SECTION 1

MERCHANT SHIP CONSTRUCTION

MERCHANT SHIP CONSTRUCTION

PART I

CLASSIFICATION OF SHIPS

Purposes—To ensure that ships are properly built, equipped and maintained, a number of 'Classification Societies' have been formed and have drawn up rules governing the construction of ships. The Societies have surveyors, who see that the ships are built in accordance with the rules and who also survey the ships periodically, to make sure that they are kept in proper condition. Each society also keeps and publishes a 'Register Book', in which all the important particulars of each ship are faithfully and accurately recorded.

British Classification Societies—The British Society is 'Lloyd's Register of Shipping'. The French Society 'The Bureau Veritas', also has a British Committee.

It should be remembered that the societies only classify ships and are a separate body from the underwriters who insure them.

The Rules—The rules of the different societies vary somewhat in detail, but are mainly very similar. They are not arbitrary and other forms of construction are allowed if they give equivalent strength.

In order to avoid confusion, Lloyd's Rules have been followed throughout this Book.

Classes of Ships—Ships built to the satisfaction of the Societies are assigned a Class, which they normally retain throughout their life, provided that they submit themselves for the required surveys and are properly maintained.

Lloyd's Rules quote a number of class notations, principally:—

100A1. All sea-going ships, built for general service.

100A1 bulk carrier. To carry dry cargoes in bulk.

100A1 container ship. To carry containers.

100A1 oil tanker. To carry oil in bulk.

100A1 chemical tanker. To carry chemicals in bulk.

100A1 liquified gas tanker. To carry liquified gases in bulk.

100A1 liquified gas carrier. To carry liquified gases in bulk.

100A1 for restricted service. For service in specified or protected waters, on specified routes, within specified operating areas, etc.

Additional notations (e.g. "strengthened for heavy cargoes") may be added to any of the above.

There are also classes for other special-purpose vessels, such as tugs, fishing vessels, trawlers, etc.

Equipment—If the ship's equipment complies in full with Lloyd's requirements, the figure 1 is included in the class (e.g. 100A1); if not, the ship will not normally be classed. In some special cases, however, the full equipment may not be considered essential and Lloyds may accept less or other equipment; the ship will then be classed 100A— or 100A.

Equipment comprises anchors, cables, mooring ropes, towing and stream wires.

Ice Class Notations—Ships which are specially strengthened for navigating in ice may be given an 'ice class notation'. There are four ice classes, based on Baltic ice conditions:—

Class 1*. Ships intended to navigate in extreme ice conditions.

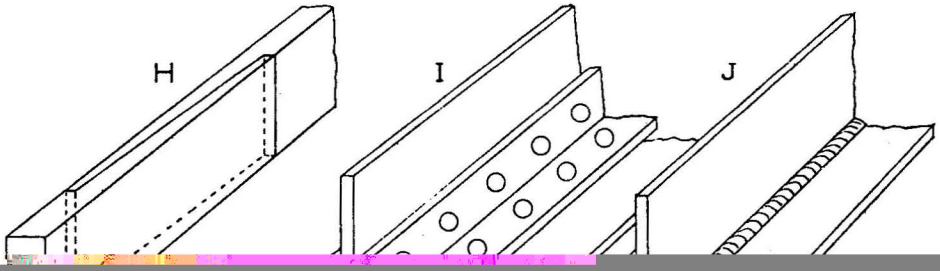
Class 1. Ships intended to navigate in severe ice conditions

CONNECTIONS

General—The various parts of a ship must be properly connected together if the ship is to be strong and rigid. The strength of any connection should,

A

CONNECTIONS (Continued)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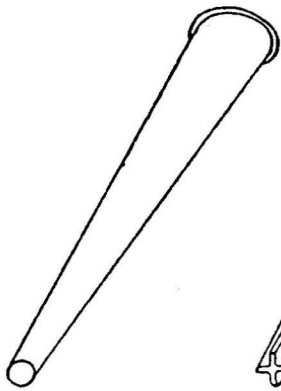
STRENGTHENING OF JOINTS AND PARTS

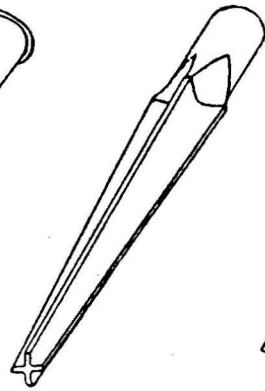
General—It is often necessary to support plating, etc., against distortion, to give greater rigidity and strength to joints, or to make up for lost strength in parts which have been cut away.

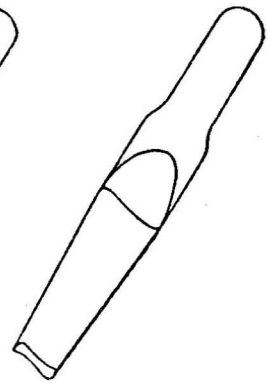
Stiffeners (Sketch R)—Large areas

RIVETING

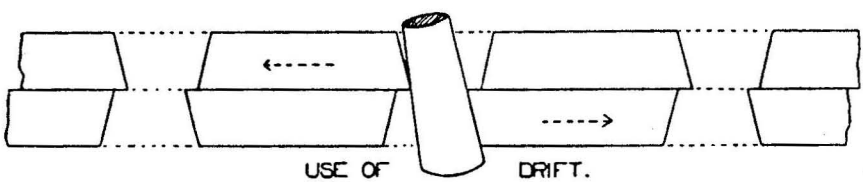


DRIFT PUNCH.

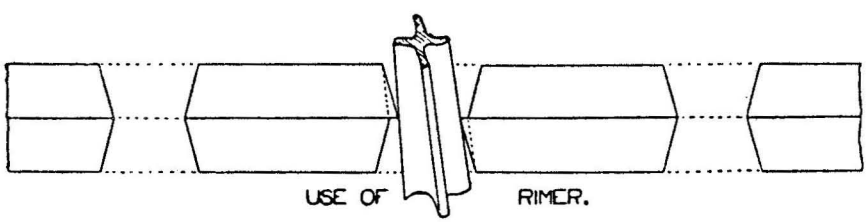




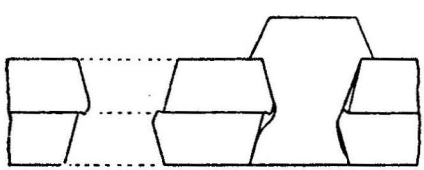
RIMERS



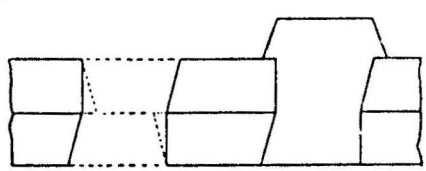
USE OF DRIFT.



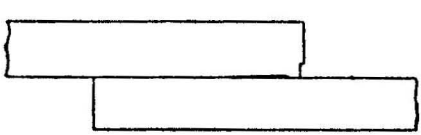
USE OF RIMER.



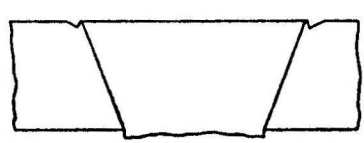
DRIFTED HOLE.



RIMERED HOLE.



CAULKED JOINT.



CAULKED RIVET.

RIVETING.

Holes which correspond are termed 'fair holes', whilst those which do not do so are termed 'unfair', 'blind', or 'partially blind'.

Unfair holes must be cleared before rivets are put into them. The tools which are used for this purpose are Rimers and Drift Punches, each of which has its own use and should not be used to do the work of the other. The drift punch should be used where holes have been punched correctly, but where the plates have not been put together quite truly. In other words, it is used as a sort of lever to 'square up' the plates. The rimer must be used where one or two holes of a row are not correctly punched. It is a cutting tool and is put into the hole and turned around until the protruding edges have been scraped off.

Caulking—Joints and rivets in watertight or oiltight work must always be caulked. This requires skilful and careful work.

Plates and bars are caulked by cutting into them with a special tool, so as to drive a small piece of steel from the edge hard up against the other surface. Parts which have to be caulked are arranged, wherever possible, so that the caulking edge faces upward, or to the right, in order that the workman can use his tools on them the more easily. Where edges which would normally finish flush with each other are to be caulked, one is stopped a little short of the other to facilitate the work (as in the connection of the garboard strake to a bar keel).

Rivets may be caulked by cutting into the plate around the rivet, so as to drive a small piece of steel hard up under the rivet head.

ELECTRIC ARC WELDING

General—One wire from an electric supply is connected to the work, whilst the other is connected to a steel rod, which is called an 'electrode'. The rod is allowed to touch the work and is then withdrawn for a short distance. This creates an electric arc, the heat of which melts the electrode and the plate edges, forming a pool of molten metal, which later cools to form a solid joint. The electrode is covered with a 'flux', which melts with the electrode, coating the molten drops of metal as they form and dripping down into the joint with them. It then floats to the surface of the molten metal in the joint and forms a protective layer of 'slag' which prevents the joint-metal from becoming oxidised. The slag is removed after cooling.

Fluxes—the main purposes of a flux are to prevent oxygen and nitrogen from attacking the hot weld-metal and to combine with and to float-out any impurities from the molten metal. The oxygen and nitrogen come mainly from the air, so the flux must be capable of keeping air away from the joint until it has cooled.

Oxygen, if present, will combine with the hot steel to form iron oxides, which may remain in and weaken the joint. It may also combine with some of the carbon in the steel to form carbon monoxide gas. This would weaken the steel by removing carbon; whilst some of the gas-bubbles might be trapped in the metal as it cools, causing cavities, called 'blow holes' in the joint.

Nitrogen can be absorbed by molten steel, causing the weld metal to become hard, brittle and liable to crack.

The composition of the flux varies in different electrodes, but it usually contains four main ingredients:—

(i) A combustible material, such as wood-pulp or 'alpha-flock', which burns to form carbon monoxide and hydrogen gases. These form a cloud of gas called a 'gas shield' around the arc during welding and keep out the air.

(ii) An 'arc-stabiliser' to help to maintain a steady electric arc and to produce a hard, brittle slag which can easily be chipped off. Various materials may be used for this: one common one being 'Rutile', which is a natural ore of titanium oxide.

(iii) 'Fluxing' materials usually silicates, such as asbestos. These combine with oxides and other impurities in the molten steel and float them out into the slag.

(iv) 'Alloying' elements, to replace any important constituents which may be burned out of the steel during welding. These are mainly manganese and carbon.

Building-up of Welds—In hand welding, it is not usually possible to deposit enough metal to fill the joint in one operation. In this case, a continuous layer of weld-metal, called a 'run', is first deposited all along the bottom of the joint. The 'slag', or protective coating of flux, which forms over the top of this run, is then removed and a second run is made on the top of the first. This is repeated until the joint has been completely built up.

Types of Weld—

Butt Welds are usually prepared by chamfering-off, or 'Veeing' the plate edges, so that the angle between them is about 60° and by spacing the plates so that there is a small gap between them at the bottom of the 'V'. A series of runs of welding is made on the Veed side and when this has been completely filled-in, one run, called a 'back run', is made on the other side of the joint. In the figure, the runs are numbered in the order in which they are made, whilst B indicates the back run. Thick plates may be double-veed: that is, veed on both sides.

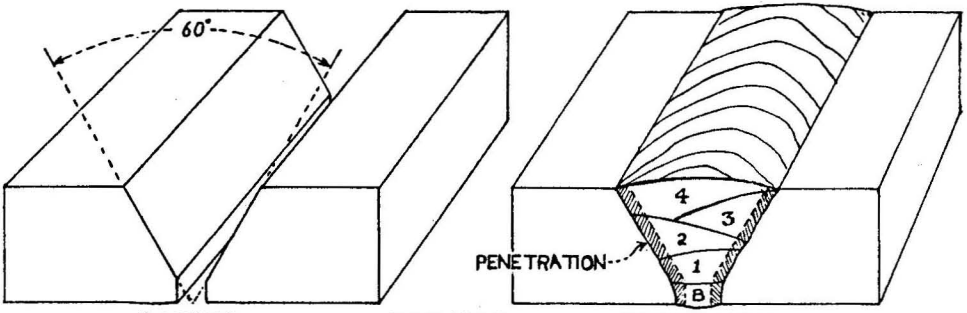
Fillet Welds are used for making T-joints and lapped joints. The leg length ('L' in figure) is governed by the thickness of the abutting part of the joint, whilst the throat thickness ('T' in figure) must be at least 70 per cent of the leg length. Fillet welds may be continuous or intermittent.

Full Penetration Fillet Welds are stronger than ordinary fillet welds and are used where special strength is required in T joints. The vertical leg of the joint is veed, so that the weld metal can penetrate right through.

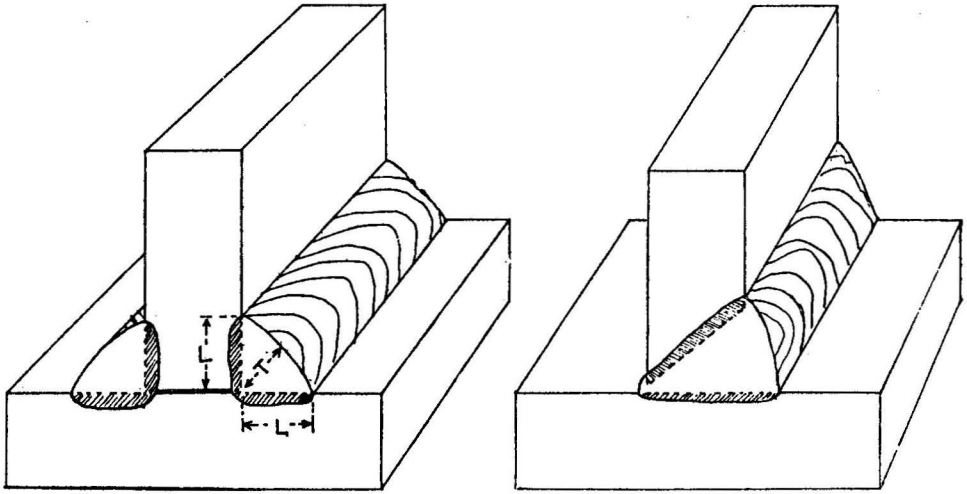
Double Continuous Fillets are used for specially important structural connections and for watertight and oiltight work.

Intermittent Fillets are used for many joints which are not required to be watertight. The length and spacing of fillets depend on the work which the joint is required to do. At the ends of structural joints, the fillets must be doubled and carried around the ends. Chain intermittent fillets are used for the more important connections and staggered intermittent fillets for others. As compared with continuous fillets, intermittent fillets reduce weight and distortion, but have some inherent disadvantages.

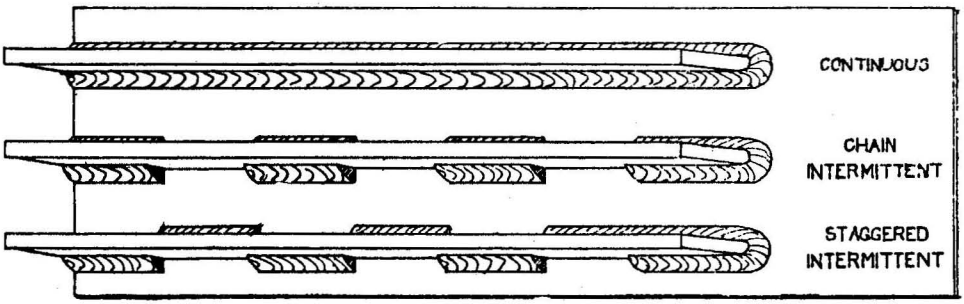
Tack Welds are spots of welding, placed at intervals and used to hold parts temporarily in place whilst a proper welded joint is being made.



"VEEING" —BUTT WELD— FINISHED WELD



ORDINARY —FILLET WELDS— FULL PENETRATION



—FILLET WELDS—

WELDING

Distortion Effects—The chief cause of distortion is the intense heat set up by the electric arc, as it melts the electrode and the edges of the work. The surrounding metal is also heated and expands, so that the edges being joined are actually a little closer together than they were when cold. After the joint has been made and has cooled, the plates on either side of the joint try to move slightly towards each other. If they are free to move, they will do so and they may also buckle to a slight extent, so that visible distortion may occur.

Some of the stresses causing this will remain in the joint, for various reasons, and these are known as 'residual stresses'. Thick plates, or those which are held firmly so that they cannot move, may not be able to buckle or to 'take-up' in this way. The stresses trying to make them do so will still exist and will remain locked in the joint, in which case they are known as 'locked-up stresses'. These stresses may also occur in joints which have been badly prepared, where considerable force may be required to pull the parts into their proper positions. When such parts are welded up and the restraining gear has been removed, the stresses will be transferred to the joint. Both residual and locked-up stresses weaken the joint and the metal around it. They cannot usually be entirely eliminated, but great care is necessary to make sure that they are kept to a minimum.

Reducing Distortion Effects—Residual and locked-up stresses can usually be kept within safe limits, if certain rules are observed. Residual stresses are reduced by starting from the middle of each joint and working outward to the ends, using what is known as 'step-back' welding. Locked-up stresses are minimised by planning the work so that at least one of the parts being joined is free to move, each time a joint is welded. When this cannot be done, the work should be arranged so as to reduce restraint to a minimum.

Where riveted and welded joints are to be used in the same parts of a ship (e.g. where welded plating is riveted to frames) the welding should usually be done before the riveting. If the riveting were done first, it might restrain the movement of the plates during welding, causing locked-up stresses and, possibly, loose rivets. Remember, however, that riveting and welding must never be combined in the same joint (*see* 'General Rules').

Preparation for Welding—It is most important that the work be properly prepared and that all surfaces are dry and thoroughly clean. The parts must fit together properly, otherwise extra locked up stresses may be introduced into the joint; also there is a danger that spaces may be left inside the finished joint and if these are large, they may cause the weld to crack.

However carefully the preparation is done, it sometimes happens that the parts do not fit properly when they are assembled for welding. In this case, any excessive gaps must be corrected before the welding is done. Butt

joints should be built-up to reduce the gap. T joints may have a liner fitted, or if the gap is too large to allow this to be done, one of the plates should be cut back and an extra piece welded in.

When a welded structure is designed, it is important to plan the order in which the various joints are to be made, or 'welding sequence'. This should be done so that the parts of the structure are reasonably free to move as each weld is made, thus reducing locked up stresses.

General Rules—Riveting and welding must never be used together in the same joint, because they behave quite differently under stress and may thus cause the joint to break. In other words, any one joint may be either riveted or welded, but never both.

Great care must be taken in designing welded structures in order to spread the stresses smoothly from part to part and to avoid dangerous stress concentrations.

Prefabrication, which is the construction of large sections in a shed before they are built into the ship, has many advantages for welded construction and should be used as much as possible. Great care must, however, be taken to design the prefabricated parts so that they fit properly.

Machine Welding—The most common type of machine welding is that called 'submerged arc welding'. In this, the electrode consists of a long wire, fed from a reel; whilst a powdered flux is poured on to the joint as it is made, so that the arc is 'submerged' under the flux.

In machine welding, the metal is melted much more quickly and deeply than is possible with hand welding. This gives deeper penetration and thus reduces the amount of veeing required for the plate edges, so that more weld metal comes from the plates and proportionately less is required from the electrode. This, in its turn, means that the joint can be filled with fewer runs: in fact, it is often possible to make the joint with a single run. It also means that the welding can be done faster, which helps to reduce distortion effects

This type of welding is most suitable for work indoors, on flat, horizontal surfaces. It cannot be used for welding in awkward places, nor, usually, for work on other than horizontal surfaces. For many purposes, also, it cannot be used for welding out of doors.

Crossing and Abutting Welds—If welds cross or meet, there is a risk that a large amount of weld metal may accumulate at the junction, producing shrinkage in two or more directions and thus causing the weld to crack. Since welded parts must necessarily cross or meet in places, it is important to prevent build-up of weld metal at the meeting-points.

Where butts and seams meet in flush plating, such as shell plating, the butt should always be completely welded first. It should be finished full out

and then gouged back to give a fair edge to the seam, which should then be welded straight through. The reason for this is that if the seam were made first, it would prevent movement of the plates on either side of the butt joint when this was welded, thus causing locked up stresses and possibly cracking of the joint.

When welds meet in a corner, the cure would be to cut away the corner of the abutting plate in a clearance hole, or 'snipe'.

When T joints meet butt welds, there is always a danger of a build-up of weld metal, whilst it would also be impossible to make the parts fit properly together if the surface of the butt weld were 'proud' of the plate. To prevent this we can either:

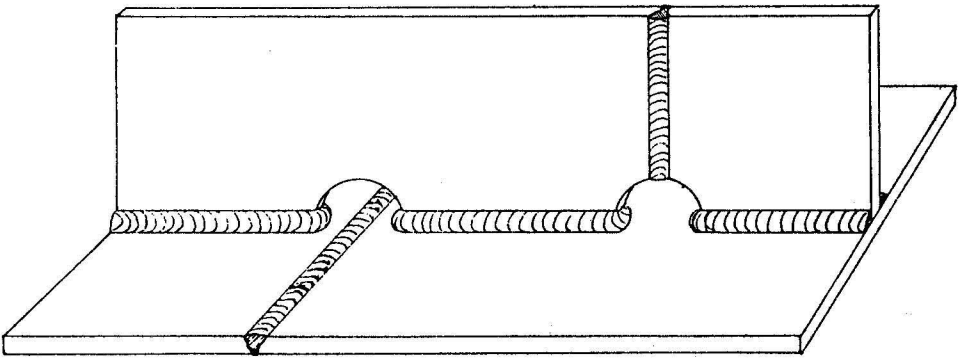
(*a*) Cut a scallop in the vertical member so as to clear the butt weld, or
(*b*) Make the butt weld first and then grind off its surface in the region of the joint, so that the crossing member is fitted and welded on to a flush surface. Lloyd's Rules require this latter to be done, whenever possible, where stiffeners cross finished butt welds in plating.

Hard Spots—A hard spot is a small local area which is considerably more rigid than the surrounding structure. A simple example is where the toe of a bracket from, say, a girder is welded to an area of plating, as shown in the sketch. The point where the toe of the bracket is welded to the plating is rigid and forms a hard spot. The stresses transmitted from the girder through the bracket would concentrate here and might cause the plating to crack. The cure for this is to fit some kind of stiffener to the plating in order to spread the load over a bigger area. The sketch shows how a plate or angle (shown dotted) could be fitted for this purpose.

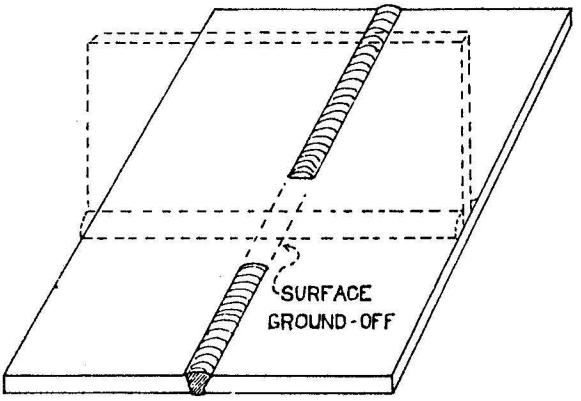
Notches—When a piece is cut out of a plate so as to leave a square, or nearly square corner, or where there is a ragged edge on a plate, the resultant 'notches' can cause stress concentrations. These may not be particularly serious in riveted structures, since the 'give' in the riveting often allows the worst of the stresses to work themselves out. With welded construction, which is more rigid, however, the notches may cause stress concentrations which cannot work themselves out, so great care must be taken to avoid them wherever possible. For this reason, the corners of cut-outs in plates must be well-rounded and may have to be reinforced by, say, face bars. Free edges of plates must be kept smooth. Scallops must have well-rounded corners and smooth edges and must not be cut where high stresses may occur.

Defects of Workmanship—Weak or faulty joints may be produced if the welder does not use the proper procedures, current, electrode or length of arc. The most common defects, which may cause the weld or plate to crack are:—

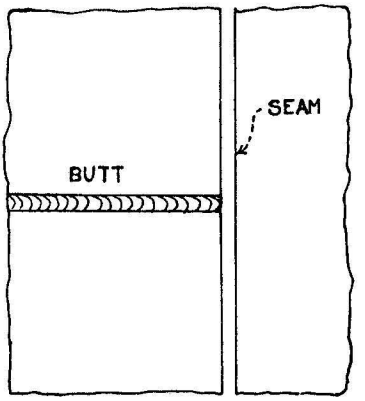
'Undercutting,' which occurs when a groove is burned in the plate close to the weld. It weakens the plate at a very dangerous point.



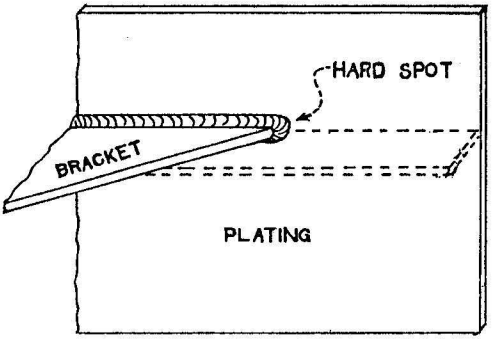
SCALLOPING AT CROSSING WELDS

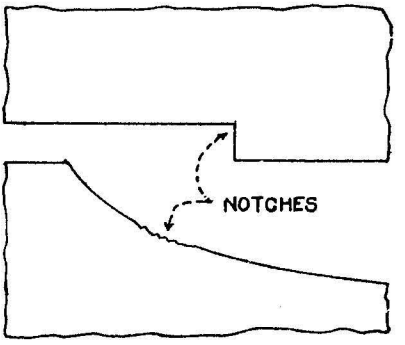


CROSSING WELDS



MEETING WELDS





WELDING

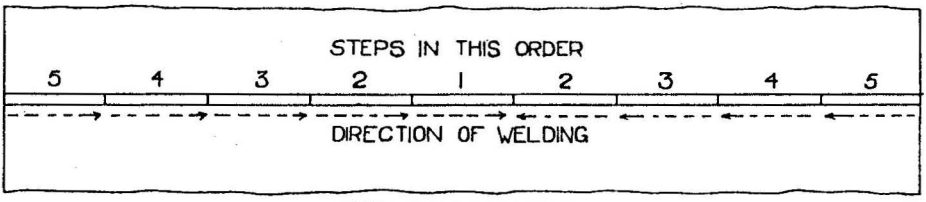
'Poor Penetration' can occur as 'incomplete penetration' if the weld metal does not fill the joint properly, so that a gap is left between runs. Alternatively, it may appear as 'lack of fusion', when the heat does not melt sufficient of the plate or of previous runs, so that the weld metal does not bond properly with the original metal.

A hollow weld-profile must be avoided, as it will weaken the joint. The surface should always be convex, whilst the weld must be carried right out and finished-off square at it's ends. In T-joints, the weld should, wherever possible, be carried right round the ends of the joint.

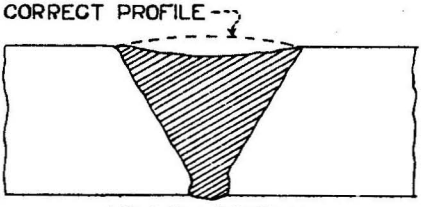
'Slag Inclusion' occurs if the slag is not completely cleaned off the top of each run before the next one is made. If this is not done properly, a certain amount of slag may be left in the joint.

'Blow holes' are rounded holes formed by gases trapped in the weld metal as it cools. 'Pipes' are elongated holes, due to the same cause.

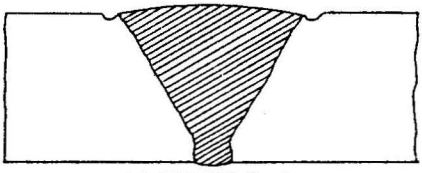
Welding of Aluminium—An 'inert gas system' is used for aluminium, for which the processes used for welding steel are not suitable. For butt-welds, the plates are veed to between 75° and 90° and a backing bar is usually attached to the underside. Argon gas is blown on to the joint through ducts in the welding head. A tungsten electrode may be used to produce the arc, which melts-down an aluminium rod held in it; or an aluminium wire may be used as an electrode.



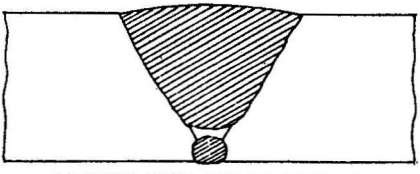
STEP-BACK WELDING



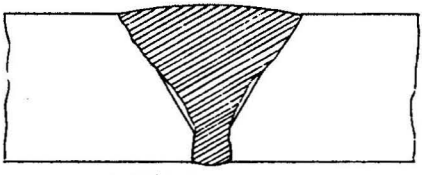
HOLLOW PROFILE



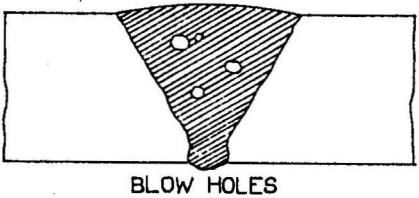
UNDERCUTTING



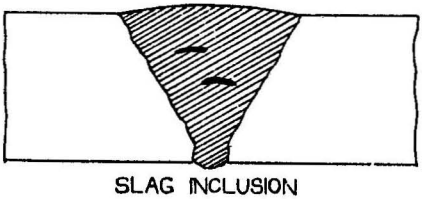
INCOMPLETE PENETRATION



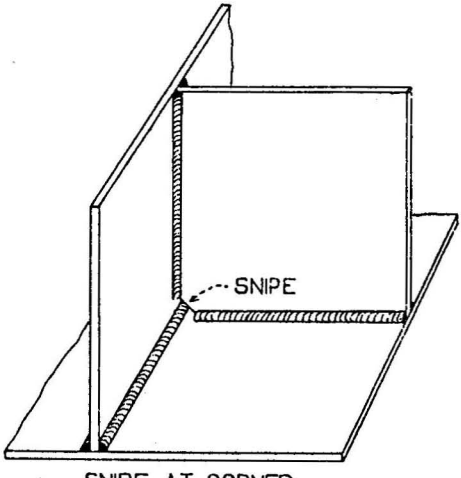
LACK OF FUSION



BLOW HOLES



SLAG INCLUSION



SNIPE AT CORNER

WELDING

GENERAL TYPES OF SHIPS

General Note—The types described in this section and shown in the sketches are the actual form of the main part of the hull. Their appearances may be altered by superstructures, but the form type will remain the same. For example, a shelter decked ship may have a forecastle, poop and bridge deck, which will give her the same appearance as a three-island ship.

Flush Decked Ship—This was the original type in which the upper deck was also the freeboard deck.

Three-Island Ship—In the early steamships, it was found necessary to raise the machinery casings in order to protect the engines from the sea. This led to the raising of the hull amidships, to form a bridge. The poop was also raised to protect the steering gear and the forecastle to house the crew and to help to keep the ship dry.

Long Bridge Ship—To give additional cargo space, one of the well-decks, either forward or aft, was enclosed.

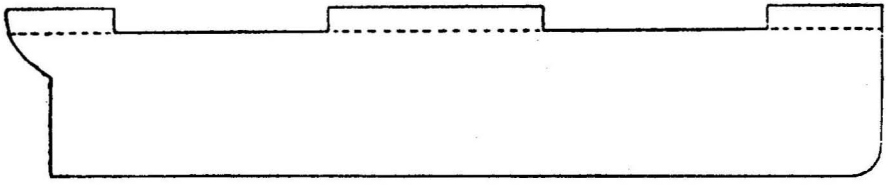
Shelter Deck Ship—The other well-deck of the long bridge ship was enclosed, to give a continuous superstructure and upper deck: usually of lighter scantlings than the main part of the hull. Later, the shelter decks became divided into two types:—

The 'Open Shelter Deck' ship, in which the superstructure was not entirely protected from the entry of sea-water. Such a ship could not load so deeply as an ordinary ship of the same depth (D).

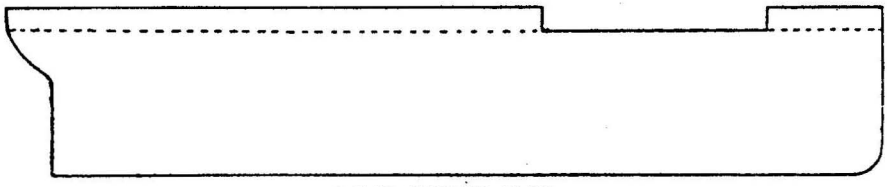
The 'Closed Shelter Deck' ship, in which the superstructure was made watertight. This ship could load more deeply than an Open Shelter Deck ship of the same size, but not quite as deeply as an ordinary full-strength ship (or 'Full-Scantling' Ship).

Ships with Raised Quarter Decks—It was found that in small screw steamers the shaft tunnel took up such a large proportion of the space in the after holds, that the ship trimmed by the head when fully loaded. To overcome this the after deck was raised for the whole or a partof its length. The raised quarter deck is not seen today in large ships, but is still used in small ships, such as coasters.

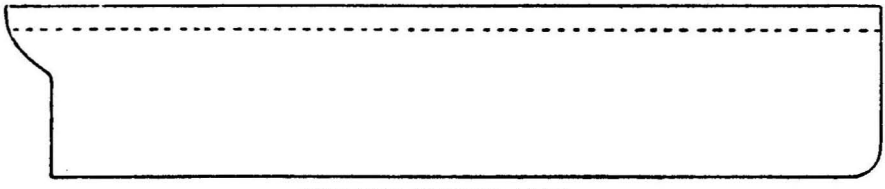
FLUSH DECKED SHIP.



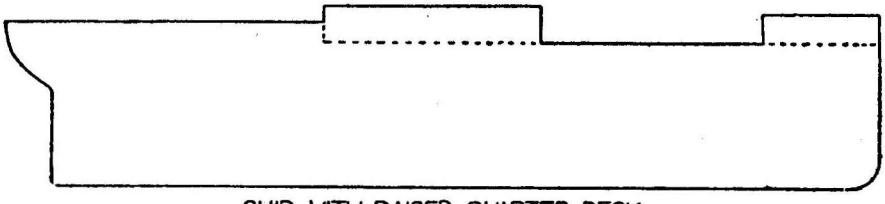
THREE ISLAND SHIP.



LONG BRIDGE SHIP.



SHELTER DECKED SHIP.



SHIP WITH RAISED QUARTER DECK.

TYPES.

STRESSES AND STRAINS IN SHIPS

Stress and Strain—Stress is load put on a piece of material or on a structure. If the stress is excessive, the material may become permanently deformed and weakened and it is then said to be 'strained'.

Types of Stress—Stresses are classified according to the way in which they act.

Tensile stresses try to pull the material apart.

Compressive stresses try to crush the material, or to cause it to buckle.

Shearing stresses may be described as the effect of forces which try to shear material across, or to make the component parts of a structure slide over each other.

Bending stresses are compound stresses produced by forces when they try to bend a piece of material.

Stress Concentrations—When a section is under load, there will usually be a large local increase of stress near any notch, hole, or abrupt change of shape of the section. This local increase is called a 'stress concentration' and it may be as great as two or three times the average stress elsewhere. It is usually at its worst where the edges of a hole or plate are left jagged, or where square-cornered holes are cut out of plates. It occurs to a lesser degree in the region of round holes, or of holes with rounded corners.

Stress concentrations can be dangerous. They may cause the steel to crack in their vicinity, particularly in welded structures, even where the normal stress would not be large enough to cause cracking. It is, therefore, important to design the ship carefully so that stress concentrations are kept to a minimum, to round off and strengthen the corners of openings, and to keep the edges of plates and holes smooth and free from notches.

Longitudinal Bending Stresses—If a beam or girder is bent, as shown in Fig. 1, the greatest tensile and compressive stresses occur at the top and bottom. Somewhere between the two, there is a line called the 'neutral axis' at which these stresses cease to exist. Shearing stresses are, however, least at the top and bottom and greatest near the neutral axis.

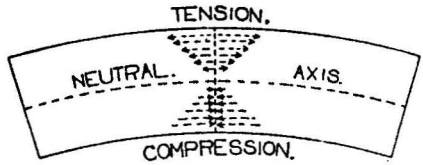
For a more detailed description of these stresses, *see* Section V.

Stresses in Ships—These may be divided into two classes, viz.:—

Structural—affecting the general structure and shape of the ship.

Local—affecting certain localities only.

A ship must be built strongly enough to resist these stresses, otherwise they may cause strains. It is, therefore, important that we should understand the principal ones and how they are caused and resisted.



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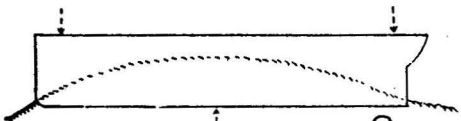

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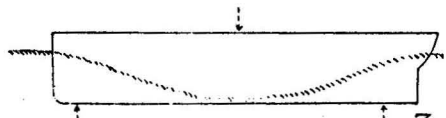

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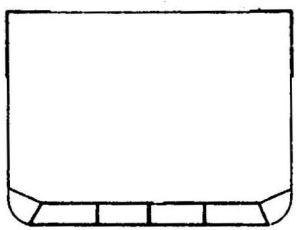

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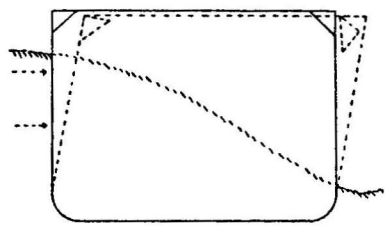

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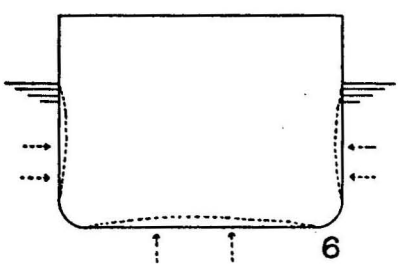

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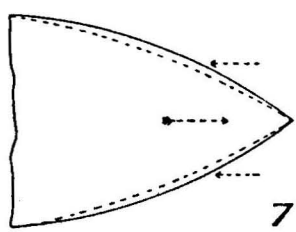

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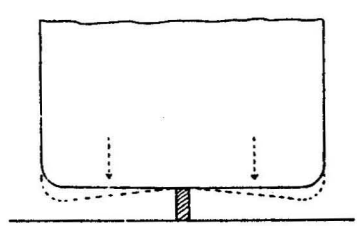


9

STRAINS IN SHIPS.

Principal Structural Stresses—Hogging and Sagging; Racking; effect of water pressure; and drydocking.

Principal Local Stresses—Panting; Pounding; effect of local weights and vibration.

Hogging and Sagging—These are longitudinal bending stresses, which may occur when a ship is in a seaway, or which may be caused in loading her. Fig. 2 shows how a ship may be hogged and Fig. 3 how she may be sagged by the action of waves. When she is being loaded, too much weight in the ends may cause her to hog, or if too much weight is placed amidships, she may sag.

The dark lines in Fig. 4 show how these stresses are resisted. At the bottom, all longitudinal work in the double bottom gives the necessary strength. At the top, the deck stringer and sheerstrake are thickened, so as to make a strong L-shaped girder on either side. Deck girders and longitudinal bulkheads also help to resist this stress. In large ships, it may be necessary to use special steels for the sheerstrake and bilge strakes: also further to strengthen the ship by fitting longitudinal frames and beams in the bottom and under the strength deck. The stresses are greatest amidships, so the strength of the parts mentioned is made greater amidships than at the ends.

In long ships, the shearing stresses which occur near the neutral axis also become an important problem. In such ships, it may be necessary to strengthen the hull at about the half-depth of the ship, in the neighbourhood of one-quarter of the length from each end.

Racking—Fig. 5 shows how a ship may be 'racked' by wave action, or by rolling in a seaway. The stress comes mainly on the corners of the ship, that is, on the tank side brackets and beam knees, which must be made strong enough to resist it. Transverse bulkheads, web frames, or cantilever frames provide very great resistance to this stress.

Effect of Water Pressure—Water pressure tends to push-in the sides and bottom of the ship. It is resisted by bulkheads and by frames and floors (Fig. 6).

Panting—Panting is an in and out motion of the plating in the bows of a ship and is caused by unequal water pressure as the bow passes through successive waves. Fig. 7 illustrates how it is caused. It is greatest in fine bowed ships. For the means adopted to resist it, *see* 'Peak Tanks'.

Pounding—When a ship is pitching, her bows often lift clear of the water and then come down heavily, as shown in Fig. 8. This is known as 'pounding' and occurs most in full-bowed ships. It may cause damage to the bottom plating and girderwork between the collision bulkhead and a point about one-quarter of the ship's length from the stem. For the strengthening to resist pounding, *see* 'Cellular Double Bottoms'.

Local Weights—Local strengthening is introduced to resist stresses set up by local weights in a ship, such as engines. This is also done where cargoes imposing extraordinary local stresses are expected to be carried.

Drydocking—It can be seen from Fig. 9 that a ship, when in drydock and supported by the keel blocks, will have a tendency to sag at the bilges. In modern ships of medium size, the cellular double bottom is usually strong enough to resist this stress without any further strengthening when the ship is light. There is always a danger, however, that such sagging may occur if the ship has much weight on board and, in this case, bilge blocks or shores should be used to prevent it. For this reason, many modern drydocks use bilge blocks as standard practice.

Vibration—Vibration from engines, propellers, etc., tends to cause strains in the after part of the ship. It is resisted by special stiffening of the cellular double bottom under engine spaces and by local stiffening in the region of the stern and after peak.

SYSTEMS OF CONSTRUCTION

General—Modern ships vary considerably in the details of their construction, according to their size and type, but almost all conform to one of three basic systems of construction.

The sketches, here, merely illustrate the main features of each system and are kept as simple as possible, for purposes of comparison. Details of construction are described later in this book.

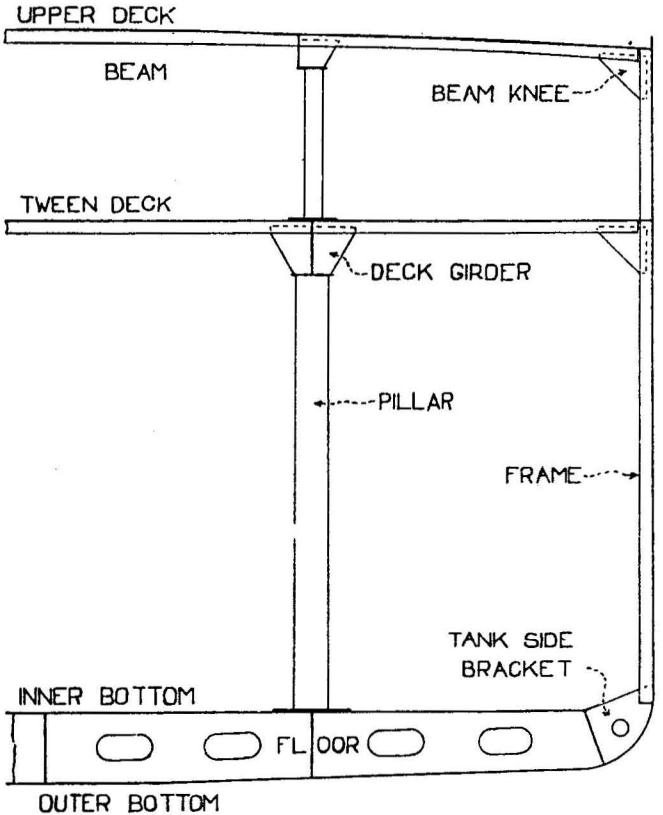
Transverse System—Wooden ships were always built on this system, because closely spaced transverse frames were needed to hold the planks together so that the seams could be caulked. It was also necessary to use it because sailing ships needed considerable transverse strength to enable them to resist the racking stresses set up by the masts and rigging. Longitudinal strength was less important in these ships because they were comparatively small and hogging and sagging stresses were not large.

This system is not the most efficient for steel steamships, but it has continued in general use until recently. This was partly because it was cheap to build and served its purpose; and partly because a suitable alternative was not available for many years.

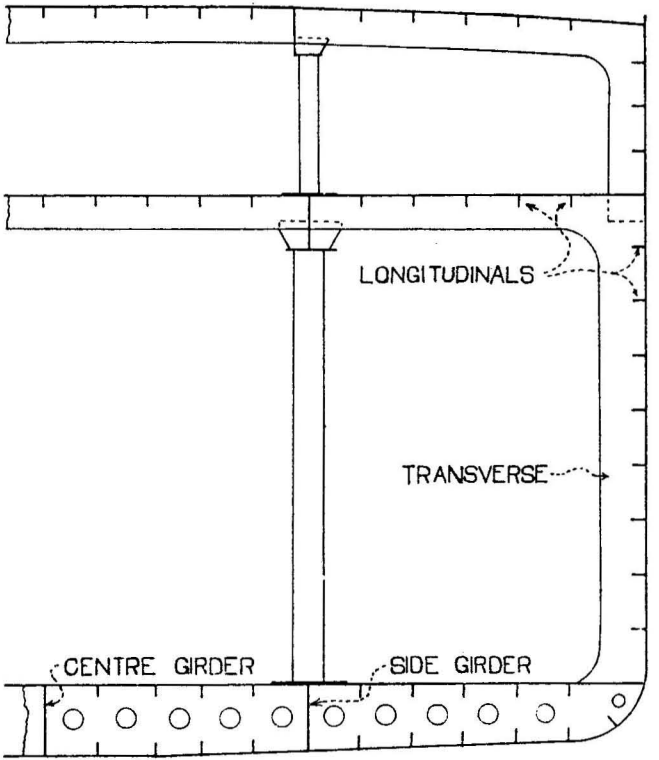
Longitudinal Systems—With the coming of steamships, racking stresses became less important, but hogging and sagging stresses became more serious as ships grew longer. It soon became obvious that more longitudinal strength could be achieved by running the frames longitudinally (fore and aft), provided that reasonable transverse strength was maintained. Various attempts were made to do this during the 19th century, but all had serious disadvantages and none were generally adopted.

Early in this century, a satisfactory system of longitudinal framing was invented, which came to be called the 'Isherwood System', after its inventor. This has longitudinal frames at the bottom, sides and decks, supported by widely spaced transverse web frames, called 'transverses'. It gives great longitudinal strength and is much used for oil-tankers and other types of bulk carrier.

A few dry cargo ships were built on this system in the past, but it is not now used for them because the transverses interfere too much with the stowage of cargo. A dry cargo ship of this type is shown in the sketch, however, because it serves as a good illustration of the system.



TRANSVERSE SYSTEM



LONGITUDINAL SYSTEM

SYSTEMS OF CONSTRUCTION—(*Continued*)

Combination System—This was introduced to overcome the disadvantages of the longitudinal system for dry cargo ships. The longitudinal frames are retained in the bottom and under the strength deck, where they give great longitudinal strength; but transverse frames are fitted on the ship's side, where the longitudinal stresses are smaller. Plate floors and heavy transverse beams are fitted at intervals to give transverse strength and to support the longitudinals.

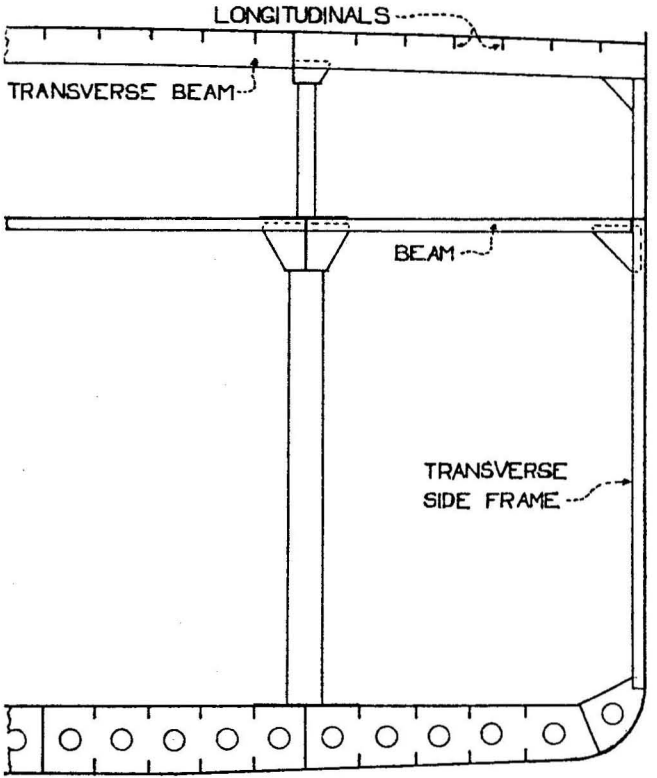
This system was not widely used for riveted ships, although a number were built in this way, but it came more into use with the coming of all-welded ships. This was partly because it was found that, if these ships were built on the transverse system, their decks and bottom tended to corrugate under hogging and sagging stresses: whereas the longitudinal frames prevent this from happening. Lloyds' Rules now require longitudinals to be fitted, in general, in the bottoms and under strength decks of all ships of over 120 metres long: so it seems that this system will eventually replace the transverse one for all larger dry cargo ships.

The combination system is also often used for small to medium-sized oil tankers and for some other types of bulk carrier, for which it has certain slight advantages.

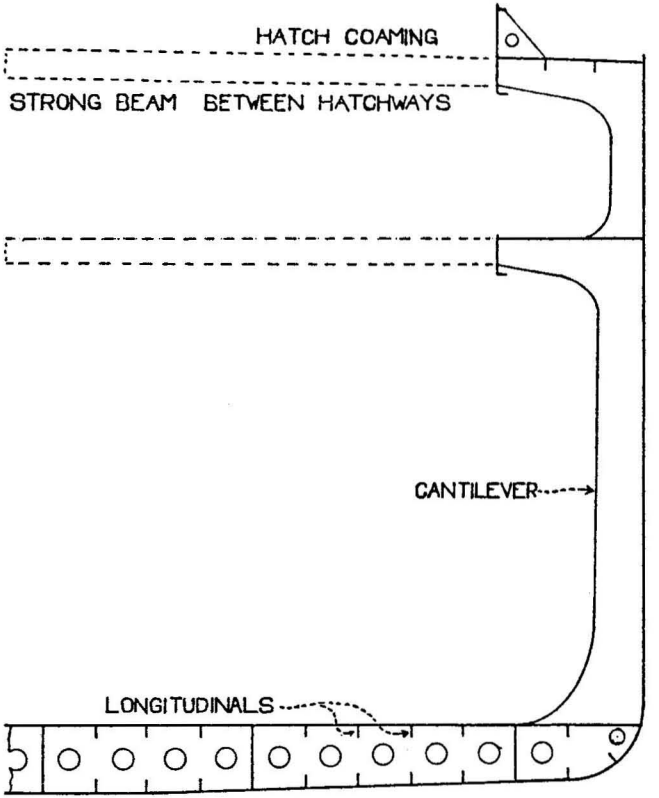
Cantilever Framing—This is really only a modification of the combination system, but is included here because of its special features. It has been developed for some modern types of ship, which have very long and wide hatchways. In these ships, there is too little left of the decks and beams to give the necessary strength to resist longitudinal and transverse stresses; so the strength has to be made up in other ways.

Transverse strength is maintained by using very strong hatch end beams wherever possible and by fitting special web frames, called 'cantilevers', at frequent intervals abreast of the hatchways.

To give longitudinal strength, the sheerstrake and deck stringer plate are much heavier than normal; whilst the hatch side coamings are extra deep and are often made continuous throughout the ship. Sometimes, the hull is also extended upwards at the sheerstrake, to form a strong box girder in place of the ordinary bulwark or rails. If the ship is of the 'twin hatch type' (with two hatches abreast), a deck girder or longitudinal bulkhead is also fitted at the centre line.



COMBINATION SYSTEM



CANTILEVER FRAMING

KEELS

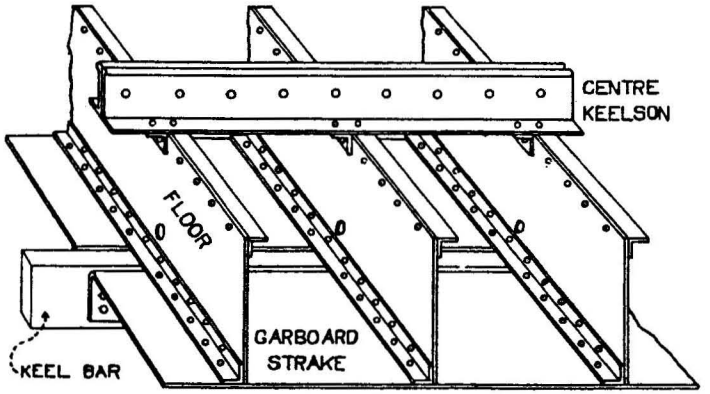
General—Bar keels were the type first used when shipbuilding changed from wood to iron. It was found that they did not provide sufficient strength for large vessels, as there was no direct connection between the keel and the floors. They are now only used in certain types of small craft. The flat plate keel is the modern type and is in general use.

Bar Keels—The depth of the bar is from three to six times its width. It is made in lengths of from 10 to 20 metres, joined by vertical scarphs which have a length of nine times the thickness of the keel.

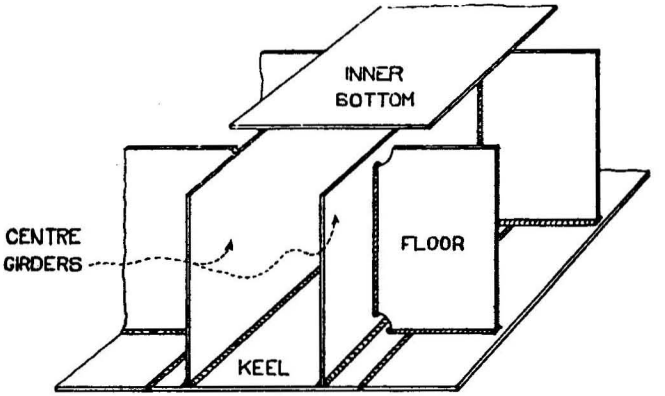
Flat Plate Keels—The keel plate may have a width of from 1 to 2 metres. It must be of full thickness for three-fifths of the length amidships, but the thickness may be gradually reduced towards the ends of the ship.

The centre girder is attached to the keel and inner bottom plating by continuous welds and no scallops are permitted in this connection. It is usually made watertight, although this is not required by the Rules.

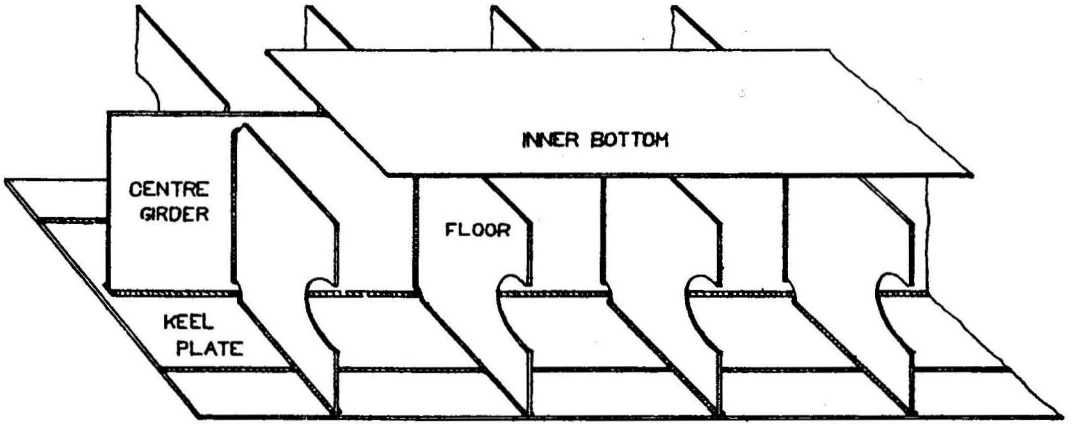
Duct Keels—Are a form of flat-plate keel, but have two centre girders instead of one. They are often fitted between the collision bulkhead and the forward engine-room bulkhead, to provide a convenient tunnel for pipes from the tanks. They are not usually fitted abaft the engine-room, because the pipes from the after tanks can be run through the tunnel. Transverse stiffening bars or brackets are often fitted on the keel plate and inner bottom plating between the two centre girders.



BAR KEEL



DUCT KEEL



FLAT PLATE KEEL

KEELS

CELLULAR DOUBLE BOTTOMS

General—Cellular double bottoms may be transversely framed, with a floor at every frame space, i.e. in line with the frames. If the ship is over 120 metres long, or if it is intended for ore or other heavy cargoes, a system of longitudinal framing must be used, with transverse plate floors at intervals.

One or more side girders, running fore and aft, are normally fitted between the floors to give extra longitudinal strength.

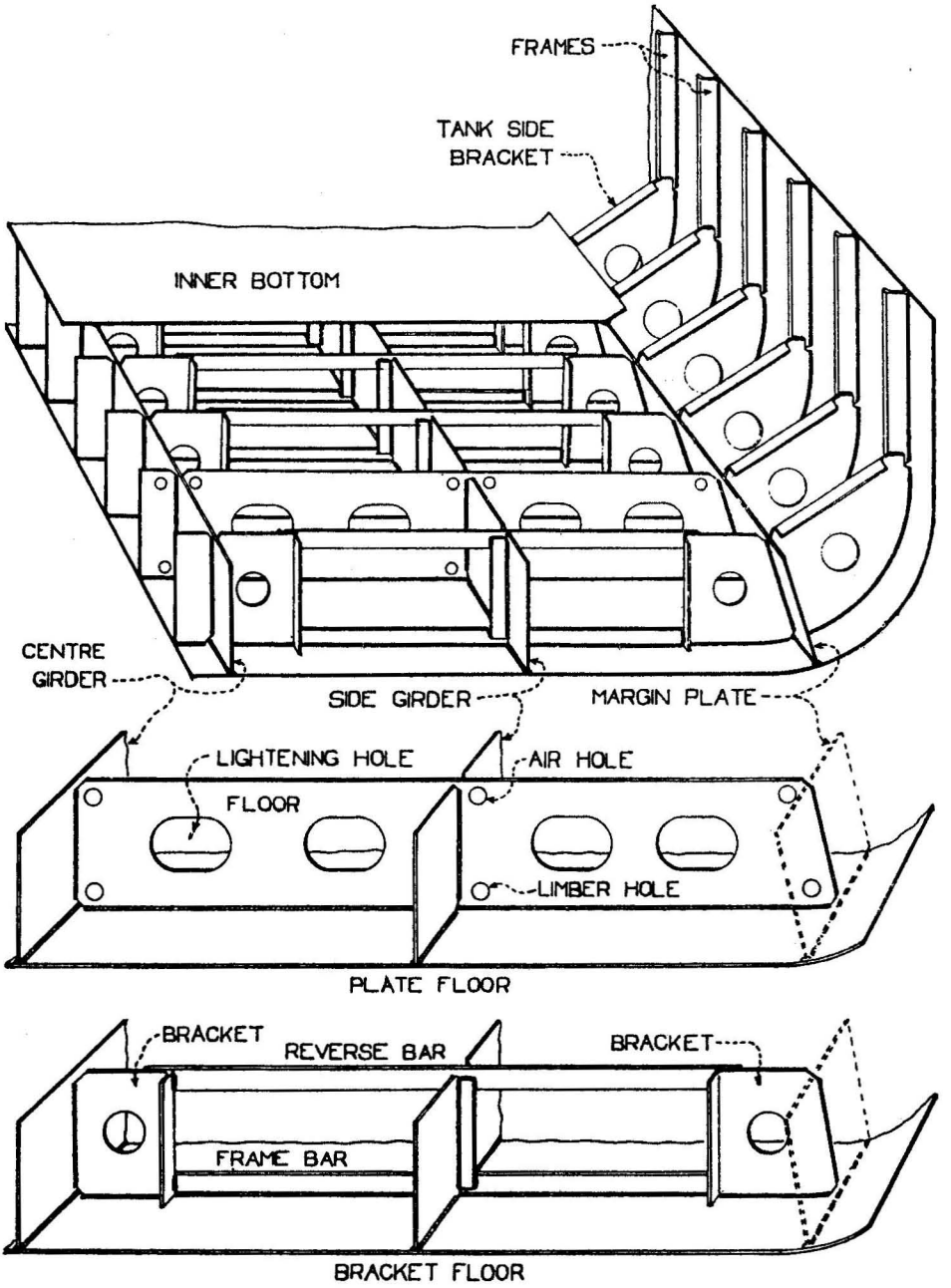
The outboard boundary of the cellular double bottom is formed by a continuous watertight 'margin plate', which is attached to the side frames by 'tank side brackets'.

Transversely-Framed Double Bottoms—These must have plate floors at every frame space under the engine-room, boilers, bulkheads and in the pounding region. Elsewhere, plate floors may be not more than 3·05 metres apart, with bracket floors at intermediate frame spaces.

Vessels of up to 20 metres in breadth must have one intercostal side girder on each side: vessels of greater breadth are to have two such girders on each side. These are to extend as far forward and aft as possible.

Plate floors consist of a plate, running transversely from the centre girder to the margin plate on each side of the ship. These have lightening holes in them unless they are to be watertight. Watertight plate floors must be fitted under or near bulkheads and if the depth of the centre girder exceeds 915 millimetres, they must have vertical stiffeners on them.

Bracket floors are a form of 'skeleton floor', in which the middle part of the floor plate is omitted and replaced by a 'frame bar' and a 'reverse bar', with a bracket at either end. The brackets are to be flanged on their free edges and their breadth is to be three-quarters of the depth of the centre girder. Intercostal side girders are attached to bracket floors by vertical bars; whilst, if the distance between the side girder and the brackets is large, other vertical bars must be fitted to reduce the span.



TRANSVERSE FRAMING IN BOTTOM

CELLULAR DOUBLE BOTTOMS—(*Continued*)

Longitudinal Framing in Double Bottoms—Lloyd's Rules now require that this shall be fitted, in general, in all ships of over 120 metres long. The longitudinals are flat bars, bulb bars, or inverted angles and are supported by plate floors not more than 3·7 metres apart. The longitudinals are attached to these floors by vertical bars, at least 150 millimetres deep, which must extend for the full depth of the floor.

Under engines, boiler bearers, bulkheads and the toes of brackets to deep tank stiffeners, plate floors are required to be fitted at every frame space.

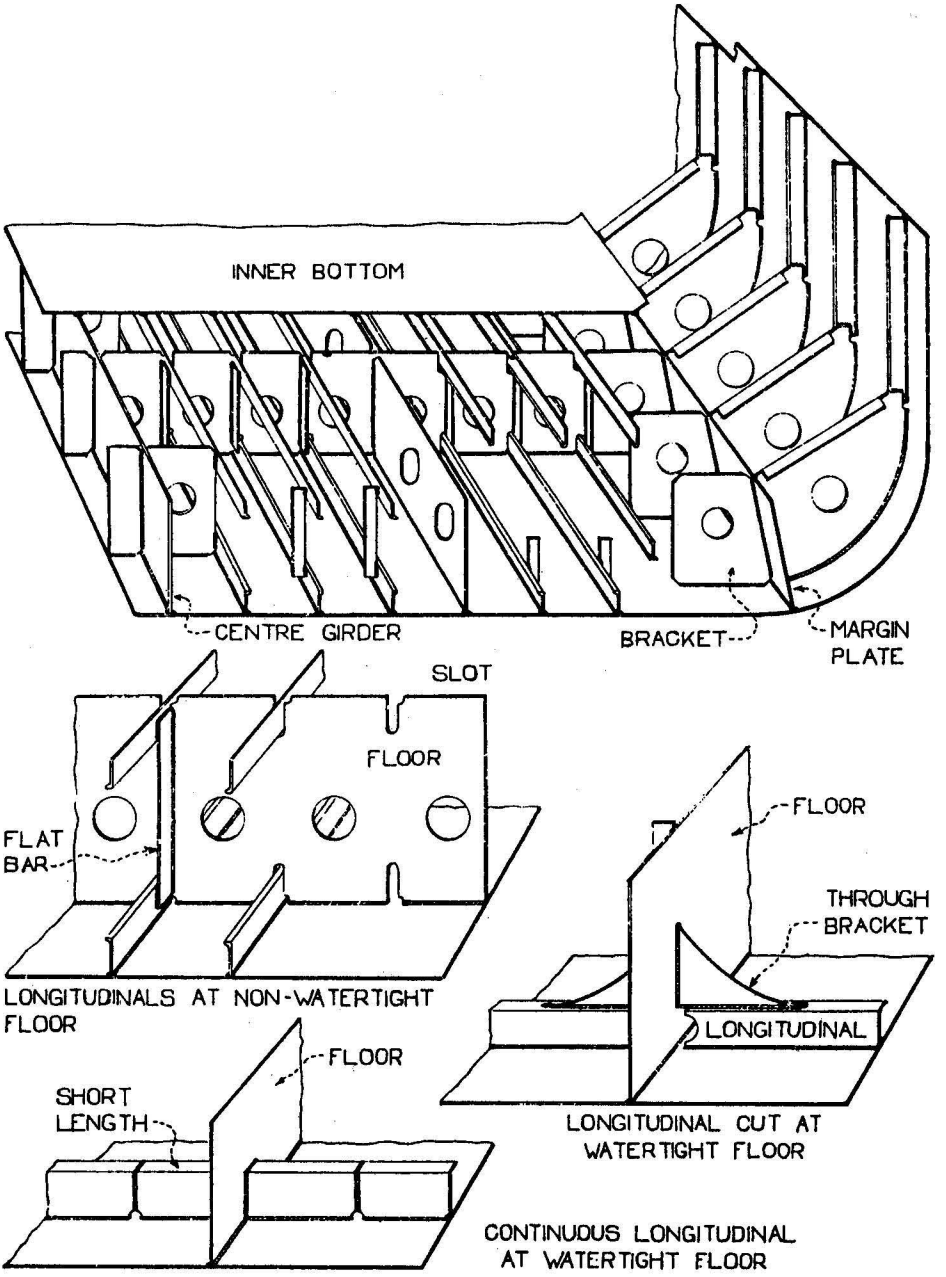
At intermediate frame spaces, between the floors, brackets are fitted from the margin plate to the nearest longitudinal. The centre girder must be supported by similar brackets, spaced no more than 1·25 metres apart.

If the plate floors are two or more frame spaces apart, vertical stiffeners, at least 100 millimetres deep, must be fitted midway between them to support the longitudinals.

One intercostal side girder is fitted on each side if the breadth of the ship exceeds 14 metres; or two on each side if the breadth exceeds 21 metres.

The longitudinals may be cut at watertight floors and attached to them by brackets if the ship is not more than 215 metres long. If the ship is longer than this, the longitudinals must be continuous: in this case, short lengths of longitudinal are passed through close-fitting slots in the floor, which are afterwards welded-up to make them watertight.

Inner Bottom Plating—The middle line strake and margin plate must always be continuous fore and aft. Other strakes are sometimes laid athwartships under bulkheads, but should be fore and aft elsewhere. The thickness of the plating is increased slightly in the engine-room and also under hatchways in which a ceiling is not fitted.



LONGITUDINAL FRAMING IN BOTTOM

CELLULAR DOUBLE BOTTOMS—(*Continued*)

Margin Plates and Tank Side Brackets—The margin plate forms the outer edge of the double bottom and must be watertight. In riveted margin plates, this was achieved by fitting a continuous angle along the lower edge and by flanging the upper edge so that the inner bottom plating could be lapped on to it and caulked. Racking stresses try to pull the tank side brackets away from the margin plate, so gussets were fitted at the upper 'corner' to strengthen the connection at this point. Later, it became common practice to fit a narrow continuous plate in lieu of the gussets.

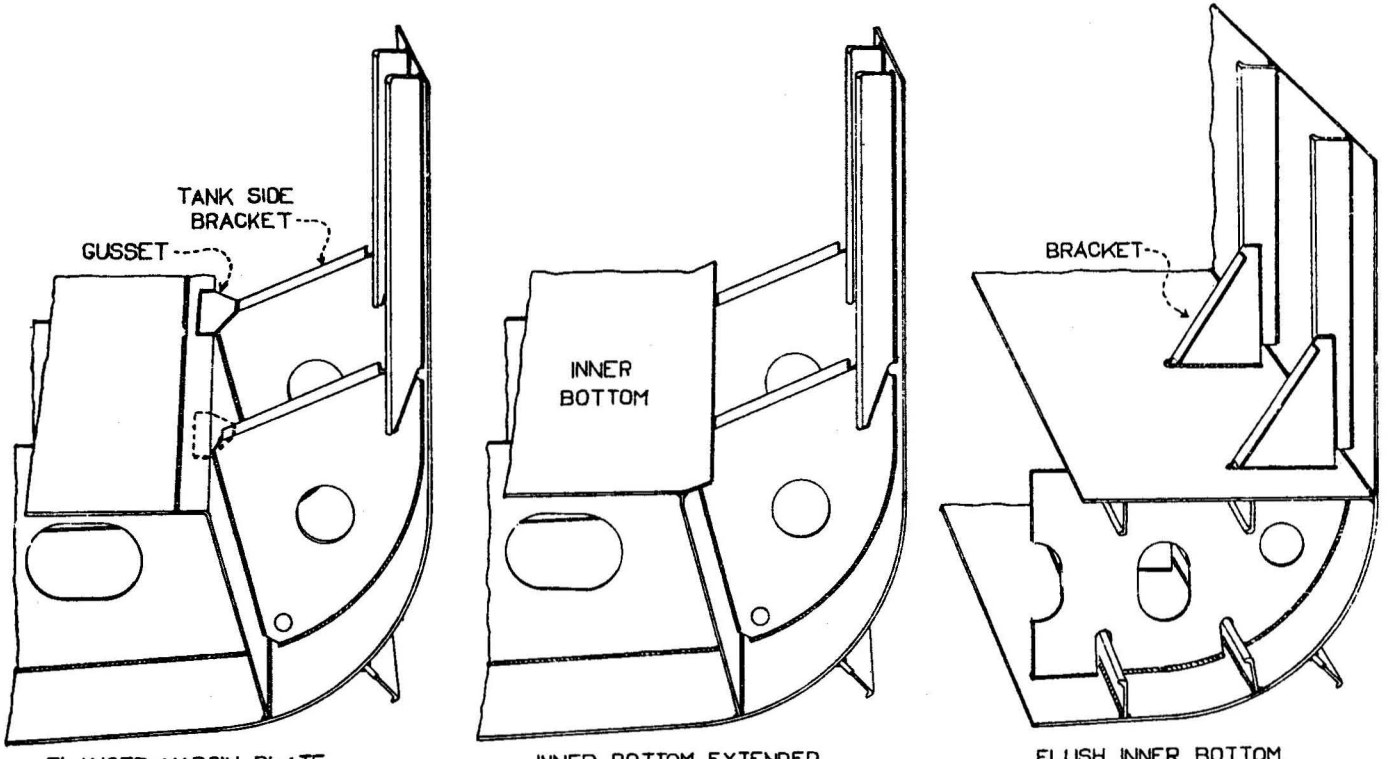
Welded margin plates are sometimes flanged, but it has become common practice to extend the inner bottom plating beyond the margin plate and to attach it to the top of the tank side brackets, instead of using gussets.

In many ships, the inner bottom is now carried out to the ship's side. When this is done, the frames are usually attached to the inner bottom by flanged brackets, as shown in the sketch. In this case, there are no actual bilges, so 'wells' or 'hat boxes' are let into the inner bottom plating to provide drainage for the holds.

Ceiling—If no ceiling is fitted in the hold, the inner bottom plating must be made 2 millimetres thicker than normal under the hatchways. If a wood ceiling is fitted, it must be embedded in some suitable composition, or laid on battens so as to leave a clear space of 12·5 millimetres between ceiling and tank top.

Welding—Most fillet welds in the bottom may be either continuous or intermittent. Continuous fillet welds must, however, be used for connecting flat bar type longitudinals to the shell plating; also for floors and girders in the pounding region. Scallops are not allowed in keel and centre girder connections, nor within 230 millimetres of any important strength member.

Tests—Cellular double bottoms are tested by filling them to a head of water equal to the maximum head that could come on them in practice. Alternatively, they may be air-tested by filling them with air at a pressure of 0·14 kg/cm^2 and using a soapy solution to detect any leaks.



FLANGED MARGIN PLATE
WITH GUSSETS

INNER BOTTOM EXTENDED
IN LIEU OF GUSSETS

FLUSH INNER BOTTOM

ARRANGEMENTS AT BILGE

CELLULAR DOUBLE BOTTOMS—(*Continued*)

Precautions Against Pounding—Pounding stresses are to be expected in the ship's bottom between points 5% of the ship's length abaft the stem and 25% of the length abaft the stem; or 30% in some cases. This is often called the 'Pounding Region', and the ship must be strengthened here as follows:—

The outer bottom plating covering the flat of the bottom must be thickened, in most cases.

The connections of the shell and inner bottom girderwork are made stronger.

In transversely-framed bottoms, plate floors are fitted at every frame space and are connected to the outer bottom plating by continuous welds. Extra intercostal side girders are to be fitted, so that the distance between side girders does not exceed 2·2 metres. Further intercostal side girders, of half the depth of the main ones, are to be fitted midway between the latter.

In longitudinally-framed bottoms, plate floors are fitted at alternate frames, longitudinals may have to be stronger than normal, and side girders must be not more than 2·1 metres apart.

Passenger Ships—Most passenger ships must be fitted with a double bottom, as follows:—

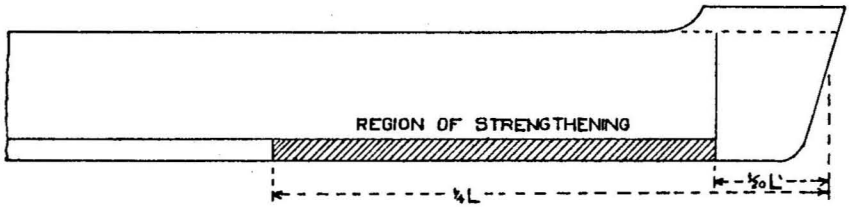
Ships of 50 to 61 metres long: from the machinery space to the collision bulkhead.

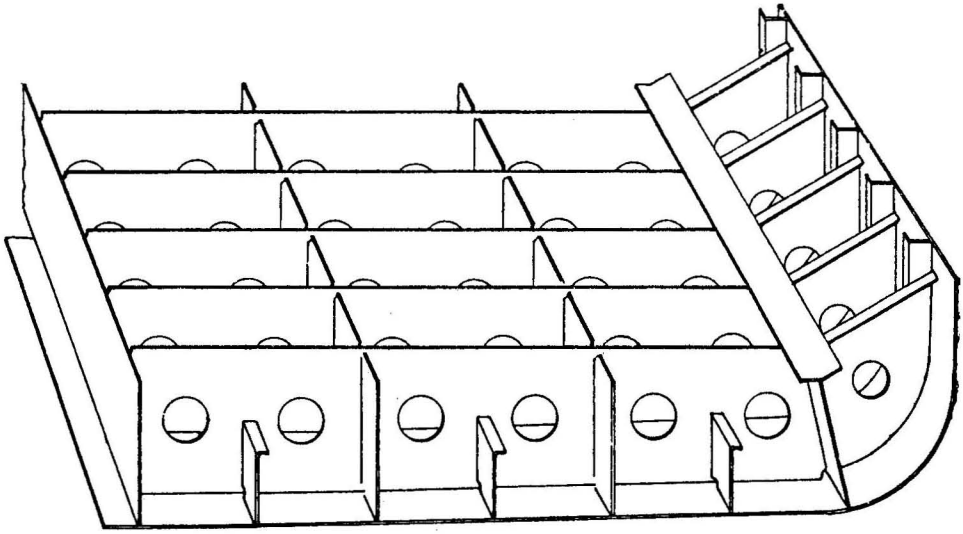
Ships of 61 to 100 metres long: from peak bulkhead to peak bulkhead, excluding the machinery spaces.

Ships of 100 metres long and over: from peak bulkhead to peak bulkhead, including the machinery spaces.

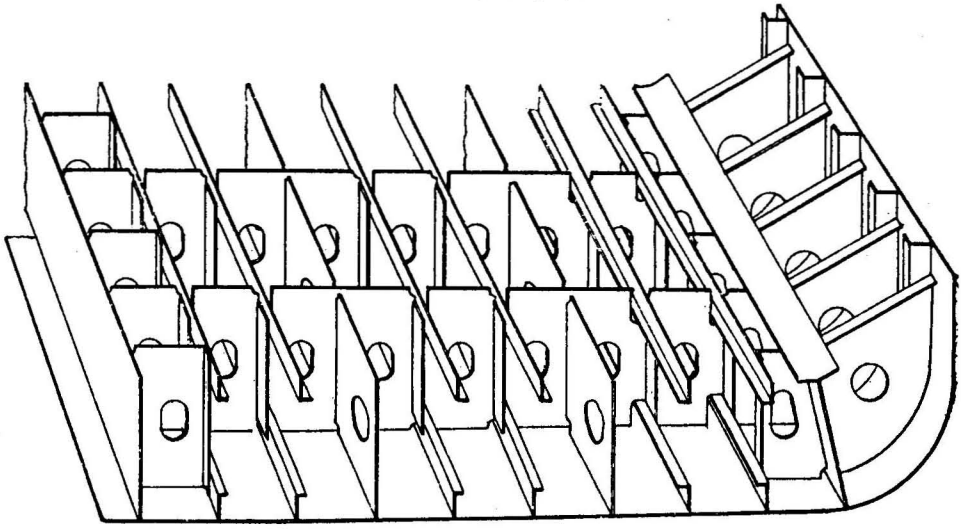
Provided that watertight compartments used exclusively for the carriage of liquids are exempt from the above requirements.

The inner bottom of a passenger ship must protect the bottom as far as the turn of the bilge. The outer edge of the margin plate must not be lower than a horizontal plane through the point where the line of the frames amidships is intersected by a tranverse line, drawn at an angle of 25° to the base line and cutting the latter at a point one-half of the ship's moulded breadth from the middle line.





TRANSVERSE FRAMING



LONGITUDINAL FRAMING

PRECAUTIONS AGAINST POUNDING

FRAMES

Riveted Frames—These have largely given way to welded frames in modern ships, although they are still occasionally fitted, even in otherwise all-welded ships. The sections most used for these are bulb angles and channels.

Welded Frames—Flat bars, bulb bars, or inverted angles may be used for these. They may be attached to shell plating by intermittent welds, or by continuous fillet welds. They are sometimes scalloped, but this is going out of favour because, although it has some advantages, it adds considerably to the difficulties and cost of workmanship if it is properly done.

Web Frames—Are heavy plate frames, which are not normally used as a system, but are fitted in certain parts of a ship to give local strength. They must be fitted in engine-rooms and at every fourth frame space in 'tween decks abaft the after peak bulkhead.

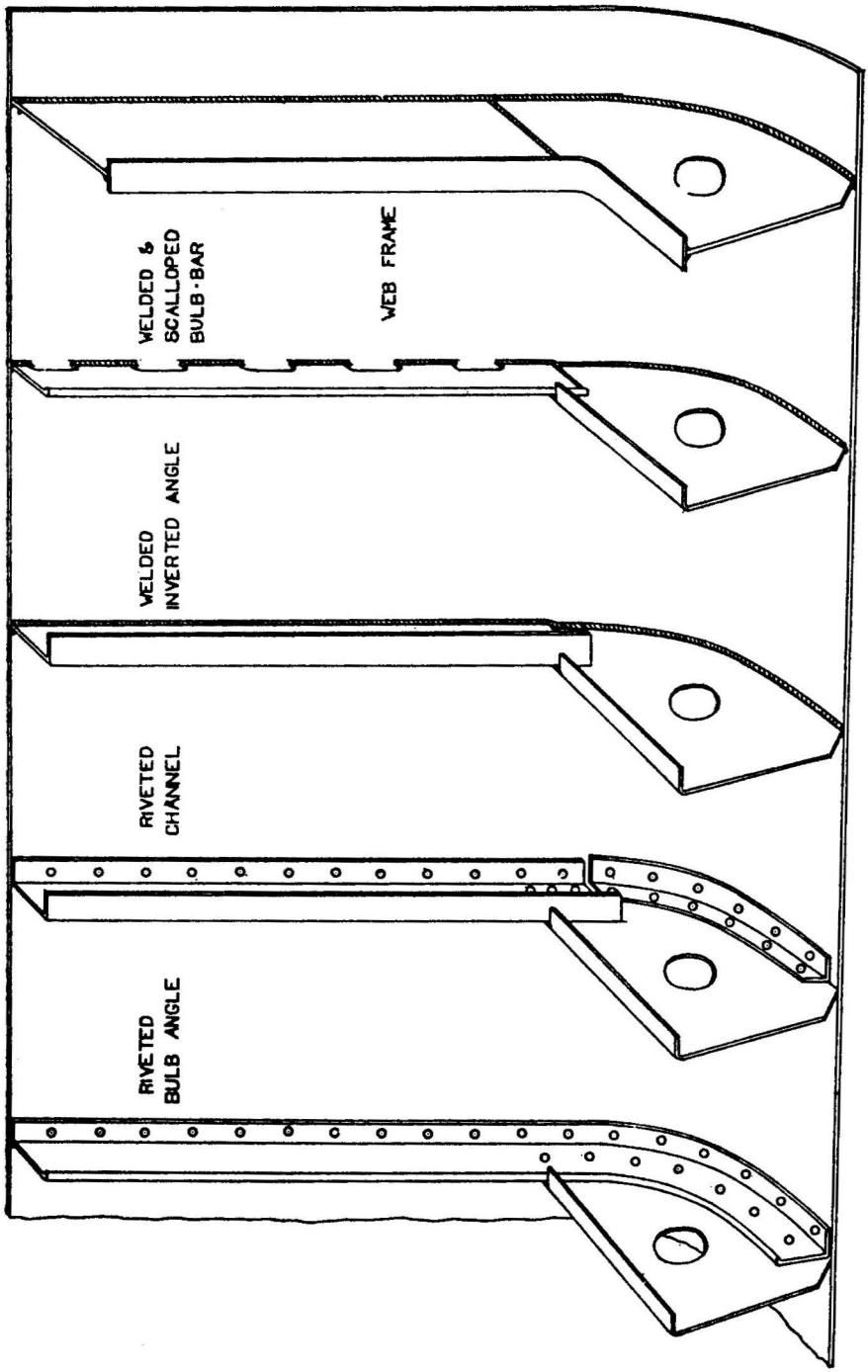
A modification of the web frame, called a 'cantilever frame', is used in some types of bulk carrier and is described in the chapter on 'systems of construction'.

Deep Framing—Is the name given to a system in which every frame is made deeper and stronger than normal, over a given area of shell plating, to provide extra local strength.

Frame Spacing—In the main body of the ship, the frame spacing may not, in general, exceed 1·00 metres. Between the collision bulkhead and a point one-fifth of the ship's length abaft the stem, it must not exceed 700 millimetres. In peak tanks and cruiser sterns, it must not exceed 610 millimetres.

Framing in 'Tween Decks—The main framing may extend at its full size to the upper deck. Alternatively, the framing in the 'tween decks may consist of lighter sections, scarphed on to the main frames at about the level of the 'tween deck.

Numbering—Frames are usually numbered from aft to forward, frame No. 1 being the first one forward of the sternpost. The frames in cruiser sterns are usually lettered from the sternpost, aft.



TYPES OF FRAME

BEAMS

Functions—Transverse beams have two main functions: to tie the sides of the ship together and to support the deck against water pressure and the weight of cargo. Longitudinal beams also contribute to the ship's longitudinal strength.

Sections—Those in general use are welded flat bars, bulb bars and inverted angles. T-bars and T-bulbs may be fitted under wood decks. H sections and various built sections are used as strong beams.

Transverse Beams—The size of transverse beams is governed by their unsupported span; the breadth of the ship; and, in some cases, by the load which the deck has to carry.

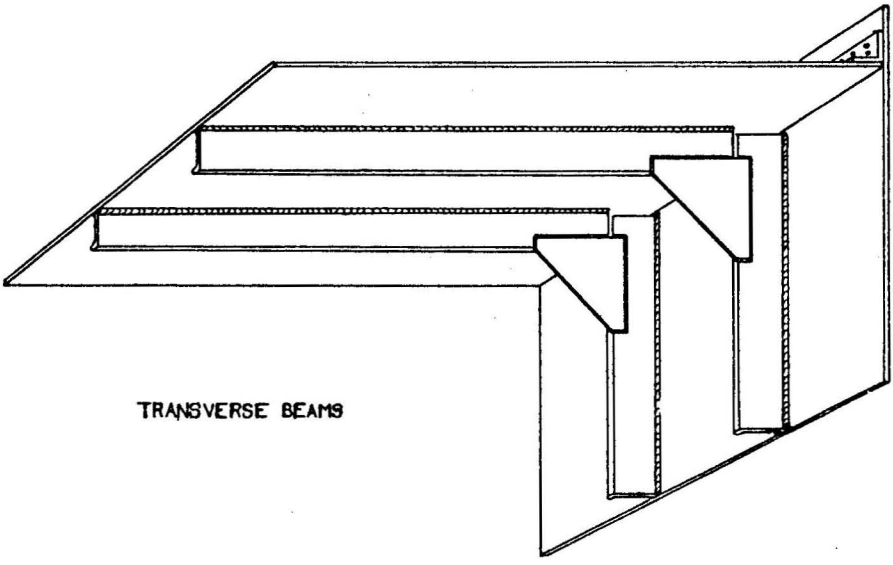
Longitudinal Beams—Or 'deck longitudinals', are now required under the strength deck in all ships of over 120 metres long. They are supported at intervals by heavy transverse beams, which must be not more than 2·5 metres apart for the forward 7½% of the ship's length, or 4·0 metres apart elsewhere. The longitudinals are connected to the transverse beams by direct welding, or by flat bars similar to those used in double bottoms.

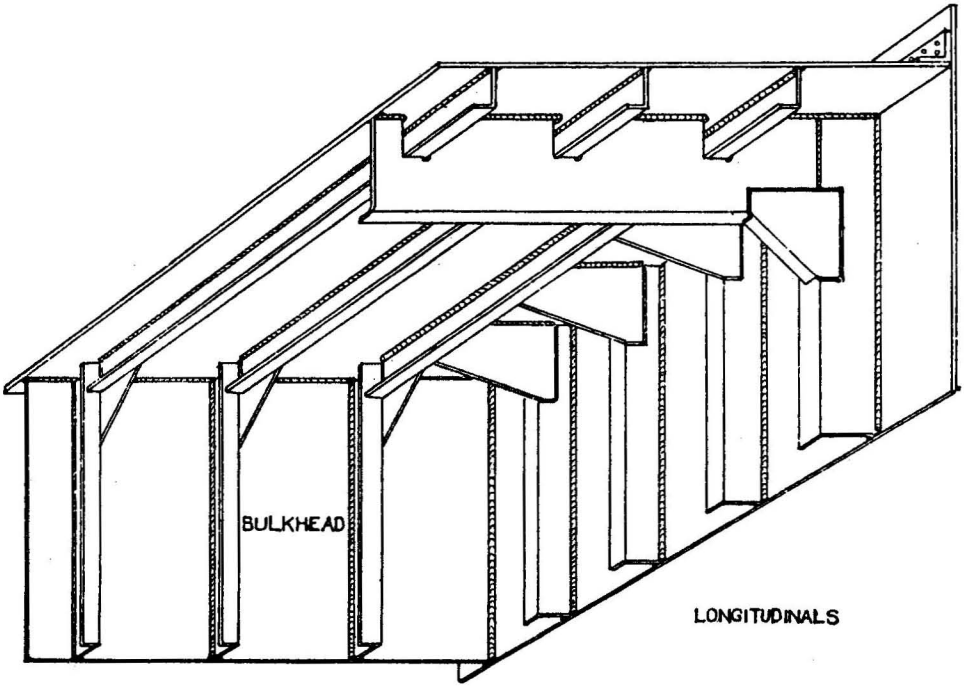
At bulkheads, the longitudinals may be cut and bracketed to the bulkhead, as for bottom longitudinals; unless the ship is more than 215 metres long, when the longitudinals must be continuous.

At hatchways, the longitudinals are cut and attached to the hatch end beams by brackets.

Strong Beams—These are often fitted in engine and boiler rooms; to support deck longitudinals; or, sometimes, as hatch end beams. In other words, a strong beam is a specially heavy beam which is fitted where great local strength is required.

Camber—Is the curvature given to weather decks to enable them to shed water. 'Tween decks are not usually cambered. The standard camber is 1/50: that is, a rise of 2 centimetres for each 1 metre of length of beam.





BEAMS

BEAMS—(*Continued*)

Half-Beams—Transverse beams which are cut at hatch side coamings are termed 'half-beams'. When the coaming does not form part of a deck girder, the half-beams are simply welded directly to it. If the coaming forms part of the deck girder, the connection is made by means of alternate flat bars and brackets (*see* 'Massed Pillaring').

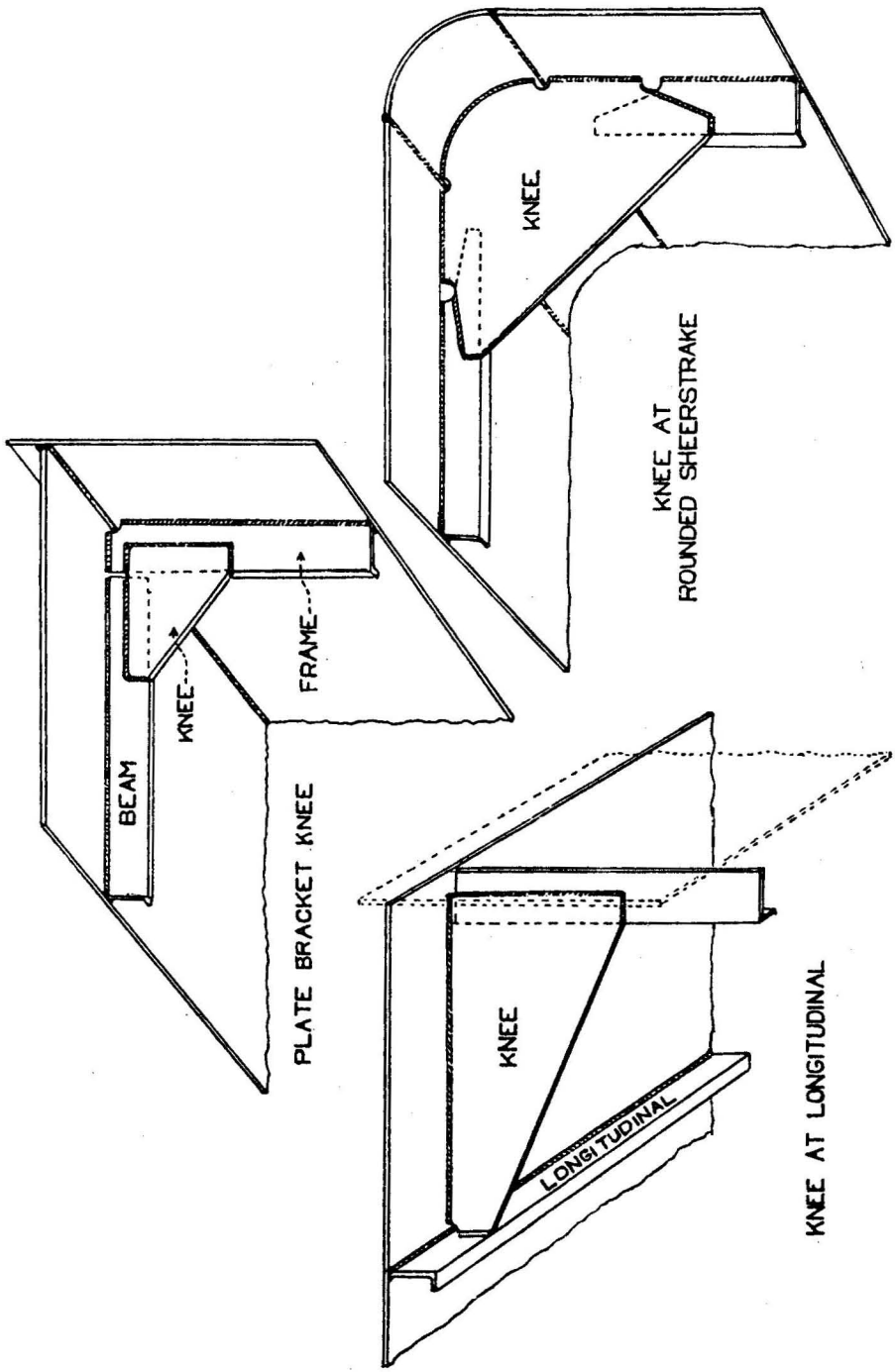
Cargoes Suspended from Beams—When cargo is to be suspended from the beams, as in the case of chilled beef, the strength of the beams must be increased by between 50% and 100%, according to circumstances.

Welding—Beams may be attached to decks by intermittent or continuous fillet welds, or they may be scalloped, in the same way as frames.

Beam Knees—These are used to connect beams to frames. There are various types, but for connecting frames to ordinary transverse beams, the 'plate bracket knee' is used almost exclusively. Welded plate bracket knees are not as efficient as they might be, because they have fairly large stress concentrations at their corners; but they are cheap and easy to fit and are strong enough for ordinary purposes.

Large knees must have a flange, at least 50 millimetres wide, on their free edge. Frames and beams need not, in general, overlap, as the knee is considered to be a sufficient connection between them.

When longitudinal beams are fitted, the knees at those frames where there is no transverse beam, must extend to the first longitudinal.


KNEE
KNEE AT
ROUNDED SHEERSTRAKE
FRAME
KNEE
BEAM
PLATE BRACKET KNEE
KNEE
LONGITUDINAL
KNEE AT LONGITUDINAL

BEAM KNEES

WATERTIGHT BULKHEADS

Uses—Bulkheads are an important element of transverse strength, particularly against racking stresses. By dividing the ship into longitudinal subdivisions, they also give protection against fire and foundering.

Number to be Fitted—All ships must have certain bulkheads, as follows:—

A collision bulkhead, not less than 5%, nor more than 8% of the ship's length abaft the stem at the load waterline.

An after peak bulkhead, to enclose the shaft tube in a watertight compartment.

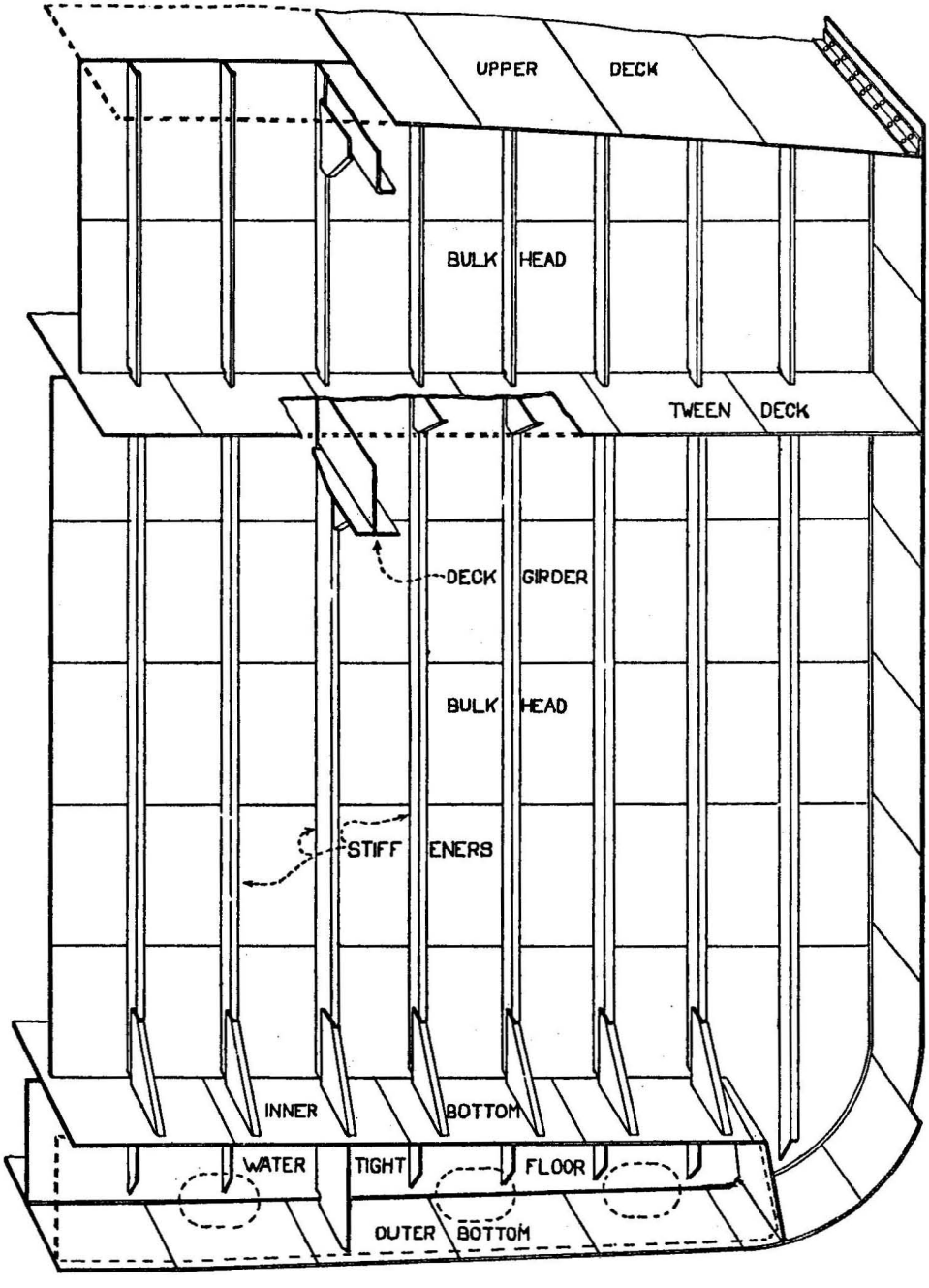
One bulkhead at each end of the machinery space.

Ships of over 90 metres long must have additional bulkheads, spaced at reasonably uniform intervals. The number to be fitted depends on the length of the ship and on whether the engines are placed amidships or aft.

Passenger Ships—The spacing quoted above is the minimum required for all ships. Passenger ships are, however, required to be subdivided by watertight bulkheads in accordance with the 'permissible length' of compartments. This is found by multiplying the 'floodable length' by the 'factor of subdivision'. (*See* Definitions: 'Bulkhead Spacing'.)

Height—Collision bulkheads must extend to the upper deck. The after peak bulkhead need only extend to the first deck above the load water line, if it forms a watertight flat. All other bulkheads must extend to the bulkhead deck, which is usually the freeboard deck.

Fitting—Bulkheads are always fitted in lieu of a frame; that is, the frame is omitted and the bulkhead takes its place. They are intercostal between decks; the decks being continuous and the bulkhead fitted in 'panels' between them.



WATERTIGHT BULKHEAD

E

WATERTIGHT BULKHEADS—(*Continued*)

Plating—Plating may be fitted either vertically or horizontally, but it is usually fitted horizontally, as this allows of a better graduation of thickness.

The thickness may be graduated, increasing from the top downwards. It is governed in each strake by the spacing and length of the stiffeners and the depth of the strake below the top of the bulkhead.

Plating in after peak bulkheads must be doubled or thickened around the stern tube to resist vibration.

Stiffeners—Stiffeners may be angles, bulb-angles, channels, or equivalent welded sections and are usually fitted vertically. Their type and size depend on the distance of the top of the bulkhead above the top of the stiffener and on the actual length of the stiffener. They are usually spaced about 75 centimetres apart, except in collision bulkheads and deep tank bulkheads, where the spacing is to be 60 centimetres.

The ends of stiffeners may be welded directly to the inner bottom or deck, or they may be attached by angle lugs or by brackets. Where brackets are used for this purpose, they must extend to the floor next to the bulkhead, whilst large brackets must be flanged. If the ship has longitudinal framing in the bottom, an extra floor must be fitted under the toes of the brackets. Stiffeners on collision bulkheads and on bulkheads forming tank boundaries must be bracketed at the head and foot.

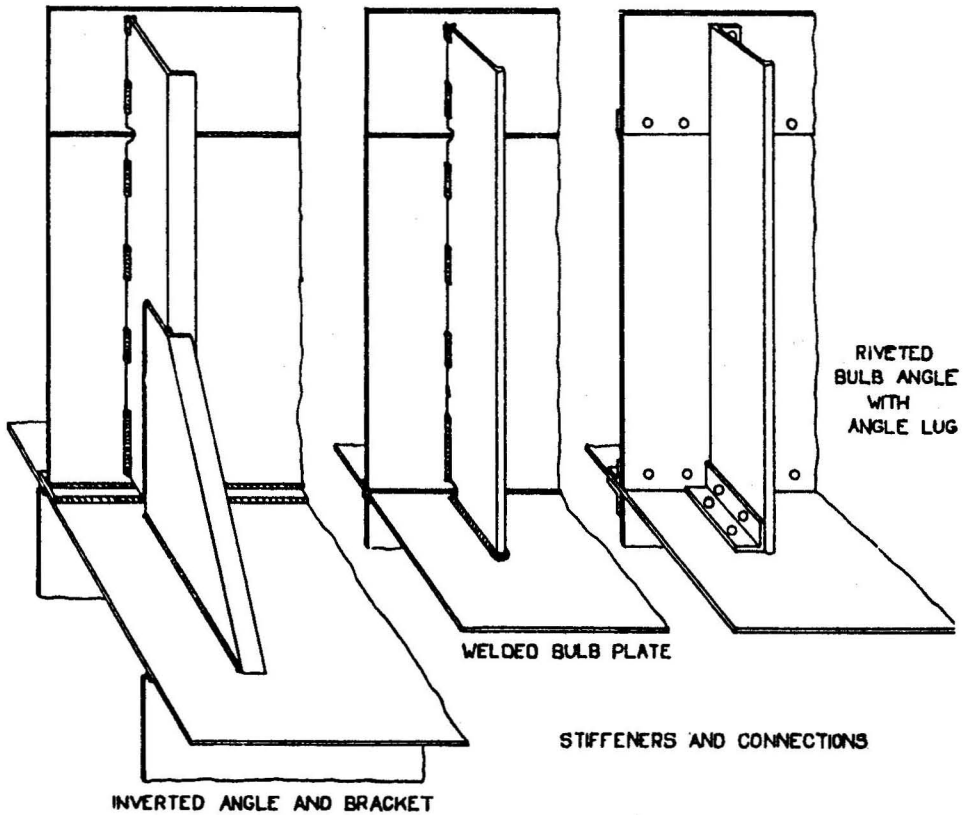
If stiffeners are cut for watertight doors, etc., the opening must be framed strongly and must have vertical, tapered web plates, extending well above the opening, fitted on each side.

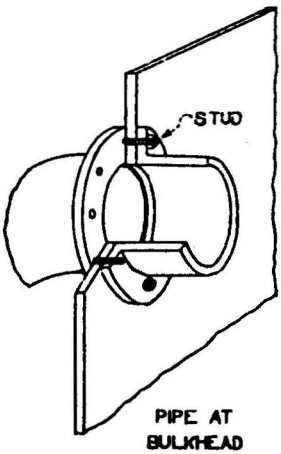
Stiffeners in the way of a deck girder are often made heavier than normal and are attached to the girder by deep, flanged brackets.

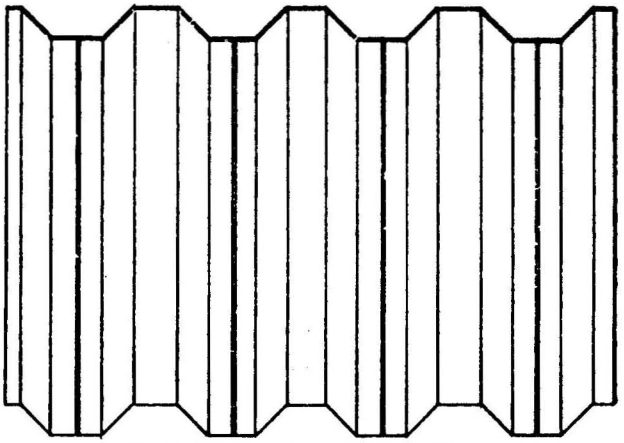
Corrugated Bulkheads—These are often fitted in oil tankers and are occasionally found in dry cargo ships. The type shown in the sketch is often called 'swedged'. The corrugations give stiffness to the plating and ordinary stiffeners are not fitted on them: although widely-spaced web stiffeners, at right angles to the corrugations, are sometimes used.

In transverse bulkheads, the corrugations may run either vertically or horizontally. In longitudinal bulkheads, only horizontal corrugations are allowed, in order to give longitudinal strength.

The thickness of the plating is governed by the width of its 'flats' and the height of the bulkhead.







BULKHEAD DETAILS

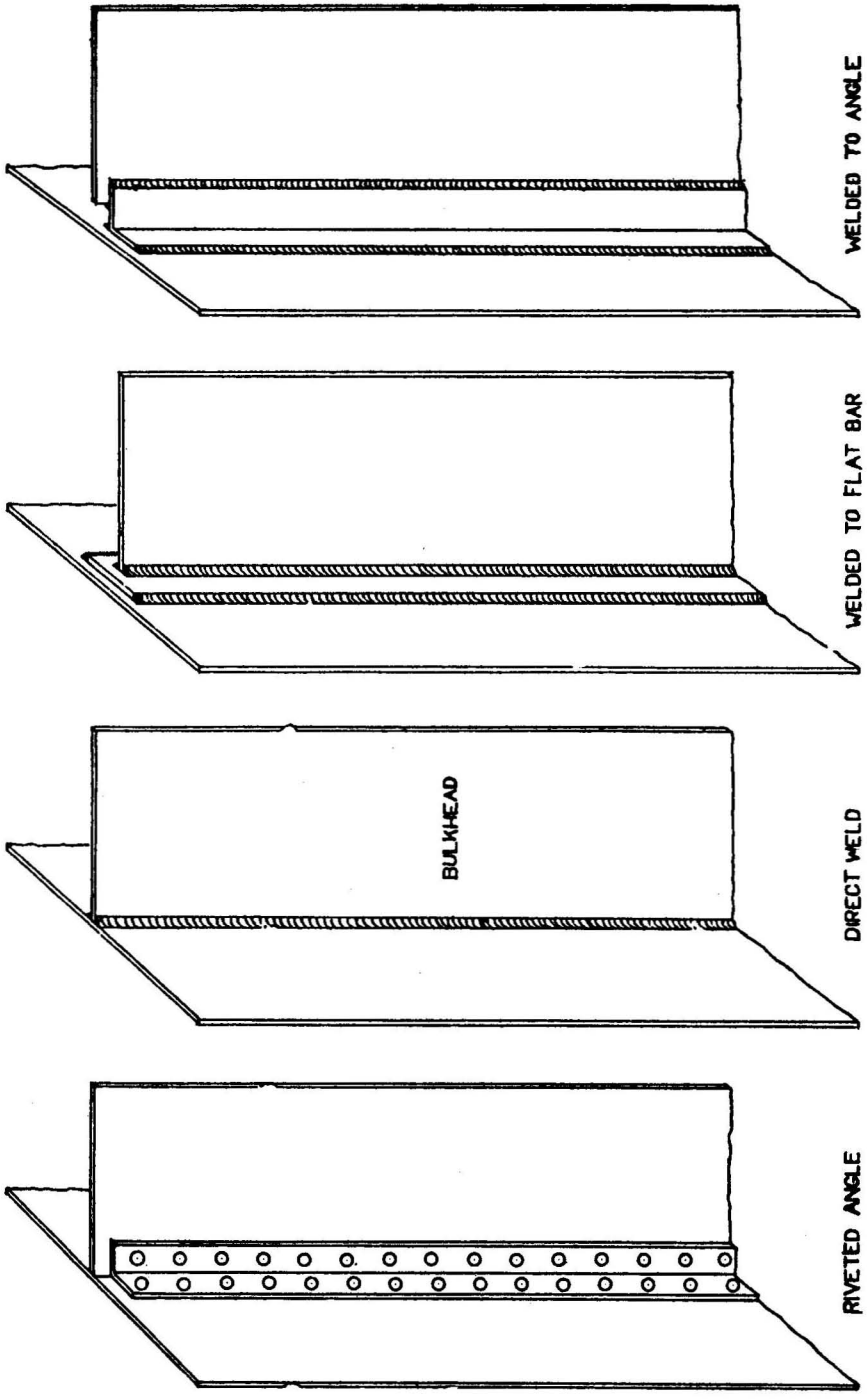
WATERTIGHT BULKHEADS—(*Continued*)

Boundaries—Riveted bulkheads are attached to the shell plating, decks and inner bottom by single angle bars.

In welded bulkheads, the boundary connections may be made by welding the bulkhead plating to the shell plating, etc. More often, the boundary connection is made by welding to a flat bar, angle, or T-bar, as shown in the sketches.

Pipes Passing Through Bulkheads—Where pipes pass through bulkheads, they are either welded, or fastened to the bulkhead by studs or bolts screwed through tapped holes in the plating. They must not be secured by ordinary bolts passing through clear holes in the plating. This ensures that, if the bolt breaks, part of it will be left in the bulkhead; otherwise, a clear hole might be left in the plating.

Tests—Bulkheads forming tank boundaries are tested by testing the tank. Peak bulkheads, other than those forming peak tank boundaries, are tested by filling the peak to the level of the load waterline. Other watertight bulkheads are hose-tested.



BOUNDARY CONNECTIONS

SYSTEMS OF PILLARING

General—Pillars are intended to support the deck above them and to tie the beams to the bottom, or deck below. They are usually fitted two or more beam spaces apart, so it is necessary to fit a deck girder, running fore and aft under the beams, to support the intermediate beams.

Ordinary Pillars—These are solid round bars or tubes, of between 60 millimetres and 150 millimetres diameter. They are usually fitted at alternate beams, with a 'deck runner' at their heads.

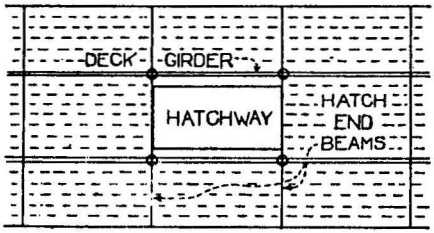
All ships originally had one row of ordinary pillars fitted at the centre-line. As ships became larger, the pillars were made heavier, or more rows were introduced.

Ordinary pillars have now been superseded as a system by massed pillaring, but are still found in some parts of ships where the deck may require local support.

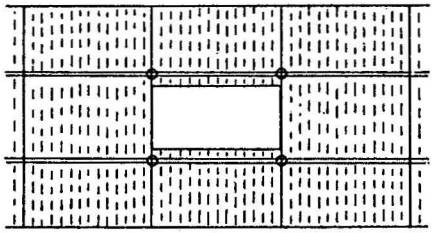
Quarter Pillars—The large number of ordinary pillars required in large ships, obstructed the holds. This obstruction was reduced by fitting a system of larger pillars, spaced further and fitted at the quarter line only. Because there were more beams to support between pillars, the deck runner was made heavier and came to be called a "deck girder"

Massed Pillars—The modern system of massed pillaring was developed from the quarter pillars by increasing their size and spacing still further. The deck girders have to be made very strong, because of their large, unsupported span. Massed pillaring may be fitted in line with the hatch coamings, in which case the coamings form a part of the deck girder. Sometimes, pillars are omitted entirely, with the deck girder made extra heavy and supported by the bulkheads alone.

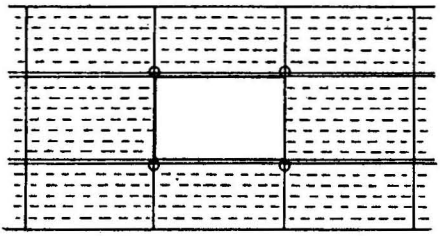
Middle Line Longitudinal Bulkheads—Partial longitudinal bulkheads may be fitted at the centre-line, in lieu of pillars. Their construction is similar to that of ordinary transverse bulkheads; except that they need not be watertight and that the stiffeners need only be not more than 1500 millimetres apart.



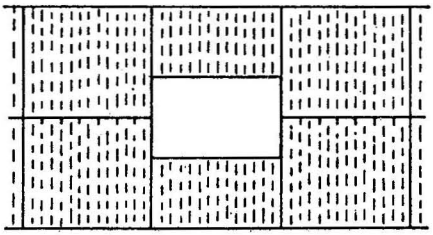
MASSED PILLARS
WITH LONGITUDINAL DECK BEAMS



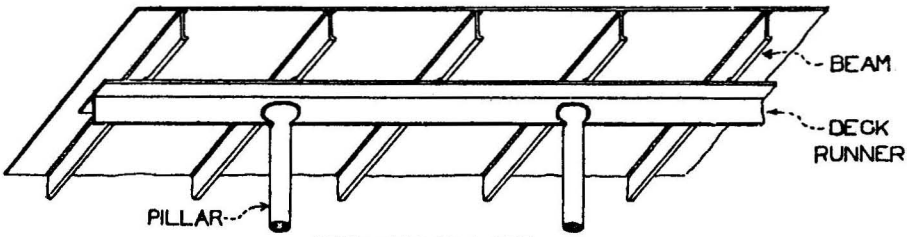
MASSED PILLARS
WITH TRANSVERSE DECK BEAMS



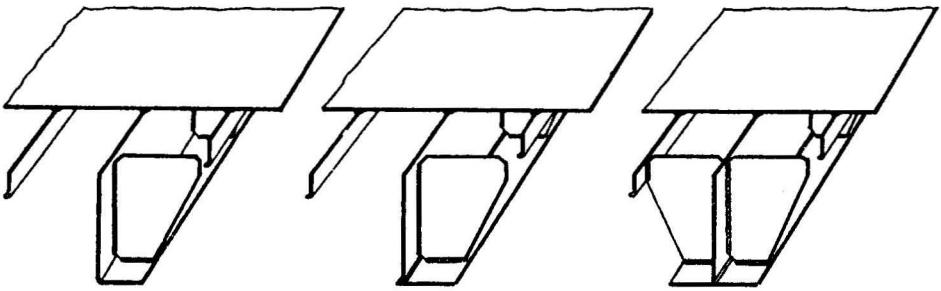
MASSED PILLARS
IN LINE WITH COAMINGS



PARTIAL LONGITUDINAL
BULKHEAD



ORDINARY PILLARS



FLANGED L-SHAPED T-SHAPED

TYPES OF DECK GIRDER

PILLARING

MASSED PILLARING

Pillars—These are usually formed of plates on the round, but are sometimes of hollow square section, or built up of angles or channel bars.

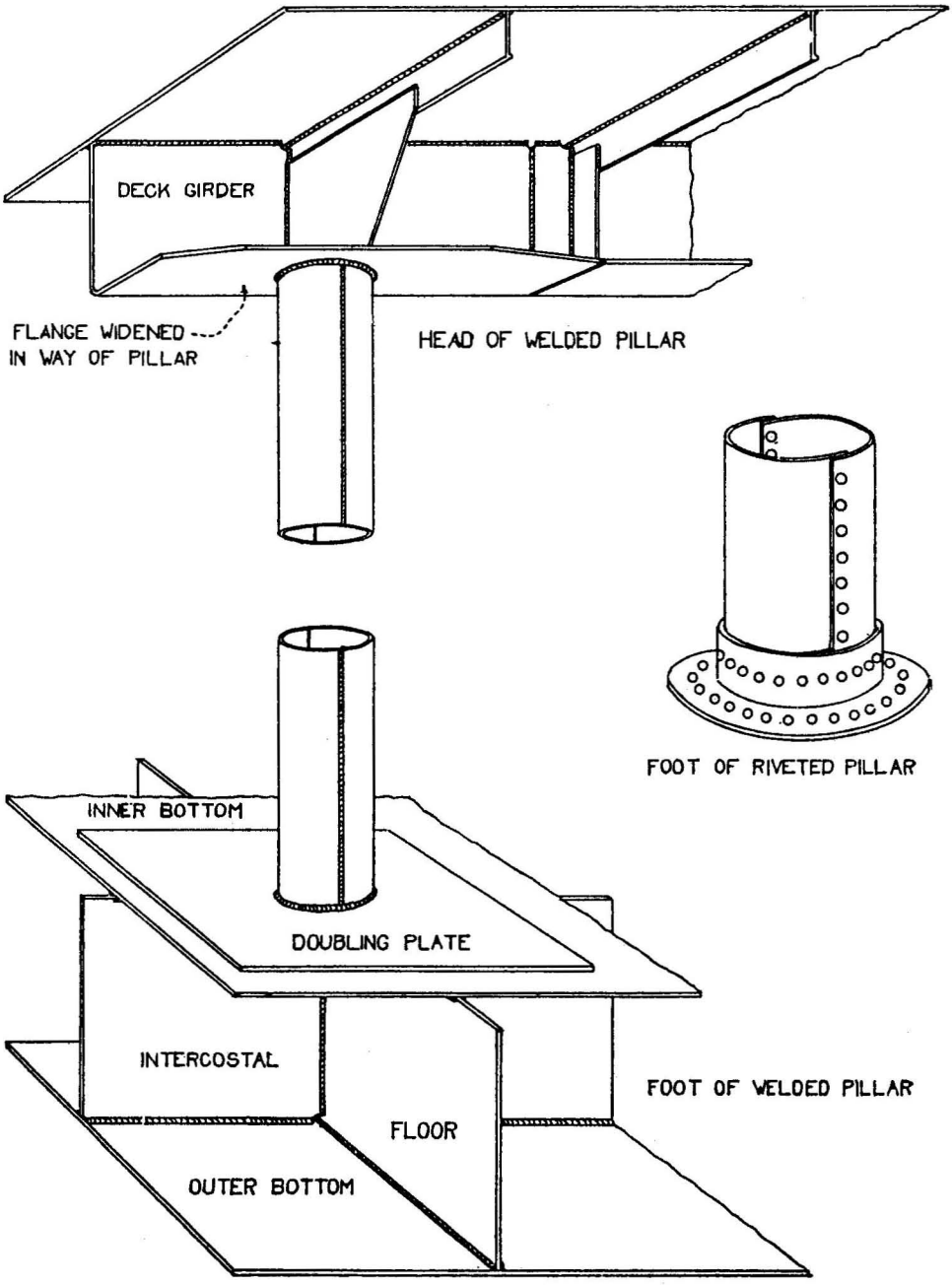
Deck Girders—The deck girder usually consists of an intercostal plate, the lower edge of which may be stiffened by a flange, by one or two riveted bulb angles, or by equivalent welded sections.

Size—The size of pillars and deck girders depends on the work they have to do: that is, by the length and width of deck supported by them and by the height of the 'tween decks above them. In the case of pillars, their length is also taken into consideration.

Fitting of Pillars—It is usual to fit two or three pillars on each side in each hold. 'Tween deck pillars should be placed directly over lower hold pillars, if possible.

Riveted round pillars are connected at the head and foot by angles. Welded ones are attached directly to the deck girder or plating. In the way of the heads of pillars, tripping brackets are fitted to the girder: whilst, if necessary, the flange may be widened in this region.

Doubling plates, or insert plates, must be fitted to the inner bottom plating under the heels of massed pillars. The heels of the pillars should rest, if possible, on the intersection of a floor and existing intercostal girder in the bottom. If this is impossible, extra intercostal girderwork must be introduced to intersect the floor under the pillar.


DECK GIRDER
FLANGE WIDENED IN WAY OF PILLAR
HEAD OF WELDED PILLAR
FOOT OF RIVETED PILLAR
INNER BOTTOM
DOUBLING PLATE
INTERCOSTAL
FOOT OF WELDED PILLAR
FLOOR
OUTER BOTTOM

PILLARS

MASSED PILLARING—(*Continued*)

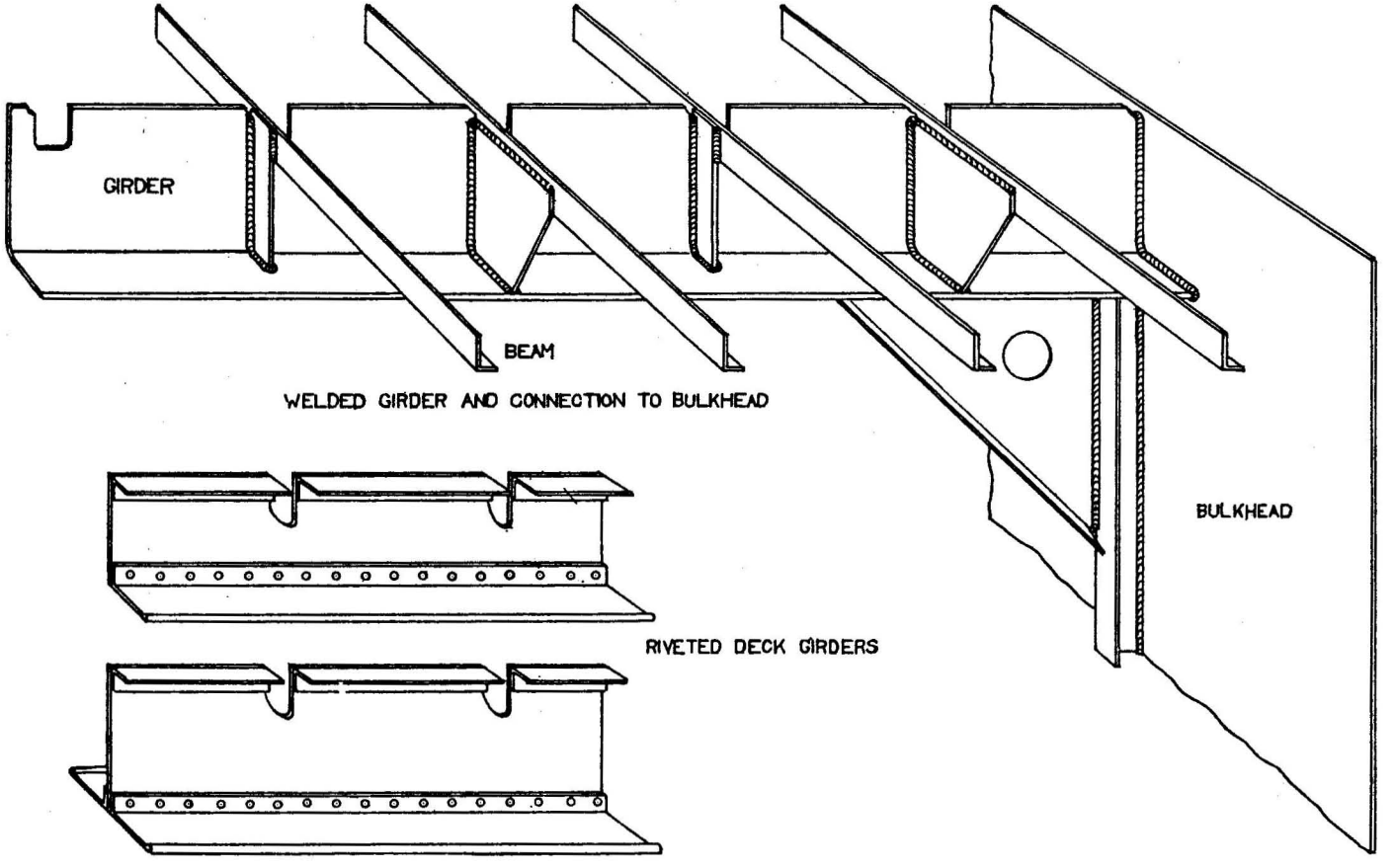
Fitting of Deck Girders—Plate girders are welded directly to the deck above.

Transverse deck beams, if fitted, are slotted through the girder. If the girder has a single flange on its lower edge (i.e. if it is L-shaped), it is attached to every second beam by a bracket on the same side of the girder as the flange. If the girder has a double flange (i.e. if it is T-shaped), brackets are fitted on both sides at every fourth beam. At intermediate beams, between brackets, the beams are attached to the girder by flat bars or by direct welding.

If there are longitudinal beams under the deck, the girder is supported by brackets which extend to the nearest longitudinal; spaced at the same distance apart as those for transverse beams.

Deck Girders at Bulkhead—Deck girders are cut at bulkheads. To maintain strength, they are attached to the bulkhead by welded brackets, which must be stiffened by welded face bars on their inner edges.

Hatch Coamings as Deck Girders—Deck girders are often fitted in line with the hatch coamings and the coaming plate is then built into the girder. In this case, the coaming has to comply with both the rules for the construction of hatch coamings and with those for deck girders.



DECK GIRDERS

HATCHWAYS

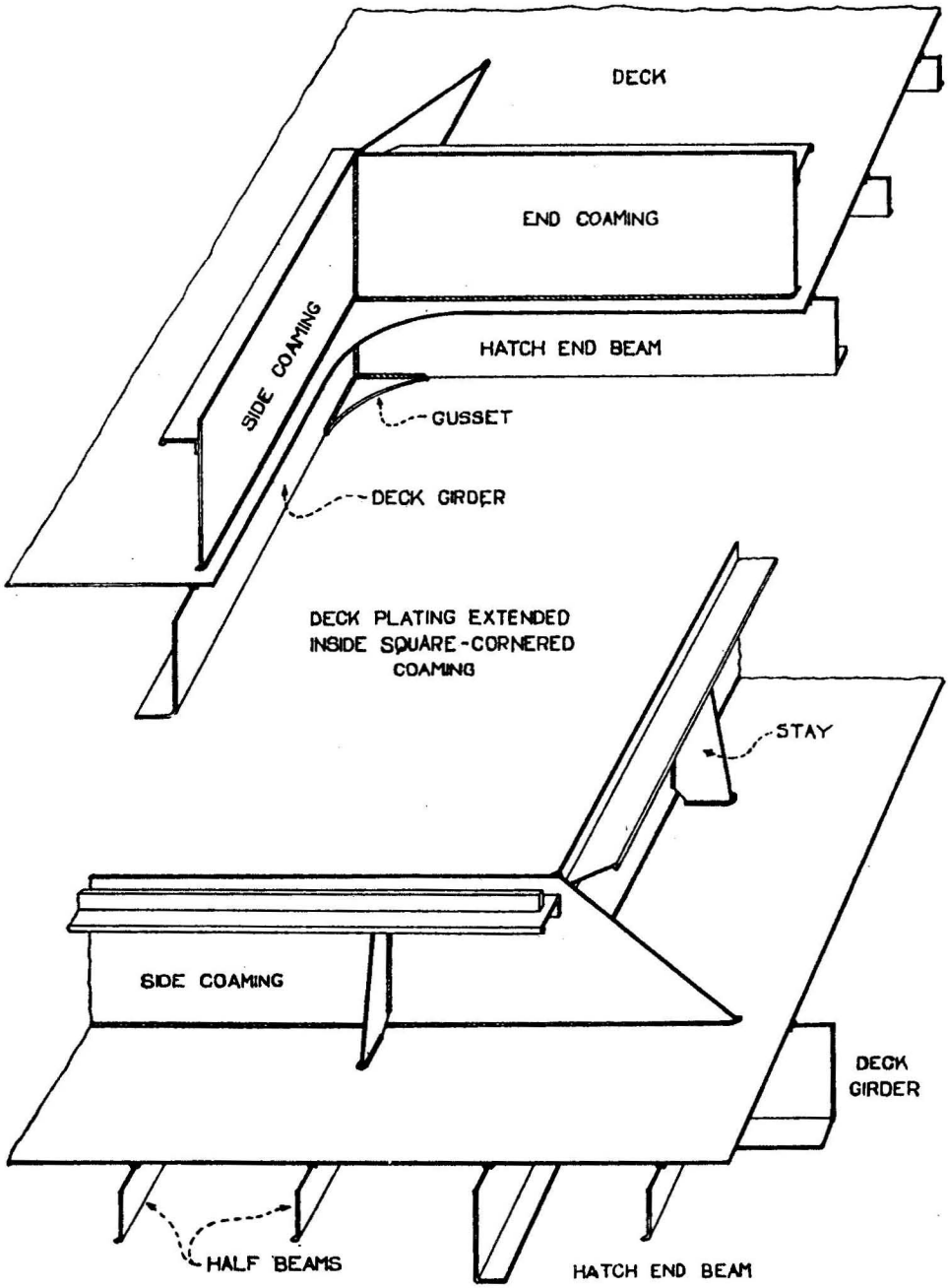
General—The resistance to longitudinal stress is much reduced in the way of hatches, on account of the large amount of material which must be cut out of the deck. Stress concentrations cause a tendency for the deck to fracture at the hatch corners. There is also a loss of resistance to loads of water or cargo on the deck, due to the beams being cut at the hatch coaming. These weaknesses must be compensated for or they might be dangerous. To give the necessary strength the deck plating must be strengthened or doubled, and the coamings and their connections must be sufficiently strong and rigid.

Deck Openings—With riveted construction, deck openings may have square corners, with doubling plates fitted at the corners.

When the deck is welded, square corners are not allowed. The openings may be elliptical or parabolic, or the corners may be rounded-off. In the latter case, the radius at the corners must be at least one-twenty fourth of the breadth of the opening; but not, in any case, less than 300 millimetres. Doubling plates are not allowed in welded decks, so insert plates must be fitted at the hatch corners instead.

Height of Coamings—Coamings on weather decks must extend well above the deck, to ensure that water cannot enter the ship's hull.

The height of coamings on freeboard decks, raised quarter decks, or within one-quarter of the ship's length from the stem on superstructure decks, is to be 600 millimetres, where they are explosed to the weather. On exposed parts of superstructure decks, abaft one-quarter of the length from the stem, the height is to be 450 millimetres. At other decks, the openings are to be suitably framed.


DECK
END COAMING
SIDE COAMING
HATCH END BEAM
GUSSET
DECK GIRDER
DECK PLATING EXTENDED
INSIDE SQUARE-CORNERED
COAMING
STAY
SIDE COAMING
DECK
GIRDER
HALF BEAMS
HATCH END BEAM

HATCHWAYS

HATCHWAYS—(*Continued*)

Coamings—Welded hatch coamings may have rounded corners, so as to fit closely inside the deck opening, but this is not common because it is then difficult to fit hatch-covers.

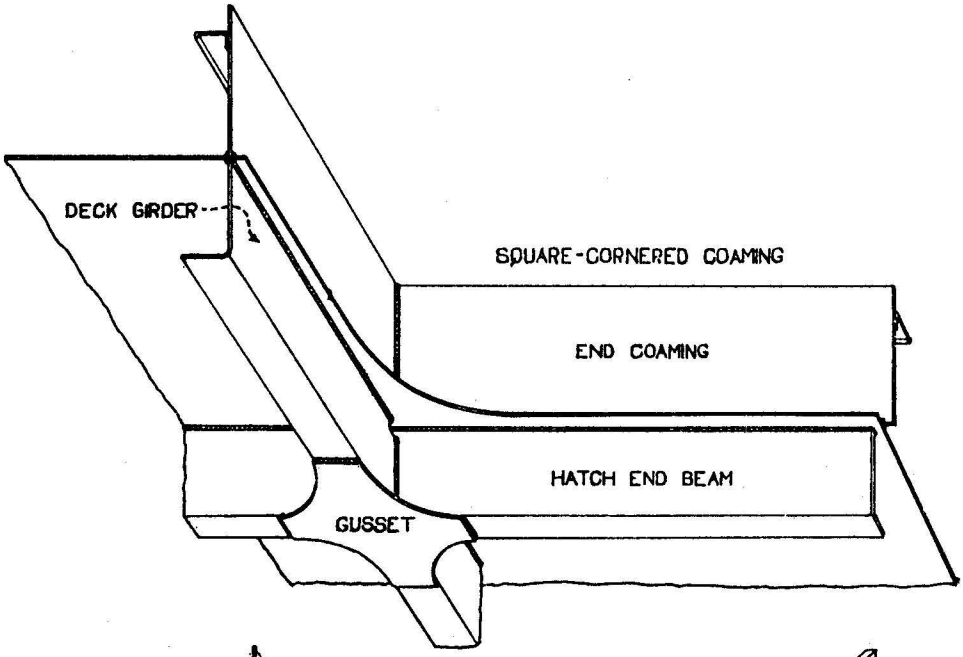
A common alternative is to fit square-cornered coamings. If this is done within 0·6 of the ship's length amidships, the ends of the side coamings must be extended beyond the hatch ends to form tapered brackets, if possible. The deck plating must be extended inside the coaming so that it can be rounded-off and its edges must be smooth and must not have anything welded to them.

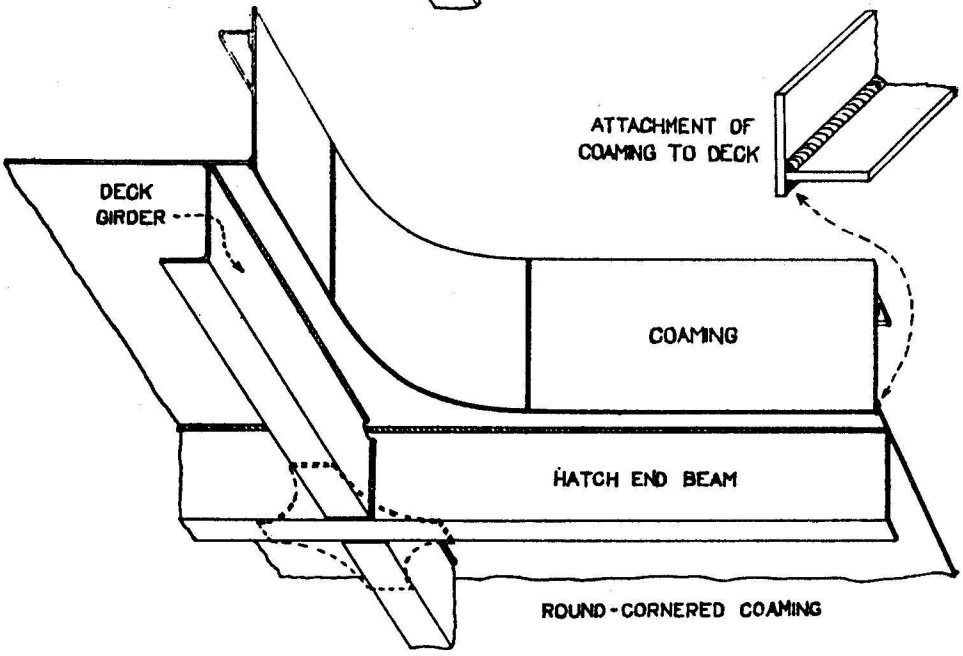
Below the deck, the deck girder may be fitted in line with the side coamings. If this is not done, and if the side coamings cannot be extended, above the deck, to beyond the hatch ends; then short pieces of girder must be fitted to extend the coamings for at least two frame spaces below the deck. In either case, horizontal gussets are fitted under the hatch corners to strengthen the connection between the side coamings and the hatch end beams.

Great care must be taken in welding hatch coamings to decks, in order to make a strong and efficient connection. Full penetration fillet welds are often used for this purpose.

If coamings are 600 millimetres or more in height, they must be stiffened by bulb-bars, at least 180 millimetres deep, fitted horizontally near the upper edge of the coaming. Vertical stays or brackets must then be fitted, not more than 3 metres apart, between the stiffener and the deck.

Hatch End Beams—The beam at each end of a hatchway is called a 'hatch end beam'. These are usually made stronger than normal and are connected to the frames by heavy, flanged beam knees, because they carry at least part of the weight of the coaming.


DECK GIRDER
SQUARE-CORNERED COAMING
END COAMING
HATCH END BEAM
GUSSET


ATTACHMENT OF
COAMING TO DECK
DECK
GIRDER
COAMING
HATCH END BEAM
ROUND-CORNERED COAMING

HATCHWAYS

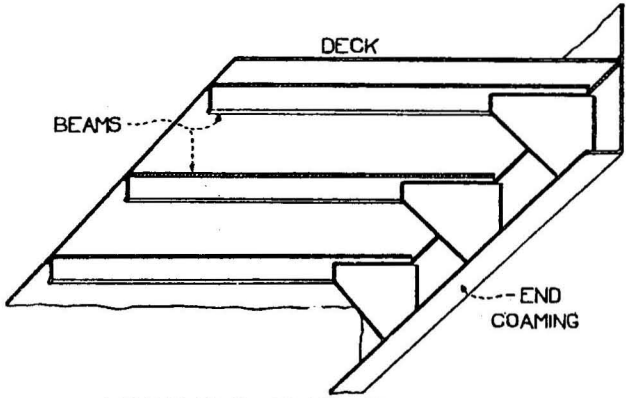
HATCHWAYS—(*Continued*)

Half Beams—Transverse beams in the way of the side coamings are cut at the latter and are called 'half beams'.

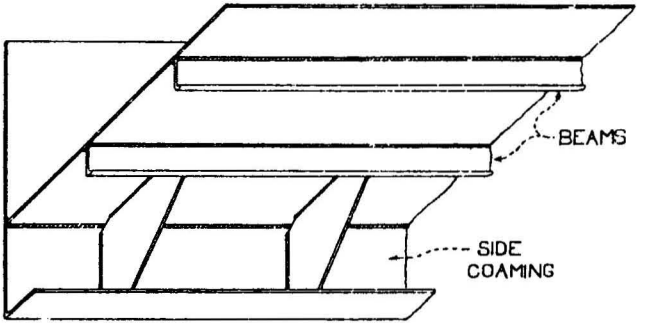
If the side coamings form part of the deck girder, the half beams are attached to them by welded bars and by brackets at alternate beams; as for deck girders.

If the side coaming does not form part of the deck girder, the connection is by direct welding; unless the deck girder is at some distance from the coaming, when brackets may be fitted between the two.

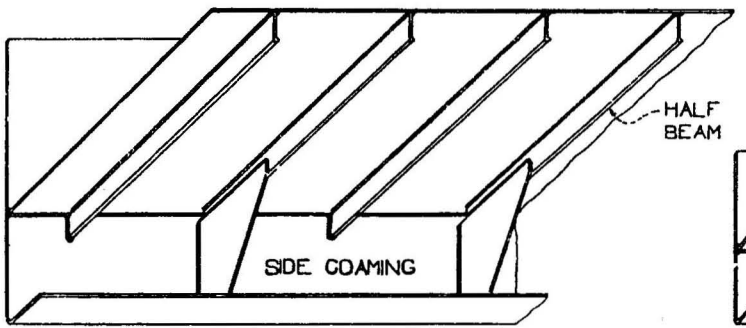
Longitudinal Beams at Coamings—If longitudinal beams are fitted under the deck, they are cut at the hatch and coaming and attached to it by brackets.



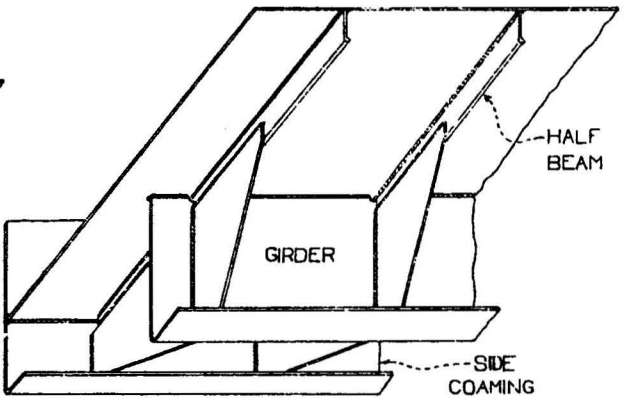
LONGITUDINAL BEAMS AT
HATCH END COAMINGS



LONGITUDINAL BEAMS AT
HATCH SIDE COAMING



COAMING AS PART OF DECK GIRDER



GIRDER AT SOME DISTANCE FROM COAMING

BEAMS AT HATCH COAMINGS

SHELL AND DECK PLATING

General—Seams, or 'Edge Laps', are joints which run fore and aft; that is, along the longer edges of the plates.

Butts, or 'End Laps', are joints which run athwartships, or vertically; that is, along the shorter edges of the plates.

Strakes are continuous, fore and aft, lines of plates.

Garboard strakes are the strakes of shell plating next to the keel on either side (i.e. the 'A Strake').

Sheerstrakes are the upper strakes of shell plating on either side, next to the upper deck. (The 'J strake' in the sketch opposite.)

The Deck Stringer is the outboard strake of deck plating, which is connected to the sheerstrake. (Strake 'E' on the deck plan, opposite.)

Stresses on Plating—The obvious purpose of plating is to keep out water and to tie together the ship's framework. It also plays an important part in resisting longitudinal bending stresses, so it needs to be stronger amidships than at the ends, particularly at the deck and bottom. In long ships, it may also be necessary to strengthen the shell plating against shearing stresses at about the half-depth of the ship, in the region of about one-quarter of the ship's length from either end.

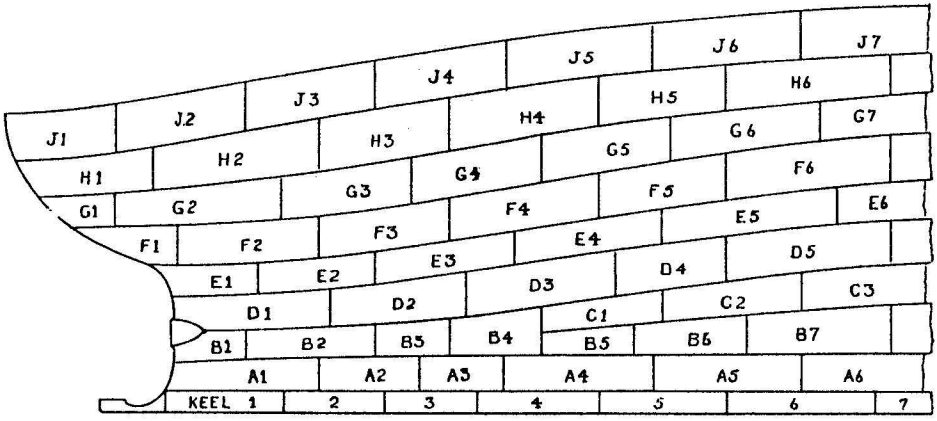
Shell Expansion and Deck Plans—These are plans which show all the plates in the hull, drawn to scale. They also show many other details, including frames, floors, deck edges, stringers, etc. The partial plans shown in the plate, opposite, are simplified and are merely intended to illustrate the fitting of shell and deck plating.

Identifying Plating—Strakes of shell plating are distinguished by letters from the keel outwards, the garboard strake being strake 'A'. The plates in each strake are usually numbered from aft to forward. For example, plate D5 would be the fifth plate from aft in the fourth strake from the keel.

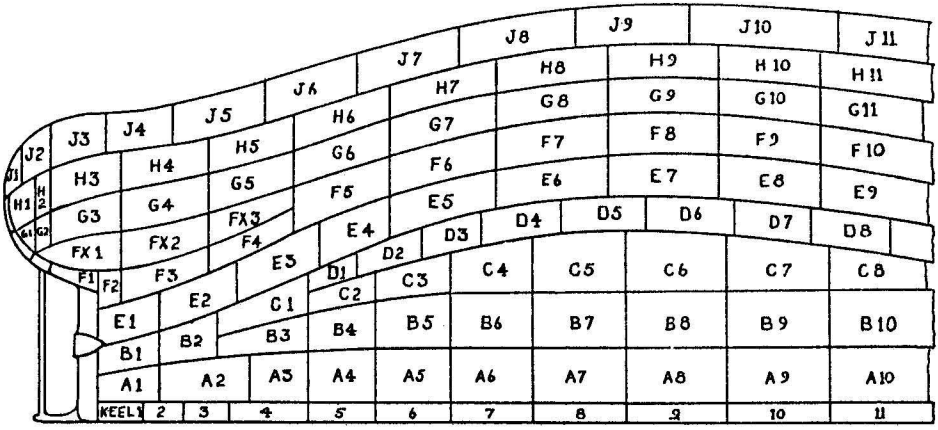
Strakes of deck plating are lettered from the centre line, outboard; whilst deck plates are numbered from aft to forward.

Stealer Plates—The girth of the ship decreases toward the ends and so the width of plates must be decreased in these parts. To save making the plates too narrow at the ends of the ship, it is usual to run a number of pairs of adjacent strakes into one. This is done by means of a stealer plate.

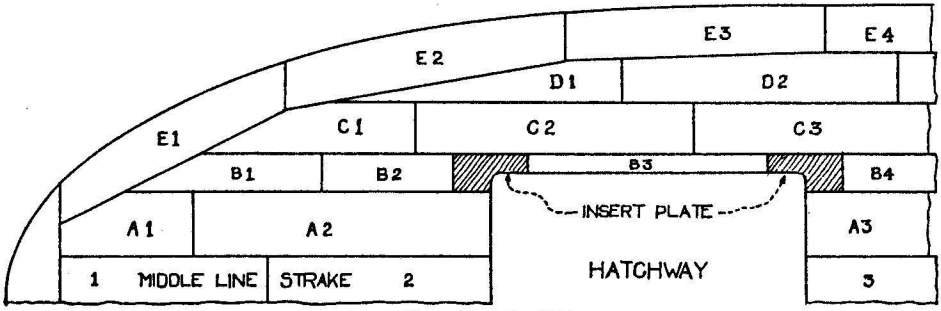
This can be seen in the upper shell expansion plan, given here; in which Plate B4 is a stealer, since it runs the B and C strakes into each other. Note how the stealer and the plates beyond it, always take the name of the lower of the strakes which are run together.



SHELL EXPANSION — SHIP PLATED AT SLIP



SHELL EXPANSION — PREFABRICATED SHIP



PLAN OF DECK PLATING

SHELL AND DECK PLATING

SHELL AND DECK PLATING—(*Continued*)

Special Plates—Shoe plates are used to connect the stem to the flat plate keel. (*See* 'Stems').

Coffin Plates are used to connect stern frames to the flat plate keel. (*See* 'Sternframes'.)

Boss Plates are shield-shaped plates fitted over the boss of the sternframe.

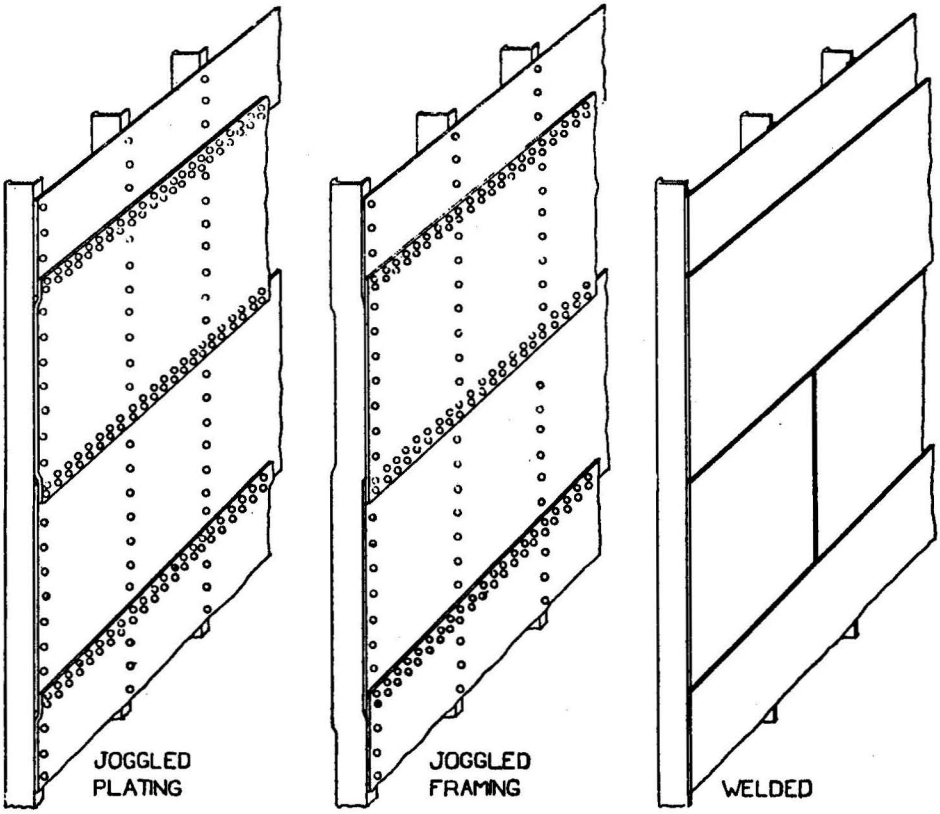
Oxter Plates are peculiarly curved plates which are fitted where the sternframe meets the overhang of the stern.

Riveted Plating—This has largely given way to welded plating, but is still sometimes used. The modern systems are Joggled Plating and Joggled Framing, both of which are light and efficient. The butts of the plating were originally riveted, but are now almost always welded. When this is done, the butts must be welded first and the seams riveted afterwards, in order that the joints may be sound.

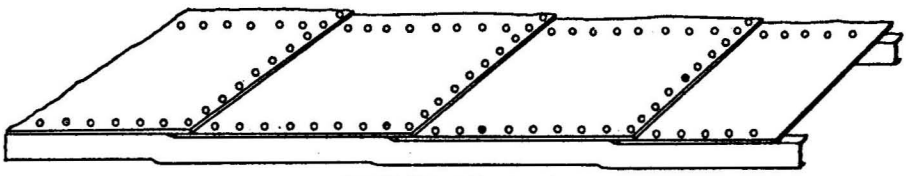
Welded Plating—The butts and seams are joined by butt welds, which gives a flush surface to the plating and also saves some weight.

Welded plating is more liable to crack, under hogging and sagging stresses, than is riveted plating; particularly in the region of the sheerstrake and the bilge. Such cracks are most likely to occur if openings are cut near the upper edge of the sheerstrake, or if notches or hard spots occur at its upper edge. For this reason, openings in the sheerstrake should have well-rounded corners and should be kept well clear of the upper edge of the plates. The upper edge of the sheerstrake should be 'dressed' (ground-off) smooth; whilst other parts should not be welded to it, if avoidable.

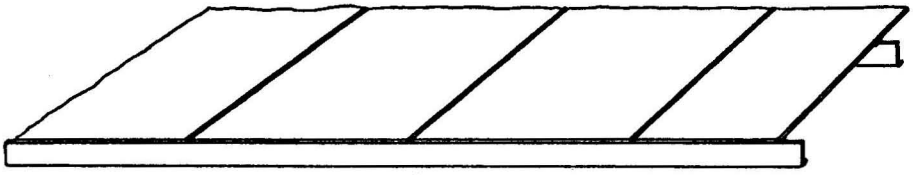
As a further precaution against cracking, special 'notch resistant' steels are now often used for some parts of the plating. Lloyds' Rules require that grades B, D, or E steels shall be used for some, or all, of the bottom and bilge plating and for the sheerstrake, according to the length of the ship.



SHELL PLATING



JOGGLED DECK BEAMS



WELDED DECK PLATING

SYSTEMS OF PLATING

SHELL AND DECK PLATING—(*Continued*)

Connection of Upper Deck Stringer to Sheerstrake—The upper deck sheerstrake may be connected to the deck stringer by a welded T-joint, using a full-penetration fillet weld. Alternatively, to reduce the risk of cracks starting at the sheerstrake, the connection may be made by means of a riveted 'deck stringer angle'; or by a rounded sheerstrake, butt welded to the deck stringer and having a radius of not less than 15 times the thickness of the plate.

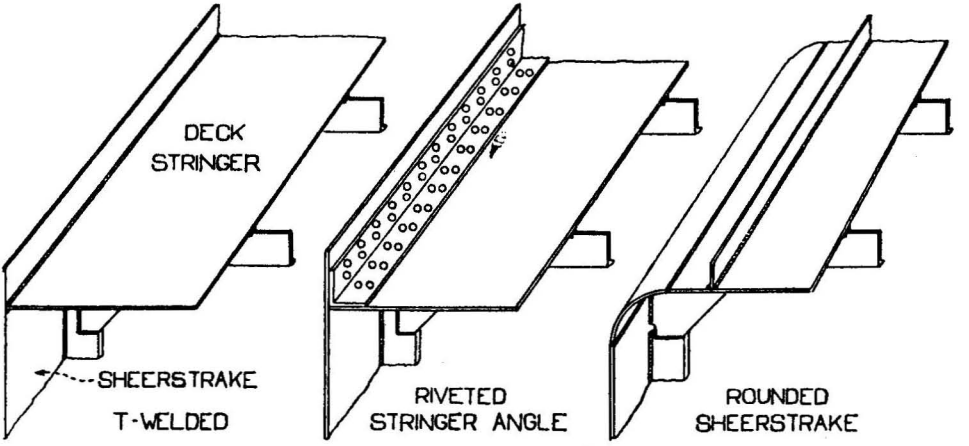
Crack Arrestors—Any small crack which occurs in all-welded plating is liable to spread (or 'grow') through adjacent plating, possibly with serious consequences. It is much less likely to spread across a riveted seam. To prevent any cracks from spreading in welded ships, strakes in which cracks are most likely to occur may have their seams riveted, instead of welded, for about the half-length amidships. Such seams are called 'crack arrestors'.

Crack arrestor seams were often used at one time, in any or all of the places shown in the sketches opposite. They are now becoming less common, because special notch-resistant steels are being increasingly used for ships' plating, in place of mild steel.

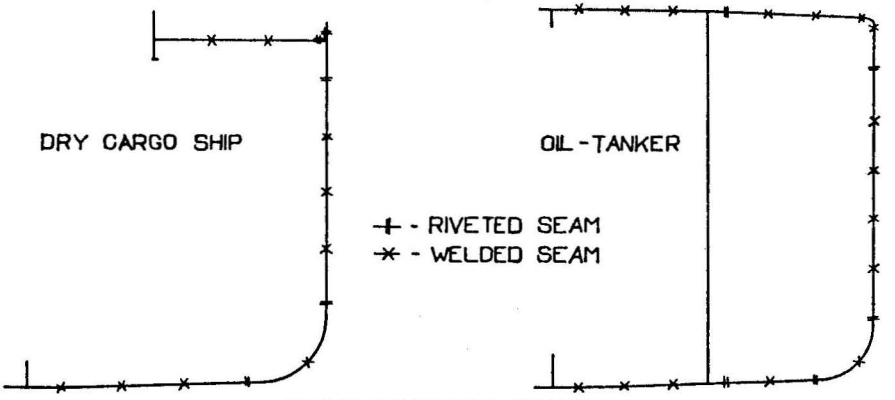
Beyond the half-length amidships, crack arrestors usually revert to welded seams: the transition from riveting to welding being dealt with as shown in the sketch. The edge of the in-strake is cut away in the way of the seam; whilst the out-strake is bent inwards for a short distance, to allow it to become flush with the in-strake. Welds are then made, inside and outside, to connect the plates and to seal the joint.

Shift of Butts—Riveted butts are weaker than the plates which they join together. It is, therefore, necessary to stagger them well away from each other to adjacent strakes of plating, so as to avoid a line of weakness around the ship's hull. This staggering is known as the 'shift of butts' and it must be very carefully controlled in riveted ships.

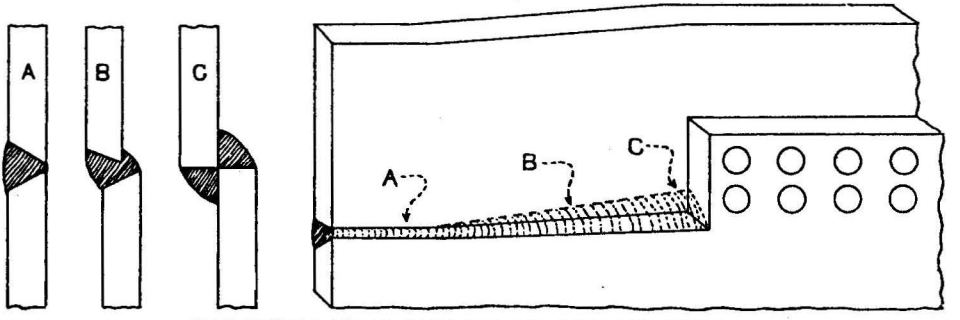
Welded butts are very much stronger than riveted ones, so the shift of butts is not very important in this case. The butts are, therefore, usually arranged as convenient for construction. When the ship is built in pre-fabricated sections, the butts are often only 'shifted' at the sheerstrake and bilge, as shown in the shell expansion plan, here.



CONNECTION OF SHEERSTRAKE TO DECK STRINGER



CRACK ARRESTOR SEAMS



TRANSITION FROM RIVETED TO WELDED SEAM

SHELL AND DECK PLATING

SHELL AND DECK PLATING—(*Continued*)

'Tween Decks at the Ship's Side—The 'tween deck stringer is usually slotted to allow the frames to pass through it. At one time, the deck was made watertight at the sides by fitting a continuous inner angle and cement chocks. Nowadays, the slots may be sealed by means of a plate collar, or 'chock', lightly welded around the frame, as shown in the sketch. Another common method of making a watertight joint at this point is to stop the deck stringer short of the frames and to weld-in sealing plates between the frames, as described in the chapter on 'Deep Tanks'.

Deck Openings—In welded ships, these must have rounded corners and must be suitably framed-in. For further details, *see* the chapter on 'Hatchways'.

Openings in Shell Plating—Any openings in the shell plating must have special arrangements to preserve strength and their corners must be rounded. When large openings, such as cargo doors, are cut in the plating, they are usually framed-in by a face bar. In this case, web frames are often placed on either side of the opening and insert plates are fitted above and below it, or sometimes right around it.

Width of Plates—The Rules lay down a definite width for deck stringers. sheerstrakes, garboard strakes and keel plates. Other strakes may be of any reasonable width.

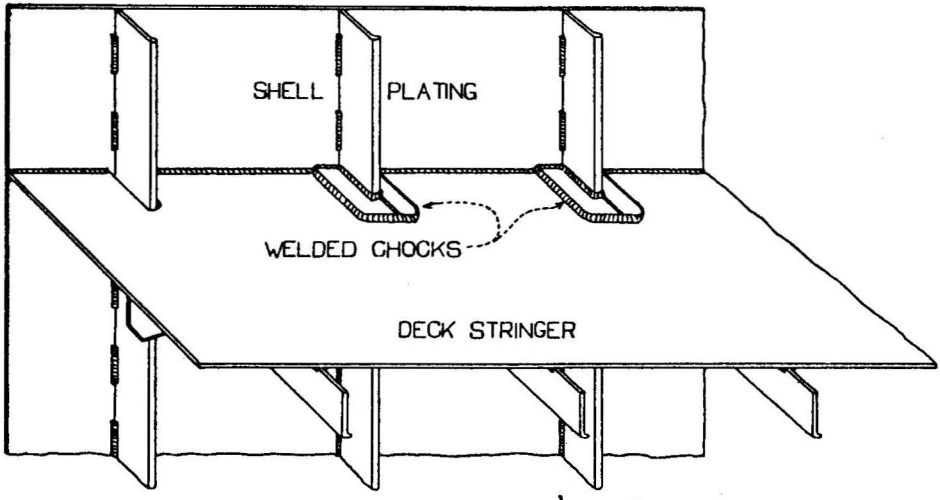
Thickness of Plates—Plating varies in thickness in different parts of the ship, whilst certain plates and strakes are made thicker than normal.

Shell and deck plating is kept at its midship thickness for four-tenths of the ship's length amidships, but is slightly reduced towards the ends of the ship: except for plates covering the flat of the bottom in the pounding region, which are thickened.

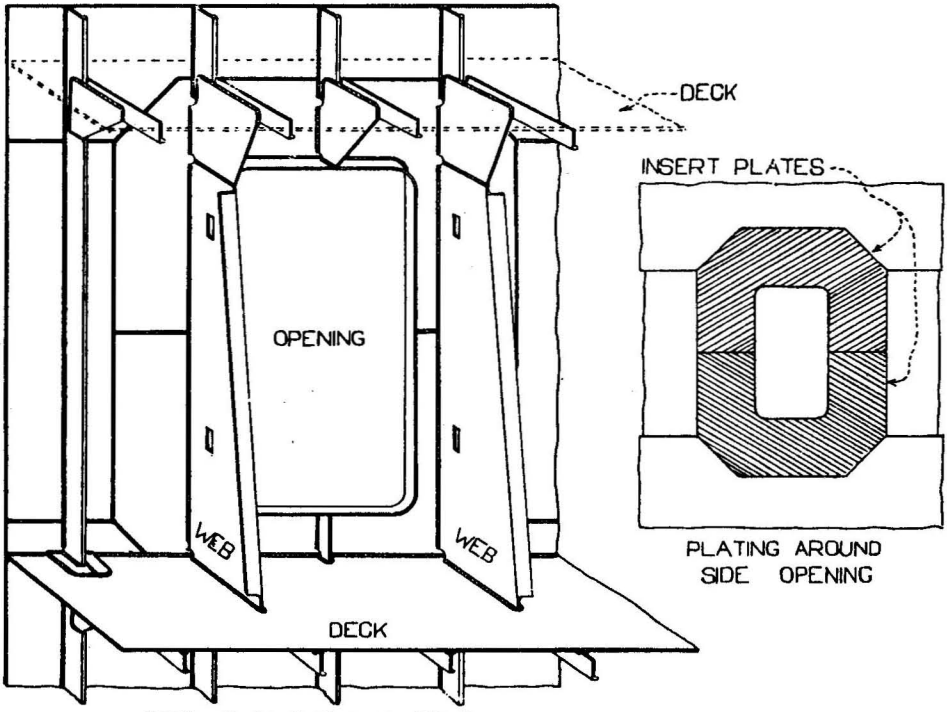
Sheerstrakes, upper deck stringers and keel plates are made thicker than other strakes.

Shell plating in the bottom and bilge is usually thicker than that in the sides of the ship.

Deck plating is thinner than normal within the line of the hatchways; whilst the plating in 'tween decks is thinner than that of upper decks.



TWEEN DECK AT SHIP'S SIDE



PLATING AROUND SIDE OPENING

OPENING IN SHELL PLATING

SHELL AND DECK PLATING

SHEATHED DECKS AND WOOD DECKS

Sheathed Decks—In passenger ships and in certain parts of other ships, a bare steel deck is undesirable; so the decks are covered, or 'sheathed', with wood or a special plastic composition. In modern ships, the steel deck is nearly always welded to give a smooth surface and is coated with some anti-corrosive composition, such as bitumastic paint, before the wood sheathing is laid on it. The latter is fastened down by bolts; or, more often, studs welded to the steel deck. The steel deck need not be made watertight, provided that the sheathing is properly caulked or sealed.

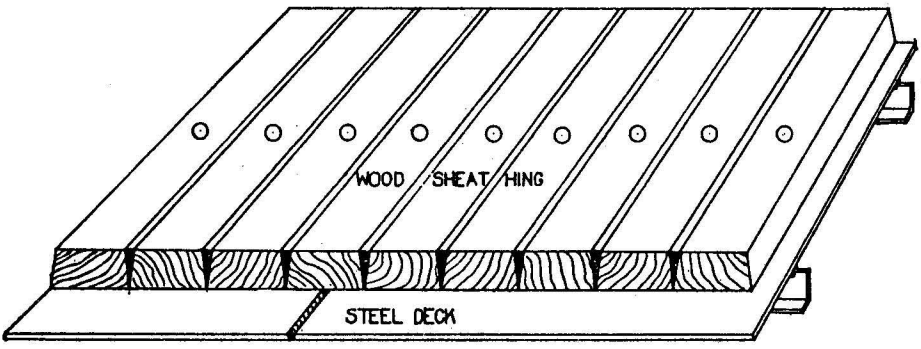
Wood Decks—These consist of planking laid directly on the beams. There is no complete steel deck under them, although deck stringer plates and certain tie plates are fitted. The planks are fastened at every beam by galvanised bolts.

Wood decks are not very strong and are difficult to keep watertight. They are, however, sometimes used in very small ships; or are used for light decks, such as boat decks and bridges, in larger vessels.

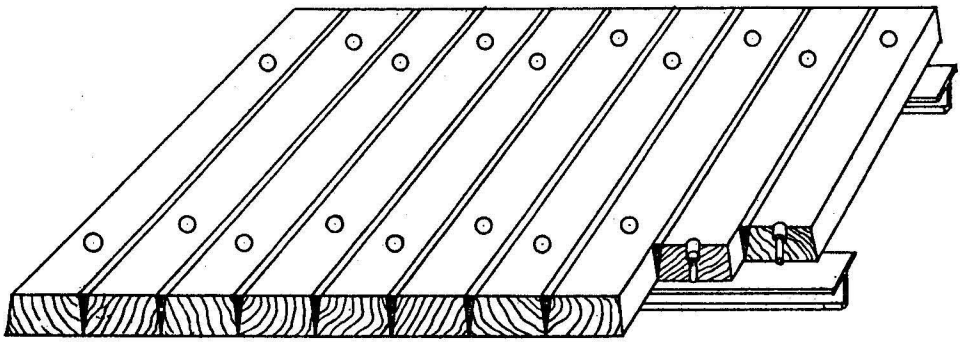
Planking—For both sheathed and wood decks, the planking is usually of pine or teak.

The heads of bolts, or nuts on studs, must be properly sunk into the wood and must have oakum or white lead under them. Turned dowels must be fitted over them and bedded in marine glue, or some similar substance. The butts of planks are usually scarphed, with a bolt or stud passing through the joint.

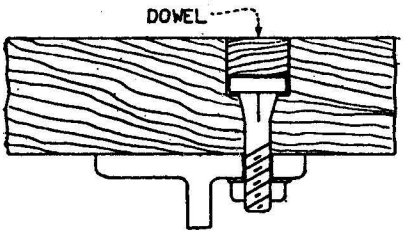
Caulking—The planking must be caulked to make it watertight. The plank edges are slightly tapered, so that the joint is open on the weather side and a fairly close fit on the inside. The joints are caulked by ramming oakum or caulking cotton into the seams and then hammering this down hard by means of a caulking tool. The weather side of the joint is then 'payed', by running molten pitch or marine glue into the seam on top of the caulking.



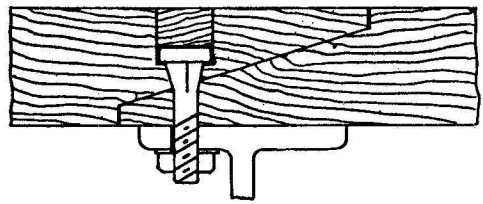
SHEATHED DECK



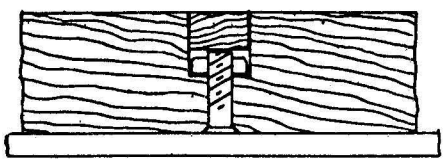
WOOD DECK



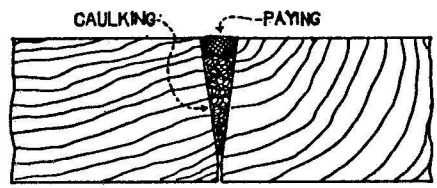
BOLT



BUTT



STUD



CAULKED SEAM

SHEATHED & WOOD DECKS

BILGE KEELS

Purpose—Bilge keels are intended to resist rolling. Their effects are complex, but may be summarised as follows:—

(*a*) Direct resistance between bilge keel and water has a comparatively weak effect.

(*b*) They slightly increase the ship's period of roll.

(*c*) They upset the transverse streamlines of the ship's hull and thus set up eddy-currents and increase the 'wave-making resistance'.

(*d*) They increase water pressure over a large area of the ship's hull and this pressure acts in such a direction as to damp the rolling.

Position—For their protection, bilge keels should always be arranged to lie within the line of the ship's side and that of the bottom of the floors. If they were to project beyond these limits, they would be more liable to damage.

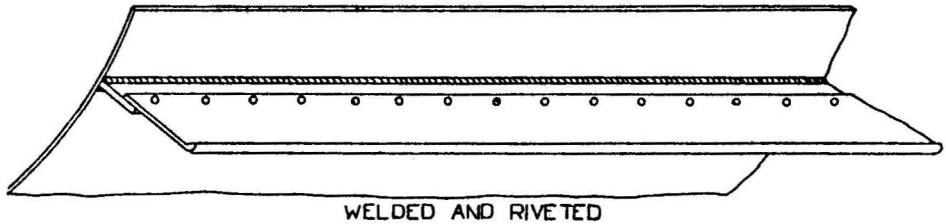
Construction—Bilge keels are sometimes ripped off, however carefully they are positioned, if the ship touches the ground. It is important to construct them so that, if this happens, the ship's shell plating will remain intact.

Riveted bilge keels are connected to the hull by a riveted angle or T-bar, which is strongly attached to the shell plating, but less strongly connected to the bulb-plate. If the bilge keel is ripped off, it will then part at the outer joint, leaving the hull intact.

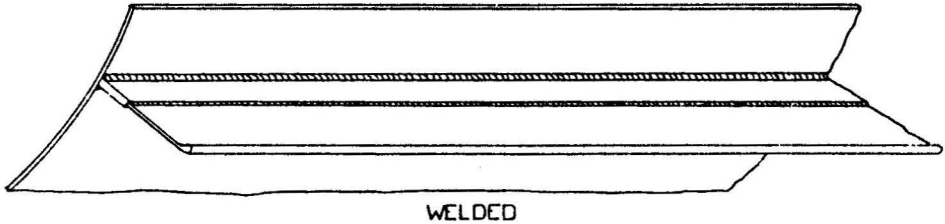
In welded ships, the bilge keels are usually attached to a continuous flat bar, welded to the shell plating. The outer joint may then be riveted, or lightly welded, so that it will part before the connection to the hull. Alternatively, the keel may be attached to the hull by intermittent welds, and is often scalloped throughout its length, so that the welds will part comparatively easily and will leave the hull undamaged.

In large ships, where the bilge keels are very deep, they may be constructed as shown in the sketch. Here, again, the outer connection is made less strong than that to the shell plating.

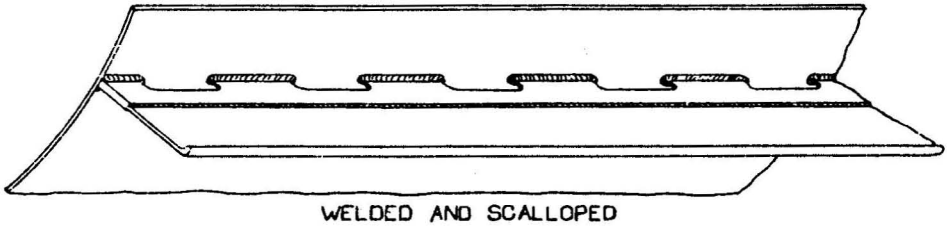
Unless they are carefully designed, the ends of bilge keels tend to produce stress concentrations which can cause the bilge plating to crack. To prevent this, the ends of the bilge keel should be tapered-off gradually and should end over a floor or tank side bracket; whilst a doubling plate should be welded to the bilge plating at this point.



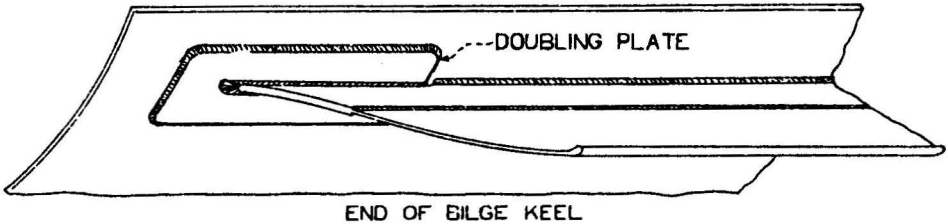
WELDED AND RIVETED



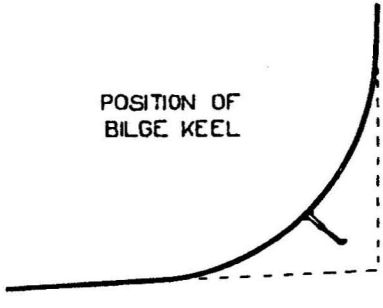
WELDED

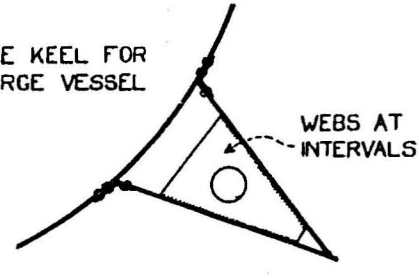


WELDED AND SCALLOPED



END OF BILGE KEEL





BILGE KEELS

DEEP TANKS

Purpose—When a ship makes a voyage in a light condition, it is usually desirable to carry a certain amount of water ballast. If the double bottom tanks alone were used for this purpose, the ship might be unduly 'stiff'; so it has become the practice to arrange one of the lower holds so that it can be filled with water when necessary. This permits a large amount of ballast to be carried, without unduly lowering the centre of gravity of the ship. Such a hold is called a Deep Tank.

In certain trades, it has been found convenient to utilise deep tanks for the carriage of liquid cargoes, or for oil fuel bunkers. In other trades, the deep tanks are still used solely for their original purpose to carry dry cargoes normally, but to be used as water ballast tanks when the ship is light.

Ordinary Deep Tanks—When a deep tank is intended for its original purpose, it is basically the same as any other hold. It must, however, be somewhat modified to enable it to carry water ballast.

A washplate must be fitted at the centre-line, to reduce free surface effect.

The hatchway must be specially constructed so as to prevent water from escaping from below.

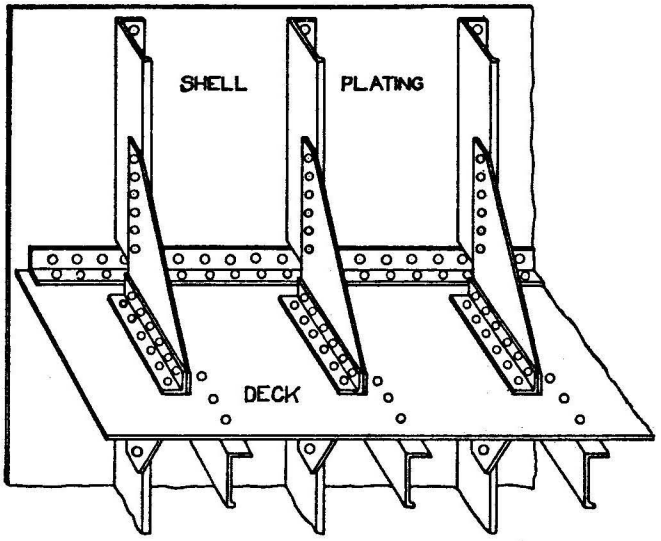
Frames are to be 15 per cent stronger than normal.

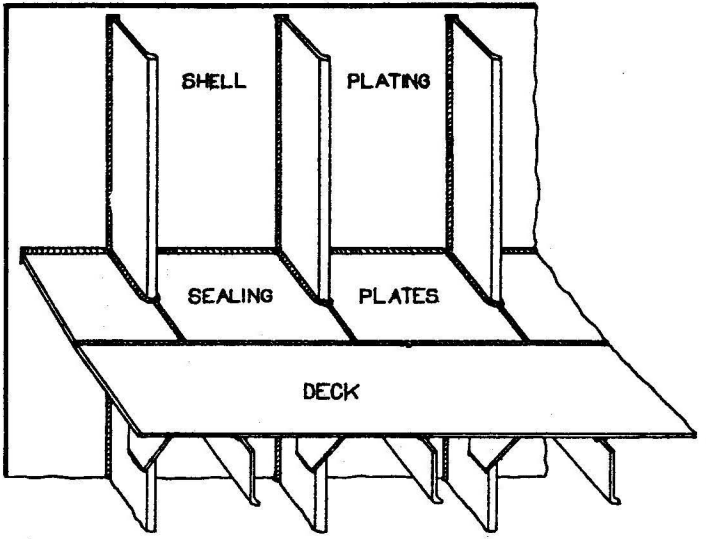
Bulkhead stiffeners must be spaced not more than 600 millimetres apart and must be bracketed at the head and foot.

The deck plating which forms the tank top must be at least 1 millimetre thicker than that of the boundary bulkheads. It must not, in any case, be thinner than normal.

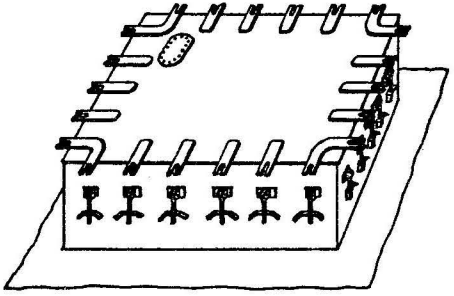
Beams may be normal, provided that their size is not less than that of the bulkhead stiffeners. They must be supported by an intercostal girder on either side of the centre line.

Where the deck edge meets the ship's side, great care is required to make a completely watertight joint. In riveted construction, the frames are often cut below the deck so that a continuous watertight stringer angle can be fitted. The frames above are then attached to the deck by brackets. In welded construction, the frames usually pass through the deck. The slots through which they pass may be sealed by welding pieces of plate over them. Alternatively, the deck plating may be stopped short, a few inches inboard of the frames, and sloping sealing-plates welded in, as shown in the sketch.

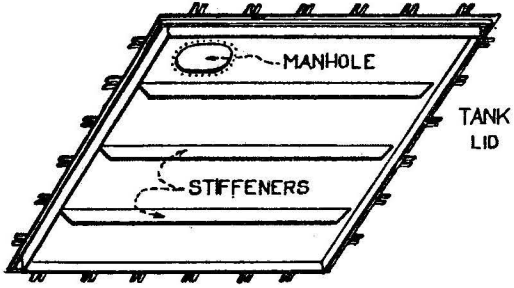


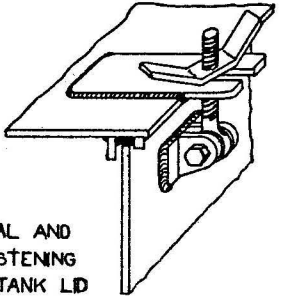


CONNECTION OF DECK TO SHIP'S SIDE



HATCHWAY





SEAL AND
FASTENING
OF TANK LID

WATERTIGHT JOINTS AT TANK-TOP

DEEP TANKS—(*Continued*)

Deep Tanks Used as Oil Fuel Bunkers—In this case, the ship's sides and the boundary bulkheads may have additional stiffening in the form of deep, horizontal girders, running right round the inside of the tank and spaced not more than 3 metres apart vertically. These girders, if used, must be stiffened on their inner edges and are connected together at the tank corners by flanged brackets. They are supported at each third frame or stiffener by brackets and are attached to intermediate frames or stiffeners.

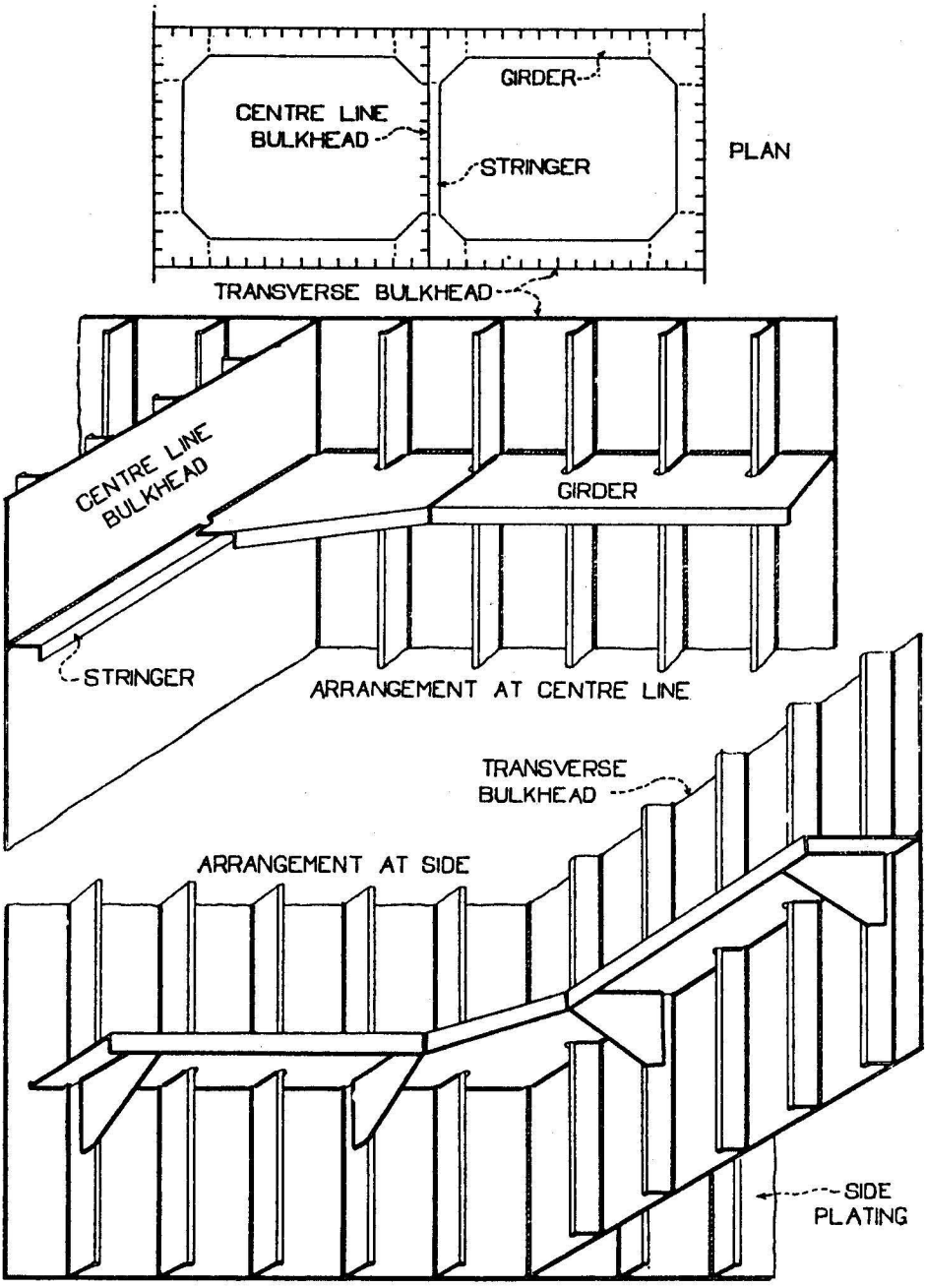
A middle line bulkhead must be fitted if the tank extends for the full breadth of the ship. This may be perforated if desired. Light intercostal stringers are fitted horizontally across it, in line with the horizontal girders, if the latter are fitted in the tank.

Quarterline girders must be fitted at the deckhead; these are often formed by deepening the ordinary deck girder.

Deep Tanks for Carrying Oil as Cargo—Deep tanks may be used for the carriage of oil cargo, provided that its flash point is not less than 60° C. In this case, the tank may be constructed in the same way as one built for oil fuel bunkers, except that a centre-line bulkhead need not be fitted unless the tank is liable only to be partly filled.

Cofferdams—Fuel oil, vegetable oil, and water, may not be carried in adjacent tanks, unless these are separated from each other by a cofferdam.

Testing—Deep tanks are tested by filling them with water to the maximum head which can come on them in practice; provided that this is not less than 2·44 metres above the tank top.



DEEP TANK FOR OIL FUEL

PEAKS AND PANTING ARRANGEMENTS

General—Peaks are those parts of the ship's hull which are forward of the collision bulkhead (the fore peak); or abaft the after peak bulkhead, excluding the overhang of the stern (the after peak). They are usually constructed so that their lower part forms a tank, which is known as a 'peak tank'.

The cellular double bottom and the longitudinal frames, if these are fitted, usually extend only from the after peak bulkhead to the collision bulkhead. Beyond this, in the peaks, a system of deep 'open floors' is fitted, with transverse frames and beams. The floors extend in one piece from side to side of the ship and are stiffened by a flange or a face bar on their upper edges. The centre girder is made intercostal between the floors, but usually only extends for a few frame spaces into the peak. Beyond this the hull usually becomes so narrow that there is no further need for a centre girder. Special strengthening is required in peaks to enable the shell plating to resist panting stresses.

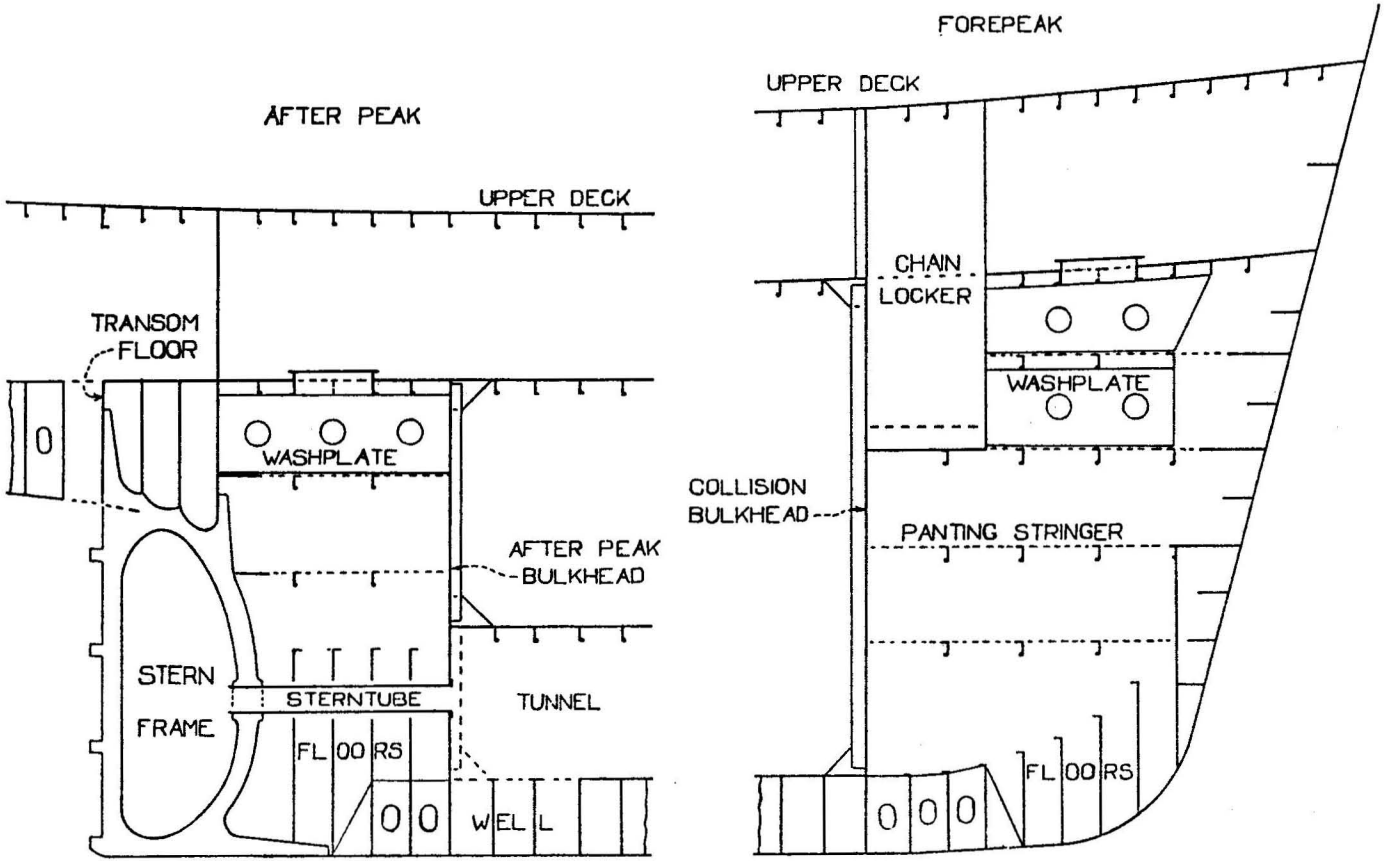
Peak Tanks—When peaks are used as tanks, they must comply with the rules for the construction of ordinary deep tanks: except that the heavy deck girders are not required to be fitted, whilst only a wash plate need be fitted at the centre line. They are tested in the same way as deep tanks.

Tests for Peaks—'Dry Peaks' are tested by filling them to the level of the load waterline. Peak tanks are tested in the same way as deep tanks.

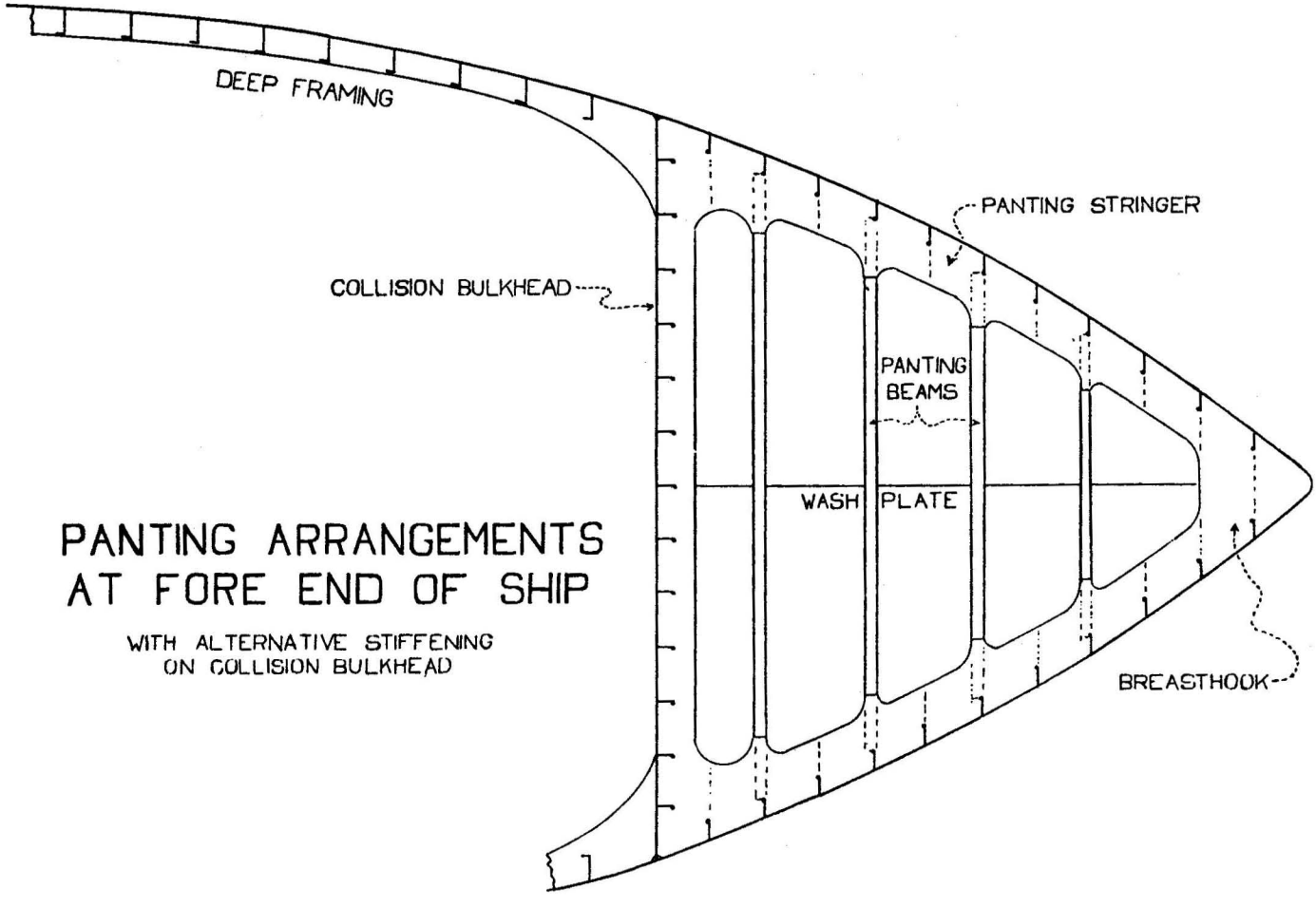
Panting Arrangements in Fore Peaks—Tiers of panting beams are fitted forward of the collision bulkhead, below the lowest deck. These are similar to ordinary deck beams and are connected to the frames by beam knees, but are only fitted at alternate frames. The tiers of beams are spaced 2·0 metres apart vertically and must be supported by wash plates or pillars. Panting stringers, similar to ordinary deck stringers, are laid on each tier of beams. To stiffen the joint between each beam and the inner edge of the stringer, the plate edge may be shaped, or gussets fitted. At intermediate frames, where no beam is fitted, the stringer is supported by a beam knee of half its depth. At their fore ends, the stringers are joined by flat plates, called 'breasthooks'.

Panting Arrangements Abaft the Collision Bulkhead—Deep framing, 20 per cent stronger than normal, must be fitted below the lowest deck, between the collision bulkhead and a point 15 per cent of the ship's length abaft the stem. The frames and tank side bracket connections must have extra riveting or stronger welding than normal. Side stringers, in line with the panting stringers, must be fitted throughout the deep-framing region: or the shell plating thickened.

After Peaks—These are constructed in the same way as fore peaks, except that the tiers of panting beams may be 2·5 metres apart vertically. The plates joining the ends of the panting stringers are called 'crutches' at this end of the ship. Welded joints may not be scalloped in this region.

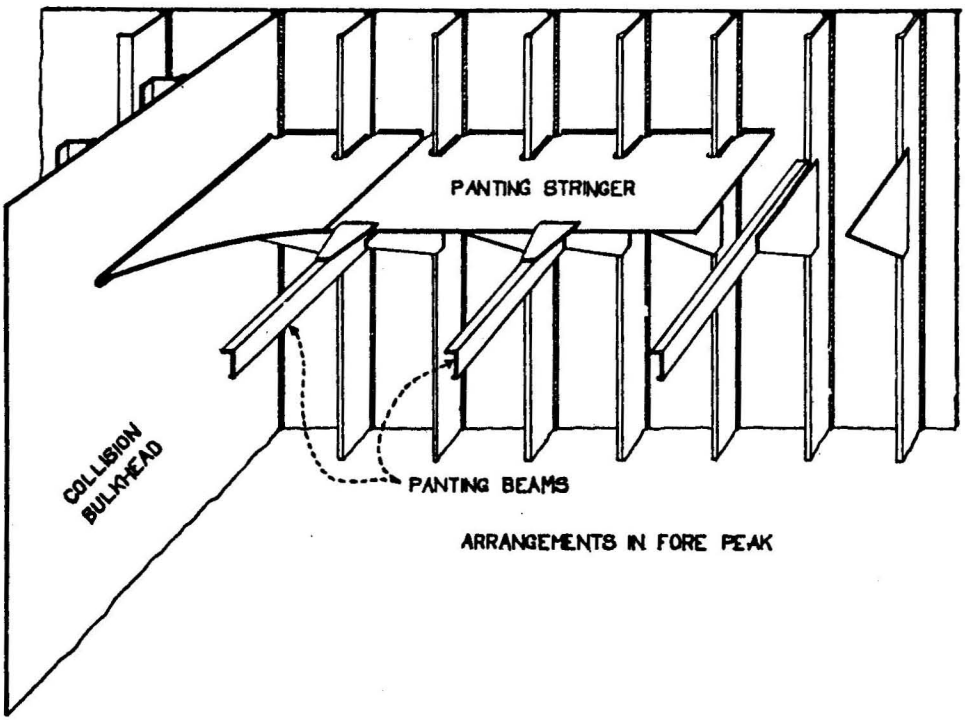

AFTER PEAK
UPPER DECK
TRANSOM FLOOR
WASHPLATE
AFTER PEAK BULKHEAD
STERN FRAME
STERNTUBE
TUNNEL
FLOORS
WELL
FOREPEAK
UPPER DECK
CHAIN LOCKER
WASHPLATE
COLLISION BULKHEAD
PANTING STRINGER
FLOORS

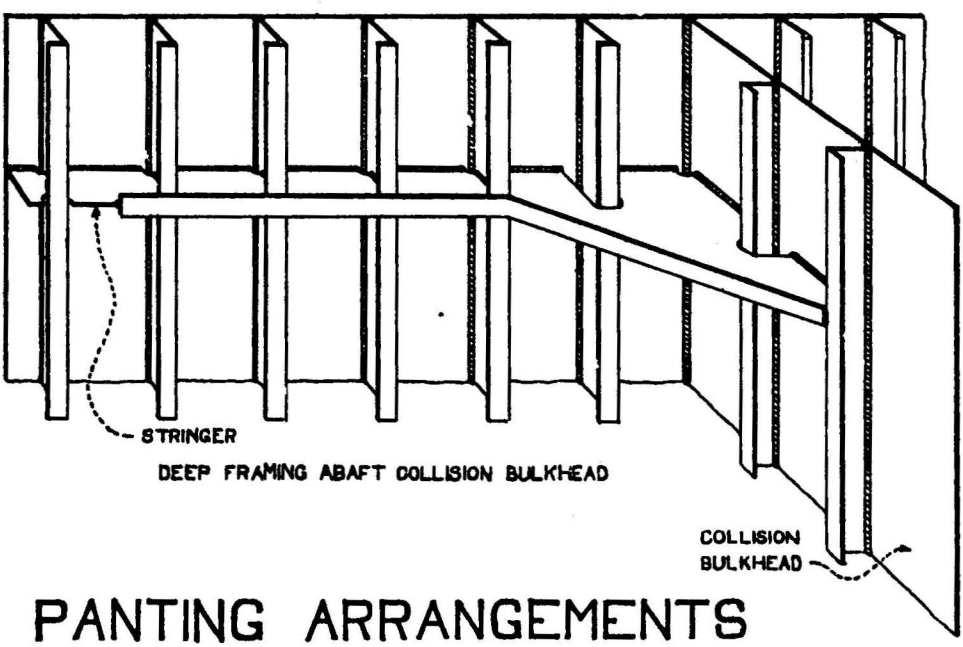
PEAKS



PANTING ARRANGEMENTS AT FORE END OF SHIP

WITH ALTERNATIVE STIFFENING ON COLLISION BULKHEAD





PANTING ARRANGEMENTS

STEMS

Bar Stems—The original and simplest form of stem, now largely superseded by the plate stem. It consists of a rectangular, forged steel bar: usually made in two pieces, scarphed together about the light waterline.

There are several methods of connecting a bar stem to a flat plate keel. One very common method is by means of a shoe plate, as shown in the sketch. The forward end of the shoe plate is dished around the stem, whilst the after end is flattened to connect with the keel plate. The centre girder, which is intercostal forward of the collision bulkhead, is attached to one side of the stem bar to complete the connection.

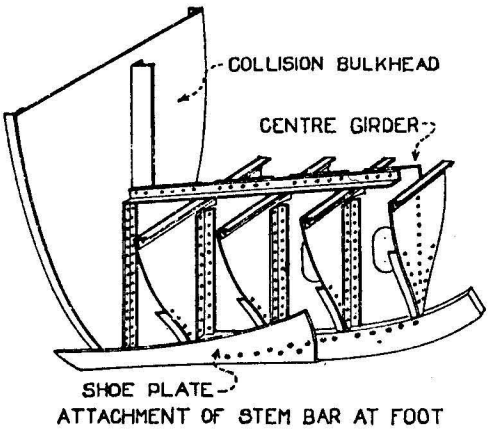
Plate Stems—The upper part of a plate stem is built up of curved plates. Lower down, where the stem becomes 'sharper', an ordinary stem bar was often fitted in riveted ships: whilst in welded ships the side plates are often welded on to a length of round bar or tube, which forms the connection between them.

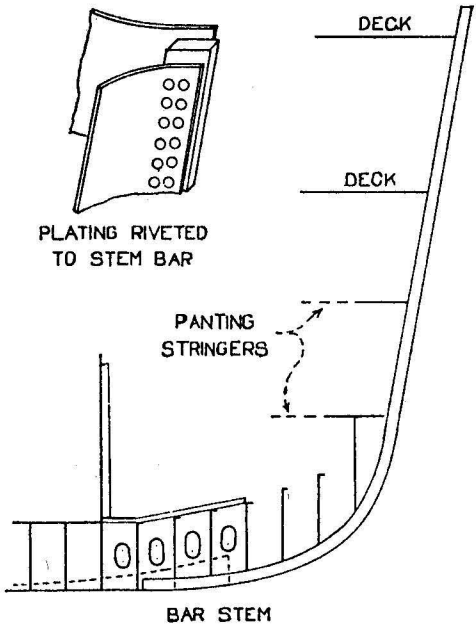
Alternatively, the plate stem may extend right down to the keel, as shown in the sketch. No stem bar is fitted and the stem is virtually a continuation of the keel plate. Where the stem is very 'sharp', it may not be possible to bend the plate to shape and the two sides may here be made separately and butt-welded together at the centre line.

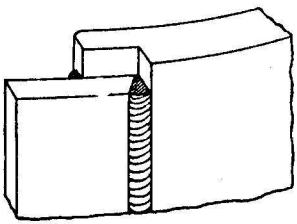
Flat, horizontal plates, or 'webs', must be fitted inside the stem to reduce its unsupported span to not more than 1·5 metres. If the radius of curvature of the plates is large, it may also be necessary to fit some form of vertical centre-line stiffener.

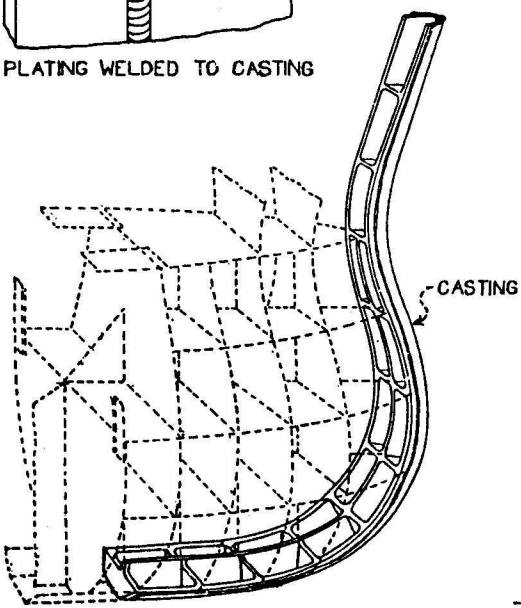
Bulbous Bows—In these, the lower part of the stem is rounded out into a bulb. Sometimes the bulb projects forward for an appreciable distance, forming a kind of ram bow. This type of bow is only fitted in those ships where it is likely to improve propulsive efficiency.

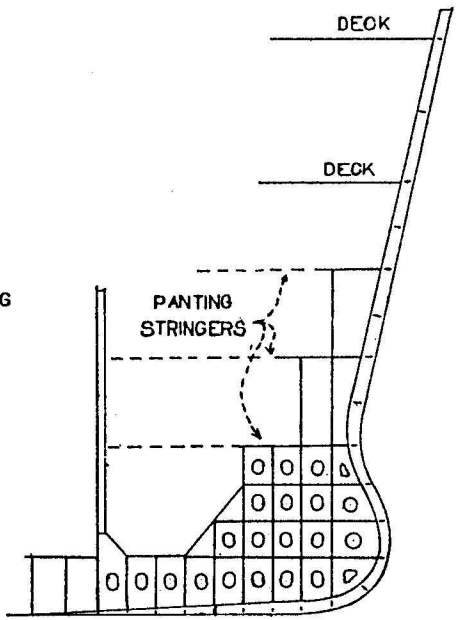
The forward part of the bulb may consist of a large casting, to which the plating is attached; or it may be built up of heavy welded plates. Above the bulb, the construction is similar to that of an ordinary plate stem. Horizontal diaphragm plates are fitted at the fore end of the bulb. Large bulbs must have a centre-line wash-bulkhead, whilst small ones must have a centre-line web.











BULBOUS BOW

STEMS

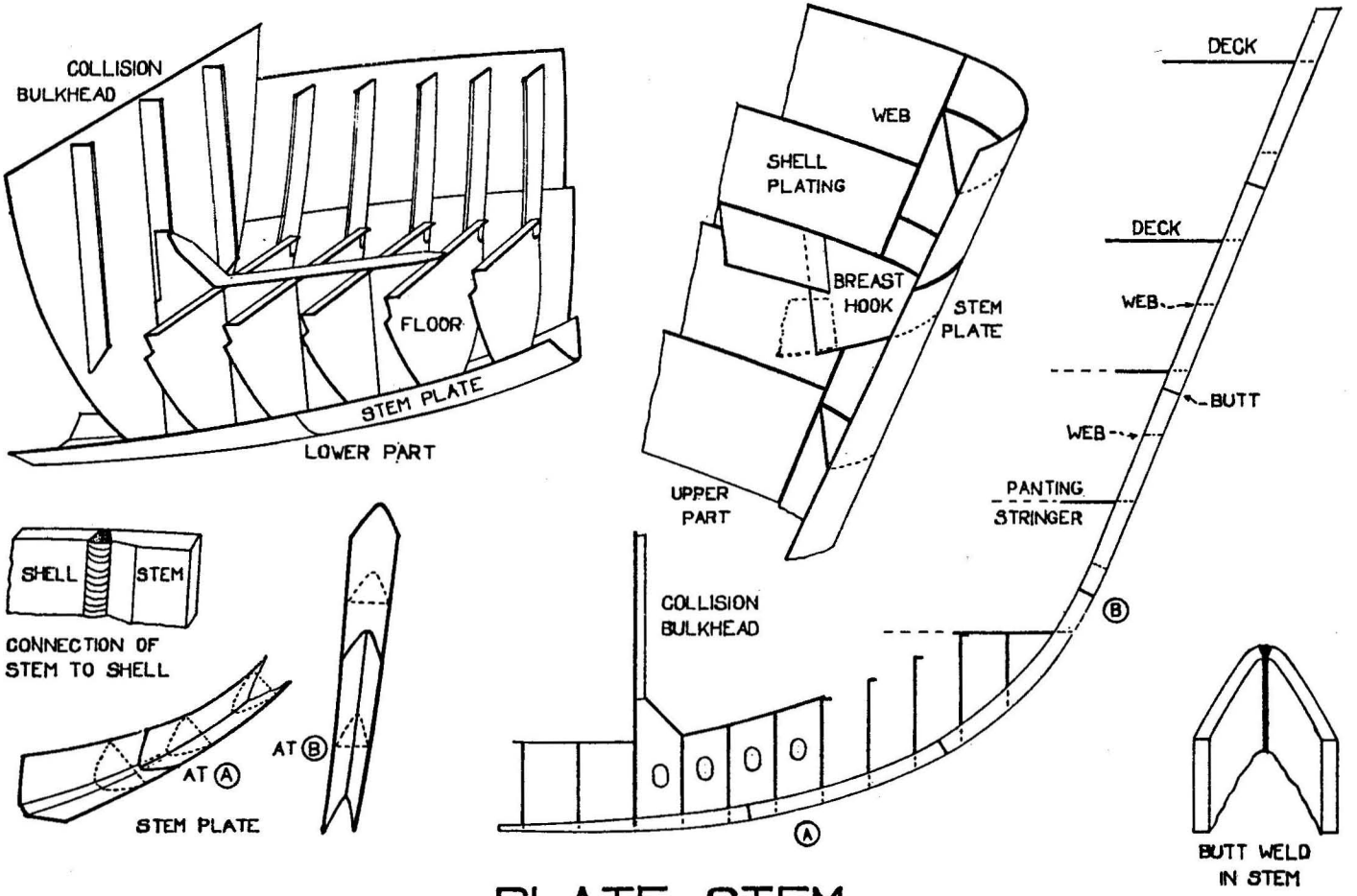

COLLISION BULKHEAD
FLOOR
STEM PLATE
LOWER PART
WEB
SHELL PLATING
BREAST HOOK
STEM PLATE
UPPER PART
DECK
DECK
WEB
BUTT
WEB
PANTING STRINGER
COLLISION BULKHEAD
B
A
SHELL
STEM
CONNECTION OF STEM TO SHELL
AT A
AT B
STEM PLATE
BUTT WELD IN STEM

PLATE STEM

RUDDERS AND STERNFRAMES

General—At one time sternframes were always solid rectangular bars. Today, they are usually streamlined castings: or are sometimes built up of heavy steel plates, welded together. Their shape and type depend largely on the type of rudder fitted.

Rudders originally consisted of a single plate, with supporting arms riveted on either side of it. This type has now been superseded, in larger ships, by double plate rudders, which are normally streamlined and are often balanced, or semi-balanced. They may be hinged on pintles and gudgeons, or they may turn about an axle which passes down through the rudder.

The stock, which turns the rudder, passes vertically upwards to the steering-gear through a gland at the shell plating, or a watertight rudder trunk. It is usually connected to the rudder by a bolted coupling, which can be disconnected so that the rudder can be lifted for maintenance without disturbing the stock. Note that the centres of the pintles, or axle, must be in the same line as the centre of the stock, to enable the rudder to turn.

The weight of the rudder may be taken by a bearing pintle, or by a bearing at the rudder head, or by a combination of both.

Double Plate Rudders—The framework of these may be a casting, or it may be built up of welded plates, with plating on either side. Most modern rudders are of this type and are usually streamlined. They may be unbalanced, with their whole area abaft the rudder stock: or balanced, with part of their area forward of the stock.

Streamlining reduces the 'drag' caused by a rudder and may also improve the ship's steering, particularly in the case of balanced rudders.

Balanced Rudders—Water pressure tries to force the blade of an unbalanced rudder amidships and thus puts considerable stress on the rudder stock and steering-gear. If part of the blade is extended forward of the stock, the pressures on this tends to counterbalance that on the after part, so that there will be less stress on the steering gear. Unfortunately, the ratio between the pressures varies with the rudder angle, so that it is not usually possible to balance a rudder for all angles. Most rudders of this type are balanced for an angle of helm of about 15° and have about one-quarter of their area forward of the stock.

Semi-balanced rudders are those in which the area forward of the stock is too small to give a full balancing effect. They are often found in twin screw ships.

Construction of Rudders—The rudder frame may be of forged or cast steel, or it may be built of web plates welded together.

The plating is usually welded to the frame. Slot welds, or continuous butt welds are commonly used for this purpose. When plate frames are used flat bars are welded to their edges to take the slot welds.

RUDDERS AND STERNFRAMES—(*Continued*)

The inside surface of the rudder is coated with bitumastic, or some similar preservative, and the space within it is now often filled with foam plastic. There must be some means of draining the rudder.

Sternframes for Single Screw Ships—If the rudder turns on pintles and gudgeons, a rudder post is fitted. This is a hollow section, streamlined, with transverse webs at intervals and a sealing plate welded-in.

For balanced rudders, various forms of sternframe are used. Most of these do not have a complete rudder post, but are usually fitted with a 'skeg' to take the lower bearing of the rudder.

Sternframes for Twin Screw Ships—Twin screw ships do not usually have a propeller aperture. If the rudder is not balanced, the sternframe consists of a simple bar or casting. With a balanced rudder, it is rather more complex, often being shaped as shown in the sketch.

Connections at the Head of the Sternframes—The rudder post extends upwards towards the top of the transom floor, to which it is connected by flanges cast on the post. In single screw ships, the propeller post is usually also extended upwards and connected to a deep floor.

Connections at the Foot of the Sternframe—The sternframe is extended forward far enough to provide a good connection with the flat plate keel; usually for two or three frame spaces. The aftermost plate of the keel, which is called the 'coffin plate', is dished around this extension.

Transom Floor—This is the floor at the head of the rudder post which supports the framework of the stern. It must have the same depth as the floors in the cellular double bottom.

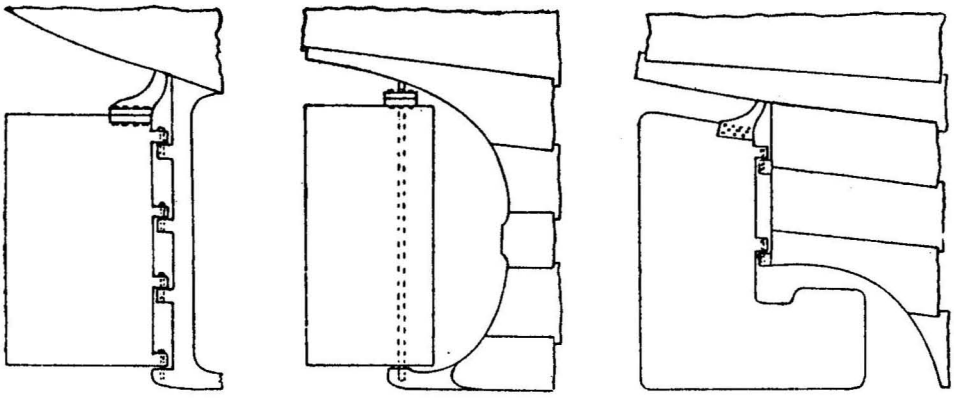
Gudgeons—These must be forged-on, or cast with, the rudder post. They are usually bushed with brass or lignum vitae to reduce friction.

Pintles—These must be of the same depth as the gudgeons in which they turn. They are sometimes fitted with liners, to reduce wear.

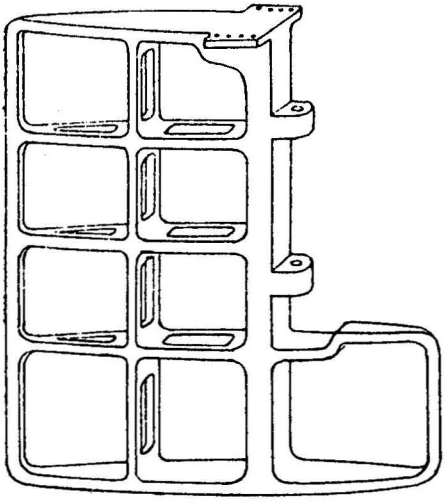
The locking pintle has a head on it, below its gudgeon, to prevent the rudder from lifting. It is usually the uppermost one.

The bearing pintle is used to take the weight of the rudder, unless a bearing at the rudder head is fitted instead. It is usually the lowest one. There are various types, but that shown in the sketch is common. In this, a hardened steel disc is placed in the bottom of the gudgeon to take wear and to reduce friction. A vertical hole in the bottom of the gudgeon allows the disc to be punched out when it needs renewing.

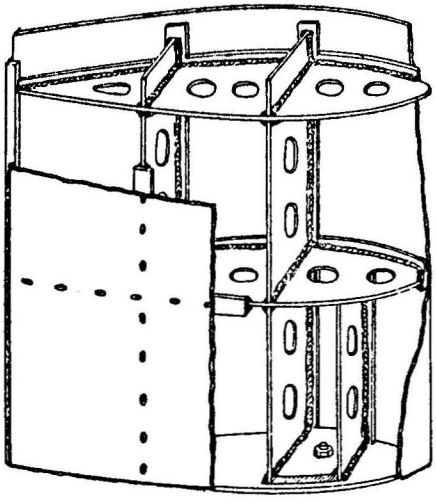
Couplings—The stock is connected to the rudder by either a vertical or a horizontal coupling, or by a vertical scarph. The bolts in the coupling must be locked by means of pins, or some s milar arrangement.



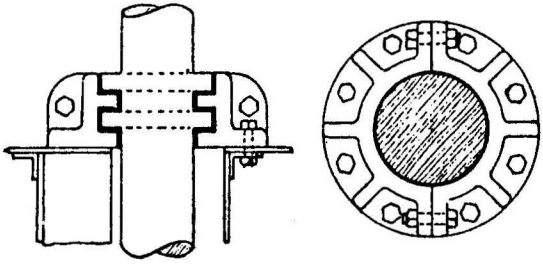
UNBALANCED BALANCED



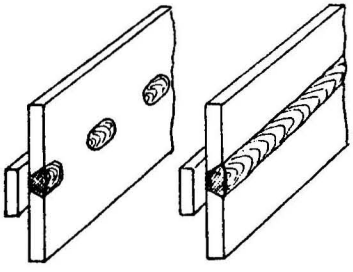
CAST STEEL FRAME



PART OF WELDED PLATE FRAME

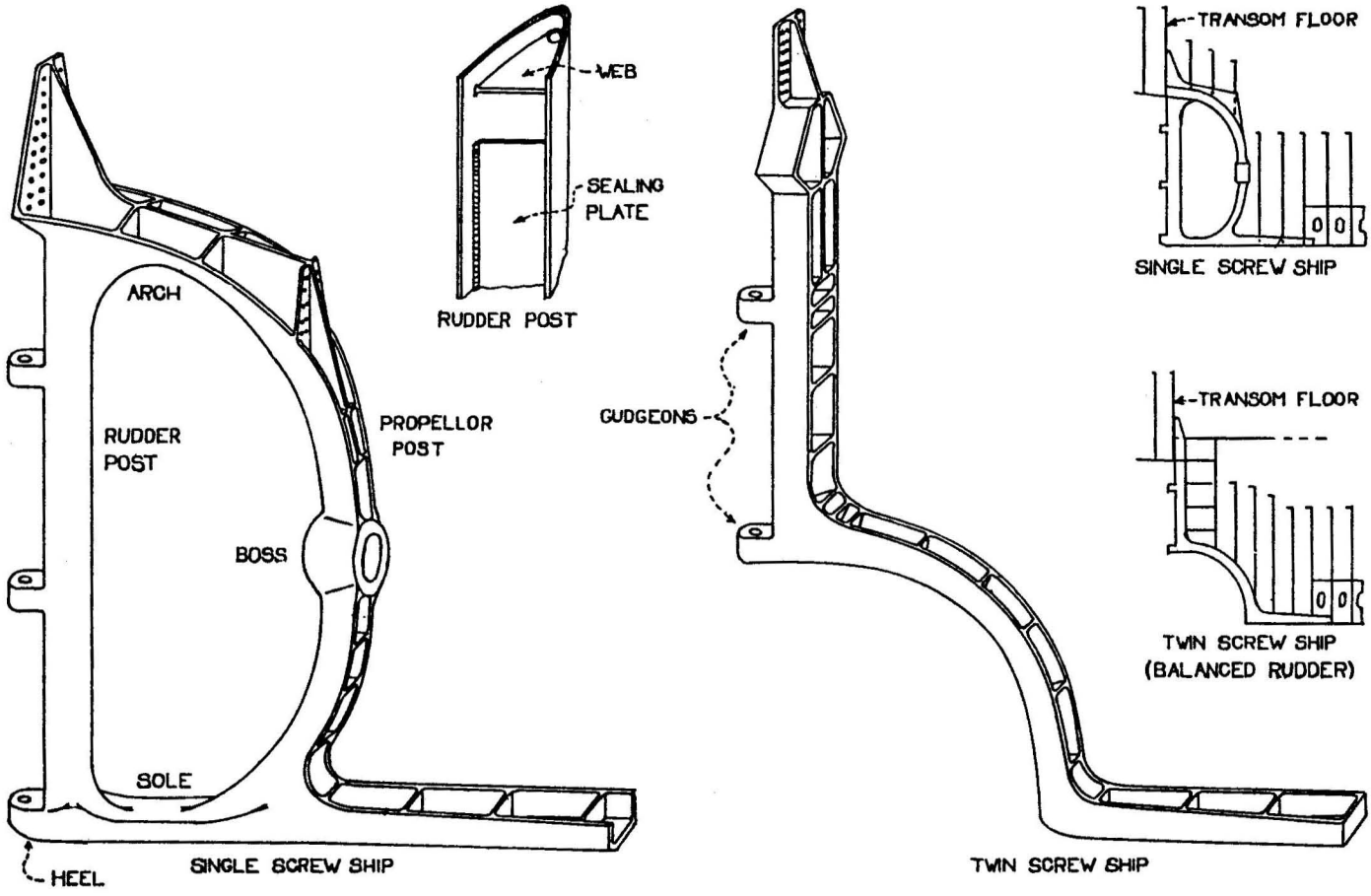


BEARING AT RUDDER HEAD

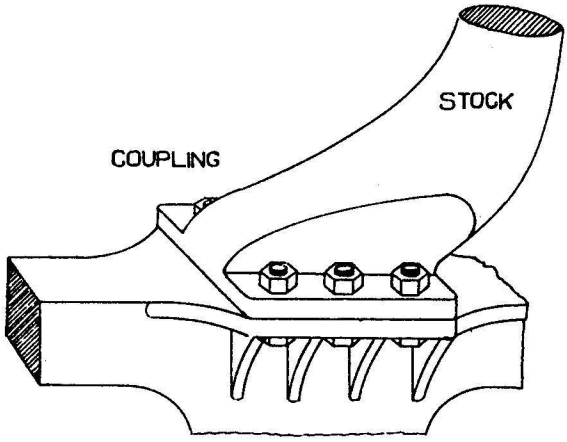


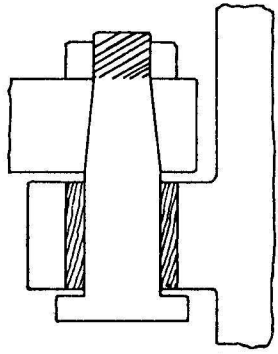
SLOT WELD BUTT WELD

DOUBLE PLATE RUDDERS.

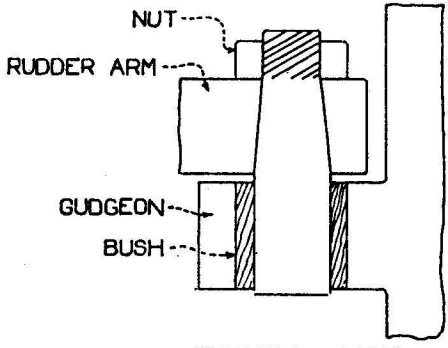


CAST STERNFRAMES

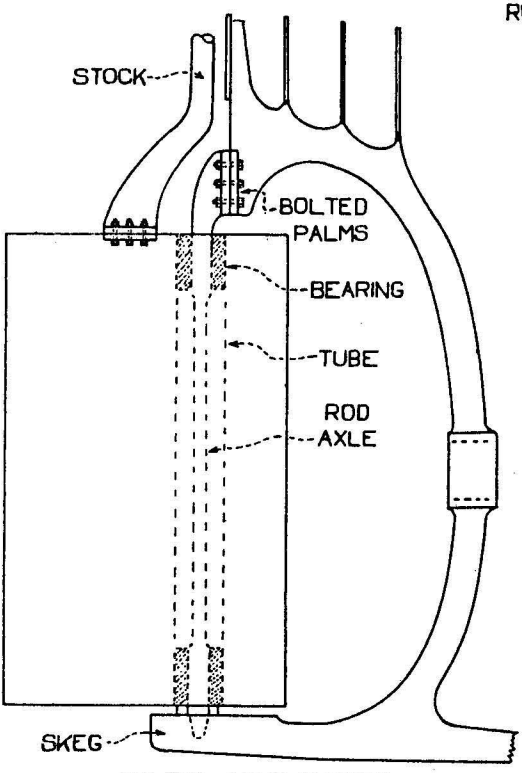




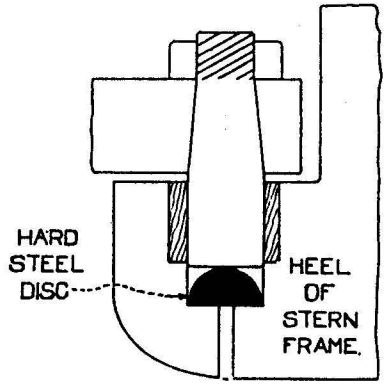
LOCKING PINTLE



ORDINARY PINTLE



BOLTED-AXLE RUDDER



BEARING PINTLE

RUDDERS

STERNS

General—The upper part of the stern of a ship extends abaft the rudder post, and there must be a special arrangement of framing to support it. This framing is mainly carried by the 'Transom', which consists of a deep, heavy floor, securely attached to the rudder post, in association with a transverse frame and beam. These are known as the 'Transom Floor', 'Transom Frame' and 'Transom Beam', respectively.

The transom floor must have the same depth as the floors in the cellular double bottom, but must be slightly thicker.

Ordinary Sterns—These were often called 'Counter', or 'Elliptical' sterns. At one time they were used almost exclusively in merchant ships, but they have now been superseded by the Cruiser Stern, or Transom Stern, and are virtually obsolete for large vessels.

Ordinary sterns had a system of 'Cant Framing', which radiated out from the transom in much the same way as the spokes of a wheel. The cant frames were attached to the transom floor by brackets; whilst the fore ends of the cant beams were lugged to the transom beam.

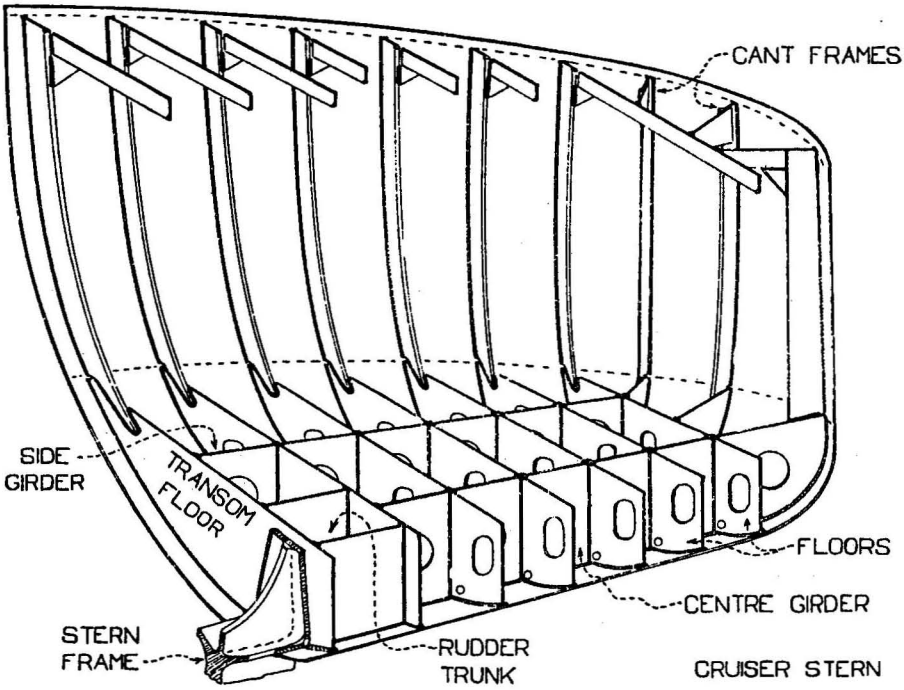
Cruiser Sterns—Have a system of ordinary transverse framing which is supported by an intercostal girder at the centre line. This girder has to be doubled, just abaft the transom floor, to allow the rudder stock to pass. A number of 'cant frames' are fitted abaft the aftermost transverse frame.

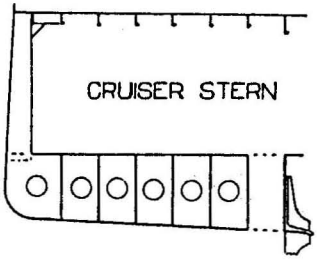
The frames are to be of the same size as bulb angle frames in peaks and are to extend to the strength deck. The frame spacing is not to exceed 610 millimetres.

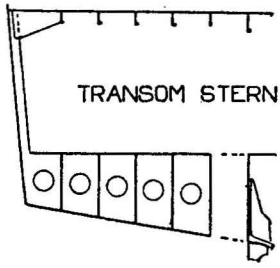
Where extra strength is required, web frames may be required and also extra longitudinal girders to support them.

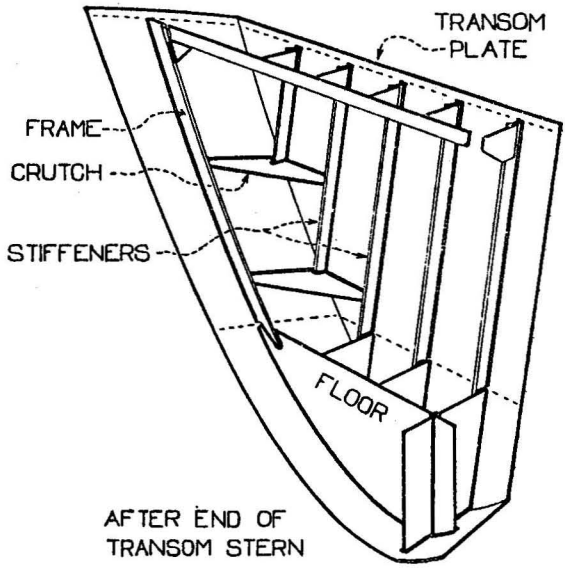
Transom Stern—This is similar to a cruiser stern, except that the cant framing at the after end is omitted and is replaced by a flat plate, called a 'transom'.

Rudder Trunk—This is often formed by carrying-up the doubled centre girder to the deck above in the form of a box. (*See* sketch.)


CANT FRAMES
SIDE GIRDER
TRANSOM FLOOR
FLOORS
CENTRE GIRDER
STERN FRAME
RUDDER TRUNK
CRUISER STERN


CRUISER STERN


TRANSOM STERN


TRANSOM PLATE
FRAME
CRUTCH
STIFFENERS
FLOOR
AFTER END OF TRANSOM STERN

STERNS

SHAFT TUNNELS

General—Shaft tunnels are fitted in order that the propeller shaft may be accessible at all times. They also prevent water from filling the holds if the stern tube be broken. In twin screw ships two shaft tunnels may be fitted, but often the whole width of the ship is decked over and the space between the shafts used for workshops, stores, etc.

At its after end, the tunnel is enlarged to form a 'tunnel recess' in order to give room for the withdrawal of the tail end shaft and for the storage of the spare shaft. Since the ship is very narrow at this part, the recess is often formed by constructing a deck right across from side to side here.

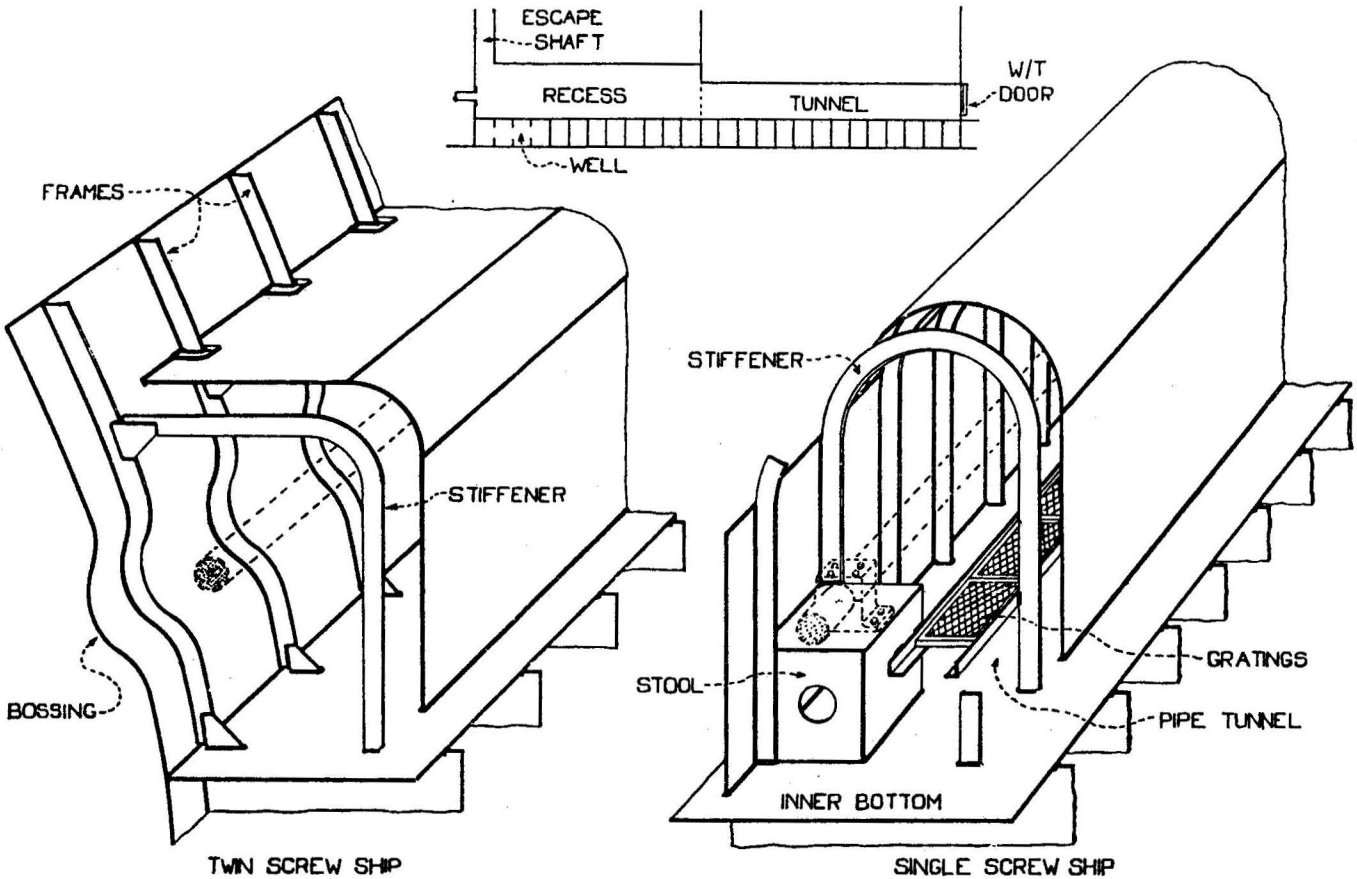
The propeller shaft runs along one side of the tunnel and is supported by bearings, called 'plummer blocks', which are carried on 'stools' attached to the tunnel and inner bottom. Gratings are laid down to form a walkway and the space below these is used as a pipe tunnel for the piping from the after tanks.

A watertight door must be fitted at the engine-room bulkhead, to enable the tunnel to be sealed-off in emergency; whilst an escape shaft must be provided at the after end.

Drainage from the tunnel is provided for by a 'tunnel well'. This is usually formed by stopping the inner bottom plating four or five floor spaces short of the after peak bulkhead and fitting a suction in the space thus formed.

Plating and Stiffeners—The tunnel plating is supported by flat bar, or bulb bar stiffeners, which are usually placed over each floor. The plating is thickened slightly in the way of hatches to guard against damage when cargo is being worked.

If the tunnel passes through a deep tank, the spacing of the stiffeners is to be the same as for a bulkhead and they must be bracketed at their feet.



SHAFT TUNNELS

STERN TUBES AND PROPELLERS

General—The purposes of the stern tube are to support the shaft and to make a watertight joint where the shaft enters the hull.

Fitting—At the fore end of the tube there is a flange which is bolted to the after peak bulkhead. At its after end the tube has a small flange cast on it and abaft this it is threaded to take a large nut. When it is in position, the flange bears against the fore side of the sternframe and the nut on the after side.

Construction—The tube itself is usually made of steel. Inside this again is a brass bush which has grooves in it, running fore and aft. Strips of lignum vitae are fitted into these grooves to act as a bearing for the shaft. The strips are kept in place by means of a ring known as the 'check ring'. which is bolted on to the after end of the tube.

Small spaces are left between the lignum vitae strips and through these the water can enter to lubricate and cool the shaft. In order to prevent this water from getting into the hull of the ship, a stuffing box is fitted at the fore end of the stern tube. The aftermost length of shafting, which revolves in the stern tube, is known as the 'Tail End Shaft'. It usually has a brass liner shrunk on to it.

In some ships the stern tube is bushed with white metal instead of lignum vitae and oil is used for lubrication. In this case special glands are used to prevent the escape of oil.

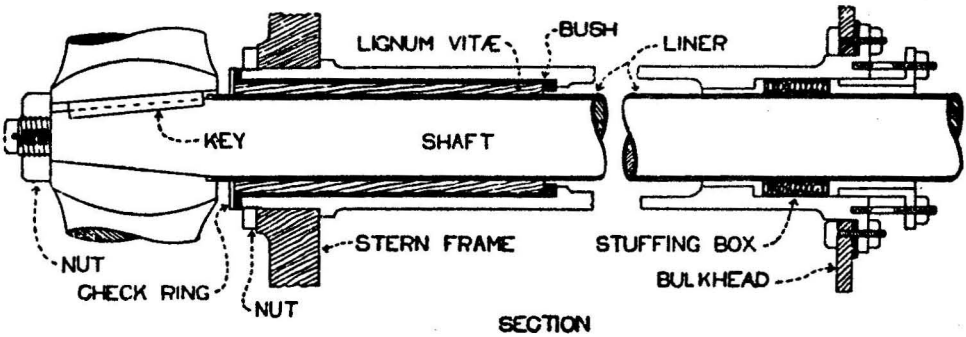
Strengthening Around Stern Tube—There is usually considerable vibration in the vicinity of the stern tube, and arrangements must be made to strengthen the ship against this.

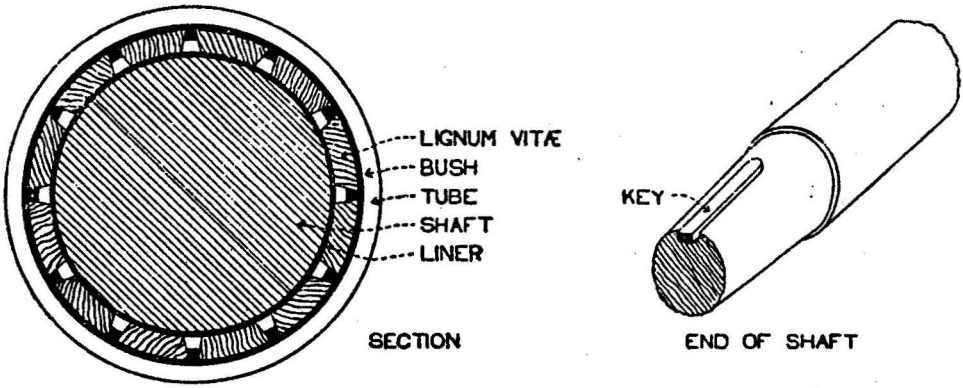
The floors must extend above the tube. If this is impossible, deep 'cross tie plates', flanged on their upper and lower edges, must be fitted above the tube.

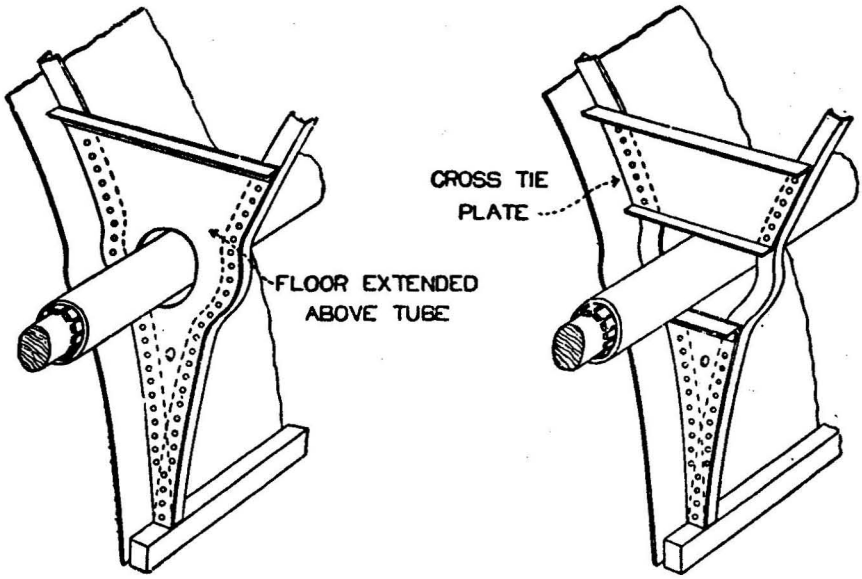
The plating of the after peak bulkhead must be thickened or doubled around the tube. The shell plating must also be thickened in this vicinity.

Propellers—Propellers may be cast in one solid piece or they may consist of a boss with the blades bolted on to it. The holes for the heads of the bolts are usually filled in with cement.

The tail end shaft is tapered at its after end to take the propeller. The latter is kept from turning on the shaft by means of a key which is inserted in a key way on the shaft before the propeller is put on. A large nut is put on the after end of the shaft to prevent the propeller from coming off. To prevent this nut from coming undone it is always made left-handed for a right-handed propeller, and it is further secured by means of a pin or some similar locking device.


LIGNUM VITÆ
BUSH
LINER
KEY
SHAFT
NUT
CHECK RING
NUT
STERN FRAME
STUFFING BOX
BULKHEAD
SECTION


LIGNUM VITÆ
BUSH
TUBE
SHAFT
LINER
SECTION
KEY
END OF SHAFT


CROSS TIE
PLATE
FLOOR EXTENDED
ABOVE TUBE

STERN TUBES

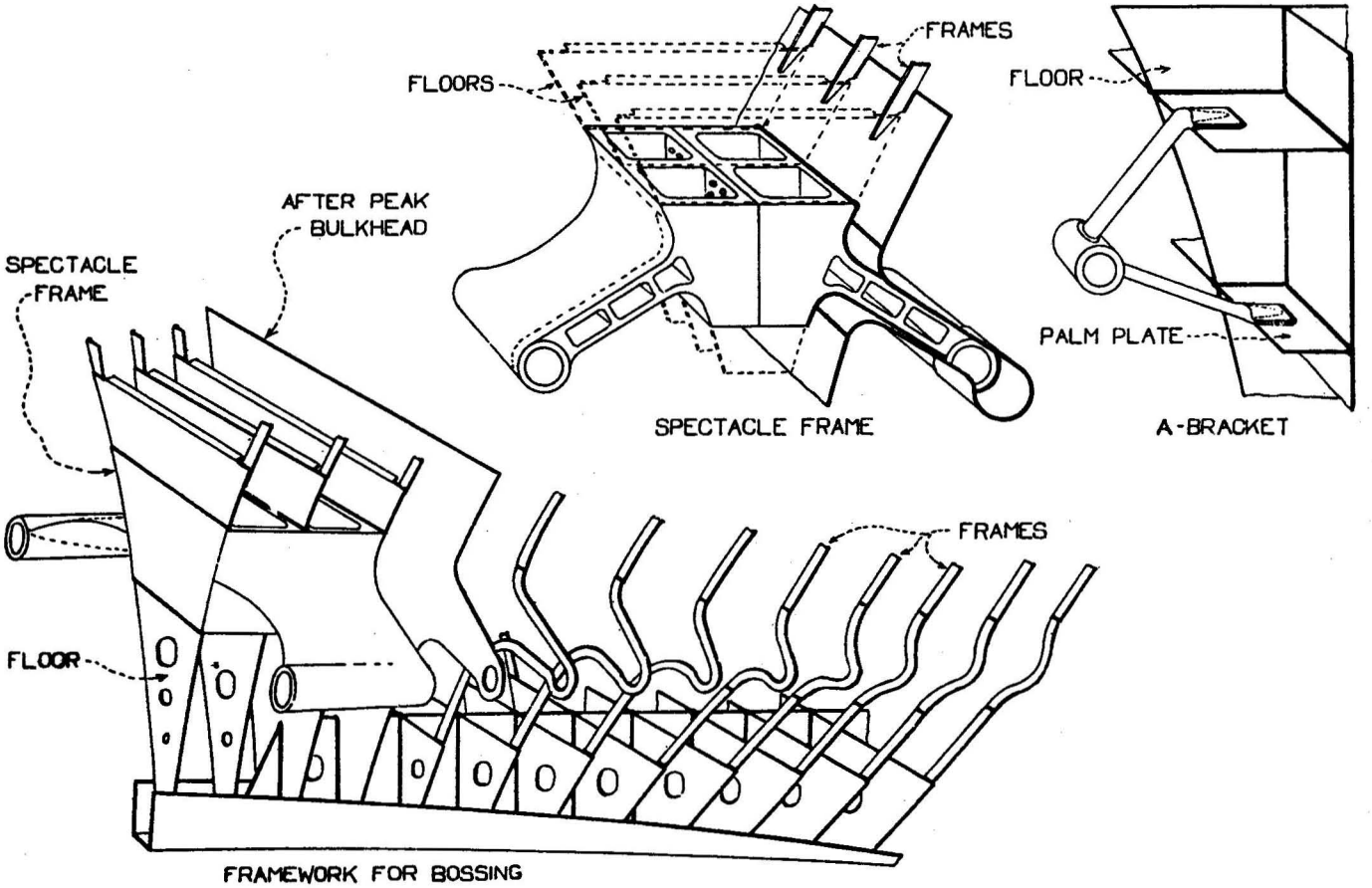
TWIN SCREWS

General—In a hull built for twin screws, special arrangements must be made to support the shafts and to avoid weakness. In some ships, the shafts leave the hull at a point forward of the propeller and are supported at their after ends by brackets, called 'A-Brackets'. In most ships, however, the hull is bossed out so as to enclose the shafts for their whole length.

A-Brackets—When these are used, a bearing and watertight gland are fitted at the point where the shaft leaves the hull.

The struts of the A-brackets are bars of streamlined section. Their inboard ends are flattened-out into palms, welded or riveted to a heavy horizontal 'palm plate', or stringer: which, in its turn, is connected to specially strengthened floors. Where the struts pass through the shell plating, welding is used to form a watertight seal.

Bossing—When the hull is bossed-out around the shafts, the bossing is formed by welding-in short, specially shaped lengths of frame bar to carry the shell plating. At the after end, the shafts are supported by a strong casting, called a 'spectacle frame', which is welded or riveted to deep, specially strengthened floors. For convenience in fitting, the spectacle frame is usually in two parts, bolted or riveted together at the centre line: or sometimes in three parts. That part of the shell plating which forms the bossing, is welded to the fore end of the spectacle frame.


FRAMES
FLOORS
FLOOR
AFTER PEAK
BULKHEAD
SPECTACLE
FRAME
PALM PLATE
SPECTACLE FRAME
A-BRACKET
FRAMES
FLOOR
FRAMEWORK FOR BOSSING

TWIN SCREWS

SUPERSTRUCTURES AND DECKHOUSES

General—A superstructure may be described as an erection above the upper deck, extending from side to side of the ship and forming a part of the main hull.

A deckhouse may be described as a comparatively light structure,more or less resembling a steel box, and used mainly for accommodation and similar purposes. It does not usually extend for the full width of the ship and is placed upon the ship's main hull, as distinct from forming an integral part of it.

Forecastles and Poops—These are usually comparatively lightly constructed. If they extend into the amidships half of the ship, however, the upper deck stringer and sheerstrake must be thickened, as for a long bridge.

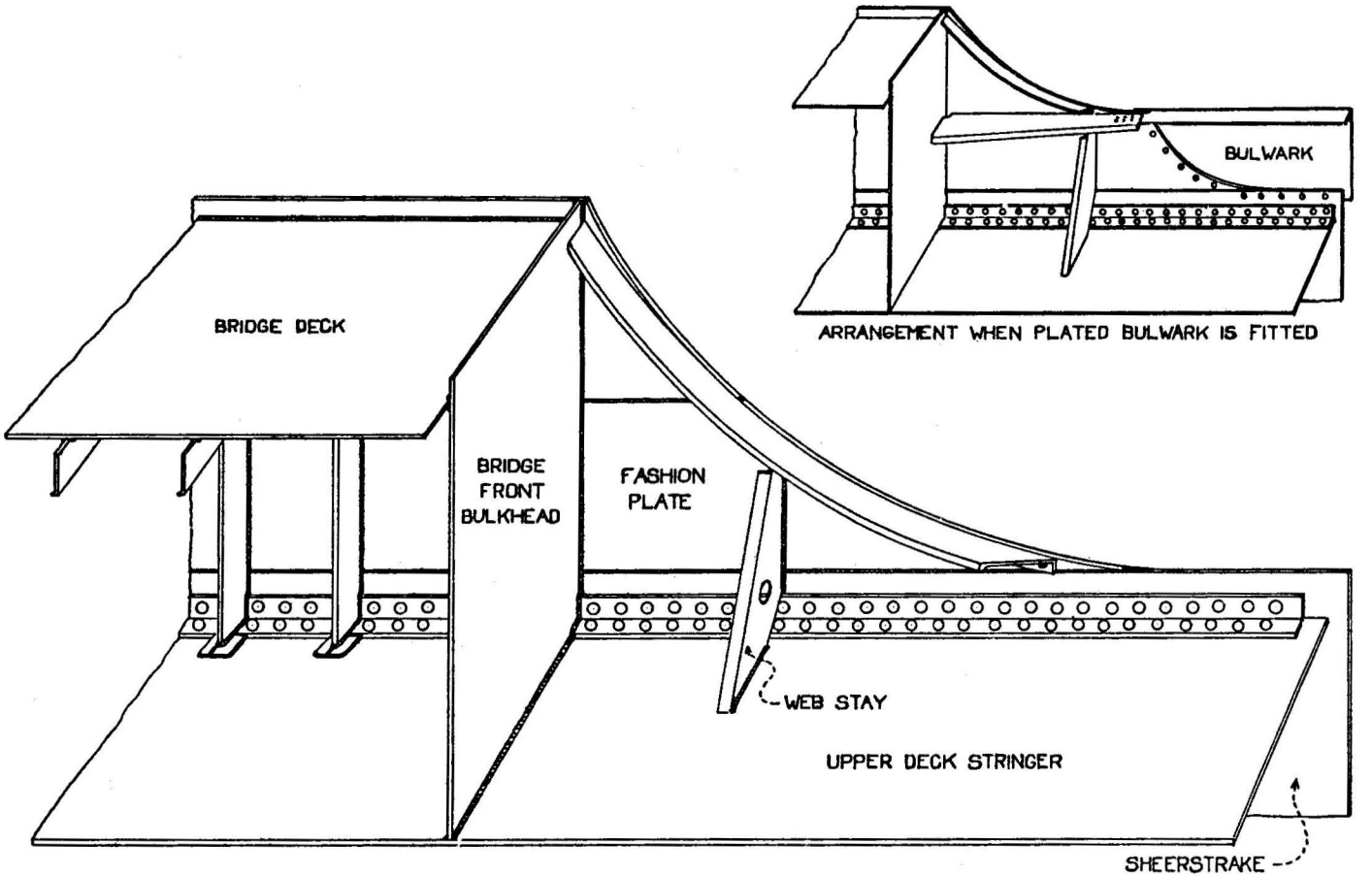
Bridges—Great care must be taken to preserve continuity of strength in the way of bridges, since the longitudinal bending stresses on the ship are greatest in their vicinity.

A 'short bridge' is one which has a length of not more than 15 per cent of the ship's length. It is constructed in the same way as a forecastle, except that the upper deck stringer and sheerstrake are thickened by 10 per cent and 30 per cent, respectively, in the vicinity of its ends.

A 'long bridge' is one which has a length of more than 15 per cent of the ship's length. It must be more strongly built than a short bridge and may be required to be strengthened by partial bulkheads or web frames if it carries large deck houses. The upper deck stringer and bridge side plating are thickened by 25 per cent and the sheerstrake by 50 per cent at the ends of a long bridge.

Bridge Side Plating—To avoid a sudden break of strength at the ends of a bridge, the bridge side plating must be tapered off into the sheerstrake. This is usually done by extending the side plating beyond the ends of the bridge and curving-off its upper edge. It is then often called a 'fashion plate'. This must be stiffened on its upper edge and also supported by web plates, placed within 1·5 metres of the bridge-ends.

If the bridge side plating is welded to the sheerstrake, as shown in the sketch, the welding must be done very carefully. Sometimes this joint is riveted in order to reduce stress concentrations. If a bulwark is fitted, it should be riveted, not welded, to the fashion plate.



END OF SUPERSTRUCTURE

SUPERSTRUCTURES AND DECKHOUSES—(*Continued*)

Bridge Front Bulkheads—These must be strong enough to resist the impact of heavy seas. The plating is fairly thick and is stiffened by welded bulb-bars, about 70 centimetres apart, attached at their heads and feet by welding or by brackets.

Poop Bulkheads—If the poop covers a machinery space, or if it has a length of more than 40 per cent of the ship's length, the poop front bulkhead must be constructed in the same way as a bridge front bulkhead. Otherwise the plating may be slightly thinner and the stiffeners may be welded flat bars.

After Bulkheads of Bridges and Forecastles—These have comparatively light plating and are stiffened by light welded bars.

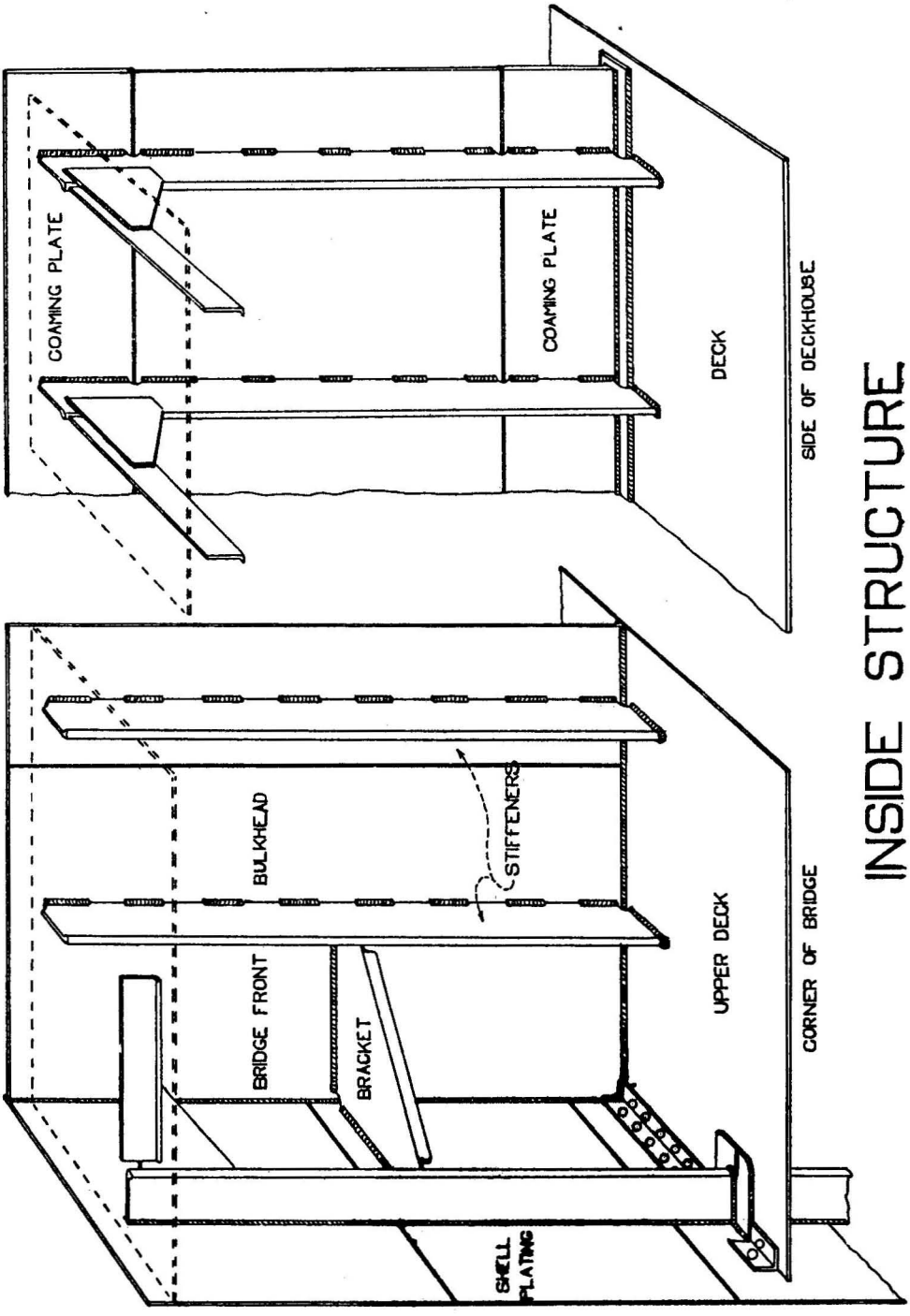
Deckhouses—Are usually connected to the deck by riveted angles or by welded T-bars.

The plating is strengthened by stiffeners, which should, so far as possible, be fitted in line with the ship's main framing. They are attached at the head and foot by angle lugs or by welding; except where there are two tiers of deckhouses, when the stiffeners of the lower tier must have bracket attachments. Partial bulkheads or web frames must also be fitted at intervals, to strengthen the sides and ends of the deckhouse.

All openings in the side plating of deckhouses must be properly framed and should have well-rounded corners. Large openings should have web frames fitted on either side of them, if possible. Continuous coaming plates should be fitted above and below doorways and similar openings.

The deck under large deck houses must be properly supported. Intercostal pillars and deck girders, or web frames, must be fitted under the corners of long deckhouses.

Aluminium deckhouses must be carefully insulated from steel decks. Methods of doing this are described in the chapter on 'Connections'.



INSIDE STRUCTURE

RAISED QUARTER DECKS

General—In an ordinary superstructure, the superstructure deck is an additional one, placed 2 or 3 metres above the upper deck, which continues throughout the superstructure.

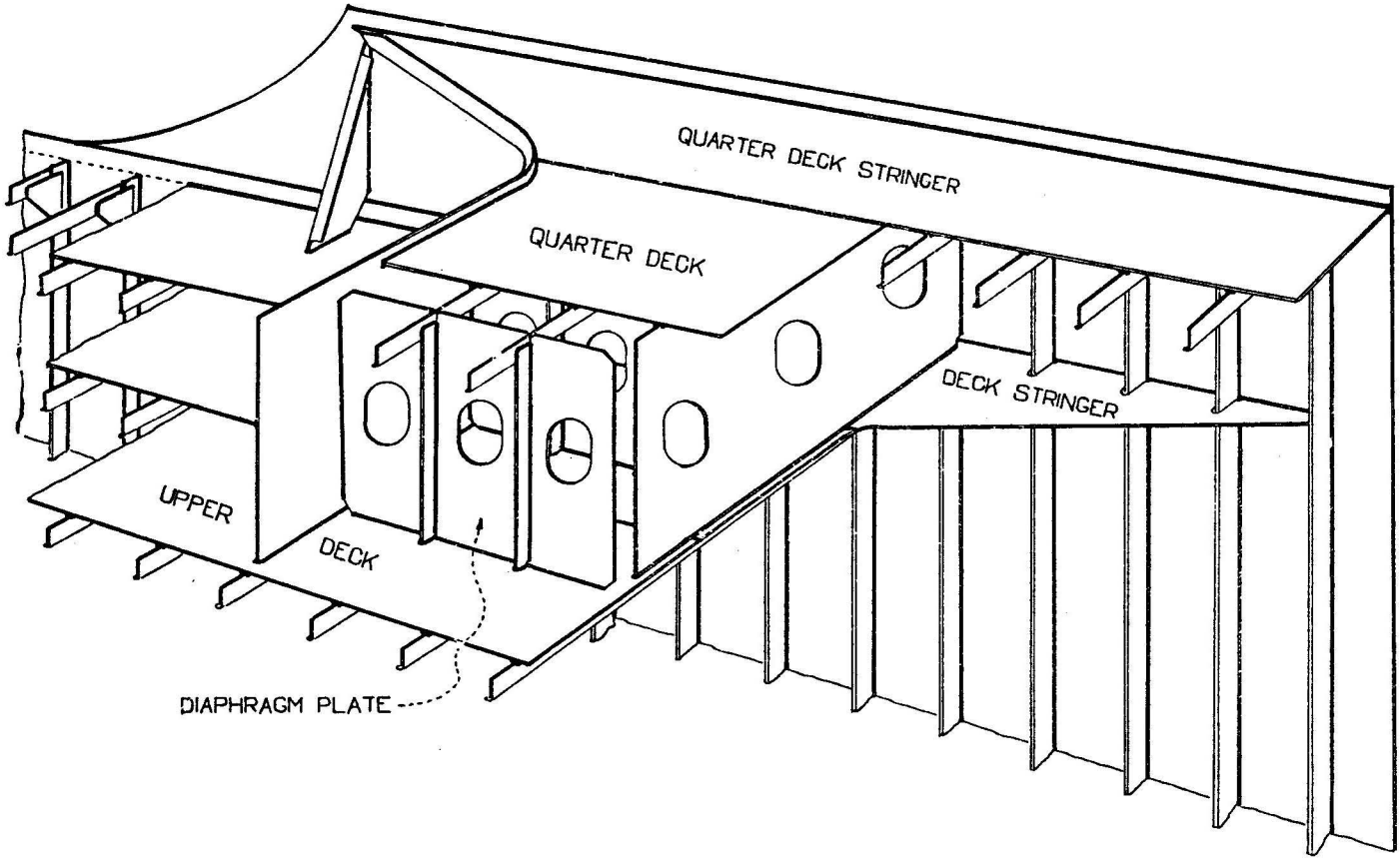
When a raised quarter deck is fitted, the actual upper deck does not continue beyond the break and, from there on, is replaced by the quarter deck. In other words the break forms a step, about 1 to 1½ metres high, in the upper deck; which then continues as the raised quarter deck.

Strength at the Break—There is a natural weakness at the break of the quarter deck, and this must be compensated for.

The upper deck stringer, or bridge deck stringer, must extend for three or four frame spaces abaft the break and the quarter deck stringer plate must extend for a similar distance forward of the break.

The upper deck plating must overlap that of the quarter deck by two or three frame spaces and diaphragm plates must be fitted between them. These may be required to have vertical stiffeners fitted to them.

The upper deck sheerstrake is made thicker and is extended for some distance abaft the break. If connected to a long bridge, the quarter deck sheerstrake must also be thickened and extended into the bridge.



BREAK OF RAISED QUARTER DECK

BULWARKS

Fitting—Bulwarks must not be welded to the sheerstrake within the half-length amidships, because this is liable to cause the plating to crack. This difficulty can be overcome by riveting the bulwark to the sheerstrake, even though it is welded elsewhere. Alternatively, we may use a 'floating bulwark', which has the advantage that the gap between it and the deck edge acts in lieu of freeing ports. This type may be riveted, but is more often used in welded ships and is particularly useful where a rounded sheerstrake is fitted.

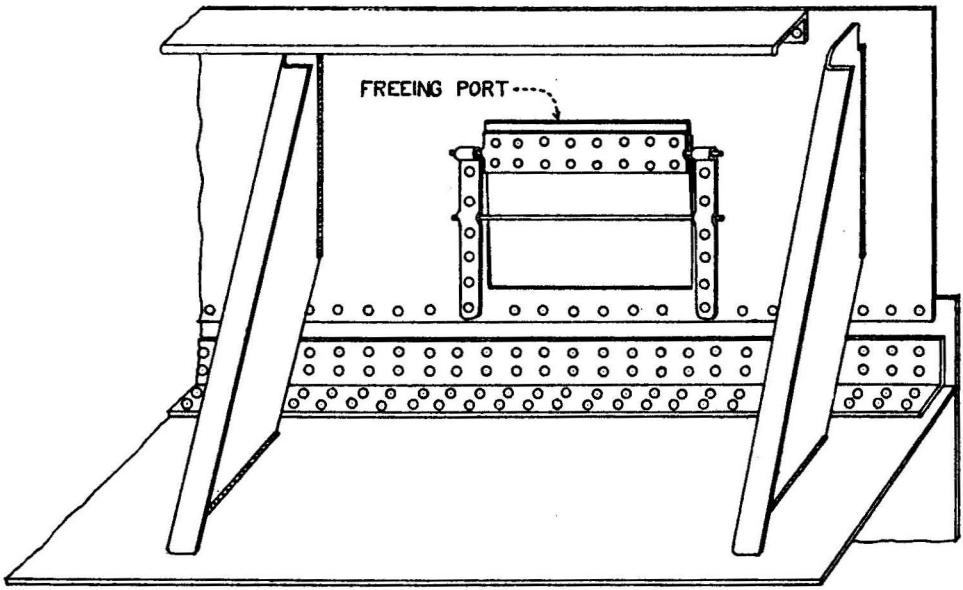
Bulwarks in exposed positions must be at least 1 metre high. They are to be supported by stanchions: these must not be more than 1·2 metres apart for the forward 7 per cent of the ship's length in some ships, but otherwise they may be not more than 1·83 metres apart. The stays nearest to the ends of bridges or long poops must be placed within 1·5 metres of the break bulkhead and must be web plates.

Openings in Plates—Where mooring pipes are fitted, the plating is to be doubled or thickened around them.

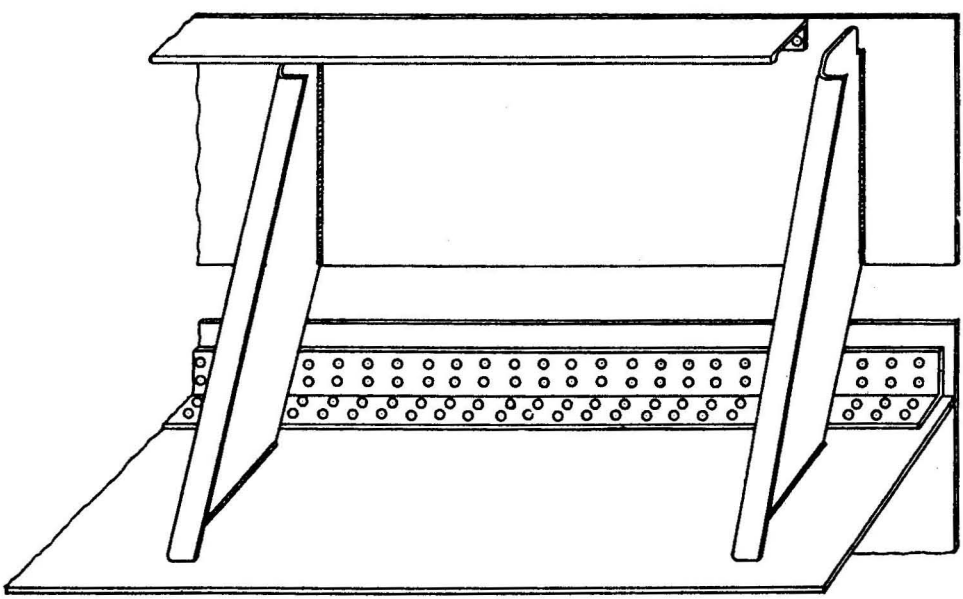
Where both the bulwark plate and the rail are cut, as for cargo gangways, the stays at the ends of the openings are to be made stronger.

Openings in bulwark plates are to be kept well away from break bulkheads.

Freeing Ports—The area of freeing ports on each side depends on the length of the well deck. The lower edges of the ports must be as near to the deck as possible. Bars, spaced about 230 millimetres apart, must be fitted across the port. Where hinged flaps are fitted, the hinges must be of non-corrodible material.



BULWARK RIVETED TO SHEERSTRAKE



FLOATING BULWARK

BULWARKS

ENGINE AND BOILER ROOMS

General Arrangements—The structural arrangements of engine and boiler rooms vary greatly from ship to ship and depend on many things, so that the rules concerning them are necessarily rather vague.

It is always necessary to cut away decks in the way of machinery spaces. The lowest deck may be cut away considerably, if not completely, to clear the engines and boilers. The other decks must also be cut, but usually to a lesser extent, to provide a shaft for the admission of light and air, to allow the boiler uptakes and ventilators to pass through and to allow parts of the machinery to be lifted or removed during overhaul. The shaft thus formed is boxed-in by the machinery casings, which usually extend for the whole length of the machinery spaces.

Vibration and the heavy local weights of engines and boilers put considerable stress on the girderwork of the double bottom, in addition to trying to force the bottom bodily downwards. This, in its turn, tends to cause the ship's sides to collapse inwards at the deck: at the very point where large openings are left in the deck plating to allow the casings to pass through. To compensate for this, it is necessary to strengthen the ship's structure in machinery spaces.

In coal-burning vessels, the 'tween deck spaces between the casings and the ship's side were partly or entirely used as bunker spaces. In modern, oil-burning ships they are generally used for cargo, accommodation, or stores.

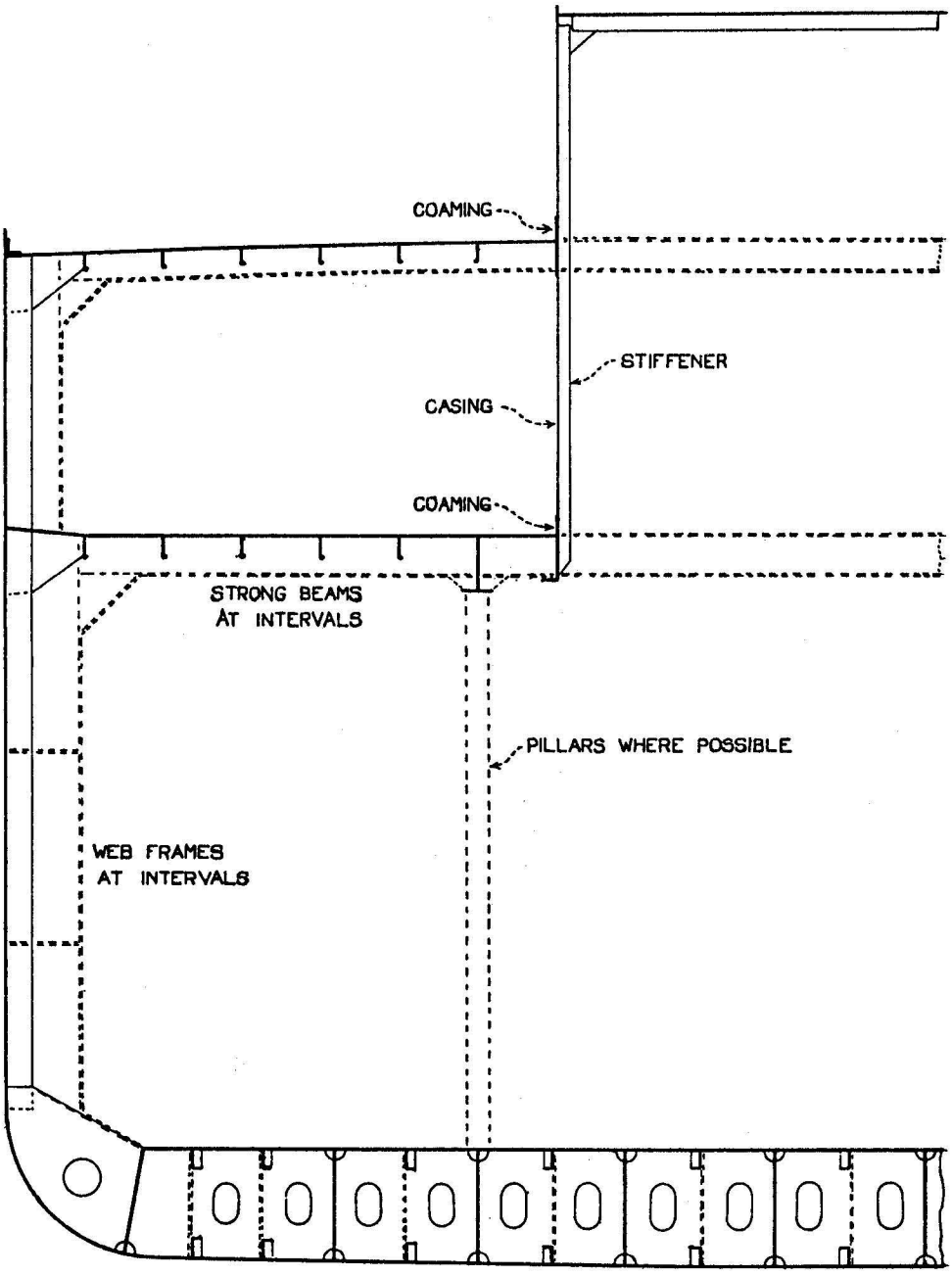
Double Bottoms—In boiler rooms, the tank side brackets and all parts of the cellular double bottom, inside and including the margin plate, are thickened. In engine rooms, the inner bottom plating only is thickened. Under engine rooms, boiler bearers and thrust blocks, solid floors must be fitted at every frame space and their reverse bars must be doubled. Extra fore and aft side girders must also be fitted under engines and thrust blocks.

Frames and Beams—Frames are thickened in boiler rooms as a precaution against corrosion. Loss of transverse strength, due to the cutting away of frames and beams, is compensated by fitting web frames and strong beams wherever possible. When permanent strong beams cannot be fitted, portable ones, bolted in place, may be fitted within the casings.

Casings—These are formed by fitting coamings, similar to hatch coamings at each deck and by welding fore and aft plates between them.

They are stiffened by vertical bars, about 750 millimetres apart.

Pillars—A system of pillaring, or some arrangement in lieu of it, must be fitted throughout.


COAMING
STIFFENER
CASING
COAMING
STRONG BEAMS
AT INTERVALS
PILLARS WHERE POSSIBLE
WEB FRAMES
AT INTERVALS

ENGINE ROOM

HATCH BEAMS AND COVERS

General—In some early ships, the hatches were sometimes placed athwartships and supported by fore and aft beams, called 'fore and afters'. Nowadays, if wooden hatch covers are used, they are placed fore and aft on athwartship beams. Steel hatch covers of various types, are often fitted in modern ships and have many advantages.

Beams—The size of hatch beams is governed by their length and spacing. They may be of a built H-section, or a deep built T-section. The ends which rest in the carriers must have doubling plates, at least 180 millimetres wide.

Roller beams are sometimes used today. These run on a special track on the hatch side coamings and have special arrangements for fixing them in position when required.

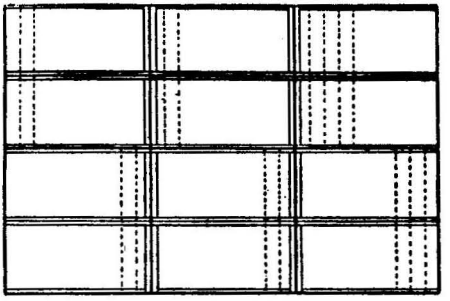
Carriers—The sockets in which the ends of ordinary hatch beams rest are called 'carriers'. At least 75 millimetres of the beam must bear on the carrier.

Hatch Covers—Wooden hatch covers must be 60 millimetres thick when their unsupported span is 1·5 metres, 82 millimetres thick for a span of 2·0 metres, or intermediate for intermediate spans. Their ends must be fitted with galvanised steel bands, about 65 millimetres wide and 3 millimetres thick.

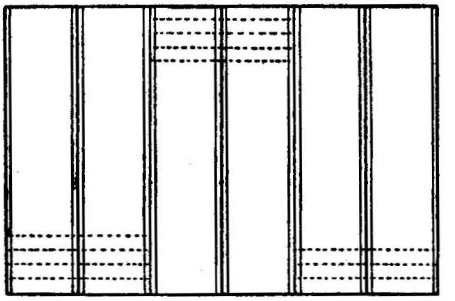
Hatch Rests—The angles which support the ends of the hatches are called 'hatch rests'. They must be at least 65 millimetres wide.

Cleats—Cleats must be not less than 65 millimetres wide and must be set to fit the taper of the wedges. They must not be more than 600 millimetres apart and the end cleats must be within 150 millimetres of the hatch ends.

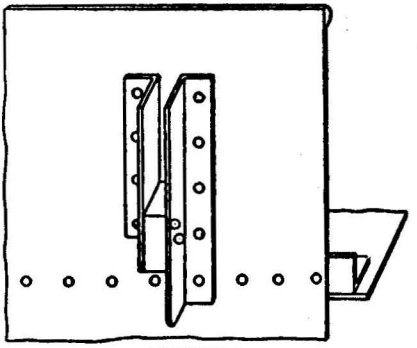
Wedges—These must be of tough wood, at least 200 millimetres long and 50 millimetres wide. They must have a taper of 1 in 6 and must be 13 millimetres thick at the toe, or narrow end.



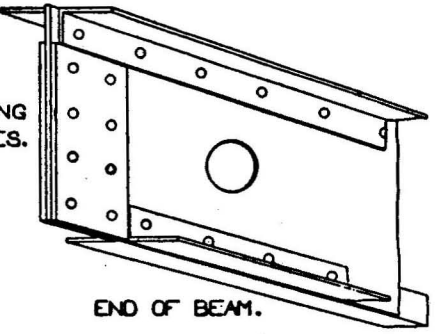
FORE AND AFTERS.



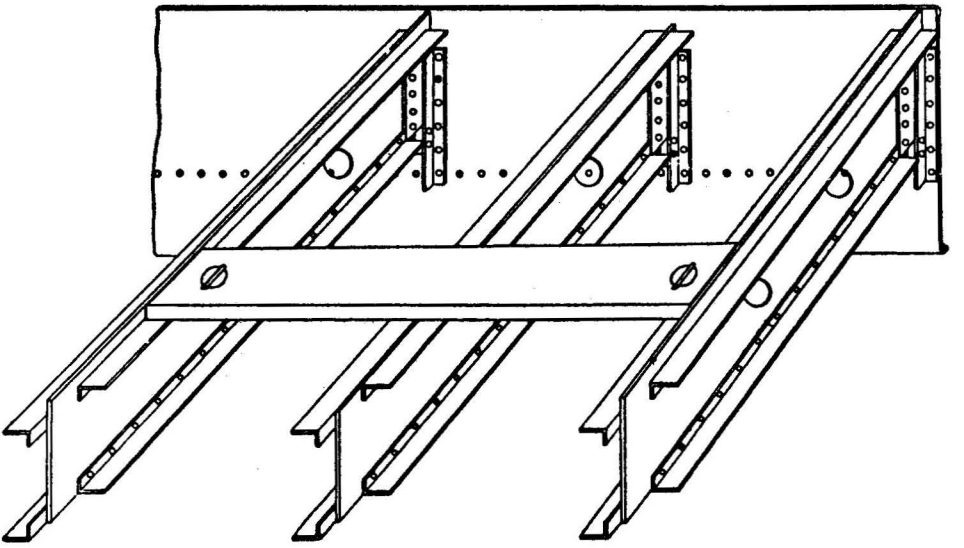
ATHWARTSHIP BEAMS.



CARRIER.



END OF BEAM.



HATCH BEAMS.

HATCH BEAMS AND COVERS—(*Continued*)

Locking Bars, Etc.—Locking bars, or some equivalent arrangement, must be provided at all hatches in which the coamings are required to be 600 millimetres in height. They must secure each section of hatches independently. If the hatch covers extend over more than one beam space, a locking bar must be provided at each end of each section of hatches.

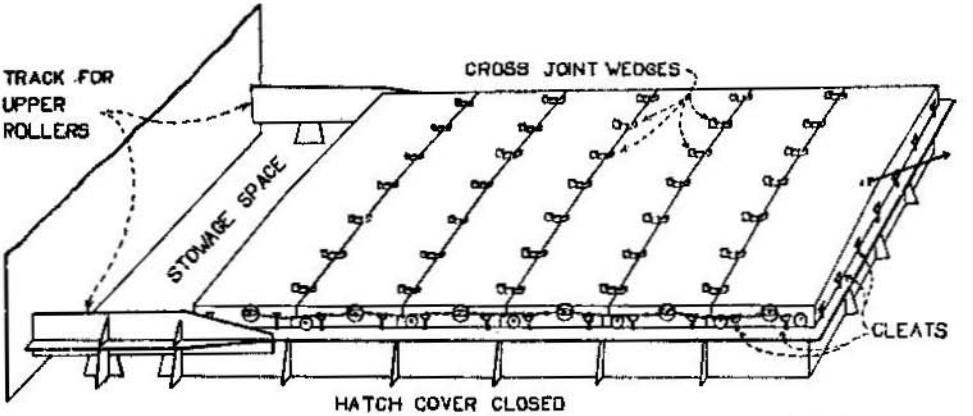
At other hatchways in exposed positions on weather decks, ring bolts or other fittings for lashings, must be provided.

Marking—The Factory and Workshops Act require all hatches and beams to be plainly marked to indicate the hatch and deck to which they belong and their position therein. This, however, does not apply where all the beams and/or hatch covers in a ship are interchangeable: nor in respect of the marking of position when all the beams and/or covers of any one hatch are interchangeable.

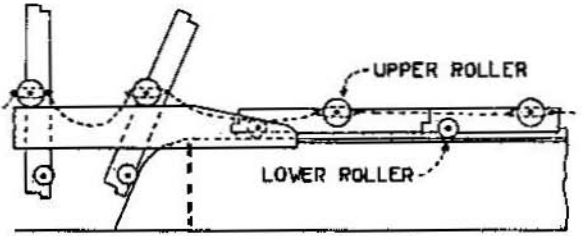
The Acts also require that hand-grips of a suitable size are to be provided in all hatches.

Steel Hatch Covers—These have many advantages and are much used in modern ships. They must have cleats about 2 metres apart, with a minimum of 2 cleats per panel. At hatch ends, one cleat is to be adjacent to the hatch corner. Cross joint wedges should be about 1·5 metres apart: or special arrangements should be made in lieu of them.

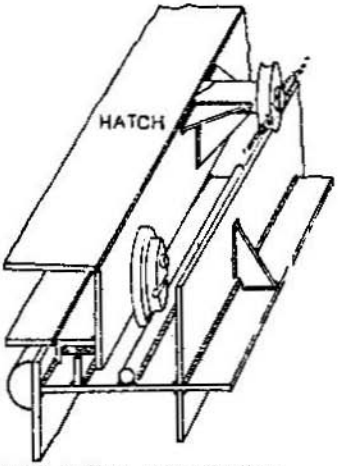
MacGregor hatch covers, as shown in the sketch, are a very strong and efficient type and do not require separate beams. The lower rollers are mounted on an eccentric bush which enables them to be raised or lowered. This enables the hatch covers to be raised for rolling and stowage, or lowered so that they can be secured and made watertight. The upper rollers engage on a special vertical plate at the end of the track and tilt the hatch into a vertical position for stowage. These upper rollers are joined by lengths of chain or wire so that they can be pulled along the track. The hatches are made watertight by rubber jointing, as shown: being pulled down by cleats and cross-joint wedges.

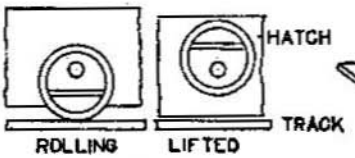


HATCH COVER CLOSED

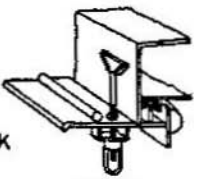


METHOD OF STOWAGE



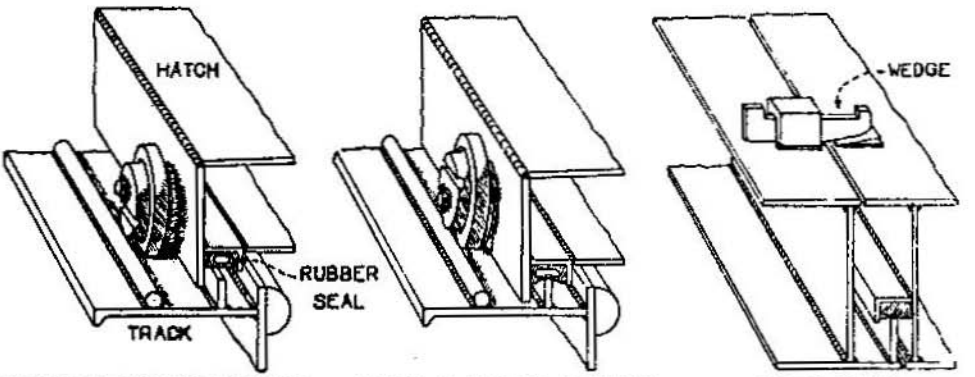


LOWER ROLLER



CLEAT

HATCH TILTING FOR STOWAGE



HATCH IN ROLLING POSITION HATCH IN CLOSED POSITION CROSS JOINT

MACGREGOR STEEL HATCHES

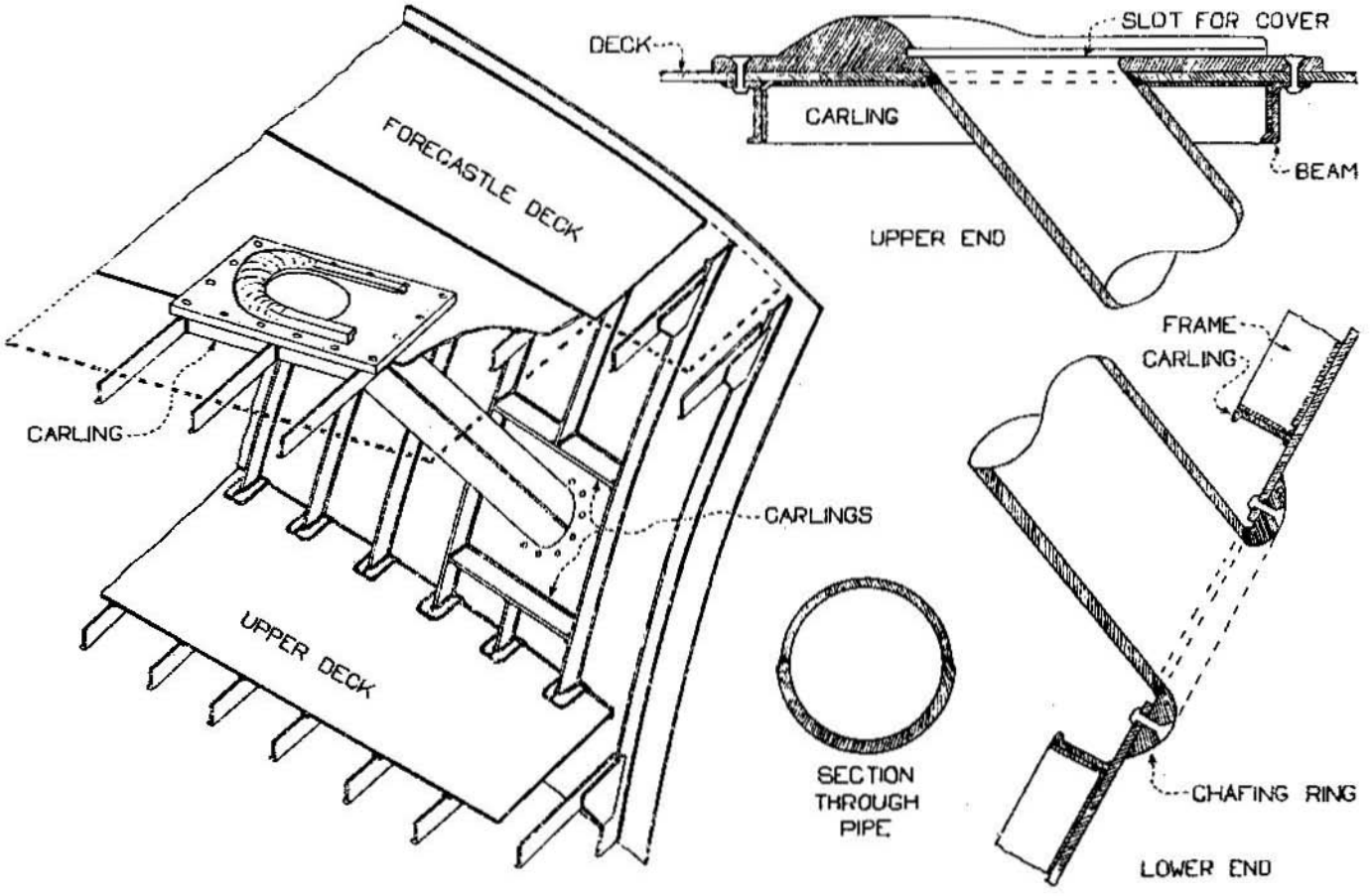
HAWSEPIPES

Hawsepipes may be made of cast steel, in which case they are usually cast from wooden models made in place in the ship. They are now often built-up of heavy plates, usually with cast steel lips welded to them.

The sketch shows one type of welded hawsepipe, with a lip, or 'chafing ring', welded to its lower edge. At the upper end it is welded to a block which has a raised lip to take the chafe of the cable, also slots into which plates can slide to close the pipe at sea. The chafing ring and block are riveted or bolted to the shell and deck plating. The lower plate of the pipe may be thickened, as shown here, or doubled to take the chafe of the cable.

The shell plating is doubled or thickened in the way of hawsepipes.

It is usually necessary to cut frames and beams, in order to allow the pipe to pass. In this case compensation is made by fitting short fore and aft pieces, called 'carlings', to support the cut ends, and the frames may be reinforced.


DECK
SLOT FOR COVER
CARLING
BEAM
UPPER END
FORECASTLE DECK
FRAME
CARLING
CARLING
CARLINGS
UPPER DECK
SECTION THROUGH PIPE
CHAFING RING
LOWER END

HAWSE PIPE

MASTS AND DERRICK POSTS

Size—The size of a mast or derrick post depends on its length from deck to hounds; on whether it is stayed or not; and on the number and safe working load of the derricks which it carries.

Construction—Masts and derrick posts are usually built up of two or three plates on the round. The plating must be doubled or thickened at the heel, deck, derrick supports and hounds. Large masts are sometimes stiffened by angles or T-bars, fitted vertically inside them.

Stepping—Masts exert a large downward thrust at their heels and must be strongly supported and stepped.

In many modern ships the masts are stepped in the 'tween decks. In this case, they are usually placed near a bulkhead, with large brackets fitted under the deck to transmit the thrust to the bulkhead. If this is not done, the 'tween deck must be specially pillared and stiffened below the heel of the mast.

Aftermasts are occasionally stepped on the tunnel. In this case, a special 'stool' is fitted on top of the tunnel, which is given extra stiffening.

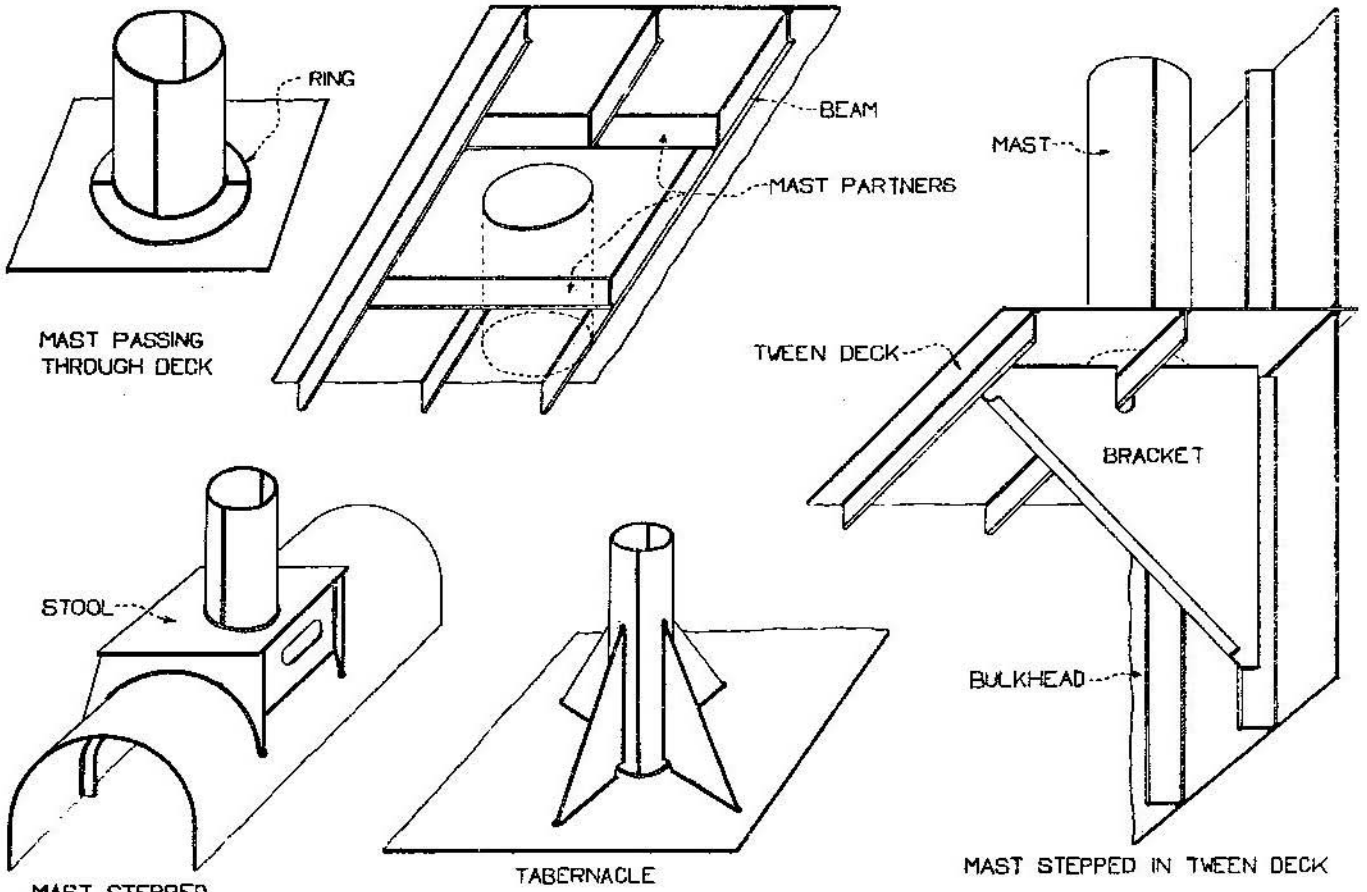
In single decked ships, the mast may be stepped on the inner bottom. Alternatively, it may be stepped on the upper deck and supported by an arrangement of brackets, known as a 'Tabernacle', or by a 'Mast House'.

Large masts, carrying heavy-lift derricks, may need partial longitudinal bulkheads or other special strengthening arrangements under their heels.

Masts Passing Through Decks—Where a mast passes through a deck, the deck plating is usually doubled or thickened. A hole, rather larger than the mast, is cut in the deck and a flat ring is then welded to the mast and deck to support the mast and to make the joint watertight.

The beams often have to be cut, to allow the mast to pass through them. In this case, the cut ends are supported by carlings, called 'mast partners'.

Staying—When masts are stayed, the stays and shrouds are attached to chain plates on the deck stringer or sheerstrake and to lugs or ring bolts on the mast. Many modern masts are unstayed, in which case they must be specially constructed and strengthened against the stresses caused by the derricks.


RING
MAST PASSING THROUGH DECK
BEAM
MAST PARTNERS
MAST
TWEEN DECK
BRACKET
BULKHEAD
MAST STEPPED IN TWEEN DECK
STOOL
MAST STEPPED ON TUNNEL
TABERNACLE

MASTS

VENTILATORS

General—It is very important that ventilators should have sufficient strength. Otherwise, if one were to carry away in bad weather, a large amount of water might find its way below deck.

Coamings—The height of coamings must be not less than 900 millimetres on upper decks which are exposed to the weather, on raised quarter decks and for one-quarter of the ship's length from forward on all superstructure decks. Abaft one-quarter of the ship's length from the stem on superstructure decks the height may be 760 millimetres.

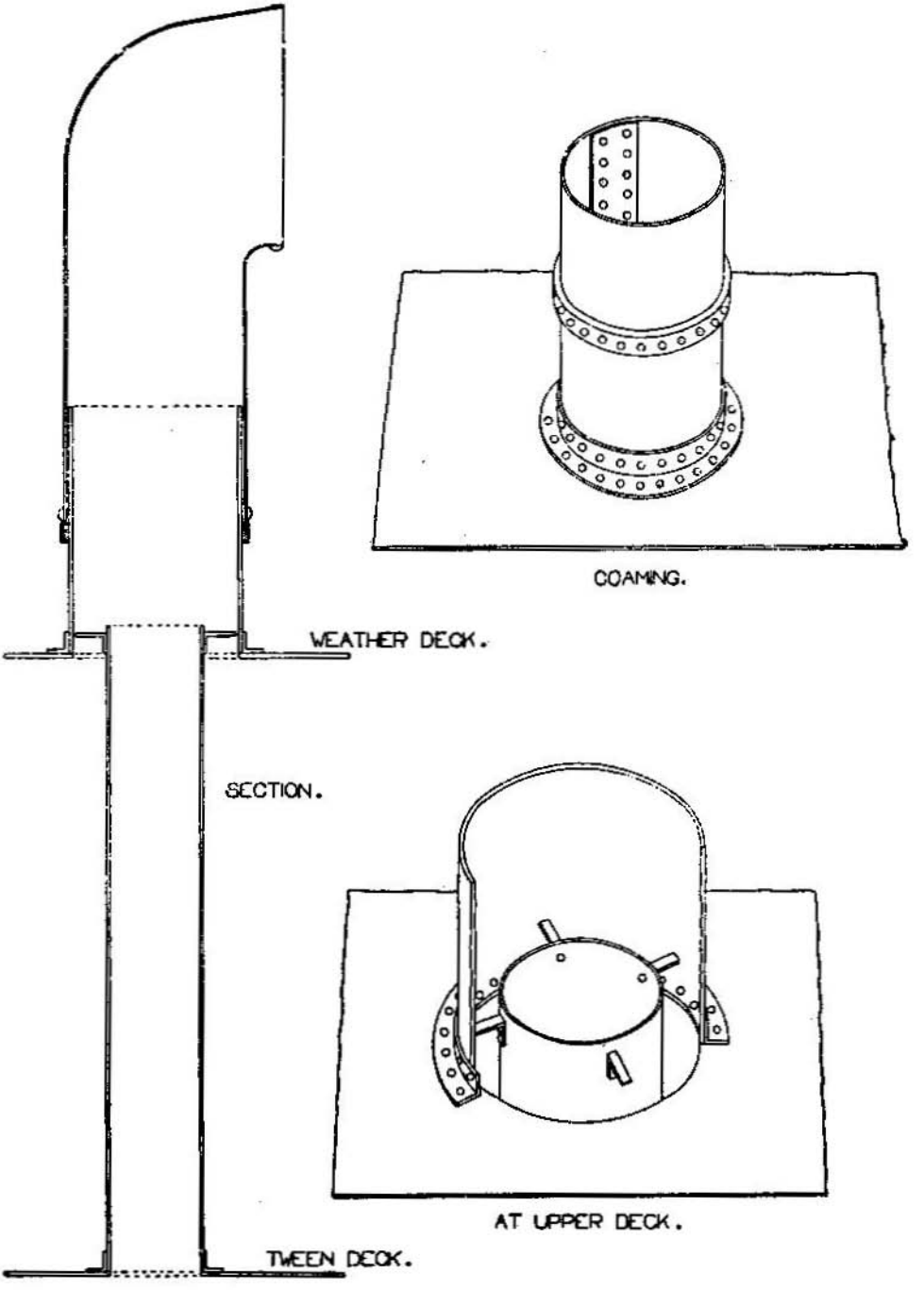
Coamings which are over 900 millimetres high must be specially supported. This is done by brackets, similar to a tabernacle, or by some similar arrangement.

Decks—The deck plating is to be stiffened in the way of ventilators.

Covers—All ventilators must have proper plugs and canvas covers or some other efficient means of sealing the coamings when the cowls are unshipped, unless the coamings are considerably higher than the minimum required.

Special Ventilators—Ventilators leading to the tunnel and to tanks must be made watertight and must be capable of resisting water pressure. Ventilators leading to tanks for oil fuel should have gauze fitted over their mouths.

Mechanical Ventilation—In most modern ships, the holds are fitted with trunking and air is supplied by fans. This gives better control of air-temperature and humidity, as well as allowing for a more uniform air-flow.



VENTILATORS.

REFRIGERATED SHIPS

General—To prevent heat from entering insulated holds, all steelwork of the ship's hull, except the 'tween decks, is insulated. It is necessary to seal all scuppers and drains so that warm air or taint cannot enter through them and also to insulate sounding pipes and thermometer tubes. Special arrangements must be made to prevent oil from leaking into the holds from adjacent tanks.

The holds may be cooled by pumping cold brine through pipes under the deckheads: alternatively, air may be drawn over nests of brine pipes in a 'cooler', and then pumped through air ducts into the holds.

Insulation—Various materials may be used for insulation, but glass fibre, cork and plastic foam are the most common. The insulation is kept in place by a lining of plywood or sheet metal, inside the frames and under the beams. This lining is usually secured by screwing it to wood battens, called 'grounds', which are bolted to the frames or beams; or by special clips.

The hatchways are sealed by wooden 'plug hatches', fitted under the ordinary hatches. Access to bilges and to manholes in double bottoms is provided by further plug hatches.

'Tween decks are usually only insulated on their undersides, the upper surface of the steel deck being left bare. A wood 'ribband', about 1 metre wide, is sometimes fitted on top of the 'tween deck at the ship's side.

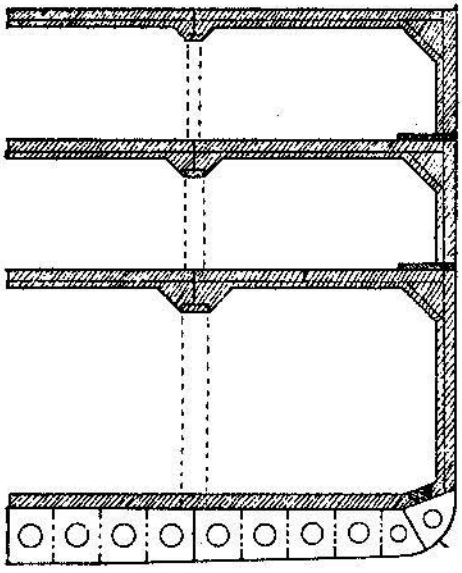
The inner bottom usually has insulation laid on it. This insulation is covered with a wood ceiling, to protect it against damage.

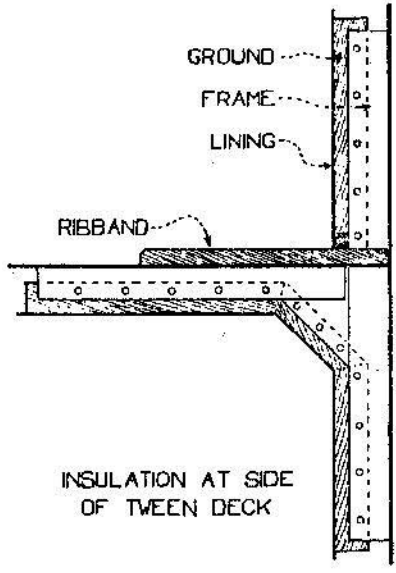
Protection from Oil—If the double bottom under an insulated hold is intended to carry oil, the insulation here must be laid on athwartships battens, so as to leave a 50 millimetre air space between insulation and tank top. Alternatively, the air space may be omitted if the insulation is laid on a thick layer of oil-impervious composition. All connections to the inner bottom and margin plate should be welded, to prevent leakage; whilst manhole cover fastenings should not pass through the inner bottom plating.

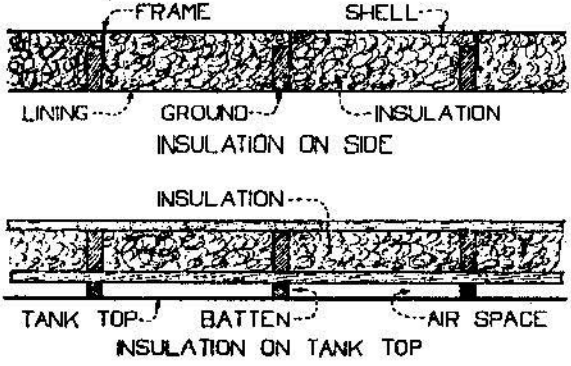
Deep tanks intended to carry oil must be separated from insulated holds by cofferdams; unless the bulkhead is completely welded and has a suitable layer of oil-impervious composition on the side nearest to the hold.

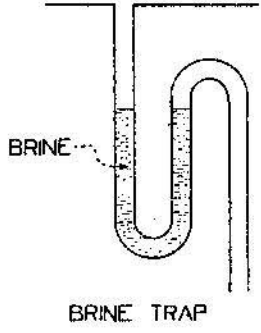
Piping—All pipes, including air and sounding pipes, must be insulated. Thermometer pipes must be insulated from the deck plating and must have an inside diameter of at least 50 millimetres.

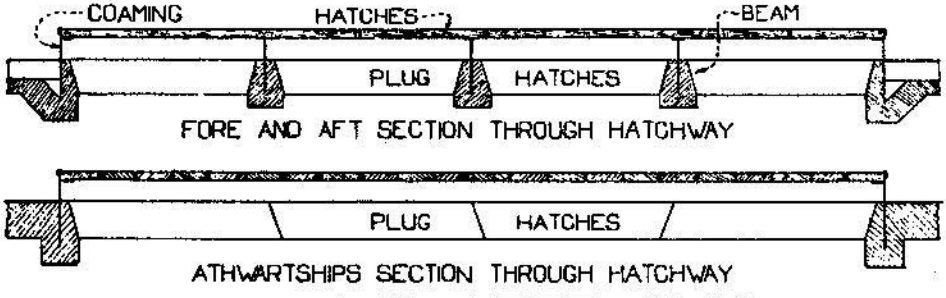
All drains which lead to the bilges must have 'brine traps', to prevent warm air and taint from entering the hold.











REFRIGERATED SHIP

STRENGTHENING FOR ICE NAVIGATION

Ice Strengthening—Ice is liable to cause damage to the shell plating, stem, sternframe, propeller and rudder in the region of the waterline. Ships which are intended to navigate in ice must, therefore, be strengthened accordingly.

There are four classes of ice strengthening, based on conditions which are met in the Baltic:—

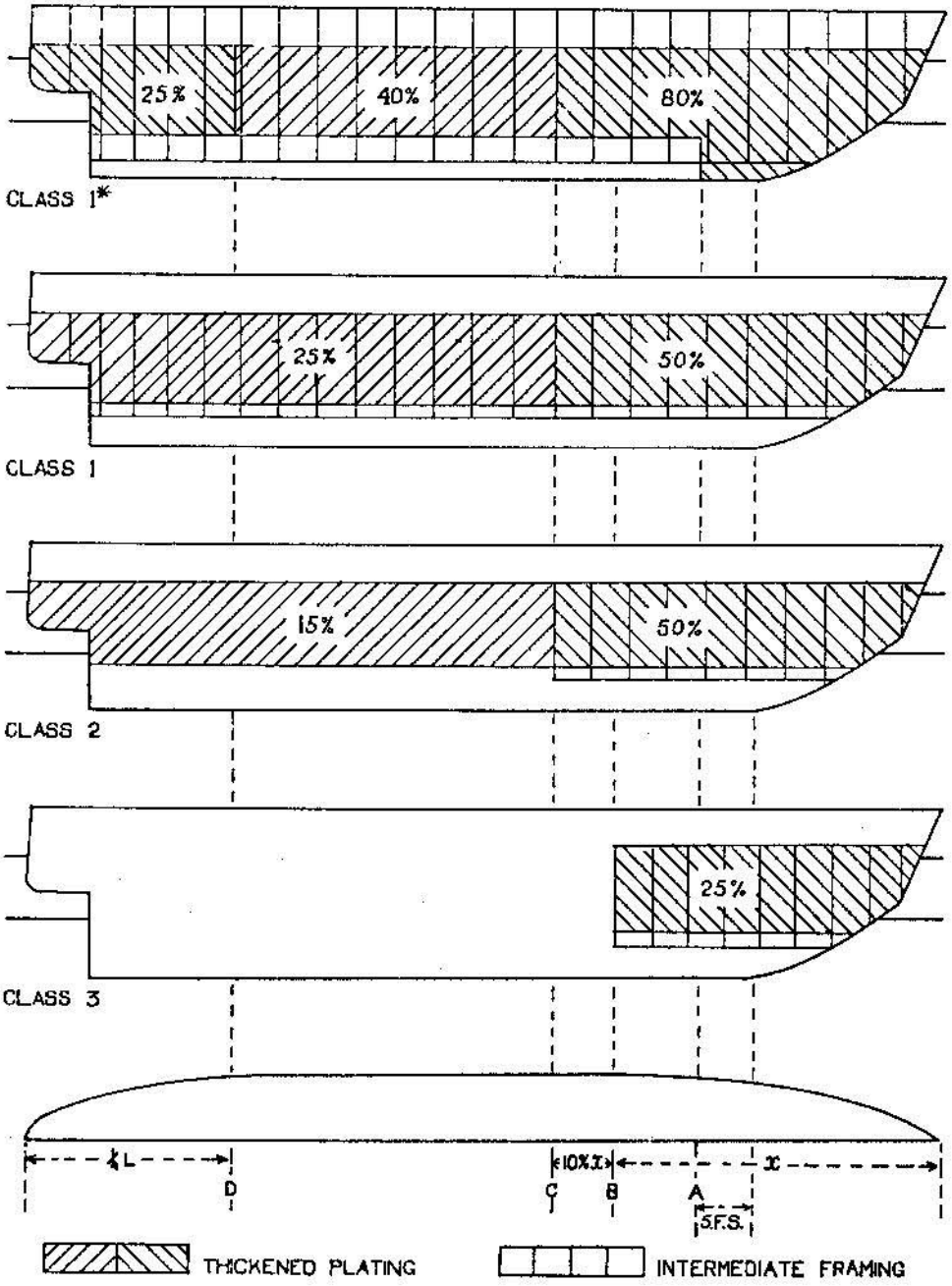
Class 1*: for extreme ice conditions.
Class 1: for severe ice conditions.
Class 2: for intermediate ice conditions.
Class 3: for light ice conditions.

Structure—Intermediate frames must be fitted between the main frames, and, except in ice class 3, connected at their ends by horizontal carlings. These intermediate frames are to be of the same size as the main frames and must be supported by tripping brackets, unless special side stringers are fitted. Welded frames may not be scalloped in the way of thickened shell plating. Heavy side stringers are required for Class 1*. They need not be fitted in the other classes unless lighter intermediate frames are used. Shell Plating is made thicker than normal over an area which depends on the ice class. A specially designed (i.e. 'icebreaker') bow must be fitted. Either a bar stem or a plate stem may be used, but these must be of steel and stronger than normal. The rudder post, solepiece and all parts of the rudder are to be made stronger.

Extent of Strengthening—This is shown in the sketch. A is 5-frame spaces abaft the point where the stem starts to rise above keel-level. B is the point at which the load waterline reaches its greatest width forward. C is at a distance from the bow which is equal to the distance of B from the bow plus 10 per cent of that distance (i.e. $\times + 10\% \times$). D is at one-quarter of the length from the stern.

In Class 1* the intermediate frames extend vertically from the level of the tops of the floors to the upper deck (or to or near the second deck in certain cases). In all other classes they extend from 915 millimetres below the light waterline to 750 millimetres above the load waterline.

The belt of thickened shell plating extends, in all cases, from 610 millimetres below the light waterline to 750 millimetres above the load waterline. Note how Class 1* ships must also have an extra area, 80 per cent thicker, covering the sides and bottom forward, below this belt. The percentages shown indicate the amount by which the plating is to be thickened in each part.



ICE STRENGTHENING

PIPES TO TANKS AND BILGES

General—It is obviously necessary to have pipes to tanks and bilges in order that tanks may be filled or emptied, and bilges periodically pumped out. The sketch shows diagrammatically how the suction pipes are arranged throughout the ship.

Valve Chest—At their engine-room end the pipes run into a 'Valve Chest', which is a large box connected by a pipe to pumps. Each pipe from the tanks or bilges has its own valve in the chest, so that any one or all of the pipes can be connected to the pumps as desired.

There are usually at least two valve chests in a ship, one for the fore end and one for the after end. Sometimes two or three chests are used for each end of the ship, each controlling a different section.

Bilge Suctions—Bilge suction pipes run fore and aft along the bilges. They may run through the lightening holes in the tank side brackets, but more often they are led up and run along the tops of the bilges. They must not pass through deep tanks, double bottom tanks, or oil fuel bunkers, unless this is unavoidable.

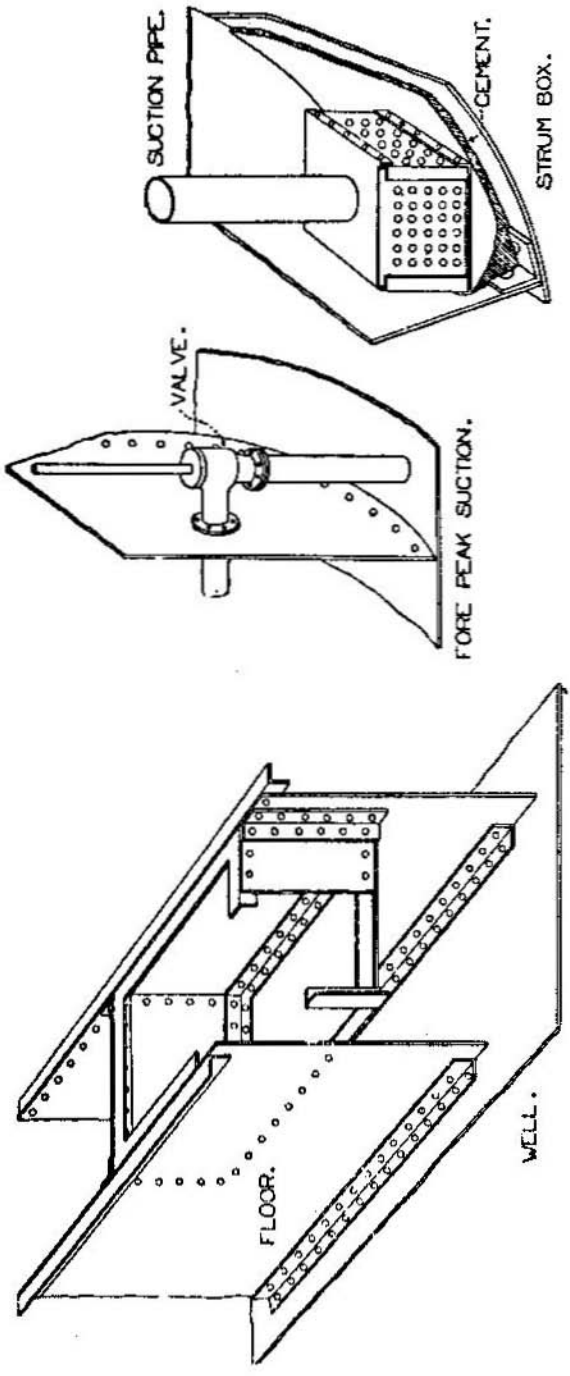
To prevent the accidental flooding of holds the bilge suction pipes must be fitted with non-return valves (i.e. valves which will allow water to flow through them in one direction only). All valves in the valve chest which control the bilge suctions must be of this type, so that whilst the bilges can be pumped out it is impossible to fill them accidentally.

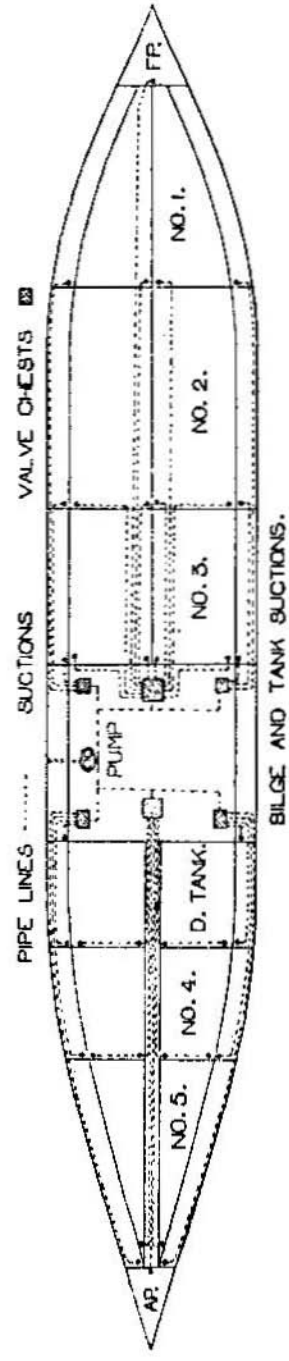
The suctions are usually placed at the after end of each hold, since ships normally trim by the stern and consequently the water collects at the after ends of the bilges.

When the cellular double bottom extends out to the ship's side there are no proper bilges. In this case the holds drain into sunken compartments in the double bottom which are known as 'wells'. These wells are boxes built up of steel plates and placed in either wing of the ship. Each well must have a capacity of at least 0·17 cubic metres.

Tank Suctions—The suction pipes to tanks in the fore end of the ship are led through the double bottom, or through a duct keel. In the after end they are usually led through the tunnel.

The suction ends of the pipes must be placed so that any water in the tank can be pumped out when the ship is on an even keel and has a list of five degrees either way. To this end it is usual to fit suctions at the centre line and in either wing of large tanks. In small tanks near the ends of the ship, one suction is fitted at the centre line only. Tanks which are sub-divided at the centre line must, of course, have at least two suctions, one on either side.


SUCTION PIPE.
CEMENT.
STRUM BOX.
VALVE.
FORE PEAK SUCTION.
FLOOR.
WELL.


FP.
NO. 1.
NO. 2.
NO. 3.
NO. 4.
NO. 5.
D. TANK.
PUMP
VALVE CHESTS
SUCTIONS
PIPE LINES
BILGE AND TANK SUCTIONS.
AP.

PIPING.

PIPES TO TANKS AND BILGES—(*Continued*)

Peak Tank Suctions—If peak tanks are used for ballast they must have suction lines leading to them. The fore peak suction must have a screw-down valve fitted on it, forward of the collision bulkhead, and capable of being worked from above the load waterline.

Deep Tank Suctions—These must be arranged so that they can be fitted with 'Blank Flanges', i.e. plates which can be bolted on to the ends of the pipes to prevent water from passing in or out. When the tanks are being used for solid cargo, the ballast pipes should be blanked-off and the bilge suctions left open. When the tanks are used for water ballast or oil fuel, the bilge suctions should be blanked-off and the ballast pipes left open.

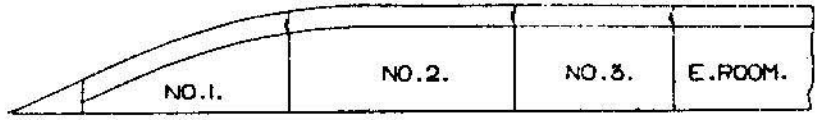
Pipes at Bulkheads—For the method of passing pipes through watertight bulkheads *see* the section on 'Bulkheads'.

Strum Boxes—A box with perforated sides, called a 'Strum Box', is fitted over the end of each suction pipe. This box strains the water when it is being pumped out and thus prevents solid matter from being drawn into and choking the pipes or valves.

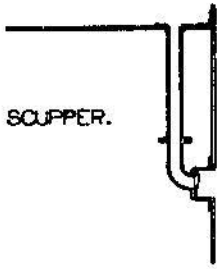
The perforations are not to be more than 10 millimetres in diameter and are to have a total area of at least twice that of the pipe. It must be possible to clear the box without disconnecting the pipe and this is usually done by making one side of the box removable.

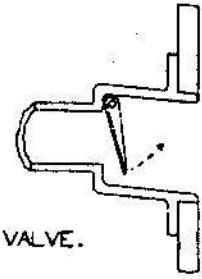
Air Pipes—These must be fitted to tanks in order that air may escape when the tanks are being filled. They must be fitted at the outboard corners of the tank, at the opposite end from the filling pipes, or at the highest point of the tank top. The total area of these pipes must normally be equal to that of the filling pipes.

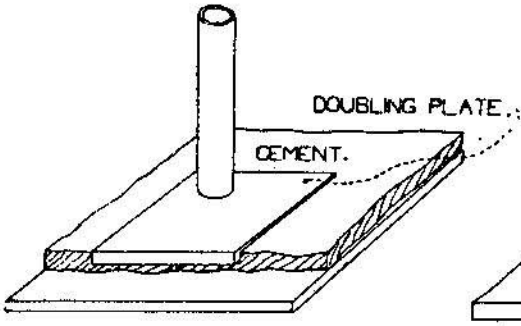
Air pipes must extend above the load water line. If they extend above the freeboard deck they are to be 760 millimetres above that deck, or 450 millimetres above other superstructure decks immediately above the freeboard deck.

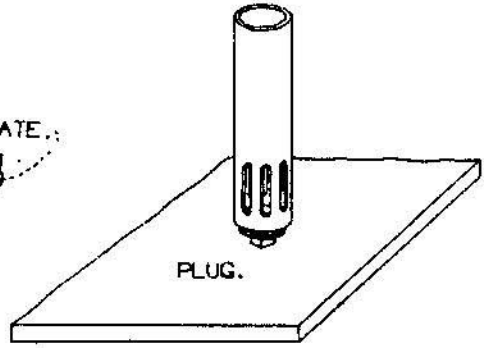


SLUICES.

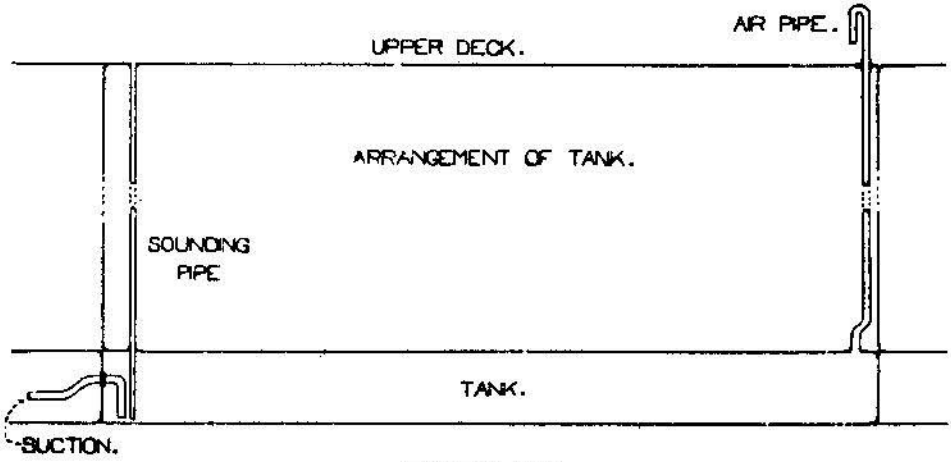








BOTTOM OF SOUNDING PIPE.



PIPING.

PIPES TO TANKS AND BILGES—(*Continued*)

Filling of Tanks—There are no separate pipes for filling tanks—they are always filled through the suction pipes.

Deep tanks and peak tanks are always filled by pumping the water into them. Double bottom tanks are sometimes filled in this way, but if there is plenty of time in which to fill them they are often 'run up', i.e. their pipe lines are connected to an inlet valve in the engine-room and the water is allowed to flow in by gravity.

Sounding Pipes—In order that the depth of water in tanks and bilges may be ascertained, sounding pipes must be fitted to them. These usually consist of straight vertical pipes, and they must extend to above the bulkhead deck except in the case of those to tanks below engine spaces. They must not be of less than 32 millimetres inside diameter, and must be placed as near as possible to the suction pipes.

There must be some arrangement at the bottom end to prevent the sounding rod from wearing through the bottom of the tank. Doubling plates, often called 'striking plates', are usually fitted for this purpose and are often welded to the bottom plating; or set in cement, as shown in the sketch. Alternatively, the end of the pipe may have a plug screwed into it and holes cut to allow the water to enter it.

Discharges—If these come from below the freeboard deck, or from within watertight deckhouses or superstructures, they must be fitted with non-return valves: except for discharges from manned engine-rooms.

Scuppers—These must be fitted at all decks. If the outlet of any scupper passes through the shell plating at a distance of more than 450 millimetres below the freeboard deck, or less than 600 millimetres above the load water-line, it must have an automatic non-return valve fitted at the shell.

Scuppers from decks below the freeboard deck must lead down to the bilges, or must be fitted with screw-down non-return valves.

Scuppers from inside superstructures may lead to the bilges: or they may lead overside if they have either screwdown, non-return valves or storm valves, according to the type of superstructure.

Most other scuppers must lead overboard.

Sluices—These are gate valves, similar to sliding watertight doors, which may be fitted in bulkheads to allow liquid to flow from one compartment to another. They are now generally prohibited, but are sometimes fitted in oil tankers which use the 'free-flow' system of discharge.

Notes

SPECIAL TYPES

Three-Hatch Ship—To facilitate the working of cargo, many modern ships are given very wide hatchways, often extending for as much as four-fifths of the width of the ship. Sometimes, for convenience and strength, two or three hatches abreast may be fitted, rather than a single wide hatch. A typical three-hatch type is shown here.

The actual deck area is small in these vessels and would not provide sufficient resistance to the longitudinal and racking stresses, so special strengthening is introduced to compensate for this.

Cantilever frames are fitted at fairly frequent intervals, with very heavy hatch-end beams. These are tied together by deep hatch side coamings at the upper deck and thus provide great transverse rigidity.

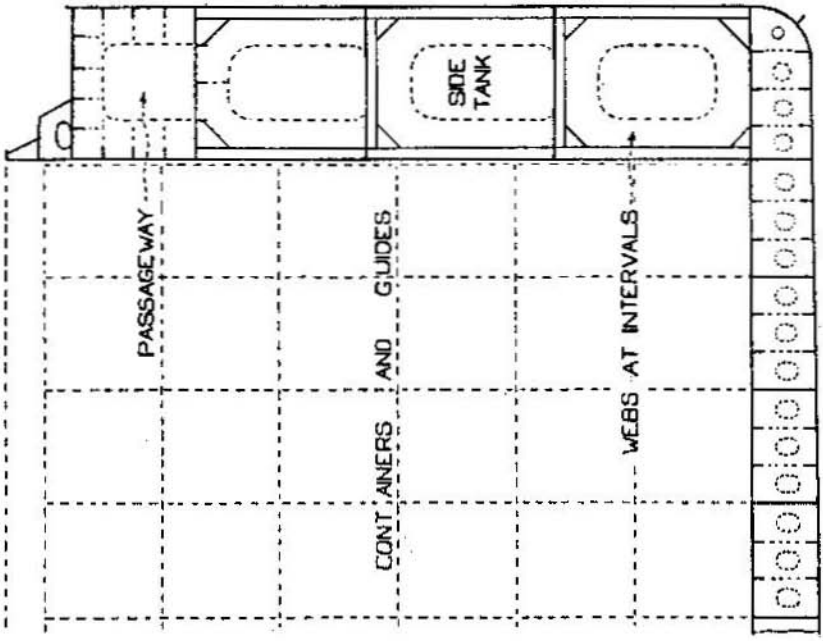
To give sufficient longitudinal strength, the deck stringer and sheerstrake are made thicker, the deep hatch side coamings are often made continuous, whilst heavy longitudinal beams are fitted under the deck stringer. In the two- or three-hatch types, the deck girder and short widths of deck plating, between the hatchways, also provide much longitudinal strength.

These vessels are sometimes adapted for use as container ships by fitting angle guides for containers in the holds.

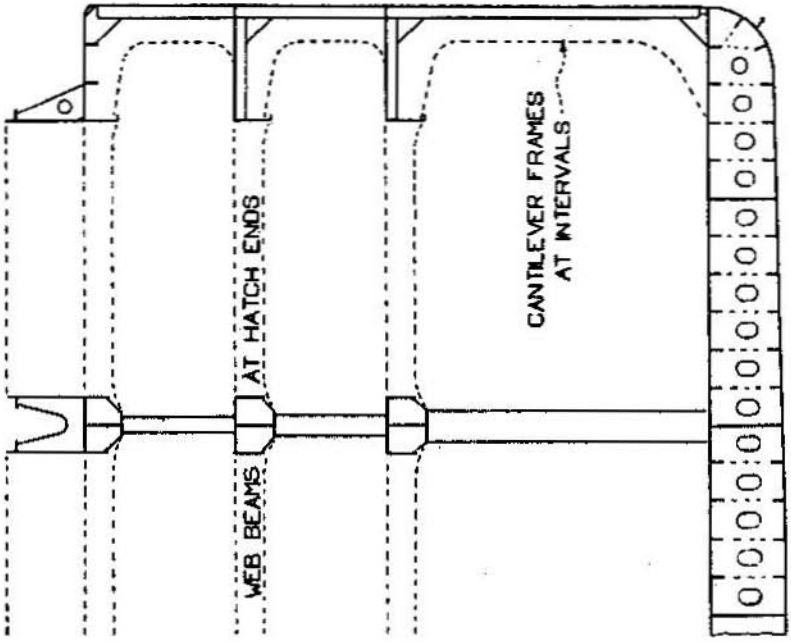
Container Ship—In certain trades, there are advantages in packing cargo into containers of standard size at the place of manufacture. Thus, when the cargo is transported, a comparatively small number of containers have to be handled, instead of a great many small pieces of cargo. This cuts handling costs and speeds up delivery.

Special ships are required to carry containers efficiently. Such ships should have large, clear holds, of suitable dimensions, as nearly rectangular as possible and fitted with angle guides to hold the containers in position. The hatchways should be large and must have heavy steel covers to carry the weight of containers on deck.

The space on either side of the holds is often plated in to provide side tanks, passageways, etc. Transverse and longitudinal strength is maintained in much the same way as in two and three hatch ships; webs being fitted at intervals in the side tanks, if necessary. The double bottom is strengthened by extra intercostal girders, arranged so as to come under the anchorage points at the corners of the containers.



CONTAINER SHIP



THREE HATCH SHIP

SPECIAL TYPES—(*Continued*)

Bulk Carrier—Ordinary ships may be used for the carriage of dry bulk cargoes, such as grain or ore, but they are not entirely suitable for this purpose. Consequently, a special type of ship called a 'Bulk Carrier' has evolved for trades where such cargoes are carried regularly. These vessels vary somewhat in design, according to the types of cargo which they may carry, but they have certain common features.

Most bulk carriers should be able to cope equally well with either light or heavy cargoes, and it should be possible to load and discharge these quickly. The ships must, therefore, have large, clear holds with no 'tween decks (or partial 'tween decks only, in some cases). The engines are placed aft, as in an oil tanker; whilst the hatches are large and usually have steel covers for safety.

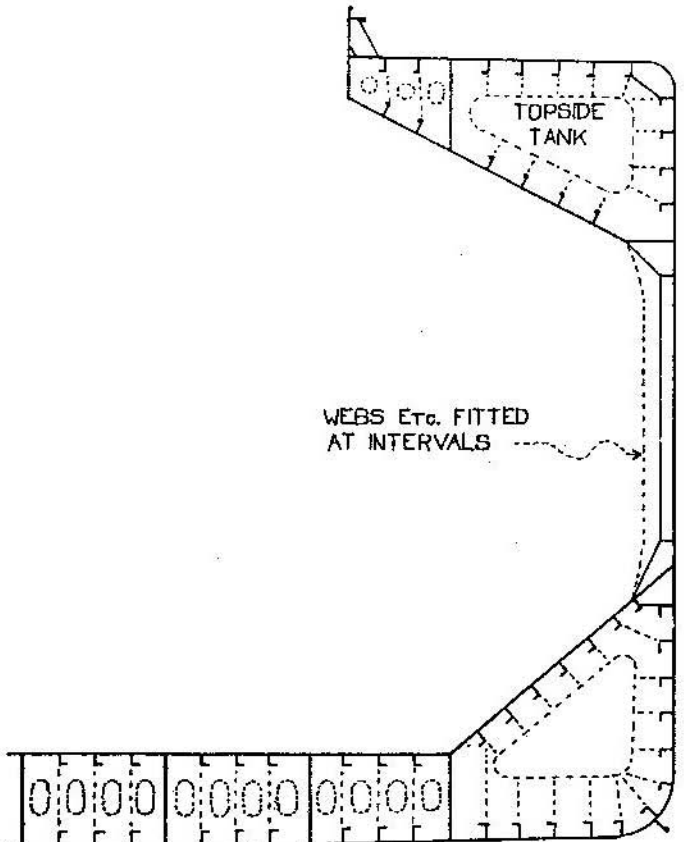
They always have some form of tanks placed high up in the ship, such as the 'Topside Tanks', shown in the sketch, to enable water ballast to be carried high up, and thus reduce GM when necessary. A deep tank is not usually fitted, since the topside tanks can be used for the same purpose when the ship is in ballast.

In the type shown in the sketch, the sloping side tanks at the bilge form a 'hopper' which assists in the handling of the bulk cargo. The sloping topside tanks make the vessel self-trimming for the carriage of cargoes such as grain.

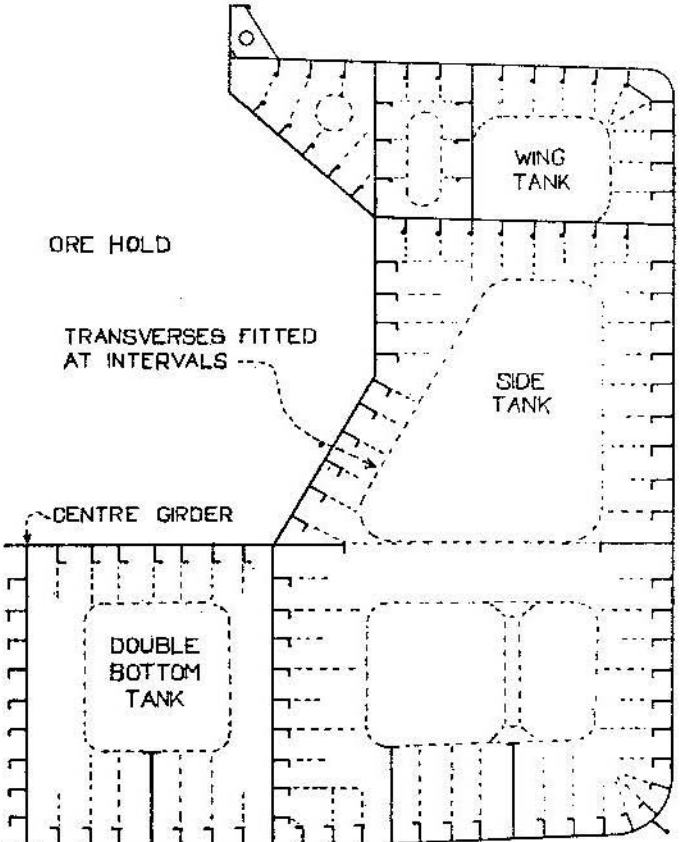
Ore Carriers—Most ores are very heavy and any ship laden with them will be down to her marks long before the holds are full. If ore is carried in an ordinary ship, a certain amount is usually loaded into the 'tween decks, but large weights are still concentrated low down in the ship. This puts great stresses on the ship's structure and also tends to make her very stiff.

The weight problem is comparatively easy to solve in ships built solely as bulk ore carriers, but ore is a 'one way' traffic and it is not easy to obtain suitable return cargoes for such ships. Many modern ore carriers are, therefore, built so that they can carry some other bulk cargo, such as oil or grain, on their return journeys. Their design thus varies according to the type of return cargo which may be available in the particular trade for which they are intended.

The sketch, opposite, shows a modern ore carrier, capable of carrying bulk oil as a return cargo. The main requirements in an ore carrier are:—(1) Adequate strength to resist concentrated loads. This is usually obtained by using longitudinal framing in the bottom and under decks, together with longitudinal bulkheads. (2) Means of keeping the weight at a reasonable height above the keel in order to reduce the GM; often achieved by fitting an unusually deep double bottom. (3) Comparatively small ore holds, to assist in loading and discharging and to reduce any tendency of the ore to shift. (4) Large hatchways to facilitate the working of the cargo; for safety, these should have steel hatch covers.



BULK CARRIER



ORE CARRIER

SPECIAL TYPES—(*Continued*)

Liquid Gas Carrying Vessels—Many gases are now often liquified and carried in bulk in specially constructed ships. In order that the gases may remain liquid, they must be kept under high pressure, or at low temperature, or both. The requirements for this depend on the type of gas, but it seems better, where possible, to avoid unduly high pressures; even though this means accepting very low temperatures in some cases.

The liquid must not normally be allowed to come into direct contact with the ship's hull, or to take up heat from the surrounding air. It is, therefore, carried in tanks which are built into the ship, but are carefully insulated from both hull and air. If the liquid is at temperatures of below —10°C, a 'secondary barrier' must be provided to contain any leakage from the tanks. The outer hull of the ship may serve for this if the temperature of the liquid is not below —55°C. At lower temperatures, the hull is not acceptable for the purpose and the secondary barrier consists of specially designed insulation, separated from the tank by a space which is often filled with nitrogen gas.

The cargo tanks may be constructed from low-temperature resistant steels, nickel steels, or aluminium alloys; depending largely on the temperature at which the cargo is to be carried. They and their supports must be carefully designed to allow for expansion and contraction, which can be considerable when cargo is loaded and discharged at such low temperatures. Various materials may be used for insulation, including foam plastics, glass fibre, or balsa wood. Supports often include thick rubber pads to give flexibility.

Special arrangements have to be made for ballasting the ship when she is light, since the cargo tanks must not be used for water.

Two main types of vessel have developed for this trade and are classed as follows:—

'Liquified Gas Carriers'—Which carry the liquified gas in bulk in independent tanks, at above-atmospheric pressure and at moderately low temperatures. The tanks are cylindrical or spherical in shape, to enable them to withstand the pressure of the gas. They are considered self-supporting, since they are strong enough to carry the loads imposed by the cargo without any support from the ship's hull, other than that necessary to keep them in place within the hull.

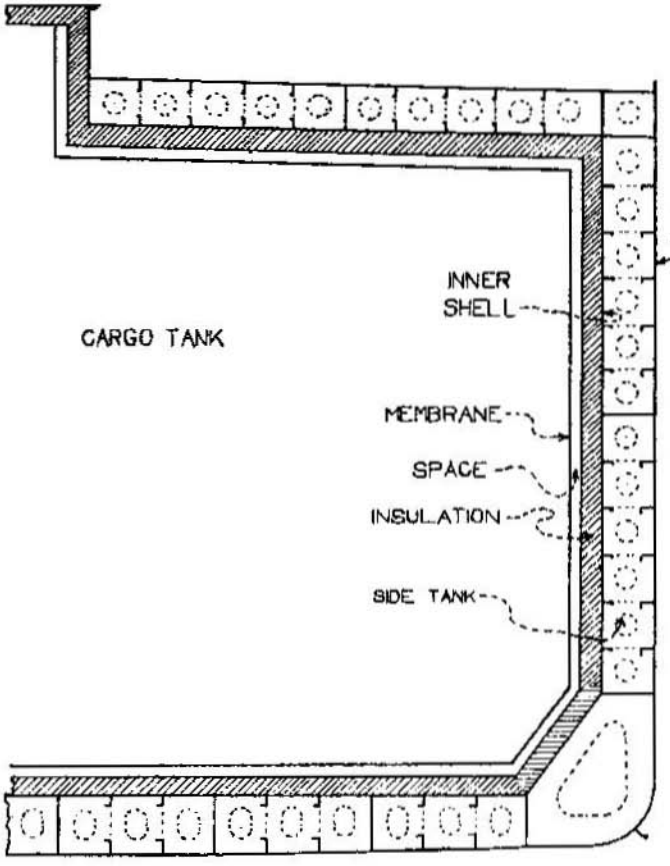
Water ballast can be carried in bottom, bilge and wing tanks, when required.

'Liquified Gas Tankers'—Which carry liquified gas in bulk in integral tanks; at, or near, atmospheric pressure and at low temperatures. The tanks are usually more or less rectangular and are not self-supporting, but are wholly or partly supported by heavy insulation. The insulation is, in its turn, supported by the surrounding hull structure.

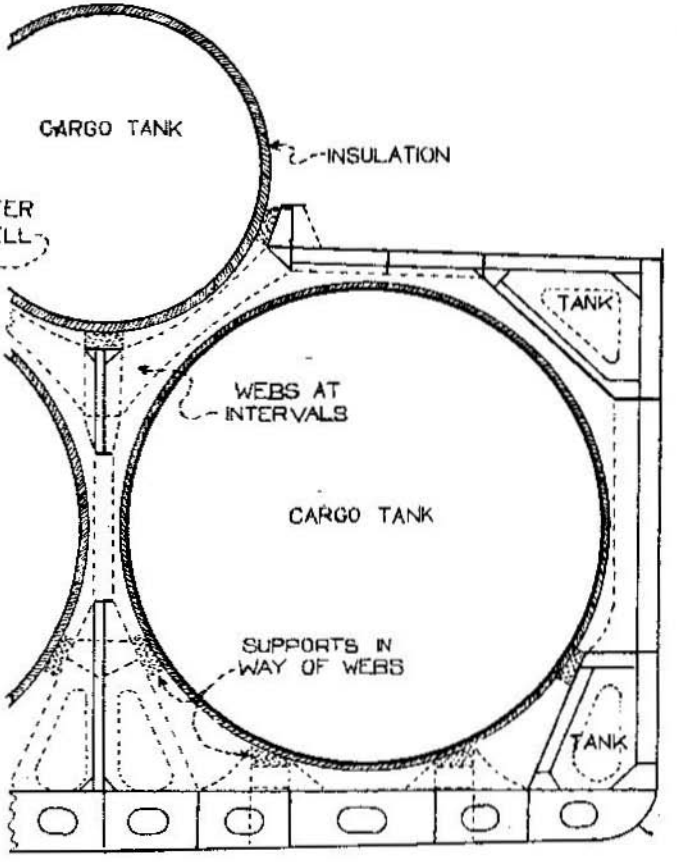
These ships usually have an outer and an inner hull; the spaces between the two being used as ballast tanks when required.

The cargo tanks may be of one of two types:—

(*a*) 'Membrane Tanks', which consist of a thin shell, or 'Membrane', often made of stainless steel; having little strength of its own and depending entirely on the support of the surrounding insulation.



GAS TANKER



GAS CARRIER

(*b*) 'Semi-Membrane Tanks', which have a stronger, lightly stiffened outer skin, but which are not strong enough to support themselves when loaded. In these, the flat areas of the skin are mainly supported by the insulation; but any rounded parts are left unsupported, so that they can flex to allow for expansion and contraction of the tank.

SECTION II

THE CONSTRUCTION OF OIL TANKERS

OIL TANKERS

General Requirements—Oil tankers must differ, in their construction, from ordinary ships because of the nature of the cargoes which they carry.

Oil contracts and expands with changes of temperature, so the tanks cannot usually be completely full and the oil will be free to wash around. This can set up quite large stresses on the hull, whilst the free surface effect will reduce the ship's stability. To minimise these effects, longitudinal bulkheads and wash plates are fitted, together with a number of transverse bulkheads, so as to divide the ship into reasonably small tanks. At one time an 'expansion trunk' was fitted to reduce the free surface of the oil, but this is now only found in very small vessels.

Tankers are subject to large longitudinal stresses and are also assigned less freeboard than other ships, so they must be very strongly built. They are always constructed on a full longitudinal or a combination system: this, together with the longitudinal bulkheads gives considerable strength. Heavy side stringers, side girders, cross ties and webs on the bulkheads all help to stiffen the hull.

All work must be oiltight, even under stress, to prevent leakage of the cargo.

The risk of fire must be considered and a special system of ventilation adopted to allow the escape of gasses. The engines are always fitted aft in a modern tanker, thus doing away with the shaft tunnel, which was always a source of danger in early tankers, owing to oil leaking into it. Cofferdams are also fitted in certain parts, to separate the tanks from the rest of the ship and from each other.

Continuity of strength must be maintained. This is, of course, important in all ships, but it presents a greater problem in tankers than in other vessels. It must be remembered that tankers are divided into a number of comparatively small, separate compartments and that longitudinal girders, etc., may be cut at transverse bulkheads.

Since the cargoes carried are liquid ones, it is necessary to have pipe-lines and pumps to handle them. In order to reduce the risk of fire, the pumps should not be in the engine-room, but in separate compartments known as 'pump rooms'.

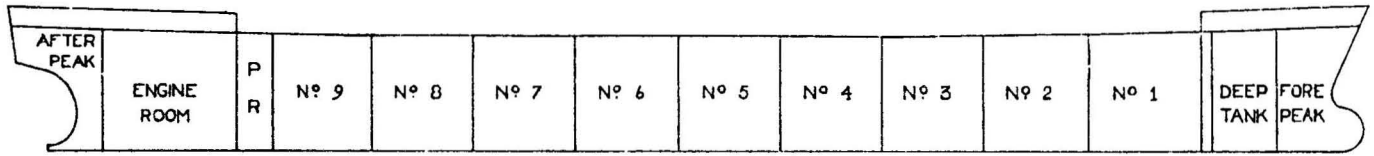
OIL TANKERS—(*Continued*)

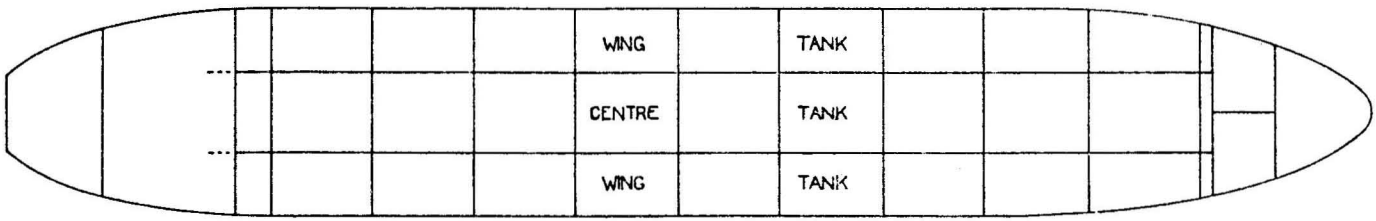
General Arrangements—Almost all modern tankers of any size are single-decked vessels, with two longitudinal bulkheads. They usually have a centre girder and a deck girder at the centre line; but a few very large vessels are built with a non-oiltight longitudinal bulkhead at the centre line. The number of transverse bulkheads fitted depends on the size of the ship and the type of oil which she is intended to carry.

Small and medium-sized tankers may be built on either the full longitudinal (Isherwood) system, or on the combination system; the latter being common. Ships of over 200 metres long must be built on the full longitudinal system. The longitudinal frames are supported by the transverse bulkheads and by deep transverse webs, called 'transverses'. The longitudinal framing always extends throughout the main tank system and may extend for the whole length of the ship: but it is usual for a system of transverse framing to be fitted at the ends of the ship, including the machinery space.

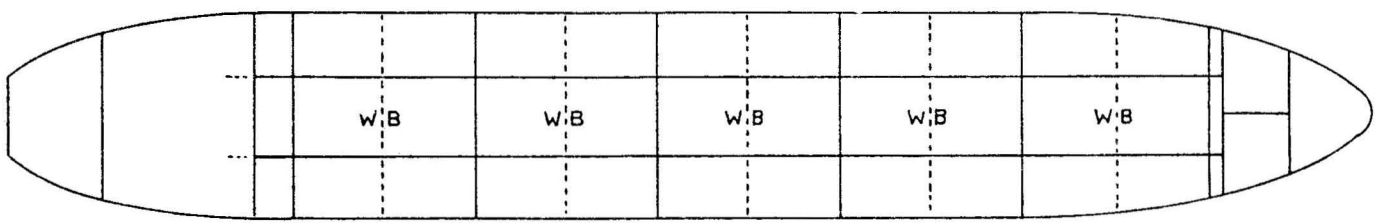
Cellular double bottoms are fitted under machinery spaces, but not, usually, elsewhere. A deep tank is nearly always fitted just forward of the cargo tanks and this is normally used for carrying bunker oil for the ship. Further bunker oil may be carried in a 'cross bunker' tank, aft; in wing tanks abreast of the engine-room; or in the cellular double bottom under the machinery space. A dry cargo hold is sometimes fitted forward, over the deep tank.

The number and position of the pump-rooms depends on the size of the ship and the type of cargo carried. They may be placed at the ends of the cargo tank system, or between groups of cargo tanks. Most modern tankers, however, have only one pump-room, just abaft the cargo tank system.





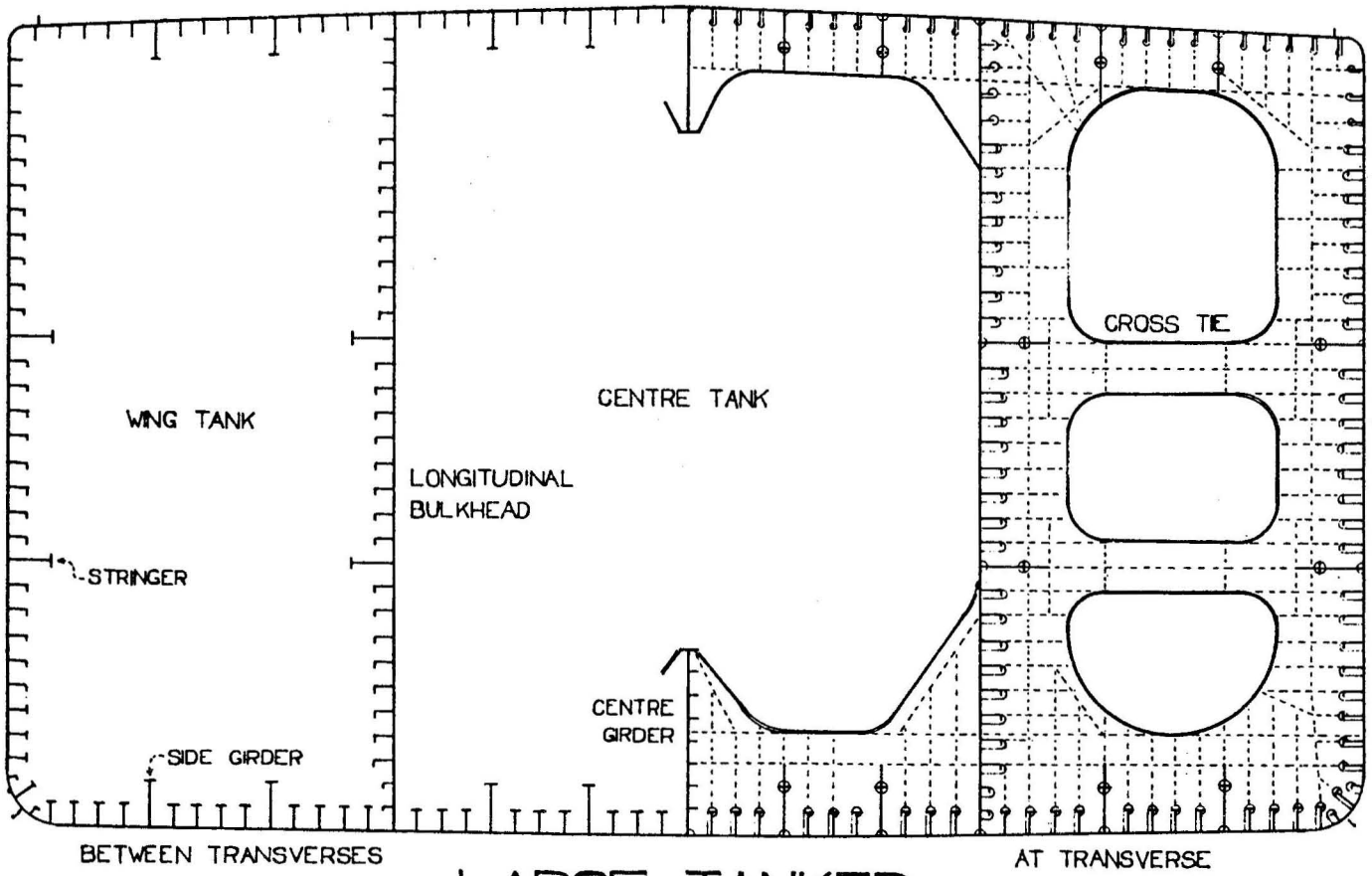
PRODUCTS CARRIER



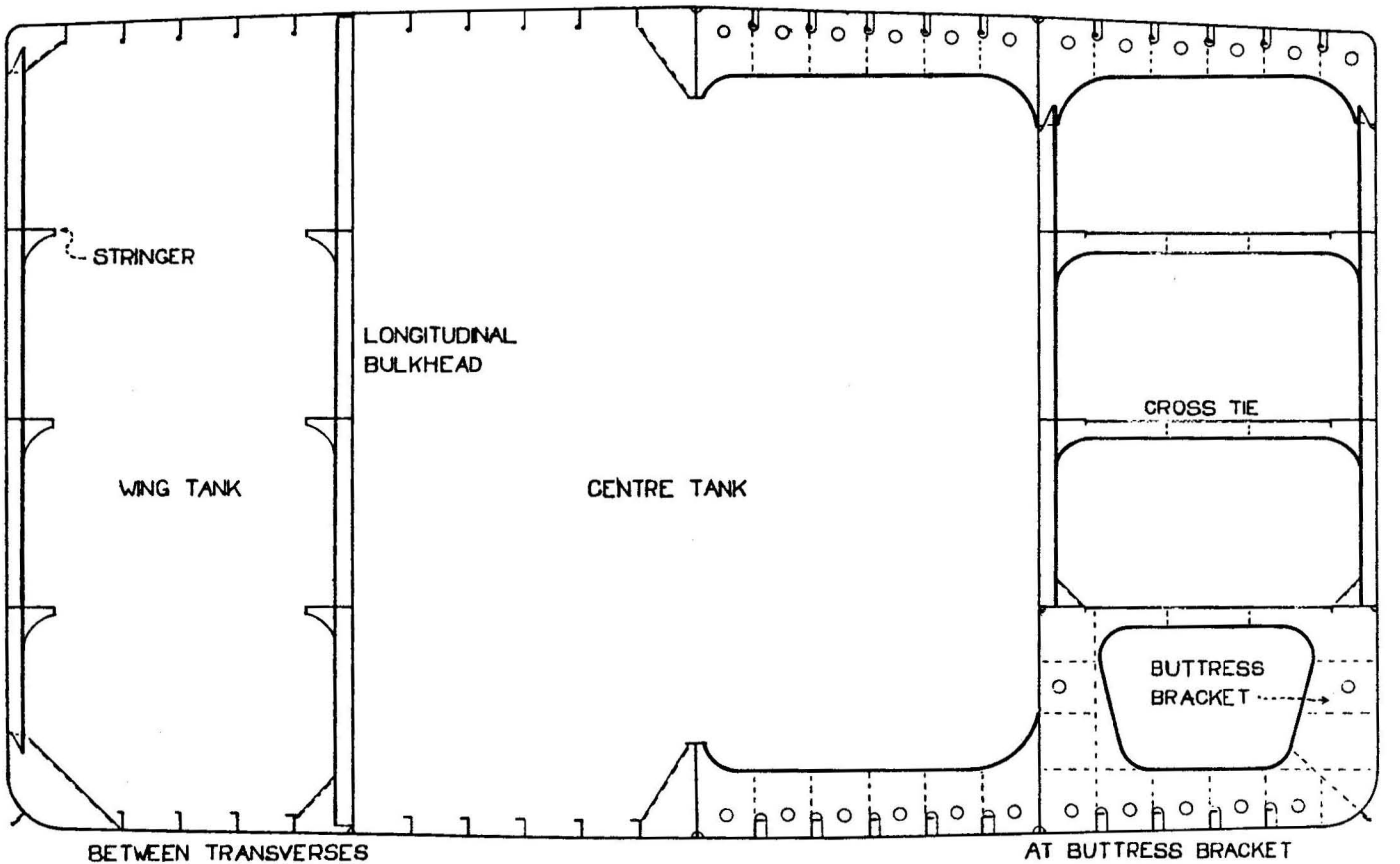
CRUDE OIL CARRIER

P R - PUMP ROOM C D - COFFERDAM W B - WASH BULKHEAD

GENERAL ARRANGEMENTS



LARGE TANKER



SMALLER TANKER

OIL TANKERS—(*Continued*)

Structure in the Bottom—In the main body of the ship, the bottom must have longitudinal frames, which may consist of flat bars, bulb bars, inverted angles, or built T-sections. These are supported by the bottom transverses, which are spaced not more than 3·6 metres apart in ships of up to 180 metres long, or 0·02 of the ship's length apart in longer ships. If corrugated longitudinal bulkheads are fitted, however, the spacing of the transverses may not, in any case, exceed 5 metres. The longitudinals pass through notches in the transverses, to which they are attached by flat bars or brackets.

A centre girder is required to support the keel plate, unless the ship has a centre-line bulkhead. This must have vertical tripping brackets, midway between the transverses, flanged or stiffened on their free edges and extending to a suitable longitudinal. Vertical stiffeners are also fitted on the centre girder, spaced not more than 990 millimetres apart; except when the centre girder is deep and has horizontal stiffeners on it. Side girders are also usual in the bottom, although they are not necessarily required.

Structure Under the Deck—This is generally similar to that of the bottom, with deck transverses placed directly over the bottom transverses, longitudinal beams, a centre-line girder and, possibly, other underdeck girders.

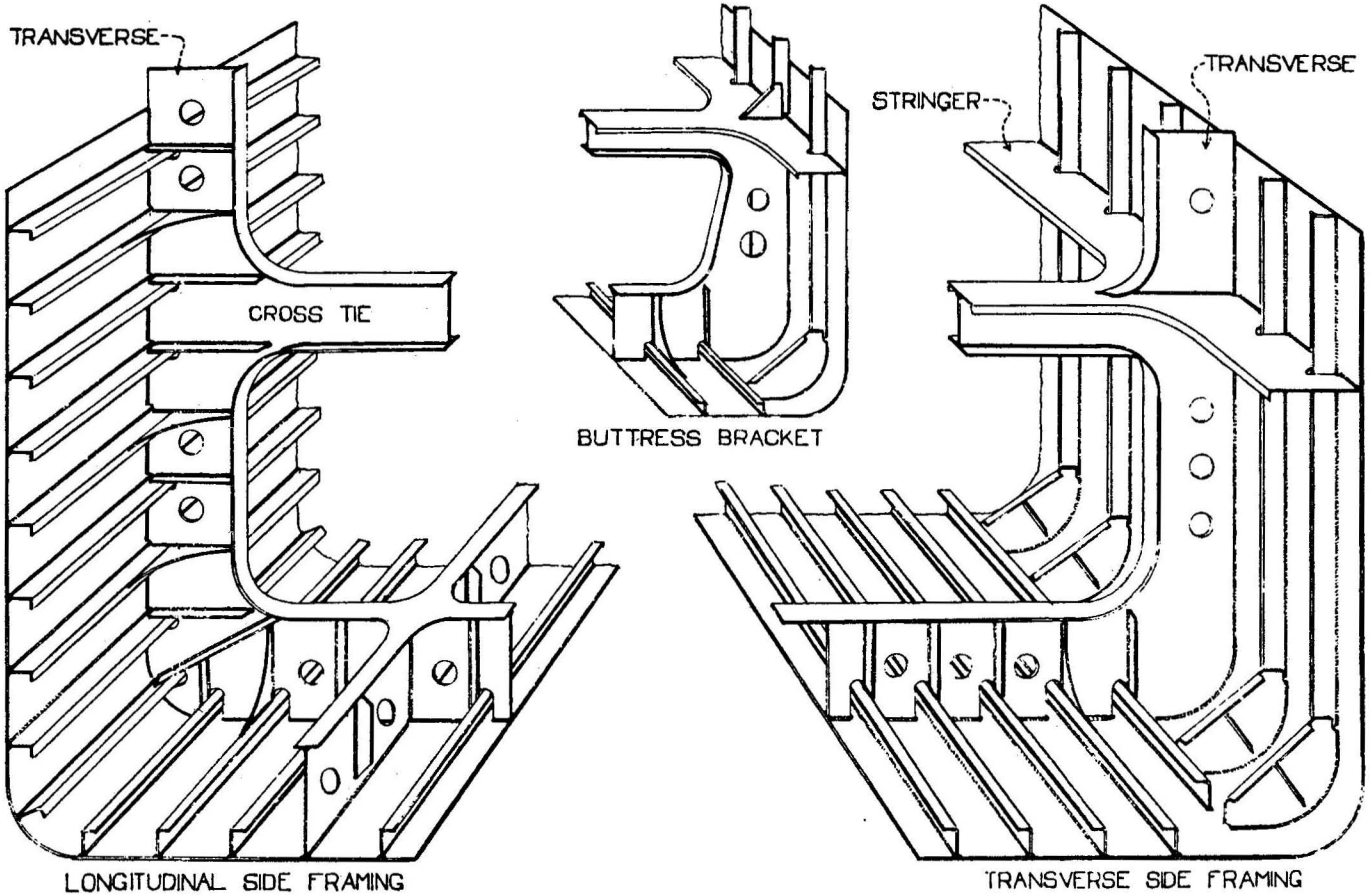
Longitudinal Side Framing—A full longitudinal system will have longitudinal frames on the ship's sides. To support these frames, side transverses are fitted in conjunction with the bottom transverses; so that each bottom, side and deck transverse together form a single girder running right around the ship. The longitudinals are connected to the transverses by flat bars or brackets, as in the bottom. Side stringers may also be fitted in large vessels.

Transverse Side Framing—This is often used in small and medium-sized tankers, to give a combination system. When this system is fitted, the ship must have one, two, or three side stringers, depending on her depth.

If the ship is more than 11 metres deep, or the distance between transverse bulkheads exceeds 15 metres, she must have a side transverse fitted at each bottom transverse: otherwise 'buttress brackets' are required, extending from the bottom transverse to the lowest side stringer.

The frames between transverses are attached at their heads by brackets, extending to the first longitudinal. At their feet, they must have flanged brackets, covering the entire round of the bilge and extending at least to the first longitudinal in the bottom.

Longitudinal Bulkheads—These may be plane or corrugated. On plane bulkheads the structure is very similar to that on the ship's side. The stiffeners run the same way as the side framing, (i.e. horizontal stiffeners with longitudinal frames, or vertical stiffeners with transverse frames), and they are attached by brackets at their ends. When side transverses are fitted, there must be vertical webs on the bulkheads. When buttress brackets are fitted



SIDE AND BILGE STRUCTURE

OIL TANKERS—(*Continued*)

at the ship's side, similar brackets are fitted at the bulkhead. If side stringers are required at the ship's side, horizontal girders are attached to the bulkhead at the same level, i.e. the structure on the bulkhead is similar to that on the ship's side.

If the bulkhead is corrugated, the corrugations must run horizontally (i.e. fore and aft). No stiffeners are needed, but vertical webs must be fitted at each bottom transverse, to support the bulkhead.

Cross Ties—These are strong horizontal 'beams' fitted between the transverses, or side stringers, and the longitudinal bulkheads, which they help to support. They are stiffened to prevent them from twisting or buckling and are connected by brackets at their ends. The cross ties are sometimes fitted diagonally, instead of horizontally.

Transverse Bulkheads—These must not be spaced more than 0·2 of the ship's length apart. If the length of any tank is more than 0·1 of the ship's length, or 15 metres, a perforated bulkhead must also be fitted, about midway between the transverse oiltight bulkheads. The purpose of this 'wash bulkhead', as it is called, is to give extra transverse strength and to reduce any fore and aft movement of the oil in the tank.

The construction of transverse bulkheads is generally similar to that of longitudinal bulkheads. If they are corrugated, the corrugations may run either horizontally or vertically and they must have stiffening webs, running at right angles to the corrugations. Vertical webs must be fitted on all transverse bulkheads in the way of the centre girder, and similar webs are often fitted at sid

SECTION IV

SURVEYS, STEEL, TONNAGE, FREEBOARD AND LOADLINES.

SURVEYS

All ships are subject to certain surveys if they are to retain their Class. Those required by the Rules are Periodical Special Surveys, Surveys of Repairs, and Annual Surveys. Certain parts of the ship should also be given a brief

Subsequent Special Surveys—At every special survey after the first, all the above requirements are to be carried out and also the following:—

The ceiling in the holds must be removed as necessary to make possible the examination of parts of the tank top, feet of stanchions and the bottom plating of bulkheads and tunnel. If the surveyor thinks it necessary, he may require the whole ceiling to be removed.

Tanks for oil fuel or fresh water ballast need not all be examined internally. An internal examination of one forward double bottom tank and one peak tank is sufficient, provided that the surveyor is satisfied from an external examination and testing of all tanks.

Anchors and cables must be ranged and put in good order, and the chain lockers examined internally.

Surveys After 10 Years—At every survey, after the ship is 10 years old the following requirements are to be carried out, in addition to the above:—

All ceiling in coal bunkers must be lifted in order that a thorough examination of the deck may be made. Mast wedging is to be taken out. Spar ceiling, pipe casings, and linings in the way of side scuttles are to be removed as required by the surveyor. Special attention must be paid to places, such as shell plating near the heels of frames, where local wasting may occur.

If the ship is over 15 years old, one after double bottom tank must be examined internally, in addition to those mentioned above.

Surveys After 20 Years:—At the first special survey after the ship is 20 years old and at every special survey thereafter, the following requirements are to be added to the above:—

The insides of bunkers and of parts in the vicinity of the boilers are to be given special attention.

Holes are to be drilled in the shell plating in order to ascertain its thickness. At least 2 holes are to be drilled in each strake of plating on each side of the ship within the midships half-length. Bottom plates which are covered with cement need not be drilled if the surveyor is otherwise satisfied.

Survey of Repairs—All repairs must be carried out under the supervision of the Surveyors if this is possible. If the ship is repaired at a port where there is no Lloyd's Surveyor, the survey must be carried out at the earliest possible opportunity.

Annual Surveys—All ships should be examined in drydock at intervals of about a year: these surveys should, if possible, be held at the same time as the freeboard surveys.

The ship must be examined externally and internally, as necessary. Special attention must be given to hatchways, ventilators, casings, and superstructure bulkheads, openings in the shell plating, windlass, rudder and steering-gear.

Docking Surveys—The ship must be examined in drydock or on a slipway; preferably at one-yearly intervals. In any case these intervals must not exceed 2 years, or 2½ years if the hull is specially protected against corrosion.

The bottom and underwater parts. particularly the shell plating, sternframe and rudder, are to be examined.

Occasional Surveys—Certain parts of the ship, which are not normally accessible, should be examined whenever the opportunity occurs.

If cement is removed in the bottom, the plating under it should be examined before new cement is laid. If engines or boilers are removed, the structure under them must be surveyed.

Whenever the ship is in drydock, the propeller and stern bush and the outsides of machinery and boiler inlets must be examined, whilst the wear down of the stern bush should be measured.

Continuous Surveys—Sometimes called 'running surveys'. If the owners so request, Lloyd's will allow the special surveys to be spread out so that part is carried out every year. When this is done, every compartment, in rotation, must be surveyed and tested at intervals of not more than five years.

TYPES AND TESTING OF STEEL

Types of Steel—Because of the introduction of all-welded ships and the increase of their size, ordinary mild steel is no longer suitable for some purposes and special steels are often used for sheerstrakes, bilge strakes and other highly-stressed parts of ships. Most of these steels are 'notch-resistant': that is, they are less likely to crack in the way of a notch when they are welded. Lloyds Rules now quote five general types:—

Grade A is ordinary mild steel.

Grade B is generally similar to grade A, but is notch-resistant.

Grades C, D and E are tougher steels and are also notch-resistant. Grade E is the strongest and grade C the least strong of the three.

In addition to the above, special high-tensile steels may be used for some purposes. These are generally similar to the ordinary grades, but have greater tensile strength. They are denoted by the suffix 'H'; that is, AH, BH, EH, etc.

Tests for Steel—All steel which is to be built into a ship must be tested at the place where it is manufactured and then stamped with a special mark, authorised by the Society. Test pieces of certain standard dimensions are to be used for this purpose.

Tests for Plates, Bars, Etc.—Test pieces taken from these must have a tensile-breaking strength of 41 to 50 kg/mm^2, with an elongation of not less than 15° to 20°, according to their thickness.

All these steels, other than Grade A steel, must withstand an impact test, known as a 'Charpy V-Notch Test', in order to determine their toughness.

Tests for Rivet Bars—The bars from which rivets are made are to be tested before being manufactured. Steel bars are to have a tensile strength of 41 to 50 kg/mm^2, with an elongation of 26 per cent for a test piece having a standard length.

Short lengths of bar, of a length equal to twice their diameter, are to be compressed, cold, to half their length without fracturing. This is called a 'dump test'.

Tests for Rivets—Rivets are to be tested after they are manufactured. The shanks are to be bent cold and hammered until the two parts touch, when they must show no fracture at the outside of the bend. When hot, the rivet heads must be flattened out until their diameter is $2\frac{1}{2}$ times that of the shank, without cracking at their outer edges.

Steel Castings—Steel castings must have a tensile strength of between 41 to 50 kg/mm^2, with an elongation of not less than 20 per cent.

Test pieces of standard dimensions are to be taken and bent cold through an angle of 120°, without fracture, the internal diameter of the bend being not greater than 60 millimetres.

All important castings must undergo a magnetic test for flaws.

Large steel castings may be further tested by drilling holes in them at all places where there is likelihood of flaws—such holes afterwards being filled up by tapping-in plugs.

Steel Forgings—Forgings which do not need to be welded are to have a tensile strength of 44 to 54 kg/mm^2, with an elongation of 22 per cent longitudinally and of 18 per cent transversely.

Test pieces are also to be bent cold through 180° without fracturing, the internal radius of the bend being not more than 12·5 millimetres for pieces cut longitudinally, and 25 millimetres for pieces cut transversely from the casting.

TONNAGES

General—Tonnages are measures of volume, expressed in terms of 1 ton per 100 cubic feet of space, or 1 ton per $3m^3$ of space. They may broadly be described as a method of assessing the approximate earning-power of a ship.

Gross tonnage consists of all enclosed spaces in the ship, with certain exclusions. Nett tonnage is found by making certain deductions from Gross tonnage.

Tonnage Deck—The tonnage deck is the upper deck in single decked ships and the second deck in all others. It is chosen arbitrarily, for convenience in measuring the ship for tonnage.

Gross Tonnage—This consists of the sum of four things:—

(*a*) The whole volume of the ship below the tonnage deck, measured inside the frames and above the top of the floors or inner bottom. This is sometimes called 'Under Deck Tonnage'.

(*b*) The cubic capacity of all spaces in the 'tween decks, between the tonnage deck and the upper deck.

(*c*) The cubic capacity of all permanently closed-in spaces on or above the upper deck, except:—

(i) Space within the hatchways is exempt if it does not total more than one-half per cent of the sum of (*a*), (*b*) and (*c*) above. (*See d*, below.)

(ii) Framed-in spaces for propelling machinery, or for lighting and ventilation of such spaces: unless the shipowner elects to have these included in the Gross Tonnage. (*See e*, below.)

(iii) Excluded spaces, as defined below.

(*d*) Excess of Hatchways, which consists of any space within the hatchways in excess of one-half per cent of the sum of (*a*), (*b*) and (*c*), above.

(*e*) The machinery spaces, referred to in (*c*) (ii), above may be included in the Gross Tonnage, subject to certain conditions, if the shipowner so wishes.

Double-bottom tanks are not included in gross tonnage. When they contain fuel, stores or cargo, however, they are temporarily added to that tonnage.

When deck cargo is carried by a foreign-going ship, it is measured and forms a temporary addition to the gross tonnage. This does not apply to home-trade ships. If cargo or stores are carried in an excluded space, that space is also temporarily added into tonnage.

Permanently Closed-in Spaces on the Upper Deck—include:—

Poops, bridges, forecastles and deckhouses; unless they have an opening in the end bulkhead of at least half the breadth of the ship.

Any other structure which extends for the full width of the ship; unless it has a side opening of at least half its length.

Spaces having overhead deck openings; unless the area of the opening is at least one-quarter of the deck area.

Passageways and recesses; unless these are completely open to the weather.

Excluded Spaces—Some permanently closed-in spaces on the upper deck are excluded from Gross Tonnage, subject to certain conditions. These include:—

Dry cargo spaces. Tanks used solely for water ballast. Spaces used solely for machinery or condensers.

Spaces used for navigation, radio and radio aids. Spaces for storage of safety equipment or batteries. Chain lockers and spaces for the capstan and anchor gear.

Skylights, domes or trunks for light or ventilation. Companion ways and access hatches to stairs or ladderways. Spaces used solely for the shelter of deck passengers during voyages of not more than 10 hours. Sheltered promenade spaces in foreign-going ships.

Washing and sanitary accommodation for master and crew. The galley and bakery.

Nett Register Tonnage—An 'Allowance for Propelling Power' and the full volume of certain spaces in the ship are deducted from the gross tonnage to give nett tonnage.

Allowance for Propelling Power—The propelling power spaces consist of the engine and boiler rooms, light and air and machinery spaces above them, shaft tunnels and trunked escape ladderways. If the volume of these is between 13 per cent and 20 per cent of the gross tonnage, 32 per cent of the gross tonnage is deducted as allowance for propelling power. If the volume exceeds 20 per cent of Gross Tonnage, the deduction is $1\frac{3}{4}$ of the actual volume. If the volume is less than 13 per cent of Gross Tonnage, the deduction is 32 per cent of Gross Tonnage proportionately reduced, e.g. for a volume of 11 per cent of Gross Tonnage, the deduction becomes $\frac{11}{13}$ of 32 per cent, or 27 per cent of Gross Tonnage. The allowance may not, except in the case of tugs, exceed 55 per cent of the tonnage which remains after all other deductions have been made.

Deductions—The following spaces are deducted in full, subject to certain requirements and provided that they have previously been included in the gross tonnage. A notice must be placed above them to indicate their purpose and goods or stores, other than those for which they are intended, must not be carried in them.

Master's and crew's accommodation, including washrooms.

Storerooms and spaces used solely for water ballast.

Spaces for donkey engine, boiler and ship's main pumps, if these are outside the engine-room.

Spaces used for navigation, radio, radio aids and for storage of safety equipment and batteries.

Chain lockers and spaces for capstan and anchor gear.

Modified Tonnage—Ships with open shelter decks have a smaller tonnage than they would otherwise have, but cannot load so deeply. For safety, it would be better if all shelter decks were closed, so a system of modified tonnage has been introduced. This allows ships with permanently enclosed 'tween decks, or closed shelter decks, to have the same reduced tonnage as open shelter-decked ships; provided that their freeboard is increased accordingly. In this case, both Tonnage and Freeboard are measured as if the second deck, and not the upper deck, were the Freeboard Deck.

Ships which are granted this modified tonnage are given a 'Tonnage Mark' on their sides, to indicate this fact.

Modified tonnages are not granted automatically, but are only given if the shipowner specifically asks for them. Otherwise, the ship is assigned ordinary loadlines and full tonnage; measured with the upper deck as the freeboard deck.

Alternative Tonnages—If the Shipowner so requests, a ship may be given two alternative tonnages: full tonnage and a modified tonnage.

For the Full tonnage, the tonnage is found in the normal way, with the upper deck taken as the Freeboard Deck.

For the Modified tonnage, a 'freeboard' is calculated on the assumption

FREEBOARD

General—A ship is assigned a freeboard for three purposes: to ensure that she cannot be loaded beyond her strength: to provide her with adequate reserve buoyancy: and to keep the decks high enough from the water to enable the crew to navigate and handle her in all weathers.

If this is to be achieved, it is important that all openings in the freeboard deck should be properly protected and closed and that provision should be made to allow the ship to free herself quickly of water which may come in upon the decks. To ensure that this is done, the ship is required to comply with certain 'Conditions of Assignment' and is not granted a loadline unless she does so.

Conditions of Assignment—The height and stiffening of hatch coamings and the construction of hatch covers, carriers, cleats and locking bars must be as mentioned earlier in this book. There must be at least two good tarpaulins per hatch. (*See* pages 66 and 118.)

Machinery space openings must be properly framed and constructed; whilst doors in them must comply with certain requirements.

Ventilators must have coamings of a given height, with means of closing them. They must be properly supported and the deck must be stiffened around them. (*See* page 126.)

If air pipes extend to above the freeboard deck, they must be of a certain minimum height and must have efficient means of closing. (*See* page 134.)

Openings in the ship's side, below the freeboard deck, must have efficient watertight doors or covers. Side scuttles below the freeboard deck, or in enclosed superstructures, must have inside deadlights.

Discharges from spaces below the freeboard deck, or within enclosed superstructures must have either one non-return valve with positive means of closing from above the freeboard deck, or two such valves without such means of closing. Valves which are attached to the ship's side must not be of cast iron.

Freeing ports on well decks must have a minimum area which depends on the length of the well and two-thirds of this area must be in the midship half of the well deck. On superstructure decks, the area must be equal to half that required for freeboard decks.

The ship must have adequate stability and must meet certain minimum requirements for range and righting levers. The stability is to be checked by an inclining experiment.

Principles of Assignment—In the first instance, the ship is assigned a Basic Minimum Freeboard', on the assumption that she conforms to certain standards of strength and form. The amount of this freeboard depends on the type and length of the ship. There are two basic types:—

Type A ships are those which are intended to carry only liquid cargoes in bulk. These are assigned less freeboard, for vessels of their length, than ships of Type B.

Type B ships include all ships other than Type A. The basic Type B ship is assigned a greater freeboard than a Type A ship of the same length. If, however, the vessel has steel hatch covers, improved protection for the crew, better freeing arrangements and special subdivision against flooding, she may be designated as Type B 60, or Type B 100. In this case, she may be assigned a freeboard which is intermediate between the Type A and Type B freeboards for a vessel of her length. Many types of bulk carrier come into the B60 or B100 categories.

If the ship's strength or form differ from the standards laid down, the freeboard is adjusted accordingly. It is also decreased if the ship has superstructure or trunks, or increased if she is flush decked.

Adjustments for Strength and Form—These are briefly as follows:—

Strength—The standard of strength is that required by the highest rules of a recognised classification society. If the ship's strength is less than this, the freeboard is increased.

Depth for freeboard—Is the ship's moulded depth, plus the thickness of the deck stringer plate and also an allowance for deck sheathing, if any. If the actual depth, measured to the upper edge of the deck line is greater than the depth for freeboard, the difference is added to the freeboard. If the depth for freeboard is the greater, the difference is subtracted from the freeboard.

Proportion of length to depth—If the depth for freeboard exceeds one-fifteenth of the ship's length, the freeboard is increased. If the depth is less than this, the freeboard may be reduced, provided that the ship has an enclosed superstructure covering at least 0·6 of the length amidships.

Coefficient of fineness—The freeboard is increased if the coefficient exceeds 0·68.

Sheer—A line parallel to the keel, is drawn so as to touch the upper deck amidships. The area between this line and the deck is called the 'sheer profile'. The standard and actual sheer profiles are compared and if the ship has an excess of sheer, the freeboard may be decreased, subject to certain conditions. If the ship has a deficiency of sheer, the freeboard is increased.

Bow height—This is the height of the ship's bow above the load waterline. If this is less than a specified minimum, the freeboard is increased.

Hatch covers—When Type B ships have steel hatch covers of an approved type, the freeboard may be reduced.

Adjustments for Superstructures—If the ship has superstructures, the freeboard is decreased by an amount which depends on the nature and length of the superstructures and the length of the ship.

Freeboards for Type A Ships—These are assigned on the same principles as those for Type B ships, except that the basic mimumum freeboard is less and the allowance for superstructures is greater than normal. The ship must also comply with certain supplementary conditions of assignment.

Supplementary Conditions of Assignment for Type A Ships—Machinery casings must be encased in a poop, or equivalent deck house. All openings on freeboard decks must have steel doors and the fiddley openings must have steel covers permanently attached.

Hatchways must have steel covers.

A permanent gangway must be fitted fore and aft at superstructure deck level, between the bridge, machinery spaces and crew's quarters, unless some equivalent means of access are provided.

Ships with bulwarks must have open rails for at least half the length of the exposed parts of the weather deck. If the ship has trunks, connecting the superstructures to each other, open rails must be fitted for the whole exposed length of the weather deck.

Timber Load Line Ships—Must comply with three supplementary conditions of assignment:—

They must have a forecastle of standard height and of length of at least 0·07 of the ship's length.

The cellular double bottoms are to have adequate longitudinal subdivisions.

Bulwarks are to be at least 1 metre high and are to be specially strengthened. If rails are fitted, these and their stanchions must be made specially strong.

Ships with Modified Tonnage—The freeboard for these ships is calculated as if the space between the upper and second decks were an 'Open Shelter Deck'; that is, on the assumption that the second deck, not the upper deck, is the freeboard deck. This freeboard is used in assigning the loadlines.

The Tonnage Mark is placed at the same level as the ship's deepest loadline, to indicate that the ship has modified tonnage and correspondingly greater freeboard.

Ships with Alternative Tonnages—The freeboard for the full tonnage is calculated in the normal way, with the upper deck taken as the freeboard deck. The loadlines are then assigned, using this freeboard.

For the modified tonnage, the 'freeboard' depends on the length of the ship on the second deck and the distance from the keel to the underside of the second deck amidships. This 'freeboard', measured downwards from the point where the second deck meets the ship's side, gives the position of the Tonnage Mark.

LOADLINES AND TONNAGE MARKS

General—The loadlines, tonnage mark and deck line must be painted in white or yellow on a dark background, or in black on a light background. All lines are 25 millimetres thick. Their upper edges mark the level to which they refer.

The Deck Line—is placed amidships and is 300 millimetres long. Its upper edge marks the level at which the top of the freeboard deck, if continued outward, would cut the outside of the shell plating. In ships which have rounded sheerstrakes, it is placed at, or sometimes below, the point where the lower edge of the curved plate meets the flat side plating. This line must be marked on all ships, including those with modified tonnage.

A Loadline Disc—Commonly called the 'Plimsoll Mark', is placed directly below the deck line. The distance from the upper edge of the deck line to the centre of the disc is the statutory summer freeboard.

Ordinary Loadlines—A vertical line is placed 540 millimetres forward of the disc. On this are marked the loadlines, which show the drafts to which the ship may be loaded. The following are required for steamships:—

S—The summer loadline: level with the centre of the loadline disc.

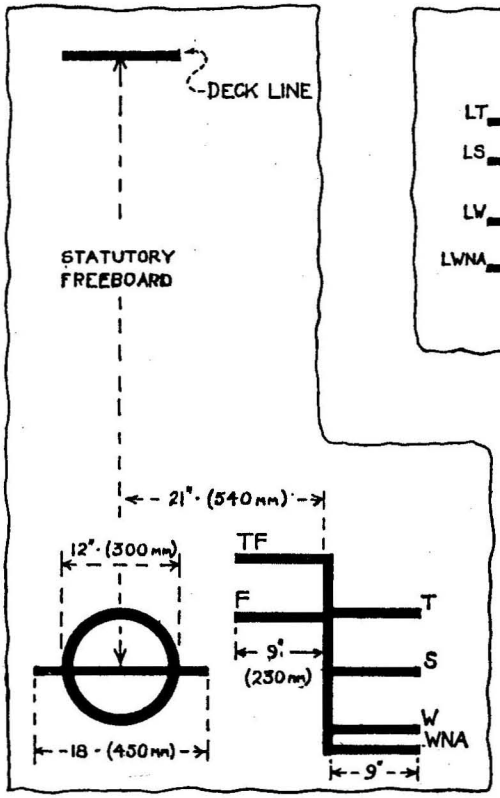
W—The winter loadline: placed at a distance of one forty-eighth of the summer draft below the summer loadline.

T—The tropical loadline: placed above the summer loadline at a distance of one forty-eighth of the summer draft.

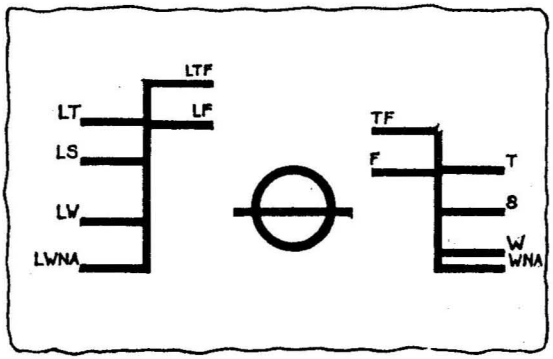
WNA—The winter North Atlantic loadline: placed 50 millimetres below the winter line. It is only marked on ships which are 100 metres or less in length.

F—The fresh water summer loadline: indicates the draft to which the ship can load in fresh water if she is to rise to her summer loadline on reaching the sea. It is found by the formula $\frac{\Delta}{4T}$ millimetres, where Δ equals the displacement of the ship at summer draft and T is the tonnes per centimetre immersion at that draft.

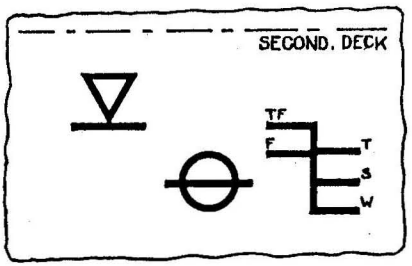
TF—The tropical fresh water loadline: indicates the draft to which the ship can load in order that she may come to her Tropical loadline on reaching the sea. It is found as for F, but is measured above the tropical loadline.



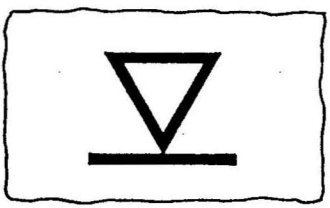
ORDINARY LOADLINES



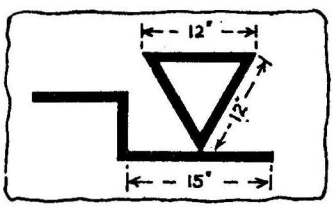
TIMBER LOADLINES



MARKS FOR MODIFIED TONNAGE

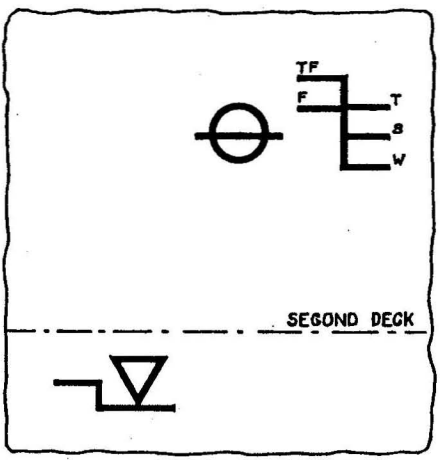


MARK FOR MODIFIED TONNAGE



MARK FOR ALTERNATIVE TONNAGE

TONNAGE MARKS



MARKS FOR ALTERNATIVE TONNAGE

LOADLINES & TONNAGE MARKS

LOADLINES AND TONNAGE MARKS—(*Continued*)

Tonnage Marks—A tonnage mark is not a loadline. It is merely placed on the ship's side to indicate that, so long as it is above water, a modified tonnage applies to the ship.

The centre of the Tonnage Mark, where the point of the triangle touches the horizontal line, is normally placed 540 millimetres abaft the centre of the loadline disc. If the ship has timber loadlines, however, the distance is 1080 millimetres.

When a ship has alternative tonnages (but not when she has only modified tonnage), an additional line may be added to the Tonnage Mark, if the Owner so requests. The distance from the upper edge of this line to the upper edge of the Tonnage Line must be one forty-eighth of the ship's moulded draft. This additional line indicates how deeply the ship may be loaded in fresh water or in the tropical zone before her tonnage changes from modified to full tonnage.

Timber Loadlines—These are marked in at a distance of 540 millimetres abaft the loadline disc. They show the drafts to which a ship so marked may load when carrying a deck cargo of timber.

LS—The summer timber loadline: placed a little higher than the ordinary summer line. The distance is such that if a ship, loaded according to the regulations, lost her deck cargo, she would rise approximately to her summer line.

LT—The tropical timber loadline: placed above the summer timber loadline at a distance of one forty-eighth of the summer draft.

LW—The winter timber loadline: placed below the summer timber loadline at a distance of one thirty-sixth of the summer draft.

LWNA—The timber winter North Atlantic loadline. If the ship is over 100 metres long, it is placed level with the W loadline. If the ship is 100 metres or less in length, it is placed level with the WNA loadline.

LF—The fresh water timber loadline: found by allowing the fresh water allowance above the LS line.

LTF—The tropical fresh water timber loadline: is found as above, but measured from the LT line.

SECTION V

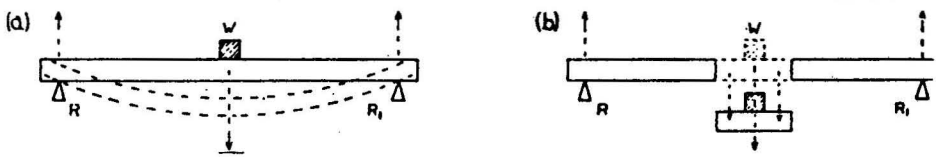
LONGITUDINAL STRESSES AND STRESS DIAGRAMS

BENDING STRESSES ON GIRDERS

General—Longitudinal bending stresses can be very large and must be considered carefully when big ships are being built and loaded. Although it is rather complex, a ship is a form of girder: so we must first consider the effects of these stresses on girders, in general, before we can apply them to ships.

Load—is the general term for weight or force exerted on a body. Loads are often expressed algebraically: those acting upwards as + and those acting downwards as —.

The Effects of Load on a Girder—Consider a weight placed on the middle of a girder which is supported at its ends (R and R_1).

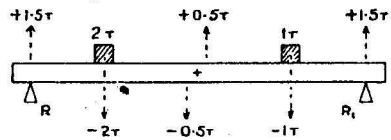


Part of the weight will be taken by each of the supports, which will each exert an upward force, called a 'reaction', on the girder. The total of the reactions at R and R_1 will equal the load, W. The load will exert a downward force on the middle of the girder. So the forces will try to bend the girder, as shown in Fig. (*a*), above.

If the girder were completely flexible, it would merely bend; but since it is more or less rigid, it will resist bending. So the forces will try to break the girder across, or to 'shear' it, as shown in Fig. (*b*), above.

Note that the same forces are trying to bend and to shear the girder, so there must be some relationship between these two effects.

Shearing Force The shearing effect, or 'Shearing Force', is the algebraic sum of all the forces (i.e. loads and reactions) acting on one side of a section.



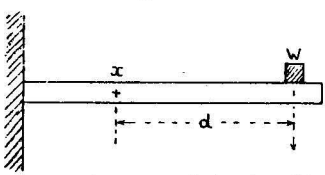
in other words, the algebraic sum of the forces, either to the right or to the left of a given point, will be numerically the same and will give the shearing force at that point.

For example; if a girder were loaded as shown here, with the weights placed on it in such a way as to give reactions of 1·5 tonnes at each support:—

Total force to the right of the centre = + 1·5 − 1·0 = + 0·5 tonnes.
Total force to the left of the centre = + 1·5 − 2·0 = − 0·5 tonnes.
So the shearing force at the centre is 0·5 tonnes.

Note that the + and − merely indicate the direction in which the forces will act to try to shear the girder.

Bending Moment—The bending effect of a load will depend on the amount of the load and on its distance from the point at which the effect is being found. In other words, the bending effect at any section will be the moment(s) of the load(s) about that section.



Take, for instance, the case of a girder which is fixed at one end and loaded at its free end, as shown here. If the load is W tonnes and the distance between the load and the point x is measured in metres, then:—

Bending Moment at $x = W \times d$ tonne-metres.

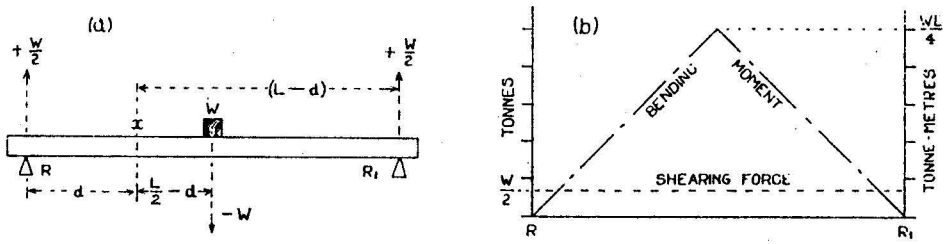
Unfortunately, the bending moment cannot usually be found as easily as this, because it will also depend on:—

(*a*) Whether the load is concentrated or spread out;

(*b*) How and where the girder is supported.

We shall see how to cope with these more complicated cases as we go along. We shall also see that bending moment is equal to the algebraic sum of all the moments acting on one side of a section (i.e. either to the right or to the left of that section).

The Effects of a Concentrated Load—Consider a girder, supported at each end and loaded at its centre, as shown in Fig. (*a*), below. Assume that the weight of the girder is negligible and that its length is L metres.



In this case, the load is $-W$ tonnes: termed $-$ because it is acting downwards. Since the load is at the centre of the girder, the reactions at the supports, R and R_1, will each equal half the load and will act upwards. So the reactions at R and R_1 will each be $+\frac{W}{2}$.

Now for some point, x:—

The only force to the left of x (towards R) is the reaction at R of $+\frac{W}{2}$.

So the shearing force at $x = +\frac{W}{2}$ tonnes

And the bending moment at x = force at $R \times$ distance d.

$$= +\frac{W}{2} \times d = +\frac{Wd}{2} \text{ tonne-metres.}$$

If the shearing force and bending moment were calculated, as above, for a series of points along the girder, it would be found that the shearing force would be $\frac{W}{2}$ tonnes at any point: whilst the bending moment would be 0 at each support, increasing to a maximum of $\frac{WL}{4}$ tonne-metres at the centre. This could be plotted in the form of a graph, as shown in Fig. (*b*).

At this stage it would be useful to consider the forces and moments to the right of x. There are two forces acting on this side: the load of $-W$ tonnes; and the reaction, at R_1, of $+\frac{W}{2}$ tonnes. In this case:—

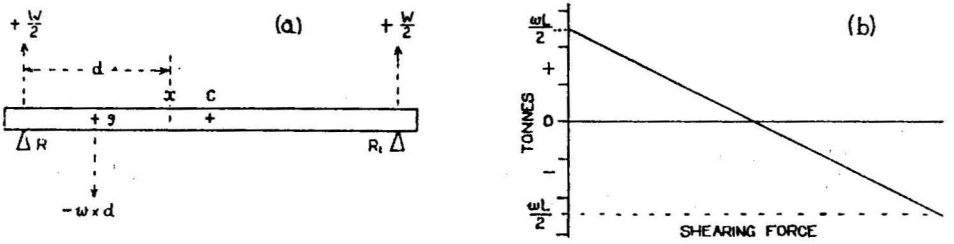
Shearing force at x $= -W + \frac{W}{2} = -\frac{W}{2}$ tonnes.

Bending moment at x $= -W\left(\frac{L}{2} - d\right) + \frac{W}{2}(L-d)$

$$= +\frac{Wd}{2} \text{ tonne-metres.}$$

Which are the same, numerically, as those obtained when working to the left of x. The shearing force has become $-$, instead of $+$, because, on this side, the girder will be trying to shear downwards at x: whereas on the left-hand side the shearing force acted upwards at x.

The Effects of a Distributed Load—Consider what would happen if a load were distributed evenly along a girder which is supported at both ends, as shown in Fig. (*a*).



Let the girder be L metres long and let a weight of W tonnes be distributed evenly along it, so that each metre of length of the girder carries a load of w tonnes. Then, $W = wL$ tonnes.

The reactions at R and R_1 will each equal half of the total load: that is, $\frac{1}{2}W$ tonnes.

Now, take forces and moments to the left of point x.

To find the shearing force at some point x:—

This, as has already been said, is the algebraic sum of all the forces on one side of a section.

Reaction at $R = +\dfrac{W}{2} = +\dfrac{wL}{2}$ tonnes.

Load between x and R = weight per metre × distance in metres.
$= -w \times d$ tonnes.

Total force to the left of x = reaction + load.

So shearing force at $x = +\dfrac{wL}{2} - wd = w\left(\dfrac{L}{2} - d\right)$ tonnes.

At the supports, the shearing force will equal the reaction, because:—

At R, $d = 0$: So shearing force $= w\left(\dfrac{L}{2} - 0\right) = +\dfrac{wL}{2}$ tonnes.

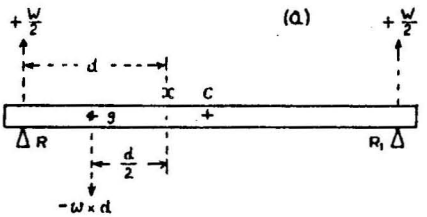
At R_1, $d = L$: So shearing force $= w\left(\dfrac{L}{2} - L\right) = -\dfrac{wL}{2}$ tonnes.

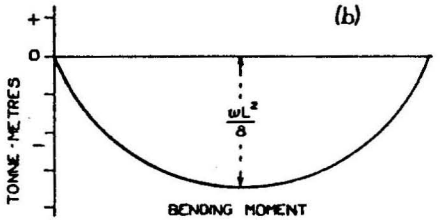
At the centre of the girder, $d = \dfrac{L}{2}$

So shearing force $= w\left(\dfrac{L}{2} - \dfrac{L}{2}\right) = 0$

If the shearing force is calculated for a series of points along the girder, a graph, or 'curve of shearing force', could be plotted; as shown in Fig. (*b*), above.

To find the bending moment:—





This, again, is the algebraic sum of all the moments on one side of a section.

Reaction at R is $+\frac{W}{2}$ tonnes, at a distance of d metres from x

So, moment of R about $x = +\frac{W}{2} \times d = +\frac{wLd}{2}$ tonne-metres.

The load on the girder, between R and $x = -w \times d$ tonnes. This will act through g, which is midway between R and x.

So, $gx = \frac{d}{2}$

And moment of the load $= -w \times d \times \frac{d}{2} = -\frac{w \times d^2}{2}$ tonne metres.

Total moment to the left of x = moment of reaction + moment of load.

Bending moment at $x = +\frac{wLd}{2} - \frac{wd^2}{2}$

At R and R_1, d will be 0.

So, bending moments at R and R_1 will also be 0.

At the centre of the girder (c): $d = \frac{L}{2}$

So, bending moment at $c = +\left(\frac{wL}{2} \times \frac{L}{2}\right) - \left[\frac{w}{2} \times \left(\frac{L}{2}\right)^2\right]$

$$= +\frac{wL^2}{4} - \frac{wL^2}{8} = +\frac{wL^2}{8}$$

If the bending moments were calculated for a series of points along the girder, a graph, or 'curve of bending moments' could be plotted, as shown in Fig. (*b*), above.

Note that the figure, above, would seem to have been drawn the wrong way up; that is, with all bending moments shown as —, instead of +. This has been done because there is a convention in Naval Architecture that hogging moments are drawn as +, and sagging moments as —: and here we have a sagging moment.

To Find Shearing Force and Bending Moment Graphically—The calculations for more complex loads, such as are experienced by ships, would be much more difficult than those so far considered. Fortunately, shearing force and bending moment can be found graphically and this will simplify the work.

To see how this can be done, reconsider the girder in the last example. The curves for this have been redrawn in the sketch opposite; with the addition of a 'curve of loads', showing the load per metre length at each part of the girder. Consider the point x.

As already shown: Shearing force at $x = xy = w\left(\frac{L}{2} - d\right)$

$= w \times$ distance xc.

This equals the area under the curve of loads between c and x.

The bending moment at $x = xz = \frac{wLd}{2} - \frac{wd^2}{2}$

But the area $ARxy$, under the curve of shearing force $= d\left(\frac{AR + xy}{2}\right)$

$$= \frac{d}{2}\left[\frac{wL}{2} + w\left(\frac{L}{2} - d\right)\right] = \frac{wLd}{2} - \frac{wd^2}{2}$$

So the bending moment at x equals the area under the curve of shearing force, between R and x.

Thus, the procedure for any point, say x, will be:—

(*a*) Draw a curve of loads.

(*b*) Find a point at which the shearing force is 0. Then find the area under the curve of loads between this point and x: this will give the shearing force at x. This can be repeated for a number of points to give the curve of shearing force.

(*c*) Find a point at which the bending moment is 0. Then find the area under the curve of shearing force between this point and x: this will give the bending moment at x. If this is repeated for a number of points, a curve of bending moments will be obtained.

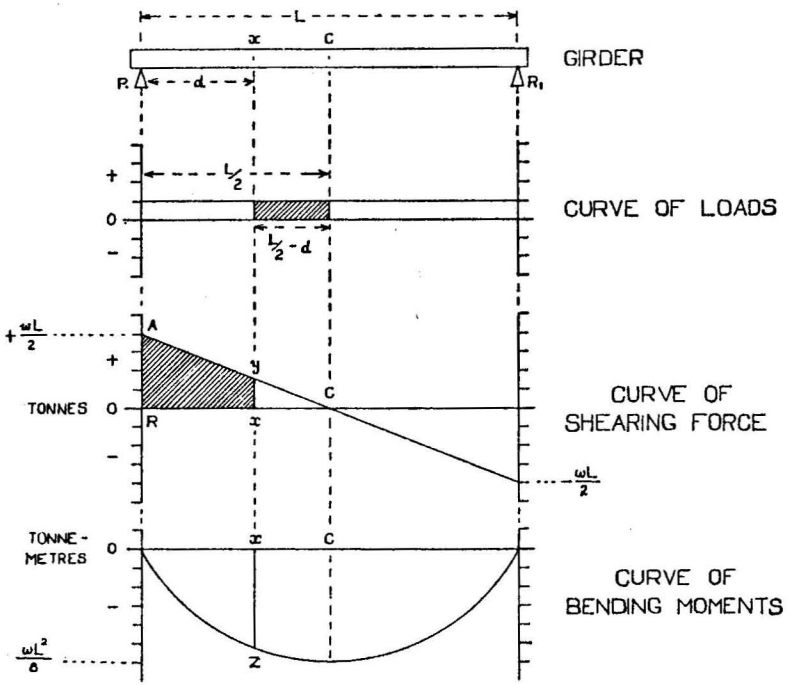
Integration—This is the name given to the process of finding the area under a curve. It consists of finding successive areas and taking their algebraic sum (+ above and − below the base line) as we go along. The sketch opposite shows how part of a curve of loads can be integrated to give a curve of shearing force: the areas being as shown.

To Find Areas Under Curves—This can be done in one of several ways:—

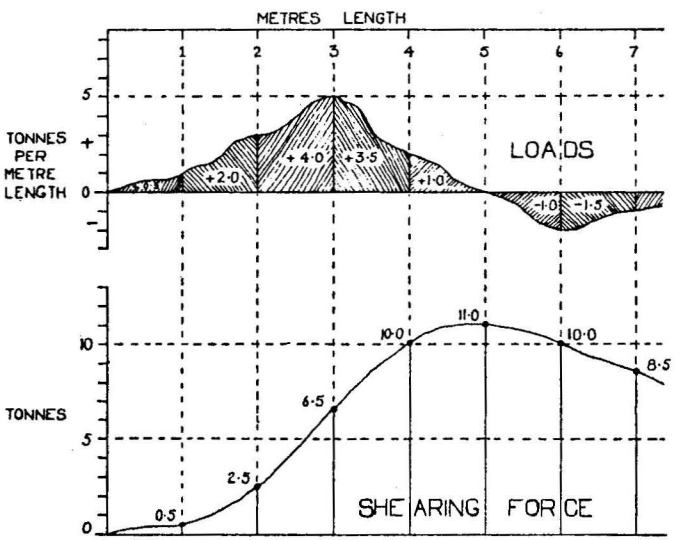
(*a*) By simple mensuration, if the 'curves' are straight lines.

(*b*) By choosing suitable ordinates and using Simpson's Rules, or integral calculus.

(*c*) By drawing the curves on squared graph paper and counting the squares under the curves. This method is simple, though rather laborious, but it can be reasonably accurate if it is done carefully.



EVENLY LOADED GIRDER



AT	AREA
1m	+ 0·5 + 2·0
2m	+ 2·5 + 4·0
3m	+ 6·5 + 3·5
4m	+ 10·0 + 1·0
5m	+ 11·0 − 1·0
6m	+ 10·0 − 1·5
7m	+ 8·5

INTEGRATION

LONGITUDINAL BENDING STRESSES ON SHIPS

The loads and bending stresses on ships are often very complex, but they can be found by the same methods as those used for any other girder. If graphical methods are used, the work is not unduly difficult.

To Find a Curve of Loads—There are no obvious points of support for a ship when she is afloat. Instead, her support comes from her buoyancy; which is spread out over the length of the ship, though not necessarily evenly. So, at any point in the ship's length, the force of buoyancy will be acting upwards and weight will be acting downwards. The load at that point will then be the difference between these two forces.

In order to obtain a curve of loads, we must, therefore, first draw two curves:—

(*a*) A curve of weights, showing the weight per metre of length at any point in the ship.

(*b*) A curve of buoyancy, showing the buoyancy per metre of length at any point in the ship.

The vertical distance between these two curves, at any point in the ship's length, will be the load at that point. If the loads are thus found for a series of points, the curve of loads can be plotted.

When these curves are being plotted, it must be remembered that the total weight must equal the total buoyancy for the ship. So:—

(*a*) The total area under the curve of buoyancy must equal the total area under the curve of weights.

(*b*) The total mean area under the curve of loads must be 0: i.e. the total area above the base line must equal the total area below that line.

To Find a Curve of Shearing Force—The shearing force must be 0 at the ends of the ship. So the curve of shearing force can be found by starting from one end, and thence integrating the areas under the curve of loads, successively, throughout the ship's length. To keep the conventions right, it is usual to work from left to right when doing this.

To Find a Curve of Bending Moment—The bending moment is also 0 at the ends of the ship. So a curve of bending moment can be found by starting from one end and integrating the areas under the curve of shearing force. To keep the convention right, in this case, it is usual to work from right to left: i.e. in the opposite direction from that taken for finding the curve of shearing force.

Remember that, by convention, hogging moments are usually drawn above the base line, and sagging moments below the base line.

Example—Let us take a very simple example to illustrate the above:—

A box-shaped lighter, 30 metres long, displaces 420 tonnes when floating in still water at an even-keel draft of 2 metres. She is divided by light transverse bulkheads into three compartments, each 10 metres long. The amidship compartment contains 160 tonnes of cargo, evenly stowed. Each end compartment contains 100 tonnes of cargo, evenly stowed. Assume that the weight per metre length of the hull is constant: i.e. that each 1-metre length of hull weighs the same and that bulkheads and ends are of negligible weight. Draw the curves of shearing force and bending moment.

(*a*) First, find the weights per metre of length for each part of the vessel:—

	Weight (*T*)	*Length* (*M*)	*Tonnes per metre length*
Cargo in midship compartment	160	10	16
Cargo in forward compartment	100	10	10
Cargo in after compartment	100	10	10
Total Cargo	360		
Displacement	420		
Hull ..	60	30	2

Total buoyancy = displacement = 420 tonnes.
Since the vessel is box-shaped and on an even keel, the buoyancy must be distributed evenly over the whole length of the vessel, so:—

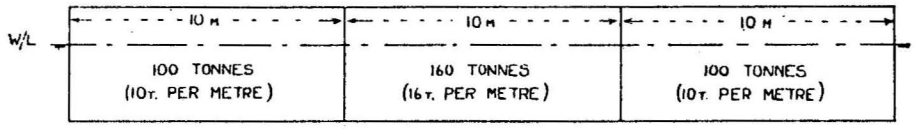
Buoyancy per metre of length = 420 ÷ 30 = 14 tonnes per metre.

These can be set out, as shown in the figure opposite, to give curves of weight and buoyancy.

(*b*) The difference between buoyancy and weights in the above curves can then be taken and plotted to give the curve of loads.

(*c*) Now, integrate the areas under the curve of loads, working from left to right. Plot the values so found, to give the curve of shearing force.

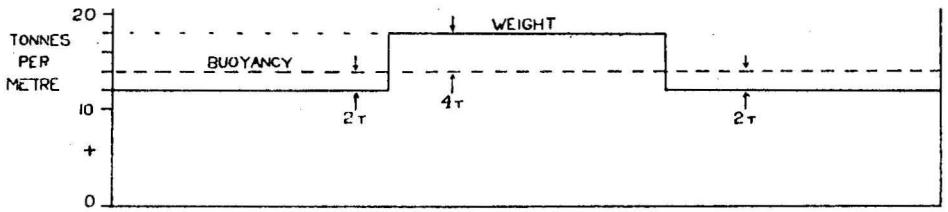
(*d*) Finally, working from right to left, integrate the areas under the curve of shearing force, to obtain the curve of bending moments.



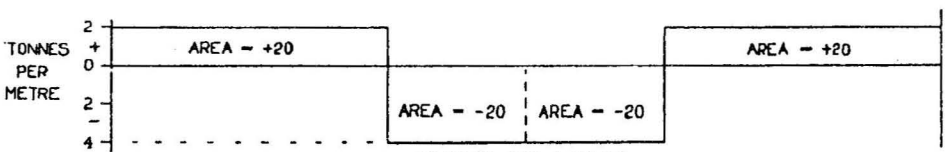
LIGHTER

HULL	2	2	2
CARGO	10	16	10
TOTAL	12	18	12

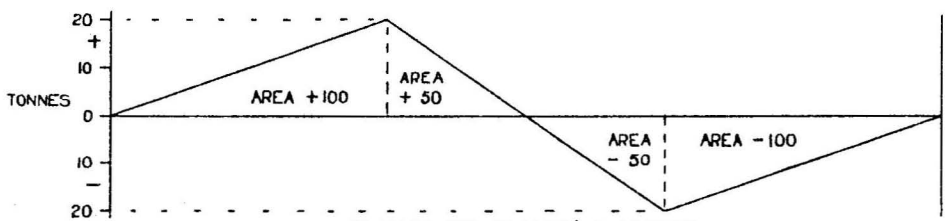
WEIGHTS



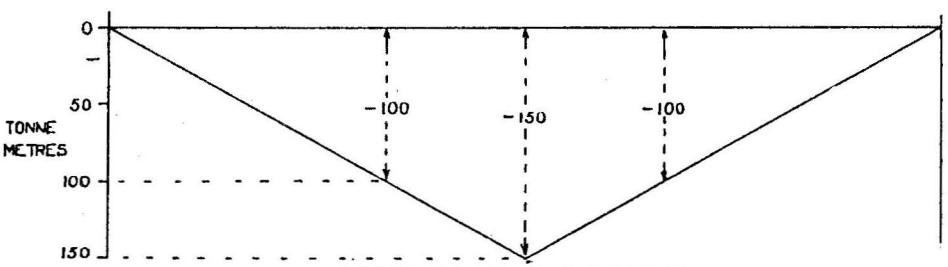
BUOYANCY AND WEIGHTS



CURVE OF LOADS



CURVE OF SHEARING FORCE



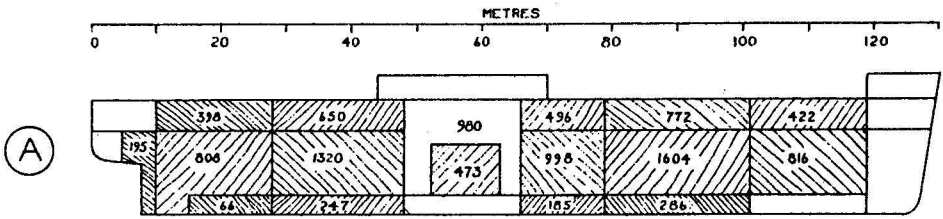
CURVE OF BENDING MOMENTS

Ship in Still Water—The curves for an actual ship will, of course, be much more complicated than those for a simple box-shaped lighter, but the methods used to construct them are basically the same. To illustrate this, consider a ship, in still water, loaded as shown in Sketch *A*, opposite. Note how the weights are set out and tabulated in terms of tonnes per metre of length. The curve of buoyancy is also plotted and a curve of loads is then found. The latter is then integrated to give the curve of shearing force, working from left to right. Finally, the curve of loads is integrated, from right to left, to give the curve of bending moment.

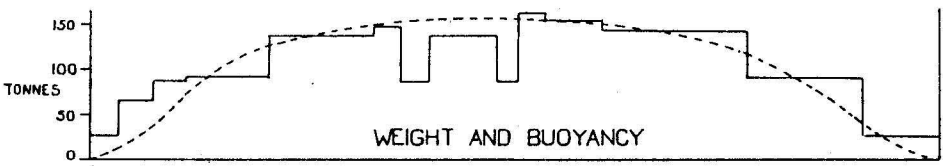
Note that at some stage in the plotting, the curves are 'faired' to give a more regular curve. This is usually done when the curve of shearing force is drawn, as shown in the sketch.

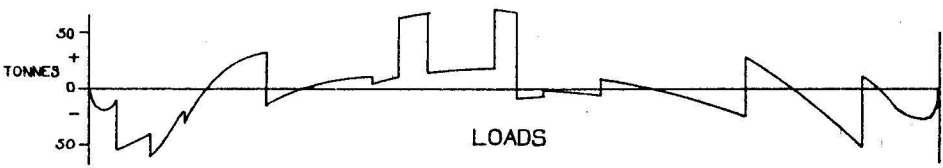
Ship in Waves—For this purpose, we usually assume conditions in which the bending stresses are likely to be at their greatest. This normally occurs when the length of the wave equals the length of the ship and when the crest or trough of a wave is amidships. The height of the waves is assumed to be one-twentieth of their length.

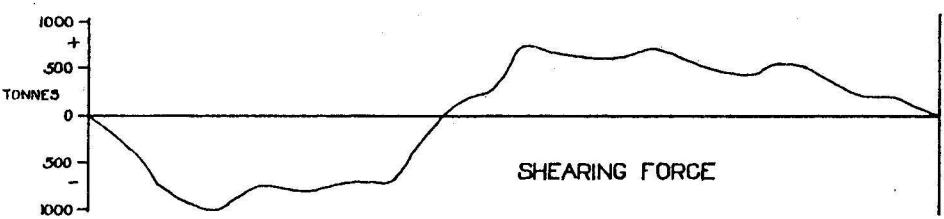
For the same ship in the same condition of loading, the curve of weights will be the same, but the buoyancy curves will be different from that of ship in still water. This is shown in Sketch *B*, overleaf; which shows the same ship as in Sketch *A*, but in a seaway instead of in still water.

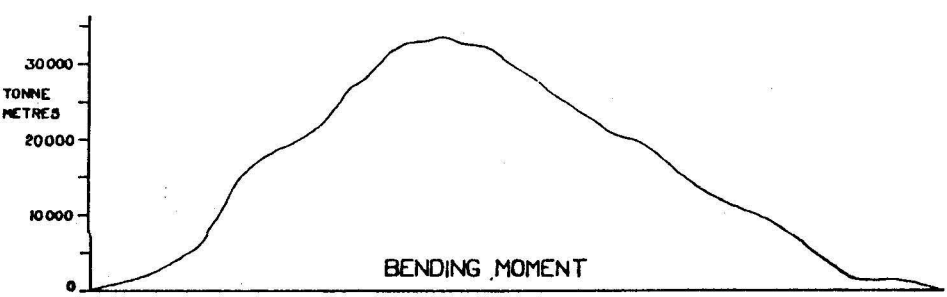


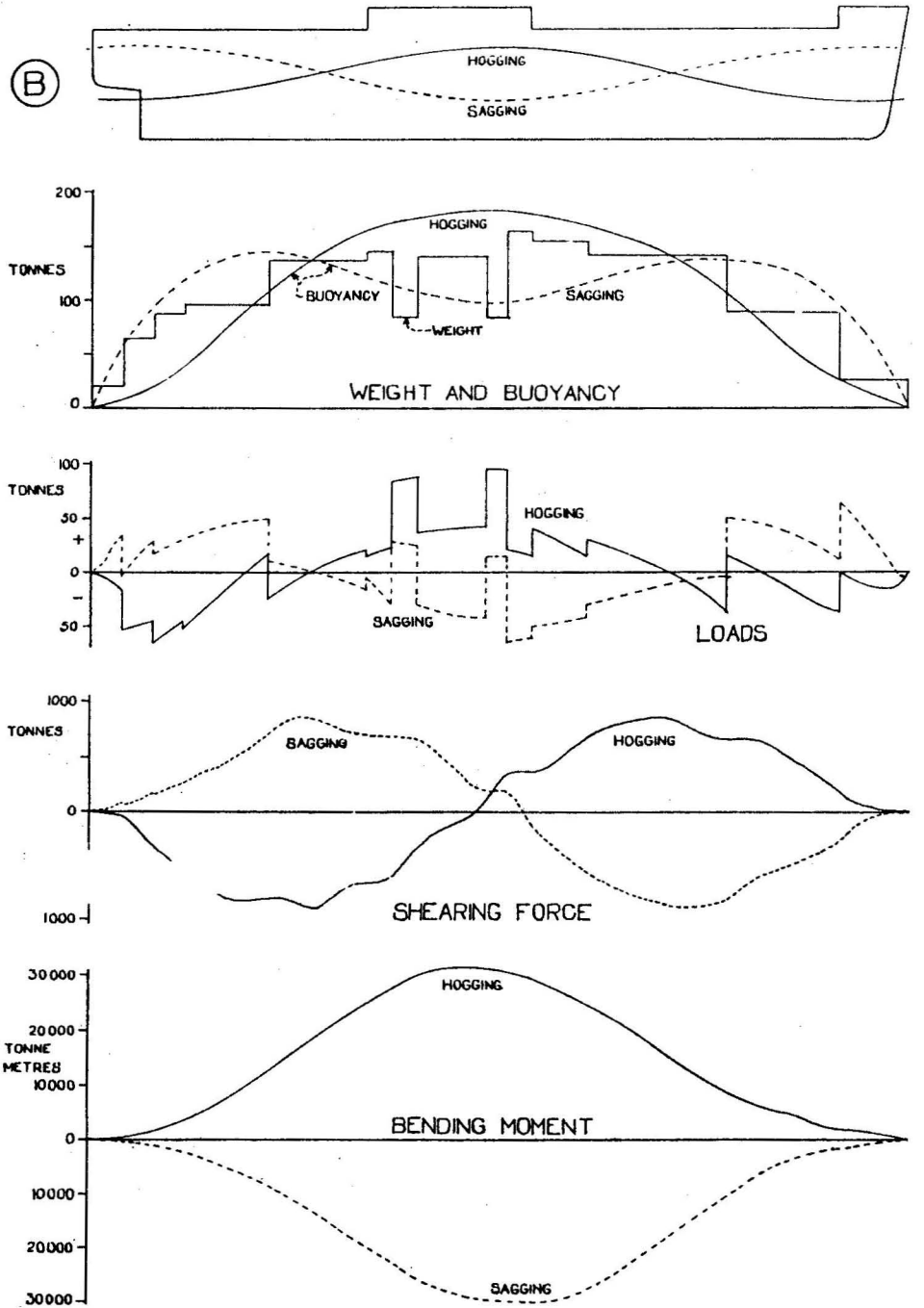
S'STR																
						6										5
HULL	20	22		23	25	26	27			26		24		22		20
CARGO/MACH		2		67	38		54			115		108		69		
FUEL/WATER		39		5	12		43			14		13				
TOTAL	20	63	89	95	135	143	89	132	89	163	155	145		91		25










B
HOGGING
SAGGING
200
TONNES
100
0
HOGGING
BUOYANCY
SAGGING
WEIGHT
WEIGHT AND BUOYANCY
100
TONNES
50
+
0
-
50
HOGGING
SAGGING
LOADS
1000
TONNES
SAGGING
HOGGING
0
1000
SHEARING FORCE
30000
20000
TONNE
METRES
10000
HOGGING
BENDING MOMENT
0
10000
20000
30000
SAGGING

SECTION VI

DEFINITIONS

Air Holes—Small holes, cut in the upper parts of floors, side girders, etc., to allow air to pass from space to space in the double bottom.

Alternative Tonnage—Under the new Tonnage Rules (1967), ships with two or more decks may have two alternative tonnages, if the Owner so requests. When such a ship is loaded to her ordinary loadlines, she has her full tonnage. When she is loaded less deeply, to a draft not greater than that indicated by a special Tonnage Mark, she has a smaller, Modified, tonnage.

Amidships—A point which is exactly halfway between the fore and after perpendiculars.

Base Line—This is an imaginary horizontal line, drawn through the upper edge of the keel, from which rise of floor, etc., may be measured.

Bending Moment—The measure of the tendency of a beam to bend about any particular section is called the 'Bending Moment' at that section.

Break—This is the end of a superstructure. For example, the 'break of the forecastle head' is at the after end of the forecastle, where it drops away to the upper deck. Special care is needed at breaks to preserve continuity of strength.

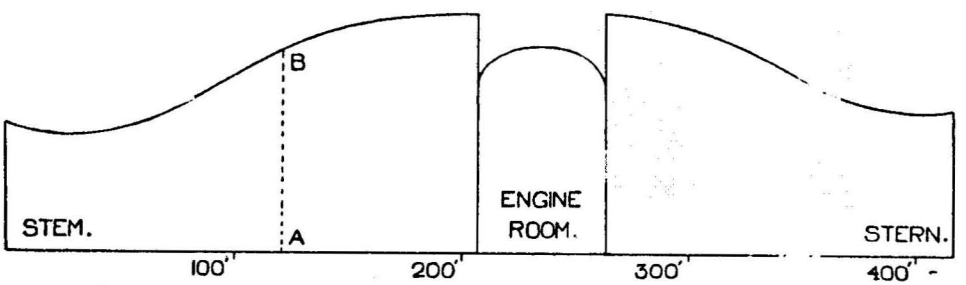
Bridges—The term 'bridge' when used in ship construction, refers to a superstructure amidships which is part of the hull, not to the deck house, carrying the navigating bridge.

A 'long bridge' is one having a length of more than 15 per cent of the length of the ship. A 'short bridge' is one which is shorter than this.

Bulkhead Spacing—In passenger ships, this is governed by the 'permissible length', which is the 'floodable length' multiplied by the 'factor of subdivision'.

The 'factor of subdivision' is a number, found by formulae, which depends on the ship's length, her volume below the margin line, the volume of the machinery spaces, the volume of passenger and crew spaces below the margin line, and the number of passengers she is intended to carry.

The 'margin line' is an imaginary line, 7½ centimetres below the bulkhead deck at the ship's sides.

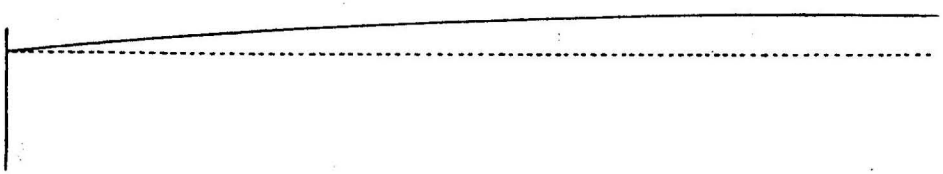


The 'curve of floodable lengths' is a graph. The lower side represents the ship's length from stem to stern. The vertical side represents the floodable length—i.e. that length of the ship which, if flooded, would sink her to the margin line. The curve itself shows the floodable length for any part of the ship, assuming that the point at which it is taken is the middle of a compartment.

The sketch shows an example of such a curve. Suppose that in the case shown we wish to find the floodable length at a distance of 120 feet from the stem. We draw a perpendicular at that point and the length from the base line to the curve (*AB* in the sketch) is the required floodable length.

Butts—The end joints of shell and deck plating.

Butt Joints—Joints in which plates, bars, etc., are joined, edge to edge, so as to give a flush surface.



Camber—This is the athwartships curvature of decks, which rise from the sides towards the centre line. It is sometimes called 'round of beam'.

Carlings—These are short fore and aft girders, fitted under a deck where extra stiffening is required. They are often found under winches, bollards, etc. Mast partners are a form of carling.

Centre Line—The centre line is the vertical plane running fore and aft through the centre of the ship.

Chain Plates—These are eyeplates, attached to the sheerstrake or to the deck stringer, to which the rigging is made fast.

Cofferdam—The name given to the space between double transverse bulkheads, spaced at least 1 metre apart, used to isolate tanks and holds from each other.

Complete Superstructure Ship—Originally this meant a ship which was built to lighter scantlings than Lloyd's full requirements: i.e. one which was less strongly built. Such a ship was not allowed to load so deeply as a normal ship.

The term is now sometimes used to refer to a ship which has a superstructure extending for her full length.

Continuity of Strength—A ship, like a chain, is as strong as its weakest part. It is useless to make one part very strong if an adjacent part which has to resist the same stresses, be weak. Hence it is of the utmost importance that continuity of strength be maintained.

When material has to be cut away, compensations must be made to preserve continuity of strength. Square corners should be avoided as far as

possible, since it has been found that these are always a source of weakness. For example, the side plating at the breaks of well decks is always run away in a curve—if it were kept square there would be a tendency for it to crack at the corners.

Parts which are very strong, by comparison with neighbouring parts, should not be allowed to end abruptly, as there would be a tendency for them to tear away where they end. They should gradually taper off and merge into the weaker parts.

Cropping of Frames—Cropping means the cutting away of corroded or damaged frames to let in a new piece.

Crown of a Tank—This is the highest point of the tank-top.

Curtain Plate—*See* 'Fish Plate'.

Deadlights—Metal covers, fitted inside portholes, to prevent the ingress of water if the porthole leaks, or the glass becomes broken.

Deck House—A comparatively light structure, built on the ship's deck, which does not, normally, extend from side to side of the ship.

Effective Superstructure—This is a superstructure, placed amidships, extending for the full width of the ship and having a length of more than 0·15 of the ship's length.

The Elastic Limit—The 'Elastic Limit' is that limit of stress beyond which a piece of metal loses some of its elasticity. In other words, when metal is subjected to stress it increases in length and, within certain limits, it returns to its original length when the stress is removed. A point is reached, however, at which it will not return to the original length, and this is termed the 'Elastic Limit'.

Entrance—The underwater part of the ship, at the fore end, where it runs away from the parallel midship part to the bow.

Face Bar—A flat, narrow bar, welded along the free edges of girders, or the inner edges of holes in plating, etc., to strengthen them.

Fairing—To adjust or straighten.

'Fairing the lines' is to adjust the lines on a ship's lines plans so that they agree with each other.

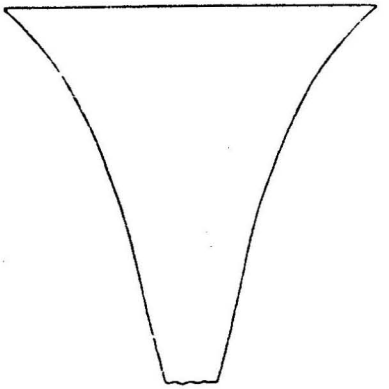
'Fairing-Off' is to remove a plate, or other part of a ship, straighten it, and then replace it.

'Fairing-On' is to straighten a part in place in the ship.

Fashion Plate—The extension of the side plating of a superstructure, usually curved, which is tapered off into the sheerstrake.

Fish Plate—The name 'fish plate', or 'curtain plate', is often applied to the narrow plate which runs fore-and-aft along the heads of the stanchions supporting a boat deck. It might be described as a kind of sheerstrake, fitted at a boat deck.

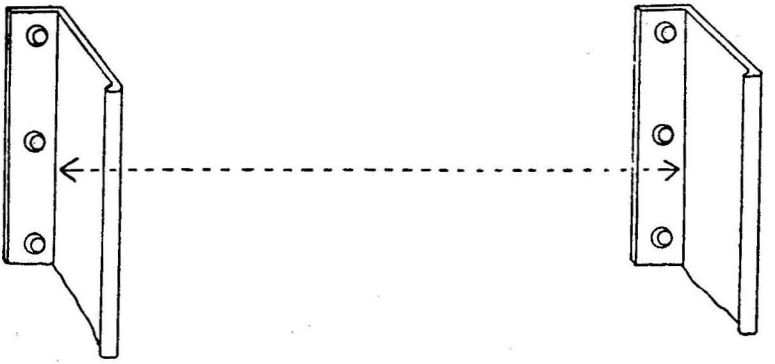
Flanging—"Flanging" means the bending over at right angles of the edge of a plate or bracket, and is a very effective way of stiffening such an edge. It is sometimes used for making a connection to another part but is not very efficient for this purpose.



Flare—This is the flaring-out of the bows of a ship. It helps to prevent water coming aboard and gives more width to the forecastle head. (*See* diagram.)

Flush Deck Ship—Is a ship having no superstructures on the freeboard deck.

Frame Spacing—Frame spacing is the distance between consecutive frames, centre to centre.



Freeboard—'Statutory freeboard' is the distance from the top of the deck line to the centre of the plimsoll mark.

The term freeboard is often taken to mean the distance from the deck line to the water.

Freeboard Deck—The 'Freeboard deck' is the uppermost complete deck with permanent means of closing all openings in its weather portions.

Full Scantling Ship—A ship built to the highest strength requirements of a Classification Society.

Full Tonnage—A ship is said to have full tonnage when the upper 'tween deck is included in her tonnage.

Gussets—These are flat triangular plates used to strengthen a joint at its ends. Common examples are those at tank side brackets and those connecting panting beams to stringers.

Half Length Amidships—Half the length of the ship about amidships: i.e. from one-quarter of the length forward of amidships to one-quarter of the length abaft amidships.

Hose Testing—Hose testing is done by playing a strong jet of water from a hose, under a pressure of at least 2·11 kg/cm^2, along a joint. If no water be forced through the joint, the latter is assumed to be watertight.

Hounds—The fitting at the head of a mast which takes the stays, etc., is called the hounds.

Intercostals—These are plates, angles, etc., fitted down between others, or cut to allow other parts to pass through them. Side girders in the inner bottom are common examples.

Landing Edges—The edges of seams are often called 'landing edges'.

Lapped Joints—Joints in which the parts are overlapped and welded or riveted together.

Length Between Perpendiculars—The length of the ship, on the load waterline, between the fore and after perpendiculars.

Length Overall The extreme length, from the foremost to the aftermost ends of the ship.

Lightening Holes—These are holes cut in non-watertight plates to reduce their weight. They must not be so large as to weaken the plate unduly.

Limber Holes—Small holes which are cut in floors and intercostals, to allow water to pass from one part of a tank to another.

Load—Load can be defined as any considerable weight or force put on a part of a ship.

Manholes—These are holes cut in plates in order to allow men to pass through into a compartment. They must not be confused with lightening holes, which can only be cut in non-watertight plates, whilst manholes are cut in watertight plates. Where they are cut in the latter they must have a watertight cover, which is usually bolted down by means of studs.

Modified Tonnage—or, 'Permanently Reduced Tonnage', may be assigned to a ship which has two or more decks, if the Owner so requests. Such a ship will have a lesser tonnage than normal, but will not be allowed to load so deeply as she could otherwise do.

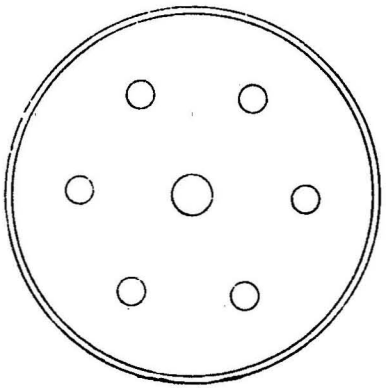
Moulded Dimensions—The dimensions of the ship, measured inside the shell and deck plating: horizontally to the outer edges of the frames: vertically from the base line to the level of the tops of the beams at the ship's side.

Non-Return Valves—Non-return valves will, when open, allow water to flow through them in one direction only. When they are closed, no water can pass through them in either direction.

The Oxy-Acetylene Blowpipe—The sketch shows the nozzle of this blowpipe. The inner hole gives a jet of oxygen only, the outer holes a jet of combined oxygen and acetylene. The flame given off has a temperature of about 4000° F., and is invaluable for cutting plates and for burning out rivets.

When plates are to be cut, they are made red hot by means of the combined jets and then the oxygen jet is turned on and the metal burns away.

The blowpipe can also be used for welding, although it is not so much used for this purpose.



Numbering of Frames and Plates—Ordinary frames are usually numbered from aft to forward, although in some building yards they are numbered from forward to aft.

Longitudinal frames, in ships built on the Isherwood system, are usually numbered from the deck downwards to the keel.

Shell plates are lettered from the keel outwards and numbered from aft.

Deck plates are lettered from the centre-line outward and numbered from aft.

Frames in cruiser sterns are usually lettered from the transom frame, aft.

Permanently Reduced Tonnage—*See* 'Modified Tonnage'.

Perpendiculars—The fore perpendicular is a vertical line at the point where the fore edge of the stem cuts the load waterline. The after perpendicular is a vertical line through the after edge of the rudder post, or the centre of the rudder stock.

Pitch of Riveting—'Pitch' is the spacing of rivets, centre to centre. It is always expressed in terms of the diameter of the rivets.

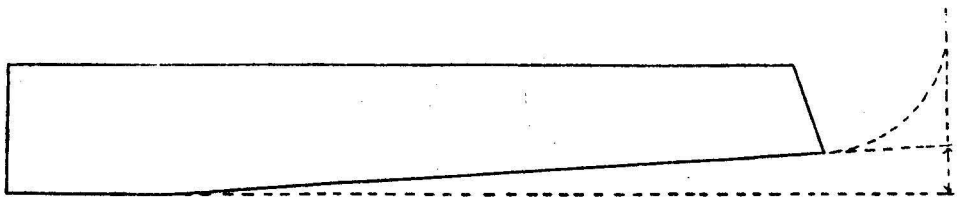
Plates on the Round—This is the term used to denote two or three curved plates, riveted or welded together to form a cylindrical section.

It is used largely for masts, massed pillars, etc.

Quarter Line—'Quarter Lines' are vertical planes running fore and aft on either side of the centre-line and about halfway between that line and the ship's side.

Rake—The slope of the stem, which is not usually vertical, but slopes aft from top to bottom.

Reserve Buoyancy—This is the volume of the hull between the water line and the freeboard deck. In other words, it amounts approximately to the difference between the actual displacement and that which the ship would have if she were submerged to her freeboard deck.



Rise of Floor—This is the upward rise of the lower edges of the floors from the keel towards the bilges.

Run—The underwater part of the ship at the after end, between the parallel midship section and the stern.

Scantlings—Scantlings are the sizes of the various parts of a ship.

Scarph—A form of joint used for thick bars, etc.

Seams—These are the joints of the longer sides of plates.

Shearing Stress—'Shearing Stress' is the force tending to make the component parts of a structure slide over each other.

The shearing stresses in a ship are usually greatest at about a quarter of the length from each end, in the vicinity of the neutral axis. Note that this stress should not be confused with longitudinal bending stresses, which are least at the neutral axis and greatest at the bottom and deck amidships.

Sheer—This is the upward rise of a ship's deck from amidships towards the bow and stern. It helps to keep the ship dry in bad weather, and also prevents the deck from becoming submerged if a forward or an after compartment becomes bilged.

The sketches illustrate this. Sketch *A* shows what might happen if a ship without sheer became flooded forward; Sketch *B* shows how this might be prevented by giving the ship sheer.

Shoring of Bulkheads—When a compartment has been accidentally holed and is full of water, the bulkheads at either end should be shored up to help them to resist the pressure. Bulkheads which are nearly rectangular should be more strongly shored at a point about two-thirds of the depth below the surface of the water in the compartment, since the greatest stress comes at this point.

Side Scuttles—The official name for a 'porthole'.

Stress—Stress is load put on a piece of material.

Strain—Strain is distortion, or molecular disturbance, of metal due to stress.

Strength Deck—This is the uppermost continuous deck, except in the way of an effective superstructure, where the superstructure deck is taken as the strength deck.

Storm Valves—These are flaps, fitted at the outboard ends of scuppers, etc., which will allow water to pass outboard, but which prevent the sea water from rushing up the pipe.

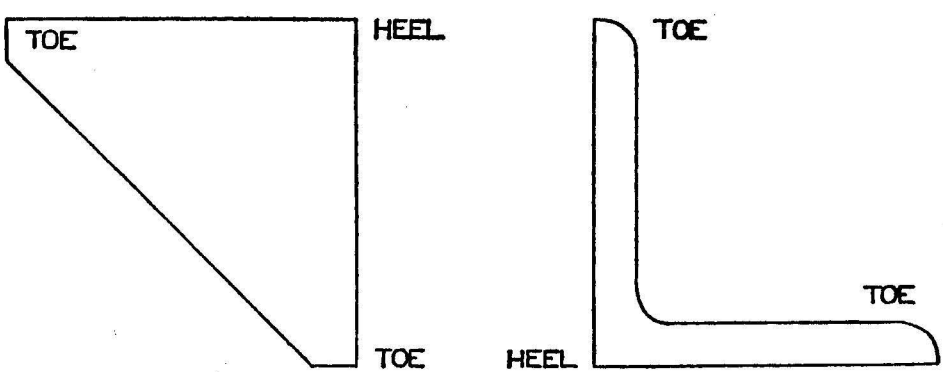
Superstructure—This is a decked structure above the freeboard deck, extending from side to side of the ship.

Superstructure Deck—The deck forming the top of a superstructure is called the 'Superstructure Deck'.

Tabernacle—'A Tabernacle' is an arrangement of brackets, used to support a mast.

Tie Plates—These are plates used to tie parts of the structure together when they are not otherwise directly connected to each other. They are found in many parts of a ship. The best-known form of tie plate is that fitted under a wood deck to tie the hatch coamings and masts to the beams and ship's sides.

Toes and Heels of Angles and Brackets—The sketches show the toes and heels of an angle and of a bracket.



Tonnage Deck—'The Tonnage Deck' is the upper deck in single decked ships and the second deck in all others.

Tonnage Mark—A line and triangle marked on the ship's side amidships to indicate that she has Modified or Alternative Tonnage.

Tripping—To give effective support, girders should be at right angles to the parts to which they are attached. If, for any reason, they twist out of their original plane, they may cease to give that support and are said to be 'tripped'.

Tumble Home—'Tumble home' is the falling-in of the ship's sides from the bilge towards the deck level, which allows any smaller projections at the deck level to clear wharves, etc.

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