REEDS MARINE ENGINEERING AND TECHNOLOGY

SHIP CONSTRUCTION
FOR MARINE ENGINEERS

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SHIP CONSTRUCTION
FOR MARINE ENGINEERS

Revised by Paul A. Russell

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PREFACE

The update of this publication comes at such an exciting time for International Shipping. Material Science is marching on at a great rate of knots, and the regulators are continually looking at ways to ensure that ships are built to a specification that is safer than before. This volume is designed to provide knowledge primarily about the construction of ships engaged in international voyages. The content is intended to cover the requirements of the various Flag Administration qualifications for marine engineers studying for the International Maritime Organization's (IMO) Standards of Training, Certification & Watchkeeping (STCW) for seafarers at the Certificates of Competency as Chief Engineering Officer, Second Engineering Officer and Engineering Officer of the Watch (EOOW) levels.

The publication complements Volume 4, 'Naval Architecture for Marine Engineers', Volume 8, 'General Engineering Knowledge', and Volume 12, 'Motor Engineering Knowledge' in the same series. It will also be found useful by those studying for STCW Chief Mate and Master's Examinations as well as students undertaking maritime degrees and SuperYacht Qualifications.

The book will also cover the subject to the level required by people starting out or working in the operation, repair and surveying of ships. It is intended to give an indication about the typical methods of construction, and it is suggested that engineers studying at sea should compare the arrangements shown in the book with those on the ship wherever possible. In this way students will relate the descriptions in the book to the actual structure of ships in preparation for the Flag Administration's Examinations. The typical examination questions are intended as a revision of the whole work.

GENERAL INTRODUCTION

International Shipping started with the needs of manufacturers to transport raw materials from suppliers and finished goods to customers. As business grew so did the distances that needed to be covered.

Traditional seafaring nations built up merchant fleets that would carry goods to and from any place that was required. No longer bound by national boundaries, ship owners would seek work for their ships on a global basis. Therefore, ship owners not only traded their vessels to and from the country of registration but they would also carry cargo to and from any other country where business was to be found. The rules for the construction and use of these vessels were set by the nation where the vessel was registered.

These nations built up considerable expertise relating to the safety of the vessels falling within their administration. Their rules covered the construction and use of the vessel as well as the competence of staff. However, the shipping industry is a global business and during the 1970s owners found that other nations were becoming interested in registering and setting the rules for operating ships on international voyages.

As the industry looked for different nations to provide the registration of their ships there was a growing need to set standards that all flag administrations could uphold. The organisation with the necessary infrastructure for completing this task was the United Nations (UN). The International Maritime Organization (IMO) is the UN's specialist agency concentrating on maritime matters.

The IMO secretariat provides the structure for the contracting member nations to record their businesses, ideas and decisions. It has its headquarters in London (UK) and has the remit for the development of all the rules and regulations that govern International Shipping. These rules cover the technical development of ships, design and specification of equipment used on board, fire protection, safety of navigation, carriage of cargos, port and flag state responsibilities and international security relating to the maritime industry. More about the rules, regulations and standards associated with ships can be found in Chapter 10.

The IMO has the member states that complete the decision making process; however they also have non-government organisations (NGOs) that provide the technical support and guidance when necessary.

The technical guidance relating to the strength, safe operation and the correct and efficient design of a ship and its associated systems comes from naval architects, marine engineers and navigation experts.

These specialists work and operate through organisations such as classification societies, the professional institutes and other organisations representing different sectors of the industry such as the 'oil' sector or 'ship masters'.

Over the past few decades there have been significant improvements in ship design and construction. Much more is known about Material Science, properties and performance characteristics. Quality assurance runs through the whole process. If the manufacturing process of the raw materials is correct and audited and the construction is closely monitored, then the finished vessel should perform to a known design specification.

This used to be the case in the past of course; however scantlings had to be larger and construction more complex due to the uncertainties in the performance of detailed parts and lack of complete understanding of how they interacted with other parts of the ship. Using modern computerised design techniques, the stresses in individual components can be calculated in a way that was not possible just a few decades ago. Classification societies are very important in providing the industry with the constructional details necessary for building ships. More can be studied about the work of these organisations in Chapter 10.

Ship design (basic concepts) – starts with the need to transport either raw materials or manufactured goods from one part of the world to another via the water route. It follows on to capture the need to also transport people and vehicles from place to place. If the vessel is to spend its working life in sheltered inshore waters or rivers, it might be built to a different set of construction rules as will a vessel that is to sail the world's oceans.

Ships that are expected to travel to areas where ice is present will need to be constructed to an ice class standard. The strategic importance of the Arctic is growing all the time as Owners are looking to take advantage of sailing in the polar regions of the world, and for this reason the IMO has developed constructional and operational guidelines for such vessels. There are seven polar classes for which the International Association of Classification Societies (IACS) has developed constructions rules and the IMO has included additional requirements for vessels operating to the 'Polar Code'.

Other 'owner's criteria' for a ship will include width, draught and height restrictions for any of the ports or routes where the vessel will be expected to travel. Types and volumes of cargo to be carried and cargo handling equipment will be considered as will, speed required and length of service. The cost of the vessel will be very important, and this will determine the standard of equipment to be fitted.

Having said that it is also fair to say that most new tonnage is being built to high standards and some of the equipment is at the cutting edge of technology. Marine propulsion motors, for example, cannot be built more powerful as material science is the limiting factor.

The basic ship types and associated terms and nomenclature appear in Chapter 1 and other design selection criteria can be found in Chapter 12.

1

SHIP TYPES AND TERMS

The design and construction of merchant ships are driven initially by commercial considerations and then by the requirement to build safe machinery. Therefore ships vary considerably in size, type, layout and function. In broad categories modern tonnage can be divided into passenger ships, cargo ships and specialised vessels built for specific types of work. This book deals with the general construction details of these ship categories.

Cargo ships may be further subdivided into those designed to carry liquid cargoes, those designed to carry non-liquid cargoes and those intended to carry specialised cargos such as gas and chemical carriers.

The larger cargo ships (over 15 000 gt) are designed to carry as much cargo, in one voyage, as possible. They usually sail between significantly sized 'hub' ports that have been designed to accommodate their size.

As ships are now so big, care must be taken when considering the passage that they will undertake as part of their required service. For example, a 250 000 gt fully laden supertanker will, most likely, not be able to sail through the Suez Canal, and will instead be forced to sail around the tip of Africa when on passage from the Middle East to Europe.

However if an owner wishes to build a vessel that is just big enough to transit the Suez Canal, then that vessel will attract the term 'Suez Max'. A similar situation exists with the Panama Canal. The largest vessel that is able to transit this canal will be called a

Passenger Ships

During the first half of the twentieth century the *passenger ship* was the only way to transport large numbers of people about the world reliably. However the development of air transport took over this role, and the *passenger ship* market changed almost overnight. The vast majority of ships in this sector are now cruise ships and ferries. Most are of a conventional design, but the *fast ferry* is very popular for short service routes.

Ferries operating in a limited area or on a short regular route are increasingly being designed using liquefied natural gas (LNG) or 'hybrid' technology as the energy source for vessel propulsion.

Universal agreement has the *passenger ship* defined as 'a vessel that is designed to carry more than 12 passengers on an international voyage'. These vessels must comply with the relevant International Maritime Organization (IMO) regulations included in the Safety Of Life At Sea (SOLAS) and the Load Line Conventions for passenger ships. Cargo ships can still carry up to 12 passengers without being reclassed as a passenger ship.

The only departure from this requirement is in the superyacht sector, where the UK's Maritime Coastguard Agency (MCA) has developed the 13–36 Passenger Yacht Code. This code is for use by the Red Ensign Group to register large passenger yachts that carry up to 36 passengers. These type of vessels find it very difficult to comply with the full requirements of the IMO regulations for passenger ships, and this led the UK administration to develop the regulations for this sector.

Passenger ships, in general, range from small river ferries to large ocean-going vessels. Cruise ships can now carry up to 4000 passengers and are designed to provide maximum comfort for all guests on board. These ships include in their services large dining rooms, luxury restaurants, theatres, cinemas, swimming pools with water slides, gymnasia, open deck spaces and shops. They usually cater to guests with a range of purchasing power and are being designed increasingly to provide the majority of rooms with a balcony and a 'sea view'.

Ferries are also being designed after listening to customers' needs. For example, ferries carrying large numbers of trucks might provide a specific place where the drivers can rest and have a meal in a restaurant that has been designed with them in mind. Ro-Ro ferries are now 'double decked' and arranged so that both decks can be loaded at the same time. This is important as the time in port for any vessel is 'non-revenue' earning

Small 'passenger vessels' are now on the increase, some supplying the ever growing needs of the 'offshore' renewable energy sector. Passenger vessels restricted to 'inland waterways' are starting to use 'hybrid' technology to meet their propulsion needs. There is an advantage for passenger comfort if electric engines can be used. However there will have to be a significant development in battery technology before the diesel engine can be removed from the system completely.

Invariably new standards are applied to passenger ships slightly ahead of cargo ships. It is also usually the case that the rules are more stringent for passenger ships, and during the 1990s there was increasing concern about the safety of very large passenger ships and new regulations appeared focusing on their construction and on the training of the crew for such vessels.

Minimum standards for crew accommodation is now required under the International Labour Organisation's (ILO) Maritime Labour Convention 2006 (MLC 2006).

A sign of the times is that most people look to manage risk as they go about their daily work. The IMO is no different and during the 1990s and into the early twentieth century they worked on developing a risk-based approach to the operation and construction of ships.

In 2006, the 82nd sitting of the IMO's Maritime Safety Committee 82 (MSC 82) adopted comprehensive amendments to SOLAS chapter II-1. This section of SOLAS relates to the subdivision and damage stability requirements for passenger and cargo ships.

Also in 2006 came the plans to improve the safety of passenger ships based around the Safe Return to Port (SRtP) concept for these ships. SRtP centres around the notion that 'your ship is your best lifeboat', and therefore if the ship can be constructed with maximum 'survivability', then there will be less of a need to resort to the much smaller and more vulnerable 'lifeboats' in the event of an accident.

The IMO amended regulations to improve the safety of passenger ships by placing more emphasis on the prevention of casualties and improving the survivability of the ship in the event of an incident, and thus allowing the passengers to stay safely on-board while the vessel returns to the nearest safe haven.

A further development for the very large passenger ship is the 'diesel electric' (power station) concept. This is where the main engines are large diesel alternators producing high voltage electricity that is used to either power the ship or run large electrical loads servicing the passengers, such as the air conditioning compressors, ventilation fans or galley and laundry equipment.

Container Ships (the Modern Cargo Liner Ships)

Ships travelling between allocated ports and having specific departure and arrival dates are considered to be running on a *liner* trade. Both passenger ships and cargo ships can be 'liner ships', however the role of carrying and delivering goods and services has now moved mostly to the domain of the cargo ship with the container vessel being the modern version.

Cargo liners are vessels designed to carry a variety of cargoes between specific ports and, as stated, the modern configuration of this type of vessel is the *container ship* and most of the non-liquid cargos and some liquid cargos are now carried around the world by this type of ship.

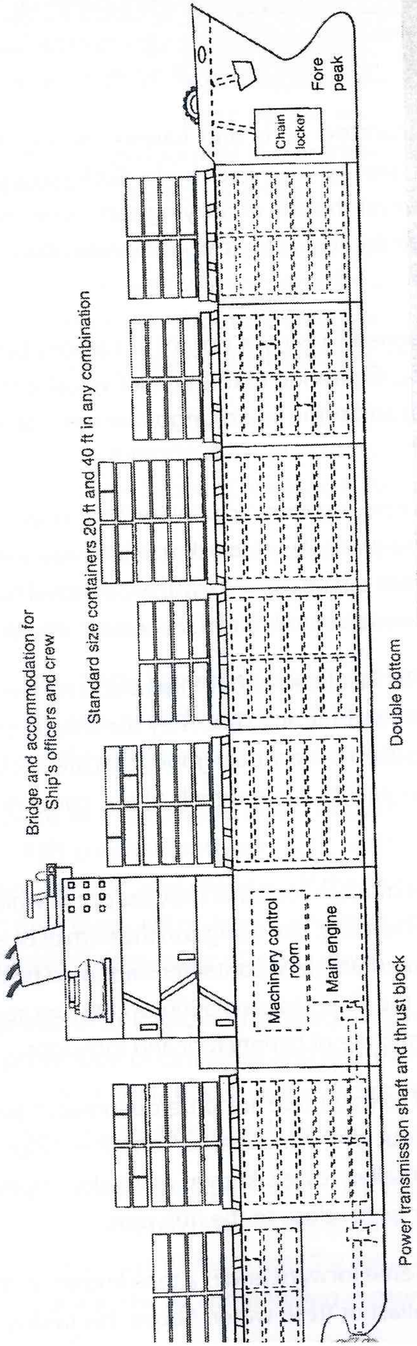
The standardisation of cargo carrying 'units' (containers) has transformed the efficiency of moving cargo from place to place. Anything that will fit into a standard (8 ft x 8 ft 6 in x 20 ft or 40 ft) sized container can be moved via an intermodal transportation system in which the container ship plays a central role in the waterborne part of that system.

The reusable containers can be insulated and refrigerated and are capable of carrying perishable cargoes such as meat, fruit and fish. They are mostly standard steel boxes with doors at one end and are used to transport goods that are packed in boxes, drums, bags and cases or stacked on pallets. More details about containers can be found in Chapter 12 of this book.

Figure 1.1 shows the layout of a modern *container ship*, the size of which can be measured by the number of containers it can carry. The sizing is in the form of twenty foot equivalent (TEU) units. This means that a medium sized container ship could be described as having a size of 9000 TEU or as having the ability to carry 9000 twenty foot containers. The actual containers carried could be a mixture of twenty foot and forty foot.

The global system is arranged so that there are large 'deep water' ports, known as 'hub ports', that are distributed about the world. Large container ships up to 18 000 TEU travel between these ports. Smaller vessels known as 'feeder' vessels move the cargo from the large ports to smaller ports, close to the hub port.

As with many ships, at the extreme forward end is a tank known as the *fore peak* which may be used to carry water ballast or fresh water. Above this tank is an area called the *chain locker* and also a *storage space*. At the after end is a tank known as the *after peak*



1.1 Container ship

double bottom space which is further subdivided into smaller tanks suitable for carrying oil fuel, fresh water and water ballast.

The *machinery space* consists of heavy equipment and as such will place considerable 'local' stresses on the structure of the ship. If placed at the aft end, as with Figure 1.2, the machinery will exert a maximum bending moment on the ship's hull. If placed in a more central position, as shown in Figure 1.1, then the 'light ship' bending moment and hull stress will be reduced. The latest diesel electric propulsion systems enable the designer to place the main diesels in the best possible place for the benefit of the hull thereby maximising the cargo carrying capacity.

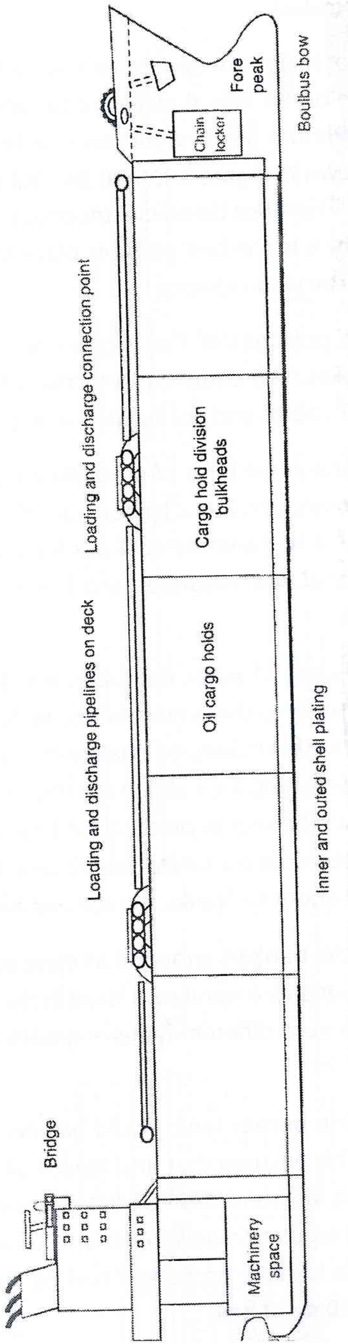
The reason for this is that the positions of the engines are not determined by the propeller shafting and gearboxes. The connection to the inboard electric motor or podded drive will be via electric cables and not by mechanical equipment.

Currently, in 2016, most ships use some form of oil as their major energy source. The general term for this fuel is *bunkers* which is a legacy from the early days of shipping when coal was the main source of fuel and the coal was loaded into *coal bunkers*. The *oil fuel bunkers* are taken on board when required and loaded into designated tanks called *bunker tanks*.

Due to the possibility of the presence of water, the fuel is transferred into *settling tanks* where any water in the mix will settle to the bottom of the tank. The water can then be drained off prior to the fuel being further treated on board with centrifugal purifiers before being used in the engines. In order to help the stability of a ship, it is generally a good idea to have the bunker tanks as low in the ship as practical, and therefore the tanks used as bunker tanks are usually the double bottom tanks. (See Volume 8, 'General Engineering Knowledge', for more information about fuel tanks, storage and treatment equipment.)

It is also advantageous to have the bunkers arranged as close to the machinery space as possible. Fuel oil storage has become a significant issue in the design of ships. This is due to the requirement to have several different types or grades of fuel stored separate from each other.

In the past this has meant that the bunker tanks could be very close to or in contact with the outer hull of the ship. This ensured that any breach of the hull in way of the tank would release oil into the sea. The new MARPOL (International Convention for the Prevention of Pollution for Ships) regulation developed in 2006 and brought into force during 2010 required new builds to have 'protected' fuel oil storage tanks when an individual tank holds more than 60 m^3 of fuel.



1.2 Oil Tanker showing engine room and pump room aft

Between the aft engine room bulkhead and the after peak bulkhead is a watertight *shaft tunnel* enclosing the shaft and allowing access to the intermediate shaft and bearings directly from the engine room. An exit in the form of a vertical trunk is arranged at the after end of the tunnel in case of emergency. In a twin screw ship it may be necessary to construct two such tunnels, although they may be joined together at the fore and aft ends.

The arrangement of the machinery space on many modern ships is further aft and therefore the propeller shafting and intermediate bearings are sighted in the machinery space. Invariably a walkway and guard rail are placed close to the rotating shaft so that the watch keeping engineer can safely inspect the drive train for correct operation at any time.

The MSC, at its 87th session in May 2010, adopted a new SOLAS regulation II-1/3-10 on goal based ship construction standards for bulk carriers and oil tankers (resolution MSC.290(87)).

These rules require that vessels have a design life of at least 25 years and that all the structural and manufacturing rules are consistent with this requirement. The class rules should consider at least:

- Extreme loads
- Design loads
- Fatigue
- Corrosion

Cargo (Tramp) Ships

General cargo (tramp) ships used to be those ships which are designed to carry any specific type of cargo and travel anywhere in the world on an irregular route. They were often hired out on a spot or time charter to carry bulk cargo or general cargo, and are usually slower and smaller than the container 'liner' vessels. The vessels may carry some or all of these cargos in containers.

To assist the safe stowage of cargo the cargo space is divided into lower *holds* and compartments between the decks, or *'tween decks*. Many ships have three decks, thus forming upper and lower 'tween decks. This system allows different cargoes to be carried in different compartments and reduces the possibility of the cargo getting

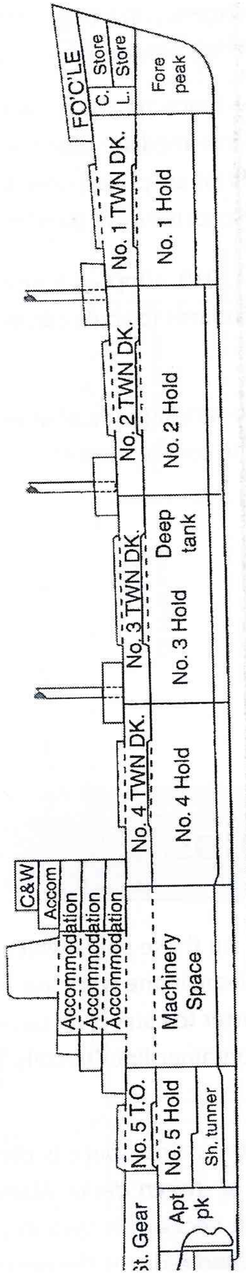


Figure 1.3 *Cargo tramp ship*

Suitable cargo handling equipment is provided in the form of hydraulic or electrically powered cranes. Heavy lift equipment may be fitted and is usually situated next to one or more hatches. A *forecastle* is fitted to reduce the amount of water shipped forward and to provide adequate working space for handling ropes and cables.

The *forecastle* also acts very effectively to protect the fwd hatches from heavy weather damage. Obviously hatch covers are a prime area to guard against a breach of watertight integrity. The hatch covers are well designed but the *forecastle* provides a very good first line of defence and deflects the full force away from the hatches.

However the work of these vessels is now being taken over by bulk carriers and smaller container vessels. Figure 1.3 shows the layout of a typical cargo tramp. The space immediately forward of the machinery space may be subdivided into lower 'tween decks and *hold/deep tank* thus improving the ability to even out the stress on the hull and/or give different options for carrying other liquids such as fuel or water.

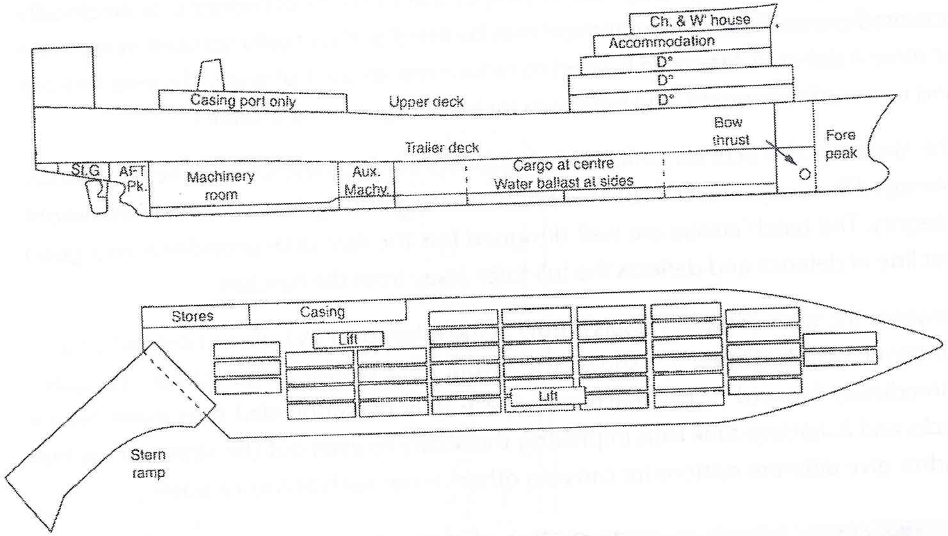
Roll-On/Roll-Off Vessels

These vessels are designed with flat decks and have moveable watertight divisions to enable vehicles and tractor-trailer units to be driven into and off the vessel under their own power. Having such a large continuous deck means that any appreciable accumulation of water will have a magnified adverse effect on the vessel's stability. This is due to the 'free surface effect' inherent in such a body of water. (See Chapter 5 of Volume 4, 'Naval Architecture for Marine Engineers'.) The Ro-Ro vessel is particularly susceptible to this feature, and all the staff should be well aware of the dangers of the ship becoming unstable if it is not operated correctly.

A ramp is fitted at one or each of the ends of the ship allowing direct access for cars, trucks and buses which remain on board in their laden state. These ramps lead to large outer doors which have in the past been a source of leakage due to damage and/or incorrect operation. Any ingress of water will come straight onto the Ro-Ro decks leading to the possible problem with free surface effect mentioned earlier.

Containers may be loaded 2 or 3 high by means of fork-lift trucks. Lifts and inter-deck ramps are used to transfer vehicles between decks and the most modern vessels have stern ramps that are angled to allow vehicles to be loaded from a straight quay (Figure 1.4).

Some specialist Ro-Ro vessels have very large car carrying capacity and are used to



▲ **Figure 1.4** *Roll-on/roll-off vessel*

Where the vessel has a combined container/Ro-Ro capacity the term *Lo-Lo* is sometimes used. This refers to the lift-on lift-off feature of the containerised cargo.

Accommodation for crew and passengers includes restaurants and fast food outlets as well as specific areas for long distance lorry drivers where they can complete 'official' rest periods that satisfies the 'drivers' hours' regulations. Again these vessels tend to work as liner vessels and ferries. The ports of Dover and Calais, either side of the English Channel, are very good examples of ports that are highly specialised in handling the Ro-Ro ferry operation.

Oil Tankers

Tankers are used to carry oil in bulk, and they can be divided into two different basic types. One type carries unrefined 'crude' oil while the other type, known as a product carrier, carries different types of 'refined' oils such as lubricating oil, naphtha, petrol or diesel oil.

The crude oil carriers are termed *very large crude carriers* (VLCC; 200 000–300 000 gt) or *ultra large crude carriers* (ULCC; 300 000+ gt). They are usually larger than the product

Modern tankers are now fitted with fixed inert gas systems (all tankers over 8000 gt as of 1 January 2016). This means that when the oil is pumped from a tank during a discharge, the space above is filled with a gas that will not support a fire or explosion. Conversely as the oil is loaded the inert gas is released. More information on these systems can be found in Chapter 9 of this volume.

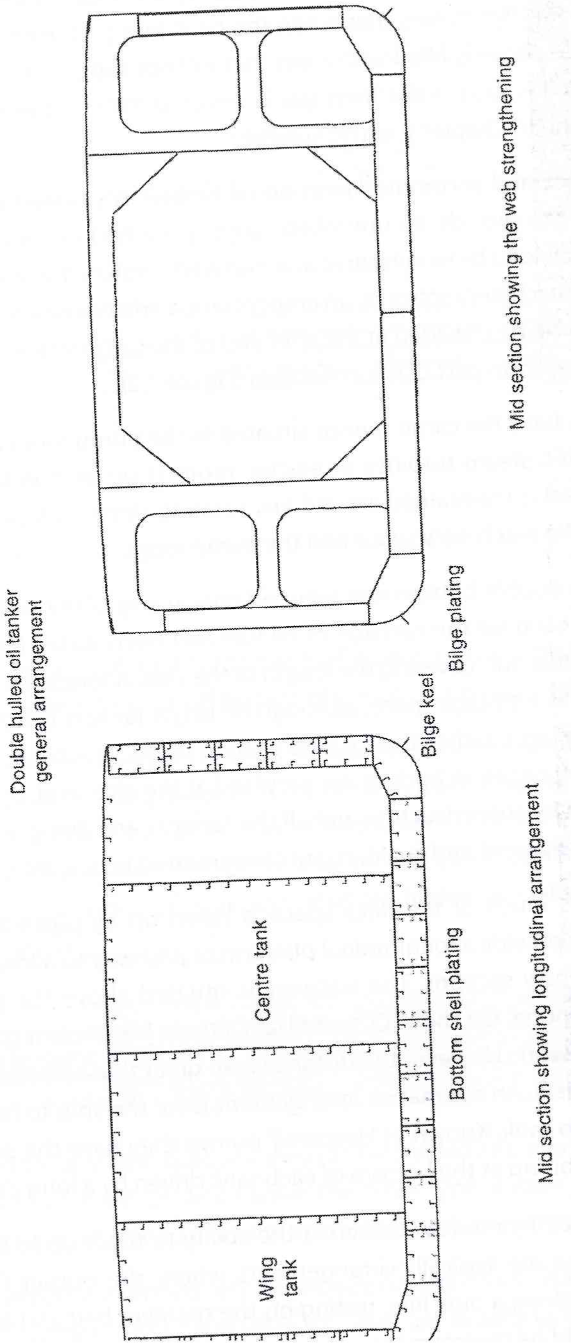
The machinery space and accommodation on oil tankers is situated aft. This means that the designers can provide an unbroken cargo space fwd of these features. The cargo tanks are subdivided by longitudinal and transverse bulkheads, and the tanks are separated from the machinery space by an empty compartment known as a cofferdam. A pump room may also be provided at the after end of the cargo space just for'd of the engine room and may form part of the cofferdam (Figure 1.2).

It is then possible to have the cargo pumps situated in the pump room and the prime mover (diesel engines, steam turbines or electric motors) situated in the machinery space. A gas tight seal is maintained around any rotating drive shaft penetrating the bulkhead between the machinery space and the pump room.

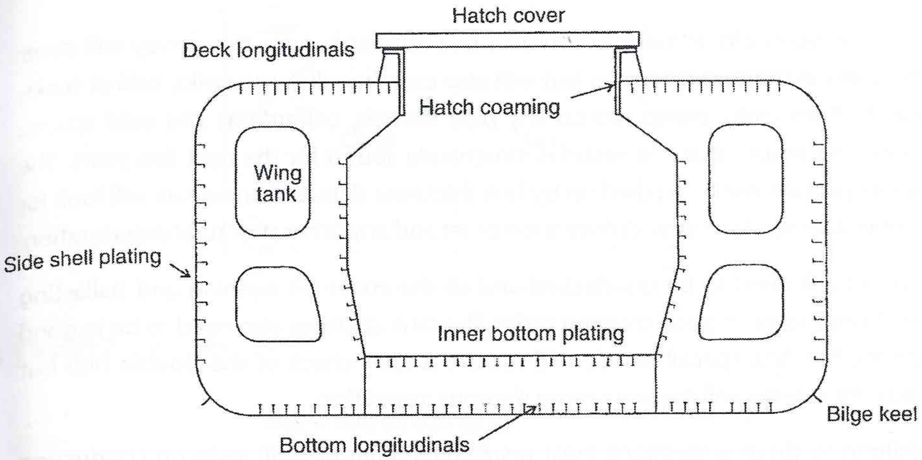
In the older vessels a double bottom was required only in way of the machinery space and may have been used for the carriage of oil fuel and fresh water. Modern vessels must now have a 'double hull' covering the length of the ship. A forecastle is sometimes required and is used as a storage space, although on larger tankers this area is usually a continuation of the deck rather than a step change in the line of the ship. As the accommodation and navigation bridges are provided at the after end, the deck space may be left unbroken by superstructure and all the services and living arrangements, including catering equipment and facilities, are concentrated in one area.

In the smaller tankers much of the deck space is taken up by pipes and hatches. Therefore it is usual to provide a longitudinal platform or pathway to allow easy access to the *forecastle* and *bow* sections. The walkway is situated above the pipes and is known as the 'flying bridge'. On the VLCCs and ULCCs there is sufficient space to walk easily around the pipework. However the distance is so great that sometimes bicycles are provided for the crew. An alternative arrangement is for the ship to have a pump allocated to each cargo tank. Known as 'deepwell' pumps they have the prime mover sited on-deck and the pump at the bottom of each tank driven by a long drive shaft.

Another feature required by modern tankers is the ability to moor up to Single Buoy Moorings (SBMs). These are typically arrangements where the output from an oil production field is fed along a pipe line, resting on the sea/river bed and leading to a mooring buoy that could be several miles away.



.5 Oil Tanker-mid-section



▲ **Figure 1.6** *Ore Carrier-mid-section and general arrangements*

Marine Forum (OCIMF) produces guidelines for the design strength of systems for mooring to SBMs.

The method is to use the anchor chain; however the angle of the pull on the securing equipment will have moved from the sea/river floor to the surface. Therefore the weight on the equipment will be at a much shallower angle.

The midship section (Figure 1.5) shows the transverse arrangement of the cargo tanks. The centre tank is usually about half the width of the ship. However perhaps the most significant developments in tanker design is that of the inclusion of 'double hulls'. Following a series of mandates, during and just after the 1990s, regulation 19 in Annex 1 of MARPOL now requires that tankers over 5000 dwt be fitted with 'double hulls' or an alternative design approved by the IMO. More on this feature can be found in Chapter 9 of this volume.

The harmonised Common Structural Rules (CSR) for Bulk Carriers and Tankers were introduced on 1 July 2015. This set of rules, developed by the International Association of Classification Societies (IACS), replaced the rules set independently for bulk carriers and for double hull oil tankers.

The first and common part covers the minimum requirements for the strength of the hull, such as expected wave loads, hull girder strength as well as minimum buckling and fatigue characteristics. A design life of 25 years is assumed and forms the base for

Tankers, five years old or more, are subject to a 'special' survey. This survey will cover all the items in the 'annual' survey but will also examine all cargo tanks, ballast tanks, double bottom tanks, pump rooms, any pipe tunnels, cofferdams and void spaces. The aim is to ensure that the vessel is structurally sound for the next five years. The survey inspection will be backed up by hull thickness data and surveyors will look for corrosion, damage, fractures, deformation or set and any other structural deterioration.

The vessel will need to be dry-docked and all the crude oil washing and ballasting systems need to be in good working order. The tank coatings also need to be in good condition. The first special survey will require a spot check of the double hull but subsequent surveys will require a more rigorous inspection.

In addition to these inspections most respectable charters will insist on conducting a 'tanker vetting' process to ensure that the vessel is in a satisfactory condition to complete its charter and that it conforms to all the necessary requirements.

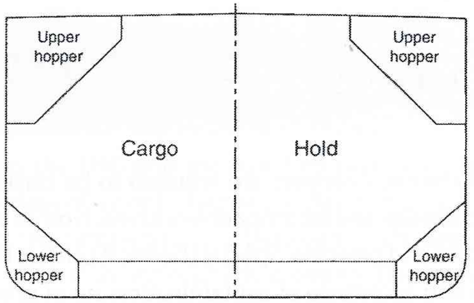
Tanker vetting will cover the condition of the vessel as well as inspect all the necessary records and documents to ensure that the tanker has been operated and maintained to the level required by the flag administration, by the classification society and by the insurers.

Bulk Carriers

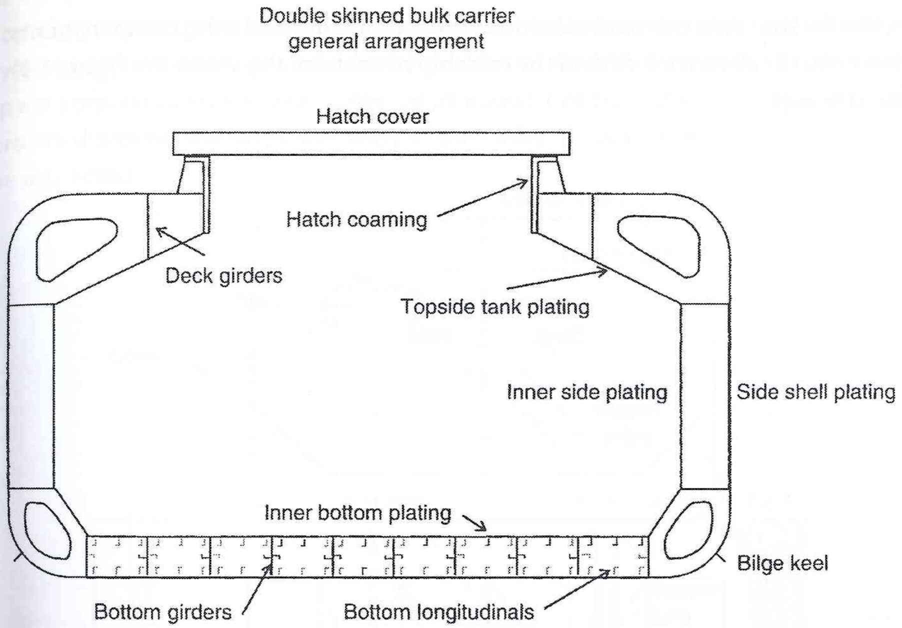
Bulk carriers are vessels built to carry such cargoes as ore, coal, grain and sugar in large quantities. They are designed for ease of loading and discharging with the machinery space aft, allowing continuous, unbroken cargo space fwd of the accommodation. They are single deck vessels having long, wide hatches, closed by steel covers. The double bottom runs from stem to stern.

In ships designed for heavy cargoes such as iron ore the double bottom is very deep and longitudinal bulkheads are fitted to restrict the cargo space (Figure 1.7). This system also raises the centre of gravity of the ore, resulting in a more comfortable ship. The double bottom and the wing compartments may be used as ballast tanks for the return voyage.

Some vessels, however, were designed to carry an alternative cargo of oil in these tanks. With lighter cargoes such as grain, the restriction of the cargo spaces is not necessary although deep hopper sides may be fitted to facilitate the discharge of cargo, either



▲ **Figure 1.7** *Ore carrier*



▲ **Figure 1.8** *Bulk carrier*

carriers are built with alternate long and short compartments. Thus if a heavy cargo such as iron ore is carried, it is loaded into the short holds.

A cargo such as bauxite would be carried in the long holds, while a light cargo such as grain or timber would occupy the whole hold space.

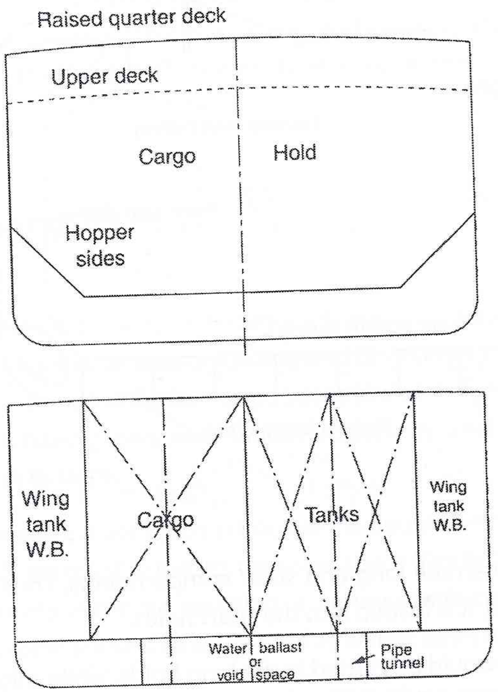
The double bottom is continuous in the cargo space, and it is raised at the sides to form hopper sides which improve the rate of discharge of cargo. Wide hatches are fitted for

Chemical Carriers

A considerable variety of chemical cargoes are required to be carried in bulk. Many of these cargoes are highly corrosive and incompatible with each other while others require close control of temperature and pressure. Special chemical carriers have been designed and built, in which safety and avoidance of contamination are of prime importance.

To avoid corrosion of the structure, stainless steel is used extensively for the tanks, while in some cases coatings of zinc silicate or polyurethane are acceptable.

Protection for the tanks is provided by double bottom tanks and wing compartments which are usually about one-fifth of the midship beam from the ship side (Figure 1.9) [Lower drawing].

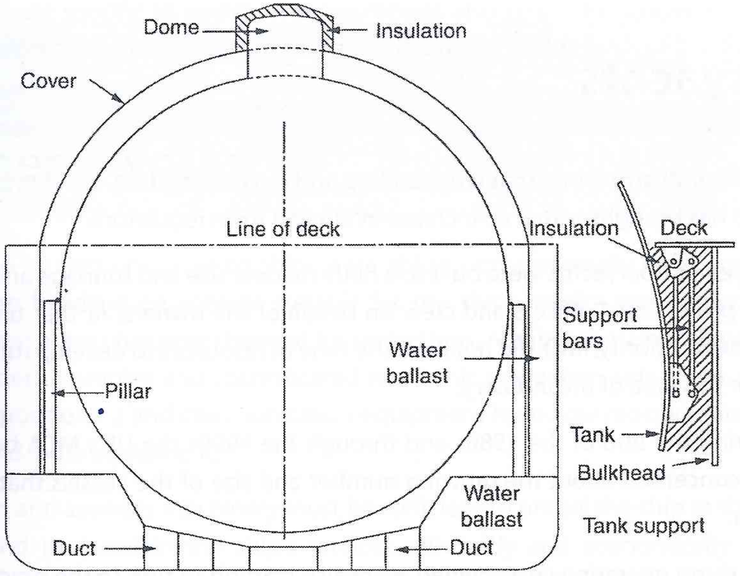


▲ **Figure 1.9** *Chemical carrier*

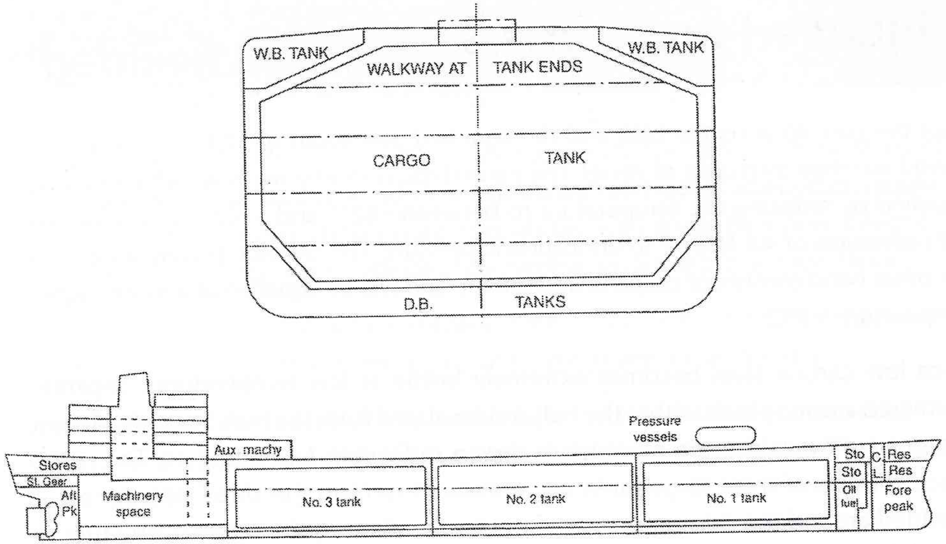
Liquefied Gas Carriers

Over the past 40 years the LNG and the liquefied petroleum gas (LPG) carriers have carved out their own class of vessel. The natural gas is mostly methane which may be liquefied by reducing the temperature to between −82°C and −162°C in association with pressures of 4.6 MN/m^2 to atmospheric pressure. The 'heavier' petroleum gas on the other hand consists of propane and butane and will be liquefied at a much higher temperature (−7°C).

Since low carbon steel becomes extremely brittle at low temperatures, separate containers must be built within the hull and insulated from the hull. Several different systems are available, one of which is shown in Figures 1.10 and 1.11. The cargo space consists of three large tanks set at about 1 m from the ship's side. Access is provided around the sides and ends of the tanks, allowing the internal structure to be inspected.



▲ **Figure 1.10** *Gas carrier with spherical tanks*



▲ **Figure 1.11** *Liquefied gas carrier*

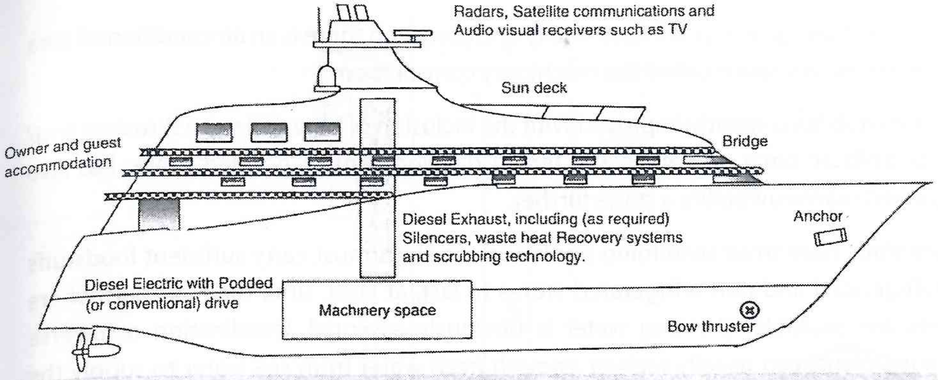
Superyachts

This area of the industry is one that is expanding and developing fast. The demand for larger vessels has brought with it an increase in interest from regulators.

Until recent years superyachts were built to a fairly modest size and tonnage and were operated by professional officers and crew on behalf of the owners. At that time the most important authority, IMO, did not have the time of resources to develop rules and guidelines for this area of the industry.

However during the end of the 1980s and through the 1990s the UK's MCA became increasingly concerned about the growing number and size of the vessels that make up this sector.

To offset the rising operating costs owners were also starting to turn to the practice of 'chartering' their yachts. This meant that there was a commercial undertone starting to take hold, and therefore the MCA felt the need to act without the blessing of the IMO. Twenty years on and flag administrations started to understand the wisdom of



▲ **Figure 1.12** *Super yacht – General arrangement*

The Large Yacht Code and the Code of Practice for Yachts carrying 13–36 passengers (the Passenger Yacht Code). The second edition introduced in 2012 sets out the requirements for yachts registered under the Red Ensign Group of flag administrations.

The rules cover all the usual items, such as the strength and standard of design of a yacht's structure, as well as things such as the use of helicopters and tenders/survival craft that are specific to yachts. The regulations also cover the requirements for the qualifications of the officers and crew that operate the yachts.

General Notes

It used to be that ocean-going ships were able to exist as totally independent units. The cargo handling equipment suitable for the ship's service was carried with the vessel. That aspect has now changed for some ships, notably container ships and large bulk carriers. Complex and sophisticated electronic navigation aids, radar and global satellite positioning and communication equipment have now mostly replaced paper charts and radio equipment.

The main and auxiliary machinery must be sufficient to propel the ship at the required speed and to maintain the ship's services efficiently and economically. Adequate redundancy and backup for all essential services are required. Accommodation, at the required standard (MLC 2006), must be provided for officers and crew with comfortable cabins, recreation rooms and dining rooms. Many ships are now also being fitted with wired or wireless internet access.

Bridges and bridge wings are now totally enclosed, and there is an air conditioned area in the machinery space called the machinery control room.

Manoeuvrability is greatly improved with the inclusion of bow and stern thrusters and/or controllable pitch propellers. The recent development of 'podded' drives has also improved manoeuvrability a stage further.

Many ships have small swimming pools and the ships must carry sufficient foodstuffs in refrigerated and non-refrigerated stores to last, at least, until the next port where stores are available. Drinking water is obviously essential. Desalination or reverse osmosis plants can usually recover enough fresh water from sea water to supply the needs of the crew and machinery. In the event of emergency it is essential that first aid, fire extinguishing and life-saving appliances are provided.

IMO now require that ships are constructed to a 'risk' assessed standards called goal based standards for bulk carriers and tankers SOLAS Ch II-1/2.28 which brings them into line with passenger ships (Figures 1.13 and 1.14).

Ship Terms

The following terms and abbreviations are in use throughout the shipbuilding industry.

Length overall (LOA)

The distance from the extreme fore part of the ship to a similar point aft and is the greatest length of the ship. This length is important when docking.

Length between perpendiculars (LBP)

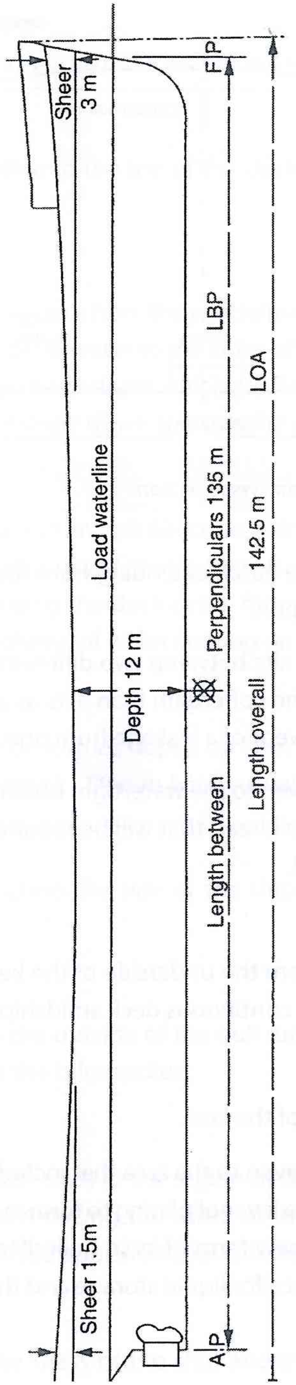
The fwd perpendicular is the point at which the Summer Load Waterline crosses the stem. The aft perpendicular is the after side of the rudder post or the centre of the rudder stock if there is no rudder post. The distance between these two points is known as the length between perpendiculars, and is used for some ship calculations.

Breadth

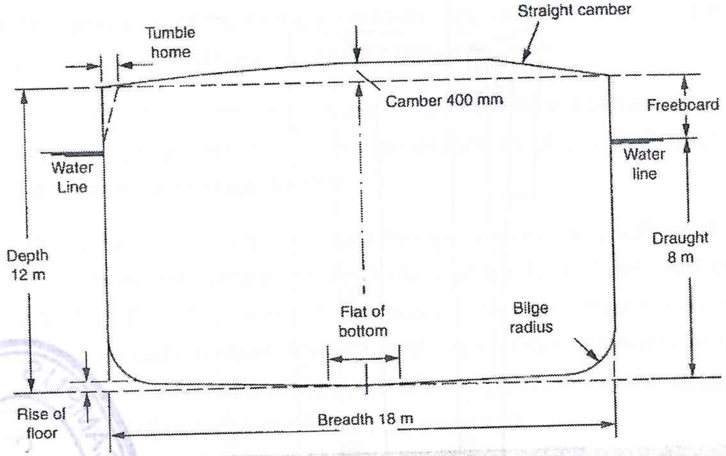
The greatest breadth of the ship, measured to the outside of the shell plating.

Breadth moulded (BMld)

The greatest breadth of the ship, measured to the inside of the inside strakes of shell



ure 1.13 *General ship's terms – Longitudinal section*



▲ Figure 1.14 *General ship's terms – Transverse section*

Coaming – is the vertical side of the hatch extending from the main deck and forming a structure for the hatch lid to sit upon.

Cofferdams – are a void space that sits between two different spaces or tanks that are usually carrying different liquids. The cofferdam than acts as a gap between the tanks, preventing contamination in the event of a leakage from one of the tanks.

Collision bulkhead – is the name given to the watertight bulkhead situated the furthest forward and is therefore the first bulkhead that will be required to take the force of an impact at the fwd end of the vessel.

Depth extreme (DExt)

The depth of the ship measured from the underside of the keel to the top of the deck beam at the side of the uppermost continuous deck amidships.

Depth moulded (DMld)

The depth measured from the top of the keel.

Double bottom – this is the name given to the area that includes the outer hull, girders and stiffeners inside the vessel and a layer of plating to form in effect a double skin. This should not be mixed up with the new form of 'twin hulled' tankers. This is due to the double bottom being used as a space for liquid storage and the twin hull arrangement being an empty space.

Draught moulded (dMld)

The draught measured from the top of the keel to the waterline.

Freeboard

The distance from the waterline to the top of the deck plating at the side of the deck amidships.

Camber or round of beam

The transverse curvature of the deck from the centreline down to the sides. This camber is used on exposed decks to drive water to the sides of the ship. Other decks are often cambered. Most modern ships have decks which are flat transversely over the width of the hatch or centre tanks and slope down towards the side of the ship.

Sheer

The curvature of the deck in a fore and aft direction, rising from midships to a maximum at the ends. The sheer forward is usually twice that aft. Sheer on exposed decks makes a ship more seaworthy by raising the deck at the fore and after ends further from the water and by reducing the volume of water coming on the deck.

Rise of floor

The bottom shell of a ship is sometimes sloped up from the keel to the bilge to facilitate drainage. This rise of floor is small, 150 mm being usual.

Bilge radius

The radius of the arc connecting the side of the ship to the bottom at the midship portion of the ship.

Bilge keel

A section of plating fixed to the outside of the hull running for the length of the ship protruding at right angles to the bilge radius.

Tumble home

In some ships the midship side shell in the region of the upper deck is curved slightly towards the centre line, thus reducing the width of the upper deck and decks above. Such tumble home improves the appearance of the ship.

Displacement

This is a measurement of the mass of the ship and everything it contains when the water. This is due to the difference in density between the salt water and fresh water. Displacement can be calculated as the underwater volume times by the density of the water that the vessel is floating in, times by the value of gravity.

Lightweight

This is a measure of the mass of the empty ship, without stores, fuel, water, crew or their effects. The hull and machinery and all the fixtures and fittings are also included in this measurement.

Deadweight

The deadweight is a measure of the mass that a ship is carrying at a given time. It is the sum of the weight of cargo, fuel, water, stores and people that a ship has on board when the measurement is taken. The deadweight is therefore the difference between the displacement and the lightweight

$$\text{Displacement} = \text{Lightweight} + \text{Deadweight}$$

It is usual to categorise a vessel by reference to its deadweight. Thus a 10 000 tonne ship is one which is capable of carrying a deadweight of 10 000 tonne.

Registered tonnage

It is necessary to have an official measurement for ships and in the past the value of the gross registered tons (grt) has been used. However there was never a universally agreed standard definition of grt.

IMO's International Convention on Tonnage Measurement of Ships entered into force in July 1982 and as a consequence the two measurements of gross tonnage (GT) and net tonnage (NT) have been agreed upon and are now in universal use for all ships.

However, they are not straight-forward mathematical calculations IMO describe 'gross tonnage' as a function of the volume of all the internal spaces within the ship. These include the volume of appendages but not volumes that are open to the sea.

The volumes are not simply added up and the actual calculation is:

$$\text{Gross tonnage} = K1\,V,$$

where $K1 = 0.2 + 0.02 \log10 \times V$ and V = the total volume of all the qualifying spaces of the ship in cubic metres.

2

STRESSES IN SHIP STRUCTURES

A number of forces act on a ship's structure; some are static forces while others are dynamic. The static forces are set up due to the difference in weight and support along the length of the ship, while the dynamic forces are created by the force of the water interacting with the ship, by the passage of waves along the ship and by the moving propulsion parts. The greatest stresses set up in the ship as a whole are due to the distribution of loads along the ship, causing longitudinal bending.

Strength of Ships – Overall Design Concept

Students will be able to see that this aspect is the fundamental starting point for calculating the overall strength of a ship. As would be expected, computers are now used extensively to assist the ship's designer to calculate the ultimate hull girder strength.

A ship may be regarded as a non-uniform beam, carrying non-uniformly distributed loads and having varying degrees of support along its length. Some of the load will be distributed evenly over a section of the ship while some will be more concentrated. The overall strength of the beam is referred to as the 'girder strength' and the overall bending moment envelope curves are used to calculate the required girder strength. Then the internal structures and the hull plating are sized and arranged to meet the minimum girder strength required for the design and duty of the vessel.

The components designed to resist the buckling of the girder and contributing to the ultimate hull strength are:

- the size, number and strength of longitudinal beams;
- the thickness and strength of the shell plating;
- the bilge keels;
- the quality of welding; and
- the number and strength of the transverse sections.

The ultimate hull girder strength for tankers, bulk carriers and now container ships is determined using a system known as the iterative-incremental method, which is where the hull girder is divided into a set of transverse elements. The forces are calculated in one element and the resultant strain (for any one given condition) is used to modify the stress calculations on the next connecting transverse element. This is repeated until the final strength profile for the hull girder has been calculated.

If we now think about the hull girder, students will be able to see that to keep the 'box section' in shape there needs to be a combination of beams running along the length of the box and a series of square shapes designed to maintain the shape of the box (see Figure 2.8).

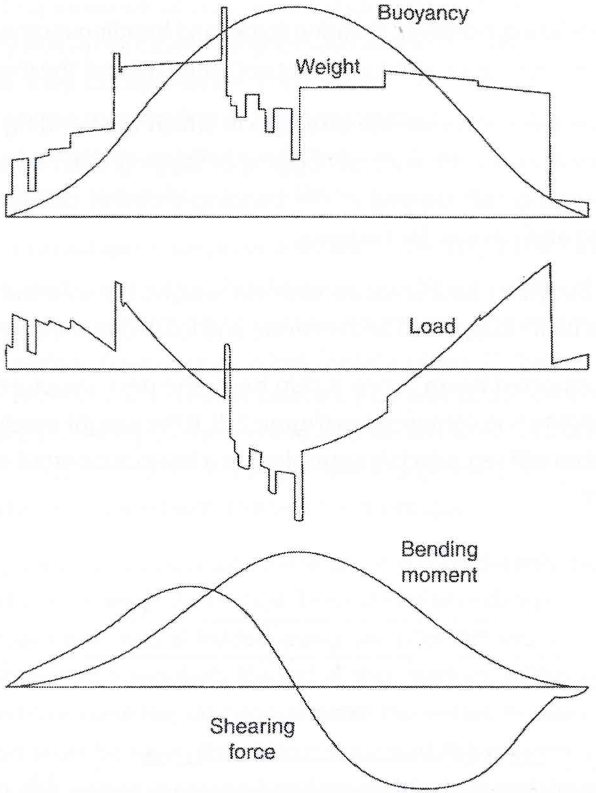
The way that these two are combined will determine the overall design of the vessel. The two systems are called longitudinal framing and transverse framing. Not only can the overall vessel be of one or the other or indeed a combination of both but so can smaller parts of the overall vessel.

Special consideration must be given to any transition from one system to the other.

Longitudinal Bending

Still water bending – static loading

If we consider a loaded ship lying in still water, then the upthrust at any 1 m length of the ship depends upon the immersed cross-sectional area of the ship at that point. If



▲ **Figure 2.1** *Load distribution*

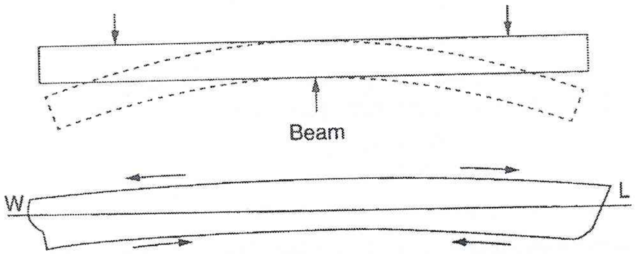
This curve increases from zero at each end to a maximum value in way of the parallel midship portion. The area of this curve represents the total upthrust exerted by the water on the ship. The total weight of a ship consists of a number of independent weights concentrated over short lengths of the ship, such as cargo, machinery, accommodation, cargo handling gear, poop and forecastle sections of the hull construction and a number of items which form continuous material over the length of the ship, such as decks, shell and tank top.

A *curve of weights* is shown in Figure 2.1. The difference between the weight and buoyancy at any point is the load at that point. In some cases the load is in excess of weight over buoyancy and in other cases there is an excess of buoyancy over weight. A load diagram formed by these differences is shown in the figure. Since the total weight must be equal to the total buoyancy (assuming that the vessel is still floating), Due to the unequal loading, however, shearing forces and bending moments are set up in the ship with the maximum bending moment occurring around the midship section.

The load distribution will determine the direction in which the bending moment will act, and this in turn will create the state of hogging or sagging. Class nomenclature for the condition of hogging and sagging in the bending moment calculations is to go negative for sagging and positive for hogging.

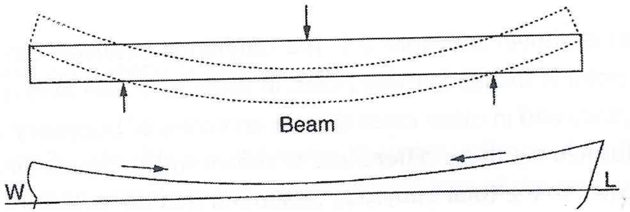
If, for example, the buoyancy amidships exceeds the weight, the ship will hog, and this may be likened to a beam supported at the centre and loaded at the ends.

As with a simply supported beam, when a ship hogs, the deck structure is in tension while the bottom plating is in compression (Figure 2.2). If the weight amidships exceeds the buoyancy, the ship will sag, which is equivalent to a beam supported at its ends and loaded at the centre.



▲ **Figure 2.2** *Hogging*

When a ship sags, the bottom shell is in tension while the deck is in compression (Figure 2.3). Students will be able to appreciate that when a hull is continuously changing between hogging and sagging, as in a rough sea, considerable cyclical stresses happen in the deck and the bottom shell plating.



Changes in bending moments also occur in a ship due to different loading conditions. This is particularly true in the case of cargoes such as iron ore which are heavy compared with the volume they occupy. When these types of cargo are loaded into a ship, especially if it is on the spot market or performing the role of a tramp ship, care must be taken to ensure a suitable distribution throughout the ship. The even distribution of stresses is calculated by using the on-board loading computer.

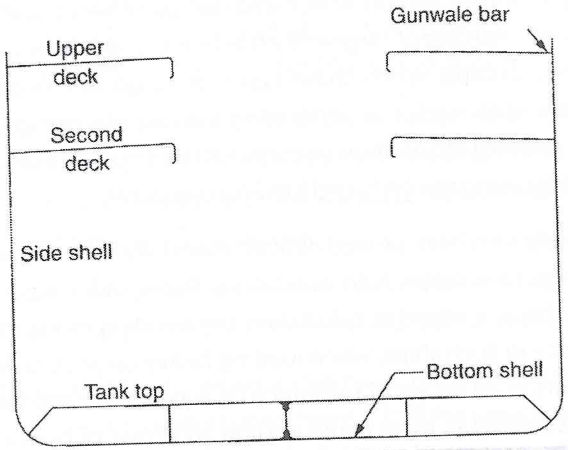
In the past these calculations have proved difficult especially if the ship has machinery space as well as deep tank/cargo hold amidships. These older vessels would also have had only a very basic method of calculating the bending moment. There would however be a tendency in such ships, when loading heavy cargoes, to leave the deep tank empty. This results in an excess of buoyancy by way of the deep tank. This action must be considered carefully as there could also be an excess of buoyancy by way of the engine room, since the machinery (especially if large two stroke engines are fitted) might be light when compared with the volume it occupies.

A ship in such a loaded condition might therefore hog considerably, creating unusually high stresses in the deck and bottom shell. This may be very dangerous and could lead to the vessel breaking in two if loaded using an incorrect sequence. If the owners intend for the ships to be regularly loaded in this manner, additional hull strength must be provided to ensure the safe operation of the vessel. In cases where there is a long transmission shaft between the main engine and the propeller, excess hogging or sagging could also lead to excessive bending of this shaft and the engineering staff would continually be checking for any overheating of the main shaft bearings.

Highly sophisticated computer tracking systems monitor the movement of containers as they are transported around the world. Therefore, container ships will have their loading and discharging sequencing calculated before the vessel reaches port. This means that the stresses and bending moments will also be calculated while the vessel is moving between ports.

The structure resisting longitudinal bending consists of all continuous longitudinal material, the portions farthest from the axis of bending (the neutral axis) being the most important (Figure 2.4). These are the *keel*, bottom shell plating, *centre girder*, side girders, tank top, tank margin, side shell, *sheerstrake*, *stringer plate*, deck plating alongside hatches and in the case of oil tankers any longitudinal bulkheads.

Buckling and/or deformation may occur at a point in the structure that is the greatest distance from the neutral axis which will become a high stress point, such as the top of a sheerstrake. Designers work to ensure that such points are avoided as far as possible,

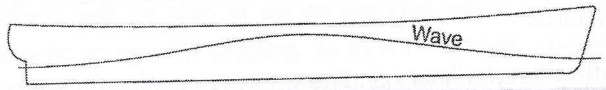


▲ **Figure 2.4** *Longitudinal material*

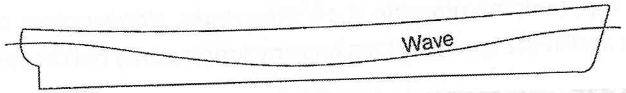
Wave bending – dynamic loading

When a ship passes through waves, alterations in the distribution of buoyancy cause alterations in the bending moment. The greatest differences occur when a ship passes through waves whose lengths from crest to crest are equal to the length of the ship thereby placing the greatest bending moment of the hull.

When the wave crest is amidships (Figure 2.5), the buoyancy amidships is increased while at the ends it is reduced. This tends to cause the ship to hog. A few seconds later the wave trough lies amidships. The buoyancy amidships is reduced while at the ends it is increased, causing the vessel to sag (Figure 2.6).



▲ **Figure 2.5** *Hogging*



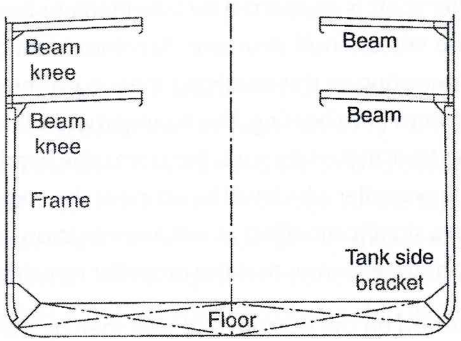
▲ **Figure 2.6** *Sagging*

has already been damaged or is corroded, then the hogging and sagging will make the weakened structure worse.

Transverse Bending and Racking

Consider the cross-section of a vessel at a point along its length (see figure 2.7). The transverse structure may be subjected to three different types of loading. These are forces:

- from the weight of the ship's structure, machinery, fuel, water and cargo;
- due to the water pressure; and
- causing longitudinal bending.



▲ **Figure 2.7** *Transverse material*

The decks must be designed to support the weight of accommodation, winches and cargo, while exposed decks may also have to withstand a tremendous weight of water that might be taken on board during heavy weather. The deck plating is connected to beams which transmit the loads to the longitudinal girders and to the side frames.

In the area of heavy local loads such as cranes and windlasses and so on, additional stiffening will be required. The shell plating and frames form pillars which support the additional weights that are situated on the deck. Tank tops are required to be strong enough to keep the cargo in place or resist the upthrust exerted by the liquid in the tanks.

In the machinery space other factors must be taken into account. Fluctuating forces the strength of the fixings means that the machinery is well supported to prevent any excess movement.

Under the position of the engine additional girders are fitted in the double bottom and the thickness of the tank top increased to ensure that the main propulsion remains fixed despite the additional stresses caused by rough weather acting upon the vessel.

Special consideration must be given to the thrust block, the propeller shaft and the propeller. Thrust to push the ship along is generated by the propeller and must be carefully transmitted to the hull of the vessel. This is a difficult process as the propeller shaft is relatively small in diameter when compared with the area of the hull.

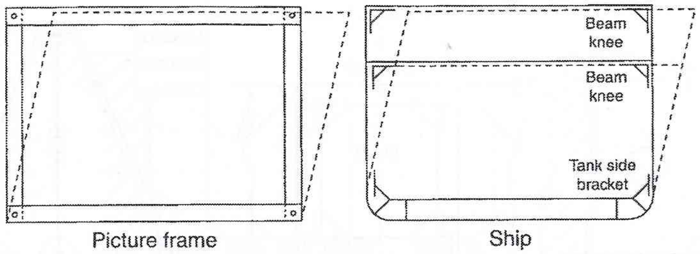
The thrust block is first in line to take the force from the propeller shaft. The important issue is for the thrust block to be connected to as large an area of the hull as possible. This will transmit the force, generated by the thrust, to the hull evenly.

The weight of the propeller shaft is supported by intermediate bearings which in turn must be supported by the vessel's hull structure. Accommodating the weight of the propeller is particularly interesting as this revolving mass is on the end of the tail shaft which is supported by the stern tube bearing. The arrangement of the stern of the vessel needs to counter the forces transmitted through the stern tube bearing. These forces will mostly be the weight of the propeller which will be acting at the end of the shaft. Any out of balance forces will have a significant effect as will any vibration caused by cavitation. These are important reasons for ensuring that the propeller remains undamaged.

A considerable force is exerted on the bottom and side shell by the water surrounding the ship and the double bottom floors and side frames are designed to withstand these forces, while the shell plating must be thick enough to prevent buckling as it spans the distance between the floors and frames.

Since water pressure increases with the depth of immersion, the load on the bottom shell plating will be greater than the load on the side shell. It follows, therefore, that the bottom shell must be thicker than the side shell to withstand the increased force. When the ship passes through waves, these forces are of a pulsating nature and may vary considerably in high waves, while in bad weather conditions the shell plating above the waterline will receive severe hammering.

When a ship rolls there is a tendency for the ship to distort transversely due to the fluctuating forces described above and in a similar way to that shown in Figure 2.8. This action is known as *racking* and is reduced or prevented by the beam knee and tank



▲ **Figure 2.8** *Racking*

The efficiency of the ship structure in withstanding longitudinal bending depends to a large extent on its girder strength and the ability of the transverse structure to prevent the buckling of the shell plating and decks.

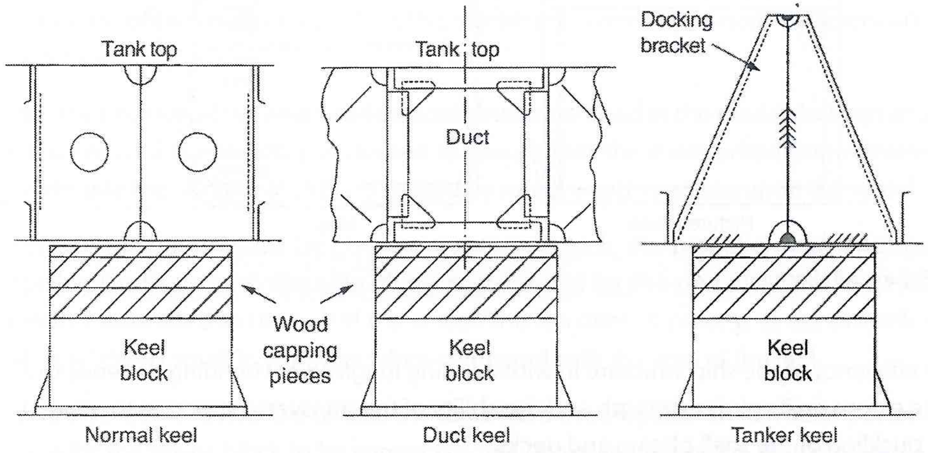
Dry-docking

A ship usually enters dry dock with a slight trim aft. Thus as the water is pumped out, the after end touches the blocks first. As more water is pumped out an upthrust is exerted by the blocks on the after end, causing the ship to change trim until the whole keel from forward to aft rests on the centre blocks. At the instant before this occurs the upthrust aft is a maximum. If the design of the ship results in this thrust being excessive, it may be necessary to strengthen the after blocks and the after end of the ship. Such a problem arises if it is necessary to dock a ship when fully loaded or when trimming severely by the stern.

As the pumping continues the load on the keel blocks is increased until the whole weight of the ship is taken by the blocks in the dry dock. The ship structure must be strong enough to withstand this unevenly distributed load. The 'docking' plan, carefully worked out before the ship arrives, ensures that the blocks are all placed in the correct position.

The strength of the hull is carefully considered during the design of the ship and there could be up to three different docking arrangements specified for each vessel. Different systems can be used on subsequent dry docks so that the spaces not examined at the last docking can be covered during the current one. It will also be obvious to students that the hull cannot be prepared and painted in the area in contact with the blocks.

In most ships the normal arrangement of keel and centre girder, together with the



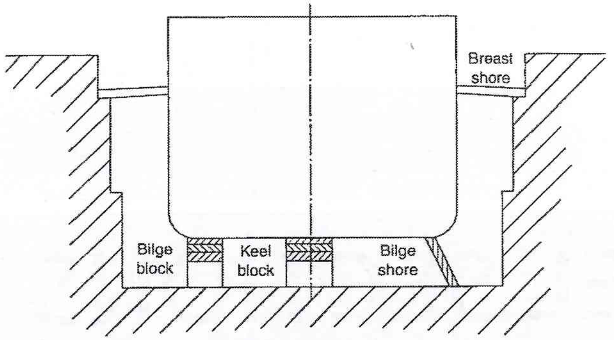
▲ **Figure 2.9** *Examples of bottom arrangements for docking*

of the keel blocks (Figure 2.9). The keel structure of a longitudinally stressed vessel such as an oil tanker, bulker or container ship is strengthened by fitting docking brackets and tying the centre girder to the adjacent longitudinal frames at intervals of about 1.5 m.

Bilge blocks or shores could be fitted to support the sides of the ship. The arrangements of the bilge blocks vary from dock to dock. In some cases they are fitted after the water is pumped out of the dock, while other dry docks may have blocks which can be slid into place while the water is still in the dock. The latter arrangement is preferable since the sides are completely supported. At the ends of the ship, where the curvature of the shell does not permit blocks to be fitted, bilge shores are used. The structure at the bilge must prevent these shores and blocks buckling the shell.

As soon as the after end touches the blocks, shores are inserted between the stern and the dock side to centralise the ship in the dock and to prevent the ship slipping off the blocks. When the ship grounds along its whole length additional shores could be fitted on both sides, holding the ship in position and preventing tipping. These shores are known as *breast shores* and have some slight effect in preventing the side shell bulging. They should preferably be placed in way of transverse bulkheads or side frames as these offer more resistance to buckling than the side placed do on their own (Figure 2.10).

When undocking the vessel care must be taken to ensure that all the ballast, fresh



▲ **Figure 2.10** *Support in dock*

Pounding

When a ship meets heavy weather and commences heaving and pitching, the rise of the fore end of the ship occasionally synchronises with the trough of a wave. The fore end then emerges from the water and re-enters with a tremendous slamming effect, known as pounding. While the event does not occur with great regularity, it may nevertheless cause damage to the bottom of the ship at the forward end. The designers must ensure that the shell plating is stiffened to prevent buckling due to the pounding. Pounding also affects the aft end section of the vessel but the effects are not nearly as great. Nevertheless provision must be made in the design of the hull to counteract the effects of pounding at the aft end.

Panting

As waves pass along the length of a ship the various parts of the vessel are subjected to varying depths of water which causes fluctuations in water pressure. This tends to create an in-and-out movement of the shell plating. The knock on effect of this is found to be greatest at the ends of the ship, particularly at the fore end, where the shell is relatively flat. Such movements are termed panting, and, if unrestricted, panting could eventually lead to fatigue of the material and must therefore be prevented as much as possible. This is achieved by the structure at the ends of the ship being stiffened to prevent any undue movement of the shell plating (see Chapter 7 for more details).

3

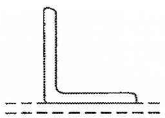
STEEL SECTIONS USED: WELDING AND MATERIALS

When iron was used in the construction of ships in preference to wood, it was found necessary to produce forms of the material suitable for connecting plates together and acting as stiffeners. These forms were called sections and were produced by passing the material through suitably shaped rollers. The development of these bars continued with the introduction of steel until many different sections were produced. These sections are used in the building of modern ships and are known as *rolled steel sections*. The most common forms are described over the next few pages.

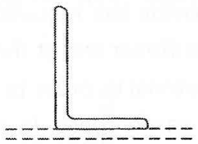
Ordinary angles

These sections may be used to join together two plates meeting at right angles or to form light stiffeners in riveted ships. Two types are employed, those having equal flanges (Figure 3.1), varying in size between 75 mm and 175 mm, and those having unequal flanges (Figure 3.2), which may be obtained in a number of sizes up to 250 mm by 100 mm, the latter type being used primarily as stiffeners.

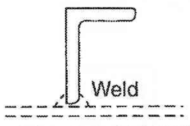
In welded ships, connecting angles are no longer required but use may be made of the unequal angles by toe-welding them to the plates, forming much more efficient



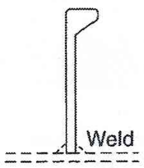
▲ **Figure 3.1** *Equal angle*



▲ **Figure 3.2** *Unequal angle*



▲ **Figure 3.3** *Toe welded angle*



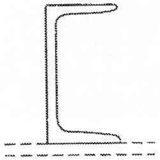
▲ **Figure 3.4** *Bulb plate*

Bulb plates

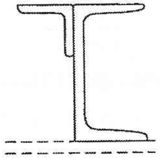
A bulb plate (Figure 3.4), having a bulb slightly heavier than the older and now unused bulb angle, has been specially developed for welded construction. A plate having a bulb on both sides has been available for many years, but its use has been severely limited due to the difficulty of attaching brackets to the web in way of the bulb. The modern section resolves this problem since the brackets may be either overlapped or butt welded to the flat portion of the bulb. Such sections are available in depths varying between 80 mm and 430 mm, being lighter than the bulb angles for equal strength. They are used for general stiffening purposes in the same way as

Channels

Channel bars (Figure 3.5) are supplied in depths varying between 160 mm and 400 mm. Channels are used for panting beams, struts, pillars and girders and heavy frames. In insulated ships it is necessary to provide the required strength of bulkheads, decks and shell with a minimum depth of stiffener and at the same time provide a flat inner surface for connecting the facing material in order to reduce the depth of insulation required and to provide maximum cargo space. In many cases, therefore, channel bars with reverse bars are used for such stiffening (Figure 3.6), reducing the depth of the members by 50 mm or 75 mm. Both the weight and the cost of this method of construction are high.



▲ **Figure 3.5** *Channel bar*



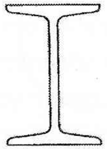
▲ **Figure 3.6** *Channel bar and reverse*

Joist or H-bars

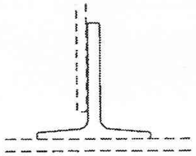
These sections have been used for many years for such items as crane rails but have relatively small flanges. The manufacturers have now produced such sections with wide flanges (Figure 3.7), which prove much more useful in ship construction. They are used for crane rails, struts and pillars, being relatively strong in all directions. In

Tee-bars

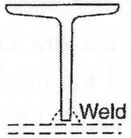
The use of the T-bar (Figure 3.8) is limited in modern ships. Occasionally they are toe-welded to bulkheads (Figure 3.9) to form heavy stiffening of small depth. Many ships have bilge keels incorporating T-bars in the connection to the shell.



▲ **Figure 3.7** *Broad flanged beam*



▲ **Figure 3.8** *Tee bar*

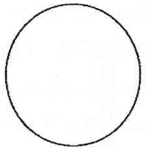


▲ **Figure 3.9** *Tee bar toe welded*

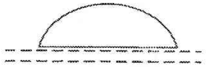
Flat bars or slabs

Flat bars are often used in ships of welded construction, particularly for light stiffening, waterways and save-alls which prevent the spread of oil. Large flat bars are used in oil tankers and bulk carriers for longitudinal stiffening where the material tends to be in tension or compression rather than subject to high bending moments. This allows for greater continuity in the vicinity of watertight or oil tight bulkheads.

Several other sections are used in ships for various reasons. Solid round bars (Figure 3.10) are used for light pillars, particularly in accommodation spaces, for welded stems and for fabricated rudders and stern frames. Half-round bars (Figure 3.11) are used for stiffening in accommodation where projections may prove dangerous (e.g. in toilets and wash places) and for protection of ropes from chafing.



▲ **Figure 3.10** *Solid round*



▲ **Figure 3.11** *Half round*

Aluminium sections

Aluminium alloys that are used in ship construction have been found to be too soft to roll successfully in section form and are therefore produced by extrusion. This method produces the different shapes by forcing the metal through a suitably shaped die. This becomes an advantage since the dies are relatively cheap to produce, allowing numerous different shapes of section to be made.

There are a few *standard sections* but the aluminium manufacturers are prepared to extrude any feasible forms of section which the shipbuilders require in reasonable quantities. Figure 3.12 shows some such sections which have been produced for use on ships built in this country.

Welding

Welding is the process of using heat to melt two separate pieces of metal and joining them together in such a way that they become one integral unit. It uses an energy source to produce the heat, such as compressed gas and/or electric currents. There are two basic types of welding: resistance or pressure welding, in which the portions of metal are brought to a welding temperature and an applied force is used to form the joint; and fusion welding, where the two parts forming the joint are raised to a melting temperature and either drawn together or joined by means of a filler wire of the same material as the adjacent members. The application of welding to shipbuilding is almost entirely restricted to fusion welding in the form of metallic arc welding, and on board the ship gas welding and cutting is also a very important and useful maintenance and repair tool.

Welding Safety

The safety of the staff on-board modern ships is obviously very important and more so as some of the activities can be potentially hazardous. Welding is one of those activities that can go very wrong and cause major problems if precautions are not taken by knowledgeable staff.

Any proposed work must be discussed at the safety brief and the necessary 'permit to work' must also be issued. The ship's safety management system is also available to guide staff on the specific company procedures necessary.

General

The most obvious hazard, which is common across the different welding techniques, is due to heat and sparks. Students will be able to see that these have the ability to start a fire if action is not taken to guard against them.

It is fairly obvious that all combustible material must be removed from the area surrounding the 'hot work' and fire extinguishing equipment kept ready nearby. However, it is less obvious to check the other side of metal bulkheads and deck heads especially if welding is being undertaken close to one of these features. Fires have also

People also become complacent about wearing protective clothing; however, when welding, at all times, protective clothing is important. In this case protection is needed against the heat causing burns, which means protective gloves and possibly additional heat resistant clothing over ordinary work clothes.

The welding process gives off fumes, and the composition of the fumes depends upon the method of welding taking place, the filler rods being used and the composition of the metals being welded. Nitrous oxide, for example, is one of the main gases present in welding fumes.

The important rule for any welding is to complete the process in a well ventilated area. If this is not possible, such as inside a small tank, then the welder must be provided with suitable fresh air breathing equipment.

The welding equipment keeps out oxygen as much as possible by surrounding the melting metal with a form of protective coating. When the welded metals are cooling the protection forms a hard, brittle outer shell. When this shell, called slag, is removed, using a chipping hammer, there is a possible danger of sharp pieces flying towards the eyes and causing harm if they are unprotected. The eye protection for this task involves using 'clear' goggles as opposed to the darkened glasses that are used for the actual welding.

Manual metal arc welding (electric arc welding)

The ultra-violet light given off by the manual metal arc (MMA) welding process is much more intense than with the gas welding process, and therefore it is vital to use the correct standard of darkened glass in the welding mask. It is also very important to check that the eye protection is in good condition, with no damage, carries the correct international quality standard and its use is understood by the person undertaking the welding. It's important to remember that not only is the welder vulnerable to eye damage from arc welding, but people passing by are also susceptible if they happen to look at the electrode just as the welder strikes an arc.

Electric shock is also a danger when using arc welding equipment. It is important that the equipment and surrounding areas be kept dry.

The wires connections and equipment must be checked for damage before any

Gas welding – eyes

As with electric arc welding, eye protection is extremely important in both gas welding and cutting. The problem is that there is always the temptation to discard the use of goggles when using the gas equipment thinking that the light given off from the gas welding process can be viewed with the naked eye. This is *not* the case and eyesight damage is bound to happen with prolonged exposure to the gas welding process.

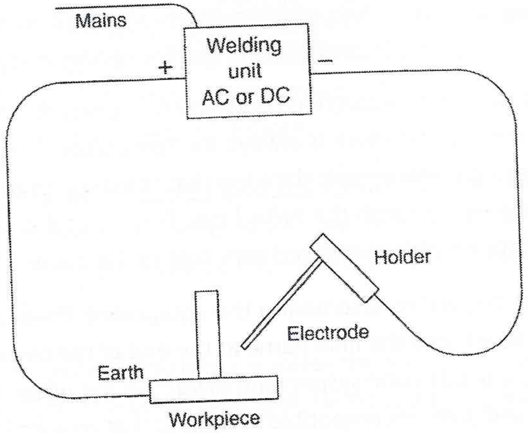
Careful attention must be paid to assembling the equipment. There are *two* separate systems that are kept apart until the final flame at the end of the torch. A combustible gas, usually acetylene, is used in one system and oxygen in the other. The two systems are *both* colour coded and given incompatible fittings, so that an acetylene hose cannot be used on an oxygen fitting. Hoses, connections and equipment must be checked for damage before use. The thread on the connections are arranged to couple up in different directions. The oxygen has a conventional 'right' handed system while the combustible gas has the less common 'left' handed thread system. Care must be taken not to force the nut from one system onto the fitting of another. If by some outside chance and by using considerable force this was accomplished, the threads will be stripped off and leakage will occur.

Welding Processes

Manual metal arc welding

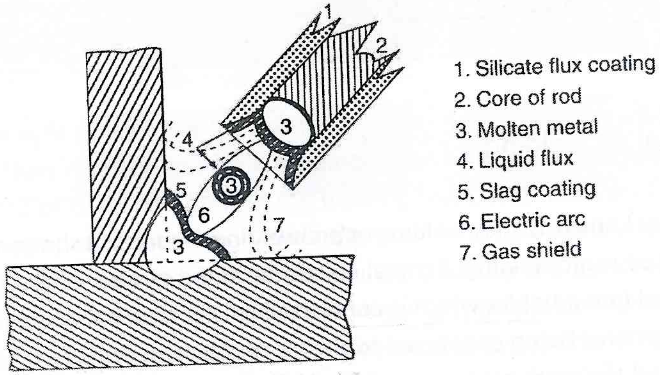
This is sometimes known as 'stick' welding or 'arc' welding. Figure 3.13 shows a simplified circuit that is used in arc welding. A metal electrode, of the same material as the work piece, is clamped into a holder which is connected to one terminal of a welding unit, the opposing terminal being connected to the work piece. An arc is formed between the electrode and the work piece or metal to be welded close to the position of the joint. The arc between the two metals to be joined, completing the circuit, creates a very high temperature which melts the two parts of the joint and the electrode. Metal particles from the electrode then transfer to the work piece, forming the weld.

The arc and the molten metal must be protected from the atmosphere to prevent



▲ **Figure 3.13** *Welding circuit*

carried with the metal particles to form a slag over the molten metal, while at the same time an inert gas is formed which creates a shield over the arc (Figure 3.14). When the weld and the parent metal have cooled, the slag is removed from over the weld by chipping with a special hammer. Care must be taken as the slag is brittle and can fly off in unexpected directions.



▲ **Figure 3.14** *Weld arc*

The MMA equipment can be one of three different types. The first, and least used, type is the equipment that uses alternating current (AC) and the welding current. This … causing cramps and heart failure in some

The DC machines can be connected with the electrode on the positive or the negative side of the circuit. Connecting to the rod on the negative side gives a deeper, more penetrating arc where the majority of the heat will be concentrated in the material being welded. While connecting the electrode to the positive side retains the heat in the electrode which means that the metal in the electrode will burn off quicker giving a higher build-up of weld material nearer the surface of the weld. This feature makes the connection to the negative side more suited to 'root' welds and connection to the positive side more suitable for 'covering' welds.

Tungsten inert gas (TIG) and metal inert gas (MIG) (sometimes referred to as argon arc welding)

It is found that with some metals, such as aluminium alloys, coated electrodes do not work very well. The coatings cause the aluminium to corrode and, being heavier than the aluminium, slag remains trapped in the weld. It is nevertheless necessary to protect the arc and in such cases an inert gas such as argon may be used for this purpose. Modern equipment uses tungsten rods and argon arc or metal wire welding in each case argon is passed through a tube, down the centre of which is the tungsten electrode. An arc is formed between the work piece and the electrode while the argon forms a shield around the arc. A separate filler wire of suitable material is used to form the joint. The tungsten electrode may be water cooled. This system of welding may be used for most metals and alloys, although care must be taken when welding aluminium as an AC machine may be required. TIG welding is used for welding metals such as aluminium/brass (Yorcalbro), stainless steels and acid resistant steels.

Techniques – to master the art of electric welding a person must practice, practice, practice. However it might be useful to think about some preparation beforehand.

Striking an arc – it may seem obvious but once the welder puts the welding mask in front of his/her face they cannot see the work area until the arc is alight. Therefore there is very much an element of hand/eye co-ordination coupled with judgement and knowledge which come together to form a mental picture that bridges the gap between being able to see the work with no mask in the way and seeing the weld progress while using the mask.

It is easiest to start with a flat work piece and looking down on the weld. The welder will learn the basic welding process before trying to weld a vertical or overhead weld which

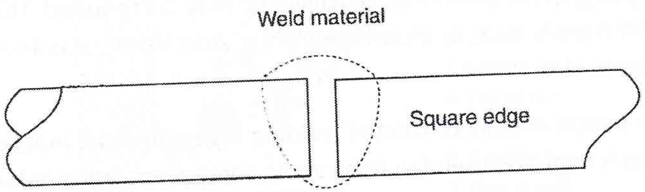
As the welding progresses the tip of the welding rod must be held in such a way as to keep a constant gap between it and the work piece. However the rod is melting away; therefore, with the MMA and the TIG welding, the welder must continually adjust the position by moving the holder closer to the work as the length of the welding stick reduces.

With the MIG or wire feed welding the filler material is pushed through the holder and the welder does not have to adjust his/her position relative to the work. In both cases a neat consistent weld is produced only if the speed at progressing the weld is correct.

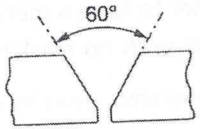
The angle at which the rod is held relative to the work is also important. If the angle is not correct then the heat going to the work piece will be uneven and may cut into the parent metal in a way that is not correct for the current weld to maintain strength.

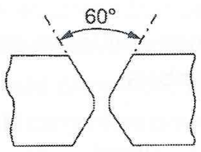
Types of joint and edge preparation

The most efficient method of joining two plates which lie in the same plane is by means of a butt weld, since the two plates then become one continuous section. A square-edge butt (Figure 3.15) may be used for plates up to about 5/6 mm thick. Above this thickness, however, it is difficult to obtain sufficient penetration and it becomes necessary to use a single vee (5–24 mm) (Figure 3.16) or a double vee butt weld (10–30 mm) (Figure 3.17).



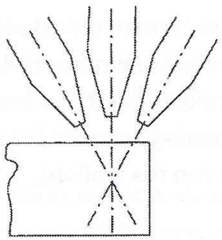
▲ **Figure 3.15** *Square edge*





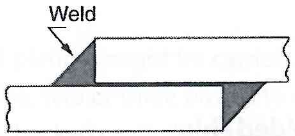
▲ **Figure 3.17** *Double vee*

The double vee welds are more economical as far as the volume of weld metal is concerned, but may require more of the difficult overhead welding and are therefore used only for large thicknesses of plating. The edge preparations for all these joints may be obtained by means of grinding or profile gas or plasma cutting torches having three nozzle burning heads which may be adjusted to suit the required angle of the joint (Figure 3.18).



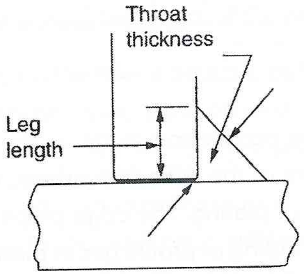
▲ **Figure 3.18** *Cutting heads*

Overlap joints (Figure 3.19) may be used in place of butt welds, but are not as efficient since they do not allow complete penetration of the material and transmit a bending moment to the weld metal. Such joints are used in practice, particularly when connecting brackets to adjacent members. Where these type of joints are allowed the overlap should be more than four time the thickness of the parent metal.



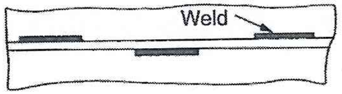
▲ **Figure 3.19** *Overlap*

Fillet welds (Figure 3.20) are used when two members meet at right angles. The strength member or may be intermittent. Continuous welds are used when the joint must be watertight and for other strength members.

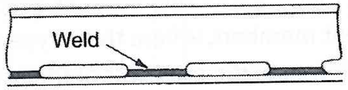


▲ **Figure 3.20** *Fillet weld*

Stiffeners, frames and beams may be connected to the shell plating by intermittent welding (Figure 3.21). In tanks, however, where the rate of corrosion is high, such joints may not be used and it is then necessary to employ continuous welding or to scallop the section (Figure 3.22). The latter method has the advantage of reducing the weight of the structure and improving the drainage, although a combination of corrosion and erosion may reduce the section between the scallops.



▲ **Figure 3.21** *Intermittent welding*



▲ **Figure 3.22** *Scalloped stiffener*

The development of the welded ship

Originally iron and steel ships were put together by overlapping the plating and fixing them with rivets and the very first welded ships followed this technique but used

The initial change came as the welded construction was much lighter than the equivalent riveted construction, due mainly to the reduction in overlaps and flanges. This meant that a welded ship could carry more cargo for the same loaded draught and warships were faster and could carry more powerful weapons. Welding, if properly carried out, is always watertight without caulking the joints, while in service riveted joints may also be prone to leaks.

With the reduction in overlaps, the outside structure of the ship is also much smoother. This leads to a reduction in hull resistance and coupled with modern hull coatings, gives far better fuel consumption. The smoother surface is easier to clean and less susceptible to corrosion. This has become an important point as the focus on vessels becoming more environmentally friendly has become more acute.

A faulty weld could still, in a modern ship, prove to be dangerous as the structure does not have the 'natural' crack arresting characteristic of the old riveted vessels. However the up to date quality assurance processes and construction techniques mean that poor welding is not a major issue and where it might happen the quality assurance process will ensure that cracked ships do not enter service without repair. Designers, shipbuilders and surveyors are also knowledgeable about 'stress raisers' and the other causes of cracks which again means that any defect can be found at an early stage.

The methods of testing welded joints are now successful and much cheaper to carry out than in the past. If a crack starts in a plate it will, under stress, pass through the plate until it reaches the edge. However in the case of the welded ship it could then also carry on and pass through the weld which if left unchecked could prove to be dangerous.

The modern answer to cracking, as in the hulls of older designs, lies in the quality of the design and building of modern ships. The classification societies take the responsibility for the designs of the hull. They specify the standard of the base metal as well as the method and standard of the welds. By taking and testing to destruction test pieces the science behind the welding techniques can be verified. It is then a matter of ensuring that the welders are able to reproduce the required structure consistently to the required design.

Long welds, such as with hull plating, might be carried out using automated welding machines. These may make one, two or three passes to complete the joint. Where this is the case the welds must be checked carefully. This can be completed using ultrasonic non-destructive testing techniques.

It is very important to start with good quality base metals. The International Association of Classification Societies (IACS) gives details of four grades of 'normal' strength steels manganese steel plates; however in particularly vulnerable areas, such as cargo oil tanks, the International Maritime Organization (IMO) requires that corrosion resistant steels are used. Shipbuilding steel also follows the 'killed steel' process of manufacture. This process removes oxygen from the mix to reduce the porosity of the final product. (See page 61 for more about the chemistry of steel.)

There are still some old vessels that have their hull made of the 'riveted' design. However these are more and more confined to 'historic' ships and some vessels sailing the Great Lakes. In the early welded vessels, surveyors may see a number of longitudinal *crack arrestors* in the main hull structure to reduce the effects of transverse cracks. These crack arrestors may be in the form of riveted seams or strakes of *extra notch tough* steel through which a crack will not pass.

Modern welded designs take great care to reduce the possibility of any cracks forming. This is accomplished by rounding the corners of openings in the structure and by avoiding other stress raising features such as

- the sudden changes in section;
- position and design shape of drainage holes; and
- termination or joining of structural members.

It must be clearly understood, however, that if the cracks appear due to the inherent weakness of the ship, that is, if the bending moment creates unduly high stresses, the crack will pass through the plates whether the ship is riveted, welded or a combination of both.

Cold conditions will have an effect on the steel and classification societies place a minimum performance standard of the specification of the steel used in shipbuilding.

The main structure of a ship can initially be viewed as a large box section or girder. That box section must be fabricated to the dimensions required by the owners to carry the specified cargos over the required route.

The parts of the structure contributing to the strength calculation of this box section are:

- shell side and bottom plating;
- longitudinal stiffeners and bulkheads;
- deck plating, longitudinals and large hatch coamings;
- inner plating, including any double hull or double bottom constructions; and

The strength of the vessel's hull will also depend upon the thickness and type of steel used in its construction. There will also be a consideration for the proposed lifetime of the vessel. Corrosion will, of course, happen to the vessel while it is in service, and the designer will have to factor this into the strength calculations for the vessel under construction.

High strength steel may have to be used at positions in the design of high stress concentrations. These could be around the construction of hatches or to reduce the high stresses caused by engines, propellers or rough weather (pounding).

Support structures for modern ships have also changed in recent years. The early welded ships required that the ship's senior staff ensure that their vessel was not overstressed at any time during loading, sailing and discharging.

To assist with this the ship had on board an instrument often referred to as a 'loading computer'. This assisted the staff to understand the stresses and stability for a given set of cargos. As the vessel was out of contact with shore based support it was the responsibility of the on-board crew to assess the stresses involved.

The structural design of modern ships is such that more sophisticated and accurate methods are required to calculate the loaded stress on a ship before it sets sail. The information required for the senior staff to calculate safe operation comes from the loading manual or the loading computer.

This manual or computer will calculate the still water bending moments and shear forces due to the loads imposed on the ship by the cargo being loaded. This may also relate to the sequencing of loading as ships have been known to fail due to, for example, heavy loads being taken on-board fore and aft with nothing in the middle. This has led to bending the hull beyond its construction capabilities leading to the failure.

The loading computers will also be able to give details of the ship's ballast sailing condition and the condition ready for docking. The most modern systems will be able to give 'what if' predictions to help the staff to see what would happen if an area became flooded.

Testing of welds

The testing of weld joints can be divided into two basic types that are fundamentally different. These are:

Destructive tests

Specimens of the weld material or welded joint are tested until failure occurs to determine their maximum strength or other characteristics. The tests are standard tests and are the same as those generally used for metals:

1. A tensile test in which the mean tensile strength must be at least 400 MN/m^2
2. A bend test in which the specimen must be bent through an angle of 90° with an internal radius of 4 times the thickness of the specimen, without cracking at the edges.
3. An impact test in which the specimen must absorb at least 47 J at different temperatures (e.g. –20°C, –10°C, 0°C, +10°C and +20°C). Known as the 'notchy test' it showed up the transition from a ductile to a more brittle state that occurs in steel with a lowering of temperature.
4. Deep penetration electrodes must show the extent of penetration by cutting through a welded section and etching the outline of the weld by means of dilute hydrochloric acid. This test may be carried out on any form of welded joint.

Types of electrode, plates and joints may be tested at regular intervals to ensure that they are maintained at the required standard, while new materials may be checked before being issued or general use. The destructive testing of production work is very useful but limited since it simply determines the strength of the joint before it was destroyed by the removal of the test piece.

Non-destructive tests

An NDT is one of those very useful tools that has seen substantial development over the past few decades.

They usually start with a visual inspection of welded joints which is most important in order to ensure that there are no obvious surface faults, such as cracks and undercut, and to check the leg length and throat thickness of fillet welds. Designers must be careful to ensure that where welds can be completed, there is also sufficient room for them to be visually inspected.

The internal weld structure is now tested with ultrasonic testing techniques. This is an NDT that uses short wavelength sound waves that travel through the metal. (see page 57). The pulsed beams penetrate the metal weld, but if any faults are detected then the waves are disrupted. The changes in the sound are detected and the results

Surface cracks which are too fine to be seen even with the aid of a magnifying glass may be outlined using a fluorescent penetrant that enters the crack and may be readily seen with the help of ultra-violet light.

Faults at or near the surface of a weld may be revealed by means of *magnetic crack detection*. An oil containing particles of iron is poured over the weld and then a light electric current is passed through the weld. At the position of any surface faults a magnetic field will be set up which will create an accumulation of the iron particles. Since the remainder of the iron stays in the oil which runs off, it is easy to see where such faults occur.

A more modern system which is being steadily established is the use of *ultrasonics*. A high frequency electric current causes a quartz crystal to vibrate at a high pitch. The vibrations are transmitted directly through the material being tested. If the material is homogeneous, the vibration is reflected from the opposite surface, converted to an electrical impulse and indicated on an oscilloscope. Any fault in the material, no matter how small, will cause an intermediate reflection which may be noted on the screen. This method is useful in that it will indicate a lamination in a plate which will not be shown on the older X-ray method of testing. Ultrasonics are now also being used to determine the thickness of plating in repair work and to avoid the necessity of drilling through the plate.

The rules of IACS state that any person carrying out a visual inspection must have sufficient knowledge and experience and any person undertaking magnetic particle testing or liquid penetrant testing must be qualified to the IACS standards. Such persons will also have certification to prove their qualifications.

IACS gives further information about the rules for testing and repair of crankshafts, propeller shafts and rudder stocks.

Magnetic particle inspection works on the principle that a defect in the metal, which could be below the surface of the metal, causes a distortion in a magnetic flux at the point of the defect. The distortion of the magnetic flux is disproportionately large and extends to the surface of the metal. This leakage of magnetic flux can then be used to attract coloured iron particles suspended in a solution.

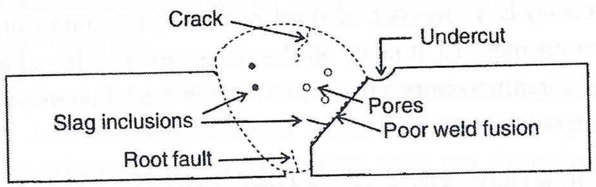
Liquid penetrant testing is a low-cost method of testing for cracks that break the surface of a non-porous material. It relies on the penetrating ability of a low surface tension fluid such as paraffin to carry a dye into a surface crack that may not be visible under normal circumstances.

Ultrasonic testing is now commonly associated with discussions about NDT. However, the added advantage of being open to a high degree of automation and, therefore, slightly less training is needed to carry out the tests successfully. It also lends itself well to testing for welding defects

Faults in welded joints (Figure 3.23)

Electric welding, using correct technique, suitable materials and conditions, should produce faultless welds. Should these requirements not be met, however, faults will occur in the joint. If the current is too high, the edge of the plate may be burned away. This is known as *undercut* and has the effect of reducing the thickness of the plate at that point. It is important to chip off all of the slag, particularly in multi-run welds, otherwise *slag inclusions* occur in the joint, again reducing the effective thickness of the weld. The type of rod and the edge preparation must be suitable to ensure *complete penetration* of the joint. In many cases a good surface appearance hides the lack of fusion beneath, and, since this fault may be continuous in the weld, could prove very dangerous. Incorrect welding technique sometimes causes bubbles of air to be trapped in the weld. These bubbles tend to force their way to the surface leaving *pipes* in the weld. Smaller bubbles in greater quantities are known as *porosity. Cracks* on or below the surface may occur due to unequal cooling rates or an accumulation of weld metal. The rate of cooling is also the cause of distortion in the plates, much of which may be reduced by correct welding procedure.

Another fault which is attributed to welding but which may occur in any thick plate, especially at extremely low temperatures, is *brittle fracture*. Several serious failures occurred during and just after World War II, when large quantities of welded work were produced. Cracks may start at relatively small faults and suddenly pass through the plating at comparatively small stresses. It is important to ensure that no faults or discontinuities occur, particularly in way of important structural members. The grade of steel used must be suitable for welding, with careful control of the manganese/carbon content in the greater thicknesses to ensure notch-tough qualities.

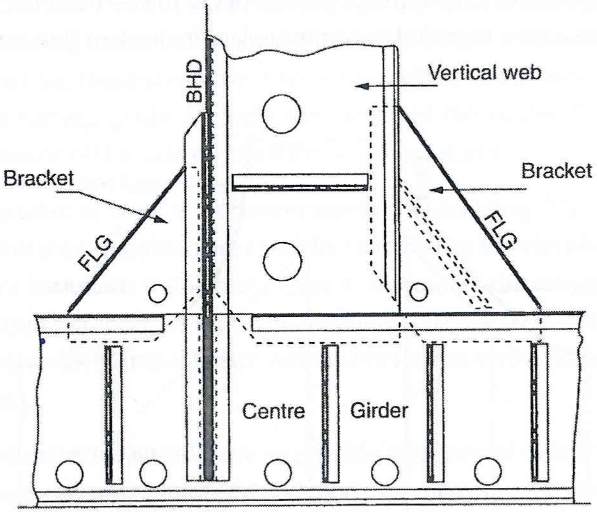


Design of welded structures

It was very quickly realised that welding is different from riveting not only as a process, but as a method of attachment. It is not correct to just update a riveted structure by welding it, and indeed the whole shipyard had to change to accommodate the new methods.

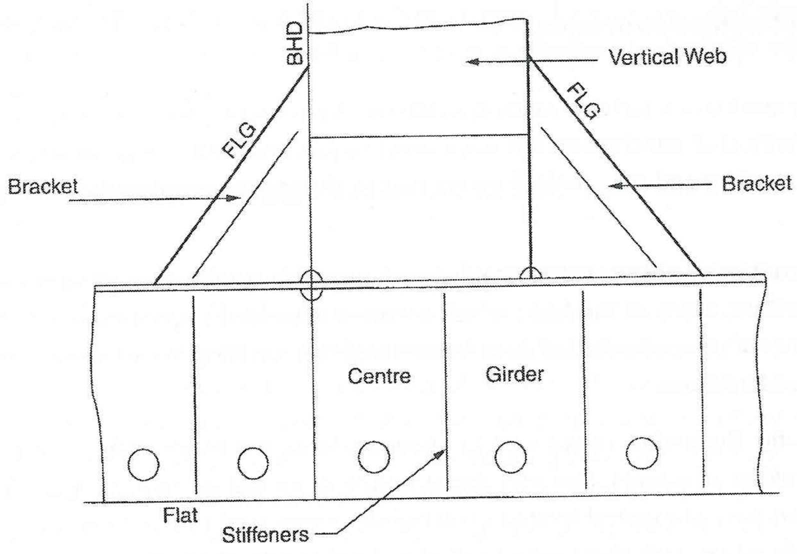
A greater continuity of material is obtained with a welded structure resulting in more efficient designs. Many of the faults which occurred in welded ships were due to the large number of components that were welded together resulting in high stress points which caused fractures.

The following illustration serves well to show students the major differences with modern welded structures. Consider the structure of an old oil tanker. Figure 3.24 which shows part of a typical 'riveted' centre girder, connected to a vertical bulkhead web. Initially when such ships were built of welded construction, the same type of design was used with the riveting being replaced by welding, resulting in the type of structure shown in Figure 3.25. Note that the 'overlap' to accommodate the rivets has been removed under the new process.



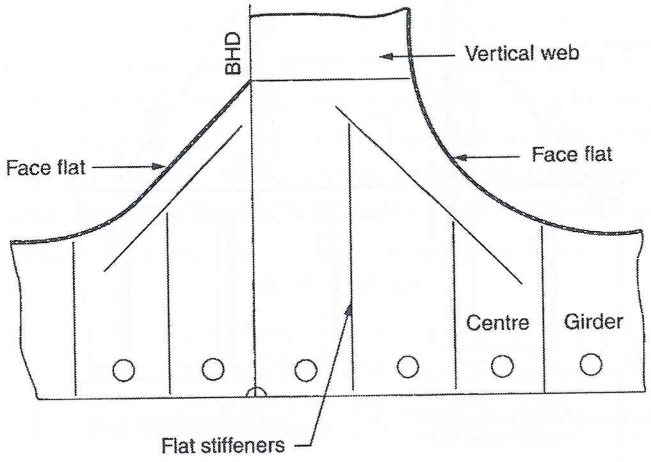
▲ **Figure 3.24** *Structure of old Oil Tanker*

However it was found with such designs that cracks occurred at the toes of the brackets



▲ **Figure 3.25** *A more recent example*

the curvature was too small. The radii were increased until eventually the whole bracket was formed by a large radius joining the bottom girder to the vertical web (Figure 3.26). This type of structure is now regarded as commonplace in modern ship tanker designs.



▲ **Figure 3.26** *Modified to remove stress raisers*

Great care must be taken to ensure that structural members on opposite sides of bulkheads are perfectly in line, otherwise cracks may occur in the plating due to shearing.

Welded structures are shown in the succeeding chapters dealing with modern ship construction.

Materials

Mild steel

Mild steel or low carbon steel in several grades has been used as a structural material for shipbuilding for over a century. It has the advantage of having a good, cost effective, strength–weight ratio. It is used in the construction of all types of ships especially for the construction of the hull. Some types such as superyachts do use alternative materials such as glass reinforced plastic (GRP).

Steel is the basic combination of iron and carbon. Mild steel contains up to about 0.25% carbon. Medium carbon steels have about 0.25–0.45% carbon and high carbon steel has between 0.45% and 1.50%. Cast iron has a carbon content of between 2.5% and 4.5%. With shipbuilding steels the oxygen is removed before solidification by adding manganese to the mix. These steels are then termed 'killed' steels. With the permission of a classification society, grade 'A' steel used can be of the 'rimmed' variety which is where a small amount of the oxygen is left in the chemical mix.

There are four grades of steel in common use in shipbuilding. The manufacturing process and chemical composition are carefully specified by the classification societies and the steels are known as IACS steels. Class also requires the results of tests to be included in any 'approval' process for the manufacturer. These tests will include tensile tests, Charpy V-notch (CVN) impact tests, weldability tests as well as tests carried out on welded specimens.

Approved manufacturers will also have to provide evidence of how they certify their steel plate for chemical composition, deoxidation, fine grain and thickness tolerance as well as any heat treatment carried out on the metal.

The steels are grades A, B, D and E, and they vary in their chemical composition and therefore in their strength and degree of CVN toughness. Grade A has the least

The disposition of the grades in any ship depends upon the thickness of the material, the part of the ship under consideration and the stress to which it may be subject. For example, the bottom shell plating of a ship within the midship portion of the ship will have the following grade requirements.

Plate thickness	Grade of steel
Up to 20.5 mm	A
20.5–25.5 mm	B
25.5–40 mm	D
Above 40 mm	E

The normal strength steel (A–E) has a 'yield strength' of 235 MN/m^2 and the tensile strength of the different grades remains constant at between 400 MN/m^2 and 520 MN/m^2. The difference lies in the chemical composition which improves the impact strength of D and E steels. Impact resistance is measured by means of a Charpy test in which specimens may be tested at a variety of temperatures. The following table shows the minimum values required by Lloyd's Register.

Type of steel	Temperature	Impact resistance
B	0°C	27 joules
D	0°C	47 joules
E	-40°C	27 joules

Higher tensile steels

As oil tankers, bulk carriers and now container ships increased in size the thickness of steel required for the main longitudinal strength members also increased. In an attempt to reduce the thickness of material and thereby reduce the light displacement of the ship, classification societies accept the use of steels of higher tensile strength. These steels are designated AH, BH, DH and EH and may be used to replace the normal

The yield strength of the higher grade steel is between 315 MN/m^2 and 390 MN/m^2 with the tensile strength being increased to between 490 MN/m^2 and 620 MN/m^2 and having the same percentage elongation as the low carbon steel. Thus it is possible to form a structure combining low carbon steel with the more expensive, but thinner higher tensile steel. The latter is used where it is most effective, that is, for upper deck plating and longitudinals, and bottom shell plating and longitudinals.

Care must be taken in the design to ensure that the hull has an acceptable standard of stiffness, otherwise the deflection of the ship may become excessive. Welding must be carried out using low hydrogen electrodes, together with a degree of preheating. Subsequent repairs must be carried out using the same type of steel and electrodes. It is a considerable advantage if the ship carries spare electrodes, while a plan of the ship should be available showing the extent of the material together with its specification.

Arctic D steel

If part of the structure of a ship is liable to be subject to particularly low temperatures, then the normal grades of steel are not suitable. A special type of steel, known as Arctic D, has been developed for this purpose. It has a higher tensile strength than normal mild steel, but its most important quality is its ability to absorb a minimum of 40 J at -55°C in a Charpy impact test using a standard specimen.

Aluminium alloys

Pure aluminium is too soft for use as a structural material and must be alloyed to provide sufficient strength in relation to the mass of material used. The aluminium is combined with copper, magnesium, silicon, iron, manganese, zinc, chromium and titanium, the manganese content varying between about 1% and 5% depending upon the alloy. The alloy must have a tensile strength of 260 MN/m^2 compared with 400–490 MN/m^2 for mild steel.

There are two major types of alloy used in shipbuilding, heat-treatable and non-heat-treatable. The former is heat-treated during manufacture and, if it is subsequently heat-treated, tends to lose its strength. Non-heat-treatable alloys may be readily welded and subject to controlled heat treatment while being worked.

The advantages of aluminium alloy in ship construction lie in the reduction in weight of hence increase the available deadweight or reduce the power required for any given deadweight and speed. Unfortunately, the melting point of the alloy (about 600°C) lies well below the requirements of a standard fire test maximum temperature (927°C). Thus if it is to be used for fire subdivisions it must be suitably insulated.

The major application of aluminium alloys as a shipbuilding material is in the construction of passenger ships, where the superstructure may be built wholly of the alloy. The saving in weight at the top of the ship reduces the necessity to carry permanent ballast to maintain adequate stability. The double saving results in an economical justification for the use of the material. Great care must be taken when attaching the aluminium superstructure to the steel deck of the main hull structure (see Chapter 12).

Other applications in passenger ships have been for cabin furniture, lifeboats and funnels.

One tremendous advantage of aluminium alloy is its ability to accept impact loads at extremely low temperatures. Thus it is an eminently suitable material for main tank structure in low-temperature gas carriers.

The fracturing of steel structures

When welding was first introduced into shipbuilding on an extensive scale, several structural failures occurred. Cracks were found in ships which were not highly stressed, indeed in some cases the estimated stress was particularly low. On investigation it was found that the cracks were of a brittle nature, indicated by the crystalline appearance of the failed material. Further studies indicated that similar types of fault had occurred in riveted ships although their consequences were not nearly as serious as with welded vessels.

Series of tests indicated that the failures were caused by brittle fracture of the material. In some cases it was apparent that the crack was initiated from a notch in the plate: a square corner on an opening or a fault in the welding. (In 1888 Lloyd's Register pointed out the dangers of square corners on openings.) At other times cracks appeared suddenly at low temperatures while the stresses were particularly low and no structural notches appeared in the area. Some cracks occurred in the vicinity of a weld and were attributed to the change in the composition of the steel due to welding. Excessive impact loading also created cracks with a crystalline appearance. Explosions near the

The consequences of brittle fracture may be reduced by fitting crack arrestors to the ship where high stresses are likely to occur. Riveted seams or strakes of extra notch tough steel used to be fitted in the decks and shell of large tankers and bulk carriers.

In modern vessels the problem of brittle fracture may be reduced or avoided by designing the structure so that notches in plating do not occur, and by using steel which has a reasonable degree of notch-toughness. Grades D and E steel lie in this category and have proved very successful in service for the main structure of ships where the plates are more than about 12 mm thick.

Much more is now known about the stresses that are set up in different parts of a ship's structure. Great care is taken over getting constructional details correct. Care must be taken with the quality of the welding. Sharp corners act to raise the stress levels within the surrounding steel plate. Changing from one framing system to the other is not straightforward.

Composites

Composite materials are materials that have been built up in different ways to form the structure required. Different combinations have different properties. The quality of the finished product is very much dependent upon the care, expertise and experience of the manufacturer. Normally the term refers to glass reinforced fibre polymers (GRP) or to carbon reinforced fibre polymers (CRP) or Kevlar.

The main advantage of composite materials is their strength-to-weight ratio which can be many times higher than steel. In the marine environment especially another potential advantage is that they are non-corrosive and therefore not affected by sea water. One of the areas where composites have impacted upon the most is with the hull of superyachts.

Composite materials are not however a wonder cure to be used in every eventuality. Engineering materials have strengths and weaknesses and composite materials are no exception. They may be brittle under some conditions and may not show the same characteristics when force is applied in different directions.

Composites can also become porous, and osmosis is sometimes a problem with GRP hulls. Manufacturing defects can also cause structural weaknesses. Within the marine field composites are gaining popularity for the construction of pipework within machinery spaces.

4

BOTTOM AND SIDE FRAMING

Double Bottom

Ocean-going ships, with the exception of tankers which now have to be double hulled, and most coastal vessels are fitted with a double bottom system of construction which extends from the fore peak bulkhead almost to the after peak bulkhead.

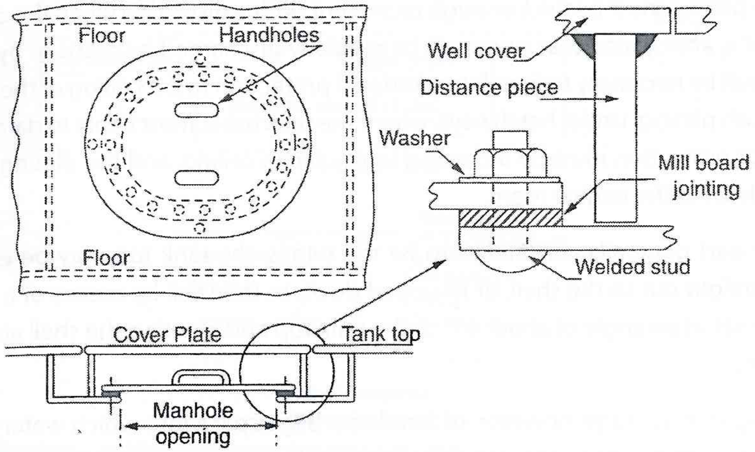
The double bottom consists of the outer shell and an inner skin or tank top between 1 m and 1.5 m above the keel. This provides a form of protection in the event of damage to the bottom shell, and it also provides protection to the environment from any oil or contaminants that may be in the bilges at the time of a breach of the hull. However, fuel and lubrication oil is currently permitted to be stored in 'double bottom' tanks.

The tank top, being continuous, contributes to the hull girder strength. From 1997 additional support was required for the platforms around the cargo and machinery areas. These added strength items are called 'solid floors' and are thicker than the normal double bottom plating.

Additional strength may also be required for high powered engines or gearboxes and thrust blocks bolted directly to the bottom plating will need to be fixed to plating of at least 19 mm thickness.

Designers must also indicate on their plans exactly how the docking loads are to be accommodated. Additional brackets or high strength material might have to be used

The double bottom space contains a considerable amount of scantlings and is therefore unsuitable for carrying much cargo. Where the regulations allow, double bottom tanks may be used for the carriage of oil fuel, fresh water and water ballast. They are subdivided longitudinally and transversely to reduce any free surface effect.



▲ **Figure 4.1** *Well-type manhole*

Double bottom tanks can be filled or emptied with the different liquids that are required to be carried, and they can also be used to correct the heel of a ship or to change the trim. Access to these tanks is arranged in the form of manholes with watertight covers (Figure 4.1) and care must be taken when entering these tanks as they are dangerous spaces and could have an oxygen depleted or poisonous atmosphere.

In the majority of ships only one watertight longitudinal division, a centre girder, is fitted, but many modern ships are designed with either three or four tanks across the ship.

During the 1970s and 1980s designers started to produce roll-on roll-off car ferries and cargo ships. The problem was that the main ro-ro deck was continuous from bow to stern and had large doors at either end. Everyone on board knew that only a very shallow depth of water across that main deck would be sufficient to capsize the vessel. Following a major disaster, where that actually happened, the rules were changed and watertight divisions were included in the design of these vessels to reduce the 'free surface effect' in the event of any water making its way onto the main deck.

A cofferdam must be fitted between a fuel tank and a fresh water tank to prevent they overflow. Since the overflow pipe usually extends above the weather deck, the tank top is subject to a tremendous head which in most cases will be sufficient as a test for water tightness and will be greater than the weight of the cargo pressing down from the hold.

The tank top plating must be thick enough to prevent undue distortion when the cargo is loaded. If it is anticipated that cargo will be regularly discharged by grabs or by fork lift trucks, it will be necessary to fit either additional protection to the ceiling of the tank or heavier flush plating. Under hatchways, where the tank top is most liable to damage, the plating or protection must be increased to the tank's ceiling, and the plating is at least 10% thicker in the engine room.

In the lower part generally considered to be the bilges, the tank top may be either continued straight out to the shell, or knuckled down to the shell by means of a tank margin plate set at an angle of about 45° to the tank top and meeting the shell almost at right angles.

It has the added advantage, however, of forming a bilge space into which water may drain and proves to be most popular. If no margin plate is fitted it is necessary to fit drain hats or wells in the after end of the tank top in each compartment so that the bilges can be pumped dry.

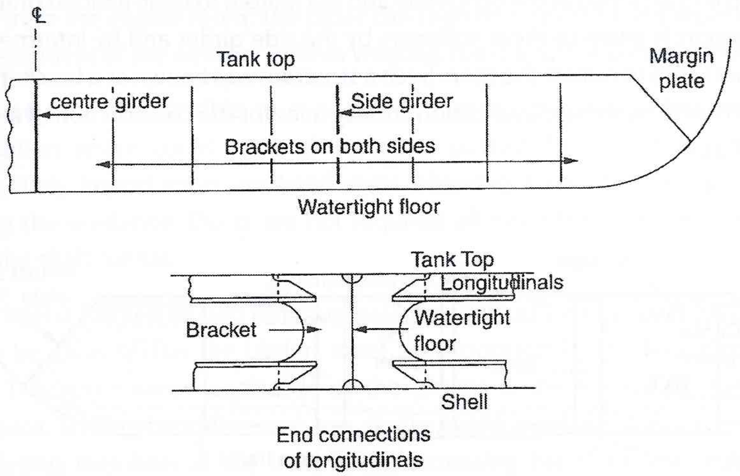
Internal structure of the hull

The hull girder strength can be enhanced with the inclusion of a continuous *centre girder* and/or *side girders*, these extending longitudinally from the fore peak to after peak bulkhead. The centre girder is usually watertight except at the extreme fore and after ends where the ship is narrow, although there are some designs of ship where the centre girder does not form a tank boundary and is therefore not watertight. From 1997 onwards the plates making up the *0.75L* midship section are to be continuous. Centre girders must also provide sufficient strength to withstand the docking loads and additional 'docking brackets' may need to be included in the design.

A pipe tunnel may be substituted for a centre girder as long as the construction of the tunnel is of sufficient strength. If the ship's designer wishes to include this feature, a full set of detailed plans must be submitted for approval.

Additional longitudinal *side girders* are fitted (at a maximum of 5 m apart) depending

The tanks are divided transversely by *watertight floors*, which in most ocean-going ships are required to be stiffened vertically, to withstand the liquid pressure. Figure 4.2 shows a typical, watertight floor.



▲ **Figure 4.2** *Watertight floor and end connections of longitudinal*

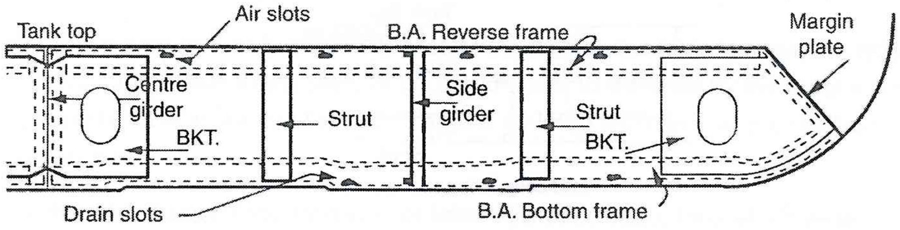
In ships less than 120 m in length the bottom shell and tank top are supported at intervals of not more than 3 m by transverse plates known as *solid floors*. The name slightly belies the structure since large lightening holes are cut in them. In addition, small air release and drain holes are also cut at the top and bottom, respectively. These holes are most important since it is essential to have adequate access and ventilation to all parts of the double bottom. There have been many cases of personnel entering tanks which have been inadequately ventilated, with resultant gassing or suffocation. *These tanks must still be regarded as enclosed spaces.*

The solid floor is usually fitted as a continuous plate extending from the centre girder to the margin plate. The side girder is therefore broken on each side of the floor plate and is referred to as being *intercostal*.

Solid floors are required at every frame space in the machinery room, in the forward quarter length and elsewhere where heavy loads are experienced, such as under bulkheads and boiler bearings.

The remaining bottom support may be of two forms:

Transverse framing was the more traditional method of ship construction which followed on from the methods used on riveted ships. The shell and tank top between the widely spaced solid floors are stiffened by bulb angles or similar sections running across the ship and attached at the centreline and the margin to large flanged brackets. Additional support is given to these stiffeners by the side girder and by intermediate struts which are fitted to reduce the span. Such a structure was known as a bracket floor and is still referred to by some classification society rules for the construction of a ship's hulls (Figure 4.3).



▲ **Figure 4.3** *Bracket floor*

Buckling caused by the distortion due to the welding of the floors and frames, together with the bending of the ship, needs to be guarded and designers are now required to specify longitudinal stiffening in the double bottom for all ships over 120 m long.

Longitudinal frames are fitted to the bottom shell and under the tank top, at intervals of about 760 mm. They are supported by the solid floors mentioned earlier, although the spacing of these floors may be increased to 3.7 m. Intermediate struts are fitted so that the unsupported span of the longitudinals does not exceed 2.5 m. Brackets are again required at the margin plate and centre girder, the latter being necessary when docking as mentioned earlier. Figure 4.4 shows an arrangement of a double bottom construction.

The longitudinals are then arranged to line up with any additional longitudinal girders which are required for machinery or thrust block support.

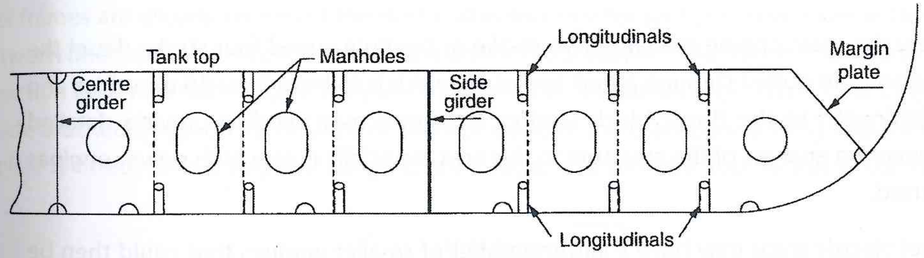
Duct keel or pipe tunnels

strength, they can be used in place of the centre girder explained on page 37 and 68. The pipe tunnel extends from within the engine room along the length of the vessel to the forward holds. This arrangement then allows the pipes to be carried beneath the hold spaces and are thus protected against cargo damage. Access into the duct is arranged from the engine room. The pipes can then be inspected and repaired at any time independent of the weather (within working constraints) and cargo operations.

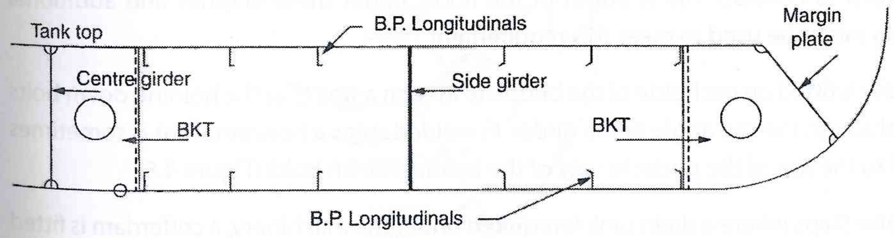
At the same time it is possible to carry oil and water pipes in the duct, preventing contamination which could occur if the pipes passed through tanks. Duct keels are particularly important in insulated ships, allowing access to the pipes without disturbing the insulation. Ducts are not required aft since the pipes may be carried through the shaft tunnel.

The duct keel is formed by two longitudinal girders up to 1.83 m apart. This distance must not be exceeded as the girders must be supported by the keel blocks when docking. The structure on each side of the girders is the normal double bottom arrangement. The keel and the tank top centre strake must be strengthened either by supporting members in the duct or by increasing the thickness of the plates considerably.

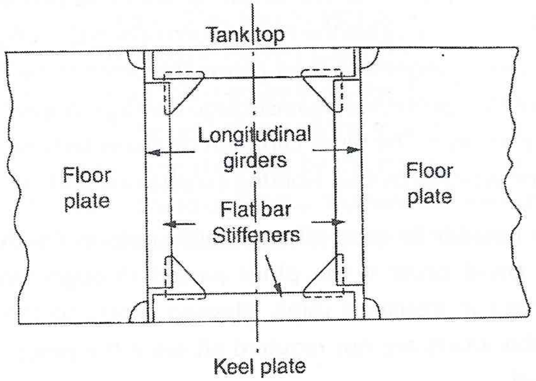
It is vital that the duct space is treated as an enclosed space and great care must be taken before any person enters the area.



Solid floor – Welded



Longitudinal framing



▲ **Figure 4.5** *Duct keel*

Double bottom in the machinery space

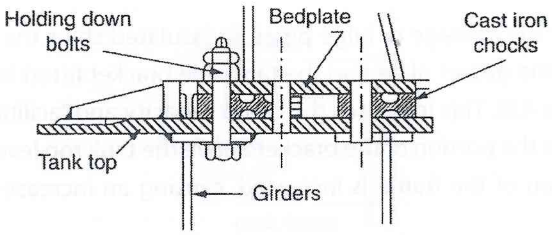
Great care must be taken in the machinery space to ensure that the main and auxiliary machinery are efficiently supported. Weak supports may cause damage to the machinery, while large unsupported panels of plating may lead to vibration of the structure.

Where the main engine is a large two stroke or medium speed four stroke diesel the bedplates are bolted through a tank top plate which is to be at least 19 mm thick and is continuous to the thrust block seating. Designers may need to provide detailed engineering analysis of the structure in this area especially if very high power engines are used.

Diesel electric ships may have a larger number of smaller engines that could then be situated higher than near the double bottom construction. In this case the designers will need to consider the strength of the floors under these engines and additional girders might be used to meet this requirement.

A girder is fitted on each side of the bedplate in such a way that the holding down bolts pass through the top angle of the girder. In welded ships a horizontal flat is sometimes fitted to the top of the girder in way of the holding down bolts (Figure 4.6).

In motor ships where a drain tank is required under the machinery, a cofferdam is fitted

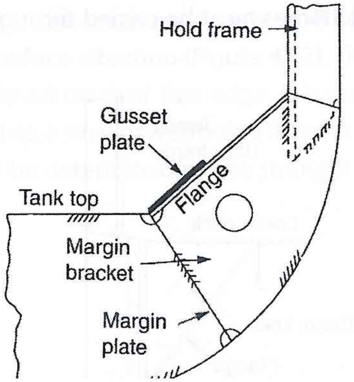


▲ **Figure 4.6** *Main Engine holding down bolts*

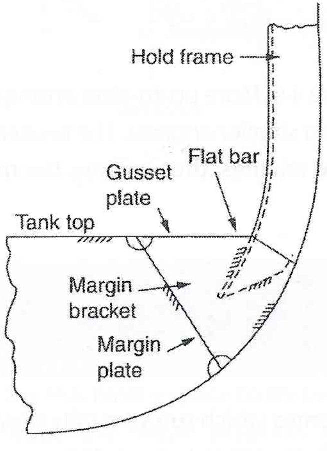
Note the cast iron chocks in Figure 4.6. More up-to-date arrangements use 'resin' chocks or resilient mountings are used on smaller engines. The resilient mountings are able to soak up more vibration from the engines, thus making the machinery space and the ship quieter.

Side Framing

The side shell is supported by frames which run vertically from the tank margin to the upper deck. These frames, which are spaced about 760 mm apart, are in the form of bulb angles and channels in riveted ships or bulb plates in welded ships. The lengths of frames are usually broken at the decks, allowing smaller sections to be used in the 'tween deck spaces where the load and span are reduced. The hold frames are of large section (300 mm bulb angle). They are connected at the tank margin to flanged tank side brackets (Figure 4.7). To prevent the free edge of the brackets buckling, a gusset plate is fitted, connecting the flange of the brackets to the tank top. A hole is cut in

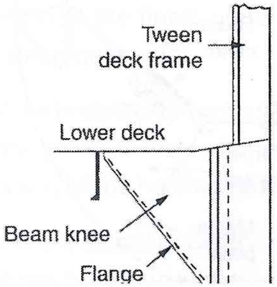


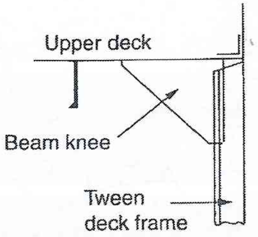
each bracket to allow the passage of bilge pipes. In insulated ships the tank top may be extended to form the gusset plate and the tank side bracket fitted below the level of the tank top (Figure 4.8). This increases the cargo capacity and facilitates the fitting of the insulation. Since the portion of the bracket above the tank top level is dispensed with, the effective span of the frame is increased, causing an increase in the size of the frame.



▲ Figure 4.8 *Tank side bracket insulated ship*

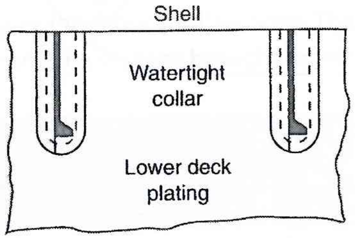
The top of the hold frames, terminate below the lowest deck and are connected to the deck by beam knees (Figure 4.9) which may be flanged on their free edge. The bottom of the 'tween deck frames are usually welded directly to the deck, the deck plating at the side being knuckled up to improve drainage. At the top, the 'tween deck frames are stopped slightly short of the upper deck and connected by beam knees (Figure 4.10). In some cases, the 'tween deck frames must be carried through the second deck and





▲ Figure 4.10 *Beam knee*

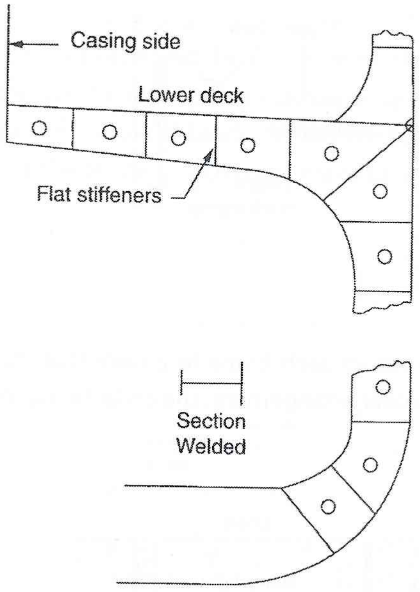
it is necessary to fit a collar round each frame to ensure that the deck is watertight. Figure 4.11 shows a typical collar arrangement, the collar being in two pieces, welded right round the edges.



▲ Figure 4.11 *Welded plate collars*

Wood sparring or similar protective lining can be fitted to the toes of the hold and 'tween deck frames to protect the cargo from damage, while the top of the tank side brackets in the holds are fitted with wood ceiling.

Web frames may be fitted in the machinery space and connected to strong beams or pillars in an attempt to reduce vibration (Figure 4.12). These web frames are about 600 mm deep and are stiffened on their free edge. It is usual to fit two or three web frames on each side of the ship, a smaller web being fitted in the 'tween decks. The exact scantling requirements will be determined by the strength calculations completed by the designer.



▲ **Figure 4.12** *Web frame*

5

SHELL AND DECKS

The external hull of a ship consists of bottom plates making up the shell, plates making up the side shell and decks which are formed by longitudinal strips of plating known as strakes. The strakes themselves are constructed of a number of plates joined end to end and large, wide plates are used to reduce the welding required. Invariably the hull of a modern ship is built up in 'pre-fabricated' sections. These sections can be built up remotely from the main site and the sections brought together to make up the final hull.

Shell Plating

The bottom and side shell plating of a ship form a major part of the longitudinal strength of the vessel. The most important part of the shell plating is that on the bottom of the ship, since this is the greatest distance from the neutral axis. As it is subjected to the highest forces, it is slightly thicker than the side shell plating.

The *keel plate* is about 30% thicker than the remainder of the bottom shell plating, since it is subject to additional wear and tear when dry-docking. The strake adjacent to the keel on each side of the ship is known as the *garboard strake* which is the same thickness as the remainder of the bottom shell plating. The uppermost line of plating in the side shell is known as the *sheerstrake* which is 10–20% thicker than the remaining side shell plating.

The thickness of the shell plating depends mainly on the length of the ship, varying between about 10 mm at 60 m and 20 mm at 150 m. The depth of the ship, the maximum draught and the frame spacing are, however, also taken into account. If the depth is increased, it is possible to reduce the thickness of the plating. In ships fitted with long bridges which extend to the sides of the ship, the depth in way of the bridge level of the upper deck, while the thicker shell plating forward and aft of the bridge must be taken past the ends of the bridge to form an efficient scarph. If the draught of the ship is increased, then the shell plating must also be increased. Thus a ship whose freeboard is measured from the upper deck has thicker shell plating than a similar ship whose freeboard is measured from the second deck. If the frame spacing is increased the shell plating is required to be increased.

The maximum bending moment of a ship occurs at or near amidships. Therefore the shell plating must be of sufficient strength to ensure its contribution to the hull girder strength, and it is reasonable to build the ship stronger amidships than at the ends. The main shell plating has its thickness maintained for 40% of its length amidships and tapered *gradually* to a minimum thickness at the ends of the ship.

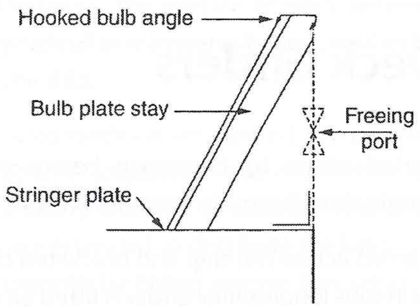
While the longitudinal strength of shell plating is of prime importance, it is as equally important to ensure that its other functions are not overlooked. Watertight hulls were made before longitudinal strength was considered. It is essential that the shell plating should be watertight and, at the same time, capable of withstanding the static and dynamic loads created by the water. The shell plating, together with the frames and double bottom floors, resist the water pressure, while the plating must be thick enough to prevent undue distortion between the frames and floors. If it is anticipated that the vessel will regularly travel through ice, the shell plating in the region of the waterline forward is increased in thickness and small intermediate frames are fitted to reduce the widths of the panels of plating. The bottom shell plating forward is increased in thickness to reduce the effects of pounding (see Chapter 7).

The shell plating and side frames act as pillars supporting the loads from the decks above and must be able to withstand the weight of the cargo. In most cases the strength of the panel which is required to withstand the water pressure is more than sufficient to support the cargo, but where the internal loading is particularly high, such as in way of a deep tank, the frames must be increased in strength.

It is necessary on exposed decks to fit some arrangement to prevent personnel falling or being washed overboard. Many ships are fitted with open rails for this purpose while others are fitted with solid plates known as *bulwarks* at least 1 m high. These bulwarks are much thinner than the normal shell plating and are not regarded as longitudinal strength members. The upper edge is stiffened by a 'hooked angle,' that is, the plate is fitted inside the flange. This covers the free edge of the plate and results in a neater arrangement. Substantial stays must be fitted from the bulwark to the deck at intervals

would then be transmitted to the bulwark causing cracks to appear. These cracks could then pass through the sheerstrake.

Large openings, known as *freeing ports*, must be cut in the bottom of the bulwark to allow the water to flow off deck when a heavy sea is shipped. Failure to clear the water could cause the ship to capsize. Rails or grids are fitted to restrict the opening to 230 mm in depth, while many ships are fitted with hinged doors on the outboard side of the freeing port (see Figure 5.1), acting as rather inefficient non-return valves. It is essential that there should be no means of bolting the door in the closed position.



▲ **Figure 5.1** *Bulwark*

Deck Plating

The deck plating of a ship carries a large proportion of the stresses due to longitudinal bending, the upper deck carrying greater loads than the second deck. The continuous plating alongside the hatches must be thick enough to withstand the loads. The plating between the hatches has little effect on the longitudinal strength. The thickness of plating depends largely upon the length of the ship and the width of deck alongside the hatchways. In narrow ships, or in vessels having wide hatches, the thickness of plating is increased. At the ends of the ship, where the bending moments are reduced, the thickness of plating may be gradually reduced in the same way as the shell plating. A minimum cross-sectional area of material alongside hatches must be maintained. Thus if part of the deck is cut away for a stairway or similar opening, compensation must be made in the form of either doubling plates or increased local plate thickness.

The deck forms a cover over the cargo, accommodation and machinery space and must scuppers. The outboard deck strake is known as the *stringer plate* and at the weather deck is usually thicker than the remaining deck plating. It may be connected to the sheerstrake by means of a continuous *stringer angle* or *gunwale bar*.

Exposed steel decks above accommodation must be sheathed with wood which acts as heat and sound insulation. As an alternative the deck may be covered with a suitable composition. The deck must be adequately protected against corrosion between the steel and the wood or composition. The deck covering is stopped short of the sides of the deck to form a waterway to aid drainage.

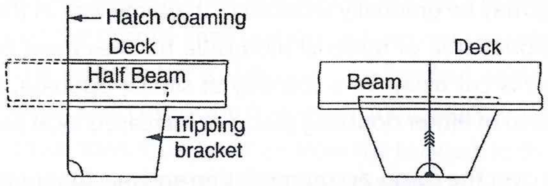
Beams and Deck Girders

The decks may be supported either by transverse beams in conjunction with longitudinal girders or by longitudinal beams in conjunction with transverse girders.

The transverse beams are carried across the ship and bracketed to the side frames by means of *beam knees*. A continuous longitudinal girder is fitted on each side of the ship alongside the hatches. The beams are bracketed or lugged to the girders, thus reducing their span. In way of the hatches, the beams are broken to allow open hatch space, and are joined at their inboard ends to either the girder or the hatch side coaming. A similar arrangement is necessary in way of the machinery casings. These broken beams are known as *half beams* and are usually shaped as bulb plates.

There are several forms of girder in use, some of which are shown in Figure 5.2.

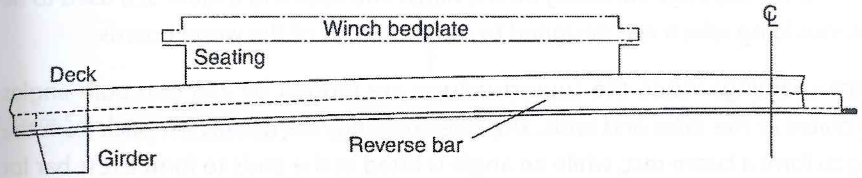
If the girder is required to form part of the hatch coaming, the flanged girder (Figure 5.2(i)) is most useful since it is easy to produce and does not require the addition of a moulding to prevent chafing of ropes. Symmetrical girders such as in Figure 5.2(ii) are more efficient but cannot form part of a hatch side coaming. Such girders must be fitted outboard of the hatch sides. The girders are bracketed to the transverse bulkheads and are supported at the hatch corners either by pillars or by hatch end



girders extending right across the ship. Tubular pillars are most often used in cargo spaces since they give utmost economy of material and, at the same time, reduce cargo damage. In deep tanks, where hollow pillars should not be used, and in machinery spaces, either built pillars or broad flanged beams prove popular.

Most modern ships are fitted with longitudinal beams which extend, as far as practicable, along the whole length of the ship outside the line of the hatches. They are bracketed to the transverse bulkheads and are supported by transverse girders which are carried right across the ship, or, in way of the hatches and machinery casings, from the side of the ship to the hatch or casing. The increase in continuous longitudinal material leads to a reduction in deck thickness. The portion of deck between the hatches may be supported either by longitudinal or transverse beams, neither having any effect on the longitudinal strength of the ship.

At points where concentrated loads are anticipated it is necessary to fit additional deck stiffening. Additional support is required in way of winches, windlasses and capstans (Figure 5.3). The deck machinery is bolted to seatings which may be riveted or welded to the deck. The seatings are extended to distribute the load. In way of the seatings, the beams are increased in strength by fitting reverse bars which extend to the adjacent girders. Solid pillars are fitted under the seatings to reduce vibration.



▲ **Figure 5.3** *Winch seating*

Hatches

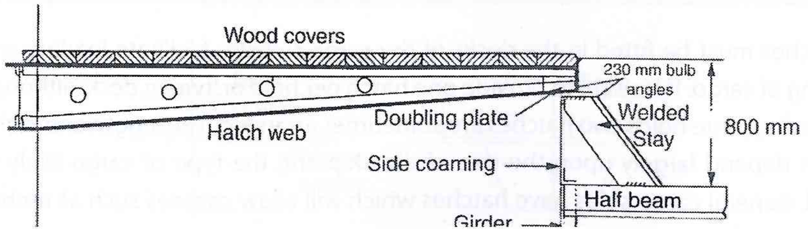
Large hatches must be fitted in the decks of dry cargo ships to facilitate loading and discharging of cargo. It is usual to provide one hatch per hold or 'tween deck, although in ships having large holds two hatches are sometimes arranged. The length and width of hatches depend largely upon the size of the ship and the type of cargo likely to be carried. General cargo ships have hatches which will allow cargoes such as timber, hatch, usually to No. 2 hold, is often increased in length. Large hatches also allow easy handling of cargoes. Bulk carriers have long, wide hatches to allow the cargo to fill the extremities of the compartment without requiring trimming manually.

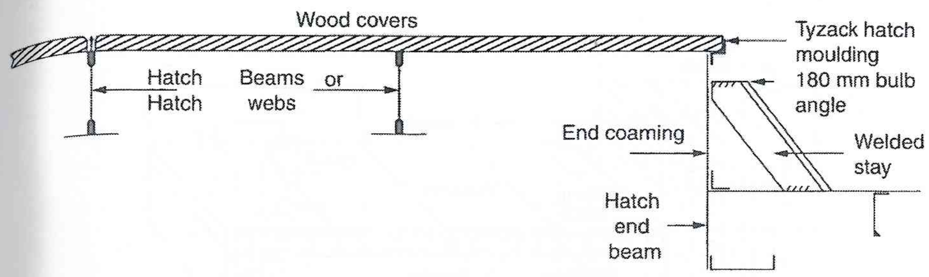
The hatches are framed by means of hatch coamings which are vertical webs forming deep stiffeners. The heights of the coamings are governed by the Load Line Rules. On weather decks they must be at least 600 mm in height at the fore end and either 450 mm or 600 mm aft depending upon the draught of the ship. Inside superstructures and on lower decks no particular height of coaming is specified. It is necessary, however, for safety considerations, to fit some form of rail around any deck opening to a height of 800 mm. It is usual, therefore, at the weather deck, to extend the coaming to a height of 800 mm. In the superstructures and on lower decks portable stanchions are provided, the rail being in the form of a wire rope. These rails are only erected when the hatch is opened.

The weather deck hatch coamings must be 11 mm thick and must be stiffened by a moulding at the top edge. Where the height of the coaming is 600 mm or more, a horizontal bulb angle or bulb plate is fitted to stiffen the coaming which has additional support in the form of stays fitted at intervals of 3 m. Figure 5.4 gives a typical section through the side coaming of a weather deck hatch. The edge stiffening is in the form of a bulb angle set back from the line of the coaming. This forms a rest to support the portable beams. The edge stiffening on the hatch end coaming (Figure 5.5) used to be a Tyzack moulding which was designed to carry the ends of the wood boards.

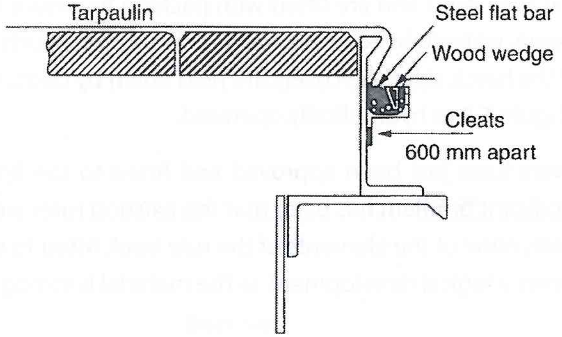
The hatch coamings inside the superstructures are formed by 230 mm bulb angles or bulb plates at the sides and ends. The side coamings are usually set back from the opening to form a beam rest, while an angle is fitted at the ends to form a rest bar for the ends of the wood covers.

The hatches used to be closed by wood boards which are supported by the portable hatch beams. The beams may be fitted in guides attached to the coamings and lifted out to clear the hatch, or fitted with rollers allowing them to be pushed to the hatch ends. The covers are made weathertight by means of tarpaulins which are wedged tight at the sides and ends (Figure 5.6), at least two tarpaulins being fitted on weather deck hatches.





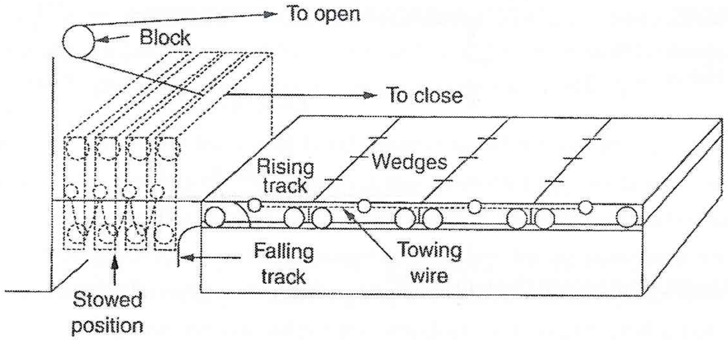
▲ **Figure 5.5** *Longitudinal section through hatch*



▲ **Figure 5.6** *Hatch closing arrangement*

Modern ships are fitted with steel hatch covers (Figure 5.7). There are many types available, from small pontoons supported by portable beams to the larger self-supporting type, the latter being the most popular. The covers are arranged in 4 to 6 sections extending right across the hatch and having rollers which rest on a runway. They are opened by rolling them to the end of the hatch where they tip automatically into the vertical position. The separate sections are joined by means of wire rope, allowing opening or closing to be a continuous action, a winch being used for the purpose.

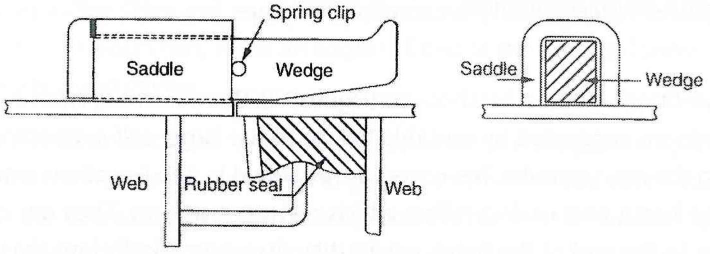
Many other systems are available, some with electric or hydraulic motors driving sprocket wheels, some in which the whole cover wraps round a powered drum, while others have hydraulic cylinders built into the covers. In the latter arrangement pairs of covers are hinged together, the pairs being linked to provide continuity. Each pair of covers has



▲ **Figure 5.7** *Steel hatch covers*

The covers interlock at their ends and are fitted with packing to ensure that when the covers are wedged down, watertight cover is provided (Figure 5.8). Such covers do not require tarpaulins. At the hatch sides the covers are held down by cleats which may be manual as shown in Figure 5.9 or hydraulically operated.

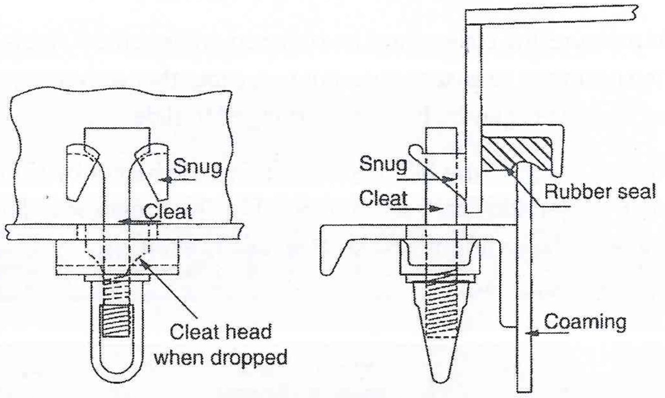
Composite hatch covers have just been approved and fitted to the first bulk carrier during 2015. One significant problem has been that the existing rules were set around steel hatches. Therefore, none of the elements of the rule book fitted to the composite structure; this is however a logical development as the material is strong and light.



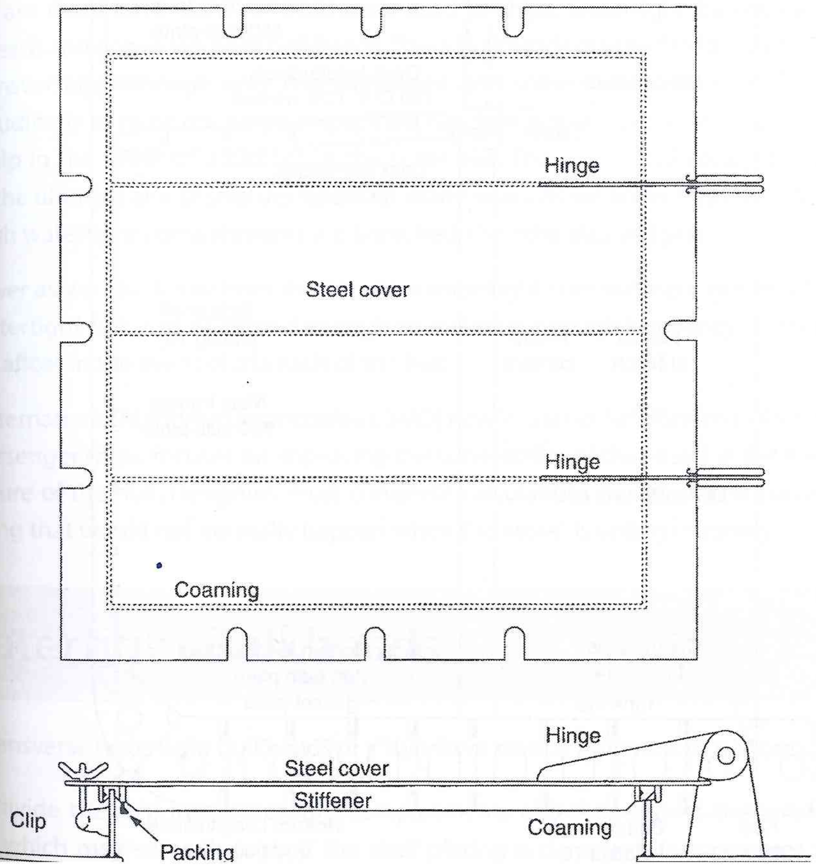
▲ **Figure 5.8** *Hatch wedges*

Hatch covers are very important and need to have the strength to withstand a pounding from the waves that could come over the side of the ship during heavy weather.

Deep tank hatches have two functions to fulfil (Figure 5.10). They must be watertight or oil tight and thus capable of withstanding a head of liquid, and they must be large

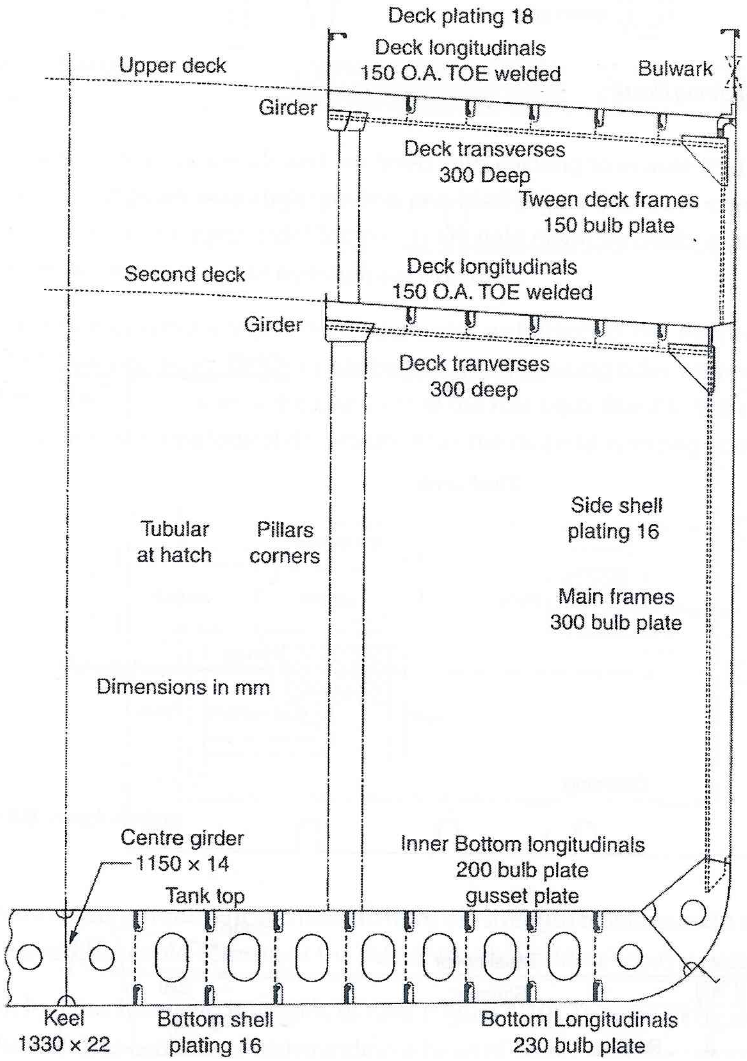


▲ **Figure 5.9** *Securing cleats*



the possible liquid pressure, the covers must be stiffened, while some suitable packing must be fitted in the coamings to ensure watertightness, together with some means of securing the cover. The covers may be hinged or arranged to slide.

Figure 5.11 summarises much of the information within this chapter by showing the relationship between the separate parts in a modern ship. The sizes or scantlings of the structure are typical for a ship of about 10,000 tonne deadweight.



6

BULKHEADS AND DEEP TANKS

There are three basic types of bulkheads used in ships; watertight bulkheads, tank bulkheads and non-watertight bulkheads. These bulkheads may be fitted longitudinally or transversely, although only non-watertight and some tank bulkheads are fitted longitudinally in most dry cargo ships. Their function is to keep enough buoyancy in the ship in the event of a rupture in the outer hull. This is a crucial concept and has been the ultimate aim of ship designers for many years. As we know from the Titanic, if enough watertight compartments are breeched, then the ship will sink.

However as we also know from the Titanic, a watertight compartment not only has to be watertight but it *must* extend enough to maintain enough buoyancy to keep the vessel afloat in the event of a breach of the hull.

The International Maritime Organization's (IMO) new initiative, Safe Return to Port (SRtP) for passenger ships, focuses on improving the survivability of the vessel in the event of a rupture of the hull. Designers must complete calculations based on compartments flooding that would not normally happen when the vessel is sailing routinely.

Watertight Bulkheads

The transverse watertight bulkheads of a ship have several functions to perform.

They divide the ship into watertight compartments and thus restrict the volume of water which may enter the ship if the shell plating is damaged. In passenger ships, form of calculation is occasionally carried out for cargo ships but results in only a slight indication of the likelihood of the vessel sinking, since the volume and type of cargo play an important role.

The IMO now requires that designers improve the 'survivability' of a vessel in the event of a collision with another ship or with a solid object. They must arrange the internal watertight structures accordingly. The watertight compartments also serve to separate different types of cargo and to divide tanks and machinery spaces from the cargo spaces.

In the event of fire, the bulkheads significantly reduce the rate of spread of the fire. Much depends upon the fire potential on each side of the bulkhead, that is, the likelihood of the material near the bulkhead being ignited.

The transverse strength of the ship is also increased by the bulkheads which have much the same effect as the ends of a box. They prevent undue distortion of the side shell and reduce racking considerably.

Longitudinal deck girders and deck longitudinals are supported at the bulkheads which therefore act as pillars, while at the same time they tie together the deck and tank top and hence reduce vertical deflection when the compartments are full of cargo. This whole structure contributes to the ultimate strength of the hull girder.

Thus it appears that the shipbuilder has a very complicated structure to design. In practice, however, it is found that a bulkhead required to withstand a load of water in the event of flooding will readily perform the remaining functions.

The number of bulkheads in a ship depends upon the length of the ship and the position of the machinery space. Each ship must have a collision bulkhead and from 2010 this should be at least *0.05L* or 10 m (whichever is the least) from the forward perpendicular and no greater than *0.08L* or *0.05L* + 3 m whichever is greater. The bulkhead must be continuous up to the uppermost continuous deck. Special considerations are made for Ro-Ro vessels that have a bow door.

The stern tube must be enclosed in a watertight compartment formed by the sternframe and the after peak bulkhead which may terminate at the first watertight deck above the waterline. A bulkhead must be fitted at each end of the machinery space although, if the engines are aft, the after peak may form the after boundary of the space.

is amidships or 6 bulkheads if the machinery is aft, while a ship 180 m in length will require 9 or 8 bulkheads, respectively. These bulkheads must extend to the freeboard deck and should preferably be equally spaced in the ship. It may be seen, however, from Chapter 1, that the holds are not usually of equal length. The bulkheads are fitted in separate sections between the tank top and the lowest deck, and in the 'tween decks.

In ships employing diesel electric propulsion systems the actual engines might not be in line across the vessel. Therefore, to keep the propulsion systems separate, giving improved redundancy, additional watertight transverse and longitudinal bulkheads would be required.

Watertight bulkheads are formed by plates which are attached to the shell, deck and tank top by welding (Figure 6.1). Since water pressure increases with the head, and