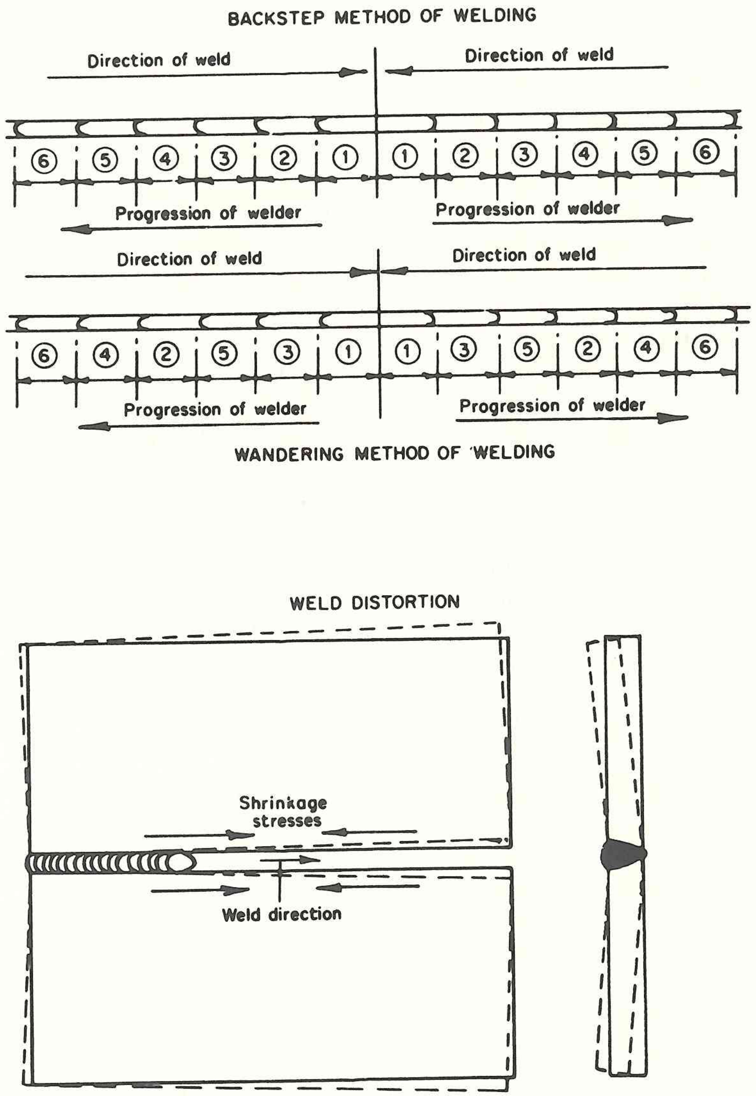


FIGURE 10.3 Backstep and wandering methods of welding

comprehensive tests before they are approved by Lloyd's Register or the other classification societies for use in ship work. Operatives are required to undergo periodical welder approval tests to ascertain their standard of workmanship.

WELD FAULTS Various faults may be observed in butt and fillet welds. These may be due to a number of factors, bad design, incorrect welding

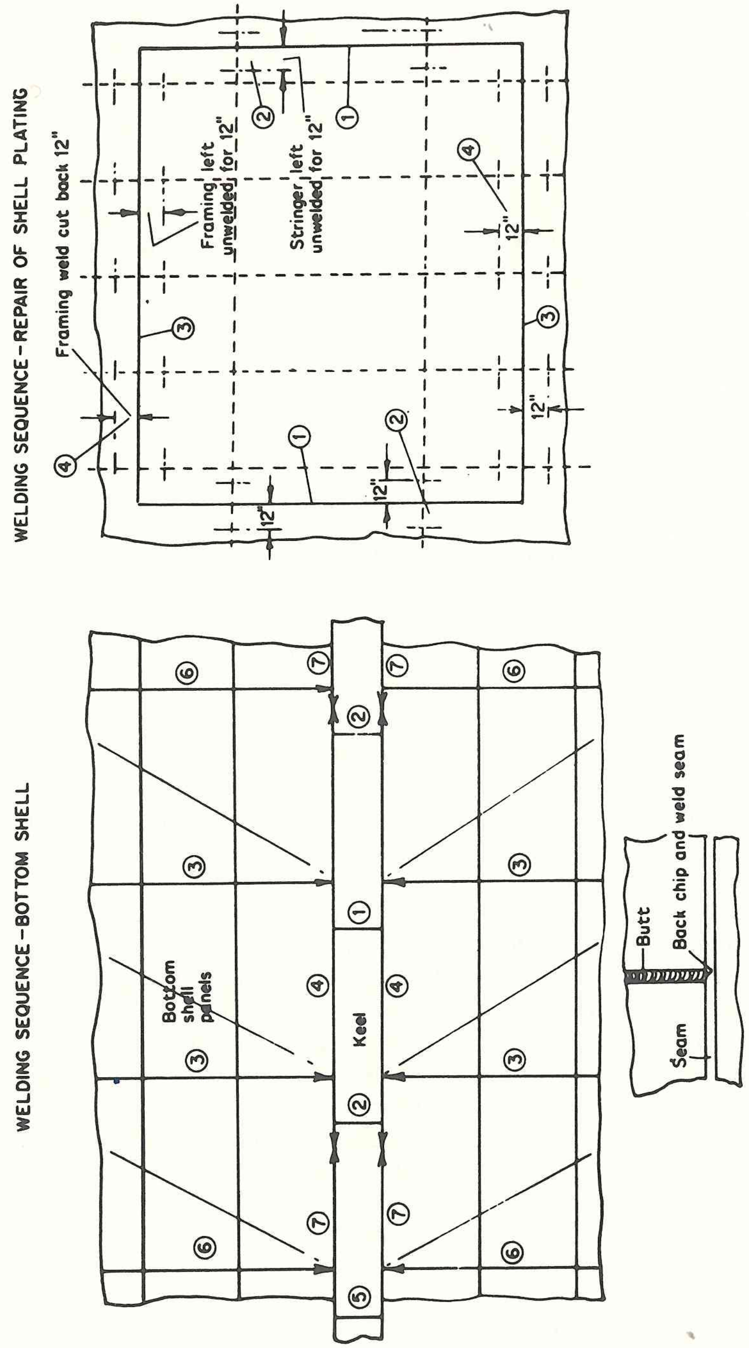


FIGURE 10.4 Welding sequences

procedure, use of wrong materials, and bad workmanship. Different faults are illustrated in Figure 10.5. The judgment of the seriousness of the fault rests with the weld inspector and surveyor, and where the weld is considered to be unacceptable it will be cut out and rewelded.

Non-destructive Testing

For obvious reasons some form of non-destructive test is required to enable the soundness of ship welds to be assessed. The various available non-destructive testing methods may be summarized as follows:

Visual examination
Dye penetrant
Magnetic particle
Radiographic
Ultrasonic

Of these five methods, the dye penetrant and magnetic particle tests have a small application in ship hull construction, being used for examining for surface cracks in stern frames and other castings. Visual, radiographic, and ultrasonic examinations are considered in more detail, as they are in common use.

Magnetic particle testing is carried out by magnetizing the casting, and spreading a fluid of magnetic particles (e.g. iron fillings suspended in paraffin) on the surface. Any discontinuity such as a surface crack will show up as the particles will concentrate at this point where there is an alteration in the magnetic field. A dye penetrant will also show up a surface flaw if it remains after the casting has been washed following the application of the dye. To aid the detection of a surface crack the dye penetrant used is often luminous and is revealed under an ultra-violet light.

Visual inspection of welds is routine procedure, and surface defects are soon noticed by the experienced inspector and surveyor. Incorrect bead shape, high spatter, undercutting, bad stop and start points, incorrect alignment, and surface cracks are all faults which may be observed at the surface. Sub-surface and internal defects are not observed, but the cost of visual inspection is low, and it can be very effective where examination is made before, during, and after welding.

The principle of radiographic inspection is simply to subject a material to radiation from one side, and record the radiation emitted from the opposite side. Any obstacle in the path of the radiation will affect the radiation density emitted and may be recorded. As radiation will expose photographic plate, for all practical weld test purposes this is used to record the consistency of the weld metal. The photographic plate records changes in radiation density emitted; for example a void will show up as a darker shadow on the radiograph.

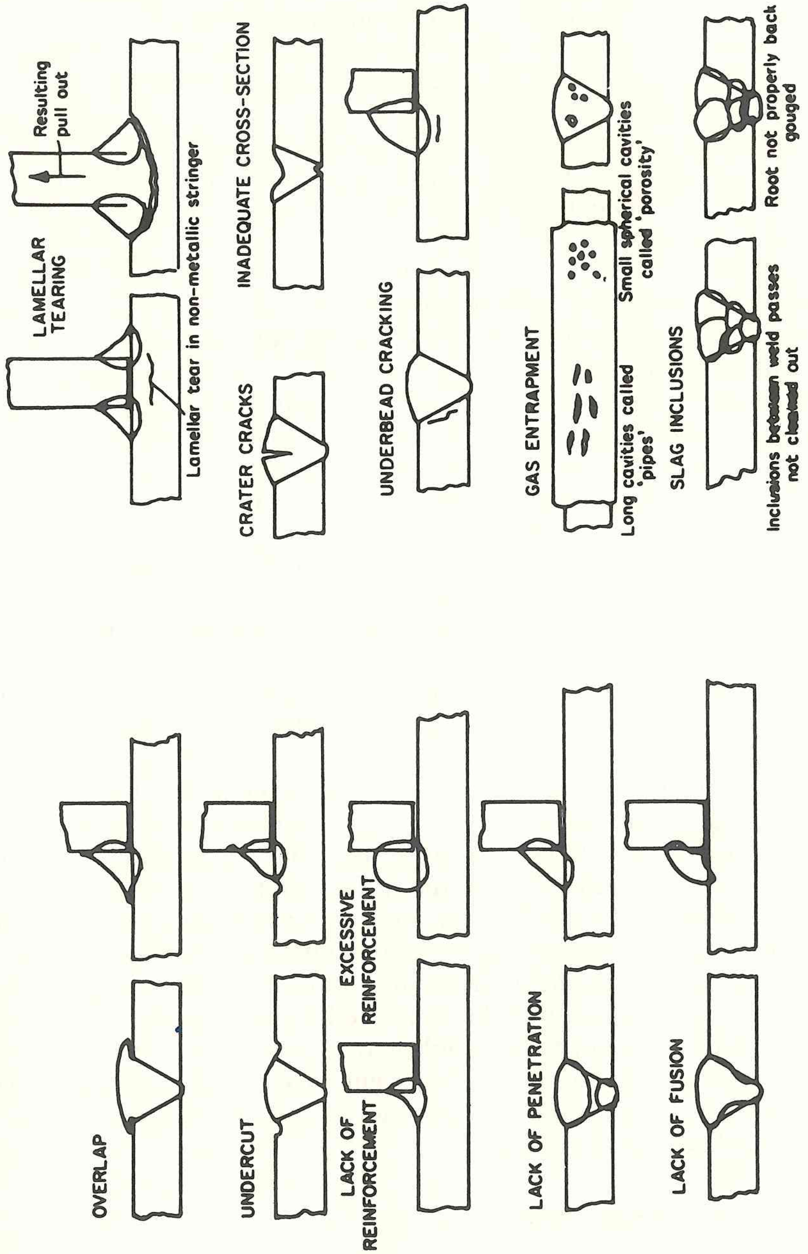


FIGURE 10.5 Weld faults

Either X-ray or gamma ray devices may be used to provide the source of radiation. X-ray equipment consists of a high voltage power source (50 to 400 kV) which is used to provide potential between a cathode and target anode in a glass vacuum tube. Only a small percentage of this energy is converted to X-rays, so that large amounts of heat have to be conducted away from the target. From the target the X-rays are projected out of the tube onto the weld surface (*see* Figure 10.6).

Where gamma ray devices are used ray emission is produced by decay of a radio-active nucleus, the rate of emission being reduced with time. The radiation given off may be magnetically separated in three parts, α-rays, β-rays and γ-rays, the γ-rays being similar to X-rays and of most importance since they are very penetrating; but this also means that heavy shielding is required. Since natural radio-active sources are in short supply, great use is made of artificial radio-active sources, namely isotopes.

To interpret the weld radiograph a large amount of experience is required, and a sound knowledge of the welding process. Radiographs usually carry the image of an 'image quality indicator' which shows the minimum change of thickness revealed by the technique. This image quality indicator may have graded steps of metal, each step being identified on the radiograph so that the minimum step thickness discernible is noted, and the sensitivity of the radiograph assessed. This indicator is placed adjacent to the weld prior to taking the radiograph.

Ultrasonic energy is being used increasingly as a tool for locating defects in welds, and has several advantages over radiography, particularly as no health hazard is involved. The technique is particularly useful for locating fine cracks which are often missed by radiography, particularly where they lie perpendicular to the emission source.

The principle of ultrasonic inspection depends on the fact that pulses of ultrasonic energy are reflected from any surface which they encounter. Ultrasonic waves travelling through a plate may be reflected from the surface of the metal and also from the surfaces of any flaws which exist in the metal. Virtually total reflection occurs at an air-metal interface, and therefore to get the ultrasonic wave into the metal a liquid is placed between the source and metal. The pattern of reflection is revealed on a cathode ray tube, which may be calibrated using a standard reference block. An experienced operator is able to recognize flaws from the cathode ray tube display, and to some extent recognition of defect types is possible. Apart from weld inspection, ultrasonic techniques are valuable for assessing the thickness of structural members.

Classification Society Weld Tests

Classification societies specify a number of destructive tests which are intended to be used for initial electrode and weld material approval. These

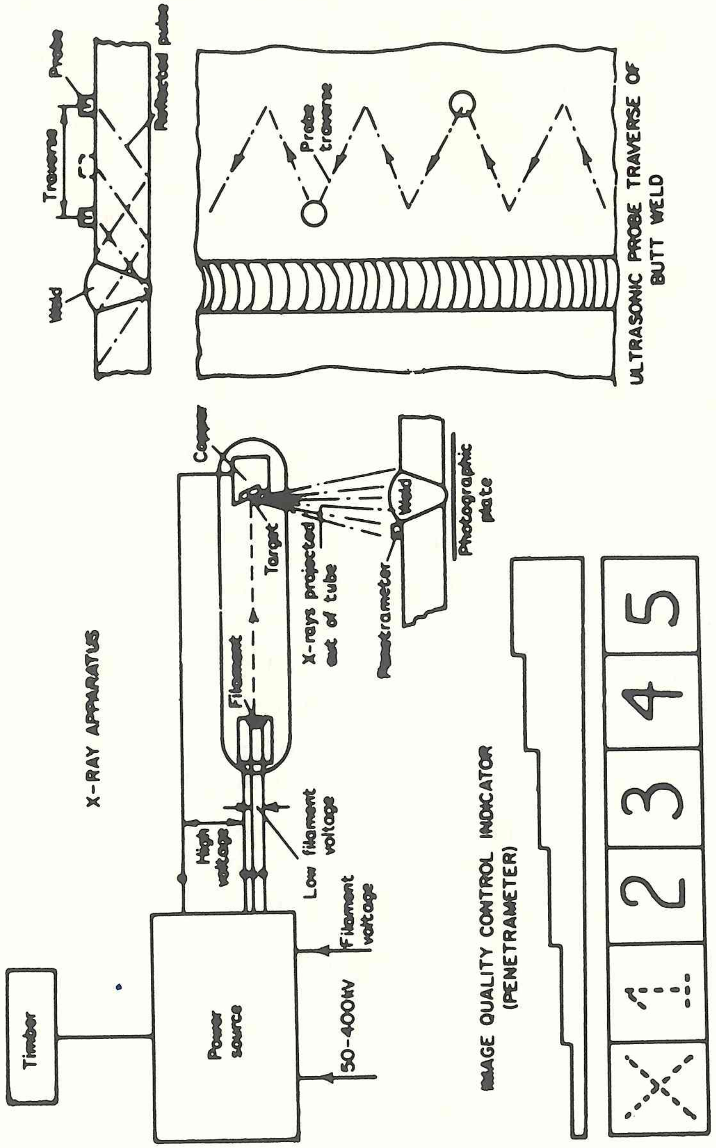


FIGURE 10.6 Inspection of welds

tests are carried out to ascertain whether the electrode or wire-flux combination submitted is suitable for shipbuilding purposes in the category specified by the manufacturer.

Tests are made for conventional electrodes, deep penetration electrodes, wire-gas, and wire-flux combinations, and consumables for electro-slag and electro-gas welding with tensile bend and impact tests being carried out on the deposited weld metal and welded plate specimens. Other tests are made for the composition of the weld metal deposited, and possible cracking.

All works where electrodes, wire-flux and wire-gas combinations and consumables for electro-slag and electro-gas welding are produced and have been initially approved are subjected to annual inspection.

Further Reading

Ailes, 'Notes on Industrial Radiography', *Shipping World and Shipbuilder*, Ship Repair Number, May 1968.

Control of Distortion in Welded Fabrications, 2nd Edition, The Welding Institute, Cambridge.

D'Archangelo, *Sound Ship Structures* (Cornell Maritime Press, 1964).

Harrison and Young, 'The Acceptability of Weld Defects', *The Naval Architect*, April, 1975.

Hislop, 'The Techniques, Applications and Scope of Non-Destructive Testing in Industry', *Trans. N.E.C. Inst.*, vol. 69, 1952–53.

Lloyd's Rules and Regulations for the Classification of Ships, Part 3, Ship Structures, Chapter 10, Welding and Structural Details.

'Significance of Defects in Welds', Proceedings of the First Conference, February 1967, The Welding Institute, Cambridge.

'Ultrasonic Testing', London, Institute of Welding, 1963.

'Welding in Shipbuilding', Symposium, 30 October–3 November, 1961, London, Institute of Welding, 1962.

Part 4

Shipyard Practice

11

Shipyard Layout

Most shipyards are well established and were originally sited in a suitable location for building small ships with methods which have now been superseded. With the growth in ship sizes and the introduction of new building methods it has been recognized that a revised shipyard layout will be advantageous. Advantages to be gained, apart from the ability to construct larger vessels, are primarily, a uniform work load, a shorter ship build cycle, and economies in construction practices. These are obtained by having a layout that lends itself to an easy flow of materials from one productive process to another with elimination of bottlenecks. Other factors of course are involved in achieving a smooth production flow, but it is an advantage to start with a shop and equipment layout which is favourable.

Very rarely has it been possible for the shipbuilder to select a new site and adopt an ideal layout. Normally the present site has to be used, and starting from the ideal it has been necessary to make modifications to allow for site peculiarities. At the same time shipbuilding has continued within the yard, and overall yard modifications have been made piecemeal in order not to hinder this work seriously.

An ideal layout for a modern shipyard is based on a production flow basis, with the yard extending back from the river or shore at which the berths or building dock are located. The furthest area from the berths is reserved for the material stockyard, and between the two are arranged in sequence the consecutive work and shop processes. Too often existing shipyards follow the river bank, and are restricted by their location in a built up area or the physical river bank slope from extending back from the river, so that modified production flow lines are required.

Planning a new shipyard, or re-planning an existing one, will involve decisions to be made on the following:

Size and type of ship to be built.
Material production per year to be achieved.
Material handling equipment to be supplied.
Machining processes to be installed.
Unit size and weight to be fabricated and erected.
Amount of outfit and engine installation to be undertaken.
Control services to be supplied.
Administration facilities required.

With the introduction of welding followed by unit fabrication and then the development of sophisticated machine tool devices for plate and section preparation, the shipyard layout had to be re-configured to exploit the higher material throughput rates these processes allowed and permit the shipbuilder to remain competitive.

Before considering the actual layout of the shipyard it is as well to consider the relationship of the work processes involved in building a ship as illustrated in Figure 11.1.

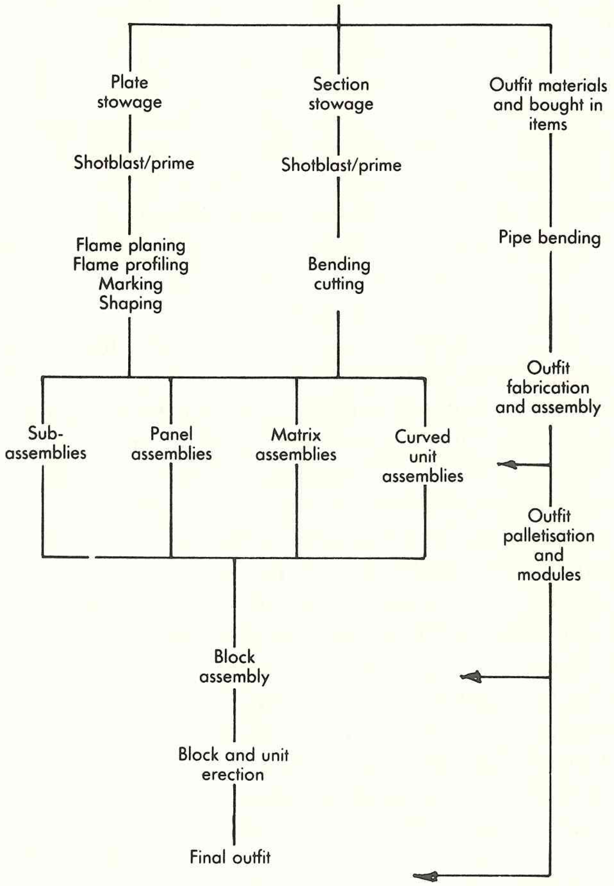


FIGURE 11.1 Shipbuilding process

Shipyards usually have a fitting out basin or berth where the virtually completed ship is tied up after launching and the finishing off work is completed. This is provided with adequate craneage and the outfitting and machinery shops are usually adjacent to it. With the major part of the outfit and machinery now being installed in modular or other form during the hull and house fabrication cycle this feature of the yard now has less significance.

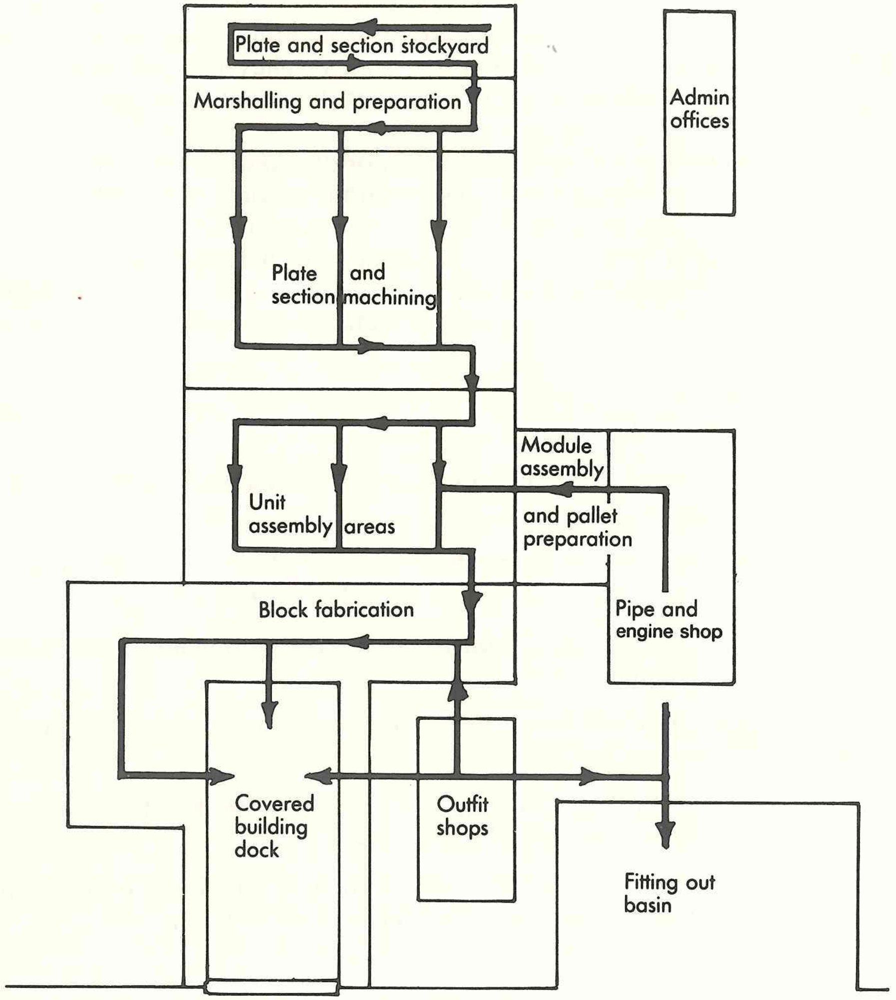


FIGURE 11.2 Shipyard layout

An idealized layout of a new shipyard is indicated in Figure 11.2 which might be appropriate for a smaller yard specializing in one or two standard type ships with a fairly high throughput so that one covered building dock or berth was sufficient.

At this point it may be convenient to mention the advantages and disadvantages of building docks as opposed to building berths. Building docks can be of advantage in the building of large vessels where launching costs are high, and there is a possibility of structural damage owing to the large stresses imposed by a conventional launch. They also give good crane clearance for positioning units. The greatest disadvantage of the building dock is its high initial cost.

Many yard re-constructions have incorporated undercover construction facilities in the form of docks or slipways within building halls. Others have building halls at the head of the slipway with advanced transfer systems installed so that the hull can be extruded out of the hall onto the slipway for launching. Such facilities permit ship construction in a factory type environment providing protection from the worst effects of weather and darkness.

Further Reading

'A Covered Shipyard at Pallion gives British Shipbuilding a New Look', *The Naval Architect*, May, 1976.

Cameron and Tennant, 'Building Dock and New Steelworking Facilities at Queen's Island, Belfast', *Trans. N.E.C. Inst.*, 1971.

'Cammell Lairds Shipyard reconstruction at Birkenhead', *The Naval Architect*, November, 1978.

Grant, 'Production Methods in Japanese Shipbuilding', *The Naval Architect*, January, 1972.

Kimber and Hargroves, 'Creating a Production Facility for Standard Ships', *The Naval Architect*, January, 1977.

McNulty and McKinstry, 'Parallel Development of Ship Production Facilities and Information Systems', *The Naval Architect*, September, 1978.

12

Ship Drawing Offices and Loftwork

The ship drawing office is traditionally responsible for producing detailed working structural and general arrangement drawings for parts of the hull and outfit. Structural drawings prepared by the drawing office will be in accordance with Lloyd's or other classification rules and subject to their approval; also owner's additional requirements and standard shipyard practices are incorporated in the drawings. General arrangements of all the accommodation and cargo spaces and stores are prepared, which allow for statutory requirements as well as shipowner's requirements and standards. Other outfit plans, piping arrangements, ventilation and air conditioning (which may often be done by an outside contractor), rigging arrangements, and furniture plans, etc., are also prepared.

Since the late 1970s, developments in computer hardware based on microchip technology have made available to industry very powerful computer systems at moderate cost. This technology has led to a significant advance in the capability of graphics systems for computer aided design and computer aided manufacture (CAD/CAM) which are commonly available to industry. Such systems are steadily replacing manual draughting and numerically controlled parts programming in many shipyards. Computer based shipbuilding systems developed during the late 1960s and early 1970s and used for numerically controlled production machines and loftwork have now been enhanced to extend their scope to the design and drawing office functions and provide interfaces with a comprehensive range of other shipyard systems.

It has been common practice for the drawing office to contain a material ordering department which was able to lift the necessary requirements from the drawings and progress them. Also the office worked in close conjunction with the loft and planning production office. With the introduction of CAD/CAM systems to the drawing office these functions have been increased and improved. The precision of the scantling drawings generated enables them to be used with greater confidence for steel ordering than was possible with manual drawings and the requisitioning information can be stored on the computer to be interfaced with the shipyards commercial systems for purchasing the material control. Sub-assembly, assembly and block drawings can be created in 2-dimensional and 3-dimensional form and a library of standard production sequences and production facilities can be called up so that the draughtsman can ensure the structural design uses the yards resources efficiently and follows established and cost effective practices. Weld lengths and types, steel weights and detailed parts lists can be processed from the information on the drawing and passed to the production control systems. A 3-dimensional steel assembly can be rotated by a draughtsman on screen to assess the best orientation for maximum downhand welding. The use of 3-dimensional drawings is particularly valuable in the area of outfit drawings where items like pipework and trunking can be 'sighted' in the 3-dimensional mode and more accurately measured before being created in the 2-dimensional drawing.

There are several drawings or tasks undertaken in the drawing office which are of special interest and warrant a little more attention.

LINES PLAN A preliminary version of this will, in effect, be prepared at the time of the conceptual design to give the required capacity, displacement and propulsive characteristics. It will subsequently be refined during the preliminary design stage and following any tank testing or other method of assessing the hulls propulsive and seakeeping characteristics. The lines plan is a drawing, to a suitable scale, of the moulded lines of the vessel in plan, profile, and section. Transverse sections of the vessel at equally spaced stations between the after and forward perpendiculars are drawn to form what is known as the body plan. Usually ten equally spaced sections are selected with half ordinates at the ends where a greater change of shape occurs. A half transverse section only is drawn since the vessel is symmetrical about the centre line, and forward half sections are drawn to the right of the centre line with aft half sections to the left. Preliminary body plans are drawn initially to give the correct displacement, trim, capacity, etc., and must be laid off in plan and elevation to ensure fairness of the hull form. When the final faired body plan is available the full lines plan is completed showing also the profile or sheer plan of the vessel and the plan of the water-line shapes at different heights above the base.

A lines plan is illustrated in Figure 12.1. The lines of the lateral sections in the sheer plan as indicated are referred to as 'bow lines' forward and 'buttock lines' aft. Bilge diagonals may be drawn with 'offsets' taken along the bilge diagonal to check fairness.

When the lines plan was completed manually the draughtsmen would compile a 'table of offsets', that is a list of the half breadths, heights of decks and stringer, etc., at each of the drawn stations. These 'offsets' and the lines plan were then passed to loftsmen for full size or 10 to 1 scale fairing, or to a computer centre for full scale fairing. Since the lines plan was often of necessity to a small scale which varied with the size of ship, the offsets tabulated from widely spaced stations and the fairing were not satisfactory for building purposes. The loftsmen or computer centre would prepare a full set of faired offsets for each frame space.

Given today's common usage of integrated design systems on the ship-

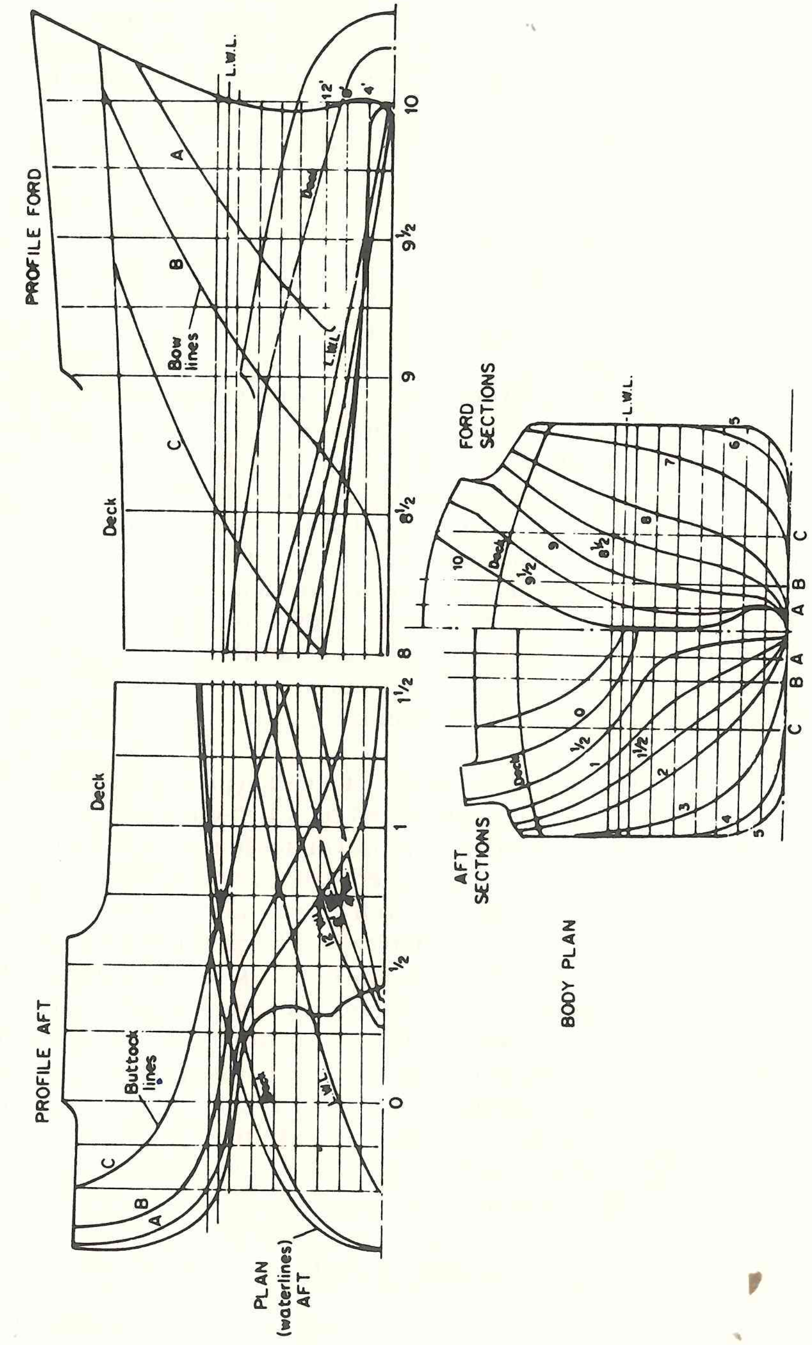


FIGURE 12.1 Lines plan

yards' computers, the conceptual creation of the hull form and its subsequent fairing for production purposes is accomplished without committing the plan to paper. The hull form is generally held in the computer system as a 3-dimensional 'wire model' which typically defines the moulded lines of all structural items so that any structural section of the ship can be generated automatically from the 'wire model'.

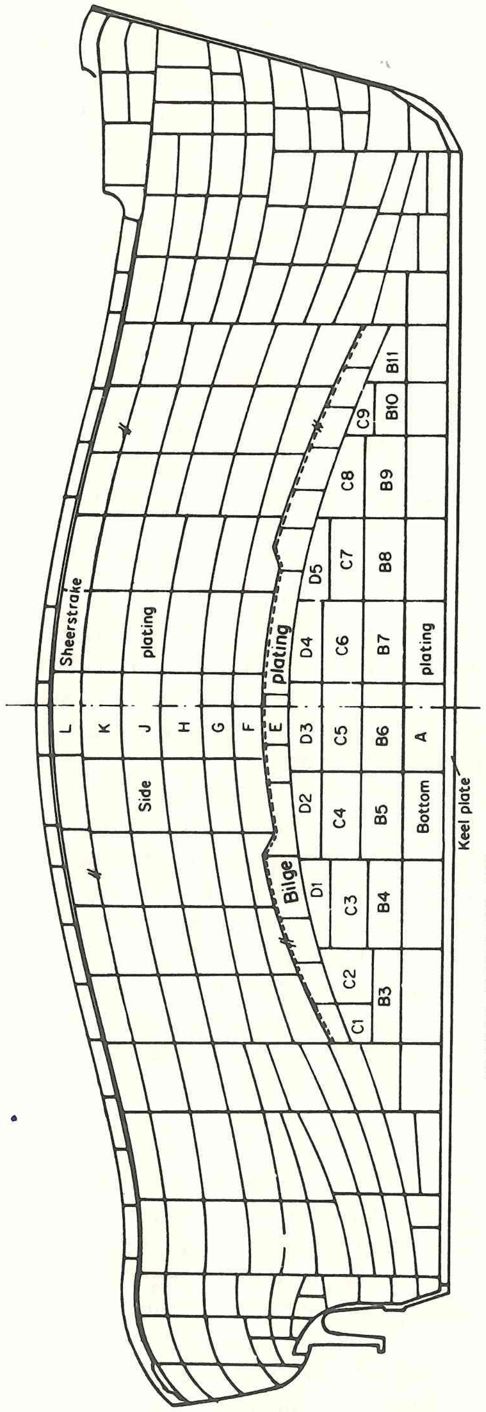
3-DIMENSIONAL REPRESENTATION OF SHELL PLATING When preparing the layout and arrangement of the shell plating at the drawing stage it is often difficult to judge the line of seams and plate shapes with a conventional two-dimensional drawing. Shipyards used to therefore make use of a 'half block model' which was in effect a scale model of half the ship's hull from the centre line outboard, mounted on a base board. The model was either made up of solid wooden sections with faired wood battens to form the exterior, or of laminated planes of wood faired as a whole. Finished with a white lacquer the model was used to draw on the frame lines, plate seams, and butts, lines of decks, stringers, girders, bulkheads, flats, stem and stern rabbets, openings in shell, bossings, etc.

With a CAD system the shell plating arrangement can be worked out at the interactive (i.e. image can be worked on and added to, modified, etc.) screen on the body plan derived from the 3-dimensional 'wire model', to create a plate line body plan. This drawing can then be used to create 3-dimensional representations of all the relevant lines on the curved surface creating in effect a visual 'half block model'.

SHELL EXPANSION The arrangement of the shell plating taken from the 3-dimensional model may be represented on a two-dimensional drawing referred to as a shell expansion. All vertical dimensions in this drawing are taken around the girth of the vessel rather than their being a direct vertical projection. This technique illustrates both the side and bottom plating as a continuous whole. In Figure 12.2 a typical shell expansion for a tanker is illustrated. This also shows the numbering of plates, and lettering of plate strakes for reference purposes and illustrates the system where strakes 'run out' as the girth decreases forward and aft. A word of caution is necessary at this point for in many modern ship shell expansions there is also a numbering system related to the erection of fabrication units rather than individual plates, and it may be difficult to use the drawing to identify individual plates. However single plates are often marked in sequence to aid ordering and production identification.

Loftwork Following Drawing Office

The mould loft in a shipyard was traditionally a large covered wooden floor area suitable for laying off ship details at full size.



FRAMING, STRINGERS, DECKS AND OPENINGS IN SIDE SHELL ARE ALSO SHOWN ON THE SHELL EXPANSION BUT HAVE BEEN OMITTED FOR CLARITY

FIGURE 12.2 Shell expansion

When the loftsmen received the scale lines plan, and offsets from the drawing office, using the traditional method the lines would be laid off full size and faired. This would mean using a great length of floor even though a contracted sheer and plan were normally drawn, and aft and forward body lines were laid over one another. Body sections were laid out full size as they were faired to form what is known as a 'scrieve board'. To avoid using up a large mould loft space for fairing the ship lines, many shipbuilders later took advantage of main frame computer programs available at various centres. These provided full size fairing so that only the scrieve board needed to be laid down from the faired offsets.

SCRIEVE BOARDS The scrieve board was used for preparing 'set bars' and levels for bending frames and for making templates and mouldings for plates which required cutting and shaping. Shell plates were developed full size on the loft floor and wooden templates made so that these plates could be marked and cut to the right shape before being fitted to the framing on the berth.

10/1 SCALE LOFTING In the late 1950s the 10/1 lofting system was introduced and was eventually widely adopted. This reduced the mold loft to a virtual drawing office and assisted in the introduction of production engineering methods. Lines could be faired on a 10/1 scale and a 10/1 scale scrieve board created. Many yards operated a flame profiling machine (*see* Chapter 13) which used 10/1 template drawings to control the cutting operation. In preparing these template drawings the developed or regular shape of the plates was drawn in pencil on to special white paper or plywood sheet painted white, and then the outline was traced in ink on to a special transparent material. The material used was critical, having to remain constant in size under different temperature and humidity conditions and having a surface which would take ink without 'furring'. Extreme accuracy was required in ensuring uniform thickness of lines etc., the lines being drawn outside, i.e. on the scrap side of the plate. Many of the outlines of plates to be cut by the profiler could be traced directly from the scrieve board, for example floors and transverses.

CAD/CAM LOFTWORK We have already seen that shipyard-installed computer systems are capable of fairing the lines full size and storing these as a 3-dimensional model. This stored information can be accessed by the loftsman in order that lofting functions such as preparing information for bending frames and longitudinals, developing shell plates, and providing shell frame sets and rolling lines or heat line bending information for plates can be done via the interactive visual display unit.

For the numerically controlled profiling machine the piece parts to be cut can be 'nested', i.e. fitted into the most economic plate which can be

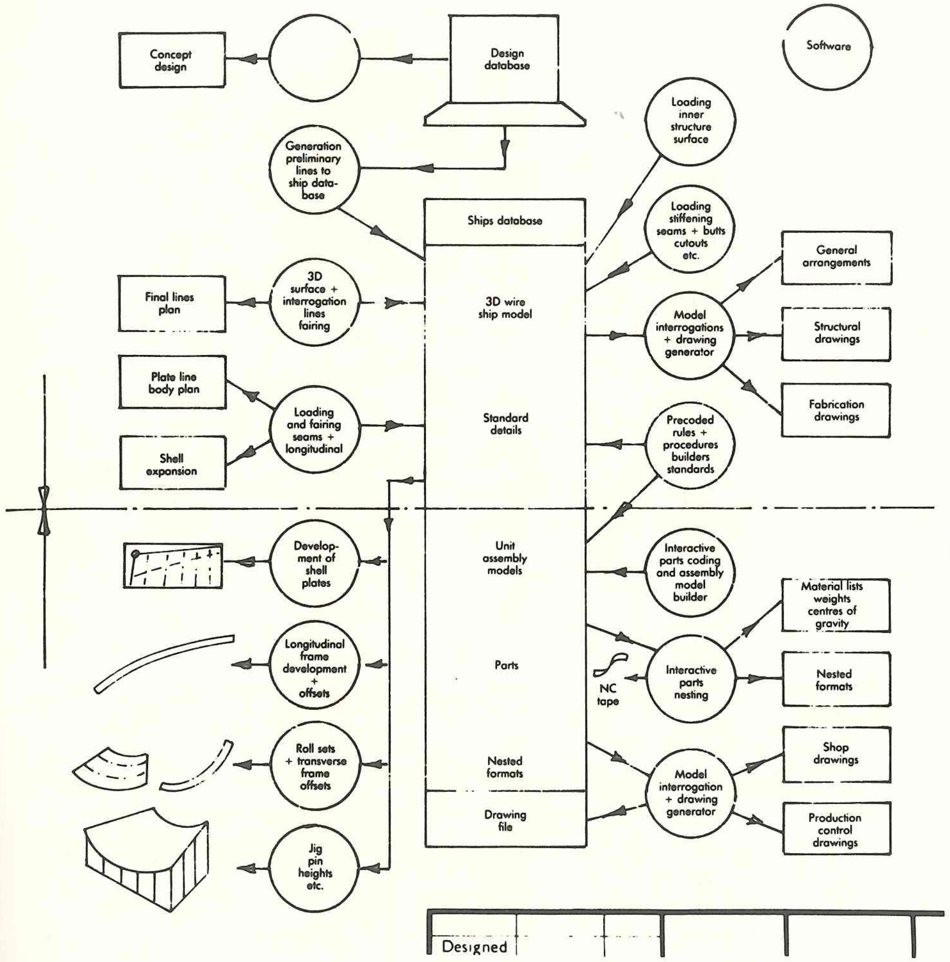


FIGURE 12.3

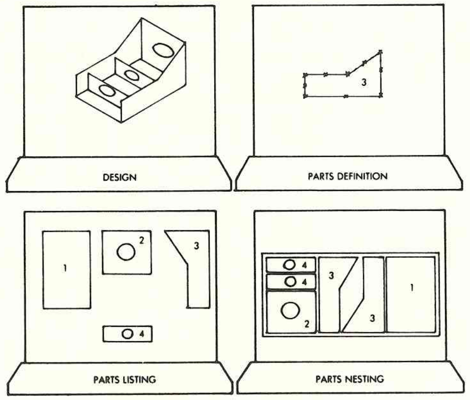


FIGURE 12.4

handled by the machine with minimum wastage. This can be done at the drawing stage when individual piece parts are abstracted for steel requisitioning and stored later being brought back to the screen for interactive nesting. The loftsman can then define the order in which parts are to be marked and cut by drawing the tool head around the parts on the graphics screen. When the burning instructions are complete he is able to replay the cutting sequence and check for errors. A check of the NC tape after it has been punched can be carried out with a plotter. Instructions for cutting flame planed plates and subsequently joining them into panel assemblies and pin heights of jigs for setting up curved shell plates for welding framing and other members to them at the assembly stage can also be determined by the loftsman.

At this stage shell plates at the extreme ends of the hull, that is those with double curvature at the stern and bulbous bow still require manual lofting using 10/1 procedures.

Further Reading

'An alternative to shell expansion drawing', *The Naval Architect*, November, 1977.

'Computer applications in the automation of shipyard operation and ship design', *The Naval Architect*, November, 1979.

Dawson, 'Computing systems for naval architects', *Ship and Boat International*, April, 1987.

Forrest and Parker, 'Steelwork Design Using Computer Graphics', *The Naval Architect*, January, 1983.

Kuo *et al.*, 'An Effective Approach to Structural Design for Production', *The Naval Architect*, February, 1984.

Proceedings of the Seminar on Advances in Design for Production, University of Southampton, April, 1984.

13
Plate and Section Preparation and Machining

This chapter deals with the working processes which a plate or section undergoes from the time it is received into the shipyard until it is in its final shape ready to be welded into a unit of the ship structure. In recent years many changes have occurred in this sphere of shipyard activity, and substantial economies can be achieved by obtaining an even flow of production at this stage.

Plate and Section Preparation

Initial preparation of material is essential for its efficiency in the completed ship structure and its marshalling on arrival is essential to the efficiency of the shipbuilding process.

STOCKYARD On arrival at the shipyard, plates and sections are temporarily stored in the stockyard. As a rule the stockyard is an uncovered space having sufficient area to provide storage for enough plates and sections required for the working of the yard some months ahead. In the United Kingdom the amount stored might be about three months' stock, but shipyards in countries which are not substantial steel producers may find it necessary to carry much larger stocks of material. In contrast a Japanese yard closely associated with a steel manufacturer claims to carry as little as one month's stock, and in some cases less.

When the plates and sections are ordered the steel mills are provided with details of the identification code for each item so that they may be marked. On arrival in the stockyard, since the coding is generally in terms of the unit structure for which each item is intended, it is convenient to store the plates and sections in their respective ship and ship unit areas. In other words the material for each ship is allotted an area of the stockyard, this area being subdivided into plots for those items intended for a major structural fabrication block of the ship.

Material delivery and storage is controlled in accordance with production engineering practices to suit the ships construction programme.

As a rule the plates are now stacked horizontally in piles as required.

Originally it was common practice to store the plates vertically in racks, which was convenient for weathering purposes, but this system is not now employed; sections are laid horizontally in convenient batches.

Where cranes are used for material handling it is important that there be adequate coverage for the full extent of the stockyard, and the material may be delivered to the covered shed areas. Cranage is generally of the electric overhead gantry type, traversing the stockyard on rails and extending into the workshop area; alternatively the plates may be placed on a roller conveyor for delivery to the workshops. Lifts are made with magnetic clamps for plates and slings for the sections, the crane capacity rarely exceeding five tonnes. To improve the handling facilities in the stockyard a device known as a 'captivator' is now available. Plates required for the work being processed may be pre-stacked at the captivator which can be remotely controlled so that as each plate is required it lifts, using magnetic clamps, the plate from the top of the pile and then transfers it to a roller conveyor. A stockyard employing this technique can in fact become highly automated.

MANGLES Mangles is the name given to a heavy set of plate straightening rolls through which the plate is passed prior to its being worked. During transit plates may become distorted, and for many of the modern machining processes it is important that the plates should be as flat as practicable. Two sets of mangles may be provided, one for heavy plate and one for light plate, but types are now available which permit a wide range of thickness to be straightened.

SHOT BLASTING All materials, plates and sections, are in most cases now shot blasted to remove rust and millscale. The principles of shot blasting are dealt with in detail in Chapter 27.

Shot blasting plant in shipyards is generally of the impeller wheel type where the abrasive is thrown at high velocity against the steel surface and may be re-circulated. The plant can be so arranged that the plate passes through vertically, but more often it is installed so that the plate may pass through in the horizontal position. In the former case equipment must be provided to allow the plate to be raised into the vertical position from the roller conveyor before it enters the blasting plant, and to lower it on removal. There is a further problem with lighter plate which may more easily distort when stood on end. The only disadvantage of the horizontal plant is the removal of spent abrasive from the top of the plate, which may be relatively easily overcome. A separate shot blast plant is often installed for sections.

PRIMING PAINT Following the shot blasting of plates and sections, the material passes immediately through an airless spray painting plant. In one pass the material is automatically sprayed with a priming paint of controlled coat thickness. A number of suitable priming paints are available; the requirements for these and their formulation may be found in Chapter 27. Following the priming paint stage a drying process may be provided.

PLATE HANDLING IN MACHINE SHOPS Throughout the machining shops overhead electric cranes having capacities from 5 to 15 tonnes may be provided to transport plates and sections to each machine process. Individual machines may have jig cranes mounted on the frame which can be employed to handle the plate during the machining process.

Distribution of plates in the shop may also be by means of electric powered trolleys sometimes referred to as a 'collacator unit' running on rails in bays between the plate working machines. Highly mechanized plant systems are also available where conveyor systems, flame cutting tables and aligning and clamping equipment are installed as integrated units.

Plate and Section Machining

A number of the methods in use for forming plates into the required shapes are time honoured. This is particularly true of the methods adopted for fitting plates to the curve of the hull, but as we have seen in the previous chapter the information for doing this can now be derived using the CAD/CAM systems available. Cutting flat plates to the required profiles has in the past decade become highly automated, very sophisticated machine tools having been introduced for this purpose. In the main, cutting is achieved by the use of an oxy-fuel flame or plasma-arcs.

PLATE PROFILERS Where a plate is to be cut into one or more or a series of complicated shapes a profiling machine is employed. At present where these employ gas cutting, the machines are generally referred to as 'flame profilers'. All flame, or plasma-arc profilers have some form of automatic control, the sophistication of which may vary considerably; the following methods of control are found in shipyards:

(*a*) 1/1 template or drawing control
(*b*) 1/10 drawing
(*c*) Numerical control.

(*a*) A full size template or drawing may be used to control a cutting machine, and can be very useful where a single item is to be cut in large numbers. The size of the item is obviously restricted, and the location from which the item is cut in a large plate is selected by the operator. Where a template is used a mechanical follower may be employed, and where a drawing is used an electronic scanning device may follow the outline. In either case simple non-automated machines are available where the operator guides the follower around the template, or tracing head around the drawing profile. Profilers of this type have a limited application in shipbuilding, but might be used for cutting a batch of standard brackets, etc.

(*b*) Some of the flame profilers found in shipyards are controlled from 10/1 drawings prepared by loftsmen as indicated in Chapter 12. The control mechanism for the machine is located in a darkened booth within the plate machining sheds. A tracing head with photo-electric cell traverses the 1/10 scale drawing located on a viewing table, following the line of the plate from the start to stop points in the sequence planned by the loftsmen. The control is linked to the machine outside, which consists of a carriage with extended arms carrying the burning heads. Two arms are generally fitted allowing the machine to cut at the same time two plates which can either be identical or mirror images. Each burning head is fitted with three nozzles allowing various edge preparation bevels to be cut. The height of the flame is automatically adjusted and speed control is maintained during the cut, although it is possible to speed up the burning head movement between the finish and start of a new cut. More recent versions of these machines have twin tracing head controls so that both sides of a plate with dissimilar curves may be cut simultaneously.

With this type of machine it is possible to obtain an accessory for marking plates. This will punch mark the plate at desired locations in a manner similar to that employed for permanent marking by hand.

(*c*) In most shipyards use is now made of numerical control for the plate profiler, rather than optical control. The principal reasons for this are that the preparation of 1/10 scale drawings requires a high standard of draughtsmanship and the training of loftsmen to do this work can be very expensive. Further introducing higher cutting speeds with the adoption of the plasma-arc process makes optical control difficult.

Numerical control implies control of the machine by means of a tape on which is recorded the co-ordinate points of a plate profile. For a simple plate shape having a profile consisting only of straight lines or circular arcs, the co-ordinates may be programmed manually, but for many ship plates the contours are much more complex. Manual programming of these contours would reduce considerably the efficiency of the process, and therefore various coded data systems were initially evolved for use with a digital computer program. With the advent of CAD/CAM systems the integrated software now developed includes, as described in Chapter 12, provision for the draftsman to perform parts programming and nesting of plate parts and the loftsman to add the cutting information and automatically generate the NC tape. The tape can be read into the director which produces command signals to the servo-mechanism of the profiling machine. The overall arrangement is shown in Figure 13.1.

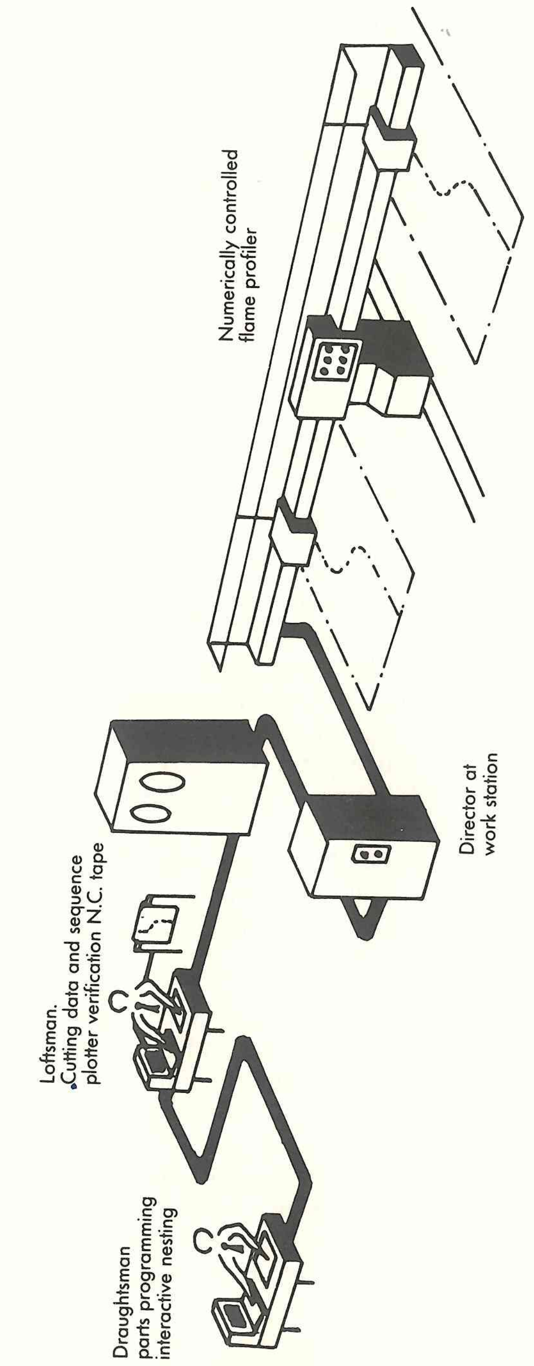


FIGURE 13.1 Numerical flame cutting control system

These machines, like the 1/10 scale optically controlled machines, may be provided with accessories for marking plates.

PLANING MACHINES Profiling machines are essentially for use where a plate requires extensive shaping with intricate cuts being made. Many of the plates in the ship's hull, particularly those in straightforward plate panels, decks, tank tops, bulkheads, and side shell, will only require trimming and edge preparation, and perhaps some shallow curves may need to be cut in shell plates. This work may be carried out on a planing machine, usually a flame planer.

A flame planer consists basically of three beams carrying burning heads, and running on two tracks, one either side of the plate working area. One beam carries two burning heads for trimming the plate sides during travel, whilst the other two beams have a single burning head traversing the beam in order to trim the plate ends. Each burning head may be fitted with triple nozzles and is used to give the required edge preparation. Plate, beam, and burning head positioning is manual, but cutting conditions are maintained once set.

Mechanical planing machines were in existence prior to the flame planer, and have an advantage where they are able to cut materials other than steels. Higher cutting speeds than that obtained with flame cutting may be obtained for vertical edges with a rotary shearing wheel on a carriage, where the plate is held by hydraulic clamping. For edge preparations, older machines with a conventional planing tool require a large number of passes and are much slower than flame planers. There are however merits in mechanically machined edge preparations where the superior finish is advantageous for critical welds. A more recent innovation in mechanical plate edge preparation is the use of milling machines. Plate edges may be prepared at high speed using a milling head, and it is even possible to edge machine batches of clamped plates with the vertical travel of the milling head.

DRILLING MACHINES Some plates or sections may need to have holes drilled in them, for example bolted covers and portable sections. Drilling machines generally consist of a single drilling head mounted on a radial arm which traverses the drill bed.

GUILLOTINES Smaller plate shapes such as beam knees and various brackets may be cut in a hydraulically operated guillotine. Plate feed to the guillotine is usually assisted by the provision of plate supporting roller castors, and positioning of the cut edge is by hand.

PRESSES Hydraulic presses may be extensively used in the shipyard for a variety of purposes. They are capable of bending, straightening, flanging, dishing, and swaging plates (*see* Figure 13.2). All of the work is done with the plate cold, and it is possible to carry out most of the work undertaken by a set of rolls. This is done at less capital cost, but the press is slower when used for bending and requires greater skill.

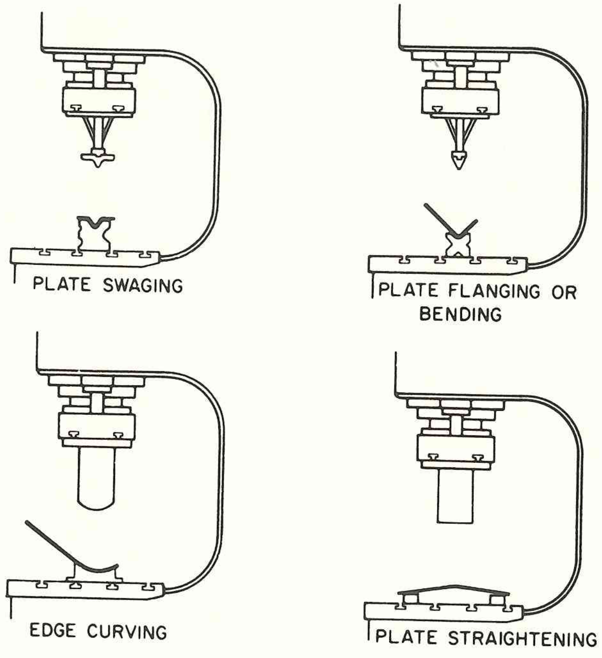


FIGURE 13.2 Gap presses

PLATE ROLLS Heavy duty bending rolls used for rolling shell plates, etc., to the correct curvature are hydraulically operated. Two lower rolls are provided and are made to revolve in the same direction so that the plate is fed between them and a slightly larger diameter top roll which runs idly (*see* Figure 13.3). Either or both ends of the top roll may be adjusted for height, and the two lower rolls have adjustable centres. With modern bending rolls, plates up to 45 mm thick may be handled and it is possible to roll plates to a half circle. These large rolls are also supplied with accessories to allow them to undertake heavy flanging work with the pressure exerted by the upper beam, for example, 'troughing' corrugated bulkhead sections.

Shorter pyramid full circle rolls are also used in shipyards, these being very useful for rolling plates to a full circle. This may be done to obtain large mast and derrick post sections for example, or bow thruster tunnel. Arrangements are made for removing the rolled full circle plate by releasing the top roller end bearing. Vertical rolls are also available and may be

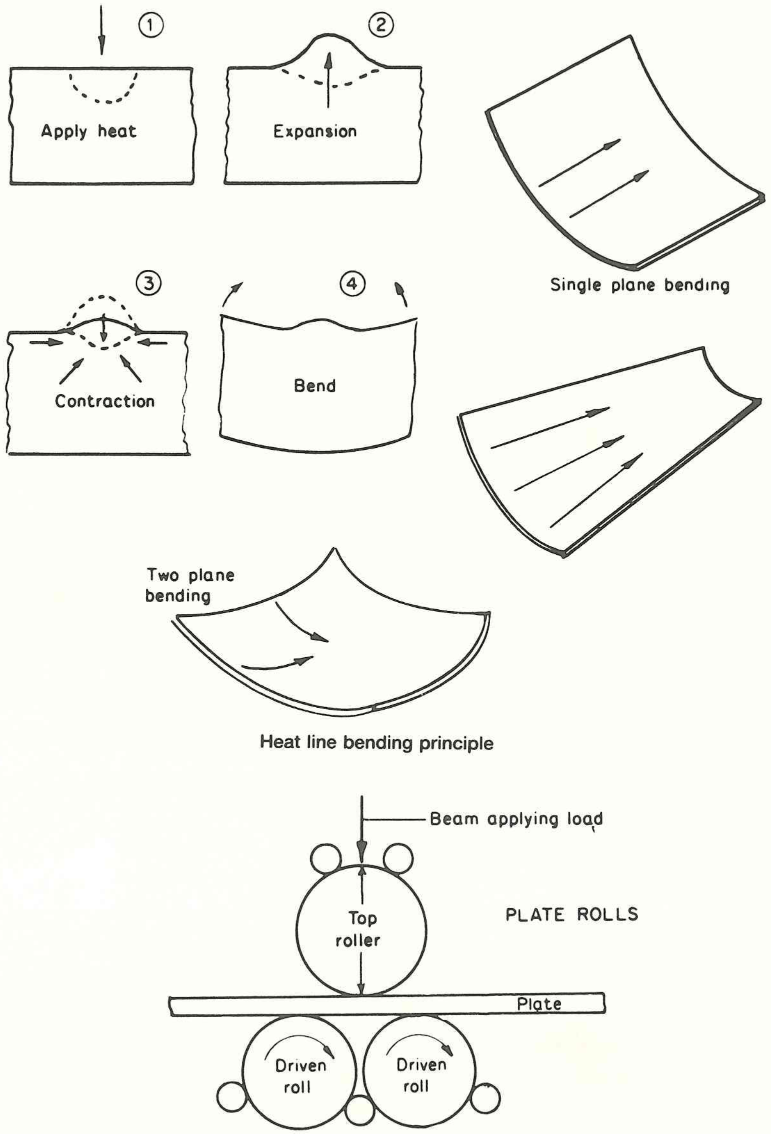


FIGURE 13.3 Forming shell plates

used to roll plates full circle, but can be much more useful for rolling heavy flats used as facing bars on transverses of large tankers, etc.

HEAT LINE BENDING A development of particular interest to shipbuilders is the 'heat line' bending procedure which can be used to obtain curvature in plates. This procedure is in use in a number of shipyards in the United Kingdom.

Heat is applied in a line to the surface of a plate by a flame torch, and then immediate cooling is obtained by air or water. The narrow heated line of material is prevented from expanding in the direction of the plate surface by the large mass of cold plate, and therefore expands outwards perpendicular to the plate surface. On cooling contraction will take place in the direction of the plate surface, causing the plate to become concave on the side to which heat was applied (*see* Figure 13.3). An experienced operator is able to make a pattern of such heat lines on a plate producing controlled distortion to obtain a required shape. Heat line bending can be more time consuming than using rolls or presses but it has an advantage in that the plate holds its form more accurately when stiffening and other members are added later in the fabrication process. This is an important consideration since shape inaccuracy can be critical at the erection stage in terms of lost production time.

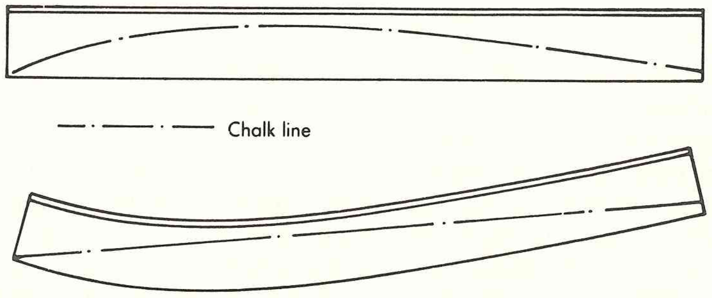
Frame Bending

The traditional system of bending side frames may still be in use for repair work, and is described as follows. A 'set-bar' which is a flat bar of soft iron is bent to the scrieve line of the frame on the scrieve board and then taken to the frame bending slabs. On these solid cast-iron slabs pierced with holes the line of the frame is marked, and modified to agree with the line of the toe of the frame. As the heated frame on cooling will tend to bend, the set-bar is sprung to allow for this change in curvature before it is fixed down on the bending slabs by means of 'dogs' and pins inserted in the slab holes. Whilst the set-bar is being fixed the frame section is heated in a long oil-fired furnace adjacent to the bending slabs. When at the right temperature it is pulled out onto the slabs and fixed with dogs and pins against the set-bar, as quickly as possible. Tools are available for forcing the frame round against the set-bar, including a portable hydraulic ram, and the toe of the web may require constant hammering to avoid buckling under compression.

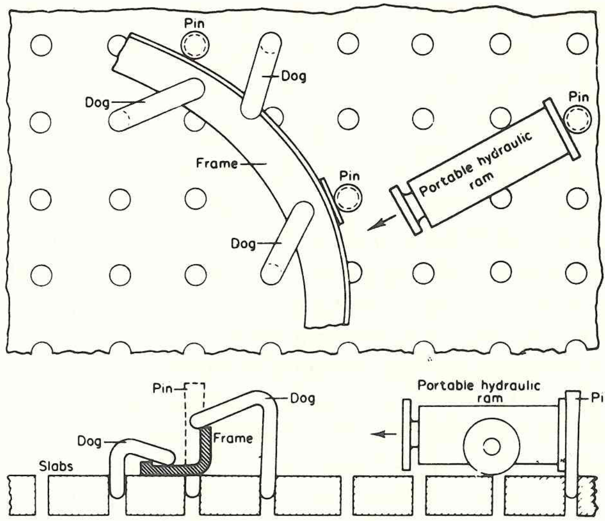
As the frames fitted have their webs perpendicular to the ship's centre line, all except those immediately amidships will require bevelling. A bevelling machine is available which is placed in front of the furnace door, and as the frame is removed it passes between its rollers which are controlled so that the flange is bent at every point to an angle indicated by a bevel board prepared by the mould loft.

Once bent the bar is put aside to cool, but is fastened down to prevent its warping in the vertical direction. When cold it is checked against the frame line drawn on the slabs. Meanwhile the set-bar is turned over and used to bend the corresponding frame for the opposite side of the ship.

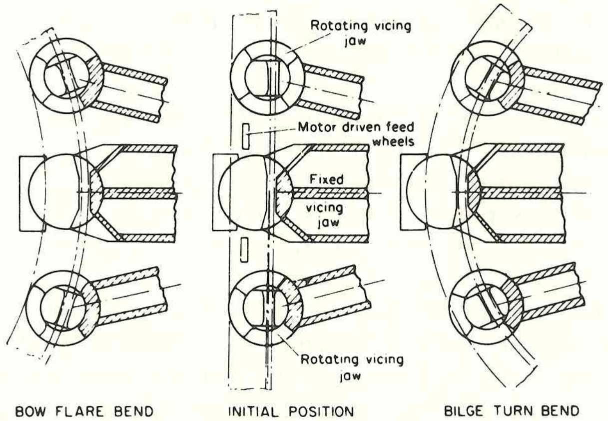
COLD FRAME BENDING It is now almost universal practice to cold bend



(a) Inverse curve bending principle



TRADITIONAL HEATED FRAME BENDING



COLD FRAME BENDING MACHINE (HYDRAULIC)

FIGURE 13.4 Frame bending

ship frames using commercially available machines for this purpose. The frames are progressively bent by application of a horizontal ram whilst the frame is held by gripping levers (Figure 13.4). Any type of rolled section can be bent in some machines with a limitation on the size of section. Obtaining the correct frame curvature can be achieved by the 'inverse curve' method or numerical control. With the 'inverse curve' method the inverse curve information can be determined for each frame by the loftsman using a CAD/CAM system. The inverse curve is drawn in chalk on the straight frame and the frame bent until the chalk line becomes straight on the curved frame (*see* Figure 13.4). A hydraulic cold frame bending machine can be controlled by numerical control tapes prepared in a similar manner to the numerically controlled flame profilers, the frame line being initially defined from the computer stored faired hull.

ROBOTICS Robots have in recent years been provided with improved control features which have made them more adaptable to the workshop floor situation. For example most robots are now available with some form of 'adaptive control' which provides feedback from the environment permitting, say, automatic adjustment of the robots path and/or its functions. Also the provision of 'off-line' programming and simulation packages makes it possible to develop and test programs for the robot remotely. Thus the robot carries on working whilst new programs are produced for it.

Many of the worlds shipyards and shipyard systems suppliers have been developing and implementing robots in shipbuilding. A large proportion of these developments have been in fully automating the machine welding processes described in Chapter 9 but other areas of adoption and trial have involved flame and plasma-arc cutting, local shot-blasting and painting, and marking. Robots developed to date for shipyard usage are either large gantry structures or small portable units. The former often have the movable robot mounted on the travelling gantry with sensors providing the adaptive control and are employed for cutting and welding processes. The latter can be manually transported, or self propelled even climbing vertically, or for robotic transportation, and have been used for local welding in difficult situations and cleaning and painting.

Many of the robot programming systems can be linked to the shipyards CAD system so that programs developed for the robot can be run 'off line' with the 3-dimensional graphics simulating the robots performance before it is put to work.

Whilst robots have advantages in their use in difficult and unpleasant work conditions and tedious repetitive work situations, their development and adoption is increasingly seen as a means to higher productivity and reduced manufacturing cost.

Further Reading

Andreassen, 'Mechanized ship and offshore module fabrication', *Shipbuilding and Marine Engineering International*, December, 1981.

Chadburn and Parker, 'A New Approach to Numerical Control for Shipbuilding', *Trans. R.I.N.A.*, 1969.

'Getting it right at Swan Hunter', *The Naval Architect*, September, 1984.

Kalogerakis, 'The use of robots in the shipbuilding industry', *The Naval Architect*, July/August, 1986.

Shama and Miller, 'A Design Study of a Numerically Controlled Frame Bending Machine', *Trans. R.I.N.A.*, 1967.

'Shipbuilding world looks on as Finns pioneer robotic gantry', *Metal Construction and British Welding Journal*, November, 1986.

14

Prefabrication

During the Second World War a large number of merchant and war ships were required to be built in a short period of time. These requirements speeded the adoption of welding in shipyards, and often led to the application of mass production techniques in shipbuilding. Prefabrication of ship units, that is the construction of individual sections of the ship's structure prior to erection, became a highly developed science. Often the units were manufactured at a location remote from the shipyard, and erection in the shipyards was carried out with schedules which still look very impressive today. Many of the more spectacular achievements in this field were obtained in the U.S.A. where much of the tonnage required during the war period was constructed using these new advances. Unfortunately the results of this crash building programme were not always entirely satisfactory; the reputation of welded structures for example suffered for quite a time as a result of wholesale application without a background of experience. Since the war prefabrication has gradually been applied to merchant ship construction as shipyards in this country have been modified to employ this technique and have gained experience of unit fabrication. Today virtually all vessels are to varying degrees prefabricated.

With riveted construction unit fabrication was rarely employed, the introduction of welding lent itself more favourably to this form of construction. With welding, simpler unit shapes (no staggered butts are required in the side shell for example) and less critical tolerances can be applied. Units may be constructed under cover, which is an attractive advantage in the British climate, not only because of working conditions, but because of the better welding conditions. It is possible to turn units over to allow downhand welding which is easier to perform and likely to provide better results. There is great advantage in keeping vertical and overhead welding to a minimum. Also central services are more readily available at the shop, with gases for cutting, air for chipping, and electric current for welding, being placed where needed. Production planning techniques may be adopted with prefabrication sequences, the material and labour being planned in unit groups and the whole shipbuilding sequence being controlled to fit the time allowed on the berth, or building dock.

Until well into the 1970s prefabrication in British yards was primarily concerned with the construction and erection of 2-dimensional and 3-dimensional steel units to form the ship structure into which the outfit and equipment was fitted at the berth and after launching at the fitting out quay. Piping systems, ventilation and the machinery units were fitted into the erected hull as independent items. Likewise the accommodation spaces were lined out and fitted with the furniture and other fittings *in situ*. Whilst the production methods applied to the steelwork fabrication and erection were time saving and cost-effective the haphazard and largely uncontrolled methods of outfitting detracted from the overall production engineering of the ship. Rather than plan outfit installation on a total ship system basis it is today common practice to plan this work for zone installation, the zone corresponding to a main compartment area which may be broken down into blocks or smaller assemblies. Pre-outfitting of each assembly or block may be of the order of 85–90 per cent. Both steelwork and outfit are highly planned for each assembly and block unit, and fabrication and outfit installation is undertaken at a work station where the facilities and material are supplied to the workforce.

Sub-Assemblies

When plates and sections have been machined they are ready for assembly into ship units. Within the fabrication shop there are often arranged a number of bays for different assemblies, for example flat plate panels, curved shell units, matrix or 'egg box' structures and some minor sub-assemblies. All these may be termed sub-assemblies if they are subsequently to be built into a large unit prior to erection. Panel assembly is usually highly automated with prepared plates being placed and tack welded prior to automatic welding of the butts, after which the plates are turned and back welded unless a single sided weld process has been used. The panel is marked and the stiffeners placed and welded automatically or with semi-automatic process. Minor sub-assemblies such as deep frames consisting of web and welded face flat may also be attached at this stage. Curved shell plates are placed on jigs and welded and the various stiffening members can be aligned and welded in a similar manner to those on a flat panel assembly. Assembly jigs may also be used for matrix or 'egg box' assemblies, for example structures of solid and bracket plate floors with longitudinal side girders which are to go into double bottom units.

Unit Fabrication

In most instances the 2-dimensional sub-assemblies will be built into 3-dimensional block assemblies. The size of the block assembly will have been decided at an early stage of the planning process ideally at the structural design stage. Constraints such as lifting capacities and dimensions that can be handled are taken into consideration also the provision of breaks at natural features ensuring the blocks are self supporting and easily accessed etc. Panel assemblies used in the block may well have dimensions restricted by the plate length that can be handled at the machining stage and this can subsequently influence block length. In the machinery area the block size and arrangements can be decided by zone outfit considerations.

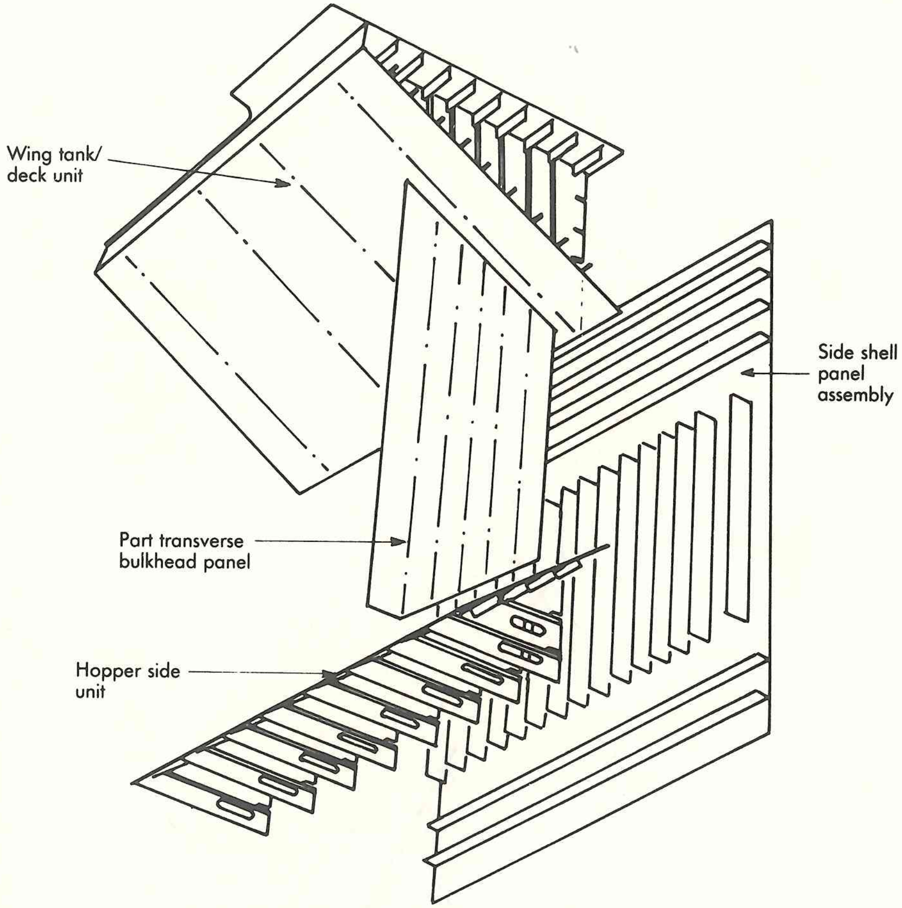


FIGURE 14.1 Bulk carrier side block unit

Each block should be designed for maximum downhand welding but may have to be turned for this purpose. Also blocks are turned to effect outfit installation particularly those containing machinery flats in the aft engine room areas where pipework etc. can be fitted on the underside of the flat with the block in the inverted position and then it is turned to install equipment above the flat (*see* Figure 14.3). A block's centre of gravity is calculated and lifting lugs so provided that these operations can be under-

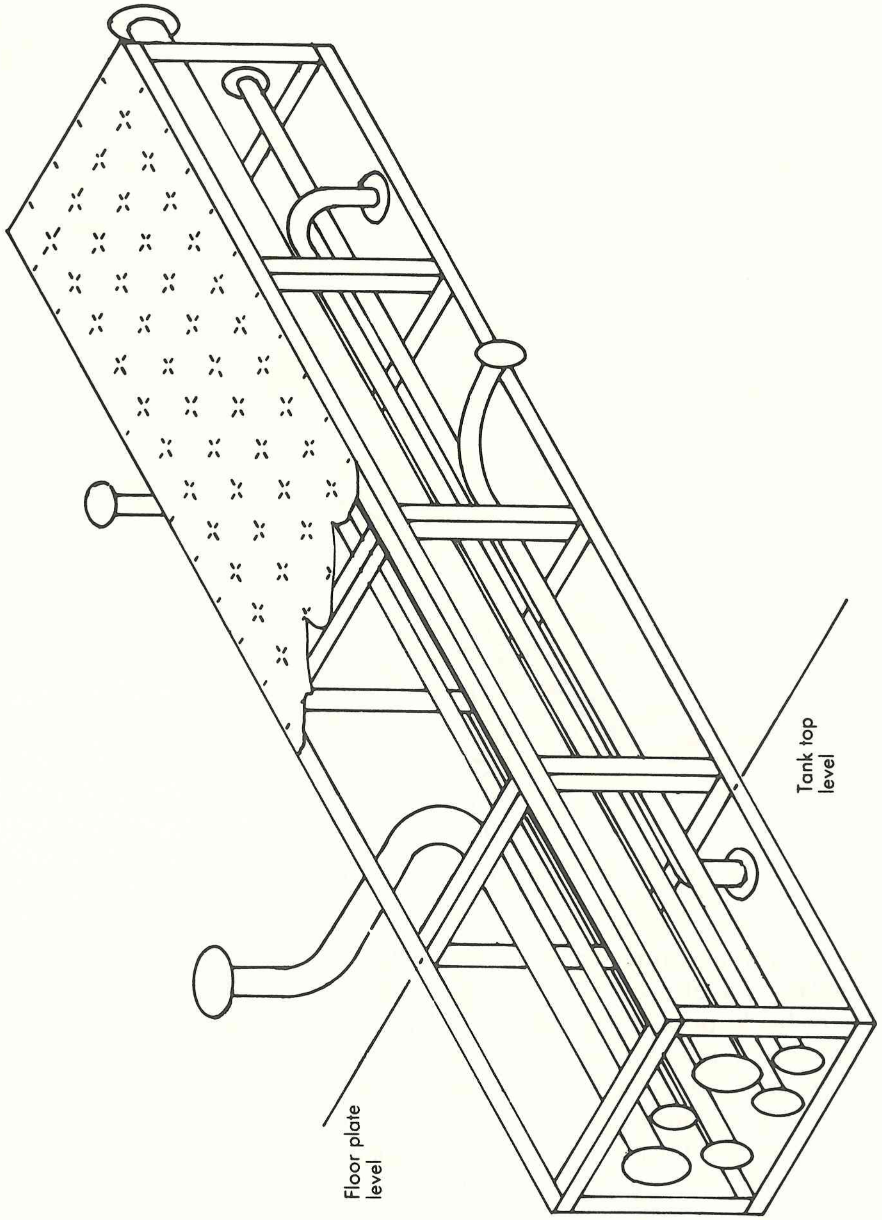


FIGURE 14.2 Pipe module

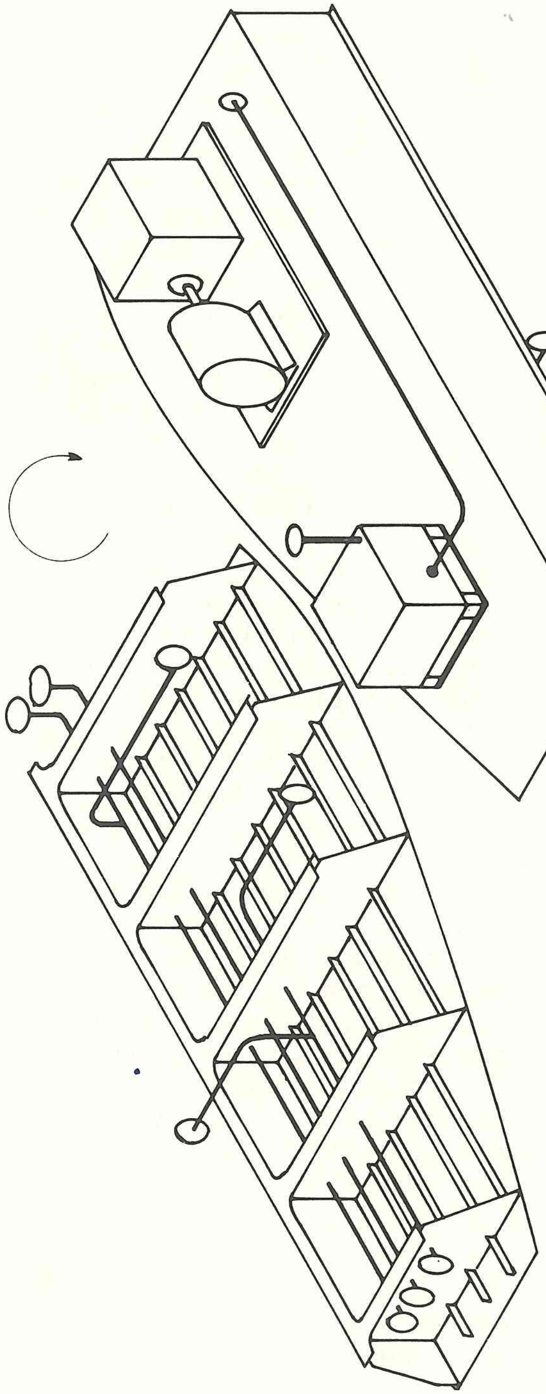


FIGURE 14.3 Assembly unit outfitted both sides

taken, and finally the block can be suspended for erection at the building dock or berth and drop into place in the correct plane.

Outfit Modules

Units of machinery, pipework and other outfit systems required for a specific zone can be planned and built up into modules and installed as such into a block fabrication. Pipework in particular lends itself to this form of assembly and can, with careful planning from the CAD stage, be arranged in groupings so that pipe bank modules can be arranged for a particular zone. Modules can range from a small pipe bank supported by light framing of pipe hangers, or a complete auxiliary machinery unit on its seating which has even been test run prior to installation, to a large modular unit which together with several similar units constitutes the bulk of a complete engine room. The latter have been developed in one European shipyard where macro-modules of the order of 10 m × 10 m × 4 m made up of square rolled hollow sections (which function as pillars when installed) and horizontal parts of the ship's structure such as flats are completely outfitted. A number of these macro-modules erected around the main engine are indistinguishable from a conventional engine room. Sub-contractors are encouraged by the shipyards to supply their equipment in module form.

Not all outfits can be incorporated into modules and a large number of piece parts have to be provided for fitting in any given zone at a particular time within the assembly shops. To maintain production engineering standards a concept of 'palletisation' has been developed whereby the piece parts for that zone are generated at the CAD/CAM stage, bought in and/or fabricated etc. and made available at the work station when the particular assembly is ready to receive them.

An 'open top' arrangement for blocks or smaller ships being outfitted under cover can facilitate installation of the items and modules.

Superstructure blocks are fabricated separately and pre-outfitted with accommodation before erection as a complete unit. Modular cabin units are a common feature of modern shipbuilding, some companies specialising in their production. Figure 14.4 shows a typical self supporting cabin/toilet module complete with pipework, ventilation, electrical fittings, wiring, and all built in furniture. An accommodation block must be specifically designed for such modules and the sequence of module access and placement in the block carefully planned.

Unit Erection

When any panel and the block assemblies are complete there will be some time buffer before their erection at the building berth or dock to allow for

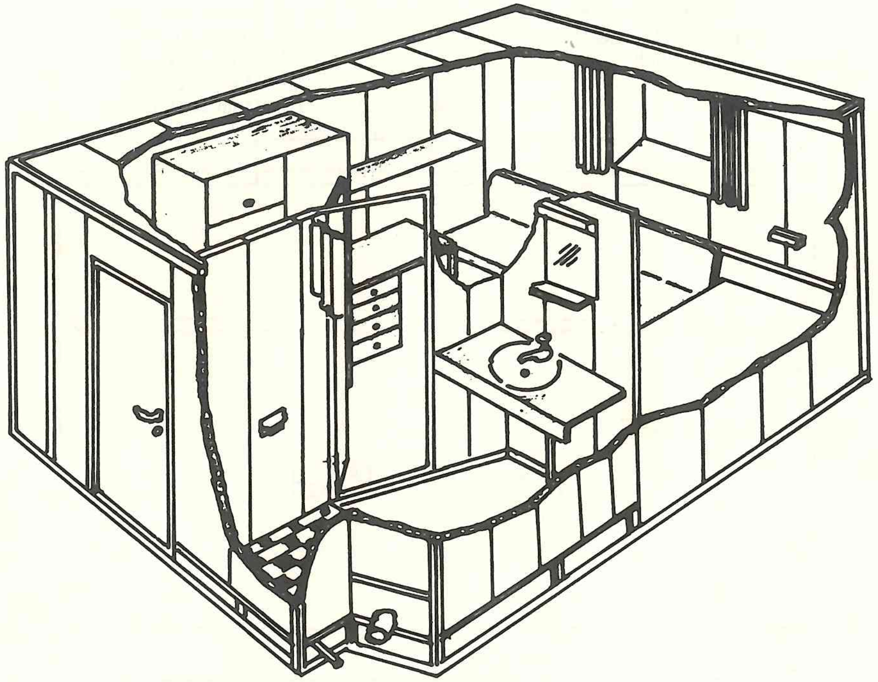


FIGURE 14.4 Cabin/toilet module

mishaps in the production schedule. Stowage is generally adjacent to the building hall and will vary in size according to the yard's practice, some yards storing a large number of units before transferring them to the berth or dock for erection in order to cut the berth/dock time to a minimum.

Sequences of erection for any particular ship vary from shipyard to shipyard and depend on a number of factors. Experience of previous ship erection schedules and difficulties given the yard's physical and equipment constraints leads to standard practices being established. These are taken into consideration at the structural design stage as are the desirability of minimizing positional welding and fairing. In general it is common practice to make a start in the region of the machinery spaces aft, obviously working from the bottom upwards, and also forward and aft. In earlier times this was done to give the engineers and other outfit workers early access to these spaces, but with the amount of pre-outfit this might not be considered so important. However, this area does still require the larger amount of finishing work. In particular the boring of the stern for the tailshaft is preferably undertaken when the after sections are fully faired and welded.

Typical erection sequences for a general cargo ship, oil tanker, and bulk

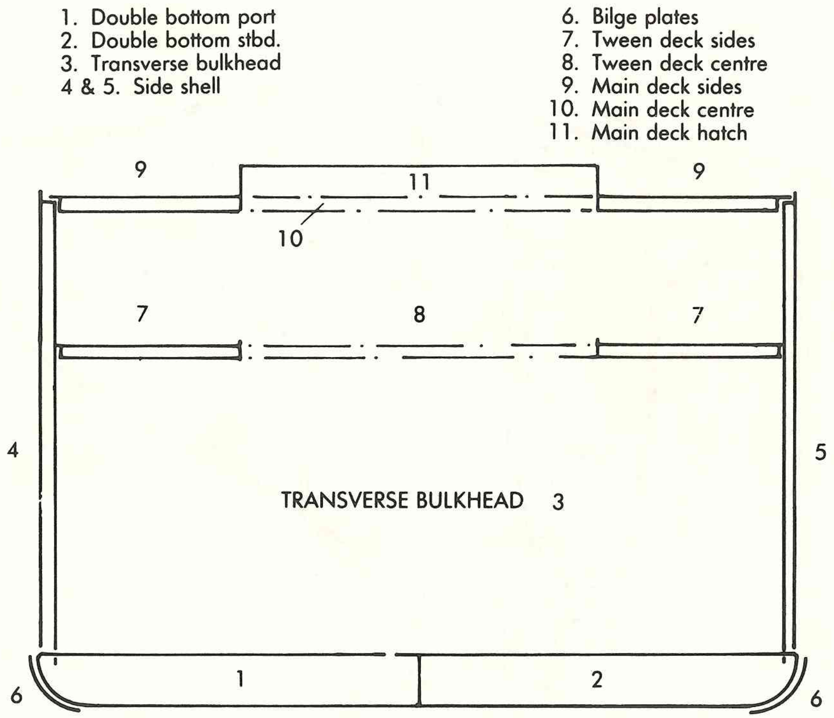


FIGURE 14.5 An erection sequence for a general cargo ship

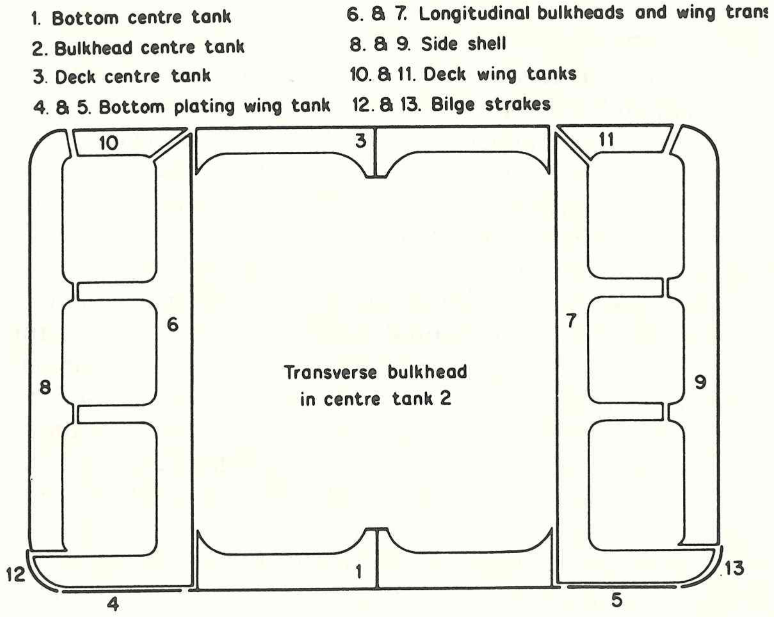


FIGURE 14.6 An erection sequence for a bulk oil tanker

carrier are shown in Figures 14.5, 14.6 and 14.7 respectively. The block assemblies for the bulk carrier are shown in Figure 14.8.

In erecting the ship units it is important to employ the correct welding sequences. These are arranged to avoid excessive 'locked in' stresses; and overlapping frames, longitudinals, stiffeners etc. may be left unwelded across unit seams and butts until these are completed in a similar manner to that described in Chapter 10.

In erecting units tolerances are a problem, more so on 3-dimensional units than with 2-dimensional units and particularly at the shaped ends of the ship where 'green' material is often left. Quality control procedures in the manufacturing shops to ensure correct dimensioning and alignment are very necessary if time-consuming, expensive and arduous work at the berth is to be avoided. Improvements in this area have been made with the use of accurate jigs for curved shell units, planned weld sequences, and use of lower heat input welding equipment, dimensional checks on piece parts, and the use of laser alignment tools for setting up datums and checking interfaces. Tolerance allowance data is built up with experience and can become very accurate when building standard ships.

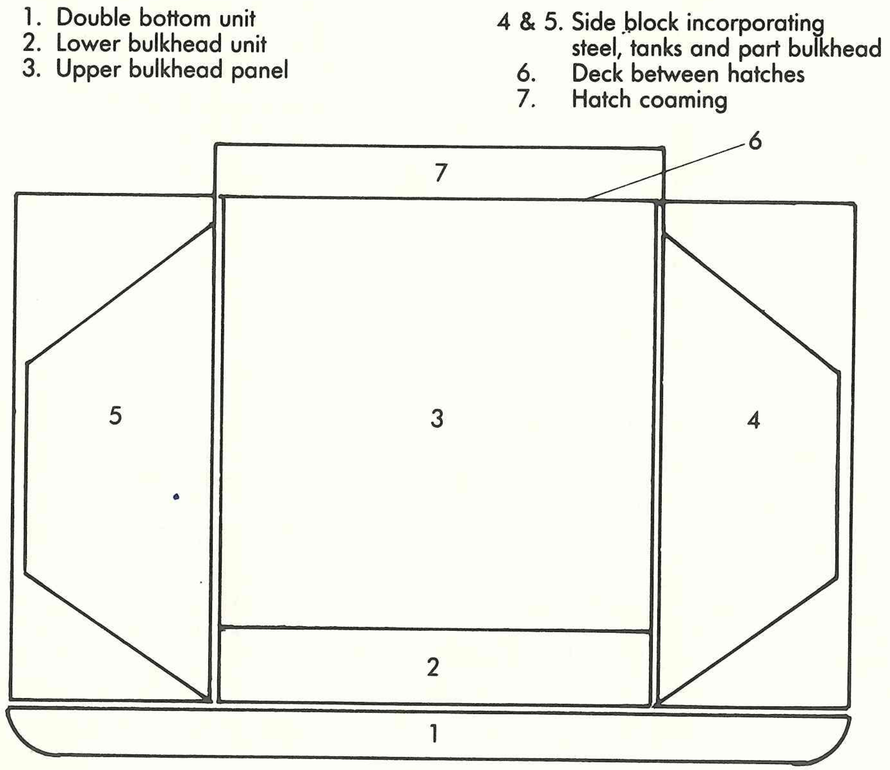


FIGURE 14.7 An erection sequence for a dry cargo bulk carrier

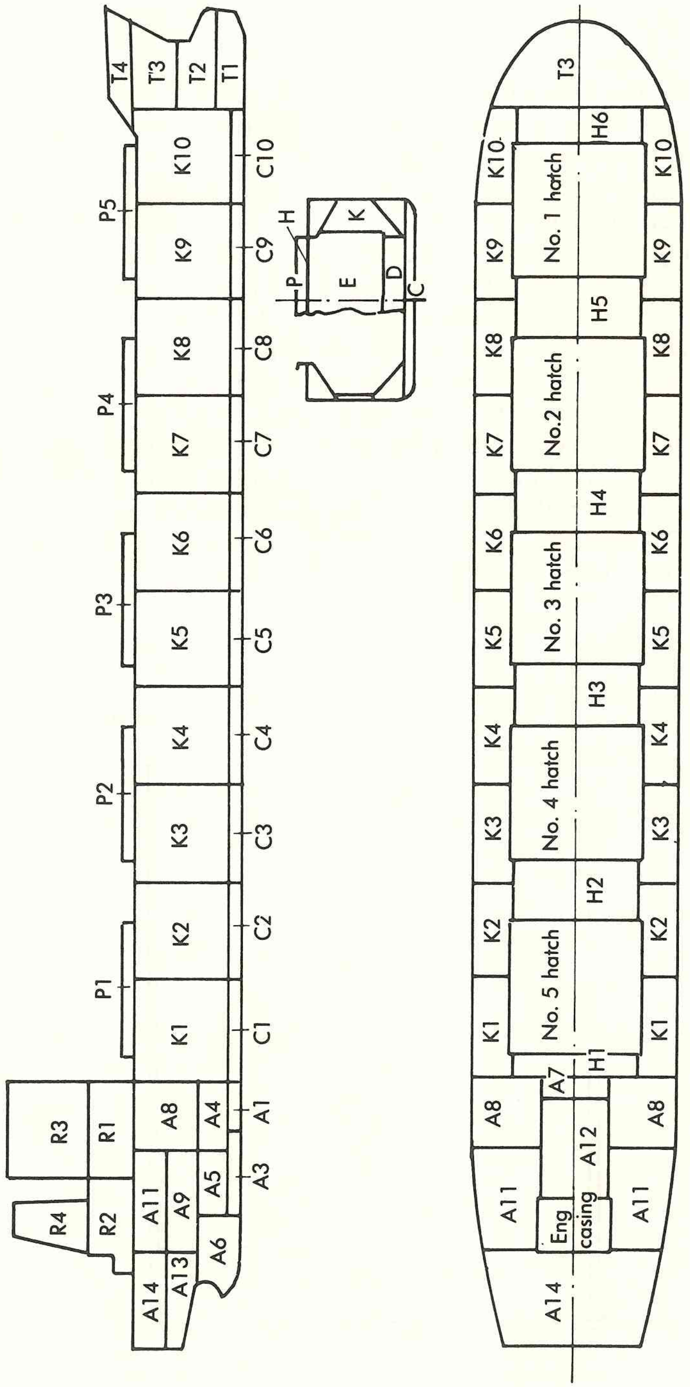


FIGURE 14.8 Typical block erection

Joining Ship Sections Afloat

Owing to the enormous increase in size of bulk carriers and tankers, shipyards with restricted facilities, berth size particularly, have examined various means of building these large ships in sections which are to be joined off the berth. In most cases the problem becomes one of joining the two hull sections afloat or in a dry-dock of sufficient size where available. Where the sections are to be joined afloat extremely accurate fit up of the sections is aided by the possibilities of ballasting the two ship halves. The two sections may then be pulled together by tackles; and for the finer adjustments hydraulic cylinders may be used, extremely accurate optical instruments being employed to mark off the sections for alignment. One method adopted is that where a cofferdam is arranged in way of the joint, a caisson is brought up against the ship's hull, and the cofferdam and caisson are pumped dry. To balance any tendency for the vessel to hog during the pumping of the cofferdam it is necessary to shift ballast in the fore and aft sections. Once the spaces are dried out welding of the complete joint may be undertaken, the resulting weld being X-rayed to test the soundness of such a critical joint. On completion of the paint scheme in way of the joint the caisson is removed.

A similar method makes use of a rubber 'U' form ring rather than a caisson which needs modification for each ship size.

If a dry-dock is available the sections may be aligned afloat and even welded above the waterline, the rest of the joint or the complete joint being secured by strongbacks. The welding of the rest or the whole joint is carried out in the dock.

Further Reading

Belch, 'Construction of Very Large Tankers in Two Parts', *The Naval Architect*, July, 1976.

Fredriksson, 'Tolerances in the Prefabrication of Ships', *Trans. R.I.N.A.*, 1962.

Proceedings of the Seminar on Advances in Design for Production, University of Southampton, April, 1984.

'Some Aspects of Building Mammoth Tankers in Two Halves', *Metal Construction and British Welding Journal*, vol. 1, No. 3, March, 1969.

'Structural Design and Fabrication in Shipbuilding', International Conference 18–20 November, 1975, London, The Welding Institute.

15
Launching

Launching involves the transference of the weight of the ship from the keel blocks, shores, etc., on which it was supported during construction, to a cradle on which it is allowed to slide into the water. Normally the vessel is launched end on, stern first, but a number of shipyards located on rivers or other narrow channels are obliged to launch the vessel sideways. Vessels have been launched bow first, but this is a rare occurrence as the buoyancy and weight moments, also the braking force, are generally more favourable when the vessel is launched stern first.

End Launches

On release of a holding mechanism the launching cradle with the ship slides down the ground ways under the action of gravity. When the stern has entered the water the vessel is partly supported by buoyancy and partly by the ground ways. If this buoyancy is inadequate after the centre of gravity of the ship has passed the way ends, the ship may tip about the way ends causing large pressures on the bottom shell and on the ends of the ground ways. To avoid this the greatest depth of water over the way ends should be utilized, and the ground ways extended into the water if necessary. Where this proves impossible it becomes necessary to strengthen the way ends and provide shoring in the bottom shell region which is likely to be damaged. These remedies are often expensive.

As the vessel travels further into the water the buoyancy becomes sufficient to lift the stern. The vessel then pivots about the forward poppets, i.e. the fore end of the launching cradle. These are designed to take the load thrown on them by the pivoting action, the load being widely distributed in order not to squeeze out the lubricant between the sliding surfaces. Shoring may also be found necessary forward in the ship to prevent structural damage at the time the stern lifts.

BUILDING SLIP Conventional slipways or berths are relatively solid and reinforced with piles to allow them to sustain the weights of ships built upon them. During building the keel blocks take the greater part of the weight, the remainder being carried by shores, and where used bilge blocks. Foundations under the probable positions of ground ways should also be

substantial since during a launch the ways are subject to large pressures.

Keel blocks are arranged so that the height of keel above the ground is 1.25 to 1.5 m, giving reasonable access, but not too high so that a large amount of packing is required (*see* Figure 15.1). At the bow the height of the keel must be sufficient to allow the ship's forefoot to dip the required amount without striking the ground during pivoting when the stern lifts at launch. To suit the declivity of the launching ways determined beforehand, the keel is also inclined to the horizontal at about 1 in 20, or more where the shipyard berths have a larger slope.

To transfer the ship from the building blocks to the launching cradle, the commonest practice is to drive wedges into the launching cradle. This lifts the ship and permits the removal of the keel and bilge blocks together with the shores. In large ships it becomes necessary to split the blocks to remove them, but several types of collapsible blocks have been used to overcome this difficulty. One type is the sand box which contains sand to a depth of 80 to 100 mm held in a steel frame located between two of the wooden blocks. This steel frame may be removed and the sand allowed to run out. Another type is a wooden block sawn diagonally, the two halves being bolted so that they collapse on removal of the bolts.

LAUNCHING WAYS AND CRADLE The fixed ground ways or standing ways on which the cradle and ship slide may be straight or have a fore and aft camber. Transversely the ground ways are normally laid straight but can be canted inwards to suit the ship's rise of floor. Usually the ground ways have a small uniform fore and aft camber say 1 in 400, the ways being the arc of a circle of large radius. This means that the lower part of the ways has a greater declivity (say 1 in 16) than the upper part of the ways (say 1 in 25). As a result a greater buoyancy for the same travel of the ship beyond the way ends is obtained, which will reduce the way end pressures. Additional advantages are increased water resistance slowing the vessel, and a bow height which is not excessive. The slope of ground ways must be adequate to allow the vessel to start sliding; and if too steep, a large amount of shoring will be required to support the bow; also the loads on the releasing arrangements will be high. Straight sliding ways have declivities of the order of 1 in 25 to 1 in 16.

Generally two ground ways are fitted, the distance between the ways being about one-third the beam of the ship. It is often desirable that the cradle should be fitted in way of longitudinal structural members, and the ground ways over slipway piling, these considerations deciding the exact spacing. Some large ships have been launched on as many as four ways, and in the Netherlands it appears to be common practice to launch vessels on a single centre line ground way. The width of the ways should be such that the launching weight of the ship does not produce pressures exceeding about 20 tonnes per square metre.

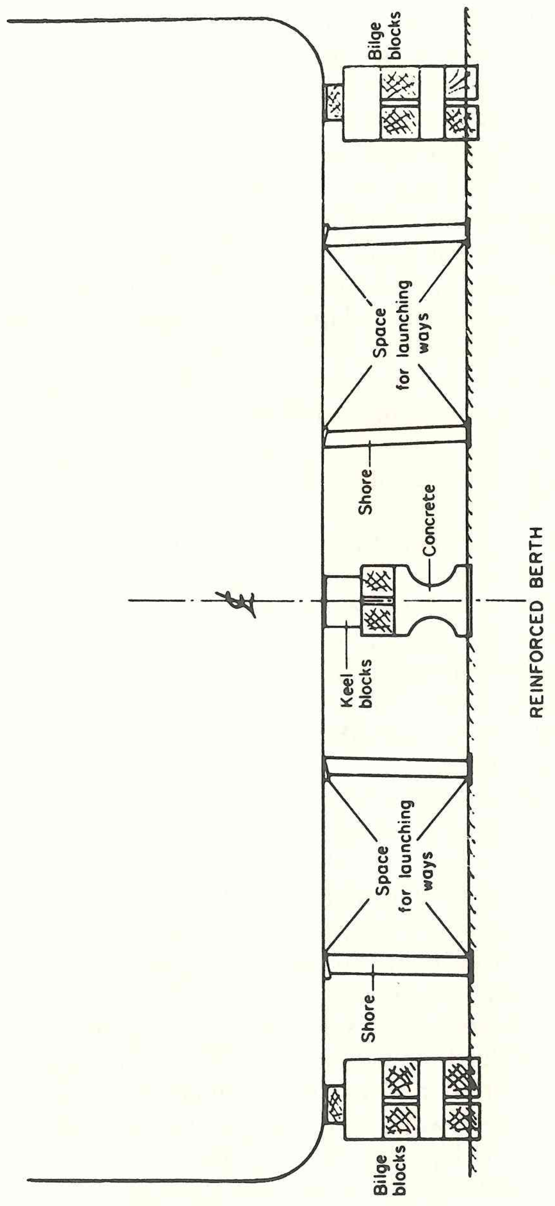


FIGURE 15.1 Building blocks

Ground ways are laid on supporting blocks and extend down to the low water mark so that they are covered by at least one metre of water at high tide. To guide the sliding ways as they move over the ground ways a ribband may be fitted to the outer edge of the ground ways. This could be fitted to the inner edge of the sliding ways, but when fitted to the ground ways has the advantage that it aids retention of the lubricating grease. Finally the ground ways are shored transversely to prevent sideways movement and longitudinally to prevent them from moving down with the ship.

The sliding ways covering about 80 per cent of the length of the vessel form the lower part of the cradle, the upper part consisting of packing, wedges, and baulks of timber with some packing fitted neatly to the line of the hull in way of the framing. In very fine lined vessels the forward end of the cradle referred to as the forward poppet will require to be relatively high, and may be built up of vertical timber props tied together by stringers or ribbands. This forward poppet will experience a maximum load which may be as much as 20 to 25 per cent of the ship's weight when the stern lifts. It is therefore designed to carry a load of this magnitude; but there is a danger in the fine lined vessel of the forward poppets being forced outwards by the downward force, i.e. the bow might break through the poppets. To prevent this, cross ties or spreaders may be passed below the forefoot of the vessel and brackets may be temporarily fastened to the shell plating at the heads of the poppets. In addition saddle plates taken under the forefoot of the ship with packing between them and the shell may be fitted to transmit the load to the fore poppets and hence ground ways.

In many modern ships the bow sections are relatively full and little support is required above the fore end of the sliding ways. Here short plate brackets may be temporarily welded between the shell plating and heavy plate wedge rider as illustrated in Figure 15.2. The design of the forward poppets is based on greater pressures than the lubricant between the sliding ways and ground ways could withstand if applied for any length of time. However as the duration of pivoting is small, and the vessel has sufficient momentum to prevent sticking at this stage, these high pressures are permissible.

At the after end of the cradle considerable packing may also be required, and again vertical timber props or plate brackets may be fitted to form the after poppet.

LUBRICANT For the ship to start sliding on release of the holding arrangements it is necessary for the ship to overcome the coefficient of friction of the launching lubricant. To do this the slope of the ways under the vessel's centre of gravity must exceed the lubricant's coefficient of friction. An estimate of the frictional resistance of the grease must be made before building the ship since the declivity of the keel is dependent to a large extent on the slope of the ways.

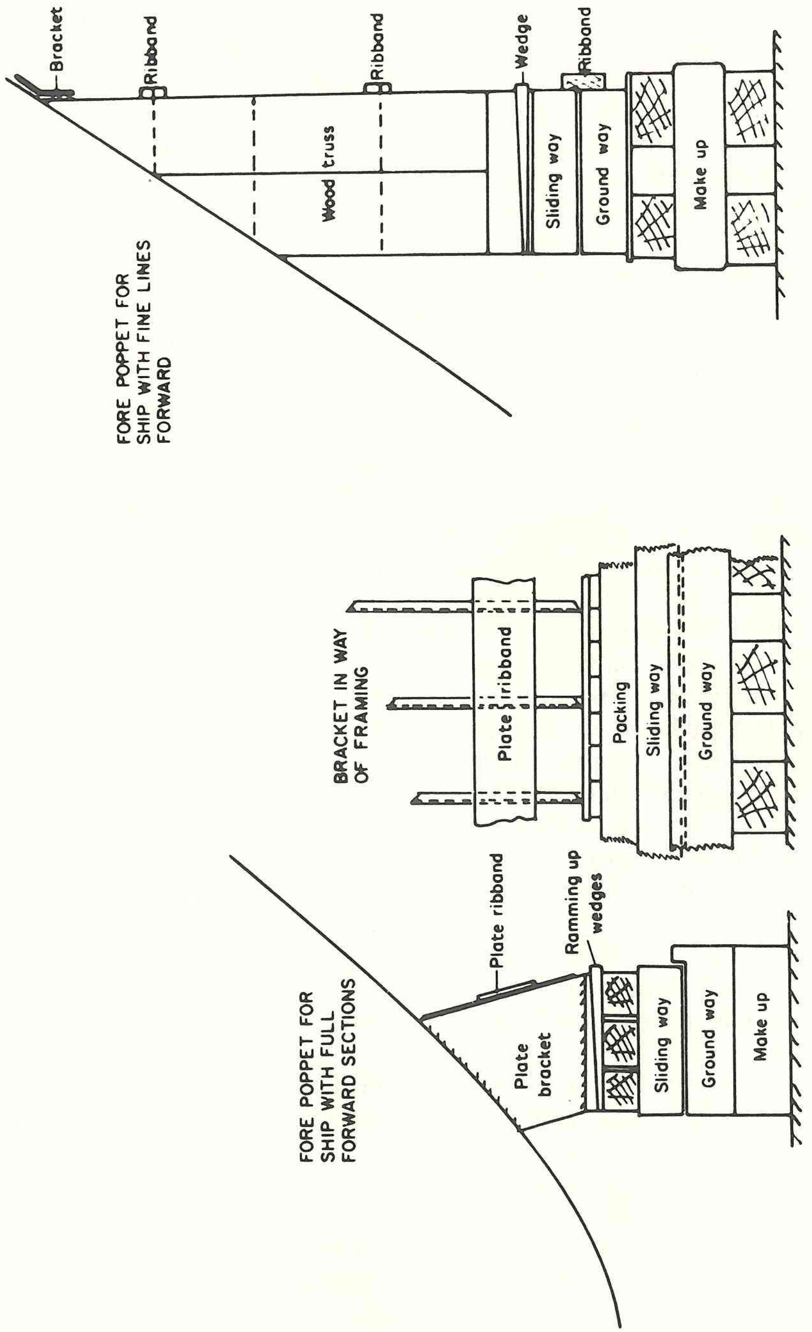


FIGURE 15.2 Launching ways—fore poppet

Formerly melted tallow was applied to the ways, allowed to harden, then covered with a coat of soft soap. Present practice is to apply mineral based greases to the ground ways, these greases being virtually unaffected by temperature changes and insoluble in water whilst adhering firmly to the ways. A commercially marketed petroleum-based launching grease is applied over the mineral grease base coat. This has a coefficient of friction which is low enough to allow initial starting and the maintenance of sliding until the initial resistance of the base coat is overcome by frictional heat. To prevent the petroleum-based grease from soaking into the sliding ways a base coat may be applied to them. Standing ways which extend into the water may be dried out at low tide prior to the launch and the base coat and grease applied.

RELEASING ARRANGEMENTS Small ships may be released by knocking away a diagonal dog-shore (*see* Figure 15.3) fitted between the sliding and standing ways.

In most cases however triggers are used to release the ship. There are several types available, hydraulic, mechanical, and electrical-mechanical triggers having been used. Electrical-mechanical triggers are commonly used for rapid simultaneous release in modern practice; the hydraulic trigger is less easily installed and less safe. The electrical-mechanical trigger illustrated in Figure 15.3 is generally located near amidships and a small pit is provided in the berth to accommodate the falling levers. A number of triggers will be fitted depending on the size of the vessel to be launched; in the case of the 75 000-tonne bulk carrier for which a launching sequence is given below six triggers were fitted for the launch.

These triggers are in effect a simple system of levers which allow the large loads acting down the ways to be balanced by a small load on the releasing gear. The principle is often compared with that of a simple mechanical reduction gearing. Simultaneous release of the triggers is achieved by means of catches held by solenoids wired in a common circuit. These are released immediately the circuit current is reversed.

LAUNCHING SEQUENCE As a guide to the procedure leading up to the launch, the following example is given for the launch of a 75 000-tonne bulk carrier. The launch ways have been built up as the ship is erected from aft; the ways have been greased and the cradle erected.

1. Four days before launch a start is made on ramming up the launch blocks, i.e. driving in the wedges (Figure 15.2) to raise ship off the building blocks. This is done by a dozen or so men using a long ramming pole, a gang working either side of the ship.
2. Two days before the launch a start is made on removing the shores.

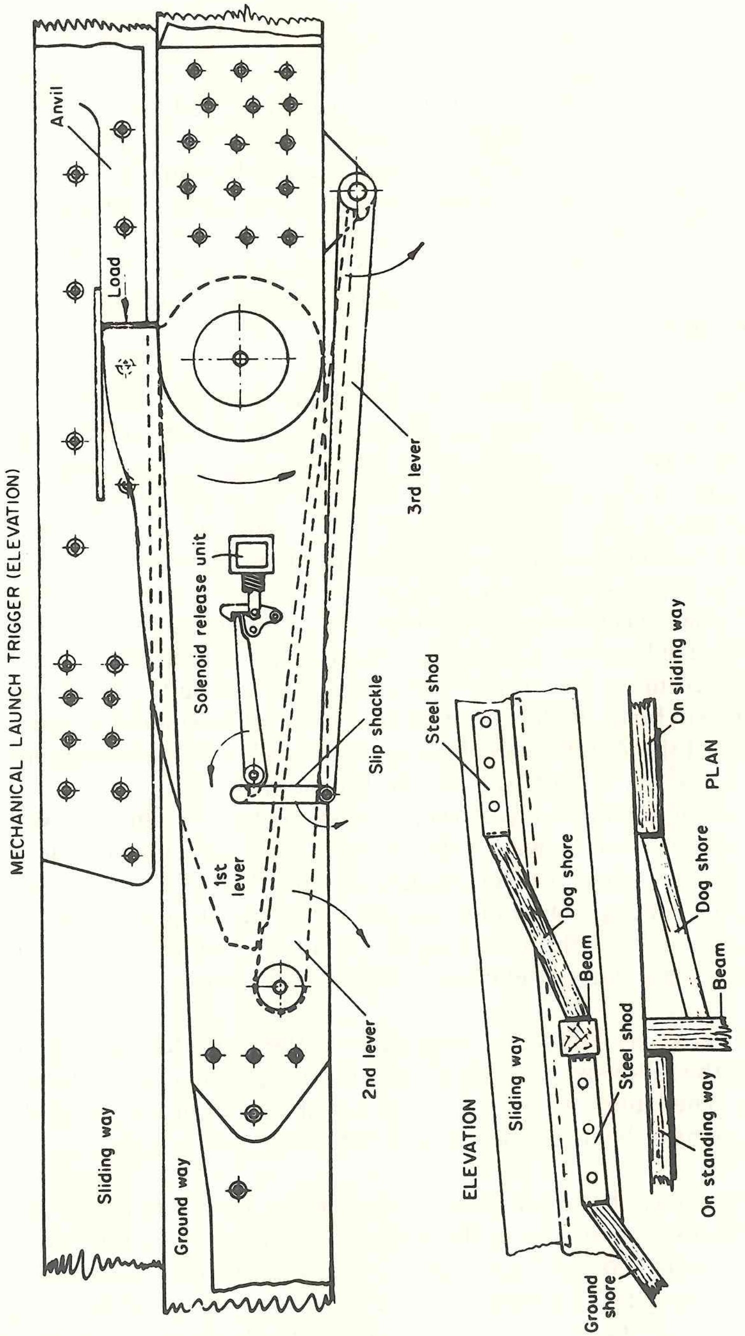


FIGURE 15.3 Release arrangements for ship launch

3. On the morning of the launch everything is removed up to the high water mark and tumbler shores are put in aft. These are inclined shores which fall away as the ship starts to move.
4. Every second keel block is then removed, and the vessel is allowed to settle.
5. An evenly distributed number of keel blocks are then taken out so that only about twenty keel blocks are left supporting the ships.
6. Half an hour before the launch the last remaining keel blocks are removed.
7. The bilge blocks are then removed.
8. The full ship's weight comes on the triggers at the time planned for the launch.
9. Release of triggers on launch by sponsor.

If the vessel fails to start under the action of gravity, the initial movement may be aided by hydraulic starting rams which are provided at the head of the cradle.

ARRESTING ARRANGEMENTS In many cases the extent of the water into which the ship is launched is restricted. It is then necessary to provide means of arresting the motion of the ship once it is in the water. There are a number of methods available for doing this, one or more being employed at most ship launches.

The commonest arrangement is to use chain drags which are generally arranged symmetrically on either side of the ship. Each chain drag is laid in the form of a horseshoe with its rounded portion away from the water, so that as the ship moves down the ways the forward portion of the drag is pulled through the remainder of the pile. This prevents any excessive shock load in the chain which would occur if the pile of chain were to be suddenly accelerated to the speed of the ship. The wire rope drag lines are attached to temporary pads on the side of the ship, and supported by rope tricing lines as they are led slightly forward and then aft along the ship's sides. Each drag line is then led forward and shackled to the chain drag (*see* Figure 15.4). As the ship is released and moves aft the tricing lines are broken in turn, the work done absorbing some of the ship's energy.

To further increase the resistance to motion of the ship wooden masks may be fitted at the stern of the ship. The mask is made as large as possible but located low down to present a flat surface to the water in the direction of the motion. Masks are often constructed of horizontal pieces of wood with spaces left between each piece to increase the resistance.

One or two shipyards are forced to provide arrangements for slewing the vessel once it has left the ways, as the river into which the ships are launched is very narrow in relation to the ship's length. Chain drags, weights, or anchors may be placed in the water to one side of the building berth for this

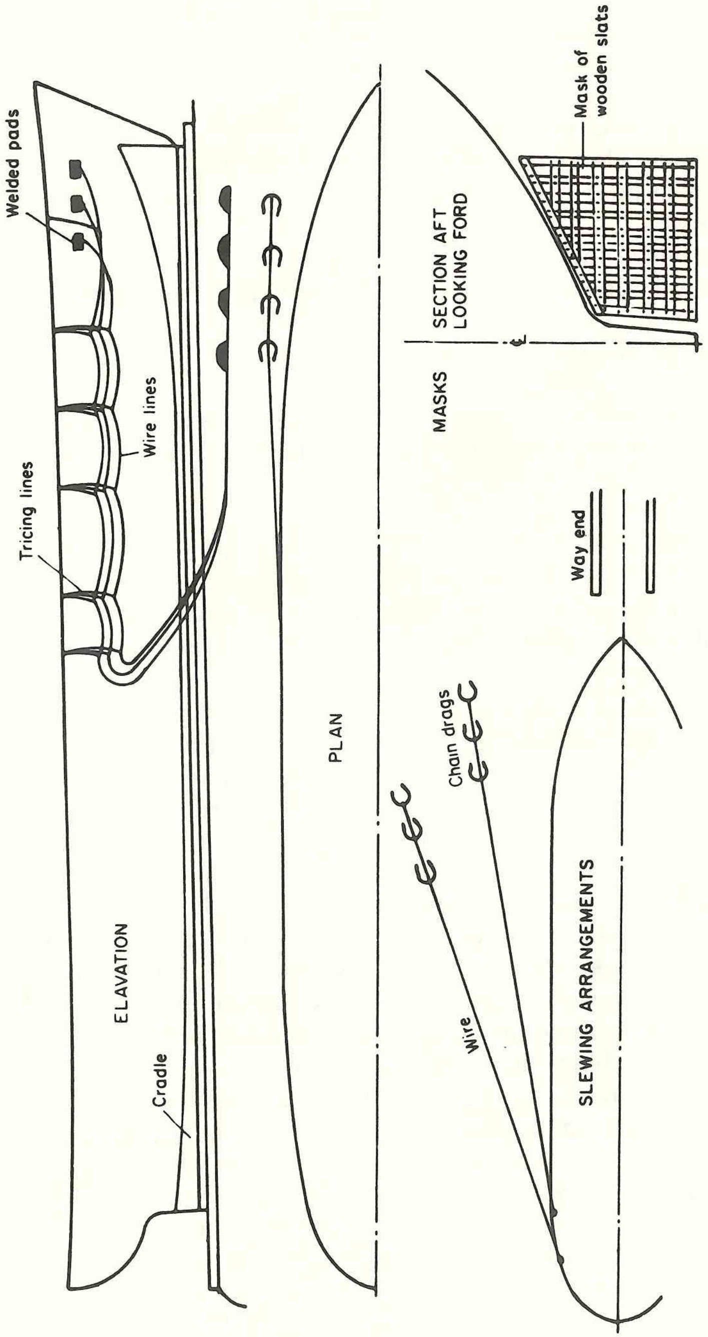


FIGURE 15.4 Arresting arrangements at launch

purpose. These are then made fast to the stern of the ship with drag lines of a predetermined length. Once the vessel is clear of the ways the slack of the lines is taken up and the stern swings so that the ship is pointing up river.

Side Launches

Side launching is often used where the width of water available is considerably restricted. There are in fact some advantages to this method, for example the absence of keel declivity, and the relatively simple cradle and short ground ways which do not extend into the water. However it means that a large area of waterfront is taken up by a single building berth, and the ship is only reasonably accessible from one side during construction.

The ground ways are arranged transversely, i.e. at right angles to the line of keel. Sliding ways also can be placed transversely with the packing above them forming the cradle, but they are generally arranged longitudinally. In this case where they are parallel to the keel the sliding ways are in groups covering two or three ground ways. Packing again forms the cradle with tie pieces between the groups of sliding ways.

One of the features of side launching is the drop where the ground ways are not extended into the water; consequently large angles of heel occur when the vessel strikes the water. As a result it is necessary to carry out careful stability calculations and close any openings before side launching a vessel. It is true of course that stability calculations are also required for a conventional end launch.

Building Docks

Perhaps the greatest advantage of the building dock is the relative simplicity of the task of getting the vessel waterborne. When it is convenient the dock may be flooded and the vessel floated out. Calculations are needed to check the stability and loads exerted by the blocks during flooding, the whole problem being similar to that of un-docking a vessel which has been dry-docked for survey or other reasons.

In some shipyards conventional berths are fitted at their river end with what is virtually a pair of dock gates. This can be of advantage when working the aft end of the ship and installing the ways. In many instances it also permits higher tides over the way ends when the gates are opened for a launch.

Ship Lifts

Whilst large ships may be extruded out of building halls on to a slipway (Chapter 11) and large sections transferred by similar means to the head of the slipway and raised on to it for joining and launching, smaller complete ships may be transferred to a ship lift for launching. Rail systems are incorporated into the building hall and lead out to the open ship lift. The best known of these ship lift systems is the patented 'Syncrolift' originally used for slipping ships for repairs and surveys but now also used by many shipyards for launching new ships. Ship lifts basically consist of platforms which can be lowered into the water and the ship landed on or floated off the platform. The platform is raised and lowered mechanically or hydraulically and is usually provided with transfer arrangements so that the vessel can be moved on or off the platform either laterally or in line with the platform.

Further Reading

Doust, 'Side Launching of Ships with Special Reference to Trawlers', *Trans. I.N.A.*, 1955.

Rowell, 'Launching Triggers', *Trans. N.E.C. Inst.*, vol. 61, 1945.

Smith and Vardon, 'Way end pressure loading and ship response during launching', *The Naval Architect*, September, 1977.

Taylor and Williams, 'Dynamic Loading on Launching Ways and Building Berths', *Trans. I.E.S.S.*, 1966–67.

Part 5

Ship Structure

Note

Throughout this Part of the book a number of requirements relating to the spacing and scantlings of various structural members are given. These are taken from Lloyd's Register Rules and are introduced to give the student an idea of the variation in dimensions and scantlings found within the ship structure. Other classification society requirements may differ, but basically the overall structure would have the same characteristics. It should be borne in mind that owner's additional requirements will result in many ships having greater scantlings and additional strengthening to the minimum indicated in the following chapters.

16
Bottom Structure

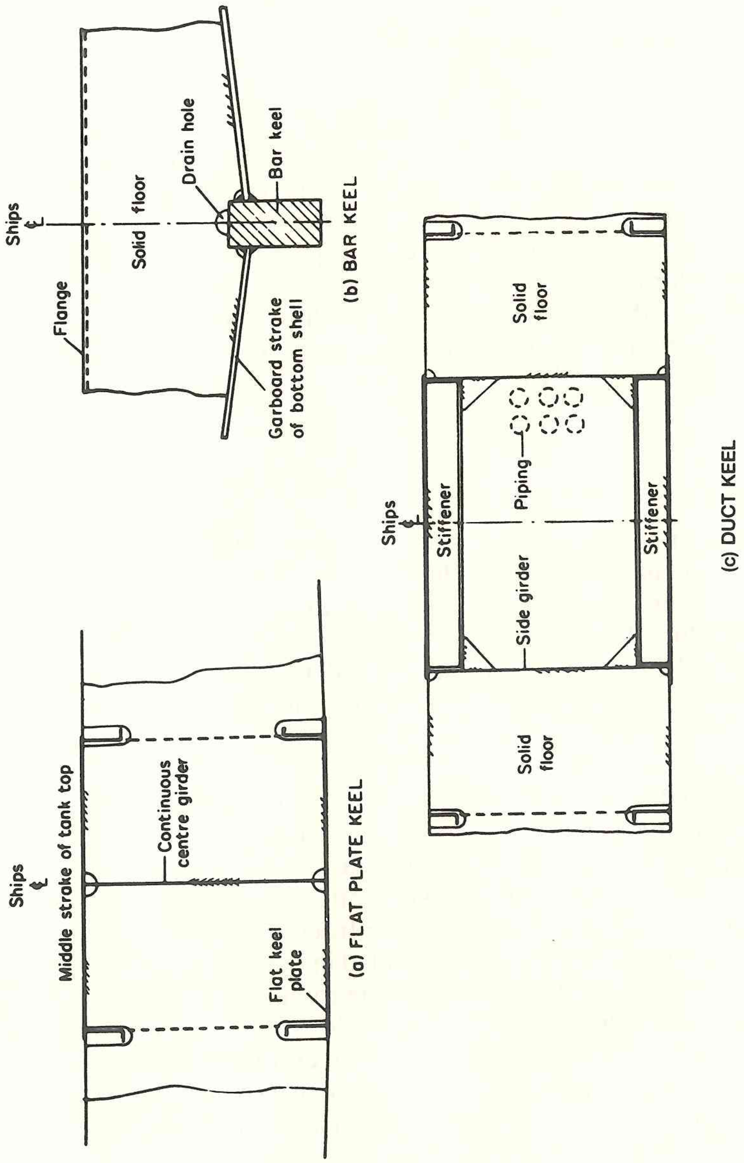
Originally ships were constructed with single bottoms, liquid fuels and fresh water being contained within separately constructed tanks. The double bottom structure which provides increased safety in the event of bottom shell damage, and also provides liquid tank space low down in the ship, has only evolved during the early part of this century. Smaller vessels, usually those trading within restricted waters, such as tugs, ferries, and some coasters, will still have a single bottom construction. Larger ocean-going vessels are conventionally fitted with some form of double bottom.

Keels

At the centre line of the bottom structure is located the keel, which is often said to form the backbone of the ship. This contributes substantially to the longitudinal strength and effectively distributes local loading caused when docking the ship. The commonest form of keel is that known as the 'flat plate' keel, and this is fitted in the majority of ocean-going and other vessels (*see* Figure 16.1(a)). A form of keel found on smaller vessels is the bar keel (Figure 16.1(b)). The bar keel may be fitted in trawlers, tugs, etc., and is also found in smaller ferries.

Where grounding is possible this type of keel is suitable with its massive scantlings, but there is always a problem of the increased draft with no additional cargo capacity. If a double bottom is fitted the keel is almost inevitably of the flat plate type, bar keels often being associated with open floors, where the plate keel may also be fitted.

Duct keels (Figure 16.1(c)) are provided in the double bottoms of some vessels. These run from the forward engine room bulkhead to the collision bulkhead and are utilized to carry the double bottom piping. The piping is then accessible when cargo is loaded, an entrance to the duct being provided at the forward end of the engine room. No duct is required aft of the engine room as the piping may be carried in the shaft tunnel. A width of not more than 2.0 m is allowed for the duct, and stregthening is provided at the tank top and keel plate to maintain continuity of strength of the transverse floors.



(a) FLAT PLATE KEEL

(b) BAR KEEL

(c) DUCT KEEL

FIGURE 16.1 Keels

Single Bottom Structure

In smaller ships having single bottoms the vertical plate open floors are fitted at every frame space and are stiffened at their upper edge. A centre line girder is fitted and one side girder is fitted each side of the centre line where the beam is less than 10 m. Where the beam is between 10 and 17 m two side girders are fitted and if any bottom shell panel has a width to length ratio greater than four additional continuous or intercostal stiffeners are fitted. The continuous centre and intercostal side girders are stiffened at their upper edge and extend as far forward and aft as possible.

The single bottom structure is shown in Figure 16.2 and for clarity a 3-dimensional representation of the structure is also provided to illustrate those members which are continuous or intercostal. Both single and double bottoms have continuous and intercostal material and there is often some confusion in the student's mind as to what is implied by these terms.

A wood ceiling may be fitted across the top of the floors if cargoes are to be carried but this does not constitute an inner bottom offering any protection if the outer bottom shell is damaged.

Double Bottom Structure

An inner bottom (or tank top) may be provided at a minimum height above the bottom shell, and maintained watertight to the bilges. This provides a considerable margin of safety, since in the event of bottom shell damage only the double bottom space may be flooded. The space is not wasted but utilized to carry oil fuel and fresh water required for the ship, as well as providing ballast capacity.

The minimum depth of the double bottom in a ship will depend on the classification society's requirement for the depth of centre girder. It may be deeper to give the required capacities of oil fuel, fresh water, and water ballast to be carried in the bottom. Water ballast bottom tanks are commonly provided right forward and aft for trimming purposes and if necessary the depth of the double bottom may be increased in these regions. In way of the machinery spaces the double bottom depth is also increased to provide appreciable capacities of lubricating oil and fuel oil. The increase in height of the inner bottom is always by a gradual taper in the longitudinal direction, no sudden discontinuities in the structure being tolerated.

Double bottoms may be framed longitudinally or transversely (*see* Figure 16.3), but where the ship's length exceeds 120 m it is considered desirable to adopt longitudinal framing. The explanation of this is that on longer ships tests and experience have shown that there is a tendency for the inner bottom and bottom shell to buckle if welded transverse framing is adopted.

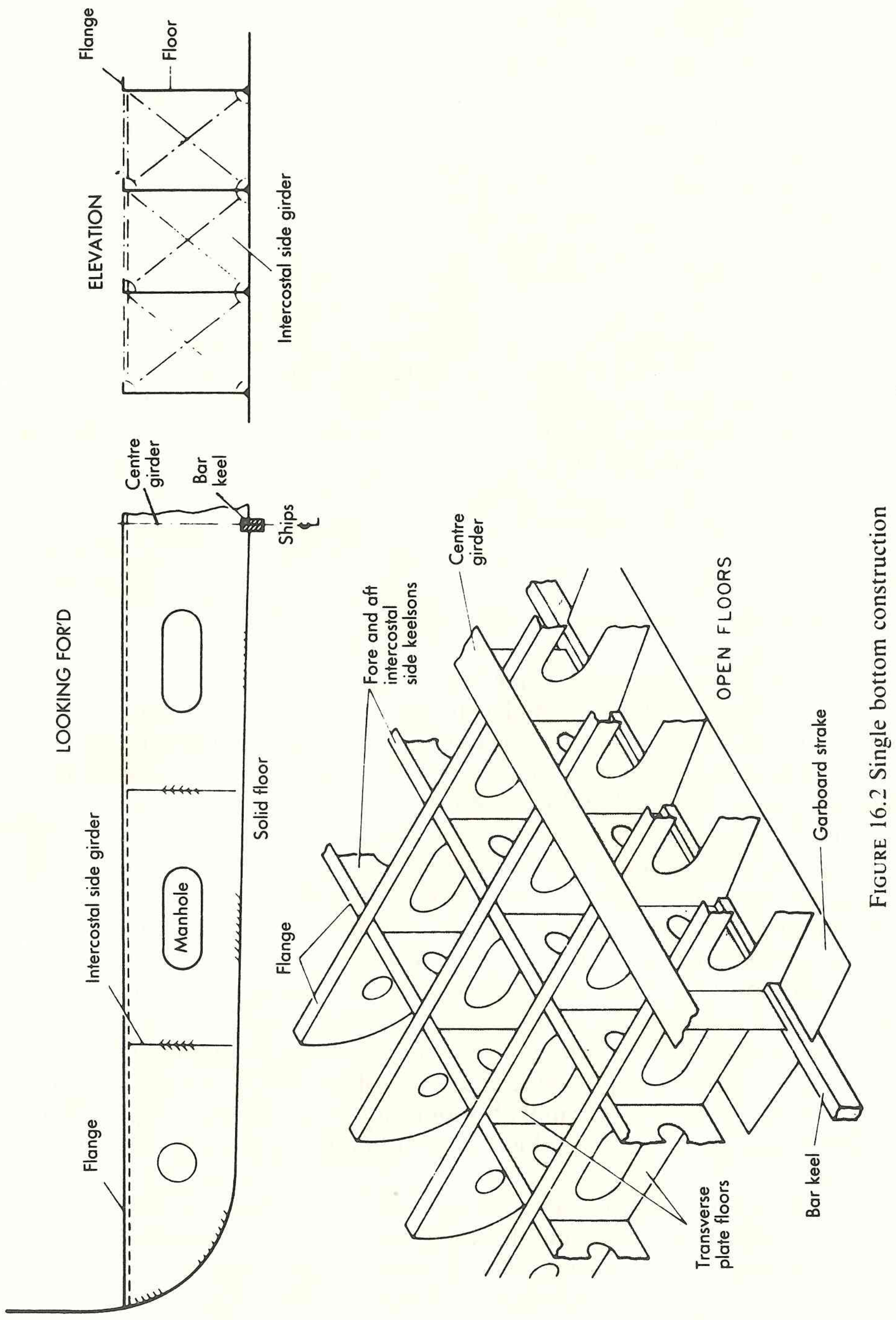


FIGURE 16.2 Single bottom construction

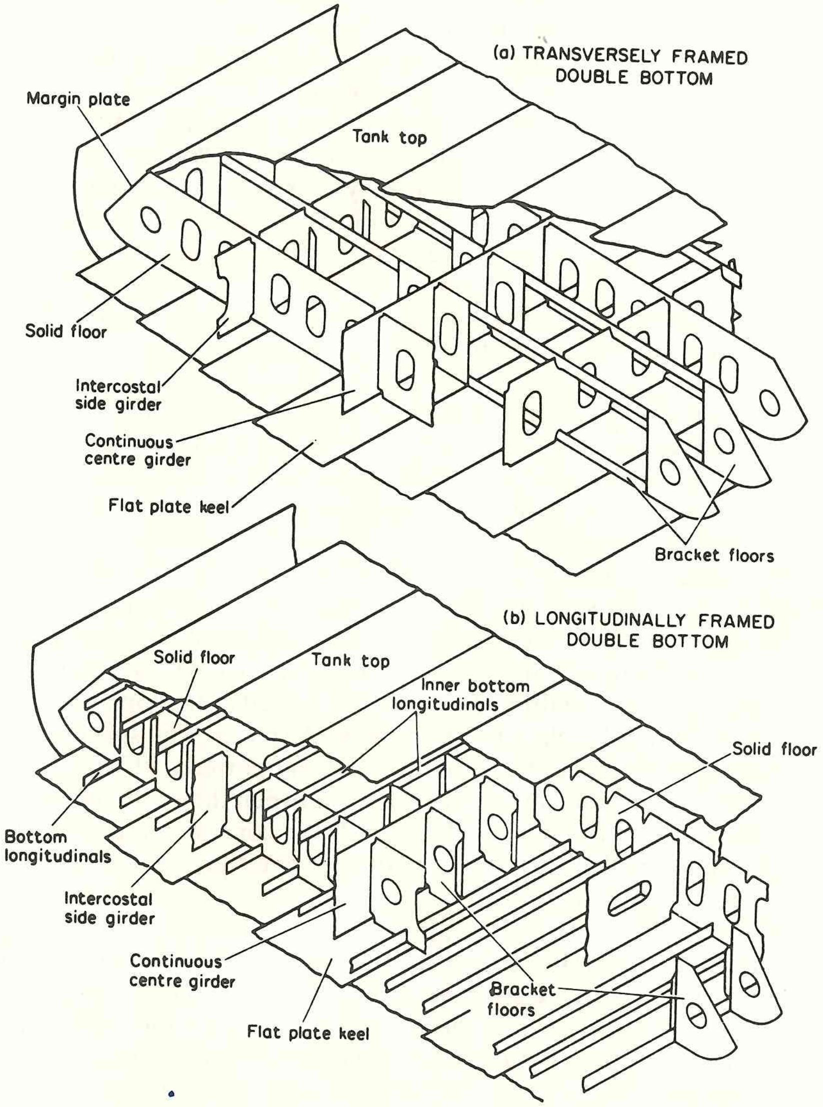


FIGURE 16.3 Double bottom construction

This buckling occurs as a result of the longitudinal bending of the hull, and may be avoided by having the plating longitudinally stiffened.

INNER BOTTOM PLATING The inner bottom plating may in a general cargo ship be sloped at the side to form a bilge for drainage purposes. It is not uncommon however for it to be extended to the ship's side, and individual bilge wells are then provided for drainage purposes (*see* Chapter

26). In vessels requiring a passenger certificate it is a statutory requirement for the tank top to extend to the ship's side. This provides a greater degree of safety since there is a substantial area of bilge which may be damaged without flooding spaces above the inner bottom.

At the centre line of the ship the middle strake of the inner bottom may be considered as the upper flange of the centre line docking girder, formed by the centre girder and keel plate. It may therefore be heavier than the other strakes of inner bottom plating. Normally a wood ceiling is provided under a hatchway in a general cargo ship, but the inner bottom plating thickness can be increased and the ceiling omitted. If grabs are used for discharging from general cargo ships the plate thickness is further increased, or a double ceiling is fitted.

FLOORS Vertical transverse plate floors are provided both where the bottom is transversely and longitudinally framed. At the ends of bottom tank spaces and under the main bulkheads, watertight or oiltight plate floors are provided. These are made watertight or oiltight by closing any holes in the plate floor and welding collars around any members which pass through the floors. Elsewhere 'solid plate floors' are fitted to strengthen the bottom transversely and support the inner bottom. These run transversely from the continuous centre girder to the bilge, and manholes provided for access through the tanks and lightening holes are cut in each solid plate floor. Also, small air and drain holes may be drilled at the top and bottom respectively of the solid plate floors in the tank spaces. The spacing of the solid plate floors varies according to the loads supported and local stresses experienced. At intermediate frame spaces between the solid plate floors, 'bracket floors' are fitted. The bracket floor consists simply of short transverse plate brackets fitted in way of the centre girder and tank sides (*see* Figures 16.4 and 16.5).

TRANSVERSELY FRAMED DOUBLE BOTTOM If the double bottom is transversely framed, then transverse solid plate floors, and bracket floors with transverse frames, provide the principal support for the inner bottom and bottom shell plating (Figure 16.4). Solid plate floors are fitted at every frame space in the engine room and in the pounding region (*see* the end of this chapter). Also they are introduced in way of boiler seats, transverse bulkheads, toes of brackets supporting stiffeners on deep tank bulkheads, and in way of any change in depth of the double bottom. Where a ship is regularly discharged by grabs, solid plate floors are also fitted at each frame. Elsewhere the solid plate floors may be spaced up to 3.0 m apart, with bracket floors at frame spaces between the solid floors. The plate brackets are flanged and their breadth is at least 75 per cent of the depth of the centre girder, at the bracket floors. To reduce the span of the frames at the bracket floor, vertical angle or channel bar struts may be fitted. Vertical

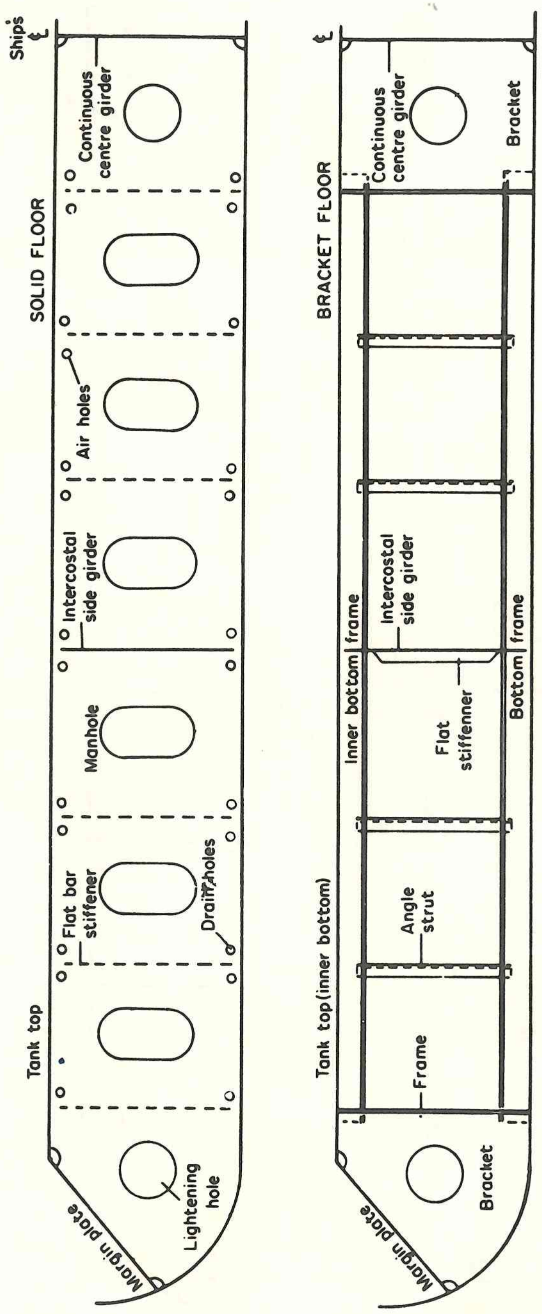


FIGURE 16.4 Transversely framed double bottom construction

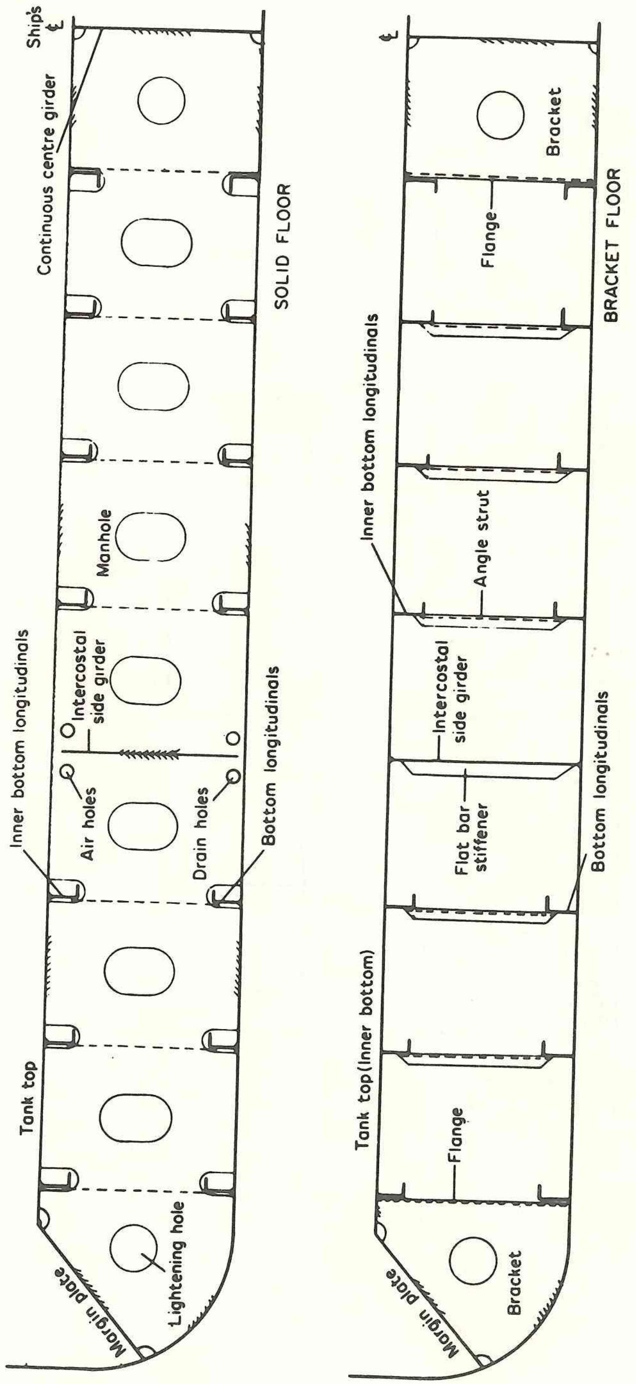


FIGURE 16.5 Longitudinally framed double bottom construction

stiffeners usually in the form of welded flats will be attached to the solid plate floors, which are further strengthened if they form a watertight or oiltight tank boundary.

One intercostal side girder is provided port and starboard where the ship's breadth exceeds 10 m but does not exceed 20 m and two are fitted port and starboard where the ship's breadth is greater. In way of the bracket floors a vertical welded flat stiffener is attached to the side girder. Additional side girders are provided in the engine room, and also in the pounding region.

LONGITUDINALLY FRAMED DOUBLE BOTTOM In a longitudinally framed double bottom, solid plate floors are fitted at every frame space under the main engines, and at alternate frames outboard of the engine seating. They are also fitted under boiler seats, transverse bulkheads, and the toes of stiffener brackets on deep tank bulkheads. Elsewhere the spacing of solid plate floors does not exceed 3.8 m, except in the pounding region where they are on alternate frame spaces. At intermediate frame spaces brackets are fitted at the tank side, and at the centre girder where they may be up to 1.25 m apart. Each bracket is flanged and will extend to the first longitudinal (Figure 16.5).

One intercostal side girder is fitted port and starboard if the ship's breadth exceeds 14 m, and where the breadth exceeds 21 m two are fitted port and starboard. These side girders always extend as far forward and aft as possible. Additional side girders are provided in the engine room, and under the main machinery, and they should run the full length of the engine room, extending three frame spaces beyond this space. Forward the extension tapers into the longitudinal framing system. In the pounding region there will also be additional intercostal side girders.

As the unsupported span of the bottom longitudinals should not exceed 2.5 m, vertical angle or channel bar struts may be provided to support the longitudinals between widely spaced solid floors.

ADDITIONAL STIFFENING IN THE POUNDING REGION If the minimum designed draft forward in any ballast or part loaded condition is less than 4.5 per cent of the ship's length then the bottom structure for 30 per cent of the ship's length forward in sea-going ships exceeding 65 m in length is to be additionally strengthened for pounding.

Where the double bottom is transversely framed, solid plate floors are fitted at every frame space in the pounding region. Intercostal side girders are fitted at a maximum spacing of 3 times the transverse floor spacing, and half height intercostal side girders are provided midway between the full height side girders.

If the double bottom is longitudinally framed in the pounding region, solid plate floors are fitted at alternate frame spaces, and intercostal side girders are provided, with a maximum spacing of 3 times the transverse floor spacing. As longitudinals are stiffening the bottom shell longitudinally, it should be noted that less side girders need be provided than where the bottom is transversely framed to resist distortion of the bottom with the slamming forces experienced.

Where the ballast draft forward is less than 1 per cent of the ship's length the additional strengthening of the pounding region is given special consideration.

Greater slamming forces (i.e. pounding) are experienced when the ship is in the lighter ballast condition, and is long and slender, by reason of the increased submersion of the bow in heavy weather with impact also on the bow flare.

BOTTOM STRUCTURE OF BULK CARRIERS Where a ship is classed for the carriage of heavy, or ore, cargoes longitudinal framing is adopted for the double bottom. A closer spacing of solid plate floors is required, the maximum spacing being 2.5 m, and also additional intercostal side girders are provided, the spacing not exceeding 3.7 m (*see* Figure 16.6).

The double bottom will be somewhat deeper than in a conventional cargo ship, a considerable ballast capacity being required; and often a pipe tunnel is provided through this space. Inner bottom plating, floors, and girders all have substantial scantlings as a result of the heavier cargo weights to be supported.

TESTING DOUBLE BOTTOM COMPARTMENTS Each compartment is tested on completion with a head of water representing the maximum pressure head which may be experienced in service, i.e. to the top of the air pipe. Alternatively air testing is carried out before any protective coatings are applied. The air pressure may be raised to 0.21 kg/cm^2, and then lowered to a test pressure of 0.14 kg/cm^2. Any suspect joints are then subjected to a soapy liquid solution test. Water head structural tests will be carried out on tanks selected by the surveyor in conjunction with the air tests carried out on the majority of tanks.

Machinery Seats

It has already been indicated that in the machinery spaces additional transverse floors and longitudinal intercostal side girders are provided to support the machinery effectively and to ensure rigidity of the structure.

The main engine seatings are in general integral with this double bottom structure, and the inner bottom in way of the engine foundation has a substantially increased thickness. Often the machinery is built up on seatings forming longitudinal bearers which are supported transversely by

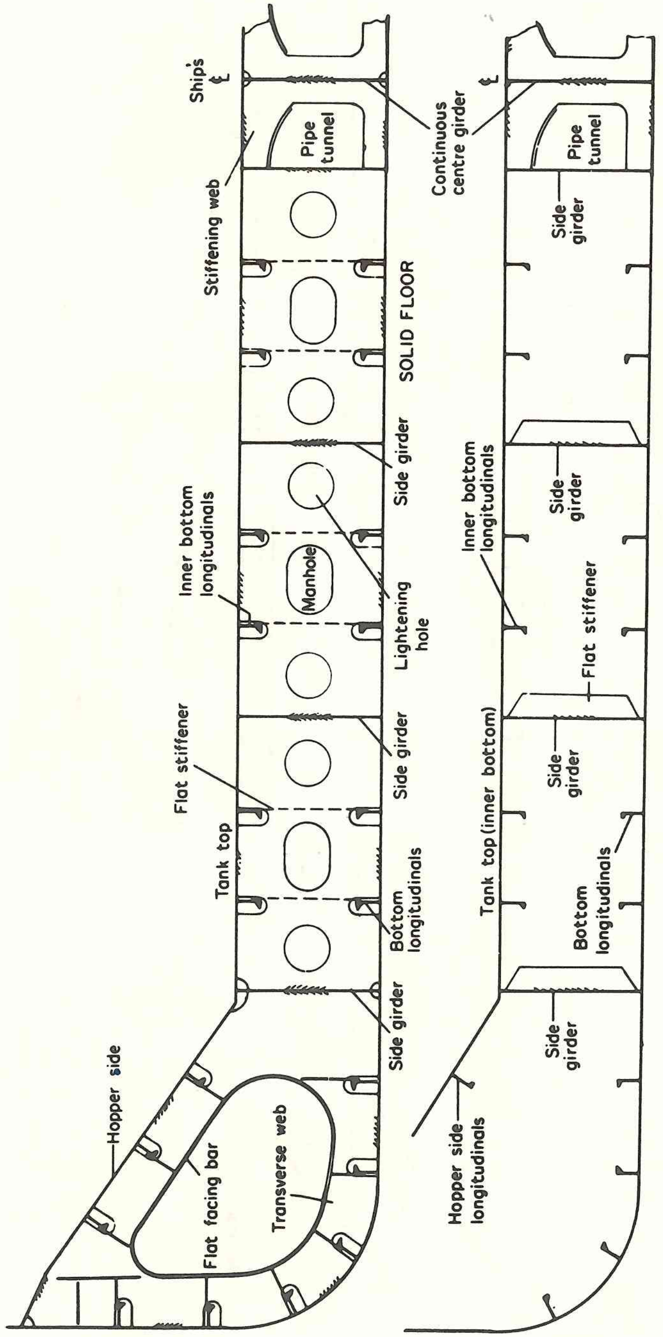


FIGURE 16.6 Bulk carrier double bottom construction

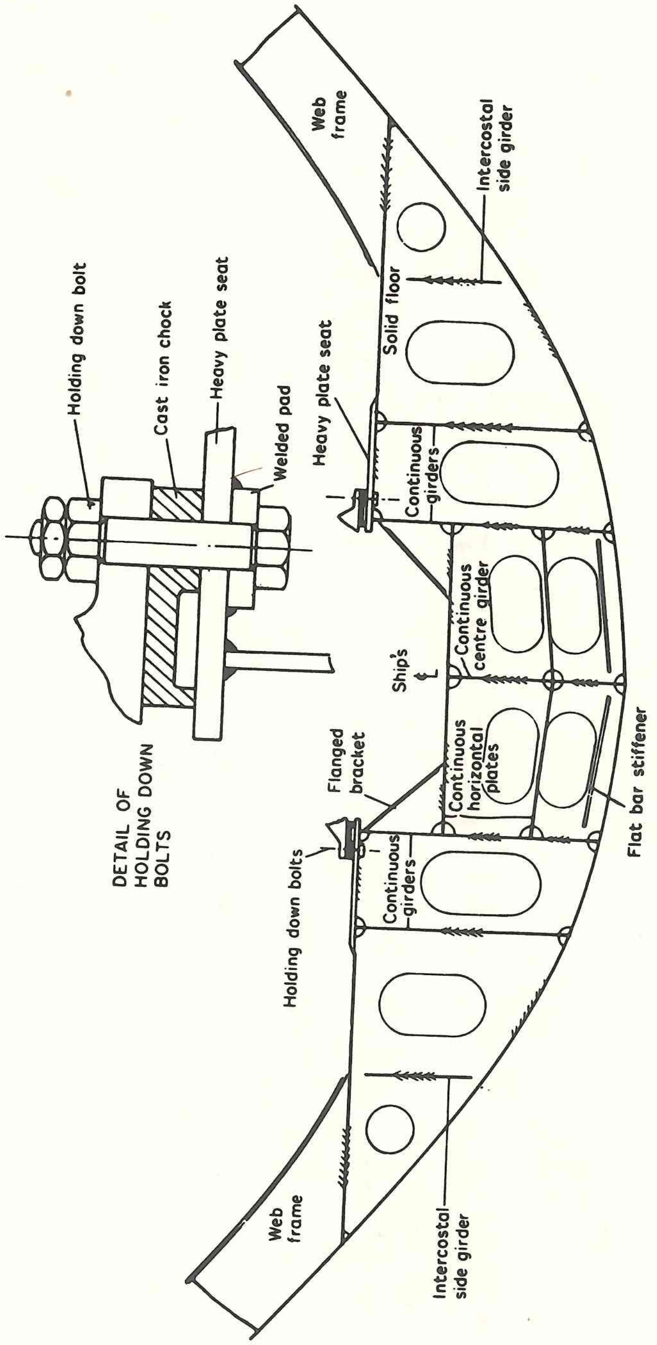


FIGURE 16.7 Engine seats

tripping brackets in line with the double bottom floors, the longitudinal bearers being in line with the double bottom side girders (*see* Figure 16.7).

Boiler bearers are similarly fabricated with support from transverse brackets and longitudinal members.

17
Shell Plating and Framing

The shell plating forms the watertight skin of the ship and at the same time, in merchant ship construction, contributes to the longitudinal strength and resists vertical shear forces. Internal strengthening of the shell plating may be both transverse and longitudinal and is designed to prevent collapse of the plating under the various loads to which it is subject.

Shell Plating

The bottom and side shell plating consists of a series of flat and curved steel plates generally of greater length than breadth butt welded together. The vertical welded joints are referred to as 'butts' and the horizontal welded joints as 'seams' (*see* Figure 17.1). Stiffening members both longitudinal and transverse are generally welded to the shell by intermittent fillet welds with a length of continuous weld at the ends of the stiffening member. Continuous welding of stiffening members to the shell is found in the after peak, the bottom shell within the forward 30 per cent of the length and where higher tensile steel is used. Framing is notched in way of welded plate butts and seams.

BOTTOM SHELL PLATING Throughout the length of the ship the width and thickness of the keel plate remain constant where a flat plate keel is fitted. Its thickness is never less than that of the adjoining bottom plating.

Strakes of bottom plating to the bilges have their greatest thickness over 40 per cent of the ship's length amidships, where the bending stresses are highest. The bottom plating then tapers to a lesser thickness at the ends of the ship, apart from increased thickness requirements in way of the pounding region (*see* Chapter 16).

SIDE SHELL PLATING As with the bottom shell plating the greater thickness of the side shell plating is maintained within 40 per cent of the vessel's midship length and then tapers to the rule thickness at the ends. The thickness may be increased in regions where high vertical shear stresses occur, usually in way of transverse bulkheads in a vessel permitted to carry heavy cargoes with some holds empty. There is also a thickness increase at the stern frame connection, at any shaft brackets, and in way of the hawse pipes where considerable chafing occurs. Further shell plate thickness increases may be found at the panting region, as discussed later in this chapter.

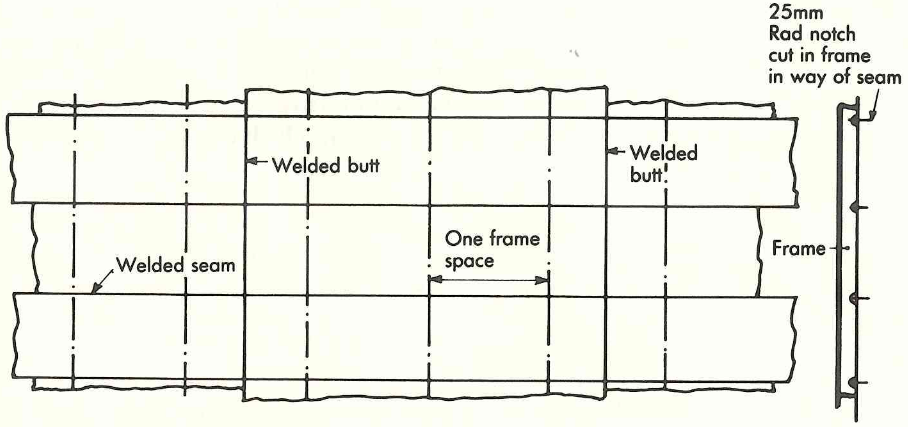


FIGURE 17.1 Shell plating

The upper strake of plating adjacent to the strength deck is referred to as the 'sheerstrake'. As the sheerstrake is at a large distance from the neutral axis it has a greater thickness than the other strakes of side shell plating. Also, being in a highly stressed region it is necessary to avoid welded attachments to the sheerstrake, or cutouts which would introduce stress raisers. The upper edge is dressed smooth, and the welding of bulwarks to the edge of the sheerstrake is not permitted within the amidships length of the ship. Scupper openings above the deck over the same length, and at the ends of the superstructure, are also prohibited in larger vessels. The connection between the sheerstrake and strength deck can present a problem, and a rounded gunwale may be adopted to solve this problem where the plating is heavy. This is often the case over the midship portion of large tankers and bulk carriers. Butt welds are then employed to make connections rather than the less satisfactory fillet weld at the perpendicular connection of the vertical sheerstrake and horizontal strength deck stringer plate. The radius of a rounded gunwale must be adequate (not less than 15 times the thickness) and any welded guardrails and fairleads are kept off the radiused plate if possible.

A smooth transition from rounded gunwale to angled sheerstrake/deck stringer connection is necessary at the ends of the ship.

All openings in the side shell have rounded corners, and openings for sea inlets, etc., are kept clear of the bilge radius if possible. Where this is not possible openings on or in the vicinity of the bilge are made elliptical.

GRADES OF STEEL FOR SHELL PLATES In large ships it is necessary to arrange strakes of steel with greater notch ductility at the more highly stressed regions. Details of Lloyd's requirements for mild steel and over 40 per cent of the length amidships are given in Table 17.1 as a guide. The Rules also require thicker plating for the members referred to in Table 17.1 outside the amidships region to have greater notch ductility.

TABLE 17.1

Requirement	*Structural member*
1. Grade D where thickness less than 15 mm otherwise Grade E.	Sheerstrake or rounded gunwale over 40 per cent of length amidships in ships exceeding 250 m in length.
2. Grade A where thickness less than 25 mm. Grade B where thickness 15 to 20 mm. Grade D where thickness 20 to 25 mm. Grade E where thickness greater than 25 mm.	Sheerstrake and rounded gunwale over 40 per cent of length amidships in ships of 250 m or less in length. Bilge strake (other than for vessels of less than 150 m with double bottom over full breadth).
3. Grade A where thickness less than 20 mm. Grade B where thickness 20 to 25 mm. Grade D where thickness 25 to 40 mm. Grade E where thickness over 40 mm.	Bottom plating including keel. Bilge strake (ships of less than 150 m and with double bottom over full breadth).
4. Grade A where thickness less than 30 mm. Grade B where thickness 30 to 40 mm. Grade D where thickness greater than 40 mm.	Side plating.

Framing

The bottom shell may be transversely or longitudinally framed, longitudinal framing being preferred particularly for vessels exceeding 120 m in length. The side shell framing may also be transversely or longitudinally framed, transverse framing being adopted in many conventional cargo ships, particularly where the maximum bale capacity is required. Bale capacities are often considerably reduced where deep transverses are fitted to support longitudinal framing. Longitudinal framing may be adopted in larger container ships and larger bulk carriers, and it is common within the hopper and topside wing tanks of the latter vessels. Transverse frames are then fitted at the side shell between the hopper and topside tanks.

TRANSVERSE FRAMING In a general cargo ship the transverse framing will consist of main and hold frames with brackets top and bottom, and lighter tween deck frames with brackets at the tops only (*see* Figure 17.2).

Scantlings of the main transverse frames are primarily dependent on their position, spacing and depth, and to some extent on the rigidity of the end connections. In way of tanks such as oil bunkers or cargo deep tanks the side frame size will be increased, except where supporting side stringers are fitted within the tank space. Frames supporting hatch end beams and those in way of deck transverses where the deck is framed longitudinally, also have increased scantlings.

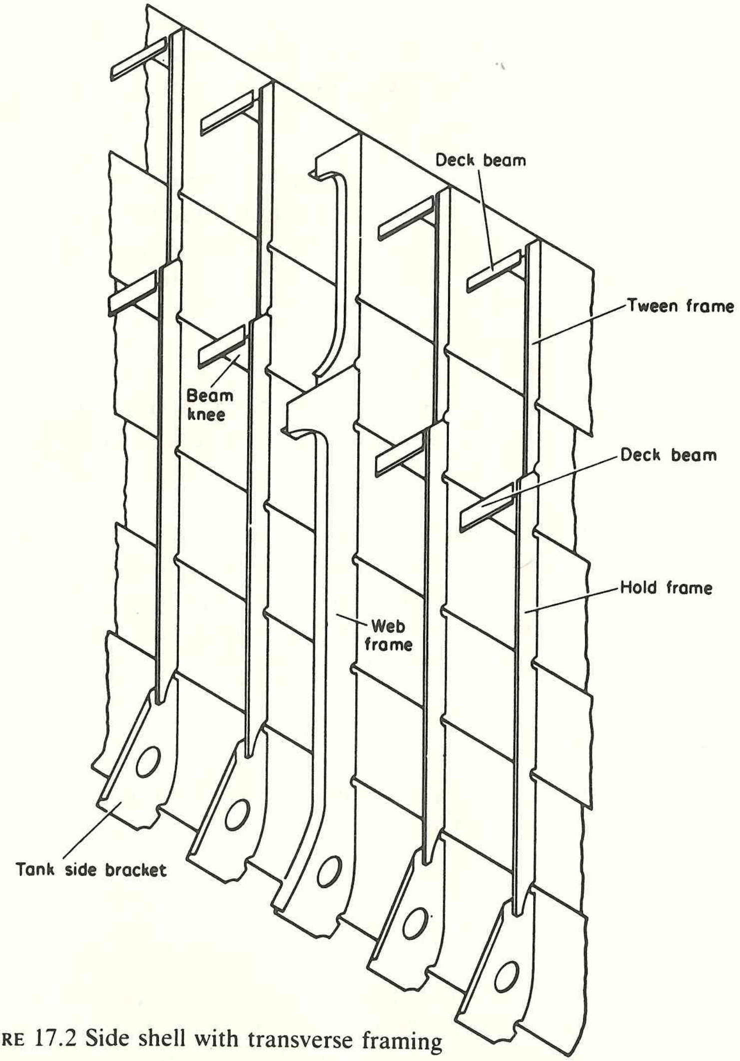


FIGURE 17.2 Side shell with transverse framing

Web frames, that is built up frames consisting of plate web and face flat, where the web is considerably deeper than the conventional transverse frame, are often introduced along the side shell (*see* Figure 17.3(a)). A number are fitted in the machinery spaces, generally not more than 5 frame spaces apart. Forward of the collision bulkhead and in any deep tank adjacent to the collision bulkhead, and in tween decks above such tanks, web frames are required at not more than 5 frame spaces apart. In the tween decks above the after peak tank, web frames are required at every fourth frame space abaft the aft peak bulkhead. In all cases the provision of web frames is intended to increase the rigidity of the transverse ship section at that point.

LONGITUDINAL FRAMING The longitudinal framing of the bottom shell is dealt with in Chapter 16. If the side shell is longitudinally framed offset bulb sections will often be employed with the greater section scantlings at the lower side shell. Direct continuity of strength is to be maintained, and many of the details are similar to those illustrated for the tanker longitudinals (*see* Chapter 22). Transverse webs are fitted to support the side longitudinals, these being spaced not more than 3.8 m apart, in ships of 100 m length or less, with increasing spacing being permitted for longer ships. In the peaks the spacing is 2.5 m where the length of ship is less than 100 m increasing linearly to a spacing of 3.5 m where the length exceeds 300 m.

Larger container ships are longitudinally framed at the sides with transverse webs arranged in line with the floors in the double bottom to ensure continuity of transverse strength. Many of these ships have a double skin construction with transverse webs and horizontal perforated flats between the two longitudinally framed skins (see Figure 17.8).

Tank Side Brackets

The lower end of the frame may be connected to the tank top or hopper side tank by means of a flanged or edge stiffened tank side bracket as illustrated in Figure 17.3(b).

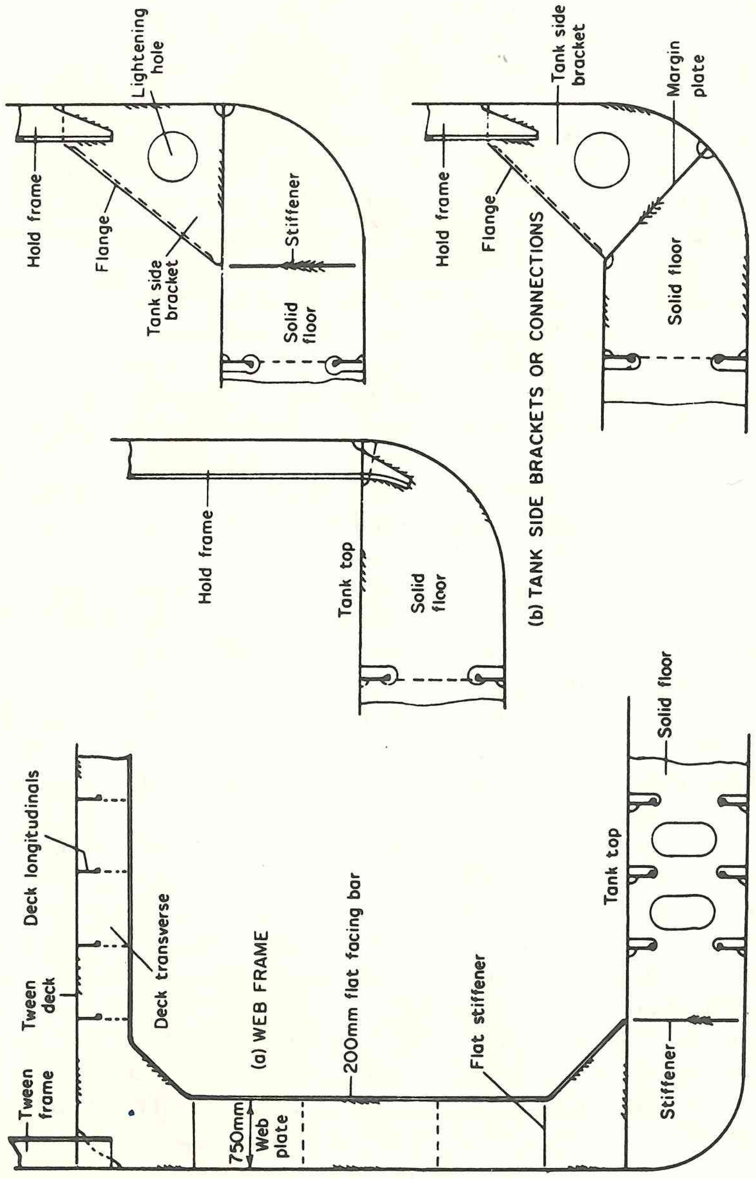
Local Strengthening of Shell Plating

The major region in which the shell plating is subjected to local forces at sea is at the forward end. Strengthening of the forward bottom shell for pounding forces is dealt with in Chapter 16. Panting which is discussed in Chapter 8 will also influence the requirements for the scantlings and strengthening of the shell forward and to a lesser extent at the aft end. Where a ship is to navigate in ice a special classification may be assigned depending on the type and severity of ice encountered (*see* Chapter 4) and this will involve strengthening the shell forward and in the waterline region.

ADDITIONAL STIFFENING FOR PANTING Additional stiffening is provided in the fore peak structure, the transverse side framing being supported by any, or a combination of the following arrangements:

(a) Side stringers spaced vertically about 2 m apart and supported by struts or beams fitted at alternate frames. These 'panting beams' are connected to the frames by brackets and if long may be supported at the ships centre line by a partial wash bulkhead. Intermediate frames are bracketed to the stringer (*see* Figure 17.4).

(b) Side stringers spaced vertically about 2 m apart and supported by web frames.



(a) WEB FRAME

(b) TANK SIDE BRACKETS OR CONNECTIONS

FIGURE 17.3 Web frame and tank side bracket

(c) Perforated flats spaced not more than 2.5 m apart. The area of perforations being not less than 10 per cent of the total area of the flat.

Aft of the forepeak in the lower hold or deep tank spaces panting stringers are fitted in line with each stringer or perforated flat in the fore peak extending back over 15 per cent of the ship length from forward. These stringers may be omitted if the shell plating thickness is increased by 15 per cent for vessels of 150 m length or less decreasing linearly to 5 per cent increase for vessels of 215 m length or more. However, where the unsupported length of the main frames exceeds 9 m panting stringers in line with alternate stringers or flats in the fore peak are to be fitted over 20 per cent of the ships length from forward whether the shell thickness is increased or not. Stringers usually take the form of a web plate with flat facing bar.

In tween deck spaces in the forward 15 per cent of the ships length intermediate panting stringers are fitted where the unsupported length of tween frame exceeds 2.6 m in lower tween decks or 3 m in upper tween decks. Alternatively the shell thickness may be increased as above.

In the aft peak space and in deep tween decks above the aft peak similar panting arrangements are required for transverse framing except that the vertical spacing of panting stringers may be up to 2.5 m apart.

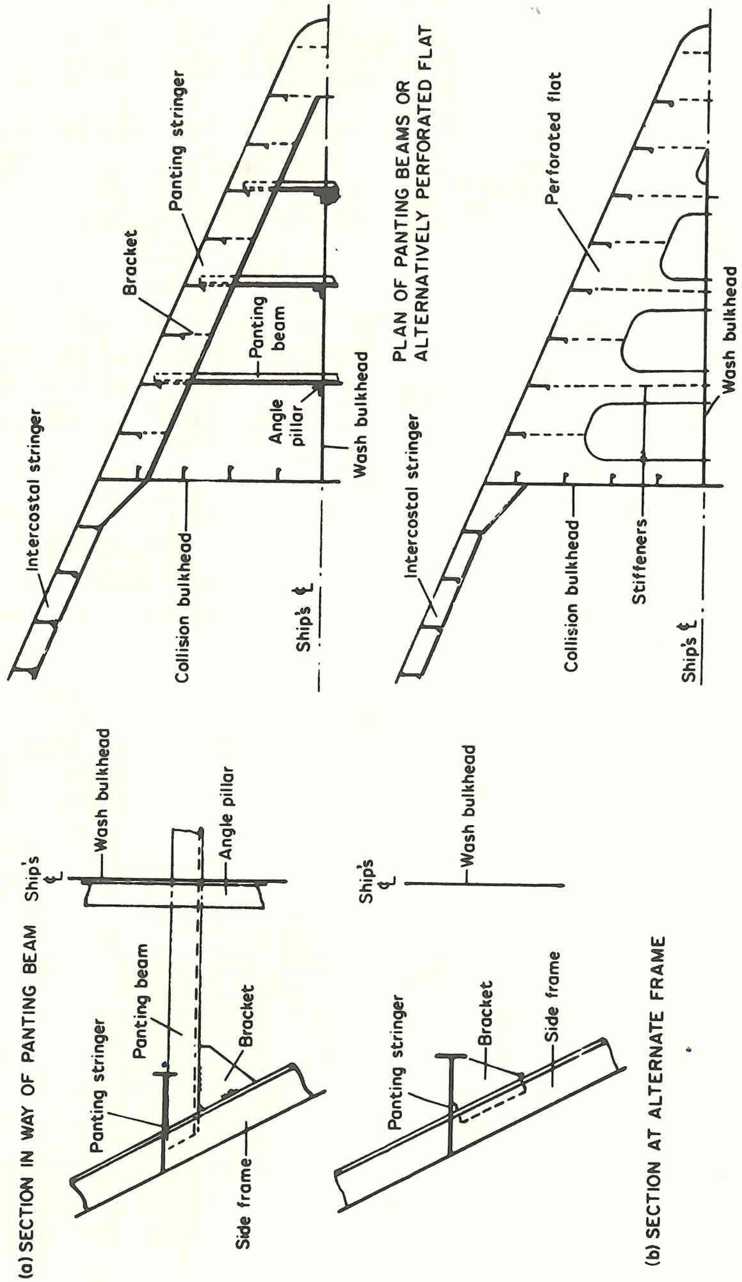
If the fore peak has longitudinal framing and the depth of tank exceeds 10 m the transverse webs supporting the longitudinals are to be supported by perforated flats or an arrangement of transverse struts or beams.

STRENGTHENING FOR NAVIGATION IN ICE If a vessel is to be assigned a special features notation for navigation in first year ice (*see* Chapter 4) the additional strengthening required involves primarily an increase in plate thickness and frame scantlings in the waterline region and the bottom forward, and may require some modifications and strengthening at the stem, stern, rudder and bossings etc.

A main ice belt zone is defined which extends above the ice load waterline (i.e. normally the summer load waterline) and below the ice light waterline (i.e. lightest waterline ship navigates ice in). The extent of this zone depends on the ice class assigned *see* Table 17.2.

TABLE 17.2 **Main Ice Belt Zone**

Class	*Above ice load waterline (mm)*	*Below ice light waterline (mm)*
1AS	600	750
1A	500	600
1B	400	500
1C	400	500
1D	400	500



(a) SECTION IN WAY OF PANTING BEAM

(b) SECTION AT ALTERNATE FRAME

FIGURE 17.4 Panting arrangements forward

The shell plating thickness in this zone is greater than on a conventional ship and increases with severity of ice class and with position from aft to forward. Below the main ice belt zone forward for at least 40 per cent of the length from forward for Ice Classes 1AS and 1A increased thickness of shell plating is required.

Transverse main and intermediate frames of the same heavier scantlings are fitted in way of the main ice belt zone to the extent indicated in Table 17.3. If the shell is longitudinally framed longitudinals of increased scantlings are fitted over the same vertical extent given in Table 17.3 for transverse framing. Both transverse and longitudinal frame scantling requirements are dependent on the severity of ice class and distance of frame from forward. The main and intermediate transverse frames terminate at the first major longitudinal member outside the minimum extent of ice framing. Transverse ice framing is supported by ice stringers and decks, and longitudinal framing by web frames the scantlings of which are increased with severity of ice class and distance from forward.

Strengthening for addition of 'Icebreaker' notation to ship type notation and assignment of special features notation for navigation in multi-year ice concerns plating and framing but are too extensive to be covered adequately in this text. For full details reference may be made to Chapter 9, Part 3. Ship Structures of Lloyd's Register of Shipping 'Rules and Regulations for the Classification of Ships'.

TABLE 17.3

Ice class	*Region*	*Minimum extent of ice framing*	
		Above ice load waterline (mm)	*Below ice load waterline (mm)*
1AS	Forward (30 per cent length from forward)	1200	To double bottom or top of floors
	Forward (abaft 30 per cent length from forward) and midships	1200	1600
	Aft	1200	1200
1A	Forward (30 per cent length from forward)	1000	1600
	Forward (abaft 30 per cent length from forward) and midships	1000	1300
	Aft	1000	1000
1D	Forward	1000	1600

Note! Forward is less than 40 per cent of the length aft of the forward perpendicular

Bilge Keel

Most ships are fitted with some form of bilge keel the prime function of

which is to help damp the rolling motion of the vessel. Other relatively minor advantages of the bilge keel are protection for the bilge on grounding, and increased longitudinal strength at the bilge.

The damping action provided by the bilge keel is relatively small but effective, and virtually without cost after the construction of the ship. It is carefully positioned on the ship so as to avoid excessive drag when the ship is under way; and to achieve a minimum drag, various positions of the bilge keel may be tested on the ship model used to predict power requirements. This bilge keel then generally runs over the midship portion of the hull, often extending further aft than forward of amidships and being virtually perpendicular to the turn of the bilge.

There are many forms of bilge keel construction, and some quite elaborate arrangements have been adopted in an attempt to improve the damping performance whilst reducing any drag. Care is required in the design of the bilge keel, for although it would not be considered as a critical strength member of the hull structure, the region of its attachment is fairly highly stressed owing to its distance from the neutral axis. Cracks have originated in the bilge keel and propogated into the bilge plate causing failure of the main structure. In general bilge keels are attached to a continuous ground bar with the butt welds in the shell plating, ground bar and bilge keel staggered (*see* Figure 17.5). Direct connection between the

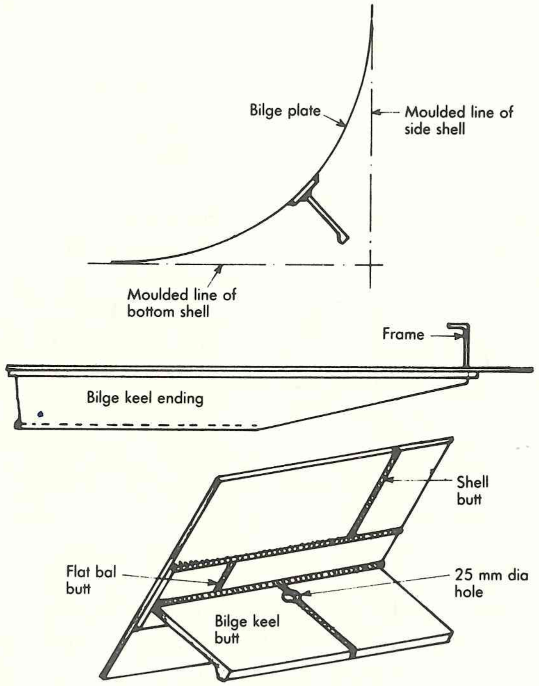


FIGURE 17.5 Bilge keels

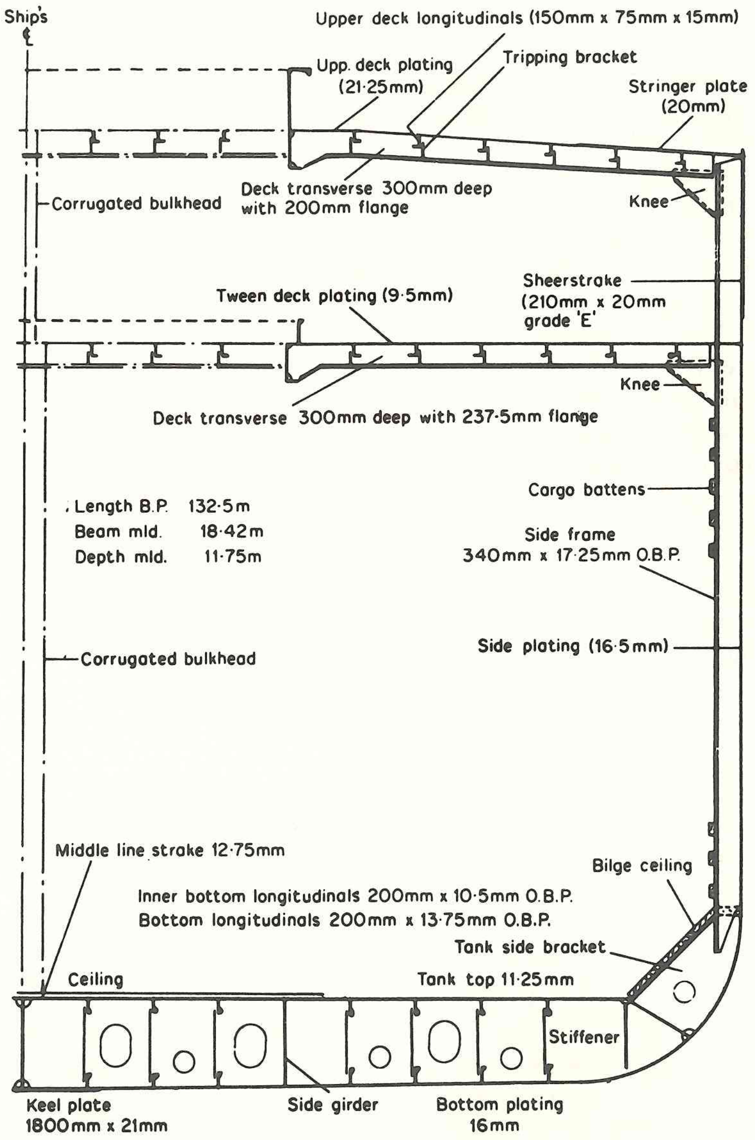


FIGURE 17.6 General cargo ship—midship section

ground bar butt welds and the bilge plate and bilge keel butt welds and the ground bar are avoided. In ships over 65 m in length, holes are drilled in the bilge keel butt welds as shown in Figure 17.5.

The ground bar thickness is at least that of the bilge plate or 14 mm

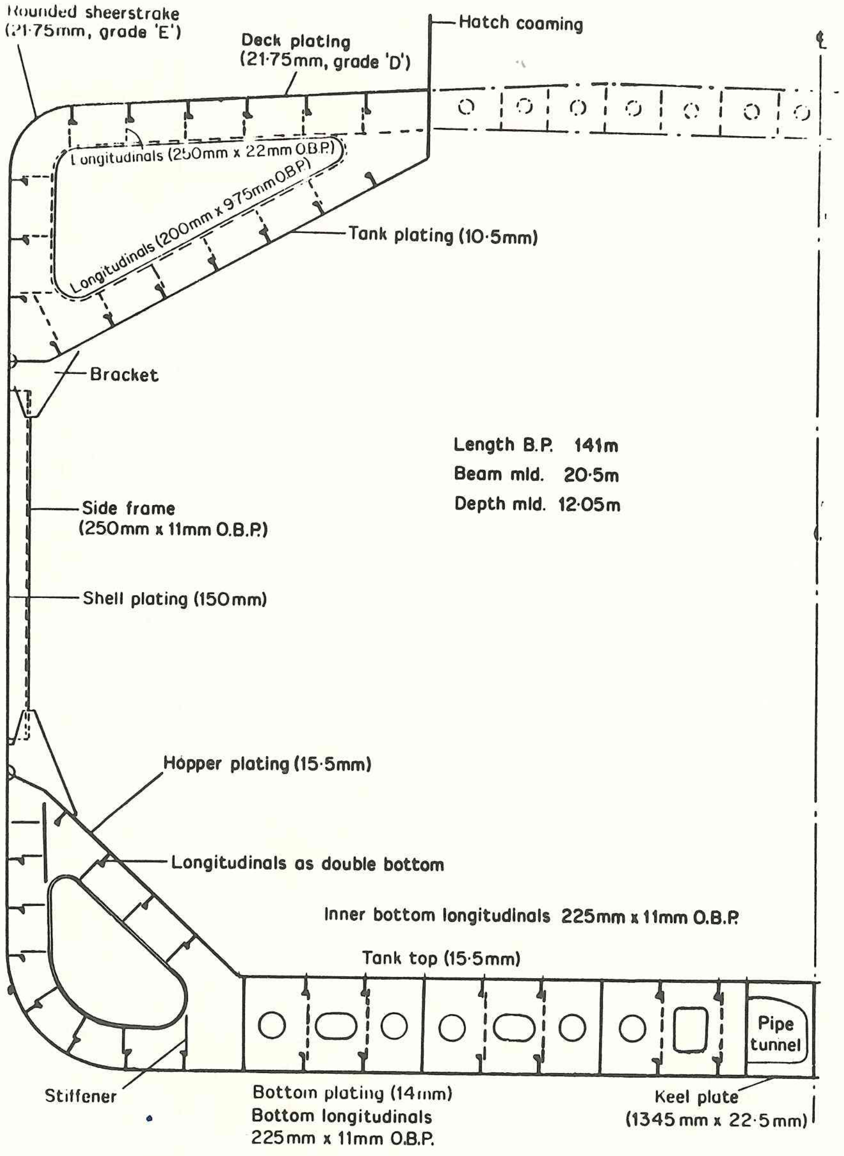
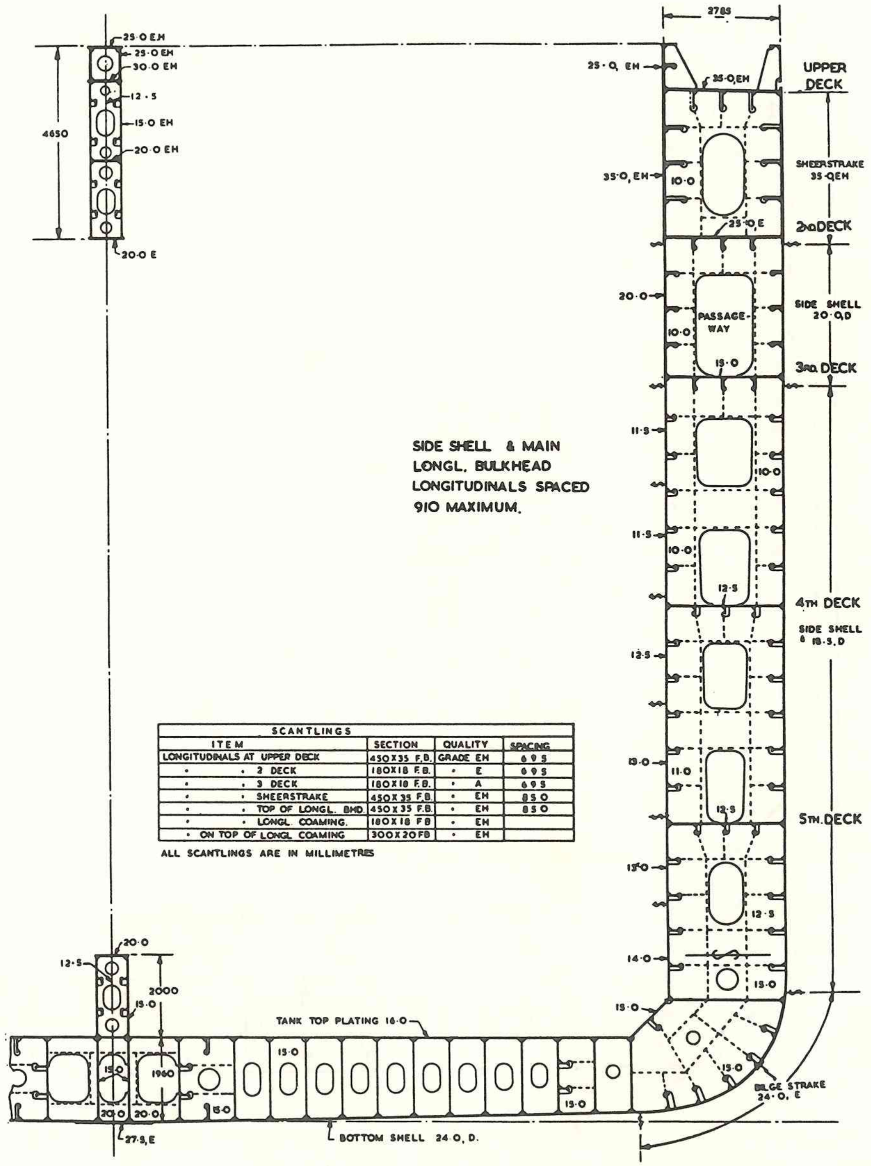


FIGURE 17.7 Bulk carrier—midship section

whichever is the lesser, and the material grade is the same as that of the bilge plate. Connection of the ground bar to the shell is by continuous fillet welds and the bilge keel is connected to the ground bar by light continuous or staggered intermittent weld. The latter lighter weld ensures that should



SCANTLINGS

ITEM	SECTION	QUALITY	SPACING
LONGITUDINALS AT UPPER DECK	450X35 F.B.	GRADE EH	695
" " 2 DECK	180X18 F.B.	" E	695
" " 3 DECK	180X18 F.B.	" A	695
" " SHEERSTRAKE	450X35 F.B.	" EH	850
" " TOP OF LONGL. BHD.	450X35 F.B.	" EH	850
" " LONGL. COAMING.	180X18 FB	" EH	
" ON TOP OF LONGL. COAMING	300X20FB	" EH	

ALL SCANTLINGS ARE IN MILLIMETRES

FIGURE 17.8 Container ship—midship section

the bilge keel be fouled failure occurs at this joint without the bilge plate being damaged.

Bilge keels are gradually tapered (at least 3 to 1) at their ends and finish in way of an internal stiffening member.

18

Bulkheads and Pillars

This chapter deals with the internal vertical structure of the ship. Much of this structure, particularly the pillars and to some extent the transverse strength bulkheads, is responsible for carrying the vertical loading experienced by the ship. The principal bulkheads subdivide the ship hull into a number of large watertight compartments, and their construction and spacing is discussed. Also considered are the boundaries of other smaller compartments such as deep tanks and the shaft tunnel.

Bulkheads

Vertical partitions in a ship arranged transversely or fore and aft are referred to as 'bulkheads'. Those bulkheads which are of greatest importance are the main hull transverse and longitudinal bulkheads dividing the ship into a number of watertight compartments. Other lighter bulkheads, named 'minor bulkheads', which act as screens further subdividing compartments into small units of accommodation or stores, are of little structural importance.

The main hull bulkheads of sufficient strength are made watertight in order that they may contain any flooding in the event of a compartment on one side of the bulkhead being bilged. Further they serve as a hull strength member not only carrying some of the ship's vertical loading but also resisting any tendency for transverse deformation of the ship. As a rule the strength of the transverse watertight bulkheads is maintained to the strength deck which may be above the freeboard deck. Finally each of the main hold bulkheads has often proved a very effective barrier to the spread of a hold or machinery space fire.

SPACING OF WATERTIGHT BULKHEADS—CARGO SHIPS The minimum number of transverse watertight bulkheads which must be fitted in a dry cargo ship are stipulated. A collision bulkhead must be fitted forward, an aft peak bulkhead must be fitted, and watertight bulkheads must be provided at either end of the machinery space. This implies that for a vessel with machinery amidships the minimum possible number of watertight bulkheads is four. With the machinery aft this minimum number may be reduced to three, the aft peak bulkhead being at the aft end of the machinery space.

Of these bulkheads perhaps the most important is the collision bulkhead forward. It is a fact that the bow of at least one out of two ships involved in a collision will be damaged. For this reason a heavy bulkhead is specified and located so that it is not so far forward as to be damaged on impact. Neither should it be too far aft so that the compartment flooded forward causes excessive trim by the bow. Lloyd's Register gives the location for ships whose length does not exceed 200 m as not less than 5 and not greater than 8 per cent of the ship's length (Lloyd's Length) from the fore end of the load waterline. As a rule this bulkhead is fitted at the minimum distance in order to gain the maximum length for cargo stowage. The aft peak bulkhead is intended to enclose the stern tubes in a watertight compartment preventing any emergency from leakage where the propeller shafts pierce the hull. It is located well aft so that the peak when flooded would not cause excessive trim by the stern. Machinery bulkheads provide a self-contained compartment for engines and boilers preventing damage to these vital components of the ship by flooding in an adjacent hold. They also localize any fire originating in these spaces.

A minimum number of watertight bulkheads will only be found in smaller cargo ships. As the size increases the classification society will recommend additional bulkheads, partly to provide greater transverse strength, and also to increase the amount of subdivision. Table 18.1 indicates the number of watertight bulkheads recommended by Lloyd's Register for any cargo ship. These should be spaced at uniform intervals, but the shipowner may require for a certain trade a longer hold, which is permitted if additional approved transverse stiffening is provided. It is possible to dispense with one watertight bulkhead altogether, with Lloyd's Register approval, if adequate approved structural compensation is introduced. In container ships the spacing is arranged to suit the standard length of containers carried.

TABLE 18.1

Bulkheads for Cargo Ships

Length of ship (metres)		*Total number of bulkheads*	
Above	*Not exceeding*	*Machinery midships*	*Machinery aft*
	65	4	3
65	85	4	4
85	105	5	5
105	115	6	5
115	125	6	6
125	145	7	6
145	165	8	7
165	190	9	8
190	To be considered individually		

Each of the main watertight hold bulkheads may extend to the uppermost continuous deck; but in the case where the freeboard is measured from the second deck they need only be taken to that deck. The collision bulkhead extends to the uppermost continuous deck and the aft peak bulkhead may terminate at the first deck above the load waterline provided this is made watertight to the stern, or to a watertight transom floor.

In the case of bulk carriers a further consideration may come into the spacing of the watertight bulkheads where a shipowner desires to obtain a reduced freeboard. It is possible with bulk carriers to obtain a reduced freeboard under The Merchant Shipping (Load Line) Rules 1968 (*see* Chapter 31) if it is possible to flood one or more compartments without loss of the vessel. For obvious reasons many shipowners will wish to obtain the maximum permissible draft for this type of vessel and the bulkhead spacing will be critical.

SPACING OF WATERTIGHT BULKHEADS—PASSENGER SHIPS Where a vessel requires a passenger certificate (carrying more than 12 passengers), it is necessary for that vessel to comply with the requirements of the Internal Convention on Safety of Life at Sea. Under this convention the subdivision of the passenger ship is strictly specified, and controlled by the authorities of the maritime countries who are signatories to the convention. In the United Kingdom the controlling authority is the Department of Transport.

The calculations involved in passenger ship subdivision are dealt with in detail in the theoretical text-books on naval architecture. However the basic principle is that the watertight bulkheads should be so spaced that when the vessel receives reasonable damage, flooding is confined. No casualty will then result either from loss of transverse stability or excessive sinkage and trim.

For a passenger ship the spacing of the watertight bulkheads is covered by statutory requirements; no such requirements exist for the cargo ship.

CONSTRUCTION OF WATERTIGHT BULKHEADS The plating of a flat transverse bulkhead is generally welded in horizontal strakes, and convenient two-dimensional units for prefabrication are formed. Smaller bulkheads may be erected as a single unit; larger bulkheads are in two or more units. It has always been the practice to use horizontal strakes of plating since the plate thickness increases with depth below the top of the bulkhead. The reason for this is that the plate thickness is directly related to the pressure exerted by the head of water when a compartment on one side of the bulkhead is flooded. Apart from the depth the plate thickness is also influenced by the supporting stiffener spacing. Heavier plating is required for the collision bulkhead, the thickness being 12 per cent greater than that of other hold bulkheads. A minimum thickness of 5.5 mm is required for any bulkhead, except those in a vessel designed for ore cargoes where the minimum thickness allowed is 10 mm.

Vertical stiffeners are fitted to the transverse watertight bulkheads of a ship, the span being less in this direction and the stiffener therefore having less tendency to deflect under load. Stiffening is usually in the form of welded inverted ordinary angle bars, or offset bulb plates, the size of the stiffener being dependent on the unsupported length, stiffener spacing, and rigidity of the end connections. Rigidity of the end connections will depend on the form of end connection, stiffeners in holds being bracketed or simply directly welded to the tank top or underside of deck, whilst upper tween stiffeners need not have any end connection at all (*see* Figure 18.1). The modulus of collision bulkhead stiffeners is 25 per cent greater than the stiffeners of hold bulkheads. Vertical stiffeners may be supported by horizontal stringers permitting a reduction in the stiffener scantling as a result of the reduced span. Horizontal stringers are mostly found on those bulkheads forming the boundaries of a tank space, and in this context are dealt with later.

It is not uncommon to find in present day ships swedged and corrugated bulkheads, the swedges like the troughs of a corrugated bulkhead being so designed and spaced as to provide sufficient rigidity to the plate bulkhead in order that conventional stiffeners may be dispensed with (*see* Figure 18.2). Both swedges and corrugations are arranged in the vertical direction like the stiffeners on transverse and short longitudinal pillar bulkheads. Since the plating is swedged or corrugated prior to its fabrication, the bulkhead will be plated vertically with a uniform thickness equivalent to that required at the base of the bulkhead. This implies that the actual plating will be somewhat heavier than that for a conventional bulkhead, and this will to a large extent offset any saving in weight gained by not fitting stiffeners.

The boundaries of the bulkhead are double continuously fillet welded directly to the shell, decks, and tank top.

A bulkhead may be erected in the vertical position prior to the fitting of decks during prefabrication on the berth. At the line of the tween decks a 'shelf plate' is fitted to the bulkhead and when erected the tween decks land on this plate which extends 300 to 400 mm from the bulkhead. The deck is lap welded to the shelf plate with an overlap of about 25 mm. In the case of a corrugated bulkhead it becomes necessary to fit filling pieces between the troughs in way of the shelf plate.

If possible the passage of piping and ventilation trunks through watertight bulkheads is avoided. However in a number of cases this is impossible and to maintain the integrity of the bulkhead the pipe is flanged at the bulkhead. Where a ventilation trunk passes through, a watertight shutter is provided.

TESTING WATERTIGHT BULKHEADS Both the collision bulkhead, as

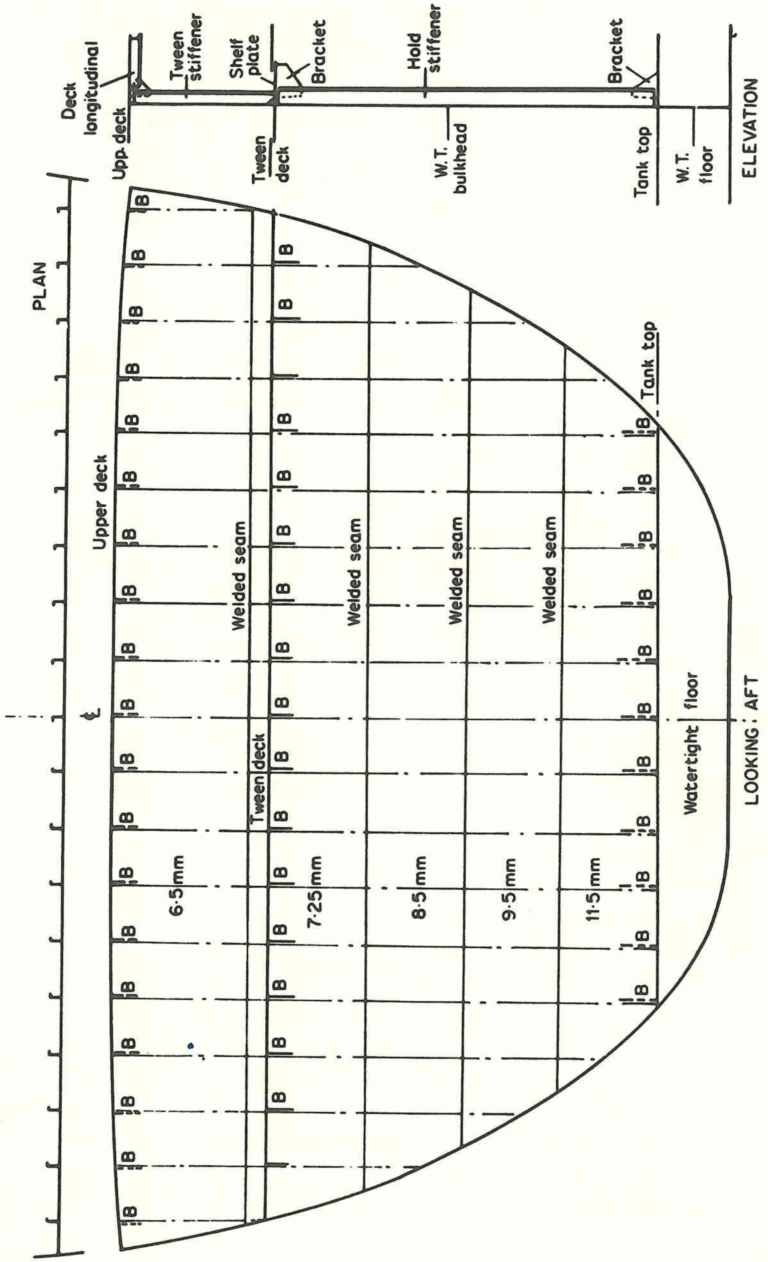


FIGURE 18.1 Plain watertight bulkhead

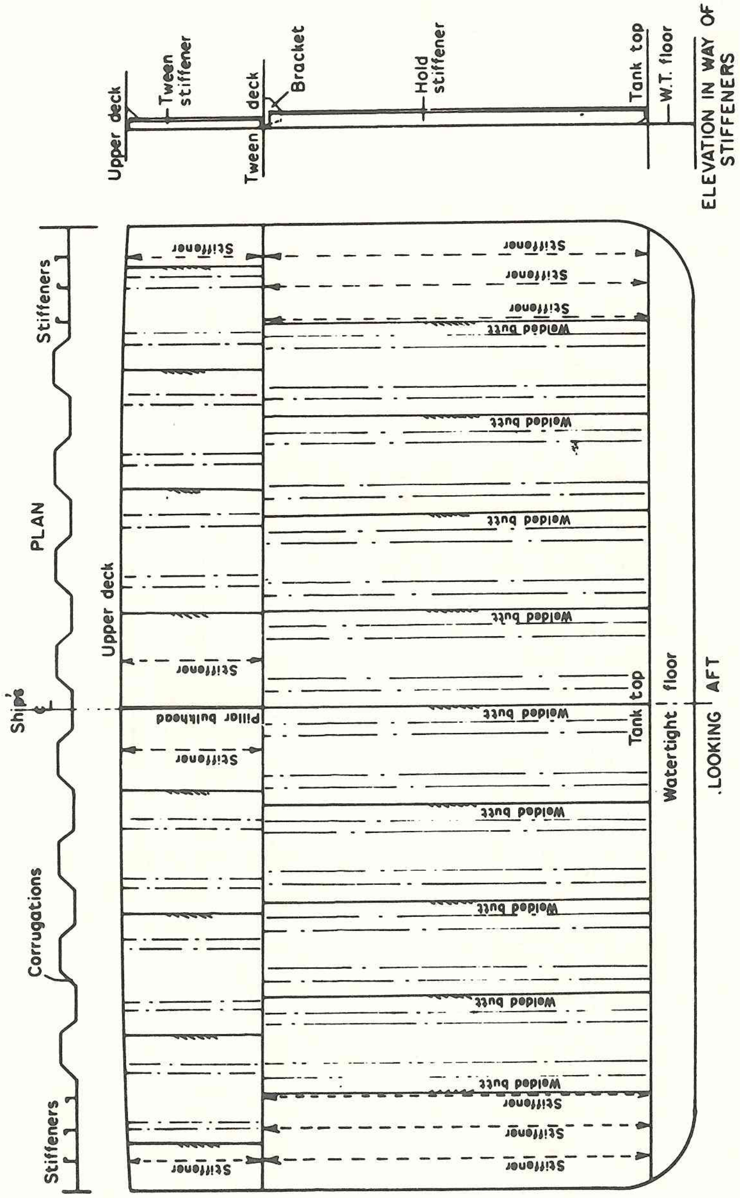


FIGURE 18.2 Corrugated watertight bulkhead

the fore peak bulkhead, and the aft peak bulkhead provided they do not form the boundaries of tanks are to be tested by filling the peaks with water to the level of the load waterline. All bulkheads, unless they form the boundaries of a tank which is regularly subject to a head of liquid, are hose tested. Since it is not considered prudent to test ordinary watertight bulkheads by filling a cargo hold, the hose test is considered satisfactory.

Watertight Doors

In order to maintain the efficiency of a watertight bulkhead it is desirable that it remains intact. However in some instances it becomes necessary to provide access between compartments on either side of a watertight bulkhead and watertight doors are fitted for this purpose. A particular example of this in cargo ships is the direct means of access required between the engine room and the shaft tunnel. In passenger ships watertight doors are more frequently found where they allow passengers to pass between one point of the accommodation and another.

Where a doorway is cut in the lower part of a watertight bulkhead care must be taken to maintain the strength of the bulkhead. The opening is to be framed and reinforced, if the vertical stiffeners are cut in way of the opening. If the stiffener spacing is increased to accommodate the opening, the scantlings of the stiffeners on either side of the opening are increased to give an equivalent strength to that of an unpierced bulkhead. The actual opening is kept as small as possible, the access to the shaft tunnel being about 1000 to 1250 mm high and about 700 mm wide. In passenger accommodation the openings would be somewhat larger.

Mild steel or cast steel watertight doors fitted below the water line are either of the vertical or horizontal sliding type. A swinging hinged type of door could prove impossible to close in the event of flooding and is not permitted. The sliding door must be capable of operation when the ship is listed 15°, and be opened or closed from the vicinity of the door as well as from a position above the bulkhead deck. At this remote control position an indicator must be provided to show whether the door is open or closed. Vertical sliding doors may be closed by a vertical screw thread which is turned by a shaft extending above the bulkhead and fitted with a crank handle. This screw thread turns in a gunmetal nut attached to the top of the door, and a crank handle is also provided at the door to allow it to be closed from this position. Often horizontal sliding doors are fitted, and these may have a vertical shaft extending above the bulkhead deck, which may be operated by hand from above the deck or at the door. This can also be power driven by an electric motor and worm gear, the vertical shaft working through bevel wheels, and horizontal screwed shafts turning in bronze nuts on the door. The horizontal sliding door may also be opened

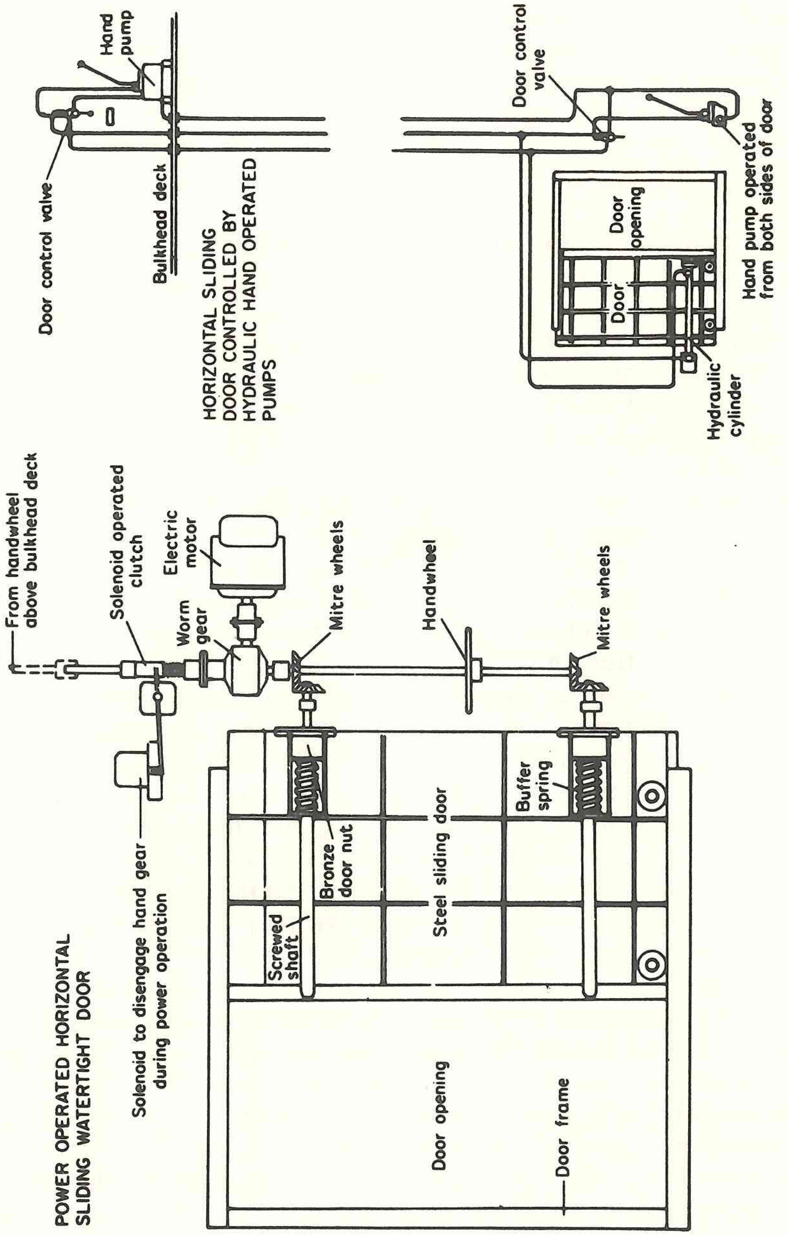


FIGURE 18.3 Watertight doors

and closed by a hydraulic ram with a hydraulic hand pump and with control at the door and above the bulkhead deck (*see* Figure 18.3). With the larger number of watertight doors fitted in passenger ships the doors may be closed by means of hydraulic power actuated by remote control from a central position above the bulkhead deck.

When in place all watertight doors are given a hose test, but those in a passenger ship are required to be tested under a head of water extending to the bulkhead deck. This may be done before the door is fitted in the ship.

In approved positions in the upper tween decks well above the waterline, hinged watertight doors are permitted. These may be similar to the weathertight doors fitted in superstructures, but are to have gunmetal pins in the hinges.

Deep Tanks

Deep tanks were often fitted adjacent to the machinery spaces amidships to provide ballast capacity, improving the draft with little trim, when the ship was light. These tanks were frequently used for carrying general cargoes, and also utilized to carry specialist liquid cargoes. In cargo liners where the carriage of certain liquid cargoes is common practice it was often an advantage to have the deep tanks adjacent to the machinery space for cargo heating purposes. However in modern cargo liners they may require to be judiciously placed in order to avoid excessive stresses in different conditions of loading. Most ships now have their machinery arranged aft or three-quarters aft, and are fitted with deep tanks forward to improve the trim in the light conditions.

CONSTRUCTION OF DEEP TANKS Bulkheads which form the boundaries of a deep tank differ from hold bulkheads in that they are regularly subjected to a head of liquid. The conventional hold bulkhead may be allowed to deflect and tolerate high stresses on the rare occasions when it has to withstand temporary flooding of a hold, but deep tank bulkheads which are regularly loaded in this manner are required to have greater rigidity, and be subject to lower stresses. As a result the plate and stiffener scantlings will be larger in way of deep tanks, and additional stiffening may be introduced.

The greater plating thickness of the tank boundary bulkheads increases with tank depth, and with increasing stiffener spacing. To provide the greater rigidity the vertical stiffeners are of heavier scantlings and more closely spaced. They must be bracketed or welded to some other form of stiffening member at their ends. Vertical stiffener sizes may be reduced, however, by fitting horizontal girders which form a continuous line of support on the bulkheads and ship's side. These horizontal girders are

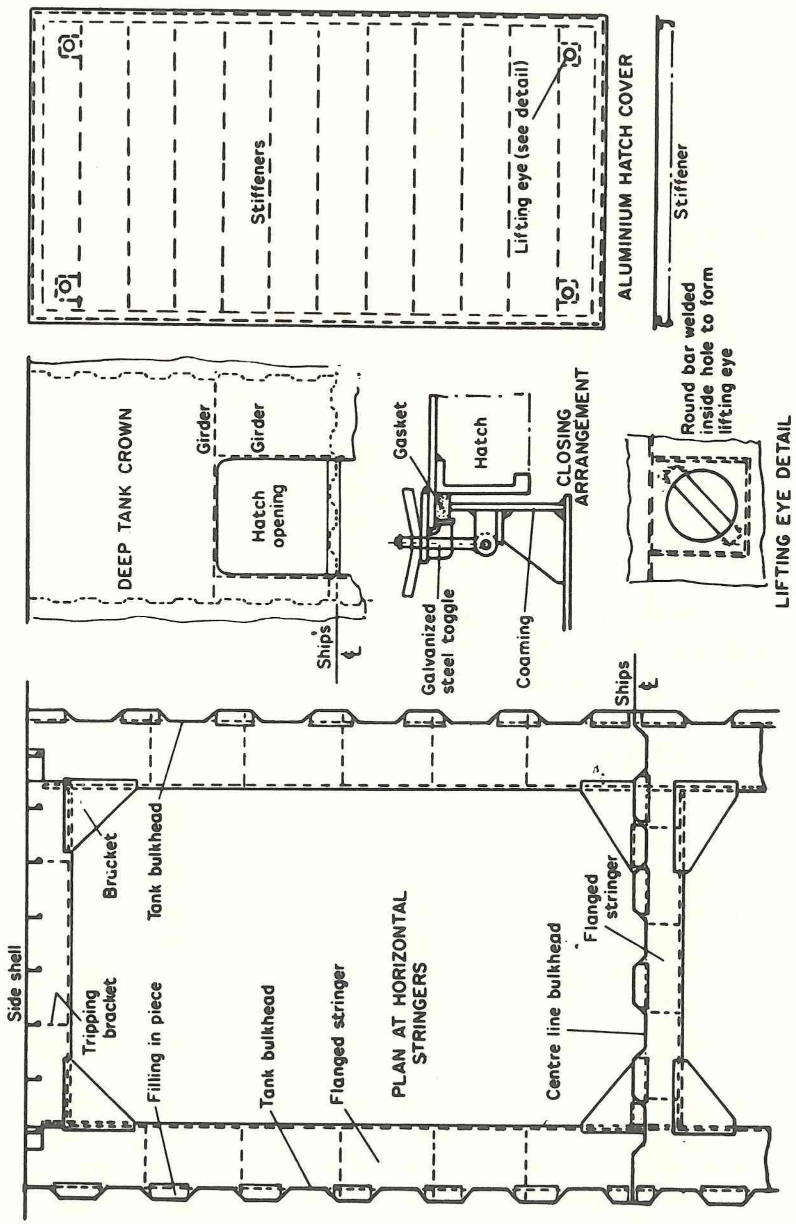


FIGURE 18.4 Construction of deep tanks

connected at their ends by flanged brackets and are supported by tripping brackets at the toes of the end brackets, and at every third stiffener or frame. Intermediate frames and stiffeners are effectively connected to the horizontal girders (*see* Figure 18.4). The side frames where no horizontal girders are fitted have their scantling strength increased by 15 per cent in way of the deep tanks.

Where deep tanks are intended to carry oil fuel for the ship's use, or oil cargoes, there will be a free surface, and it is necessary to fit a centre line bulkhead where the tanks extend from side to side of the ship. This bulkhead may be intact or perforated, and where intact the scantlings will be the same as for boundary bulkheads. If perforated, the area of perforations is sufficient to reduce liquid pressures, and the bulkhead stiffeners have considerably reduced scantlings, surging being avoided by limiting the perforation area.

Both swedged and corrugated plating can be used to advantage in the construction of deep tanks since, without the conventional stiffening, tanks are more easily cleaned. With conventional welded stiffening it may be convenient to arrange the stiffeners outside the tank so that the boundary bulkhead has a plain inside for ease of cleaning.

In cargo ships where various liquid cargoes are carried, arrangements may be made to fit cofferdams between deep tanks. As these tanks may also be fitted immediately forward of the machine space, a pipe tunnel is generally fitted through them with access from the engine room. This tunnel carries the bilge piping as it is undesirable to pass this through the deep tanks carrying oil cargoes.

TESTING DEEP TANKS Deep tanks are tested by subjecting them to the maximum head of water to which they might be subject in service (i.e. to the top of the air pipe). This should not be less than 2.45 m above the crown of the tank.

Topside Tanks

Standard general bulk carriers are fitted with topside tanks which may be used for water ballast, and in some instances are used for the carriage of light grains. The thickness of the sloping bulkhead of this tank is determined in a similar manner to that of the deep tank bulkheads. In present practice, as indicated in Chapter 17, the topside tank is generally stiffened internally by longitudinal framing supported by transverses (*see* Figure 17.7). Transverses are arranged in line with the end of the main cargo hatchways; and in large ships, a fore and aft diaphragm may be fitted at half the width of the tank, between the deck and the sloping plating.

Shaft Tunnel

When the ship's machinery is not located fully aft it is necessary to enclose the propeller shaft or shafts in a watertight tunnel between the aft end of the machinery space and the aft peak bulkhead. This protects the shaft from the cargo and provides a watertight compartment which will contain any flooding resulting from damage to the watertight gland at the aft peak bulkhead. The tunnel should be large enought to permit access for inspection and repair of the shafting. A sliding watertight door which may be opened from either side is provided at the forward end in the machinery space bulkhead. Two means of escape from the shaft tunnel must be provided, and as a rule there is a ladder in a watertight trunk leading to an escape hatch on the deck above the waterline, at the aft end of the shaft tunnel. Where the ship narrows at its after end the aftermost hold may be completely plated over at the level of the shaft tunnel to form a tunnel flat, as the narrow stowage space either side of the conventional shaft tunnel could not be utilized. The additional space under this tunnel flat is often used to stow the spare tail shaft. Shaft tunnels also provide a convenient means of carrying piping aft, which is then accessible and protected from cargo damage.

CONSTRUCTION OF THE SHAFT TUNNEL The thickness of the tunnel plating is determined in the same manner as that for the watertight bulkheads. Where the top of the tunnel is well rounded the thickness of the top plating may be reduced, but where the top is flat it is increased. Under hatchways the top plating must be increased in thickness unless it is covered by wood of a specified thickness. Vertical stiffeners supporting the tunnel plating have similar scantlings to the watertight bulkhead stiffeners, and their lower end is welded to the tank top (*see* Figure 18.5). On completion the shaft tunnel structure is subject to a hose test.

At intervals along the length of the shaft, stools are built which support the shaft bearings. A walkway is installed on one side of the shaft to permit inspection, and as a result, in a single screw ship the shaft tunnel will be offset from the ship's centre line. This walkway is formed by gratings laid on angle bearers supported by struts, etc., any piping is then led along underneath the walkway.

Pillars

The prime function of the pillars is to carry the load of the decks and weights upon the decks vertically down to the ship's bottom structure where these loads are supported by the upward buoyant forces. A secondary function of pillars is to tie together the structure in a vertical direction. Within the main

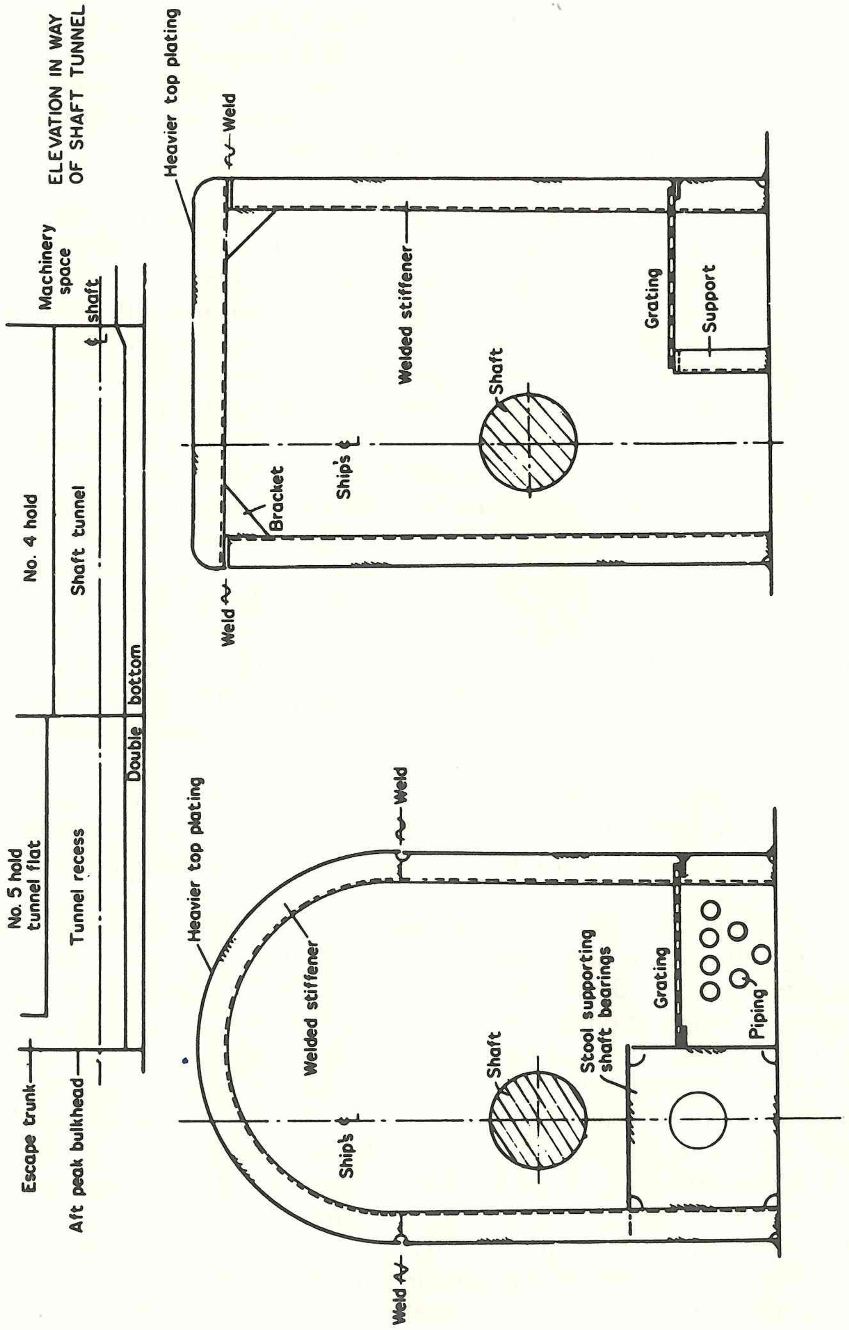


FIGURE 18.5 Shaft tunnels

hull of a cargo ship two different forms of pillar may be found, those in the holds invariably fulfilling the first function, and those in the machinery spaces fulfilling the latter function. Hold pillars primarily in compression are often without bracket connections at their ends, whilst machinery space pillars are heavily bracketed at their ends to permit tensile loadings. This latter type of pillar may also be found in tank spaces where the crown of tank under pressure can put the pillar in tension.

SPACING OF HOLD PILLARS Since pillars located in holds will interfere with the stowage arrangements, widely spaced pillars of large fabricated section are used rather than small, solid, closely spaced pillar systems. The arrangement most often found in cargo ships, is a two-row pillar system, with pillars at the hatch corners or mid-length of hatch supporting deck girders adjacent to the hatch sides. As the deck girder size is to some extent dependent on the supported span, where only a mid-hatch length pillar is fitted the girder scantlings will be greater than that where two hatch corner pillars are fitted. In fact pillars may be eliminated altogether where it is important that a clear space should be provided, but the deck girder will then be considerably larger, and may be supported at its ends by webs at the bulkhead. Substantial transverse cantilevers may also be fitted to support the side decks. Pillars may also be fitted in holds on the ship's centre line at the hatch end, to support the heavy hatch end beams securely connected to and supporting the hatch side girders. In a similar position it is not unusual to find short corrugated fore and aft pillar bulkheads. These run from the forward or aft side of the hatch opening to the adjacent transverse bulkhead on the ship's centre line.

To maintain continuity of loading the tween pillars are arranged directly above the hold pillars. If this is not possible stiffening arrangements should be made to carry the load from the tween pillar to the hold pillar below.

PILLAR CONSTRUCTION It has already been seen that the hold pillar is primarily subject to a compressive loading, and if buckling is to be avoided in service the required cross-section must be designed with both the load carried and length of pillar in mind. The ideal section for a compressive strut is the tubular section and this is often adopted for hold pillars, hollow rectangular and octagonal sections also being used. For economic reasons the sections are fabricated in lengths from steel plate, and for the hollow rectangular section welded channels or angles may also be used (*see* Figure 18.6). A small flat bar or cope bar may be tack welded inside these pillar sections to allow them to be welded externally.

Pillars have a bearing fit, and it is important that the loads at the head and heel of the pillar should be well distributed. At the head of the pillar a continuous weld is made to a doubling plate supported by brackets. Details of the head fitting vary from ship to ship and depend very much on the form

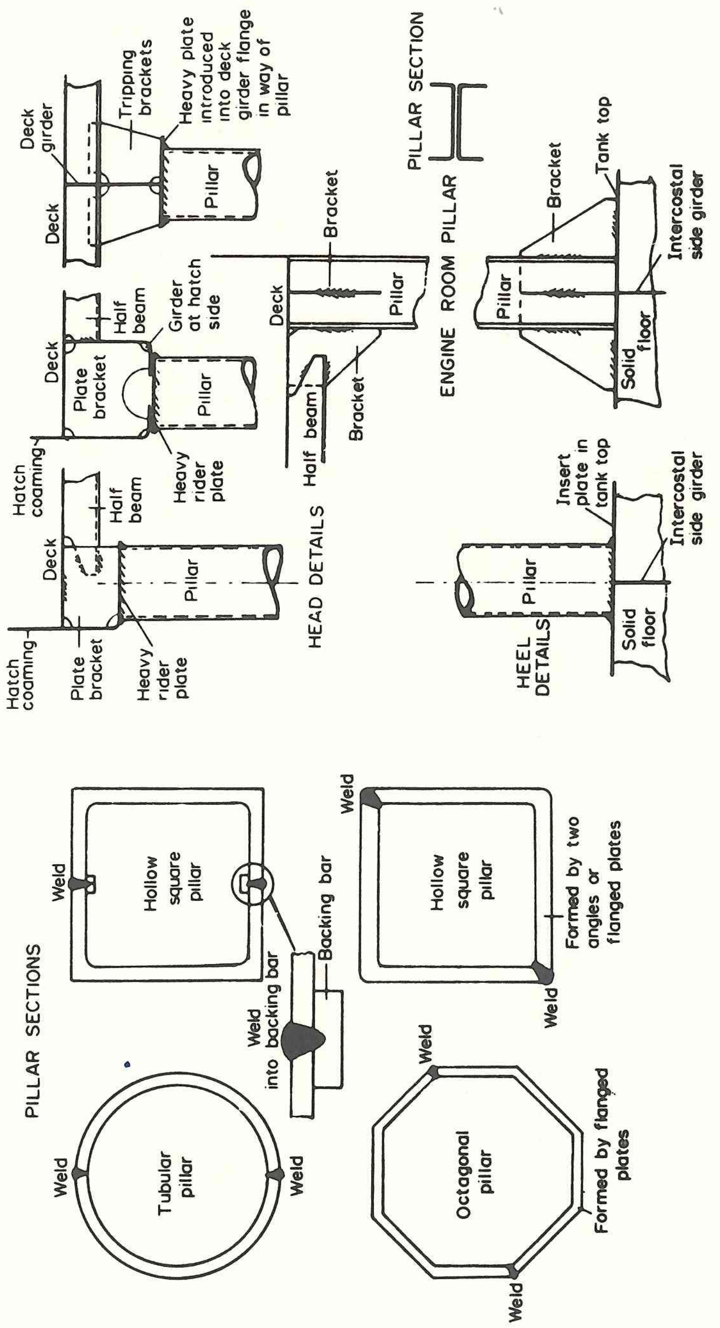


FIGURE 18.6 Pillars

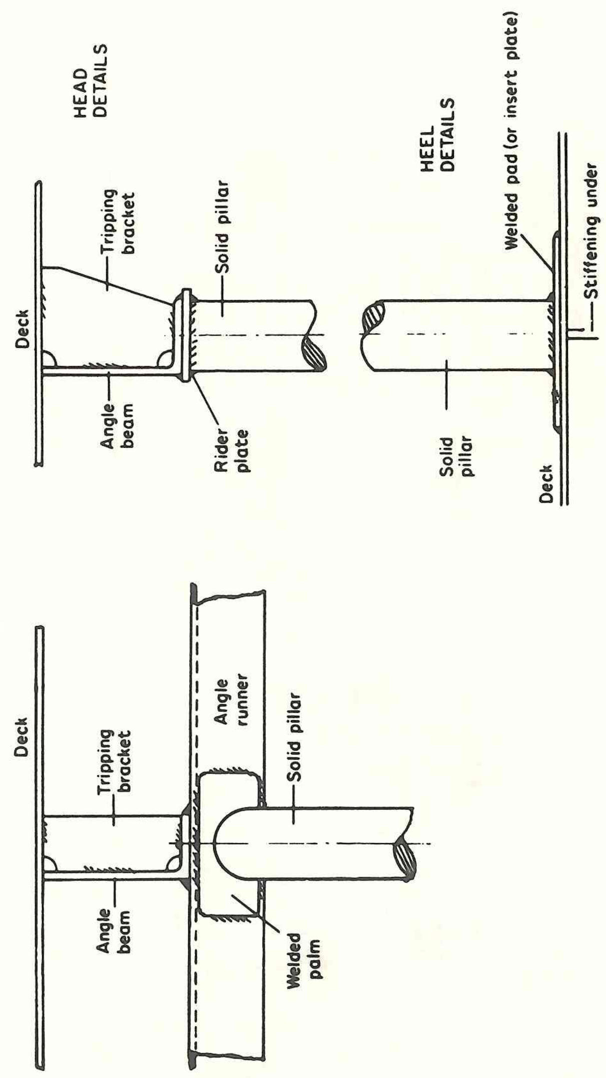


FIGURE 18.7 Small solid pillars

of hatch side or deck girder which they support. The heel of the hold pillar lands on a heavy doubling or insert plate at the tank top and it is commonly arranged that the point of loading will coincide with a solid floor/side girder intersection in the double bottom below. Where this is not possible partial floors and short intercostal side girders may be fitted to distribute the load.

Machinery space pillars are fabricated from angles, channels, or rolled steel joists, and are heavily bracketed to suitably stiffened members (Figure 18.6).

SMALL PILLARS Within the accommodation and in relatively small vessels solid round steel pillars having diameters seldom exceeding 150 mm may be fitted. These may have forged palms at their head and heel, the head being welded to a continuous angle fore and aft runner which supports the deck. Alternatively the pillar head may have a direct continuous weld connection to an inverted angle beam or deck girder, with suitable tripping brackets fitted directly above. The heel is then directly welded to the deck which is suitably stiffened below (*see* Figure 18.7).

Rolled hollow steel section pillars of similar size with direct welded head and heel fittings are commonly used today in lieu of small solid pillars.