19
Decks, Hatches, and Superstructures

Decks at different levels in a ship serve various functions; they may be either watertight decks, strength decks, or simply cargo and passenger accommodation decks. Watertight decks are fitted to maintain the integrity of the main watertight hull, and the most important is the freeboard deck which is the uppermost deck having permanent means of closing all openings in the exposed portions of that deck. Although all decks contribute to some extent to the strength of the ship, the most important is that which forms the upper flange of the main hull girder, called the 'strength deck'. Lighter decks which are not watertight may be fitted to provide platforms for passenger accommodation and permit more flexible cargo loading arrangements. In general cargo ships these lighter decks form tweens which provide spaces in which goods may be stowed without their being crushed by a large amount of other cargo stowed above them.

To permit loading and discharging of cargo, openings must be cut in the decks, and these may be closed by non-watertight or watertight hatches. Other openings are required for personal access through the decks; and in way of the machinery space casing openings are provided which allow the removal of machinery items when necessary, and also provide light and air to this space. These openings are protected by houses or superstructures, which are extended to provide accommodation and navigating space. Forward and aft on the uppermost continuous deck a forecastle and often a poop may be provided to protect the ends of the ship at sea.

Decks

The weather decks of ships are cambered, the camber being parabolic or straight. There may be advantages in fitting horizontal decks in some ships, particularly if containers are carried and regular cross-sections are desired. Short lengths of internal deck or flats are as a rule horizontal.

Decks are arranged in plate panels with transverse or longitudinal stiffening, and local stiffening in way of any openings. Longitudinal deck girders may support the transverse framing, and deep transverses the longitudinal framing (*see* Figure 19.1).

DECK PLATING The heaviest deck plating will be found abreast the hatch

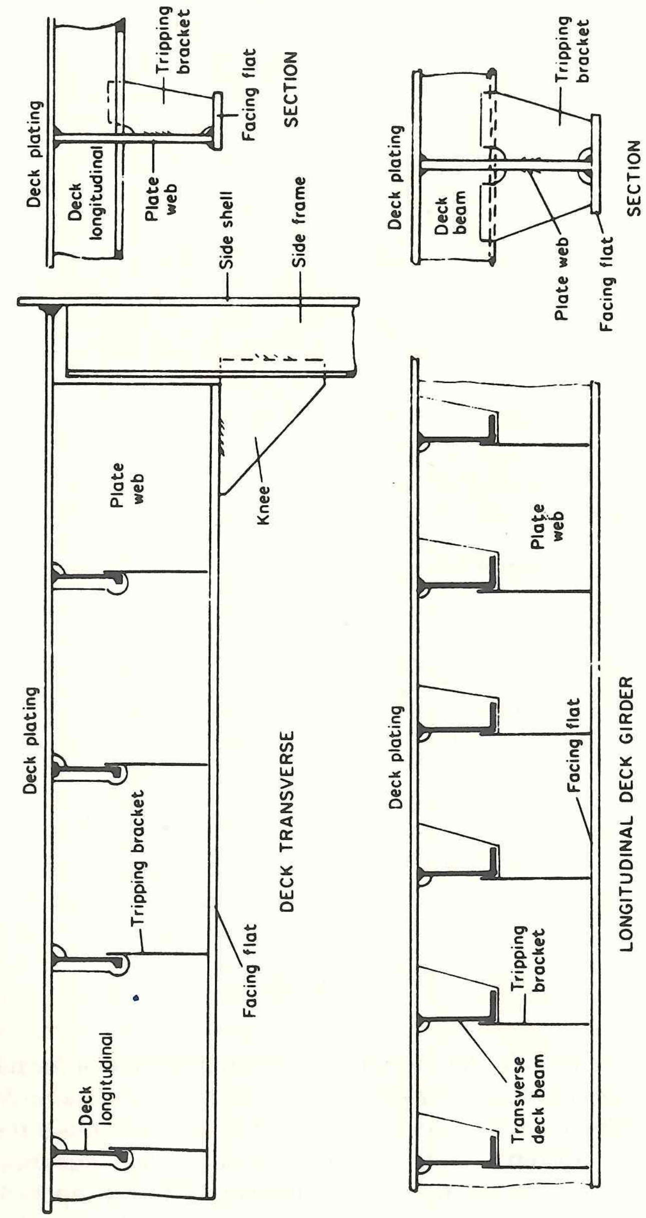


FIGURE 19.1 Deck supports

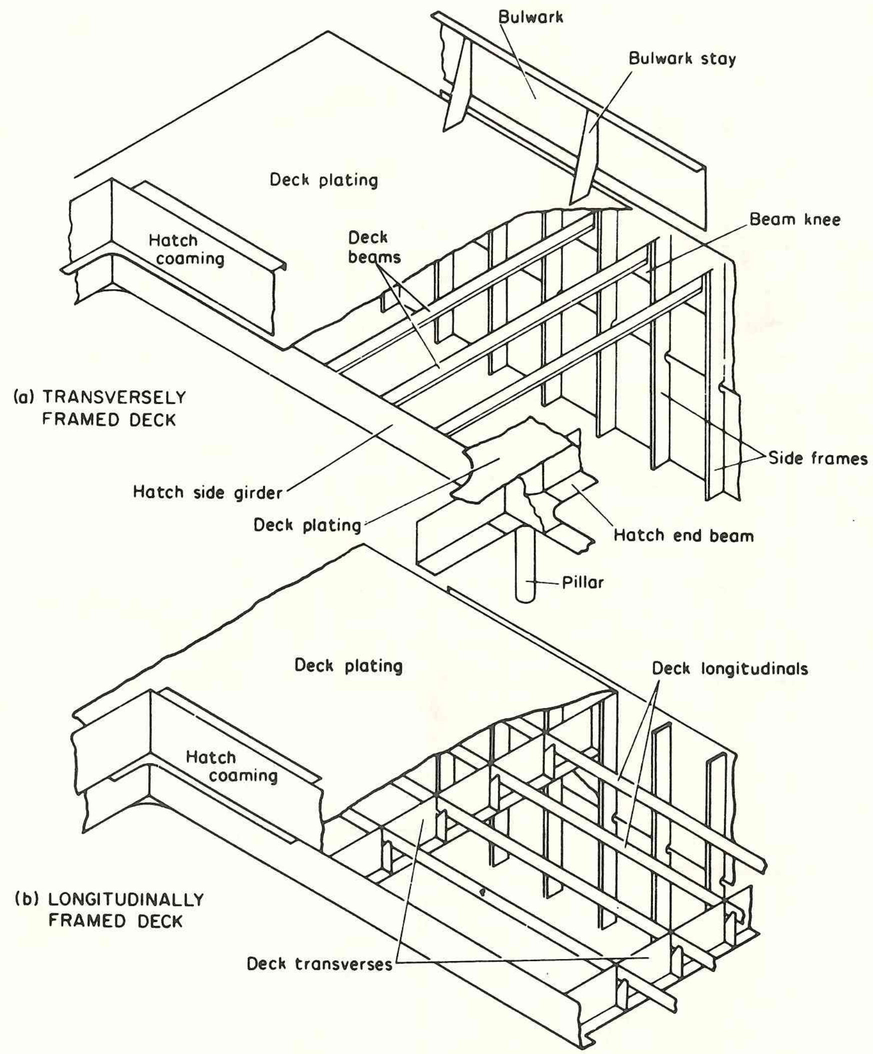


FIGURE 19.2 Deck construction

openings of the strength deck. Plating which lies within the line of the hatch openings contributes little to the longitudinal strength of the deck and it is therefore appreciably lighter. As the greatest longitudinal bending stresses will occur over the midship region, the greatest deck plate thickness is maintained over 40 per cent of the length amidships, and it tapers to a minimum thickness permitted at the ends of the ship. Locally the plating thickness may be increased where higher stresses occur owing to discontinuities in the structure or concentrated loads.

Other thickness increases may occur where large deck loads are carried, where fork lift trucks or other wheeled vehicles are to be used, and in way of deep tanks. Where the strength deck plating exceeds 30 mm it is to be Grade B steel and if it exceeds 40 mm Grade D over the midships region, at the ends of the superstructure and in way of the cargo hold region in container ships. The stringer plate (i.e. the strake of deck plating adjacent to the sheerstrake) of ships less than 260 m in length is of Grade B steel if the thickness is more than 15 mm, Grade D if more than 25 mm thickness over the midships region and within the cargo hold region of container ships. Where the steel deck temperatures fall below 0°C in refrigerated cargo ships the steel will be of Grades B, D and E depending on thickness.

On decks other than the strength deck the variation in plate thickness is similar, but lighter scantlings are in use.

Weather decks may be covered with wood sheathing or an approved composition, which not only improves their appearance, but also provides protection from heat in way of any accommodation. Since this provides some additional strength, reductions in the deck plate thickness are permitted; and on superstructure decks the plating thickness may be further decreased within deckhouses, if sheathed. Before fitting any form of sheathing the deck is treated to prevent corrosion between the deck plating and sheathing (*see* Figure 19.3).

Any openings abreast the hatch openings in a deck are kept to a minimum and clear of the hatch corners. If such openings are cut, compensation is required to restore the sectional area of deck. All large openings in the decks have well rounded corners, with insert plates fitted, unless the corners are parabolic or elliptical with the major axis fore and aft, local stress concentrations being reduced if the latter type of corner is cut (*see* Figure 19.4).

DECK STIFFENING Decks may be framed transversely or longitudinally but outside the line of openings it is preferred that longitudinal framing should be adopted for the strength deck.

When the decks are longitudinally framed the scantlings of the longitudinals are dependent on their spacing, the length of ship, whether they are inside or outside the line of hatch openings, their span and the deck loading. Deck transverses support the longitudinals, and these are built from a deep web plate with flange or welded face flat, and are bracketed to the side frame (Figure 19.1). Within the forward 7.5 per cent of the ship's length, the forecastle and weather deck transverses are closely spaced and the longitudinal scantlings increased, the additional transverse and longitudinal stiffening forward being designed to avoid buckling of the deck plating on impact when shipping seas.

Transversely framed decks are fitted with deck beams at every frame, and these have scantlings which are dependent on their span, spacing, and

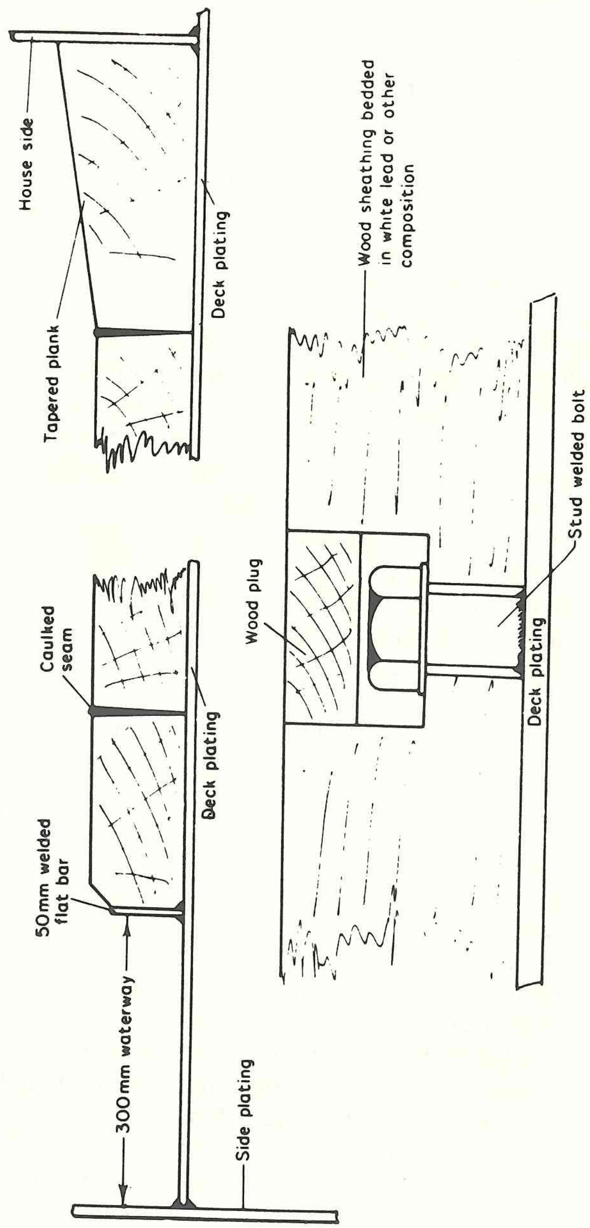


FIGURE 19.3 Deck sheathing

location in the ship. Those fitted right forward on weather decks, like the longitudinal framing forward, have heavier scantlings, and the frame spacing is also decreased in this region so they will be closer together. Beams fitted in way of deep tanks, peak tanks, and oil bunkers may also have increased scantlings as they are required to have the same rigidity as the stiffeners of the tank boundary bulkheads. Deck beams are supported by longitudinal deck girders which have similar scantlings to deck transverses fitted with any longitudinal framing. Within the forward 7.5 per cent of the ship's length these deck girders are more closely spaced on the forecastle and weather decks. Elsewhere the spacing is arranged to suit the deck loads carried and the pillar arrangements adopted. Each beam is connected to the frame by a 'beam knee' and abreast the hatches 'half beams' are fitted with a suitable supporting connection at the hatch side girder (*see* Figure 19.2).

Both longitudinals and deck beam scantlings are increased in way of cargo decks where fork lift trucks, and other wheeled vehicles which cause large point loads, are used.

In way of the hatches fore and aft side girders are fitted to support the inboard ends of the half beams, and transverses. At the ends of the hatches heavy transverse beams are fitted and these may be connected at the intersection with the hatch side girder by horizontal gusset plates (Figure 19.4). Where the deck plating extends inside the coamings of hatches amidships the side coaming is extended in the form of tapered brackets.

Hatches

The basic regulations covering the construction and means of closing hatches in weathertight decks are contained within the Conditions of Assignment of Freeboard of the Load Line Rules 1968 (*see* Chapter 31). Lloyd's Register provides formulae for determining the minimum scantlings of steel covers, which will be within the requirements of the Load Line Rules. Only the maximum permitted stresses and deflections of covers under specified loadings are given by the Load Line Rules. Under these regulations ships fitted with approved steel covers having direct securing arrangements may have reduced B-100 or B-60 freeboards if they meet the subdivision requirements, but in general they are assigned standard cargo ship Type B freeboards. If steel pontoon type covers which are self-supporting and have no direct securing arrangements are fitted, then the standard Type B freeboard only is assigned. Where portable beams are fitted with wood or light steel covers and tarpaulins, then the ship has an increased Type B freeboard, i.e. there is a draft penalty. This means that most ships are fitted exclusively with the stronger stiffened self-supporting steel covers.

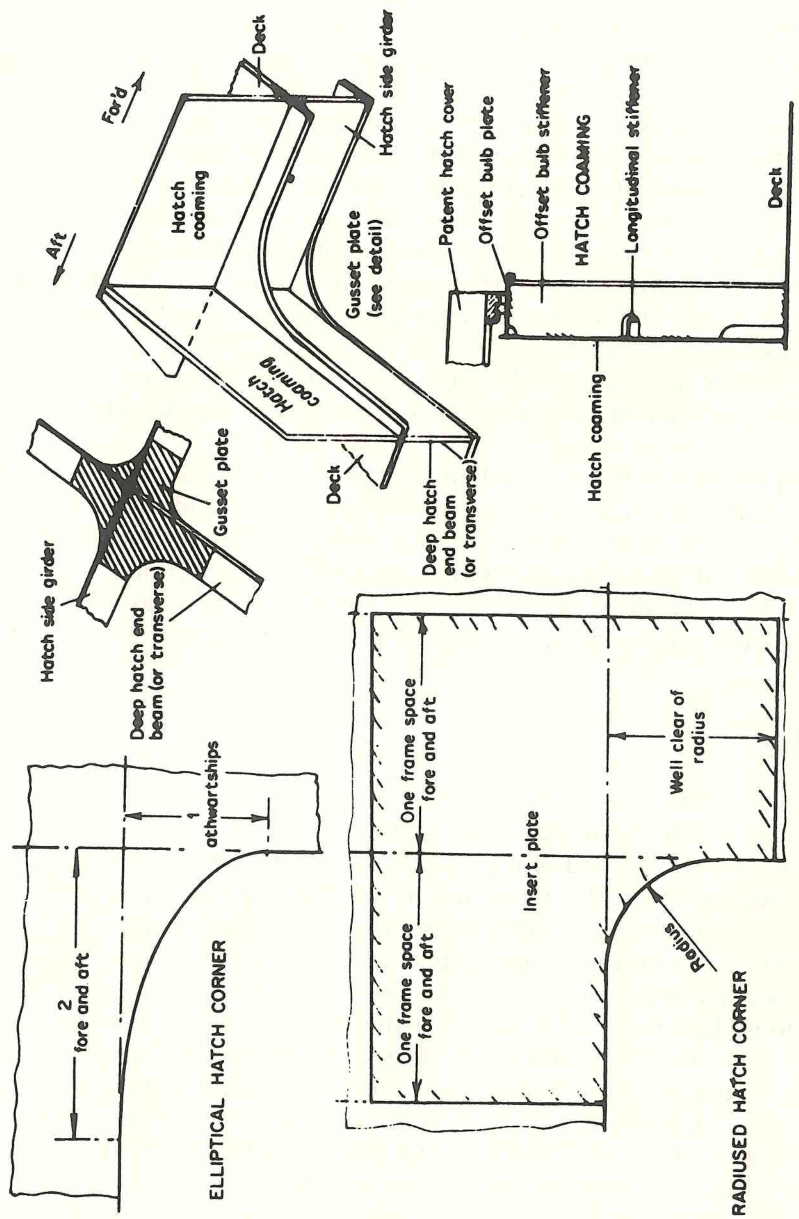


FIGURE 19.4 Hatch openings

HATCH COAMINGS Heights of coamings and cover closing arrangements in some instances depend on the hatch position. The positions differentiate between regions which are more exposed than others. Position 1 indicates that the hatch is on the exposed freeboard deck, raised quarter deck, or superstructure decks within 25 per cent of the ship's length from forward. Position 2 indicates that the hatch is located on exposed superstructure decks abaft the forward 25 per cent of the ship's length.

Hatches which are at Position 1 have coamings at least 600 mm high, and those at Position 2 have coamings at least 450 mm high, the height being measured above the sheathing. Provision is made for lowering these heights or omitting the coaming altogether if directly secured steel covers are fitted and it can be shown that the safety of the ship would not be impaired in any sea condition. Where the coaming height is 600 mm or more the horizontal edge is stiffened by a horizontal bulb flat and supporting stays to the deck are fitted. Coamings less than 600 mm high are stiffened by a cope or similar bar at their upper edge. The steel coamings extend down to the lower edge of the deck beams, which are then effectively attached to the coamings (Figure 19.4).

HATCH COVERS A number of patent steel covers, such as those manufactured by MacGregor-Navire International A.B., are available, which will comply with the requirements outlined by the International Conference on Load Lines 1966 and are in accordance with the requirements of the classification societies. The means of securing the hatches and maintaining their watertightness is tested initially and at periodic surveys. These patent covers vary in type the principal ones being fore and aft single pull, folding, roll-up, piggy back, pontoon and side rolling. These are illustrated in Figure 19.5. Single pull covers may be opened or closed by built in electric motors in the leading cover panel (first out of stowage) which drive chain wheels, one on each outboard side of the panel. Each panel wheel is permanently engaged on a fixed chain located along each hatch side coaming. In operation the leading panel pushes the others into stowage and pulls them into the closed position. Alternatively single pull covers are opened or closed by hydraulic or electric motors situated on the hatch end coaming at the ships centre line driving endless chains running along the full length of the hatch side coaming port and starboard and connected to the leading panel. Vertical stowage of panels is at one end of the hatch and covers may have a nesting characteristic if space is at a premium, also on large hatches opening may be to both ends with vertical stowage at each end. Folding covers may be of direct pull type where suitable lifting gear is carried onboard or can be opened or closed by externally mounted hydraulic cylinders actuating the leading panels. The roll-up cover is effectively a continuous articulated slab which is opened by rolling it onto a powered stowage drum at the hatch end. The drum rotation is reversed to close the

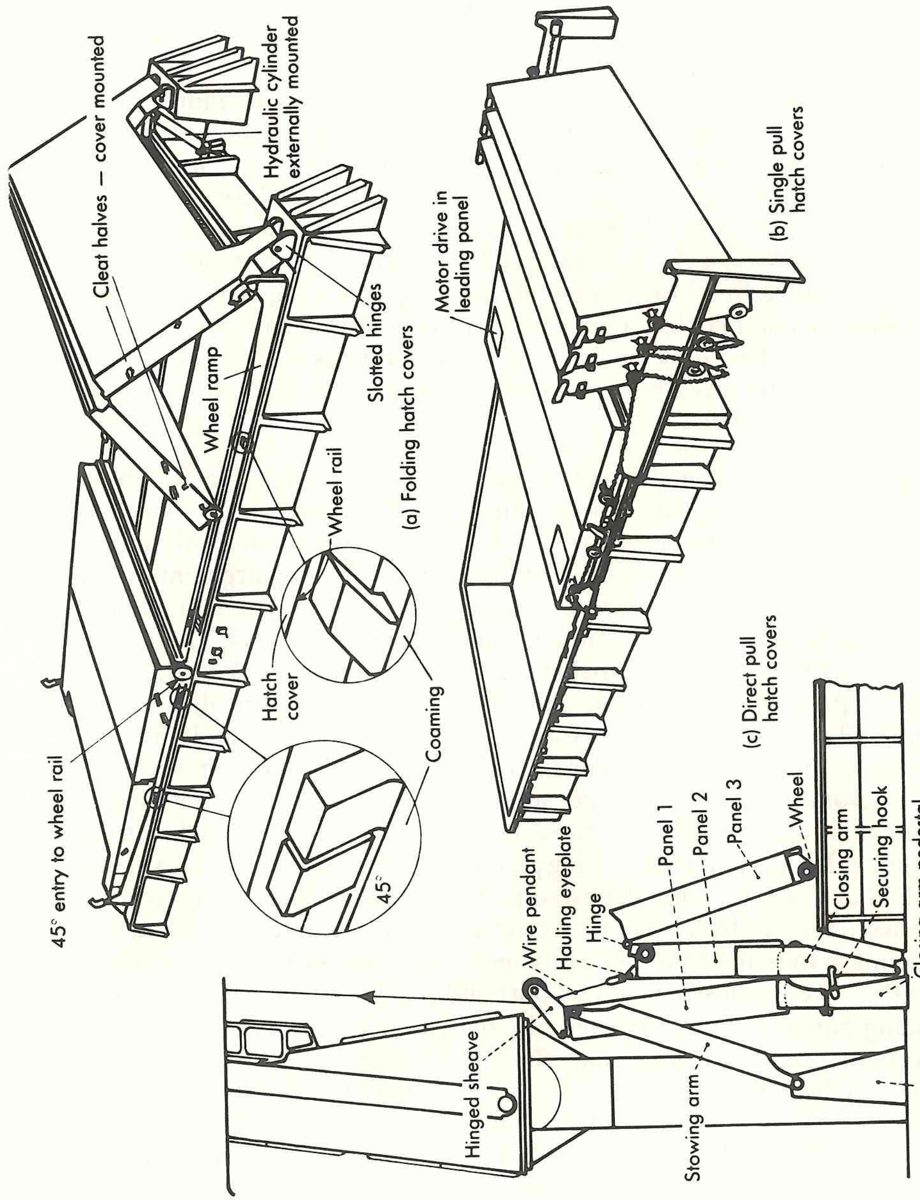


FIGURE 19.5

hatch. Piggy back covers permit horizontal stowage of panels avoiding fouling of lifting devices particularly in way of very large openings such as on bulk carriers and container ships where the hatch need only be partially open for working. The covers consist of a dumb panel which is raised by high lift cylinders and a motorised panel which is rolled underneath the dumb panel. Both panels can then be moved 'piggy back' style to the fully opened hatch position port or starboard or partially opened position fore and aft. Pontoon covers are commonly used on container ships being lifted by the ships or shore cranes with the container spreader. They are closed weathertight in a similar manner to the other patent covers. Side rolling covers can operate on similar principles to the single pull cover except that they remain in the horizontal stowed position when the hatch is open. Various other forms of cover are marketed, and tween deck steel covers are available to be fitted flush with the deck, which is essential nowadays when stowing cargoes in the tweens. To obtain weathertightness the patent covers have mating boundaries fitted with rubber gaskets; likewise at the hatch coamings, gaskets are fitted and hand or automatically operated cleats are provided to close the covers (*see* Figure 19.6). The gasket and cleat arrangements will vary with the type of cover.

Pontoon covers of steel with internal stiffening may be fitted, these being constructed to provide their own support without the use of portable beams. Each pontoon section may span the full hatch width, and cover perhaps one-quarter of the hatch length. They are strong enough to permit Type B freeboards to be assigned to the ship, but to satisfy the weathertightness requirements they are covered with tarpaulins and battening devices.

Where portable beams are fitted wood or stiffened steel plate covers may be used. These and the stiffened beams have the required statutory scantlings but an increase in the freeboard is the penalty for fitting such covers. The beams sit in sockets at the hatch coamings and the covers are protected by at least two tarpaulins. At the coaming the tarpaulins are made fast by battens and wedges fitted in cleats and the sections of the cover are held down by locked bars or other securing arrangements (*see* Figure 19.7).

Bulwarks

Bulwarks fitted on weather decks are provided as protection for personnel and are not intended as a major structural feature. They are therefore of light scantlings, and their connections to the adjacent structures are of some importance if high stresses in the bulwarks are to be avoided. Freeing ports are cut in bulwarks forming wells on decks in order that water may quickly drain away. The required area of freeing ports is in accordance with the Load Line Rules 1968 (*see* Chapter 31).

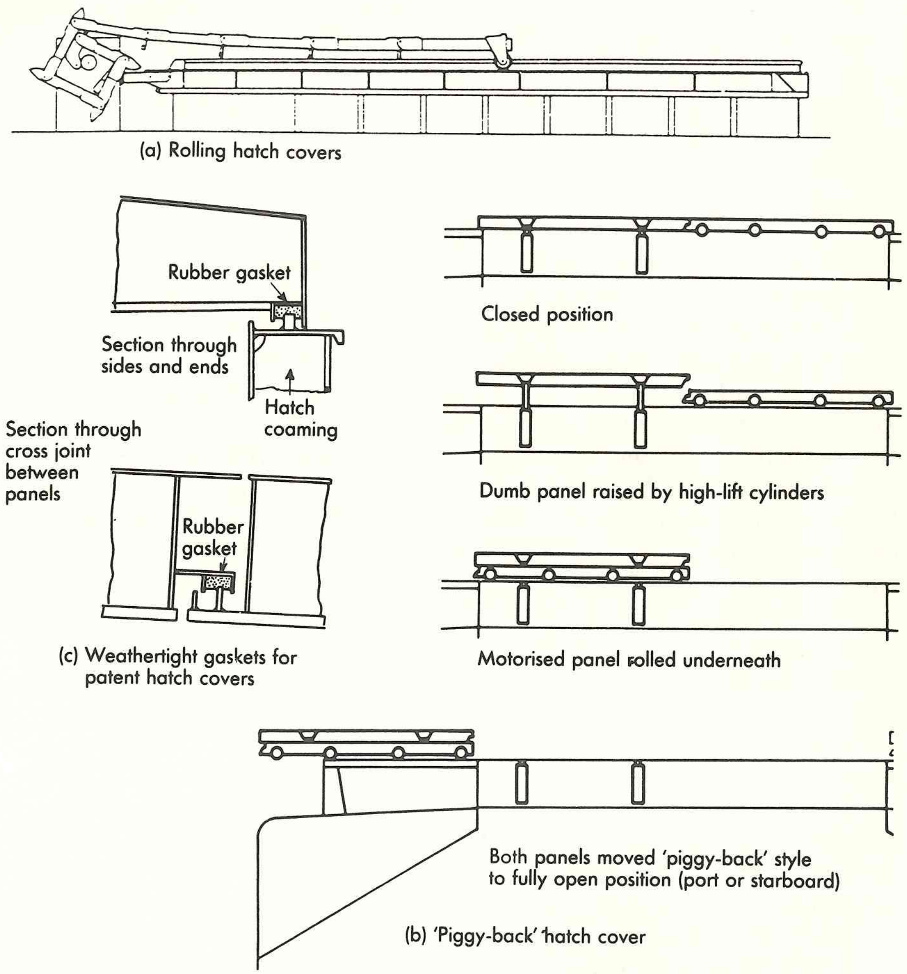


FIGURE 19.6

CONSTRUCTION OF BULWARKS Bulwarks should be at least 1 m high on the exposed freeboard and superstructure decks, but a reduced height may be permitted if this interferes with the working of the ship. The bulwark consists of a vertical plate stiffened at its top by a strong rail section (often a bulb angle or plate) and is supported by stays from the deck (Figure 19.7). On the forecastle of ships assigned B-100 and B-60 freeboards the stays are more closely spaced. Where the bulwark is cut for any reason, the corners are well rounded and compensation is also provided. No openings are permitted in bulwarks near the ends of the superstructures.

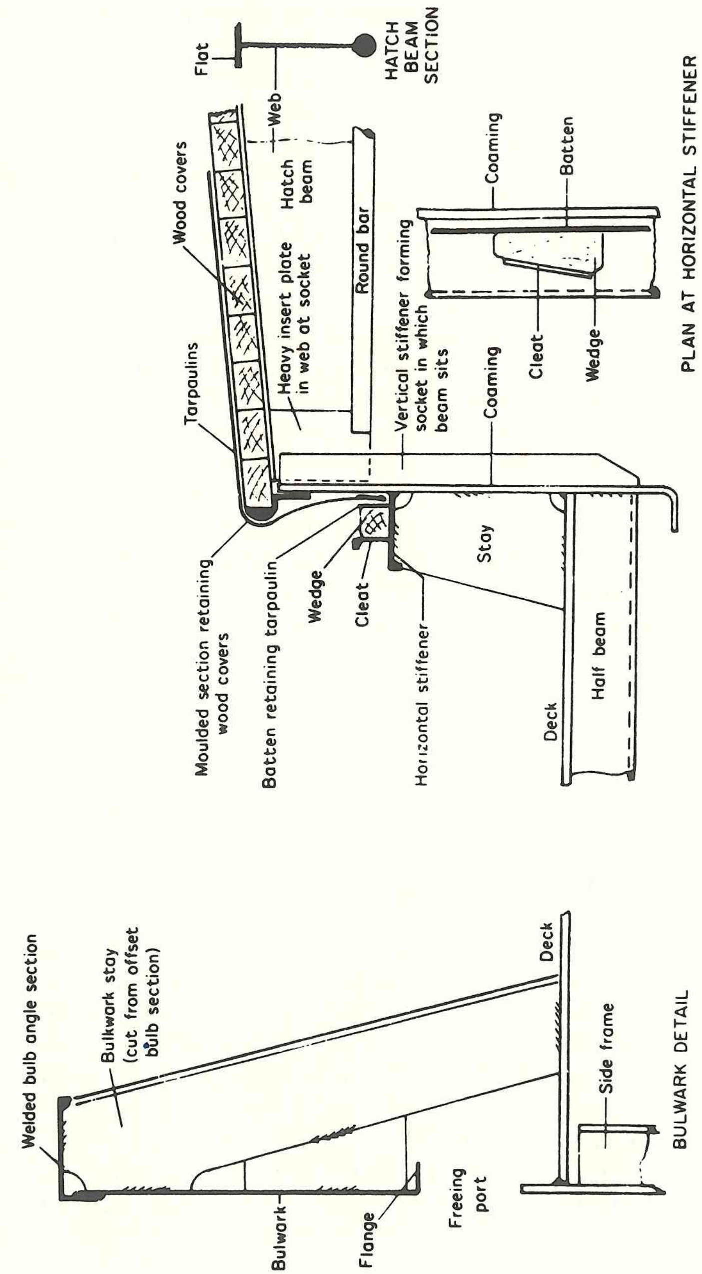


FIGURE 19.7 Portable hatch covers and bulwarks

Superstructures and Deckhouses

Superstructures might be defined as those erections above the freeboard deck which extend to the ship's side or almost to the side. Deckhouses are those erections on deck which are well within the line of the ship's side. Both structures are of importance in the assignment of the load line as they provide protection for the openings through the freeboard deck. Of particular importance in this respect are the end bulkheads of the superstructures, particularly the bridge front which is to withstand the force of any seas shipped. The bridge structure amidships or the poop aft are, in accordance with statutory regulations, provided as protection for the machinery openings. It is possible however to dispense with these houses or superstructures and increase considerably the scantlings of the exposed machinery casing; but in other than very small vessels it is unlikely that such an arrangement would be adopted. Unless an excessive sheer is provided on the uppermost deck it is necessary to fit a forecastle forward to give added protection in a seaway. Each structure is utilized to the full, the after structure carrying virtually all the accommodation in modern ships. The crew may be located all aft in the poop structure or partly housed in any bridge structure with the navigating spaces. Passenger liners have considerable areas of superstructures covering tiers of decks and these will house the majority of passengers and some of the crew.

Of great structural importance is the strength of the vessel where superstructures and deckhouses terminate and are non-continuous. At these discontinuities, discussed in Chapter 8, large stresses may arise and additional strengthening will be required locally as indicated in the following notes on the construction. Long superstructures amidships exceeding 15 per cent of the ship's length receive special consideration as they contribute to the longitudinal strength of the ship, and as such must have scantlings consistent with the main hull strength members.

FORECASTLE Sea-going ships must be fitted with a forecastle which extends at least 7 per cent of the ship's length aft of the stem, and a minimum height of the bow at the forecastle deck above the summer load line is stipulated. By increasing the upper deck sheer at the forward end to obtain the same height of bow, the forecastle might be dispensed with, but in practice this construction is seldom found. The side and end plating of the forecastle has a thickness which is dependent on the ship's length and the frame and stiffener spacing adopted, the side plating being somewhat heavier than the aft end plating. If a long forecastle is fitted such that its end bulkhead comes within 50 per cent of the ship's length amidships, additional stiffening is required.

BRIDGE STRUCTURES The side of bridge superstructures whose length exceeds 15 per cent of the ship's length will have a greater thickness than the sides of other houses, the scantling being similar to that required for the ship's side shell. All bridge superstructures and midship deckhouses will have a heavily plated bridge front, and the aft end plating will be lighter than the front and sides. Likewise the stiffening members fitted at the forward end will have greater scantlings than those at the sides and aft end. Additional stiffening in the form of web frames or partial bulkheads will be found where there are large erections above the bridge deck. These are intended to support the sides and ends of the houses above and are preferably arranged over the watertight bulkheads below. Under concentrated loads on the superstructure decks, for example under lifeboat davits, web frames are also provided.

The longer bridge superstructure which is transmitting the main hull girder stresses requires considerable strengthening at the ends. At this major discontinuity, the upper deck sheerstrake thickness is increased by 20 per cent, the upper deck stringer plate by 20 per cent, and the bridge side plating by 25 per cent. The latter plating is tapered into the upper deck sheerstrake with a generous radius, as shown in Figure 19.8(a), stiffened at its upper edge, and supported by webs not more than 1.5 m apart. At the ends of short bridge superstructures less strengthening is required, but local stresses may still be high and therefore the upper deck sheerstrake thickness is still increased by 20 per cent and the upper deck stringer by 20 per cent.

POOP STRUCTURE Where there is no midship deckhouse or bridge superstructure the poop front will be heavily constructed, its scantlings being similar to those required for a bridge front. In other ships it is relatively exposed and therefore needs adequate strengthening in all cases. If the poop front comes within 50 per cent of the ship's length amidships, the discontinuity formed in the main hull girder is to be considerably strengthened, as for a long bridge exceeding 15 per cent of the ship's length. Where deckhouses are built above the poop deck these are supported by webs or short transverse bulkheads in the same manner as those houses fitted amidships. The after end of any poop house will have increased scantlings since it is more exposed than other aft end house bulkheads.

PASSENGER SHIP SUPERSTRUCTURES It is shown in Chapter 8 that with conventional beam theory the bending stress distribution is linear, increasing from zero at the neutral axis to a maximum at the upper deck and bottom. If a long superstructure is fitted the stress distribution remains linear and the strength deck is above the upper deck in way of the superstructure deck. If a short superstructure is fitted the stress distribution will be broken at the upper deck, which is the strength deck, the stresses in the superstructure deck being less than those in the upper deck. The long

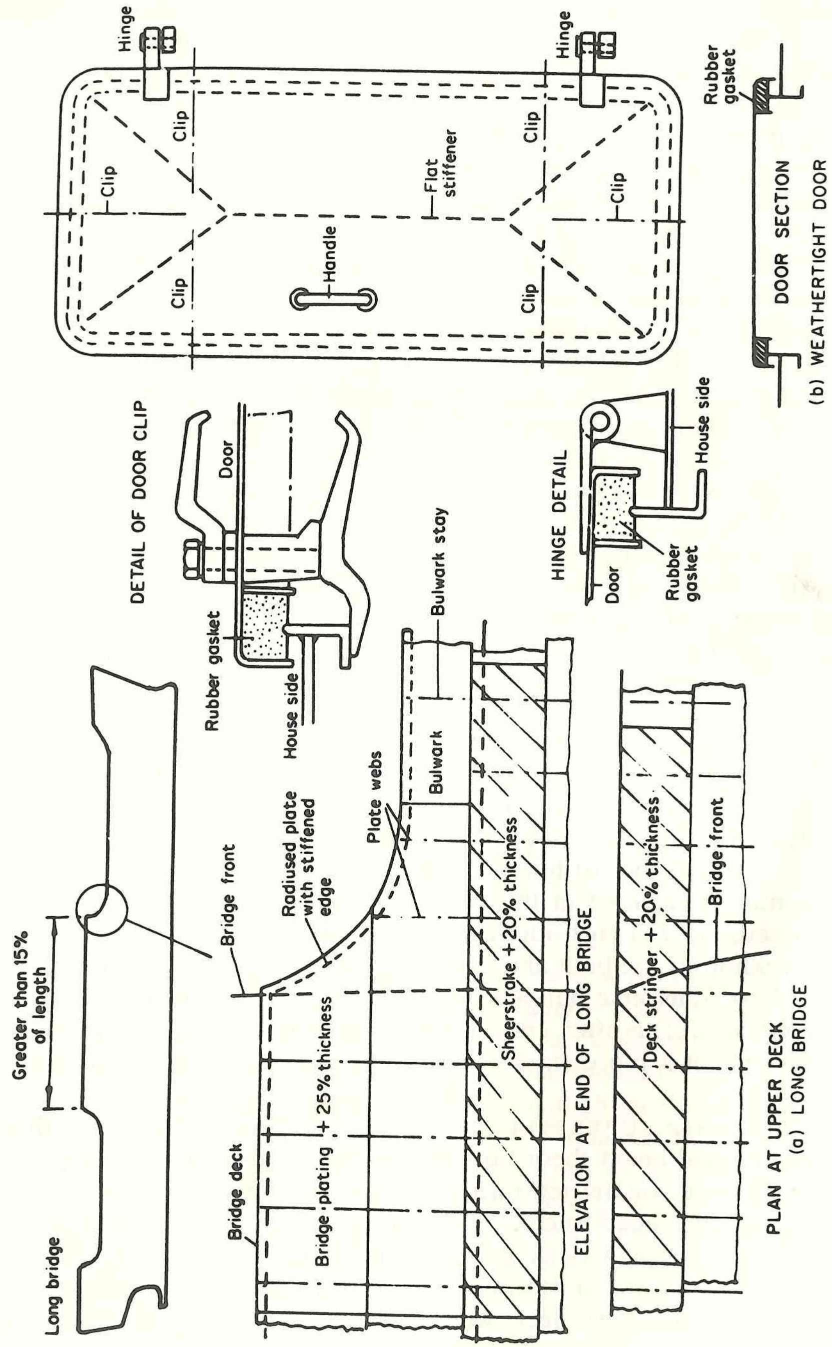


FIGURE 19.8

superstructure is referred to as an 'effective superstructure' the erections contributing to the overall strength of the hull girder, and therefore they are substantially built.

In passenger ships with large superstructures the present practice is to make the structure effective with adequate scantlings. Some older ships have been fitted with expansion joints which are in effect transverse cuts introduced to relieve the hull bending stresses in the houses. It has been shown that at the end of deck erections the stresses do not conform to beam theory and the ends are ineffective in contributing to the longitudinal strength. The expansion joints were therefore so arranged that this 'end effect' extended from joint to joint, and lighter scantlings were then permitted for the superstructure. Unfortunately the expansion joint often provided an ideal 'notch' in the structure from which cracks initiated. Aluminium alloy superstructures offer an alternative to the use of expansion joints, since the low modulus of elasticity of the material results in lower stresses in the houses than would be the case with a steel superstructure, all other considerations being equal.

WEATHERTIGHT DOORS The integrity of houses on the freeboard and other decks which protect the openings in these decks must be maintained. Access openings must be provided to the houses and weathertight doors are fitted to these openings. These must comply with the requirements of the Load Line Rules 1968 (*see* Chapter 31) and are steel doors which may be secured and made watertight from either side. Weathertightness is maintained by a rubber gasket at the frame of the door (*see* Figure 19.8(b)).

Further Reading

'The Design and Care of Weather Deck Hatch Covers', *The Naval Architect*, January, 1976.

20
Fore End Structure

Consideration is given in this chapter to the structure forward of the collision bulkhead. The chain locker is included as it is usually fitted forward of the collision bulkhead below the second deck or upper deck, or in the forecastle itself. An overall view of the fore end structure is shown in Figure 20.1, and it can be seen that the panting stiffening arrangements are of particular importance. These have already been dealt with in detail in Chapter 17 as they are closely associated with the shell plating.

On the forecastle deck the heavy windlass seating is securely fastened, and given considerable support. The deck plating thickness is increased locally, and smaller pillars with heavier beams and local fore and aft intercostals, or a centre line pillar bulkhead, may be fitted below the windlass.

Stem

On many conventional ships a stem bar, which is a solid round bar, is fitted from the keel to the waterline region, and a radiused plate is fitted above the waterline to form the upper part of the stem. This forms what is referred to as a 'soft nose' stem, which in the event of a collision will buckle under load, keeping the impact damage to a minimum. Older ships may well have solid bar stems which are riveted and of square section, and as the stem may also have no rake it could cause considerable damage on impact because of its rigidity. Other forms of stem construction are not uncommon; small ships such as tugs and trawlers often have a solid stem bar extending to the top of the bow, and large liners may have steel castings or forgings forming the lower part of the stem. A specially designed bow is required for ships assigned Ice Class AC notations and additional scantlings are required for the stems of ships assigned other ice classes (*see* Chapter 17).

The solid round bar is welded inside the keel plate at its lower end, and inside the radiused stem plate at its upper end, the shell being welded each side (Figure 20.1). It is necessary to support that part of the stem which is formed by radiused plates with 'breast hooks', i.e. horizontal plate webs, between the decks and below the lowest deck, in order to reduce the unsupported span of the stem. Where the plate radius is large, further stiffening is provided by a vertical stiffener on the centre line. The thickness

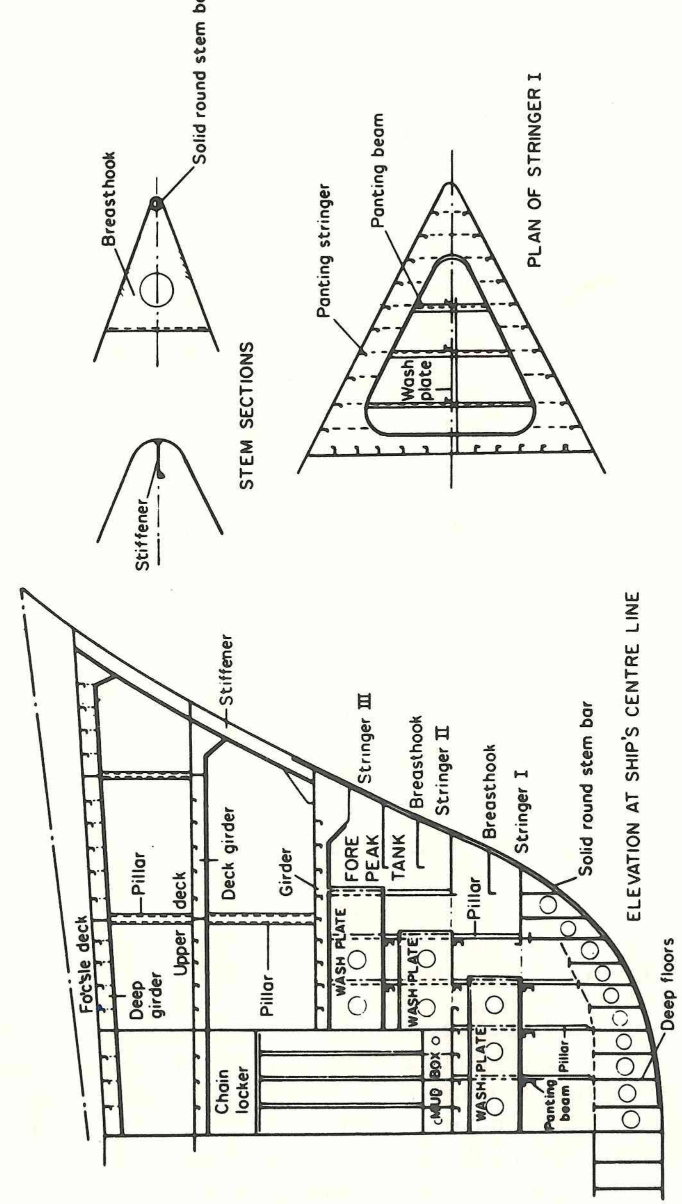


FIGURE 20.1 Fore end construction

of these plates will be in excess of that required for the side shell forward, but the thickness may taper to that of the side shell at the stem head.

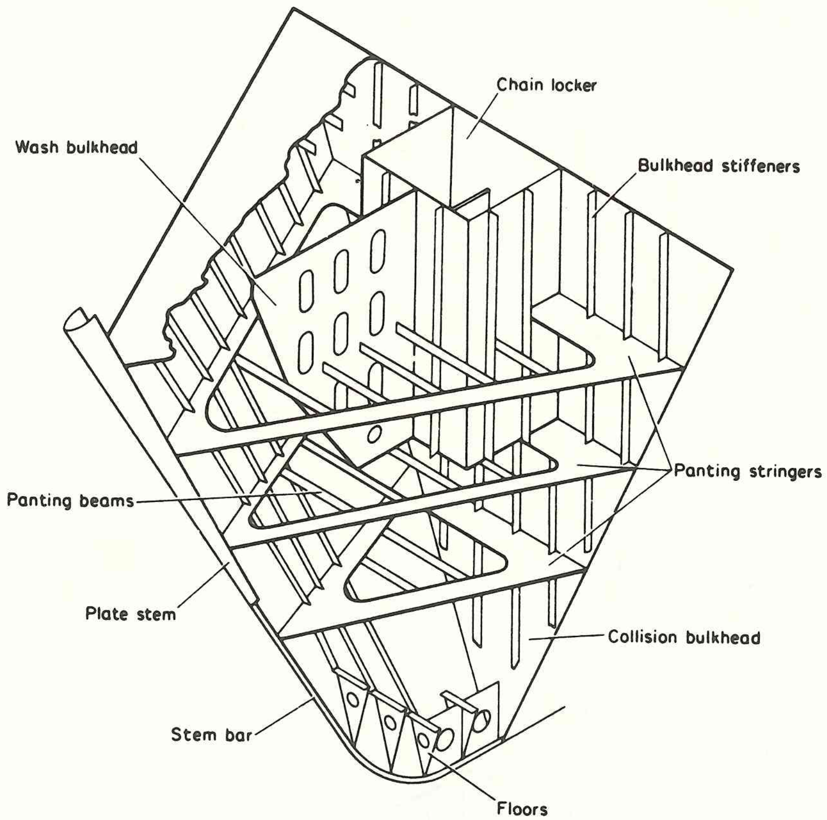


FIGURE 20.2 Fore end structure

Bulbous Bows

Vessels operating at higher speeds, and those with high block coefficients, are often found to have a bulbous or protruding bow below the waterline. The arguments for and against fitting some form of bulbous bow are the province of text-books on naval architecture, but it may be indicated that like most peculiarities of the immersed hull form this feature is usually intended to reduce the vessel's resistance to motion under certain conditions.

From the construction point of view the bulbous bow does not present any great difficulty if this aspect has been considered when the bulb form is

designed. In general however a greater degree of plate curvature is involved, unless a rather convenient cylindrical form is adopted and fitted into the bow as a single unit. This has in fact been done successfully; but in general the protrusion forms a continuation of the side shell. Floors are fitted at every frame space in the bulb, and a centre line wash bulkhead is introduced when the bulb is large. Transverses are fitted at about every fifth frame in long bulbs (*see* Figure 20.3). Smaller bulbs have a centre line web but not a wash bulkhead; and in all bulbous bows horizontal diaphragm plates are fitted. Shell plating covering the bulb has an increased thickness similar to that of a radiused plate stem below the waterline. This increased thickness should in particular cover any area likely to be damaged by the anchors and chains; and in designing the bow fouling of the anchors should be taken into consideration.

Chain Locker

A chain locker is often arranged in the position forward of the collision bulkhead shown in Figure 20.1, below either the main deck or the second deck. It can also be fitted in the forecastle or aft of the collision bulkhead, in which case it must be watertight and have proper means of drainage. Chain locker dimensions are determined in relation to the length and size of cable, the depth being such that the cable is easily stowed, and a direct lead at all times is provided to the mouth of the chain pipe. Port and starboard cables are stowed separately in the locker, and the inboard ends of each are secured to the bottom of the centre line bulkhead or underside of deck (*see* Figure 20.4). It is desirable to have an arrangement for slipping the cable from outside the chain locker.

CONSTRUCTION OF CHAIN LOCKER The locker does not as a rule have the same breadth as the ship, but has conventionally stiffened forward and side bulkheads, the stiffeners being conveniently arranged outside the locker if possible to prevent their being damaged. A false bottom may be formed by perforated plates on bearers arranged at a height above the floor of the locker. Where fitted this provides a mudbox which can be cleaned and is drained by a centre line suction, the bottom plating sloping inboard. To separate the locker into port and starboard compartments a centre line bulkhead is fitted. This bulkhead does not extend to the crown of the locker, but allows working space above the two compartments. Access to the bottom of the locker is provided by means of foot holes cut in the bulkhead, and the stiffeners fitted to this bulkhead are of the vertical flush cope bar type. Any projections which would be damaged by the chains are thus avoided. The upper edge of the bulkhead is similarly stiffened and may provide a standing platform, with a short ladder leading from the hatch in

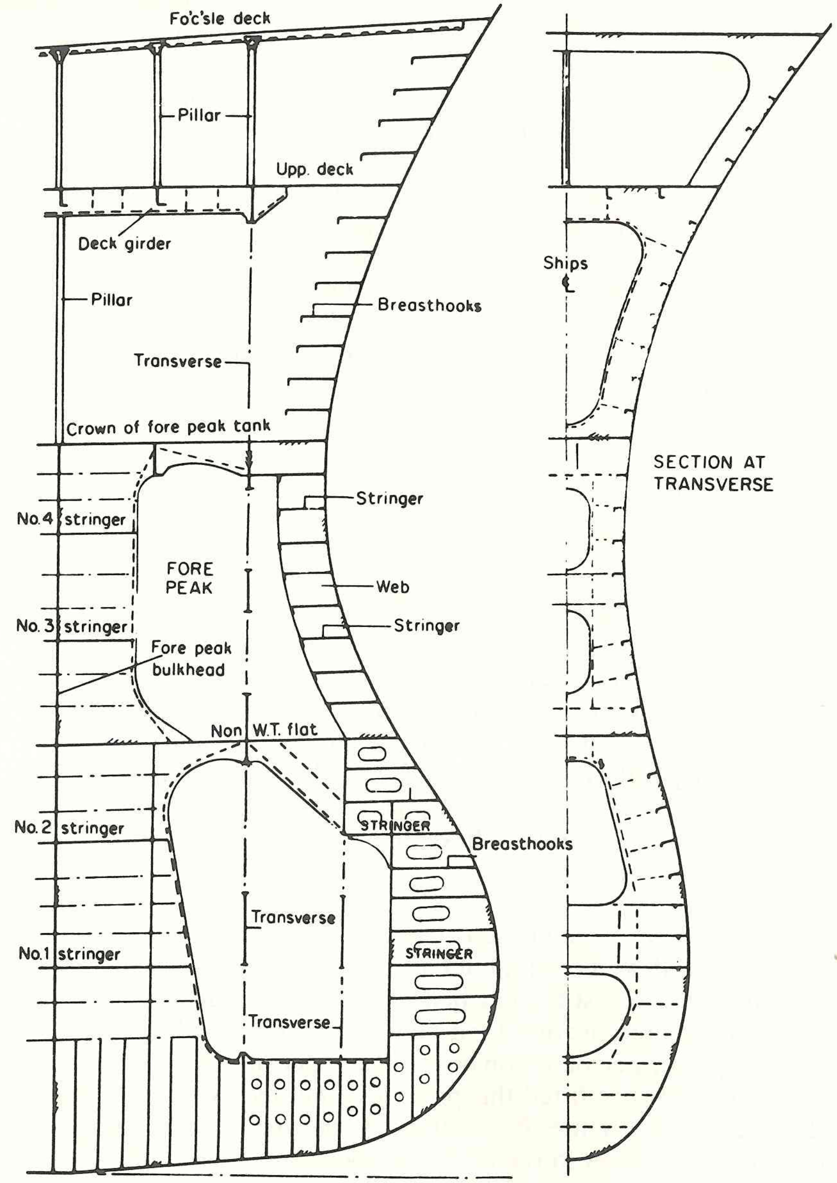


FIGURE 20.3 Bulbous bow

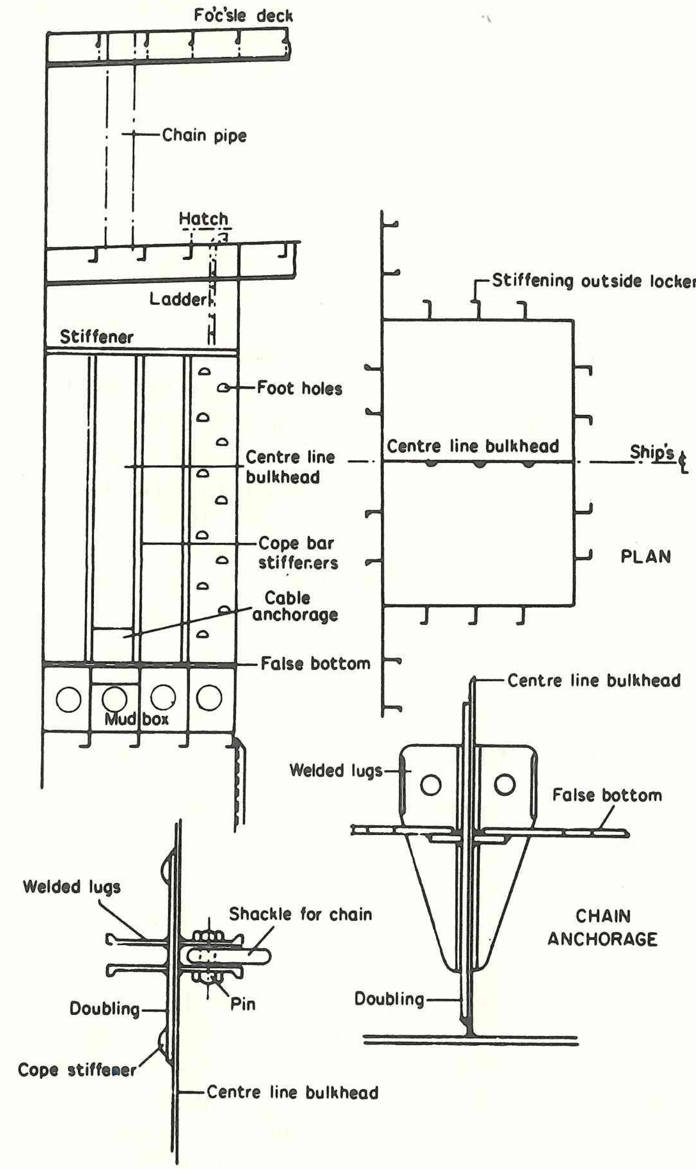


FIGURE 20.4 Chain locker construction

the deck forming the crown of the locker. Each cable is fed to the appropriate locker compartment through port and starboard chain pipes from the forecastle deck. These chain pipes or spurling pipes are of tubular construction with castings or other rounded end mouldings to prevent chafing.

Hawse Pipes

To provide an easy lead for the cable from the windlass to the anchors, the hawse pipes must be carefully fitted. It is not uncommon for a temporary scale model of the relevant fore end structure to be constructed, and the positions of the hawse pipes may be experimented with in order to obtain the best lead. This model need not be elaborate but made simply of cardboard and wood, and the best hawse pipe arrangement will permit the anchor to be raised and lowered smoothly, and housed properly.

Tubular hawse pipes are generally fabricated, and castings are welded at the shell and deck to prevent chafing (*see* Figure 20.5). Additional stiffening in way of the hawse pipes is required at the side shell. On higher speed vessels a recess is often provided in the shell for anchor stowage; this helps to reduce any drag caused by the stowed anchor and prevents serious damage in the event of a collision.

Bow Steering Arrangements

Double-ended ferries are provided with a rudder at either end which is locked in position when it is at the fore end of the vessel under way.

Bow Thrust Units

For manoeuvring in confined waters at low speeds, lateral bow thrust units are particularly useful. These are often found in research vessels, or drilling platform vessels where very accurate positioning must be maintained. They are also to be found in large ships and cross-channel vessels where they are provided as an aid to docking. The thrust unit consists as a rule of controllable pitch or reversible impeller fitted in an athwartships watertight tunnel. Control of the unit is from the bridge, but the driving motor is in way of the impeller. Thrust provided by the impellers are low; 16 tonnes is perhaps the largest fitted, but the unit size does not need to be large as small thrusts are very effective. It is true however that the greatest thrust is provided at zero speed and as the vessel gets under way the unit becomes much less effective.

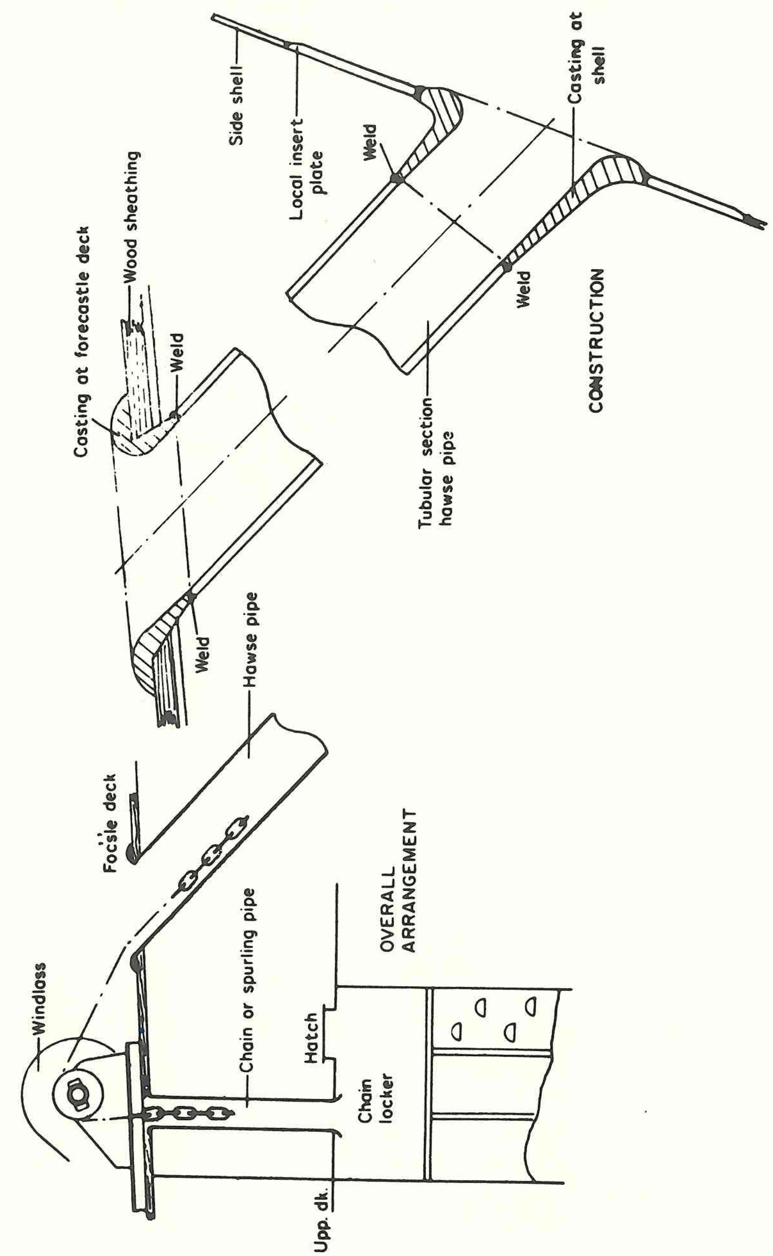


FIGURE 20.5 Hawse pipes

From a construction point of view the most important feature is the provision of fairing sections at the ends of the athwartship tunnel in way of the shell. It has been shown that an appreciable increase in hull resistance and hence power may result if this detail is neglected. The best way of avoiding this is to close the tunnels at either end when they are not in use. This is possible, flush mounted, butterfly action, hydraulically operated doors being available for this purpose.

21 Aft End Structure

Considerable attention is paid to the overall design of the stern in order to improve flow into and away from the propeller. The cruiser stern (*see* Figure 21.1) was for many years the favoured stern type for ocean going ships, but today most of these vessels have a transom stern (*see* Figure 21.2). A cruiser stern presents a more pleasant profile and is hydrodynamically efficient, but the transom stern offers a greater deck area aft, is a simpler construction, and can also provide improved flow around the stern.

Many forms of rudder are available and the type and form fitted is intended to give the best manoeuvring characteristics. Both the shape of the stern and the rudder type will dictate the form of the stern frame, and this will be further influenced by the required propeller size. Of particular importance at the after end are the arrangements which permit both the propeller shaft and the rudder stock to pierce the intact watertight hull. The safety of the ship may depend on these arrangements. Where more than one screw propeller is to provide the thrust required to propel the ship, bossings or 'A' brackets will be fitted to support the outboard shafts.

Stern Construction

As the cruiser stern overhang may be subjected to large slamming forces a substantial construction with adequate stiffening is required. Solid floors are fitted at every frame space, and a heavy centre line girder is fitted right aft at the shell and decks. The stern plating is stiffened by cant frames or webs with short cant beams supporting the decks and led to the adjacent heavy transverse deck beam. Further stiffening of the plating is provided, or adopted in lieu of cant frames, by horizontal stringers extending to the first transverse frame.

Cant frames are not required where the transom stern is adopted, as the flat stern plating may be stiffened with vertical stiffeners (Figure 21.2). Deep floors and a centre line girder are provided at the lower region of the transom stern construction.

Panting arrangements at the aft end are dealt with in Chapter 17.

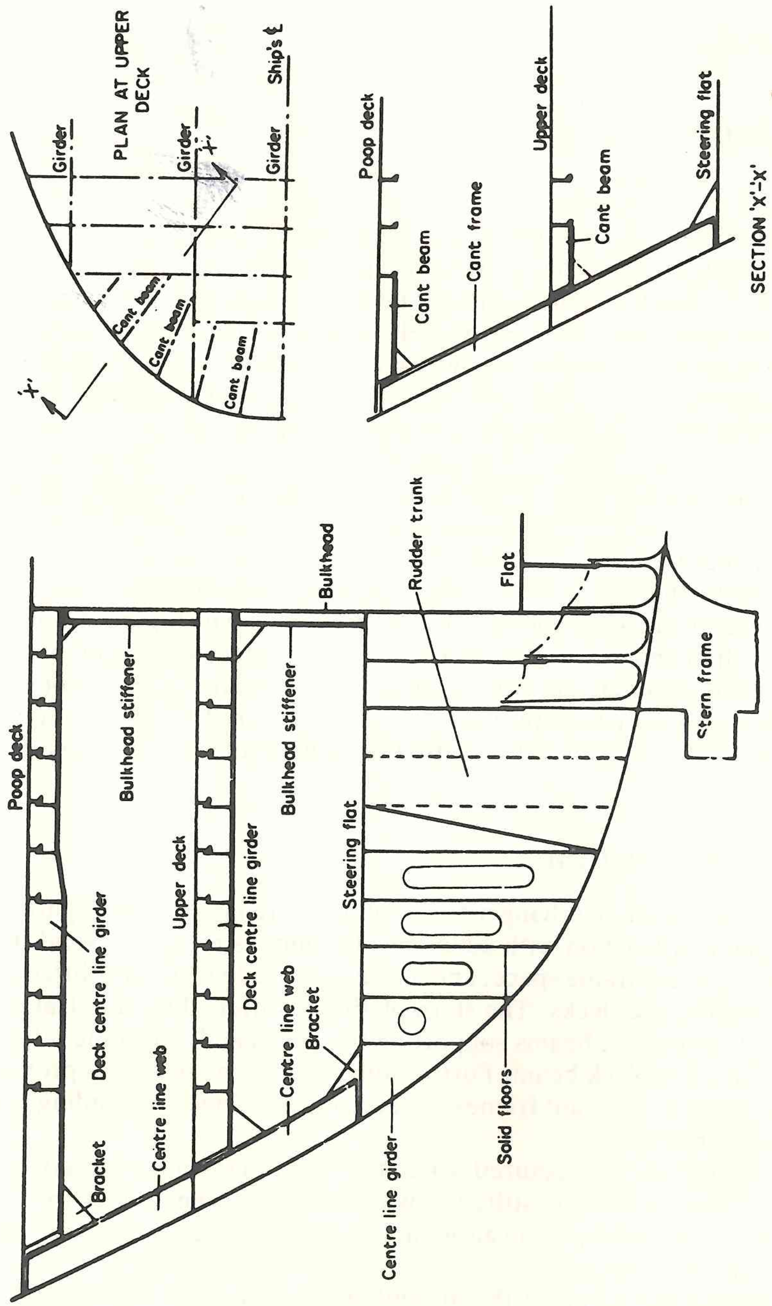


FIGURE 21.1 Cruiser stern

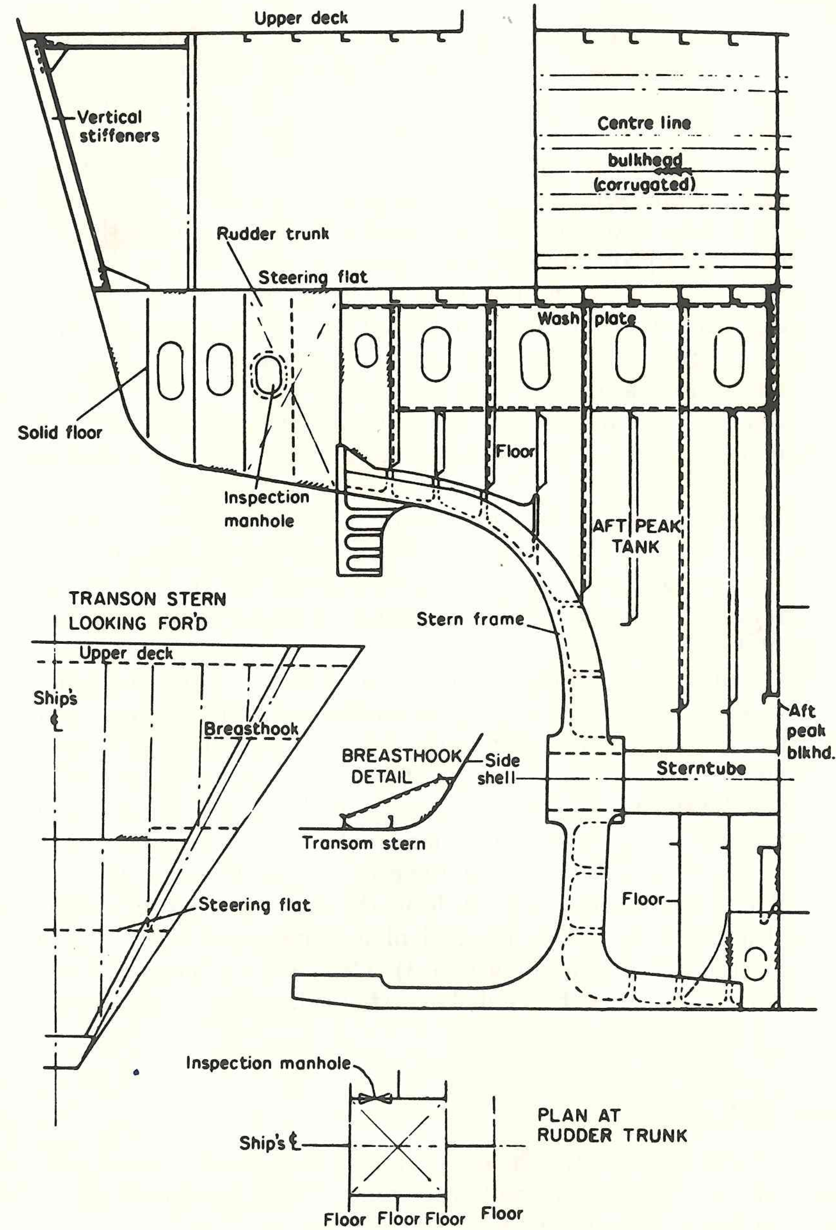


FIGURE 21.2 Transom stern

Stern Frame

It has already been indicated that the form of the stern frame is influenced by the stern profile and rudder type. To prevent serious vibration at the after end there must be adequate clearances between the propeller and stern frame, and this will to a large extent dictate its overall size.

The stern frame of a ship may be cast, forged, or fabricated from steel plate and sections. On larger ships it is generally either cast or fabricated, the casting being undertaken by a specialist works outside the shipyard. To ease the casting problem with larger stern frames and also the transport problem it may be cast in more than one piece and then welded together when erected in the shipyard. Fabricated stern frames are often produced by the shipyard itself, plates and bars being welded together to produce a form similar to that obtained by casting (*see* Figure 21.3). Forged stern frames are also produced by a specialist manufacturer and may also be made in more than one piece where the size is excessive or shape complicated.

Sternpost sections are of a streamline form, in order to prevent eddies being formed being the posts, which can lead to an increase in the hull resistance. Welded joints in cast steel sections will need careful preparation and preheat. Both the cast and fabricated sections are supported by horizontal webs.

Two forms of stern frame are shown in Figure 21.3, one being a casting and the other fabricated, so that the similarity of the finished sections is indicated. Of particular interest is the connection of the stern frame to the hull structure for, if this is not substantial, the revolving propeller supported by the stern frame may set up serious vibrations. The rudder post is carried up into the main hull and connected to the transom floor which has an increased plate thickness. Also the propeller post may be extended into the hull and connected to a deep floor, the lower sole piece being carried forward and connected to the keel plate. Side shell plates are directly welded to the stern frame (Figure 21.3), a 'rabbet', i.e. a recess, sometimes being provided to allow the shell plate to fit flush with the sternpost section.

Rudders

Many of the rudders which are found on present-day ships are semi-balanced, i.e. they have a small proportion of their lateral area forward of the turning axis (less than 20 per cent). Balanced rudders with a larger area forward of the axis (25 to 30 per cent), and un-balanced rudders with the full area aft of the axis are also fitted. The object of balance is to achieve a reduction in torque since the centre of lateral pressure is brought nearer the turning axis. However the fully balanced rudder will at low angles tend to

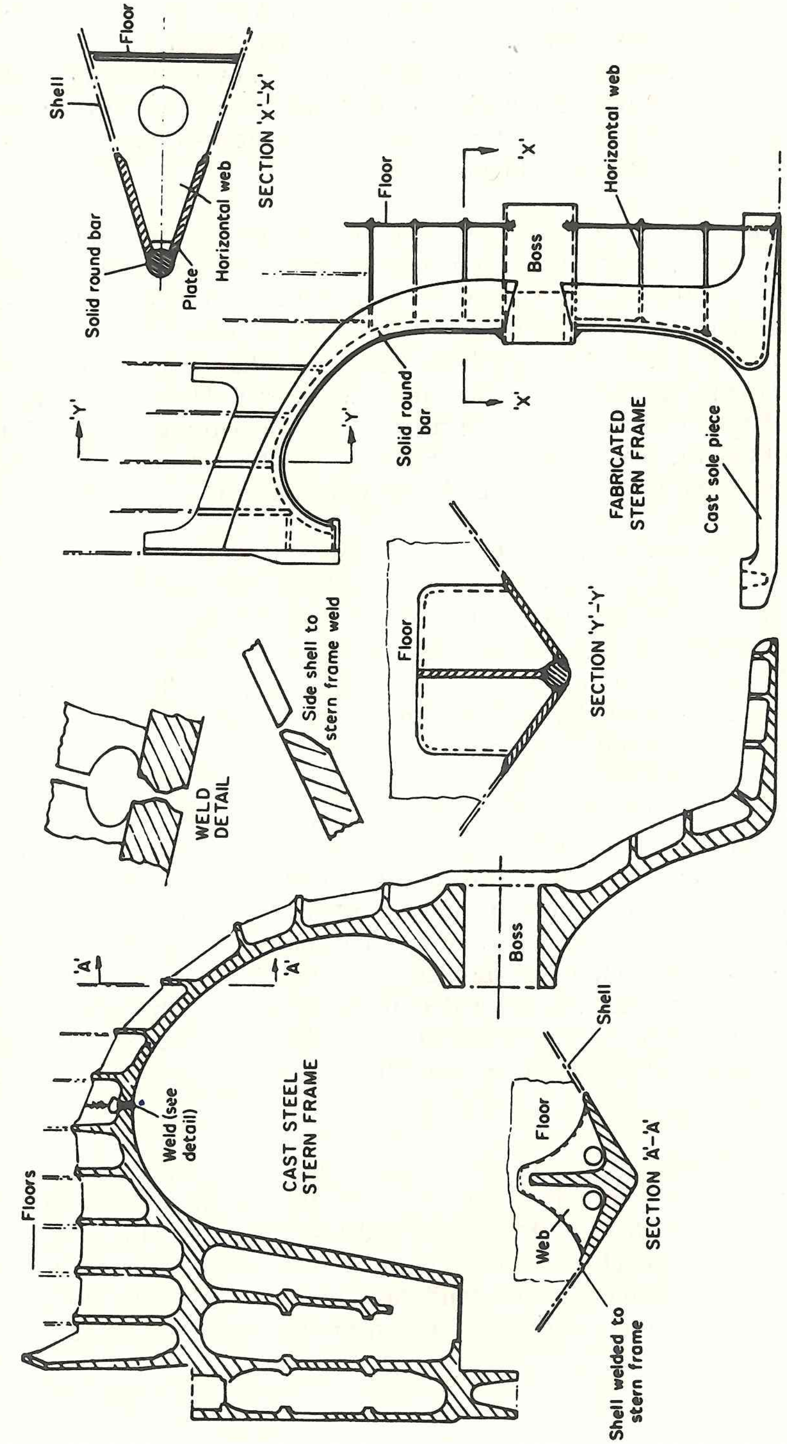


FIGURE 21.3 Stern frames

drive the gear, which does not matter a great deal with power steering gears but is less satisfactory with any form of direct hand gear.

Designs of rudders are various, and patent types are available, all of which claim increased efficiencies of one form or another. Two common forms of rudder are shown in Figure 21.4 each being associated with one of the stern frames shown in Figure 21.3.

RUDDER CONSTRUCTION Modern rudders are of streamlined form except those on small vessels, and are fabricated from steel plate, the plate sides being stiffened by internal webs. Where the rudder is fully fabricated, one side plate is prepared and the vertical and horizontal stiffening webs are welded to this plate. The other plate, often called the 'closing plate', is then welded to the internal framing from the exterior only. This may be achieved by welding flat bars to the webs prior to fitting the closing plate, and then slot welding the plate as shown in Figure 21.4. Other rudders may have a cast frame and webs with welded side and closing plates which are also shown in Figure 21.4.

Minor features of the rudders are the provision of a drain hole at the bottom with a plug, and a lifting hole which can take the form of a short piece of tube welded through the rudder with doubling at the side and closing plates. To prevent internal corrosion the interior surfaces are suitably coated, and in some cases the rudder may be filled with an inert plastic foam. The rudder is tested when complete under a head of water 2.45 m above the top of the rudder.

RUDDER PINTLES Pintles on which the rudder turns in the gudgeons have a taper on the radius, and a bearing length which exceeds the diameter. Older ships may have a brass or bronze liner shrunk on the pintles which turn in lignum vitae (hardwood) bearings fitted in the gudgeons. Modern practice is to use synthetic materials like 'Tufnol' for the bearings, and in some cases stainless steels for the liners. In either case lubrication of the bearing is provided by the water in which it is immersed. Until recently it has not been found practicable to provide oil-lubricated metal bearings for the pintles, but the 'Queen Elizabeth 2' has this innovation.

RUDDER STOCK A rudder stock may be of cast or forged steel, and its diameter is determined in accordance with the torque and any bending moment it is to withstand. At its lower end it is connected to the rudder by a horizontal or vertical bolted coupling, the bolts having a cross-sectional area which is adequate to withstand the torque applied to the stock. This coupling enables the rudder to be lifted from the pintles for inspection and service.

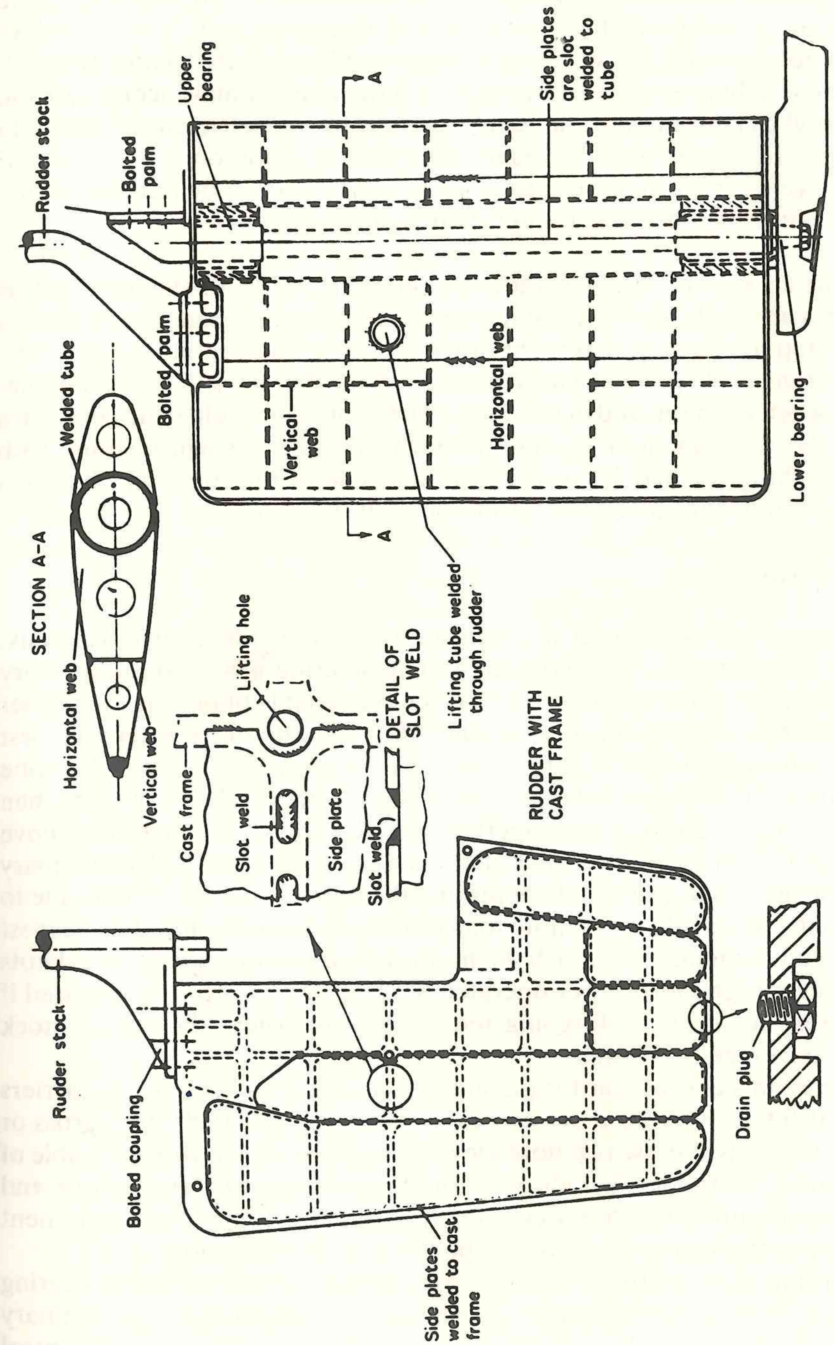


FIGURE 21.4 Rudders

RUDDER BEARING The weight of the rudder may be carried partly by the lower pintle and partly by a rudder bearer within the hull. In some rudder types, for example, the spade type which is only supported within the hull, the full weight is borne by the bearer. A rudder bearer may incorporate the watertight gland fitted at the upper end of the rudder trunk as shown in Figure 21.5. Most of the rudder's weight may come onto the bearer if excessive wear down of the lower pintle occurs, and the bearers illustrated have cast iron cones which limit their wear down.

RUDDER TRUNK Rudder stocks are carried in the rudder trunk, which as a rule is not made watertight at its lower end, but a watertight gland is fitted at the top of the trunk where the stock enters the intact hull (Figure 21.5). This trunk is kept reasonably short so that the stock has a minimum unsupported length, and may be constructed of plates welded in a box form with the transom floor forming its forward end. A small opening with watertight cover may be provided in one side of the trunk which allows inspection of the stock from inside the hull in an emergency.

Steering Gear

Unless the main steering gear comprises two or more identical power units, every ship is to be provided with a main steering gear and an auxiliary steering gear. The main steering gear is to be capable of putting the rudder over from 35° on one side to 35° on the other side with the ship at its deepest draft and running ahead at maximum service speed, and under the same conditions from 35° on either side to 30° on the other side in not more than 28 seconds. It is to be power operated where necessary to meet the above conditions and where the stock diameter exceeds 120 mm. The auxiliary steering gear is to be capable of putting the rudder over 15° on one side to 15° on the other side in not more than 60 seconds with the ship at its deepest draft and running ahead at half the maximum service speed or 7 knots whichever is greater. Power operated auxiliary steering gear is required if necessary to meet the forgoing requirement or where the rudder stock diameter exceeds 230 mm.

The main steering gear for oil tankers, chemical tankers, or gas carriers of 10,000 tons gross or more and every other ship of 70,000 tons gross or more is to consist of two or more identical power units which are capable of operating the rudder as indicated for the main steering gear above and whilst operating with all power units. If a passenger ship, this requirement is to be met when any one of the power units is inoperable.

Steering gear control for power operated main and auxiliary steering gears is from the bridge and steering gear compartment, the auxiliary steering gear control being independent of the main steering gear control (but not duplication of the wheel or steering lever).

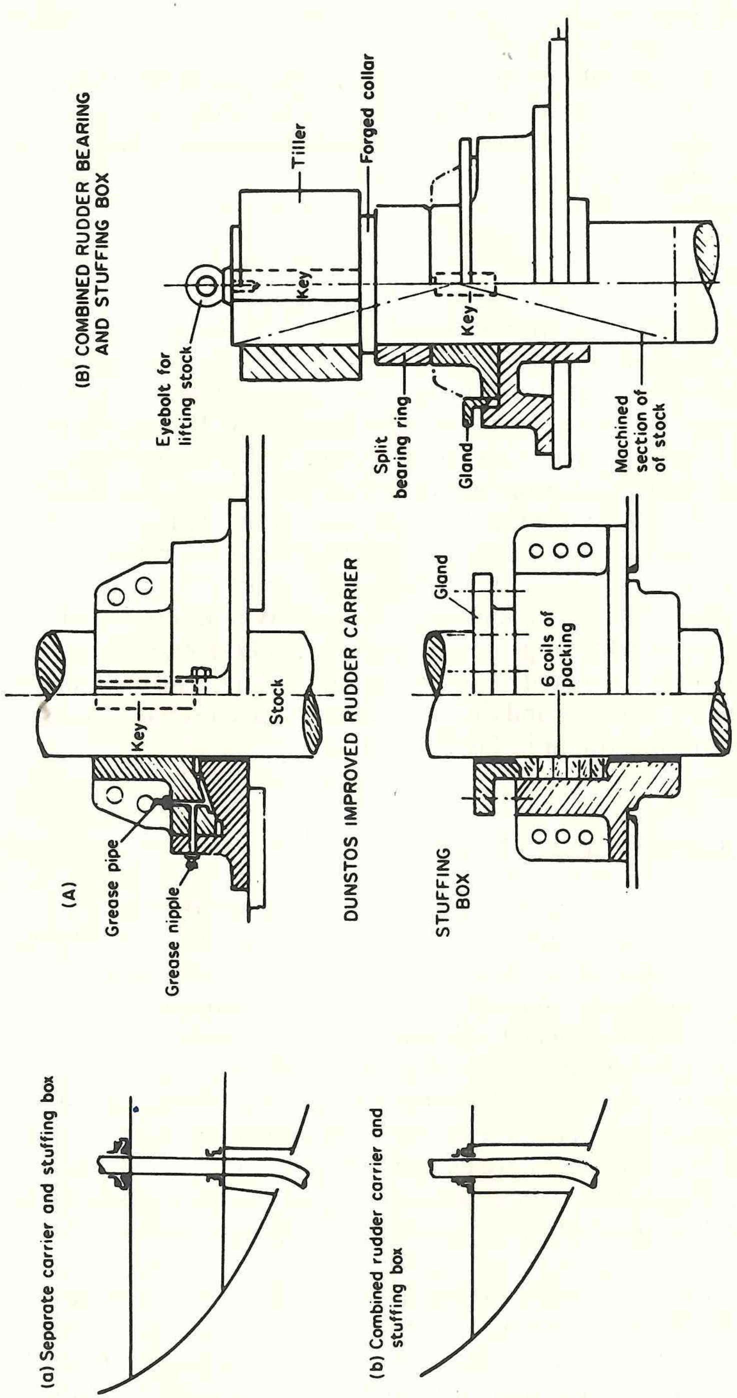


FIGURE 21.5 Rudder bearings

Steering gear on ocean-going ships is generally of the electro-hydraulic type.

Where the rudder stock is greater than 230 mm an alternative power supply is to be provided automatically from the ship's emergency power supply or from an independent source of power located in the steering gear compartment.

Sterntube

A sterntube forms the after bearing for the propeller shaft, and incorporates the watertight gland where the shaft passes through the intact hull. Two forms of sterntube are in use, that most commonly fitted having water-lubricated bearings with the after end open to the sea. The other type is closed at both ends and has metal bearing surfaces lubricated by oil. In the former type the bearings were traditionally lignum vitae strips and the tail shaft (aft section of propeller shaft) was fitted with a brass liner, but Tufnol strips are now often fitted. The latter form of sterntube is preferred in many ships with machinery aft, where the short shaft is to be relatively stiff and only small deflections are tolerated. Where this patent oil lubricated sterntube is fitted, glands are provided at both ends to retain the oil and prevent the ingress of water, white metal (high lead content) bearing surfaces being provided and the oil supplied from a reservoir. Both types of sterntube are illustrated in Figure 21.6.

Shaft Bossing and 'A' Brackets

Twin-screw or multi-screw vessels have propeller shafts which leave the line of shell at some distance forward of the stern. To support the shaft overhang, bossings or 'A' brackets may be fitted. Bossings are a common feature on the larger multiple-screw passenger ships and are in effect a moulding of the shell which takes in the line of shaft for some distance. Access from inside the hull is thus provided to the shaft over a great proportion of its length, and it is afforded greater protection. Many large liners having high speeds are shown to have benefited by a decrease in resistance when bossings have been fitted rather than 'A' brackets. However large liners of more recent design have in some instances had extended shafts solely supported by 'A' brackets of improved design.

CONSTRUCTION OF BOSSING AND 'A' BRACKETS The shaped frames and plating forming the bossing terminate in a casting known as the 'spectacle frame' which provides the aftermost bearing for the shaft. This may be cast or fabricated and forms a box-like section athwartships which is

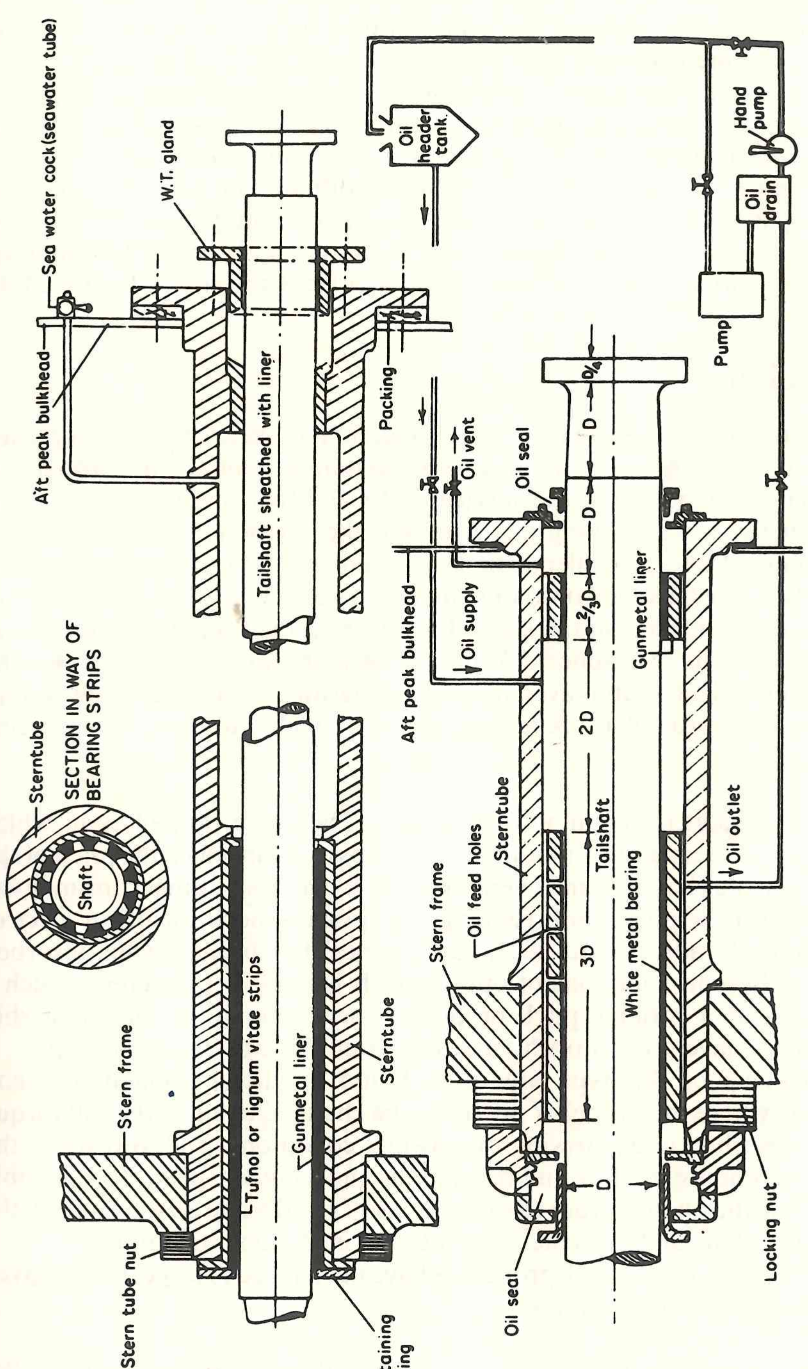


FIGURE 21.6 Sterntubes

rigidly connected to heavy plate floors. The arms carrying the shafts extend from this section which may be split in two or more parts in some instances to aid alignment when it is erected (*see* Figure 21.7).

'A' brackets may be cast, or fabricated, particular attention being paid to the strut section to avoid increases in resistance and cavitation. The connections to the main hull are of particular importance since considerable rigidity of the structure is required. Although on smaller vessels the upper palms may simply be welded to a reinforcing pad at the shell, on larger vessels the upper ends of the struts enter the main hull and are connected to a heavy floor with additional local stiffening (Figure 21.7).

Propellers

Ship propellers may have from three to six similar blades, the number being consistent with the design requirements. It is important that the propeller is adequately immersed at the service drafts and that there are good clearances between its working diameter and the surrounding hull structure. The bore of the propeller boss is tapered to fit the tail shaft and the propeller may be keyed onto this shaft; a large locking nut is then fitted to secure the propeller on the shaft. For securing the propeller a patent nut with a built in hydraulic jack providing a frictional grip between the propeller and tail shaft is available. This 'Pilgrim nut' may also be used with keyless bore propellers. A fairing cone is provided to cover the securing nut.

CONTROLLABLE PITCH PROPELLERS These are propellers in which the blades are separately mounted on the boss, and in which the pitch of the blades can be changed, and even reversed, by means of a mechanism in the boss, whilst the propeller is running. The pitch is mechanically or electro-mechanically adjusted to allow the engines' full power to be absorbed under different conditions of operation. It is incorrect to refer to such a propeller as a variable pitch propeller since virtually all merchant ship propellers have a fixed pitch variation from blade root to blade tip.

Propellers of this type are often found on diesel-engined tugs and trawlers where the propeller pitch may be changed to allow the full torque to be absorbed under towing or trawling conditions, and also when the vessel is running freely at full revolutions and a higher speed. It is possible to reverse the pitch in order to stop the vessel rapidly and go astern, with the propeller shaft and propeller still rotating in the one direction.

Large controllable pitch propellers have been fitted to large diesel-driven bulk carriers in recent years.

SHROUDED PROPELLERS To increase the thrust provided by a propeller

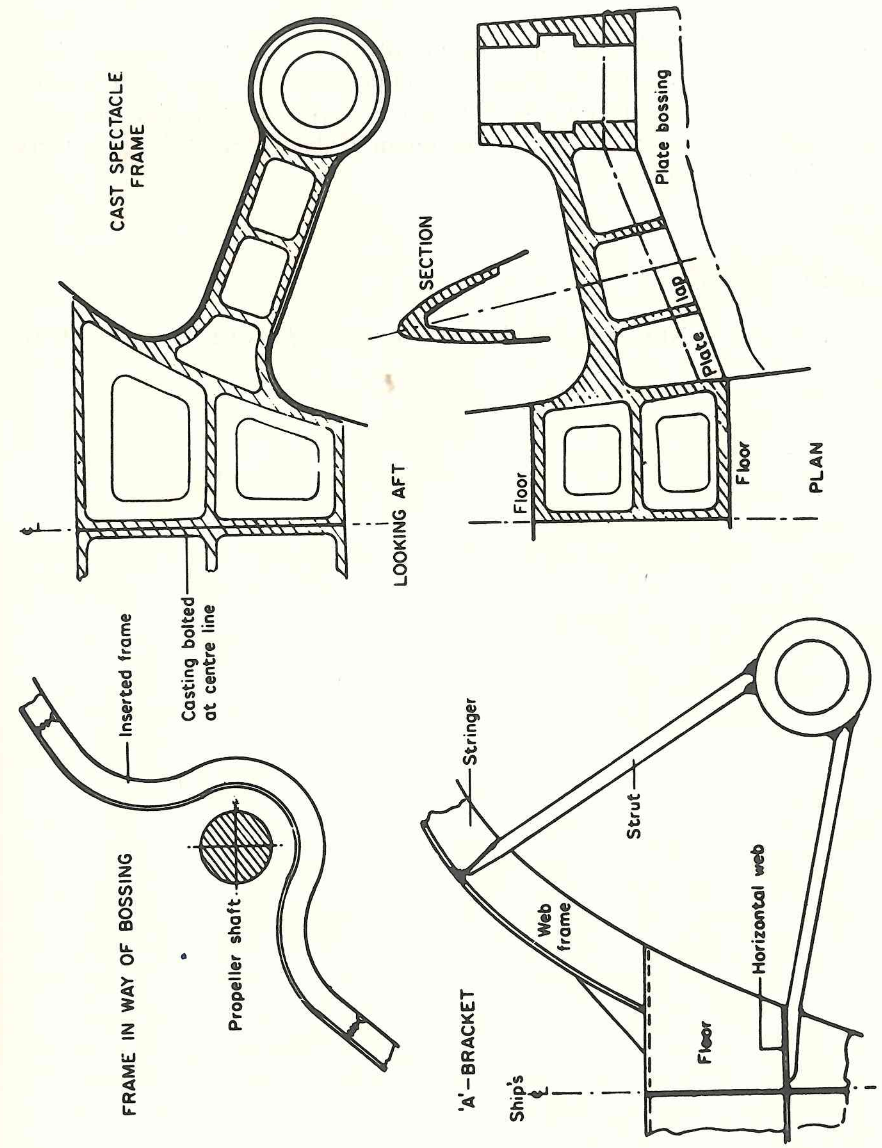


FIGURE 21.7 Bossings and 'A' brackets

of given diameter at low speeds and high slips it may be enclosed in a nozzle. Single-screw tugs and trawlers are often fitted with the patent 'Kort nozzle' where under a heavy tow the propeller is working at a high slip. This nozzle has a reducing diameter aft and is relatively short in relation to the diameter, to avoid increasing the directional stability thus making steering difficult.

When running freely the slip is much lower, and it might appear that there was little advantage in fitting a shrouded propeller. However serious consideration has been given to fitting this form of propeller on large single-screw tankers where there is a problem of absorbing the large powers on the limited diameter.

Further Reading

'Pilgrim Propeller Nut', *Shipbuilding and Shipping Record*, 17 April, 1970.

22
Tanker Construction

Ships designed specifically to carry bulk liquid cargoes are generally referred to as tankers. Tankers are commonly associated with the carriage of oil, but a wide variety of liquids are carried in smaller tank vessels and there are a growing number of larger tank vessels dedicated to carrying chemicals in bulk.

Oil Tankers

Small tankers involved principally in the coastal trade commonly have a single longitudinal bulkhead on the centre line providing two athwartship tanks. The machinery is aft, and an expansion trunk, if fitted, is on the centre line in the way of the tank spaces (*see* Figure 22.1). Larger ocean-going tankers have at least two longitudinal bulkheads providing three athwartship tanks, and the machinery is again arranged aft (*see* Figures 22.2 and 22.3).

This chapter is concerned with the construction of the larger ocean-going type, which may be considered in two classes. There are those ships which carry refined oil products, and perhaps some other cargoes like molasses, which tend to be in the smaller 12 000 tonnes to 50 000 tonnes deadweight range. Then there are the crude oil carriers which extend to the 500 000 tonnes deadweight range. The former vessels have a greater number of tanks, and more complicated pumping arrangements which permit the carriage of a number of different products on a single voyage.

Both types of ship have traditionally been single flush deck ships with longitudinal bulkheads and a structure within the tank spaces consisting of a grillage of longitudinal and transverse members. Recent developments have seen designs offered particularly for products carriers with a double hull and bulkhead cofferdam arrangement where the structure is principally orientated in the longitudinal direction. These designs offer plane surfaces within the tank space simplifying cleaning, ample segregated ballast capacity in the double hull, and increased safety. One of these designs also offers a partial return to the trunk concept with a high dome having sloping sides to reduce sloshing of the oil cargo.

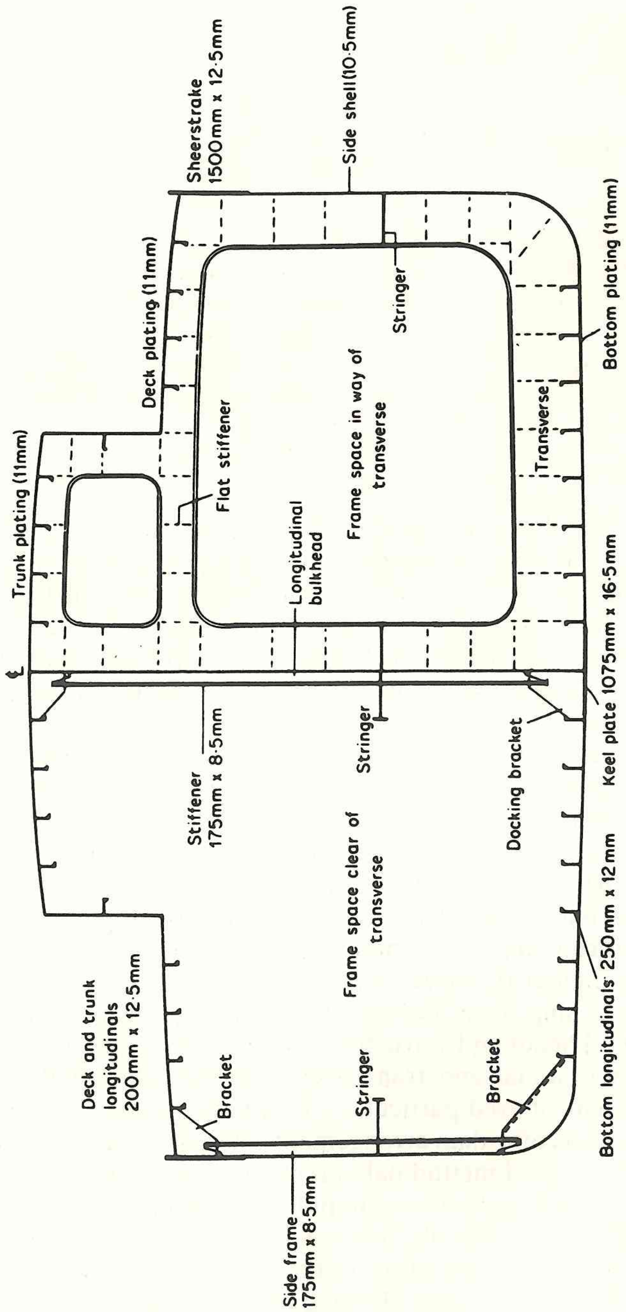


FIGURE 22.1 Midship section of coastal tanker with trunk

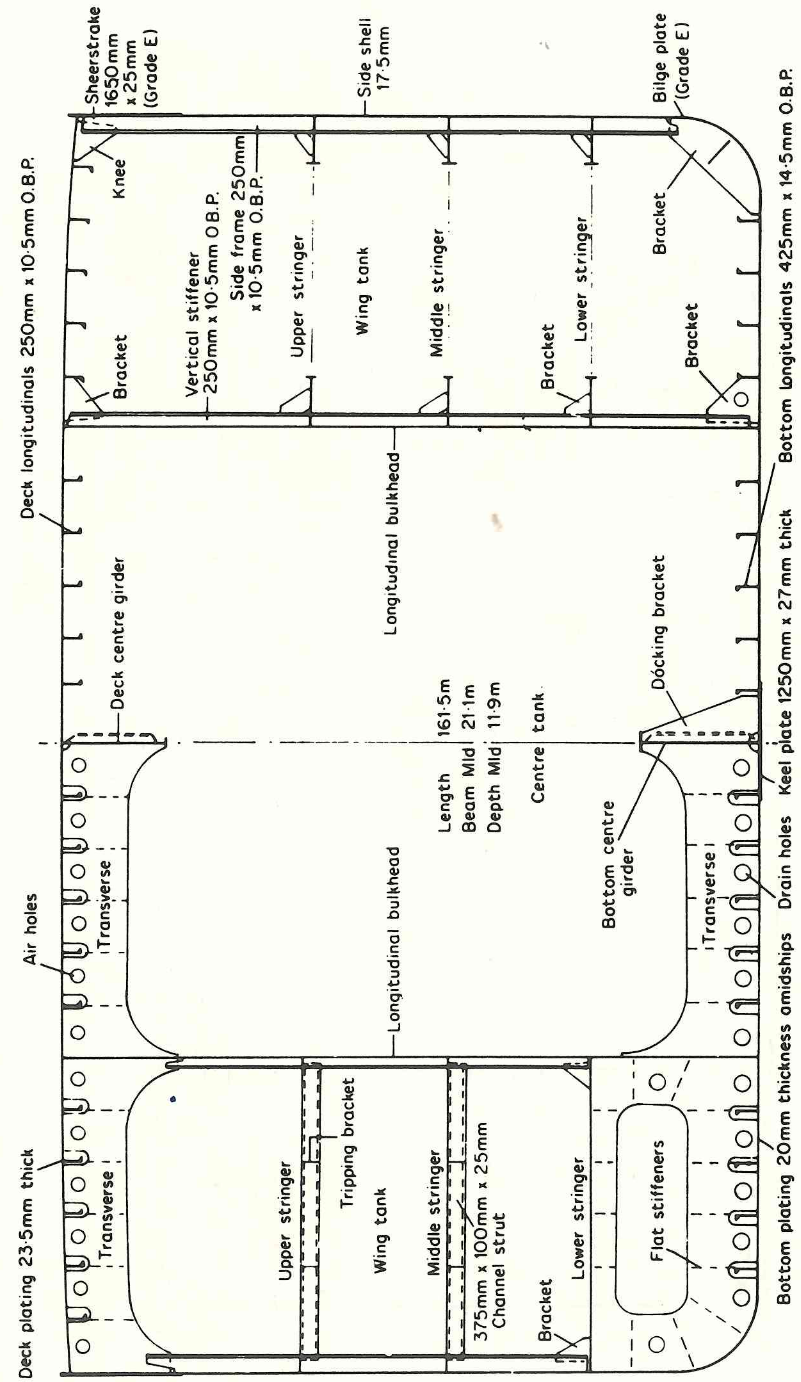


FIGURE 22.2 Midship section of oil tanker

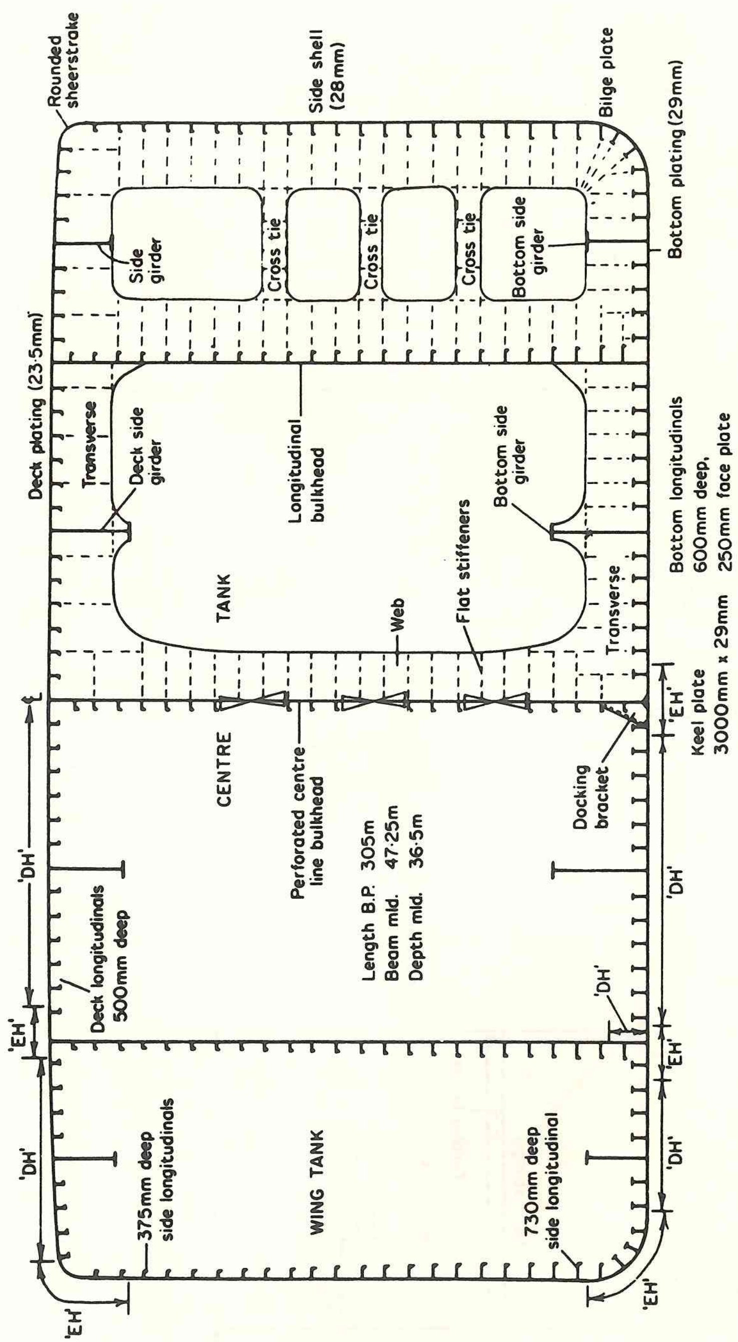


FIGURE 22.3 Midship section of large tanker

Materials for Tanker Construction

Mild steel is used throughout the structure, but higher tensile steels may also be introduced in the more highly stressed regions of the larger vessels.

MILD STEEL As with dry cargo ships it is a requirement that Grade B, D and E steels be used for the heavier plating of the main hull strength members where the greatest stresses arise in tankers. These requirements are the same as those indicated in Table 17.1. Grade E plates which we have equated with the 'crack arrester strake' concept (see Chapter 8) will be seen to be required over the midship region in ships exceeding 250 mm in length and are also required as shown in Table 22.1.

TABLE 22.1

Use of grade E steel in tankers

Location	*Thickness*
Stringer plate, sheerstrake, rounded gunwale.	Greater than 15 mm
Bilge strake, deck strake in way of longitudinal bulkhead.	Greater than 25 mm
Main deck plating, bottom plating, keel, upper strake of longitudinal bulkhead.	Greater than 40 mm

HIGHER TENSILE STEEL Higher tensile steels are often used for the deck and bottom regions of the larger tankers. As indicated in Chapter 5 this leads to a reduction in the scantlings of these structural items with advantages both for the shipbuilder and owner. The extent of this plating and section material is indicated in Figure 22.3, which shows the midship section of a very large tanker. Where higher tensile steels are used a greater thickness than for mild steel may be used for a structural member before a higher notch toughness grade is required. For example if Grade EH plate were being used over the midship region in a ship exceeding 250 m in length the requirements would be as shown in Table 22.2.

TABLE 22.2

Use of grade EH steel in tankers

Location	*Thickness*
Stringer plate, sheerstrake, rounded gunwale.	Greater than 20 mm
Bilge strake, deck strake in way of longitudinal bulkhead.	Greater than 30 mm
Main deck plating, bottom plating, keel, upper strake of longitudinal bulkead.	Greater than 40 mm

Table 22.2 should be compared with Table 22.1

CORROSION CONTROL Where approved corrosion control systems are fitted within the tank spaces a reduction in thickness of 10 per cent is allowed on internal tank members, protected on both sides, i.e. bulkheads, transverses, cross ties, and transverse framing. For tank boundary members, i.e. deck, shell and bottom plating, and longitudinal and centre girders, a reduction of 5 per cent is permitted. Where the corrosion control systems consist of anodes securely fitted in the tanks, aluminium and aluminium alloy anodes are only permitted in locations where the potential energy is less than 28 kg.m, and magnesium anodes are permitted only in clean water ballast tanks. They present a fire hazard, should they cause sparks on falling against steel within an oil tank.

Construction in Tank Spaces

Ocean-going tankers have a longitudinally framed bottom shell and deck through the tank spaces. The side shell may however be either longitudinally framed or transversely framed, and the longitudinal bulkheads longitudinally or vertically stiffened in other than the larger tankers. Lloyd's Register generally requires full longitudinal framing once the vessel's length exceeds 150 m.

TRANSVERSE SIDE FRAMING Where transverse framing is adopted in smaller and medium size tankers the frames are supported by horizontal stringers (Figure 22.2), and the numbers of stringers depends on the depth of the ship. At the ends of the side frames bracket connections are made, the lower bracket covering the round of bilge and extending to the adjacent bottom longitudinal clear of the transverse. At the upper end the bracket connection is to the underside of deck clear of transverses, and bracket connections are also arranged at the stringers.

LONGITUDINAL FRAMING Deck and bottom longitudinals have the greatest scantlings since they are stiffening the more highly stressed flanges of the hull girder. At the side shell the upper longitudinals have the least scantlings, and a uniform increase in size occurs down the side shell until the bilge is reached. The bilge longitudinal size then approaches that of the bottom shell. An important feature of the longitudinal framing is that continuity of strength is maintained, particularly at the bulkheads forming the ends of the tanks. This feature is increasingly important as the ship length is extended, the bottom and deck longitudinals being continuous through the bulkhead where the ship length is excessive, unless an alternative arrangement is permitted by the classification society (*see* Figure 22.4). Higher tensile steel longitudinals are to be continuous irrespective of ship length.

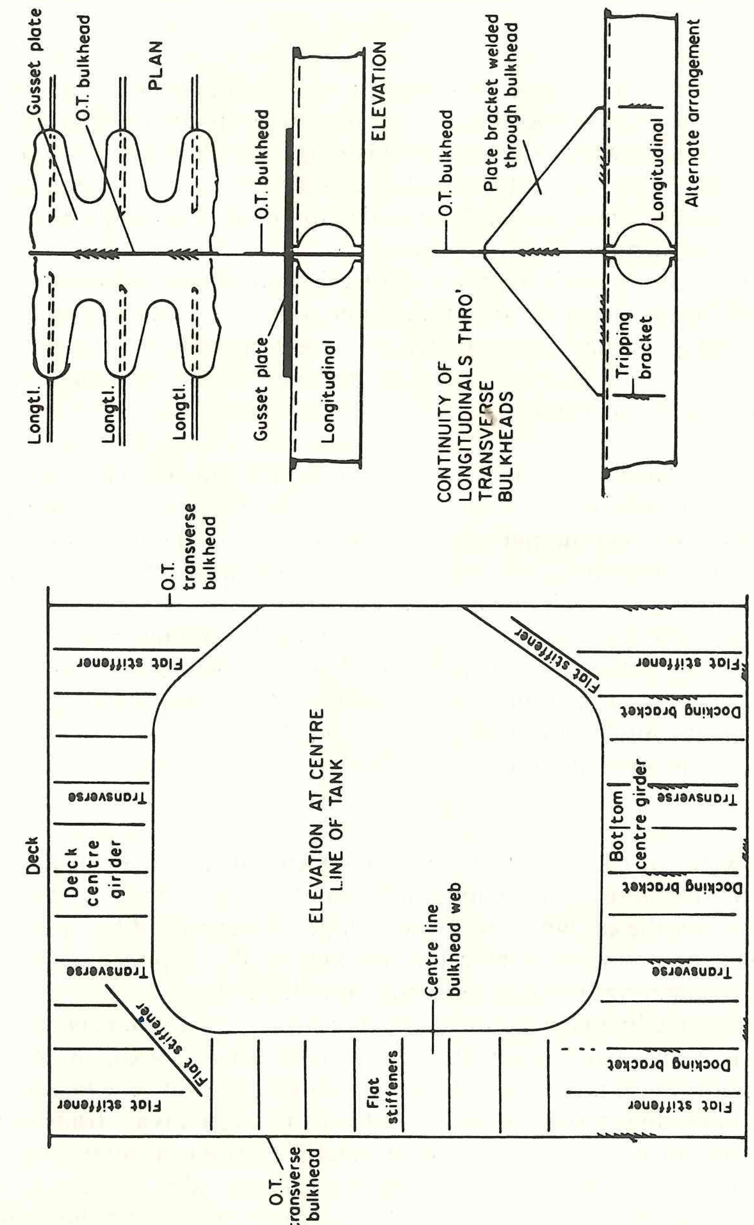


FIGURE 22.4 Longitudinal framing of oil tankers

The longitudinals can be offset bulb plates which may be built up to give the required scantling on large ships. It is not however uncommon to find on many tankers longitudinals having a web and symmetrical flat plate flange.

BOTTOM, SIDE, AND DECK TRANSVERSES To support the longitudinal framing at the deck and bottom shell, transverse webs are fitted at regular intervals. Similarly where the side shell is longitudinally framed a vertical transverse web is arranged at the shell. Between the transverse bulkheads the transverse webs may be evenly spaced at intervals of say 3 m on smaller vessels to 5 m or more on larger vessels.

Transverses are as a rule built of a plate web, and heavier flat face bar the depth being adequate to allow sufficient material abreast the slots through which the longitudinals pass. In way of the longitudinals flat vertical stiffeners are fitted, and horizontal stiffeners may be provided if the transverse depth is excessive.

CROSS TIES Horizontal cross ties are introduced in the wing tanks to connect the vertical webs at the ship's side and longitudinal bulkhead, where these are longitudinally framed (Figure 22.3). The cross ties are designed to stiffen the tank side boundary bulkhead structure against transverse distortion under liquid pressure.

Two or three horizontal cross ties are provided depending on the vessel's depth, but diagonal cross ties may be fitted and will be found on a number of ships. The cross tie is often simply a face plate, vertically stiffened if very deep, and horizontally stiffened to prevent buckling and distortion in that direction. At its ends the cross tie is bracketed to the vertical transverse webs.

BOTTOM AND DECK GIRDERS Stiffening arrangements at the bottom shall require for ships with two longitudinal bulkheads either a deep centre girder between the oiltight transverse bulkheads supported by up to five transverses, or a smaller centre line docking girder supporting bottom transverses spanning between longitudinal bulkheads.

Bottom centre line girders are supported by stiffened brackets midway between the transverses, which are often referred to as 'docking brackets'. These support the centre line girder which constitutes, with the heavy keel plate, the immediate structure through which docking loads are transmitted when the vessel is placed on the keel blocks. Further stiffening for the centre line girder, and also for other girders, is provided by vertical flat stiffeners. At the transverse oiltight bulkhead the bottom centre line girder will be faired into a vertical centre line web.

The deck also has a continuous or intercostal centre line girder which

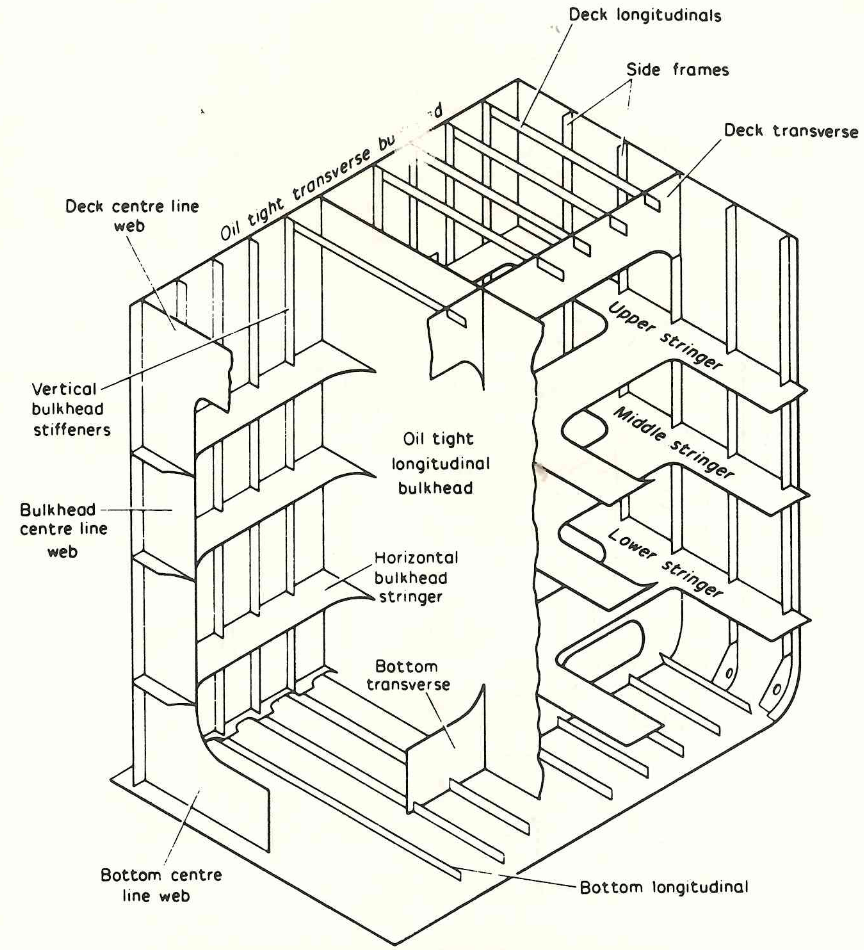


FIGURE 22.5 Compositely framed oil tanker

together with the bottom centre girder and vertical bulkhead web forms a continuous ring of material on the ship's centre line (Figure 22.4).

Bulkheads

Bulkhead spacing throughout the cargo tank space is determined by the permissible length of cargo tanks. The length of wing tanks is not to exceed whichever is the greater of 10 m or 15 per cent of the ship's loadline length where only a centre line bulkhead is fitted or 20 per cent of the ship's load line length where two or three longitudinal bulkheads are fitted. The centre

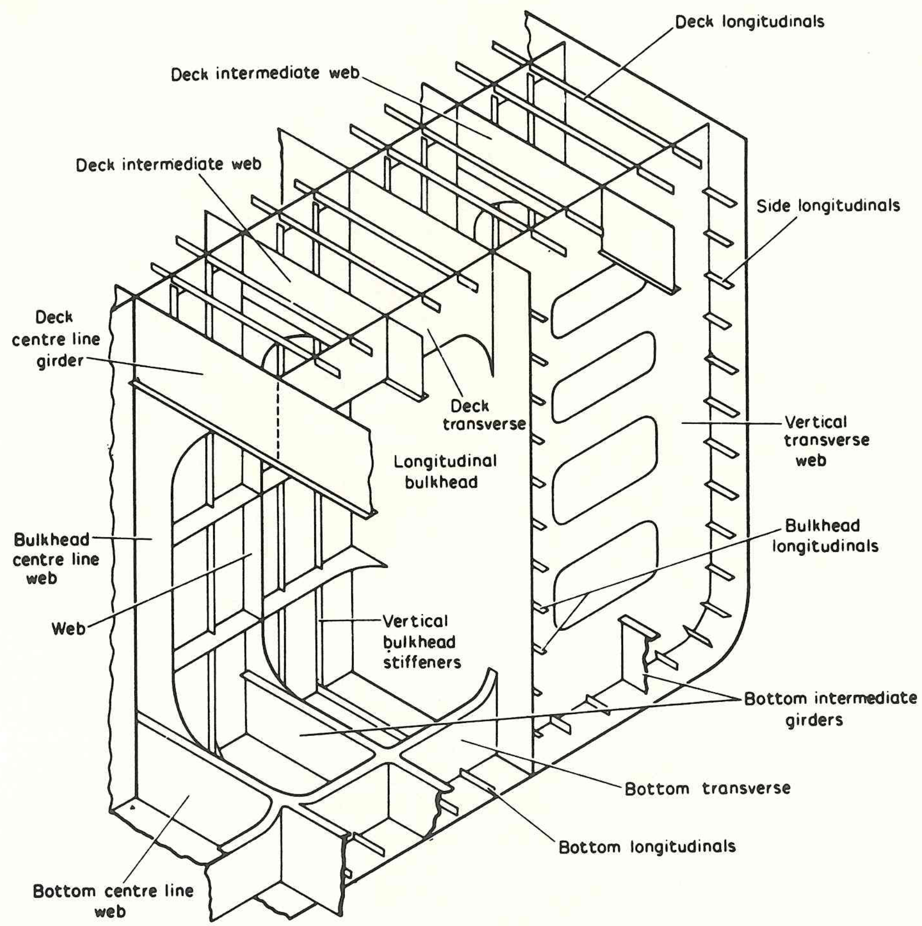


FIGURE 22.6 Longitudinally framed oil tanker

line tanks may have the same maximum lengths provided the width of wing tank is greater than 20 per cent of the ship's beam. A lesser length of centre tank is permitted if the wing tank width is less than 20 per cent of the ship's beam. If the longitudinal bulkheads are perforated the maximum tank lengths are 10 m or 10 per cent of the ship's loadline length, whichever is greater. Where a deep bottom centre line girder is fitted as opposed to a smaller centre line docking girder the spacing of transverse bulkheads is not to exceed 10 per cent of the ship's loadline length or 15 m whichever is the greater. A wash bulkhead may be fitted at mid-tank length for this purpose. Cofferdams, which may be formed with two adjacent oiltight transverse bulkheads at least 760 mm apart, are required at the ends of the cargo space. However in many cases a pump room is fitted at the after end of the

cargo space (also forward on some products carriers), and a ballast tank is fitted at the forward end, each of these compartments being accepted in lieu of a cofferdam. A cofferdam is also provided between any accommodation and oil cargo tanks.

Construction of the transverse bulkheads is similar to that in other ships, the bulkhead being oiltight. Vertical stiffeners are fitted, or corrugated plating is provided with the corrugations running either vertically or horizontally. Horizontal stringers support the vertical stiffeners and corrugations, and vertical webs support any horizontal corrugations. Further support is provided by the vertical centre line web which is as a rule deeper on one side of the bulkhead than on the other, unless the tank is very long and the web may then be symmetrical either side of the bulkhead.

The two longitudinal bulkheads which are oiltight may be conventionally stiffened or corrugated with the corrugations running horizontally. Conventional stiffening is arranged vertically where the side framing is vertical, and arranged longitudinally when the side is longitudinally framed. Vertical webs are fitted to the longitudinal bulkhead when this is corrugated or longitudinally framed. Corrugated longitudinal bulkheads are only permitted in ships of less than 200 m in length.

Hatchways

Oiltight hatchways provide at the exposed deck access to the tank spaces. The openings for these are kept as small as possible, and the corners are well rounded, circular openings being not uncommon. Coamings provided for the openings should be of steel and at least 600 mm high, and suitably fastened steel or other approved material covers are fitted (*see* Figure 23.7). Patent oiltight hatches are available and approved with both steel and fibreglass covers.

Access to the cofferdams and water ballast tanks may be by similar hatches in the deck, or alternatively a watertight manhole may be fitted with a cover of suitable thickness. Other openings are provided in the deck for ullage plugs and tank cleaning, these being on the open deck, and not within enclosed deck spaces.

Testing Tanks

Each cargo tank and cofferdam may be tested separately when complete by filling the tank with water to a head 2.45 m above the highest point of the tank excluding the hatchways, and by filling the cofferdam to the top of the hatch. Water testing on the building berth or dry dock may be undesirable owing to the size of flooded tanks which gives rise to large stresses on the

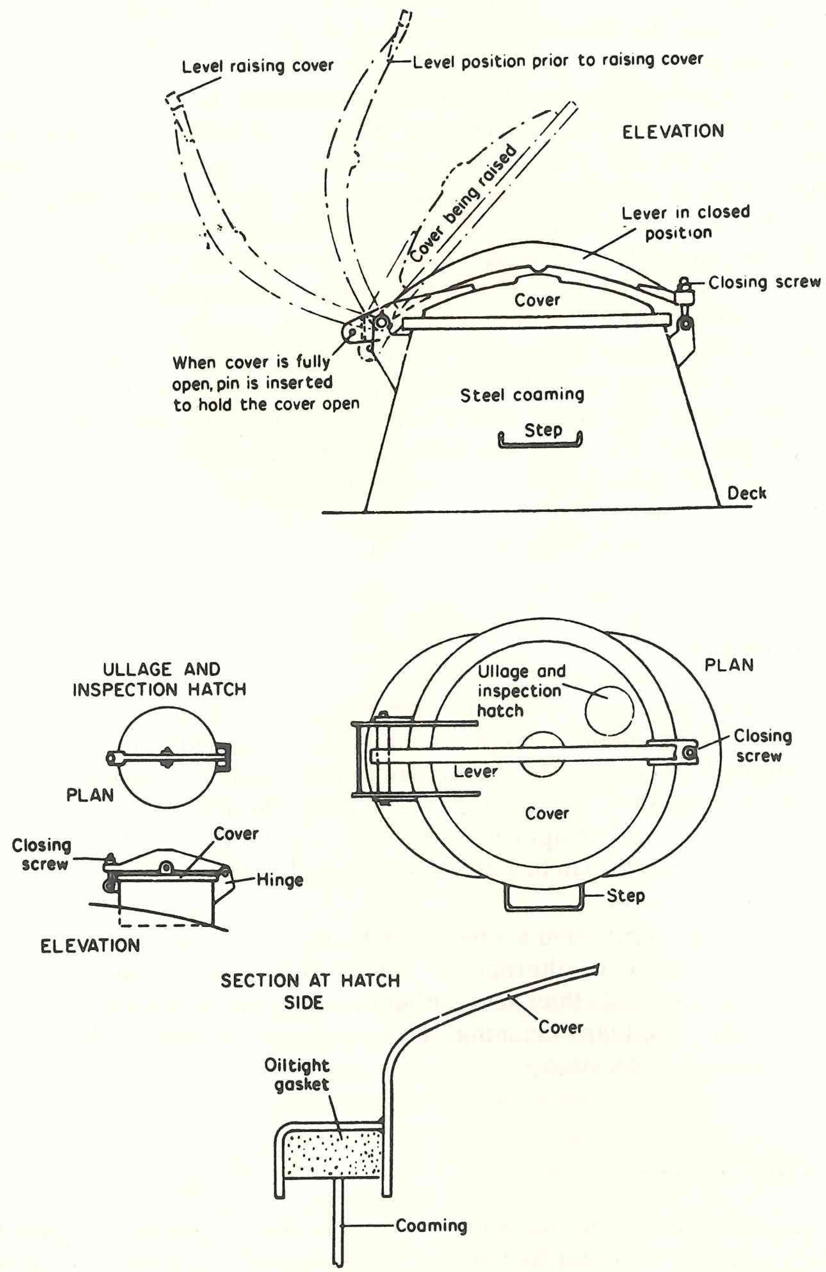


FIGURE 22.7 ASCA—tank hatch cover (Type 2)

supporting material and structure. Testing afloat is therefore permitted, each tank being filled separately until about half the tanks are full when the bottom and lower side shell in the empty tanks are examined. Water is then transferred to the empty tanks, and the remainder of the bottom and side shell is inspected. This testing may take place after the application of protective coatings, provided that welds have been carefully examined beforehand.

In practice a combination of a structural water test, and air leak test is often used. The air leak test is carried out on the building berth, the tanks being subject to an air pressure similar to that required for testing double bottom tanks. A water pressure test is carried out on one centre tank and two wing tanks selected by the surveyors.

Clean water ballast tanks are tested in the same manner as the cargo tanks, but bunkers and deep tank test requirements are similar to those in dry cargo ships, i.e. a head of water 2.45 m above the crown of the tank is applied. Any bulkhead not forming a tank boundary is hose tested.

Fore End Structure

Forward of the tank space deep tanks may be fitted. Framing throughout this space and the fore peak may be transverse, longitudinal, or a combination of both.

DEEP TANK If transverse framing is adopted forward floors are fitted at every frame space in conjunction with a centre line girder or centre line bulkhead and intercostal side girders not more than three times the transverse frame spacing apart. If longitudinal bulkheads are fitted port and starboard in the cargo tanks these may be extended to the fore side of the deep tank in lieu of a centre line bulkhead. Above the floors the transverse frames are supported by stringers spaced not more than 5 m apart which are either supported by web frames connected to deep beams to form a vertical ring frame, or connected to longitudinal stringers on the transverse bulkheads to form horizontal ring frames. Alternatively, in narrow tanks perforated flats may be fitted at 5 m spacings.

Longitudinally framed deep tanks are supported by side transverses five frame spaces apart. Where the depth of the tank exceeds 16 m the side transverses, also the web frames in a transversely framed tank, either have one or more deep stringers fitted, cross ties, or perforated flats with deep beams in way of the transverses or webs.

A longitudinal bulkhead generally must be provided if the tank width exceeds 50 per cent of the ship's beam and may solely be a wash bulkhead on the centre line. Where the breadth of tank exceeds 70 per cent of the ship's beam, at least one solid bulkhead on the centre line is recommended.

FOREPEAK A transversely framed forepeak has a similar construction to that of a conventional cargo ship and includes the usual panting arrangements (*see* Chapter 20). If the forepeak is longitudinally framed the side transverses have a maximum spacing of between 2.5 m and 3.5 m depending on length of ship, and are connected to transverses arranged under the decks in line with the side transverses. Forecastles have web frames to support any longitudinal side framing, and the forecastle deck will be supported by pillars at its forward end.

After End Structure

The machinery is arranged aft in ocean-going tankers, and a transversely framed double bottom structure is adopted in way of the machinery space. Constructional details of this double bottom are similar to those of the conventional dry cargo ship with floors at each frame space, additional side girders, and the engine seating integral with the bottom stiffening members.

Transverse or longitudinal side and deck framing may be adopted in way of the engine room and aft of this space. If transversely framed, web frames are fitted not more than five frame spaces apart below the lowest deck and may be supported by side stringers. The web frames may be extended into the poop; and where an all-houses aft arrangement is adopted they may also extend into the superstructure. Similar transverse webs are introduced to support any longitudinal framing adopted in a machinery space. Transverse webs have the same spacing as web frames except in tween decks above the aft peak where the maximum spacing is four frame spaces.

The aft peak and stern construction follows that of other merchant ship types, a centre line bulkhead being provided in the aft peak.

Superstructures

To permit the assignment of deeper freeboards for oil tankers, the conditions of assignment of load line (*see* Chapter 31) stipulate the requirements for protective housings enclosing openings in the freeboard and other decks. They also require provision of a forecastle covering 7 per cent of the ship's length forward.

Structurally the houses are similar to those of other vessels, special attention being paid to the discontinuities in way of breaks at the ends of the houses. Particular attention must be paid to any endings in the midship length of the hull. As the machinery is aft the poop front merits special attention, and is in fact structurally similar to the bridge front, since its integrity is essential.

A particular feature of the tanker with its lower freeboard is the requirement for an access gangway at the level of the first tier of superstructure between accommodation spaces. This is still often found on vessels with all accommodation aft, although the regulations would permit a rail or similar safety arrangement at the deck level. The provision of a gangway in the latter case is at the owner's wish, and is an added safety factor at greater initial cost, requiring additional maintenance. Another feature is the absence of bulwarks on the main decks, the regulations requiring the provision of open rails over at least half the length of the wells, which are often awash in heavy weather.

Chemical Tankers

The structural configuration and arrangements of chemical tankers often are basically similar to those described for oil tankers. For some chemical tankers, however, arrangements may also include a double bottom in way of cargo tanks, a double skin construction or deck cofferdams or any combination of these. Certain more hazardous cargoes may also require tanks which are separate from the hull structure or are to be so installed that the tank structure is not subject to major hull stresses. In the latter cases the scantlings and arrangements may be similar to ships carrying liquefied gases described in Chapter 23.

Further Reading

'A golden gamble', *The Naval Architect*, February, 1986.

'New product tanker borrows LNG carrier tank technology', Fairplay, 2nd April, 1987.

23
Liquefied Gas Carriers

A large number of ships are in service which are designed to carry gasses in liquid form in bulk. Most of these ships are designed to carry liquefied petroleum gas (LPG) whilst a much smaller number of ships are designed to carry liquefied natural gas (LNG).

Liquefied Petroleum Gas (LPG)

LPG is the name originally given by the oil industry to a mixture of petroleum hydrocarbons principally propane and butane and mixtures of the two. LPG is used as a clean fuel for domestic and industrial purposes. These gases may be converted to the liquid form and transported in one of three conditions:

(1) Solely under pressure at ambient temperature.
(2) Fully refrigerated at their boiling point (−30°C to −48°C).
(3) Semi-refrigerated at reduced temperature and elevated pressure.

A number of other gases with similar physical properties such as ammonia, propylene and ethylene are commonly shipped on LPG carriers. These gases are liquefied and transported in the same conditions as LPG except ethylene which boils at a much lower temperature (−104°C) and which is therefore carried in the fully refrigerated or semi-refrigerated condition.

Liquefied Natural Gas (LNG)

LNG is natural gas from which most of the impurities such as sulphur and carbon dioxide have been removed. It is cooled to or near its boiling point of −165°C at or near atmospheric pressure and is transported in this form as predominantly liquid methane. Methane has a critical pressure of 45.6 kg/cm^2 at a critical temperature of −82.5°C, i.e. the pressure and temperature above which liquefication cannot occur, so that methane can only be liquefied by pressure at very low temperatures.

The IMO International Gas Carrier Code

In 1975 the 9th Assembly of IMO adopted the code for the construction and equipment of ships carrying liquefied gases in bulk, A.328 (IX) which provides international standards for ships which transport liquefied gases in bulk. It became mandatory in 1986 and is generally referred to as the IMO International Gas Carrier Code. The requirements of this code are incorporated in the rules for ships carrying liquefied gases published by Lloyd's and other classification societies.

The code covers damage limitations to cargo tanks and ship survival in the event of collision or grounding, ship arrangements for safety, cargo containment and handling, materials of construction, environmental controls, fire protection, use of cargo as fuel etc. Of particular interest in the context of ship construction is the section on cargo containment which defines the basic cargo container types and indicates if a secondary barrier is required, i.e. a lining outside the cargo containment which protects the ships hull structure from the embrittling effect of the low temperature should cargo leak from the primary tank structure. The cargo containment types are described below.

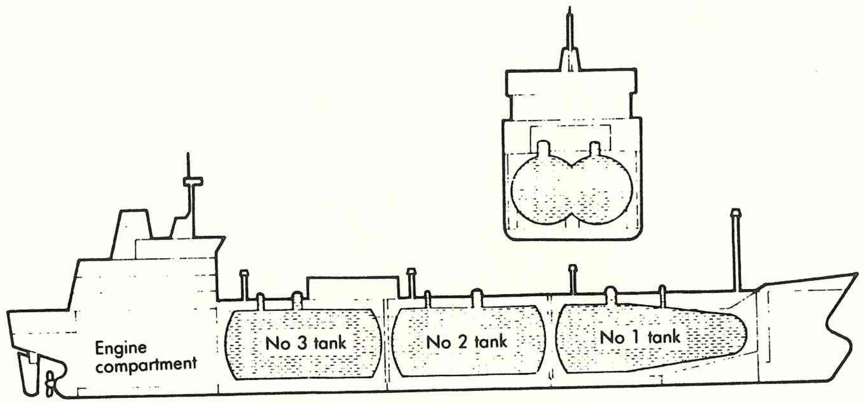
INTEGRAL TANKS Those tanks which form a structural part of the ships hull and are influenced in the same manner and by the same loads which stress the adjacent hull structure. These are used for the carriage of LPG at or near atmospheric conditions, butane for example, where no provision for thermal expansion and contraction of the tank is necessary.

MEMBRANE TANKS These are non-self-supporting tanks consisting of a thin layer (membrane) supported through insulation by the adjacent hull structure. The membrane is designed in such a way that thermal and other expansion or contraction is compensated for without undue stressing of the membrane. Membrane tanks are primarily used for LNG cargoes (*see* Figure 23.4).

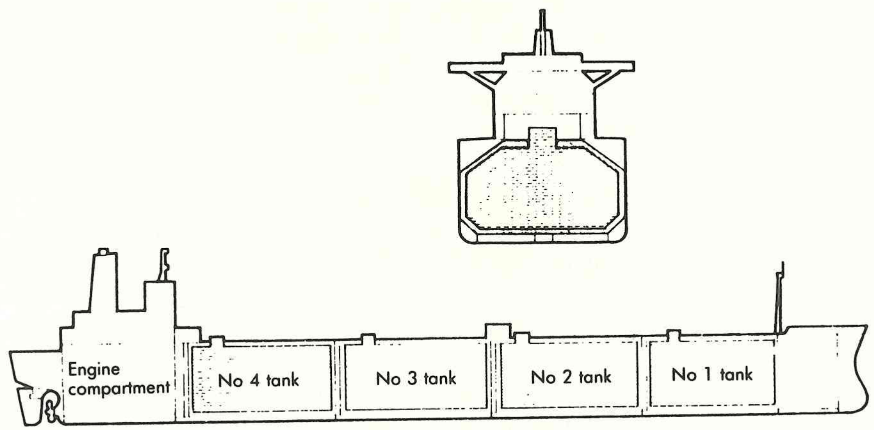
SEMI-MEMBRANE TANKS These are non-self-supporting tanks in the load condition. The flat portions of the tank are supported, transferring the weight and dynamic forces through the hull, but the rounded corners and edges are not supported so that tank expansion and contraction is accommodated. Such tanks were developed for the carriage of LNG, but have been used for a few LPG ships.

INDEPENDENT TANKS These are self supporting and independent of the hull. There are three types:

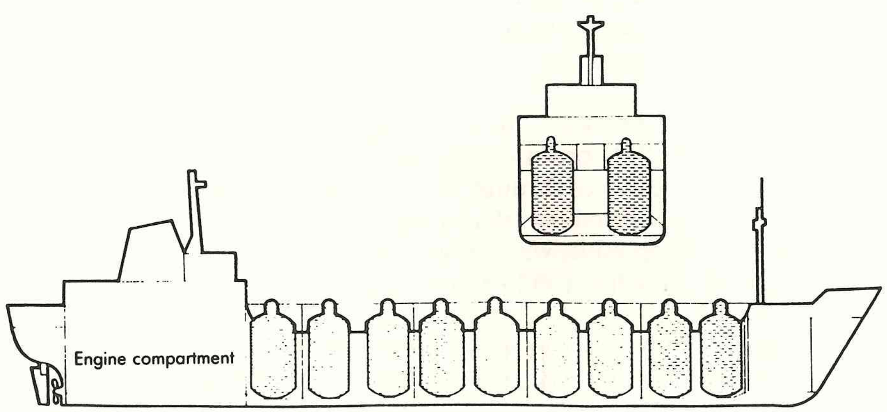
'Type A', which are designed primarily using standard traditional



5,200 cu. m. semi-pressurized/fully refrigerated LPG/NH_3 carrier



73,200 cu. m. fully refrigerated LPG carrier



4,000 cu. m. fully pressurized LPG carrier

FIGURE 23.1

methods of ship-structural analysis. LPG at or near atmospheric pressure or LNG may be carried in such tanks (*see* Figure 23.2).

'Type B', which are designed using more sophisticated analytical tools and methods to determine stress levels, fatigue life and crack propogation characteristics. The overall design concept of these tanks is based on the so-called 'crack detection before failure principle' which permits their use with a reduced secondary barrier (*see* Figure 23.3). LNG is normally carried in such tanks.

'Type C', which are designed as pressure vessels, the dominant design criteria being the vapour pressure. Normally used for LPG and occasionally ethylene.

INTERNAL INSULATION TANKS Which are non-self-supporting and consist of thermal insulation materials, the inner surface of which is exposed to the cargo supported by the adjacent inner hull or an independent tank. There are two types:

'Type 1', where the insulation or combination of insulation and one or more liners act only as the primary barrier. The inner hull or independent tank forms the secondary barrier.

'Type 2', where the insulation or combination of insulation and one or more liners act as both the primary and secondary barrier and are clearly distinguishable as such.

The liners on their own do not act as liquid barriers and therefore differ from membranes. These tanks are a later addition to the Code and Type 1 is known to have been used for the carriage of LPG.

SECONDARY BARRIER PROTECTION The requirements for secondary barrier protection are given in Table 23.1.

Liquefied Petroleum Gas Ships

Ships carrying LPG are categorised by their cargo containment system.

FULLY PRESSURISED TANKS The capacity of fully pressurised ships is usually less than 2000 m^3 of propane, butane or anhydrous ammonia carried in two to six uninsulated horizontal cylindrical pressure vessels arranged below or partly below deck. These independent tanks of Type C are normally designed for working pressures up to 17.5 kg/cm^2 which corresponds to the vapour pressure of propane at 45°C, the maximum ambient temperature the vessel is likely to operate in. The tanks can be

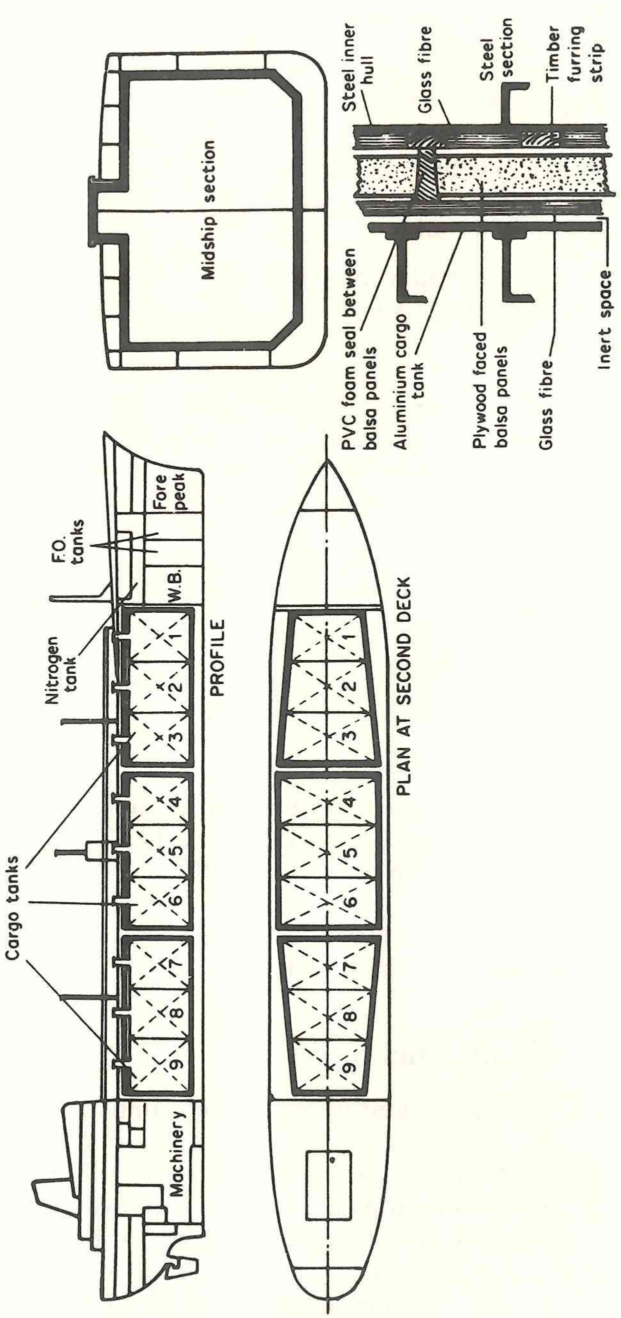


FIGURE 23.2 Liquid methane carrier

TABLE 23.1

Basic tank type	*Cargo temperature at atmospheric pressure*	*−10°C and above*	*Below −10°C Down to −55°C*	*Below −55°C*
		No secondary barrier required	Hull may act as secondary barrier	Separate secondary barrier required
Integral			Tank type not normally allowed	
Membrane			Complete secondary barrier	
Semi-membrane			Complete secondary barrier	
Independent				
Type A			Complete secondary barrier	
Type B			Partial secondary barrier	
Type C			No secondary barrier	
Internal insulation				
Type 1			Complete secondary barrier	
Type 2			Complete secondary barrier incorporated	

constructed from ordinary grades of steel, are mounted in cradle-shaped foundations, and if below deck are fitted with domes protruding through the deck to which are fitted all connections. Wash bulkheads are fitted in very long tanks. The shape of the tanks generally prevents good utilisation of the underdeck space.

SEMI-PRESSURISED (OR SEMI-REFRIGERATED) TANKS The capacity of semi-pressurised ships ranges up to about 5000 m^3 the cargoes carried being similar to fully-pressurised ships. The independent Type C tanks are generally constructed of ordinary grades of steel suitable for a temperature of −5°C and are designed for a maximum pressure of about 8 kg/cm^2. The outer surface of the tank is insulated and refrigeration or reliquification plant cools the cargo and maintains the working pressure. Cargo tanks are often horizontal cylinders mounted on two saddle supports and many designs (*see* Figure 23.1) incorporate bio-lobe tanks to better utilise the underdeck space and improve payload.

FULLY-REFRIGERATED TANKS The capacity of fully-refrigerated ships ranges from 10,000 m^3 to 100.000 m^3 the smaller ships in the range being multi-product carriers whilst the larger vessels tend to be single product carriers on a permanent route. Tanks fall almost exclusively into the prismatic, independent Type A category with tops sloped to reduce free surface and bottom corners sloped to suit the bilge structure. In most cases they are subdivided along the centreline by a liquid-tight bulkhead which extends to the underside of the dome projecting through the deck which is

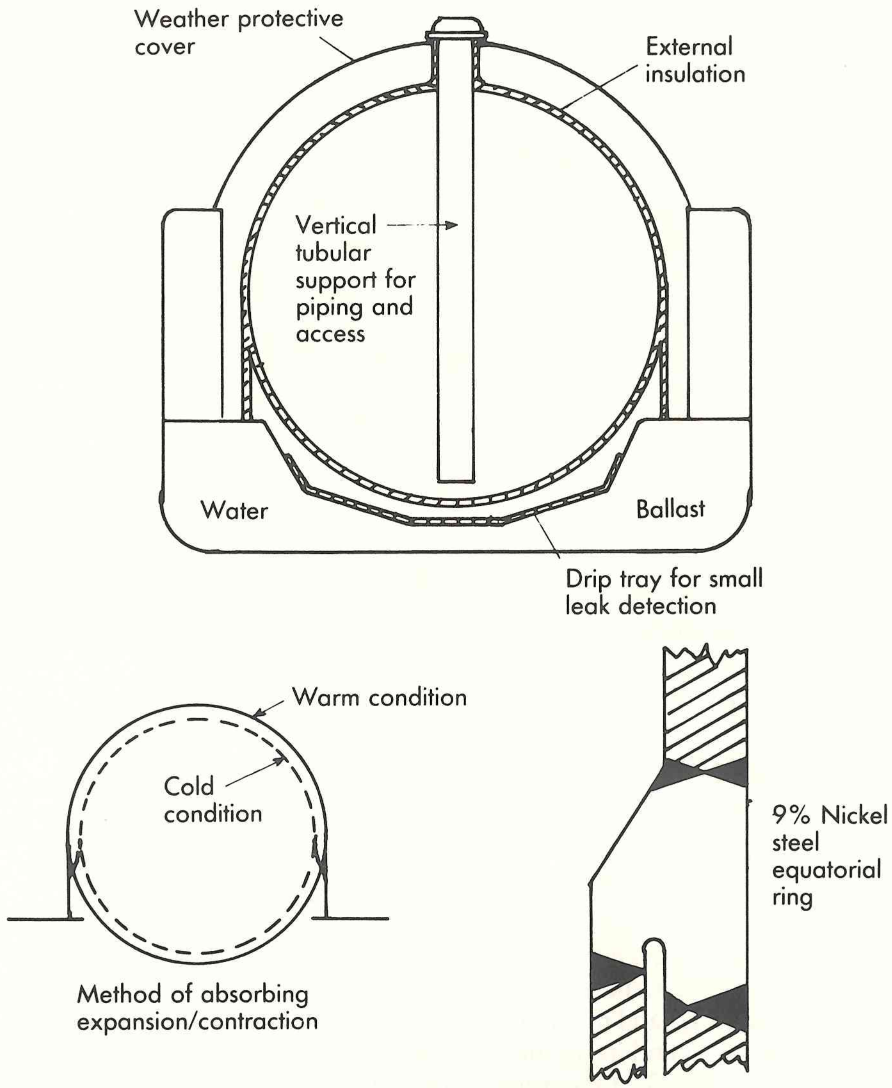


FIGURE 23.3 Kvaerner-Moss spherical tank

used for access and piping connections etc. The tanks sit on insulated bearing blocks so that surfaces are accessible for inspection and are located by anti-roll and pitch keys in such a manner that expansion and contraction can take place relative to the ships structure. Anti-flotation chocks are provided to prevent the tank floating off the bearings if the hold were flooded. Tanks are constructed of a notch ductile steel for the normal minimum operating temperature of −43°C the boiling point of propane.

The ship has a double hull extending over the bottom and bilge area, the secondary barrier being provided by low temperature (notch ductile) steel at the inner bottom, sloping bilge tank, part side shell, and sloping bottom of topside tank. Transverse bulkheads may be single or double plate (cofferdam) type between cargo holds. Insulation can be either on the tank or the secondary barrier for this type of ship.

Liquefied Natural Gas Ships

There are over twenty approved patent designs of containment vessel for LNG ships, the majority of which fall into the membrane or independent tank categories. Those types which have been or are more commonly found in service are described below. A feature of LNG ships is their double hull construction within which are fitted the cargo tanks and the secondary barrier system.

INDEPENDENT TYPE A TANKS Early LNG ships such as the 'Methane Princess' and 'Methane Progress' were fitted with self-supporting tanks of aluminium alloy having centreline bulkheads (*see* Figure 23.2). The balsa wood insulation system was attached to the inner hull (secondary barrier) and each insulated hold contained three tanks. Later vessels built with tanks of this category have adopted a prismatic tank design.

INDEPENDENT TYPE B TANKS The Kvaerner-Moss group have designed an independent Type B tank containment system which has been well accepted and is installed in a good number of LNG ships. Tanks consist of either an aluminium alloy or 9 per cent nickel steel sphere welded to a vertical cylindrical skirt of the same material which is its only connection to the hull (*see* Figure 23.3). The sphere expands and contracts freely all movements being compensated for in the top half of the skirt. The outer surface of the sphere and part of the skirt is covered with a polyurethane foam insulation. The system is fitted with a partial secondary barrier consisting of a drip tray under the tank and splash shields at the sides. In accordance with its Type B notation, each tank is provided with sensors which will detect leakage and allow timely repairs before any crack reaches critical proportions.

Spherical tanks make poor use of available cargo space, a substantial hull being required to house, say, 5 large spheres providing a cargo-carrying capacity of 125 000 m³. Above deck the spheres are protected by substantial weather covers.

MEMBRANE TANKS Two common membrane tank designs are those developed and associated with the French companies Gaz Transport and

Technigaz. The Gaz Transport system uses a 36 per cent nickel-iron alloy called 'Invar' for both the primary and secondary barriers. Invar has a very low coefficient of thermal expansion which makes any corrugations in the tank structure unnecessary. The Invar sheet membrane used is only 0.5 to 0.7 mm thick which makes for a very light structure. Insulation consists of plywood boxes filled with perlite (*see* Figure 23.4).

The Technigaz system utilises a stainless steel membrane system where tanks are constructed of corrugated sheet in such a way that each sheet is free to contract and expand independently of the adjacent sheet. This forms the inner primary barrier and a balsa insulation and secondary barrier similar to that fitted to the Independent Type A tanks described earlier is fitted (*see* Figure 23.4).

SEMI-MEMBRANE TYPE B TANKS The Japanese ship builder IHI has designed a semi-membrane, Type B tank to carry LNG cargoes which has been used in a number of LPG carriers. The rectangular tank consists of plane unstiffened walls with moderately sloped roof and rounded edges and corners which are not supported so that expansion and contraction is accommodated. The tank is of 15 to 25 mm thick aluminium alloy supported on a layer of PVC insulation and the partial secondary barrier is made of plywood 25 mm thick integral with a PVC foam insulation.

General Arrangement of Gas Carriers

Gas carriers have a similar overall arrangement to tankers in that their machinery and accommodation are aft and the cargo containment is spread over the rest of the ship to forward where the forecastle is fitted.

Specific gravity of LPG cargoes can vary from 0.58 to 0.97 whilst LNG ships are often designed for a cargo specific gravity of 0.5 so that a characteristic of LNG ships in particular and most LPG ships is their low draft and high freeboards. Water ballast cannot be carried in the cargo tanks so adequate provision is made for it within the double hull spaces, double bottom, bilge tank, and upper wing tank spaces.

The double hull feature of LNG carriers and many LPG ships is a required safety feature and the tanks of LPG ships which do not have this feature are required to be a minimum distance inboard of the shell.

Fore end and aft end structure is similar to that for other ships. The cargo section is transversely or longitudinally framed depending primarily on size in the same manner as other cargo ships, the inner hull receiving special consideration where it is required to support the containment system.

All gas ships have spaces around the tanks which are monitored for gas leaks and in many ships these spaces are also inerted, an inert gas system being fitted aboard the ship. Liquid gas cargoes are carried under positive

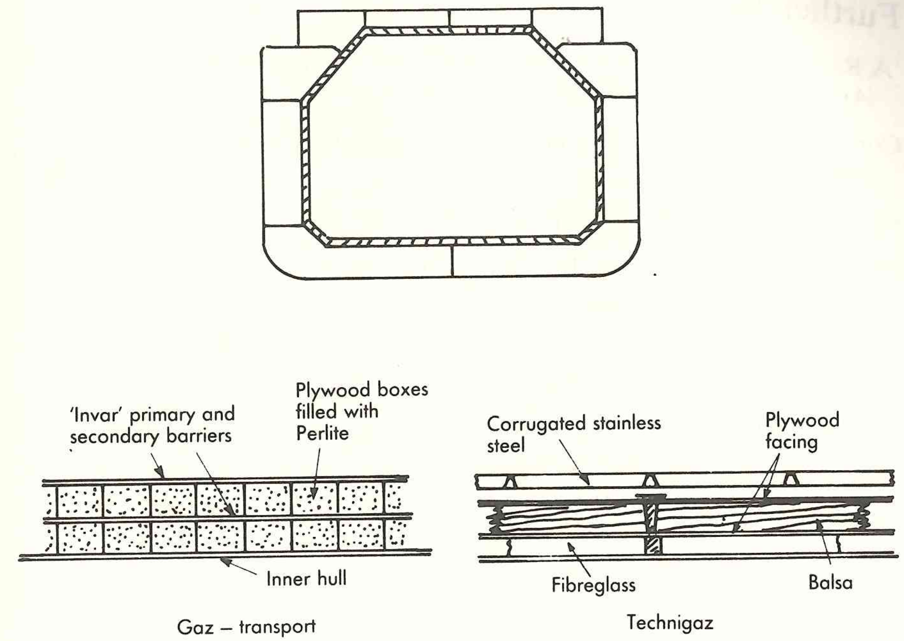


FIGURE 23.4 Membrane systems

pressure at all times so that no air can enter the tanks and create a flammable mixture.

Liquefaction equipment is provided aboard LPG ships, 'boil off' vapour from the tanks due to any heat ingress is drawn into the liquefaction plant and returned to the tank. Boil off vapour from LNG ship tanks can be utilised as a boiler fuel in steam ships, otherwise it is vented to atmosphere, although this is not permitted in many ports, and several other solutions have been developed to overcome this problem.

Lloyd's Classification

For liquefied gas ships Lloyd's Register may assign either one of two classes namely '100A liquefied gas tanker' where the vessel is designed to carry liquefied gases in bulk in integral or membrane tanks, or '100A1 liquefied gas carrier' where the vessel is designed to carry liquefied gases in bulk in independent tanks. Class notations in respect of the type of tanks, names of gases carried, maximum vapour pressure and minimum cargo temperature etc. may be added.

Further Reading

'A Review of LNG Tanker Design and Containment Systems', *The Naval Architect*, October, 1972.

Corlett and Leathard, 'Methane Transportation by Sea', *Trans. R.I.N.A.*, 1960.

Ffooks, 'Gas Carriers', Fairplay Publications Ltd, 1984.

'First LPG Carriers with Internal Polyurethane Insulation', *The Naval Architect*, May, 1977.

'The Design of Tankers for the Carriage of Liquefied Petroleum Gases', *The Naval Architect*, January, 1973.

Thomas 'Whither the LNG Ship' *The Naval Architect*. July, 1975.

Part 6

Outfit

24
Derricks, Masts, and Rigging

When ordering a new ship the shipowner normally specifies the number, safe working load, position, and any special features of the cargo handling derricks to be fitted. The shipbuilder or an outside specialist consultant is then responsible for the detailed design of each derrick rig, together with the various fittings at the derricks and mast. Where patent derricks and masts are fitted the patentee may supply the drawings, etc., to the shipyard, who then build and erect these rigs. Masts, except some patent types, are the responsibility of the shipbuilders, blocks, wire, and usually derrick booms being supplied by an outside manufacturer to the shipyard's specification.

Masts and Sampson Posts

Masts on a general cargo ship may fulfil a number of functions but their prime use in modern ships is to carry and support the derricks used for cargo handling. Single masts are often fitted, but many ships now have various forms of bipod mast which are often more suitable for supporting derricks, although some types can restrict the view from the bridge. Sampson posts are also popular, particularly at the ends of houses, and are often fitted at the other hatches also.

The strength of masts and sampson posts is indicated by the classification societies. As a result of the span loads and derrick boom thrusts, a single mast or post may be considered similar to a built-in cantilever with axial and bending loads. Some torque may also be allowed for where the post has a cross-tree arrangement to an adjacent post. Where shrouds and preventers are fitted these must be allowed for, which makes the calculations somewhat more difficult. In modern ships there is a tendency to simplify the rigging which can restrict cargo handling. Shrouds are often dispensed with and preventers may only be rigged when heavy derricks are used. Each mast or post has adequate scantlings so that they may remain unstayed.

MAST CONSTRUCTION AND STIFFENING Tubular steel sections are commonly used in mast and post construction, the sections being rolled in short lengths and welded in the shipyard. The short lengths may be tapered and are of different plate thickness to allow for the greater stresses experienced at the base of the mast. Where connections are made for fittings such as the gooseneck and a masthead span swivel, doubling or welded reinforcing pads may be provided. To obtain the necessary mast scantlings, excessive doubling or internal stiffeners are rarely found in modern practice, except where a heavier derrick than that for which the mast was originally designed is carried. Higher tensile steels are often used to advantage in mast construction, giving less weight high up in the ship and dispensing with the need for any form of support, without excessive scantlings.

Cross-trees, mast tables, etc., may be fabricated from welded steel plates and sections.

Derrick booms are as a rule welded lengths of seamless tubular steel. The middle length may have a greater diameter to allow for the bending moment, to which the boom is subject in addition to the axial thrust.

At the base of the mast adequate rigidity must be provided, the amount of additional structural stiffening increasing with the size of derricks carried by the mast. Many cargo ships have mast houses into which the masts are built, the house being suitably strengthened. These houses need not be designed to support the mast, the structure being of light scantlings, and the support provided by stiffening in the tweens. Where the house is strengthened the masts or posts generally land on the upper deck, but where heavy derricks are installed the mast may then land on the upper tween deck. Since the derricks and mast are as a rule midway between holds they land over the hold transverse bulkheads which lend further support.

Heavy derrick masts will require extensive stiffening arrangements in the mast house, and also in the tweens, with support for the transverse bulkhead so that the loads are transmitted through the structure to the ship's bottom. Partial longitudinal and transverse bulkheads with deck girders may provide the mast house stiffening. Stiffened plate webs at the ship's centre line in the tweens, and heavier stiffeners on the transverse bulkhead in the hold then provide the additional strengthening below decks (*see* Figure 24.1). Heavy insert plates are fitted in way of the mast at the various decks.

Derrick Rigs

Various forms of derrick rig may be used aboard the cargo ship, the commonest use of the single derrick being as a 'single swinging derrick' (*see* Figure 24.2(a)). Adjacent derrick booms may be used in 'union purchase' (24.2(b)) the booms being fixed in the overboard and inboard positions. Cargo is lifted from the hatch and swung outboard by the operator controlling the winches for the cargo runner. Variations on this rig are often adopted; for example the 'butterfly' rig (Figure 24.2(c)) which is used where cargo is discharged from a hold to both sides of the ship.

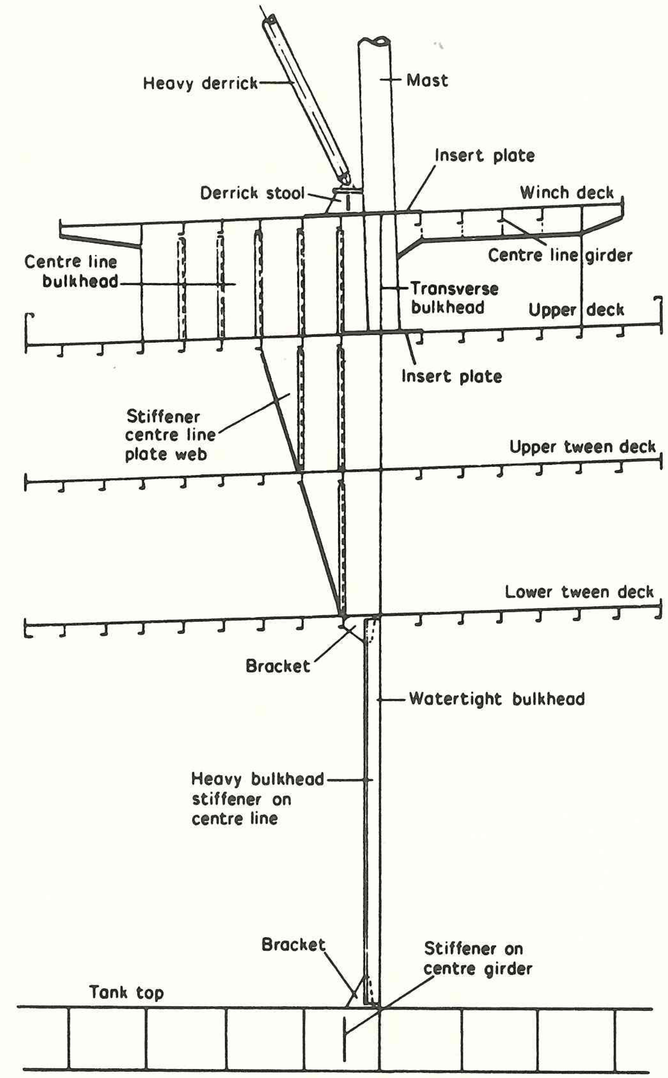


FIGURE 24.1 Stiffening in way of mast and heavy derrick

Where a weight exceeding the safe working load of the derricks is to be lifted the 'yo-yo' rig is sometimes adopted (Figure 24.2(d)). The heads of the derricks are brought together, and a travelling block may be arranged on the cargo runner or a wire connecting the two cargo purchases as illustrated. Both the 'butterfly' and 'yo-yo' rigs give a load pattern similar to the 'union purchase' and 'single swinging derrick' rigs for which calculations are made, but the guy loads with each can be particularly severe.

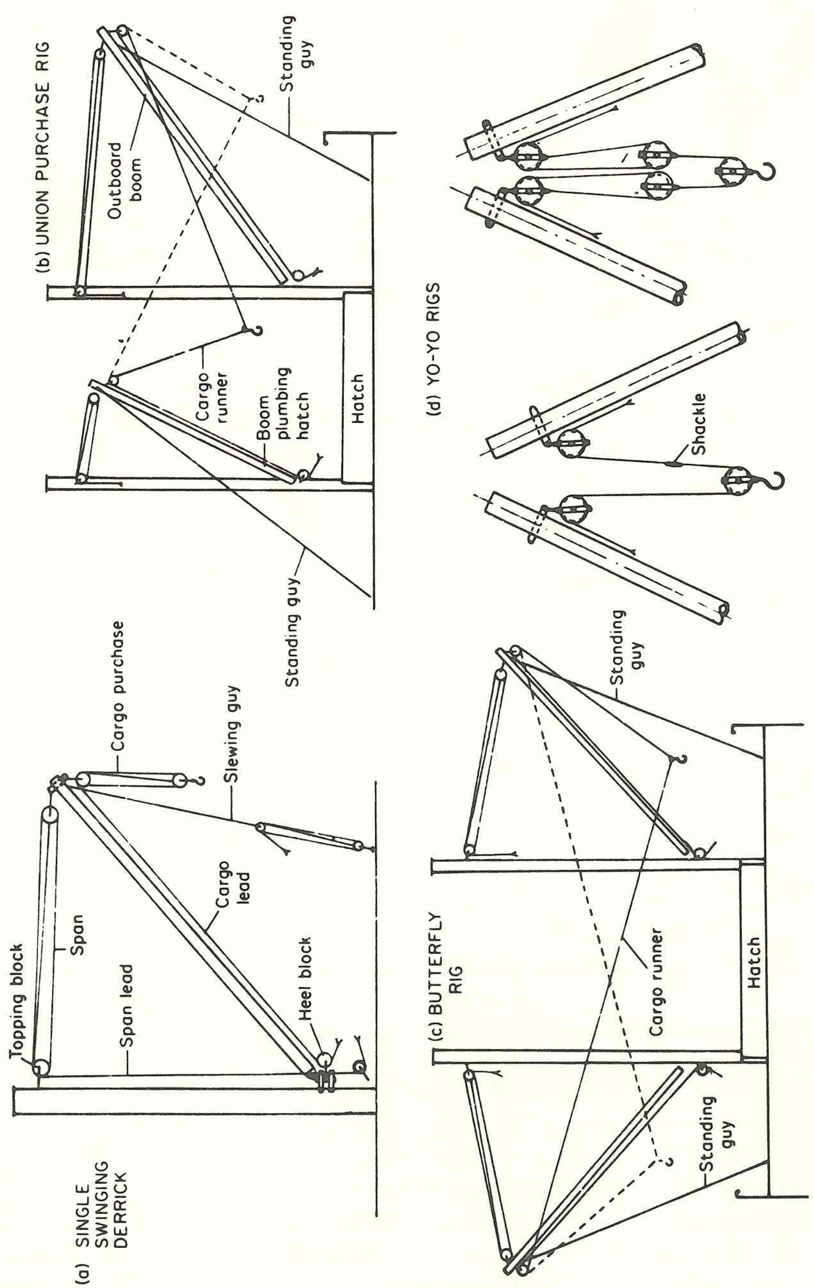


FIGURE 24.2 Derrick rigs

Patent derricks are generally of the single swinging type with some form of powered slewing. The Hallen swinging derrick is shown diagrammatically in Figure 24.3(a). This type of derrick may be installed at the ship's centre line to reach outboard on both sides of the ship and is controlled by a single operator in a manner not unlike the operation of a mechanical crane. As a rule the safe working load of this type of derrick is between 10 and 80 tonnes.

Of particular note in the very heavy lift range is the patent Stülken derrick (Figure 24.3(b)) marketed by Blohm and Voss A.G., which may have a safe working load of between 80 and 300 tonnes. One advantage that this derrick has is its ability to serve two hatches, the boom swinging through an arc between the posts in the fore and aft direction.

FORCES IN DERRICK RIGS The geometry of the derrick rig will to a large extent influence the loads carried by the rig components. Those dimensions which have the greatest influence are the length of boom, the distance between the boom heel and the masthead span connection (height of suspension), and the angle at which the boom is topped.

When the ratio between boom length and height of suspension is increased the boom thrust will be higher; therefore should a long boom be required the height of suspension must be adequate. It is not unusual however for shipowners to object to having posts at the bridge front and if the height of suspension is then restricted there is some limitation on the boom length, which can make working cargo from that position difficult. The angle at which the derrick is topped has no effect on the axial thrust, but the lead from the cargo purchase often increases the thrust as it is led parallel to the boom on all except heavy lift derricks.

Loads carried by the span are dependent on both the ratio of boom length to height of suspension and the angle at which the derrick is topped. The span load is greater at a lower angle to the horizontal, and increases with longer booms for a given suspension height.

To determine these forces simple space and force diagrams may be drawn and the resultant forces determined to give the required wire sizes, block and connection safe working loads, and the thrust experienced by the boom. The horizontal and vertical components of the span load and boom thrust are also used to determine the mast scantlings. Force diagrams are shown for the rig components of the single swinging derrick illustrated in Figure 24.4.

For a safe working load of 15 tonnes or less the forces may be calculated with the derrick at angles of 30° and 70° to the horizontal unless the owner specifies that the derrick is to be used at a lower angle (not less than 15°). At safe working loads greater than 15 tonnes the forces may be calculated at an angle of 45° to the horizontal. The loads on all the blocks except the lower block of a cargo purchase will be the resultant of the two forces to which the

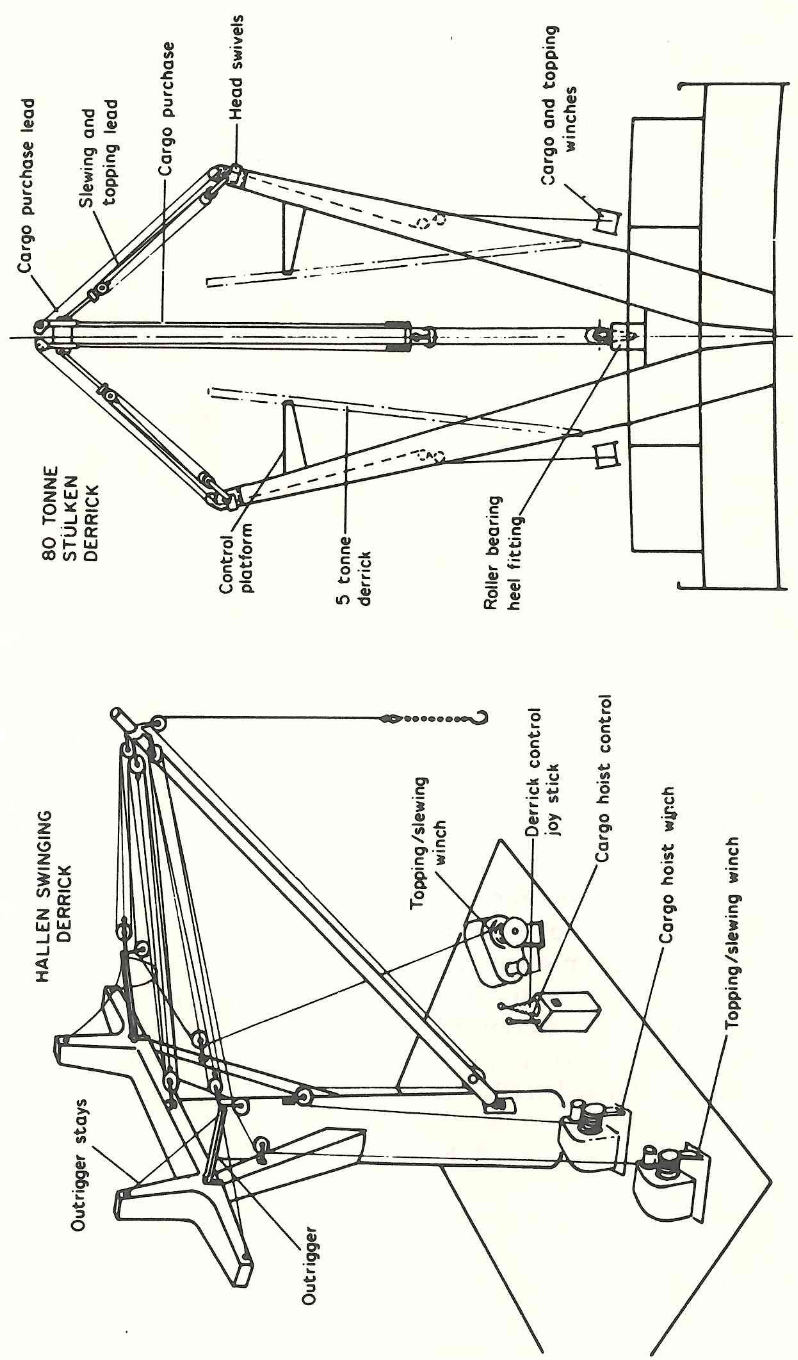


FIGURE 24.3 Patent derricks

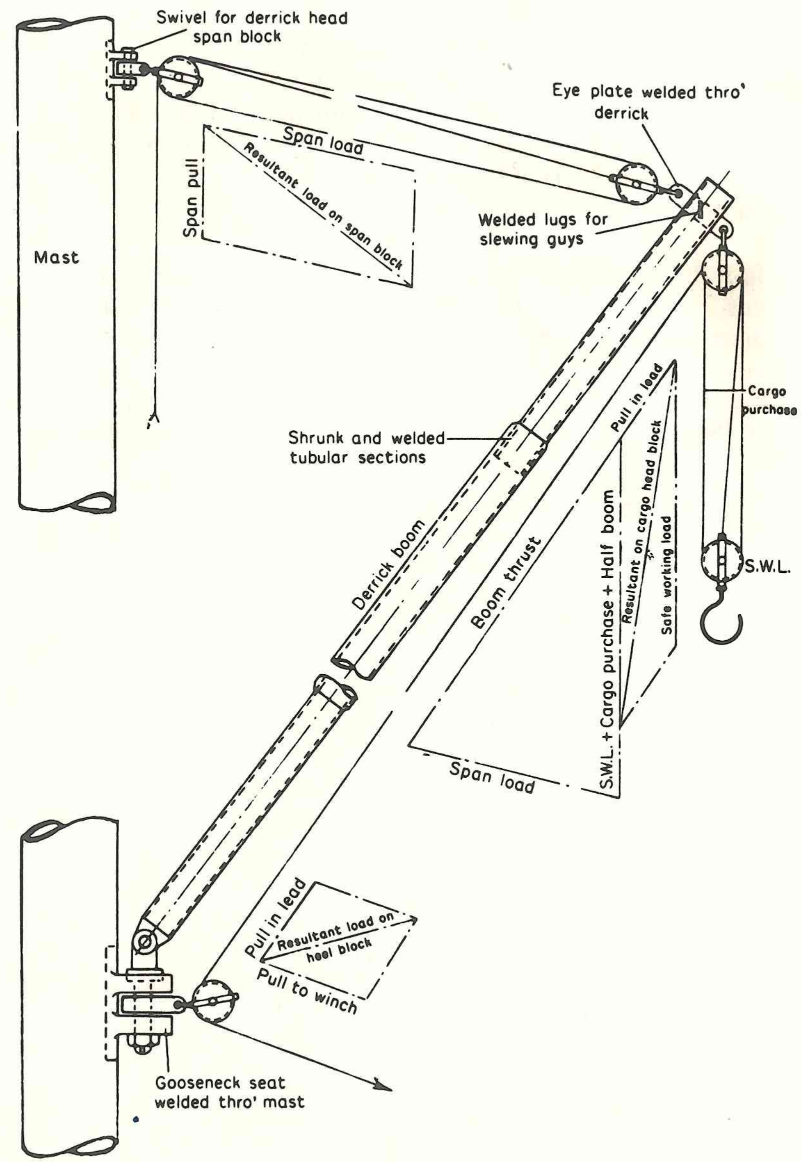


FIGURE 24.4 Forces in single swinging derrick rig

block is subjected. A single sheave block has a safe working load which is half the resultant, and multi-sheave blocks have a safe working load which is the same as the resultant.

In determining the span loads and boom thrusts, not only is the derrick safe working load considered to be supported by the span, but also the weight of the cargo purchase and half the boom weight. The other half of the boom weight is supported by the gooseneck fitting.

Allowances must be made for the frictional resistance of the blocks when determining the forces. This includes an allowance for the rope friction, i.e. the effort required to bend and unbend the rope around the pulley, as well as an allowance for journal friction. Shipbuilders using British Standards adopt the following assumed cumulative friction values.

Small and medium sheaves	8 per cent sheave with bushed plain bearings
	5 per cent sheave with ball or roller bearings
Large diameter sheaves	6 per cent sheave with bushed plain bearings
	4 per cent sheave with ball or roller bearings
Derrick exceeding 80 tonnes S.W.L.	5 per cent sheave with bushed plain bearings
	3 per cent sheave with ball or roller bearings

Force diagrams which are more involved than those for the single swinging derrick are prepared for the union purchase rig. These diagrams indicate the safe working load of the rig, the 'limiting height', the boom thrusts which are greater with this rig, and the optimum guy leads. The 'limiting height' is that height below which all positions of the lifted weight will result in an included angle between the outboard and inboard runners of less than 120°. At 120° if the boom heads are level the inboard and outboard runners will experience a force equivalent to the cargo weight (*see* Figure 24.5). Usually the runner size determines the safe working load in union purchase, but the thrust experienced by the derrick boom can determine this value where only light derricks are fitted. The positioning of the guys can be important to the loads experienced by the span and the guys themselves. If these are at too narrow an angle to the boom, excessive tension in the guys will result; a good lead is therefore essential. Unfortunately in practice the magnitude of the guy loads is not always appreciated, but more attention has been paid to this problem of late and preventers are now often set up to reduce the load in the guy. There is available a suitable preventer for this purpose; the use of old runners, etc., as preventers should not be tolerated.

In union purchase rigs it is possible to obtain a condition where the load comes off the outboard span, and the boom may then close to the mast under load. This condition is referred to as 'jack-knifing', and may be apparent from the force diagram prepared for the rig, since the triangle of forces does not close. At the design stage the guy positions can be adjusted to avoid this happening. In practice this condition appears to occur occasionally where derricks are used in union purchase at the bridge front. Here the positioning of the guys is made difficult by the presence of the bridge structure, but the correct placing of a suitable preventer should overcome this problem.

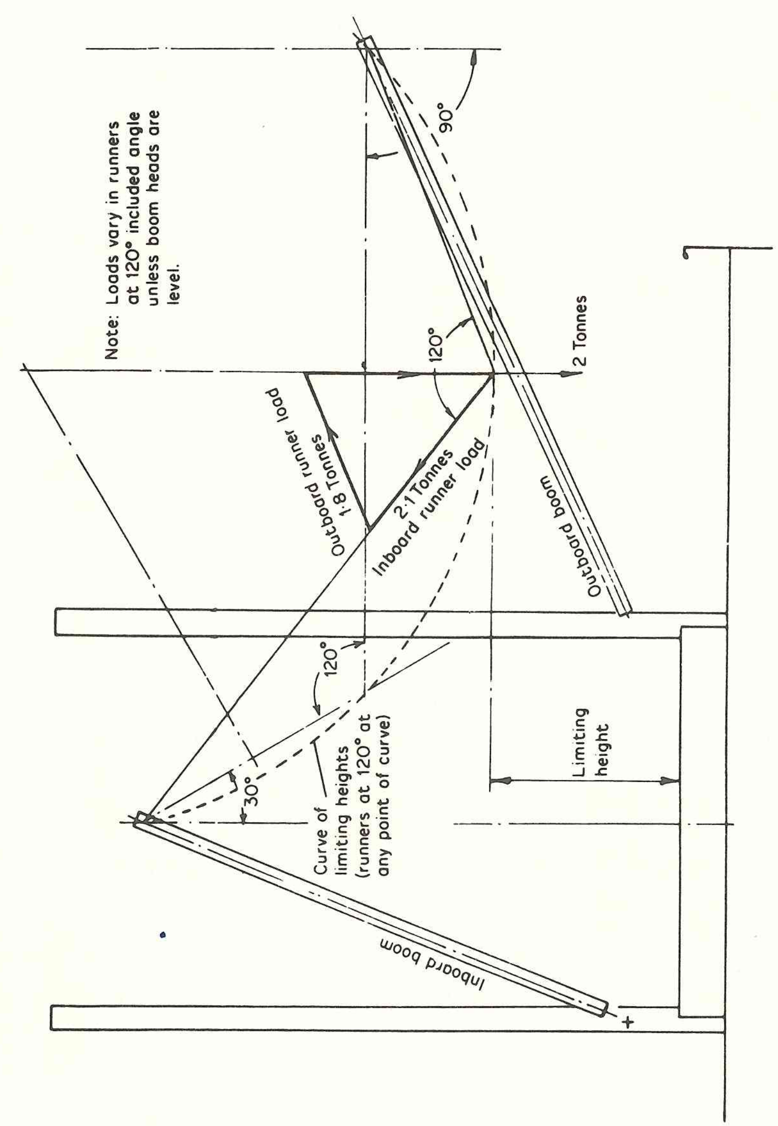


FIGURE 24.5 Forces in cargo runners of union purchase rig

INITIAL TESTS AND RE-TESTS OF DERRICK RIGS To comply with the Factories Acts (Docks Regulations) ships' derricks designed to operate as single swinging derricks are initially tested with a proof load which exceeds the specified safe working load of the derrick by the following amounts:

S.W.L. Less than 20 tonnes—25 per cent in excess of S.W.L.
S.W.L. 20 to 50 tonnes—5 tonnes in excess of S.W.L.
S.W.L. over 50 tonnes—10 per cent in excess of S.W.L.

Heavy lift derricks are tested at an angle of not more than 45° to the horizontal and other derricks at an angle of not more than 30° to the horizontal. During the test the boom is swung as far as possible in both directions, and any derrick intended to be raised by power under load is raised to its maximum working angle at the outermost position.

Before the test for a heavy derrick it is usual to ensure that the vessel has adequate transverse stability. Before, during, and after all tests it is necessary to ensure that none of the components of the rig show signs of any failure; and it is good practice to have a preventer rigged during the test as a precaution against any of the span gear carrying away. On completion of the test the heel of the derrick boom is clearly marked with:

(*a*) Its safe working load in single purchase.
(*b*) Its safe working load in double purchase, if it is designed for that purpose.
(*c*) Its safe working load in union purchase, if it is designed for that purpose, the letter 'U' preceding the safe working load.

e.g. S.W.L. 3/5 tonnes S.W.L. (U) 2 tonnes
and a certificate of test and examination is issued in an approved form.

Re-tests are required if the rig is substantially modified or a major part is damaged and repaired. Annual inspections of the rig are required, and a thorough examination is necessary every four years. If the examiner is not satisfied with the rig he may request a re-test. In the case of heavy derricks the annual inspection is waived if they are inspected on such occasions as they are rigged.

The International Labour Organisation (ILO) Convention, 152 adopted, 25th June, 1979, requires examination by a competent person once in every 12 months and re-testing at least once in every 5 years.

Deck Cranes

A common feature on many modern cargo ships is deck cranes, which replace the derricks. Generally they are considered as an alternative to the union purchase rig. Deck cranes have a number of advantages, the rigging

time being negligible, and the crane is able to pick up and land permitted loads anywhere within its working radius. The safe working loads of cranes is generally of the order of 10 to 15 tonnes and larger cranes are available capable of lifts from 30 to 40 tonnes. As with the union purchase rig the crane is intended for rapid cargo loading and discharging duties with loads which only occasionally exceed, say, 3 tonnes. There is some controversy regarding the merits of cranes as opposed to the union purchase rig, but evidence is available to show that the crane is perhaps less efficient with very light loads.

Cranes may often be positioned on the ship's centre line, but this may require an extremely long jib when the ship's beam is large and a reasonable outreach is desired. Transverse positional cranes may then be fitted which, when not under load, can be moved port or starboard and secured to work the hatch and give the desired outreach. Alternatively fixed cranes, one at each end of the hatch, may be placed at opposite corners. This is an arrangement which is useful in discharging to port and starboard simultaneously. There is also a crane which is mounted on a hatch cover section capable of travelling under load along the hatch coaming in the longitudinal direction.

Deck cranes are available from specialist manufacturers and the shipbuilder would be responsible for installation, any local strengthening, and seatings.

Further Reading

'Advances in Shipboard Cargo-handling Gear', *The Naval Architect*, July, 1976.

Code of Practice for the Construction and Survey of Ships' Cargo Handling Gear, Lloyd's Register of Shipping.

Hopper *et al.*, 'Cargo Handling and its Effect on Dry Cargo Ship Design', *Trans. R.I.N.A.*, 1964.

McCaully, *The Chain Tester's Handbook*, The Chain Testers Association of Great Britain.

Memorandum on Ships' Derrick Rigs, B.S. 1700: 1963, British Standards Institution.

Safe Working Loads of Lifting Tackle, Linder, Coubro Scrutton Ltd., and Maritime and Industrial Services Ltd.

Specification for Galvanised Steel Wire Ropes for Shipping Purposes, B.S. 365: 1962, British Standards Institution.

Specification for Ships' Cargo Blocks, MA 47: 1977, British Standards Institution.

25
Cargo Access, Handling and Restraint

To speed cargo handling and storage in modern ships apart from changes in ship design (Chapter 3), the introduction of mechanically handled hatch covers (Chapter 19) and improved lifting devices (Chapter 24), various patented or specially manufactured items may be brought into the shipyard and fitted to the ship by the shipbuilder. Some notable items which fall into this category are described in this chapter. These primarily relate to cargo access handling and restraint in ro-ro ships, container ships and vessels in which palletised cargo is carried.

Stern and Bow Doors

Ro-ro vessels may be fitted with stern doors of the hinge down or hinge up type which if large are articulated. Bow doors are either of the visor type or of the side hinged type ('barn door' type). These are situated above the freeboard deck and where the bow doors lead to a complete or long forward enclosed superstructure Lloyd's require an inner door to be fitted which is part of the collision bulkhead. This would also be in keeping with the SOLAS requirements for passenger ships where the collision bulkhead is to be extended weathertight to the deck next above the bulkhead deck, but need not be fitted directly above that bulkhead. A sloping weathertight vehicle ramp may be fitted in some ships to form the collision bulkhead above the freeboard deck and the inner door is omitted. This ramp may extend forward of the specified limit for the collision bulkhead above a height of more than 2.3 m above the bulkhead deck, i.e. above the height of a conventional tween deck space. Stern and bow door strengths are equivalent to the strength of the surrounding structure and where they give access to enclosed superstructures they are required to close weathertight.

Stern doors and bow visors can be mechanically raised and lowered with wire rope and purchase arrangements but in general they and the side hinged bow doors are hydraulically opened and closed (*see* Figure 25.1). These weathertight doors are gasketted and cleated.

Ramps

Ro-ro ships fitted with ramps usually have a stern ramp, but some vessels

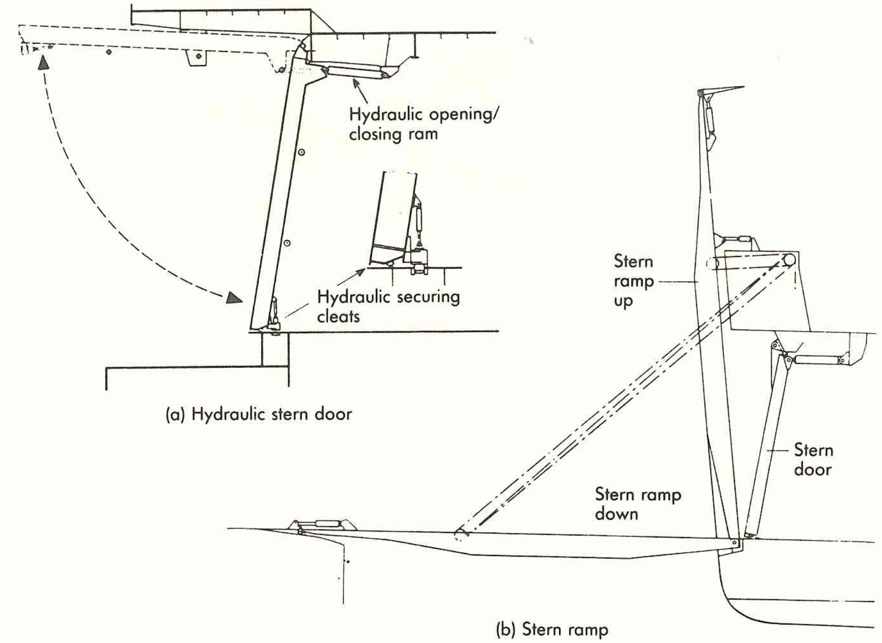


FIGURE 25.1

fitted with bow doors may also have a bow ramp which doubles as the inner weathertight door (see above) and is lowered onto a linkspan when the bow visor or side hinged doors have been opened. Ramps may also be fitted internally to give access from deck to deck. These can be hydraulically or mechanically tilted to serve more than one deck and can be fixed in the horizontal position to serve as decks themselves (*see* Figure 25.2). In some ships they can even be raised into the hatch space and serve as weathertight covers.

Stern ramps can be fixed axial ramps, fixed quarter ramps, slewing ramps or semi-slewing quarter ramps (*see* Figure 25.3). The axial stern ramp may also serve as the stern door and can be lowered or raised hydraulically or by wire rope arrangements. The quarter ramp was designed for ro-ro ships using ports which are not provided with right angled quays or link span connections. The large articulated quarter ramp is raised and lowered by wire rope purchase arrangements to hydraulic winches. Slewing ramps serve a similar purpose to the quarter ramp, but are more flexible. The slewing ramp moves around the stern on a curved guide rail, the movement being affected by the lifting and lowering wire purchases which are led to hydraulic winches.

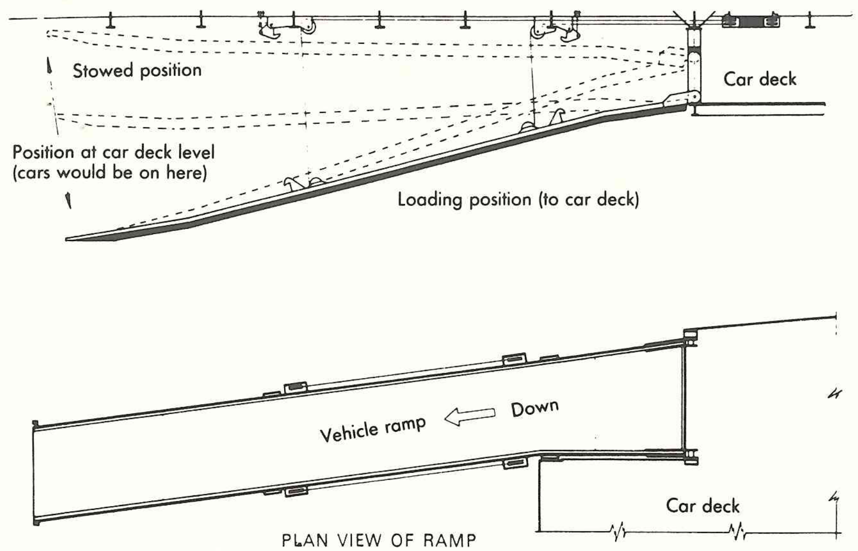


FIGURE 25.2

Side Doors and Loaders

Side door/ramps are available for ro-ro operations and are similar to stern door/ramp installations. Most side door installations, however, are intended for quayside fork lift operations with palletised cargo being loaded onto a platform at the door by the quayside forklift and stowed in the ship by another forklift truck. Instead of a loading platform on ships trading to ports with high tidal ranges a ramp onto which the quayside forklift truck drives may be fitted. Elevator platforms may be fitted immediately inboard of the side door to service various tween decks and the hold. A particular type of elevator system is that developed for the transportation of paper products especially newsprint. The quayside forklift places the newsprint rolls on the height-adjustable loading platform which together with the elevator platform is fitted with roller conveyors. Movement of the roller conveyors is automatic, the newsprint rolls being transferred from the loading platform to the elevator platform which travels to the pre-selected deck or hold level for unloading (*see* Figure 25.4).

Upward folding doors with hydraulic cylinders actuating the hinge are usually fitted to the side opening, the load platform being fitted inside the door and hinged at the bottom of the opening, automatically being lowered when the door is opened. Combined side door/hatch covers are fitted in designs where the ship is low in the water relative to the height of quay in

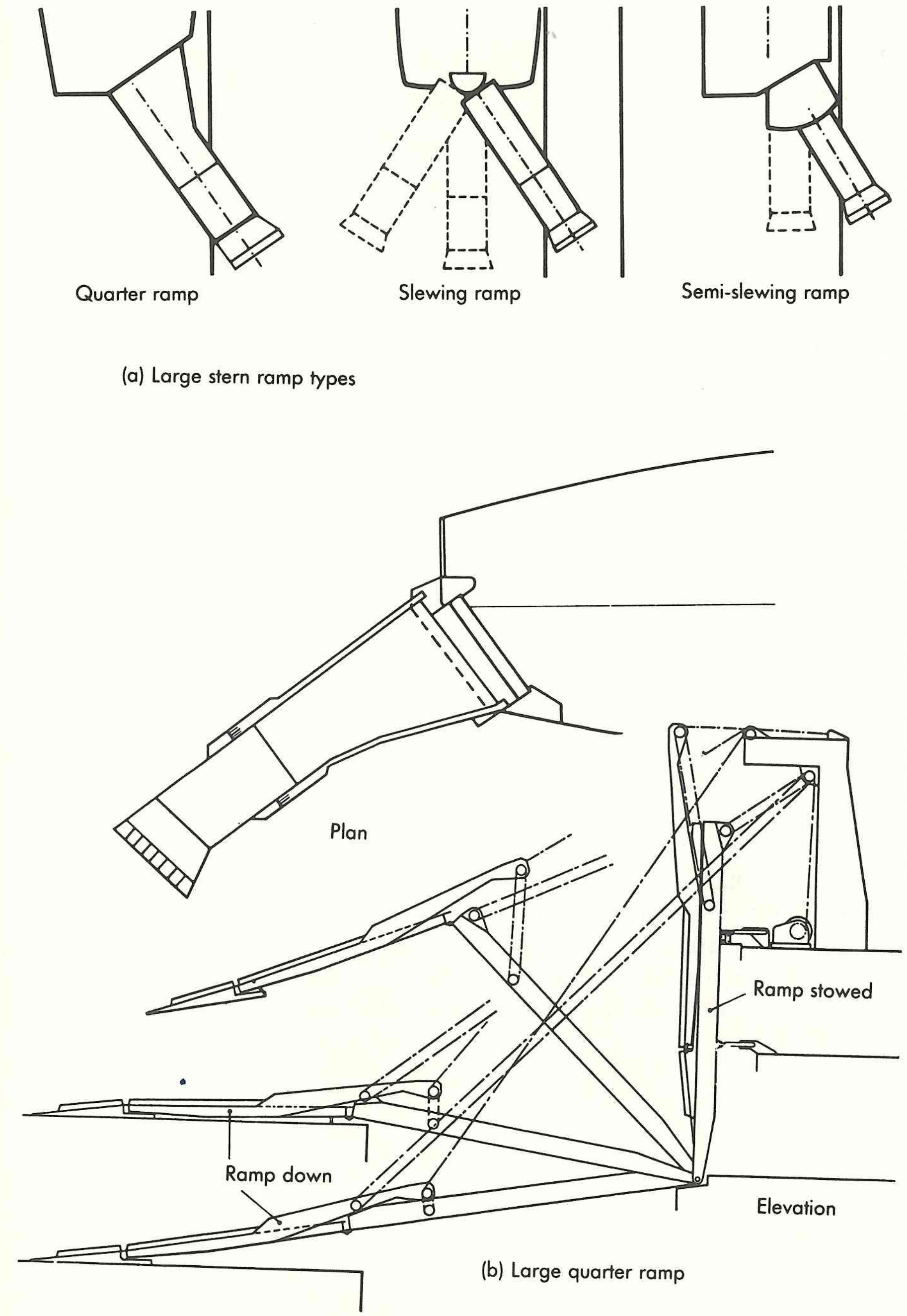
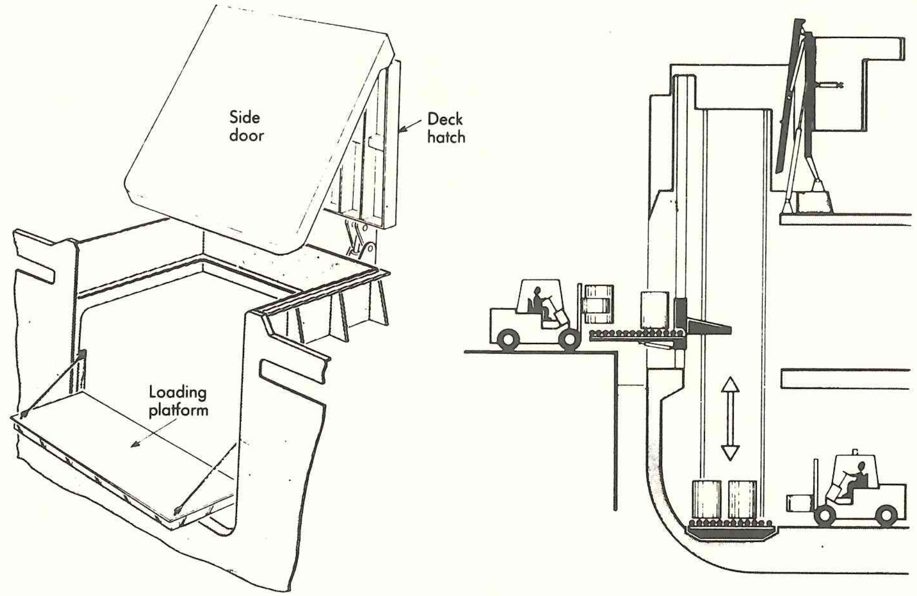


FIGURE 25.3



(a) Side door/hatch cover

(b) Side port conveyor system

FIGURE 25.4

order to provide sufficient head room for forklift truck operation (*see* Figure 25.4). With the side port elevator system referred to above a combined door/hatch is fitted to the hatch carrying part of the tower which houses the upper part of the cargo elevator.

A side loader that dispenses with the need for a side door is the MacGregor-Navire International A.B.'s 'Rotoloader'. This can be a fixed or portable installation. The unit load is raised from the quay to a point above the ships side, swung inboard through 180° on a rotating frame unit and lowered through the hatch to the hold or tween.

Portable Decks

Portable decks are fitted in a variety of ships permitting flexibility of stowage arrangements and allowing totally different cargoes to be carried on different voyages. An extreme example is a 50,000 tonne deadweight bulk carrier fitted with hoistable car decks stowed under the hold wing tanks when taking ore from Australia to Japan and lowered for the return voyage when 3000 cars are carried. The car deck is the most common form of portable deck and common in ro-ro ferries. Hoistable decks are lowered

from and stowed at the deckhead by hoist wires led through a hydraulic jigger winch. Folding decks stow at the sides and ends of ship spaces and are generally hydraulically lowered into the horizontal position. Lloyd's Register include requirements for movable decks in their Rules and if the ship is fitted with portable decks complying with these rules at the owners or builders request the class notation 'movable decks' may be assigned.

Scissors Lift

Cargo can be lowered or raised between decks or to the hold by means of a scissors lift which is often fitted in ro-ro ships as an alternative to internal ramps it taking up less room. The hydraulic cylinder powered scissors lift is also often designed to transfer heavy unit loads.

Cargo Restraint

In ro-ro and container ships the lashing of cargo is an important safety consideration and usually calls for fittings which will permit rapid and easy but effective securing of the cargo because of short ship turn around times. The shipbuilder is responsible for the deck and perhaps hatch fittings for the securing devices and will look to the ship operator for guidance on their type and positions. On the decks of ro-ro ships where the direction of lashing is unpredictable and vehicles must transverse the fitting a cloverleaf deck socket in conjunction with an elephants foot type of end lashing is popular (*see* Figure 25.5).

Containers have very little strength in any direction other than vertically through the corner posts thus it is necessary to provide substantial support to the containers when they are on the ship. Stowage of containers is with their longer dimension fore and aft since the ship motion transmitted to cargo is greater in rolling than pitching and it is therefore prudent to limit any possible cargo movement within the container to the shorter transverse dimension. Also of course when off loading the fore and aft container is more easily received by road or rail transport. Below decks containers are restrained in vertical cell guides which are typically 150 × 150 × 12 angles and they are structurally supported so that any dynamic forces other than purely vertical are transmitted as much as possible through the ships structure and not into the containers. The cell guides are not to form an integral part of the ships structure, they are to be so designed that they do not carry the main hull stresses. Where four container corners are adjacent the cell guides may be built into a composite pillar (*see* Figure 25.5). The clearance between container and cell guide is critical. If it is too small the container will jam, if it is too large when one container lands on the one

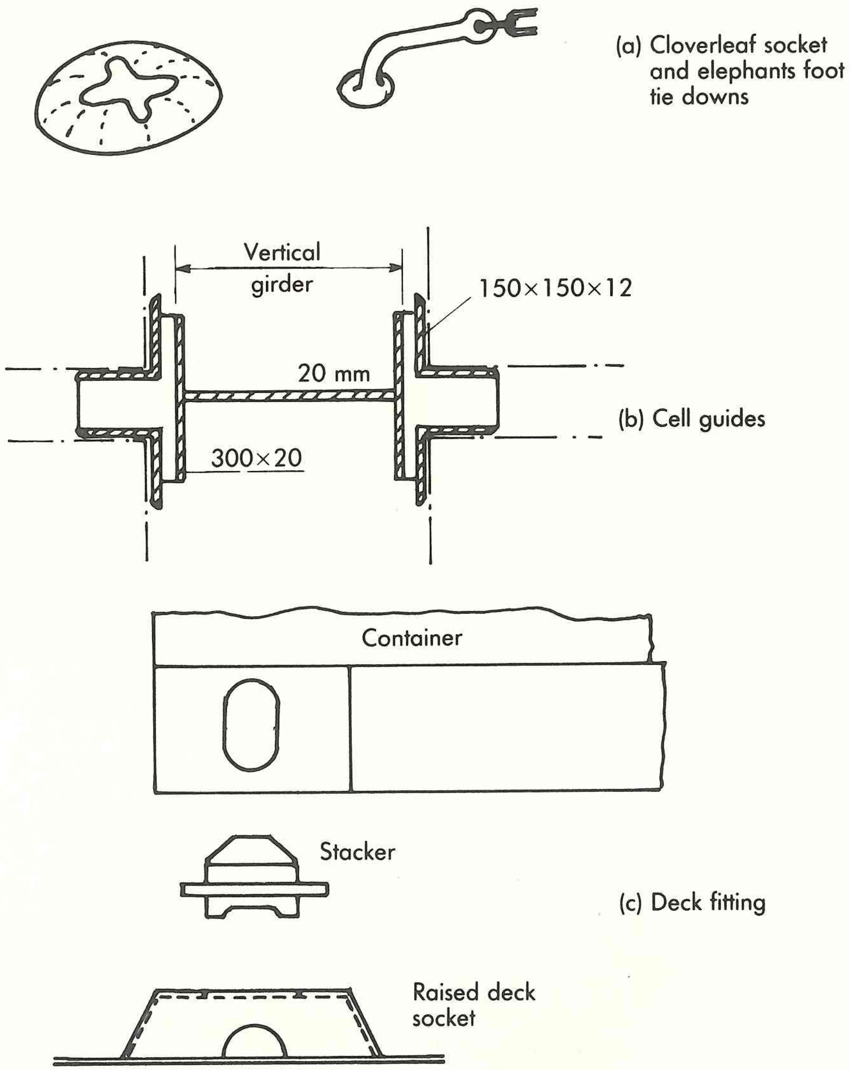


FIGURE 25.5

below the corner posts and castings which accept a maximum eccentricity may not mate. Lloyd's stipulate a maximum clearance of 25 mm in transverse direction and 40 mm in the longitudinal direction. The tolerances are such that the cell guides have to be fitted to an accuracy exceeding normal shipyard practice with the use of jigs to ensure the dimensions are maintained following welding. Lloyd's require that the cell guide not deviate

from its intended line by more than 4 mm in transverse direction and 5 mm in longitudinal direction. Lead in devices are fitted at the top of the guides.

Above deck cell guides may also be provided there being several patented arrangements such as the MacGregor-Navire International A.B. 'Stackcell' system. These are not widely used however and many ships carrying containers above deck rely on various deck and hatch sockets with locking and non-locking stackers mating with the standard container corners plus lashings to secure the containers. With locking stackers less lashings are required therefore the more expensive twistlock is often favoured. Deck sockets like the container corner fitting contain the standard I.S.O. hole into which the stackers fit (*see* Figure 25.5).

Further Reading

Cole, 'The Securing of I.S.O. Containers Theory and Practice—An ICHCA Survey' International Cargo Handling Co-ordination Association, 1981.

26
Pumping and Piping Arrangements

In the construction of a merchant ship the shipbuilder is concerned with the installation of the statutory bilge drainage, ballasting, general services, and where required the liquid cargo loading and discharging, pumping and piping arrangements. Piping arrangements may also be fitted in oil tankers for tank washing and for introducing inert gas into the tanks.

Bilge and Ballast Pumping and Piping

All cargo ships are provided with pumping and piping arrangements so that any watertight compartment or watertight section of a compartment can be pumped out when the vessel has a list of up to 5°, and is on an even keel. In the case of passenger ships, each compartment or section of a compartment may be pumped out following a casualty under all practical conditions whether the ship is listed or not.

The arrangements in the machinery space are such that this space may be pumped out through two suctions under the above conditions. One suction is from the main bilge line and the other from an independent power driven pump. An emergency bilge suction is also provided in machinery spaces, and may be connected to the main circulating water pump (for condenser) in steam ships, or the main cooling water pump in motor ships.

BILGE SUCTIONS As the vessel is to be pumped out when listed it is necessary to fit port and starboard suctions in other than very narrow spaces. Generally vessels are designed to have a moderate trim by the stern in service, and the suctions will therefore be placed in the after part of the compartment. However, where a ship has a single hold which exceeds 33.5 m in length suctions are also arranged in the forward half length of the hold. On many vessels a sloping margin plate is fitted and a natural bilge is formed with the suctions conveniently located within this recess. Adequate drainage to the bilge is provided where a ceiling covers this space. If however the tank top extends to the ship sides, bilge wells having a capacity of at least 0.17 m^3, may be arranged in the wings of the compartment. In a passenger ship these bilge wells must not extend to within 460 mm of the bottom shell so as to retain a reasonable margin of safety where the inner bottom height is effectively reduced. The shaft tunnel of the ship is drained

by means of a well located at the after end, and the bilge suction is taken from the main bilge line (*see* Figure 26.1).

At the open ends of bilge suctions in holds and other compartments, outside the machinery space and shaft tunnel, a strum box is provided. The strum box is a perforated plate box welded to the mouth of the bilge line (Figure 26.1) which prevents debris being taken up by the bilge pump suction. Perforations in the strum box do not exceed 10 mm in diameter, and their total cross-sectional area is at least twice that required for the bore of the bilge pipe. Strums are arranged at a reasonable height above the bottom of the bilge or drain well to allow a clear flow of water and to permit easy cleaning. In the machinery space and shaft tunnel the pipe from the bilges is led to the mud box which is accessible for regular cleaning. Each mud box contains a mesh to collect sludge and foreign objects entering the end of the pipe.

BILGE PUMPS AND PIPE SYSTEMS Cargo ships have at least two power driven bilge pumping units in the machinery space connected to the main bilge line, and passenger ships have at least three.

In passenger ships the power driven bilge pumps are where practicable placed in separate watertight compartments, so that all three are not easily flooded by the same damage. Where the passenger ship has a length in excess of 91.5 m it is a requirement that at least one of these pumps will always be serviceable in reasonable damage situations. A submersible pump may be supplied with its source of power above the bulkhead deck. Alternatively the pumps are so distributed throughout the length of the ship that it is inconceivable that one might not be able to work in the event of reasonable damage.

Suction connections are led to each hold or compartment from the main bilge line. Valves are introduced to prevent one watertight compartment from being placed in direct communication with another, and to prevent dry cargo spaces and machinery spaces being placed in direct communication with tanks or pumps having sea inlets. These screw-down non-return valves are often provided in a bilge valve distribution chest, or may be fitted directly in the connections to the bilge main. The bilge pipes which are used to drain cargo and machinery spaces are kept separate from the sea inlet pipes and ballast pipes which are used for filling or emptying tanks where the water and oil are carried. Often a separate 'dirty ballast' system is arranged to overcome this problem.

If possible the bilge pipes are kept out of the double bottom tanks, and in way of a deep tank are led through a pipe tunnel. If the peaks are used as tanks then a power pump suction is led to each peak. Only two pipes are permitted to pass through the collision bulkhead below the bulkhead deck and a screw-down valve operated from above the bulkhead deck is provided for each pipe in a chest on the forward side of the bulkhead. An

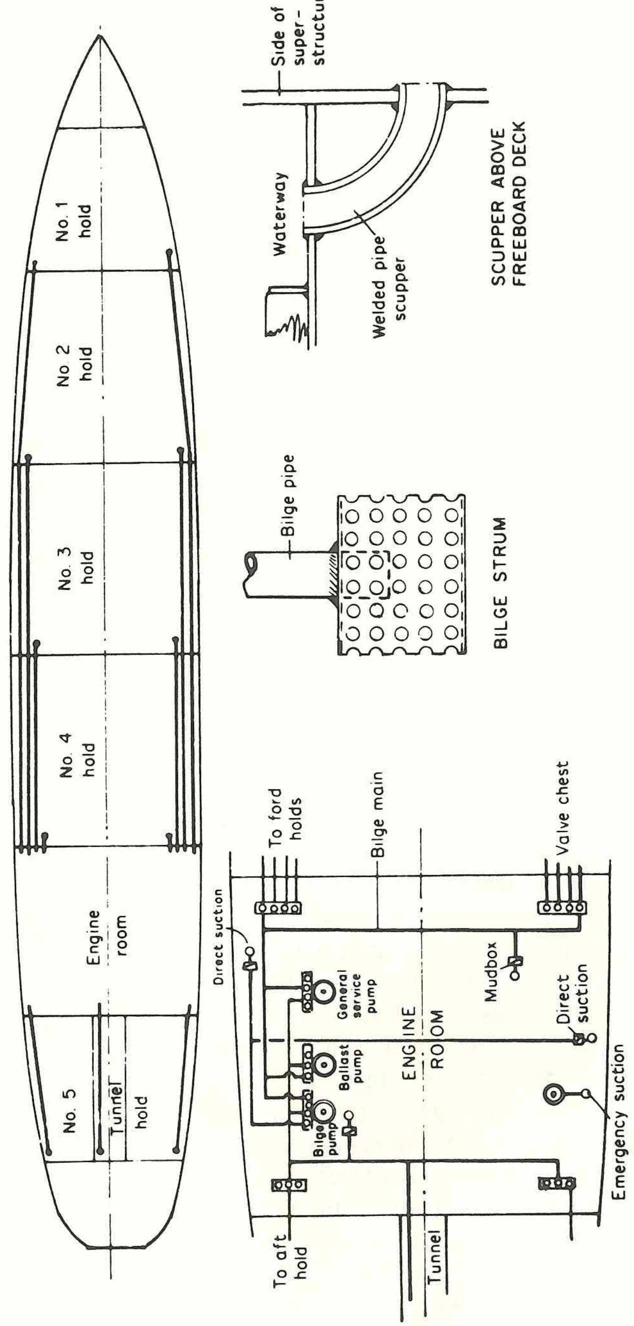


FIGURE 26.1 Bilge piping arrangement

indicator is provided to show at the valve operating position whether it is open or closed.

Bilge mains in passenger ships are kept within 20 per cent of the ship's beam of the side shell, and any piping outside this region or in a duct keel is fitted with a non-return valve. These requirements are intended to prevent any compartment from becoming flooded when the ship is grounded or otherwise damaged and a bilge pipe is severed. Many passenger ships are provided with divided deep tanks or side tanks which permit cross flooding arrangements limiting the list after a casualty. This cross flooding is generally controlled by valves operated from above the bulkhead deck, but self-acting arrangements can also be adopted.

Bilge and ballast piping may be of cast or wrought iron, steel, copper, or other approved materials. Lead or other heat sensitive materials are not permitted. The piping is fitted in lengths which are adequately supported and have flanged connections, provision being made for expansion in each range of pipes.

SCUPPERS Scuppers are fitted at the ship's side to drain the decks. Below the freeboard decks and within intact houses on the freeboard deck these scuppers are led to the bilges. They may alternatively be led overboard if they are above the waterline, and are fitted with a non-return valve operated from above the freeboard deck. Those scuppers at a reasonable distance above the waterline may be fitted with two or possibly one automatic non-return valve which does not have positive means of closing (*see* Chapter 31). Scuppers draining open decks above the freeboard decks are led directly overboard (Figure 26.1).

General Service Pipes and Pumping

Pumps and substantial piping systems are provided in ships to supply the essential services of hot and cold fresh water for personal use, and salt water for sanitary and fire fighting purposes.

Many large passenger ships are provided with a large low-pressure distilling plant for producing fresh water during the voyage, as the capacities required would otherwise need considerable tank space. This space is better utilized to carry oil fuel, improving the ship's range. Independent tanks supplying the fresh water required for drinking and culinary purposes, and fresh washing water, etc., may be taken from the double bottom tanks, the pumps for each supply being independent also. Hot fresh water is supplied initially from the cold fresh water system, through a non-return valve into a storage type hot water heater fitted with heater coils, and then the heated water is pumped to the outlet.

The sanitary system supplies sea water for flushing water closets, etc., and may be provided with a hydro-pneumatic pump in cargo vessels, but on larger passenger ships where the demand is heavier, a continuously operating power pump is required.

It is a statutory requirement that a fire main and deck wash system should be supplied. This has hose outlets on the various decks, and is supplied by power driven pumps in the machinery spaces. Provision may be made for washing down the anchor chain from a connection to the fire main.

Air and Sounding Pipes

Air pipes are provided for all tanks to prevent air being trapped under pressure in the tank when it is filled, or a vacuum being created when it is emptied. The air pipes may be fitted at the opposite end of the tank to the filling pipe and/or at the highest point of the tank. Each air pipe from a double bottom tank, deep tanks which extend to the ship's side, or any tank which may be run up from the sea, is led up above the bulkhead deck. From oil fuel and cargo oil tanks, cofferdams, and all tanks which can be pumped up, the air pipes are led to an open deck, in a position where no danger will result from leaking oil or vapours. The heights above decks and closing arrangements are covered by the Load Line Conditions of Assignment (*see* Chapter 31).

Sounding pipes are provided to all tanks, and compartments not readily accessible, and are located so that soundings are taken in the vicinity of the suctions, i.e. at the lowest point of the tank. Each sounding pipe is made as straight as possible and is led above the bulkhead deck, except in some machinery spaces where this might not be practicable. A minimum bore of 32 mm is in general required for sounding pipes; but where they pass through refrigeration spaces, to allow for icing, a minimum bore of 65 mm is required where the temperature is at 0°C or less. Underneath the sounding pipe a striking plate is provided where the sounding rod drops in the bilge well, etc. Sometimes a slotted sounding pipe is fitted to indicate the depth of liquid present, and the closed end must be substantial to allow for the sounding rod striking it regularly. Various patent tank sounding devices are available and can be fitted in lieu of sounding pipes, as long as they satisfy the requirements of the classification society.

Sea Inlets

Where the piping system requires water to be drawn from the sea, for example fire and washdeck, ballast and machinery cooling systems, the inlet valve is fitted to a substantial box within the line of the shell plate containing the sea inlet opening (*see* Figure 26.2). This opening is to have

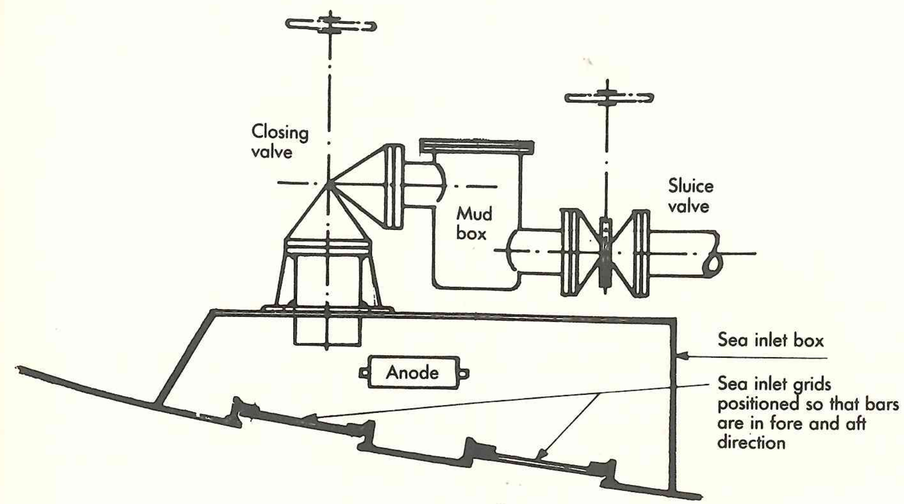


FIGURE 26.2 Sea inlet

rounded corners and be kept clear of the bilge strake if possible. The sea inlet box is to have the same thickness as the adjacent shell but is not to be less than 12.5 mm thick and need not exceed 25 mm. Sea inlets in tanker pumprooms within 40 per cent of the ships midship length are required to have compensation generally in the form of a heavier insert plate in the shell. A grill may be fitted over the opening and a sacrificial anode will normally be fitted because the valve metal and steelbox set up a galvanic cell (*see* Chapter 27).

Cargo Pumping and Piping Arrangements in Tankers

Cargo pumps are provided in tankers to load and discharge cargo, and also to ballast some of the tanks which becomes necessary when making voyages in the unloaded condition. Many modern tankers have clean ballast capacity and these tanks are served by a separate pumping system.

The particular cargo pumping system adopted depends very much on the range of cargo carried. A fairly straightforward system is available for the larger bulk oil carrier, carrying a single product. Where smaller tankers carry a number of oil products at one time, which must be kept separate, the pumping system is more complex.

SINGLE PRODUCT/CRUDE OIL CARRIER Where a single oil product is carried, and where larger tankers are designed solely to carry crude oil, a single pump room is fitted aft, adjacent to the machinery spaces. The piping

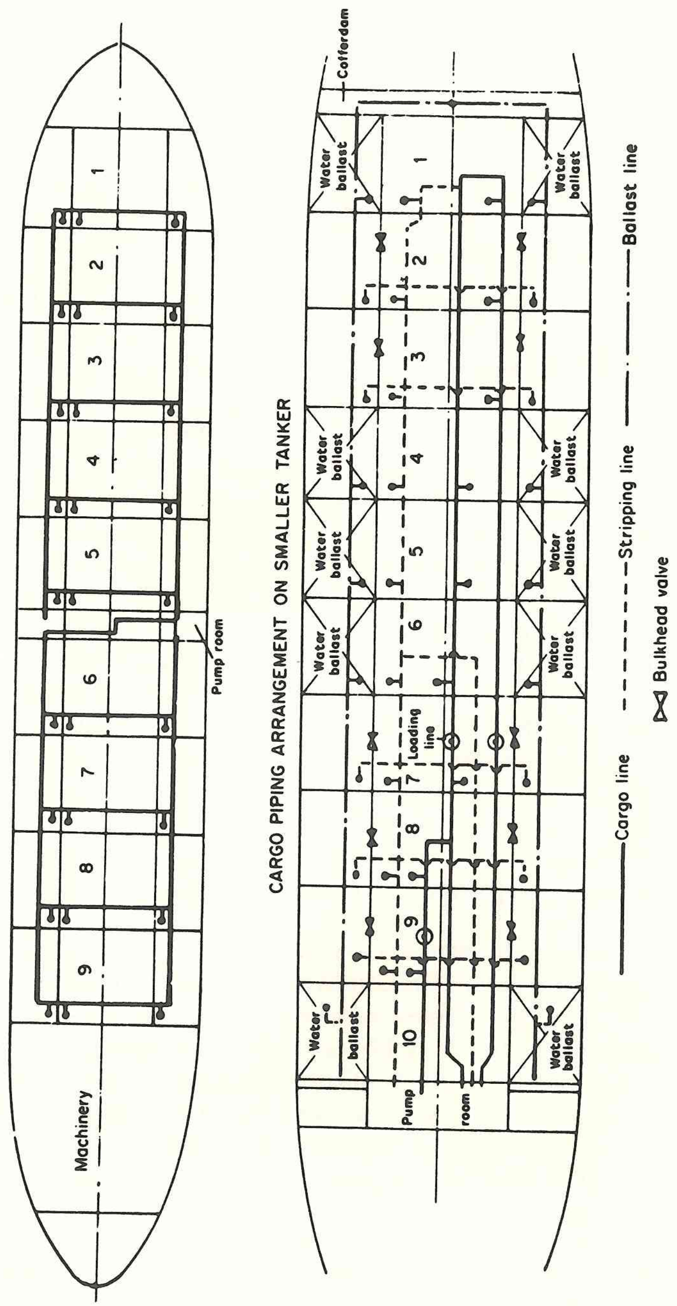


FIGURE 26.3 Diagrammatic ring main cargo piping arrangement

system is of the 'direct line' type, three or four lines being provided, each with suctions from a group of tanks (*see* Figure 26.4). Each pump discharge is led up to the deck mains which run forward to the transverse loading and discharging connections.

A few large tankers have a discharge system which relies on hydraulically controlled sluice valves in the tank bulkheads. These permit a flow of the oil to a common suction in the after tank space. Many large tankers partially adopt this system, sluice valves being provided in the longitudinal bulkheads, and the oil is allowed to find its way from the wing tanks to the centre tanks. Suctions from the main cargo lines are located in the centre tanks. Such an arrangement is shown in Figure 26.4, which also indicates the separate stripping system, and clean ballast lines.

MULTI-PRODUCTS TANKERS Where a number of oil products are carried, the more complex pumping arrangements require two and in some cases three pump rooms to be fitted. One may be fitted aft adjacent to the machinery space, a second amidships, and where a third pump room is provided this is forward. On many older tankers the piping was often arranged on the 'ring main' system to provide flexibility of pumping conditions (*see* Figure 26.3). To obtain the optimum number of different pumping combinations in modern multi-product carriers the tanks may be fitted with individual suction lines.

CARGO PUMPS On modern tankers the main cargo pumps are of the centrifugal type, either geared-turbine or motor driven, and have a very high pumping capacity, those on the large tankers being capable of discharging say 3500 m^3/hour. Because of their high capacities the centrifugal cargo pumps are unsuitable for emptying tanks completely, and for this purpose reciprocating stripping pumps with capacities of, say, 350 m^3/hour are provided with a separate stripping line.

CARGO TANK WASHING After discharge of cargoes oil tanker cargo tanks can be cleaned by either hot or cold water, fresh or seawater, or by crude oil washing. Water cleaning machines can be fixed in a tank or may be portable, the portable machine being connected by hose to a deck water-main before being introduced through a tank cleaning hatch into the tank. Crude oil carriers can have fixed washing equipment in the tanks connected to the cargo pumps via cross-connections at the ships manifold to the cleaning main and can use crude oil instead of water as the washing medium. This is usually done while the tanker is discharging cargo and it enables re-dissolving of oil fractions adhering to the tank surfaces to take place so that these residues can be discharged with the cargo. There may then be no need to water wash tanks for the removal of residues unless clean water ballast is to be carried in the tank.

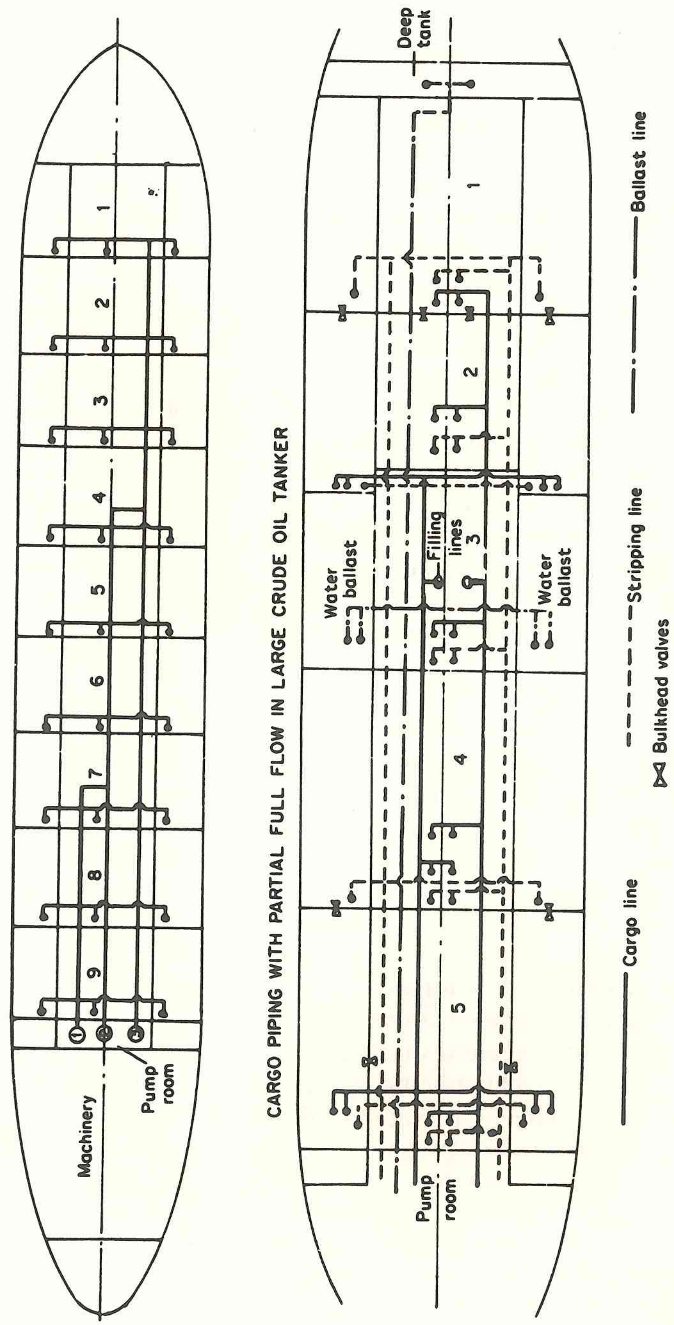


FIGURE 26.4 Diagrammatic arrangement of direct line cargo piping

INERT GAS SYSTEM For oil tankers of 20 000 tonnes deadweight and upwards protection of the cargo tanks is required to be achieved by a fixed inert gas system. The inert gas system is to be so designed and operated as to render and maintain the atmosphere of the cargo tanks non-flammable, other than when the tanks are gas free. Hydrocarbon gas normally encountered in oil tanks cannot burn in an atmosphere containing less than 11 per cent of oxygen by volume, thus if the oxygen content in a cargo tank is kept below, say, 8 per cent by volume fire or explosion in the vapour space should not occur. Inert gas introduced into the tank will reduce the air (oxygen) content.

On an oil tanker, inert gas may be produced by one of two processes:

(1) Ships with main or auxiliary boilers normally use the flue gas which contains typically only 2 to 4 per cent by volume of oxygen. This is scrubbed with sea water to cool it and to remove sulphur dioxide and particulates, and it is then blown into the tanks through a fixed pipe distribution system.

(2) On diesel engined ships the engine exhaust gas will contain too high an oxygen level for use as an inert gas. An inert gas generating plant may then be used to produce gas by burning diesel or light fuel oil. The gas is scrubbed and used in the same way as boiler flue gas.

Non-return barriers in the form of a deck water seal, and non-return valve are maintained between the machinery space and deck distribution system to ensure no petroleum gas or liquid petroleum passes back through the system to the machinery space.

Further Reading

Day *et al.*, 'Development of an inert gas system for oil tankers', *The Naval Architect*, January, 1972.

Platt, 'Modern Tanker Practice for Cargo Handling Equipment', *Trans. I.E.S.S.*, 1958–59.

27
Corrosion Control and Paint Systems

Nature and Forms of Corrosion

There is a natural tendency for nearly all metals to react with their environment. The result of this reaction is the creation of a corrosion product which is generally a substance of very similar chemical composition to the original mineral from which the metal was produced.

ATMOSPHERIC CORROSION Protection against atmospheric corrosion is important during the construction of a ship, both on the building berth and in the shops. Serious rusting may occur where the relative humidity is above about 70 per cent; the atmosphere in British shipyards is unfortunately sufficiently humid to permit atmospheric corrision throughout most of the year. But even in humid atmospheres the rate of rusting is determined mainly by the pollution of the air through smoke and/or sea salts.

CORROSION DUE TO IMMERSION When a ship is in service the bottom area is completely immersed and the waterline or boot topping region may be intermittently immersed in sea water. Under normal operating conditions a great deal of care is required to prevent excessive corrosion of these portions of the hull. A steel hull in this environment can provide ideal conditions for the formation of electro-chemical corrosion cells.

ELECTRO-CHEMICAL NATURE OF CORROSION Any metal in tending to revert to its original mineral state releases energy. At ordinary temperatures in aqueous solutions the transformation of a metal atom into a mineral molecule occurs by the metal passing into solution. During this process the atom loses one or more electrons and becomes an ion, i.e. an electrically charged atom, with the production of an electric current (the released energy). This reaction may only occur if an electron acceptor is present in the aqueous solution. Thus any corrosion reaction is always accompanied by a flow of electricity from one metallic area to another through a solution in which the conduction of an electric current occurs by the passage of ions. Such a solution is referred to as an electrolyte solution; and because of its high salt content sea water is a good electrolyte solution.

A simple corrosion cell is formed by two different metals in an electrolyte solution (a galvanic cell) as illustrated in Figure 27.1. It is not essential to

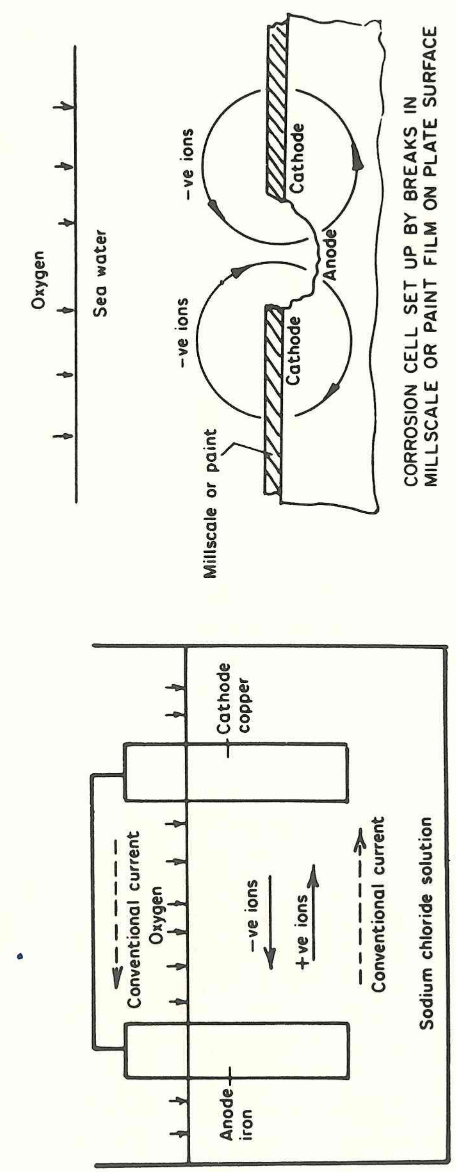


FIGURE 27.1 Corrosion cell

have two different metals as we shall see later. As illustrated a pure iron plate and a similar pure copper plate are immersed in a sodium chloride solution which is in contact with oxygen at the surface. Without any connection the corrosion reaction on each plate would be small. Once the two plates are connected externally to form an electrical path then the corrosion rate of the iron will increase considerably, and the corrosion on the copper will cease. The iron electrode by means of which the electrons leave the cell and by way of which the conventional current enters the cell is the anode. This is the electrode at which the oxidation or corrosion normally takes place. The copper electrode by means of which the electrons enter the cell and by way of which the conventional current leaves the cell is the cathode, at which no corrosion occurs. A passage of current through the electrolyte solution is by means of a flow of negative ions to the anode and a flow of positive ions to the cathode.

Electro-chemical corrosion in aqueous solutions will result from any anodic and cathodic areas coupled in the solution whether they are metals of different potential in the environment or they possess different potentials as the result of physical differences on the metal surface. The latter is typified by steel plate carrying broken millscale in sea water (Figure 27.1) or corrosion currents flowing between areas of well painted plate and areas of defective paintwork.

In atmospheric corrosion and corrosion involving immersion both oxygen and an electrolyte play an important part. Plates freely exposed to the atmosphere will receive plenty of oxygen but little moisture, and the moisture present therefore becomes the controlling factor. Under conditions of total immersion it is the presence of oxygen which becomes the controlling factor.

BIMETALLIC (GALVANIC) CORROSION Although it is true to say that all corrosion is basically galvanic, the term 'galvanic corrosion' is usually applied when two different metals form a corrosion cell.

Many ship corrosion problems are associated with the coupling of metallic parts of different potential which consequently form corrosion cells under service conditions. The corrosion rates of metals and alloys in sea water have been extensively investigated and as a result galvanic series of metals and alloys in sea water have been obtained.

A typical galvanic series in sea water is shown in Table 27.1.

The positions of the metals in the table apply only in a sea water environment; and where metals are grouped together they have no strong tendency to form couples with each other. Some metals appear twice because they are capable of having both a passive and an active state. A metal is said to be passive when the surface is exposed to an electrolyte solution and a reaction is expected but the metal shows no sign of corrosion. It is generally agreed that passivation results from the formation of a

TABLE 27.1

Galvanic Series of Metals and Alloys in Sea Water

Noble (cathodic or protected) end

Platinum, gold
Silver
Titanium
Stainless steels, passive
Nickel, passive
High duty bronzes
Copper
Nickel, active
Millscale
Naval brass
Lead, tin
Stainless steels, active
Iron, steel, cast iron
Aluminium alloys
Aluminium
Zinc
Magnesium

Ignoble (anodic or corroding) end

current barrier on the metal surface, usually in the form of an oxide film. This thin protective film forms, and a change in the overall potential of the metal occurs when a critical current density is exceeded at the anodes of the local corrosion cells on the metal surface.

Among the more common bimetallic corrosion cell problems in ship hulls are those formed by the mild steel hull with the bronze or nickel alloy propeller. Also above the waterline problems exist with the attachment of bronze and aluminium alloy fittings. Where aluminium superstructures are introduced, the attachment to the steel hull and the fitting of steel equipment to the superstructure require special attention. This latter problem is overcome by insulating the two metals and preventing the ingress of water as illustrated in Figure 27.2. A further development is the use of explosion-bonded aluminium/steel transition joints also illustrated. These joints are free of any crevices, the exposed aluminium to steel interface being readily protected by paint.

STRESS CORROSION Corrosion and subsequent failure associated with varying forms of applied stress is not uncommon in marine structures. Internal stresses produced by non-uniform cold working are often more dangerous than applied stresses. For example, localized corrosion is often evident at cold flanged brackets. A particular case of stress corrosion in marine structures has occurred with early wrought aluminium magnesium alloy rivets. With a magnesium content above about 5 per cent stress corrosion failures with cold driven rivets were not uncommon. Here the

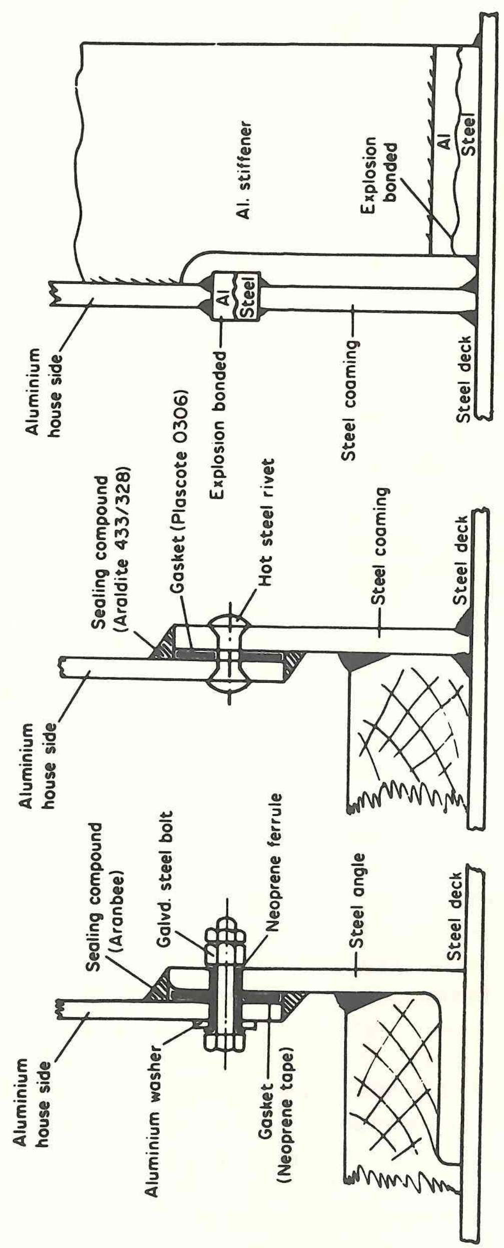


FIGURE 27.2 Aluminium to steel connections

corrosive attack is associated with a precipitate at the grain boundaries, produced by excessive cold working, which is anodic towards the solid solution forming the grains of the alloy. Failure occurs along an intergranular path. Specifications for aluminium/magnesium alloy rivets now limit the magnesium content.

CORROSION/EROSION Erosion is essentially a mechanical action but it is associated with electro-chemical corrosion in producing two forms of metal deterioration. Firstly, in what is known as 'impingement attack' the action is mainly electro-chemical but it is initiated by erosion. Air bubbles entrained in the flow of water and striking a metal surface may erode away any protective film that may be present locally. The eroded surface becomes anodic to the surrounding surface and corrosion occurs. This type of attack can occur in most places where there is water flow, but particularly where features give rise to turbulent flow. Sea water discharges from the hull are a particular case, the effects being worse if warm water is discharged.

Cavitation damage is also associated with a rapidly flowing liquid environment. At certain regions in the flow (often associated with a velocity increase resulting from a contraction of the flow stream) the local pressures drop below that of the absolute vapour pressure. Vapour cavities, that is areas of partial vacuum, are formed locally, but when the pressure increases clear of this region the vapour cavities collapse or 'implode'. This collapse occurs with the release of considerable energy, and if it occurs adjacent to a metal surface damage results. The damage shows itself as pitting which is thought to be predominantly due to the effects of the mechanical damage. However it is also considered that electrochemical action may play some part in the damage after the initial erosion.

Corrosion Control

The prevention of corrosion may be broadly considered in two forms, cathodic protection and the application of protective coatings.

CATHODIC PROTECTION Only where metals are immersed in an electrolyte can the possible onset of corrosion be prevented by cathodic protection. The fundamental principle of cathodic protection is that the anodic corrosion reactions are suppressed by the application of an opposing current. This superimposed direct electric current enters the metal at every point lowering the potential of the anode metal of the local corrosion cells so that they become cathodes.

There are two main types of cathodic protection installation, sacrificial anode systems and impressed current systems.

SACRIFICIAL ANODE SYSTEMS Sacrificial anodes are metals or alloys attached to the hull which have a more anodic, i.e. less noble, potential than steel when immersed in sea water. These anodes supply the cathodic protection current, but will be consumed in doing so and therefore require replacement for the protection to be maintained.

This system has been used for many years, the fitting of zinc plates in way of bronze propellers and other immersed fittings being common practice. Initially results with zinc anodes were not always very effective owing to the use of unsuitable zinc alloys. Modern anodes are based on alloys of zinc, aluminium, or magnesium which have undergone many tests to examine their suitability; high purity zinc anodes are also used. The cost, with various other practical considerations, may decide which type is to be fitted.

Sacrificial anodes may be fitted within the hull, and are often fitted in ballast tanks. However, magnesium anodes are not used in the cargo-ballast tanks of oil carriers owing to the 'spark hazard'. Should any part of the anode fall and strike the tank structure when gaseous conditions exist an explosion could result. Aluminium anode systems may be safely employed.

IMPRESSED CURRENT SYSTEMS These systems are applicable to the protection of the immersed external hull only. The principle of the systems is that a voltage difference is maintained between the hull and fitted anodes, which will protect the hull against corrosion, but not overprotect it thus wasting current. For normal operating conditions the potential difference is maintained by means of an externally mounted silver/silver chloride reference cell detecting the voltage difference between itself and the hull. An amplifier controller is used to amplify the micro-range reference cell current, and it compares this with the preset protective potential value which is to be maintained. Using the amplified D.C. signal from the controller a saturable reactor controls a larger current from the ship's electrical system which is supplied to the hull anodes. An A.C. current from the electrical system would be rectified before distribution to the anodes. Figure 27.3 shows such a system.

Originally consumable anodes were employed but in recent systems non-consumable relatively noble metals are used; these include lead/silver and platinum/palladium alloys, and platinized titanium anodes are also used.

A similar impressed current system employs a consumable anode in the form of an aluminium wire up to 45 metres long which is trailed behind the ship whilst at sea. No protection is provided in port.

Although the initial cost is high, these systems are claimed to be more flexible, to have a longer life, to reduce significantly hull maintenance, and to weigh less than the sacrificial anode systems.

Care is required in their use in port alongside ships or other unprotected steel structures.

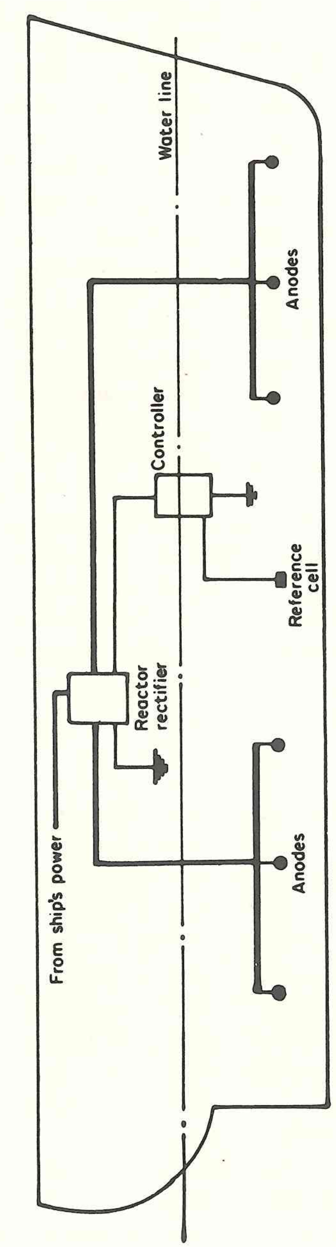


FIGURE 27.3 Impressed current cathode protection system

Paints

Paint consists of pigment dispersed in a liquid referred to as the 'vehicle'. When spread out thinly the vehicle changes in time to an adherent dry film. The drying may take place through one of the following processes.

(*a*) When the vehicle consists of solid resinous material dissolved in a volatile solvent, the latter evaporates after application of the paint, leaving a dry film.

(*b*) A liquid like linseed oil as a constituent of the vehicle may produce a dry paint film by reacting chemically with the surrounding air.

(*c*) A chemical reaction may occur between the constituents of the vehicle after application, to produce a dry paint film. The reactive ingredients may be separated in two containers ('two-pack paints') and mixed before application. Alternatively ingredients which only react at higher temperatures may be selected, or the reactants may be diluted with a solvent so that the reaction occurs only slowly in the can.

Corrosion-inhibiting paints for application to steel have the following vehicle types:

(*a*) *Bitumen or pitch* Simple solutions of bitumen or pitch are available in solvent naphtha or white spirit. The bitumen or pitch may also be blended by heat with other materials to form a vehicle.

(*b*) *Oil based* These consist mainly of vegetable drying oils, such as linseed oil and tung oil. To accelerate the drying by the natural reaction with oxygen, driers are added.

(*c*) *Oleo-resinous* The vehicle incorporates natural or artificial resins into drying oils. Some of these resins may react with the oil to give a faster drying vehicle. Other resins do not react with the oil but heat is applied to dissolve the resin and cause the oil to body.

(*d*) *Alkyd resin* These vehicles provide a further improvement in the drying time and film forming properties of drying oils. The name alkyd arises from the ingredients, alcohols and acids. Alkyds need not be made from oil, as an oil-fatty acid or an oil-free acid may be used.

(*Note*. Vehicle types (*b*) and (*d*) are not suitable for underwater service, and only certain kinds of (*c*) are suitable for such service.)

(*e*) *Chemical-resistant* Vehicles of this type show extremely good resistance to severe conditions of exposure. As any number of important vehicle types come under this general heading these are dealt with individually.

(i) *Epoxy resins* Chemicals which may be produced from petroleum and natural gas are the source of epoxy resins. These paints have very good adhesion, apart from their excellent chemical resistance. They may also have good flexibility and toughness where co-reacting resins are introduced. Epoxy resins are expensive owing to the removal of unwanted side products during their manufacture, and the gloss finish may tend to 'chalk' making it unsuitable for many external decorative finishes. These paints often consist of a 'two-pack' formulation, a solution of epoxy resin together with a solution of cold curing agent, such as an amine or a polyamide resin, being mixed prior to application. The mixed paint has a relatively slow curing rate at temperatures below 10°C. Epoxy resin paints should not be confused with epoxy-ester paints which are unsuitable for underwater use. Epoxy-ester paints can be considered as alkyd equivalents, as they are usually made with epoxy resins and oil-fatty acids.

(ii) *Coal tar/epoxy resin* This vehicle type is similar to the epoxy resin vehicle except that, as a two-pack product, a grade of coal tar pitch is blended with the resin. A formulation of this type combines to some extent the chemical resistance of the epoxy resin with the impermeability of coal tar.

(iii) *Chlorinated rubber and isomerized rubber* The vehicle in this case consists of a solution of plasticized chlorinated rubber, or isomerized rubber. Isomerized rubber is produced chemically from natural rubber, and it has the same chemical composition but a different molecular structure. Both these derivatives of natural rubber have a wide range of solubility in organic solvents, and so allow a vehicle of higher solid content. On drying, the film thickness is greater than would be obtained if natural rubber were used. High build coatings of this type are available, thickening or thixotropic agents being added to produce a paint which can be applied in much thicker coats. Coats of this type are particularly resistant to attack from acids and alkalis.

(iv) *Polyurethane resins* A reaction between isocyanates and hydroxyl-containing compounds produces 'urethane' and this reaction has been adapted to produce polymeric compounds from which paint film, fibres, and adhesives may be obtained. Paint films so produced have received considerable attention in recent years, and since there is a variety of isocyanate reactions, both one-pack and two-pack polyurethane paints are available. These paints have many good properties; toughness, hardness, gloss, abrasion resistance, as well as chemical and weather resistance. Polyurethanes are not used under water on steel ships, only on superstructures, etc., but they are very popular on yachts where their good gloss is appreciated.

(v) *Vinyl resins* Vinyl resins are obtained by the polymerization of organic compounds containing the vinyl group. The solids content of these paints is low; therefore the dry film is thin, and more coats are required than for most paints. As vinyl resin paints have poor adhesion to bare steel surfaces they are generally applied over a pretreatment primer. Vinyl paint systems are among the most effective for the underwater protection of steel.

(*f*) *Zinc-rich paints* Paints containing metallic zinc as a pigment in sufficient quantity to ensure electrical conductivity through the dry paint film to the steel are capable of protecting the steel cathodically. The pigment content of the dry paint film should be greater than 90 per cent, the vehicle being an epoxy resin, chlorinated rubber, or similar medium.

ANTI-FOULING PAINTS Anti-fouling paints consist of a vehicle with pigments which give body and colour together with materials toxic to marine vegetable and animal growth. Copper is the best known toxin used in anti-fouling paints.

To prolong the useful life of the paint the toxic compounds must dissolve slowly in sea water. Once the release rate falls below a level necessary to prevent settlement of marine organisms the anti-fouling composition is no longer effective. On merchant ships the effective period for traditional compositions was about 12 months. Demands in particular from large tanker owners wishing to reduce very high docking costs led to specially developed anti-fouling compositions with an effective life up to 24 months in the early 1970s. Subsequent developments of constant emission organic toxin antifoulings having a leaching rate independent of exposure time saw the paint technologists by chance discover coatings which also tended to become smoother in service. These so called self-polishing antifoulings with a lifetime that is proportional to applied thickness and therefore theoretically unlimited, smooth rather than roughen with time and result in reduced friction drag. Though more expensive than their traditional counterparts, given the claim that each 10 micron (10^{-3}mm) increase in hull roughness can result in a 1 per cent increase in fuel consumption their self polishing characteristic as well as their longer effective life, up to 5 years protection between drydockings, can be attractive to the shipowner.

Protection by Means of Paints

It is often assumed that all paint coatings prevent attack on the metal

covered simply by excluding the corrosive agency, whether air or water. This is often the main and sometimes the only form of protection; however there are many paints which afford protection even though they present a porous surface or contain various discontinuities.

For example certain pigments in paints confer protection on steel even where it is exposed at a discontinuity. If the reactions at the anode and cathode of the corrosion cell which form positive and negative ions respectively, are inhibited, protection is afforded. Good examples of pigments of this type are red lead and zinc chromate, red lead being an anodic inhibitor, and zinc chromate a cathodic inhibitor. A second mode of protection occurs at gaps where the paint is richly pigmented with a metal anodic to the basis metal. Zinc dust is a commercially available pigment which fulfils this requirement for coating steel in a salt water environment. The zinc dust is the sacrificial anode with respect to the steel.

Anti-fouling paints offer protection against vegetable and animal growth which can lead to increased resistance requiring additional power, hence fuel, to maintain the same speed. The greater the time spent at sea the less the fouling; but areas of operation and seasons also decide the amount of fouling, and with modern anti-fouling compounds the problem today is less important.

SURFACE PREPARATION Good surface preparation is essential to successful painting, the primary cause of many paint failures being the inadequacy of the initial material preparation.

It is particularly important before painting new steel that any millscale should be removed. Millscale is a thin layer of iron oxides which forms on the steel surface during hot rolling of the plates and sections. Not only does the non-uniform millscale set up corrosion cells as illustrated previously, but it may also come away from the surface removing any paint film applied over it.

The most common methods employed to prepare steel surfaces for painting are:

Blast cleaning
Pickling
Flame cleaning
Preparation by hand.

(*a*) *Blast cleaning* is the most efficient method for preparing the surface. Following the blast cleaning it is desirable to brush the surface, and apply a coat of priming paint as soon as possible since the metal is liable to rust rapidly.

There are two main types of blasting equipment available, an impeller wheel plant where the abrasive is thrown at high velocity against the metal surface, and a nozzle type where a jet of abrasive impinges on the metal surface. The latter type should preferably be fitted with vacuum recovery equipment, rather than allow the spent abrasive and dust to be discharged to atmosphere, as is often the case in ship repair work. Impeller wheel plants which are self-contained and collect the dust and re-circulate the clean abrasive are generally fitted within the shipbuilding shops.

Cast iron and steel grit, or steel shot which is preferred, may be used for the abrasive, but non-metallic abrasives are also available. The use of sand is prohibited in the United Kingdom because the fine dust produced may cause silicosis.

(*b*) *Pickling* involves the immersion of the metal in an acid solution, usually hydrochloric or sulphuric acid in order to remove the millscale and rust from the surface. After immersion in these acids the metal will require a thorough hot water rinse. It is preferable that the treatment is followed by application of a priming coat.

(*c*) Using an *oxy-acetylene flame* the millscale and rust may be removed from a steel surface. The process does not entirely remove the millscale and rust, but it can be quite useful for cleaning plates under inclement weather conditions, the flame drying out the plate.

(*d*) *Hand cleaning* by various forms of wire brush is often not very satisfactory, and would only be used where the millscale has been loosened by weathering, i.e. exposure to atmosphere over a long period.

Blast cleaning is preferred for best results and economy in shipbuilding; pickling which also gives good results can be expensive and less applicable to production schemes; flame cleaning is much less effective; and hand cleaning gives the worst results.

TEMPORARY PAINT PROTECTION DURING BUILDING After the steel is blast cleaned it may be several months before it is built into the ship and finally painted. It is desirable to protect the material against rusting in this period as the final paint will offer the best protection when applied over perfectly clean steel.

The formulation of a prefabrication primer for immediate application after blasting must meet a number of requirements. It should dry rapidly to permit handling of the plates within a few minutes, it should be non-toxic, and it should not produce harmful porosity in welds nor give off obnoxious fumes during welding or cutting. It must also be compatible with any subsequent paint finishes to be applied. Satisfactory formulations are available, for example a primer consisting of zinc dust in an epoxy resin.

PAINT SYSTEMS ON SHIPS The paint system applied to any part of a ship will be dictated by the environment to which that part of the structure is exposed. Traditionally the painting of the external ship structure was divided into three regions.

(*a*) Below the water-line where the plates are continually immersed in sea water.
(*b*) The water-line or boot topping region where immersion is intermittent and a lot of abrasion occurs.
(*c*) The topsides and superstructure exposed to an atmosphere laden with salt spray, and subject to damage through cargo handling.

However now that tougher paints are used for the ship's bottom the distinction between regions need not be so well defined, one scheme covering the bottom and water-line regions.

Internally by far the greatest problem is the provision of coatings for various liquid cargo and salt water ballast tanks.

(*a*) *Below the Water-line* The ship's bottom has priming coats of corrosion-inhibiting paint applied which are followed by an anti-fouling paint. Paints used for steels immersed in sea water are required to resist alkaline conditions. The reason for this is that an iron alloy immersed in a sodium chloride solution having the necessary supply of dissolved oxygen gives rise to corrosion cells with caustic soda produced at the cathodes. Further the paint should have a good electrical resistance so that the flow of corrosion currents between the steel and sea water is limited. These requirements make the standard non-marine structural steel primer red lead in linseed oil unsuitable for ship use below the water-line. Suitable corrosion-inhibiting paints for ships' bottoms are pitch or bitumen types, chlorinated rubber, coal tar/epoxy resin, or vinyl resin paints. The anti-fouling paints may be applied after the corrosion-inhibiting coatings and should not come into direct contact with the steel hull, since the toxic compounds present may cause corrosion.

(*b*) *Water-line or Boot Topping Region* Generally modern practice requires a complete paint system for the hull above the water-line. This may be based on vinyl and alkyd resins or on polyurethane resin paints.

(*c*) *Superstructures* Red lead or zinc chromate based primers are commonly used. White finishing paints are then used extensively for superstructures. These are usually oleo-resinous or alkyd paints which may be based on 'non-yellowing' oils, linseed oil-based paints which yellow on exposure being avoided on modern ships.

Where aluminium superstructures are fitted, under no circumstance should lead based paints be applied; zinc chromate paints are generally supplied for application to aluminium.

CARGO AND BALLAST TANKS Severe corrosion may occur in a ship's cargo tanks as the combined result of carrying liquid cargoes and sea water ballast, with warm or cold sea water cleaning between voyages. This is particularly true of oil tankers. Tankers carrying 'white oil' cargoes suffer more general corrosion than those carrying crude oils which deposit a film on the tank surface providing some protection against corrosion. The latter type may however experience severe local pitting corrosion due to the non-uniformity of the deposited film, and subsequent corrosion of any bare plate when sea water ballast is carried. Epoxy resin paints are used extensively within these tanks, and vinyl resins and zinc rich coatings may also be used.

Typical marine paint systems are shown in Table 27.2.

TABLE 27.2

Typical Marine Paint Systems for New Ships

Type of paint	*Coats*	*Dry film thickness*
1. *Ships bottom*		
(a) Blast primer or holding primer	1	25 microns
(b) (i) Chlorinated rubber anticorrosive system or	3	75 microns/coat
(ii) Vinyl–pitch anticorrosive system or	3	75 microns/coat
(iii) Pitch–epoxy	2	125 microns/coat
(c) (i) Economic antifouling or	2 sides 1 flat bottom	50 microns/coat
(ii) Premium antifouling or	2 sides 1 flat bottom	75 microns/coat
(iii) Advanced self-polishing antifouling	3	Depends on speed/ sailing time/time between docking
2. *Boottop and topsides*		
(a) Conventional system based on:		
(i) Water resistant vehicle incorporating corrosion inhibiting pigments plus	3	50 microns/coat
(ii) Oleo-resinous vehicle gloss coat with good abrasion resistance	1	40 microns
(b) High performance system based on:		
(i) Two pack epoxy red oxide primer plus	1	25 microns
(ii) Two pack epoxy high build coating plus	1	125 microns
(iii) Two pack epoxy based gloss finishing coat	2	50 microns/coat
3. *Superstructure – external*		
(a) Conventional system based on:		
(i) Water resistant vehicle incorporating corrosion inhibiting pigments plus	2	50 microns/coat

Type of paint	*Coats*	*Dry film thickness*
(ii) Alkyd resin vehicle undercoat plus	1	40 microns
(iii) Alkyd resin vehicle finishing coat with gloss and colour retention	1	40 microns
(b) High performance system based on:		
(i) Two pack epoxy red oxide primer plus	1	25 microns
(ii) Two pack epoxy high build coating plus	1	125 microns
(iii) Two pack polyurethane finishing coat with high chalk resistance, gloss and colour retention	1	40 microns
4. *Dry cargo holds*		
(i) Water resistant vehicle incorporating corrosion inhibiting pigments plus	2	50 microns/coat
(ii) Oleo-resinous vehicle with aluminium flake pigment	1	25 microns
5. *Tanks – crude oil*		
High performance two pack coal tar/epoxy	2	125 microns/coat
6. *Tanks – product and chemical tankers*		
(i) Two pack epoxy oxide primer	1	25 microns
(ii) Two pack epoxy high build coating	2	125 microns/coat

Further Reading

Adams and Hudson, 'The Corrosion of Cargo Ships and its Prevention', *Trans. I.N.A.*, 1956.

'Any old paint—not likely', *The Naval Architect*, July/August, 1985.

Daniel, 'A Study of Abrasive Blasted Surfaces and their Effect on Paint Thicknesses', *Trans. R.I.N.A.*, 1969.

Ellwood, 'Aspects of the Corrosion of Metals', *Trans. I.E.S.S.*, 1963–64.

Frederick, 'Surface Preparation of Ship Plate for New Construction', *R.I.N.A. Publication M.T.M.*, no. 3.

Introduction to Paint Technology, Oil and Colour Chemists Association.

Kulkarni, 'Ship-based Equipment to remove Marine Growth from the Hull', *The Naval Architect*, October, 1973.

'Marine coatings: efficiency, economy and long life remains key industry aims', *The Naval Architect*, February, 1987.

Morgan, 'Impressed Current Hull Protection', *Shipbuilding and Shipping Record*, 10 March, 1966.

'Recommended Practice for Protection of Ships Underwater and Boot-topping Plating from Corrosion and Fouling', *B.S.R.A.*, 1966.

Rogers, *Marine Corrosion*, International Monographs on Corrosion Science and Technology (Newnes, 1968).

Siverwright, 'The Case for Cathodic Protection', *Shipbuilding and Shipping Record*, International Marine Design and Equipment Number, 1967.

Telfer, 'Some Aspects of the External Maintenance of Tankers', *The Naval Architect*, July, 1972.

Townsin *et al.*, 'Speed, Power and Roughness: The Economics of Outer Bottom Maintenance', *The Naval Architect*, September, 1980.

Turner, *Introduction to Paint Chemistry* (Chapman and Hall, 1967).

West, 'Protection of Ships Hulls', *R.I.N.A. Publication M.T.M.*, no. 2.

28
Ventilation, Refrigeration, and Insulation

Adequate ventilating and air conditioning systems are installed in ships to provide reasonable comfort for the crew and passengers, and to maintain cargo at the correct temperature and humidity. Insulation is provided to maintain refrigerated cargo room temperatures, and to a lesser extent to maintain air conditioning requirements, and overcome acoustic problems in accommodation.

Ventilation

In most ships a combination of natural and mechanical ventilation is provided in the accommodation and machinery spaces. Mechanical supply is common, and a natural exhaust may be permitted in a number of compartments; but where fumes, etc., are present, for example from galleys, a mechanical exhaust is required. This is also the case with many public rooms, often crowded and where smoking is permitted. The mechanical supply is by means of light steel sheet trunking, with louvres at each outlet. Fans may be of the quiet running centrifugal type with a separately mounted motor.

The holds of most dry cargo ships are ventilated by a mechanical supply and natural exhaust system. Here the object is to reduce the hold temperatures if necessary and prevent large amounts of condensation accumulating on the hull and cargo. Often the cargo hold fans which are of the axial type are located in the mast houses, although they have been positioned in derrick posts where these posts are used to ventilate the tweens and holds (*see* Figure 28.1). Dry cargo ships may also be fitted with de-humidification facilities, controls being provided so that each hold can be supplied with dry air or outside air. If dry air is desired when the weather dew-point approaches or is above the temperature in the hold, the air supply or recirculating air may be drawn through a conditioning plant where it comes into contact with a moisture absorbing solution. A dry air fan then passes this de-humidified air to the cargo hold ventilation system.

Air conditioning is a common feature in the accommodation of modern ships. Room temperatures are controlled by a thermostat, heated or chilled air may then be supplied as required and humidity control is also provided. Trunking and louvres are similar to those for mechanical ventilation,

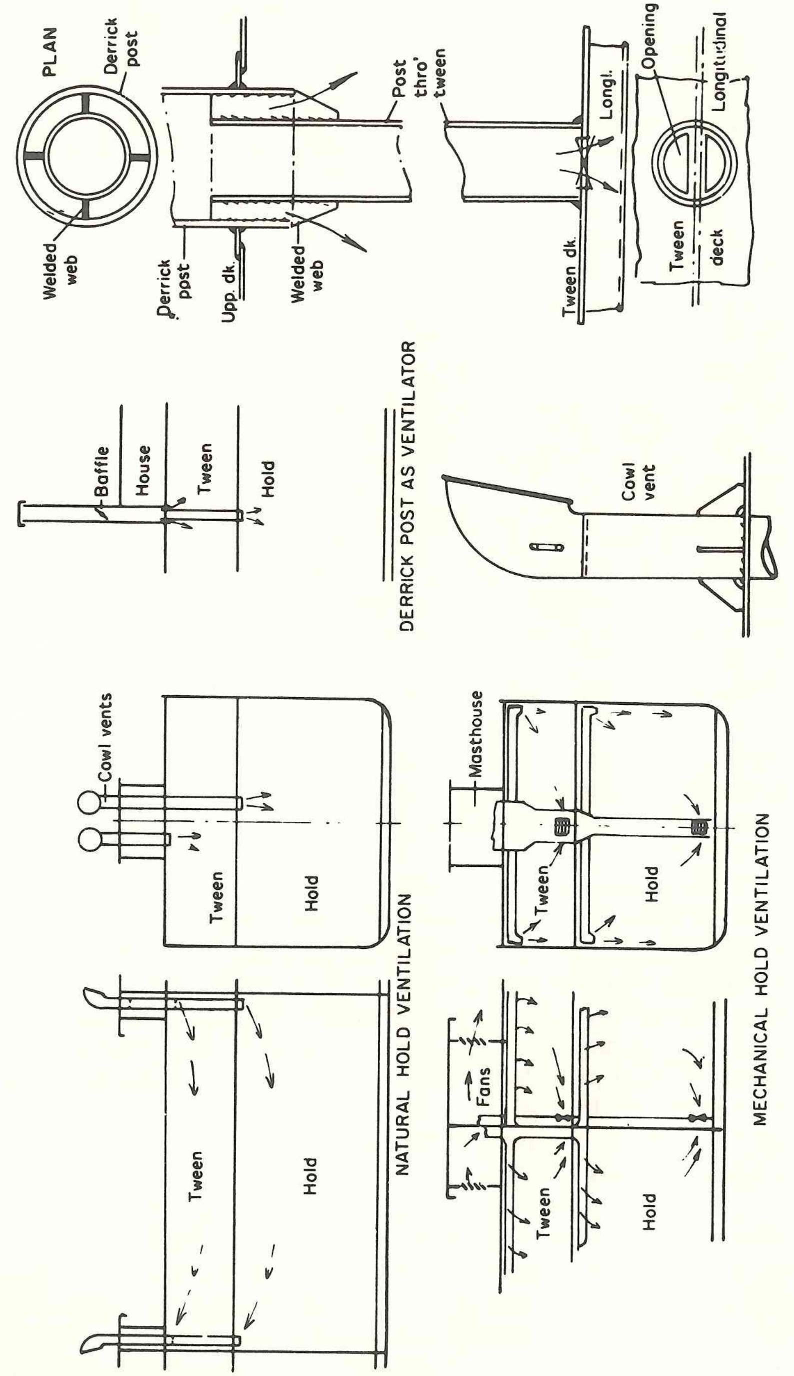


FIGURE 28.1 Hold ventilation

smaller bore trunking being possible if a high velocity system is introduced. Local air conditioning units are available and may serve an individual suite if desired, with their own control.

Refrigeration

Many perishable cargoes are carried in refrigerated compartments on dry cargo ships, and there are an appreciable number of vessels specifically designed for carrying refrigerated cargo only. The midship section of such a ship with the line of insulation is shown in Figure 28.2.

STOWAGE OF REFRIGERATED CARGO Chilled meat cargo is hung from the strengthened deck stiffening members, and the tween deck height is arranged to provide space below the hung carcasses for the circulation of air. Frozen meat is stacked in the holds of the ship. Fruits and vegetables are stowed in a manner which permits an adequate flow of air to be maintained around the crates, etc.

As a rule the refrigerated rooms in general cargo ships are made rectangular to keep down insulation costs.

REFRIGERATION SYSTEMS Brine made by dissolving calcium chloride in fresh water will have a freezing point well below the desired temperatures of the refrigerated compartments. Cold brine may be pumped at controlled rates to give the correct working temperature, and it is led from the evaporator of the refrigerating machine to pipes at the top of the cold compartment. The brine absorbs heat from the compartments and returns to the evaporator where it is again cooled and recirculated.

Air must be continually circulated where fruit is carried to disperse any pockets of carbon dioxide gas given off by the ripening fruit. The brine is then led into grid boxes and air drawn from the bottom of the compartments by fans is blown over the brine grids into the compartments via trunking arranged along the ceiling.

Insulation

As the steel hull structure is an excellent conductor of heat, some form of insulation must be provided at the boundaries of the refrigerated compartments if the desired temperatures are to be maintained economically.

Cork, glass fibre, and various foam plastics in sheet or granulated form may be used for insulating purposes, also air spaces which are less efficient.

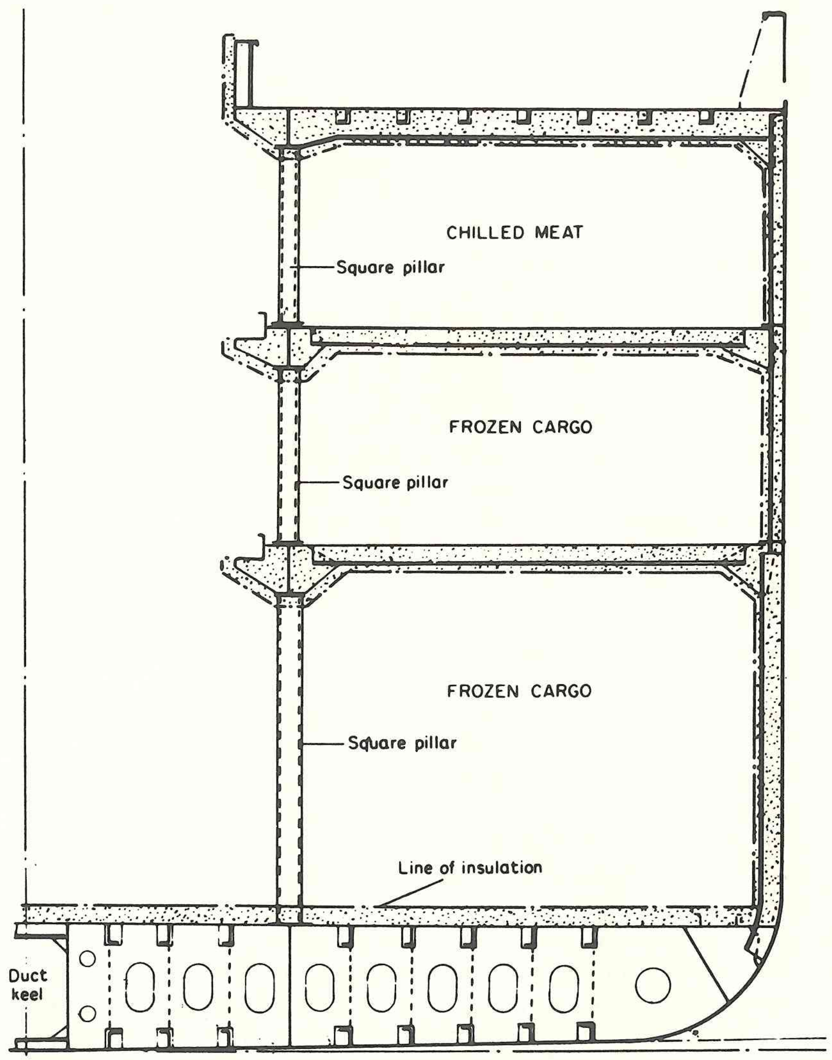


FIGURE 28.2 Midship section of refrigerated cargo ship

Glass fibre is often used in modern ships as it has a number of advantages over the other materials, for example, it is extremely light, vermin-proof, and fire-resistant, and it will not absorb moisture. On the decks and particularly at the tank top the insulation must often be load-bearing material, and cork might be preferred, but fibre glass can be supported by tongue and grooved board linings and wood bearers. The thickness of the insulation depends on the type of material used and the temperature to be maintained in the compartment. However the depth of stiffening members

often determines the final depth. Insulating material is retained at the sides by galvanized sheet steel or aluminium alloy sheet screwed to wood grounds on the frames or other stiffening members (*see* Figure 28.3).

Insulation on the boundaries of oil tanks, e.g. on the tank top above an oil fuel double bottom tank, has an air space of at least 50 mm between the insulation and steel. If a coating of approved oil-resisting composition with a thickness of about 5 mm is applied the air gap may be dispensed with.

Suitable insulated doors are provided to cold rooms in general cargo ships, and in refrigerated cargo ships the hold and tween hatches may be insulated. Patent steel covers or pontoon covers may be filled with a suitable insulating material to prevent heat losses.

A particular problem in insulated spaces is drainage, as ordinary scuppers would nullify the effects of the insulation. To overcome this problem brine traps are provided in drains from the tween deck chambers and insulated holds. The brine in the trap forms an effective seal against ingress of warm air, and it will not freeze, preventing the drain from removing water from the compartment (Figure 28.3).

Refrigerated Container Ships

Many of the container ships operating on trade routes where refrigerated cargoes were carried in conventional refrigerated cargo liners ('reefer ships') have provision for carrying refrigerated containers and have largely replaced the latter.

The I.S.O. containers (usually 20 foot size since with most refrigerated cargoes 40 foot size would be too heavy) are insulated, and below decks the end of each hold may be fitted with brine coolers which serve each stack of containers. Air from the brine coolers is ducted to and from each insulated container. Connection of each container to the cold air ducts is by means of an automatic coupling which is remotely controlled and can be engaged when the container is correctly positioned in the cell guides.

The below decks system described with fully insulated containers means that heavy insulation of the hold space is unnecessary. On the ships sides, bulkheads and deckhead about 50 mm of foam insulation with a fire retardent coating may be fitted and the tank top covered with 75 mm of cork and bitumastic. If provision is only made for the ship to carry a part load of under deck refrigerated containers these are generally arranged in the after holds adjacent to the machinery space.

On deck refrigerated containers are generally serviced by clip-on air cooled electric motor drive cooling units. The units are plugged into the ships electrical system by way of suitable deck sockets. Similar water cooled units have been used for below deck containers on short haul voyages.

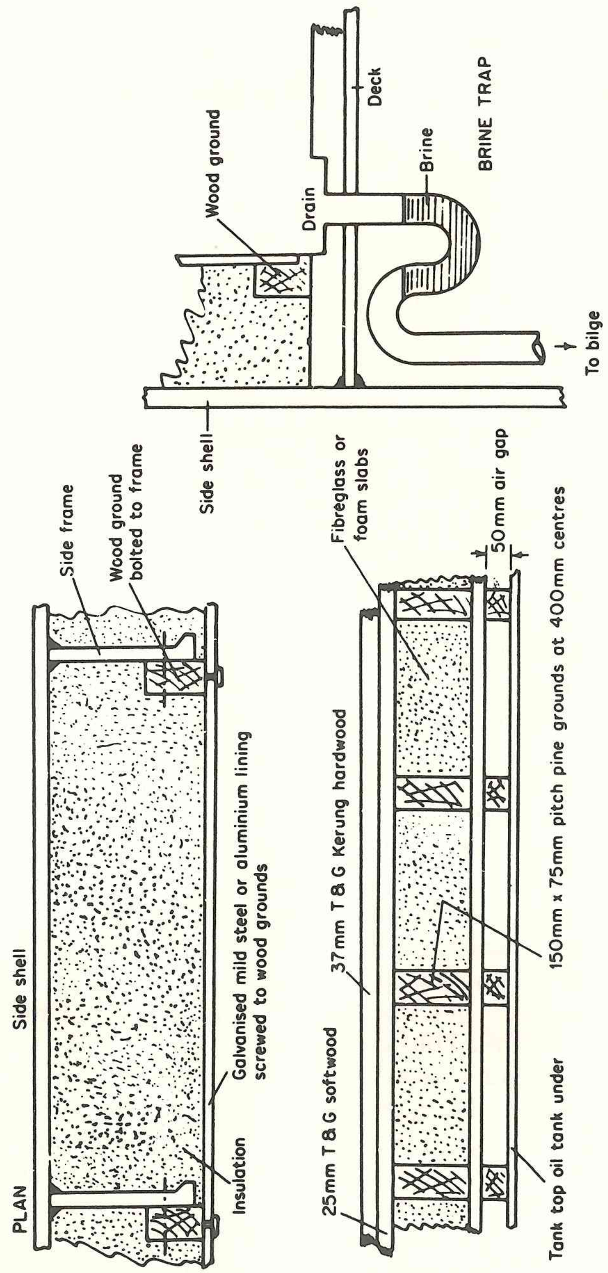


FIGURE 28.3 Insulation details

Further Reading

Arnold, 'Air Conditioning Development', *Shipbuilding and Shipping Record*, International Design and Equipment Number, 1967.

Jones and Macvicar, 'The Development of Air Conditioning in Ships', *Trans. I.N.A.*, 1959.

Lindberg, 'Present and Future Trends in Marine Air Conditioning and Ventilation', *Shipbuilding and Shipping Record*, Marine Design International, 1971.

Wren and Nohr Larsen, 'Marine Air Conditioning Plant—A Review of Design Principles', *Shipbuilding and Shipping Record*, Marine Design International, 1969.

Part 7

International Regulations

29
Inter-Governmental Maritime Organization

The Inter-Governmental Maritime Organization (IMO) is a specialized agency of the United Nations. It has as its objectives co-operation amongst national governments in technical matters concerning international shipping with a view to achieving the highest practical standards of safety at sea and efficiency of navigation. The functions of IMO, only as it affects ship construction, are dealt with in this book.

Organization of IMO

The Assembly which is the supreme governing body of IMO and consists of representatives of all member states (130 in April 1987) meets every two years and determines policy, the work programme, votes the budget, approves all recommendations made by IMO and elects Members of the Council and Maritime Safety Committee. The Council consists of an agreed number (32 in April 1987) of representatives of member states elected for a term of two years. It normally meets twice a year and is IMO's governing body between Assembly sessions. The Maritime Safety Committee members elected for a term of four years normally meets twice a year and deals with the technical work of IMO. In order to facilitate the technical work carried out by the Maritime Safety Committee various sub-committees are set up to deal with specific subjects such as tonnage measurement, fire protection, etc. There is a permanent secretariat with a staff of international civil servants located in London to service the organization.

Work of IMO

The Organization is responsible for convening and preparing international conferences on subjects within its sphere of action, for the purpose of concluding international conventions or agreements. Provided it is approved by an agreed majority of the members, a subsequent amendment to the convention proposed by a government that is party to the convention may be adopted. Conventions and amendments do not come into force until stipulated numbers of member countries have ratified, that is, adopted them.

Of particular relevance and dealt with in the following chapters are the following conventions:

International Convention on Tonnage Measurement, 1969
International Convention on Load Lines of Ships, 1966
International Convention for the Safety of Life at Sea (SOLAS), 1974.

The latter and its subsequent amendments and protocols includes requirements in respect of fire protection in ships which is dealt with in Chapter 32.

Relationship with National Authorities

Member countries have their own governmental agency concerned with maritime safety which drafts and enforces the shipping legislation of that country. The conventions and amendments are ratified by the member country when they are incorporated in that country's national legislation relating to ships registered in that country and which make international voyages. A national authority also has a responsibility in ensuring that ships which are not registered in that country but are visiting its ports are complying with the provisions of the Safety Conventions in force. Ships which are trading internationally are required to have current International Safety Convention Certificates issued by or on behalf of the governmental agency of the country in which they are registered. These consist of

(*a*) For passenger ships a certificate called a Passenger Ship Safety Certificate valid for not longer than one year.
(*b*) For cargo ships of 500 tons gross or more the following certificates:

- (i) A Cargo Ship Safety Construction Certificate valid for not more than five years.
- (ii) A Cargo Ship Safety Equipment Certificate valid for not more than two years. (In some countries only valid for one year.)
- (iii) A Cargo Ship Safety Radio Telegraphy Certificate or Cargo Ship Safety Radio Telephony Certificate.

Both passenger and cargo ships would have an International Load Line Convention Certificate valid for not more than five years. In addition each vessel would have an International Tonnage Certificate issued by or on behalf of the national authority.

Relationship with Classification Societies

The Classification Societies (*see* Chapter 4) have an international association which attends the IMO Assembly meetings on an observer basis. Many of the member countries of IMO have authorized different classification societies to issue one or more of the Safety Convention Certificates on their behalf. This is particularly true in respect of assignment and issuing of Load Line Certificates where Load Line surveys are often undertaken in a foreign port. The initials of the assigning classification society rather than the governmental agency are commonly observed on a ship's Plimsoll mark. Smaller countries with limited maritime technical expertise to service their governmental agency particularly if they have a large register of ships trading internationally may rely entirely on the classification societies to issue their Safety Convention Certificates.

Further Reading

Katsoulis, 'IMO Regulations for Ship Design', *R.I.N.A. Monograph* (M5).

Singh, 'International Conventions of Merchant Shipping', *British Shipping Laws*, 2nd Edition, vol. 8, Stevens and Sons.

30
Tonnage

Gross tonnage is a measure of the internal capacity of the ship and net tonnage is intended to give an idea of the earning or useful capacity of the ship. Various port dues and other charges may be assessed on the gross and net tonnages.

International Convention on Tonnage Measurement of Ships 1969

An International Conference on Tonnage Measurement was convened by IMO in 1969 with the intention of producing a universally acceptable system of tonnage measurement. The International Convention on Tonnage Measurement of Ships 1969 was prepared at this conference and this convention came into force on the 8th July, 1982. All ships constructed on or after that date are measured for tonnage in accordance with the 1969 Convention. Ships built prior to that date were if the owner so desired permitted to retain their existing tonnages for a period of 12 years from that date, i.e. all ships are required to be measured in accordance with the 1969 Convention by 18th July, 1994.

Tonnages

GROSS TONNAGE The gross tonnage (GT) is determined by the following formula:

$$GT = K_1 V$$

where
$K_1 = 0.2 + 0.02 \log_{10} V$
V = total volume of all enclosed spaces in cubic metres.

NET TONNAGE The net tonnage (NT) is determined by the following formula:

(1) For passenger ships (i.e. ships carrying 13 passengers or more)

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

(2) For other ships:

$$NT = K_2 V_c \left(\frac{4d}{3D}\right)^2$$

where

V_c = total volume of cargo spaces in cubic metres.
d = moulded draft amidships in metres (summer load line draft or deepest subdivision load line in case of passenger ships).
D = moulded depth in metres amidships.
$K_2 = 0.2 + 0.02 \log_{10} V_c$
$K_3 = 1.25 \dfrac{(GT + 10000)}{10000}$
N_1 = number of passengers in cabins with not more than 8 berths.
N_2 = number of other passengers.
$N_1 + N_2$ = total number of passengers the ship is permitted to carry.

The factor $\left(\frac{4d}{3D}\right)^2$ is not taken to be 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; and NT is not to be taken as less than 0.30 GT.

It will be noted that vessels with high freeboards, i.e. low draft to depth ($^d/_D$) ratios will have low net tonnages. Squaring this ratio can result in excessively low nett tonnages hence the limiting value of 0.30 GT.

Measurement

Measurement for tonnage and issue of an International Tonnage Certificate is the responsibility of the appropriate maritime authority in the country of registration of the ship. Most maritime authorities have authorised various classification societies and perhaps other bodies to act on their behalf to measure ships and issue the International Tonnage Certificate.

The volumes to be included in the calculation of gross and net tonnages are measured, irrespective of the fitting of insulation or other linings to the inner side of the shell or structural boundary plating in metal, i.e. the moulded dimensions are used. It is possible for the surveyor to compute tonnages directly from the moulded lines of the ship or computer stored offsets. This is in contrast to the previous regulations where the surveyor was required to physically measure spaces to the inside of frames and linings.

Compensated Tonnage

For a good many years the gross tonnage has been used as a measure for comparing the output of various shipbuilding countries. Gross tonnage was never intended to be used for statistical purposes and, although it may have served this purpose, it can give very misleading impressions. For example the building of a 65 000 gross ton passenger liner may involve considerably more man-hours and capital than the construction of a 150 000 gross ton oil tanker.

A system of compensated tonnage has been introduced and suggested as a means of overcoming this problem. Factors are given for each ship type and the gross tonnage of the vessel may be multiplied by the appropriate

TABLE 30.1

Compensated Tonnage Coefficients

Type		*Coefficient*
Cargo under	5000 tons dwt.	1.60
	5000 tons dwt. and over	1.00
	Passenger cargo	1.60
	High speed cargo liner	1.60
	Container ships	1.90
Tankers under	30 000 tons dwt.	0.65
	30 to 50 000 tons dwt.	0.50
	50 to 80 000 tons dwt.	0.45
	80 to 160 000 tons dwt.	0.40
	160 to 250 000 tons dwt.	0.35
	Over 250 000 tons dwt.	0.30
Multiple purpose (all sizes)		0.80
Bulk carriers under (incl. ore/oil)	30 000 tons dwt.	0.60
	30 to 50 000 tons dwt.	0.50
	50 to 100 000 tons dwt.	0.45
	Over 100 000 tons dwt.	0.40
Refrigerated cargo		2.00
Fish factory ships		2.00
Gas carriers and chemical tankers		2.20
Passenger ships		3.00
Ferry boats		2.00
Fishing vessels and misc. vessels		1.50

factor to give the compensated tonnage. Compensated tonnage factors agreed by the Association of West European Shipbuilders in 1968 are given in Table 30.1.

As an example the 65 000 gross ton passenger ship would have a compensated tonnage of 195 000 tons, and a 150 000 gross ton oil tanker (312 000 deadweight tons) a compensated tonnage of 45 000 tons.

Further Reading

Corkill, *The Tonnage Measurement of Ships—Towards a Universal System* (Fairplay Publications Ltd).

Wilson, 'The 1969 International Conference on Tonnage Measurement of Ships', *Trans. R.I.N.A.*, 1970.

31
Load Line Rules

Reference to 'rules' in this chapter means the rules applied in Britain, i.e. 'The Merchant Shipping (Load Line) Rules 1968 (S1 1968 No. 1053)' which incorporate the requirements of the International Convention on Load Lines of Ships 1966.

Freeboard Computation

Basic freeboards are given in the rules which are dependent on the length and type of vessel.

Ships are divided into types 'A' and 'B'. Type 'A' ships are those which are designed to carry only liquid cargoes in bulk, and in which the cargo tanks have only small access openings closed by watertight gasketed covers of steel or equivalent material. These vessels benefit from the minimum assignable freeboard. All ships which do not come within the provisions regarding Type 'A' ships are considered as Type 'B' ships.

As a considerable variety of ships will come within the Type 'B' category, a reduction or increase from the basic table Type 'B' freeboard is made in the following cases:

(*a*) Vessels having hatchways fitted with portable beams and covers on exposed freeboard or raised quarter decks, and within 25 per cent of the ship's length from the F.P. on exposed superstructure decks, are to have the basic freeboard increased.

(*b*) Vessels having steel weathertight covers fitted with gaskets and clamping devices, improved measures for the protection of the crew, better freeing arrangements, and satisfactory sub-division characteristics may obtain a reduction in the basic freeboard given for a Type 'B' ship. This reduction may be increased up to the total difference between the values for Type 'A' and Type 'B' basic freeboards. The Type 'B' ship, which is effectively adopting Type 'A' basic freeboard, is referred to as a Type 'B-100' and its final calculated freeboard will be almost the same as that for a Type 'A' ship. Other Type 'B' vessels which comply with not such severe sub-division requirements can be assigned a basic freeboard reduced by up to 60 per cent of the difference between 'B' and 'A' basic values.

Obtaining the maximum possible draft can be important in many Type 'B' vessels, and careful consideration at the initial design stage with regard to sub-division requirements can result in the ship being able to load to deeper drafts. This is particularly the case with bulk carriers since these vessels can often be designed to obtain the 'B-60' freeboards; and where this is impossible some reduction in freeboard may still be possible. The Convention allows freeboards between that assigned to a Type 'B' and a Type 'B-60' where it can be established that a one-compartment standard of sub-division can be obtained at the draft of a Type 'B' vessel, but not at the draft of a Type 'B-60'.

Ore carriers of normal layout arranged with two longitudinal bulkheads and having the side compartments as water ballast tanks, are particularly suited to the assignment of Type 'B-100' freeboards, where the bulkhead positions are carefully arranged. In the case of Type 'A', Type 'B-100', and Type 'B-60' vessels over 225 m the machinery space is also to be treated as a floodable compartment. The full sub-division requirements are given below.

Type	*Length*	*Sub-division requirements*
A	Less than 150 m	None
A	Greater than 150 m Less than 225 m	To withstand the flooding of any compartment within the cargo tank length which is designed to be empty when the ship is loaded to the summer water-line at an assumed permeability of 0.95
A	Greater than 225 m	As above, but the machinery space also to be treated as a floodable compartment with an assumed permeability of 0.85
B+	—	None
B	—	None
B–60	100 to 225 m	To withstand the flooding of any single damaged compartment within the cargo hold length at an assumed permeability of 0.95
B–60	Greater than 225 m	As above, but the machinery space also to be treated as a floodable compartment at an assumed permeability of 0.85
B–100	100 to 225 m	To withstand the flooding of any two adjacent fore and aft compartments within the cargo hold length at an assumed permeability of 0.95
B–100	Greater than 225 m	As above, but the machinery space, taken alone, also to be treated as a floodable compartment at an assumed permeability of 0.85

Damage is assumed as being for the full depth of the ship, with a penetration of 1/5 the beam clear of main transverse bulkheads. After flooding the final water-line is to be below the lower edge of any opening through which progressive flooding may take place. The maximum angle of heel is to be 15°, and the metacentric height in the flooded condition should be positive.

Having decided the type of ship, the computation of freeboard is comparatively simple, a number of corrections being applied to the rule basic freeboard given for Type 'A' and Type 'B' ships against length of ship. The length (L) is defined as 96 per cent of the total length on the water-line at 85 per cent of the least moulded depth, or as the length measured from the fore side of the stem to the axis of the rudder stock on the water-line, if that is greater.

The corrections to the basic freeboard are as follows:

(*a*) *Flush Deck Correction* The basic freeboard for a Type 'B' ship of not more than 100 m in length having superstructures with an effective length of up to 35 per cent of the freeboard length (L) is increased by:

$$7.5(100 - L)\left(0.35 - \frac{E}{L}\right) \text{ mm}$$

where E = effective length of superstructure in metres.

(*b*) *Block Coefficient Correction* Where the block coefficient C_b exceeds 0.68, the basic freeboard (as modified above, if applicable) is multiplied by the ratio

$$\frac{C_b + 0.68}{1.36}$$

C_b is defined in the rules as $\nabla/(L \,.\, B \,.\, d)$, where ∇ is the moulded displacement at a draft d, which is 85 per cent of the least moulded depth.

(*c*) *Depth Correction* The depth (D) for freeboard is given in the rules. Where D exceeds $L/15$ the freeboard is increased by $(D - (L/15))\,R$ mm, where R is $L/0.48$ at lengths less than 120 m and 250 at lengths of 120 m and above. Where D is less than $L/15$ no reduction is made, except in the case of a ship with an enclosed superstructure covering at least $0.6L$ amidships. This deduction, where allowed, is at the rate described above.

(*d*) *Superstructure Correction* Where the effective length of superstructure is $1.0L$, the freeboard may be reduced by 350 mm at 24 m length of ship, 860 mm at 85 m length, and 1070 mm at 122 m length and above. Deductions at intermediate lengths are obtained by linear interpolation. Where the total effective length of superstructures and trunks is less than $1.0L$ the deduction is a percentage of the above. These percentages are given in tabular form in the rules, and the associated notes give corrections for size of forecastles with Type 'B' ships.

(*e*) *Sheer Correction* The area under the actual sheer curve is compared with the area under a standard parabolic sheer curve, the aft ordinate of which (S_A) is given by $25(L/3 + 10)$ mm and the forward ordinate (S_F) by $2S_A$ mm. Where a poop or fo'c'sle is of greater than standard height, an addition to the sheer of the freeboard deck may be made.

The correction for deficiency or excess of sheer is the difference between the actual sheer and the standard sheer multiplied by $(0.75 - S/2L)$ where S is the total mean enclosed length of superstructure. Where the sheer is less than standard the correction is added to the freeboard. If the sheer is in excess of standard a deduction may be made from the freeboard if the superstructure covers $0.1L$ abaft and $0.1L$ forward of amidships. No deduction for excess sheer may be made if no superstructure covers amidships. Where superstructure covers less than $0.1L$ abaft and forward of amidships the deduction is obtained by linear interpolation. The maximum deduction for excess sheer is limited to 125 mm per 100 m of length.

If the above corrections are made to the basic freeboard, the final calculated freeboard will correspond to the maximum geometric summer draft for the vessel. The final freeboard may, however, be increased if the bow height is insufficient, or the owners request the assignment of freeboards corresponding to a draft which is less than the maximum possible. Bow height is defined as the vertical distance at the forward perpendicular between the water-line corresponding to the assigned summer freeboard and the top of the exposed deck at the side. This height should not be less than the values quoted in Paragraph 16, Schedule 5 of the Rules.

MINIMUM FREEBOARDS The minimum freeboard in the summer zone is the freeboard described above; however, it may not be less than 50 mm. In the tropical and winter zones the minimum freeboard is obtained by deducting and adding respectively 1/48th of the summer moulded draft. The tropical freeboard is, however, also limited to a minimum of 50 mm. The freeboard for a ship of not more than 100 m length in the winter North Atlantic zone is the winter freeboard plus 50 mm. For other ships, the winter North Atlantic freeboard is the winter freeboard. The minimum freeboard in fresh water is obtained by deducting from the summer or tropical freeboard the quantity:

$$\frac{\text{Displacement in S.W.}}{4 \times \text{TPC}} \text{ mm}$$

where TPC is the tonnes per cm immersion at the water-line, and displacement is in tonnes.

TIMBER FREEBOARDS If a vessel is carrying timber on the exposed decks it is considered that the deck cargo affords additional buoyancy and a greater degree of protection against the sea. Ships thus arranged are granted a smaller freeboard than would be assigned to a Type 'B' vessel, provided they comply with the additional conditions of assignment for timber-carrying vessels. No reduction of freeboard may be made in ships which already have Type 'A' or reduced Type 'B' freeboards. The freeboards are computed as described above, but have a different superstructure correction, this being modified by the use of different percentage deductions given in the rules for timber freeboards. Winter timber freeboard is obtained by adding to the summer timber freeboard 1/36th of the moulded summer timber draft. Winter North Atlantic timber freeboard is the same as for normal freeboards, and the tropical timber freeboard is obtained by deducting from the summer timber freeboard 1/48th of the moulded summer timber draft. The fresh water timber freeboard is determined as for normal freeboards.

Conditions of Assignment of Freeboard

(1) The construction of the ship must be such that her general structural strength will be sufficient for the freeboards to be assigned. The design and construction of the ship must be such that her stability in all probable loading conditions is sufficient for the freeboards assigned. Stability criteria are given in Paragraph 2 (2), Schedule 4 of the Rules.

(2) *Superstructure End Bulkheads* To be of efficient construction to the satisfaction of the Administration. The heights of the sills of openings at the ends of enclosed superstructures should be at least 380 mm above the deck.

(3) *Hatchways closed by Portable Covers with Tarpaulins* The coamings should be of substantial construction with a height above deck of at least 600 mm on exposed freeboard and R.Q.D. and on exposed superstructure decks within ¼ of the ship's length from F.P. (Position 1) and at least 450 mm on exposed superstructure decks outside ¼ of the ship's length from F.P. (Position 2).

The width of bearing surface for the covers should be at least 65 mm. Where covers are of wood the thickness should be at least 60 mm with a span of not more than 1.5 m. For mild steel portable covers, the strength is calculated with assumed loads. The assumed loads on hatchways in Position 1 may be not less than 1 tonne/sq. metre for ships 24 metres in length and should not be less than 0.75 tonnes/sq. metre for hatchways in Position 2. Where the ship's length is 100 m or greater the assumed loads on hatchways at Position 1 and Position 2 are 1.75 tonnes/sq. metre, and 1.30 tonnes/sq. metre respectively. At intermediate lengths the loads are obtained by interpolation.

The product of the maximum stress thus calculated and the factor 4.25 should not exceed the minimum ultimate strength of the material. The deflection is limited to 0.0028 times the span under these loads.

For portable beams of mild steel the assumed loads above are adopted, and the product of the maximum stress thus calculated and the factor 5 should not exceed the minimum ultimate strength of the material. Deflections are not to exceed 0.0022 times the span under these loads.

Mild steel pontoon covers used in place of portable beams are to have their strength calculated with the assumed loads above. The product of the maximum stress so calculated and the factor 5 should not exceed the minimum ultimate strength of the material, and the deflection is limited to 0.0022 times the span. Mild steel plating forming the tops of the covers should have a thickness which is not less than 1 per cent of the stiffener spacing or 6 mm if that is greater. Covers of other material should be of equivalent strength. Carriers and sockets are to be of substantial construction and where rolling beams are fitted it should be ensured that beams remain in position when the hatchway is closed.

Cleats are set to fit the taper of wedges. They are at least 65 mm wide, spaced not more than 600 mm centre to centre; and not more than 150 mm from the hatch covers. Battens and wedges should be efficient and in good condition. Wedges should be of tough wood or equivalent material, with a taper of not more than 1 in 6, and should be not less than 13 mm thick at the toes.

At least two tarpaulins in good condition should be provided for each hatchway, and should be of approved material, strength, and waterproof. Steel bars or equivalent are to be provided to secure each section of the hatchway covers after the tarpaulins are battened down, and covers of more than 1.5 m in length should be secured by at least two such securing appliances.

(4) *Hatchways closed by Weathertight Steel Covers* Coaming heights are as for those hatchways with portable beam covers. This height may be reduced or omitted altogether on condition that the Administration is satisfied that the safety of the ship is not thereby impaired. Mild steel covers should have their strength calculated assuming the loads given previously. The product of the maximum stress thus calculated and the factor of 4.25 should not exceed the minimum ultimate strength of the material, and deflections are limited to not more than 0.0028 times the span under these loads. Mild steel plating forming the tops of the covers should not be less in thickness than 1 per cent of the spacing of stiffeners or 6 mm if that is greater. The strength and stiffness of covers made of other materials is to be of equivalent strength.

Means of securing weathertightness should be to the satisfaction of the Administration, the tightness being maintained in any sea condition.

(5) *Machinery Space Openings* These are to be properly framed and efficiently enclosed by steel casings of ample strength. Where casings are not protected by other structures their strength is to be specially considered. Steel doors to be fitted for access should have the sills at least 600 mm above the deck in Position 1, and at least 380 mm above the deck in Position 2. Fiddley, funnel, or machinery space ventilator coamings on exposed decks are to be as high above deck as reasonable.

(6) *Other Openings in Freeboard and Superstructure Decks* Manholes and flush scuttles in Positions 1 or 2 or within superstructures other than enclosed superstructures should be closed by substantial weathertight covers. Other openings than those considered are to be protected by an enclosed superstructure or deckhouse, or companionway of equivalent strength. Doors for access should be of steel, and the sills should have the same heights as above.

(7) *Ventilators* Should have steel coamings and where they exceed 900 mm in height they should be specially supported. In Position 1 ventilator coamings should be of height 900 mm above deck, and in Position 2 760 mm above deck. Vent openings should be provided with efficient weathertight closing appliances except in the case of coamings exceeding 4.5 m in height in Position 1 and 2.3 m in height in Position 2, above deck.

(8) *Air Pipes* Exposed parts of pipe shall be of substantial construction. The height from the deck should be at least 760 mm on the freeboard deck, and 450 mm on superstructure decks. A lower height may be approved if these heights interfere with working arrangements. Permanently attached means of closing the pipe openings should be provided

(9) *Cargo Ports and other similar Side Openings* Below the freeboard deck to be fitted with watertight doors to ensure the ship's structural integrity. Unless permitted by the Administration the lower edge of such openings should not be below a line drawn parallel to the freeboard deck at side, which has at its lowest point the upper edge of the uppermost load line.

(10) *Scuppers, Inlets, and Discharges* Discharges led through the shell either from spaces below the freeboard deck or from within superstructures and deckhouses on the freeboard deck fitted with weathertight doors should be fitted with efficient and accessible means for preventing water from passing inboard. Normally this should be an automatic non-return valve with means of closing provided above the freeboard deck. Where the vertical distance from the summer water-line to the inboard end of the discharge pipe exceeds $0.02L$ the discharge may have two automatic non-return valves without positive means of closing, provided the inboard valve is always accessible. Where the distance exceeds $0.02L$ a single automatic non-return valve without positive means of closing may be accepted. In manned machinery spaces, main and auxiliary sea inlets and discharges in connection with the operation of machinery may be controlled locally. Scuppers and discharge pipes originating at any level and penetrating the shell either more than 450 mm below the freeboard deck or less than 600 mm above the summer water-line should be fitted with an automatic non-return valve. Scuppers leading from superstructures or deckhouses not fitted with weathertight doors should be led overboard.

(11) *Side Scuttles* Below the freeboard deck or within the enclosed superstructures side scuttles should be fitted with efficient hinged, watertight, inside deadlights. No side scuttle should be fitted with its sill below a line drawn parallel to the freeboard deck at side and having its lowest point 2.5 per cent of the ship's breadth above the summer water-line or 500 mm whichever is the greater distance.

(12) *Freeing Ports* The minimum freeing port area (A) on each side of the ship where sheer in way of the well is standard or greater than standard, is given, in square metres, by—

$A = 0.7 + 0.035l$ where l is the length of bulwark in the well and is less than 20 m

and $A = 0.07l$ where l is greater than 20 m.

In no case need l be greater than $0.7L$. If the bulwark is greater than 1.2 m in height A is increased by 0.004 sq. m/m of length of well for each 0.1 m difference in height. If the bulwark is less than 0.9 m in height, A is reduced by 0.004 sq. m/m of length of well for each 0.1 m difference in height. Where there is no sheer A is increased by 50 per cent and with less than standard sheer the per cent increase is obtained by interpolation.

The lower edges of freeing ports should be as near the deck as practicable. Two-thirds of the freeing port area is required to be provided in the half of the well nearest the lowest point of the sheer curve, where the deck has sheer. Openings in the bulwarks are protected by bars spaced approximately 230 mm apart. If shutters are fitted, these should be prevented from jamming.

(13) *Protection of Crew* Efficient guard-rails or bulwarks of minimum height 1 metre are to be fitted on all exposed parts of freeboard and superstructure decks. A lower rail may be permitted by the Administration. The maximum vertical spacing between deck and lower rail is 230 mm, and between other rails is 380 mm.

Satisfactory means should be provided for protection of crew in getting to and from their quarters and other parts used in the working of the ship.

SPECIAL CONDITIONS OF ASSIGNMENT FOR TYPE 'A' SHIPS

(1) *Machinery Casings* To be protected by an enclosed poop or bridge of standard height, or deckhouse of equivalent strength and height. The casing may be exposed if there are no doors fitted giving access from the freeboard deck, or if a weathertight door is fitted and leads to a passageway separated from the stairway to the engine room by a second weathertight door of equivalent material.

(2) *Gangway and Access* An efficiently constructed fore and aft gangway should be fitted at the level of the superstructure deck between poop and midship bridge or deckhouse, or equivalent means such as passages below deck. If houses are all aft, satisfactory arrangements should be made to allow crew to reach all parts of the ship for working purposes.

(3) *Hatchways* All exposed hatchways on freeboard and forecastle decks or on top of expansion trunks are to be provided with efficient watertight covers of steel or equivalent material.

(4) *Freeing Arrangements* Should have open rail fitted for at least half the length of the exposed parts of the weather deck, with the upper edge of the sheer strake being kept as low as possible. Where superstructures are connected by trunks, open rails should be fitted for the whole length of the exposed parts of the freeboard deck in way of the trunk.

Further Reading

Murray-Smith, 'The 1966 International Conference on Load Lines', *Trans. R.I.N.A.*, 1969.

32
Structural Fire Protection

Of the requirements of the International Conventions for the Safety of Life at Sea those having a particular influence on ship construction are the requirements relating to structural fire protection. Varying requirements for vessels engaged in international voyages are given for passenger ships carrying more than thirty-six passengers, passenger ships carrying not more than thirty-six passengers, cargo ships and tankers.

Requirements

Ships carrying more than thirty-six passengers are required to have accommodation spaces and main divisional bulkheads and decks which are generally of incombustible material in association with either an automatic fire detection and alarm system or an automatic sprinkler and alarm system. The hull, superstructure, and deckhouses are subdivided by 'A' class divisions into main vertical zones the length of which on any one deck should not exceed 40 m. Main horizontal zones of 'A' class divisions are fitted to provide a barrier between sprinklered and non-sprinklered zones of the ship. Bulkheads within the main vertical zones are required to be 'A', 'B' or 'C' class divisions depending on the fire risk of the adjoining spaces and whether adjoining spaces are within sprinkler or non-sprinkler zones.

Passenger vessels carrying not more than thirty-six passengers are required to have the hull, superstructure and deckhouses subdivided into main vertical zones by 'A' class divisions. The accommodation and service spaces are to be protected either by all enclosure bulkheads within the space being of at least 'B' class divisions or only the corridor bulkheads being of at least 'B' class divisions where an approved automatic fire detection and alarm system is installed.

Cargo ships exceeding 500 tonnes gross are generally to be constructed of steel or equivalent material and to be fitted with one of the following methods of fire protection in accommodation and service spaces.

'Method Ic' All internal divisional bulkheads constructed of non-combustible 'B' or 'C' class divisions and no installation of an automatic sprinkler, fire detection and alarm system in the accommodation and service spaces, except smoke detection and manually operated alarm points which are to be installed in all corridors, stairways and escape routes.

'Method IIc' An approved automatic sprinkler, fire detection and fire alarm system is installed in all spaces in which a fire might be expected to originate, and in general there is no restriction on the type of divisions used for internal bulkheads.

'Method IIIc' A fixed fire detection and fire alarm system is installed in all spaces in which a fire might be expected to originate, and in general there is no restriction on the type of divisions used for internal bulkheads except that in no case must the area of any accommodation space bounded by an 'A' or 'B' class division exceed 50 square metres.

Crowns of casings of main machinery spaces are to be of steel construction and insulated. Bulkheads and decks separating adjacent spaces are required to have appropriate A, B or C ratings depending on the fire risk of adjoining spaces. Cargo spaces of ships 2000 tonnes gross and over are to be protected by a fixed gas fire-extinguishing system or its equivalent unless they carry bulk or other cargoes considered by the authorities to be a low fire risk. Cargo ships carrying dangerous goods are subject to special fire protection precautions.

In the construction of tankers, particular attention is paid to the exterior boundaries of superstructures and deckhouses which face the cargo oil tanks. Accommodation boundaries facing the cargo area are insulated to A60 standard, no doors are allowed in such boundaries giving access to the accommodation and any windows are to be of non-opening type and fitted with steel covers if in the first tier on the main deck. Bulkheads and decks separating adjacent spaces of varying fire risk are required to have appropriate A, B, and C ratings within the accommodation space. For new tankers of 20 000 tonnes deadweight and upwards the cargo tanks deck area and cargo tanks are protected by a fixed deck foam system and a fixed inert gas system (*see* Chapter 26). Tankers of less than 2000 tonnes deadweight are provided with a fixed deck foam system in way of the cargo tanks.

'A', 'B' and 'C' Class Divisions

'A' class divisions are constructed of steel or equivalent material and are to be capable of preventing the passage of smoke and flame to the end of a one-hour standard fire test. A plain stiffened steel bulkhead or deck has what is known as an A–O rating. By adding insulation in the form of approved incombustible materials to the steel an increased time is taken for

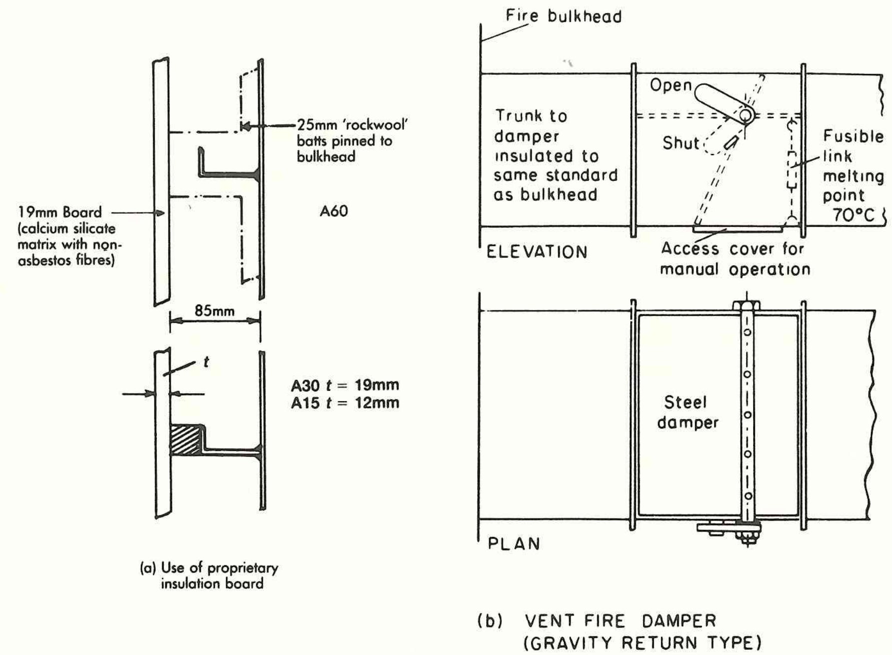


FIGURE 32.1

the average temperature of the unexposed side to rise to 139°C above the original temperature or not more than 180°C at any one point above the original temperature during the standard fire test. The 'A' class division rating is related to this time as follows.

Class	*Time (min)*
A–60	60
A–30	30
A–15	15
A–0	0

Figure 32.1 shows typical steel divisions with typical proprietary non-asbestos fibre reinforced silicate board insulation. 'B' class divisions are those which are constructed as to be capable of preventing the passage of flame to the end of half an hour of the standard fire test. Various patent board materials are commonly used where 'B' class divisions are required and there are two ratings B–0 and B–15. These relate to the insulation value such that the average temperature of the unexposed side does not rise more than 139°C above the original temperature and at any one point more than 225°C above the original temperature when the material is subjected to the standard fire test within the following times.

Class	*Time (min)*
B–15	15
B–0	0

'C' class divisions are constructed of approved incombustible materials but do not need to meet with any specified requirements relative to passage of smoke and flame nor temperature rise.

The standard fire test referred to is a test in which a specimen of the division with a surface area of not less than 4.65 sq. m and height or length of 2.44 m is exposed in a test furnace to a series of time-temperature relationships, defined by a smooth curve drawn through the following points.

At end of first 5 minutes	538°C
At end of first 10 minutes	704°C
At end of first 30 minutes	843°C
At end of first 60 minutes	927°C

Some typical examples of fire divisions are given below for a passenger ship carrying more than thirty-six passengers.

Bulkhead	*Adjacent compartments*	*Class*
Main fire zone	Galley/passageway	A–60
Main fire zone	Wheelhouse/passageway	A–30
Within fire zone	Fan room/stairway	A–15
Within fire zone	Cabin/passageway (non-sprinklered zone)	B–15
Within fire zone	Cabin/passageway (sprinklered zone)	B–0

Openings in Fire Protection Divisions

Generally openings in fire divisions are to be fitted with permanently attached means of closing which have the same fire resisting rating as the division. Suitable arrangements are made to ensure that the fire resistance of a division is not impaired where it is pierced for the passage of pipes, vent trunks, electrical cables, etc.

Greatest care is necessary in the case of openings in the main fire zone divisions. Door openings in the main fire zone bulkheads and stairway enclosures are fitted with fire doors of equivalent fire integrity and are self-closing against an inclination of 3½° opposing closure. Such doors are capable of closure from a control station either simultaneously or in groups and also individually from a position adjacent to the door. Vent trunking runs are ideally contained within one fire zone but where they must pass through a main fire zone bulkhead or deck a fail safe automatic-closing fire damper is fitted within the trunk adjacent to the bulkhead or deck. This usually takes the form of a steel flap in the trunk which is held open by a

weighted hinge secured by an external fusible link. The flap must also be capable of being released manually and there is some form of indication as to whether the flap is open or closed (*see* Figure 32.1).

Protection of Special Category Spaces

A special category space is an enclosed space above or below the bulkhead deck used for the carriage of motor vehicles with fuel for their own propulsion in their own tanks and to which passengers have access. Obvious examples are the garage spaces in ro-ro passenger ferries and vehicle decks in ro-ro cargo ships. Such spaces cannot have the normal main vertical fire zoning without interfering with the working of the ship.

Equivalent protection is provided in such spaces by ensuring that the horizontal and vertical boundaries of the space are treated as main fire zone divisions and an efficient fixed fire-extinguishing system is fitted within the space. This takes the form of a fixed pressure water spraying system generally in association with an automatic fire detection system. Special scupper arrangements are provided to clear the deck of the water deposited by the system in the event of a fire to avoid a drastic reduction in stability.

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