Ship Construction

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Third Edition

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Preface

This text is primarily aimed at students in Nautical Schools and elsewhere following BTEC courses in nautical science (incorporating Department of Transport Parts 1 and 2 examinations) and in naval architecture and shipbuilding. The subject matter is also presented in sufficient depth to cover the syllabus for more advanced students preparing for the B.Sc. (Nautical Science) and Extra Master's Certificate. Students following professional courses in shipbuilding will also find the book useful as background reading.

Considerable changes have occurred in shipbuilding practice with the introduction of new technology and this book attempts to present modern shipyard techniques without neglecting basic principles. Shipbuilding covers a wide field of crafts and, with new developments occurring regularly, it would be difficult to cover every facet fully within the scope of the average textbook. For this reason further reading references are given at the end of most chapters, these being selected from books, transactions, and periodicals which are likely to be found in the libraries of Polytechnics and other technical institutions.

Acknowledgments

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I would also like to thank Lloyds Register of Shipping for permission to indicate various requirements of their 'Rules and Regulations for the Classification of Ships'.

D. J. E.

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Part 1

Introduction to Shipbuilding

1
Basic Design of the Ship

The economic factor is of prime importance in designing a merchant ship. An owner requires a ship which will give him the best possible returns for his initial investment and running costs. This means that the final design should be arrived at taking into account not only present economic considerations, but also those likely to develop within the life of the ship.

With the aid of computers it is possible to make a study of a large number of varying design parameters and to arrive at a ship design which is not only technically feasible but, more importantly, is the most economically efficient.

Preparation of the Design

The initial design of a ship generally proceeds through three stages: concept; preliminary; and contract design. The process of initial design is often illustrated by the design spiral (Figure 1.1) which indicates that given the objectives of the design, the designer works towards the best solution adjusting and balancing the interrelated parameters as he goes.

A concept design should, from the objectives, provide sufficient information for a basic techno-economic assessment of the alternatives to be made. Economic criteria derived are usually net present value, required freight rate and yield. Preliminary design refines and analyses the agreed concept design, fills out the arrangements and structure and aims at optimizing service performance. At this stage the builder should have sufficient information to tender. Contract design details the final arrangements and systems agreed with the owner and satisfies the building contract conditions.

Total design is not complete at this stage, it has only just started, post-contract design entails in particular design for production where the structure, outfit and systems are planned in detail to achieve a cost and time effective building cycle. Production of the ship must also be given consideration in the earlier design stages, particularly where it places constraints on the design or can affect costs.

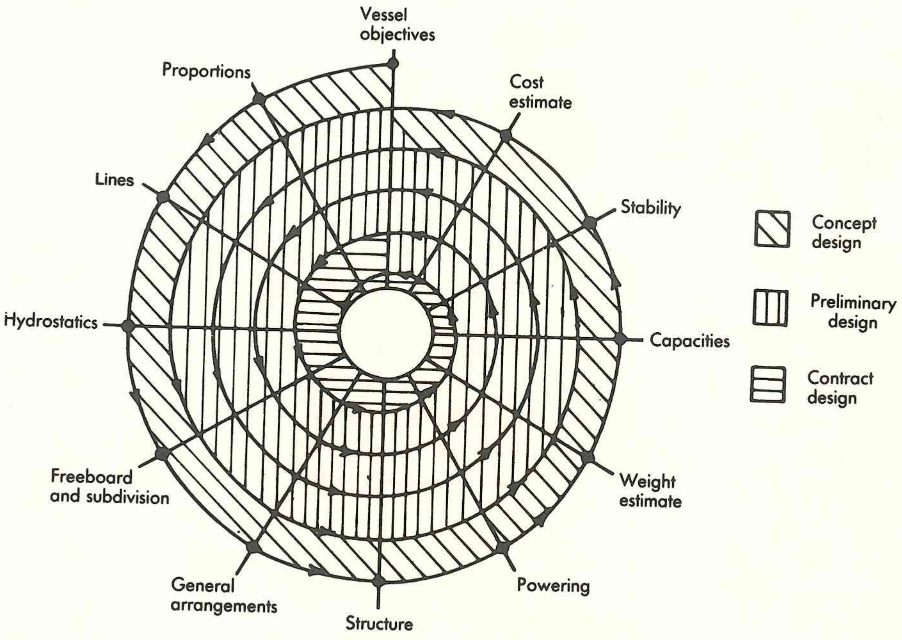

FIGURE 1.1 Design spiral

Information Provided by Design

When the preliminary design has been selected the following information is available:

Dimensions
Displacement
Stability
Propulsive characteristics and hull form
Preliminary general arrangement
Principal structural details

Each item of information may be considered in more detail, together with any restraints placed on these items by the ships service or other factors outside the designer's control.

1. The dimensions are primarily influenced by the cargo carrying capacity of the vessel. In the case of the passenger vessel, dimensions are influenced by the height and length of superstructure containing the accommodation. Length where not specified as a maximum should be a minimum consistent with the required speed and hull form. Increase of length produces higher longitudinal bending stresses requiring additional strengthening and a greater displacement for the same cargo weight. Breadth may be such as to provide adequate transverse stability. A minimum depth is controlled by the draft plus a statutory freeboard; but an increase in depth will result in a reduction of the longitudinal bending stresses, providing an increase in strength, or allowing a reduction in scantlings. Increased depth is therefore preferred to increased length. Draft is often limited by area of operation but if it can be increased to give a greater depth this can be an advantage.

Many vessels are required to make passages through various canals and this will place a limitation on the dimensions. The Suez Canal has a draft limit, locks in the Panama Canal and St. Lawrence Seaway limit length, beam and draft. In the Manchester Ship Canal locks place limitations on the main dimensions and there is also a limitation on the height above the water-line because of bridges.

2. Displacement is made up of lightweight plus deadweight. The lightweight is the weight of vessel as built, including boiler water, lubricating oil, and cooling water system. Deadweight is the difference between the lightweight and loaded displacement, i.e. it is the weight of cargo plus weights of fuel, stores, water ballast, fresh water, crew and passengers, and baggage. When carrying weight cargoes (e.g. ore) it is desirable to keep the lightweight as small as possible consistent with adequate strength. Since only cargo weight of the total deadweight is earning capital, other items should be kept to a minimum as long as the vessel fulfils its commitments.

3. In determining the dimensions statical stability is kept in mind in order to ensure that this is sufficient in all possible conditions of loading. Beam and depth are the main influences. Statutory freeboard and sheer are important together with the weight distribution in arranging the vessel's layout.

4. Propulsive performance involves ensuring that the vessel attains the required speeds. The hull form is such that it economically offers a minimum resistance to motion so that a minimum power with economically lightest machinery is installed without losing the specified cargo capacity.

A service speed is the average speed at sea with normal service power and loading under average weather conditions. A trial speed is the average speed obtained using the maximum power over a measured course in calm weather with a clean hull and specified load condition. This speed may be a knot or so more than the service speed.

Unless a hull form similar to that of a known performance vessel is used, tank tests of a model hull are generally specified nowadays. These provide the designer with a range of speeds and corresponding powers for the hull form, and may suggest modifications to the form. Published data from accumulated ship records and hull tests may be used to prepare the hull form initially.

The owner may often specify the type and make of main propulsion machinery installation with which their operating personnel are familiar.

5. The *general arrangement* is prepared in co-operation with the owner, allowing for standards of accommodation peculiar to that company, also peculiarities of cargo and stowage requirements. Efficient working of the vessel must be kept in mind throughout and compliance with the regulations of the various authorities involved on trade routes must also be taken into account. Some consultation with shipboard employees' representative organizations may also be necessary in the final accommodation arrangements.

6. Almost all vessels will be built to the requirements of a classification society such as Lloyd's Register. The standard of classification specified will determine the structural scantlings and these will be taken out by the shipbuilder. Owners often specify thicknesses and material requirements in excess of those required by classification societies and these must of course be complied with. Also special structural features peculiar to the trade or owner's fleet may be asked for.

Purchase of a New Vessel

In recent years the practice of owners commissioning 'one off' designs for cargo ships from consultant naval architects, shipyards or their own technical staff has increasingly given way to the selection of an appropriate 'stock design' to suit their particular needs. To determine which stock design, the shipowner must undertake a detailed project analysis involving consideration of the proposed market, route, port facilities, competition, political and labour factors, and cash flow projections. Also taken into account will be the choice of shipbuilder where relevant factors such as the provision of government subsidies/grants or supplier credit can be important as well as the price, date of delivery, and yards reputation. Most stock designs offer some features which can be modified, such as outfit, cargo handling equipment, or alternate manufacture of main engine, for which the owner will have to pay extra.

Purchase of a passenger vessel will still follow earlier procedures for a 'one-off' design but there are shipyards concentrating on this type of construction and the owner may be drawn to them for this reason. A non-standard cargo ship of any form and a number of specialist ships will also require a 'one-off' design. Having decided on his basic requirements, i.e. the vessel's objectives, after an appropriate project analysis the larger shipowners may employ their own technical staff to prepare the tender specification and submit this to shipbuilders who wish to tender for the building of the ship. The final building specification and design is prepared by the successful tendering shipbuilder in co-operation with the owners technical staff. The latter may oversee construction of the vessel and approve the builders drawings and calculations. Other shipowners may retain a firm of consultants or approach a firm who may assist with preliminary design studies and will prepare the tender specifications and in some cases call tenders on behalf of the owner. Often the consultants will also assist the owners in evaluating the tenders and oversee the construction on their behalf.

Ship Contracts

The successful tendering shipbuilder will prepare a building specification for approval by the owner or his representative which will form part of the contract between the two parties and thus have legal status. This technical specification will normally include the following information:

Brief description and essential qualities and characteristics of ship.
Principal dimensions.
Deadweight, cargo and tank capacities etc.
Speed and power requirements.
Stability requirements.
Quality and standard of workmanship.
Survey and certificates.
Accommodation details.
Trial conditions.
Equipment and fittings.
Machinery details, including the electrical installation, will normally be produced as a separate section of the specification.

Most shipbuilding contracts are based on one of a number of standard forms of contract which have been established to obtain some uniformity in the contract relationships between builders and purchasers. Three of the most common standard forms of contract have been established by:

1. AWES—Association of West European Shipbuilders.
2. MARAD Maritime Administration, USA.
3. SAJ Shipowners Association of Japan.

The AWES standard form of contract includes:

1. Subject of contract (vessel details etc.).
2. Inspection and approval.
3. Modifications.
4. Trials.
5. Guarantee (speed, capacity, fuel consumption).
6. Delivery of vessel.

7. Price.
8. Property (rights to specification, plans etc.).
9. Insurance.
10. Defaults by the contractor.
12. Guarantee (after delivery).
13. Contract expenses.
14. Patents.
15. Reference to expert and arbitration.
16. Conditions for contract to become effective.
17. Legal domicile (of purchaser).
18. Assignment (transfer of purchasers rights to third party).

Irrespective of the source of the owner's funds for purchasing the ship payment to the shipbuilder is usually made as progress payments which are stipulated in the contract under item 7 above. A typical payment schedule may have been as follows:

10 per cent on signing contract.
10 per cent on arrival of materials on site.
10 per cent on keel laying.
20 per cent on launching.
50 per cent on delivery.

Given modern construction techniques, where the shipbuilder's cash flow during the building cycle can be very different from that indicated above with traditional building methods, the shipbuilder will probably prefer payments to be tied to different key events. Also of concern to the shipbuilder employing modern building procedures is item 3 in the standard form of contract where modifications called for at a late date by the owner can have a dramatic effect on costs and delivery date given the detail now introduced at an early stage of the fabrication process.

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2

Ship Dimensions and Form

The hull form of a ship may be defined by a number of dimensions and terms which are often referred to during and after building the vessel. An explanation of the principal terms is given below:

After Perpendicular (A.P.): A perpendicular drawn to the waterline at the point where the aft side of the rudder post meets the summer load line. Where no rudder post is fitted it is taken as the centre line of the rudder stock.

Forward Perpendicular (F.P.): A perpendicular drawn to the waterline at the point where the foreside of the stem meets the summer load line.

Length Between Perpendiculars (L.B.P.): The length between the forward and aft perpendiculars measured along the summer load line.

Amidships: A point midway between the after and forward perpendiculars.

Length Overall (L.O.A.): Length of vessel taken over all extremities.

Lloyd's Length: Used for obtaining scantlings if the vessel is classed with Lloyd's Register. It is the same as length between perpendiculars except that it must not be less than 96 per cent and need not be more than 97 per cent of the extreme length on the summer load line. If the ship has an unusual stem or stern arrangement the length is given special consideration.

Moulded dimensions are often referred to; these are taken to the inside of plating on a steel ship.

Base Line: A horizontal line drawn at the top of the keel plate. All vertical moulded dimensions are measured relative to this line.

Moulded Beam: Measured at the midship section is the maximum moulded breadth of the ship.

Moulded Draft: Measured from the base line to the summer load line at the midship section.

Moulded Depth: Measured from the base line to the heel of the upper deck beam at the ship's side amidships.

Extreme Beam: The maximum beam taken over all extremities.

Extreme Draft: Taken from the lowest point of keel to the summer load line. Draft marks represent extreme drafts.

Extreme Depth: Depth of vessel at ship's side from upper deck to lowest point of keel.

Half Breadth: Since a ship's hull is symmetrical about the longitudinal centre line, often only the half beam or half breadth at any section is given.

Freeboard: The vertical distance measured at the ship's side between the summer load line (or service draft) and the freeboard deck. The freeboard deck is normally the uppermost complete deck exposed to weather and sea which has permanent means of closing all openings, and below which all openings in the ship's side have watertight closings.

Sheer: Curvature of decks in the longitudinal direction. Measured as the height of deck at side at any point above the height of deck at side amidships.

Camber (or Round of Beam): Curvature of decks in the transverse direction. Measured as the height of deck at centre above the height of deck at side.

Rise of Floor (or Deadrise): The rise of the bottom shell plating line above the base line. This rise is measured at the line of moulded beam.

Half Siding of Keel: The horizontal flat portion of the bottom shell measured to port or starboard of the ship's longitudinal centre line. This is a useful dimension to know when dry-docking.

Tumblehome: The inward curvature of the side shell above the summer load line.

Flare: The outward curvature of the side shell above the waterline. It promotes dryness and is therefore associated with the fore end of ship.

Stem Rake: Inclination of the stem line from the vertical.

Keel Rake: Inclination of the keel line from the horizontal. Trawlers and tugs often have keels raked aft to give greater depth aft where the propeller diameter is proportionately larger in this type of vessel. Small craft occasionally have forward rake of keel to bring propellers above the line of keel.

Tween Deck Height: Vertical distance between adjacent decks measured from the tops of deck beams at ship side.

Parallel Middle Body: The length over which the midship section remains constant in area and shape.

Entrance: The immersed body of the vessel forward of the parallel middle body.

Run: The immersed body of the vessel aft of the parallel middle body.

Tonnage: This is often referred to when the size of the vessel is discussed, and the gross tonnage is quoted from Lloyd's Register. Tonnage is a measure of the enclosed internal volume of the vessel (originally computed as 100 cubic feet per ton). This is dealt with in detail in Chapter 30.

The principal dimensions of the ship are illustrated in Figure 2.1.

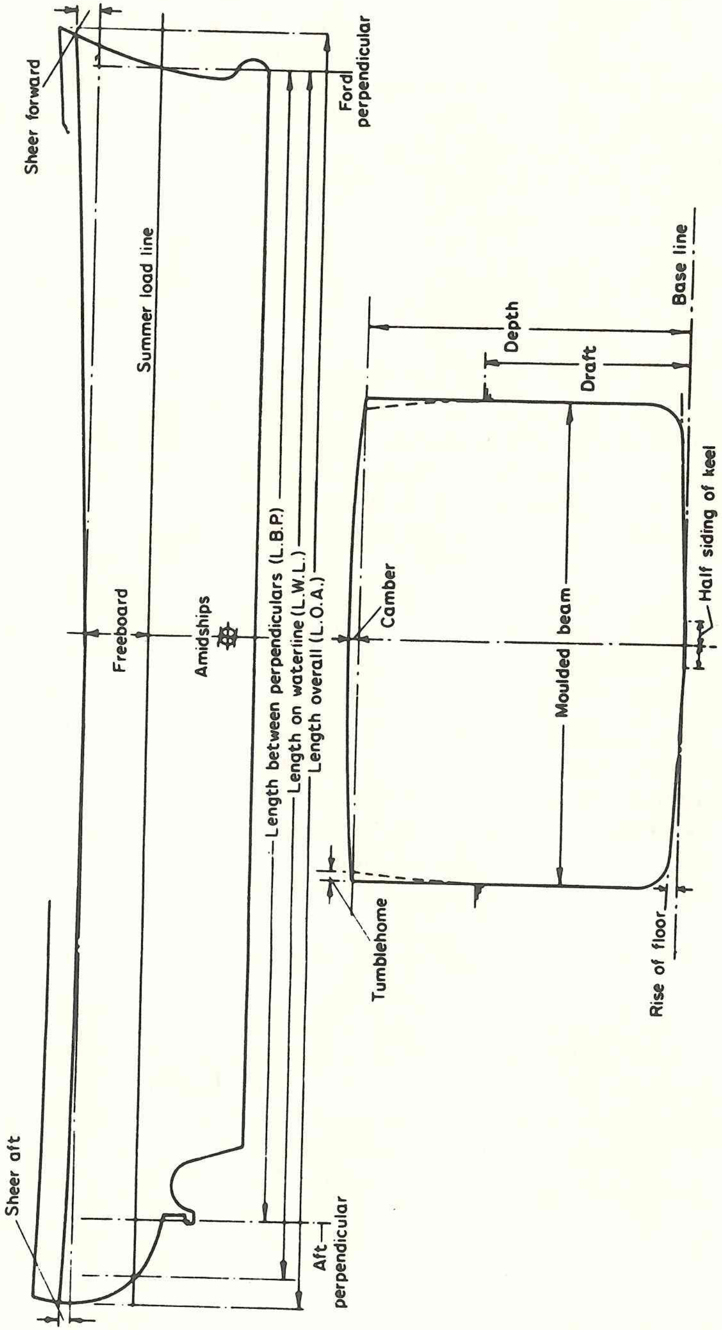


FIGURE 2.1 Principal ship dimensions

3
Development of Ship Types

A breakdown into broad working groups of the various craft which the shipbuilder might be concerned with are shown in Figure 3.1. This covers a wide range and reflects the adaptability of the shipbuilding industry. It is obviously not possible to cover the construction of all those types in a single volume. The development of the vessels with which the text is primarily concerned, namely dry cargo ships, bulk carriers, tankers, and passenger ships follows.

Dry Cargo Ships

If the development of the dry cargo ship from the time of introduction of steam propulsion is considered the pattern of change is similar to that shown in Figure 3.2. The first steam ships followed in most respects the design of the sailing ship having a flush deck with the machinery openings protected only by low coamings and glass skylights. At quite an early stage it was decided to protect the machinery openings with an enclosed bridge structure. Erections forming a forecastle and poop were also introduced at the forward end and aft end respectively for protection. This resulted in what is popularly known as the 'three island type'. A number of designs at that time also combined bridge and poop, and a few combined bridge and forecastle, so that a single well was formed.

Another form of erection introduced was the raised quarter deck. Raised quarter decks were often associated with smaller deadweight carrying vessels, e.g. colliers. With the machinery space aft which is proportionately large in a small vessel there is a tendency for the vessel to trim by the bow when fully loaded. By fitting a raised quarter deck in way of the after holds this tendency was eliminated. A raised quarter deck does not have the full height of a tween deck, above the upper deck.

Further departures from the 'three island type' were brought about by the carriage of cargo and cattle on deck, and the designs included a light covering built over the wells for the protection of these cargoes. This resulted in the awning or spar deck type of ship, the temporarily enclosed spaces being exempt from tonnage measurement since they were not permanently closed spaces. These awning or spar deck structures eventually became an integral part of the ship structure but retained a lighter

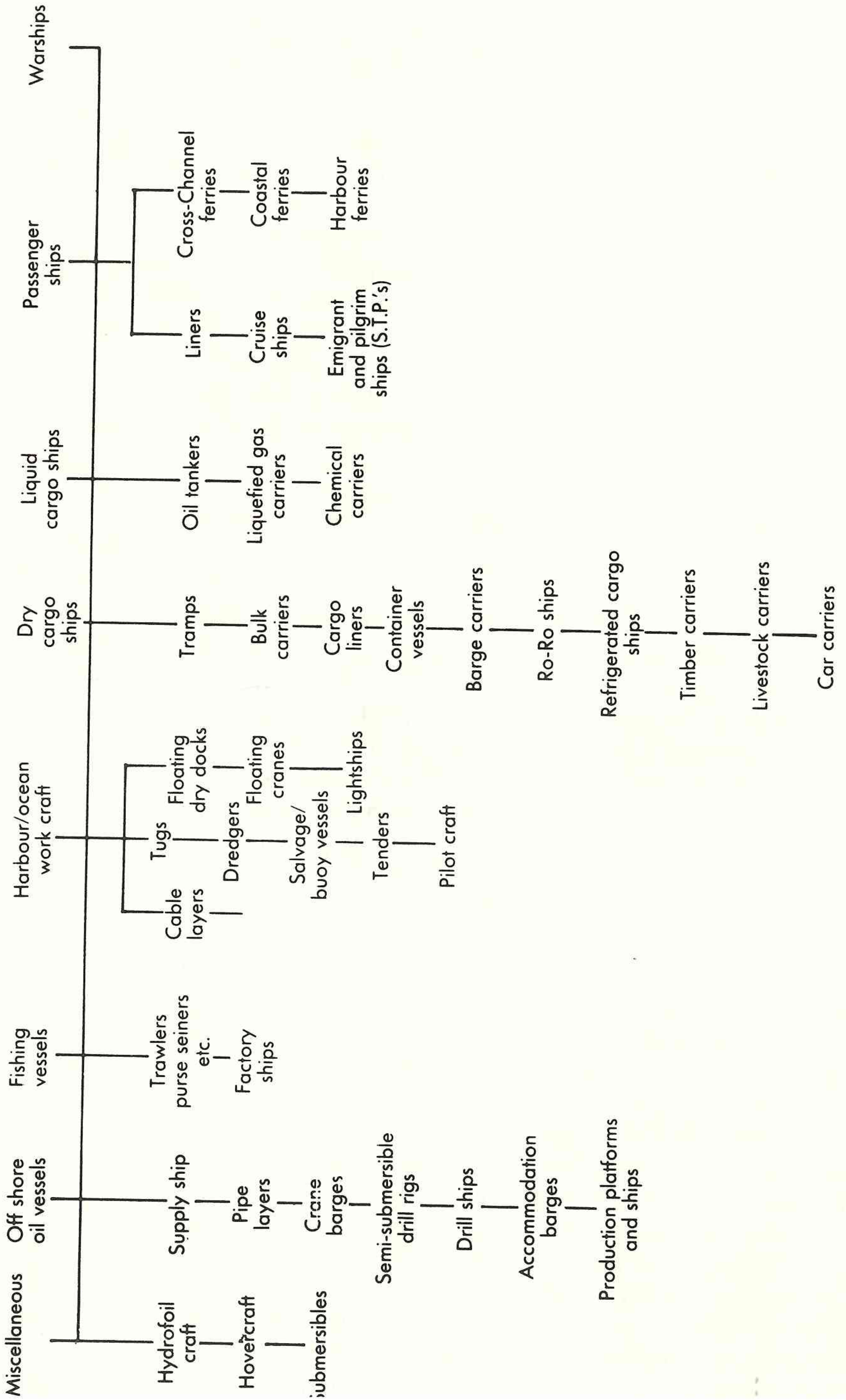


FIGURE 3.1 Ship types

structure than the upper deck structure of other two-deck ships, later referred to as 'full scantling' vessels. The 'shelter deck type' as this form of vessel became known, apart from having a lighter upper structure, was to have the freeboard measured from the second deck, and the tween deck space was exempt from tonnage measurement. This exemption was obtained by the provision of openings in the shelter deck and tween deck bulkheads complying with certain statutory regulations.

At a later date what are known as open/closed shelter deck ships were developed. These were full scantling ships having the prescribed openings so that the tween deck was exempt from tonnage measurement when the vessel was operating at a load draft where the freeboard was measured from the second deck. It was possible to close permanently these temporary openings and re-assign the freeboard, it then being measured from the upper deck so that the vessel might load to a deeper draft, and the tween deck was no longer exempt from tonnage measurement.

Open shelter deck vessels were popular with shipowners for a long period. However, during that time much consideration was given to their safety and the undesirable form of temporary openings in the main hull structure. Eliminating these openings without substantially altering the tonnage values was the object of much discussion and deliberation. Finally Tonnage Regulations introduced in 1966 provided for the assignment of a tonnage mark, at a stipulated distance below the second deck. A vessel having a 'modified tonnage' had tonnage measured to the second deck only, i.e. the tween deck was exempt, but the tonnage mark was not to be submerged. Where a vessel was assigned 'alternative tonnages' (the equivalent of previous open/closed shelter deck ship), tonnage was taken as that to the second deck when the tonnage mark was not submerged. When the tonnage mark was submerged, tonnage was taken as that to the upper deck, the freeboard being a minimum measured from the upper deck. The tonnage mark concept effectively dispensed with the undesirable tonnage openings. Further changes to tonnage requirements in 1969 led to a universal system of tonnage measurement without the need for tonnage marks although some older ships may retain such marks and their original tonnages up to 1994 (see Chapter 30).

Originally the machinery position was amidships with paddle wheel propulsion. Also with coal being burnt as the propulsive fuel, bunkers were then favourably placed amidships for trim purposes. With the use of oil fuel this problem was more or less overcome, and with screw propulsion their are definite advantages in having the machinery aft. Taking the machinery right aft can produce an excessive trim by the stern in the light condition and the vessel is provided with deep tanks forward. This might lead to a large bending moment in the ballast condition, and compromise is often reached by having the machinery three-quarters aft. That is, there are say three or four holds forward and one aft of the machinery space. In either arrange-

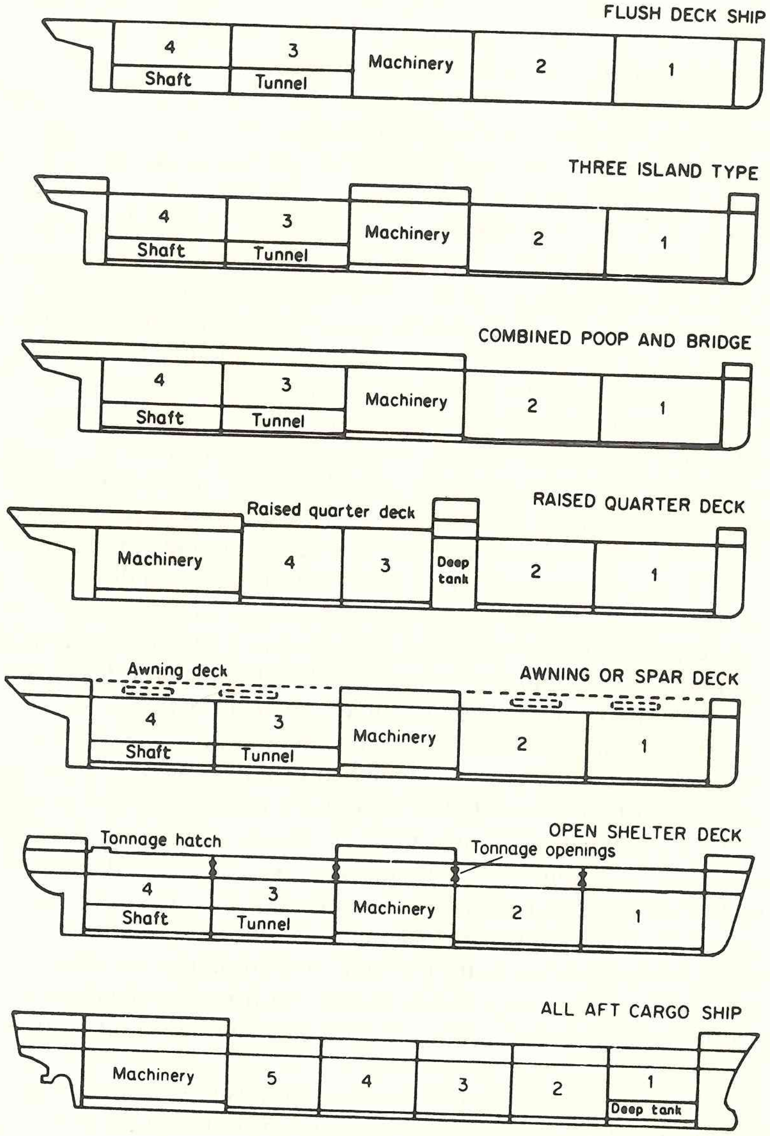


FIGURE 3.2 Development of cargo ship

ment the amidships portion with its better stowage shape is reserved for cargo, and shaft spaces lost to cargo are reduced.

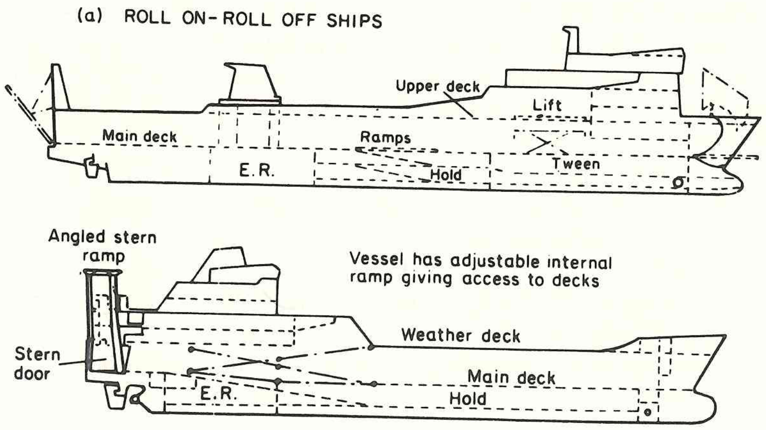
The all aft cargo ship illustrating the final evolution of the dry cargo ship in Figure 3.2 could represent the sophisticated cargo liners of the mid-1960s. By the mid-1970s most of the cargo liner trades have been taken over by the container ship and much of the short haul trade undertaken by the conventional dry cargo ship has passed to the 'roll on roll off' (ro-ro) type of vessel. A feature of the container ship is the stowage of the rectangular container units within the fuller rectangular portion of the hull and their arrangement in tiers above the main deck level. In order to facilitate removal and placing of the container units of internationally agreed standard (I.S.O.) dimensions hold and hatch widths and lengths are common. The narrow deck width outboard of the hatch opening forms the crown of a double shell space containing wing ballast tanks and passageways (*see* Figure 17.8). Considerable ballast is required in particular for the larger container ships trading to the Far East where the beam depth ratio is low to allow transit of the Panama Canal.

A further development in the cargo liner trade has seen the introduction of the barge-carrying vessel. This type of ship has particular advantage in maintaining a scheduled service between the ports at the mouths of large river systems such as that between the Mississippi river in the U.S.A. and the Rhine in Europe. Standard unit cargo barges are carried on board ship and placed overboard or lifted onboard at terminal ports by large deck mounted gantries or elevator platforms in association with travelling rails. Other designs make provision for floating the barges in and out of the carrying ship which can be ballasted to accommodate them.

Ro-ro ships are characterized by the stern and in some cases bow or side doors giving access to a vehicle deck above the waterline but below the upper deck. Access within the ship may be provided in the form of ramps or lifts leading from this vehicle deck to upper decks or hold below. Ro-ro ships may be fitted with various patent ramps for loading and discharging through the shell doors when not trading to regular ports where link-span and other shore side facilities which are designed to suit are available. Cargo is carried in vehicles and trailers or in unitized form loaded by fork lift and other trucks. In order to permit the drive through vehicle deck a restriction is placed on the height of machinery space and the ro-ro ship was among the first to popularize the geared medium speed diesel engine with a lesser height than its slow speed counterpart. A similar consideration led to the use of the gas turbine in a few of this ship-type and they were located in the superstructure clear of the vehicle deck and drove electric motors below the vehicle deck. Rising oil prices eventually led to replacement of the gas turbine by conventional below deck diesel motor propulsion.

Since the last war there has been a steady increase in the speed of the dry cargo ship and this is reflected in the hull form of modern vessels. A much finer hull is apparent particularly in those vessels engaged in the longer cargo liner trades. Use of bulbous bow forms and open water sterns are employed to advantage and considerable flare may be seen in the bows of container ships to reduce wetness on deck where containers are stowed. In some early container ships it is thought that this was probably overdone leading to an undesirable tendency for the main hull to whip during periods when the bows pitched into head seas. Larger container ships have the house three-quarters aft and the full beam is maintained right to the stern to give the largest possible container capacity.

Cargo handling equipment, which remained relatively static for a long period, has received considerable attention in the past two decades. This has been primarily brought about by an awareness of the loss of revenue caused by the long periods of time the vessel may spend in port discharging and loading cargoes. Conventional cargo vessels are now fitted with folding steel hatch covers of one patent type or another or slab covers of steel, the object being to improve maintenance and to speed cargo handling. Various new lifting devices and derrick forms have been designed, and winches, etc. introduced to simplify as well as increase the rate of loading and discharge.



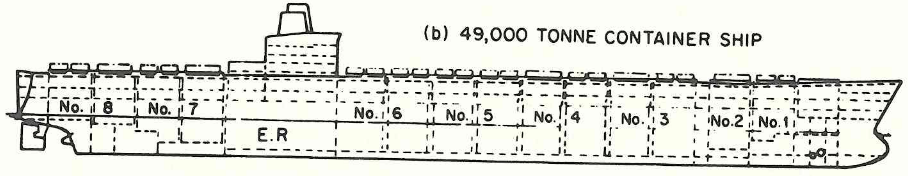


FIGURE 3.3

Bulk Carriers

The large bulk carrier originated as an ore carrier on the Great Lakes at the beginning of the present century. For quite a long period to the Second World War pure bulk carriers were only built spasmodically for ocean trading, since a large amount of these cargoes could be carried by general cargo tramps with the advantage of their being able to take return cargoes

It is interesting to recall, however, that a series of turret-deck steamers were built for ore carrying purposes between 1904 and 1910 and a section through such a vessel is illustrated in Figure 3.4(a). Since 1945 an increasing number of ocean-going ore carriers have been built and in particular a large number of general bulk carriers. The form of ore carrier with double bottom and side ballast tanks first appeared in 1917, only at that time the side tanks did not extend to the full hold depth. Also to overcome the disadvantage that the vessel was only usefully employed on one leg of the voyage the oil/ore carrier was evolved at the same time. This type carries oil in the wing tanks as shown in Figure 3.4(c), the passageway shown for crew protection being fitted in order to obtain the deeper draft given to tankers. The general bulk carrier often takes the form shown in Figure 3.4(d) with double bottom, hopper sides, and deck wing tanks. These latter tanks have been used for the carriage of light grain cargoes as well as water ballast. A more refined form of general bulk carrier patented by the MacGregor International Organization is illustrated in Figure 3.4(e). The patentees indicate that this 'universal bulk carrier' offers a very flexible range of cargo stowage solutions, taking oil, ore, grain, and coal cargoes. A further interesting development is shown in Figure 3.4(f) which shows a general cargo ship fitted with alternate holds of short length. On single voyages the vessel may carry heavy bulk cargoes in the short holds to give a reasonable cargo distribution. Special strengthening is required of the side shell at ends of the short holds to allow for shear forces, and the bending moments require special consideration.

Since the bulk carrier makes many voyages in ballast a large ballast capacity is provided to give adequate immersion of the propeller. This is so arranged that the vessel does not have too low a centre of gravity on a ballast voyage, and this is also a condition which one would wish to avoid when fully loaded.

A general arrangement of a typical bulk carrier shows a clear deck with machinery aft. Large hatches with steel covers are designed to facilitate rapid loading and discharge of the cargo. In fact it has been suggested that general cargo ships are rapidly assuming the characteristics of bulk carriers where the desirability for a quick turn round in port was recognized at an earlier date. The size of this type of vessel has also steadily increased in recent years, and ore carriers have reached the 250 000 tonnes deadweight mark.

Oil Tankers

The form of vessels specifically designed for the carriage of oil cargoes has not undergone a great deal of change since the 1880s when the vessel illustrated in Figure 3.5(a) was constructed. Today the expansion tank and

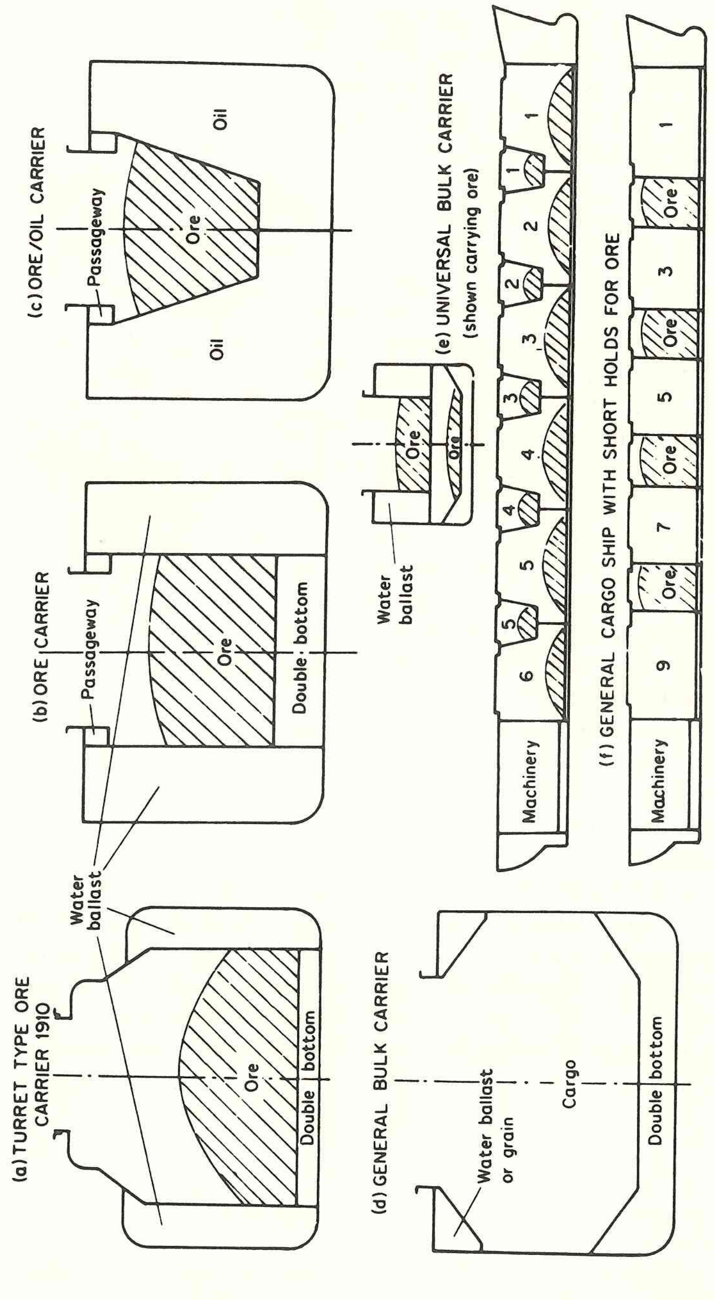


FIGURE 3.4 Bulk carriers

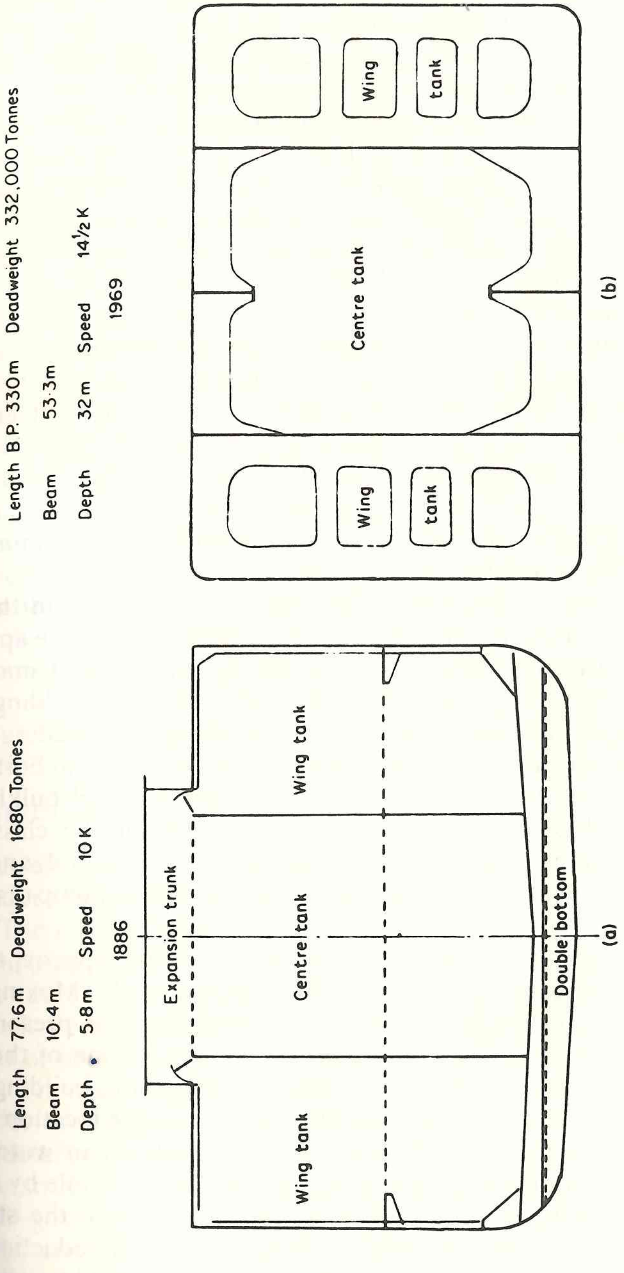


FIGURE 3.5 Oil tankers

double bottom within the cargo space of ocean-going tankers have been eliminated. The greatest developments have been in the growth of size and changes in structural arrangements.

The growth in size of ocean-going vessels from 1880 to the end of the Second World War was gradual, the average deadweight rising from 1500 tonnes to about 12 000 tonnes. Since then the average deadweight has increased rapidly to about 20 000 tonnes in 1953 and about 30 000 tonnes in 1959. Today there are afloat tankers ranging from 100 000 tonnes deadweight to 500 000 tonnes deadweight. It should be made clear that the larger size of vessel is the crude oil carrier, and fuel oil carriers tend to remain within the smaller deadweights.

Service speeds of oil tankers have shown an increase since the war, going from 12 knots to 16 or 17 knots. The service speed is related to the optimum economic operation of the tanker. Also the optimum size of tanker is very much related to current market economics. The tanker fleet growth increased enormously to meet the expanding demand for oil until 1973/1974 when the OPEC price increases slowed that expansion and led to a slump in the tanker market. As a result it is unlikely that such a significant rise in tanker size and further rise in speed will be noted in the years immediately following the substantial oil price increases.

Structurally one of the greatest developments has been in the use of welding, oil tankers being amongst the first vessels to utilize the application of welding. Little difficulty is experienced in making and maintaining welded oiltight joints: the same cannot be said of riveting. Welding has also allowed cheap prefabrication methods to be adopted. Longitudinal framing was adopted at an early date, and is utilized for the deck and bottom shell on all ocean-going vessels, also for side and longitudinal bulkheads on larger vessels. Revision of the construction rules of the classification societies allowed the length of the tank spaces to be increased, and this led to a reduction in steel weight, and also facilitated ease of pump discharging cargoes.

As far as the general arrangement is concerned there appears always to have been a trend towards placing the machinery aft. Moving all the accommodation and bridge aft is a common feature at present and is desirable from the fire protection point of view. Location of the accommodation and messes in one area is more economic from a building point of view since all services are only to be provided at a single location. A more recent innovation in the tank spaces is to provide clean water ballast capacity, mainly in the midship region. This is made possible by the large cubic capacity of the tanker, and is designed to reduce the still water bending moment when fully loaded, thus allowing a reduction in the scantlings. It also provides for elimination of the cargo hold forward where the clean ballast tanks are suitably arranged to avoid ballast condition trim problems. Using clean water ballast tanks reduces corrosion problems, since rapid corrosion is associated with tank spaces which are subject to alternate oil and sea water ballast cargoes. Requirements of the International Convention for the Prevention of Pollution from Ships 1973 have the effect of limiting tank size and making it desirable to fit double bottom and wing tank spaces throughout the cargo tank length for clean water ballast. These requirements are intended to minimize pollution of the sea by oil in the event of collision or stranding of the tanker.

Cargo handling equipment has also developed; large crude oil vessels may now use the 'full flow' system, discharging from the aftermost tank space. Not all operators are in favour of this system, however, and more conventional piping systems are used in a large number of vessels with a partial full flow arrangement. Most of the large crude oil vessels have a single pump room aft, and are provided with high speed centrifugal pumps with increasing capacities for discharging and loading cargoes. Stripping pumps often remain of the reciprocating type, but vacuum pumps are also available. Tank cleaning is now normally accomplished by means of water-driven rotating machines, rather than by hosing down the tank by hand. In building the vessel the location of tank cleaning openings needs careful consideration for too many can be detrimental to the hull strength, but complete access for cleaning must be achieved.

Slop tanks are provided in modern oil tankers into which the oily residues of tank cleaning and any dirty ballast are pumped. These are allowed to settle for sufficient time for the oil and seawater to separate and the seawater is then pumped overboard whilst the oil is handled as normal cargo.

Passenger Ships

Early passenger ships did not have the tiers of superstructures associated with modern vessels, and they also had a narrower beam in relation to the length. The reason for the absence of superstructure decks was the Merchant Shipping Act 1894 which limited the number of passengers carried on the upper deck. An amendment to this Act in 1906 removed this restriction and vessels were built with several tiers of superstructures. This produced problems of strength and stability, stability being improved by an increase in beam. The transmission of stresses to the superstructure from the main hull girder created much difference of opinion and still does. Both light superstructures of a discontinuous nature, i.e. fitted with expansion joints, and superstructures with scantlings able to contribute to the strength of the main hull girder were introduced. Present practice, where the length of superstructure is appreciable and has its sides close to the ship sides, does not require the fitting of expansion joints. Where aluminium superstructures are fitted in modern ships it is possible to accept greater deformation than would be possible with steel and no similar problem exists.

The introduction of aluminium superstructures has provided increased passenger accommodation on the same draft, and/or a lowering of the lightweight centre of gravity with improved stability. This is brought about by the lighter weight of the aluminium structure.

A feature of the general arrangement is the reduction in the size of the machinery space in this time. It is easy to see the reason for this if the 'Aquitania', built in 1914 and having direct drive turbines with twenty-one double-ended scotch boilers, is compared with the 'Queen Elizabeth 2'. The latter as originally built had geared drive turbines with three water tube boilers. Several modern liners have had their machinery placed aft; this gives over the best part of the vessel amidships entirely to passenger accommodation. Against this advantage, however, allowance must be made for an increased bending moment if a suitable trim is to be obtained.

Passenger accommodation standards have increased substantially, the volume of space allotted per passenger rising steadily. Tween deck clearances are greater and public rooms extend through two decks, which was not the case in early ships where a single saloon was fitted. Provision of air conditioning throughout the accommodation and fitting of stabilizing devices have also added to passenger comfort. Particular attention has been paid to fire safety in the modern passenger ship, structural materials of low fire risk being utilized in association with automatic extinguishing and detection systems.

In recent times there has been a demise of the large passenger liner and larger passenger ships are now either cruise ships, cross-channel ferries or special trade passenger (S.T.P.) ships. The latter are unberthed immigrant or pilgrim passenger ships operating in the Middle East to South East Asian region.

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Part 2

Materials and Strength of Ships

4

Classification Societies

A cargo shipper and the underwriter requested to insure a maritime risk require some assurance that any particular vessel is structurally fit to undertake a proposed voyage. To enable the shipper and underwriter to distinguish the good risk from the bad a system of classification has been formulated over a period of some two hundred years. During this period reliable organizations have been created for the initial and continuing inspection of ships so that classification may be assessed and maintained.

The principal maritime nations have the following classification societies:

Great Britain—Lloyd's Register of Shipping
France—Bureau Veritas
Germany—Germanischer Lloyd
Norway—Det Norske Veritas
Italy—Registro Italiano Navale
United States of America—American Bureau of Shipping
Russia—Register of Shipping of the USSR
Japan—Nippon Kaizi Ngokai

These classification societies publish rules and regulations which are principally concerned with the strength of the ship, the provision of adequate equipment, and the reliability of the machinery. Ships may be built in any country to a particular classification society's rules, and they are not restricted to classification by the relevant society of the country where they are built. Classification is not compulsory but the shipowner with an unclassed ship will be required to satisfy governmental regulating bodies that it has sufficient structural strength for assignment of a load line and issue of a safety construction certificate.

Only the requirements of Lloyd's Register of Shipping which is the oldest of the classification societies are dealt with in detail. Founded in 1760 and reconstituted in 1834, Lloyd's Register was amalgamated with the British Corporation, the only other British classification society in existence at that time, in 1949. Steel ships built in accordance with Lloyd's Register rules or equivalent standards, are assigned a class in the Register Book, and continue to be classed so long as they are maintained in accordance with the Rules.

Lloyd's Register Classification Symbols

All ships classed by Lloyd's Register of Shipping are assigned one or more character symbols. The majority of ships are assigned the characters 100A1 or ✠100A1.

The character figure 100 is assigned to all ships considered suitable for sea-going service. The character letter A is assigned to all ships which are built in accordance with or accepted into class as complying with the Society's Rules and Regulations. The character figure 1 is assigned to ships carrying on board anchor and/or mooring equipment complying with the Society's Rules and Regulations. Ships which the Society agree need not be fitted with anchor and mooring equipment may be assigned the character letter N in lieu of the character figure 1. The Maltese Cross mark is assigned to new ships constructed under the Society's Special Survey, i.e. a surveyor has been in attendance during the construction period to inspect the materials and workmanship.

There may be appended to the character symbols, when considered necessary by the Society or requested by the owner, a number of class notations. These class notations may consist of one or a combination of the following. Type notation, cargo notation, special duties notation, special features notation, service restriction notation. Type notation indicates that the ship has been constructed in compliance with particular rules applying to that type of ship, e.g. 100A1 'Bulk Carrier'. Cargo notation indicates the ship has been designed to carry one or more specific cargoes, e.g. 'Sulphuric acid'. This does not preclude it from carrying other cargoes for which it might be suitable. Special duties notation indicate the ship has been designed for special duties other than those implied by type or cargo notation, e.g. 'research'. Special features notation indicates the ship incorporates special features which significantly affect the design, e.g. 'movable decks'. Service restriction notation indicates the ship has been classed on the understanding it is operated only in a specified area and/or under specified conditions, e.g. 'Great Lakes and St. Lawrence'.

The class notation ✠ LMC indicates that the machinery has been constructed, installed and tested under the Society's Special Survey and in accordance with the Society's Rules and Regulations. Various other notations relating to the main and auxiliary machinery may also be assigned.

Vessels with a refrigerated cargo installation constructed, installed and tested under the Society's Special Survey and in accordance with its Rules and Regulations may be assigned the notation ✠ Lloyds RMC. A classed liquefied gas carrier or tanker in which the cargo reliquefaction or cargo refrigeration equipment is approved, installed and tested in accordance with the Society's Rules and Regulations may be assigned the notation ✠ Lloyds RMC (LG).

Where additional strengthening is fitted for navigation in ice conditions an appropriate notation may be assigned. The notations fall into two groups: those where additional strengthening is added for first-year ice, i.e. service where waters ice up in winter only; and those where additional strengthening is added for multi-year ice, i.e. service in Artic and Antarctic. It is the responsibility of the owner to determine which notation is most suitable for his requirements.

Notations are:

FIRST-YEAR ICE

Special features notations are:

Ice Class 1As	unbroken level ice with thickness of 1 m.
Ice Class 1A	unbroken level ice with thickness of 0.8 m.
Ice Class 1B	unbroken level ice with thickness of 0.6 m.
Ice Class 1C	unbroken level ice with thickness of 0.4 m.
Ice Class 1D	same as 1C but only requirements for strengthening the forward region, the rudder and steering arrangements apply.

MULTI-YEAR ICE

The addition of the term 'icebreaking' to the ship type notation, e.g. 'icebreaking tanker' plus the following special features notation:

Ice Class AC1	Arctic or Antarctic ice conditions equivalent to unbroken ice with a thickness of 1 m.
Ice Class AC1.5	Arctic or Antarctic ice conditions equivalent to unbroken ice with a thickness of 1.5 m.
Ice Class AC2	Arctic or Antarctic ice conditions equivalent to unbroken ice with a thickness of 2 m.
Ice Class AC3	Arctic or Antarctic ice conditions equivalent to unbroken ice with a thickness of 3 m.

Ships specially designed for icebreaking duties are assigned the ship type notation 'icebreaker' plus the appropriate special features notation for the degree of ice strengthening provided.

Periodical Surveys

To maintain the assigned class the vessel has to be examined by the Society's surveyors at regular periods.

The major hull items to be examined at these surveys only are indicated below.

ANNUAL SURVEYS All steel ships are required to be surveyed at intervals of approximately one year. These annual surveys are where practicable held concurrently with statutory annual or other load line surveys. At the survey the surveyor is to examine the condition of all closing appliances covered by the conditions of assignment of minimum freeboard, the freeboard marks, and auxiliary steering gear particularly rod and chain gear. Watertight doors and other penetrations of watertight bulkheads are also examined and the structural fire protection verified. The general condition of the vessel is assessed, and anchors and cables are inspected where possible at these annual surveys. At the second and third annual survey after the fourth and subsequent special surveys on cargo ships or the third and subsequent special surveys on oil tankers an after and a forward hold or tank are to be examined internally. For ships of 120 m length or more, water ballast tanks may be required to be examined at the second or third survey after each special survey.

DOCKING SURVEYS Ships under 15 years old are required to be examined in drydock on two occasions in any five-year period but with a period not exceeding three years between dockings. Ships 15 years old and over are required to be examined in drydock at two-yearly intervals with extension to two and a half years when a suitable high resistance paint is applied to the underwater portion of the hull. At the docking survey particular attention is paid to the shell plating, stern frame and rudder, and all parts of the structure particularly liable to corrosion and chafing, and any unfairness of bottom.

IN-WATER SURVEYS The Society may accept in-water surveys in lieu of any one of the two dockings required in a five-year period for ships less than 15 years old. The in-water survey is to provide the information normally obtained for the docking survey. Generally consideration is only given to an in-water survey of large ships where a suitable high resistance paint has been applied to the underwater hull.

SPECIAL SURVEYS All steel ships classed with Lloyd's Register are subjected to special surveys. These surveys become due at four-yearly intervals, the first four years from the date of build or date of special survey for classification and thereafter four years from the date of the previous special survey. Where it is inconvenient for the owner to fulfil this requirement Lloyd's will allow a period of grace not exceeding twelve months from the due date providing the surveyor is able to assess the general condition of the vessel about the time of the due date. Special surveys may, where the vessel is on a regular schedule, be carried out over an extended period, and be commenced prior to the due date, but should not extend over a period greater than twelve months.

At the request of an owner, Lloyd's Register may agree to the survey of a hull being carried out on a continuous survey basis, all compartments of the hull being opened up for survey and testing in rotation, with an interval of five years between consecutive examinations of each part.

The hull requirements at a special survey, the details of the compartments to be opened up, and the material to be inspected at any special survey are listed in detail in the Rules and Regulations (Part 1, Chapter 3). Special survey hull requirements are divided into four ship age groups as follows:

1. Special survey of ships under five years old
2. Special survey of ships between five and ten years old
3. Special survey of ships over ten years old
4. First special survey held after ship is twenty years old and at every special survey thereafter.

In each case the amount of inspection required increases and more material is removed so that the condition of the bare steel may be assessed. It should be noted that where the surveyor is allowed to ascertain by drilling or other approved means the thickness of material, non-destructive methods such as ultrasonics are available in contemporary practice for this purpose.

When classification is required for a ship not built under the supervision of the Society's surveyors, plans showing the main scantlings and arrangements of the actual ship are submitted to the Society for approval. Also supplied are particulars of the manufacture and testing of the materials of construction, together with full details of the equipment. Where plans, etc., are not available, the Society's surveyors are to be allowed to lift the relevant information from the ship. At the special survey for classification all the hull requirements for special surveys (1), (2), and (3) are to be carried out. Ships over twenty years old are also to comply with the hull requirements of special survey (4), and oil tankers must comply with the additional requirements stipulated in the Rules and Regulations. During this survey the surveyor assesses the standard of the workmanship, and verifies the scantlings and arrangements submitted for approval. It should be noted that the special survey for classification will receive special consideration from Lloyd's Register in the case of a vessel transferred from another recognized Classification Society. Periodical surveys where the vessel is classed are subsequently held as in the case of ships built under survey, being dated from the date of special survey for classification.

Damage Repairs

When a vessel requires repairs to damaged equipment or to the hull it is necessary for the work to be carried out to the satisfaction of Lloyd's

Register surveyors. In order that the ship maintains its class, approval of the repairs undertaken must be obtained from the surveyors either at the time of the repair or at the earliest opportunity.

Further Reading

Lloyd's Register of Shipping, 'Rules and Regulations for the Classification of Ships', Part 1, Regulations, Chapters 2 and 3.

5
Steels

The production of all steels used for shipbuilding purposes starts with the smelting of iron ore and the making of pig-iron. Normally the iron ore is smelted in a blast furnace, which is a large, slightly conical structure lined with a refractory material. To provide the heat for smelting, coke is used and limestone is also added. This makes the slag formed by the incombustible impurities in the iron ore fluid, so that it can be drawn off. Air necessary for combustion is blown in through a ring of holes near the bottom, and the coke, ore, and limestone are charged into the top of the furnace in rotation. Molten metal may be drawn off at intervals from a hole or spout at the bottom of the furnace and run into moulds formed in a bed of sand or into metal moulds.

The resultant pig-iron is from 92 to 97 per cent iron, the remainder being carbon, silicon, manganese, sulphur, and phosphorus. In the subsequent manufacture of steels the pig-iron is refined, in other words the impurities are reduced.

Manufacture of Steels

Steels may be broadly considered as alloys of iron and carbon, the carbon percentage varying from about 0.1 per cent in mild steels to about 1.8 per cent in some hardened steels. These may be produced by one of four different processes, the open hearth process, the Bessemer converter process, the electric furnace process, or an oxygen process. Processes may be either an acid or basic process according to the chemical nature of the slag produced. Acid processes are used to refine pig-iron low in phosphorus and sulphur which are rich in silicon and therefore produce an acid slag. The furnace lining is constructed of an acid material so that it will prevent a reaction with the slag. A basic process is used to refine pig-iron that is rich in phosphorus and low in silicon. Phosphorus can be removed only by introducing a large amount of lime, which produces a basic slag. The furnace lining must then be of a basic refractory to prevent a reaction with the slag. About 85 per cent of all steel produced in Britain is of the *basic* type, and with modern techniques is almost as good as the *acid* steels produced with superior ores.

Only the open hearth, electric furnace, and oxygen processes are described here as the Bessemer converter process is not used for shipbuilding steels.

OPEN HEARTH PROCESS The open hearth furnace is capable of producing large quantities of steel, handling 150 to 300 tonnes in a single melt. It consists of a shallow bath, roofed in, and set above two brick-lined heating chambers. At the ends are openings for heated air and fuel (gas or oil) to be introduced into the furnace. Also these permit the escape of the burned gas which is used for heating the air and fuel. Every twenty minutes or so the flow of air and fuel is reversed.

In this process a mixture of pig-iron and steel scrap is melted in the furnace, carbon and the impurities being oxidized. Oxidization is produced by the oxygen present in the iron oxide of the pig-iron. Subsequently carbon, manganese, and other elements are added to eliminate iron oxides and give the required chemical composition.

ELECTRIC FURNACES Electric furnaces are generally of two types, the arc furnace and the high-frequency induction furnace. The former is used for refining a charge to give the required composition, whereas the latter may only be used for melting down a charge whose composition is similar to that finally required. For this reason only the arc furnace is considered in any detail. In an arc furnace melting is produced by striking an arc between electrodes suspended from the roof of the furnace and the charge itself in the hearth of the furnace. A charge consists of pig-iron and steel scrap and the process enables consistent results to be obtained and the final composition of the steel can be accurately controlled.

Electric furnace processes are often used for the production of high-grade alloy steels.

OXYGEN PROCESS This is a modern steelmaking process by which a molten charge of pig-iron and steel scrap with alloying elements is contained in a basic lined converter. A jet of high purity gaseous oxygen is then directed onto the surface of the liquid metal in order to refine it.

Steel from the open hearth or electric furnace is tapped into large ladles and poured into ingot moulds. It is allowed to cool in these moulds, until it becomes reasonably solidified permitting it to be transferred to 'soaking pits' where the ingot is reheated to the required temperature for rolling.

CHEMICAL ADDITIONS TO STEELS Additions of chemical elements to steels during the above processes serve several purposes. They may be used to deoxidize the metal, to remove impurities and bring them out into the slag, and finally to bring about the desired composition.

The amount of deoxidizing elements added determines whether the steels are 'rimmed steels' or 'killed steels'. Rimmed steels are produced when only small additions of deoxidizing material are added to the molten metal. Only those steels having less than 0.2 per cent carbon and less than 0.6 per cent manganese can be rimmed. Owing to the absence of deoxidizing material, the oxygen in the steel combines with the carbon and other gases present and a large volume of gas is liberated. So long as the metal is molten the gas passes upwards through the molten metal. When solidification takes place in ingot form, initially from the sides and bottom and then across the top, the gases can no longer leave the metal. In the central portion of the ingot a large quantity of gas is trapped with the result that the core of the rimmed ingot is a mass of blow holes. Normally the hot rolling of the ingot into thin sheet is sufficient to weld the surfaces of the blow holes together, but this material is unsuitable for thicker plate.

The term 'killed' steel indicates that the metal has solidified in the ingot mould with little or no evolution of gas. This has been prevented by the addition of sufficient quantities of deoxidizing material, normally silicon or aluminium. Steel of this type has a high degree of chemical homogeneity, and killed steels are superior to rimmed steels. Where the process of deoxidation is only partially carried out by restricting the amount of deoxidizing material a 'semi-killed' steel is produced.

In the ingot mould the steel gradually solidifies from the sides and base as mentioned previously. The melting points of impurities like sulphides and phosphides in the steel are lower than that of the pure metal and these will tend to separate out and collect towards the centre and top of the ingot which is the last to solidify. This forms what is known as the 'segregate' in way of the noticeable contraction at the top of the ingot. Owing to the high concentration of impurities at this point this portion of the ingot is often discarded prior to rolling plate and sections.

Heat Treatment of Steels

The properties of steels may be altered greatly by the heat treatment to which the steel is subsequently subjected. These heat treatments bring about a change in the mechanical properties principally by modifying the steel's structure. Those heat treatments which concern shipbuilding materials are described.

ANNEALING This consists of heating the steel at a slow rate to a temperature of say 850°C to 950°C, and then cooling it in the furnace at a very slow rate. The objects of annealing are to relieve any internal stresses, to soften the steel, or to bring the steel to a condition suitable for a subsequent heat treatment.

NORMALIZING This is carried out by heating the steel slowly to a temperature similar to that for annealing and allowing it to cool in air. The resulting faster cooling rate produces a harder stronger steel than annealing, and also refines the grain size.

QUENCHING (OR HARDENING) Steel is heated to temperatures similar to that for annealing and normalizing, and then quenched in water or oil. The fast cooling rate produces a very hard structure with a higher tensile strength.

TEMPERING Quenched steels may be further heated to a temperature somewhat between atmospheric and 680°C, and some alloy steels are then cooled fairly rapidly by quenching in oil or water. The object of this treatment is to relieve the severe internal stresses produced by the original hardening process and to make the material less brittle but retain the higher tensile stress.

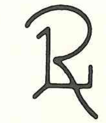
STRESS RELIEVING To relieve internal stresses the temperature of the steel may be raised so that no structural change of the material occurs and then it may be slowly cooled.

Steel Sections

A range of steel sections are rolled hot from the ingots. The more common types associated with shipbuilding are shown in Figure 5.1. It is preferable to limit the sections required for shipbuilding to those readily available, that is the standard types; otherwise the steel mill is required to set up rolls for a small amount of material which is not very economic.

Shipbuilding Steels

Steel for hull construction purposes is usually mild steel containing 0.15 per cent to 0.23 per cent carbon, and a reasonably high manganese content. Both sulphur and phosphorus in the mild steel are kept to a minimum (less than 0.05 per cent). Higher contents of both are detrimental to the welding properties of the steel, and cracks can develop during the rolling process if the sulphur content is high.

Steel for a ship classed with Lloyd's Register is produced by an approved manufacturer, and inspection and prescribed tests are carried out at the steel mill before dispatch. All test pieces are selected and stamped by a surveyor or his authorized deputy. Every finished item is clearly marked with the Society's brand  where it complies with the Society's requirements.

Ship classification societies originally had varying specifications for steel; but in 1959, the major societies agreed to standardize their requirements in order to reduce the required grades of steel to a minimum. There are now five different qualities of steel employed in merchant ship construction.

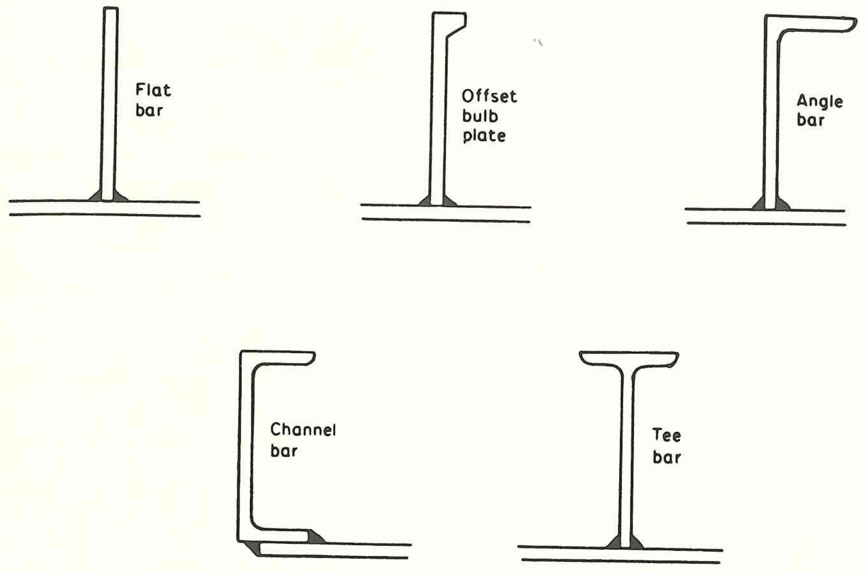


FIGURE 5.1 Steel sections for shipbuilding

These are graded A, B, C, D and E, Grade A being an ordinary mild steel to Lloyd's Register requirements and generally used in Britain. Grade B is a better quality mild steel than Grade A and specified where thicker plates are required in the more critical regions. Grades C, D and E possess increasing notch-touch characteristics, Grade C being to American Bureau of Shipping requirements. Lloyd's Register requirements for Grades A, B, D and E steels may be found in Chapter 3 of Lloyd's Rules for the Manufacture, Testing and Certification of Materials.

High Tensile Steels

Steels having a higher strength than that of mild steel are employed in the more highly stressed regions of large tankers, container ships and bulk carriers. Use of higher strength steels allows reductions in thickness of deck, bottom shell, and framing where fitted in the midships portion of larger vessels; it does, however, lead to larger deflections. The weldability of higher tensile steels is an important consideration in their application in ship structures and the question of reduced fatigue life with these steels has been suggested.

Higher tensile steels used for hull construction purposes are manufactured and tested in accordance with Lloyd's Register requirements. Full specifications of the methods of manufacture, chemical composition, heat treatment, and mechanical properties required for the higher tensile steels are given in Chapter 3 of Lloyd's Rules for the Manufacture, Testing and Certification of Materials. The major classification societies have agreed on requirements for higher tensile hull structural steels supplied in two strength levels with differing values of specified minimum yield strength, i.e. 32 and 36 (kg/mm^2). Lloyd's requirements make provision for a third 34s, the 's' denoting that it is additional to the agreed requirements. Each strength level is further subdivided into the three grades – A, D and E – followed by the letter H, i.e.:

AH 32, AH 34s, AH36 for grade A application
DH 32, DH 34s, DH36 for grade D application
EH 32, EH 34s, EH36 for grade E application.

Steel Castings

Molten steel produced by the open hearth, electric furnace, or oxygen process is poured into a carefully constructed mould and allowed to solidify to the shape required. After removal from the mould a heat treatment is required, for example annealing, or normalizing and tempering, to reduce brittleness. Stern frames, rudder frames, spectacle frames for bossings, and other structural components may be produced as castings.

Steel Forgings

Forging is simply a method of shaping a metal by heating it to a temperature where it becomes more or less plastic and then hammering or squeezing it to the required form. Forgings are manufactured from killed steel made by the open hearth, electric furnace, or oxygen process, the steel being in the form of ingots cast in chill moulds. Adequate top and bottom discards are made to ensure no harmful segregations in the finished forgings and the sound ingot is gradually and uniformly hot worked. Where possible the working of the metal is such that metal flow is in the most favourable direction with regard to the mode of stressing in service. Subsequent heat treatment is required, preferably annealing or normalizing and tempering, to remove effects of working and non-uniform cooling.

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6

Aluminium Alloy

There are three advantages which aluminium alloys have over mild steel in the construction of ships. Firstly aluminium is lighter than mild steel (approximate weights being aluminium 2.723 tonnes/m^3, mild steel 7.84 tonnes/m^3), and with an aluminium structure it has been suggested that up to 60 per cent of the weight of a steel structure may be saved. This is in fact the principal advantage as far as merchant ships are concerned, the other two advantages of aluminium being a high resistance to corrosion and its non-magnetic properties. The non-magnetic properties can have advantages in warships and locally in way of the magnetic compass, but they are generally of little importance in merchant vessels. Good corrosion properties can be utilized, but correct maintenance procedures and careful insulation from the adjoining steel structure are necessary. A major disadvantage of the use of aluminium alloys is their high initial cost (this has been estimated at 8 to 10 times the price of steel on a tonnage basis). This high initial cost must be offset by an increased earning capacity of the vessel, resulting from a reduced lightship weight or increased passenger accommodation on the same draft.

The total application of aluminium alloys to a ship's structure as an economic proposition is difficult to assess and only on smaller ships has this been attempted. A number of vessels have been fitted with superstructures of aluminium alloy and, apart from the resulting reduction in displacement, benefits have been obtained in improving the transverse stability. Since the reduced weight of superstructure is at a position above the ship's centre of gravity this ensures a lower centre of gravity than that obtained with a comparable steel structure. If the vessel's stability is critical this result may be used to give a larger metacentric height for initial stability. When the vessel already has adequate initial stability the beam may be reduced with a further saving in hull weight. With finer proportions the hull weight can be still further reduced because of the lower power requirements resulting in a saving in machinery weight. Because of the improved stability a number of passenger ships have had the passenger accommodation extended to increase the earning capacity rather than reducing the beam.

Only in those vessels having a fairly high speed and hence power, also ships where the deadweight/lightweight ratio is low, are appreciable savings to be expected. Such ships are moderate- and high-speed passenger vessels like cross-channel and passenger liners having a low deadweight. A very small number of cargo liners have been fitted with an aluminium alloy superstructure, principally to clear a fixed draft over a river bar with maximum cargo.

Production of Aluminium

For aluminium production at the present time the ore, bauxite, is mined containing roughly 56 per cent aluminium. The actual extraction of the aluminium from the ore is a complicated and costly process involving two distinct stages. Firstly the bauxite is purified to obtain pure aluminium oxide known as alumina; the alumina is then reduced to a metallic aluminium. The metal is cast in pig or ingot forms and alloys are added where required before the metal is cast into billets or slabs for subsequent rolling, extrusion, or other forming operations.

Sectional material is mostly produced by the extrusion process. This involves forcing a billet of the hot material through a die of the desired shape. More intricate shapes are produced by this method than are possible with steel where the sections are rolled. However, the range of thickness of section may be limited since each thickness requires a different die. Typical sections are shown in Figure 6.1.

ALUMINIUM ALLOYS Pure aluminium has a low tensile strength and is of little use for structural purposes; therefore the pure metal is alloyed with small percentages of other materials to give greater tensile strengths. There are a number of aluminium alloys in use, but these may be separated into two distinct groups, non-heat treated alloys and heat treated alloys. The latter as implied are subjected to a carefully controlled heating and cooling cycle in order to improve the tensile strength.

Non-heat treated alloys are mainly used in Britain for ship structural purposes, being readily worked and welded with the correct techniques and procedures. The principal alloying constituent is magnesium for this material and a range of alloys are available with the magnesium content varying from 2 to 7 per cent. For shipbuilding purposes, however, those alloys with magnesium content ranging from 3 to 5 per cent are commonly used, since at lower magnesium contents the tensile strength is insufficient. With high magnesium content difficulties are experienced in working the material and some difficulty may be experienced with corrosion.

Table 6.1 indicates the desired chemical composition for aluminium alloy plates, sections, and bars to meet Lloyd's Register requirements for shipyard use. An aluminium alloy in general use for shipbuilding and complying with Lloyd's Register requirements is B.S. 1470–NP8 for plate, and B.S. 1474 NE 8M for extruded sections. British Standards prefix N is non-heat treated, P is plate, and E indicates extruded material.

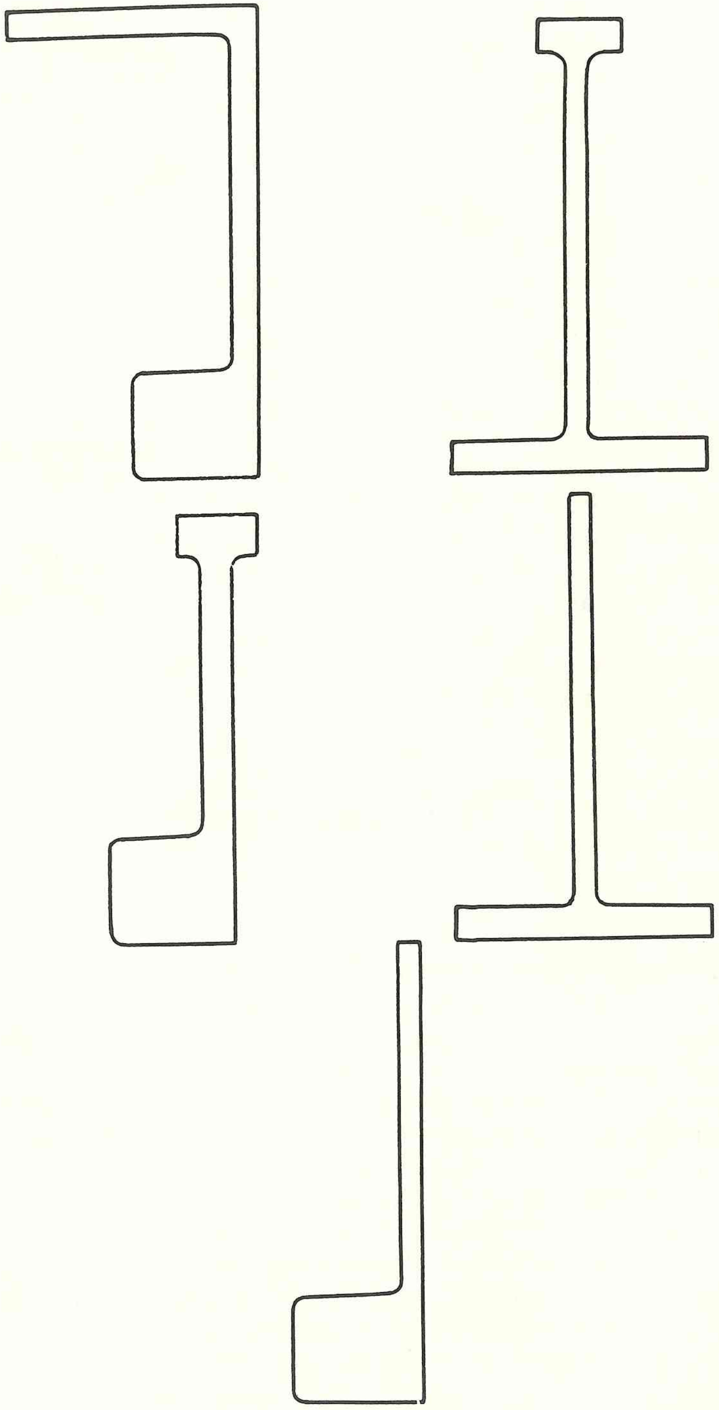

FIGURE 6.1 Typical aluminium alloy sections

Cold working of the non-heat treated plate has the effect of strengthening the material and this can be employed to advantage. However, at the same time the plate becomes less ductile, and if cold working is considerable the material may crack; this places a limit on the amount of cold forming possible in ship building.

With aluminium alloys a suitable heat treatment is necessary to obtain a high tensile strength. A heat treated aluminium alloy which is suitable for shipbuilding purposes is one having as its main alloying constituents magnesium and silicon. These form a compound Mg_2Si and the resulting alloy has very good resistance to corrosion and a higher ultimate tensile strength than that of the non-heat treated alloys. Since the material is heat treated to achieve this increased strength subsequent heating, for example welding or hot forming, may destroy the improved properties locally. Aluminium alloys of this type have been used extensively in the U.S.A. with riveted ship construction, and also to some extent in Britain, for riveted sections.

RIVETING Riveting may be used to attach stiffening members to light aluminium alloy plated structures where appearance is important and distortion from the heat input of welding is to be avoided.

The commonest stock for forging rivets for shipbuilding purposes is a non-heat treatable alloy NR5 (R for rivet material) which contains 3–4 per cent magnesium. Non-heat treated alloy rivets may be driven cold or hot. In driving the rivets cold relatively few heavy blows are applied and the rivet is quickly closed to avoid too much cold work, i.e. becoming work hardened

TABLE 6.1

Composition of aluminium alloys for shipyard use

	Non-heat treated	*Heat treated*
Copper	not more than 0.1 per cent	not more than 0.1 per cent
Magnesium	not more than 5.6 per cent not less than 3.5 per cent	not more than 1.4 per cent not less than 0.4 per cent
Silicon	not more than 0.5 per cent	not more than 1.6 per cent not less than 0.6 per cent
Iron	not more than 0.5 per cent	not more than 0.5 per cent
Manganese	not more than 1.0 per cent	not more than 1.0 per cent not less than 0.2 per cent
Zinc	not more than 0.2 per cent	not more than 0.2 per cent
Chromium	not more than 0.35 per cent	not more than 0.35 per cent
Titanium + Zirconium	not more than 0.2 per cent	not more than 0.2 per cent
Aluminium	The remainder	

so that it cannot be driven home. Where the rivets are driven hot the temperature must be carefully controlled to avoid metallurgical damage. The shear strength of hot driven rivets is slightly less than that of cold driven rivets.

Fire Protection

It was considered necessary to mention when discussing aluminium alloys that fire protection is more critical in ships in which this material is used because of the low melting point of aluminium alloys. During a fire the temperatures reached may be sufficient to cause a collapse of the structure unless protection is provided. The insulation on the main bulkheads in passenger ships will have to be sufficient to make the aluminium bulkhead equivalent to a steel bulkhead for fire purposes.

For the same reason it is general practice to fit steel machinery casings through an aluminium superstructure on cargo ships.

Further Reading

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7

Testing of Materials

Metals are tested to ensure that their strength, ductility, and toughness are suitable for the function they are required to perform.

In comparing the strengths of various metals stresses and strains are often referred to and require to be defined. Stress is a measure of the ability of a material to transmit a load, and the intensity of stress in the material, which is the load per unit area, is often stated. The load per unit area is simply obtained by dividing the applied load by the cross-sectional area of the material, e.g. if a tensile load of P kg is applied to a rod having a cross-sectional area of A mm^2, then the tensile stress in the material of the rod is $\frac{P}{A}$ kg/mm^2 (*see* Figure 7.1).

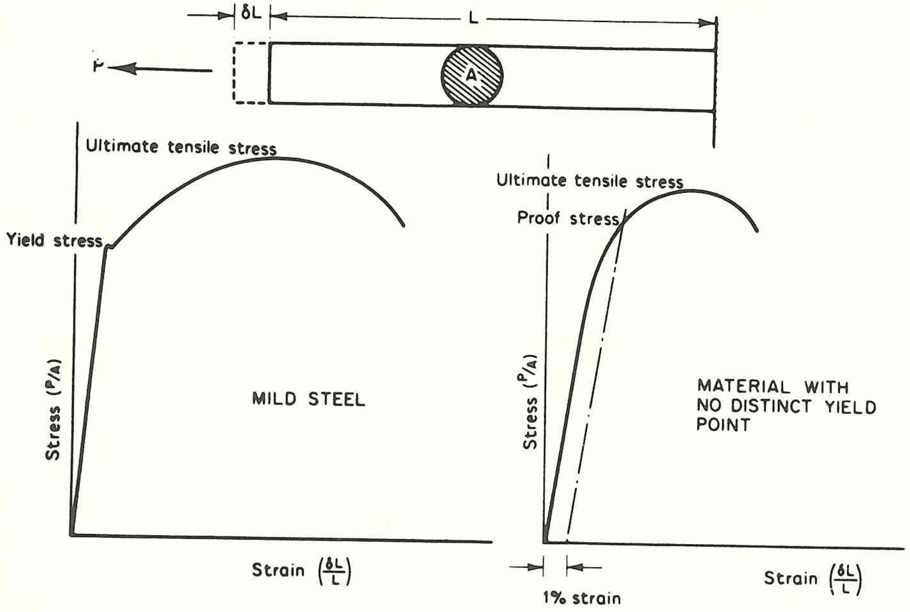

FIGURE 7.1 Stress/strain relationship of shipbuilding materials

Total strain is defined as the total deformation which a body undergoes when subjected to an applied load. The strain is the deformation per unit length or unit volume, e.g. if the tensile load P applied to the rod of original length l produces an elongation, or extension, of the rod of amount δl, then the tensile strain to which the material of the rod is subjected is given by the extension per unit length, i.e.

$$\frac{\text{extension}}{\text{original length}} \quad \text{or} \quad \frac{\delta l}{l}$$

It can be shown that the load on the rod may be increased uniformly and the resulting extension will also increase uniformly until a certain load is reached. This indicates that the load is proportional to extension and hence stress and strain are proportional since the cross-sectional area and original length of the rod remain constant. For most metals this direct proportionality holds until what is known as the 'elastic limit' is reached. The metal behaves elastically to this point, the rod for example returning to its original length if the load is removed before the 'elastic limit' is reached.

If a mild steel bar is placed in a testing machine and the extensions are recorded for uniformly increasing loads, a graph of load against extension, or stress against strain may be plotted as in Figure 7.1. This shows the straight line relationship (i.e. direct proportionality) between stress and strain up to the elastic limit.

Since stress is directly proportional to strain, the stress is equal to a constant which is in fact the slope of the straight line part of the graph, and is given by:

$$\text{A constant} = \text{stress} \div \text{strain}.$$

This constant is referred to as Young's Modulus for the metal and is denoted E (for mild steel its value is approximately 21 100 kg/mm^2 or 21.1 tonnes/mm^2).

The yield stress for a metal corresponds to the stress at the 'yield point', that is the point at which the metal no longer behaves elastically. Ultimate tensile stress is the maximum load to which the metal is subjected, divided by the original cross-sectional area. Beyond the yield point the metal behaves plastically which means that the metal deforms at a greater, unproportional, rate when the yield stress is exceeded, and will not return to its original dimensions on removal of the load. It becomes deformed or is often said to be permanently 'set'.

Many metals do not have a clearly defined yield point; for example, aluminium having a stress/strain curve over its lower range which is a straight line becoming gradually curved without any sharp transformation on yielding as shown by mild steel (*see* Figure 7.1). A 'proof stress' is quoted for the material and this may be obtained by setting off on the base some percentage of the strain, say 0.2 per cent, and drawing a line parallel to the straight portion of curve. The inter-section of this line with the actual stress/strain curve marks the proof stress.

It is worth noting at this stage that the ship's structure is designed for working stresses which are within the elastic range and much lower than the ultimate tensile strength of the material to allow a reasonable factor of safety.

Classification Society Tests for Hull Materials

Both mild steel and higher tensile steel plates and sections built into a ship are to be produced at works approved by the appropriate classification society. During production an analysis of the material is required and so are prescribed tests of the rolled metal. Similar analyses and tests are required by the classification societies for steel forgings and steel castings, in order to maintain an approved quality.

Destructive tests are made on specimens obtained from the same product as the finished material in accordance with the societies' requirements which may be found in the appropriate rules. These tests usually take the form of a tensile test, and impact test.

TENSILE TEST The basic principle of this test has already been described, a specimen of given dimensions being subject to an axial pull and a minimum specified yield stress, ultimate tensile stress, and elongation must be obtained. In order to make comparisons between the elongation of tensile test pieces of the same material the test pieces must have the same proportions of sectional area and gauge length. Therefore a standard gauge length equal to 5.65 times the square root of the cross-sectional area, which is equivalent to a gauge length of five times the diameter is adopted by the major classification societies.

IMPACT TESTS There are several forms of impact test, but the Charpy V notch test or Charpy U notch test is commonly specified and therefore described in this text. The object of the impact test is to determine the toughness of the material, that is its ability to withstand fracture under shock loading.

In Figure 7.2 the principle of the Charpy test machine is illustrated as also is the standard test specimen for a Charpy V notch test. This specimen is placed on an anvil and the pendulum is allowed to swing so that the striker hits the specimen opposite the notch and fractures it. Energy absorbed in fracturing the specimen is automatically recorded by the machine. Basically, making allowances for friction, the energy absorbed in fracturing the specimen is the difference between the potential energy the pendulum possesses before being released, and that which it attains in swinging past the vertical after fracturing the specimen. A specified average impact energy for the specimens tested must be obtained at the specified test temperature, fracture energy being dependent on temperature as will be illustrated in Chapter 8.

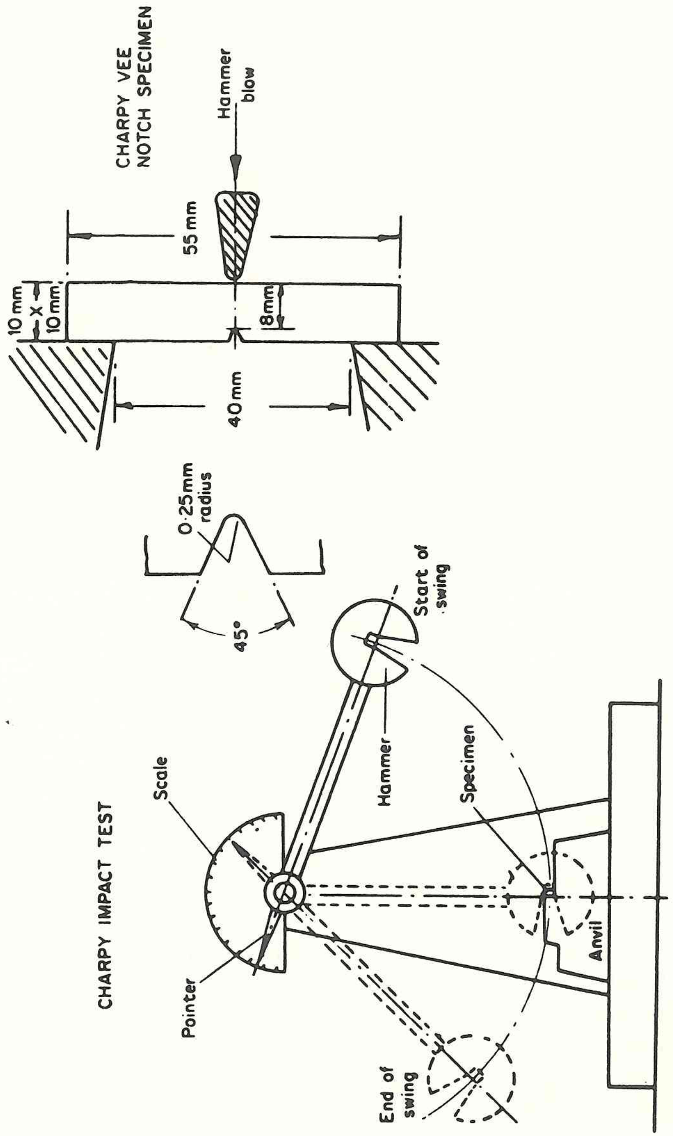

FIGURE 7.2 Charpy impact test

ALUMINIUM ALLOY TESTS Aluminium alloy plate and section material is subject to specified tensile tests. Bar material for aluminium alloy rivets is subject to a tensile test and also a dump test. The latter test requires compression of the bar until its diameter is increased to 1.6 times the original diameter without cracking occurring. Selected manufactured rivets are also subjected to the same dump test.

8

Stresses to which a Ship is Subject

The stresses experienced by the ship floating in still water and when at sea may conveniently be considered separately.

Vertical Shear and Longitudinal Bending in Still Water

If a homogeneous body of uniform cross-section and weight is floating in still water, at any section the weight and buoyancy forces are equal and opposite. Therefore there is no resultant force at a section and the body will not be stressed or deformed. A ship floating in still water has an unevenly distributed weight owing to both cargo distribution and structural distribution. The buoyancy distribution is also non-uniform since the underwater sectional area is not constant along the length. Total weight and total buoyancy are of course balanced, but at each section there will be a resultant force or load, either an excess of buoyancy or excess of load. Since the vessel remains intact there are vertical upward and downward forces tending to distort the vessel (*see* Figure 8.1) which are referred to as vertical shearing forces, since they tend to shear the vertical material in the hull.

The ship shown in Figure 8.1 will be loaded in a similar manner to the beam shown below it, and will tend to bend in a similar manner owing to the variation in vertical loading. It can be seen that the upper fibres of the beam would be in tension; similarly the material forming the deck of the ship with this loading. Conversely the lower fibres of the beam, and likewise the material forming the bottom of the ship, will be in compression. A vessel bending in this manner is said to be 'hogging' and if it takes up the reverse form with excess weight amidships is said to be 'sagging'. When sagging the deck will be in compression and the bottom shell in tension. Lying in still water the vessel is subjected to bending moments, either hogging or sagging depending on the relative weight and buoyancy forces, and it will also be subjected to vertical shear forces.

Bending Moments in a Seaway

When a ship is in a seaway the waves with their troughs and crests produce a greater variation in the buoyant forces and therefore can increase the bending moment, vertical shear force, and stresses. Classically the extreme

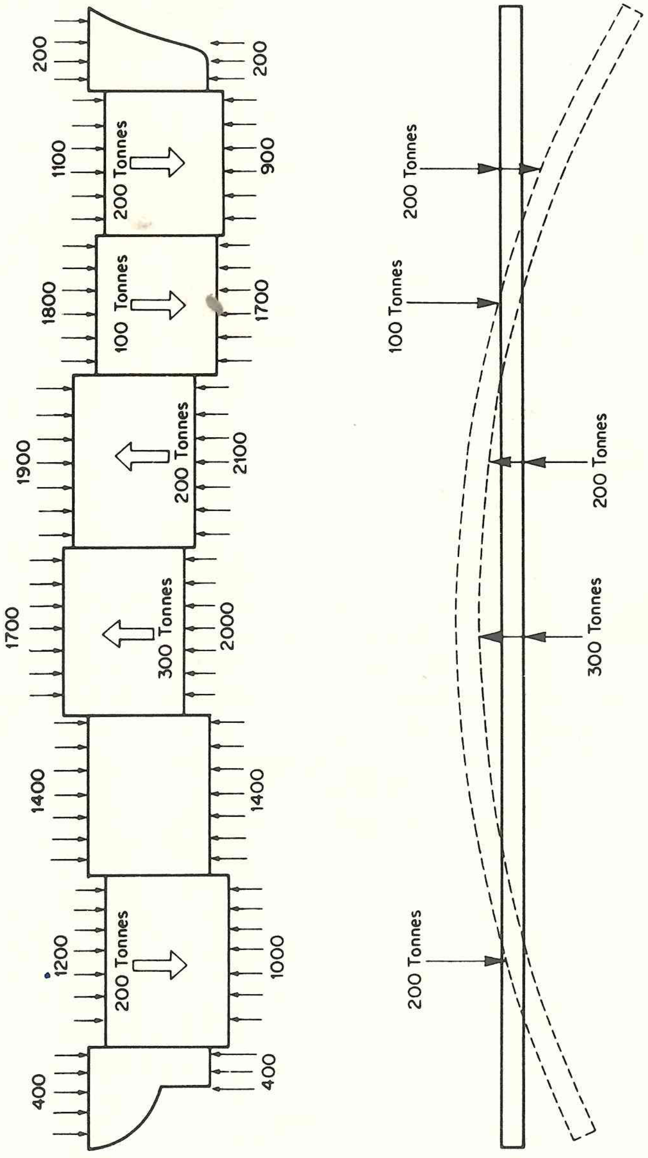

FIGURE 8.1 Vertical shear and longitudinal bending in still water

effects can be illustrated with the vessel balanced on a wave of length equal to that of the ship. If the crest of the wave is amidships the buoyancy forces will tend to 'hog' the vessel; if the trough is amidships the buoyancy forces will tend to 'sag' the ship (Figure 8.2). In a seaway the overall effect is an increase of bending moment from that in still water when the greater buoyancy variation is taken into account.

Longitudinal Shear Forces

When the vessel hogs and sags in still water and at sea shear forces similar to the vertical shear forces will be present in the longitudinal plane (Figure 8.2). Vertical and longitudinal shear stresses are complimentary and exist in conjunction with a change of bending moment between adjacent sections of the hull girder. The magnitude of the longitudinal shear force is greatest at the neutral axis and decreases towards the top and bottom of the girder.

Bending Stresses

From classic bending theory the bending stress (σ) at any point in a beam is given by:

$$\sigma = \frac{M}{I} \times y$$

where M = applied bending moment.
y = distance of point considered from neutral axis.
I = second moment of area of cross-section of beam about the neutral axis.

When the beam bends it is seen that the extreme fibres are, say in the case of hogging, in tension at the top and in compression at the bottom. Somewhere between the two there is a position where the fibres are neither in tension nor compression. This position is called the *neutral axis*, and at the farthest fibres from the neutral axis the greatest stress occurs for plane bending. It should be noted that the neutral axis always contains the centre of gravity of the cross-section. In the equation the second moment of area (I) of the section is a divisor; therefore the greater the value of the second moment of area the less the bending stress will be. This second moment of area of section varies as the (depth)^2 and therefore a small increase in depth of the section can be very beneficial in reducing the bending stress. Occasionally reference is made to the sectional modulus (Z) of a beam; this is simply the ratio between the second moment of area and the distance of the point considered from the neutral axis, i.e. $I/y = Z$.

The bending stress (σ) is then given by $\sigma = \frac{M}{Z}$.

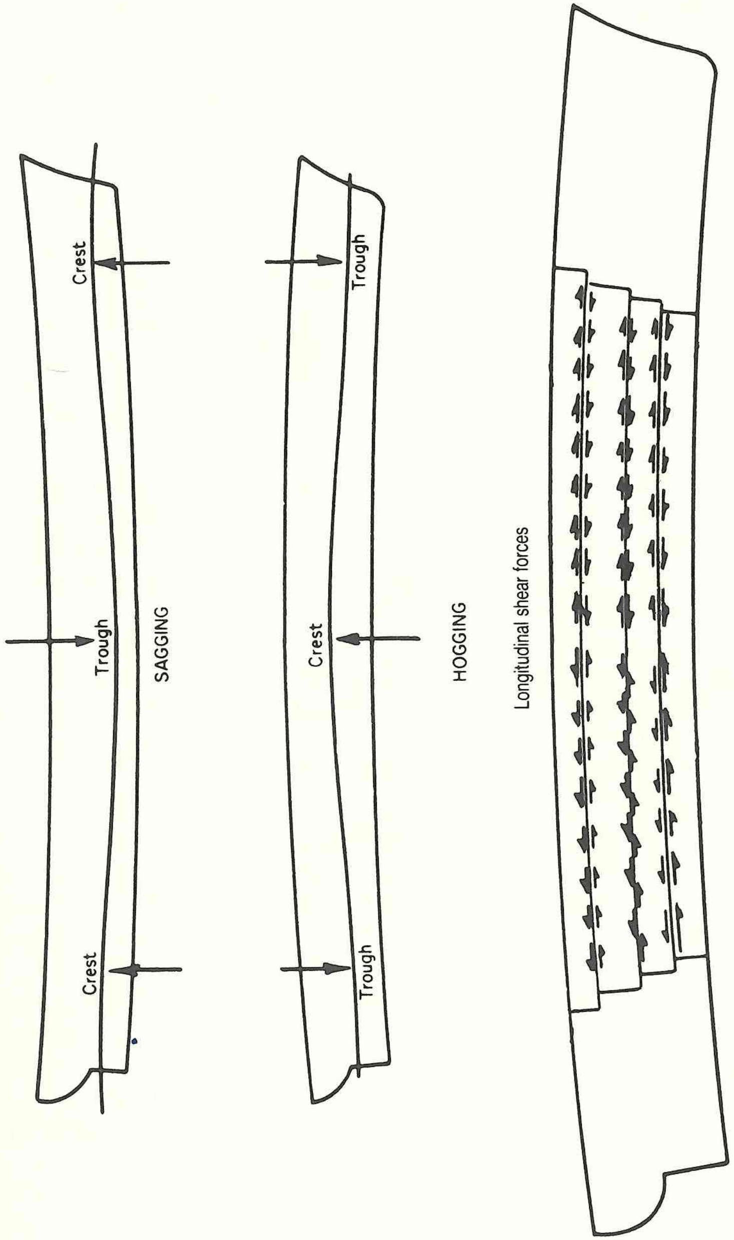

FIGURE 8.2 Wave bending moments

THE SHIP AS A BEAM It was seen earlier that the ship bends like a beam; and in fact the hull can be considered as a box-shaped girder for which the position of the neutral axis and second moment of area may be calculated. The deck and bottom shell form the flanges of the hull girder, and are far more important to longitudinal strength than the sides which form the web of the girder and carry the shear forces. The box shaped hull girder and a conventional *I* girder may be compared as in Figure 8.3.

In a ship the neutral axis is generally nearer the bottom, since the bottom shell will be heavier than the deck, having to resist water pressure as well as the bending stresses. In calculating the second moment of area of the cross-section all longitudinal material is of greatest importance and the further the material from the neutral axis the greater will be its second moment of area about the netrual axis. However, at greater distances from the neutral axis the sectional modulus will be reduced and correspondingly higher stress may occur in extreme hull girder plates such as the deck stringer, sheerstrake, and bilge. These strakes of plating are generally heavier than other plating.

Bending stresses are greater over the middle portion of the length and it is owing to this variation that Lloyd's give maximum scantlings over 40 per cent of the length amidships. Other scantlings may taper towards the ends of the ship, apart from locally highly stressed regions where other forms of loading are encountered.

STRENGTH DECK The deck forming the uppermost flange of the main hull girder is often referred to as the strength deck. This is to some extent a misleading term since all continuous decks are in fact strength decks if properly constructed. Along the length of the ship the top flange of the hull girder, i.e. the strength deck, may step from deck to deck where large superstructures are fitted or there is a natural break, for instance in way of a raised quarter deck. Larger superstructures tend to deform with the main hull and stresses of appreciable magnitude will occur in the structure. Early vessels fitted with large superstructures of light construction demonstrated this to their cost. Attempts to avoid fracture have been made by fitting expansion joints which make the light structure discontinuous. These are not entirely successful and the expansion joint may itself form a stress concentration at the strength deck which one would wish to avoid. In modern construction the superstructure is usually made continuous and of such strength that its sectional modulus is equivalent to that which the strength deck would have if no superstructure were fitted (*see* Chapter 19).

Transverse Stresses

When a ship experiences transverse forces these tend to change the shape of the vessel's cross sections and thereby introduce transverse stresses. These

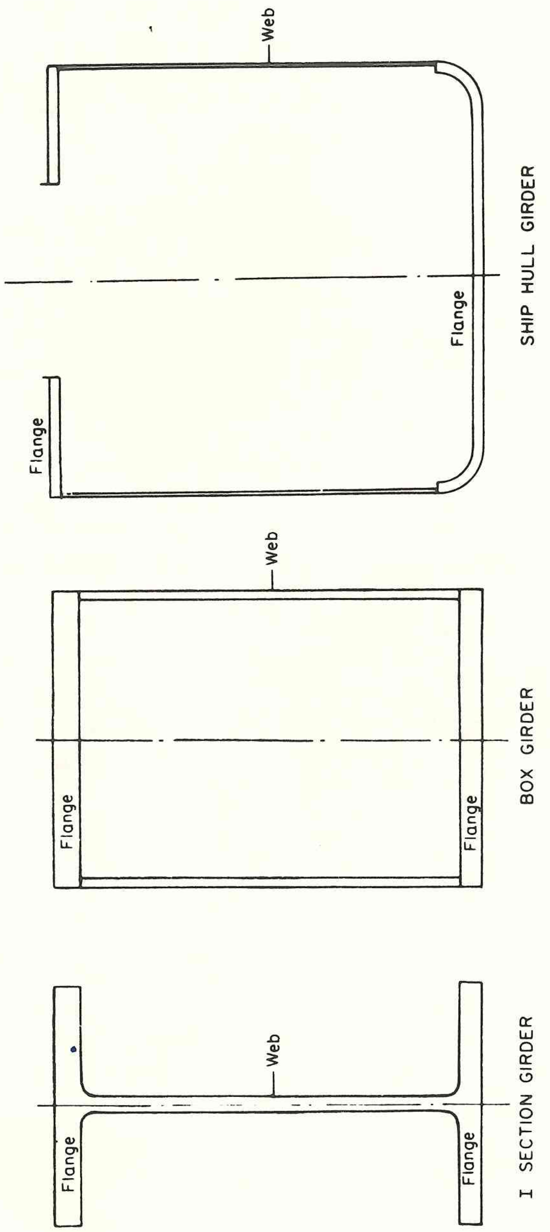

FIGURE 8.3 Box girder and I girder

forces may be produced by hydrostatic loads and impact of seas or cargo and structural weights both directly and as the result of reactions due to change of ship motion.

RACKING When a ship is rolling, the deck tends to move laterally relative to the bottom structure, and the shell on one side to move vertically relative to the other side. This type of deformation is referred to as 'racking'. Transverse bulkheads primarily resist such transverse deformation, the side frames contribution being insignificant provided the transverse bulkheads are at their usual regular spacings.

TORSION When any body is subject to a twisting moment which is commonly referred to as torque, that body is said to be in 'torsion'. A ship heading obliquely (45°) to a wave will be subjected to righting moments of opposite direction at its ends twisting the hull and putting it in 'torsion'. In most ships these torsional moments and stresses are negligible but in ships with extremely wide and long deck openings they are significant. A particular example is the larger container ship where at the topsides a heavy torsion box girder structure including the upper deck is provided to accommodate the torsional stresses (see Figures 8.4 and 17.8).

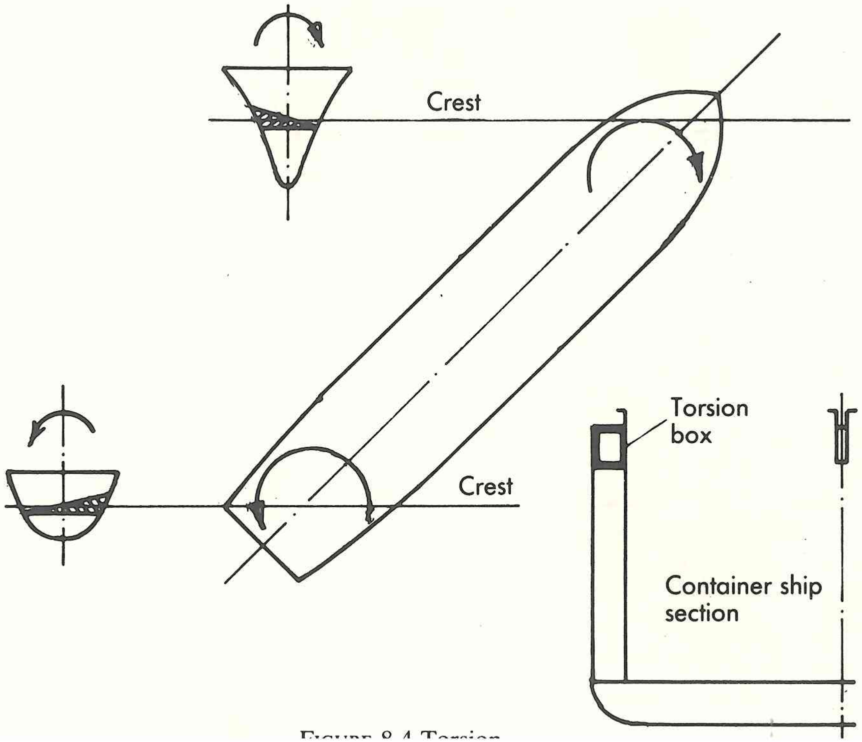

FIGURE 8.4 Torsion

Local Stresses

PANTING Panting refers to a tendency for the shell plating to work 'in' and 'out' in a bellows-like fashion, and is caused by the fluctuating pressures on the hull at the ends when the ship is amongst waves. These forces are most severe when the vessel is running into waves and is pitching heavily, the large pressures occurring over a short time cycle. Strengthening to resist panting both forward and aft is covered in Chapter 17.

POUNDING Severe local stresses occur in way of the bottom shell and framing forward when a vessel is driven into head seas. These pounding stresses, as they are known, are likely to be most severe in a lightly ballasted condition, and occur over an area of the bottom shell aft of the collision bulkhead. Additional stiffening is required in this region, and this is dealt with in Chapter 16.

OTHER LOCAL STRESSES Ship structural members are often subjected to high stresses in localized areas, and great care is required to ensure that these areas are correctly designed. This is particularly the case where various load carrying members of the ship intersect, examples being where longitudinals meet at transverse bulkheads and at intersections of longitudinal and transverse bulkheads. Another highly stressed area occurs where there is a discontinuity of the hull girder at ends of deck house structures, also at hatch and other opening corners, and where there are sudden breaks in the bulwarks.

Brittle Fracture

With the large-scale introduction of welding in ship construction much consideration has been given to the correct selection of materials and structural design to prevent the possibility of brittle fracture occurring. During the Second World War the incidence of this phenomenon was high amongst tonnage hastily constructed, whilst little was known about the mechanics of brittle fracture. Although instances of brittle fracture were recorded in riveted ships the consequences were more disastrous in the welded vessels because of the continuity of metal provided by the welded joint as opposed to the riveted lap which tended to limit the propagating crack.

Brittle fracture occurs when an otherwise elastic material fractures without any apparent sign or little evidence of material deformation prior to failure. Fracture occurs instantaneously with little warning and the vessel's overall structure need not be subject to a high stress at the time. Mild steel used extensively in ship construction is particularly prone to brittle-fracture given the conditions necessary to trigger it off. The subject is too complex to be dealt with in detail and many aspects are still being investigated, but it is known that the following factors influence the possibility of brittle fracture.

(*a*) A sharp notch is present in the structure from which the fracture initiates.
(*b*) A tensile stress is present.
(*c*) There is a temperature above which brittle fracture will not occur.
(*d*) The metallurgical properties of the steel plate.
(*e*) Thick plate is more prone.

A brittle fracture is distinguishable from a ductile failure by the lack of deformation at the edge of the tear, and its bright granular appearance. A ductile failure has a dull grey appearance. The brittle fracture is also distinguished by the apparent chevron marking, which aids location of the fracture initiation point since these tend to point in that direction.

The factors which are known to exist where a brittle fracture may occur must be considered if this is to be avoided. Firstly the design of individual items of ship structure must be such that sharp notches where cracks may be initiated are avoided. With welded structures as large as a ship the complete elimination of crack initiation is not entirely possible owing to the existence of small faults in the welds, a complete weld examination not being practicable. Steel specified for the hull construction should therefore have good 'notch ductility' at the service temperatures particularly where thick plate is used. Provision of steel having good 'notch ductility' properties has the effect of making it difficult for a crack to propagate. Notch ductility is a measure of the relative toughness of the steel, which has already been seen to be determined by an impact test. Steels specified for ship construction have elements added (particularly manganese with a carbon limit), and may also be subjected to a controlled heat treatment, which will enhance the notch tough properties. To illustrate the improved notch ductility of a manganese/carbon steel against a plain carbon steel Figure 8.4 is included. Grade D and Grade E steels which have higher notch ductility are employed where thick plate is used and in way of higher stressed regions, as will be seen when the ship structural details are considered later.

In association with the problem of brittle fracture it was not uncommon at one time to hear reference to the term 'crack arrester'. The term related to the now outdated practice of introducing riveted seams in cargo ships to subdivide the vessel into welded substructures so that any possible crack propagation was limited to the substructure. In particular such a 'crack arrester' was usually specified in the sheerstrake/stringer plate area of larger ships. Today strakes of higher notch toughness steel are required to be fitted in such areas. Lloyd's, for example, require the mild steel

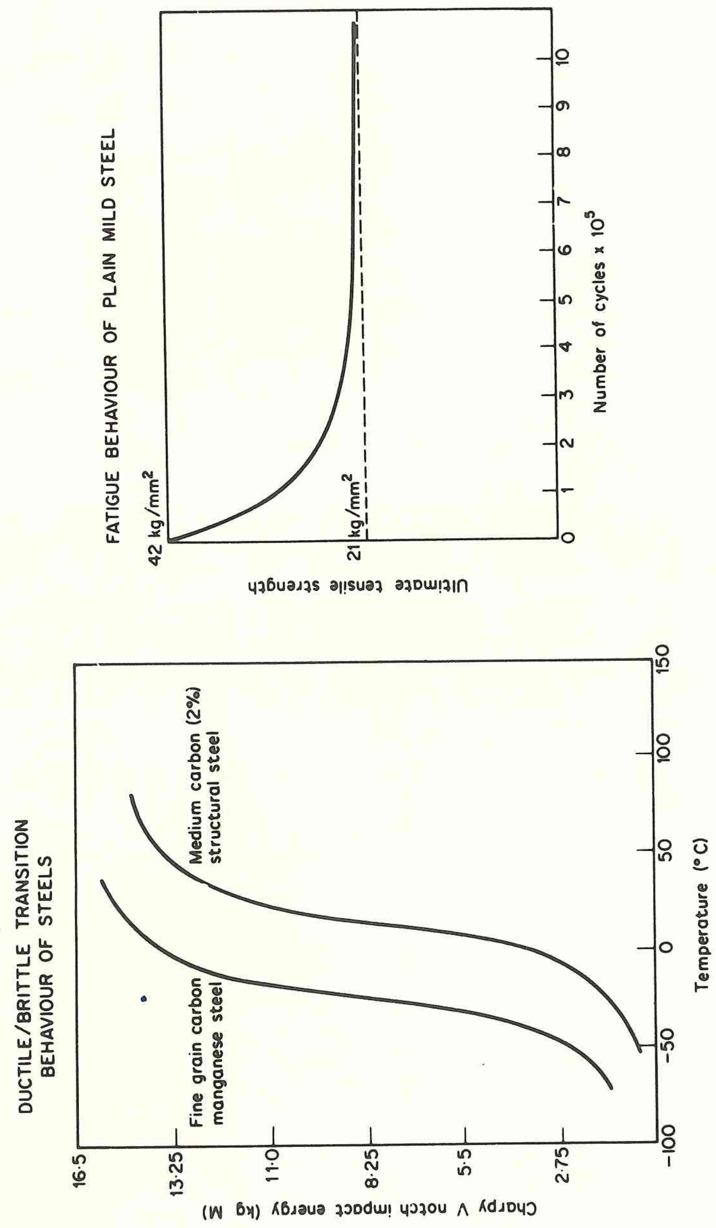

FIGURE 8.5

sheerstrake and stringer plate at the strength deck over the midships portion of vessels of no more than 250 metres in length to be Grade D if less than 15 mm thick and Grade E if of greater thickness (see Chapter 17).

Fatigue Failures

Unlike brittle fracture, fatigue fracture occurs very slowly and can in fact take years to propagate. The greatest danger with fatigue fractures is that they occur at low stresses which are applied to a structure repeatedly over a period of time (Figure 8.4). A fatigue crack once initiated may grow unnoticed until the load bearing member is reduced to a cross-sectional area which is insufficient to carry the applied load. Fatigue failures are associated with sharp notches or discontinuities in structures, and are especially prevalent at 'hard spots', i.e. regions of high rigidity in ship structures.

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Part 3

Welding and Cutting

9

Welding and Cutting Processes used in Shipbuilding

Initially welding was used in ships as a means of repairing various metal parts. During the First World War various authorities connected with shipbuilding, including Lloyd's Register, undertook research into welding and in some cases prototype welded structures were built. However, riveting remained the predominant method employed for joining ship plates and sections until the time of the Second World War. During and after this war the use and development of welding for shipbuilding purposes was widespread, and welding has now totally replaced riveting.

There are many advantages to be gained from employing welding in ships as opposed to having a riveted construction. These may be considered as advantages in both building and in operating the ship.

For the shipbuilder the advantages are:

(*a*) Welding lends itself to the adoption of prefabrication techniques.
(*b*) It is easier to obtain watertightness and oiltightness with welded joints.
(*c*) Joints are produced more quickly.
(*d*) Less skilled labour is required.

For the shipowner the advantages are:

(*a*) Reduced hull steel weight; therefore more deadweight.
(*b*) Less maintenance, from slack rivets, etc.
(*c*) The smoother hull with the elimination of laps leads to a reduced skin friction resistance which can reduce fuel costs.

Other than some blacksmith work involving solid-phase welding, the welding processes employed in shipbuilding are of the fusion welding type. Fusion welding is achieved by means of a heat source which is intense enough to melt the edges of the material to be joined as it is traversed along the joint. Gas welding, arc welding, and resistance welding all provide heat sources of sufficient intensity to achieve fusion welds.

Gas Welding

A gas flame was probably the first form of heat source to be used for fusion welding, and a variety of fuel gases with oxygen have been used to produce a high temperature flame. The most commonly used gas in use is acetylene which gives an intense concentrated flame (average temperature 3000°C) when burnt in oxygen.

An oxy-acetylene flame has two distinct regions, an inner cone, in which the oxygen for combustion is supplied via the torch, and a surrounding envelope in which some or all the oxygen for combustion is drawn from the surrounding air. By varying the ratio of oxygen to acetylene in the gas mixture supplied by the torch it is possible to vary the efficiency of the combustion and alter the nature of the flame (Figure 9.1). If the oxygen supply is slightly greater than the supply of acetylene by volume, what is known as an 'oxidizing' flame is obtained. This type of flame may be used for welding materials of high thermal conductivity, e.g. copper, but not steels as the steel may be decarburized and the weld pool depleted of silicon. With equal amounts of acetylene and oxygen a 'neutral' flame is obtained, and this would normally be used for welding steels and most other metals. Where the acetylene supply exceeds the oxygen by volume a 'carburizing' flame is obtained, the excess acetylene decomposing and producing sub-microscopic particles of carbon. These readily go into solution in the molten steel, and can produce metallurgical problems in service.

The outer envelope of the oxy-acetylene flame by consuming the surrounding oxygen to some extent protects the molten weld metal pool from the surrounding air. If unprotected the oxygen may diffuse into the molten metal and produce porosity when the weld metal cools. With metals containing refractory oxides, such as stainless steels and aluminium, it is necessary to use an active flux to remove the oxides during the welding process.

Both oxygen and acetylene are supplied in cylinders, the oxygen under pressure and the acetylene dissolved in acetone since it cannot be compressed. Each cylinder which is distinctly coloured (red—acetylene, black—oxygen) has a regulator for controlling the working gas pressures. The welding torch consists of a long thick copper nozzle, a gas mixer body, and valves for adjusting the oxygen and acetylene flow rates. Usually a welding rod is used to provide filler metal for the joint, but in some cases the parts to be joined may be fused together without any filler metal. Gas welding techniques are shown in Figure 9.1.

Oxy-acetylene welding tends to be slower than other fusion welding processes because the process temperature is low in comparison with the melting temperature of the metal, and because the heat must be transferred from the flame to the plate. The process is therefore only really applicable to thinner mild steel plate, thicknesses up to 7 mm being welded with this process with a speed of 3 to 4 metres per hour. In shipbuilding oxy-acetylene welding can be employed in the fabrication of ventilation and air conditioning trunking, cable trays, and light steel furniture; some plumbing

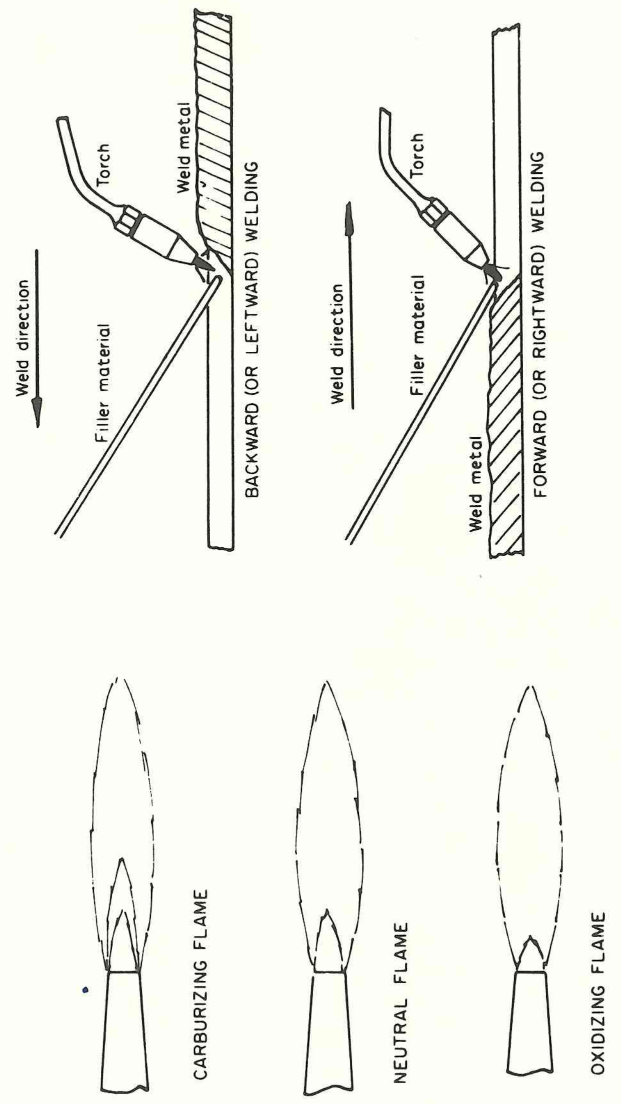

FIGURE 9.1 Gas welding

and similar work may also make use of gas welding. These trades may also employ the gas flame for brazing purposes, where joints are obtained without reaching the fusion temperature of the material being joined.

Electric Arc Welding

The basic principle of electric arc welding is that a wire or electrode is connected to a source of electrical supply with a return lead to the plates to be welded. If the electrode is brought into contact with the plates an electric current flows in the circuit. By removing the electrode a short distance from the plate, so that the electric current is able to jump the gap, a high temperature electrical arc is created. This will melt the plate edges and the end of the electrode if this is of the consumable type.

Electrical power sources vary, D.C. generators or rectifiers with variable or constant voltage characteristics being available as well as A.C. transformers with variable voltage characteristics for single or multiple operation. The latter are most commonly used in shipbuilding.

Illustrated in Figure 9.2 are the range of manual, semi-automatic, and automatic electric arc welding processes which might be employed in shipbuilding. Each of these electric arc welding processes is discussed below with its application.

SLAG SHIELDED PROCESSES Metal arc welding started as bare wire welding, the wire being attached to normal power lines. This gave unsatisfactory welds, and subsequently it was discovered that by dipping the wire in lime a more stable arc was obtained. As a result of further developments many forms of slag are now available for coating the wire or for deposition on the joint prior to welding.

Manual Welding Electrodes The core wire normally used for mild steel electrodes is rimming steel. This is ideal for wire drawing purposes, and elements used to 'kill' steel such as silicon or aluminium tend to destabilize the arc, making 'killed' steels unsuitable. Coatings for the electrodes normally consist of a mixture of mineral silicates, oxides, fluorides, carbonates, hydrocarbons, and powdered metal alloys plus a liquid binder. After mixing, the coating is then extruded onto the core wire and the finished electrodes are dried in batches in ovens.

Electrode coatings should provide gas shielding for the arc, easy striking and arc stability, a protective slag, good weld shape, and most important of all a gas shield consuming the surrounding oxygen and protecting the molten weld metal. Various electrode types are available and are covered by B.S. 639: 1976 the type often being defined by the nature of the coating. The more important types are the rutile and basic (or low hydrogen) electrodes. Rutile electrodes have coatings containing a high percentage of

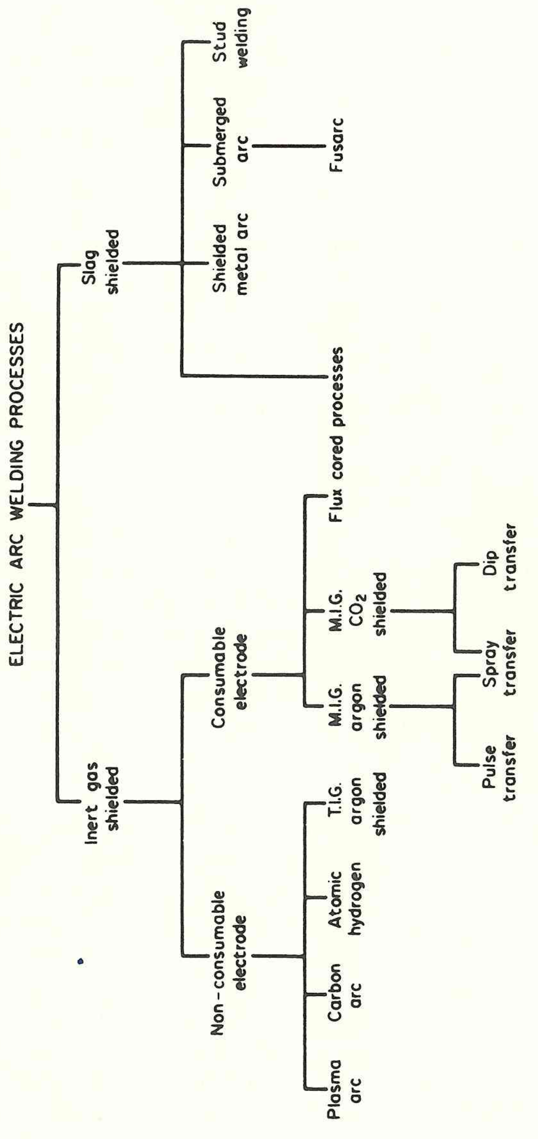

FIGURE 9.2 Electric arc welding processes

titania, and are general purpose electrodes which are easily controlled and give a good weld finish with sound properties. Basic or low hydrogen electrodes, the coating of which has a high lime content, are manufactured with the moisture content of the coating reduced to a minimum to ensure low hydrogen properties. The mechanical properties of weld metal deposited with this type of electrode are superior to those of other types, and basic electrodes are generally specified for welding the higher tensile strength steels. Where high restraint occurs, for example at the final erection seam weld between two athwartships rings of unit structure, low hydrogen electrodes may also be employed. An experienced welder is required where this type of electrode is used since it is less easily controlled.

Welding with manual electrodes may be accomplished in the downhand position, for example welding at the deck from above, also in the horizontal vertical, or vertical positions, for example across or up a bulkhead, and in the overhead position, for example welding at the deck from below (Figure 9.3). Welding in any of these positions requires selection of the correct electrode (positional suitability stipulated by manufacturer), correct current, correct technique, and inevitably experience, particularly for the vertical and overhead positions.

Gravity Welding To increase a manual electrode operator's efficiency, gravity welding equipment is available for shipyard use (Figure 9.3). This consists of a tripod, the longest leg of which is a rail down which a sliding carriage with electrode holder travels. The weight of the holder and electrode under gravity produce the travel, and the sliding angle may be adjusted to vary the metal deposit. At the foot of the rail a stop is located and as soon as the electrode reaches this stop, a carriage trip mechanism is released allowing the electrode holder to spring sideways extinguishing the arc.

Automatic Welding with Coated Electrodes The 'Fusarc' welding process marketed by the British Oxygen Company is used on a large scale in British shipyards for the downhand welding of flat panels of mild steel plating. 'Fusarc' machines traverse the plate at a set speed and the flux covered wire is fed continuously to give the correct arc length and deposition of weld metal. Flux covering of the continuous wire is retained by means of auxiliary wire spirals (Figure 9.4). It is claimed that the process can tolerate reasonably dirty plates, and it is a convenient process for welding outdoors at the berth where climatic conditions are not always ideal.

Additional shielding may be supplied in the form of carbon dioxide gas, (Fusarc/CO_2 process) which together with the flux covering of the electrode wire allows higher welding currents to be used with higher welding speeds. A twin fillet version is also available for use in welding sections to plate panels.

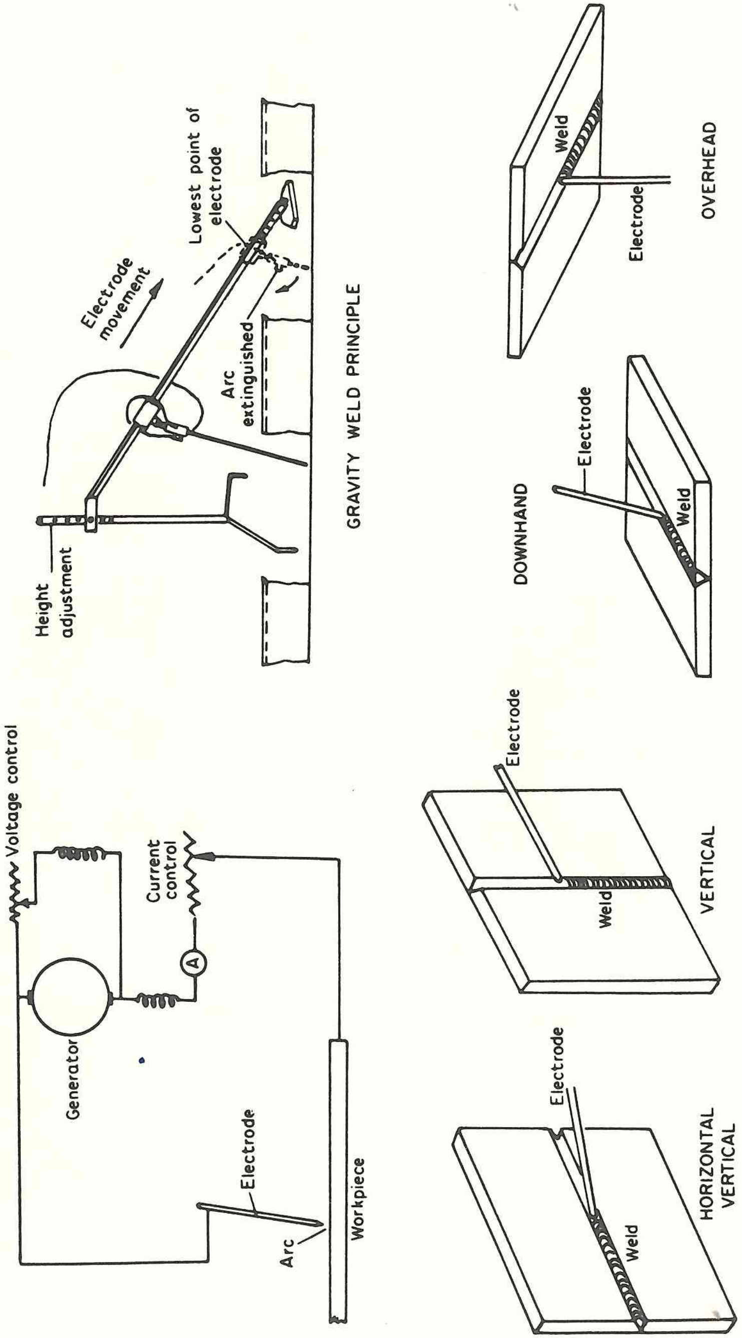

FIGURE 9.3 Manual arc welding

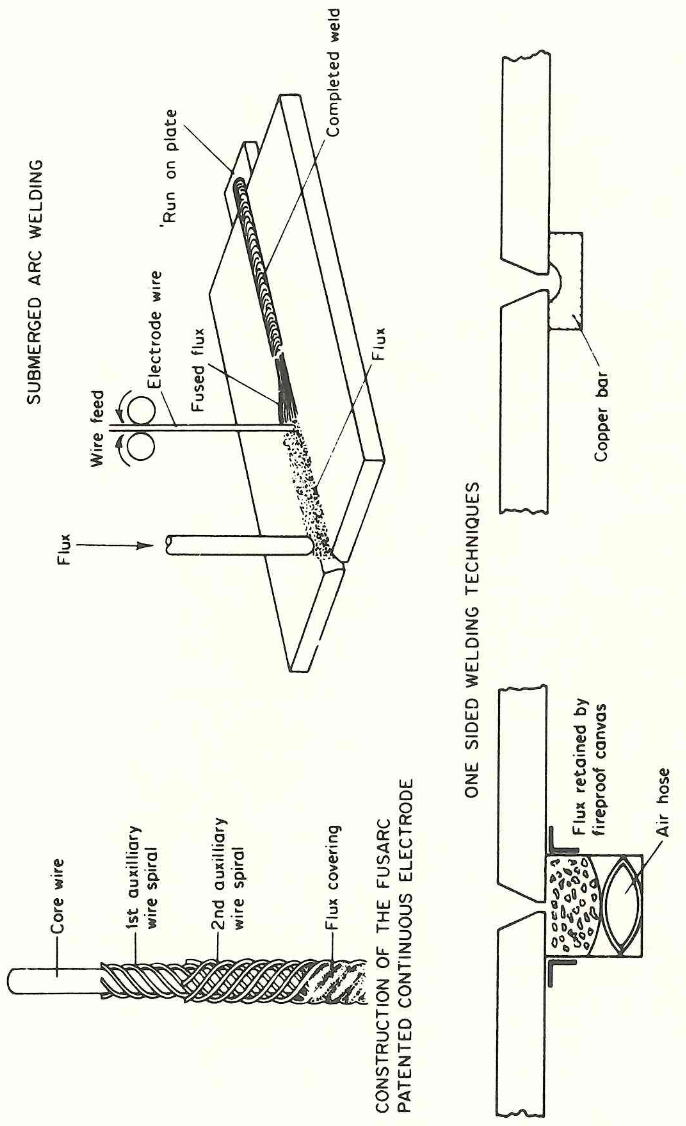

FIGURE 9.4 Automatic arc welding

Submerged Arc Welding This is an arc welding process in which the arc is maintained within a blanket of granulated flux (*see* Figure 9.4). A consumable filler wire is employed and the arc is maintained between this wire and the parent plate. Around the arc the granulated flux breaks down and provides some gases, and a highly protective thermally insulating molten container for the arc. This allows a high concentration of heat, making the process very efficient and suitable for heavy deposits at fast speeds. After welding the molten metal is protected by a layer of fused flux which together with the unfused flux may be recovered before cooling.

The process is basically only intended for downhand applications, and where it is used for single pass welding of any size it is essential to use some form of backing bar because of the comparatively large weld pool obtained. Here the backing bar may be of copper and water cooled, or a flux trough may be provided to form the underbead (Figure 9.4). The copper backing bar or flux trough can be arranged as a fixture in a shop and additional equipment provided to semi-automate the welding of plate panels from one side. This eliminates the turning, reducing the plate handling required, the problem of limited headroom, and weld time.

In general the process is employed under cover using fairly clean plates and is at a disadvantage at the berth. A semi-automatic submerged arc process is marketed, which may be used for small non-repetitive jobs.

Stud Welding Stud welding may be classed as a shielded arc process, the arc being drawn between the stud (electrode) and the plate to which the stud is to be attached. Each stud is inserted into a stud welding gun chuck, and a ceramic ferrule is slipped over it before the stud is placed against the plate surface. On depressing the gun trigger the stud is automatically retracted from the plate and the arc established, melting the end of the stud and the local plate surface. When the arcing period is complete, the current is automatically shut off and the stud driven into a molten pool of weld metal so attaching stud to plate.

Apart from the stud welding gun the equipment includes a control unit for timing the period of current flow. Granular flux is contained within the end of each stud to create a protective atmosphere during arcing. The ceramic ferrule which surrounds the weld area restricts the access of air to the weld zone; it also concentrates the heat of the arc, and confines the molten metal to the weld area (*see* Figure 9.5).

Stud welding is often used in shipbuilding, generally for the fastening of stud bolts to secure wood sheathing to decks, insulation to bulkheads, etc. Apart from various forms of stud bolts, items like stud hooks and rings are also available.

GAS SHIELDED ARC WELDING PROCESSES The application of bare wire welding with gas shielding has developed comparatively recently, and

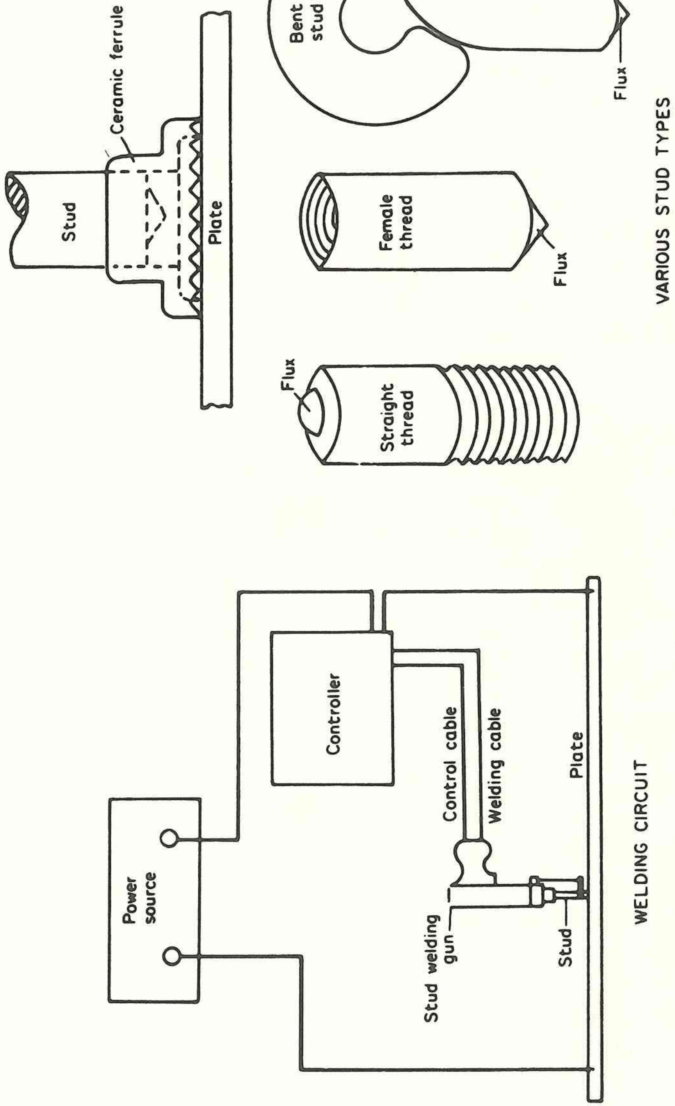

FIGURE 9.5 Stud welding

is being adopted where suitable for the welding of steel in shipyards as well as for welding aluminium where its application is well established. Gas shielded processes are principally of an automatic or semi-automatic nature.

Tungsten Inert Gas Welding (T.I.G.) In the T.I.G. welding process the arc is drawn between a watercooled non-consumable tungsten electrode and the plate (Figure 9.6). An inert gas shield is provided to protect the weld metal from the atmosphere, and filler metal may be added to the weld pool as required. Ignition of the arc is obtained by means of a high frequency discharge across the gap since it is not advisable to strike an arc on the plate with the tungsten electrode. Normally in Britain the inert gas shield used for welding aluminium and steel is argon. Only plate thicknesses of less than 6 mm would normally be welded by this process, and in particular aluminium sheet, a skilled operator being required for manual work. This may also be referred to as T.A.G.S. welding, i.e. tungsten arc gas-shielded welding.

Metal Inert Gas Welding (M.I.G.) This is in effect an extension of T.I.G. welding, the electrode in this process becoming a consumable metal wire.

Basically the process is as illustrated in Figure 9.6, a wire feed motor supplying wire via guide rollers through a contact tube in the torch to the arc. An inert gas is supplied to the torch to shield the arc, and electrical connections are made to the contact tube and workpiece. Welding is almost always done with a D.C. source and electrode positive for regular metal transfer, and when welding aluminium to remove the oxide film by the action of the arc cathode. Although the process may be fully automatic, semi-automatic processes as illustrated with hand gun are now in greater use, and are particularly suitable in many cases for application to shipyard work.

Initially aluminium accounted for most of the M.I.G. welding, with argon being used as the inert shielding gas. Much of the welding undertaken on aluminium deckhouses, and liquid methane gas tanks of specialized carriers, has made use of this process. Generally larger wire sizes and heavier currents have been employed in this work, metal transfer in the arc being by means of a spray transfer, that is metal droplets being projected at high speed across the arc. At low currents metal transfer in the arc is rather difficult and very little fusion of the plate results, which has made the welding of light aluminium plate rather difficult with the M.I.G./argon process. The introduction of the 'pulsed arc' process has to some extent overcome this problem and made positional welding easier. Here a low level current is used with high level pulses of current which detach the metal from the electrode and accelerate it across the arc to give good penetration.

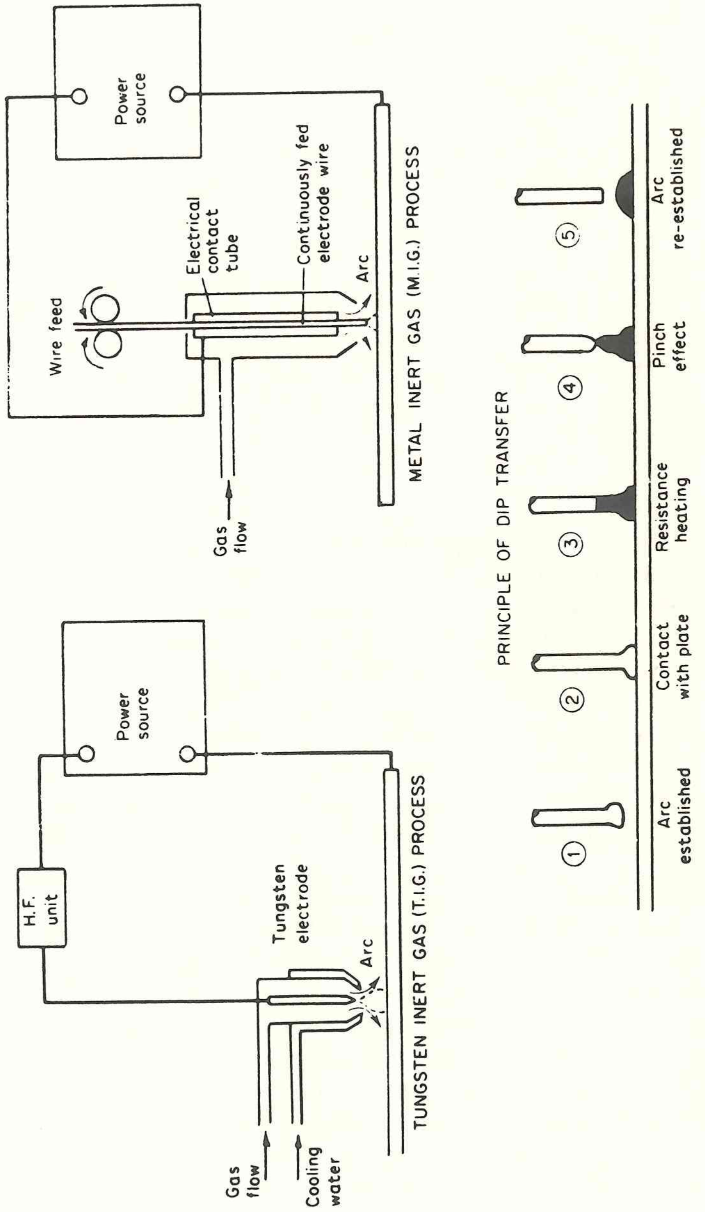

FIGURE 9.6 Metal inert gas welding

Early work on the welding of mild steel with the metal inert gas process made use of argon as a shielding gas; but as this gas is rather expensive, and satisfactory welding could only be accomplished in the downhand position, an alternative shielding gas was sought. Research in this direction was concentrated on the use of CO_2 as the shielding gas, and the M.I.G./CO_2 process is now widely used for welding mild steel. Using higher current values with thicker steel plate a fine spray transfer of the metal from the electrode across the arc is achieved, with a deep penetration. Wire diameters in excess of 1.6 mm are used, and currents above about 350 amps are required to obtain this form of transfer. Much of the higher current work is undertaken with automatic machines, but some semi-automatic torches are available to operate in this range in the hands of skilled welders. Welding is downhand only.

On thinner plating where lower currents would be employed a different mode of transfer of metal in the arc is achieved with the M.I.G./CO_2 process. This form of welding is referred to as the dip transfer (or short circuiting) process. The sequence of metal transfer is (*see* Figure 9.6):

1. Establish the arc.
2. Wire fed into arc until it makes contact with plate.
3. Resistance heating of wire in contact with plate.
4. Pinch effect, detaching heated portion of wire as droplet of molten metal.
5. Re-establish the arc.

To prevent a rapid rise of current and 'blast off' of the end of the wire when it short circuits on the plate, variable inductance is introduced in the electrical circuit. Smaller wire diameters, 0.8 mm and 1.2 mm, are used where the dip transfer method is employed on lighter plate at low currents. The process is suitable for welding light mild steel plate in all positions. It may be used in shipbuilding as a semi-automatic process, particularly for welding deckhouses and other light steel assemblies.

The pulsed M.I.G./argon process, developed for positional welding of light aluminium plate, may be used for positional welding of light steel plate but is likely to prove more expensive.

Use of the M.I.G. semi-automatic processes can considerably increase weld output, and lower costs.

This form of welding may also be collectively referred to as M.A.G.S. welding, i.e. metal arc gas-shielded welding.

Other Welding Processes

There are one or two welding processes which cannot strictly be classified as

ELECTRO-SLAG WELDING The electro-slag welding process has been introduced to this country in recent years and may be used for the automatic vertical welding of thicker steel plate. It is claimed that the welding of plates of thickness down to 13 mm can be economical, but it is usual to weld somewhat heavier plates with this process. Heavy cast sections more than 380 mm in thickness can in fact be welded.

To start the weld an arc is struck, but welding is achieved by resistance path heating through the flux, the initial arcing having been discouraged once welding is started. In Figure 9.7 the basic electro-slag process is illustrated; the current passes into the weld pool through the wire, and the copper water-cooled shoes retain the molten pool of weld metal. These may be mechanized so that they move up the plate as the weld is completed, flux being fed into the weld manually by the operator. A square edge preparation is used on the plates, and it is found that the final weld metal has a high plate dilution. 'Run on' and 'run off' plates are required for stopping and starting the weld, and it is desirable that the weld should be continuous. If a stoppage occurs it will be impossible to avoid a major slag inclusion in the weld, and it may then be necessary to cut out the original metal and start again. If very good weld properties are required with a fine grain structure (electro-slag welds tend to have a coarse grain structure) it is necessary to carry out a local normalizing treatment.

A further development of electro-slag welding is to use a consumable guide for the electrode wire; this allows the machine to be positioned at the top of the weld, and eliminates the equipment which would have to be supplied to permit the machine to climb the weld. A consumable guide may be in the form of a steel tube or composite plate which is clamped rigidly into the weld gap clear of the sides. During the welding process the guide melts off into the slag and molten metal weld pool. Shoes of limited length may be clamped into place to contain the molten weld pool, and they can be 'leap-frogged' over an adjacent pair in order to climb the joint with the weld.

ELECTRO-GAS WELDING Probably of greater interest to the shipbuilder is a further development, electro-gas welding. This is in fact an arc welding process which combines features of CO_2 gas shielded welding with those of electro-slag welding. The process is claimed to be more suitable for welding plates in the thickness range of 13 to 40 mm with square or vee edge preparations. Water-cooled copper shoes similar to those for the electro-slag welding process are used, but a flux-cored electrode rather than a bare wire is fed into the weld pool. Fusion is obtained by means of an arc established between the surface of the weld pool and the wire, and the CO_2 gas shield is supplied from separate nozzles or holes located centrally near the top of the copper shoes.

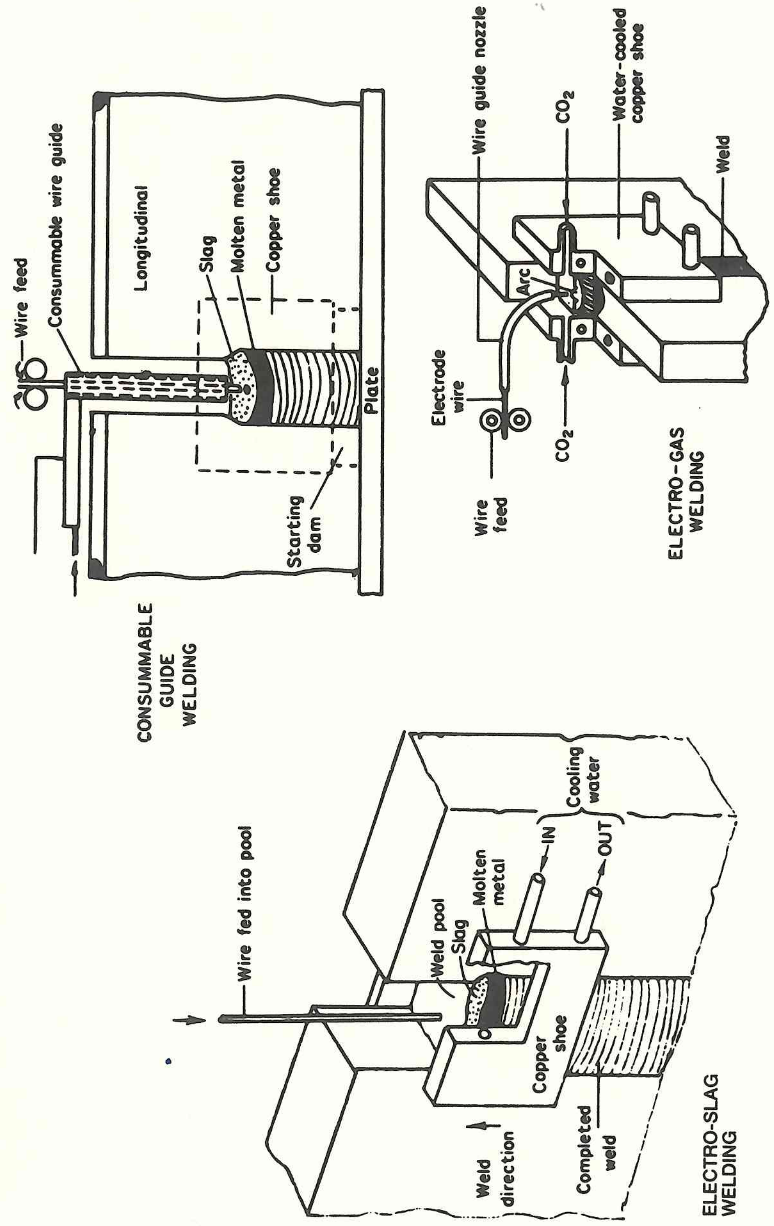

FIGURE 9.7 Electro-slag and Electro-gas welding

welding of vertical butts in the side shell panels at the berth. For this form of weld the electro-gas process might well be preferable using a vee butt preparation, since this would permit the butt to be completed manually if any breakdown occurred. A square butt with appreciable gap would be almost impossible to bridge manually. Consumable guide welding has proved very useful for welding butts in larger section bottom longitudinals on tankers, etc., only a short guide and fixed shoes being required.

THERMIT WELDING This is a very useful method of welding which may be used to weld together large steel sections, for example parts of a stern frame. It is in fact often used to repair castings or forgings of this nature. Thermit welding is basically a fusion process, the required heat being evolved from a mixture of powdered aluminium and iron oxide. The ends of the part to be welded are initially built into a sand or graphite mould, whilst the mixture is poured into a refractory lined crucible. Ignition of this mixture is obtained with the aid of a highly inflammable powder consisting mostly of barium peroxide. During the subsequent reaction within the crucible the oxygen leaves the iron oxide and combines with the aluminium producing aluminium oxide, or slag, and superheated thermit steel. This steel is run into the mould where it preheats and eventually fuses and mixes with the ends of the parts to be joined. On cooling a continuous joint is formed and the mould is removed.

Cutting Processes

Steel plates and sections are mostly cut to shape in shipyards using a gas cutting technique, but the introduction of competitive plasma-arc cutting machines has led to their use in shipyards.

GAS CUTTING Gas cutting is achieved by what is basically a chemical/thermal reaction occurring with iron and iron alloys only. Iron or its alloys may be heated to a temperature at which the iron will rapidly oxidize in an atmosphere of high purity oxygen.

The principle of the process as applied to the cutting of steel plates and sections in shipbuilding is as follows. Over a small area the metal is preheated to a given temperature, and a confined stream of oxygen is then blown onto this area. The iron is then oxidized in a narrow band, and the molten oxide and metal are removed by the kinetic energy of the oxygen stream. A narrow parallel sided gap is then left between the cut edges. Throughout the cutting operation the preheat flame is left on to heat the top of the cut since most of the heat produced by the reaction at the cutting front is not instantaneous, and tends to be liberated at the lower level of the cut only. Alloying elements in small amounts are dissolved in the slag and removed when cutting steel. However, if they are present in large quantities, alloying elements, especially chromium, will retard and even prevent cutting. The reason for this is that they either decrease the fluidity of the slag or produce a tenacious oxide film over the surface which prevents further oxidation of the iron. This may be overcome by introducing an iron rich powder into the cutting area, a process often referred to as 'powder cutting'. When cutting stainless steels which have a high chromium content 'powder cutting' would be employed.

Generally acetylene is used with oxygen to provide the preheat flame but other gases can be used: propane for example or hydrogen which is used for underwater work because of its compressibility. Apart from the torch, the equipment is similar to that for gas welding. The torch has valves for controlling the volume of acetylene and oxygen provided for the preheat flame, and it has a separate valve for controlling the oxygen jet (*see* Figure 9.8).

The oxy-acetylene cutting process has been highly automated for use in shipyards; these developments are considered in Chapter 13. Hand burning with an oxy-acetylene flame is used extensively for small jobbing work, and during the fabrication and erection of units.

PLASMA-ARC CUTTING Plasma in this sense is a mass of ionized gas which will conduct electricity. An electrode is connected to the negative terminal of a D.C. supply and a gas shield is supplied for the arc from a nozzle which has a bore less than the natural diameter of the arc. As a result a constricted arc is obtained which has a temperature considerably higher than that of an open arc. The arc is established between the electrode and workpiece when the ionized conducting gas comes into contact with the work. This gas is ionized in the first place by a subsidiary electrical discharge between the electrode and the nozzle. Plates are cut by the high temperature concentrated arc melting the material locally (Figure 9.8).

The plasma-arc process has been used for cutting aluminium and stainless steel with argon mixtures. It was until recently not competitive with the oxy-acetylene cutting of carbon steels owing to the high cost of consumables and a poorer cut produced. More recent developments have made the process more competitive, with air or oxygen being used instead of the inert gases. Besides reducing costs the use of air or oxygen provides an additional source of heat with an iron-oxygen reaction. Consequently the speed and quality of cutting are improved.

Invariably this form of cutting is highly automated, its greatest advantages being speed of cut and ability to cut metals other than steel.

GOUGING Both gas and arc welding processes may be modified to produce means of gouging out shallow depressions in plates to form edge preparations for welding purposes where precision is not important. Gouging is particularly useful in shipbuilding for cleaning out the backs of welds

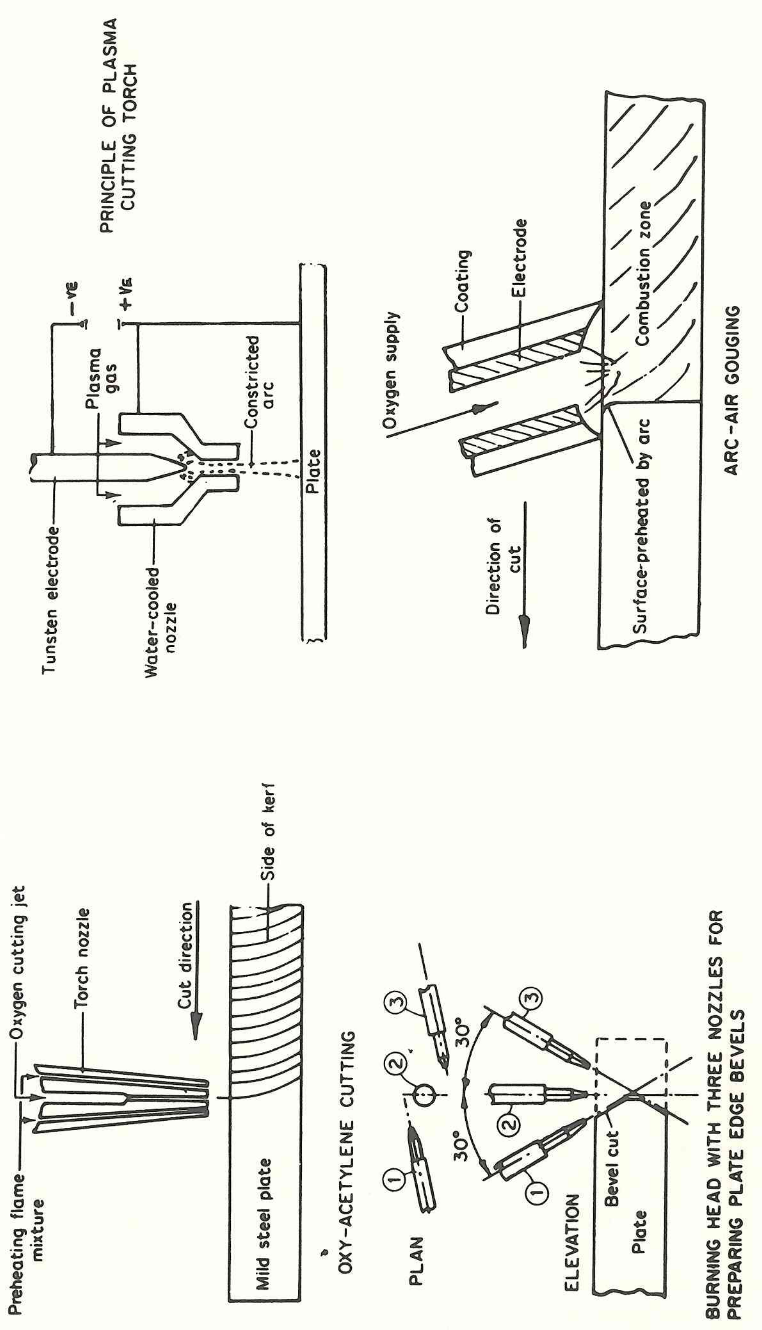

FIGURE 9.8 Metal cutting processes

to expose clean metal prior to depositing a weld back run. The alternative to gouging for this task is mechanical chipping which is slow and arduous. Usually where gouging is applied for this purpose what is known as 'arc-air' gouging is used. A tubular electrode is employed, the electrode metal conducting the current and maintaining an arc of sufficient intensity to heat the workpiece to incadescence. Whilst the arc is maintained, a stream of oxygen is discharged from the bore of the electrode which ignites the incadescent electrode metal and the combustible elements of the workpiece. At the same time the kinetic energy of the excess oxygen removes the products of combustion, and produces a cut. Held at an angle to the plate the electrode will gouge out the unwanted material (Figure 9.8).

A gas cutting torch may be provided with special nozzles which allow gouging to be accomplished when the torch is held at an acute angle to the plate.

LASER CUTTING Profile cutting and planing at high speeds can be obtained with a concentrated laser beam and the introduction to shipbuilding of this technique has been evaluated, in particular for a robot cutting head. In a laser beam the light is of one wavelength, travels in the same direction, and is coherent, i.e. all the waves are in phase. Such a beam can be focused to give high energy densities. For welding and cutting the beam is generated in a CO_2 laser. This consists of a tube filled with a mixture of CO_2, nitrogen, and helium which is caused to fluoresce by a high-voltage discharge. The tube emits infra-red radiation with a wavelength of about 1.6 μm and is capable of delivering outputs up to 20 kw.

Laser cutting relies on keyholing to penetrate the thickness, and the molten metal is blown out of the hole by a gas jet. A nozzle is fitted concentric with the output from a CO_2 laser so that a gas jet can be directed at the work coaxial with the laser beam. The jet can be an inert gas, nitrogen or in the case of steel, oxygen. With oxygen there is an exothermic reaction with the steel giving additional heat as in oxy-fuel cutting. The thermal keyholing gives a narrow straight sided cut compared with the normal cut obtained by other processes relying on a chemical reaction.

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10

Welding Practice and Testing Welds

The strongest welded joint which may be produced in two plates subsequently subjected to a tensile pull is the butt joint. A butt joint is one where the two joined plates are in the same plane, and in any welded structure it is desirable that butt joints should be used wherever possible.

In mild steel the weld metal tends to have a higher yield strength than the plate material (*see* Figure 10.1). Under tension it is found that initial yielding usually occurs adjacent to a butt weld in the plate when the yield strength of the plate material is reached locally. Since a good butt weld in tension has a strength equivalent to that of the mild steel plate it is not considered as a line of structural weakness.

Lapped joints, where fillet welds are used to connect the plates, should be avoided in strength members of a welded structure. As the fillet welds are in shear when the plates are in tension the strength of the joint is very much less than that of the plate material or butt joint. Fillet welds are unavoidable where sections or plates are connected at an angle to an adjacent plate, but often there is not the same problem as the loading is different. The fatigue strength of fillet welds is also inferior to that of a butt weld.

Welding Practice

In making a butt weld with manual arc welding, where the plate thickness exceeds say 5 to 6 mm it will become necessary to make more than one welding pass to deposit sufficient weld metal to close the joint. With the higher current automatic welding processes thicker plates may be welded with a single pass, but at greater thicknesses multi-pass welds become necessary.

In ship work unless a permanent backing bar is used, or the 'one sided' welding technique (Chapter 9, submerged arc welding) is adopted during fabrication, a back run of weld is required to ensure complete weld penetration. This is made on the reverse side of the joint after cleaning out the slag, etc., by chipping or gouging. Permanent backing bars may conveniently be introduced where it is desired to weld from one side only during erection at the berth. A good example is the use of a cut-down channel bar used as a deck beam, the upper flange providing the backing bar for a deck panel butt weld, made by machine above.

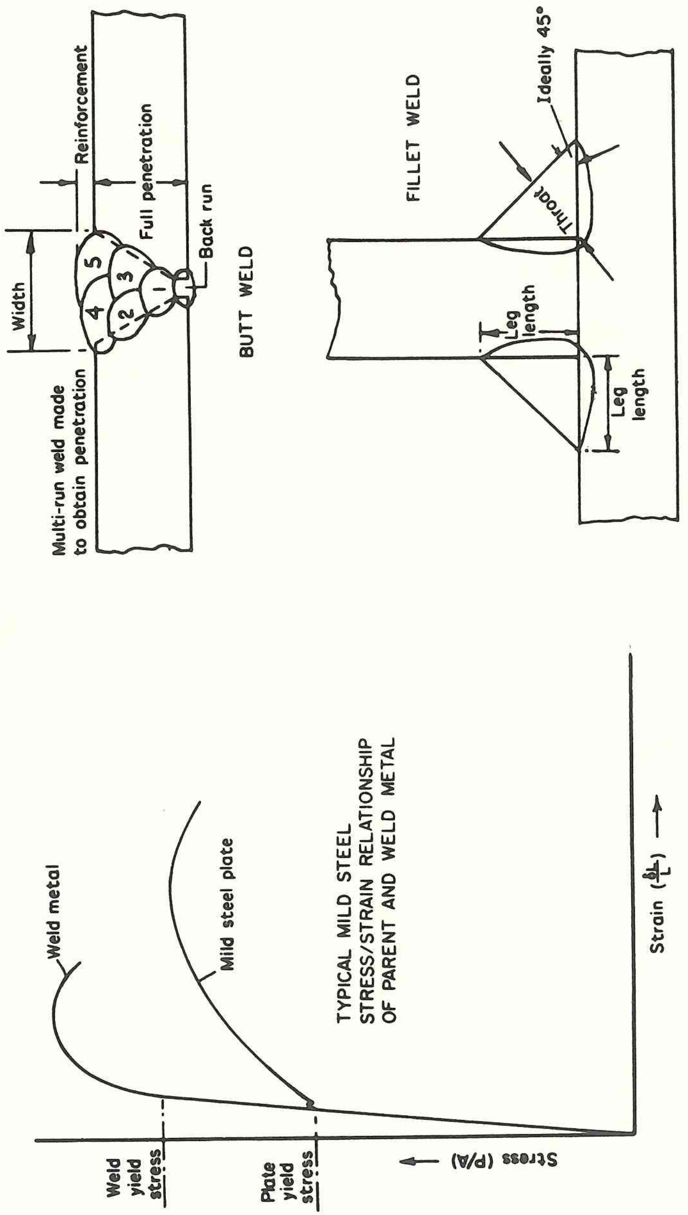

FIGURE 10.1 Typical mild steel stress/strain relationship of parent and weld metal

Tack welds are used throughout the construction to hold plates and sections in place after alignment and prior to completion of the full butt or fillet weld. These are short light runs of weld metal, which may be welded over, or cut out in more critical joints during the final welding of the joint.

Fillet welds may be continuous or intermittent depending on the structural effectiveness of the member to be welded. Where fillets are intermittent they may be either staggered or chain welded (*see* Figure 10.2), the member may also be scalloped to give the same result when continuously welded.

On thicker plates it becomes necessary to bevel the edges of plates which are to be butted together in order to achieve complete penetration of the weld metal (Figure 10.2). This operation may be carried out whilst profiling or trimming the plate edges which must be aligned correctly. Most edge preparations are made by gas burning heads having three nozzles out of phase which can be set at different angles to give the required bevels. Alternatively the edge preparation may be obtained by mechanical machining methods using either a planing or milling tool. For very high quality welds in thick plate, particularly of the higher tensile types of steel, mechanical machining may well be specified. It is worth noting that there is little to choose between the two as far as metallurgical damage goes, but mechanical methods provide a better finish.

Plates of varying thickness may be butt welded together at different locations, a good example being where heavy insert plates are fitted. Insert plates are preferred to doubling plates in welded construction, and the heavy plate is chamfered to the thickness of the adjacent thinner plate before the butt edge preparation is made.

To ease the assembly of welded units it is common practice to make use of what is known as an 'egg box' construction. Within the double bottom unit the floors and side girders may be slotted at their intersections so that they fit neatly together prior to construction.

Welding Sequences

During the welding operation heat is applied to the plate, and because of this the metal will expand, and on cooling contract. A weld on cooling and contracting tends to pull the plate with it. This results in a structural deflection, the restraining action of the plate preventing the weld from contracting fully. The actual distortion of a welded structure is difficult to predict owing to the lack of knowledge of the degree of restraint. It is known however that shrinkage in butt welds does occur principally along the length of the weld, and to a lesser extent across it. If a high restraint is provided in an effort to control distortion the structure will contain high residual stresses, which are to be avoided.

In order to minimize distortion the 'backstep' and 'wandering' methods of welding are often used, the length of each step being the amount of weld

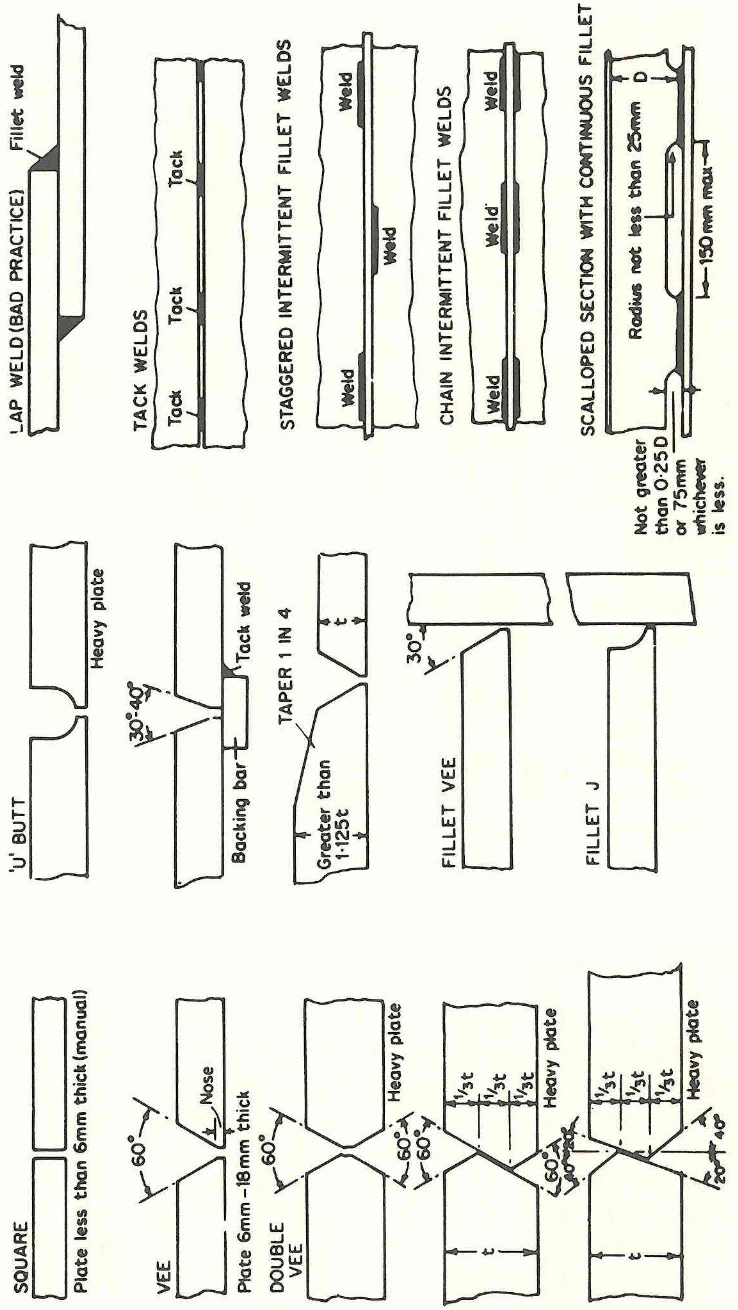

FIGURE 10.2 Plate edge preparations

metal laid down by an electrode to suit the required cross-section of weld (*see* Figure 10.3).

To reduce distortion and limit the residual stresses in the structure it is important that a correct welding sequence should be utilized throughout the construction. This applies both during the fabrication of units and at erection and joining of units on the berth.

Of the more important welds in the construction of the ship the sequences involving welding of butts and seams in plating panels may be considered (*see* Figure 10.4). At T intersections it is necessary to weld the butt first fully, then gouge out the ends to renew the seam edge preparation before welding the seam. Welding the seam first would cause high restraint across the plate strake and when the butt was finished a crack might occur. General practice when welding shell panels is to start by welding the central butts and then adjacent seams, working outwards both transversely and longitudinally. Ships' structural panels have various forms of stiffener attached to the plate panels, these generally being welded to the panel after completing the welding of the panel plates. These stiffening members are left unwelded across the butts and seams of the plates until these are completed, if they are attached at some intermediate stage.

Erection welding sequences generally follow the principles laid down for plating panels. In welded ships the lower side plating seams should not be welded before the upper seams, particularly the deck and gunwale seams. If this sequence of welding the side shell were adopted the upper portion of the hull structure would tend to be shortened causing the hull to rise from the blocks at the ends. Where in modern construction the side shell and deck plating are erected in blocks and a suitable welding sequence is employed this problem does not arise.

In repair work correct welding sequences are also important, particularly where new material is fitted into the existing relatively rigid structure. Again the procedure follows the general pattern for butts and seams in plate panels. If a new shell plate is to be welded in place the seams and butts in the surrounding structure are cut back 300 to 375 mm from the opening; likewise the connection of the stiffening in way of the opening. The inserted plate panel is then welded to within 300 to 375 mm of the free edges, the butts are completed, and then the seams after welding any longitudinal stiffening across the butts. Finally the vertical framing is welded in way of the seams (Figure 10.4).

Testing Welds

For economic reasons much of the weld testing carried out in shipbuilding is done visually by trained inspectors. Spot checks at convenient intervals are made on the more important welds in merchant ship construction, generally using radiographic equipment. Welding materials are subjected to