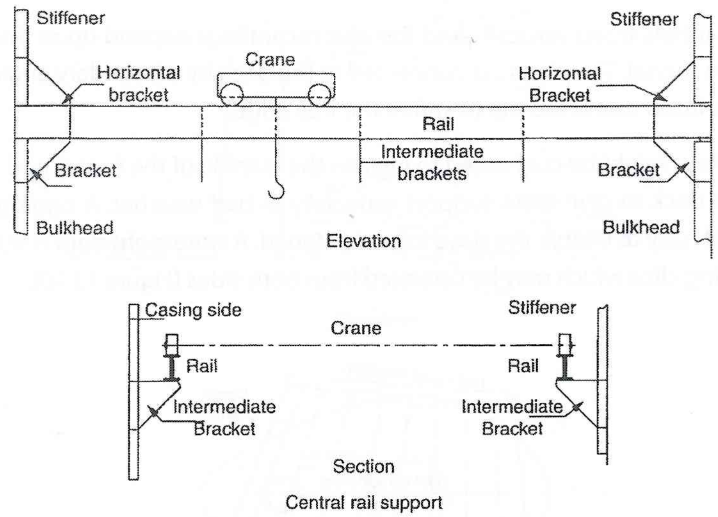
▲ **Figure 12.8** *Elevation of engine casing*

The casing sides in way of accommodation are insulated to reduce the heat transfer from the engine room. While such transfer would be an advantage in reducing the engine room temperature, the accommodation would be most uncomfortable. A suitable insulant would be glass fibre in slab form since it has high thermal efficiency and is fire resistant. The insulation is fitted inside the casing and is faced with sheet steel cladding.

Two strong beams are fitted at upper deck or bridge deck level to tie the two sides of the casing together. These strong beams are fitted in line with the web frames and are each in the form of two channel bars at adjacent frame spaces, with a shelf plate joining the two channels.

Efficient lifting gear is essential in the engine room to allow the removal of machinery parts for inspection, maintenance and repair. The main equipment is a travelling crane of 5 or 6 tonne lifting capacity on two longitudinal rails which run the full length of the casing. The rails are formed by rolled steel joists, efficiently connected to the ends of the casing or the engine room bulkheads by means of large brackets. Intermediate brackets may be fitted to reduce movement of the rails, as long as they do not obstruct the crane. Figure 12.9 shows a typical arrangement.

The height of the rails depends upon the height and type of the machinery, sufficient clearance being allowed to remove long components such as piston rods and cylinder liners. Large two-stroke crosshead engines will need more space above the engine than will the four-stroke trunk type engines as their components are much shorter. Manufacturers of the larger engines have developed a special 'double jib' crane to



▲ **Figure 12.9** *Central rail support*

between the rails is arranged to allow the machinery to be removed from the ship. An alternative method used in some ships is to carry two cranes on transverse rails. This reduces the length of the rails but no intermediate support may be fitted.

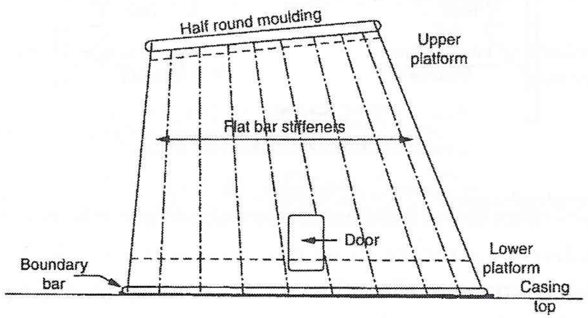
Funnel

The size and shape of the funnel depends upon the requirements of the ship-owners, builders and designers. At one time tall funnels were fitted to steam ships to obtain the required natural draught and, in passenger ships, to ensure that the smoke and grit were carried clear of the decks. Modern steamships fitted with forced draught boilers did not require such high funnels and the funnel is now a feature of the design of the ship, enhancing the appearance and being a suitable feature for the owners' house markings.

They are sometimes built much larger than necessary, particularly in motor ships where the engine exhaust could be small. They may be circular, elliptical or pear shaped, when seen in a plan view, while there are many varied shapes in side elevation. In many cases the funnel is also designed to house some storage space and/or auxiliary machinery such as ventilating fan units.

angles or flat bars fitted vertically and the exact scantlings depend upon the size and shape of the funnel. The plating is connected to the deck by a boundary angle, while a moulding is fitted round the top to stiffen the free edge.

Steel wire stays might be connected to lugs on the outside of the funnel and to similar lugs on the deck to give extra support especially in bad weather. A rigging screw is fitted to each stay to enable the stays to be tightened. A watertight door is fitted in the funnel, having clips which may be operated from both sides (Figure 12.10).

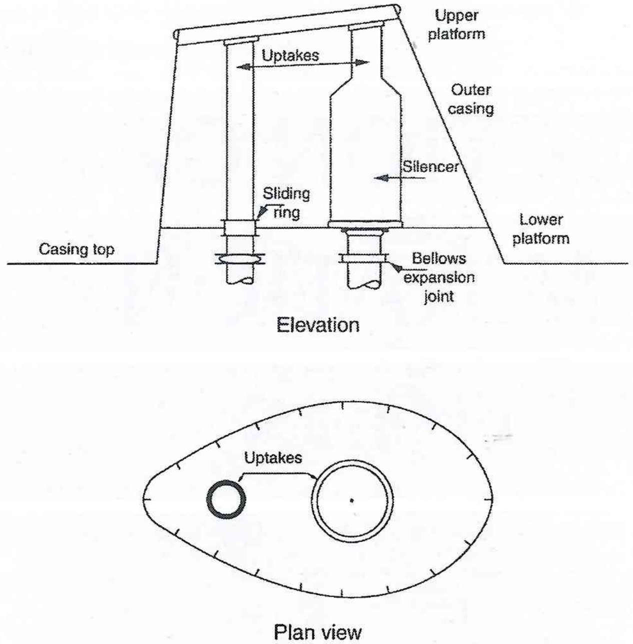


▲ **Figure 12.10** *Funnel construction*

The uptakes from the boilers, generators and main engine are carried up inside the funnel and are sometime stopped almost level with the top of the funnel (Figure 12.11). A steel platform is fitted at a height of about 1 m inside the funnel. This platform extends right across the funnel, holes being cut in for the uptakes and access. The uptakes are not connected directly to this platform because of possible expansion, but a ring is fitted above and below the plating, with a gap which allows the pipe to slide.

Additional bellows expansion joints are arranged where necessary. At the top a single platform or separate platforms may be fitted to support the uptakes, the latter being connected by means of an angle ring to the platform. In motor ships a silencer must be fitted in the funnel to the main engine exhaust. This unit is supported on a separate seat. Ladders and gratings are fitted inside the funnel to allow access for inspection and maintenance.

The construction of the exhaust trunking in passenger ships could extend up and point towards the aft end of the vessel. This construction, as mentioned earlier, is to stop any exhaust fumes or debris from being projected across any of the passenger areas. The



▲ **Figure 12.11** *Arrangement of funnel uptakes*

engine exhaust gas and then fed back into the main boiler where the steam produced is used to provide heating for the ship. Another area of development that affects the design of the funnel is the possible requirement to fit Selective Catalytic Reduction Systems to improve the environmental performance of the vessel.

SELECTION OF EXAMINATION QUESTIONS – CLASS 2

1. Sketch and describe a watertight door. What routine maintenance must be carried out to ensure that the door is always in working order?
2. Draw an outline midship section of a ship and show the position of the following items: (a) sheer strake, (b) garboard strake, (c) stringer, (d) bilge plating, (e) keel plate, (f) floors, (g) frames.
3. With the aid of a sketch showing only the compartments concerned, show the arrangement of windlass and anchor cables. How is the end of the cable secured in the chain locker? What is meant by the terms: (a) hawse pipe, (b) spurling pipe, (c) cable lifter, (d) cable stopper?
4. Sketch and describe the construction of a cruiser stern fitted to a single screw ship and discuss its advantages.
5. Sketch and explain how a large ship is supported in dry dock. Describe the change in the hull stresses that are imposed on a ship resting on the blocks. Detail the precautions that should be taken when refloating the ship in a dry dock.
6. Sketch and describe a transverse section of either an oil tanker or a bulk carrier having two longitudinal bulkheads.

8. Explain what is meant by *longitudinal framing* and *transverse framing*. Which types of ships would have these methods of construction?
9. Explain with the aid of sketches the terms *hogging* and *sagging* with reference to a ship meeting waves having the same length as the vessel. What portions of the structure resist these stresses?
10. Describe with the aid of sketches the terms: (a) camber, (b) sheer, (c) rise of floor, (d) flare. What is the purpose of these?
11. A ship has a small hole below the waterline. What would be the procedure in making a cement box around the hole?
12. Show how the hatch and main hold of a refrigerated vessel are insulated. What materials are used? How are the compartments drained?
13. Sketch and describe a stern frame. Show how the frame is attached to the adjoining structure. State the materials used together with their properties.
14. Sketch and describe a deep tank, giving details of the watertight hatch.
15. Sketch and describe a weather deck hatch coaming giving details of the attachment of the half beams. Do the half beams give any strength to the deck?
16. Sketch and describe the different floors used in the construction of a double bottom, indicating where each type is employed. Give details of the attachment of the floors to the adjacent structure.
17. Sketch and describe a transverse watertight bulkhead of a cargo vessel. Show details of the stiffening and the boundary connections.
18. Describe with the aid of a sketch the following types of keel. Showing how they are attached to the ship's hull: (a) bilge keel, (b) flat plate keel, (c) duct keel.
19. What are the main functions of: (a) fore peak, (b) after peak, (c) deep tank, (d) double bottom? Give examples of the liquids carried in these tanks.
20. Describe the causes of corrosion in a ship's structure and the methods used to reduce wastage. What parts of the ship are most liable to attack?
21. Sketch and describe a rudder suitable for a ship 120 m long and speed 14 knots. Show how the rudder is supported.
22. Explain the initial examination that would be carried out on the exterior of a ship's hull when in dry dock. State who would complete this examination and the salient points of the inspection necessary to determine the work schedule for the dry dock. Discuss the nature of the defects liable to be found in these areas.
23. Explain, with the aid of sketches where the arrangement of the following features on a ship: (a) spurling pipe, (b) centre girder, (c) cofferdam, (d) collision bulkhead,

24. What precautions must be taken on entering ballast or fuel tanks when empty? Explain why these precautions are necessary.
25. Describe the different methods of ships transporting liquefied petroleum gases (LPG) where: (a) pressurised system, (b) fully refrigerated system, (c) semi-refrigerated system is used.
26. Sketch and describe the spectacle frame of a twin screw ship. Show how it is attached to the ship.
27. Explain why the plating of the hull and transverse watertight bulkheads are arranged horizontally. Which sections of the ship's structure constitute the strength members, and what design considerations do they receive?
28. Define the following terms: (a) displacement, (b) gross tonnage, (c) net tonnage, (d) deadweight.
29. What are cofferdams and where are they situated? Describe their use in oil tankers.
30. Sketch the panting arrangements at the fore end of a vessel.
31. Explain the following ship conditions and reflect on the type of vessel and/or cargo carried: (a) stiff, (b) tender.
32 Explain why and where transverse bulkheads are fitted in a ship. In which ships are longitudinal bulkheads fitted and what is their purpose?
33. Sketch the construction of a bulbous bow and explain why these are fitted to ships.
34. Sketch and describe an arrangement of funnel uptakes for a motor ship or a steam ship, giving details of the method of support in the outer funnel.
35. Explain the possible reasons for corrosion under each of the following:
    Connection between aluminium superstructure and steel deck. (3 marks)
    In crude oil cargo tanks. (3 marks)
    Explain how in each case corrosion can be inhibited. (4 marks)
36. (i) Sketch the arrangement of a (bow or stern thruster, showing the main power unit, and labelling the principal components. (4 marks)
    (ii) Explain how this unit operates. (4 marks)
    (iii) Give reasons for its installation (2 marks)
37. (I) Sketch the arrangement of a fin stabiliser unit where the fins retract into a recess in the hull. (4 marks)
    (ii) Describe how the extension/retraction sequence is carried out. (4 marks)
    (iii) Define how the action of fin stabilisers effects steering. (2 marks)
38. (i) State three different corrosion problems encountered in ship structure. (3 marks)

39. Sketch a watertight door giving details of the closing mechanism showing how the watertightness is maintained. (6 marks)
    Describe the procedure for testing the following for watertightness:
    (i) A watertight door. (2 marks)
    (ii) A deep tank bulkhead, and (2 marks)
    (iii) A hold-bulkhead in a dry cargo ship. (2 marks)
40. Explain why the 'build up' by welding, patching, cropping or plate replacement is best suited to the following structural defects:
    (i) Severe pitting at one spot on deck stringer. (3 marks)
    (ii) External wastage of side plating below scuppers. (3 marks)
    (iii) Extensive wastage of side plating along waterline. (4 marks)

SELECTION OF EXAMINATION QUESTIONS – CLASS 1

1. Sketch and describe the methods used to connect the shell plating to the side frames. How is a deck made watertight where pierced by a side frame?
2. Sketch and describe a hatch fitted to an oil tanker. When is this hatch opened?
3. Discuss the forces acting on a ship when floating and when in dry dock.
4. Explain three possible sources of shipboard vibration. Describe how you would trace the source of the forces causing severe in-service vibrations and the measures that could be taken to reduce the severity of the vibrations.
5. Explain why a tanker is normally assigned a minimum basic freeboard less than that of other types of ship.
6. Sketch and describe a gravity davit. What maintenance is required to ensure its efficient working?
7. Sketch a transverse section through a cargo ship showing the arrangement of the frames and the double bottom.
8. Sketch and describe the arrangements to support stern tubes in a twin screw ship.
9. Explain in detail the forces acting on the fore end of a vessel. Sketch the arrangements made to withstand their effects.

11. Sketch and describe a welded watertight bulkhead indicating plate thickness and stiffener sizes. How is it made watertight? Show how ballast pipes, electric cables and intermediate shafting are taken through the bulkhead.
12. Sketch and describe the arrangement of a rudder stock and gland and the method of suspension of a pintleless rudder. How is the wear-down measured? What prevents the rudder jumping?
13. By what means is the fire risk in passenger accommodation reduced to a minimum? Describe with the aid of diagrammatic sketches the arrangements for fire fighting in the accommodation of a large passenger liner.
14. Sketch the arrangement of a keyless propeller showing how it is fitted to the tailshaft. Discuss the advantages and disadvantages of this design. Explain the method of driving the propeller on to the shaft and how it is locked in position.
15. Explain what is meant by the following terms: (a) exempted space, (b) deductible space, and (c) net tonnage. Give two examples of (a) and (b).
16. Explain the purposes of a collision bulkhead. Describe with the aid of sketches the construction of a collision bulkhead paying particular attention to the strength and attachment to the adjacent structure.
17. Describe the effect of and the precautions against the dangers due to water accumulation during fire fighting: (a) while the ship is in dry dock, (b) while the ship is at sea.
18. What precautions are taken before dry-docking a vessel? What precautions are taken before re-flooding the dock? What fire precautions are taken while in dock?
19. Why and where are deep tanks fitted in cargo ships? Describe the arrangements for filling, emptying and drainage.
20. Sketch the following ship stabilisation systems: (a) bilge keel, (b) activated fins, (c) active tanks, (d) passive tank. Explain how each one completes the stabilisation process.
21. Explain the different types of materials that are replacing steel in the building of ships. Describe the vessels concerned and give reasoned explanations why they have replaced mild steel. State the precautions which must be observed when aluminium structures are fastened to steel hulls.
22. Explain with the aid of sketches what is meant by breast hooks and panting beams, giving approximate scantlings. Where are they fitted and what is their purpose?
23. Sketch and describe the freeboard markings on a ship. By what means are they determined? How do the authorities prevent these marks being changed?

25. Explain the main causes of corrosion in a ship's internal structure, where this is likely to occur and the measures which can be taken to minimise this action.

26. Draw a cross-section through a modern oil tanker in way of an oil tight bulkhead.

Explain the different methods of generating inert gas for use in a very large crude carrier (VLCC).

27. Sketch the distribution layout of the piping and associated equipment of an inert gas system and explain the safety features incorporated in the system.

28. Sketch and describe the construction of a corrugated bulkhead. What are the advantages and disadvantages of such a bulkhead compared with the normal flat bulkhead?

29. Where do discontinuities occur in the structure of large vessels and how are their effects minimised?

30. Sketch and describe the various types of floors used in a cellular double bottom, and state where they are used.

31. Show how an aluminium superstructure is fastened to a steel deck. Explain why special precautions must be taken and what would happen if no such measures were taken.

32. Sketch and describe briefly: (a) bilge keel, (b) duct keel, (c) chain locker, (d) hawse pipe.

33. Define *hogging* and *sagging*. What members of the vessel are affected by these conditions? State the stresses in these members in each condition.

34. Explain how a bulk carrier is constructed to resist high concentrated loads value.

35. Define the following: gross tonnage, net tonnage, propelling power allowance.

36. Sketch and describe a sternframe. What material is used in its construction and why is this material suitable?

37. Describe with the aid of sketches the arrangements to withstand pounding in a ship.

38. Sketch any two of the following, giving approximate sizes: (a) a peak tank top manhole, (b) a windlass bed, (c) a bilge keel for a large, ocean-going liner, (d) a bollard.

39. Explain the main constructional differences between the following types of vessels: (a) container ship, (b) gas carrier, (c) bulk carrier.

40. Describe the methods adopted in large passenger vessels to prevent the spread of

41. Sketch and describe the essential features of ships used for transporting liquefied gas in bulk: (a) free-standing prismatic tanks, (b) membrane tanks, (c) free-standing spherical tanks.

42. A ship suffers stern damage due to collision with a quay. How would the ship be inspected to determine the extent of the damage? If the propeller were damaged state the procedure in fitting the spare propeller.

43. What important factors are involved before new tonnage can be called a *classified* ship?

44. Sketch and describe two types of modern rudders. How are they supported in the ship?

45. Explain the main items to be inspected on the ship's hull during an in-water survey while the vessel is afloat.

Explain why a remote controlled unmanned vehicle could be utilised for the examination of the ship's flat bottom.

46. Describe the destructive and non-destructive tests which may be carried out on welding materials or welded joints.

47. Why may tank cleaning be dangerous? State any precautions which should be taken. How does the density of the gas vary throughout the tank during cleaning?

48. A vessel has taken a sudden list in a calm sea. What investigations should be made to ascertain the cause and what steps should be taken to right the vessel?

49. Explain the reasons for each of the following practices:
   (i) Use of neoprene washers in the connection between aluminium superstructures and ships' main structure. (4 marks)
   (ii) Attachment of anodic blocks to the underwater surface of a hull. (3 marks)
   (iii) External shotblasting and priming of hull plating. (3 marks)

50. Describe the conditions where an 'Underwater hull survey' is permitted as an alternative to dry-docking.
   (i) Explain which parts in particular should be inspected during such a survey. (5 marks)
   (ii) Describe briefly how such a survey is conducted from a position on board the vessel concerned. (5 marks)

51. (i) Sketch the arrangement of a podded drive. (4 marks)
   (ii) Explain how the unit operates. (4 marks)
   (iii) Compare the advantages of such units with a more traditional drive and bow/stern thrusters. (2 marks)

52. (i) Sketch a watertight door showing the frame and closing arrangement and the attachment to the bulkhead. Add in the additional reinforcement carried by the bulkhead to compensate for the aperture.

53. Explain the different contributions made to the reduction of hull resistance by the following:
   (i) Complete abrasive blasting of hull plating, initially before paint application and during service. (3 marks)
   (ii) Self-polishing underwater copolymer antifouling coatings. (3 marks)
   (iii) Impressed electrical current. (2 marks)
   (iv) Tunnel thrusters. (2 marks)

54. Explain how the 'build up' by welding, patching, cropping or plate replacement is best suited to repairing the following defects:
   (i) Perforated hollow rudder. (3 marks)
   (ii) Bilge keel partially torn away from hull. (3 marks)
   (iii) Hull pierced, together with heavy indentation of bow below hawse pipe. (4 marks)

55. (i) Explain the advantages and disadvantages of the different stern arrangements for single and twin screw propulsion. (3 marks)
   (il) Give reasons for the introduction of the ducted propeller. (4 marks)
   (ii) Explain why the podded drive has an advantage over the more traditional dive systems. (3 marks)

56. (i) Make a sketch of the essential features of the activating gear fin stabilisers. (5 marks)
   (ii) Explain the operation. (5 marks)

57. Explain why the following conditions can contribute to reduction in ship speed:
   (i) Damaged propeller blades. (2 marks)
   (ii) Indentation of hull plating. (2 marks)
   (iii) Hole in hollow rudder plating. (2 marks)
   (iv) Ship in ballast. (2 marks)
   (v) Heavily fouled hull. (2 marks)

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