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INTRODUCTION TO SHIPBUILDING

Ministry of Education and Science of Ukraine
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INTRODUCTION TO SHIPBUILDING

STUDY GUIDE

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The fundamentals of shipbuilding are presented in English. The guide covers the main types of ships, basics of hydrostatics, propulsion, maneuverability, and seakeeping. It provides essential information on classification societies, hull structure, hull strength, and shipbuilding materials, ship equipment and systems, ship power plants and electrical equipment, as well as ship propulsion systems. Key concepts related to ship construction and ship repair are also explained.

The guide is intended for Ukrainian and international students studying at shipbuilding and maritime higher education institutions and learning courses related to shipbuilding, ship repair, and ship operation. The material may also be useful to a wide range of specialists.

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CONTEXT

ABSTRACT

This course provides students with a basics of marine engineering. Students will study main types of ships, lines plan, hull characteristics, basics of ship's buoyancy, stability, resistance, manoeuvrability, seakeeping and basics about flooding calculations. The course also includes introduction to the strength and ship hull structure, vessel devices and equipment, power plants, electrical equipment of ships, hull systems and ship propulsion system. Basics of shipyard technology, welding and ship docking and maintenance are covered.

The textbook includes all the necessary materials providing students the basic knowledge about ships and shipbuilding. The textbook corresponds to educational programs «Ships and Ocean Engineering», «Ship hull building» of the specialty G11 «Mechanical Engineering», specialization G11.04 Shipbuilding, field of knowledge G «Engineering, Production and Construction». The textbook is intended for students of the first educational level – bachelor's degree. The content is also useful for students of specialty J5 «Maritime and inland water transport» and for a wide audience.

The purpose of the textbook is to present the minimum material to provide readers with a basic knowledge of ships and shipbuilding.

Introduction, chapters 1–4, 7–12, 15 have been written by D. Lytvynenko, chapters 13–14 have been written O. Shchedrolosiev, and V. Sotsenko has written Chapters 5–6.

The authors are grateful to the reviewers for their comments when discussing the content of the manual.

1 GENERAL INFORMATION ABOUT SHIPS

15.1 Types of Ships

A ship is a complex and large transport vehicle, essential for various functions, from global trade and passenger transportation to research and national defense. Its design, construction, and operation are adapted to the demands of long and intensive maritime operations. Understanding the essence of a ship includes recognizing its size, structure, types, and the critical roles it plays in the modern world.

Cargo ships are classified into various types based on purpose, size, type of cargo, etc. [1].

The economic factor is of prime importance in designing a merchant ship. Every owner wants maximum return on their investment which means a ship's construction not only depends on the current economic necessities but the factor of future adaptability also plays a part.

From the preliminary design of a vessel due for construction, the following information can be obtained:

1) dimensions;
2) displacement;
3) stability;
4) propulsive characteristics and hull form;
5) preliminary general arrangement;
6) principal structural details.

The type of ship plays an important role in deciding the above-mentioned parameters.

Ships are mainly classified into the following types: container ships, bulk carriers, tanker ships, passenger ships, naval ships, offshore ships, and special purpose ships.

Container ships. As the name suggests, a vessel structured specifically to hold huge quantities of cargo compacted in different types of containers is referred to as a container vessel or container ship (see fig. 1.1).

Figure 1.1 – Container ship

Types of container ships on the basis of sizes: a) Panamax; b) Suezmax; c) Post-Panamax; d) Post-Suezmax; e) Post-Malaccamax.

Refrigerated Container Ships: these vessels carry refrigerated cargo (mainly in refrigerated containers).

Bulk carriers (see fig. 1.2) are a type of ship that transports cargo (generally dry cargo) in bulk quantities. The cargo transported in such ships is loose cargo i.e. without any specific packaging and generally contains items like food grains, ores, coals, and even cement.

Types of bulk carriers: conventional bulkers; geared bulker; gearless bulker; self-discharging bulker; Lakers; BIBO («Bulk-In, Bags Out»).

Figure 1.2 – Bulk Carrier Ship

Some other forms of dry cargo are:

– *Tramps:* a boat or ship engaged in the tramp trade is one which does not have a fixed schedule or published ports of call.
– *Cargo liners:* an ocean liner is a ship designed to transport cargo from point A to point B. The classic example of such a voyage would be a transatlantic crossing from Europe to America.

Tanker ships are specialised vessels for carrying a large amount of liquid cargo (see fig. 1.3). Tankers are further subdivided into different types on the basis of the cargo they carry.

The main types of tankers are:

– *Oil Tankers:* oil tankers mainly carry crude oil and its by-products.
– *Liquefied Gas Carriers:* A gas carrier (or gas tanker) is a ship designed to transport LPG, LNG or liquefied chemical gases in bulk.
– *Chemical and Product Carriers:* A chemical tanker is a type of tanker ship designed to transport chemicals and different liquid products in bulk.

Figure 1.3 – Tanker ship

– *Other types of tankers:* Some other types of tankers are juice tankers, wine tankers, integrated tug barges, etc.

On the basis of their size, tankers are further divided into various types such as VLCC, ULCC, Panamax, Aframax, Suezmax, Capesize, Handymax, Lighters, and Handy.

Ro-Ro Ships. Ro-Ro (see fig. 1.4–1.5) is an acronym for Roll-on/roll-off. Roll-on/roll-off ships are vessels that are used to carry wheeled cargo.

The types of Ro-Ro are: Pure Car Carrier (PCC) and Pure Car and Truck Carrier (PCTC) RoRo Ships; Container Vessel + Ro-Ro (ConRo) Ship; General Cargo + Ro-Ro Ship (GenRo) Ships; RoPax; Complete RoRo Ships.

Figure 1.4 – Roll-on Roll-Off Ship

Figure 1.5 – Discharging of the Ro-Ro Ship

Passenger ships (see fig. 1.6), as the name suggests, are mainly used for transiting passengers.

Figure 1.6 – Passenger ship

They are mainly classified into:

1. Vessels for transiting passengers (and vehicles) on short-distance routes are called *ferries.*
2. *Cruise Ships* are mainly used for recreational activities. Cruise ships are like luxurious floating hotels with state-of-the-art facilities.

They are further classified as:

– liners, cruise ships, pilgrimage ships;
– cross channel ferries, coastal ferries, harbor ferries;
– Arctic and Antarctic cruises.

Offshore vessels mainly help in oil exploration and construction jobs at sea (see fig. 1.7).

Some of the main ones are:

– *supply ships* are vessels that supply to offshore rigs;
– *pipelayers* are vessels engaged in laying pipes and cables;
– *crane vessels, crane ships, or floating cranes* are ships specialized in lifting heavy loads;

Figure 1.7 – Offshore vessel

- *semi-submersible drill rigs* are mobile offshore drilling units to make stable platforms for drilling oil and gas;
- *drill ships* are merchant vessels designed for use in exploratory offshore drilling of new oil and gas wells or for scientific drilling purposes;
- *accommodation barges* could be a stand-alone floating hotel or can include accommodation as well as space for cargo;
- *production platforms* are used to extract and process oil and natural gas or to temporarily store product until it can be brought to shore for refining and marketing;
- *Floating Storage Unit (FSU)* is a floating vessel mainly used for storage of oil and by-products;
- *Floating Production and Storage Unit (FPSO)* is a floating vessel used by the offshore oil and gas industry for the production and processing of hydrocarbons, and for the storage of oil;

– *anchor handling vessels* are used for offshore construction and installation operations;
– *diving vessels* are vessels used by divers for diving in the ocean for underwater jobs.

Fishing Vessels. Ships or boats used for recreational or commercial fishing at sea are called fishing vessels (see fig. 1.8). Fishing vessels are mainly classified into two types – trawlers and non-trawling vessels.

Figure 1.8 – Fishing vessels

Trawlers, Purse Seiners. A fishing trawler, also known as a dragger, is a commercial fishing vessel designed to operate fishing trawls. Trawling is a method of fishing that involves actively dragging or pulling a trawl through the water behind one or more trawlers. A purse seine is a large wall of netting deployed around an entire area or school of fish. The seine floats along the top line with a lead line threaded through rings along the bottom. Once a school of fish is located, a skiff encircles the school with the net.

A factory ship, also known as a fish processing vessel, is a large ocean-going vessel with extensive onboard facilities for processing and freezing caught fish.

Speciality vessels are constructed and used for specific purposes.

A tug (tugboat) is a boat or ship that manoeuvres vessels by pushing or towing them (see fig. 1.9).

Figure 1.9 – Tug

A tender is a boat or a larger ship used to service or support other boats or ships, generally by transporting people and/or supplies is called a tender vessel.

Pilot crafts are used for the transportation of harbor pilots.

Cable laying vessels help in laying cables on to the sea bed.

Research vessels are special types of vessels used for carrying out a variety of research at sea. Some of the most common types of research vessels are seismic vessels, hydrographic vessels, oceanographic vessels, polar vessels, etc.

Salvage vessels are vessels engaged in salvage operations; and recovery of lost property at sea.

A lightvessel, or lightship is a ship which acts as a lighthouse. They are used in waters that are too deep or otherwise unsuitable for lighthouse construction.

A barge is a flat-bottomed boat, built mainly for river and canal transport of heavy goods.

Timber carriers are vessels that carry timber.

Livestock carriers are vessels that carry livestock/animals.

Ice breaker ships are used for cutting ice deposits in extremely cold climate conditions to make waters navigational.

High-speed crafts are a special type of technologically advanced high-performance (typically high-speed) marine vehicles (see fig. 1.10). Though most of these technologies are not used in commercial vessels, a few have been successfully implemented and tested in conventional merchant vessels of small scale.

Some of the main types of high-speed crafts are:

- multihulls including wave piercers;
- small waterplane area, twin-hull ships (SWATH);
- surface effect ships (SES) and hovercrafts;
- hydrofoils;
- Wing in Ground Crafts (WIG).

Dredgers are vessels with excavation tools used for removing sand and other types of deposits from the seabed (see fig. 1.11). Dredgers are used for several purposes such as making shallow coastal areas navigational, deep-sea mining etc.

Dredgers are mainly classified into two types: mechanical dredgers and hydraulic dredgers.

Figure 1.10 – High-Speed Craft

Figure 1.11 – Trailing suction hopper dredger (TSHD)

1.2 Categories of seagoing vessels according to mode of support

Ships can also be classified by the means of physical support while in operation. Three broad classifications that are frequently used by naval architects are shown in fig. 1.12, reproduced from [2]. Types of ship supports are the following: aerostatic support, hydrodynamic support, and hydrostatic support.

Aerostatic support is achieved when the vessel rides on a cushion of air generated by lift fans. These vessels tend to be lighter weight and higher speed vessels. The two basic types of vessels supported aerostatically are air cushion vehicles (ACV) and surface effect ships (SES).

Hydrodynamic Support. Hydro is the prefix for water and dynamic indicates movement. The two basic types of vessels supported hydrodynamically are planing vessels and hydrofoils.

Hydrostatic Support. Hydrostatically supported vessels are by far the most common type of waterborne craft and the predominant vessel support. They describe any vessel that is supported by «Archimedes' Principle».

Definition of Archimedes Principle: «An object partially or fully submerged in a fluid will experience a resultant vertical force equal in magnitude to the weight of the volume of fluid displaced by the object». This force is often referred to as the «buoyant force» or the «force of buoyancy».

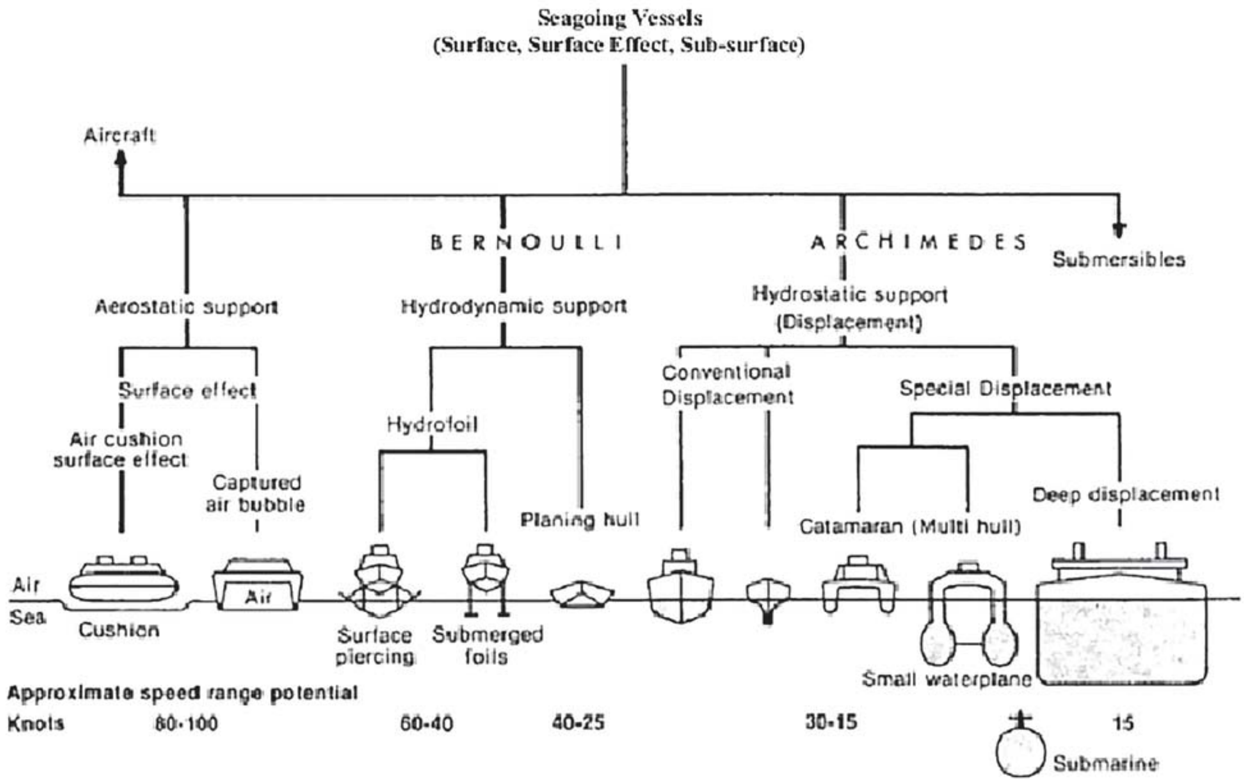

Figure 1.12 – Categories of Seagoing Vessels According to Mode of Support [2]

2 GEOMETRY OF A SHIP HULL

2.1 Principal dimensions of ships

A ship's hull form determines many of its main attributes, stability characteristics and resistance, and therefore the power needed for a given speed, seaworthiness, manoeuvrability and load-carrying capacity. It is important, therefore, that hull shape be defined accurately. The basic descriptors such as length and beam used must be defined [3].

A ship's hull is three dimensional and is usually symmetrical about a fore and aft plane. The hull envelope shape is defined by its intersection with three sets of mutually orthogonal planes. The horizontal planes are known as waterplanes and the lines of intersection are known as *waterlines*. The planes parallel to the middle line plane cut the hull in *buttock lines*, the middle line plane itself defining the *profile*. The intersections of the transverse, that is the athwartships, planes define the *transverse sections*.

Two sets of main hull dimensions are used. *Moulded* dimensions are those between the inner surfaces of the hull envelope. Dimensions measured to the outside of the plating are meant if there is no qualifying adjective. Moulded dimensions are used to find the internal volumes of the hull – a rough indicator of earning capacity.

Five different lengths used in naval architecture are defined below. The first three lengths are those most commonly used to define the ship form and are as follows (fig. 2.1):

– *The length between perpendiculars* (L_{BP} or L_{PP}) is the distance measured along the summer load waterplane (the design waterplane for warships) from the after to the fore perpendicular. The after perpendicular is commonly taken as the line passing through the rudder stock. The fore perpendicular is the vertical line through the intersection of the forward side of the stem with the summer load waterline.

– *The length overall* (L_{OA}) is the distance between the extreme points forward and aft measured parallel to the summer (or design) waterline. Forward the point may be on the raked stem or on a bulbous bow.
– *The length on the water line* (L_{WL}) is the length on the waterline, at which the ship happens to be floating between the intersections of the bow and after end with the waterline. If not otherwise stated the summer load (or design) waterline is to be understood.

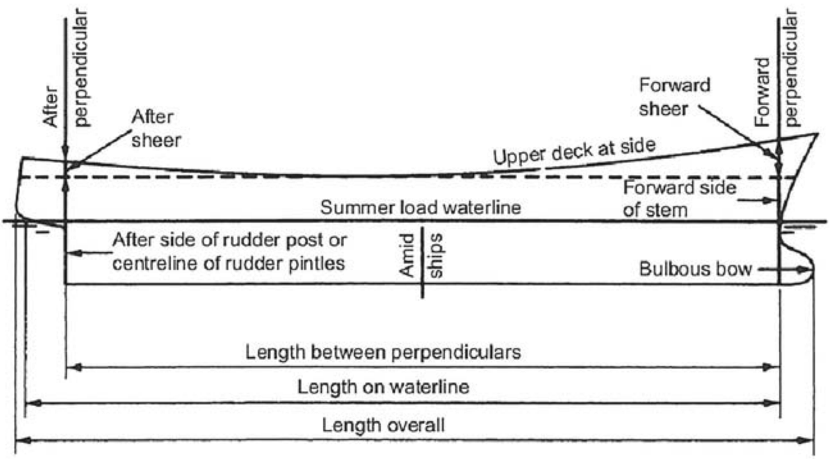

Figure 2.1 – Principal dimensions [3]

The mid-point between the perpendiculars is called *amidships* or *mid-ships*. The section of the ship at this point by a plane normal to both the summer waterplane and the centre-line plane of the ship is called the *midship section*. It may not be the largest section of the ship – in general this will be a section somewhat aft of amidships. The breadth of the ship at any point is called the *beam*. Unless otherwise qualified, the beam quoted is usually that amidships at the summer waterplane. Referring to fig. 2.2, the *moulded beam* is the greatest distance between the inside of plating on the two sides of the ship at the greatest width at the section chosen. The *breadth extreme* is measured to the outside of plating but will also take account of any over-hangs or flare.

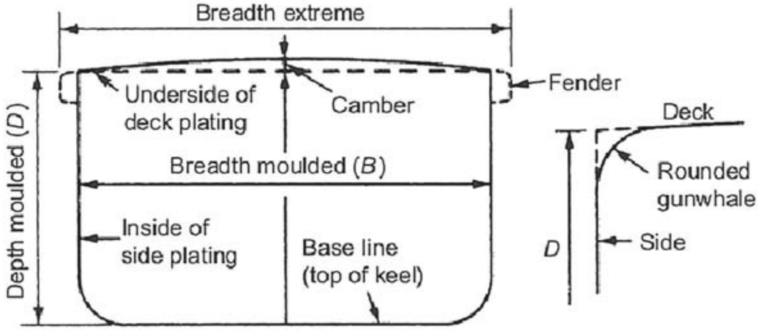

Figure 2.2 – Breadth measurements [3]

The ship depth (fig. 2.2) varies along the length but is usually quoted for amidships. The moulded depth is measured from the underside of the deck plating at the ship's side to the top of the inner flat keel plate. Unless otherwise specified, the depth is to the uppermost continuous deck. Where a rounded deck edge, gunwhale, is fitted the convention used is indicated in fig. 2.2.

The *draught* of the ship at any point along its length is the distance from the keel to the waterline. If a *moulded draught* is quoted, it is measured from the inside of the keel plating. For navigation purposes, it is important to know the maximum draught. This will be taken to the bottom of any projection below keel such as a bulbous bow, propeller or sonar dome. If a waterline is not quoted, the design waterline is usually intended. To aid the captain, draught marks are placed near the bow and stern and remote reading devices for draught are often provided.

The difference between the draughts forward and aft is referred to as the *trim*. Trim is said to be *by the bow* or *by the stern* depending upon whether the draught is greater forward or aft, respectively. Often draughts are quoted for the two perpendiculars. Being a flexible structure, a ship will usually bend slightly fore and aft, the curvature varying with the loading. The ship is said to *hog* or *sag* when the curvature is concave down or up respectively.

2.2 Representing the hull form

The hull form is portrayed graphically by the lines plan or sheer plan (fig. 2.3). This shows the various curves of intersection between the hull and the three sets of orthogonal planes. For symmetrical ships, only one-half is shown. The curves showing the intersections of vertical fore and aft planes with the hull are grouped in the *sheer profile*, the waterlines in the *half-breadth plan*, and the sections by transverse planes in the *body plan*. In merchant ships, the transverse sections are numbered from aft to forward. The distances of the various intersection points from the middle line plane are called *offsets*.

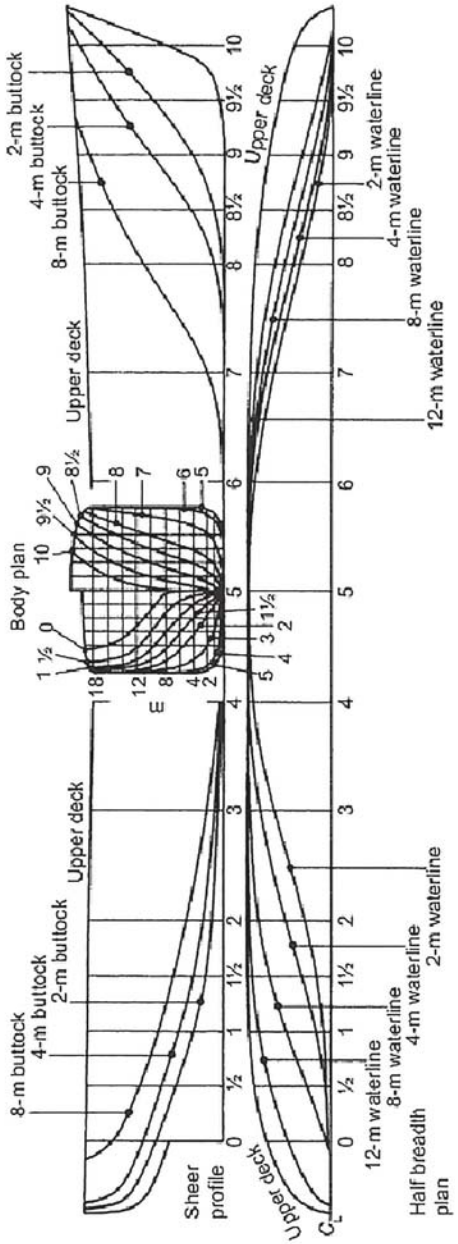

Figure 2.3 – Lines plan [3]

2.3 Hull characteristics

Having defined the hull form, it is possible to derive a number of characteristics which have significance in determining the general performance of the ship. As a floating body, a ship in equilibrium will displace its own weight of water. Thus the volume of the hull below the design load waterline must represent a weight of water equal to the weight of the ship at its designed load. This displacement, as it is called, can be defined as:

$$\Delta = \rho g \nabla, \tag{2.1}$$

where ρ is the density of the water in which the ship is floating, g is the acceleration due to gravity and ∇ is the underwater volume (volume of displacement).

It is useful to have a feel for the fineness of the hull form. This is provided by a number of *form coefficients or coefficients of fineness*. These are defined as follows.

1. Block coefficient:

$$C_B = \frac{\nabla}{L_{PP} BT}, \tag{2.2}$$

where L_{pp} is the length between perpendiculars; B is the extreme breadth underwater; and T is the mean draught.

2. Coefficient of fineness of waterplane:

$$C_{WP} = \frac{A_W}{L_{WL} B}, \tag{2.3}$$

where A_W is waterplane area, L_{WL} is the waterline length.

3. Midship section coefficient:

$$C_M = \frac{A_M}{BT}, \tag{2.4}$$

where A_M is the midship section area, and B is the extreme underwater breadth amidships.

4. Longitudinal prismatic coefficient:

$$C_p = \frac{\nabla}{A_M L_{PP}}. \tag{2.5}$$

Note that $C_M \cdot Cp = C_B$.

5. Vertical prismatic coefficient

$$C_{VP} = \frac{\nabla}{A_W T}. \tag{2.6}$$

Some typical values (for rough guidance only) are presented in table 2.1.

Table 2.1 – **Typical Values of Form Coefficients [3]**

Type of Ship	Block Coefficient	Prismatic Coefficient	Midship Area Coefficient
Crude oil carrier	0,82–0,86	0,82–0,90	0,98–0,99
Product carrier	0,78–0,83	0,80–0,85	0,96–0,98
Dry bulk carrier	0,75–0,84	0,76–0,85	0,97–0,98
Cargo ship	0,60–0,75	0,61–0,76	0,97–0,98
Passenger ship	0,58–0,62	0,60–0,67	0,90–0,95
Container ship	0,60–0,64	0,60–0,68	0,97–0,98
Ferries	0,55–0,60	0,62–0,68	0,90–0,95
Frigate	0,45–0,48	0,60–0,64	0,75–0,78
Tug	0,54–0,58	0,62–0,64	0,90–0,92
Yacht	0,15–0,20	0,50–0,54	0,30–0,35
Icebreaker	0,60–0,70		

The values of these coefficients can provide useful information about the ship form. For instance, the low values of block coefficient for cargo liners would be used for high-speed refrigerated ships. The low block coefficient value for icebreakers reflects the hull form forward which is shaped to help the ship drive itself up on to the ice and break it.

The block coefficient indicates whether the form is full or fine. Large values will lead to greater wavemaking resistance at speed. A slow ship can afford a relatively high block coefficient as its resistance is predominately frictional. A high value is good for cargo carrying.

A ship's *displacement* significantly influences its behaviour at sea. Displacement is a force but the term *mass displacement* can also be used. Displacement varies in service from light displacement to fully loaded displacement. For most performance studies, the latter is usually assumed.

Although influencing its behaviour in service, displacement is not a direct measure of a ship's carrying capacity, i.e. its earning power. To measure capacity, *deadweight* and *tonnage* are used.

Deadweight, or *deadmass*, is the difference between the load displacement up to the minimum permitted freeboard and the lightweight or light displacement. Lightweight is the weight of the hull and machinery, so the deadweight includes the cargo, fuel, water, crew and effects. The term cargo deadweight is used for the cargo alone. A table of deadweight against draught, for fresh and salt water, is provided to a ship's master in the form of a deadweight scale. This may be in the form of a diagram, a set of tables or, more likely these days, as software.

Ton in this usage originally derived from tun, which was a wine cask. The number of tuns a ship could carry was a measure of its capacity. Thus tonnage is a volume measure, not a weight measure, and for many years the standard ton was taken as 100 cubic feet (2,83 m^3). Because of the way it is now calculated, the unit of tonnage can no longer be regarded as a figure with a fixed volume of 2.83 m^3. Two 'tonnages' are of interest to the international community, namely:

– the *gross tonnage* based on the volume of all enclosed spaces and representing the overall size of a vessel;
– the *net tonnage* based on the volume of cargo spaces plus the volume of passenger spaces multiplied by a coefficient so representing its carrying capacity.

The Plimsoll line is a reference mark located on a ship's hull that indicates the maximum depth to which the vessel may be safely immersed when loaded with cargo [4]. This depth varies with a ship's dimensions, type of cargo, time of year, and the water densities encountered in port and at sea. Once these factors have been accounted for, a ship's captain can determine the appropriate Plimsoll line needed for the voyage (see fig. 2.4).

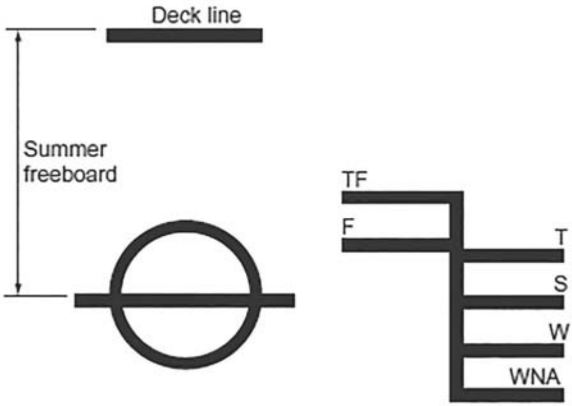

Figure 2.4 – Plimsoll mark on the hull of a ship [3]

Explanations of symbols used in the fig. 2.4 are as follows:
– TF – Tropical Fresh Water;
– T – Tropical;
– F – Fresh Water;
– S – Summer;
– W – Winter;
– WNA – Winter North Atlantic.

3 BUOYANCY AND STABILITY

3.1 Buoyancy

A ship floating at rest in calm water is acted upon by two forces, weight and buoyancy. Weight is the downward force on the ship. The *total weight force* acts on the ship as if it were concentrated at the balancing point or the *centre of gravity* (G). Buoyancy is the upward force of all the hydrostatic pressures on the hull. The horizontal components of the water pressures on unit areas of the ship's sides and bottom, increasing with depth, act in opposite directions and cancel each other. The vertical components of the water pressures on unit areas combine to form an upward force equal to the weight of the water displaced by the underwater hull volume. This weight varies slightly with the specific gravity of the water. The centre of buoyancy (B) lies at the geometric centre of the immersed volume. The ship sinks in the water until the total weight force exactly equals the buoyancy force ($\rho g \nabla$), in accordance with *Archimedes' principle* [5].

In an early stage of the design, the ship weight is estimated as the sum of the weights of the cargo, hull, fittings, equipment, propelling and auxiliary machinery, piping systems, electrical and electronic gear, fuel, water, consumable stores, passengers, and crew, plus a margin of a few percent for weights that are underestimated. At a later stage, the weights are calculated more precisely or are taken from actual weights of similar items. In many cases, the weight estimates are revised constantly as the design proceeds to avoid an ultimate overweight that might seriously detract from the ship's performance.

As the underwater and above-water portions of the hull are fashioned, the naval architect maintains a running check of the estimated weights and calculated buoyancy volumes, as well as the products of these weights and volumes times the horizontal fore-and-aft distances or «moment arms» of each from the transverse vertical reference plane at mid-length. These products are known as the longitudinal weight and buoyancy moments.

For the ship to float at the level attitude or zero trim desired, *G* and *B* must lie in the same vertical transverse plane (fig. 3.1). If their calculated positions are different, and the size, proportions, and shape of the underwater hull are satisfactory, it is customary to shift the weights within the hull until the desired trim is attained.

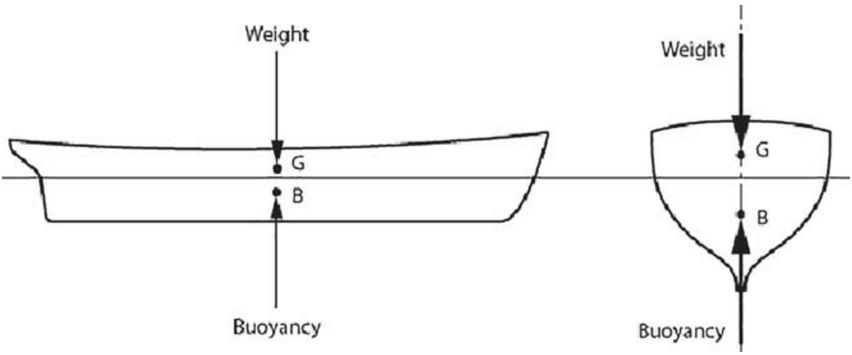

Figure 3.1 – Equilibrium conditions for a ship floating at rest in calm water

3.2 Stability

Ships are designed to float upright. Stability is the ability of a totally submerged or partly submerged body floating upright, when brought out of balance, to come back to the upright position when the reason for the list no longer exists.

A difference is made between longitudinal stability and transverse stability. We will look at transverse stability only. Stability for small list angles of 6 degrees is called *initial stability* [6–9].

When a floating body is brought to a listing position, without adding or removing weight, a buoyancy wedge is formed and filled on the lower side of the body, while a wedge is lost on the high side. When the volume of the submerged part during listing does not change, both wedges have the same volume.

Due to the above wedges, the centre of buoyancy (B) of the whole submerged part is moving from the initial position towards the direction of the low side, where a wedge is formed, by the formation and loss of the wedges (see fig. 3.2). The locations of B at varying angles are all on a virtual curve.

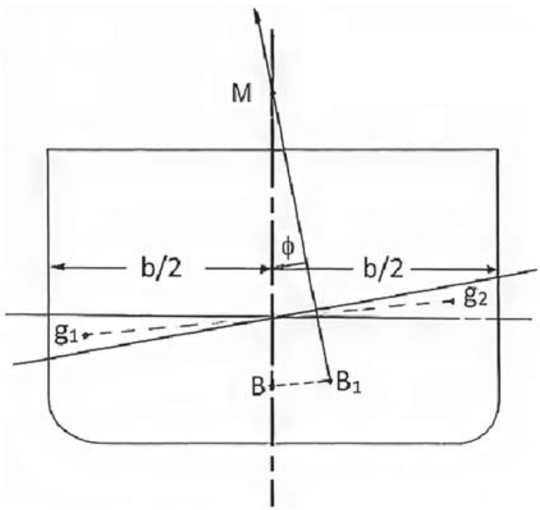

Figure 3.2 – Transverse stability at small angles

When looking at the transverse model, the body, now a midship section of a normal ship, is brought to a list (φ), with a small angle. The buoyancy force has a vertical direction, a vector, originating in *B*, and pointing upwards, perpendicular to the waterline (see fig. 3.3). When a ship is inclined, the center of buoyancy shifts off the centerline while the center of gravity remains in the same location. Since the forces of buoyancy and gravity are equal and act along parallel lines, but in opposite directions, a rotation is developed. This is called a couple, two moments acting simultaneously to produce rotation. This rotation returns the ship to where the forces of buoyancy and gravity balance out [9].

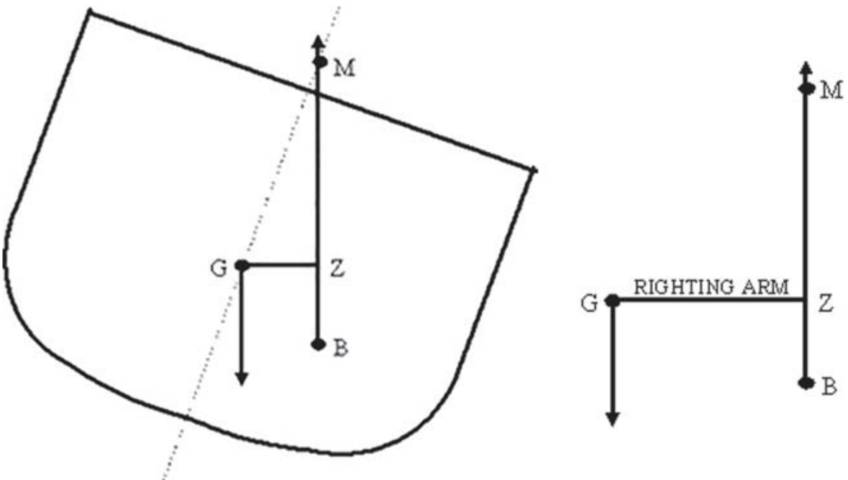

Figure 3.3 – The stability triangle [9]

Metacentre (*M*) is the point the virtually suspended ship is attached. If the centre of gravity *G* is located below *M*, then the stability is positive. If the centre of gravity *G* is located above *M*, then the stability is negative. The distance between *M* and *B* depends on the draught and the width of the waterline.

The distance between the forces of buoyancy and gravity is known as the ship's righting arm. As shown above, the righting arm is a perpendicular line drawn from the center of gravity to the point of intersection on the force of buoyancy line.

For small angles of heel (0 through 7 to 10°, metacenter doesn't move), the value for the ship's righting arm (*GZ*) may be found by using trigonometry (fig. 3.4).

$$GZ = GM \sin\theta \approx GM \cdot \theta. \tag{3.1}$$

With initial stability (0 to 7–10°) the metacenter does not move. Therefore, the size of the ship's Righting Arm, *GZ*, is directly proportional to the size of the ship's metacentric height, *GM*. Thus, *GM* is a good measure of the ship's initial stability.

The *righting moment* is the best measure of a ship's overall stability. It describes the ship's true tendency to resist inclination and return to equilibrium. The righting moment is equal to the ship's righting arm (*GZ*) multiplied by the ship's displacement.

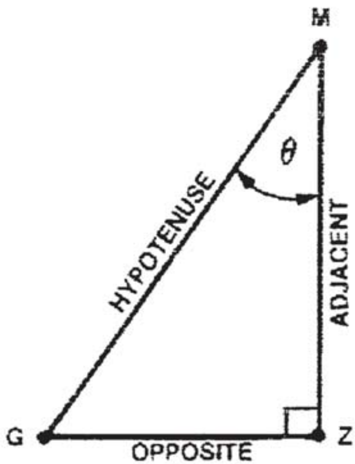

Figure 3.4 – Using the sine function to solve for the righting arm [9]

$$M_{\text{right}} = GZ \cdot \Delta. \tag{3.2}$$

The positions of gravity and the metacenter will indicate the initial stability of a ship. Following damage, the ship will assume one of the following three stability conditions [9].

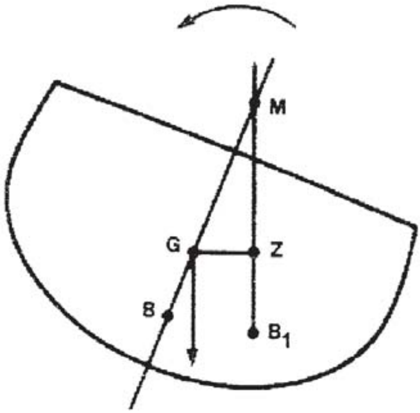

Figure 3.5 – Stable condition [9]

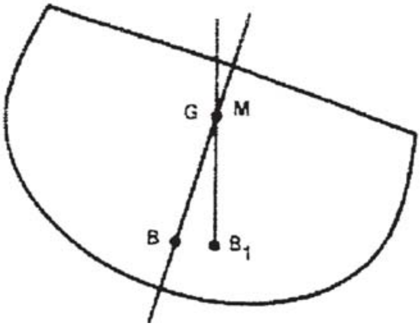

Figure 3.6 – Neutral condition [9]

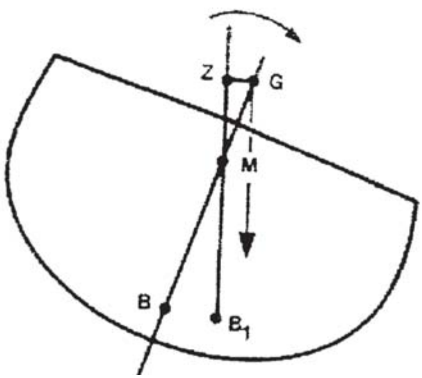

Figure 3.7 – Unstable condition [9]

1. Positive stability. The metacenter is located above the ship's center of gravity. As the ship is inclined, righting arms are created which tend to return the ship to it's original, vertical position (see fig. 3.5).

2. Neutral stability. The metacenter and the ship's center of gravity are in the same location (see fig. 3.6). As the ship is inclined, no righting arms are created (until the metacenter starts to move after the ship is inclined past 7–10°).

3. Negative stability. The ship's center of gravity is located above the metacenter. As the ship is inclined, negative righting arms (called upsetting arms) are created which tend to capsize the ship (see fig. 3.7).

To ensure the stability of a ship under various operating conditions and loads, specialized software solutions are used. These programs allow for precise modeling of stability, conducting analyses in different scenarios, and ensuring the ship's compliance with international norms and standards.

Some examples of the software for calculating ship stability are presented below.

DelftShip is a versatile and user-friendly software application designed for naval architects, marine engineers, and shipbuilders [10]. It is widely used for ship design and stability calculations (see fig. 3.8). Developed by Delftship B. V., this software offers powerful tools for modeling, analyzing, and optimizing ship hull forms and their stability characteristics.

NAPA (Naval Architectural Package) is a comprehensive software suite developed by NAPA Ltd., primarily used in the maritime industry for ship design, analysis, and operations management [11]. It is trusted worldwide by naval architects, shipbuilders, and operators for its advanced capabilities in hydrodynamics, stability analysis, structural design, and optimization (see fig. 3.9).

3.3 Flooding calculations

It is important that a ship should be capable of sustaining at least a moderate degree of damage without sinking or capsizing. Ships are usually subdivided internally into watertight compartments to limit the extent of flooding that follows structural damage due to collision, grounding or stress of weather. During the design of the ship calculations are carried out to enable the naval architect to define a satisfactory disposition of major bulkheads to meet suitable safety standards and to examine the consequences of flooding certain spaces, or combinations of spaces, within a ship. With certain classes of ship, principally those carrying passengers, there are legal requirements to meet certain standards of subdivision.

Figure 3.8 – DeltShip software [10]

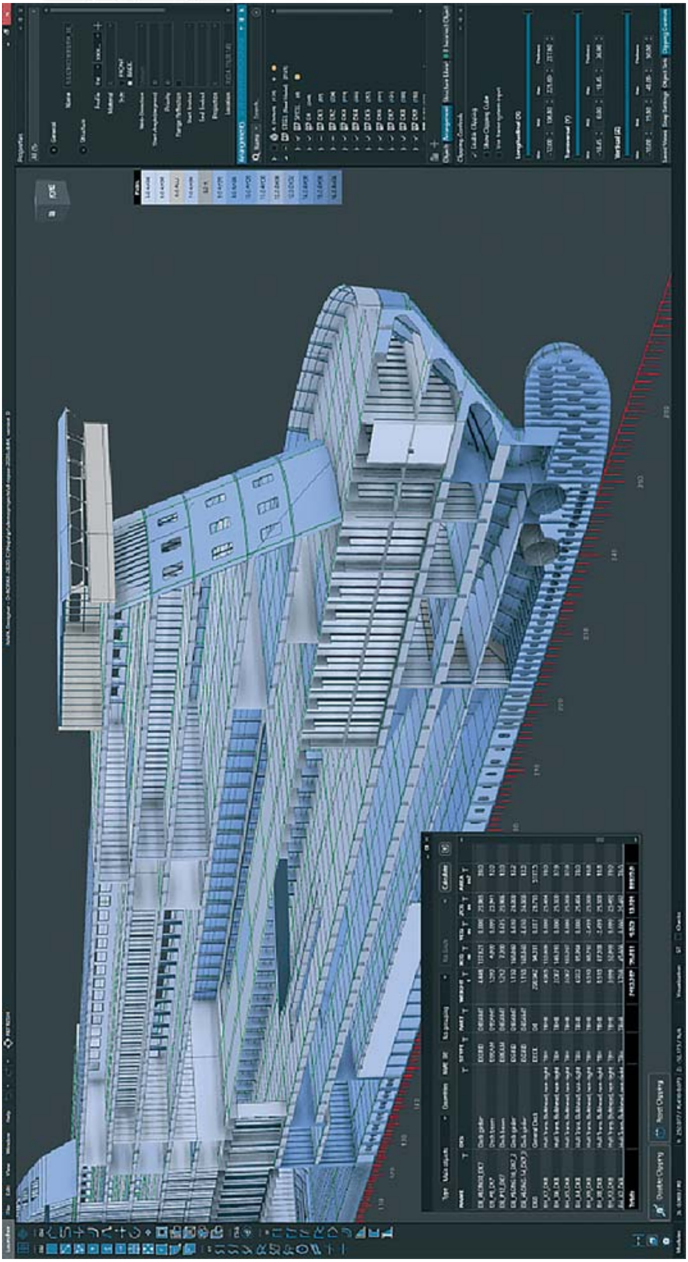

Figure 3.9 – NAPA software [11]

For other ships there is no legal necessity to meet such requirements, but the ships are allowed to load to a deeper draught if they do. Naval vessels must obviously meet very high standards of subdivision in order to fulfil their military role. Leisure craft are a special case in that foam filled buoyancy spaces are frequently used to ensure the craft survives damage. Nevertheless calculations are still needed to obtain an adequate disposition of such *buoyancy*.

4 SHIP RESISTANCE, MANOEUVRABILITY AND SEAKEEPING

4.1 Introduction to ship resistance

One of the most important considerations for a naval architect is the powering requirement for a ship. Once the hull form has been decided upon, it is necessary to determine the amount of engine power that will enable the ship to meet its operational requirements. Knowing the power required to propel a ship enables the naval architect to select a propulsion plant, determine the amount of fuel storage required, and refine the ship's center of gravity estimate.

As a ship moves through calm water, the ship experiences a force acting opposite to its direction of motion. This force is the water's resistance to the motion of the ship, which is referred to as «total hull resistance» (R_T). It is this resistance force that is used to calculate a ship's effective horsepower. A ship's calm water resistance is a function of many factors, including ship speed, hull form (draft, beam, length, wetted surface area), and water temperature. Total hull resistance increases as speed increases, as shown in fig. 4.1.

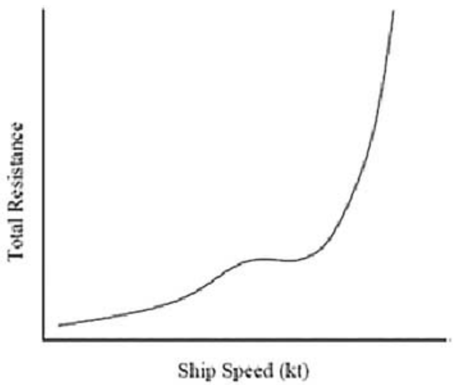

Figure 4.1 – Dependency between ship's speed and total resistance

The overall resistance of a ship may be broken into the following resistance components [12–14].

1. Frictional resistance. As a ship moves through the water, the friction of the water acting over the entire wetted surface of the hull causes a net force opposing the ship's motion. This frictional resistance is a function of the hull's wetted surface area, surface roughness, and water viscosity. Viscosity is a temperature dependent property of a fluid that describes its resistance to flow. Syrup is said to be a very viscous liquid; the fluid particles in syrup being very resistant to flow between adjacent particles and to other bodies. On the other hand, alcohol has a low viscosity with little interaction between particles. Although water has low viscosity, water produces a significant friction force opposing ship motion. Experimental data have shown that water friction can account for up to 85% of a hull's total resistance at low speed and 40–50% of resistance for some ships at higher speeds.

2. Pressure resistance. The fore and aft components of the pressure force *P* acting on each element of hull surface can be summed over the hull to produce a *total pressure resistance.* The frictional drag arises purely because of the viscosity, but the pressure drag is due in part to viscous effects and to hull wavemaking. An alternative physical breakdown of resistance considers *energy dissipation*.

3. Total viscous resistance. Figure 4.2 shows a body submerged in an ideal (inviscid) fluid. As the fluid flows around the body, there is a pressure distribution normal to the body. In the forward section of the hull there is a component of pressure resisting motion, and in the aft section of the body there is a component of pressure assisting motion. In an ideal fluid these pressure forces are equal and the body experiences no resistance.

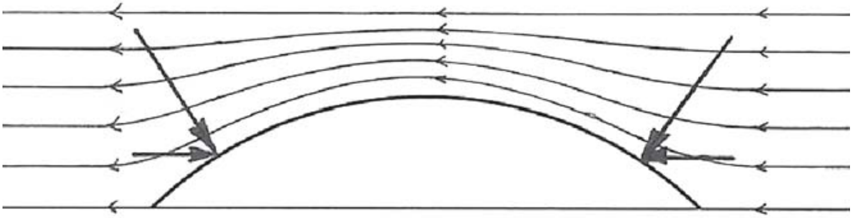

Figure 4.2 – Ideal flow around a submerged body

Unfortunately, water is not an ideal fluid, and therefore the body will experience resistance. fig. 4.3 shows a hull submerged in a real fluid with viscosity. Fluid particles cling to the body, resulting in the formation of a «boundary layer» where the flow rapidly changes speed, from zero speed at the side of the body, to the free-stream speed. Two forms of resistance happen as a result of viscosity (skin frictional resistance and viscous pressure resistance). Friction arises from the shear stresses in the fluid and acts tangential to the body. Viscous pressure resistance acts normal to the body.

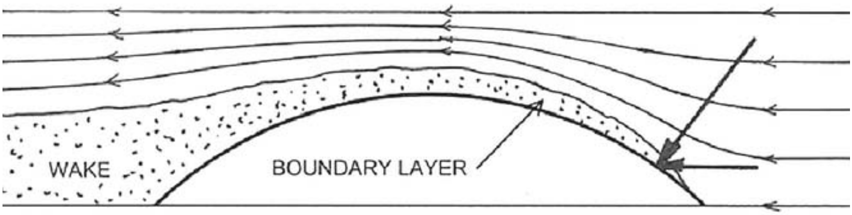

Figure 4.3 – Flow around a body submerged in water

4. Total wave resistance. The wave pattern created by the hull can be measured and analysed using its component waves. The creation of waves requires energy. As ship speed increases, the height of the waves produced by the ship increases, and therefore, the energy required to produce these waves also increases. This lost energy is referred to as wave-making resistance and often becomes a limiting factor in the speed of a ship. An object moving through the water creates both divergent waves, which spread outward from the ship, and transverse waves (see fig. 4.4).

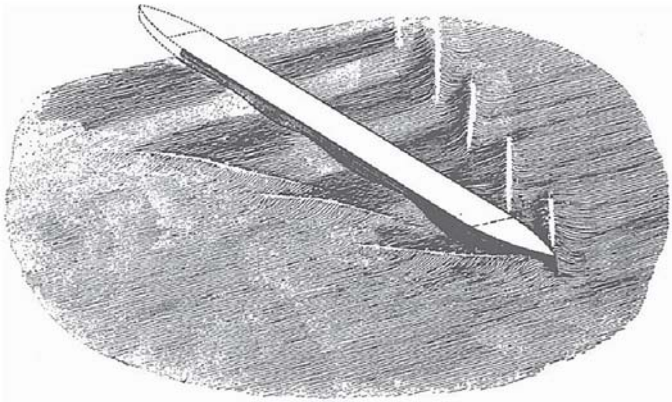

Figure 4.4 – Froude's sketch of a characteristic wave train for ships [13]

Thus, by physical measurement, it is possible to identify the following methods of breaking down the total resistance of a hull [12]:

1) pressure resistance + frictional resistance;
2) viscous resistance + remainder;
3) wave resistance + remainder.

These three can be combined to give a final resistance breakdown as:

Total resistance = Frictional resistance +
+ Viscous pressure resistance + Wave resistance.

A summary of these basic hydrodynamic components of ship resistance is shown in fig. 4.5.

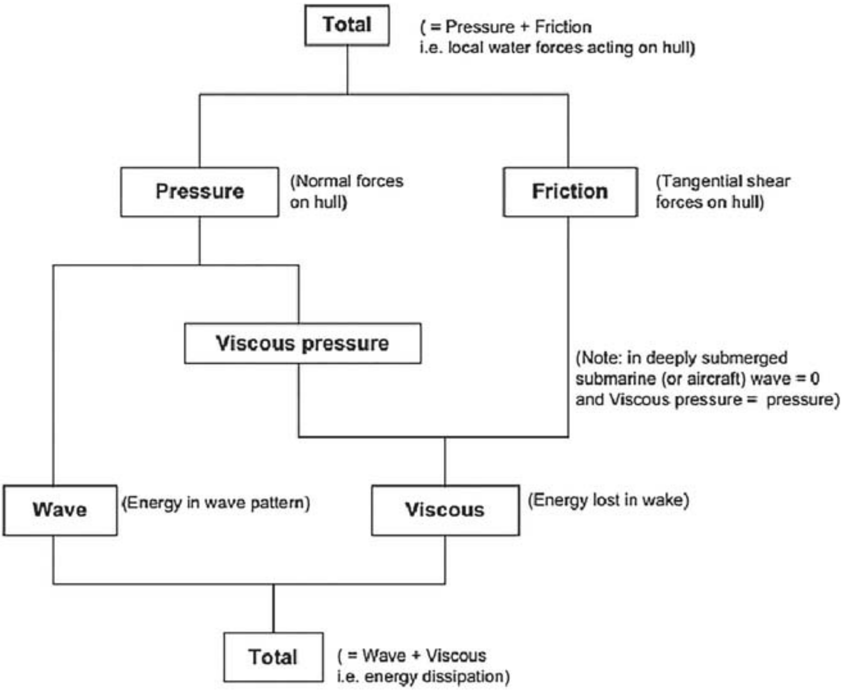

Figure 4.5 – Basic resistance components [12]

4.2 Manoeuvrability

All ships require to be controllable in direction in the horizontal plane so that they can proceed on a straight path, turn, or take other avoiding action as may be dictated by the operational situation. They must further be capable of doing this consistently and reliably not only in calm water but also in waves or in conditions of strong wind [3; 14; 15].

Considering control in the horizontal plane, a study of a ship's manoeuvrability must embrace the following.

– The ease with which it can be maintained on a given course. The term steering is commonly applied to this action, and the prime factor affecting the ship's performance is her directional or dynamic stability.

– The response of the ship to movements of her control surfaces, the rudders, either in initiating or terminating a rate of change of heading.
– The response to other control devices, such as bow thrusters.
– The ability to turn completely round within a specified space.

Once built, a ship's maneuvering characteristics are quantified during its sea trials. These can be split into three broad categories [3; 14; 15].

1. In many operational circumstances, it is more important for a ship to be able to proceed in a straight line than turn. That is, with the rudder set at midships, and in the absence of external forces, the ship will travel in a straight line. This is termed *straight line stability*. Despite this requirement, many hull forms do not have this level of directional stability. In particular, ships which are relatively short and wide such as tugs or harbor utility vessels and in certain circumstances, small combatants tend to have poor straight line stability.
2. In opposition to the requirement for straightline stability, it is also required for the ship to turn in a satisfactory manner when a rudder order is given. In particular: the ship must respond to its rudder and change heading in a specified minimum time; here should be minimum overshoot of heading after a rudder order is given. In practice, both these response quantities are dependant upon the magnitude of the rudder's dimensions, the rudder angle and ship speed.
3. It is most important for ships to be maneuverable when traveling at slow speeds. This is because evolutions such as canal transits and port entrances are performed at slow

speeds for safety reasons. Unfortunately, this is when the ship's rudder is least effective. Levels of slow speed maneuverability are specified in terms of turning circle and other quantifiable parameters at speeds below 5 knots.

4. The need for good directional stability (in particular controls fixed straightline stability) and minimum ship response oppose each other. For example, for a fixed rudder area, increasing the length of a ship will make it more directionally stable but less responsive to its rudder, similar effect is created by increasing the amount of vertical flat surface at the stern. However, increasing rudder area will always improve the response characteristics of a hull form and usually improve its directional stability as well. But, rudder dimensions are limited by the stern geometry. Also, larger rudders will increase drag and so reduce ship speed.

4.3 Seakeeping

In their broadest sense, the terms seakeeping and seaworthiness cover all those features of a vessel which influence its ability to remain at sea in all conditions, for which it has been designed, and carry out its intended mission [3; 14; 15]. They should, therefore, embrace stability, strength, manoeuvrability, and endurance as well as the motions of the ship and related phenomena.

Datailed deifinition: *seakeeping* is the study of the motions of a ship or floating structure, whin subjected to waves, and the resulting effects of humans, systems and mission capability.

A ship can be viewed as a rigid body that has six degrees of freedom (see fig. 4.6). The first three (1–3) motions are linear motions, and the last three (4–6) are rotational motions. All motions are measured relative to the ship itself.

The kinds of seas the ship experiences have an important influence on ship's motions. Larger waves produce, in general, larger motions. But, indeed, different ships experiencing the same waves behave differently, so ship characteristics are also important.

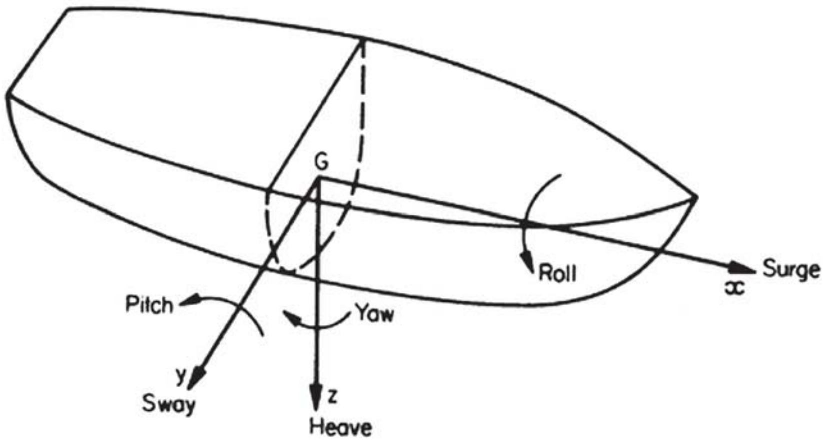

Figure 4.6 – Ship motions [14]

The problem of seakeeping analysis can be broken into three main components: waves (the input to the system), ship characteristics (the system), ship motions (the output of the system).

Some characteristics used for describing of water waves are as follows:

- *H* – wave height (always twice the wave amplitude);
- λ – wave length (distance frome one crest – or trought – to the next);
- *c* – wave celerity;
- *T* – wave period (time interval between successive crests – or troughs – passing a fixed point);
- *H*/λ – wave steepness.

The period of a ship’s roll motions (free oscillations) for calm water conditions may be estimated as follows

$$T_{б} = \frac{cB}{\sqrt{h}}, \qquad (4.1)$$

where B is ship’s breadth; h is metacentric height; c = 0,77… 0,78.

Pitch and roll motions of a ship in conditions of real wave surface consist of free and forced oscillatory motions.

5 INTRODUCTION TO SHIP DESIGN

5.1 Ship design spiral

In naval architecture, the design spiral (fig. 5.1) serves as an iterative framework for ship design. The spiral comprises of 4 phases of design, namely, concept design, preliminary design, contract design, and detailed design.

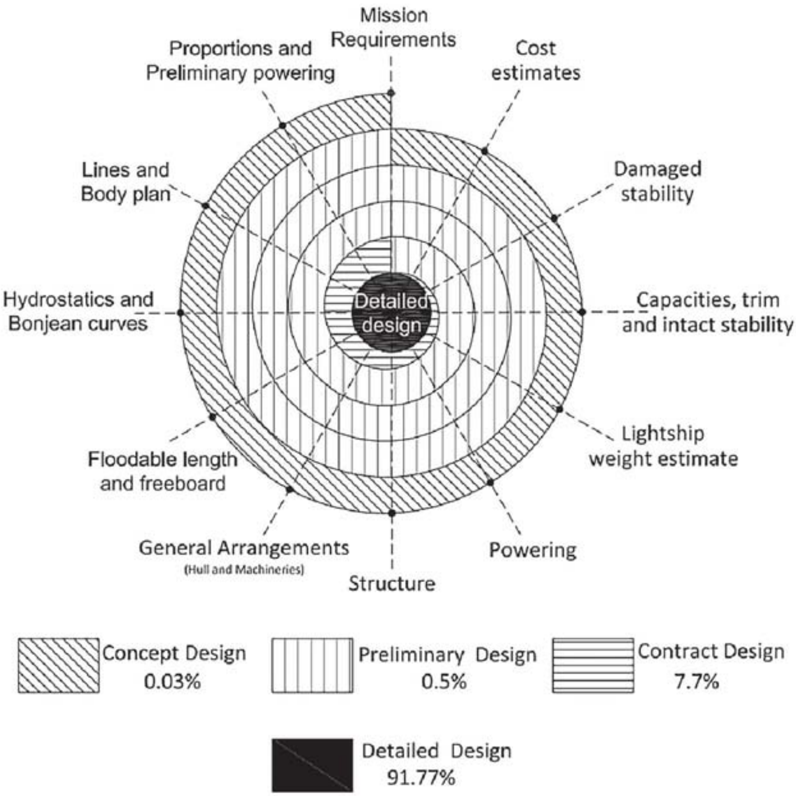

Figure 5.1 – Typical design spiral [16]

The different stages are defined as follows [16].

- The concept design stage is just the translation of the mission requirements to the ship. In this phase, a basic outline is created by taking into consideration all the steps of the design process.
- The preliminary design stage comprises iterations that help refine the concept design. Some properties defined during concept design do not change (e.g., ship dimensions, weight, and power).
- The contract design stage involves an iteration or two where the major characteristics of the ship are unchanged. The plan and specifications are prepared in this stage and are a part of the contract for the shipowner.
- In the detailed design phase, the production plans are made. This phase is the most time-consuming.

5.2 Mission requirements and ship design parameters

At the concept design stage, mission requirements should be clearly defined. These requirements are based on the shipowner's specifications, which may include vessel type, speed, deadweight capacity, cargo volume, port size constraints, fuel consumption, and budget. The objective is to ensure economic efficiency without compromising safety. The priority of these requirements varies by ship type. For naval vessels, mission planning emphasizes combat capabilities, balance, and performance rather than cost. For commercial vessels, such as cargo or passenger ships, economic feasibility and operational efficiency are key factors [16].

The ship design process does not begin by jumping directly into specific technical parameters. Instead, concept design decisions must account for vessel type, size, and speed, among other factors. The assumption that a larger ship is always more economical is not necessarily true, as factors such as port constraints, cargo handling facilities, route planning, and alternative cargo configurations must be considered. Fleet simulation studies often play a crucial role in defining mission requirements, helping to determine optimal operational conditions.

Once the mission requirements are defined, the next step is determining the ship's design variables. These include dimensions, hull characteristics, weight distribution, volume capacities, propulsion power, and electrical loads. Changes in these variables directly impact the ship's shape, size, and performance. Some parameters are calculated using fundamental engineering principles, while others rely on parametric models based on past experience. The objective is to achieve a fully balanced and viable design for further refinement in subsequent design phases. A successful design must meet all technical, stability, regulatory, and operational constraints while optimizing performance.

5.3 Environmental parameters

Ships operate in challenging environments where wind-generated waves and other external forces significantly affect their function. The primary environmental challenges include:

– increased hull resistance, leading to speed reduction and higher fuel consumption;
– ship motions that may cause structural damage, cargo displacement, and discomfort for crew and passengers;
– difficulties in maintaining course stability, maneuverability, and directional control.

To accurately predict these effects, oceanic wave patterns are analyzed using data from geographically distributed buoy measurements and satellite observations. For submarines and offshore platforms, underwater currents and tidal variations are also critical factors. Corrosion from seawater is another major concern, requiring protective coatings and treatments to maintain structural integrity. Marine fouling, caused by biological growth on the hull's wetted surface, increases resistance and must be controlled through proper maintenance.

For ships operating in ice-covered waters, structural reinforcements are necessary to withstand extreme loads. The primary effects of ice on ships include:

– high localized structural stress, particularly on the hull's side shell and bottom;
– increased resistance due to ice-breaking and crushing forces;
– greater maneuvering challenges and higher power requirements.

5.4 Economic parameters

In ship design, it is critical to get an overview of the relationship between ship form and size and main cost resources (amortised in the case of basic building costs), namely hull, outfitting equipment, machinery, and fuel. The total cost of ships is not constant, i.e., a long and narrow ship costs less than a short and full ship. Also note that an increase in beam and/or fullness increases cost. The shorter the ship, the higher the share of fuel costs and the lower the share of the outfit and, up to a point, hull costs. Machinery costs do not vary significantly for ships of a similar type and mission requirements. On the other hand, the type of ship and its operations will also affect the overall operational economic model. For example, for a naval ship, a lifetime cost model is more appropriate. For a commercial vessel, such as a Ro-Ro, an amortised annual cost model is more suitable. For a commercial ship, before an economic model/criterion can be defined and assessed, we must have a model to estimate the annual cash flow shows whether enough cash is generated for the operations to be funded. There is only one source of inward cash flow, namely, ship revenues, and five major sources of costs, namely [16]:

- operational costs (including repair and maintenance);
- voyage costs (mainly fuel costs and port-related costs);
- cargo handling costs;
- amortised capital costs (consisting of capital and interest);
- taxes and dividends.

Freight rates, fuel prices, interest rates can fluctuate in accordance with market pressure and, thus, cause ambiguities when incorporated into the ship design model. Such costs are very difficult to predict, particularly in a model applicable to the life of the ship. The ship owner/operator has to set a freight rate, which is determined by market forces. An economic criterion has to be set to help control risks associated with cost fluctuations. Furthermore, this criterion must enable comparisons between investments in various marine transportation operations and services and investment opportunities in other sectors.

5.5 Ship main dimensions

In early design stage there are two main methods for the estimation of the main dimensions namely (a) the empirical and (b) the parametric [16]. In the empirical method, the basis of assessment depends on the utilization of statistical data of similarly built ships. Data may come from an open-source or a commercial/internal database and are usually represented on graphs. The method is based on two assumptions: (a) data are reliable; (b) ships included in the database are economically and efficiently designed. In the parametric method, a study from scratch is conducted seeking for a suitable combination of dimensions and form coefficients that satisfy some selected objectives and design constraints. For instance, a ship's main dimensions can be estimated based on an optimization model for selected economic objectives such as minimum operating or building cost. The parametric method is used when there is a lack of data on the same type and size of the new design.

Selection factors. Although the main objective in selecting the main dimensions is to fulfil the owner's requirements in terms of payload and speed, IMO regulations and the Classification requirements may affect design. Accordingly, assorted factors should be considered during the selection of ship main dimensions and form coefficients. These factors may help design for (a) hydrodynamic performance (resistance & propulsion, seakeeping, and maneuverability); (b) transverse and longitudinal stability; (c) structural strength; (d) sufficient volume for cargo, and also ensure sustainable construction costs. The basic design factors are categorized as described below.

Factors affecting ship length (L). Length is a function of displacement and speed. It has a significant influence on the weight of the steel structure and accommodation/outfitting, hence on the construction cost. Also, it strongly affects both the ship's calm water resistance and seakeeping performance (motions, accelerations, dynamic loads, added resistance, and speed loss in seaways).

Factors affecting the Breadth (B), Draught (T), and Depth (D). These dimensions are coupled in fine form coefficients. The volume of a hold depends on the type of cargo, the stowage factor, and mainly affects the depth required; *B* has a significant influence on transverse stability and cargo-carrying capacity. Maneuvering and propulsion efficiency are affected by *T*. In rough seas, both breadth and draught affect the wave added resistance, while draught affects slamming. The required freeboard affects the selection of both draught and depth of the ship. Consequently, breadth, draught, and depth are key in damage stability pertaining to safety against flooding and capsize. The coupling of the length with the draught has a compelling impact on the longitudinal strength.

Operational limitations (e.g., port drafts and confinement, shipyard dry dock principal particulars, crossing channel width and depth limitations, bridge crossings, etc.; see table 1) that may override an initially set mission and performance objectives.

Table 5.1 – **Canal constraints on ship design**

Canal	Constraints
Kiel	LOA < 315 m B < 40 m T < 9,5 m
Panama	LOA < 290 m B < 32.24 m T < 13 m
New Panama canal	LOA < 427 m B < 55 m T < 18,3 m
St Lawrence	LOA < 222 m B < 23 m T < 7,6 m
Suez	T < 18,29 m

There are three practical approaches that may be used to decide the main dimensions of a ship. Those are known as Normand's number, statistical and direct calculations approaches.

Normand's number approach is defined as a factor by which the change in one or various weight components is multiplied to give the change in the total displacement of a ship [16].

$$N = \frac{d\Delta}{dW} = \frac{\Delta}{\Delta - (W_H + W_O) - \frac{2}{3}(W_M + W_F)}, \qquad (5.1)$$

where dW is the difference between the deadweight of the new design and the reference ship, $d\Delta$ is the difference in displacement between the new design and the reference ship, W_H is the hull weight of the reference ship, W_O is the outfitting weight of the reference ship, W_M is the machinery weight of the reference ship, and W_F is the fuel weight of the reference ship.

A challenge in Normand's number approach is the lack of available data. Empirical charts are summarized in figures 5.2 and 5.3. The main ship dimensions are calculated by setting one or two of the reference ship's characteristics as constant (e.g., C_b).

In the statistical approach, the empirical method is used to select the main dimensions. There are various procedures, curves, and regression-based equations that may be used to decide on selecting a ship's main characteristics. An example of the procedure to be followed is given as presented below.

- The displacement of the new design is calculated based on tabular values of deadweight displacement ratios. Deadweight should be known as an owner requirement.
- The length of the ship is calculated using regression-based equations. The block coefficient is calculated using regression-based equations.

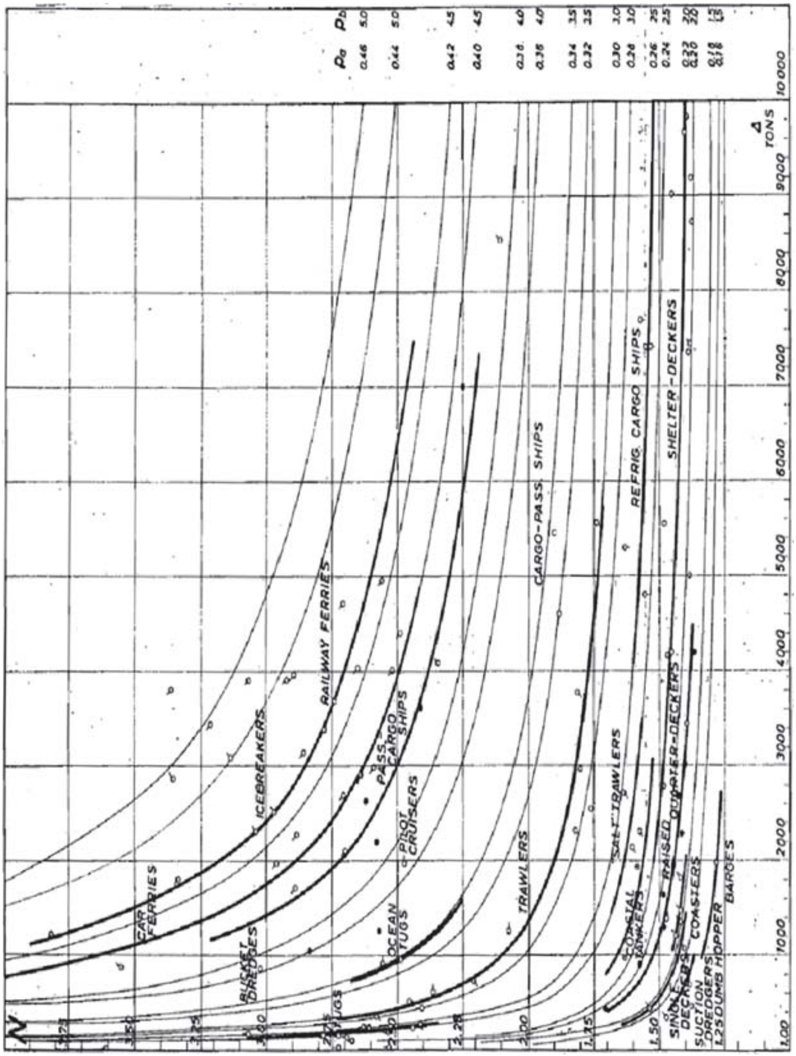

Figure 5.2 – Normand's number for merchant ships less than 10,000 tons [16]

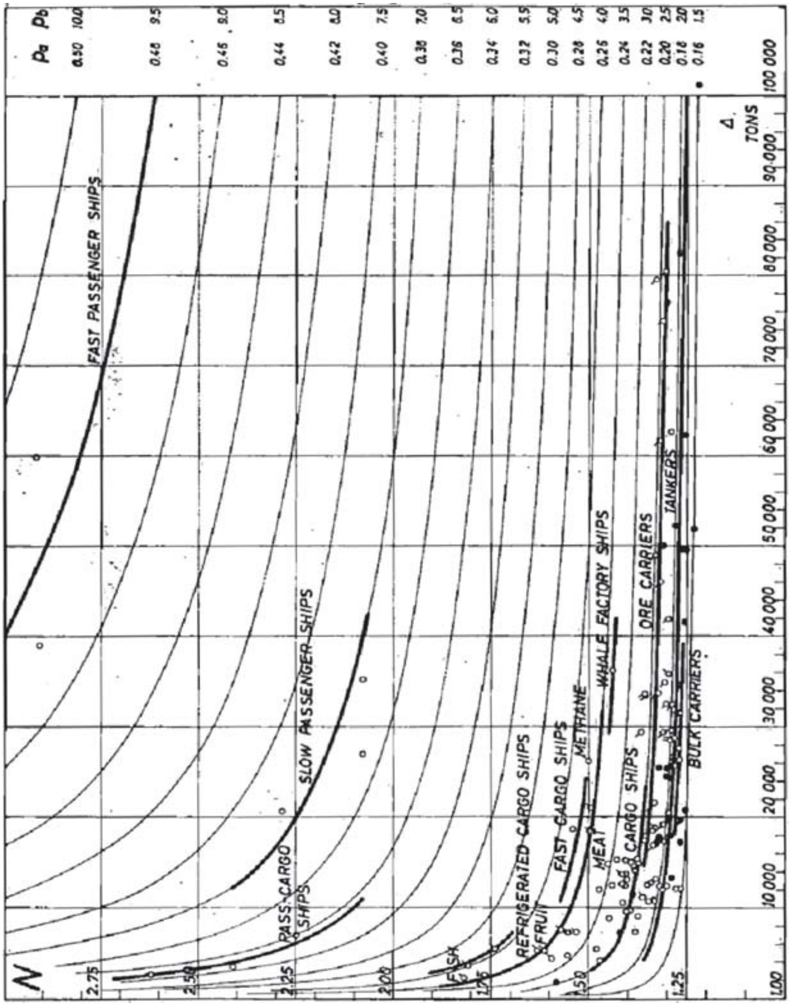

Figure 5.3 – Normand's number for merchant ships up to 100,000 tons [16]

– The length-to-breadth ratio is estimated based on empirical formulae or tabular values. Hence, breadth is calculated.
– The draught is calculated based on displacement, breadth, length, and the block coefficient. Any limitations on the draught, D/T or B/T ratios should be considered.
– The length-to-depth ratio is calculated based on tabular values from statistical data.
– The depth is obtained.

Direct calculations may be used when there is a lack of data from similar types or sizes of ships, or when the new design is uncommon in shape and/or size, it is crucial to start the design from scratch based on objectives, requirements, and constraints. In such cases, the purpose of the designer is to seek the best combination of dimensions and form characteristics that will satisfy the given objectives. However, at preliminary design stages definition of accurate relationships between the different ship parameters and design economic objectives may be challenging. Thus, solutions are implemented at the detailed design stage through the use of a mathematical optimization model embedded in commercial software (e.g., NAPA, Rhinoceros, MAXSURF, etc.).

6 SHIPPING REGULATIONS. CLASSIFICATION SOCIETIES. MATERIALS OF SHIPS

6.1 Shipping regulations

There can be various physical constraints while designing a ship, as the path, the ports, and the seas she encounters vary and matter. While the ship is being constructed, the shipyard should consider those. Technical constraints relate to the limitations of ship equipment and systems (e.g., propulsion, power generation and delivery, etc.), material choice, and degradation etc.

These limitations are linked to budget and regulatory restrictions and should be considered at early design stages. Shipping laws, rules, and regulations are available to ensure that ship design activities are carried out without endangering the safety of the crew and passengers, the integrity of the hull and cargo, and the marine environment. This section outlines some of the key background to maritime regulation with the view to increase the reader's understanding of the importance of regulations for naval architecture design and shipping practice. Further knowledge is available under the following websites [16]:

– International Maritime Organization (www.imo.org);
– International Labor Organization (www.ilo.org);
– International Association of Classification Societies (www.iacs.org);
– The European Maritime Safety Agency (www.emsa.org);
– The Paris MOU port state control authorities (https://www.parismou.org/);

- The Oil Companies International Maritime Forum (https://www.ocimf.org/);
- The Cruise Lines International Association (https://cruising.org/);
- The Baltic Environmental Protection Commission (https://helcom.fi/);
- The Baltic exchange (https://www.balticexchange.com/);
- RightShip (https://www.rightship.com/);
- The Green Award Foundation (https://www.greenaward.org/).

Because ships can sail around the world between different states, it is appropriate to have worldwide regulations to avoid a situation where each coastal state has its own rules on issues like ship structure, manning, etc. Thus, maritime safety regulation starts from the international level (the United Nations – UN), but it is also monitored at supranational (the European Union – EU), national , and regional levels (see fig. 6.1).

The modern format of the international regulatory framework is based on the UN Convention on the Law of the Sea (UNCLOS), introduced in 1994. The convention establishes the most fundamental rules governing all uses of the oceans and their resources, including the movements of ships. Under this convention, states are obliged to prevent and control marine pollution and are liable for damage caused by the violation of their international obligations to combat such pollution. UN delegates maritime issues to two UN agencies, namely the International Maritime Organization (IMO) and the International Labour Organization (ILO).

IMO is the agency responsible for ship safety, pollution, and security. ILO is responsible for the laws governing maritime personnel. The main instrument of both agencies is

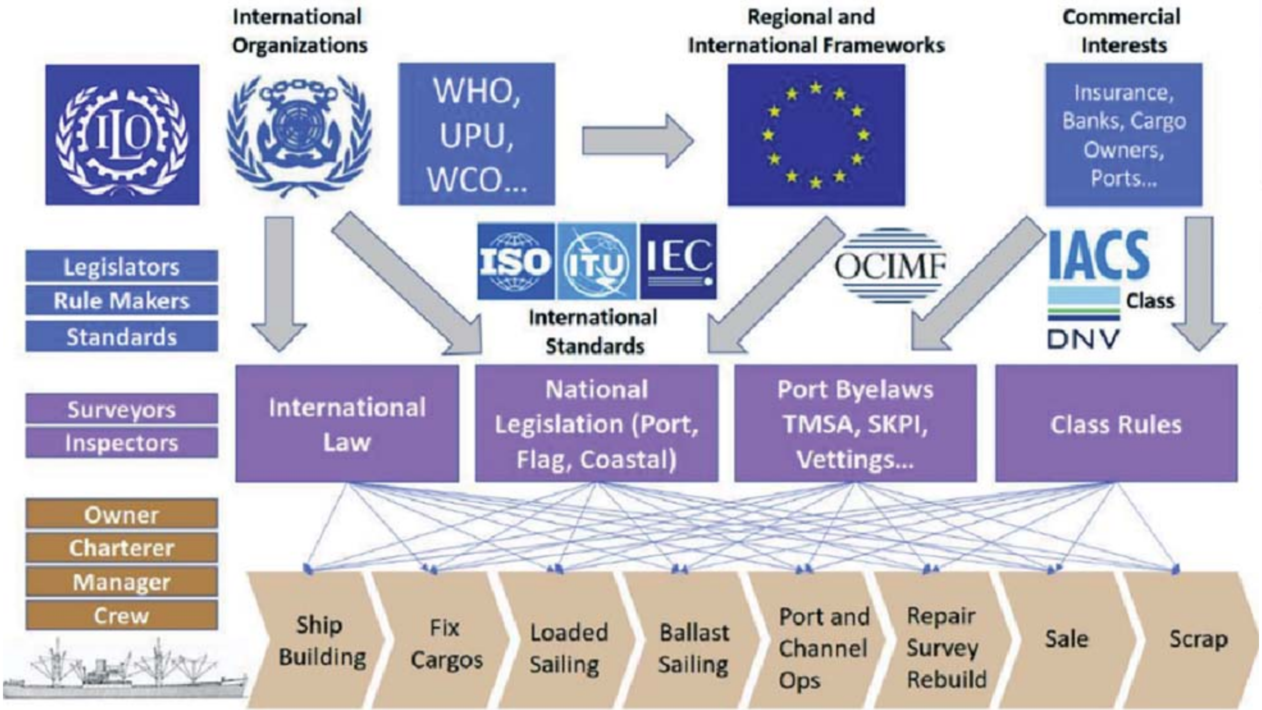

Figure 6.1 – The interplay of maritime regulations [16]

conventions, which become laws when they are enacted by each UN member state. IMO and ILO also give codes, guidelines, or recommended practices on important matters not considered suitable for regulation by formal treaty instruments. Key regulatory instruments that influence ship design are the codes for Safety of Life at Sea (SOLAS) and the International Code for Maritime Pollution Prevention (MARPOL).

6.2 Classification societies

A cargo shipper and the underwriter requested to insure a maritime risk require some assurance that any particular vessel is structurally fit to undertake a proposed voyage. To enable the shipper and underwriter to distinguish the good risk from the bad, a system of classification has been formulated over a period of some two hundred years. During this period, reliable organizations have been created for the initial and continuing inspection of ships so that classification may be assessed and maintained [17].

Classification societies establish standards, usually called classification rules, regulating the design and maintenance of ships, and conduct periodic surveys to implement these standards. Classification societies have their own individual histories, some having been in business for more than 100 years. Their primary purpose is to perform inspections and surveys of vessels to verify that they are maintained to the requirements of classification societies' rules and standards. These inspections and surveys are performed at periodic intervals to ensure compliance with the respective rules [18].

The International Association of Classification Societies (IACS) was formed by seven leading societies on 11 September 1968. IACS presently consists of 10 member societies and one associate member. With 90% of the world's cargo-carrying tonnage covered by the rules of IACS members, IACS plays a vital role in improving the standards of the maritime industry. The value of their combined and unique levels of knowledge and experience has been widely recognized. In 1969, IACS was given consultative status with the IMO with the first permanent representative appointed in 1976.

In recent years, the principal classification societies have developed software packages for use by shipyards that incorporate dynamic-based criteria for the scantlings, structural arrangements, and details of ship structures. This was a response to a perception that the traditional semi-empirical published classification rules based on experience could be inadequate for new and larger vessel trends [17].

To maintain the assigned class, the vessel has to be examined by the Society's surveyors at regular intervals. The major hull items to be examined at these surveys only: annual surveys, intermediate surveys, docking surveys, in-water surveys, and special surveys.

6.3 Materials of ships

There is a wide range of materials used in shipbuilding, comprising ferrous metals, non-ferrous metals, plastics, GRP (Glass Reinforced Plastics/fibre glass) and wood. The most widely used material in shipbuilding remains steel, especially plain carbon or mild steel, approximately 90% of the materials.

Steel for hull construction purposes is usually mild steel containing 0,15 percent to 0,23 percent carbon and a reasonably high manganese content [17]. Both sulphur and phosphorus in the mild steel are kept to a minimum (less than 0,05 per cent). Higher contents of both are detrimental to the welding properties of the steel, and cracks can develop during the rolling process if the sulphur content is high.

Materials issues relating to the construction of a ship:

- strength;
- weldability;
- toughness;
- marine corrosion;
- formability;
- the cost.

A vessel hull is always in contact with water (both fresh river and saline sea water) and is exposed to other impacts, for example, on a pier while mooring at a seaport. Therefore, the hull material must ensure the set level of strength, flexibility and viscoelasticity under different thermal conditions. Rolled steel used to manufacture vessel and ship hulls must be sufficiently resistant to corrosion, but at the same time be easily deformed (bending and cutting) and welded at dockyards.

Strength is a measure of the material property to resist deformation and to maintain its shape. It is quantified in terms of *yield stress* or *ultimate tensile strength*. High carbon steels and metal alloys have higher strength than pure metals. Ceramic also exhibit high strength characteristics.

Hardness is a measure of the material property to resist indentation, abrasion and wear. It is quantified by hardness scale such as Rockwell and Brinell hardness scale that measure indentation/penetration under a load. Hardness and Strength correlate well because both properties are related to inter-molecular bonding. A high-strength material is typically resistant to wear and abrasion.

Ductility is a measure of the material property to deform before failure. It is quantified by reading the value of strain at the fracture point on the stress strain curve. Ductile materials can be pulled or drawn into pipes, wire, and other structural shapes. Examples of ductile material: low carbon steel, aluminum, copper, brass.

Toughness is a measure of the material ability to absorb energy. It is measured by two methods: integration of stress strain curve and Charpy test

Ship classification societies originally had varying specifications for steel; but in 1959, the major societies agreed to standardize their requirements in order to reduce the required grades of steel to a minimum. There are now five different qualities of steel employed in merchant ship construction. These are graded A, B, C, D and E [19].

- Grade A is a mild steel used in the majority of the ship structures of less than 20 mm thickness such as bulkheads, tank top, non strength decks and superstructures.
- Grade B is a better quality mild steel than Grade A and specified where thicker plates are required in the more critical regions.
- Grade D is a 'notch-tough' steel which resists the spread of cracks and has higher strength. It is used for structures greater than 25 mm thick.
- Grade E is an 'extra notch tough' steel because this is a heat-treated Grade D steel used for very thick plating in excess of 50mm thick. It is used for sheer strakes, bilge strakes, keels i.e. all high-stress regions of the ship.

Steels having a higher strength than that of mild steel are employed in the more highly stressed regions of large tankers, container ships and bulk carriers.

A range of steel sections is rolled hot from the ingots. The more common types associated with shipbuilding are shown in fig. 6.2. It is preferable to limit the sections required for shipbuilding to those readily available, that is, the standard types; otherwise, the steel mill is required to set up rolls for a small amount of material, which is not very economical.

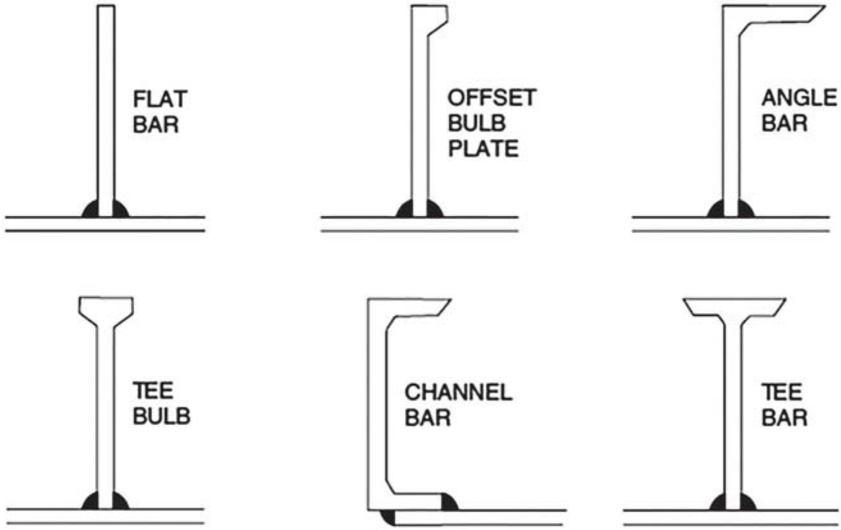

Figure 6.2 – Steel sections of shipbuilding [17]

There are three advantages which aluminium alloys have over mild steel in the construction of ships [17]. Firstly, aluminium is lighter than mild steel (approximate weights being aluminium 2,723 tonnes/m^3, mild steel 7,84 tonnes/m^3), and with an aluminium structure, it has been suggested that up to 60 per cent of the weight of a steel structure may be saved. This is in fact the principal advantage as far as merchant ships are concerned, the other two advantages of aluminium being a high resistance to corrosion and its non-magnetic properties. The non-magnetic properties can have advantages in warships and locally in the way of the magnetic compass, but they are generally of little importance in merchant vessels. Good corrosion properties can be utilised, but correct maintenance procedures and careful insulation from the adjoining steel structure are necessary. A major disadvantage of the use of aluminium alloys is their high initial cost (this has been estimated at 8 to 10 times the price of steel on a tonnage basis). This high initial cost must be offset by an increased earning capacity of the vessel, resulting from a reduced light-ship weight or increased passenger accommodation on the same draft.

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

Only in those vessels having a fairly high speed and hence power, also in ships where the deadweight/lightweight ratio is low, are appreciable savings to be expected. Such ships are moderate- and high-speed passenger vessels like cross-channel and passenger liners, having a low deadweight. A very small number of cargo liners have been fitted with an aluminium alloy superstructure, principally to clear a fixed draft over a river bar with maximum cargo. Aluminium alloy is now extensively used for the construction of multi-hull and other high-speed ferries where its higher strength-to-weight ratio is used to good advantage.

6.4 Mechanical properties of materials

Metals are tested to ensure that their strength, ductility, and toughness are suitable for the function they are required to perform. In comparing the strengths of various metals, stresses.

A stress-strain curve is all about how a particular material behaves under various levels of stress until it breaks down or fractures. Stress is a measure of the ability of a material to transmit a load, and the intensity of stress in the material, which is the load per unit area, is often stated. Stress σ may be calculated as follows

$$\sigma = \frac{P}{A}, \tag{6.1}$$

where P is acting force, A is area of a detail. The units of stress is Pa or N/m^2.

Total strain is defined as the total deformation that a body undergoes when subjected to an applied load. The strain is the deformation per unit length. Strain ε may be calculated as follows

$$\varepsilon = \frac{\delta l}{l}, \tag{6.2}$$

where δl is the elongation of the considered detail due to the force P; l is the initial length of a detail.

If a mild steel bar is placed in a testing machine and the extensions are recorded for uniformly increasing loads, a graph of load against extension, or stress against strain, may be plotted as in fig. 6.3.

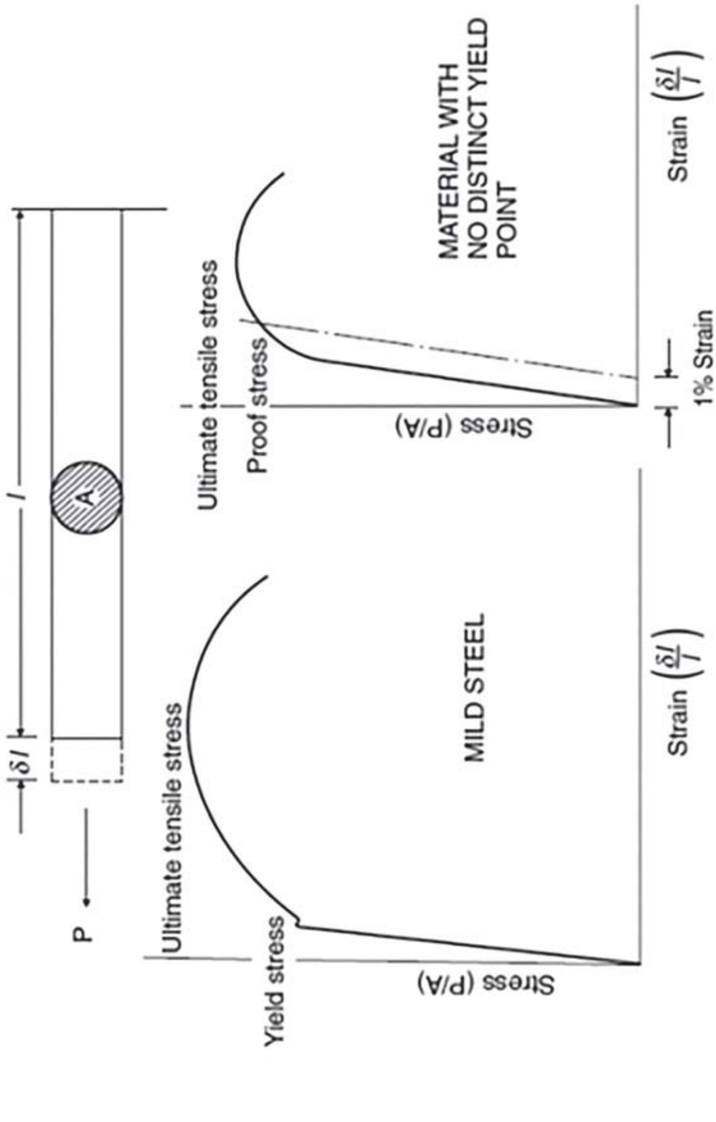

Figure 6.3 – Stress/strain relationship of shipbuilding materials [17]

7 HULL STRUCTURE OF A SHIP

7.1 Definitions of hull elements

1. Keel. At the center line of the bottom structure is located the keel, which is often said to form the backbone of the ship. This contributes substantially to the longitudinal strength and effectively distributes local loading caused when docking the ship. The commonest form of keel is that known as the ‘flat plate’ keel, and this is fitted in the majority of ocean-going and other vessels (see fig. 7.1). A form of keel found on smaller vessels is the bar keel. The bar keel may be fitted in trawlers, tugs, etc., and is also found in smaller ferries. Duct keels (fig. 7.2) are provided in the double bottoms of some vessels. These run from the forward engine room bulkhead to the collision bulkhead and are utilized to carry the double-bottom piping. The piping is then accessible when cargo is loaded, an entrance to the duct being provided at the forward end of the engine room. No duct is required aft of the engine room as the piping may be carried in the shaft tunnel.

2. Girders are heavy scantling longitudinal stiffeners situated at the bottom, sides, and deck, with greater dimensions than longitudinal. Large bars, I-beams, or high scantling L-sections are placed at definite intervals between longitudinals in the top and bottom structure [1]. The keel is often a girder of high dimensions (see fig. 7.1–7.2).

3. Floors: These are made up of cross members that are mounted perpendicular to the keel and girders. They usually stiffen the bottom shell plating against lateral loads and, for double bottom constructions, also help support the inner

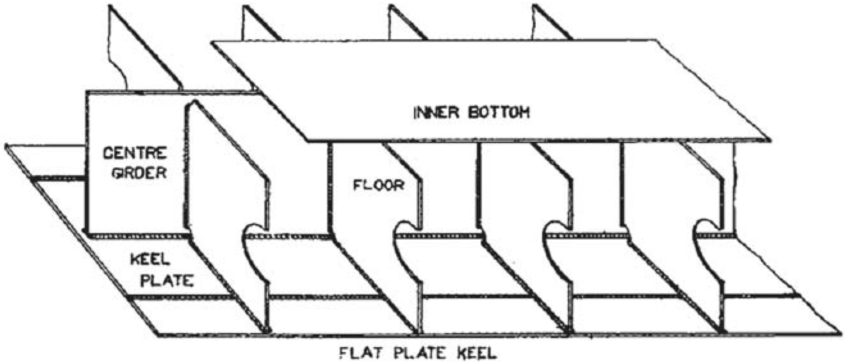

Figure 7.1 – Flat keel [20]

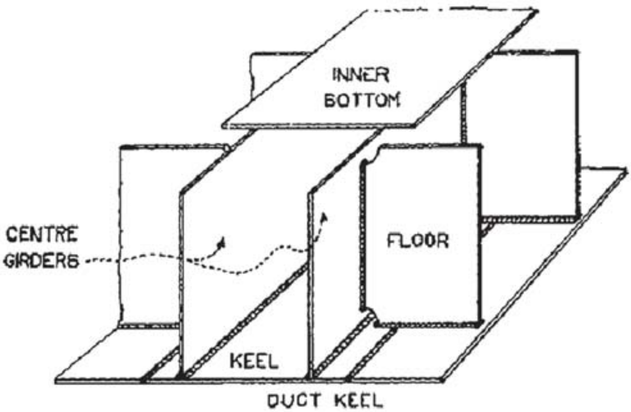

Figure 7.2 – Duct keel [20]

bottom plating. Floors are generally of two types, solid floors and bracket floors. (see fig. 7.3–7.4). Watertight floors are fitted beneath the main bulkheads and are also used to subdivide the double-bottom space into tanks for ballast water, fuel oil, or fresh water. Solid plate floors of non-watertight construction are lightened by manholes. Manholes are provided for access through the tanks, and lightening holes are cut to reduce the steel weight of these floors. Also, small air and drain holes may be drilled at the top and bottom edges of the solid plate floors in the tank spaces. Bracket floors are fitted between solid plate floors. Bracket floors consist of plate brackets attached to the center girder and the side shell with bulb plate or angle stiffeners running between. The stiffeners are supported by angle bar struts at intervals and by any side girders.

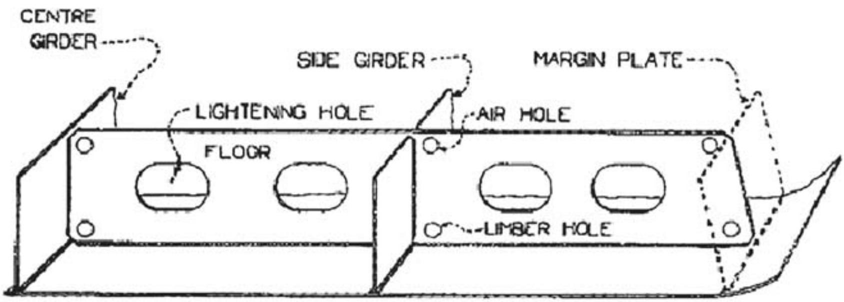

Figure 7.3 – Plate floor [20]

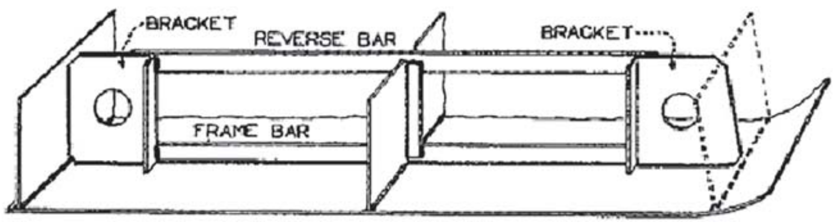

Figure 7.4 – Bracket or open floor [20]

4. Frames: These are vertical members that make up the framing of the vertical part of the hull (fig. 7.5). Frame type and spacing vary considerably depending on the ship's construction.

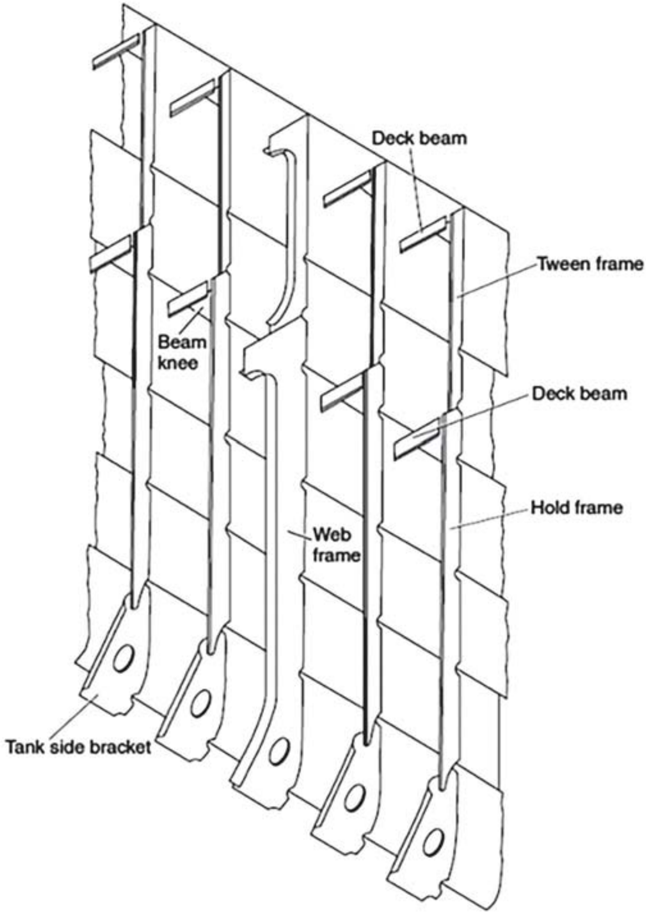

Figure 7.5 – Side shell with transverse framing [17]

5. Deck beams: they are transverse stiffening members running laterally and strengthening the deck plating (see fig. 7.6).

6. Deck girders: These are longitudinal members that combine with the beams to form the longitudinal framing of the deck.

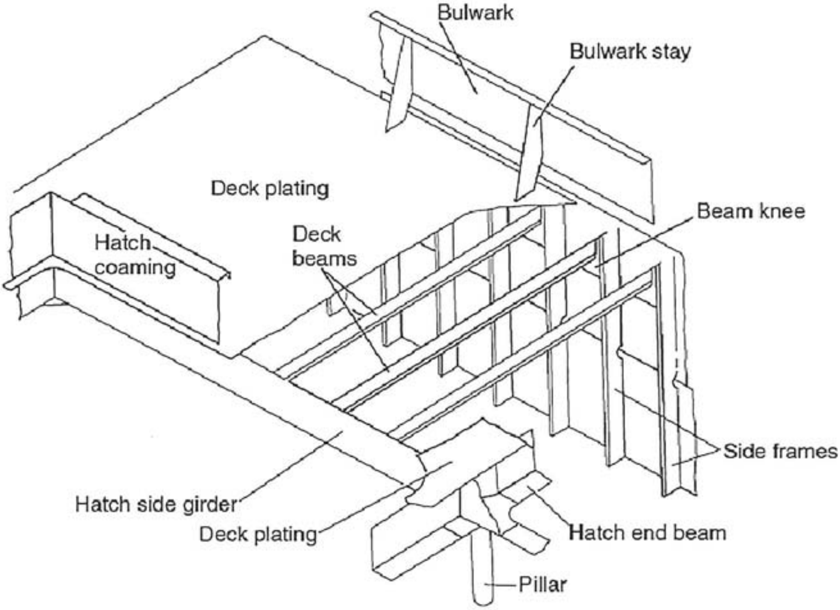

Figure 7.6 – Transversely framed deck [17]

7. Longitudinals are stiffeners that run in a longitudinal direction, i.e., from forward to aft. They resist the longitudinal loads and their effects, like bending stresses and buckling, and support other connected members. They have definite scantlings and are uniformly spaced depending on the vessel's bottom and the decks (see fig. 7.7).

8. Web frames: Oversized members that replace a frame at certain locations on a ship (see fig. 7.5).

9. Bracket: A general term that identifies any part used to connect two members.

10. Beam knee: Bracket located at the end of deck beams that connect the beam and frame to the shell plating.

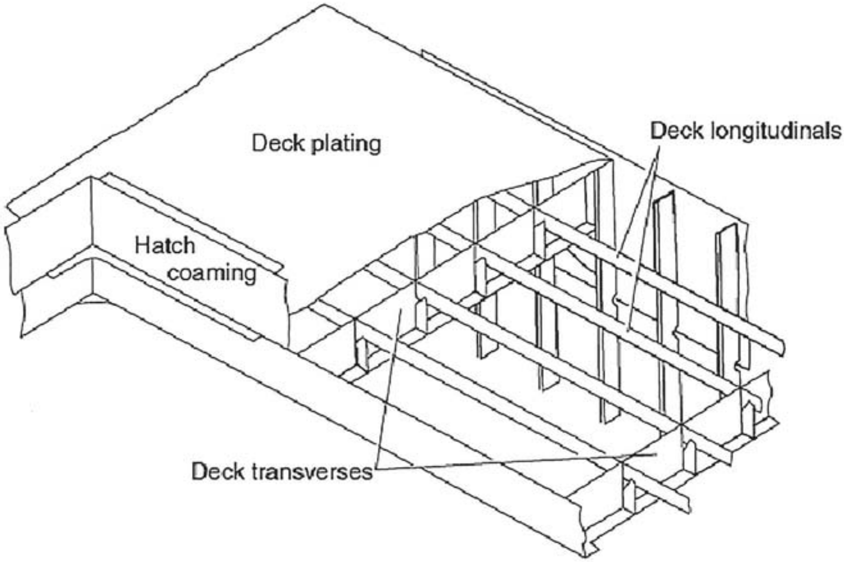

Figure 7.7 – Longitudinally framed deck [17]

11. Pillar: Vertical member inside a ship that connects the deck to the ship's bottom, where it is installed between two tween decks, especially around hatches. They are quite bulky and complicate cargo handling inside holds.

12. *The shell plating* forms the watertight skin of the ship and at the same time contributes to the longitudinal strength and resists vertical shear forces.

13. The double bottom is the watertight space between the bottom plating and the tank top. Its height varies according to the size and type of ship, but it is generally between 0,75 and 1,5 metres. A double bottom is divided into several watertight compartments by watertight floors and girders. These compartments can be used to store fuel, oil, and ballast water (see fig. 7.8 and fig. 7.9).

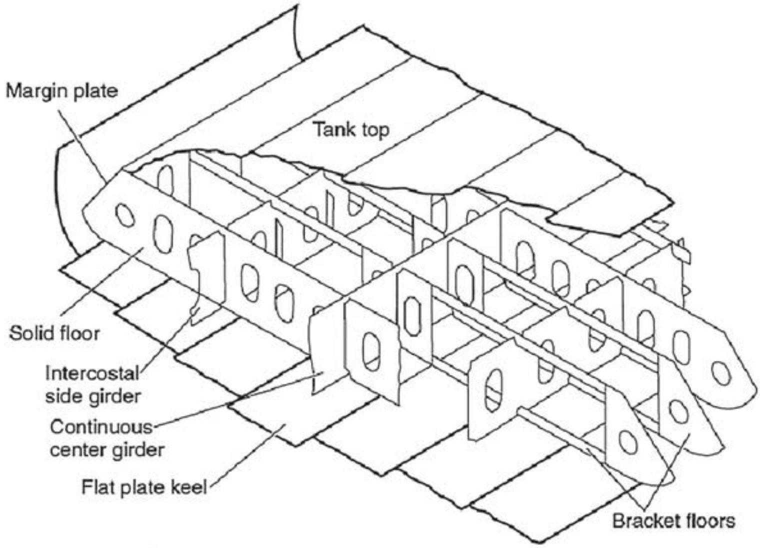

Figure 7.8 – Transverse stability at small angles

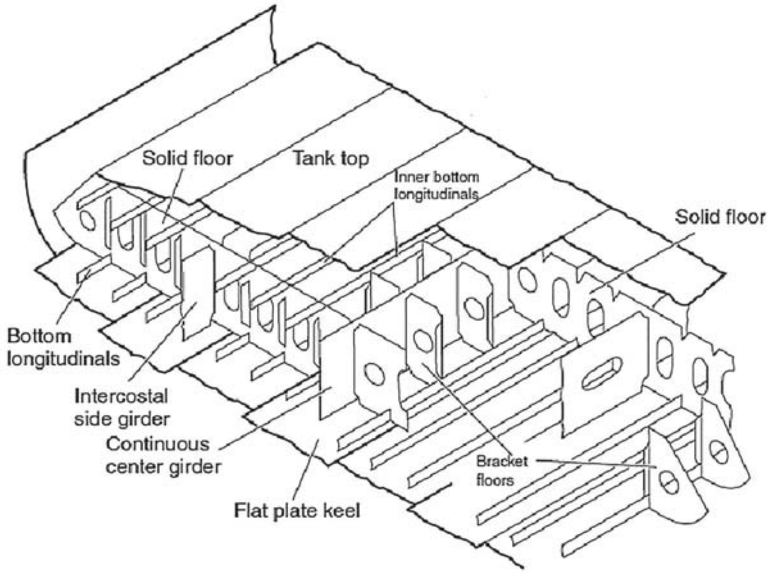

Figure 7.9 – Longitudinally framed double bottom [17]

7.2 Types of construction

1. Transverse framing is used primarily for ships less than 120 metres in length. There are more transverse members like frames than longitudinals, which are comparatively closely spaced. This is due to the effects of lateral loading. The floors, frames, and beams form rings spaced closely together (see fig. 7.10).

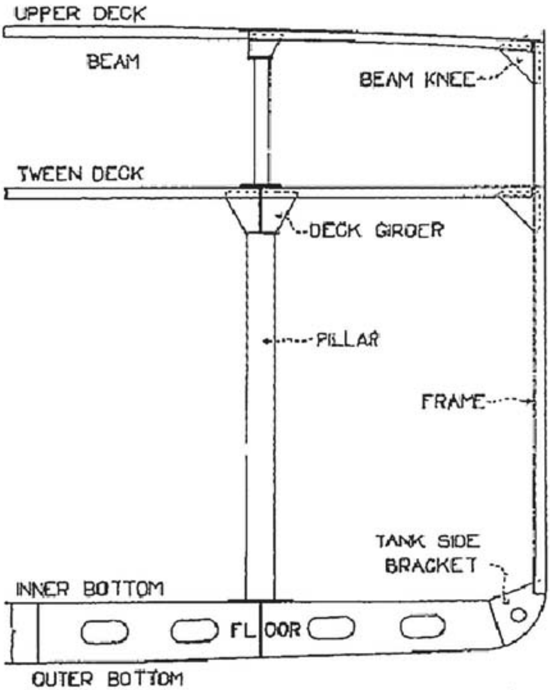

Figure 7.10 – Transverse framing system [20]

2. Longitudinal framing is mandatory for very large ships, oil tankers and bulk-ore carriers. Longer vessels are more susceptible to flexural or longitudinal loading effects, and hence they have closely spaced longitudinal members greater than transverse. The rings are formed of floors, deck beams and web frames that replace the frames. These rings are farther apart than in transverse framing (see fig. 7.11).

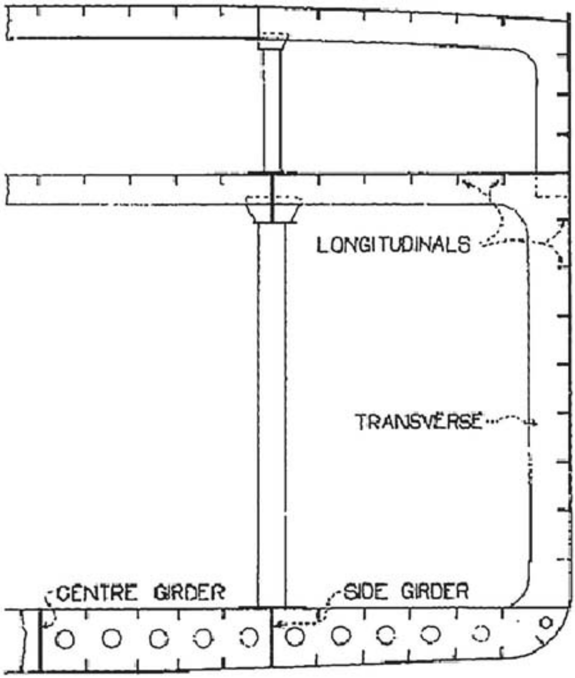

Figure 7.11 – Longitudinal framing system [20]

3. Mixed framing. Mixed framing combines longitudinal and transverse framing. One type of framing is used in one part of the ship and the other type is used in another part. The most common combination is longitudinal framing for the bottoms and the deck, and transverse framing for the sides.

8 INTRODUCTION TO THE STRENGTH OF A SHIP HULL

8.1 Forces acting on a ship

There are many forces acting on a ship. The pattern of forces on a ship is very complicated and largely depends on the following [21]:

– the weight of the empty ship;
– the weight of the cargo, fuel, ballast, provisions, etc.;
– moving of a ship in the waves;
– vibration caused by engines, propeller, pitching;
– incident forces caused by docking, collisions.

The mentioned causes the ship to be deflected. When the force stops acting, the ship will regain its original shape. Every ship is different, and some have more or less of this flexibility. If, however, the forces exceed a certain limit, the deformation can be permanent.

Consider loads acting on the fore and aft parts of a ship. What are impact loads? As the name suggests, impact loads act suddenly and are of large intensity in response to the natural structural response of the entire ship hull. The on-coming waves hitting the fore part of the hull generate a large amount of impact pressure, creating impact loads which in turn generate a pattern of rapid vibrations onto the material in what we call *whipping*.

Impact loads also depend on the relative motion between the vessel and the water surface. Thus, pertaining to suitable design, velocity constraints, and surge direction are key determinants of the net effect of impact loads.

In rough sea states, the bow of the ship performs an oscillatory motion, as mentioned in *pounding*. The fore bottom floor emerges from the water and again plunges into the sea. This incessant emergence and hitting the water may spark off a vibration in the hull girder. These high-frequency vibrations cause severe loading on the entire structure and may sometimes exceed the wave-induced stress, aggravating the situation when both are superimposed. Whipping, thus, is a straightforward outcome of *slamming*, which can also induce higher girder bending moments and fatigue damage to the entire structure of the ship.

Green Water. The waves encountered by a ship on rough sea states are highly unpredictable. These giant waves can go up to tremendous heights and upon interaction with the ship's forward, end may lash itself on to the exposed weather deck in an event marked as the wave slap/green water.

Pounding. This forces are induced due to the slamming motion of the ship triggered due to heaving or high pitching motions. This situation is further aggravated in the case of empty or light ballasted conditions of ships. This intense pounding stresses the incident on the plating spread over a large area extending a considerable amount of length even behind the forward collision bulkhead. Slamming can be mostly bow-flare slamming, stern slamming, or bottom slamming (see fig. 8.1).

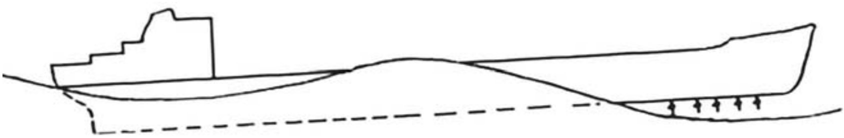

Figure 8.1 – Bottom slamming

8.2 Longitudinal strength

When a ship is in calm water, the total upward force will equal the total weight of the ship. Locally, this equilibrium will not be realized. The local differences between upward pressure and the local weight give rise to shearing forces that lead to longitudinal tensions. The shearing force is the force that wants to shift the plane from one part of the ship to another. The submerged part of the ship clearly shows the difference in volume between the midships, the fore, and the aft ship; this is the reason for the difference in upward pressure [21].

Thus, the longitudinal forces occur because (fig. 8.2, fig. 8.3):

a) the weights in the ship are not homogeneous in the fore and aft direction;
b) the upward pressure differs because of the shape of the underwater body.

In fig. 8.2 the black vectors pepresents the upward pressure and the weight of the ship, the red vectors give the resultant per section. In fig. 8.3, the black vectors give the resultant shearing forces between the different compartments, the red vectors give the resultant per section.

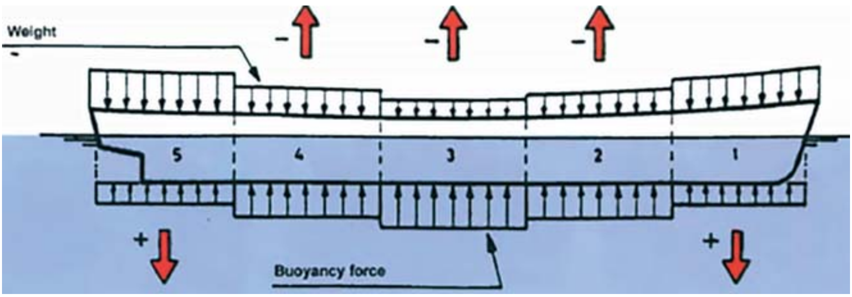

Figure 8.2 – Weight and buoyancy distribution along the ship's length [21]

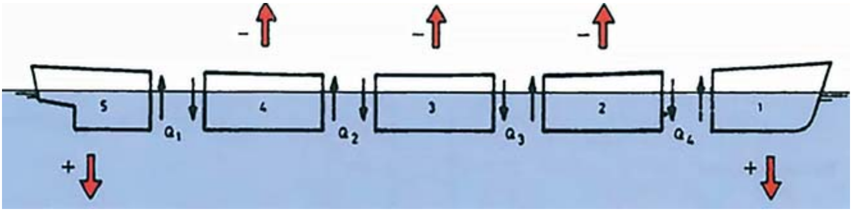

Figure 8.3 – Explanation of shear forces distribution along the ship's length [21]

Uneven load distribution will produce a longitudinal bending moment. The longitudinal bending moment will create a significant stress in the structure called bending stress.

Typical distribution of weight and buoyancy (external) forces along with shear force and bending moment (internal) along the ship's length in calm water is presented in the fig. 8.4.

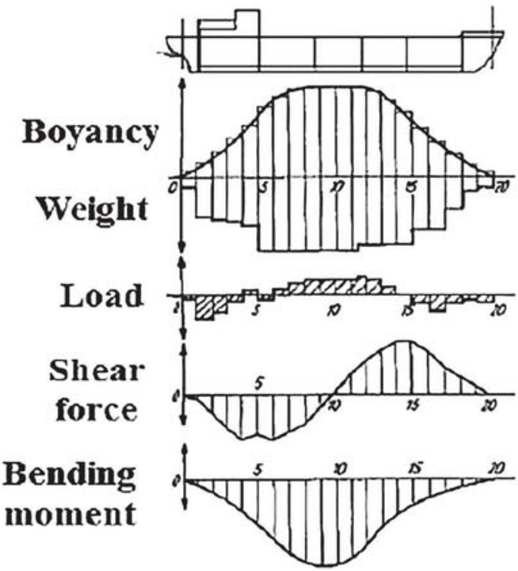

Figure 8.4 – Typical distribution of weight, buoyancy, shear forces and bending moment aling the ship's length [22]

8.3 Various stresses in strength members of ship structure

All strength members of ship structure are subjected to several types of stresses induced by external and internal loads. The fabrication of ship structural members by gas cutting, forming, welding and assembly work induce complicated systems of residual stresses. These residual stresses do not appear in the structural members as they are in equilibrium internally. The hull girder of a ship is subjected to longitudinal vertical and horizontal bending moments, shear forces and torsional moments. These hull girder loadings induce stresses referred to as *primary stresses* in the primary strength members. Strength members of ship structure assemblies are subjected to cargo and external water pressure loadings which induce stresses called *secondary stresses*. Tertiary strength members are subjected to tertiary loadings which induce a third type of stresses called *tertiary stresses*. The bottom plating is subjected to additional local loadings exerted by the external hydrostatic water pressure. These local loadings cause bending of bottom plate panels and thus induce local bending stresses. The compounding of these stresses for some strength members could reach unacceptable high values of equivalent stresses, which may exceed the allowable stresses of the material and cause structural failure.

Under certain conditions, the ship hull girder is subjected to other types of loadings and stresses. The main causes of these stresses are the presence of thermal gradients, the launching of the ship, occurrence of accidents such as grounding, collision, etc.

The total stress at any point on the ship hull girder is composed of one or more of the following categories of stresses:

- primary stresses: hull girder stresses;
- secondary stresses: induced in secondary structures;

– local stresses: induced by cargo and local pressures;
– fabrication stresses: residual stresses (cutting, forming, welding and assembly work).

The most common process of calculating the strength of ship structures is based on the calculation of longitudinal strength and local strength. The stress and the strength of each ship structural member should be estimated on the basis of compounded stresses imposed in them by the longitudinal bending action of the ship hull girder and the induced bending under the local loads, see fig. 8.5.

8.4 Vibrations on ships

Sources of ship vibration (see fig. 8.6) are listed below.

Internal sources of ship vibration are as follows:

1. Main & Auxiliary Machines
– main Propulsion Engine (esp. 4 or 5 cylinder engine) generating large unbalanced force at high frequency close to the hull's natural frequency.
– rotary machines (Electric motors, auxiliary machines, etc) generate high frequency but low amplitude.
– reciprocating engines – usually low frequency.
2. Unbalanced Shaft (frequency = shaft RPM).

Unbalance occurs when the center of mass is different from the center of rotation. This can be caused by improper assembly, material buildup, wear, or broken or missing parts. Detection is high-level radial vibration.

Misalignment is a condition when two coupled machines have shafts whose center lines are not parallel and intersecting, or where one or more bearings are offset or cocked. Misalignment can be caused by improper assembly and adjustment, foundation failure, thermal growth, or locked coupling. Detection is high-level axial vibration.

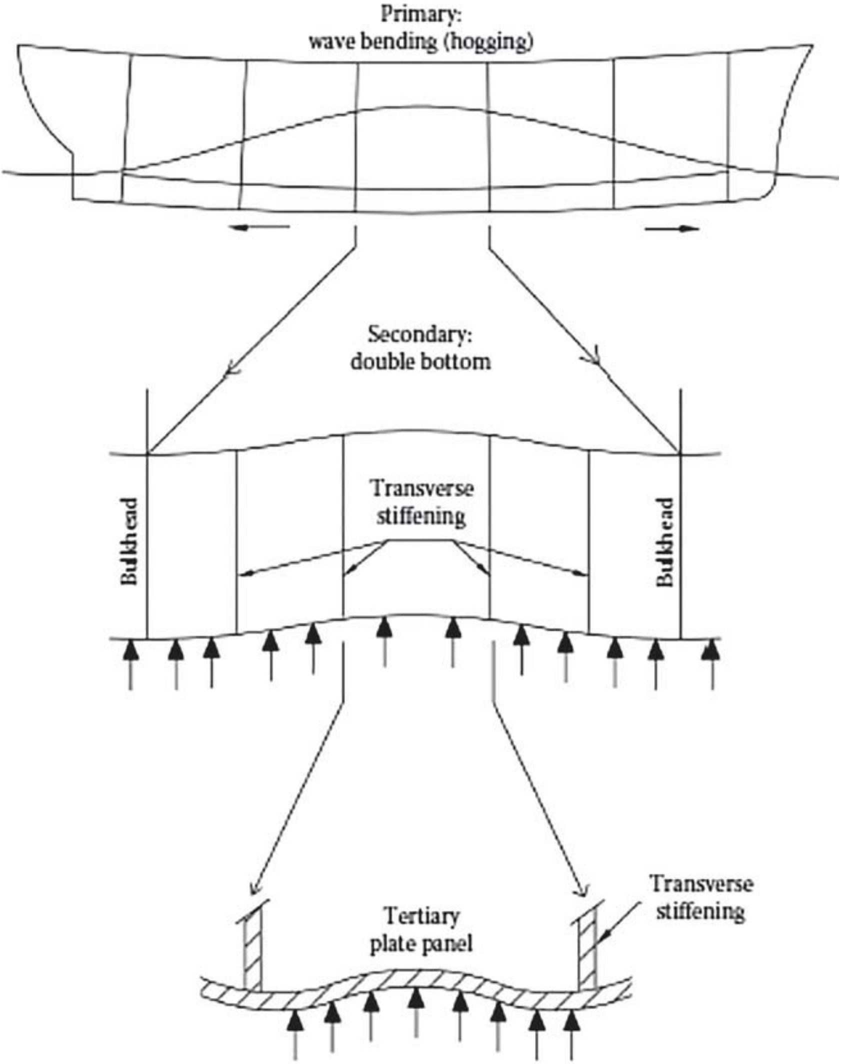

Figure 8.5 – Primary, secondary, and tertiary response of ship structures [23]

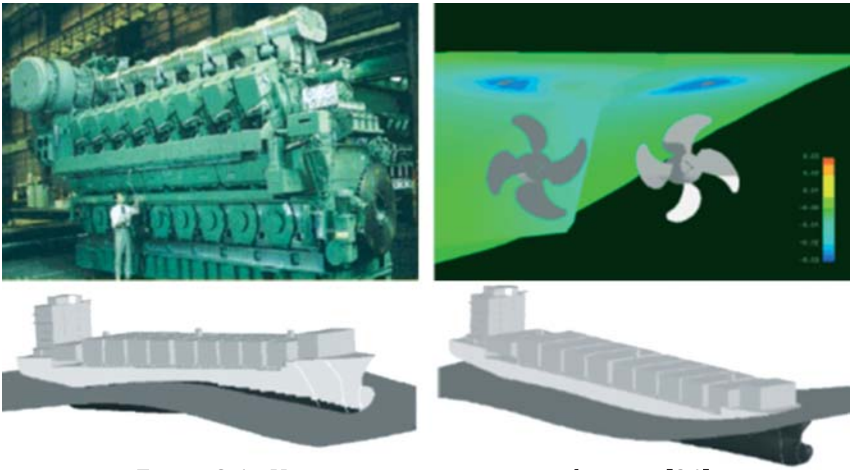

Figure 8.6 – Various sources exciting vibration [24].
Source: Germanischer Lloyd

External sources of ship vibration are as follows.

1. Hydrodynamic loading on propeller blades in non-uniform flow (freq. = RPM × No. of blades). More pronounced for low propeller submergence and in shallow water.
2. Unstable cavitation of blades.
3. Vortex induced forces (not on the propeller), Eg, Brackets that hold the propeller.
4. Slamming Load – short duration forces, but give rise to high frequency forces.

In response to excitation forces, the ship executes elastic vibrations, some of which are observed only *locally* and some are observed throughout the *hull*.

Local Vibration: Usually high frequency and lower amplitude.

– Difficult to predetermine.
– Amended easily post-construction (common practice to overlook during the design stage).

Hull Vibration: Lower frequency and higher amplitude (Compared to local). It must be carefully considered and avoided in the design stage itself.

9 VESSEL DEVICES AND EQUIPMENT

9.1 Ship rudders

Clearly, the rudder is the most important control surface on the hull. There are a multiplicity of different types. The magnitude of all the rudder types' dimensions is limited by the hull, specifically the stern’s properties.

A balanced rudder is a rudder in which the axis of rotation of the rudder is behind its front edge (see fig. 9.1). This means that when the rudder is turned, the pressure of water caused by the ship's movement through the water acts upon the forward part to exert a force which increases the angle of deflection, so counteracting the pressure acting on the after part, which acts to reduce the angle of deflection.

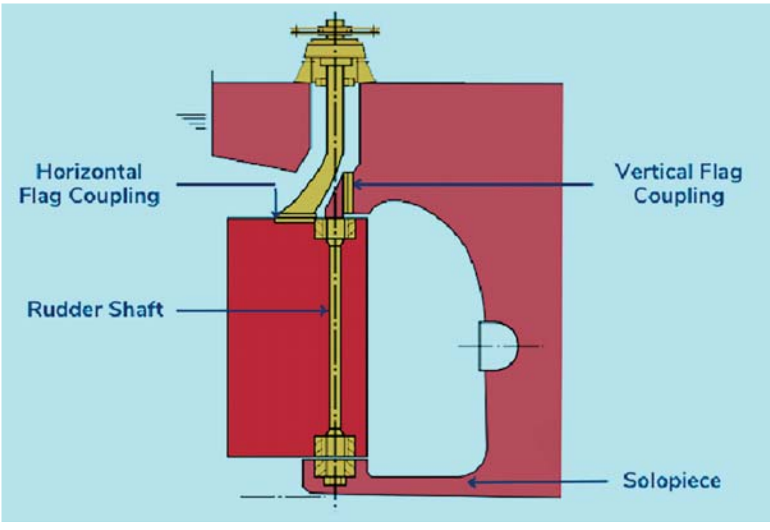

Figure 9.1 – Balanced rudder with shaft [1]

A degree of semi-balance is normal to avoid rudder instability i.e. the area in front of the pivot is less than that behind. This allows the rudder to be moved with less effort than is necessary with an unbalanced rudder.

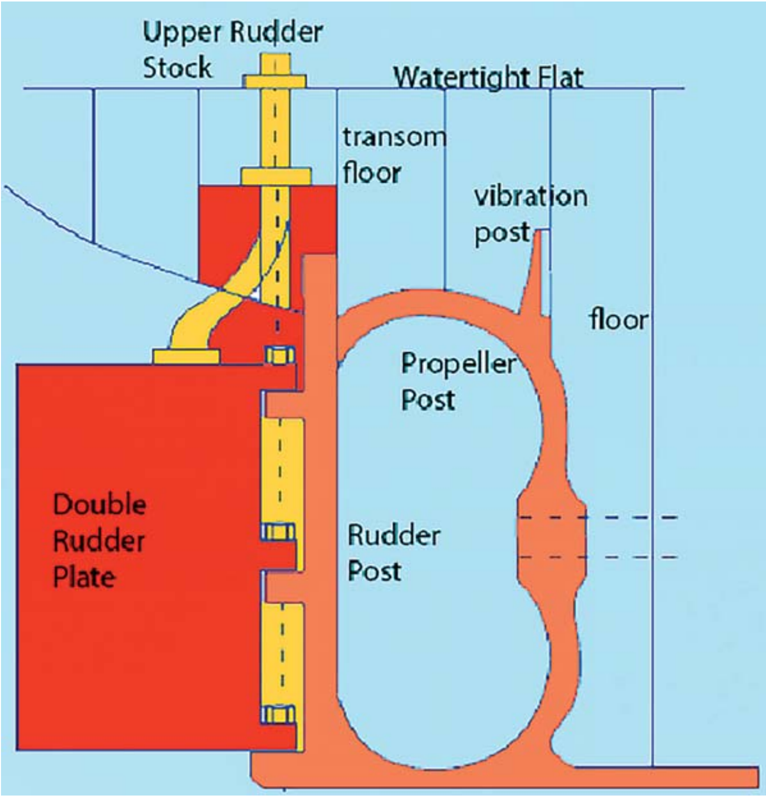

Figure 9.2 – Scheme of unbalanced rudder [1]

Unbalanced Rudders. These rudders have their stocks attached at the forward most point of their span (see fig. 9.2). Unlike balanced rudders, the rudder stock runs along the chord length of the rudder. The reason is simple. In this case, the torque required to turn the rudder is way higher than what is required for a corresponding balanced rudder. So, the topmost part of the rudder has to be fixed to the spindle so as to prevent it from vertical displacement from its natural position. However, unbalanced rudders are not widely used now.

Semi-Balanced Rudder. If you have been able to visualize a balanced and unbalanced rudder by now, it should be pretty easy to visualize a semi-balanced rudder. In fact, the rudder you see on most ships are semi-balanced in the modern industry. The name semi-balanced itself implies, that the rudder is partly balanced and partly unbalanced. If you refer to the figure below, you'll see that a portion of the chord length from the top is unbalanced, and the remaining chord length is balanced.

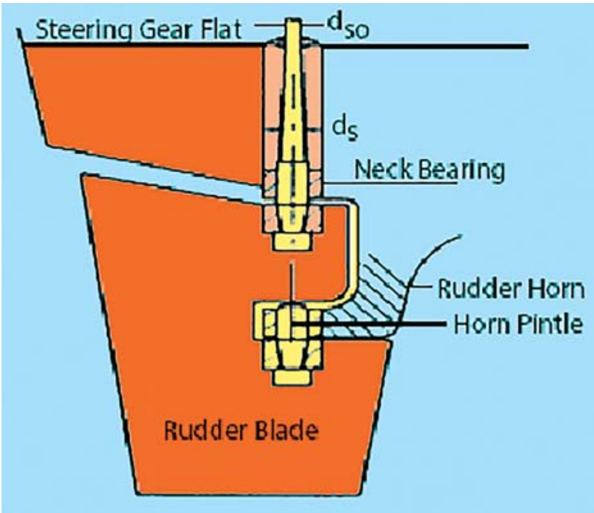

Figure 9.3 – Scheme of semi-balanced rudder [1]

The selection of the proper type of rudder is as important as the location of the rudder behind the propeller. The location of the rudder should be such that it is properly oriented within the propeller's outflow, so as to produce the required turning moment on the ship. A slight change in the rudder type, dimension, and position can bring about a huge variation in the ship's response to the rudder, as well as the turning ability of the ship.

How Does A Rudder Help In Turning A Ship? When the helmsman changed the rudder angle from zero to some angle towards the starboard, at that very moment, a lift force acts on the rudder. The direction of the lift force is towards the port side, as illustrated in fig. 9.4.

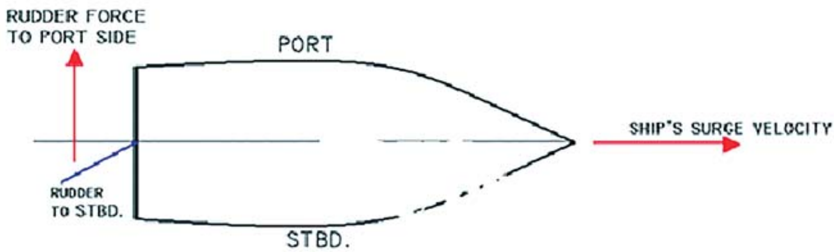

Figure 9.4 – Rudder force on a ship with rudder to starboard [1]

This rudder force, as you can see, is directed along a transverse direction to the ship. It creates a moment about the centre of gravity of the ship, in the direction as shown in fig. 9.5.

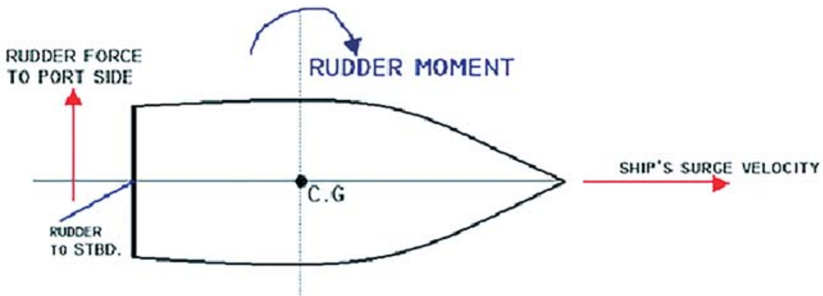

Figure 9.5 – Rudder moment when rudder is moved to starboard [1]

The rudder is incomparably smaller than the size of the hull that is to be turned by it. The hydrodynamic moment is in the same direction as the rudder moment (both trying to turn the ship to starboard). The rudder angle keeps the rudder moment intact, which in turn keeps the hydrodynamic moment intact. The resultant moment diagram for a ship performing a starboard turn is as shown in Figure below.

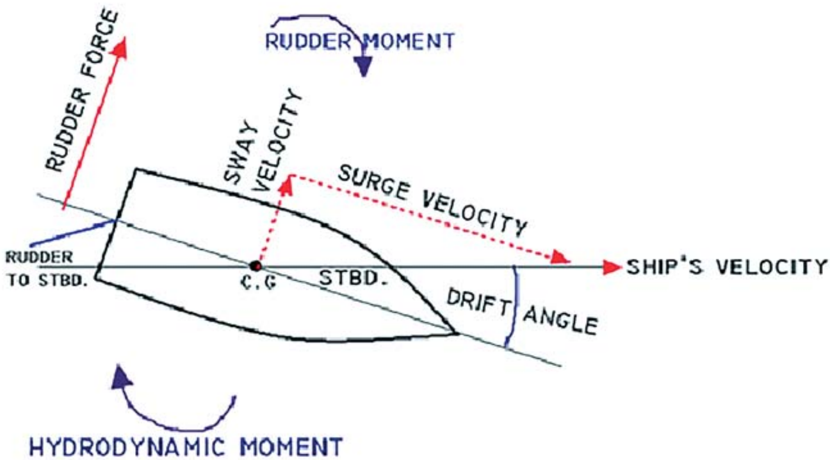

Figure 9.6 – Moments acting on a ship during starboard turn [1]

9.2 Anchor equipment

The purpose of the anchor gear (or ground tackle) is to fix the position of a ship in shallow water by using the sea-bed [21]. Reasons for doing this can be:

- the ship has to wait until the berth becomes vacant;
- the load or discharge cargo when a port does not have a berth for the ship, either temporarily or permanently;
- to help with manoeuvring if the ship does not have a bow thruster and/or no tugboats are available;
- in emergency cases to avoid grounding.

Overview of anchor equipment are as follows (fig. 9.7).

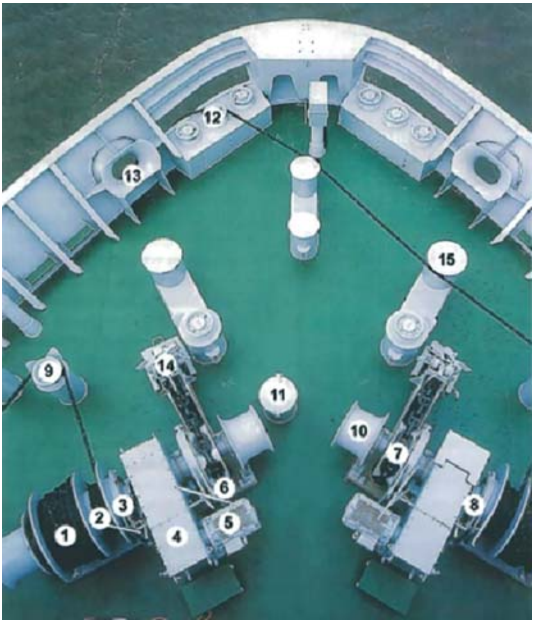

Figure 9.7 – Forecastle deck [21].

Explanatory notes: 1– storage part of the mooring drum; 2 – pulling section of the drum (working part); 3 – brake band; 4 – gearbox; 5 – electro-motor; 6 – spurling pipe; 7 – chain in the gypsy wheel; 8 – dog clutch; 9 – guide roller; 10 – warping head; 11 – hatch to chain locker; 12 – guide roller, guide pulleys; 13 – fairlead; 14 – chain topper; 15 – bollard (double)

Anchors can be distinguished as:

– conventional types;
– HHP-anchors (high holding power);
– SHHP-anchors (super high holding power).

Common conventional anchor types are: Spek, Hall, Union, Daldt. Accepted HHP anchors are AC14, Pool and Danforth. CQR and plow-type anchors are only used for small crafts.

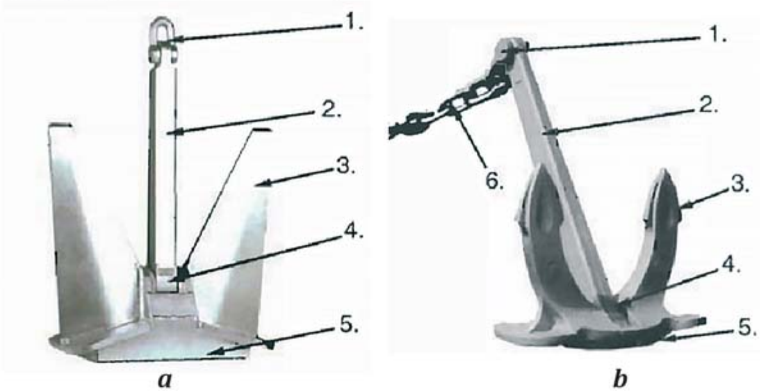

Figure 9.8 – Elements of anchors:
a – Pool anchor (HHP) Type HG «Pool N»;
b – Hall anchor (conventional anchor) [21].

Explanatory notes: 1 – crown/shackle; 2 – shank; 3 – flukes; 4 – crown pin; 5 – crown plate; 6 – anchor chain with swivel

The anchor chain runs from the chain locker, through the spurling pipe, via the gypsy wheel of the windlass through the hawse pipe, to the anchor. The anchor chain consists of links with studs to prevent kinks in the chain. The chain is composed of length (shackles), each with a length of 27,5 m. The shackles are interconnected by a kenter shackle.

A D-shackle connects the anchor and the chain. A swivel is usually fixed on the chain and allows the anchor to rotate independently from the chain. The swivel can also be connected directly to the anchor.

The anchor chain also plays a major role in absorbing a certain portion of forces away from the main structure and anchor head. For instance, during storms or other similar weather conditions, the vessel or offshore rig tends to pitch and heel. This motion can intensify, causing damage to the vessel. To dampen these forces, the anchor rode is designed to absorb a certain amount of the load. Since anchor chains and cables are built to withstand large forces, they are not drastically damaged or deformed by such loads. This absorption of forces away from the main structure and anchor is known as dampening [1].

Important factors to keep in mind while selecting or designing the anchor chain are the

- maximum permissible loads;
- ease of storage;
- the expected length of the rode.

The stresses need to be checked for every unit of the rode. Metal chains have links as their primary unit component, while ropes and cables have fibres.

Anchor chains are stored in a chain locker set deep within the hull of the vessel. These are ventilated enclosures that are used to store the anchor while it is not in use, and to house the remaining length of the anchor chain while it is deployed. It can be accessed by engineers and personnel for routine checks or long-term maintenance. Generally, the floor of the chain locker is reinforced, so that it can bear the extra weight of the metal rode. To haul the chain out of the locker, a series of heavy-duty motors and gears are set up on the deck in pairs.

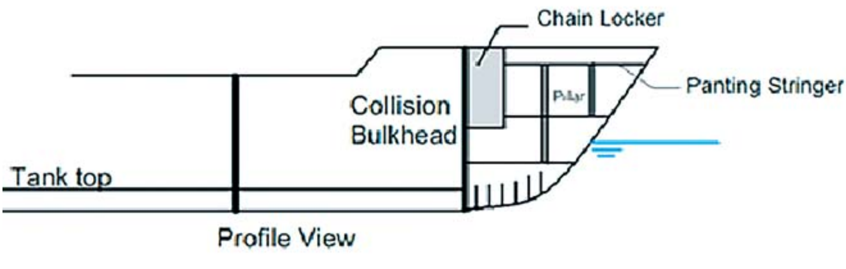

Figure 9.9 – Location of Chain Locker [1]

9.3 Mooring equipment

Mooring is any long-lasting arrangement that keeps a floating vessel in place when docked in a port. A ship is received at quays, piers, breakwaters, docks, anchor floats, and fastening floats. It is secured to a port, so it does not move freely, increasing the risk of collision with other ships [1].

Mooring is often accomplished using thick ropes called mooring lines or hawsers. The lines are fixed to deck fittings on the vessel at one end and to fittings such as bollards, rings, and cleats on the other end.

Mooring requires cooperation between people on a pier and on a vessel. Once a mooring line is attached to a bollard, it is pulled tight. Large ships generally tighten their mooring lines using heavy machinery called *mooring winches*.

The heaviest cargo ships may require more than a dozen mooring lines. Small vessels can generally be moored by four to six mooring lines.

Mooring lines are usually made from manila rope or a synthetic material such as nylon. Some ships use wire rope for one or more of their mooring lines. Wire rope is hard to handle and maintain. There is also risk associated with using wire rope on a ship's stern in the vicinity of its propeller. Mooring lines and hawsers may also be made by combining wire rope and synthetic line. A typical mooring scheme is presented in fig. 9.10.

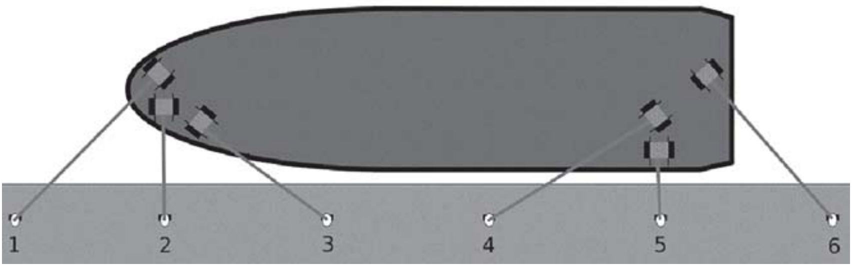

Figure 9.10 – Typical mooring lines scheme [25]

Explanatory notes are in the table 9.1 below.

Table 9.1 – **Mooring lines**

Number	Name	Purpose
1	Head line	Keep forward part of the ship against the dock
2	Forward Breast Line	Keep close to pier
3	Forward or Head Spring	Prevent forward movement
4	Back or Aft Spring	Prevent back movement
5	Aft Breast line	Keep close to pier
6	Stern line	Prevent forwards movement

Mooring gear in foredeck of a tanker is shown in fig. 9.11.

Figure 9.11 – Foredeck of a tanker [21].

Explanatory notes: 1 – warping head; 2 – drum; 3 – bollards; 4 – eyes to connect the stoppers; 5 – guide roller; 6 – center lead; 7 – leadway; 8 – head line; 9 – forward spring

9.4 Deck lifting equipment

Deck lifting equipment such as gantry cranes, general cargo crane, provision crane, derrick etc. help in carrying heavy loads/cargo on board ships.

Most cargo is moved with aid of loading gear. Only very small and lightweight cargo is still moved by man-power. The loading gear is either present on the ship (self-discharger) or at the transfer yard. In the latter case the quay has a large array of mobile cranes capable of moving across the length of the quay.

There are many types of cargo gear for ships and just as many insentives for choosing one or the other.

Marine *deck crane* is a type of simple machine, usually equipped with a wire ropes, cranes, hoist rope, and sheaves, which can be used for loading and unloading cargo. Deck cranes are employed to lift both heavy and light materials with a 360-degree rotating boom. Deck cranes can also move horizontally to transport material from one place to another.

The picture below shows a ship with common revolving cranes. The crane house is attached with slewing bearing to a pillar, which is part of the ship. The slewing bearing is a very large double-turning bearing [21]. An electrical or a hydraulic motor grabs in the pinion of the turning ring, which is a large ring-shaped cogwheel that rotates the crane. The crane cannot rotate unrestricted by because of electrical lines running to and rom crane.

The crane cabin is a steel construction with windows that give the crane driver a wide view of the area of activity. The wire drum(s), drives engine(s) and the controls the security are all located in the crane house. The diameter is 2–3 metres.

The crane jib is hinged to the crane, making lowering and topping possible. The crane jib consists of one or two beams.

Figure 9.12 – Container feeder ship deck crane [21].

Explanatory notes: 1 – foundation; 2 – slewing bearing; 3 – crane house; 4 – jib

The jib is designed in such a way that it has the desired strength, while its weight is minimal and its stiffness is maximal. The different types of revolving cranes can be distinguished mainly on the basis of where the jib is attached to the crane house.

A *derrick* is a lifting device that consists of a derrick boom, which is raised, lowered down and moved sideways by several different purchases (see fig. 9.13).

Side-load systems (see fig. 9.14) are used for the transshipment of small cargo units like pallets, rolls of paper, and general cargo. The system comprises of one or more doors in the side of the ship and one or more elevators situated behind these doors to transport the cargo from the ramp at quay level to the holds or vice versa.

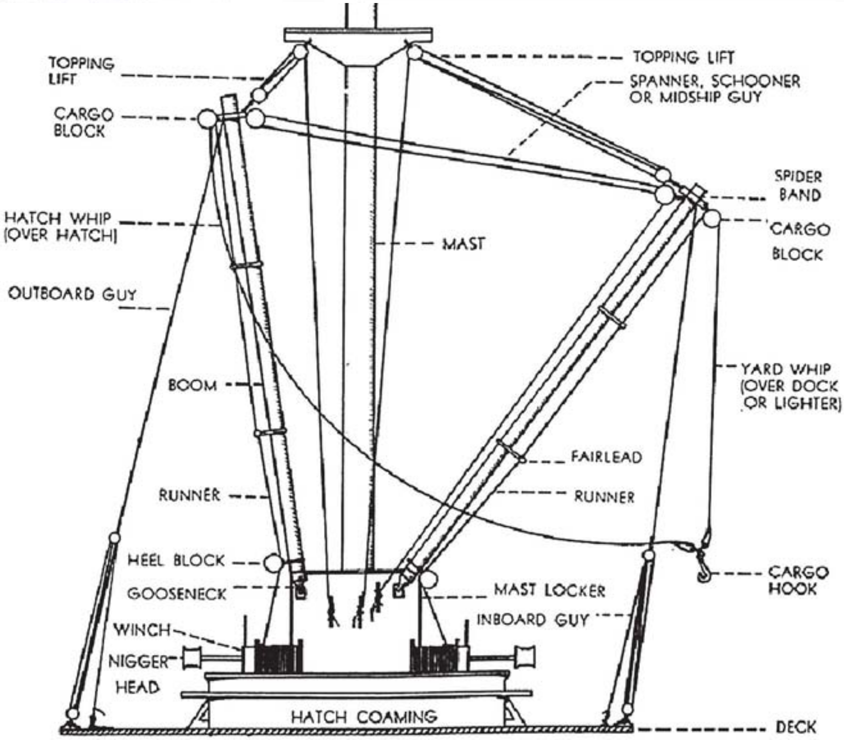

Figure 9.13 – Scheme of a typical derrick [26]

RoRo-vessels are ships where the cargo is driven on board via ramps (see fig. 9.15). Loading and discharging can take place quickly because all the cargo is driven on board. An advantage of this is that the ship is independent of the shore facilities.

In general, ramps have sufficient length to be used both in high and low tides. Opening and closing is done with a winch or hydraulic cylinders. There are many safety measures for locking and sealing the side doors and ramps.

Figure 9.14 – Ship with three side doors [21]

Figure 9.15 – Ship with quarter ramp [21]

9.5 Emergency and life-saving equipment on ships

Life-saving appliances are those appliances that protect human life at sea. The devices are documented as part of the International Convention for the Safety of Life at Sea, or SOLAS Convention.

In the SOLAS Convention and other maritime related standards, the safety of human life is paramount. Ships and other watercraft carry life saving appliances including lifeboats, lifebuoys, life-jackets, life raft and many others. Life-saving appliances are mandatory. The number and type of life-saving appliances differ from vessel to vessel, and the code gives a minimum requirement to comply in order to make a ship seaworthy.

Onboard life-saving appliances include the following items:

1) lifebuoys and life jackets;
2) immersion suits, anti-exposure suits, and thermal protective aids;
3) lifeboats;
4) life-rafts;
5) rescue boats;
6) rocket parachute flares;
7) hand flares;
8) buoyant smoke signals;
9) launching and embarkation appliances;
10) marine evacuation systems;
11) line-throwing appliances;
12) general emergency alarm system;
13) public address system.

Vessel devices and equipment also include *towing gear* and *special gear* (stern ramps for instance).

The following figure shows the typical arrangement of the tow line connection for towing from the bow.

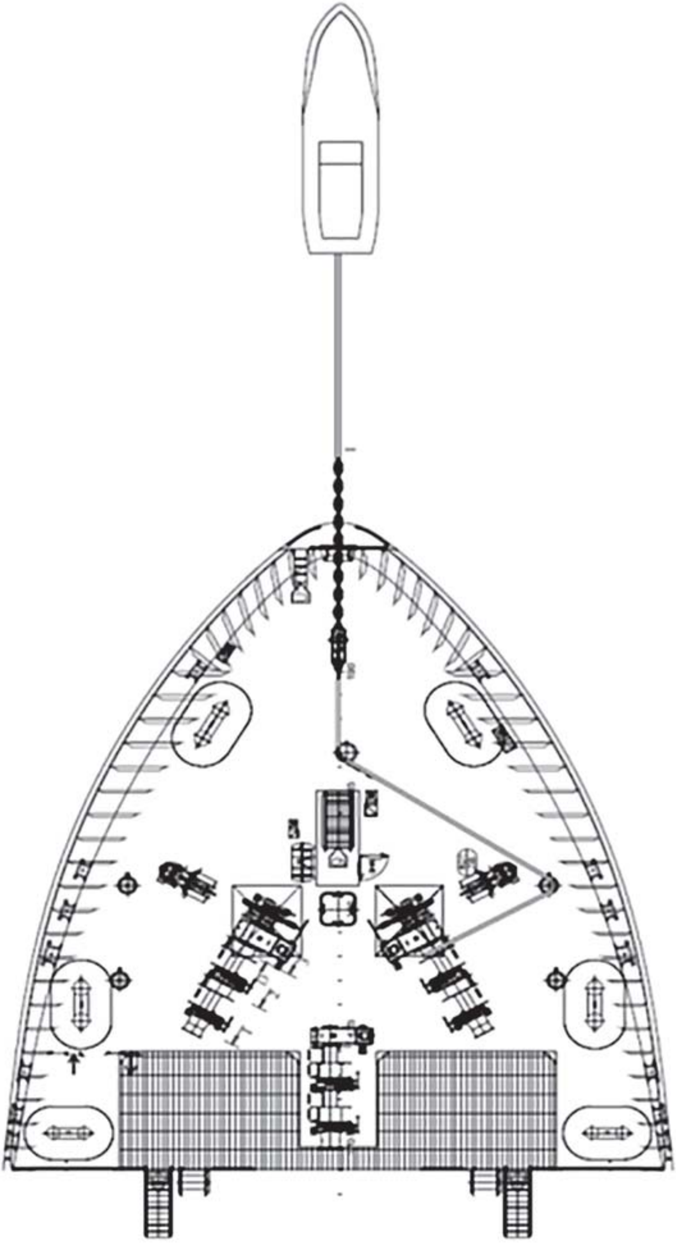

Figure 9.16 – Typical arrangement of tow line connection for towing from bow [27]

10 POWER PLANTS OF SHIPS

The ship's propulsion is normally done by propellers. In most cases by only one. That propeller is rotated via a shafting system driven by a diesel engine. Again, in most cases, the propeller is one with a fixed pitch with a so-called monobloc casting. The shafting consists of the propeller shaft or tail shaft and at least one intermediate shaft.

A ship's engine room is complex, complete, and compact (see fig. 10.1). An engine room of an average cargo ship normally contains one main engine.

Figure 10.1 – Engine room of the ferry ship [28]

10.1 Diesel power plants

The cross-section of a typical marine diesel engine is presented in fig. 10.2.

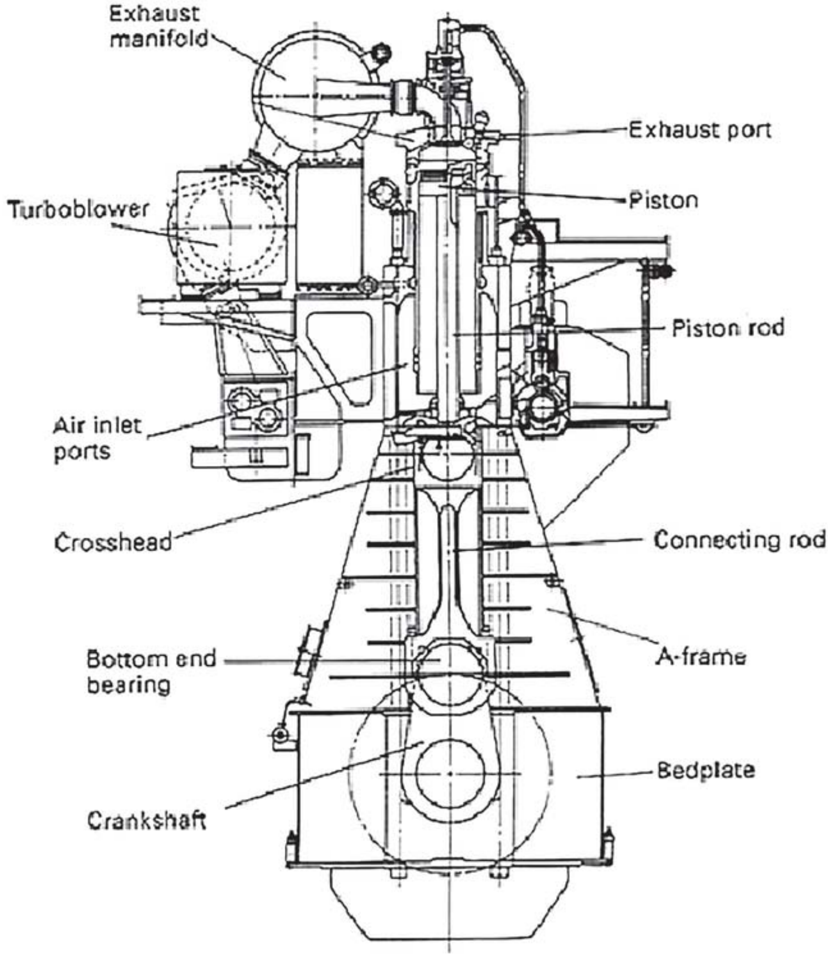

Figure 10.2 – Marine diesel engine – cross section [29]

Engine types. Propulsion diesel engines can be divided into three groups [21].

1. *High-speed* four-stroke diesel engines, RPM (revolutions per minute) above 960.
2. *Medium-speed* four-stroke diesel engines, RPM ranging 240–960.
3. *Low-speed engine (crosshead)* two-stroke diesel engines, RPM range below 240.

10.2 Marine steam and gas turbines

Steam turbines generally were used as a main engine in several kinds of ships which need more power to propel during 1800's and the mid of the 20th century. After that time, the use of steam turbines was in decrease because of higher oil price and the introduction of new technologies as the diesel engines and gas turbines. Nowadays, steam turbines are used as a main engine and/or combine engine with turbo generator or reduction gear in the high power required ships which are nuclear naval and commercial vessels, LNG carriers, super tankers, ice breakers, cruise ships and FPSO vessels.

Steam turbine is a heat engine that converts the high temperature and high pressure steam's heat energy to mechanical energy or electrical energy with its fixed and moving blades and alternators.

For the shipping industry, the advantages of the *gas turbine* have always been eclipsed by the disadvantages. Principally, the high fuel and initial cost have made it an unattractive option for ship owners. The largest consumers of the marine gas turbine have traditionally been the navies and military of the world. Recent developments in gas turbine technology, coupled with lower oil prices (of the late eighties and nineties) and profitability in certain markets, as made ship owners reconsider the values of the marine gas turbine [30].

In a gas turbine, a pressurized gas spins the turbine. In all modern gas turbine engines, the engine produces its own pressurized gas, and it does this by burning something like propane, natural gas, kerosene or jet fuel. The heat that comes from burning the fuel expands air, and the high-speed rush of this hot air spins the turbine. They have three parts (see fig. 10.3):

1) a compressor that compresses the incoming air to high pressure;
2) a combustion area that burns the fuel and produces high-pressure, high-velocity gas;
3) a turbine that extracts the energy from the high-pressure, high-velocity gas flowing from the combustion chamber.

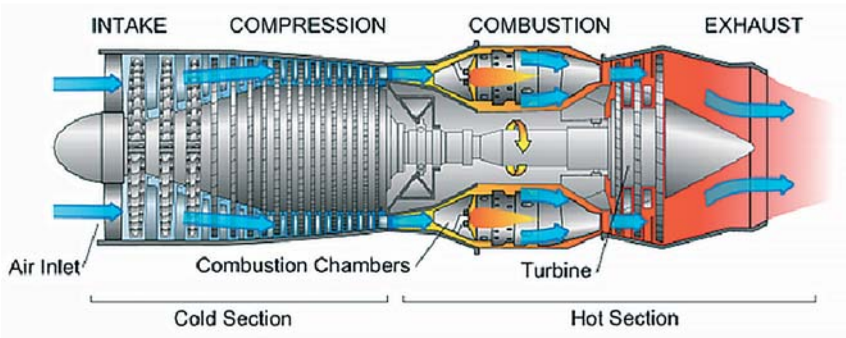

Figure 10.3 – Scheme of the gas turbine [31]

Gas turbine engines have a great power-to-weight ratio compared to reciprocating engines and are smaller, but compared to a reciprocating engine of the same size, they are expensive.

10.3 Nuclear power plants

The components of the nuclear power plant include a high-strength steel reactor vessel, heat exchanger(s) (steam generator), and associated piping, pumps, and valves. Each reactor plant contains over 100 tons of lead shielding, part of which is made radioactive by contact with radioactive material or by neutron activation of impurities in the lead [32].

The propulsion plant of a nuclear-powered ship or submarine uses a nuclear reactor to generate heat. The heat comes from the fissioning of nuclear fuel contained within the reactor. Since the fissioning process also produces radiation, shields are placed around the reactor so that the crew is protected.

In the steam generators, the heat from the water in the primary system is transferred to the secondary system to create steam. The secondary system is isolated from the primary system so that the water in the two systems does not intermix (fig. 10.4).

In the secondary system, the steam flows from the steam generators to drive the turbine generators, which supply the ship with electricity, and to the main propulsion turbines, which drive the propeller. After passing through the turbines, the steam is condensed into water which is fed back to the steam generators by the feed pumps. Thus, both the primary and secondary systems are closed systems where water is recirculated and renewed. Since there is no step in the generation of this power which requires the presence of air or oxygen, this allows the ship to operate completely independent from the earth's atmosphere for extended periods of time.

Naval reactors undergo repeated power changes for ship maneuvering, unlike civilian counterparts which operate at steady state.

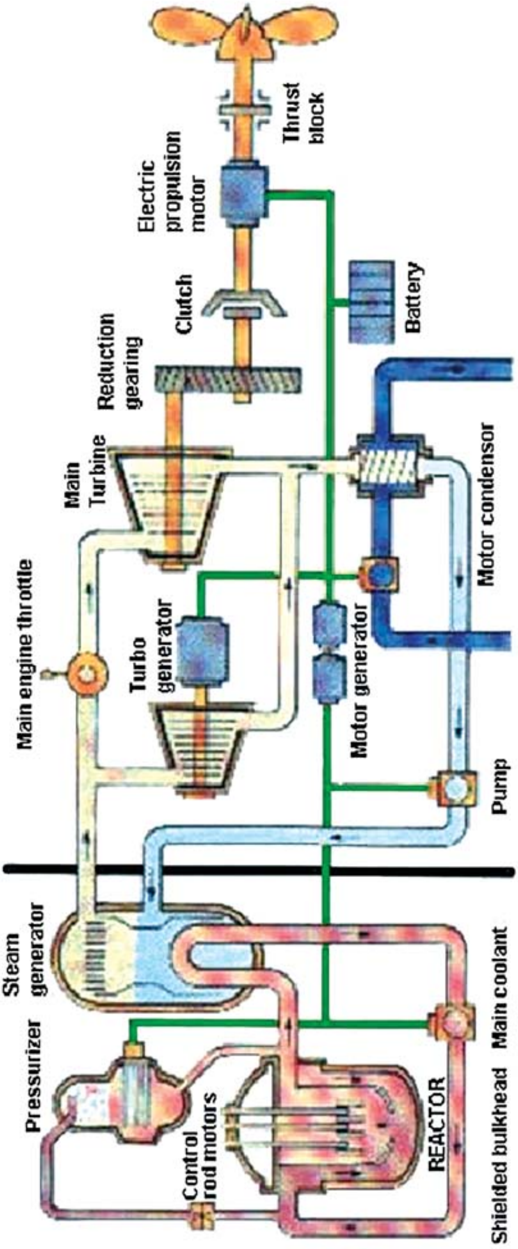

Figure 10.4 – Pressurized-water naval nuclear propulsion system [33]

Nuclear safety, radiation, shock, quieting, and operating performance requirements in addition to operation in close proximity to the crew dictate exceptionally high standards for component manufacturing and quality assurance. The internals of a naval reactor remain inaccessible for inspection or replacement throughout a long core life – unlike a typical commercial nuclear reactor, which is opened for refueling roughly every eighteen months.

10.4 Hybrid electric propulsion system

Hybrid electric propulsion system is mainly composed of mechanical systems and electrical systems, as shown in fig. 10.5.

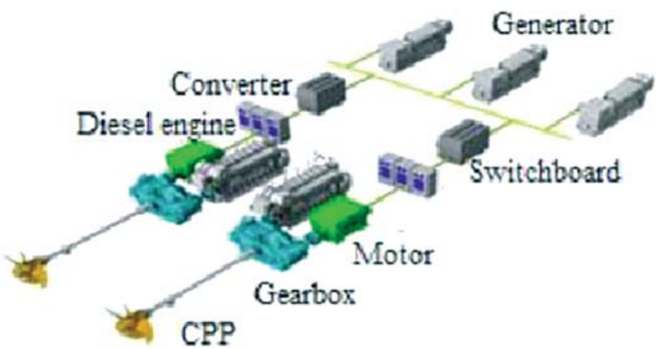

Figure 10.5 – Composition of hybrid propulsion system [34]

10.5 Methanol engine

Methanol is an organic chemical and the simplest aliphatic alcohol, with the formula CH_3OH. It is a light, volatile, colourless, flammable liquid with a distinctive alcoholic odour similar to that of ethanol. Due to its very low viscosity compared to conventional HFO and diesel, special efforts are needed to ensure proper combustion and to prevent leaks in seals. The use of methanol on board ships is governed by the IMO IGF Code on low flashpoint fuels, which mandates many of the practical considerations that need to be taken when working with methanol [35].

A key consideration is the fuel delivery system, which has to be safe for technicians carrying out maintenance or repairs. In practice, this simply means to avoid direct contact with methanol. For this reason, methanol engines are equipped with double-walled fuel distribution systems, similar to LNG vessels. Methanol vapour is heavier than air, and it will therefore move downwards; hence, the placement of gas detectors and ventilation at lower elevations is essential. Additionally, the entire system, including the engine itself, is designed to be purged with nitrogen, ensuring that operators can work on the engine safely. In contrast to HFO, there is no need to heat the fuel; on the contrary, the fuel sometimes has to be cooled before injection.

Engine retrofit requirements are presented below [35]:

– Methanol needs a pilot fuel or other ignition enhancer to operate. Battery packs for power ramp-up might be required.
– Methanol engines are equipped with double-walled fuel distribution systems capable of being purged with nitrogen.
– (Dual-fuel) LNG engines are most suited for methanol, as LNG engines and equipment also adhere to the IGF code.
– The conventional fuel system can be kept operable as a spare system.

Using methanol as a fuel generally promotes a cleaner lubricant environment, but induces significantly greater engine wear compared to fuel oil. This wear may affect engine operation and durability.

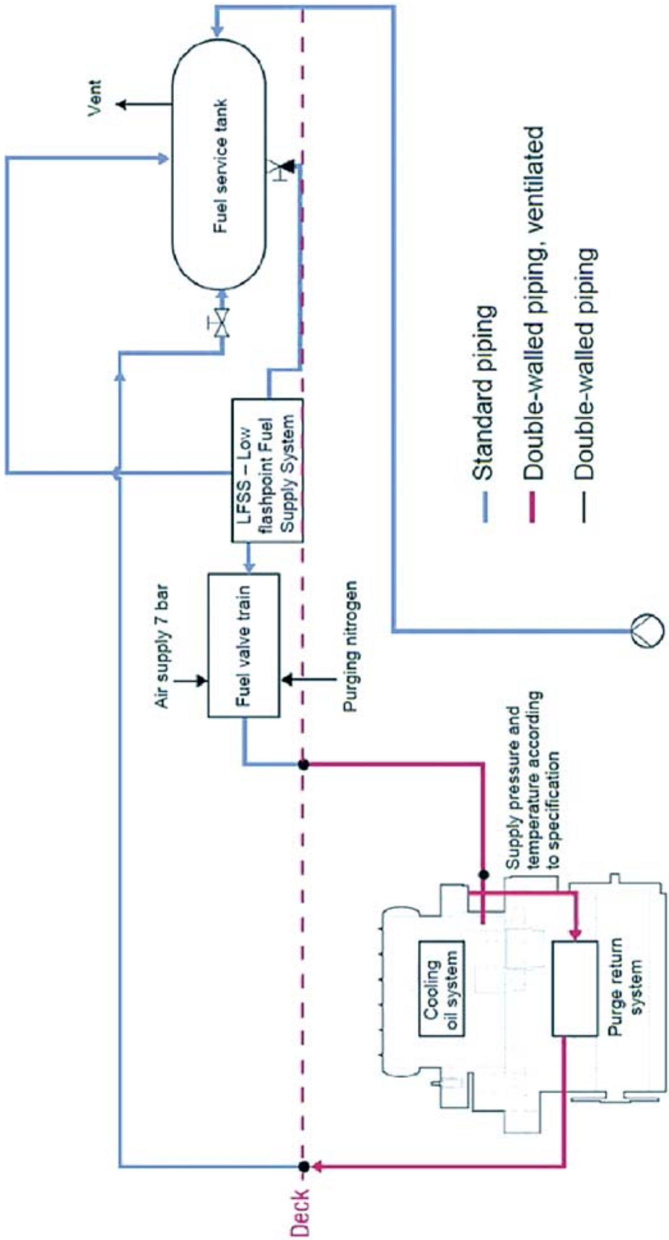

Figure 10.6 – Schematic overview of methanol fuel system [35]

For engine retrofitting, fuel injection is to be modified to achieve higher injection pressure for igniting methanol. Consequently, most engines running on methanol will still require a pilot fuel or other ignition enhancer to operate. The low cetane number is a property that methanol shares with LNG, and the engine will need a cetane enhancer in order to ignite. In the dual-fuel solution, a small amount of diesel oil is used as a pilot fuel.

For heavy-duty operations and to accommodate high power ramp-up requirements, battery packs might be required, as methanol engines tend to have lower response time. This requirement is similar to when dual-fuel LNG engines were made and engine manufacturers are continuously improving methanol combustion engines to increase power ramp up.

11 ELECTRICAL EQUIPMENT OF SHIPS

11.1 Typical electrical equipment

Typical electrical equipment of ships includes the following.

1. Generator is a simple device to convert mechanical energy into electrical energy (fig. 11.1).

Figure 11.1 – Main-engine driven generator [21]

2. Electric motors. Electric motors are simple devices to convert electrical energy into mechanical energy.

3. Cables. Cables from the connections between the different parts of the electric installation and are nowadays available as low-smoke, low toxic and even fire-resistant types (fig. 11.2).

Figure 11.2 – Cable trays and pipes in the corridor between the forward and aft engine room of a stone dumping vessel [21]

4. Switchboards and switchgear assemblies. Switchboards and other shwichgear assemblies basically serve to connect and disconnect generators and consumers to the main power supply system (fig. 11.3). They contain also the protection devices of the generators, the cables, and the consumers against overload and short-circuits.

5. Circuit breakers and contactors. A circuit breaker is designed to close and interrupt a short-circuit current a few times only without maintenance. A contractor is designed to with-

Figure 11.3 – The main switchboard device [21]

stand thousands of times the starting currents of electric motors. A circuit breaker is therefore not suitable to start a large motor.

6. Emergency generator is a generator with the same characteristics as a main generator but located in a space separated from the main generators and independent of any equipment outside this space (see fig. 11.4).

Figure 11.4 – Emergency generator [21]

7. Navigation and nautical equipment of a ship normally include following: one radar with ARPA (automatic radar plotting aid) function; a second radar for ships bigger than 500 GRT (gross registered tonnage); two independent automatic position fixing system (GPS or DGPS); one echosounder; one log with speed and distance indication; one magnetic standard compass; one gyrocompass; one automatic pilot.

8. Communication systems (internal and external).

11.2 Marine electricity generation

Marine electricity generation can be done onboard ships by diesel, shaft, or steam-driven generators. A shaft generator is a term used by the marine industry. It means an a.c. generator (alternator) that is to be driven by the ship's main engine. The main ship propulsion shaft from the engine to the propeller passes through a large gearbox, and this gearbox can have more than one auxiliary shaft for driving pieces of equipment such as compressors or hydraulic pumps, or maybe an alternator. This application for an alternator just has the general description, and is known to all as: the *shaft generator*.

Before the shaft generator can be used to supply power, the ship's main engine and therefore propeller shaft, must be running at a fixed speed appropriate for the shaft generator to supply a useable output of voltage and frequency. Most ships operate at 450V, 60Hz. This means that the only time the shaft generator may be used to supply power is when the ship is at sea and cruising at a constant speed.

Under cruising conditions, the ship's main engine has plenty of power to spare. It therefore makes good economic sense to make use of the main engine and 'stand down' the diesel-engined generators that are used at all times when the ship's main engine is either running too fast or too slow. This happens mostly when the ship is approaching or leaving port, or in heavy traffic areas, or in difficult navigational areas.

Marine shaft generators are often required to operate in a multi-function role [36]. They could operate as an alternator to provide the vessel's primary electrical power supply. This is the conventional use of an alternator for Power Take Out (PTO). They could operate as an electric motor to provide a short/medium-term power boost alongside the propulsion engine. This is known as Power Take In (PTI). Alternatively, the shaft generator could operate as an independent method of propulsion when the main engine is out of commission. This is normally a very short-term or emergency use known as Power Take Home (PTH).

The shaft generator is operating as an alternator, driven from the main propulsion engine, providing the primary power supply for the vessel's electrical systems. The following drawing shows a typical PTO layout with power flow direction.

Internal communication systems include talk-back, automatic telephone, public address systems, and sound-powered telephone. Talk-back system is normally installed in the wheelhouse, engine room, steering-gear room, and on the fore-deck and after-deck. The main station is normally installed in the wheelhouse and can communicate with each substation. The sub-stations can only make a connection to the main station and not to other sub-station.

Automatic telephone system. With a system that is identical to your telephone at home, duplex conversation between telephones is possible.

Sound-powered telephone. This system is independent of the vessel's main power supply and meets the demands for emergency communication between vital positions on board, such as the wheelhouse and engine room. Most automatic telephone systems operate nowadays through a UPS system [36].

Public address system. With this system one way communication is possible. It is used to address large quantities of people and to page people. It is also used to give the general alarm signals.

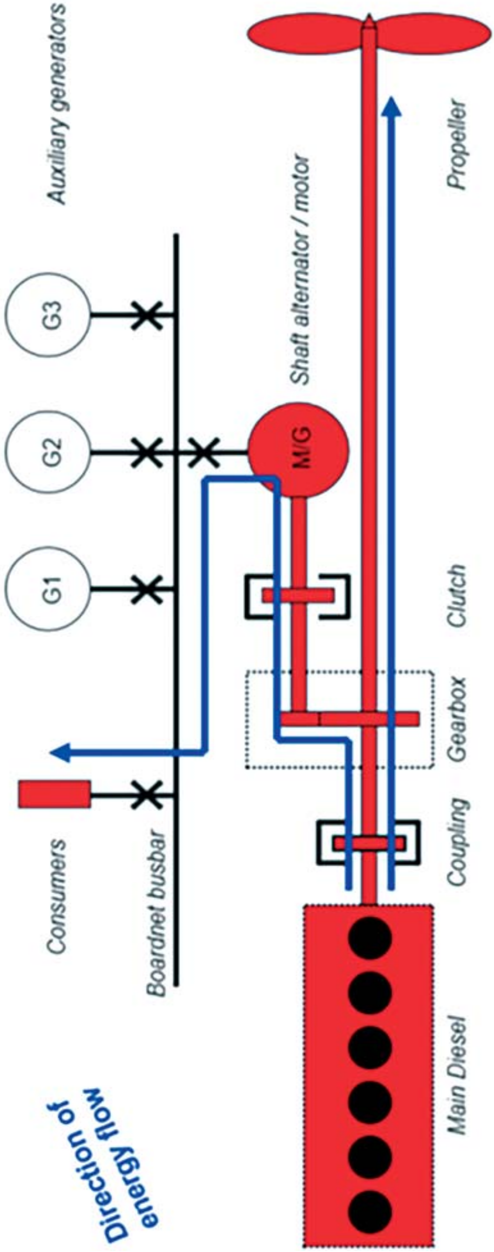

Figure 11.5 – Power Take Out mode of operation [36]

External communication system. GMDSS stands for Global Maritime Distress and Safety System. It uses the satellite communications now available through the International Maritime Satellite (INMARSAT) system. INMARSAT is a cooperative organization that includes about sixty countries. The fund and take compensation according to each member’s use of the system. Geostationary satellites are sited about 36 000 kilometres over the equator to provide complete global coverage except in the extreme north and south arctic regions.

12 HULL SYSTEMS

12.1 Fire protection systems of a ship

Fire protection on ships is provided by detection and fire-fighting equipment together with structural features which are intended to contain an outbreak of fire and the employment, when required, of non-combustible materials to prevent its spread [37].

Two basically different types of equipment are available on board a ship for the control of fires. These are small portable extinguishers and large fixed installations. The small portable extinguishers are for small fires which, by prompt on-the-spot action, can be rapidly extinguished. The fixed installation is used when the fire cannot be fought or restrained by portable equipment, or there is perhaps a greater danger if associated areas were to be set on fire.

The use of fixed installations requires evacuation of the area containing the fire, which, if it is the machinery space, means the loss of effective control of the ship.

A special category space is an enclosed space above or below the bulkhead deck used for the carriage of motor vehicles with fuel for their own propulsion in their own tanks and to which passengers have access. Obvious examples are the garage spaces in Ro-Ro passenger ferries and vehicle decks in Ro-Ro cargo ships. Such spaces cannot have the normal main vertical fire zoning without interfering with the working of the ship. Equivalent protection is provided in such spaces by ensuring that the horizontal and vertical boundaries of the space are treated as main fire zone divisions and an efficient fixed fire-extinguishing system is fitted within the space. This takes the form of a fixed-pressure water spraying system, generally in association with an automatic fire detection system. Special scupper arrangements are provided to clear the deck of the water deposited by the system in the event of a fire to avoid a drastic reduction in stability.

12.2 Bilge and ballast systems

The bilge system is used to remove small quantities of fluid that have leaked or condensed into a dry space. The system serves the machinery spaces, cargo holds, cofferdams, voids, stores, tunnels, and pump rooms. Each space has its own piping, but the pump is likely to be shared [38].

The emergency bilge suction or bilge injection valve is used to prevent flooding of the ship. It is a direct suction from the machinery space bilge, which is connected to the largest capacity pump or pumps. An emergency bilge pump is required for passenger ships but may also be fitted as an extra on cargo ships. It must be a completely independent unit capable of operating even if submerged.

Bilge and ballast systems are interconnected so that each can perform the other's function in an emergency, i.e., a ballast pump could be used to pump out a flooded engine room. They are connected by means of a cross-over valve.

The ballast system is arranged to ensure that water can be drawn from any tank or the sea and discharged to any other tank or the sea as required to trim the vessel.

12.3 Air conditioning system

A typical recirculating system contains a fan to produce the airflow through the system, a cooling coil where the heat from the air is transferred to the cooling medium, and ductwork to distribute the air through duct terminals and to return the air to the cooling coil. Many recirculating systems contain heaters for use in the heating season or for use in maintaining a specific relative humidity requirement [37].

Air conditioning is based on the ventilation requirement for accommodation and incorporates heating with any necessary humidification, and importantly, cooling with dehumidification as necessary. Comfortable conditions depend on the temperature and humidity, but are also sensitive to air movement, air freshness, and purity.

A very significant factor affecting an air conditioning system is the rapidly changing climatic conditions. The equipment has to perform within these variations and has to meet the differing requirements of the occupied spaces of the ship.

12.4 Marine sanitation device

Marine sanitation device, commonly known as an «MSD» is a piece of machinery or a mechanical system that is dedicated to treat, process, and/or store raw, untreated sewage that can accumulate onboard water vessels. It does not refer to portable devices such as portable toilets.

U.S. coust guard has certified three kinds of Marine Sanitation Devices [39].

– A Type I MSD has a flow-through discharge design. The sewage is broken down and processed through the use of chlorination and/or maceration. The bacteria count per one hundred milliliters of water must be less than one thousand. Discharges from Type I MSDs must not have evident floating solids. Type I MSDs also rely heavily on chlorination and maceration to break down solids and kill any bacteria present.

– Type II MSDs are similar to Type I, with a flow-through discharge. However, the sewage is broken up through the use of aerobic bacteria or some other biological digestion process. The bacteria count found in one hundred milliliters of water produced from this system cannot be greater than two hundred.
– Type III MSDs have a different design compared to Type I and Type II. It typically consists of a large storage tank that holds treated or untreated sewage that is held and released when the vessel returns to port. In port, the Type III discharge is transferred to a wastewater treatment facility. However, Type III MSDs can also consist of a holding tank with advanced technologies, including but not limited to incineration, recirculation, and composting. The residuals are not discharged to water, but are transferred when the vessel is in port.

12.5 Refrigeration systems

On a ship, a refrigeration system is used to carry refrigerated cargo, food, and provisions. During which the temperature of the space or its content is reduced considerably below that of the surroundings. Thus preventing possible growth of harmful bacteria, decay of perishable food, fermentation, or damage to cargo [40].

In small ships like large commercial fishing vessels, a refrigeration system is used for keeping the catch (fish catch during voyage) at a desired temperature, to prevent them from spoiling.

While on large reefer ship's the refrigeration plant is used to reduce, control, and maintain the temperature of perishable cargo such as food, liquefied gas, and chemicals. The same plant can also be used to provide/used for provision room on ships carrying food (fish/meat/vegetables) for the crew members.

A cooling effect is produced when liquid evaporates, absorbing heat from the body/medium to convert into gas molecules. This is why applying a volatile liquid such as thinner or surgical spirit gives us a cold sensation.

The vapor compression cycle consists of circulating liquid refrigerant via a closed system consisting of four stages, i.e, compression, condensation, expansion, and evaporation. The circulating liquid refrigerant alternately gets compressed and expanded, undergoing phase change.

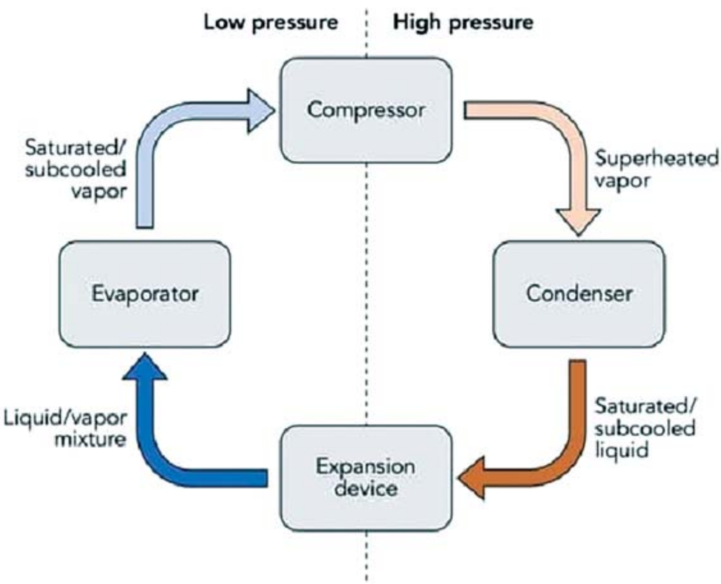

Figure 12.1 – Vapor compression cycle [40]

The refrigerant thus absorbs and removes heat from the spaces being cooled surrounding the evaporator and rejects the heat elsewhere (i.e, space surrounding the condenser).

In an ideal vapor-compression cycle, the system undergoes a series of four process including isotropic compression, isobaric heat rejection in condenser, throttling process in expansion valve, and isobaric heat addition in evaporator.

12.6 Insulation

As the steel hull structure is an excellent conductor of heat, some form of insulation must be provided at the boundaries of the refrigerated compartments if the desired temperatures are to be maintained economically [17].

Cork, glass fibre, and various foam plastics in sheet or granulated form may be used for insulating purposes, also air spaces which are less efficient. Glass fibre is often used in modern ships as it has a number of advantages over the other materials; for example, it is extremely light, vermin-proof, and fire-resistant, and it will not absorb moisture. Mineral wool slabs are also used, and such products have the benefit of fire protection as well as insulation.

On the decks and particularly at the tank top, the insulation must often be load-bearing material, and cork might be preferred, but fibreglass can be supported by tongue and grooved board linings and wood bearers. The thickness of the insulation depends on the type of material used and the temperature to be maintained in the compartment. However, the depth of stiffening members often determines the final depth. Insulating material is retained at the sides by galvanized sheet steel or aluminium alloy sheet screwed to wood grounds on the frames or other stiffening members (see fig. 12.2).

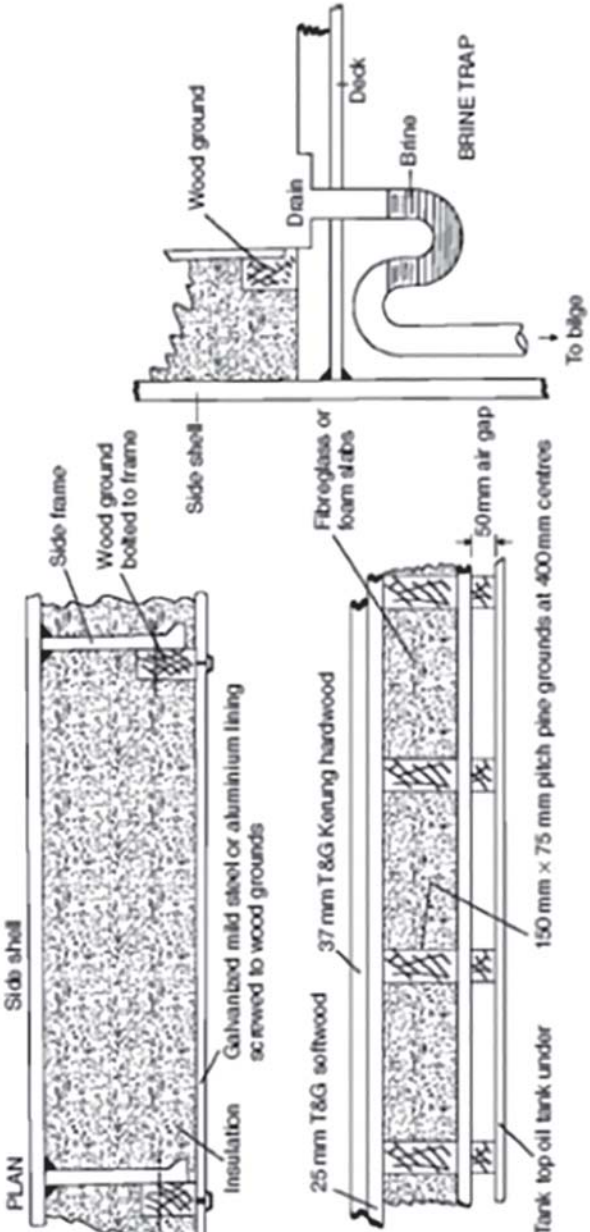

Figure 12.2 – Insulation details [17]

13 SHIPYARD PRACTICE

13.1 Shipyard layout and shipbuilding process

Shipyards were usually found along river banks, or in protected harbors, giving sheltered water and their basic arrangement did not vary. An ideal layout for a modern shipyard is based on a production flow basis, as in fig. 13.1.

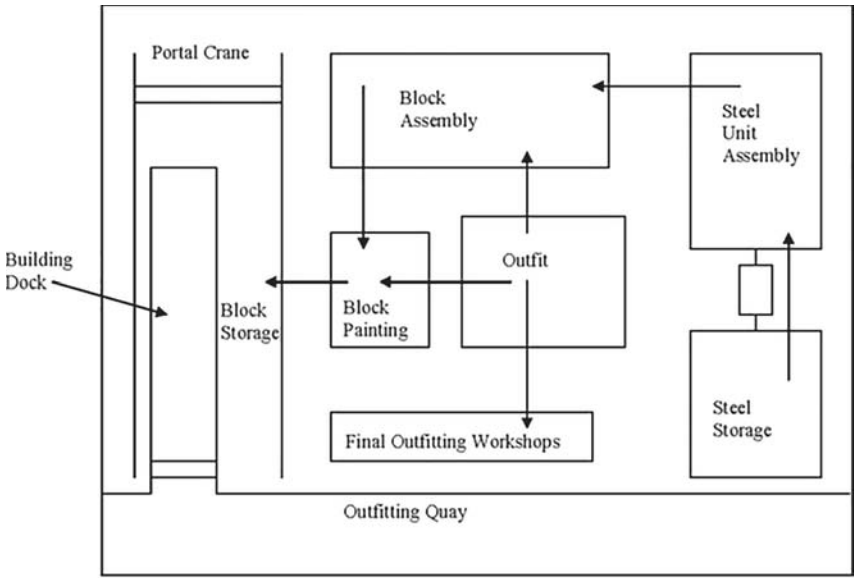

Figure 13.1 – The shipyard layout [17]

Shipbuilding process includes following streps:

1) design;
2) steel cutting;
3) block assembly;
4) painting;

5) block erection;
6) launching & outfitting;
7) sea trials and delivery.

Work processes involved in building a ship are illustrated in fig. 13.2.

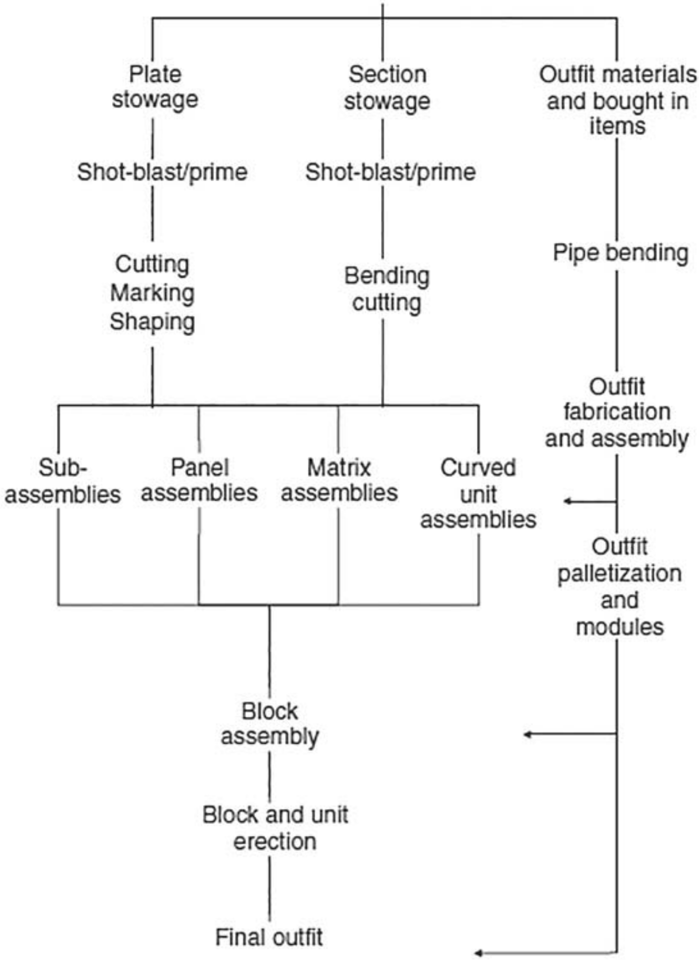

Figure 13.2 – Shipbuilding process [17]

13.2 Plate and section preparation

For efficient ship production, the steel material must be in an ideal condition when it is ready to be processed, and its marshaling into order for production on arrival is essential to the efficiency of the shipbuilding process [17].

Stockyard. On arrival at the shipyard, plates and sections are temporarily stored in the stockyard. In larger shipyards, the stockyard is an uncovered space having sufficient area to provide storage for enough plates and sections required for the working of the yard, some months ahead. The stockyard is needed because the production schedule of a steelmaker will not conform to the needs of one particular shipyard.

Usually, a water wash or gas heating system is provided that heats the plate ready for subsequent paint drying. A wash system will also remove debris, and in some cases, snow or ice.

During production at the steelworks, the plates may acquire locked-in stresses, which are released with the use of thermal processes in the shipyard. This can cause distortion, which slows production. Also, during transit to the shipyard, plates may become distorted, and for many of the modern machining processes, it is important that the plates should be as flat as practicable. This is a set of *plate-straightening rolls* through which the plate is passed prior to its being worked.

Plates and sections are, in almost all cases, now *shot-blasted* to remove rust and millscale. Following the shot-blasting of plates and sections, the material passes immediately through an airless *spray painting* plant. In one pass the material is automatically sprayed with a priming paint of controlled coat thickness. Following the priming paint stage a drying process may be provided.

Plate and section part preparation. A number of the methods in use for forming plates into the required shapes have been in use for many years. This is particularly true of the methods adopted for fitting plates and frames to the curve of the hull. The information for doing this can now be derived using the CAD/CAM systems available.

Cutting flat plates to the required profiles has become highly automated, with very sophisticated machine tools having been introduced for this purpose. In the main, cutting is achieved by the use of an oxy-fuel flame or plasma arcs.

Where a plate is to be cut into one or more (or a series of) complicated shapes, a profiling machine is employed. Cutting is achieved by the use of an oxy-fuel gas or plasma-arc flame, or plasma-arc profilers are usually numerically controlled. In this case, the computer-generated information on the plate geometry is fed directly to the cutting machine. The information is processed so that, in addition to the shape of the plate part, the start and finish of cutting, the speed of cutting, and information to mark the plate are provided. Marking is generally done using an inkjet printing system, although some machines use a powder that is fused onto the plate using gas heating. Provision can also be made for the shrinkage of the plate part as it cools after cutting. The predicted shrinkage of the plate part is added to the nominal dimensions from the CAD system, so after cooling, the part size is correct. The overall arrangement is shown in fig. 13.3.

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

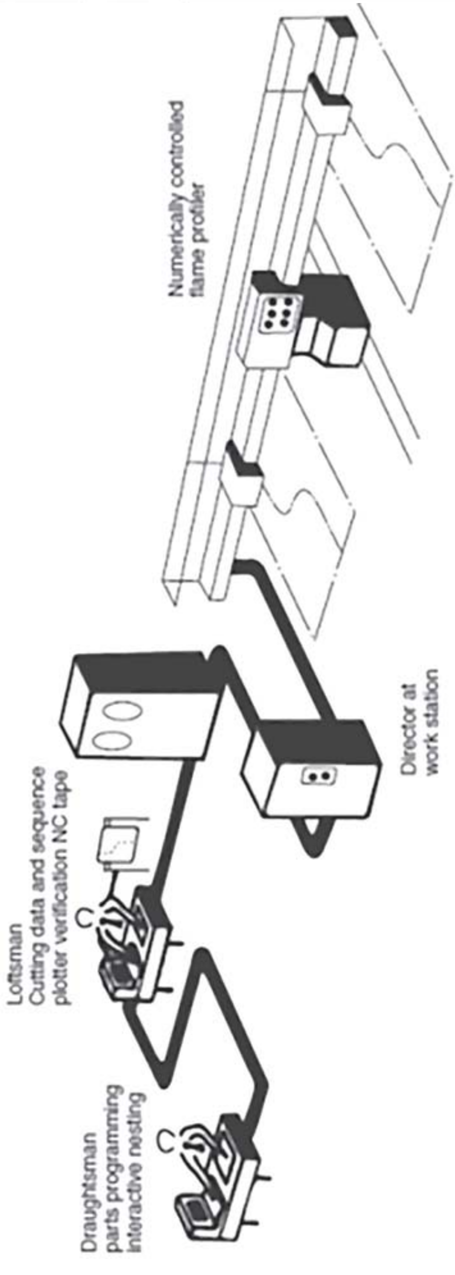

Figure 13.3 – Numerical flame cutting control system [17]

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

Mechanical planing machines were in existence prior to the flame planer, and have an advantage where they are able to cut materials other than steels.

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

Hydraulic presses may be extensively used in the shipyard for a variety of purposes. They are capable of bending, straightening, flanging, dishing, and swaging plates (see fig. 13.4). All of the work is done with the plate cold, and it is possible to carry out most of the work undertaken by a set of rolls. This is done at less capital cost, but the press is slower when used for bending and requires greater skill.

Heavy-duty bending rolls used for rolling shell plates, etc., to the correct curvature are hydraulically operated. Two lower rolls are provided and are made to revolve in the same direction so that the plate is fed between them and a slightly larger diameter top roll that runs idly (see fig. 13.5). Either or both ends of the top roll may be adjusted for height, and the two lower rolls have adjustable centers. With modern bending rolls, plates up to 45 mm thick may be handled, and it is possible to roll plates into a half circle.

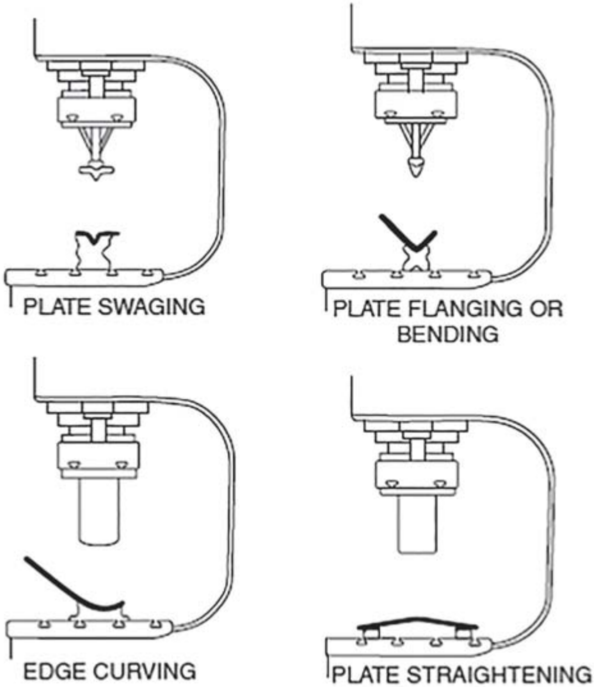

Figure 13.4 – Gap presses [17]

The 'heat-line' bending procedure is a widely used technique to obtain curvature in steel plates for shipbuilding purposes. It is, however, a process that until recently relied on highly skilled personnel and did not guarantee constant accuracy of shapes formed.

Frame bending. The traditional system of bending side frames may still be in use for repair work, and is described as follows. A 'set-bar', which is a flat bar of soft iron, is bent to the scrieve line of the frame on the scrieve board and then taken to the frame bending slabs. On these solid cast-iron slabs pierced with holes, the line of the frame is marked and modified to agree with the line of the toe of the frame.

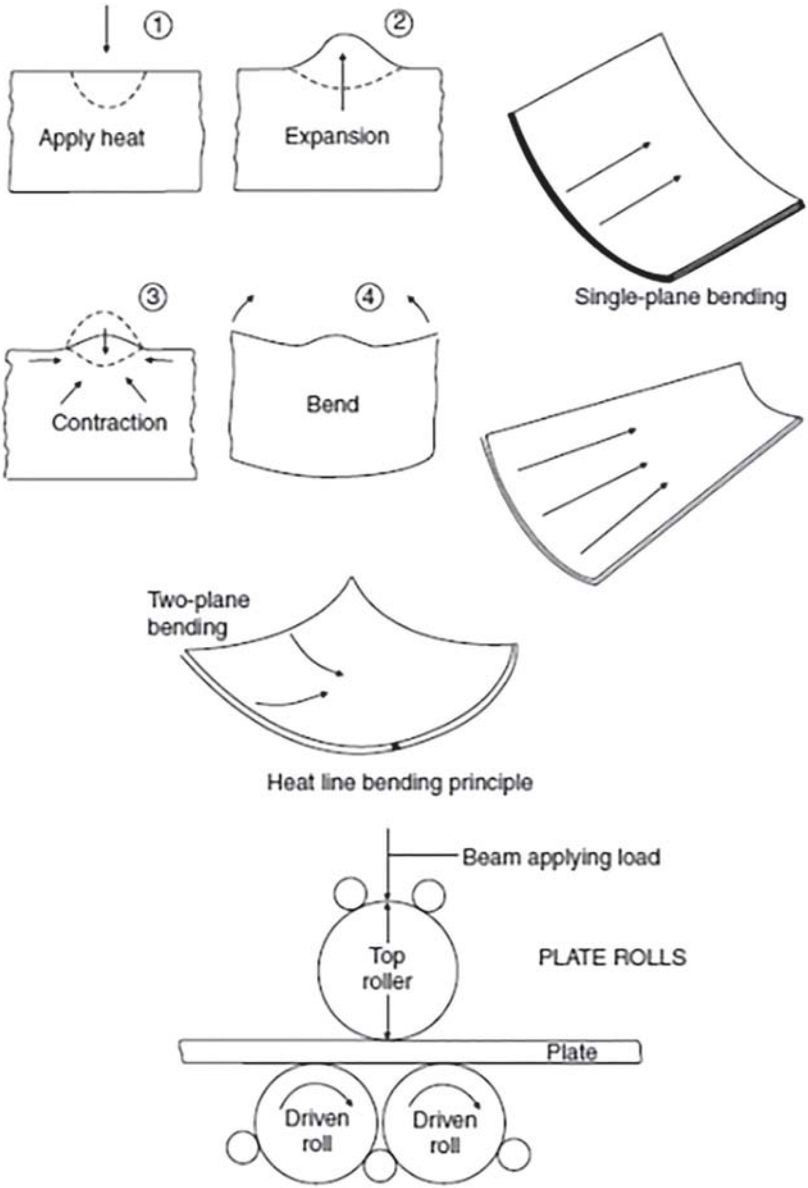

Figure 13.5 – Forming shell plates [17]

As the heated frame on cooling will tend to bend, the set-bar is sprung to allow for this change in curvature before it is fixed down on the bending slabs by means of 'dogs' and pins inserted in the slab holes. Whilst the set-bar is being fixed, the frame section is heated in a long oil-fired furnace adjacent to the bending slabs. When at the right temperature, it is pulled out onto the slabs and fixed with dogs and pins against the set -bar, as quickly as possible.

It is now almost universal practice to cold-bend ship frames using commercially available machines for this purpose. The frames are progressively bent by application of a horizontal ram whilst the frame is held by gripping levers.

13.3 Assembly of ship structure

Once the plates and frames are prepared and given the required shape, they are welded according to the structural drawings prepared by the design department of the shipyard.

Assembly is any process that takes a number of steel piece parts or larger structures and combines them into a larger structure. For very large ships, assembly consists of a number of stages, putting together increasingly larger elements of the ship. The number of stages varies between shipyards and especially varies with ship size. There is not really a 'typical' ship, but as an illustration, considering a Panamax bulk carrier with around 10,000 tonnes of steel, a length of around 250 meters, and a breadth of 32 meters, then the following assemblies can be described [17]:

– Minor assembly: Brackets, intercostal floors or girders, bulwarks, two-dimensional assemblies with five parts and a maximum size of 2 meters by 5 meters, weight below 2 tonnes.

– Subassembly: A flat or curved panel, an egg box structure or other internal structure up to around 12 meters by 12 meters, weight up to 20 tonnes.
– Unit assembly: A structure that can be erected in the building dock, typically one or two panels and associated internal structure, weight up to 60 tonnes.
– Block: An assembly of two or more units into a bottom or side block, weighing up to 200 tonnes.

The above are only illustrative and the dimensions and weights will vary for larger or smaller ships.

The hull is divided longitudinally into blocks (fig. 13.6), and each block is again divided into assemblies and sub-assemblies.

When plates and sections are machined, they are ready to be welded into two-dimensional structures called sub-assemblies. This is carried out in the prefabrication Shops. A sub-assembly would consist of a plate (straight or curved) and its corresponding strengthening stiffeners welded to it. For example, for a particular block, a panel of outer bottom shell and outer bottom longitudinals would form a sub-assembly. Assemblies may be prepared by manual welding or automatic welding, depending on the complexity of the job and the efficiency of the shipyard. Often, flat panels are manufactured by automatic welding, where the stiffeners are marked on the panel, and welded by robotically controlled welding torches.

Adjacent sub-assemblies are welded together to form three-dimensional structures called block assemblies. The size of assemblies is decided in the design stages, considering the crane capacities and the special layout of the shipyard. It is ensured by all shipyards that all joining processes are carried out mostly by downhand welding. In case of blocks towards the aft of the ship where equipment and pipework

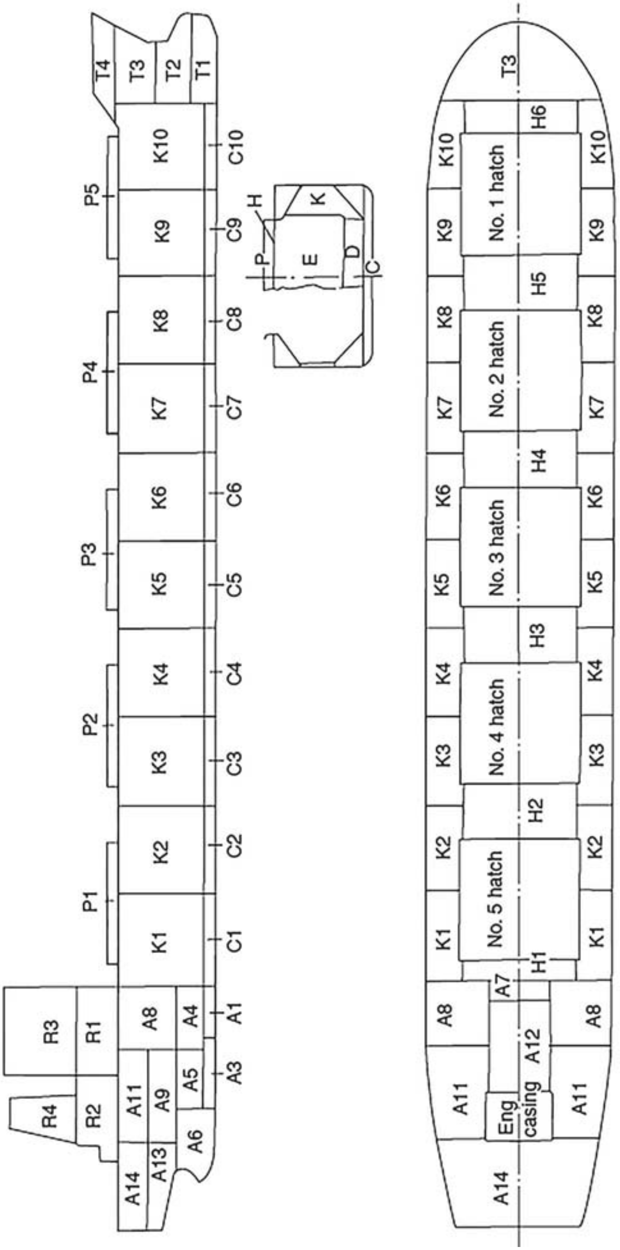

Figure 13.6 – Typical block erection for a single-hull bulk carrier [17]

are a major part of the blocks, first the assembly is upturned to fit the piping on the underside, and overturned again by cranes for fitting of the equipment. For example, the double bottom is used to house pipes, and most of the equipment is housed on foundations over the double bottom plating. In order to manufacture such an assembly with a pipe and associated pipework, first, the assembly is turned so that the pipework can be installed on the underside of the double bottom. The assembly is then overturned by cranes for the pump to be erected on the double bottom plating. A schematic of this process is shown in fig. 13.7.

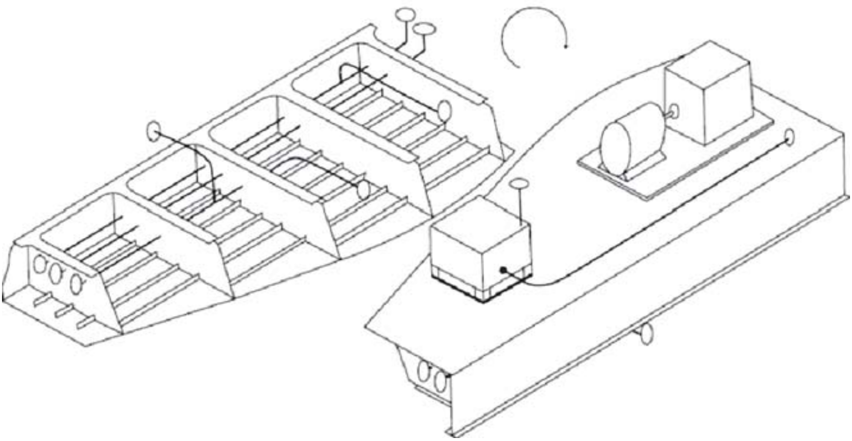

Figure 13.7 – Assembly unit outfitted on both sides [17]

For an established medium-sized yard with building berth or hall having modest craneage, typical erection sequences for a large double-hull oil tanker are shown fig. 13.8.

The assemblies are erected and welded to their adjacent structures in the above sequence. The sequence is pre-decided in the design and modelling stage using CAD/CAM

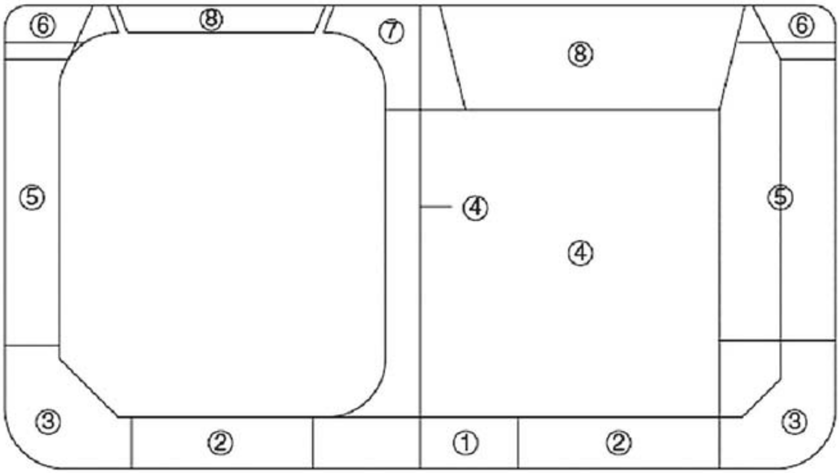

Figure 13.8 – Units on a block of a double hull tanker

Explanatory notes: 1 – double bottom centre unit;
2 – double bottom wing unit; 3 – bilge unit;
4 – longitudinal or transverse bulkhead unit; double hull side unit;
5 – deck side unit; 6 – centre deck unit; 8 – main deck unit

optimisation techniques, so that minimum shifting of assemblies is required, and proper use of carnage facilities is ensured.

Once all blocks are erected based on their welding sequences, they are now ready to be joined. This process is carried out at a different site.

13.4 Ship launching

Launching of ships is one of the most important procedures of the entire ship construction process. The ship launching slipway, a structure consisting of a sloping way down to the water from the shipyard, is an essential aspect of the ship launching procedure and has been extensively used for launching newly made or repaired ships.

Traditionally, ship launching in the water is done using four main types of methods. These methods are [1]:

1) gravitational type launching;
2) floating-out type launching;
3) mechanical type launching;
4) airbag launching.

Gravitational type launching. The gravitational type launching system is further divided into three main types, which are:

– longitudinal oiled slideway launching;
– longitudinal steel – roller slideway launching;
– side oiled slideway launching.

Figure 13.8 – Longitudinal oiled slideway launching [1]

The longitudinal oiled slideway launching is one of the oldest forms of launching systems (see fig. 13.9). Using this system, the ship slides on a slideway and under its own weight enters the water. Oil or wax is used to assist in the sliding process.

The floating-out type launching is carried out for ships which are built in dry-docks and are launched by filling the dock with water. The floating-out type launching system is a simple, effective, and safe procedure (see fig. 13.10).

Mechanical launching uses cranes or mechanical systems to lift smaller vessels into the water.

Figure 13.10 – The floating-out type launching [1]

Airbags launching. Launching ships using airbags is an innovative and safe technique to launch ships into water. These airbags are usually cylindrical in shape, with hemi-spherical heads at both ends. They are made of reinforced rubber layers and have high load capacity. This method can easily be used in all types and sizes of vessels [1].

13.5 Welding in shipbuilding

Welding is one of the most widely used hot-work processes used in the shipbuilding industry. The development in welding technology has enabled the industry to produce perfectly watertight and oil-tight joints [1].

The three main welding techniques that are used in a shipyard are as follows:

– arc welding;
– gas welding;
– resistance welding.

The fundamental principle of arc welding is to connect a metal electrode to an electrical power supply, forming a closed circuit if the plate is touched with the electrode. When the electrode is raised from the plate by a few millimetres, the electric current jumps the gap and an electrical arc is created at high temperature. This results in melting the parent metal and the metal in the electrode, allowing both metals to fuse.

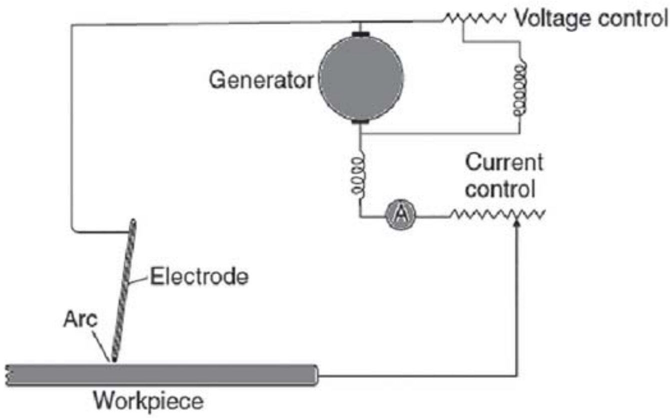

Figure 13.11 – Circuit diagram of arc welding process [1]

Arc shielding is an important aspect of all arc welding processes. In order to prevent oxidation the fused metal, the arc is shielded from the ambient air, and contact with oxygen and water vapour are cut off. The two mostly used shielding techniques used by shipyards are as follows [1]:

– slag shielded arc welding;
– inert gas shielded arc welding.

Slag is the residue left over after the parent metals and the electrode metal have fused. It forms a layer over the arc and the welded joint, protecting it from oxidation. The presence of slag stabilises the arc, providing a better weld quality.

Shielded metal arc welding. The filler metal of most electrodes used in the shipbuilding industry is mild steel. Mild steel drawn in the form of rods is coated with a mixture of mineral oxides, fluorides, silicates, hydrocarbons, and a liquefied binder which binds them together to form a solid envelope around the fuller metal. This coating forms the slag, stabilises the arc and prevents oxidation of the joint. Shielded metal arc welding is used in the fabrication of panels, grillages, tank units, etc. They are used in manual arc welding processes, and can help achieve welding at different positions, namely:

– down hand welding;
– overhead welding;
– vertical welding.

Positional flexibility with this welding process makes it the only welding process used to weld the underside of overhead deck plates.

Submerged arc welding. In this welding process, the arc is sparked and maintained under a blanket of granulated flux, which is laid on the weld joint before the arc strikes the joint.

Gas shielded arc welding processes use a blanket of gas, instead of flux, to provide insulation to the arc against the ambient environment. They are used extensively in shipyards to weld the comparatively lighter structures.

Tungsten inert gas welding (TIG). In this welding process, the arc is created between a non-consumable tungsten electrode and the parent metal plates. The tungsten electrode is surrounded by a nozzle that maintains a continuous flow of an inert gas around the arc. This inert gas shields the arc from oxygen, hence stabilising it and preventing oxidation of the weld pool. A filler rod is introduced into the arc, which helps in the fusion of the two metals. The inert gas used in this process is usually Argon. TIG welding is preferred for plates of thickness usually less than 6 to 8 mm.

Metal inert gas welding (MIG). Metal inert gas welding is, in a way, an advancement on tungsten inert gas welding, where the electrode is a consumable metal wire.

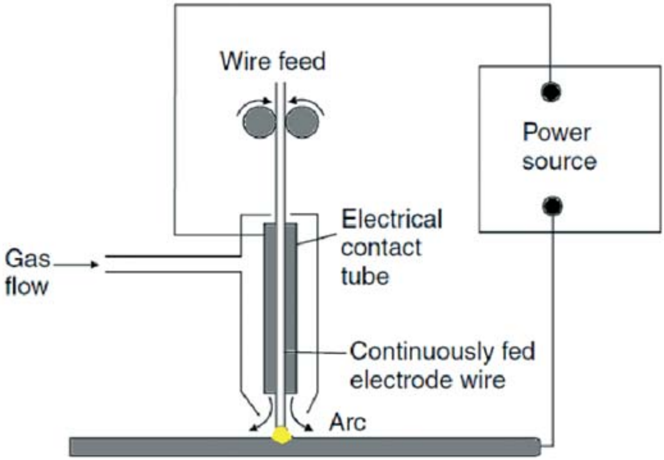

Figure 13.12 – Metal Inert Gas Welding [1]

Every weld joint is inspected by a team of trained inspectors for weld defects. Welding defects may arise due to a lack of skill in welders, use of incorrect materials, or improper welding methods, and ambient conditions.

The most common weld defects are as follows:

1) lamellar tearing;
2) crater cracks;
3) inadequate cross-section or insufficient penetration of weld pool;
4) underbead cutting;
5) gas entrapment within the weld pool;
6) slag inclusions within the weld joint;

7) overlaps;
8) undercuts;
9) lack of reinforcement;
10) excessive reinforcement or extra deposition;
11) lack of fusion within the weld pool.

The most commonly used non-destructive methods of weld quality inspection are listed below

– visual inspection;
– dye penetrant inspection (dpi);
– magnetic particle testing;
– radiographic testing;
– ultrasonic testing.

14 DOCKING. SHIP MAINTENANCE AND REPAIR

14.1 Docking

According to SOLAS every ship should be dry-docked at least twice every 5 years (see fig. 14.1). The maximum time lapse between two dry-dockings should not exceed three years. Only when special provisions have been made during construction, one of dry-docking may be replaced by an in-water survey [21]. Additionally, dry-docking is performed due to damage below the waterline and before of solving of ship.

Figure 14.1 – Huge ship in the dock [21]

The process of docking is done with the aid of a series of drawings and plans, which are prepared by designers based on certain calculations. Hence, knowing docking processes, docking calculations, and understanding how to read docking plans is an important skill for designers working in shipyards.

Methods of dry-docking:

- floating dock;
- excavated dock (graving dock);
- patent slip;
- lift and subsequent horizontal transport of the ship.

14.2 Maintenance

Ship maintenance is usually divided into hull and engine maintenance. Hull maintenance is normally done in dry-dock. This is basically for examination by Class of the underwater parts. When no repairs are to be carried out, it means only examination, cleaning and repainting of the ship's outside hull. Maintenance of decks, and everything inside the shell-plating is usually done by the ship's crew. When the ship is set dry in drydock the outside of the hull is cleaned using high-pressure water jets, at least 100 Bar, to remove dirt and fouling, and to make the hull reade for perainting.

Figure 14.2 – The old paint-layer is removed by gritblasting [21]

After drying, and cleaning, the vessel has to be examined in dry-dock by the Classification surveyor, normally accompanied by owner's representative and the shipyard in ored to investigate the condition of the underwater parts. No defects underwater are to be neglected, to prevent unforeseen repeirs during operational time. Emphasis shall be put on the rudder and propeller, tailshaft, indents damage, paint-condition, corrosion, fractures, welding, and inlet and outlet pipe-stubs.

Most of engine maintenance is done while the ship is in operation, partly during voyage. Items which only can be done when the ship is now underway are done in port.

14.3 Repairs

Repair yards have equipment totally different from newbuilding yards. Their dry-docks are deeper: a ship in operation is heavier than an empty newly built hull [21]. Also cranes do not need to have the lifting capacity of those in a newbuilding yard. The workshops are differently equipped: other machines, for small and sometimes big repair works. Repair yards are used to normal maintenance work, but must have the flexibility to carry out repairs.

Typical repairs are related to certain ship types. Bulk carriers always have works to be done to hatchcovers, crude tankers to pipelines in the tank and pump room and to valves, hopper dredgers to bottom-valves, container ships to container guides, etc.

A repair yard always has shops and/or departments for hull, machinery, pipe repairs, electrical repairs, wood-work and cleaning and painting (see fig. 14.3 and fig. 14.4).

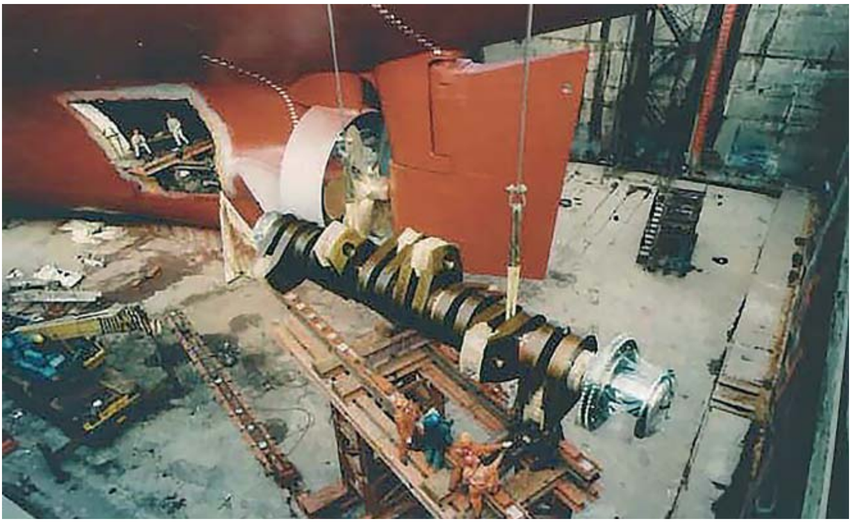

Figure 14.3 – Exchange of crank shaft [21]

Figure 14.4 – Exchange of hull part [21]

Related to ship repairs, more than to newbuilding, is carrying out conversions. Existing ships are sometimes modified into something totally different from the original ship. Caroships are simply lengthened (see fig. 14.5), original steam propulsion is changed to diesel, bulk carriers are converted into drill ships.

Figure 14.5 – A passenger ship is being lengthened to increase capacity [21]

15 SHIP PROPULSION SYSTEM AND PROPELLER

15.1 Marine propeller shaft

The propulsion systems onboard ships power the vessel by converting rotational motion into translational motion. This is similar in theory to the famous Archimedes' Screw mechanism credited to the Greek Mathematician Archimedes in c. 234 BC [1].

The rotational energy is provided by two to four marine engines located in the engine compartment of a ship. Both two and four-stroke engines are used depending on the size and required use of the vessel.

The marine engines generally run on diesel, although attempts are being made to turn to energy-friendly alternatives.

The most commonly used type of marine engine is the reciprocating diesel engine that has a higher efficiency compared to other models. These engines can be classified into three types based on their revolutions per minute (rpm). The three categories- slow, medium, and high speed have their own benefits based upon the type of ship to be powered.

For instance, large ships require a low-speed but high-torque propulsion system to power them. For such vessels, a low-output speed engine can be selected.

The issue with using slow-speed engines is the large space they take up as compared to the other engines. Thus, a space-effective solution would be to install high-speed engines in the ship and then reduce the torque before it reaches the propellers.

For this, a gearbox is a very useful component that can be used to manipulate rotational torque transfer. It is attached to the marine propeller shaft and reduces the power transmitted to the propeller.

The slow-speed engines pose no problem to the transfer of torque and do not require an additional gearbox. The gearbox in the other speed engines is attached in between the intermediary and propeller shafts.

15.2 Components of propeller shafts

The marine propeller shaft is divided into three main components [1] (see fig. 15.1):

- the thrust shaft,
- intermediate shaft(s), and
- tail shaft.

The thrust shaft is the primary shaft emerging out of the engine. It directly receives the rotational motion from the crankshaft and rotates at the maximum velocity in high-speed engines. For high rpm engines, the thrust shaft is further connected to other components that lie further aft.

The next component is the intermediate shaft. There is no specific restriction on the number of intermediary shafts that a ship can have. However, beyond 2 shafts, it can be difficult to service and maintain. The reason for this is the large catenary force acting on the entire propeller shaft. This force tends to deform and damage parts due to their weight. The only reason to have multiple intermediary shafts is that the engines are located far away from the propellers.

The last part is the tail shaft. It is directly connected to the propellers and lies mainly encased in the stern tube. The tail shaft is connected to the intermediate shaft by a gearbox that manipulates torque transfer. The tail shaft is built to withstand a variety of forces that may act at the stern of the ship.

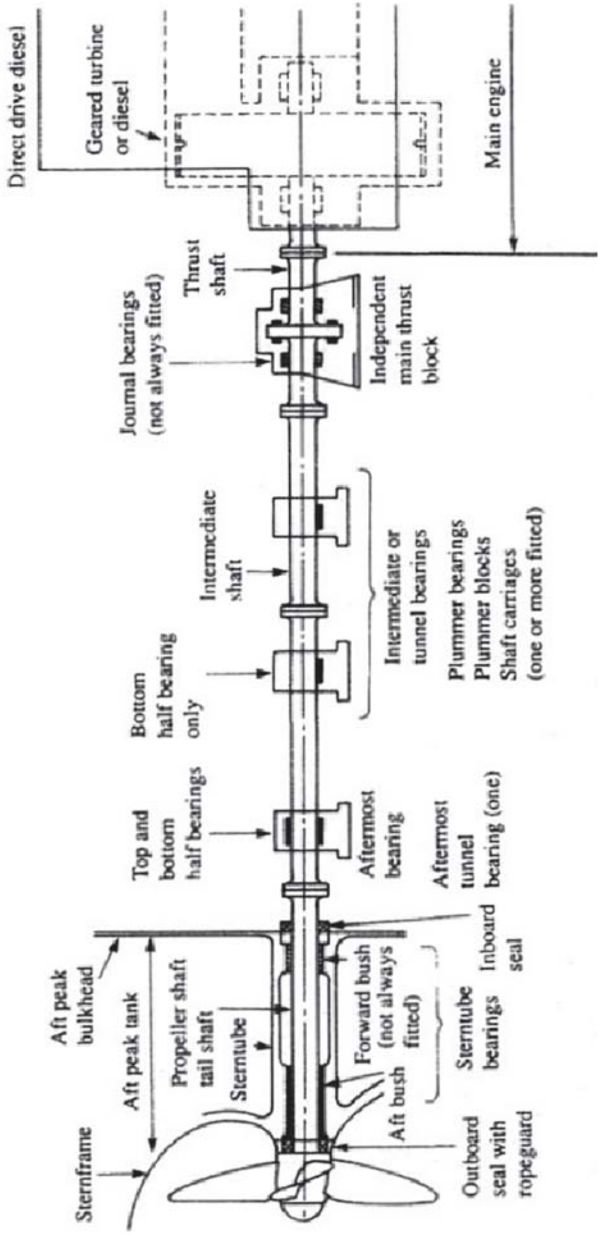

Figure 15.1 – Propeller shaft system [37]

The next component is the *coupled bearing* that connects two adjacent shafts. The coupling is achieved by virtue of joints that are usually rigid and do not flex. The coupling units are bolted to each other using high-strength fasteners that can withstand a large number of vibrational stresses.

Shaft bearings are components that are used to support and bear the load of the shafts. They run along the length of the shaft and ensure smooth rotation. These bearings are constructed differently based on their location.

The last part of the marine propeller shaft system is the thrust blocks. These blocks support the propeller shafts at regular intervals. These blocks transfer the excess power from the shafts into the hull of the ship.

Stern tube arrangement refers to the manner in which the tail shaft is borne by the stern tube that is located at the aft of the vessel. The stern tube is a hollow, horizontal tube that serves as the primary connection between the propellers and the rest of the vessel.

Attached to the stern frame, the stern tube acts as a plug at the rear of the vessel. The stern frame is the primary structural member that supports the stern overhang that lies above the propellers and rudder.

The stern tube houses the tail shaft of the marine drive shaft system and serves two main purposes which are withstanding load and sealing the entire vessel at the aft portion.

Since the stern tube serves as the primary link between the vessel and the propeller, it must be able to withstand a tremendous amount of force that is exerted by the suspended propellers. In addition, it should provide sufficient room for the propeller hub to actually move without creating friction.

To handle the load, white metal is a commonly used material that can withstand the required loads. Sufficient lubrication is also provided within the stern tube to ensure the smooth functioning of the entire marine propulsion system.

Along with supporting the structural weight and forces of the propeller, the stern tube also needs to be able to effectively seal the vessel. It prevents water from entering through the aft and achieves this by using a combination of seals along its length. The stern tube has two main seals located at its aft and fore regions.

This serves as dual protection against any possible leaks that may occur over long periods of time. These seals can be of three main types stuffing boxes, lip seals, and radial face seals. Stuffing boxes are built out of a variety of packing materials that are used to plug the stern tube.

Lip seals are gland seals that are used to prevent lubricants from seeping out into the water. They also serve the dual purpose of preventing water from entering the stern tube. Lastly, radial face seals extend radially out from any points of ingress and use a spring system to seal the entire structure. They are composed of two main parts that join to completely seal the rear portion.

The stern tube plays an important role in marine propulsion since it absorbs and dampens a considerable amount of power away from the propeller. In an effort to completely seal the stern section of the ship, it may also hamper the rotational abilities of the propeller shafts.

Marine propeller shafts play an important role in the naval industry. Various points are to be considered while designing and building the shafts and stern tube. Properly aligning the shafts is extremely important. Since there can be between two to four shafts, having each one centred accurately prevents any mishaps from occurring.

In case the alignment is off by even a fraction of a millimetre, the entire propeller shaft may rapidly oscillate. This would result in large stresses that would permanently deform and damage the entire shaft. When procuring marine shafts, it is important to ensure the highest quality of materials along with proper manufacturing techniques.

15.3 Ship propeller

A ship propeller is used for propulsion in most types of vessels, irrespective of their type and size. The notion of 'pushing' or 'propelling' a ship forward came into being since the advent of ships themselves [1].

A marine propeller consists of a number of blades (2–7) mounted on a boss, which is like the backbone of the entire arrangement (see fig. 15.2). It mates with the rotating shaft, which corresponds with the engine room mechanism.

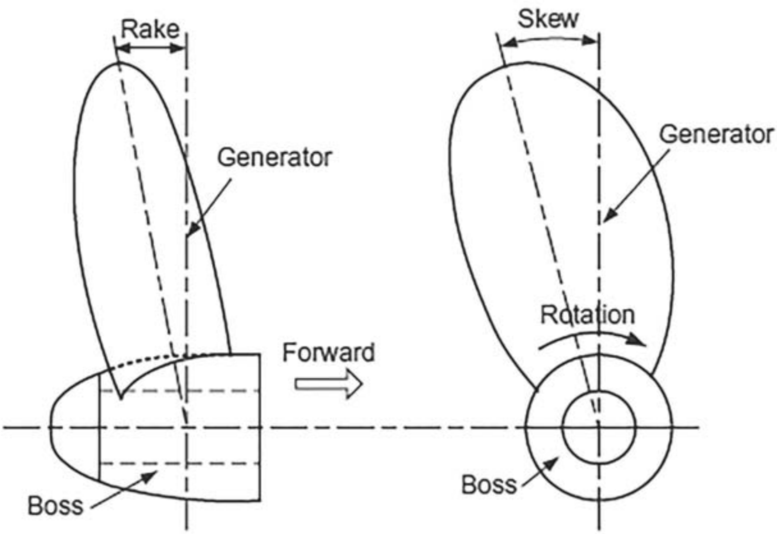

Figure 15.2 – Propeller geometry [12]

The shaft transmits the power delivered from the engine (with losses, of course) and, in turn, rotates the blades mounted on the hub/boss.

Detailed studies of the hydrodynamic behaviour of propellers in different water conditions have shown that the delivered thrust and thus the resultant efficiency are inversely proportional to the size/diameter of the boss. Thus, modern designs have evolved with the smaller yet stronger boss so as to maintain a safety trade-off in terms of strength.

Blades are mounted on the hub similar to thin aerofoil sections, which can create a hydrodynamic lift required to produce thrust. Over time, blades have evolved into innumerable designs and shapes foiled, twisted, and torqued in a typical manner apt for the vessel at design speed and displacement.

The ship propeller has two hydrodynamic surfaces: the face and back. To put it simply, the cross-section of blades coupled with the boss, when looked at from behind the ship, is called the face, also known as the 'palm'. The opposite face is called Back (see fig. 15.3).

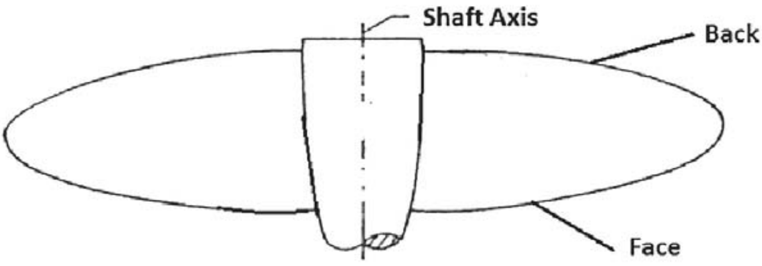

Figure 15.3 – Plan of a propeller section showing face and back [1]

To put it simply, there are two edges of a ship propeller blade. The edge that pierces the water surface first in order of succession is termed the leading edge. Depending upon the sense of rotation of the propeller (whether it rotates clockwise or anticlockwise), either of the two edges can become the leading edge. The other edge, which follows or 'lags behind' the leading edge, is termed the trailing edge.

The point of attachment of the blades with the ship's propeller boss or hub is called the root. The tip is the furthest point of the propeller blade from the root and tapers like a leaf. It has the least section width. It joins the leading and trailing edges as well as remains the same for the face and the back.

Pitch is defined as the lateral distance traversed by a fixed point when the screw turns about its own axis. It is exactly the same in the case of propellers. Pitch in case of a propeller is a measure of how much the propeller would «drive» or «Push forward» when it is freely turned about its own axis (see fig. 15.4). So, an obvious question that may arise in your minds is: Does the propeller actually displace forward? The answer is no. It is coupled through an intrinsic shafting mechanism to the main engine. But validating Newton's third law, it generates a reaction force in the wake region astern which thrusts the vessel forward.

When the propeller is viewed from sideways, we see that the blades of the propeller are not perpendicular to the surface of the hub. It is 'tilted' at an angle either towards the fore-end or the aft end of the ship. This is termed as *Rake* (fig. 15.4).

We now shift our reference to the Y–Z plane (which appears when we look at the ship propeller surface from behind). The blade appears to be 'Skewed', that is, bent or twisted sideways. The skew of a propeller is clearly shown in the figure below.

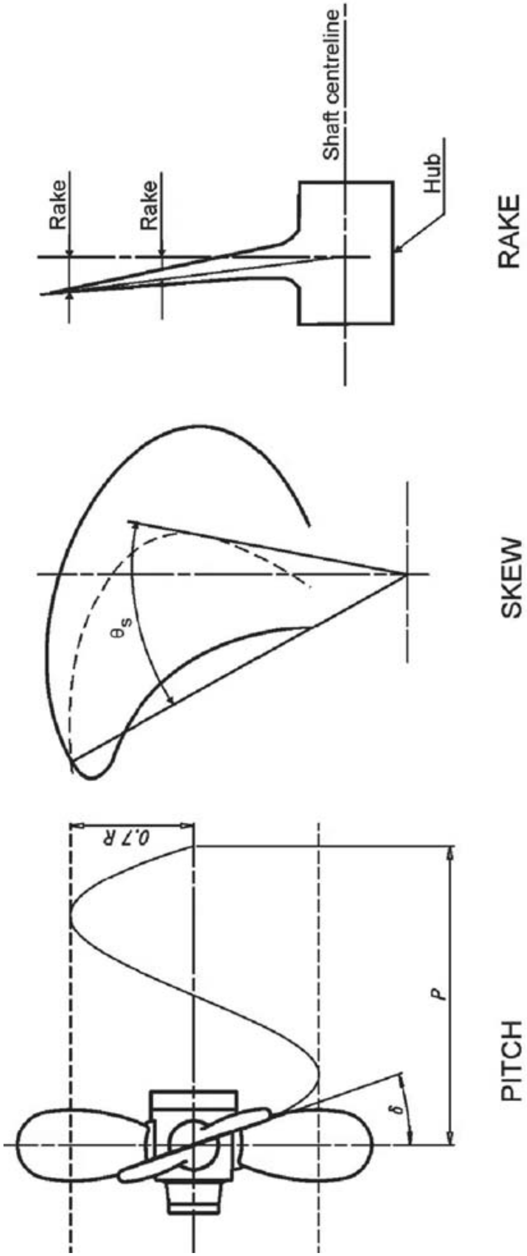

Figure 15.4 – Pitch, skew and rake of a propeller [41]

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Викладено англійською мовою основи суднобудування. Розглянуто основні типи суден, поняття із статики, ходовості, керованості та мореходності судна. Наведено основні відомості про класифікаційні товариства, конструкцію корпуса судна, його міцність й суднобудівні матеріали, суднові пристрої та системи, суднові енергетичні установки та електроустаткування, пропульсивну установку суден. Викладено основні поняття про побудову судна та судноремонт.

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