THE STRESS ANALYSIS OF HULL GIRDER AND SUPERSTRUCTURE INTERACTION

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Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Civil Engineering
(Computer Aided Structural Analysis & Design)

By

Plumber Saifuddin S.
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Guide
Dr. Chakradhar Iyyunni

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CERTIFICATE

This is to certify that the Major Project entitled "The Stress Analysis of Hull girder and Superstructure Interaction" submitted by Mr. Saifuddin Plumber (06MCL015), towards the partial fulfillment of the requirements for the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) of Nirma University of Science and Technology, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this Major Project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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ABSTRACT

Ships are the vital element in the modern world. Ships are used worldwide for variety of functions, sizes and in sea environments. They still carry 95 per cent of the trade. Although aircraft has displaced the translation liners, ships still carry large number of people on pleasure cruises and on the multiplicity of ferries operating in all areas of globe. Ships and other marine structures are needed to exploit the riches of the deep sea.

The primary aim of the study is to understand the stress analysis of hull girder and superstructure interaction for various load combinations such as deadweights and wave loads. The study also concerns with scantling of midship frame and shell plates.

In this study the scantling of midship frame for 250 passengers cum 100 T cargo vessel is carried out. The ship is 85.2 m long, 15 m wide and the hull height is of 9m. Scantlings are done for an ordinary frame irrespective of its location in the midship. Scantling calculations are performed as per LR-part4, chapter1. Loading requirements for scantling is fulfilled by LR-part 3.

The stress analysis for interaction between superstructure and hull girder is carried out for different load combinations. The deck plan of ship is divided in different load regions depending upon GA drawings. The external sea pressure is calculated as per ABS. In another case, study also includes wave loads as provided by SAP2000 program. The program uses Stokes 5^{th} order theory and Morison equation to calculate the wave forces. For modeling of ship, its shape is approximated to straight surface instead of three dimensional curvatures. The ship is analyzed as a box beam hinged on two nodes at ends. The analysis is performed for sagging condition with two wave crests at each end of the ship.

Modeling and analysis of ship is done in SAP-2000 considering environmental and non-generated loads. The project consists of the static analysis of the ship. The in-

place static analysis is carried out using SAP-2000 program. To observe the effect of deckhouse on hull girder stresses, the dimension of deckhouse is varied in length and breadth. Stress reduction is observed when there is superstructure on hull as compare to hull without superstructure. This reduction in stresses depends on the size of the deckhouse. When the sides of deckhouse are coplanar with hull and length is almost 40 per cent of hull length, this stress reduction becomes significant.

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ABBREVIATION NOTATION AND NOMENCLATURE

A_M	midship section area
A_W	waterplane area
AFT	after side of ship
AP	after perpendicular
ABS	American Bureau of Shipping
a	plan area at water level
B	beam or molded breadth
C_B	block co-efficient
C_M	midship section co-efficient
C_P	longitudinal prismatic co-efficient
C_{VP}	vertical prismatic co-efficient
C	wave parameter taken equal to:
	$C = 10.75 - \left(\frac{300-L}{100}\right)^{1.5}$ for $90 \leq L < 300m$
	$C = 10.75$ for $300 \leq L < 350m$
D	depth of ship
DWL	design water line
F	free board
FWD	forward side of ship
FP	forward perpendicular
f_p	Coefficient corresponding to the probability
F_M	Distribution factor
g	gravity acceleration
IRS	Indian Registry of Shipping
L	length of ship – generally between perpendiculars
LOA	length overall
L_{PP}	length between perpendiculars
L_{WL}	length of waterline
LR	Lloyd’s register
S	wetted surface

Sheer	longitudinal profile of deck
T	draft or draught
Δ	displacement force
V	displacement volume
ρ	sea water density, taken equal to 1.025 t/m^3
x,y,z	X, Y and Z co-ordinates, in m, of any point considered
M_{SW}	Design still water bending moment, in kN-m, at hull transverse section
	$M_{SW}=M_{SW,H}$ in hogging condition
	$M_{SW}=M_{SW,S}$ in sagging condition
M_{WV}	Vertical wave bending moment, in kN-m, at the hull transverse section
	$M_{WV}=M_{WV,H}$ in hogging condition
	$M_{WV}=M_{WV,S}$ in sagging condition
M_{WH}	Horizontal wave bending moment, in kN-m, at the hull transverse section
Q_{SW}	Design still water shear force, in kN-m, at the hull transverse section
Q_{WV}	Vertical wave shear force, in kN, at the hull transverse section
P_S	Still water pressure, in kN/m^2
P_W	Wave pressure or dynamic pressures, in kN/m^2
λ	Wave length in meter

1. INTRODUCTION

1.1 GENERAL

Ships are largest mobile structures built by man. Structural requirements are influenced by size and intended services. They are amongst the most complex of structures and this is due to their mobility. Three dimensional curved surface and shape of hull helps in overcoming water resistance. Shell plating is also one of the strength members for hull.

The size and principal characteristics of a new ship are determined primarily by its requirements. In addition to basic functional considerations there are requirements such as stability, low resistance and high propulsive efficiency, and navigational limitations on draft, all of which influence the choice of dimensions and form. The ship's structure must be designed within these and other basic constraints, to sustain all the loads expected to arise in its seagoing environment. As a result, a ship's structure possesses certain distinctive features not found in other man-made structures. In contrast to land-based structure, the ship does not rest on a fixed foundation but derives its entire support from buoyant pressures exerted by a dynamic and ever changing fluid environment.

1.2 TYPES OF SHIP

There are many types of ships are in the ocean. Their purpose ranges between transportation, navy and sports. Each purpose requires its own type of ship. Some of the ships are explained below. These ships are shown in Figure 1.1.

1.2.1 Passenger ship

Passenger ships are classified by United Kingdom as follows

Class I – Long international voyages

Class II - Short international voyages

Class II (A) - Other than international voyages

Class III – At no time more than 70 miles from the point of their departure and not more than 18 miles from the coast of United Kingdom, and which are at sea only in fine weather and during restricted periods.

Class IV – Voyages in smooth or partially smooth water.

Class V – Voyages only in smooth waters.

Class VI – Ships engaged on voyages with not more than 250 passengers on board, to sea, or in smooth or partially smooth waters, in all cases in fine weather and during restricted periods.

Class VI (A) – Ships carrying not more than 50 passengers for a distance of not more than 6 miles on voyages to or from isolated communities, islands.

1.2.2 Ferries and RoRo ship

These ships are meant to transport people and goods in their own vehicles shore to shore economically and quicker. As a result the concept of integrated transport system aroused to Roll-on – Roll off ships and to ferries. A ship of course rises and falls with the tide so that embarkations of vehicles need vertical adjustment and, indeed, restraint.

1.2.3 Aircraft carriers

The characteristic of an aircraft carrier are profoundly affected by the type of aircraft that it is required to operate, which may be fixed wing, deflected jet, vertical take off or helicopter.

1.2.4 Bulk cargo carriers

Cargo which may be carried in bulk includes oil, ore, chemicals, vegetable oils, liquefied gas, coal, grain and forest products. For economic reasons most oil is carried worldwide in very large crude carriers, $VLCC_S$ and such 500 vessels pursue on oceans. They may carry 300,000 tones of crude oil in holds arranged longitudinally and abreast.

1.2.5 Submarines

Submarines are vehicles designed to operate principally at considerable depth. Most applications to date have been to warships. Commercial applications have been oceanographic research vessels and small vehicles for pipe laying and servicing well - head on the sea bed. Submarines are uneconomical for general commercial work.

1.2.6 Container ships

The container ships are like hollow shoeboxes, stowing containers below a single deck which have very large hatches. Various systems are designed to hold the container into the ship. More of them may be carried above the deck in stacks. There has also evolved an open container ship constructed like a double skinned U without a deck. The container may be locked together by fittings so that they are unable to move even in severe weather.

1.2.7 Frigates and destroyers

These are the large vessels. The lengths will be in range of 100 to 150m, with length to beam ratio of about 8:1. The larger ships can fulfill more of these roles and operate effectively in more severe conditions. The roles covered by these ships are:

- Anti-air warfare (AAW)
- Anti-submarine warfare (ASW)
- Anti-surface warfare (ASuW)
- Task force protection
- Self defense
- Shore bombardment

1.2.8 Tugs

Tugs perform variety of tasks and their design varies accordingly. They are needed to pull or push dumb barges or pull drones in inland waterways; they are needed to pull or push large ships in confined waters and docks, and they needed to tow large ships on long ocean voyages. Tugs are capable of firefighting and salvage duties and may carry large capacity pumps for this purpose.

1.1 OBJECTIVES OF STUDY

The objective of present study is to understand the contribution of superstructure to the hull girder strength. The main objectives of study are as follows,

a) To understand the ship terminologies.
b) To perform the scantling calculations for midship region.
c) To perform the stress analysis to see the effect of superstructure to hull girder strength.

1.4 SCOPE OF WORK

The project work is concerned with the stress analysis of the ship for superstructure contribution to the hull girder strength. Various theoretical aspects considered are scantling of midship and the sea behavior. To achieve the above objectives the scope of work is performed in two parts, part-1 and part-2.

An investigative study is carried out.

1) Clear the understanding about ship geometry and various aspects of ship.
2) To study the rule books such as LR and IRS to understand the load requirements in different sections of ship.
3) Perform the scantling calculations as per LR-part4 in midship regions.

Ship is analyzed under various loads and loading conditions using SAP2000.

4) Calculation of various loads such as Deadweight and wave loads for analysis in SAP2000.

5) Calculations of wave loads as per ABS guide lines.
6) Prepare an approximate model of ship is SAP to perform the analysis.
7) Varying the superstructure dimensions to observe its effect on hull global stresses.

1.5 ORGANIZATION OF MAJOR PROJECT

The major project is organized in following chapters.

- Chapter 1 presents the introduction and background of work.
- Chapter 2 shows brief literature review pertaining to ship industry.
- Chapter 3 deals with the brief explanation of various ship terminologies.
- Chapter 4 gives load calculations of deadweight and wave induce loads.
- Chapter 5 shows scantling calculations for midship frame.
- Chapter 6 presents the modeling consideration made in SAP2000 for analysis.
- Chapter 7 gives results and conclusion of the work.

2. LITERATURE SURVEY

2.1 General

In this chapter, Survey from various literatures such as class rules and references has been carried out to support the present study. The survey has provided the knowledge for basic ship terminology, its sea going behavior. Class rules have enabled to make scantling calculation.

2.2 Literature review

Brief review of study of various references is as follows.

- Determination of wave loads for ship structural analysis (B. P. Phelps)

The paper presents the methods for evaluating hydrodynamic loads on ships in order to assess their applicability to RAN ships. Methods for calculating still water loads and wav bending loads using the Static-Balance method are outlined and comparisons of the methods provided. The use of Strip Theory methods to determine the probable and design extreme amplitude shear force or bending for a particular sea state is explained and predictions are compared with full scale measurements. Methods for long term load predictions such as Adamchak's Method and load shortening curves are also discussed. Methods for applications of these loads to finite element models are given and the particular case of an analysis of an RAN ship is discussed.

- Principles of Naval Architecture, volume-I, Second revision , Edward V. Lewis, Editor, Published by, The Society of Naval Architects and Marine Engineers

Chapter1 deals with the graphical and numerical description of hull forms and of flotation and stability that follow. Chapter2 considers stability in normal intact condition, while chapther3 discusses floatation and stability in damaged conditions. Finally chapter4 deals with principles of hull structural design, first under static calm water conditions, and then introducing the effect of waves which also is covered.

- Principles of Naval Architecture, volume-III, Second revision , Edward V. Lewis, Editor, Published by, The Society of Naval Architects and Marine Engineers

Volume III contains two chapter, motion in waves and controllability. The first chapter deals with origin and propagation of ocean waves. Concept of various energy spectra is also covered. Chapter also includes ship responses to regular wave and control of ship motion, and some of the design aspects of ship in a seaway. The next chapter deals with stability and control of ship at sea and maneuvering criteria for ship.

3. BASIC SHIP THEORY

In this chapter, we discuss aspects of basic ship theory. This includes ship geometry and structural aspects of various ship elements.

3.1 PRINCIPLE PARTICULARS OF VESSEL

The general arrangement of 250 passengers and 100 T cargo capacity ship is shown in Figure 3.1. The salient features of ship are as follows,

Length O.A.	: 88.80 m
Length W.L.	: 82.42 m
Length B.P.	: 80.42 m
Breadth MLD.	: 15.5 m
Draft design	: 3.40 m
Scantling draft	: 3.50 m
Depth MLD. To MDK.	: 6.30 m
Frame spacing	: 600 mm
Speed	: 15 Knots
M.E. engine power	: 2 x 1950 K.W.
Passenger	: 252
Officers and crew	: 39
Generators	: 3 x 450 K.W.

3.2 SHIP PARTICULARS

The shape and purpose of ship can be defined by the various ship terminologies. These terminologies which describe the ship are explained as follows.

3.2.1 Ship's Lines

The curved surface of ship's hull can be dictated by lines. These lines are the perpendicular projection of hull form with the three mutually perpendicular planes namely buttocks, waterlines and bodyplan.

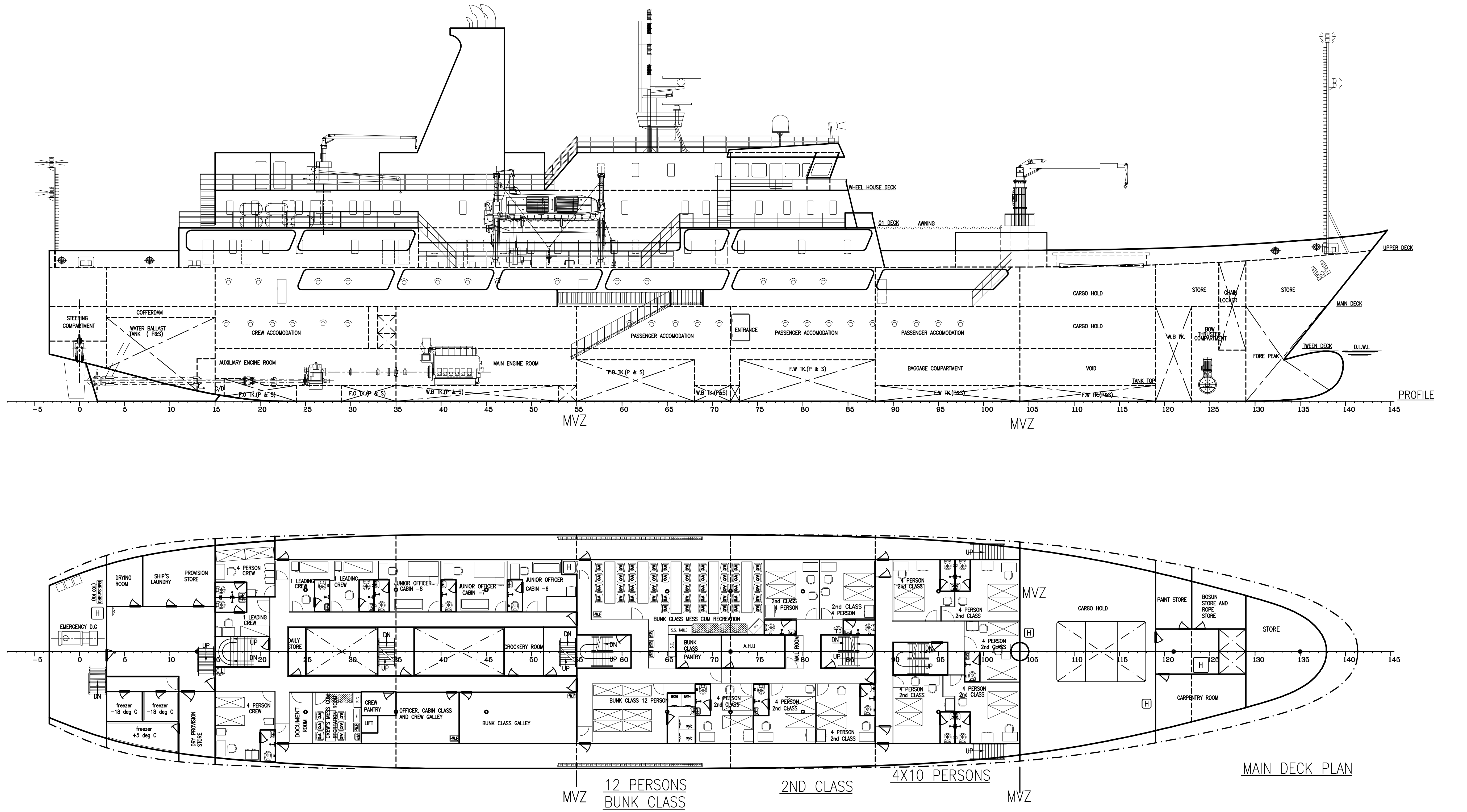


Fig. 3.1 General arrangement drawing

The profile or sheer plan of the hull form can be obtained by the intersection of vertical plane through the center line of the ship. Parallel planes at convenient distance from the centerplane are known as buttock planes. They help in defining the vessels shape. The profile on centerplane shows the bow and stern profiles.

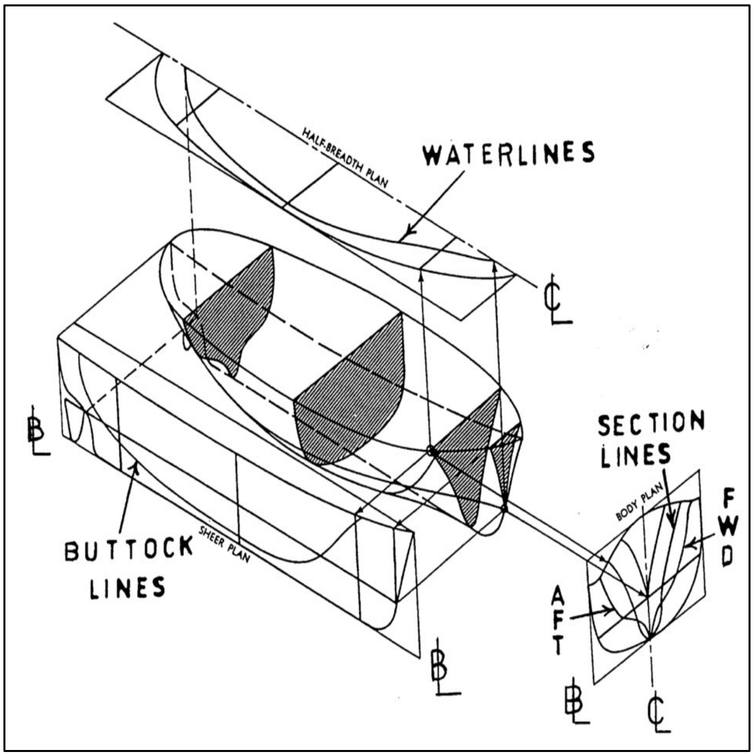


Fig. 3.2 Sheer plan, half-breadth plan, and body plan

Half-breadth or waterlines plan shows the intersection of the hull from with planes parallel to the horizontal baseplane, which is called the base line. All such planes are called waterline planes, or waterplanes. Most ships are symmetrical about the centerplane, and the lines drawing shows waterlines in the half-breadth plan on only one side of the centerline.

The body plan shows the shapes of sections determined by the intersection of the hull form with planes perpendicular to the buttock and waterline planes. Planes defining the body plan are known as body plan stations. They are usually spaced equally apart. The body plan shows sections on one side of the centerline only-those in the forebody on the right hand side and those in the afterbody on the left. The surface formed by lines of hull is the outer edges of the frames or inside the 'skin.' Such surface is known as molded surface of the ship in steel, aluminum or wooden vessel.

3.2.2 Length between Perpendiculars

A vertical line in the sheer plan is drawn as shown in Figure 3.3, as the intersection of the DWL, which is often the estimated summer load line, and the forward side of the stem. This known as the forward perpendicular, abbreviated as FP.

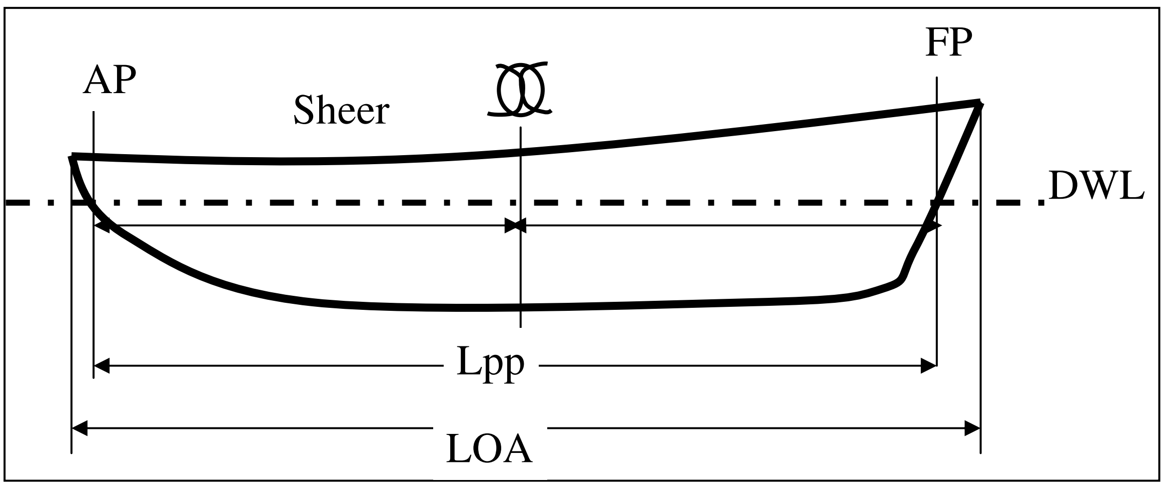


Fig. 3.3 Deck profile

A corresponding vertical line is drawn at the stern, designated the after perpendicular or AP. When there is a rudder post the AP is located where the after side of the rudder post intersects the DWL.

An important characteristic of a ship is its length between perpendiculars, sometimes abbreviated LBP or L_{pp}. This represents the fore-and-aft distance between the FP and AP, and is generally the same as the length L.

L, for use in the rules, is not to be less than 96 percent and need not be greater than 97 percent of the length on the summer load line.

The summer load line is the deepest waterline to which a merchant vessel may legally be loaded during the summer months in certain specified geographical zones.

DWL represents the design waterline, near which the fully loaded ship is intended to float. All waterlines are identified by their height above the baseline.

3.2.3 Midship Section

An important matter for any ship is the location and shape of the midship cross section, generally designated by the symbol Φ. It was originally used to indicate the fullest cross section of the vessel. In any case, the usual practice in modern commercial vessels of most types is to halfway between the perpendiculars, while in naval ships it is usually midway between the ends of the DWL.

3.2.4 Body Plan Station

The LBP is divided into 10 or 20 or 40 intervals by body plan planes. The location of this plane known as body plan station and are indicated by straight lines drawn in the profile and half-breadth plans. These body plan stations help in calculation of underwater characteristic of the form. Body plan stations are customarily numbered from the bow, with the FP designated as station 0.

3.2.5 Molded Base Line: Molded Dimensions

The molded base line represents a plane in space to which many vertical heights are referred. It also represents the bottom of the vessel’s molded surface. The distance form K to B is one-half of the important dimension known as the molded beam or molded breadth of the vessel, which is normally a maximum at the midship station.

3.2.6 Characteristic of the Sections

In Figure 3.4 from the point A the molded line of the bottom of the midship section extends towards the side in a straight line AC. This line often is inclined upwards slightly and intersects, at the point C, the vertical line EB drawn tangent to the widest part of the underwater body.

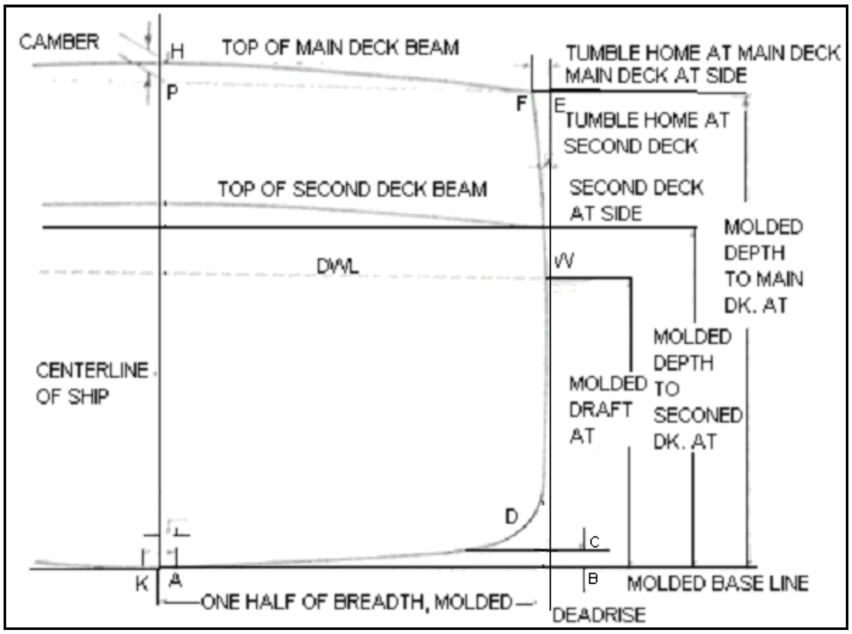


Fig. 3.4 Body plan

The line AC is known as the floor line, and the distance BC is referred to as the deadrise, rise of floor, or rise of bottom.

The point K at the vessel's centerline is at the lowest part of the molded surface and the distance KA is the half-side dimension of the flat portion of the molded surface in the vicinity of the keel i.e., to the beginning of the deadrise.

The curved portion of the section, as at D, which joins the floor line with the side, is known as the turn of bilge and may be further describe as a "hard" or as an "easy" turn of bilge, where hard refers to a small radius of curvature. The turn of bilge throughout the parallel middle body is usually, but not necessarily, a circular arc, and the radius of this curve is known as the bilge radius.

The molded line of the side above the waterline sometimes extends inboard somewhat to meet the line of the top of the main deck beam. In Figure 3.4 this intersection is at the point F. the horizontal distance EF is known as tumble home at the deck. The opposite of tumble home is known as flare, and it is measured in a similar way.

A horizontal line through F in Figure 3.4 meets the centerline of the section at P; the distance PH is called camber or round of beam. The camber curve may be an arc of a circle or parabola. Standard past practice has been to provide about 2 percent of the total breadth of the ship as camber amidships. The use of camber accomplishes the important function of assuring that rain water and water shipped aboard will drain off readily.

3.2.7 Area Curves of Form

Sectional area curve as shown in Figure 3.5 is particularly relative to resistance. The sectional area curve represents the longitudinal distribution of cross sectional area below the DWL. The horizontal scale, or abscissa represents longitudinal distances along the length of ship, it is clear that the area under the curve represents the volume of water displaced by the vessel up to the DWL, or volume of displacement. The centroid of the vessel's sectional area curve is at the same longitudinal location as the center of buoyancy, LCB.

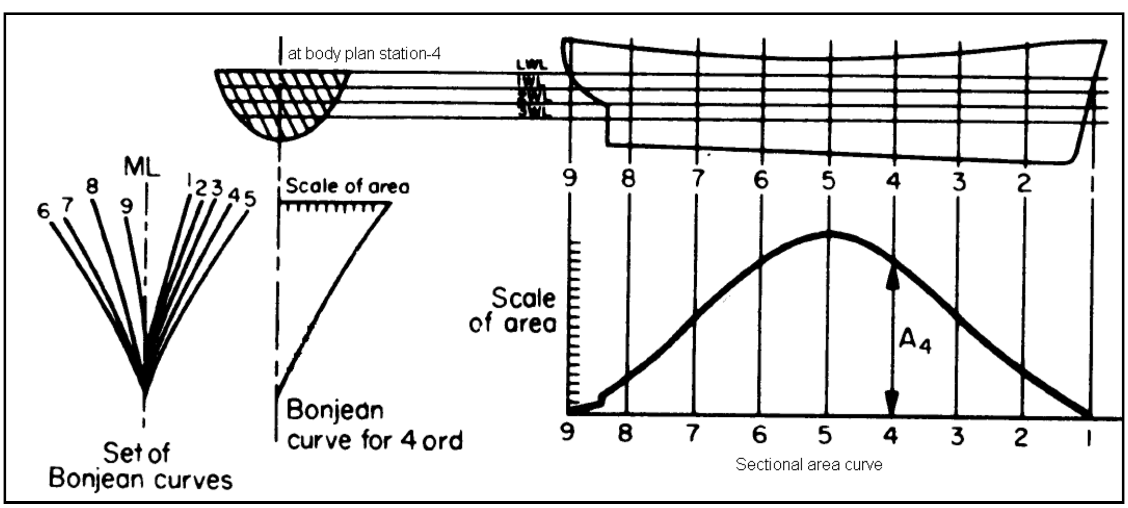


Fig. 3.5 Sectional area curve and Bonjean curves

The curves of cross sectional area for all body plan stations are collectively called Bonjean Curves. One of the principal uses of Bonjean Curves is determining volume of displacement of the ship at any level or trimmed waterline. The moment of area of each section about the molded baseline when integrated longitudinally, gives the moment of volume of displacement about the molded baseline and hence vertical height of center of buoyancy.

3.2.8 Molded Draft and Keel Draft

The depth of waterline at which the vessel is floating from the bottom is called draft. It indicates the amount of water a vessel draws. Drafts are measured at different locations along the ship length. They are known as molded drafts if measured to the molded baseline; keel drafts if measured to the bottom of the keel.

The difference between drafts forward and aft is called trim. If the draft aft exceeds that forward, the vessel is said to have trim by the stern. An excess of draft forward causes trim by the bow- or trim by the head.

3.3 DISPLACEMENT AND WEIGHT RELATIONSHIP

3.3.1 Archimedes' Principle

The Archimedes' principle states that a body immersed wholly or partially in a fluid is buoyed up by a force that equals the weight of the displaced fluid. Thus, the weight is considered to be a downward force that is proportional to the body's mass; the equal buoyant force is proportional to the mass of the displaced fluid.

3.3.2 Effect of Density of Medium

A decrease in the density of the fluid in which a vessel floats requires an increase in the volume of displacement V in order to satisfy static equilibrium requirements. Therefore, a ship moving from salt water to fresh water, for example, experiences an increase in draft, δT. This increase can be calculated by equating the increase in displacement volume to the volume of a layer of buoyancy of uniform thickness, δT, distributed over the original load waterplane. The increase in displacement volume,

$$V_F - V_S = V_S \frac{\rho_S}{\rho_F} - V_S = V_S\left(\frac{\rho_S}{\rho_F} - 1\right) \quad \dots (3.1)$$

Where, subscript S refers to salt water, subscript F to fresh water. But, the volume due to increased layer of buoyancy is, $V_F - V_S = A_{WP} \cdot \delta T$. hence,

$$A_{WP} \cdot \delta T = V_S\left(\frac{\rho_S}{\rho_F} - 1\right) \quad \dots (3.2)$$

and the increase in draft is,

$$\delta T = \frac{V_S}{A_{WP}}\left(\frac{\rho_S}{\rho_F} - 1\right) = \frac{V_S(\gamma_S - 1)}{A_{WP}} \quad \dots (3.3)$$

Where V is displacement volume, ρ is mass density, A_{WP} is waterplane area, and $\rho_S/\rho_F = \gamma_S$ is specific gravity.

The centroid of the underwater body may shift, both vertically and longitudinally, with such a change in medium. In particular, an increase in draft as a result of a decrease in fluid density causes the vertical location of the center of buoyancy to rise with respect to the keel as a result of the increase in displacement volume V.

It is important to use the correct density of the water in making displacement calculations. There is about a 2 ½ percent difference between the density of fresh water, as in the Great Lakes, and the salt water of the oceans. The water in some rivers and harbors is usually brackish, and its density may vary considerably with the tides. When drafts readings are taken to determine displacement, samples of the water should be taken at the same time in order to determine its density.

3.4 COEFFICIENTS OF SHIP FORM

3.4.1 Block Coefficient, C_B

This is defined as the ratio of the volume of displacement V of the molded form up to waterline to the volume of a rectangular prism with length, breadth and depth equal to the length, breadth and mean draft of the ship, at that waterline. Thus,

$$C_B = \frac{V}{L \times B \times T}$$

Where L is length, B is breadth and T is mean molded draft to the prevailing waterline. Values of C_B at design displacement may vary from about 0.36 for a fine high-speed vessel to about 0.92 for a slow and full Great Lakes bulk carrier.

3.4.2 Midship Coefficient, C_M

The midship section coefficient, C_M, sometimes called simply midship coefficient, at any draft is the ratio of the immersed area of the midship station to that of a rectangle of breadth equal to molded breadth and depth equal to the molded draft amidships. Thus,

$$C_M = \frac{\text{Immersed area of midship secion}}{B \times T}$$

Values of C_M may range from about 0.75 t 0.995 for normal ships, while for vessels of extreme form with a slack bilge and a hollow garboard area amidships, C_M might be as low as 0.62.

3.4.3 Prismatic Coefficient, C_P

The prismatic coefficient, sometimes called longitudinal prismatic coefficient, or simply longitudinal coefficient, gives the ratio between the volume of displacement V and a prism whose length equals the length of the ship and whose cross section equals the midship section area. Thus,

$$C_P = \frac{V}{L \times \text{immersed area of midship section}}$$

$$= \frac{V}{L \times B \times T \times C_M} = \frac{C_B}{C_M}$$

Prismatic coefficient is a frequently used parameter in studies of speed and power. Usual range of values is form about 0.50 to about 0.90. A vessel with a low value of C_P is said to have a fine hull form, while one with a high value of C_P has a full hull form.

3.4.4 Waterplane Coefficient, C_{WP}

The waterplane coefficient is defined as the ratio between the area of the waterplane A_{WP} and the area of a circumscribing rectangle. Thus,

$$C_{WP} = \frac{A_{WP}}{L \times B}$$

The values of C_{WP} at the DWL range from about 0.65 to 0.95, depending upon type of ship, speed, and other factors.

3.4.5 Vertical prismatic Coefficient, C_{VP}

This coefficient is the ratio of the volume of a vessel's displacement to the volume of a cylindrical solid with a depth equal to the vessel's molded mean draft and with a uniform horizontal cross section equal to the area of the vessel's waterplane at that draft.

$$C_{VP} = \frac{V}{C_{WP} \times L \times B \times T} = \frac{C_B}{C_{WP}}$$

3.5 FORM PARAMETERS AND RESISTANCE

There can be no absolutes in terms of optimum form. Frictional resistance is directly related to the wetted surface area and any reduction in this will reduce skin friction resistance. Other form changes are likely to have most affected on wave – making resistance but may also affect frictional resistance because of consequential changes in surface area and flow velocities around the hull.

3.5.1 Length

An increase in length will increase frictional resistance but usually reduce wave – making resistance but this is complicated by the interaction of the bow and stern wave systems. Thus while fast ships will benefit overall from being longer than slow ships, there will be bands of length in which the benefits will be greater or less.

3.5.2 Prismatic coefficient

The main effect is on wave – making resistance and choice of prismatic coefficient is not therefore so important for slow ships where it is likely to be chosen to give better cargo carrying capacity. For fast ships the desirable prismatic coefficient will increase with the speed to length ratio.

3.5.3 Fullness of form

Fullness may be represented by the block or prismatic coefficient. For most ships resistance will increase as either coefficient increases. In moderate speed ships, power can always be reduced by reducing block coefficient so that machinery and fuel weights can be reduced. However, for given overall dimensions, a lower block coefficient means fewer payloads.

3.5.4 Slimness

Slimness can be defined by the ratio of the length of the cube root of the volume of displacement or in terms of a volumetric coefficient which is the volume of displacement divided by the cube of the length. Generally in high speed forms with low block coefficient, the displacement length ration must be kept low to avoid excessive resistance. For slow ships this is not so important. Fast ships require larger length to beam ratios than slow ships.

3.5.5 Breadth to draught ratio

Generally resistance increases with increases in breadth to draught ratio within the normal working range of this variable. This can again be explained by the angles at the ends of the waterlines increasing and causing a greater disturbance in the water. With very high values of beam to draught ratio the flow around the hull would tend to be in the vertical plane rather than the horizontal. This could lead to a reduction in resistance.

3.5.6 Length of parallel middle body

In high speed ships with low block coefficient there is usually no parallel middle body. In ships of moderate and high block coefficient, parallel middle body is needed to avoid the ends becoming too full. For a given block coefficient, as the length of parallel middle body increases the ends become finer and vice versa. Thus there will be an optimum value of parallel middle body for a given block coefficient.

3.5.7 Section shape

It is not possible to generalize on the shape of section to adopt but slow to moderate speed ships tend to have U-shaped sections in the fore body and V-shaped sections aft. It can be argued that the U-sections forward keep more of the ship’s volume away from the waterline and so reduce wave-making.

3.5.8 Bulbous bow

The principle of the bulbous bow is that it is sized, shaped and positioned so as to create a wave system at the bow which partially cancels out the ship’s own bow wave system, so reducing wave – making resistance. This can only be done over a limited speed range and at the expense of resistance at other speeds. Many merchant ships operate at a steady speed for much of their lives so the bulb can be designed for that speed. It was originally applied to moderate to high speed ships but has also been found to be beneficial in relatively slow ships such as tankers and bulk carriers and these ships now often have bulbous bows. The effectiveness of the bulb in the slower ships, where wave-making resistance is only a small percentage of the total, suggests the bulb reduces frictional resistance as well. This is thought to be due to the change in flow velocities which it creates over the hull. Sometimes the bulb is sited well forward and it can extend beyond the fore perpendicular.

3.6 NATURE OF SHIP STRUCTURE

When ships are in rough weather at sea they are heavily loaded and strained. It moves quite violently and structure groans as the parts move relative to each other. The complete structural problem is dynamic but, situation in calm water should be considered first. The scantlings of ship structure must include allowances for corrosion and wear which can be expected.

3.6.1 Function of Ship Structural Components

Ship's structural components are designed to perform multiple tasks in addition to that of providing structural integrity of the ship.

The shell plating is the prime strength member and also a watertight envelope of the ship, having a shape that provides adequate stability against capsizing, low resistance to forward motion, acceptable controllability and good propulsive characteristics.

Bulkheads that contribute substantially to the strength of the hull may also serve as liquid-tight boundaries of internal compartments.

The configuration of structural decks is usually governed by the arrangement of internal spaces, but they may be called upon to resist local distributed and concentrated loads, as well as contributing to longitudinal and transverse strength.

3.6.2 Structural components

3.6.2.1 *KEEL*

It is the large center plane girder runs longitudinally along the bottom of the ship. Keels are of three types, Bar keels, Flat plate keels and Duct keels. The flat plate keel is the modern type and is in general use. Flat plate keel may have a width of from 1 to 2 meters. It must be of full thickness in amidships, but the thickness may be gradually reduced towards the ends of ship.

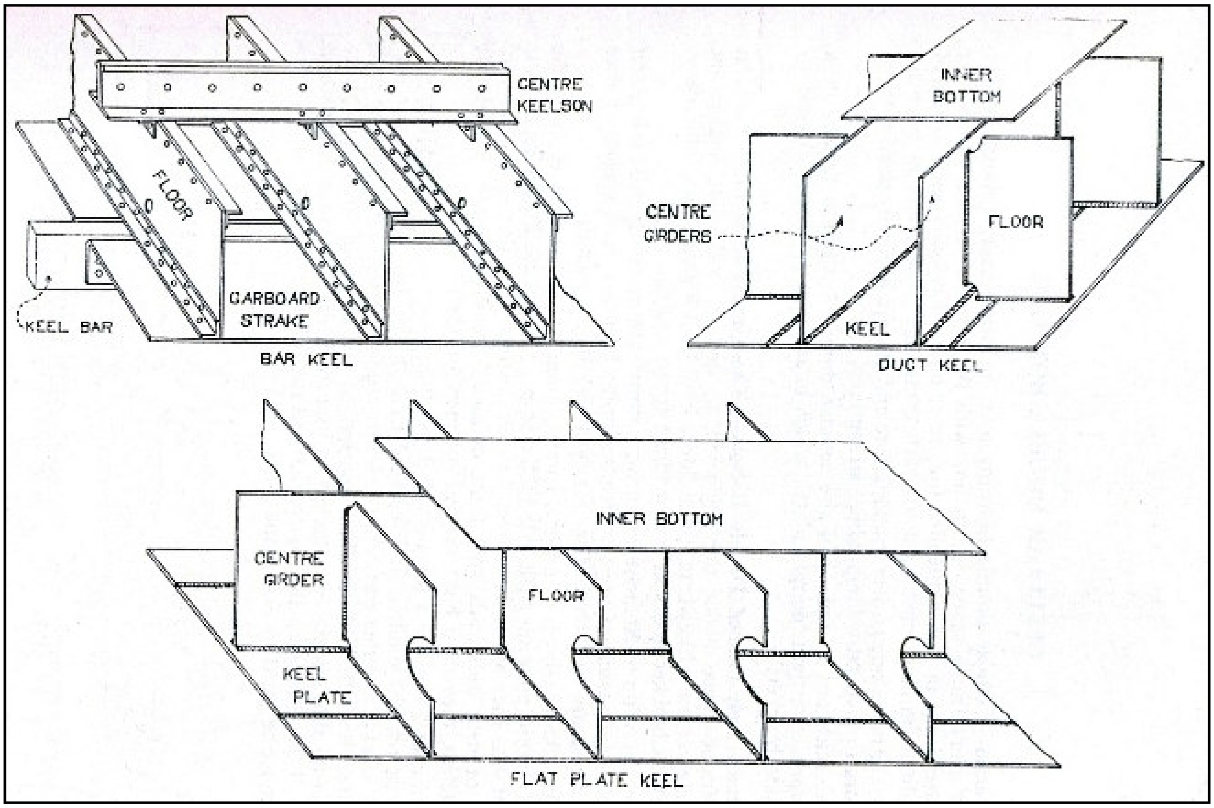


Fig. 3.6 Keel

3.6.2.2 *PLATING*

The purpose of plating is to keep out water and to tie together the ship's framework. It also plays an important part in resisting longitudinal bending stresses, so it needs to be stronger amidships than at the ends, particularly at the deck and bottom. Plates are also meant to resist hydrostatic pressure or side impacts.

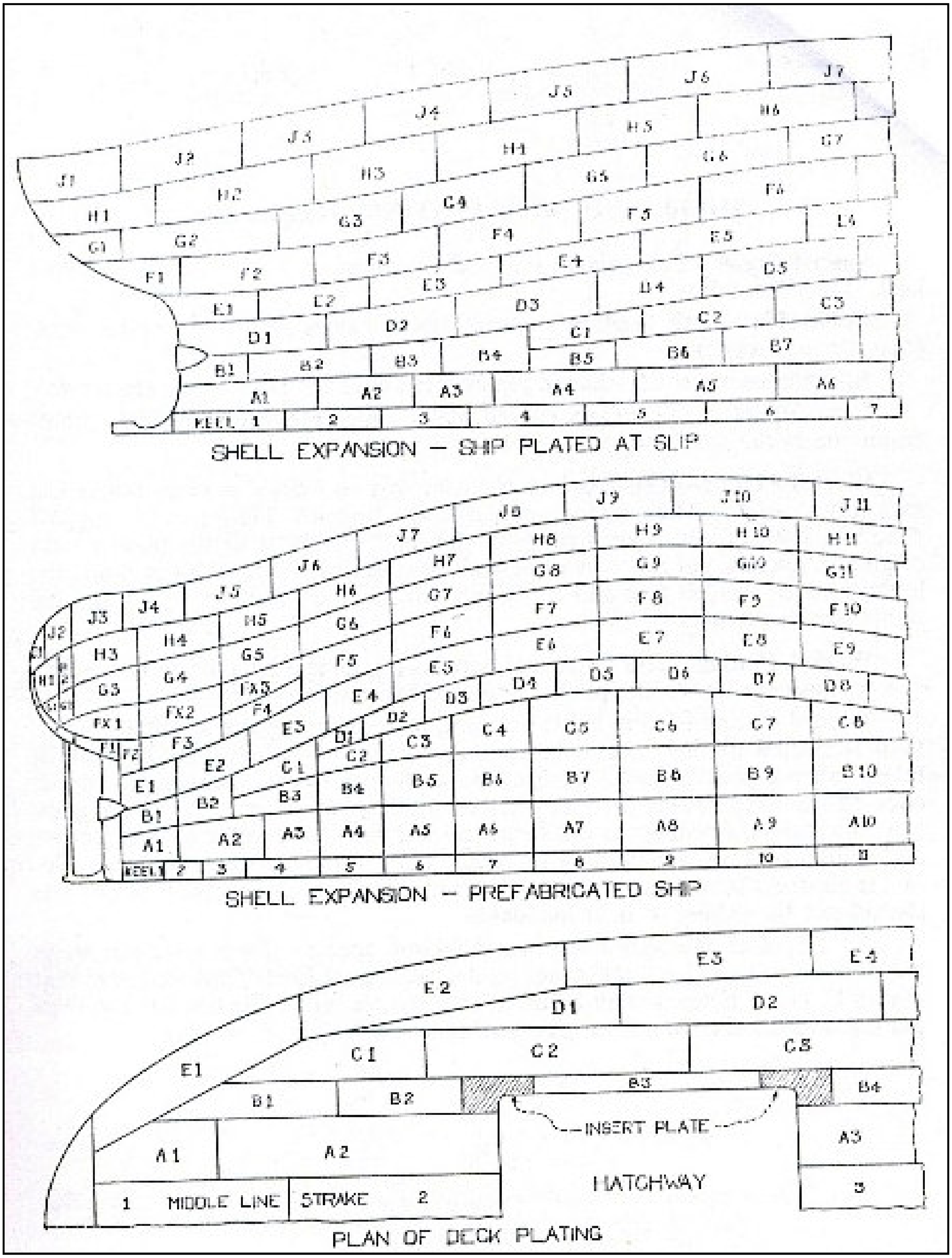


Fig. 3.7 Shell and deck plates

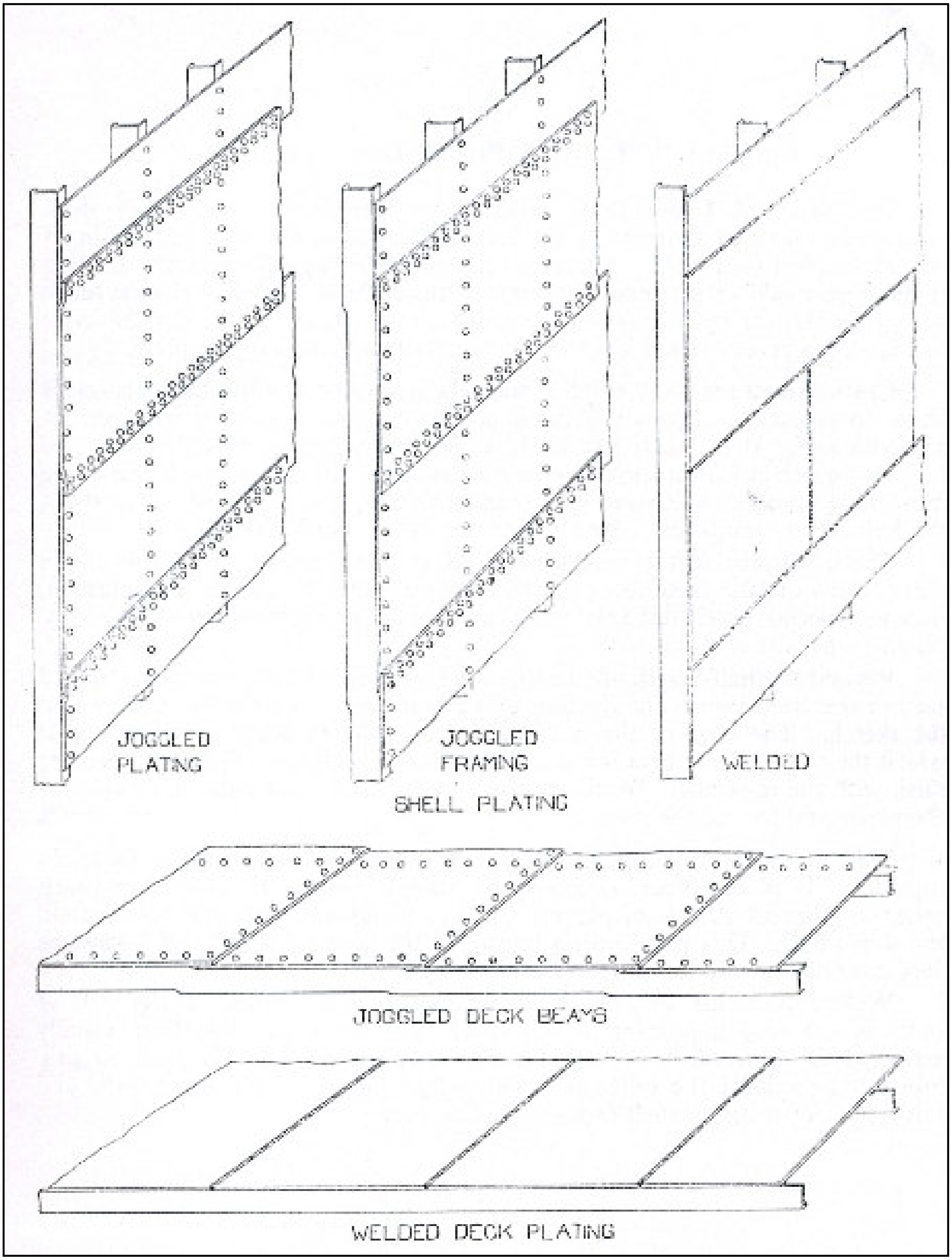


Fig. 3.8 System of plating

3.6.2.3 *BULKHEADS*

The main hull bulkheads are watertight in order in order that they may contain any flooding in the event of a compartment on one side of the bulkhead being bilged. They serve as a hull strength member not only carrying some of the ship's vertical loading but also resisting any tendency for transverse deformation of the ship.

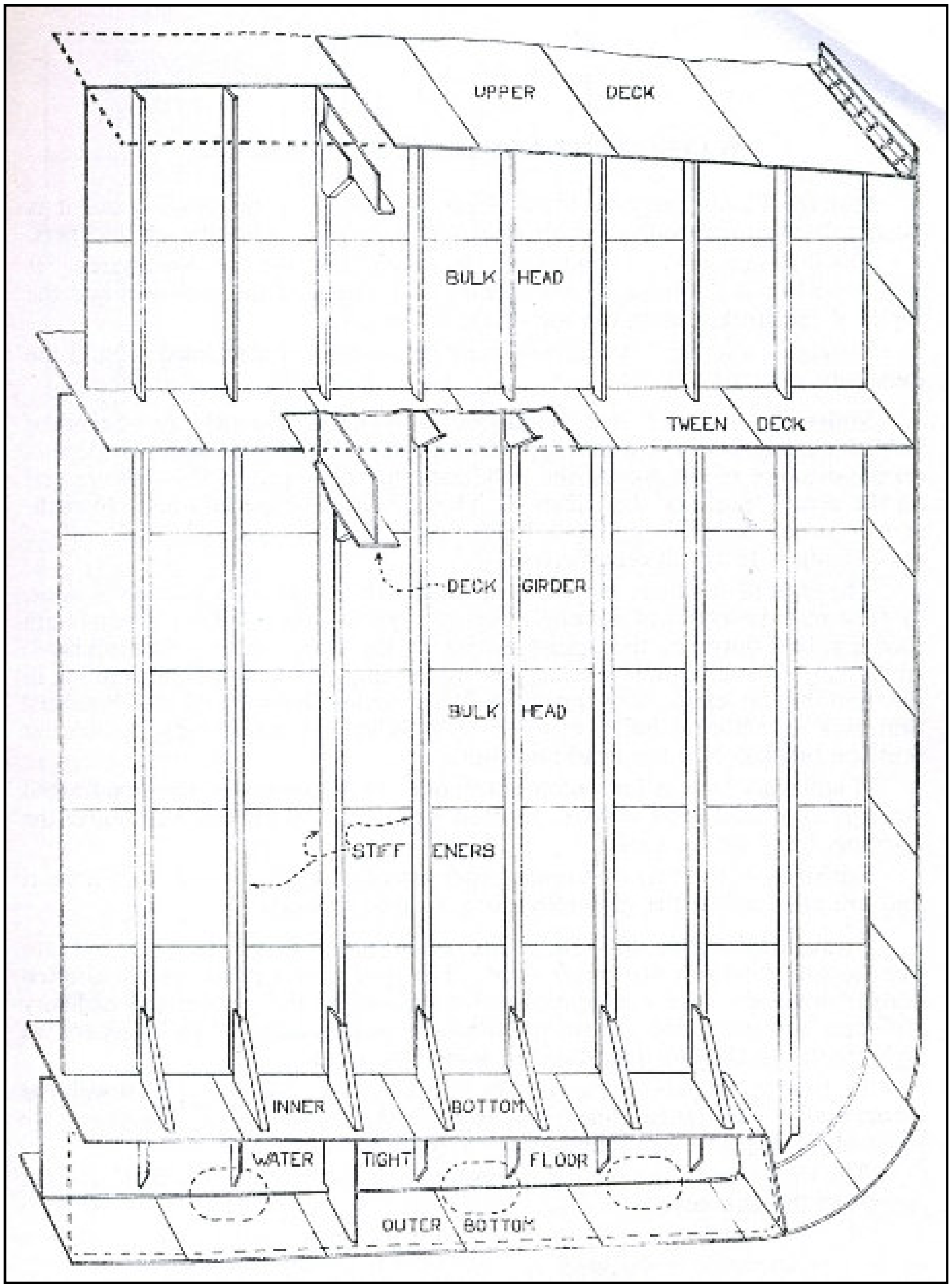


Fig. 3.9 Watertight bulkhead

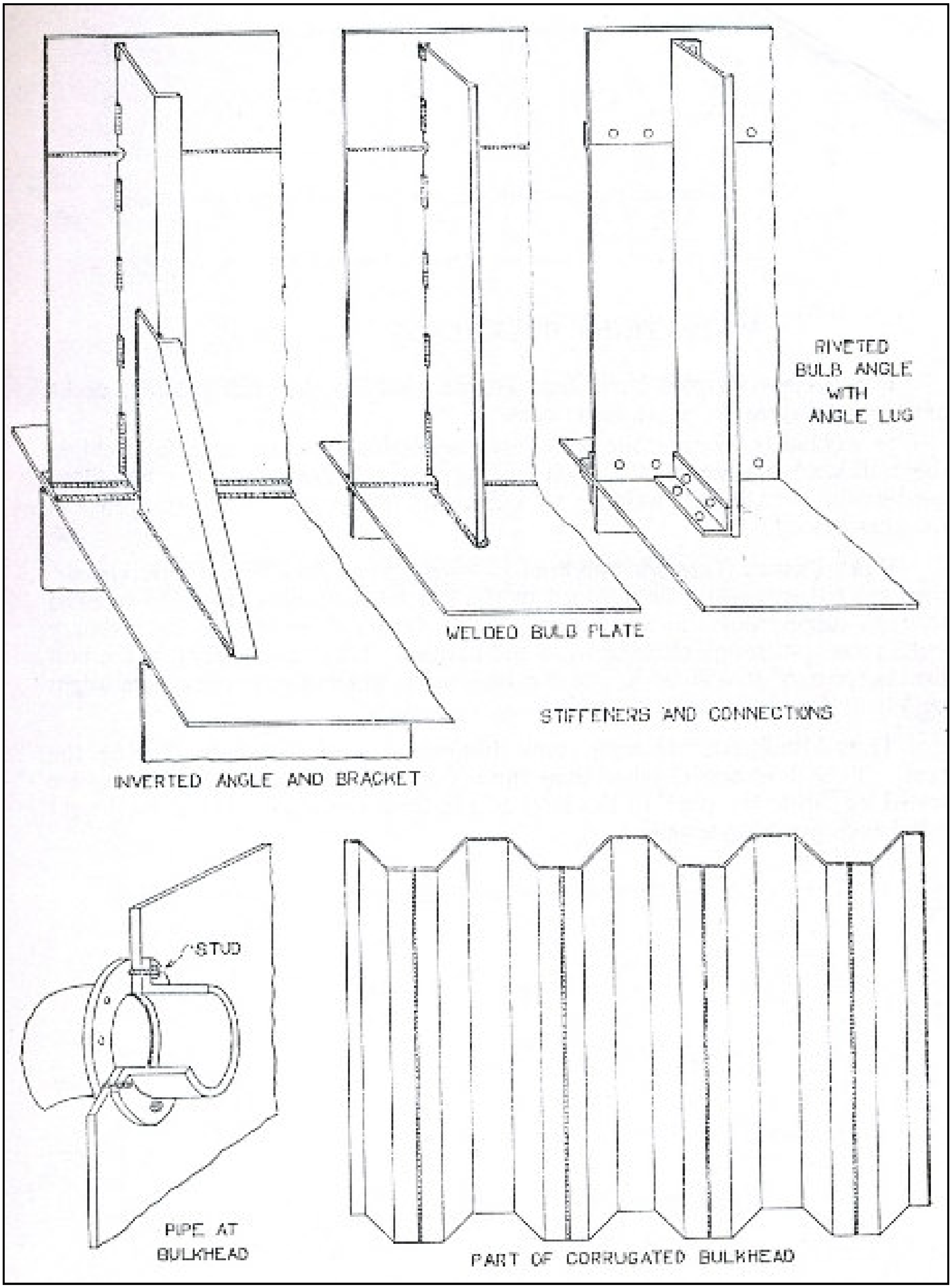


Fig. 3.10 Bulkhead details

3.6.2.4 *FRAMES*

These are the transverse members running through keel to the deck. Function of these frames is to resist hydrostatic pressure, waves, impacts etc. In the main body of the ship, the frame spacing may not exceed 1.0 meters. Between the collision bulkheads and a point one-fifth of the ship's length abaft the stem, it must not exceed 700 mm. In peak tanks and cruiser sterns, it must not exceed 600 mm.

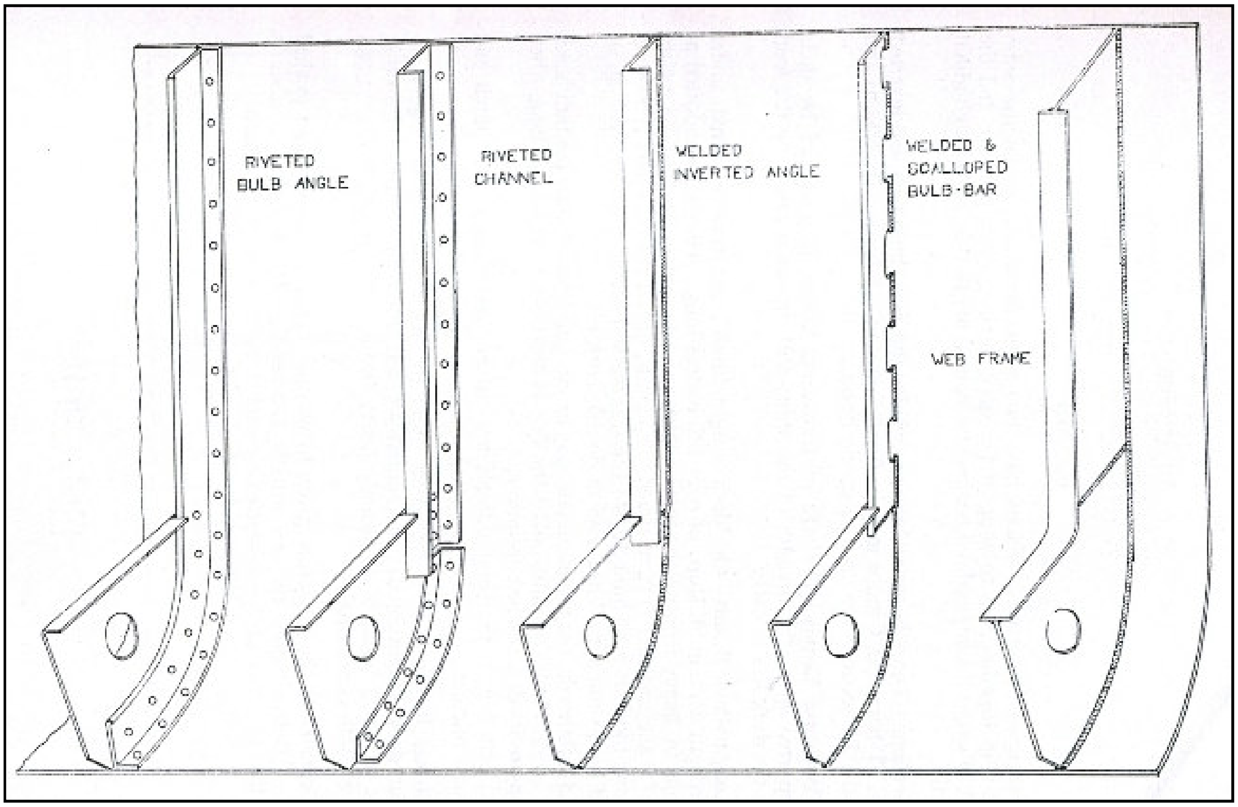


Fig. 3.11 Types of transverse frames

3.6.2.5 *DOUBLE BOTTOMS*

Double bottoms in a ship are provided to carry for the storage of oil fuel, fresh water and water ballast. Water ballast bottom tanks commonly provided right forward and aft for trimming purposes. Double bottoms may be framed longitudinally or transversely, but where the ship's length exceeds 120m it is desirable to adopt longitudinal framing. In the machinery spaces which are adjacent to the after peak are required to be transversely framed.

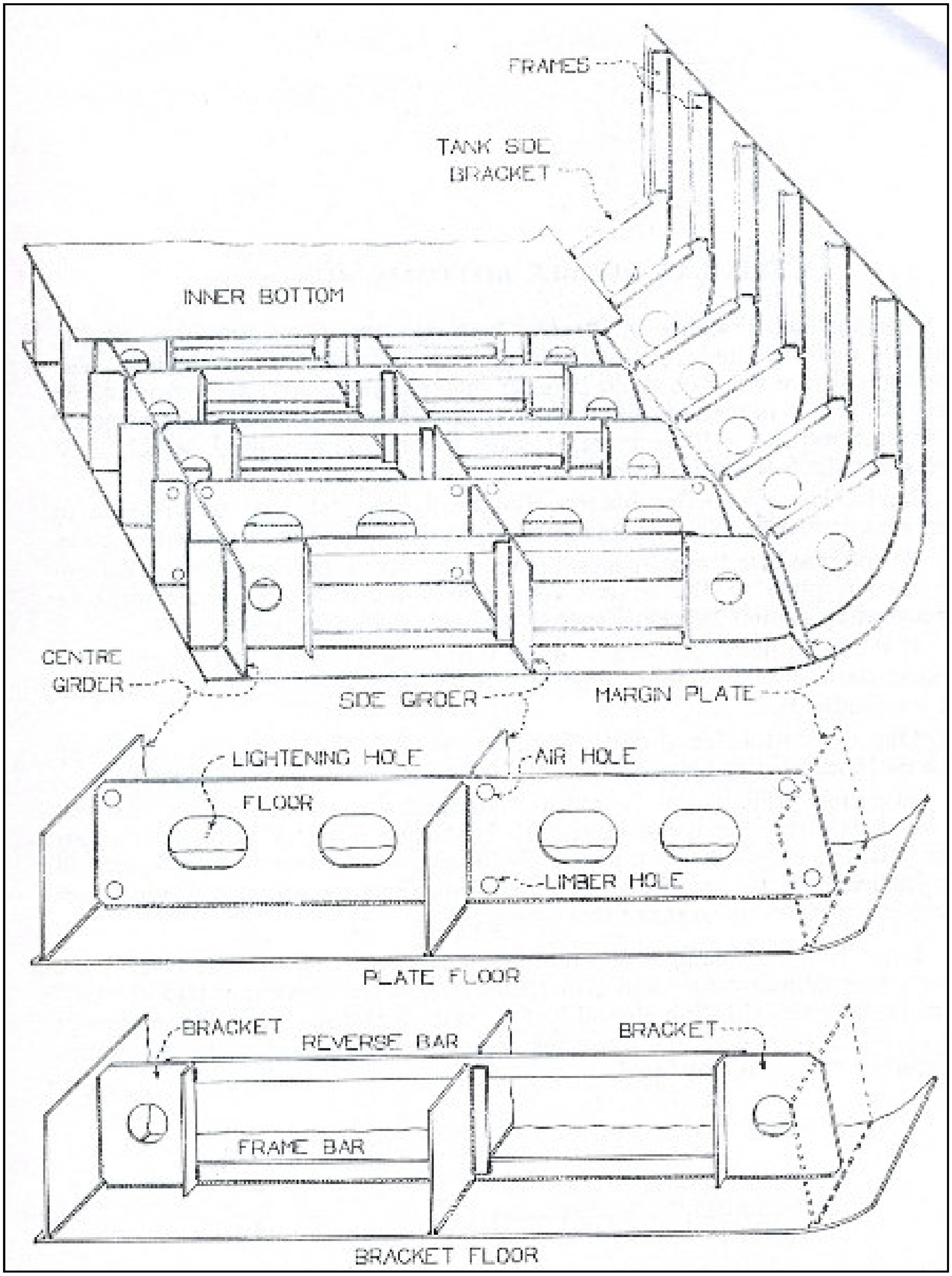


Fig. 3.12 Transverse framing in double bottom

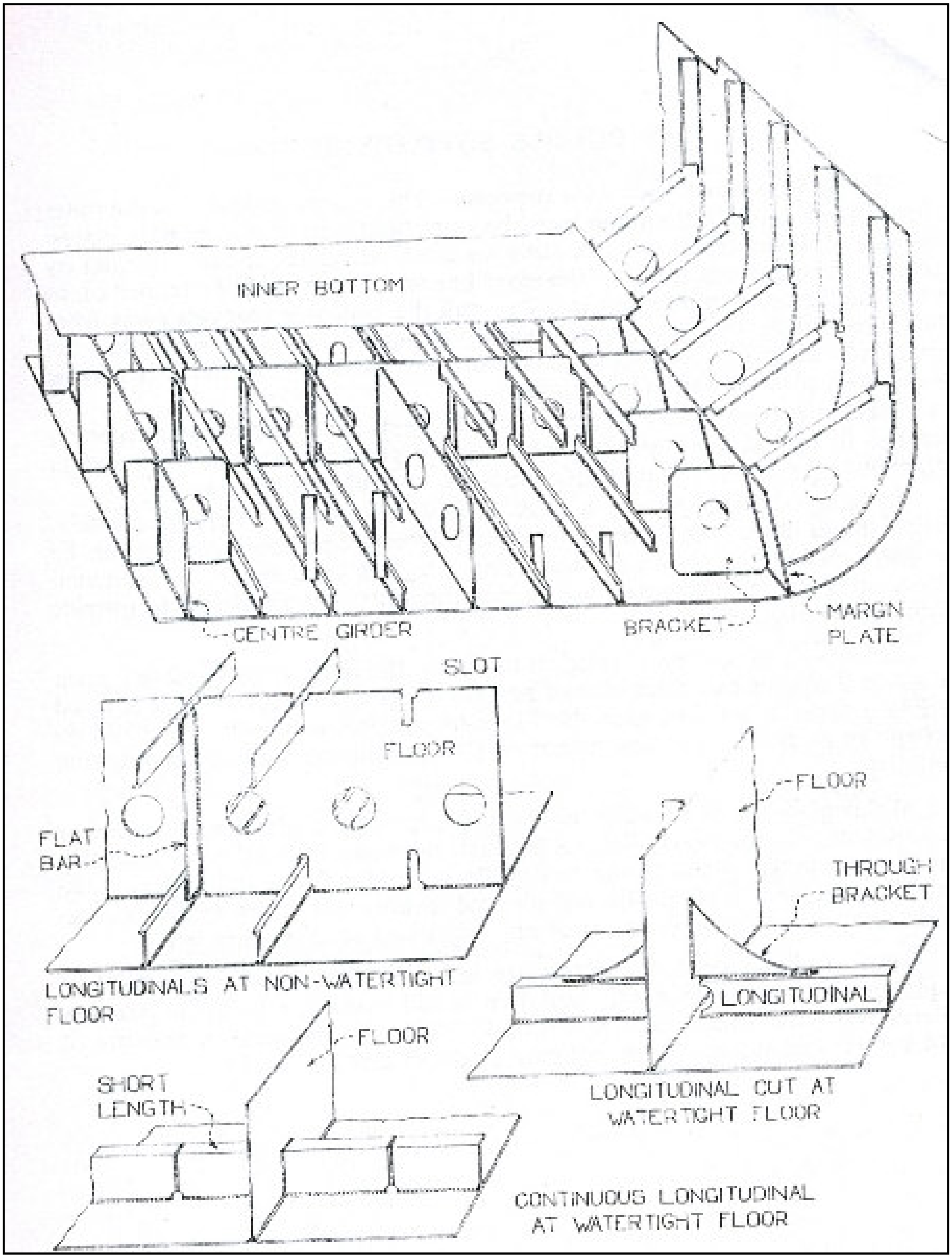


Fig. 3.13 Longitudinal framing in double bottom

3.6.2.6 *DECKS*

Decks may be watertight decks, strength decks, or simply cargo and passenger accommodation decks. Watertight decks are fitted to maintain the integrity of the main watertight hull, and the most important is the freeboard deck. The deck forms upper flange of the main hull girder, called the strength deck. Lighter decks which are not watertight provide platforms for passenger accommodation and cargo loading arrangements. Decks are arranged in plate panels with transverse or longitudinal stiffening, and local stiffening in way of any openings. Longitudinal deck girders may support the transverse framing, and deep transverse the longitudinal framing.

3.7 Nature of Structural Failure

The ship is essentially an elastic beam floating on the water surface and subject to range of fluctuating and quasi-steady loads. Those loads will generate bending moments and shear forces which may act over the ship as a whole or be localized. The former will include the action of the sea. The latter will include the forces on heavy items composed of gravity forces and dynamic forces due to the accelerations imparted by the ship's motion. Then there is the thrust due to the main propulsion forces.

Ship structural failure may occur as a result of a variety of causes, and the severity of the failure may vary from a minor aesthetic degradation to catastrophic failure resulting in loss of the ship. From the point of view of structural analysis, there are four possible ways of failing

- (a) tensile or compressive yield of the material
- (b) compressive instability (buckling)
- (c) Low – cycle fatigue
- (d) Brittle fracture

The first mode of failure occurs when the stress in a structural member exceeds a level that results in a permanent plastic deformation of the material of which the member is constructed. This stress level is termed as material yield stress. At a somewhat higher stress, termed as ultimate stress, fracture of the material occurs.

Instability failure of a structural member loaded in compression may occur at a stress level that is substantially lower than the material yield stress. A plate in compression will also have a critical buckling load whose value depends on the plate thickness, lateral dimensions, edge support conditions and material modulus of elasticity.

Fatigue failure occurs as a result of a cumulative effect in a structural member that is exposed to a stress pattern alternating from tension to compression through many cycles. Two categories of fatigue damage are generally recognized and they are termed high-cycle and low-cycle fatigue. In high-cycle fatigue, failure is initiated in the form of small cracks, which grows slowly and which may often be detected and repaired before the structure is endangered. High-cycle fatigue involves several millions of cycles of relatively low stress and is typically encountered in machine parts rotating at high speed or in structural components exposed to severe and prolonged vibration. Low-cycle fatigue involves higher stress levels, up to and beyond yield, which may result in cracks being initiated after several thousand cycles. The loading environment that is typical of ships and ocean structures is of such a nature that the cyclical stresses may be of a relatively low level during the greater part of the time, with occasional periods of very high stress levels caused by storms. Exposure to such load conditions may result in the occurrence of low-cycle fatigue cracks after an interval of a few years. These cracks may grow to serious size if they are not detected and repaired.

In the brittle fracture, a small crack suddenly begins to grow and travels almost explosively through a major portion of the structure. The originating crack is usually found to have started as a result of poor design or manufacturing practice, as in the case of a square hatch corner.

4. LOADS ON SHIP

The adequacy of a structure can only be realistically determined if it is assessed with sound knowledge of loads that are likely to be applied on that structure. It is generally accepted, that both hydrostatic and self-weight loads can be determined for a given ship condition with a high degree of confidence. The evaluation of wave generated hydrodynamic loads, however, is less reliable and there is less guidance as to how to handle the dynamic nature of the loading as well as transient effects such as slamming.

4.1 DISPLACEMENT AND TONNAGE

4.1.1 Displacement

A ship's *displacement* significantly influences its behavior at sea. Displacement is a force and is expressed in Newton but the term *mass displacement* can also be used.

4.1.2 Deadweight

Although influencing its behavior, 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.

The deadweight or dead mass in terms of mass, is the difference between the load displacement up to the minimum permitted freeboard and the lightweight or light displacement. The 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 often provided to a ship's master in the form of a deadweight scale.

4.1.3 Tonnage

Ton is 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. Two ‘tonnages’ are of interest to the international community-one to represent the overall size of a vessel and one to represent its carrying capacity. The former can be regarded as a measure of the difficulty of handling and berthing and the latter of earning ability.

The two parameters of gross and net tonnage are used. Gross tonnage is based on the volume of all enclosed spaces. Net tonnage is the volume of the cargo space plus the volume of passenger spaces multiplied by a coefficient to bring it generally into line with previous calculations of tonnage.

4.1.4 Load lines

The load line is popularly associated with the name of Samuel Plimson who introduced a bill to Parliament to limit the draught to which a ship could be loaded. This reflects the need for some minimum watertight volume of ship above the waterline. That is a minimum freeboard to provide a reserve of buoyancy when a ship moves through waves, to ensure and adequate range of stability and enough buoyancy following damage to keep the ship afloat long enough for people to get off.

4.2 LOADING CONDITIONS

Possible loading conditions of a ship are calculated and information is supplied to the master. It is usually in the form of a profile of the ship indicating the positions of all loads on board, a statement of the end draughts, the trim of the ship and the metacentric height. Stability information in the form of curves of statical stability is often supplied. The usual loading conditions covered are:

1. The lightship
2. Fully loaded departure condition with homogeneous cargo
3. Fully loaded arrival condition with homogeneous cargo
4. Ballast condition
5. Other likely service conditions

4.3 CLASSIFICATION OF LOADS

Loads acting on the ship structure are classified in to four categories based on nature of load and response of ship.

(a) Static loads are loads that change only when the total weight of the ship changes, as a result of loading or discharge of cargo, consumption of fuel, or modification to the ship itself.

1. Weight of the ship and its content.
2. Static buoyancy of the ship at rest or moving.
3. Thermal loads resulting from nonlinear temperature gradients within the hull
4. Concentrated loads caused by dry-docking and grounding.

(b) Low-frequency dynamic loads are loads that vary in time with periods ranging from a few seconds to several minutes. The loads are called dynamic because they originate mainly in the action of the waves through which the ship moves and are, therefore, always changing with time. They may be differentiated into the following components:

1. wave-induced hull pressure variations.
2. Hull pressure variations caused by oscillatory ship motions.
3. Inertial reactions resulting from the acceleration of the mass of the ship and its contents.

(c) High-frequency dynamic loads are time-varying loads of sufficiently high frequency that they may induce vibratory response of the ship structure. Some of the exciting loads may be quite small in magnitude but, as a result of resonant amplification, they can give rise to large stresses and deflections. For example,

1. Hydrodynamic loads induced by propulsive devices on hull or appendages.
2. Loads imparted to the hull by reciprocating or unbalanced rotating machinery.

3. Hydro elastic loads resulting from interaction of appendages with the flow past the ship.
4. Wave-induced loads primarily due to short waves whose frequency of encounter overlaps the lower natural frequencies of hull vibration and which, therefore, may excite appreciable resonant response, termed springing.

(d) Impact loads are loads resulting from slamming or wave impact on the forefoot, bow flare and other parts of the hull structure, including the effects of green water on deck. Impact loads may induce transient hull vibration that is termed whipping.

In addition, there may be specialized operational loads, which part or all of the structure may be called upon to withstand. These loads may be static or dynamic. Some examples are:

- Ice loads in the case of a vessel intended for icebreaking or arctic navigation.
- Loads caused by impact with other vessels, pier or other obstacles, as in the case of tugs and barge.
- Impact of cargo handling equipment, such as grabs clamshells used in unloading certain commodities.
- Structural thermal loads imposed by special cargo carried at nonambient temperature or pressure.
- Sloshing and impact loads on internal structural caused by movement of liquids in tanks.
- Landing of aircraft or helicopters.
- Accidental loads caused by collision or grounding.

4.4 DESIGN LOADS AS PER "LLOYD'S REGISTER"

The derivation of scantlings for decks, tank tops, transverse bulkhead is obtained by the design pressure/heads as per LR, part3, chapter 3, section 5.

Ship decks are divided in various load regions according to their location in GA drawings. Load in these regions are provided as uniform surface loads in live load case. These load regions are shown in Figure 4.1. Load intensity in these classified regions is given in the Table 4.1.

Table 4.1 Load intensity in load regions

Load region	Load intensity in kN/m^2	Remark
Cargo	7.07 x H_{td}	LR-part3, chap3, sec.-5
Passenger	8.5	LR-part3, chap3, sec.-5
Machinery space	18.37	LR-part3, chap3, sec.-5
Ship store	14.14	LR-part3, chap3, sec.-5
Mess cum recreation	8.5 x 1.5	Approximate
Work shop	8.5 x 1.5	Approximate
Baggage compartment	14.14	Approximate

H_{td}= height between two decks

4.5 SEA ENVIRONMENT

Ship motions at sea have always been a problem. Naval architect responsibility has been to insure not only that the ship can safely ride out the roughest storms but that it can proceed on course under severe conditions with a minimum of delay, or carry out other specific missions successfully.

The understanding of ship motions at sea, and the ability to predict the behavior of any ship or marine structure in the design stage, begins with the study of the nature of the ocean waves that constitute the environment of the seagoing vessel.

The outstanding characteristic of the open ocean is its irregularity, not only when storm winds are blowing but even under relatively calm conditions. Oceanographers have found that irregular seas can be described by statistical mathematics on the basis of the assumption that a large number of regular waves having different lengths, directions, and amplitudes are linearly superimposed.

Apart from submerged submarines, ships operate on the interface between air and water. The properties of both fluids are important.

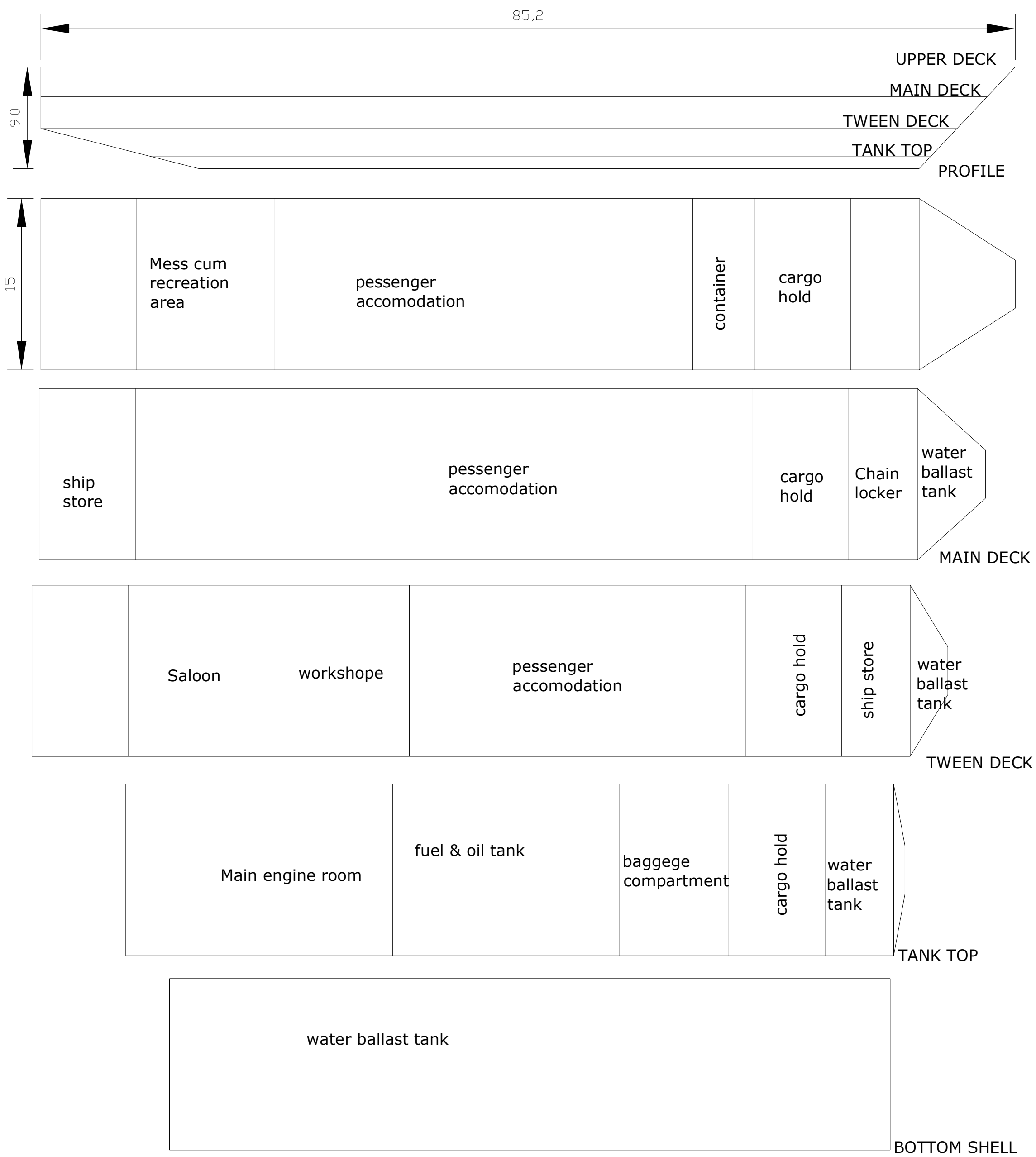


Fig. 4.1 Load regions

4.5.1 Basic Properties

- Water

Water is effectively incompressible so its density does not vary with depth as such. Density of water does vary with temperature and salinity as does its kinematic viscosity. The density of sea water increases with increasing salinity. The figures in table are based on standard salinity of 3.5 per cent.

Table 4.2 Water properties

Temperature °C	Density Kg/m^3		Kinematic viscosity m^2/s x 10^6	
	Fresh water	Salt water	Fresh water	Salt water
0	999.8	1028.0	1.787	1.828
10	999.6	1026.9	1.306	1.354
20	998.1	1024.7	1.004	1.054
30	995.6	1021.7	0.801	0.849

The naval architect has traditionally used approximate figures in calculations. These have include taking a mass density of fresh water as 62.2lb/ft^3 (36 cubic feet per ton) and of sea water as 64lb/ft^3 (35 cubic feet per ton). The corresponding 'preferred' values in SI units are 1.000 tonne/m^3 and 1.025 tonne/m^3 respectively.

- Air

At standard barometric pressure and temperature, with 70 per cent humidity air has been taken as having a mass of 0.08 lb/ft^3 (13 cubic feet per lb). The corresponding preferred SI figure is 1.28 kg/m^3.

- Temperatures

The ambient temperature of sea and air a ship is likely to meet in service determine the amount of air conditioning and insulation to be provided besides affecting the power produced by machinery. Extreme air temperatures of 52°C in the tropics in harbor and 38°C at sea, have been recorded: also -40°C in the arctic in harbor and -30°C at sea.

- Wind

Unfortunately for the ship designer and operator the air and the sea are seldom still. Strong wind can add to the resistance a ship experiences and make maneuvering difficult. Beam winds will make a ship heel and winds create waves. The wave characteristics depend upon the wind’s strength, the time for which it acts, its duration and the distance over which it acts, its fetch. The term sea is applied to waves generated locally by a wind. When waves have travelled out of the generation area they are termed swell. The wave form depends also upon depth to water, currents and local geographic features.

- Waves

An understanding of the behavior of a vessel in still water is essential but a ship’s natural environment is far from still, the main disturbing forces coming from waves.

To an observer the sea surface looks very irregular, even confused. For many years it defied any attempt at mathematical definition. The essential nature of this apparently random surface was understood by R. E. Froude who, in 1905, postulated that irregular wave systems are only a compound of a number of regular systems, individually of comparatively small amplitude, and covering a range of periods. Further he stated that the effect of such a compound wave system on a ship would be ‘more or less the compound of the effects proper to the individual units composing it’. This is the basis for all modern studies of waves and ship motion.

4.5.2 Ocean Waves

The visible characteristic of waves in the open ocean is their irregularity. Study of wave records confirms this irregularity of the sea, both in time and space. Over a fairly wide area and often for a period of a half-hour or more the sea may maintain a characteristic appearance, because record analyses indicate it is very nearly statistically steady or stationary. At other times or places the sea conditions will be quite different, and yet there will again be a characteristic appearance, with different but steady statistical parameters.

Storm waves are generated by the interaction of wind and the water surface. There are at least two physical processes involved, these being the friction between air and water and the local pressure fields associated with the wind blowing over the wave surface. Although a great deal of work has been done on the theory of wave generation by wind, no completely satisfactory mechanism has yet been devised to explain the transfer of energy form wind to sea.

Total wave system is the result of many local interactions distributed over space and time. These events can be expected to be independent unless they are very close in both space and time. Each event will add a small local disturbance to the existing wave system. Within the storm area, there will be wave interactions and wave-breaking processes that will affect and limit the growth and propagation of waves from the many local disturbances.

If wave amplitudes are small the principle of linear superposition governs the propagation and dispersion of the wave systems outside the generating area.

An important characteristic of water waves that affects the propagation of wave systems is that in deep water the phase velocity, or celerity, of a simple regular wave, such as can be generated in an experimental tank, is a function of wavelength. Longer waves travel faster than shorter waves.

4.5.3 Ship’s response to wave

The response of a ship advancing in a seaway is a complicated phenomenon involving the interaction between the vessel dynamics and several hydrodynamic forces.

A seaway is considered a random process and spectral techniques can be used to define the characteristics of the seaway. The response of the ship to a seaway is also random process, and therefore the same spectral techniques can be used to analyze the ship responses.

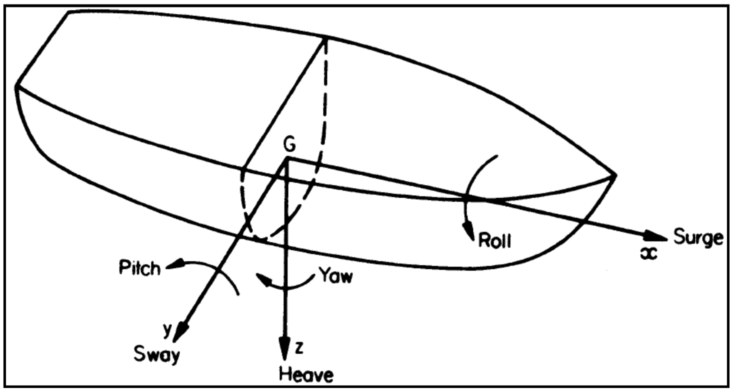


Fig. 4.2 Ship motions

A ship advancing at a steady mean forward speed with arbitrary heading in a train of regular waves will move in six degrees of freedom. That is, the ship's motion can be considered to be made up of three translational components, surge, sway and heave, and three rotational component, roll, pitch and yaw. Excessive amplitudes of ship motions are undesirable. They can make ship board task hazardous or even impossible, and reduce crew efficiency and passenger comfort. A ship with short period of roll is said to be 'stiff' – compare the stiff spring – and one with long period is said to be 'tender'. Most people find a long period of roll less unpleasant than a short period of roll.

4.6 FORCES ON A SHIP IN STILL WATER

The buoyancy forces acting on a ship must equal in total the sum of the weight of the ship. However, over any given unit length of the hull the forces will not balance out. If the mass per unit length at some point is m and the immersed cross – sectional area is a, then at that point:

Buoyancy per unit length = $\rho g a$ and

The weight per unit length = mg

Hence the net force per unit length = $\rho ga - mg$

If this net loading is integrated along the length there will be, for any point, a force tending to shear the structure such that:

Shear force, S=$\int(\rho ga - mg)\,dx$ ... (4.1)

the integration being from one end to the point concerned.

Integrating a second time gives the longitudinal bending moment.

That is:

Longitudinal bending moment, M=$\int S dx = \iint(\rho ga - mg) dx dx$ ... (4.2)

For any given loading of the ship the draughts at which it floats can be calculated. Knowing the weight distribution, and finding the buoyancy distribution form the Bonjean curves, gives the net load per unit length.

4.7 FORCES ON A SHIP IN A SEAWAY

The mass distribution is the same in waves as in still water assuming the same loading condition. The differences in the forces acting are the buoyancy forces and the inertia forces on the masses arising from the motion accelerations, mainly those due to pitch and heave. The buoyancy forces vary from those in still water by virtue of the different draughts at each point along the length due to the wave profile and the pressure changes with depth due to the orbital motion of the wave particles.

4.8 STANDARD STATIC LONGITUDINAL STRENGTH APPROACH

The ship is assumed to be poised, in a state of equilibrium, on a trochoidal wave of length equal to that of the ship. This is a situation that can never occur in practice but the results can be used to indicate the maximum bending moments the ship is likely to experience in waves. The choice of wave height is important. To a first order it can be assumed that bending moments will be proportional to wave height. Two heights have been commonly used L/20 and $0.607(L)^{0.5}$ where L is in meters. The latter has been more generally used because it was felt to represent more closely the wave proportions likely to be met in deep oceans. Steeper waves have been used for smaller vessels operating in areas such as the North Sea.

Two conditions are considered, one with a wave crest amidships and the other with wave crests at the ends of the ship. In the former the ship will hog and in the latter it will sag. By moving the ship to various positions in relation to the wave crest the cycle of bending moment experienced by the ship can be computed.
The bending moments obtained include the still water moments. It is useful to separate the two as, whilst the still water bending moment depends upon the mass distribution besides the buoyancy distribution, the bending moment due to the waves themselves depends only on the geometry to the ship and wave.
First the ship must be balanced on the wave. This is not easy and can involve a number of successive approximation to the ship's attitude before the buoyancy force equals the weight and the centre of buoyancy is in line with the centre of gravity. One method of facilitating the process was proposed by Muckle. Assume now that a balance has been obtained and the buoyancy and mass distribution curves are as shown in Figure 4.3.

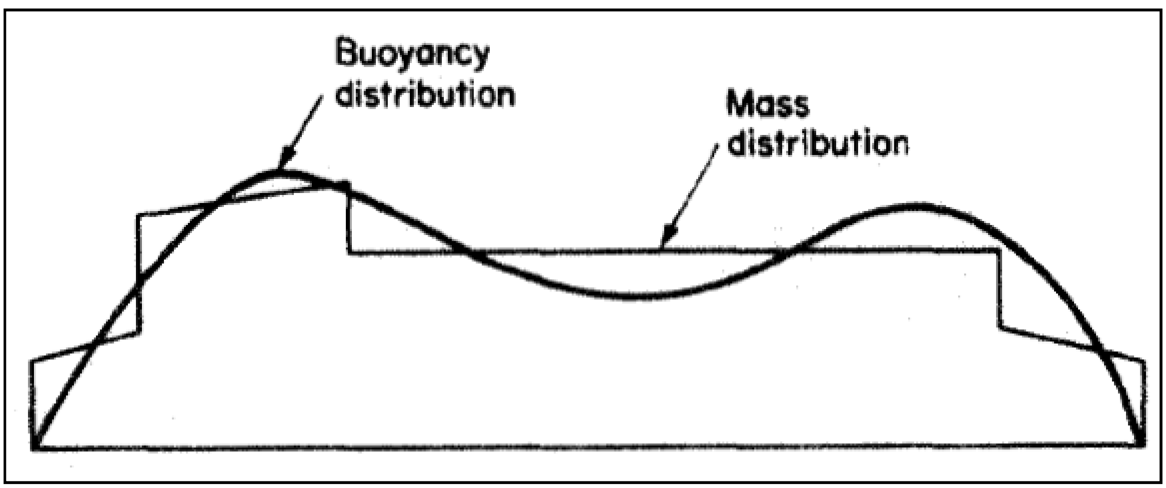


Fig. 4.3 Buoyancy and mass distribution

If A is the cross sectional area at any point, allowing for the wave profile, the net load per unit length at that point is $\rho g A - mg$, from which the shearing force and bending moment are:

$$F = \int (\rho g A - mg) dx$$

$$M = \int F dx = \iint (\rho g A - mg) dx dx$$

The integrals are evaluated by dividing the ship into a number of sections calculating the mean buoyancy and weight per unit length in each section, and evaluating the shearing force and bending moment by approximate integration.

4.9 WAVE INDUCE LOADS

The wave loading on ship structure is usually the most important of all loadings for which the structure must be designed. The forces on the hull are caused by the motion of the water due to the waves which are generated by the action of the wind on the surface of the sea. Determination of these forces requires the sea state computation using idealization of the wave surface profile and wave kinematics given by an appropriate wave theory.

The difficulty in calculating this load arises from the fact that the sea is highly irregular. Classification societies have provided the formulae in order to calculate wave load and ship response. Wave induced loads are low-frequency dynamic loads. Four procedures of estimating the wave induced loads may be used.

(a) Approximate methods
(b) Strain and Pressure measurements on actual ships
(c) Laboratory measurement of loads on models
(d) Direct computation of the wave induced fluid loads

(a) Approximate methods

The ship is imagined to be in a state of static equilibrium on either the crest or trough of a wave whose length is equal to the ship length L, and height is L/20 or 0.607 $L^{0.5}$. Where L is in meters.

Two conditions are considered, one with wave crest amidships and the other with wave crests at the ends of the ship. In the former the ship will hog and in the latter it will sag. In some cases the hogging and sagging was exaggerated by modifying the mass distribution. The Rules of the ABS define and extreme wave bending moment which, in conjunction with the still water moment.

$M_w = C_2 L^2 B H K_b$

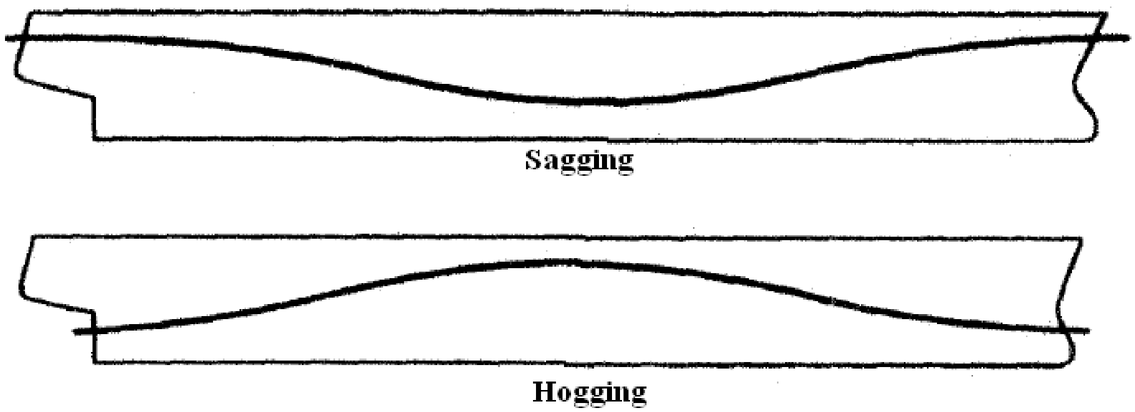


Fig. 4.4 Ship on wave

Where

C_2 and K_b are coefficients depending on the block coefficient

L, B are length and breadth of the ship respectively

H is a wave height or bending moment coefficient dependent upon L.

(b) Strain and Pressure measurements on actual ships

Full –scale measurements cannot be used to obtain specific data for a ship design. Full-scale measurements suffer from serious drawbacks that are the difficulty in accurately measuring the sea environment for correlation with the measured loads. A completely satisfactory instrument has not yet been achieved to develop expendable wave buoys, or ship borne wave.

(c) Laboratory measurement of loads on models

In this procedure, a model geometrically and dynamically similar to the ship is equipped with instruments that measures vertical or horizontal shear and bending moment, or torsional moment, amidships and at other sections. This may be accomplished by recording the forces or deflections between several segments produced by transverse cuts through the model. Impact loads can also be determined by recording pressures at several points distributed over the model surface. The experiments are conducted in a towing tank that is equipped to produce either regular or random waves.

(d) Direct computation of the wave-induced fluid loads

Appropriate hydrodynamic theories used in calculating ship motions in waves are applied to computing the pressure forces caused by the waves and by the ship motion in response to those waves.

4.10 Basic Wave Parameters

The wave is described by the three basic parameters, wave height **H**, wavelength **L**, and wave period **T**, at a depth, **d** from the still water level (SWL) to the ocean floor as shown in the Figure 4.5

Wavelength (**L**): This is the horizontal distance between similar points on two successive waves, measured in the direction of propagation of wave.

Wave Period (**T**): It is the time required for a crest to travel a distance of one wavelength.

Wave Height (**H**): This is the vertical distance between the crest and the adjacent trough of a wave.

Wave Celerity (c): The speed of a given crest or trough in the wave is called the celerity, for a periodic wave,

$$C = \frac{L}{T} \text{ also } C = \frac{\omega}{k}$$

Wave amplitude (A): It is defined as half the wave height.

$$A = \frac{H}{2}$$

Wave Number (k): The wave number k is given as,

$$k = \frac{2\pi}{L}$$

Circular Frequency (ω): Circular frequency is given as,

$$\omega = \frac{2\pi}{T}$$

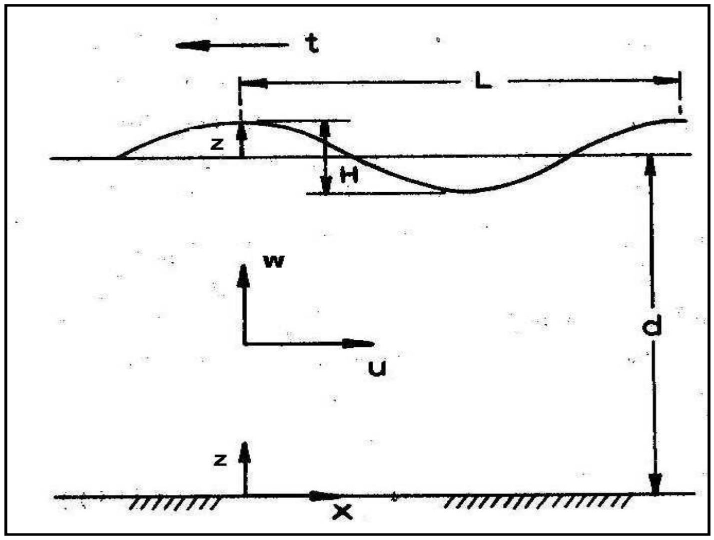


Fig. 4.5 Basic wave parameters

Wave Slope: Wave slope is defined as the ratio of wave height by wavelength, H/L
For regular waves,

$$\frac{\omega}{k} = \frac{L}{T} = C$$

4.11 WAVE THEORIES

Wave theories predict the water particle velocities and accelerations, the surface profile and pressure at any location, and in general completely describe the water motion. It is assumed that the waves are two-dimensional in the XZ plane, that the ocean floor is flat of undisturbed depth, d from the still water level (SWL) and that the waves are progressive in the positive X direction.

4.11.1 Stokes Higher Order Wave Theories

Stokes theories are based on equations developed for waves of finite amplitude by considering terms of higher than first order in solving the La-Place equation. The Stokes waves, of successively higher order; give wave surface profiles that are steeper in the crests and flatter in the trough than those given by small amplitude wave theory, and which more closely resemble waves actually observed in the oceans.

Another important aspect of higher order Stokes waves is that the particle orbits are not closed, as assumed by linear theory, and thus the phenomenon of mass transport is accounted for, such waves being known as progressive waves. Stokes further determined that should the inclined angle between two tangents to the surface profile at the wave crest become less than 120^0, the wave would become unstable, i.e., the particle velocity at the crest would exceed the celerity and the wave breaks. This corresponds closely with observations of deep-water waves, but Michel and later Havelock demonstrated the theoretical limit for maximum steepness in deep-water to be,

$$\frac{H_0}{L_0} = 0.142 \approx \frac{1}{7}$$

The corresponding wavelength and celerity are given by,

$L = 1.2L_o$ & $c = 1.2c_o$

4.12 HULL GIREDER LOADS AS PER "ABS"

Sign conventions of bending moments and shear forces.

Absolute values are to be taken for bending moments and shear forces. The sign conventions of vertical bending moments, horizontal bending moments and shear forces at any ship transverse section are explained below.

- The vertical bending moments M_{SW} and M_{WV} are positive when they induce tensile stresses in the strength deck (hogging bending moment) and are negative in the opposite case (sagging bending moment)
- The horizontal bending moment M_{WH} is positive when it induces tensile stresses in the starboard and negative in the opposite case.
- The vertical shear force Q_{SW}, Q_{WV} is positive in the case of downward resulting forces preceding and upward resulting forces following the ship transverse section under consideration, and is negative in the opposite case.

4.12.1 Still water loads

In general the vertical still water bending moment and the shear force of the individual loading condition is to be applied. The shipbuilder has to submit for each of the loading condition in a longitudinal strength calculation.

The values of still water vertical bending moment and shear force are to be treated as the upper limits with respect to hull girder strength.

In general, the design cargo and ballast loading conditions, based on amount of bunker, fresh water and stores at departure and arrival, are to be considered for the M_{SW} and Q_{SW} calculations. Where the amount of disposition of consumables at any intermediate stage of the voyage are considered more severe. Also, where any ballasting and/or deballasting is intended during voyage, calculations of the intermediate condition are also to be considered.

4.12.1.1 *Still water bending moment*

The design still water bending moment $M_{SW,H}$ and $M_{SW,S}$ at any hull transverse section are the maximum still water bending moments calculated, in hogging and sagging conditions, respectively, at that hull transverse section. If the design still water bending moments are not defined, at a preliminary design stage, at any hull transverse section, the longitudinal distributions shown in Figure 4.6 may be considered.

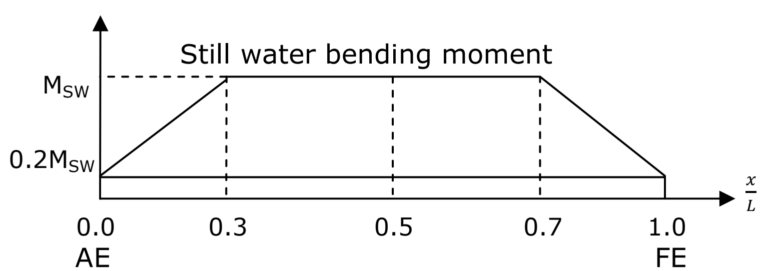


Fig. 4.6 Preliminary still water bending moment distribution

In Figure 4.6, MSW is the design still water bending moment amidships, in hogging or sagging conditions, whose values are to be taken not less than those obtained, in KN-m, from the following formulae;

- Hogging conditions:

  $M_{SW,H}=175CL^2B\ (C_B+0.7)10^{-3} - M_{WV,H}$ ... (4.3)

- Sagging conditions:

  $M_{SW,S}=175CL^2B\ (C_B+0.7)10^{-3} - M_{WV,S}$ ... (4.4)

4.12.2 Wave Loads

Vertical wave bending moments.

- Intact condition

The vertical wave bending moments in intact condition at any hull transverse section are obtained, in KN-m, from the following formulae:

- Hogging conditions:

$$M_{WV,H}=190F_M f_p C L^2 B C_B 10^{-3} \quad \text{... (4.5)}$$

- Sagging conditions:

$$M_{WV,S}=110F_M f_p C L^2 B(C_B+0.7)10^{-3} \quad \text{... (4.6)}$$

fp: Coefficient corresponding to the probability level, taken equal to:

fp=1.0 for strength assessments corresponding to the probability level of 10^{-8}

fp=0.5 for strength assessments corresponding to the probability level of 10^{-4}

FM=distribution factor defined in Table 4.3.

Table 4.3 Distribution factor

Hull transverse section location	Distribution factor FM
0≤x<0.4L	$2.5\frac{x}{L}$
0.4L≤x≤0.65L	1.0
0.65L<x≤L	$2.86\left(1-\frac{x}{L}\right)$

- Flooded condition

The vertical wave bending moments in flooded condition at any hull transverse section are obtained, in KN-m from the following formula:

$$M_{WV,F}=0.8M_{WV} \quad \text{... (4.7)}$$

- Harbor condition

The vertical wave bending moments in harbor condition at any hull transverse section are obtained, in KN-m, from the following formula:

$$M_{WV,P}=0.4M_{WV} \quad \text{... (4.8)}$$

4.12.3 Load Cases

For the local strength analysis and for the direct strength analysis, the load cases are the mutually exclusive load cases H1, H2, F1, F2, R1, R2, P1 and P2.

➢ Equivalent design wave

Regular waves that generate response value equivalent to the long-term response values of the load components considered being predominant to the structural members are set as Equivalent Design Waves (EDWs). They consist of:

- Regular waves when the vertical wave bending moment becomes maximum in head sea (EDW "H")
- Regular waves when the vertical wave bending moments maximum in following sea (EDW "F")
- Regular waves when the roll motion becomes maximum (EDW "R")
- Regular waves when the hydrodynamic pressure at he waterline becomes maximum (WDW "P")

The load cases corresponding to the equivalent design waves (EDWs) are defined in Table 4.4. The corresponding hull girder loads and motions of the ship are indicated in Table 4.5.

Table 4.4 Definition of load cases

Load case	H1	H2	F1	F2	R1	R2	P1	P2
EWD	"H"		"F"		"R"		"P"	
Heading	Head		Follow		Beam (Port: weather side)		Beam (Port: weather side)	
Effect	Max. Bending Moment		Max. bending moment		Max. Roll		Max. Ext. Pressure	
	Sagging	Hogging	Sagging	Hogging	(+)	(-)	(+)	(-)

Table 4.5 Reference hull girder loads and motions of ship

Load case	H1	H2	F1	F2	R1	R2	P1	P2
Vert. BM & SF	Yes		Yes		-		Yes	
Hor. BM	-		-		Yes		-	
Heave	Down	Up	-	-	Down	Up	Down	Up
Pitch	Bow down	Bow up	-	-				
Roll	-	-	-	-	Stbd up	Stbd down	Stbd up	Stbd down
Surge	Stern	Bow	-	-	-	-	-	-
Sway	-	-	-	-	-	-	Port	Stbd

4.12.4 External Pressure on side shell and bottom

The total pressure *p* at any point of the hull, in kN/m^2, to be obtained from the following formula is not to be negative:

$p = p_s + p_w$

Where:

p_s: Hydrostatic pressure

p_w: wave pressure equal to the hydrodynamic pressure

4.12.4.1 *Hydrostatic pressure*

The hydrostatic pressure p_s at any point of the hull in kN/m^2, corresponding to the draught in still water is obtained, for each loading condition, from the formulae in Table 4.6

Table4.6 Hydrostatic pressure p_s

Location	Hydrostatic pressure, p_s, in kN/m^3
Points at and below the waterline $(z \le T_{LCi})$	$\rho g(T_{LCi} - z)$
Points above the waterline $(z > T_{LCi})$	0

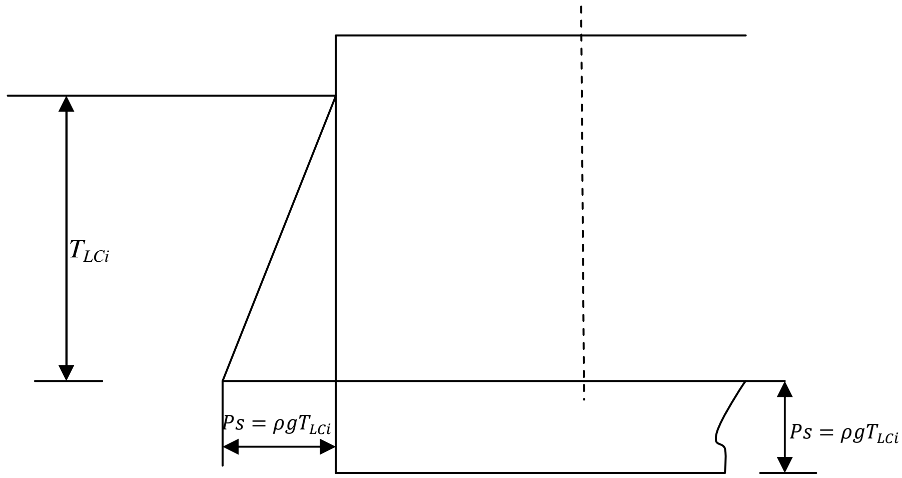


Fig. 4.7 Hydrostatic pressure p_s

4.12.4.2 *Hydrodynamic pressures for load cases H1, H2, F1 and F2*

The hydrodynamic pressures p_H and p_F, for load cases H1, H2, F1 and F2, at any point of the hull below the waterline are to be obtained, kN/m^2, from table

The distribution of pressure p_{F2} is schematically given in Figure 4.8

Table 4.7 Hydrodynamic pressures for load cases H1, H2, F1 and F2

Load case	Hydrodynamic pressure, in kN/m^2
H1	$p_{H1} = -k_l k_p p_{HF}$
H2	$p_{H2} = k_l k_p p_{HF}$
F1	$p_{F1} = -p_{HF}$
F2	$p_{F2} = p_{HF}$

Where:

$p_{HF} = 3 f_p f_{nl} C \sqrt{\frac{L+\lambda-125}{L}} \left(\frac{z}{T_{LCi}} + \frac{|2y|}{B_i} + 1\right)$; with $\frac{|2y|}{B_i} \leq 1.0$ and z is to be taken not greater than T_{LCi}

f_{nl} : Coefficient considering nonlinear effect, taken equal to:

f_{nl}=0.9 for the probability level of 10^{-8}

f_{nl}=1.0 for the probability level of 10^{-4}

k_l: Amplitude coefficient in the longitudinal direction of the ship, taken equal to:

$k_l = 1 + \frac{12}{C_B}\left(1 - \sqrt{\frac{|2y|}{B}}\right)\left|\frac{x}{L} - 0.5\right|^3$ for 0.0$\leq x/L \leq 0.5$

$k_l = 1 + \frac{6}{C_B}\left(3 - \frac{|4y|}{B}\right)\left|\frac{x}{L} - 0.5\right|^3$ for 0.5$\leq x/L \leq 1.0$

kp: Phase coefficient in the longitudinal direction of the spin, taken equal to:

$k_p = \left(1.25 - \frac{T_{LC}}{T_S}\right) cos\left(\frac{2\pi|x-0.5L|}{L}\right) - \frac{T_{LC}}{T_S} + 0.25$, for local strength analysis in condition other than full load condition, for direct strength analysis and for fatigue strength assessments k_p=-1.0, for local strength analysis in full load condition

λ: Wave length, in m, taken equal to:

$\lambda = 0.6\left(1 + \frac{T_{LC}}{T_S}\right)L$ for load cases H1 and H2 ...(4.9)

$\lambda = 0.6\left(1 + \frac{2}{3}\frac{T_{LC}}{T_S}\right)L$ for load cases F1 and F2 ...(4.10)

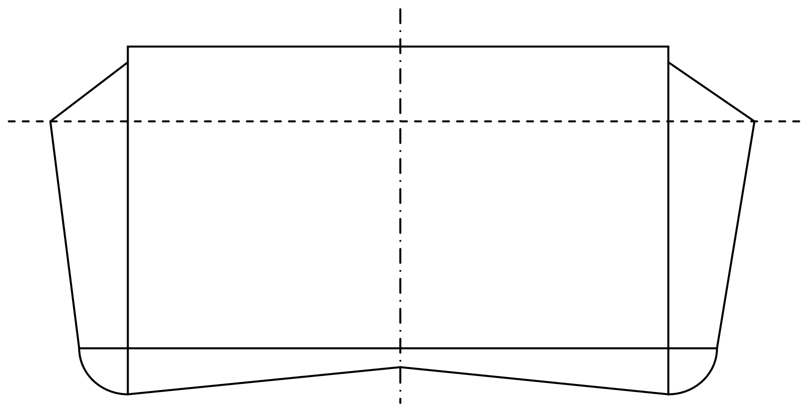


Fig. 4.8 Distribution of hydrodynamic pressure p_{F2} at midship

4.12.5 Calculation of External sea pressure

Hydrostatic and hydrodynamic pressures as per ABS are calculated for the 250 passenger and 100T cargo capacity vessel. The procedure followed in calculation is shown in Appendix A, Section A.2. The pressure distribution obtained as per ABS along the ship length and width is shown in graphs below. It is observed that the pressure varies along the length and width of the ship. The pressure is calculated from draft level to bottom of the ship. The pressure variation in longitudinal direction is shown from stern to bow.

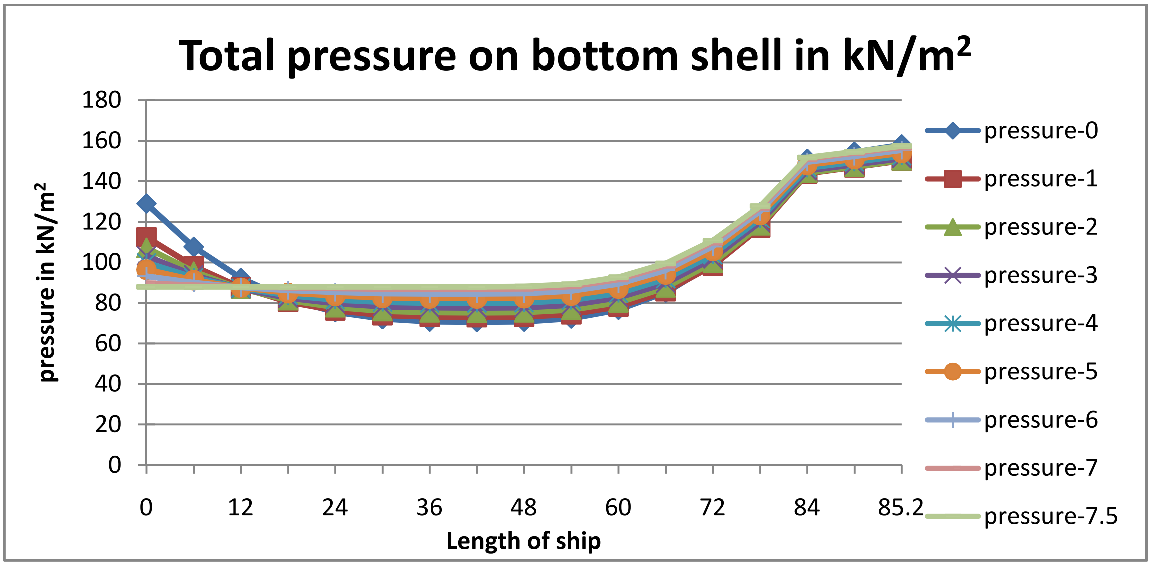


Chart 4.1 total pressure on bottom shell

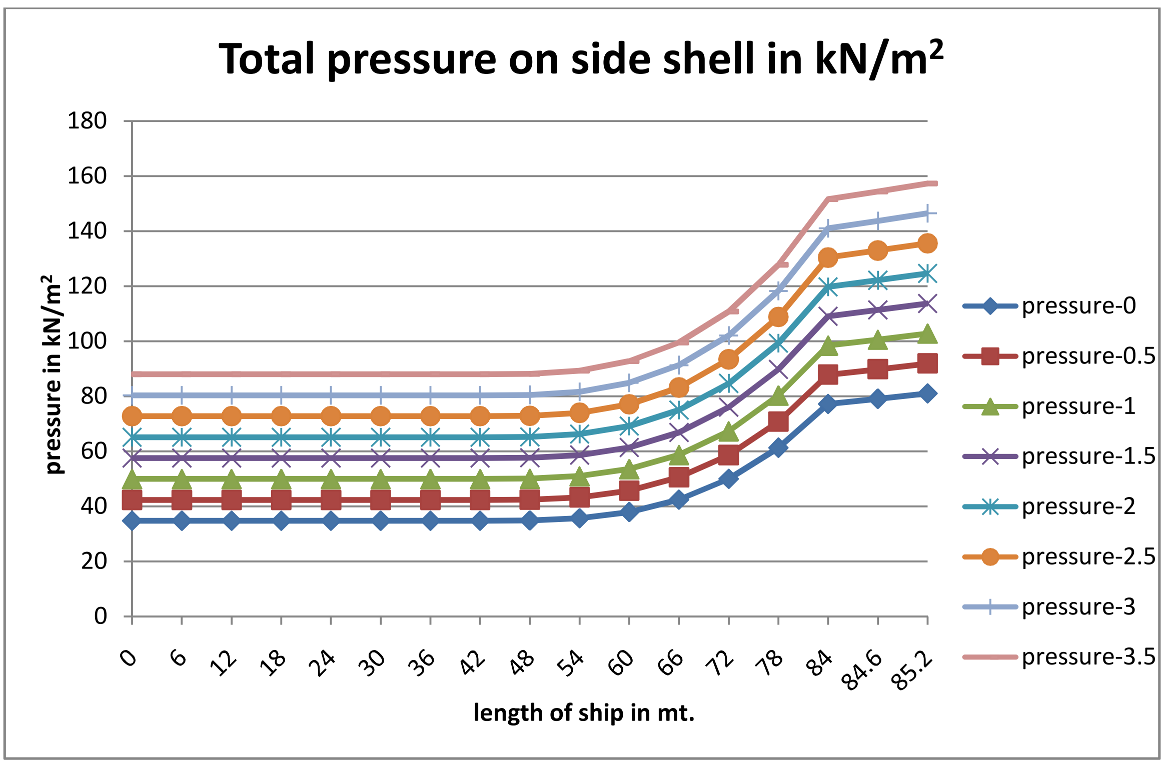


Chart 4.2 Total pressure on side shell

4.13 WAVE LOAD AS PER 'SAP'

The wave loads on a ship are dynamic in nature. The SAP2000 includes analysis of offshore structures as per API RP 2A WSD. It includes wave analysis with various parameters for a wave loading.

4.13.1 Static Wave Analysis

The procedure, for a given wave direction, begins with the specification of the design wave height and the associated wave period, storm water depth, and current profile.

An apparent wave period is determined, accounting for the Doppler effect of the current on the wave.

- The two-dimensional wave kinematics is determined from an appropriate wave theory for the specified wave height, storm water depth, and apparent period.
- The horizontal components of wave-induced particle velocities and accelerations are reduced by the wave kinematics factor which accounts primarily for wave directional spreading.
- The effective local current profile is determined by multiplying the specified current profile by the current blockage factor.
- The effective local current profile is combined vectorially with the wave kinematics to determine locally incident fluid velocities and accelerations for use in Morison's equation.
- Drag and inertia force coefficients are determined as functions of wave and current parameters; and member shape, roughness (marine growth), size and orientation.
- Local wave/current forces are calculated for all members using Morison's equation.
- The global force is computed as the vector sum of all the local forces.

Doppler Effect: When the direction of water current and wave are same then the wave length of wave will increase and if direction is opposite then the wave length will decrease. This effect is called Doppler Effect.

4.13.2 SAP2000 Input for Wave Analysis

The wave loads on a ship are dynamic in nature. The SAP2000 includes analysis of offshore structures as per API RP 2A WSD. It includes wave analysis with various parameters for a wave loading.

The inputs to the SAP-2000 file are as follows:-

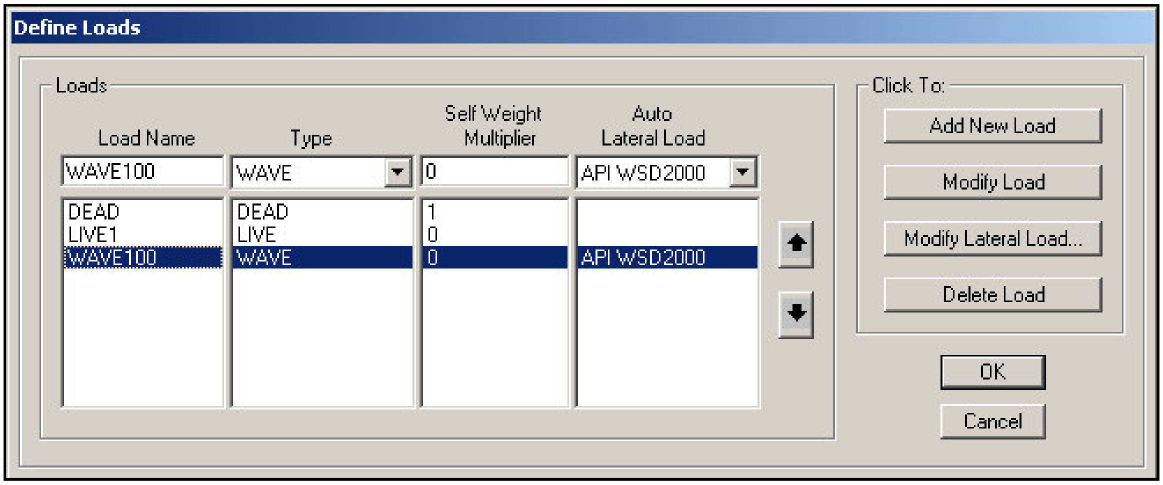


Fig. 4.9 Defining wave load case

- **Wave theory**

Stoke's fifth order wave theory is used for wave kinematics.

- **Drag and Inertia Coefficients**: (As per API RP 2A-WSD)

The drag and inertia coefficients are used in Morison's equation when calculating the wave forces acting on the structure. By default a wave load is specified to have API Default drag and inertia coefficients. The values for the API Default drag and inertia coefficients depend on whether the location considered is above or below the specified high tide elevation as shown in the following table.

Table 4.8 API default drag and inertia coefficient

Location	Drag coefficient	Inertia coefficient
Above high tide elevation (Smooth)	0.65	1.6
Below at high tide elevation (Smooth)	1.05	1.2

- **Marine growth**

Marine growth is accumulated on submerged members. Its main effect is to increase the wave forces on the members by increasing not only exposed areas and volumes, but also the drag coefficient due to higher surface roughness. In addition, it increases the unit mass of the member, resulting in higher gravity loads and in lower member frequencies. Depending upon geographic location, the thickness of marine growth can reach 0.3m or more. It is accounted for in design through appropriate increases in the diameters and masses of the submerged members.

The marine growth term is associated with fix structure in ocean. Ship is a moving object in the sea. Therefore, in analysis of the ship the marine growth is neglected. The marine growth thickness on the structure is specified as a function of depth. By default a wave load is specified to have no marine growth in SAP2000.

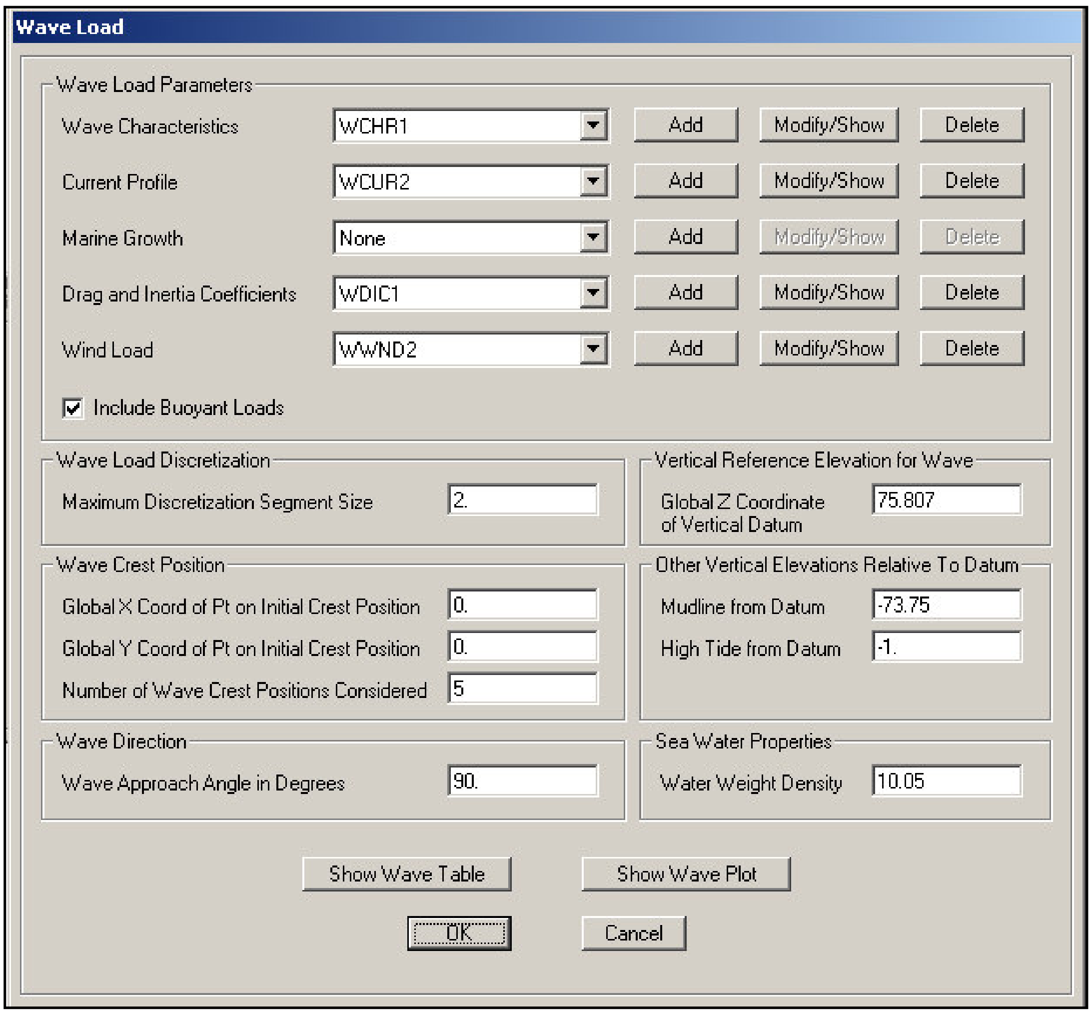


Fig. 4.10 Wave load form

- **Water depth**

Water depth of the platform location corresponding to Chart Datum (CD) level is 73.75 m. The design water depth is computed as below:

Design water depth = Storm mean water level (SMWL)

SMWL = CD + high tide level

= 73.75 m + 2.057 m (assume)

Design water depth is found to be **75.807 m.**

- **Wave load discretization length**

The wave load discretization is the maximum discretization length for distributed wave loads that are applied to objects in the model. For example, consider a distributed wave load acting along a frame element. A value is calculated for the wave load at points along the frame element that are no further apart than the specified wave load discretization length. The magnitude of the distributed wave load is assumed to vary linearly between these calculated locations.

The maximum discretization segment length considered is 2.000 m.

- **Wave crest position**

The global X and Y coordinates of a point on the initial wave crest position. The numbers of wave crest positions to be considered. The meaning of the number of wave crest positions to be considered is explained by the example shown in Figure 4.11, which shows a case of four wave crest positions.

The location of the initial wave crest position is uniquely identified by the specified global X and Y coordinates on the initial wave crest and the specified wave approach angle (wave direction). The distance from one wave crest to the next wave crest is equal to the wave length, identified as WL in Figure 4.11. When four wave crest positions are considered, the wave length is broken into quarters and the four positions considered are as shown in Figure 4.11b.

The first position considered is at the specified initial wave crest position. The second position considered is one quarter the wave length away from the initial position measured in the direction of the wave. The third position considered is one half the wave lengths away from the initial position, and the fourth position is three quarters the wave length away from the initial position. The wave crest position considered 0 in X & Y direction i.e stern and number of wave crest position is 5.

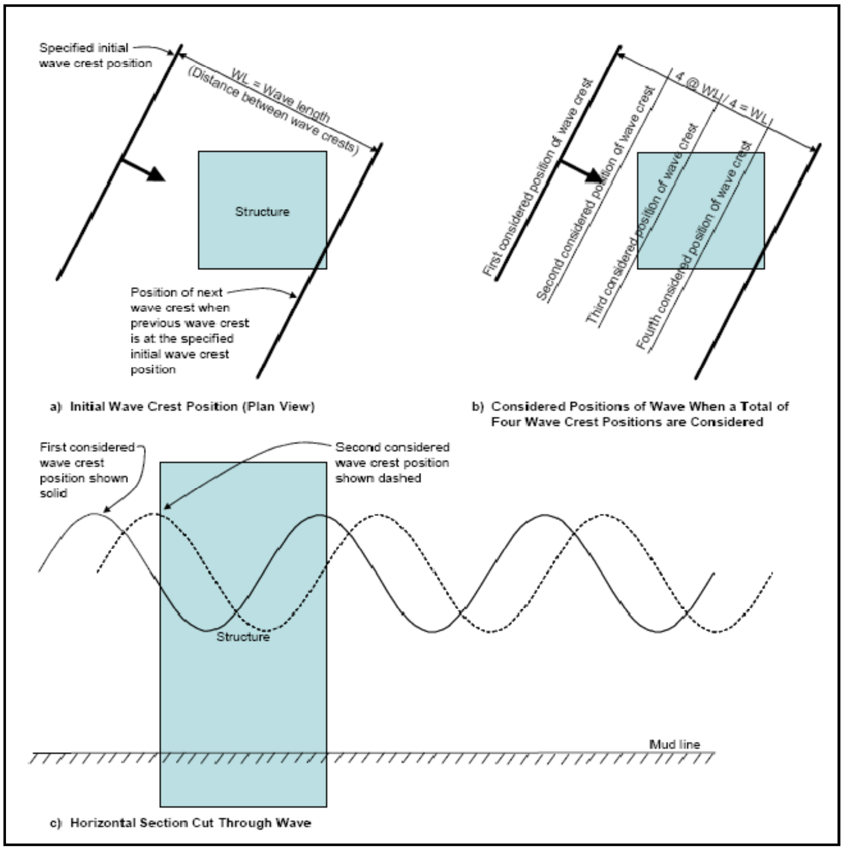


Fig. 4.11 Wave crest position

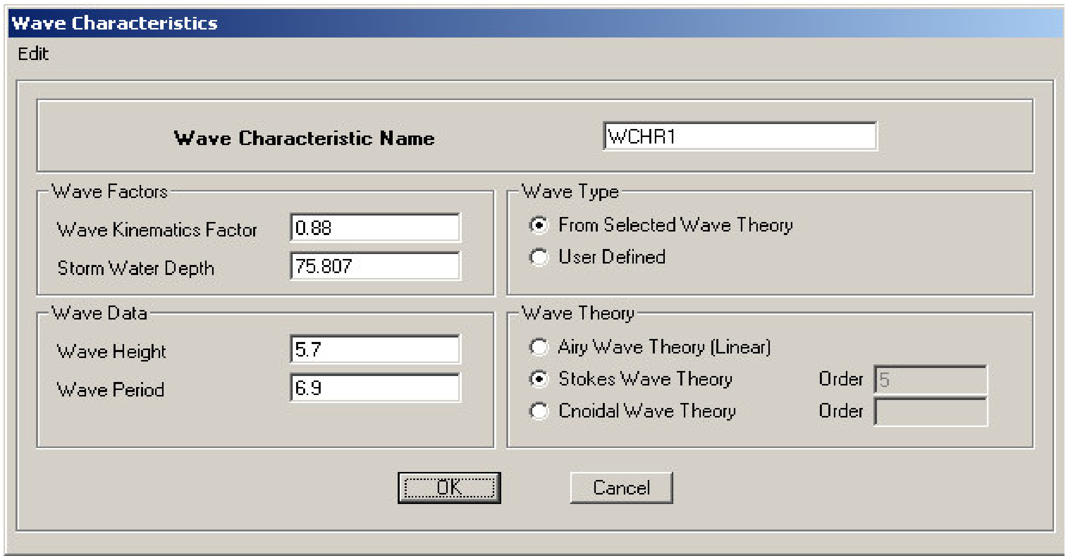


Fig. 4.12 Wave characteristic form

- ### Water Density

The water density for sea water is 10.0536 kN/m^3.

- ### Wave Kinematics factor

The Two-dimensional regular wave kinematics from Stream Function or Stokes V wave theory do not account for wave directional spreading or irregularity in wave profile shape. These "real world" wave characteristics can be approximately modeled in deterministic wave analyses by multiplying the horizontal velocities and accelerations from the two-dimensional regular wave solution by a wave kinematics factor. Wave kinematics measurements support a factor in the range 0.85 to 0.95 for tropical storms and 0.95 to 1.00 for extra tropical storms.

Wave kinematics factor = 0.88

- ### Current blockage factor

The current speed in the vicinity of the structure is reduced from the specified "free stream" value by blockage. In other words, the presence of the structure causes the incident flow to diverge; some of the incident flow goes around the structure rather than through it, and the current speed within the structure is reduced. Since global deck loads are determined by summing local loads from Morison's equation, the appropriate local current speed should be used.

Current blockage factor=0.8

➢ Current load

The total current is the vector sum of the tidal, circulation, and storm-generated currents. The relative magnitude of these components, and thus their importance for computing loads, varies with offshore location. Tidal currents are generally weak. Figure 4.13 shows a tidal current profile typical of the western shore line. The effects of current superimposed on waves are taken into account by adding the corresponding fluid velocities vectorally. Since the drag force varies with the square of the velocity, this addition can greatly increase the forces.

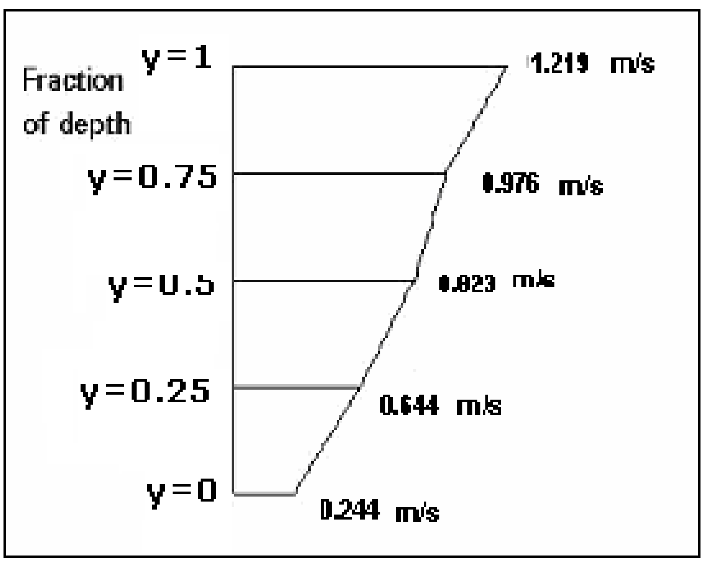


Fig. 4.13 Typical current profile of western shore line

At y=0, vertical datum at d= 73.75 × 0 = 0 m

At y=0.25, vertical datum at d= 73.75 × 0.25 = 18.438 m

At y=0.5, vertical datum at d= 73.75 × 0.5 = 36.875 m

At y=0.75, vertical datum at d= 73.75 × 0.75 = 55.313 m

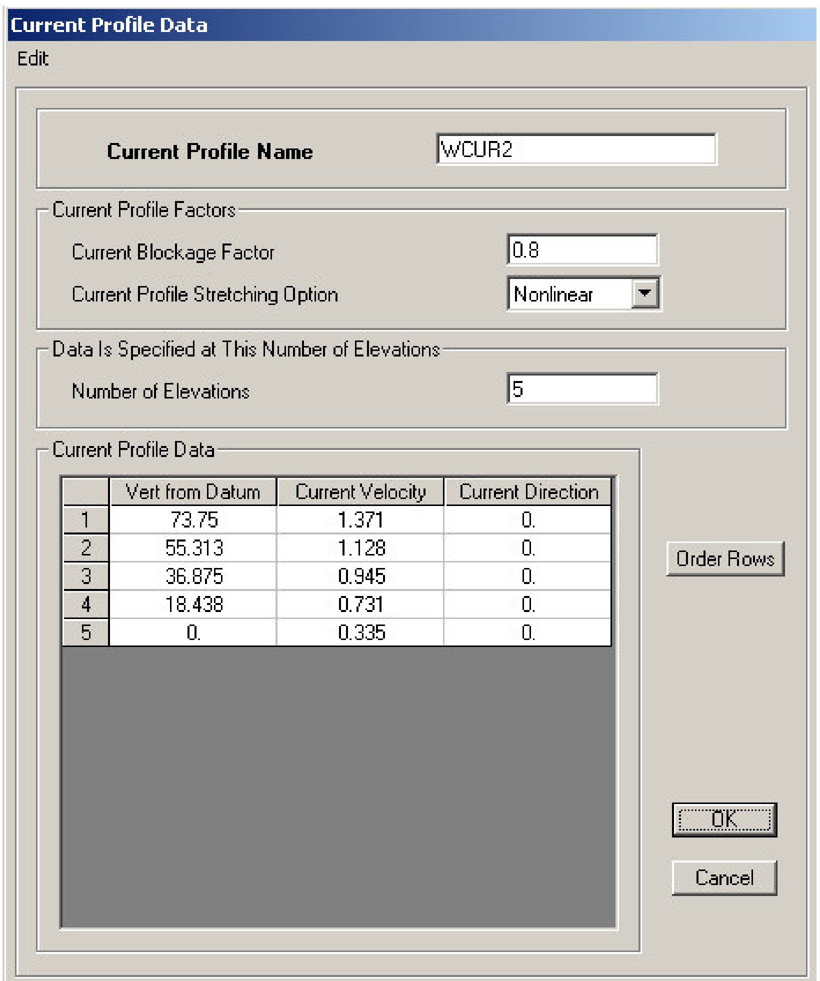
At y=1.0, vertical datum at d= 73.75 × 1.0 = 73.75 m

➢ Current Profile

A qualified oceanographer should determine the variation of current speed and direction with depth. The profile of Storm-generated currents in the upper layer of the ocean is the subject of active research.

➢ Current Associated with waves

Due consideration should be given to the possible superposition of current and waves. In those cases where this superposition is necessary the current velocity should be added vectorially to the wave particle velocity before the total force is computed as Morison Equation. Where there is sufficient knowledge of wave/current joint probability, it may be used to advantage.


Current Profile Data

Edit

Current Profile Name WCUR2

Current Profile Factors

Current Blockage Factor 0.8

Current Profile Stretching Option Nonlinear

Data Is Specified at This Number of Elevations

Number of Elevations 5

Current Profile Data

	Vert from Datum	Current Velocity	Current Direction
1	73.75	1.371	0.
2	55.313	1.128	0.
3	36.875	0.945	0.
4	18.438	0.731	0.
5	0.	0.335	0.

Order Rows

OK

Cancel

Fig. 4.14 Current Profile Form

5. SCANTLING OF MIDSHIP FRAME (250 PASSENGERS CUM 100 T CARGO VESSEL)

5.1 DECK STRUCTURE

FRAMING SYSTEM: LONGITUDINAL

Spacing between longitudinal: 600 mm

Spacing between transverse: 1800 mm

Decks:

- Tank top
- Tween deck
- Main deck
- Upper deck
- 01 deck
- Wheel house (02) deck
- Wheel house top (03) deck

Members:

- Secondary longitudinal stiffeners
- Transverse girders
- Primary longitudinal girders
- Hatch side girders
- Hatch end girders
- Cantilever girders
- Side shell stiffeners
- Stiffeners (bulkhead) pillars
- Circular pillars
- Bulkheads
- Deck plate

SYMBOLS AND DEFINITION

L, L_1 – Length between perpendiculars in meters

B – Molded breadth in meters

D – Depth in meters measured from top of the keel to top of the deck beam at side

T – Scantling draft in meters

k_L, k – Higher tensile steel factor

e – Base of natural logarithms

L – Overall length of stiffening members or pillars in meters

l_e – effective length of stiffening members or pillars in meters

t – Thickness of plating in mm

s – Spacing of secondary stiffeners in mm

C_w – wave head in meters

$= 7.71 \times 10^{-2} L e^{-0.0044L}$

S – Spacing of primary members in meters

Z – Section modulus of stiffening member in cm^3

ρ – Relative density of liquid carried in tank but is not to be taken less than 1.025

5.2 DECK PLATING

According to LR (2005), PART 4, minimum plate thickness calculation for deck plates is to comply with "LR PART-4, CHAPTER-1" Deck plate thickness varies on type of stiffeners adopted. In the given ship, the stiffeners are provided in longitudinal direction. Stiffening the plates helps in reducing the scantling of plate and increases its buckling strength. Calculation sheets for deck plate thickness are presented in Appendix – A. Refer Figure 5.1

Table 5.1 Deck Plates

NO.	MEMBER	PLATE THICKNESS
1.	TANK TOP	8 MM
2.	TANK TOP IWO BALLAST	10 MM

3.	TWEEN DECK	7 MM
4.	MAIN DECK	7 MM
5.	UPPER DECK	7 MM

5.3 SHELL PLATING

Shell plates are subjected to hydrostatic pressure, waves and impacts. LR (2005), PART 4, gives the guidelines for designing the shell plating. Shell plates are stiffened transversely for the given case. Scantling for shell plates can be referred from Appendix-B. Refer Figure 5.1

Table 5.2 Shell Plates

NO.	MEMBER	PLATE THICKNESS
1.	BOTTOM IWO BALLAST TANK	12 MM
2.	BOTTOM ELSEWHERE	10 MM
3.	SIDE SHELL	9 MM
4.	SHEER STRAKE	9 MM
5.	SIDE PLATING BET MAIN DECK TO UPPER DECK	9 MM

5.4 DECK LONGITUDINAL AND TRANSVERSES

According to LR (2005), PART 4, minimum Z calculation longitudinal and transverses is to comply with "LR PART-4, CHAPTER-1." Refer Figure 5.2

Steps for scantling:

1. The span of stiffeners is cut by beams. So the effective span of stiffeners is spacing of two beams.
2. The spacing of longitudinal stiffeners is 600 mm and effective span is distance between two beams i.e. 1.8 m.
3. The load bearing area of stiffener is effective span multiply be spacing.
4. The pressure is considered according to its location, which is given in LR-part 3, chapter – 3, section 5.
5. Analogous procedure can be adopted for the scantling of beams and girders.

Table 5.3 Deck Longitudinal and Transverses

NO.	LOCATION	MEMBER	SECTION MODULUS
1.	STRENGTH/WEATHER DECK	STIFFENER	14.86 CM^3
2.	CARGO DECK	STIFFENER	11.66 CM^3
3.	ACCOMMODATION DECK	STIFFENER	9.91 CM^3
4.	STRENGTH/WEATHER DECK	BEAM	23.86 CM^3
5.	CARGO DECK	BEAM	26.69 CM^3
6.	ACCOMMODATION DECK	BEAM	32.42 CM^3
7.	CARGO SPACES	GIRDER	164.16 CM^3

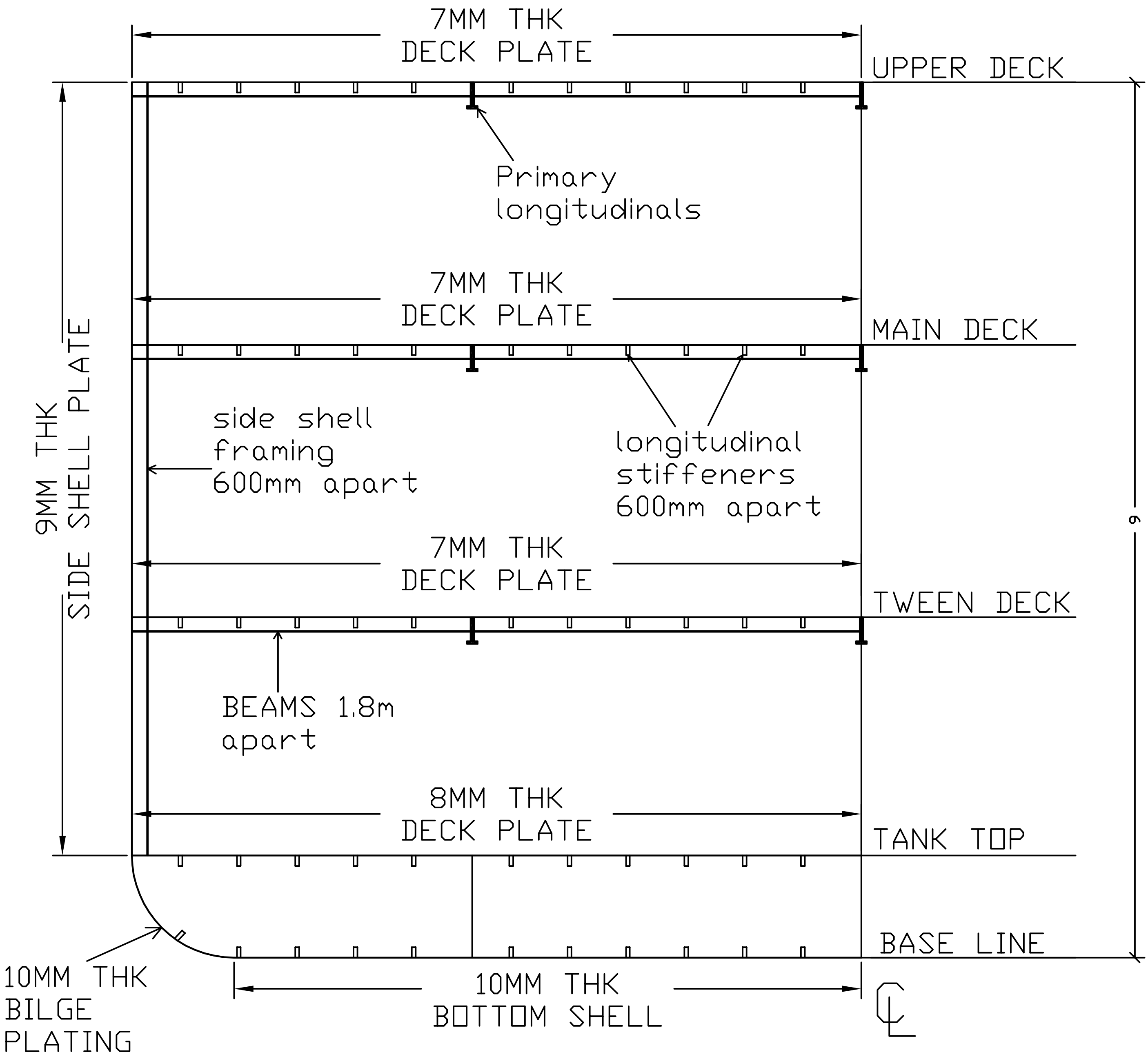


Fig. 5.1
Details of plate thickness

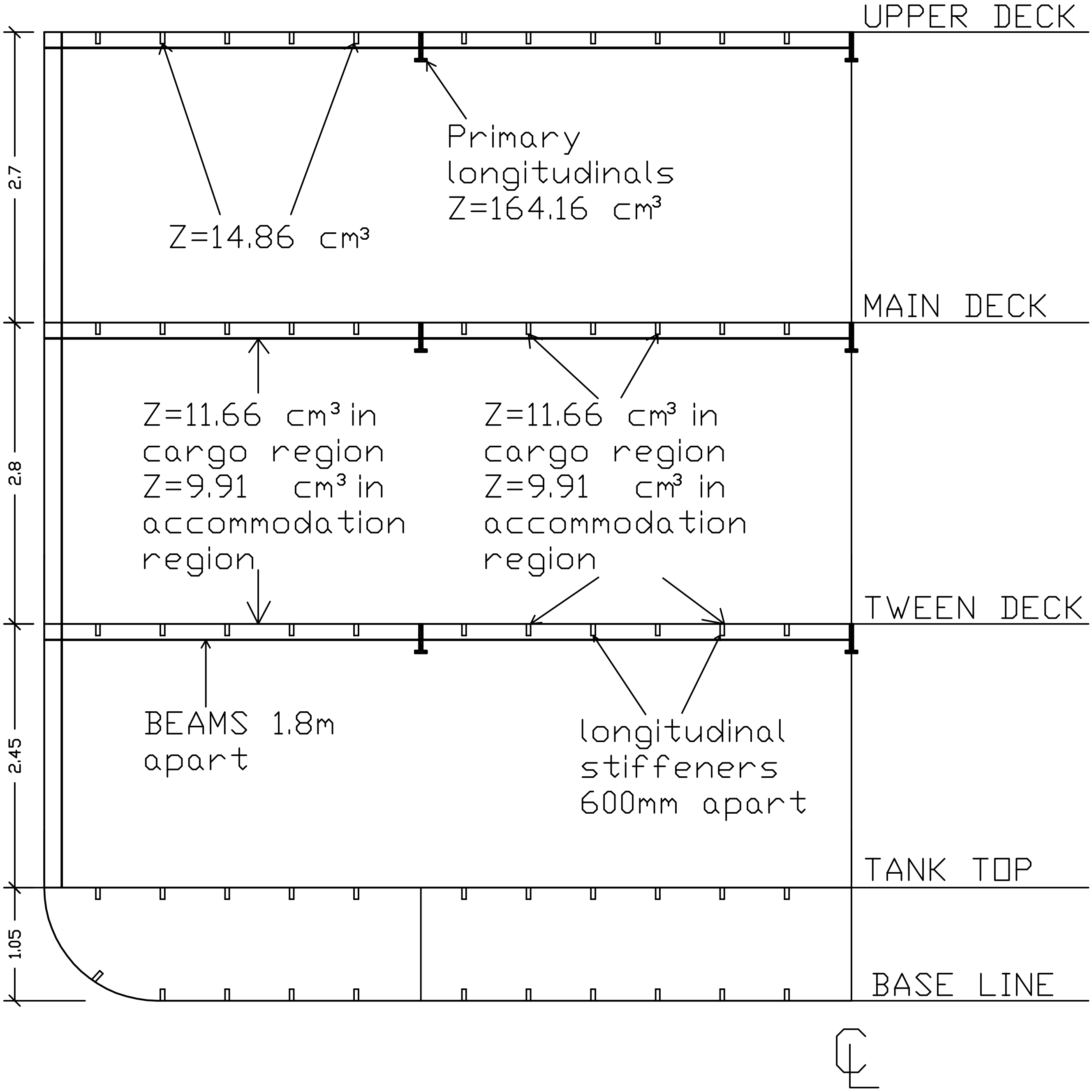


Fig. 5.2
Details of section modulus for girder

6. ANALYSIS OF SHIP IN SAP2000

6.1 SUPERSTRUCTURE

The terms *deckhouse* and *superstructure* refer to a structure usually of shorter length than the entire ship and erected above the strength deck of the ship. If its sides are coplanar with the ship's sides it is referred to as a superstructure. If its width less than that of the ship, it is called a deckhouse.

Superstructures and deckhouses are major discontinuities in the ship girder. They contribute to the longitudinal strength but will not be fully efficient in so doing. They should not be ignored as, although this would 'play safe' in calculating the main hull strength, it would run the risk that the superstructure itself would not be strong enough to take the loads imposed on it at sea. Also they are potential sources of stress concentrations, particularly at their ends. For this reason they should not be ended close to highly stressed areas such as amidships.

A superstructure is joined to the main hull at its lower boundary. As the ship sags or hogs this boundary becomes compressed and extended respectively. Thus the superstructure tends to be arched in the opposite sense to the main hull. If the two structures are not to separate, there will be shear forces due to the stretch or compression and normal forces trying to keep the two in contact.

The ability of the superstructure to accept these forces, and contribute to the section modulus for longitudinal bending, is regarded as efficiency. It is expressed as:

$$Superstructure\ efficiency = \frac{\sigma_{0} - \sigma_{a}}{\sigma_{0} - \sigma} \qquad \ldots(6.1)$$

Where $\sigma_{0,}\sigma_{a}$ and σ are the upper deck stresses if no superstructure were present, the stress calculated and that for a fully effective superstructure.

The efficiency of superstructures can be increased by making them long, extending them the fully width of the hull, keeping their section reasonably constant and paying careful attention to the securing's to the main hull.

Using a low modulus material for the superstructure, for instance GRP, can ease the interaction problem. With a Young's modulus of the order of $\frac{1}{10}$ of that of steel, the superstructure makes little contribution to the longitudinal strength. In the past some designers have used expansion joints at points along the length of the superstructure. The idea was to stop the superstructure taking load.

Finite element analysis would be carried out to ensure the stresses were acceptable where the ends joined the main hull. A typical mesh is shown in Figure 6.1.

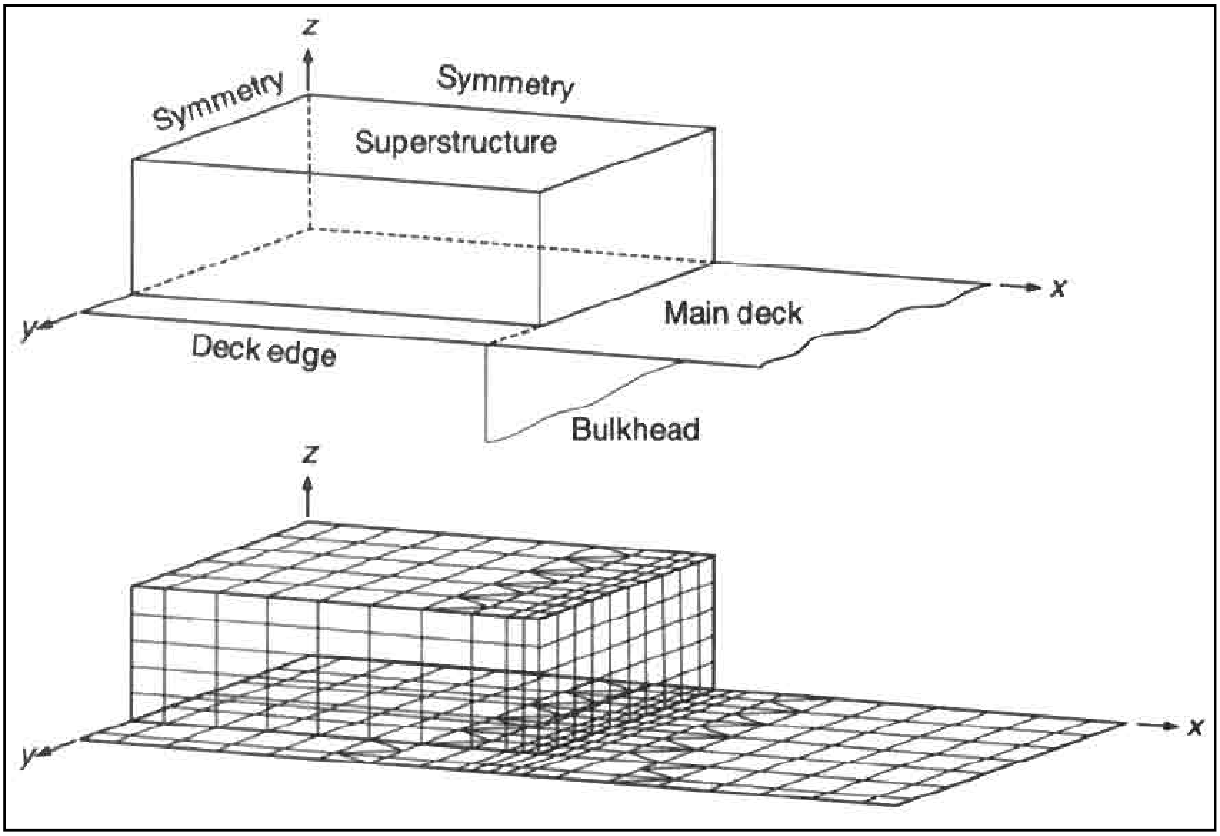


Fig. 6.1 Superstructure mesh

6.2 MODELING IN SAP2000

SAP2000 is the latest release of the SAP series of computer programs. SAP is a finite element analysis program that was initially developed at the University of California-Berkeley more than 25 years ago. Since development, SAP has been used widely for structural analysis. The ongoing usage of the program coupled with continuing program upgrades are strong indicators that most program bugs have been identified and corrected.

SAP2000 is software package from Computers and Structures, Inc. for structural analysis and design. Each package is a fully integrated system for modeling, analyzing, designing, and optimizing structures of a particular type. SAP2000 for general structures includes analysis of bridges, stadiums, towers, industrial plants, offshore structures, piping systems, buildings, dams, soils, machine parts and many others.

6.2.1 Ship Modeling Details

The ship dimensions are as shown in Figure 6.2. The salient details of the ship are as follows which are considered in modeling.

Ship particular	detail
Type	Passenger cum cargo
Length	85.2 m
Width	15 m
Height (hull)	9 m
No. of decks	4
Frame spacing	1800 mm
Stiffener spacing	600 mm
No. transverse frames	143
No. of longitudinal girders	3

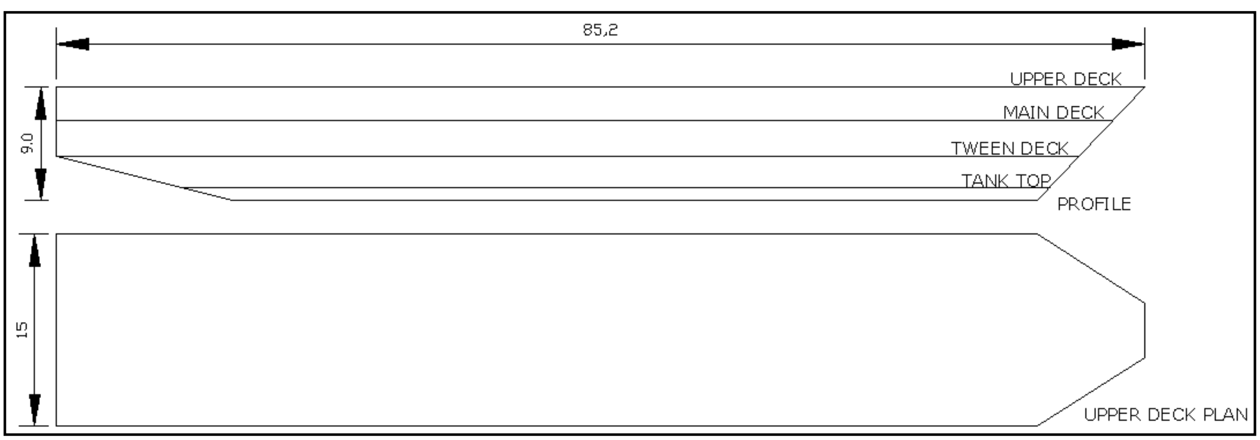


Fig. 6.2 Ship profile and top deck plan

6.2.2 Structural members of ship

Midship section of ship is shown Figure 6.3. It shows various structural members of ship. They are primary longitudinal, longitudinal stiffeners, transverse beam, deck plate, bottom plate and side shell.

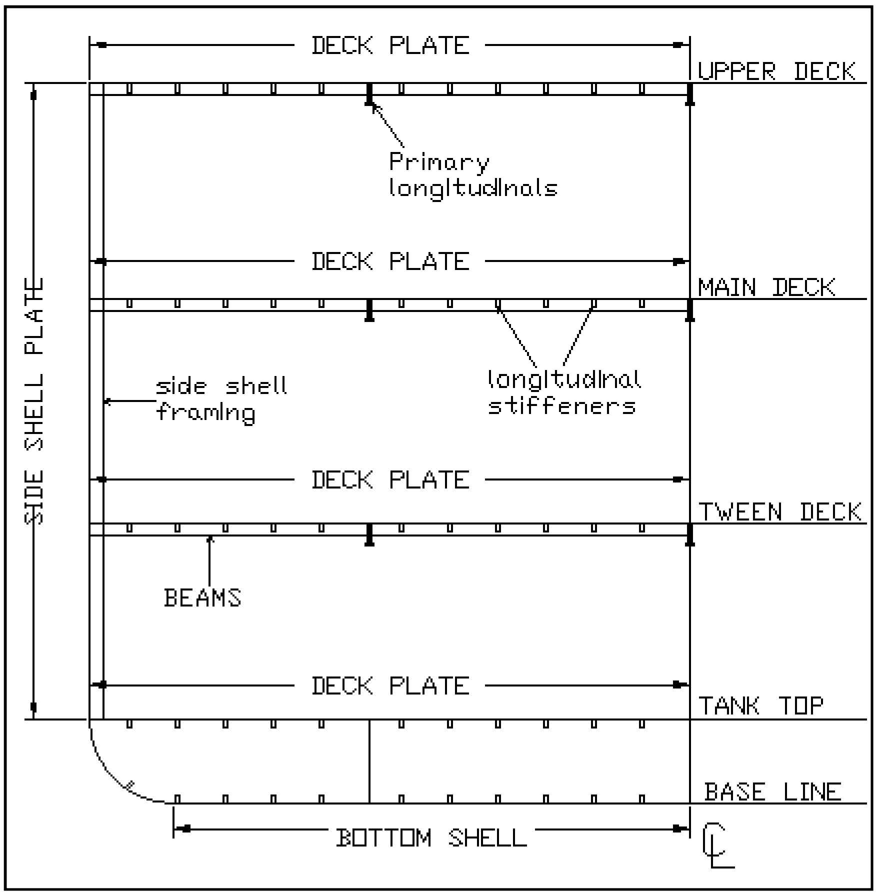


Fig. 6.3 Structural members in midship section

The transverse beams are provided at spacing of 1800mm on each deck level, while longitudinal stiffeners are placed at 600mm spacing in longitudinal direction. Three primary girders are provided on each deck level. They are placed symmetrically about the center line as shown in Figure 6.3. Structural details of midship frame is shown Figure 5.1 and 5.2 in chapter 5. The sections that are used in modeling are mention below in Table 6.1.

Table 6.1 section of structural elements

No.	Element	Section
1.	Top deck plate	7 mm
2.	Main deck plate	7 mm
3.	Tween deck plate	7 mm
4.	Tank top plate	8 mm
5.	Bottom shell plate	10 mm
6.	Side shell plate	9 mm
7.	Bulkheads	8 mm
8.	Longitudinal stiffener	HP80x6
9.	Primary girder	PL300x10+160x12FF
10.	Transverse beam	PL150x10+75x12FF

6.2.3 Assumptions

- Outer shell of Ship is modeled as flat surface whereas in actual it is three dimensional curvature.
- Slight curvature in bottom shell is ignored.
- The parabolic arch of bow is approximated by trapezoidal shape.
- Bilge is not provided in the modeled ship.
- Water pressure in water ballast tanks is ignored considering the worst case take place when ballast tanks are empty.
- In cargo regions minimum cargo density of 7 kN/m^3 is considered as per IRS.
- Deadweights are applied as uniform loads on decks in gravity direction.
- Analysis case is considered for sagging condition i.e. wave crests are at end of ship as shown in Figure 6.4 and 6.5.
- Worst condition considered while bottom tank is empty.
- Environment condition is considered as per the data available.

6.2.4 Approach to Problem

- Hull is modeled in SAP one without deckhouse on top and other with deckhouse as shown in Figure 6.4 and 6.5.

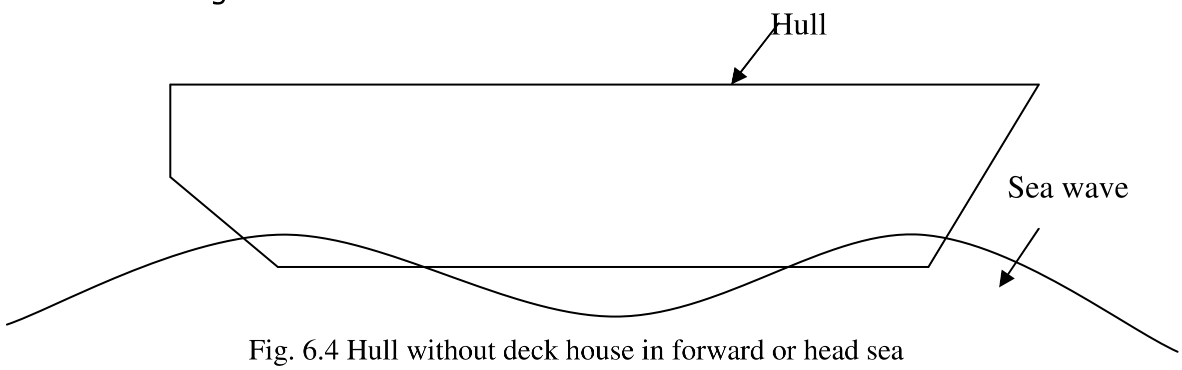


Fig. 6.4 Hull without deck house in forward or head sea

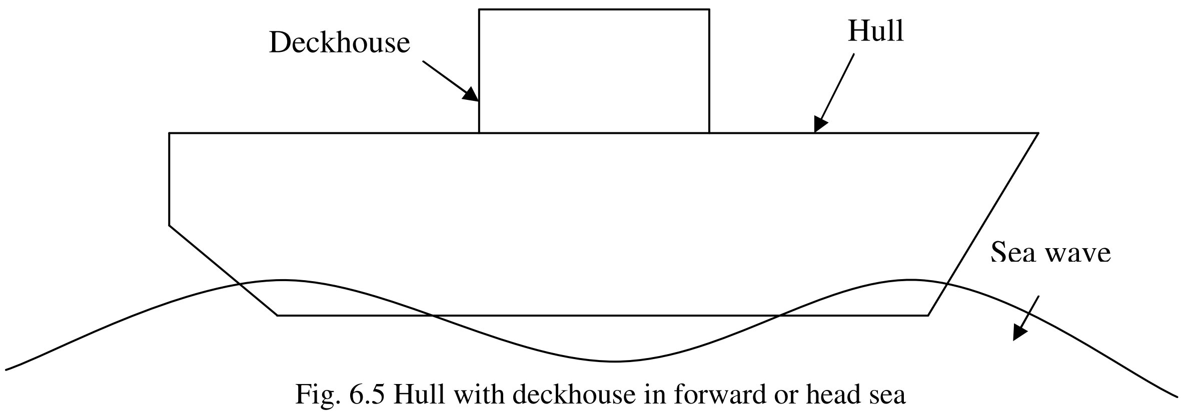


Fig. 6.5 Hull with deckhouse in forward or head sea

- Both ship models are assigned with identical loads and boundary conditions.
- Different sizes of deckhouse are used to observe their effect on hull girder stresses.
- Support conditions are provided as hinges at base as shown in Figure 6.6.

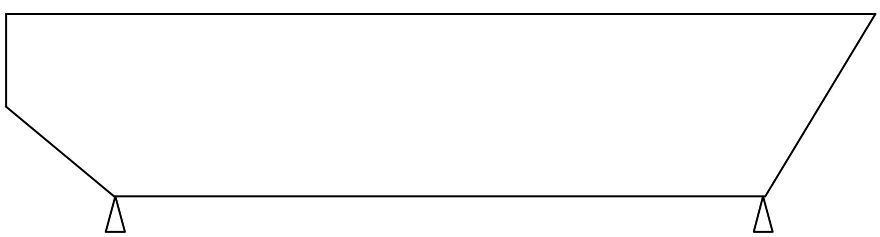


Fig. 6.6 Boundary condition

- When hinges are provided, an equivalent buoyancy force is applied on the submerge part of the ship.

- Internal loads such as passenger, crew, cargo and machinery are provided as per rules of LLOYD's Register and IRS (Indian Registry of Shipping).
- Wave induced loads are calculated as per ABS (American Bureau of Shipping)
- Wave force as given by SAP is also applied as different load case.

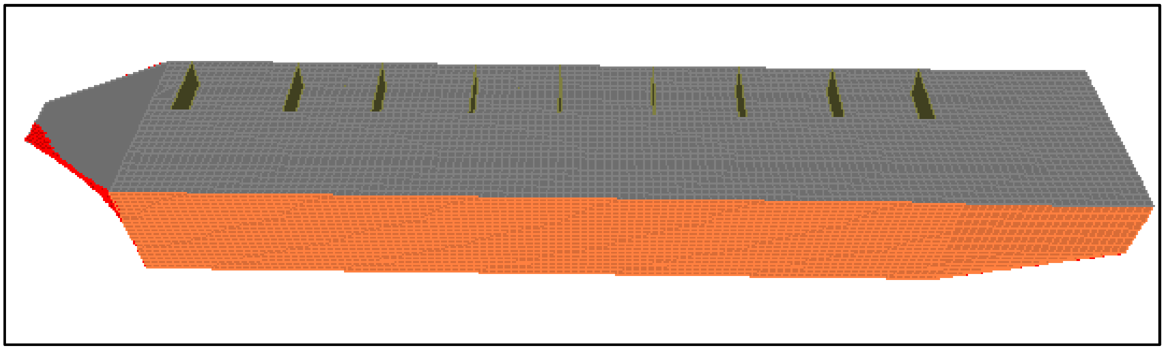


Fig. 6.7 3D view of SAP model without deckhouse

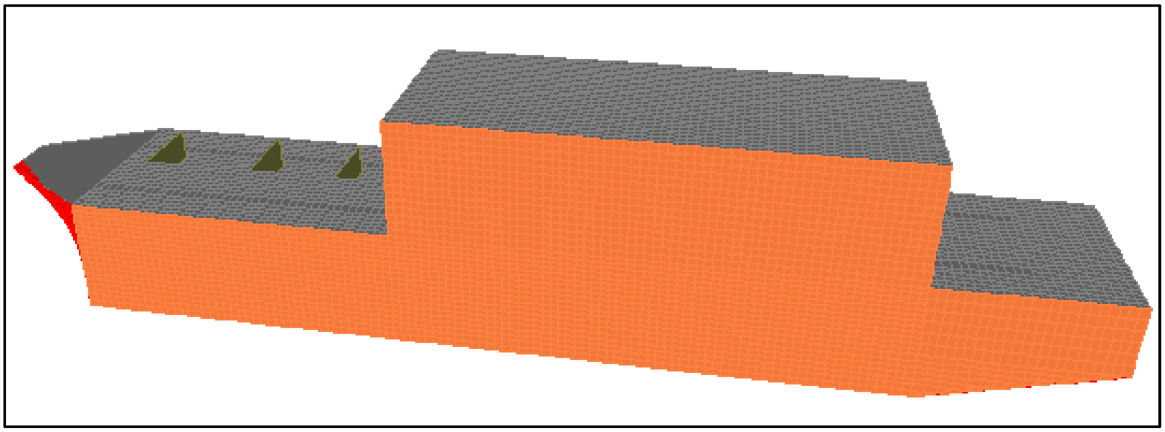


Fig. 6.8 3D view of SAP model with deckhouse

6.2.5 Co-ordinate System

The origin of the global co-ordinate system of the ship is fixed at the stern. The positive X-axis is towards the starboard, positive Y-axis is towards the bow and the positive Z-axis is vertically upwards from the bottom.

6.2.6 Ship Structure

A ship's structure can be broken down into three key areas, plate fields, simple beam structures and complex beam structures.

6.2.6.1 *Plate Fields*

Plate fields are assessed from a local and global perspective. For example bottom plating can be assessed with local sea pressure loads applied to the plate field bounded by transverse framing and longitudinal stiffeners. An assessment of stress, deflection, vibration and buckling can be made from local considerations. However when the ship is bending due to global forces, then the bottom plate will be subjected to global stresses and deflections.

6.2.6.2 *Simple beams*

Simple beam structures are those that can be analyzed using one dimensional analysis and local loads. An example is a deck beam between two longitudinal girders. The beam is simply analyzed as a one dimensional fixed ended beam with a uniform pressure load.

6.2.6.3 *Complex beam structure*

Complex beam structures are two or three dimensional structures subjected to simple or combined loading. An example of this is a hull structure comprised of side frames, deck frames, longitudinal girders and compression posts that is being subjected to deck pressure and sea pressure simultaneously.

6.2.6.4 *Geometry Creation*

To model a ship's structure it is often necessary to make some assumptions. For example slight curvature in a bottom shell can usually be ignored and be approximated by a straight line. Small chins between bottom and side plates are also often ignored. You need to consider what results you are looking for. For example if you are looking for stress concentrations in the superstructure of a global model, the omission of the chine structure should not impact your results.

6.2.7 Analysis Data

The global structural analysis is carried out for the 250passenger cum 100T cargo ship is based on details provided. The environmental data were made available for the analysis. Equivalent sections have been design as per LLOYD's register.

6.2.8 Deckhouse Combinations

To perform the analysis two type of ship models are modeled.

1. Without deckhouse
2. With deckhouse

To observe the effect of deckhouse on hull stresses various combinations of deckhouses are used. They are shown in Figure 6.10

Table 6.2 deckhouse combinations

No.	Width in meter	Length in meter			
1	15	42	30	20	10
2	11	42	30	20	10
3	8	42	30	20	10

6.2.9 Load application

When considering how model should be loaded the first step is to consult the classification society rules. They all have very good sections dedicated to calculating the loads expected for various locations on the ship. They should only be considered as a guide and your own judgment will be required. In some cases the rule values may be too high and in others they may be too low. While rule values must be used for strength calculations, actual loads can usually be used when considering deflection and vibration.

Once decided on which values to use, applying them to model is quite straight forward. Simply select the member to be loaded, assign the load value and select the orientation of the load with reference to either a global coordinate system or a local member coordinate system.

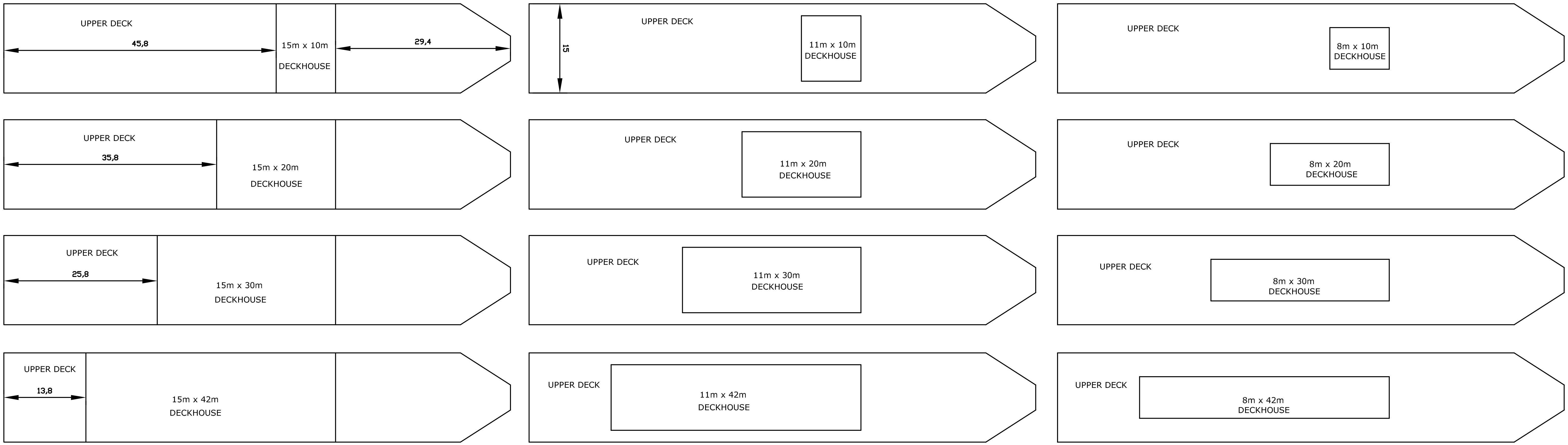


Fig. 6.10 Deckhouse combinations

6.2.9.1 *Dead weight*

Deadweight on deck includes self weight of the structure and other non-generated loads. These loads are applied in gravity direction on deck as per the load regions defined in Figure 5.3, chapther5. The Figure 6.9 shows the deadweight on decks in kN/m^3.

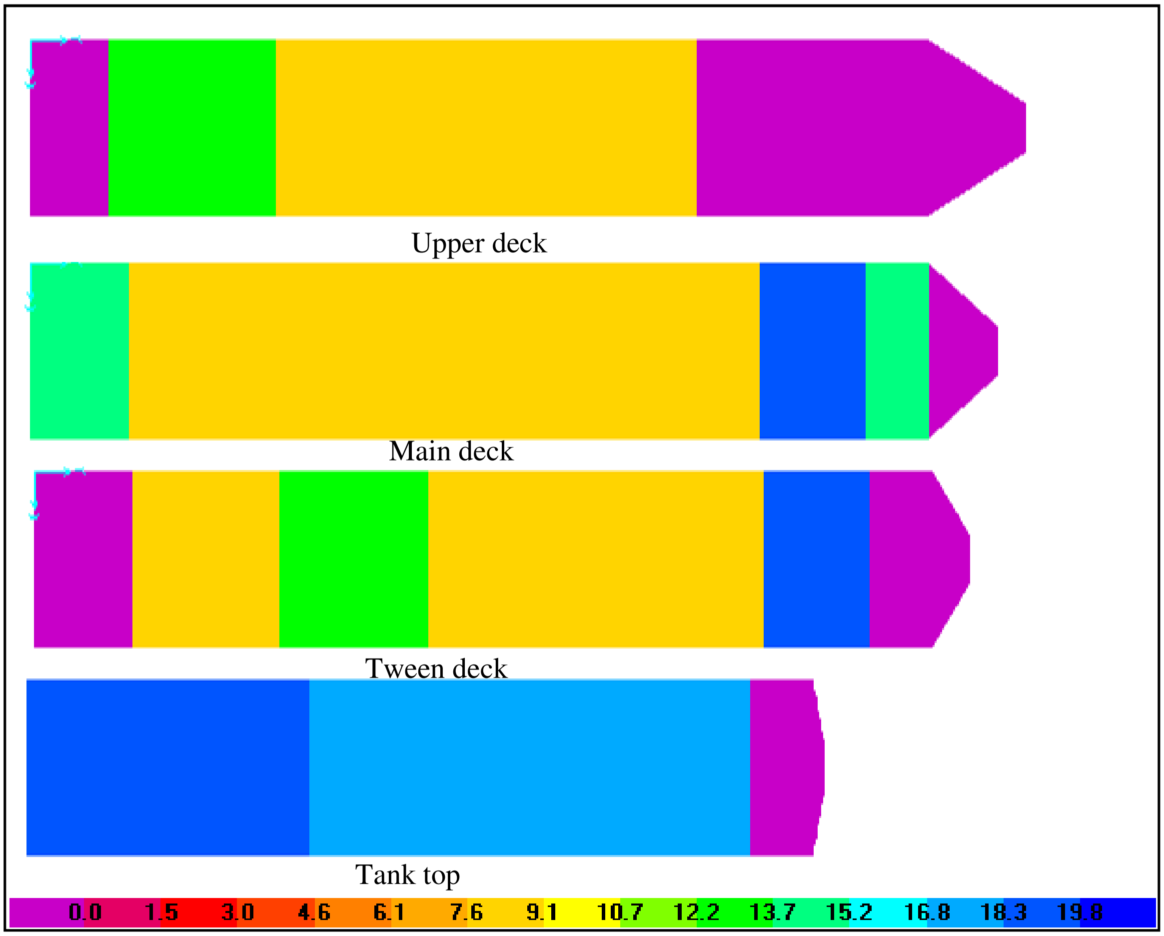


Fig. 6.9 Deadweight on decks

6.2.9.2 *Wave induce loads*

➢ External sea pressure as per ABS

External water pressure as per ABS is calculated as shown in chapter4. The distribution of pressure is also shown in chart1, chapter4. This pressure is applied to the external shell as surface pressure in N/mm^2 in longitudinal and beam direction. Applied pressure on model is shown in Figures 6.11, 6.12, 6.13 below.

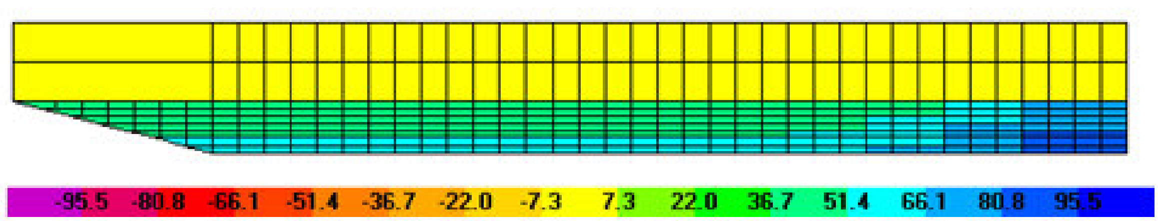


Fig. 6.10 External water pressure on side shell

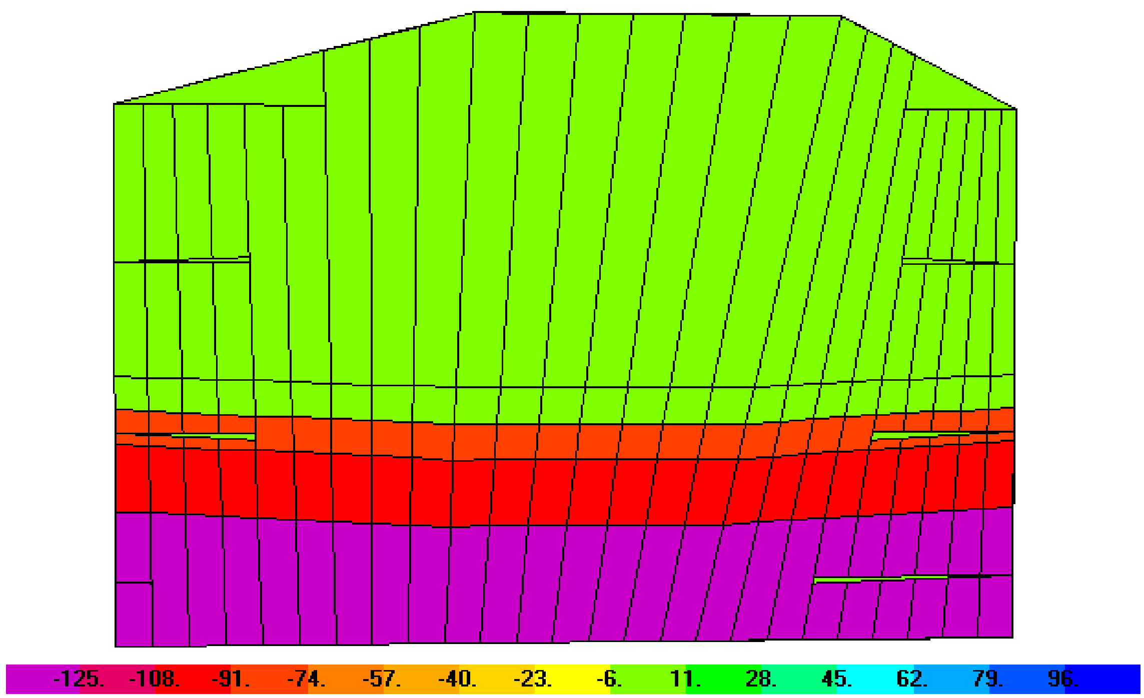


Fig. 6.11 External water pressure on bow

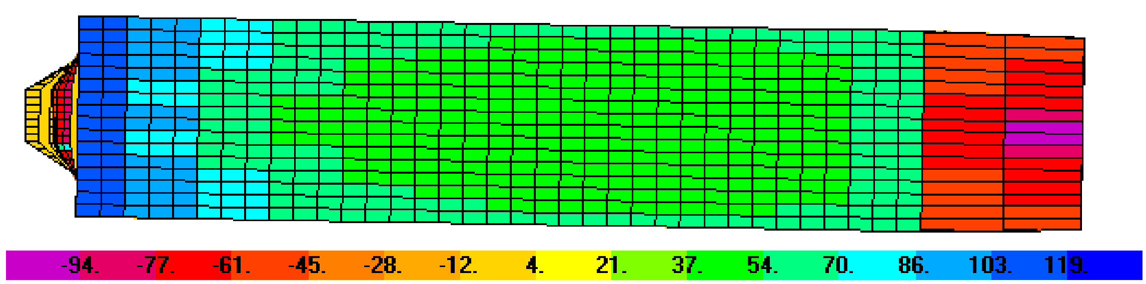


Fig. 6.12 External water pressure on bottom shell

- Wave loads as per SAP2000

The new version of SAP2000 includes analysis of offshore structures as per API RP 2A WSD. It includes wave analysis with various parameters for a wave loading.

These parameters are defined in chapter 4. Wave parameters obtained are as follows,

Wave height = 5.7 m

Time period = 6.9 sec

Wave length = 95.43 m

Stokes 5th order theory is used to calculate the wave particle velocity and acceleration. The wave pressure distribution is shown in Figure 6.14.

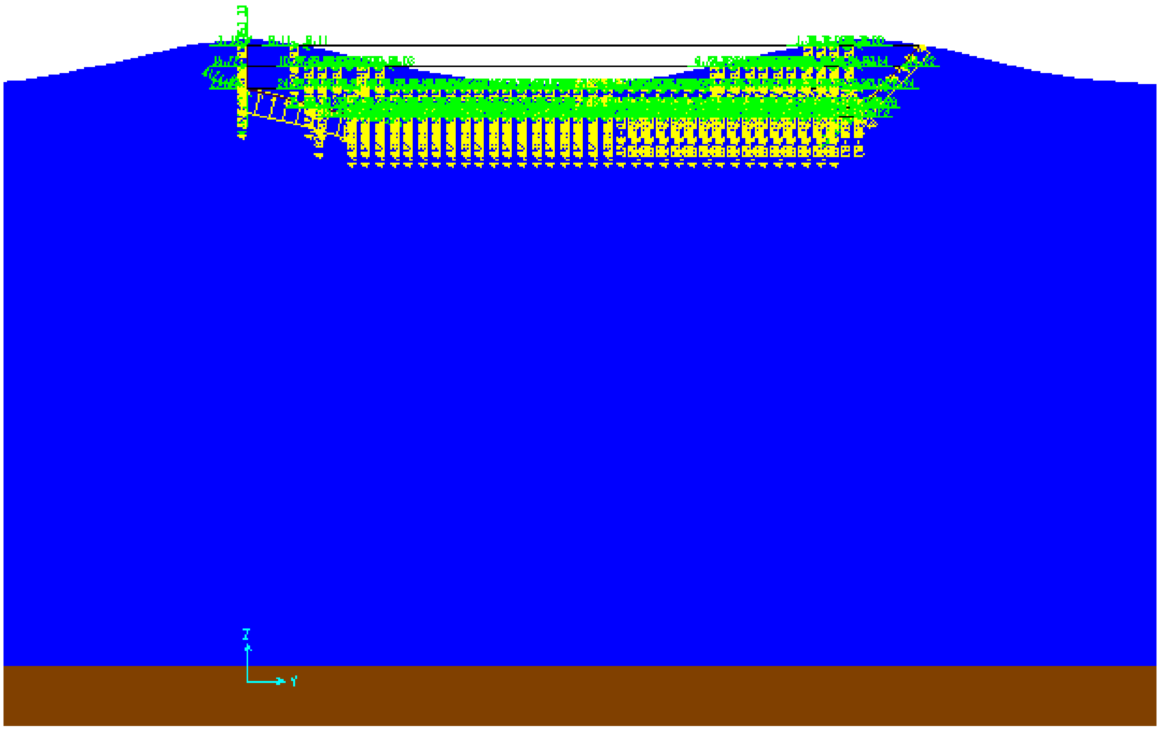


Fig. 6.13 wave pressure distribution as per SAP2000

6.3 SUMMARY

- The layout of the ship is show in Figure 6.2. First figure shows the profile of ship with different deck levels, while other shows top deck plan. Figure 6.7 and 6.8 shows the 3D model of ship with and without deckhouse in SAP2000.
- For analysis deadweight and wave loads are added linearly. For wave analyses head sea condition is considered.
- The analysis uses SAP2000 for calculating stresses on hull shell and decks.

- The stresses are measured in midship region of hull shell at different and these stresses are plotted in chart 7.4, 7.5, 7.6.
- The values of displacement are measured approximately on the line passing through the centre of gravity of hull. The chart 7.1, 7.2, and 7.3 depicts deform shape of the hull under the combine load of deadweight and wave induced loads. It shows sagging of hull under the applied loads.

7. RESULTS AND CONCLUSION

7.1 SHELL ELEMENT INTERNAL STRESSES OUTPUT CONVENTION

The six faces of a shell element are defined as the positive 1 face, negative 1 face, positive 2 face, negative 2 face, positive 3 face and negative 3 face as shown in the Figure 7.1 below. In this definition the numbers 1, 2 and 3 correspond to the local axes of the shell element. The positive 1 face of the element is the face that is perpendicular to the 1-axis of the element whose outward normal (pointing away from the element) is in the positive 1-axis direction. The negative 1 face of the element is a face that is perpendicular to the 1-axis of the element whose outward normal (pointing away from the element) is in the negative 1-axis direction. The other faces have similar definitions.

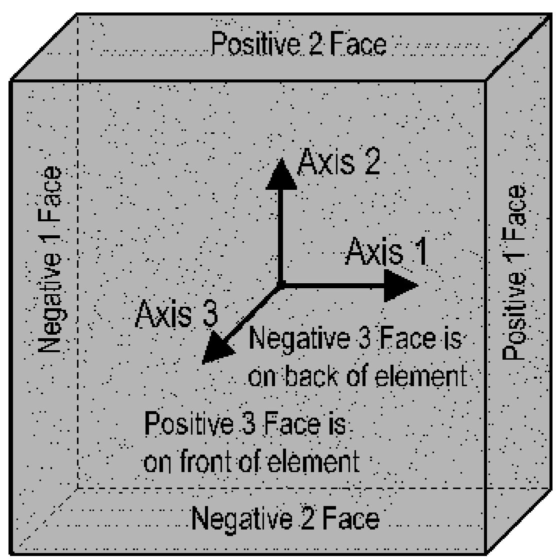


Fig. 7.1 Six faces of shell element

The basic shell element stresses are identified as S11, S22, S12, S13, and S23. An S21 might also be expected, but S21 is always equal to S12, so it is not actually necessary to report S21. Sij stresses (where i can be equal to 1 or 2 and j can be equal to 1, 2 or 3) are stresses that occur on face i of an element in direction j. Direction j refers to the local axis direction of the shell element. Thus S11 stresses occur on face 1 of the element (perpendicular to the local 1 axis) and are acting in the direction parallel to the local 1 axis (that is, the stresses act normal to face 1). The Figure 7.2 below shows examples of each of these basic types of shell stresses. SAP2000 reports internal stresses for shell elements at the four corner points of the appropriate face of the element.

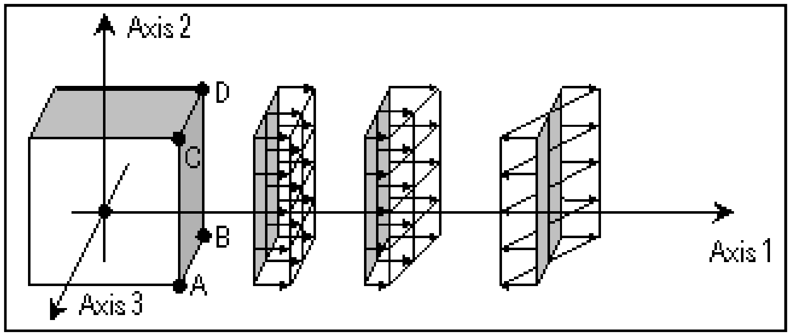


Fig. 7.2 Example of membrane direct stresses, S11

7.2 RESULTS

The modeling and analysis is performed in SAP2000. The results obtained in the analysis are shown in form of graphs. Graphs 7.1, 7.2 and 7.3 show the deflected shape of the ship under the combination of deadweight and buoyancy forces. Graphs 7.4, 7.5, and 7.6 show the stresses measured in midship region. These stresses are in longitudinal direction i.e. S11. Graphs 7.7, 7.8 and 7.9 are comparative graphs to observe the effectiveness of deckhouse.

7.2.1 Deflection Charts

Deflection in vertical direction is measured through out the length of ship on line approximately passing trough the C.G. of the ship. The displacement of ship in vertical direction is very small as compare to its length. Therefore it is difficult to observe the deflected shape of hull. As a result charts 7.1, 7.2 and 7.3 are plotted to obtain the deflected shape of ship. Different series in the graph indicates the variation in length of deckhouse for a particular width of deckhouse. For example in chart7.1, deflection of hull girder with the deckhouse of sizes 10 x 8m, 20 x 8m, 30 x 8m and 42 x 8m is shown. The chart also shows the deflection of hull without deckhouse on top of it. The horizontal axis represents the length to hull from stern to bow.

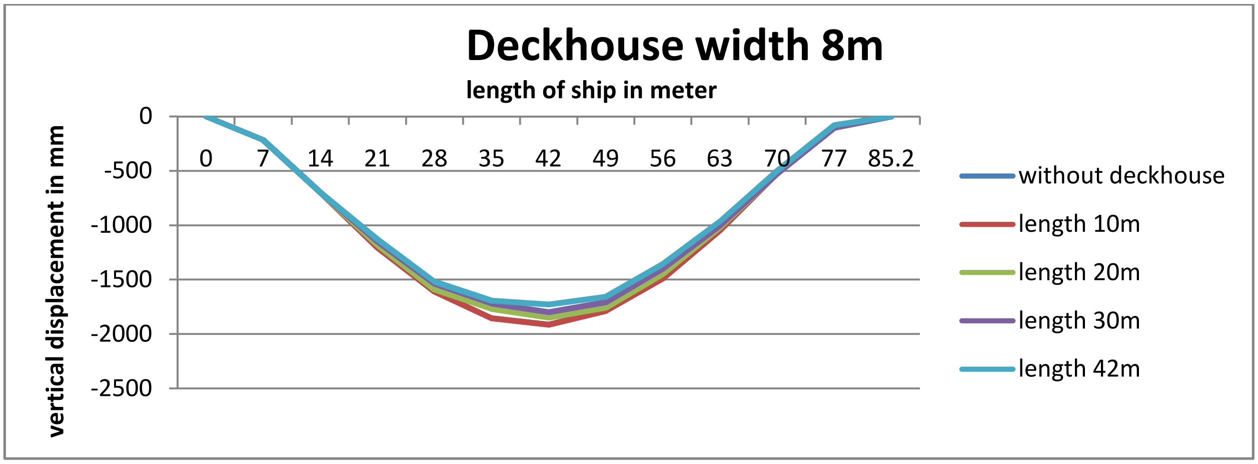


Chart 7.1 plots of hull girder deflection values for deckhouse of 8m width in vertical direction

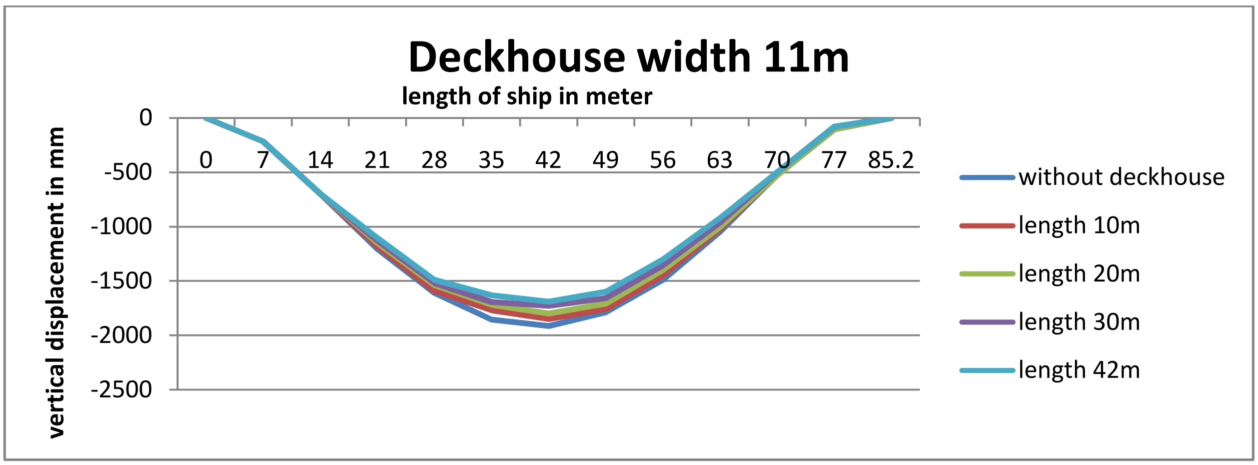


Chart 7.2 plots of hull girder deflection values for deckhouse of 11m width in vertical direction

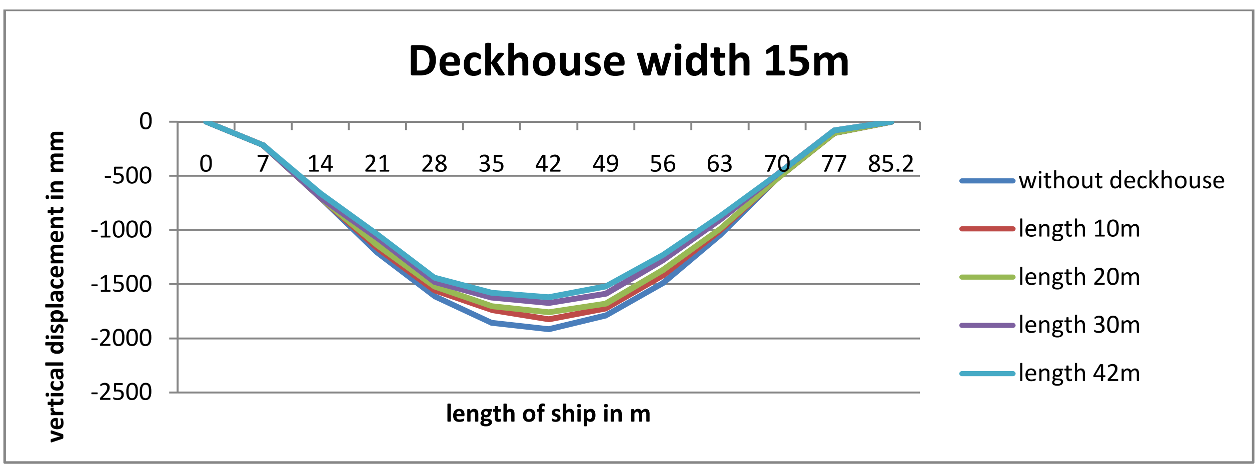


Chart 7.3 plots of hull girder deflection values for deckhouse of 15m width in vertical direction

7.2.2 Longitudinal Stress S11 charts

The stresses in outer shell of the hull are observed. The stresses in the longitudinal direction i.e. S11 are plotted in the graphs. These stress values are taken in midship region at different level of hull to cover the entire height of the hull. The chart 7.4, 7.5 and 7.6 shows comparison of longitudinal stresses between the hull with deckhouse and without deckhouse. For one width of deckhouse with its different lengths are tried to observe the effect of deckhouse. For example, in chart7.4 horizontal axis represents the length of deckhouse for width of 8m. Zero value on horizontal axis shows hull without deckhouse on top. Series shows the height of hull at which the stresses are observed.

Chart 7.7, 7.8, 7.9 and 7.10 shows the comparison of longitudinal stresses between the hull with different sizes of deckhouse on top. These charts are drawn to observe the dimensions of deckhouse for which stresses are reduced effectively on hull shell. Horizontal axis in these charts represents the height of hull at which the stresses are obtained. Zero value on horizontal axis represents the bottom of the hull and 9m shows the top of hull. For one length of deckhouse with its different widths are tried to observe the effectiveness of deckhouse. Series shows the different widths of deckhouse for a particular length for which stresses are measured.

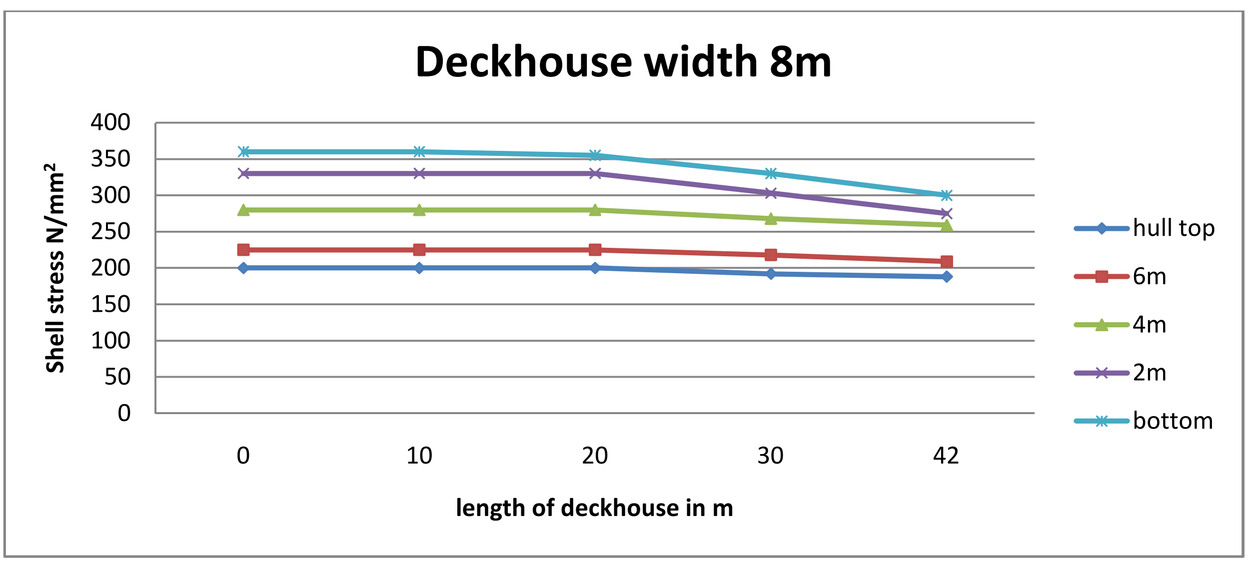


Chart 7.4 plots of hull girder longitudinal stresses for deckhouse of 8m width

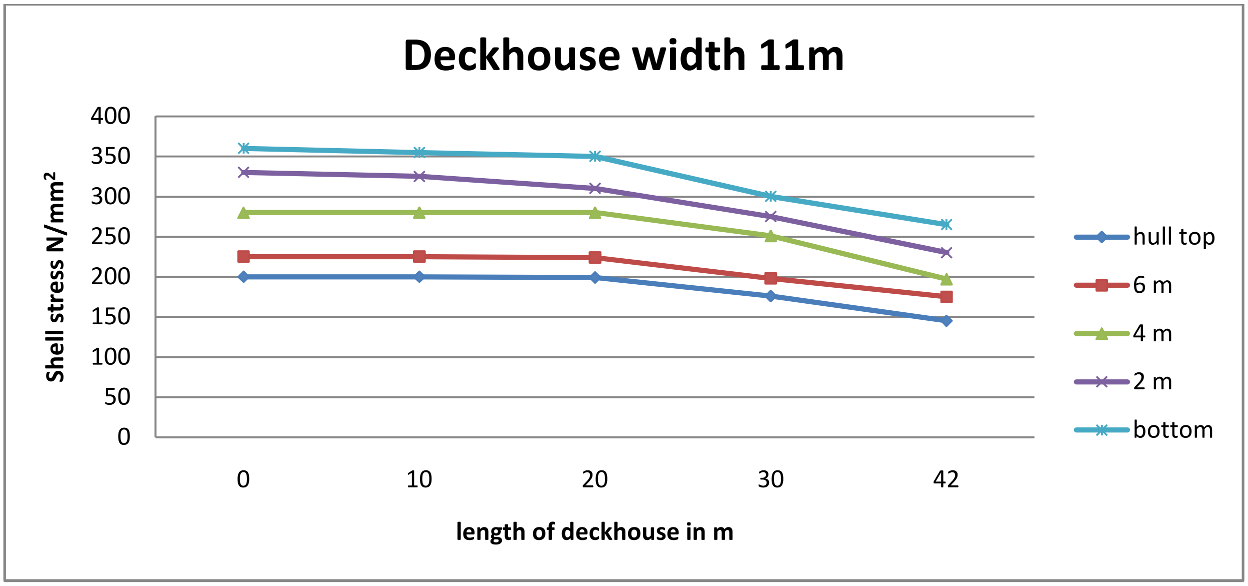


Chart 7.5 plots of hull girder longitudinal stresses for deckhouse of 11m width

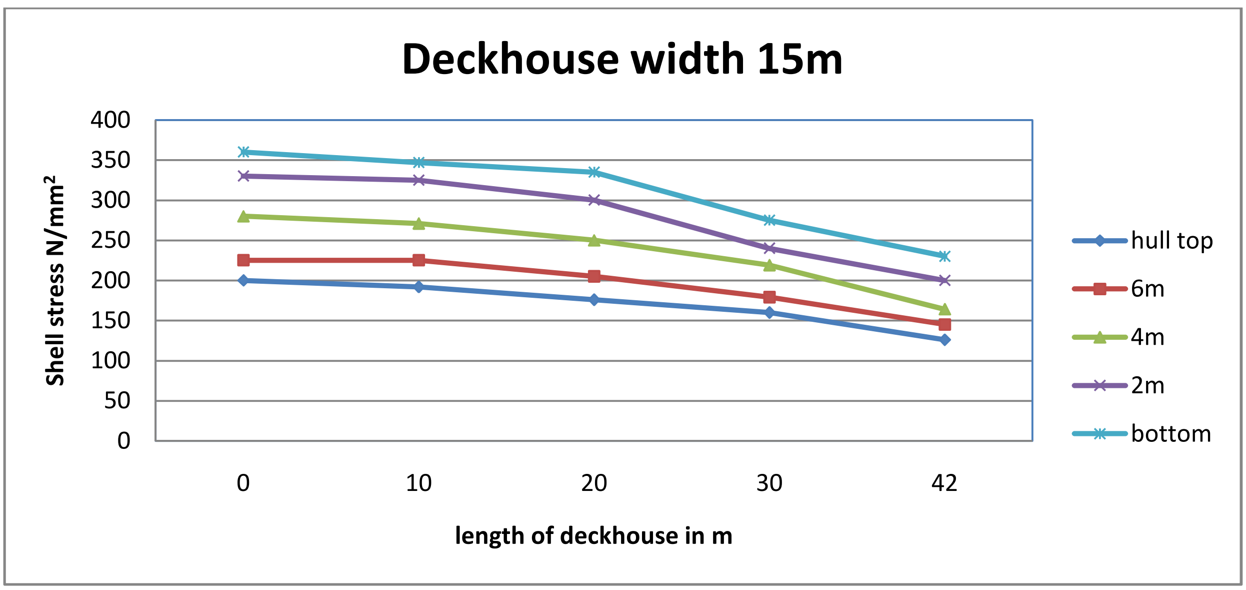


Chart 7.6 plots of hull girder longitudinal stresses for deckhouse of 15m in width

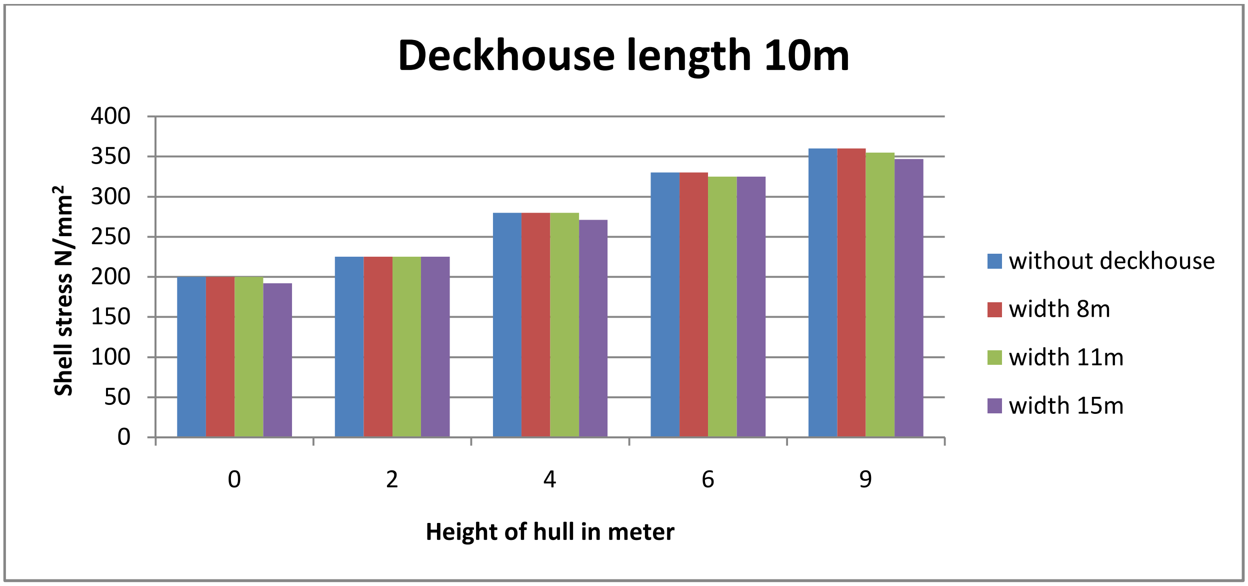


Chart 7.7 plot of hull girder longitudinal stress for deckhouse of 10m in length

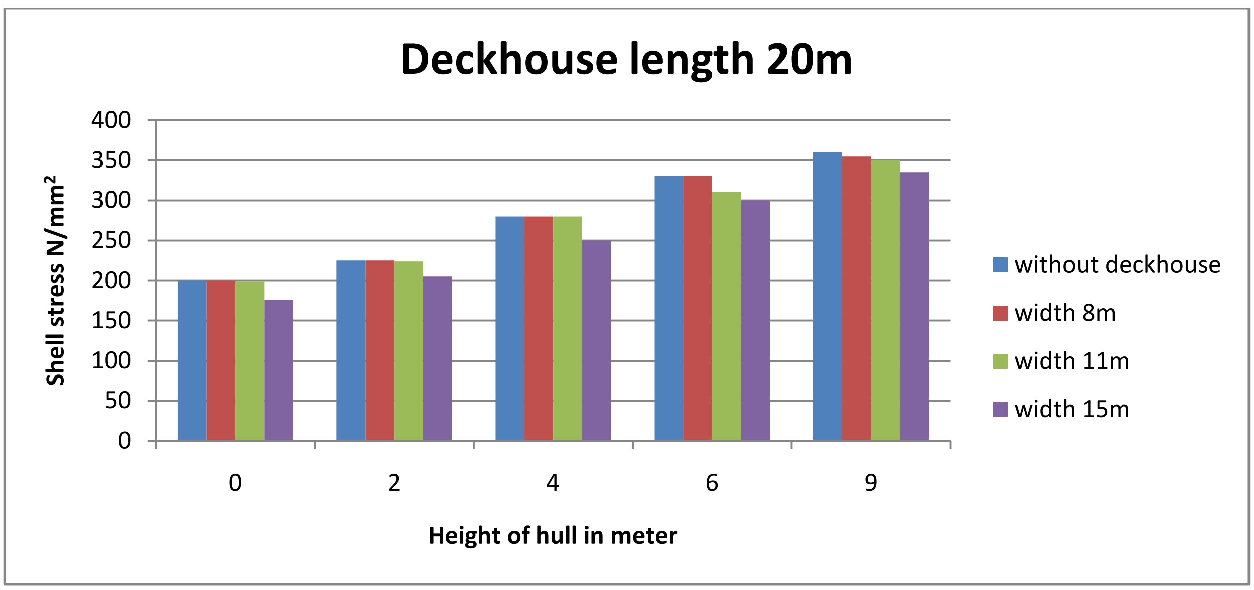


Chart 7.8 plot of hull girder longitudinal stress for deckhouse of 20m in length

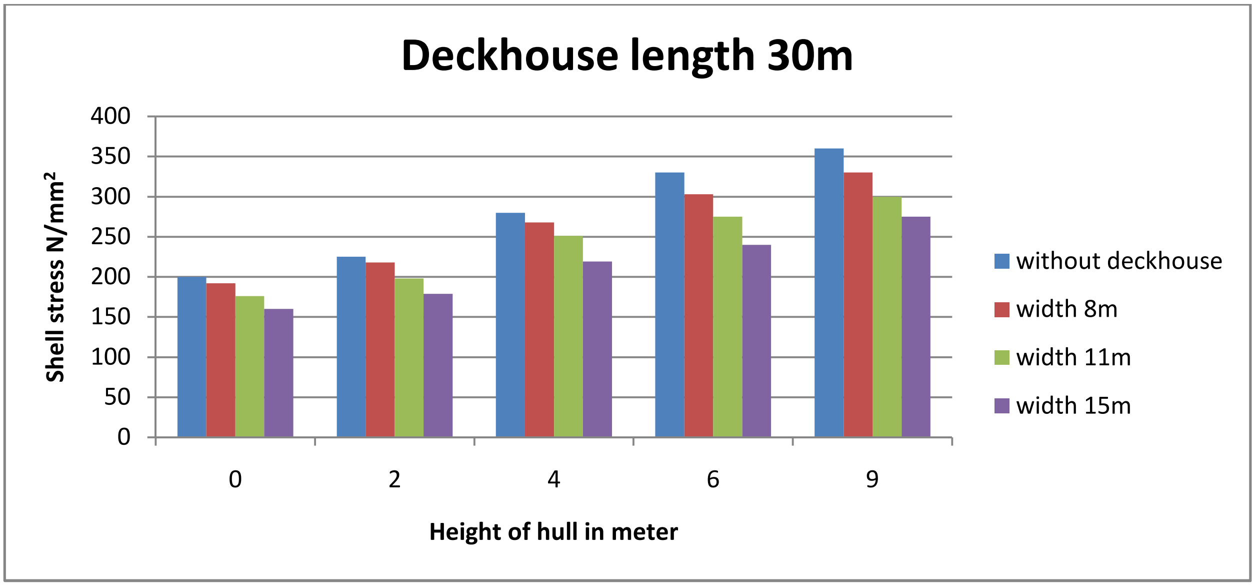


Chart 7.9 plot of hull girder longitudinal stress for deckhouse of 30m in length

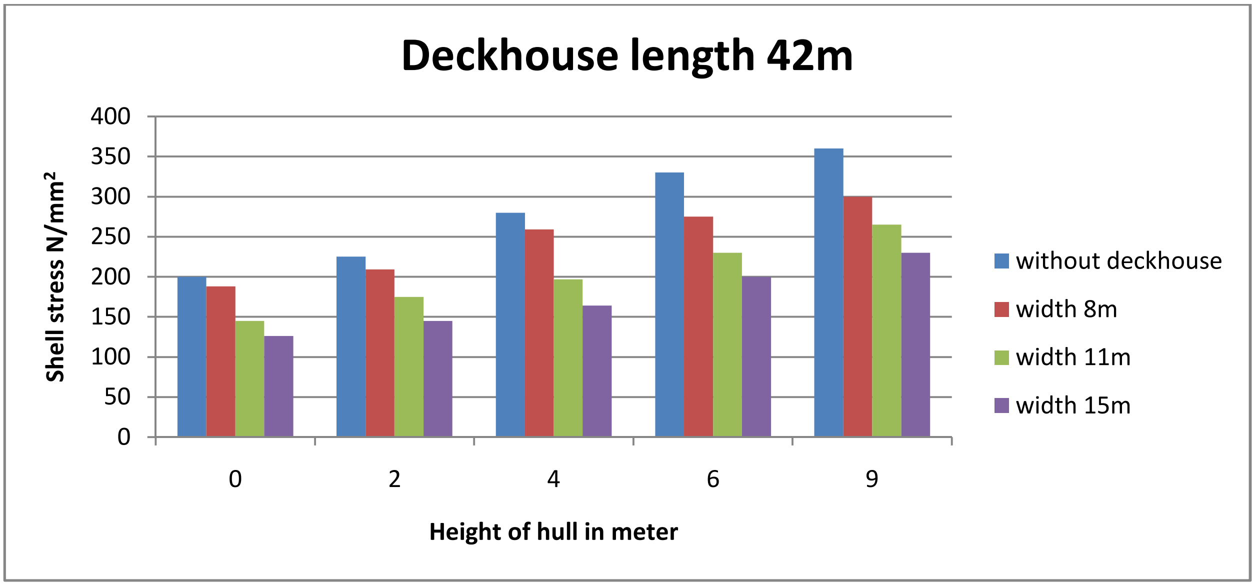


Chart 7.9 plot of hull girder longitudinal stress for deckhouse of 42m in length

7.3 DISCUSSION

The results that are obtained during the analysis are discussed below.

- The chart 7.1, 7.2 and 7.2 depict deflected shape of the ship.
- The maximum displacement is observed in midship area.
- In modeling the ship is considered as a box beam resting on hinges at ends therefore the displacement at ends is zero.
- The shape of displacement graph shows that the ship is in sagging condition, because in the analysis the wave crest positions are defined at bow and stern.
- The maximum displacement in the ship is observed when there is no deckhouse on top.
- When the deckhouse width is 8m, there is almost no effect on displacement of ship when compare to hull without deckhouse. But when the length of deckhouse becomes 30m and 42m, with 8m width there is slight decrease in displacement is observed in midship.
- For 11m wide deckhouse, displacement reduction becomes evident when it is compare with hull without deckhouse. As the length of 11m wide deckhouse increases the reduction in displacement also increases.
- When the sides of deckhouse become coplanar with hull sides, the displacement reduces significantly. For shorter length of deckhouse the reduction is less but when the length of deckhouse increases to 30m and 42 m, displacement in midship reduces from 1915mm to 1674mm and 1620mm respectively.
- Charts 7.4, 7.5 and 7.6 show the plot of longitudinal stresses on side shell which is obtained in midship region.
- Stresses are observed from bottom of hull to the hull top. The stresses obtained are higher than the yield strength of the steel i.e. 235 N/mm^2. This could be because of certain assumptions that are made in modeling.
- It is clearly seen that, for all widths of deckhouse the stresses are decreased as the length of deckhouse increases. For the length of 10m and 20m this reduction is not significant. But as the length increases to 30m and 42m, sharp dip is noticed in stresses.

- This reduction in stress becomes more significant when the width of deckhouse becomes 11m and 15m.
- The trend of reduction remains same through out the height of hull for all combinations.
- Charts 7.7, 7.8, 7.9 and 7.10 give the comparison of longitudinal stresses without superstructure and with superstructure with different widths and lengths.
- It can be seen that the stresses increases from bottom of hull to the top of hull in all the cases.
- For deckhouses of 10m x 8m and 20m x 8m, there is hardly any reduction in stresses when compare to hull without deckhouse. But when sides of deckhouse become coplanar i.e. 11m and 15 m wide with 10m and 20m lengths, there is slight reduction is noticed in stresses.
- From chart 7.9 and 7.10, when deckhouse length increases to 30m and 42m, the stresses reduces very significantly as the width of deckhouse increases from 8m to 15m. This reduction in stresses can be observed at all the level of hull.

7.4 CONCLUSION

The scantling obtained by LR-rules for structural elements can also be calculated by first principle and similar results can be obtained. Deck plates which are not exposed to the water require less scantling as compare to shell plates. Secondary elements are provided in longitudinal direction that helps in reducing plate thickness and increases buckling strength of plates as well. The longitudinal girders and stiffeners contribute to the hull girder longitudinal strength tremendously in addition to plates.

In the wave analysis, it is considered that wave crests are positioned at bow and stern, therefore the deflected shape of the ship shows in sagging condition. When wave crest is position in midship region, hogging was obtained for one case, but not reported here. The displacement is higher in case of hull without deckhouse as compare to hull with deckhouse which means that the rigidity of ship increases with the deckhouse on top. For smaller sizes of deckhouse this reduction is negligible, but as the size of deckhouse increases the reduction in displacement also increases. When deckhouse is of length 40 per cent of ship length or more and sides are coplanar to hull shell, then the displacement can be reduced to 15 per cent of hull without deckhouse. As per boundary condition the hinges are placed at ends of ship, this result in zero displacement at ends.

The longitudinal stresses on hull shell are observed. These stresses increase from bottom of hull to top. In some places of hull these stresses are higher than the yield stress of material. This may be because of ignoring minor structural elements in modeling which do not contribute to the longitudinal strength directly. It is clear from the results that there is stress reduction observed when there is deckhouse on top of hull. But this reduction is dependent on the size of deckhouse. Deckhouse with smaller dimensions has no significant contribution to hull girder strength. When the length of deckhouse is about 40 per cent of ship length or more, their contribution to the hull girder strength becomes significant. Increase in length of deckhouse is more significant as compare to increase in width because as longitudinal dimension increases its longitudinal strength also increases. When the sides of long deckhouses are coplanar with sides of hull they act as a hull itself.

So, from the present study it can be said that when the length of deckhouse is more than 40 per cent of ship length and width is 80 per cent or more of ship width, its effectively contributes to the longitudinal strength of hull. To obtain the effectiveness of deckhouse it should be efficiently connected to upper deck of hull. The connection of the deckhouse to the upper deck depends on if there is a need to increase for longitudinal strength. In modern construction, the two are disconnected.

7.5 FUTURE LINE OF ACTION

The work carried out in this dissertation can be used as an input for further work explained as follows:

- Analysis of ship in Maestro for global strength in longitudinal direction.
- Design of ship as per ABS rule.
- Perform FEA analysis for hot spot areas in ship.

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APPENDIX-A

A.1 SYMBOLS AND DEFINITION (As per LR-Part4, Chapter-1,Sec.-1.5)

L, L_1 – Length between perpendiculars in meters

B – Molded breadth in meters

D – Depth in meters measured from top of the keel to top of the deck beam at side

T – Scantling draft in meters

k_L, k – Higher tensile steel factor

e – Base of natural logarithms

L – Overall length of stiffening members or pillars in meters

l_e – effective length of stiffening members or pillars in meters

t – Thickness of plating in mm

s – Spacing of secondary stiffeners in mm

C_w – wave head in meters

$= 7.71 \times 10^{-2} L e^{-0.0044L}$

S – Spacing of primary members in meters

Z – Section modulus of stiffening member in cm^3

ρ – Relative density of liquid carried in tank but is not to be taken less than 1.025

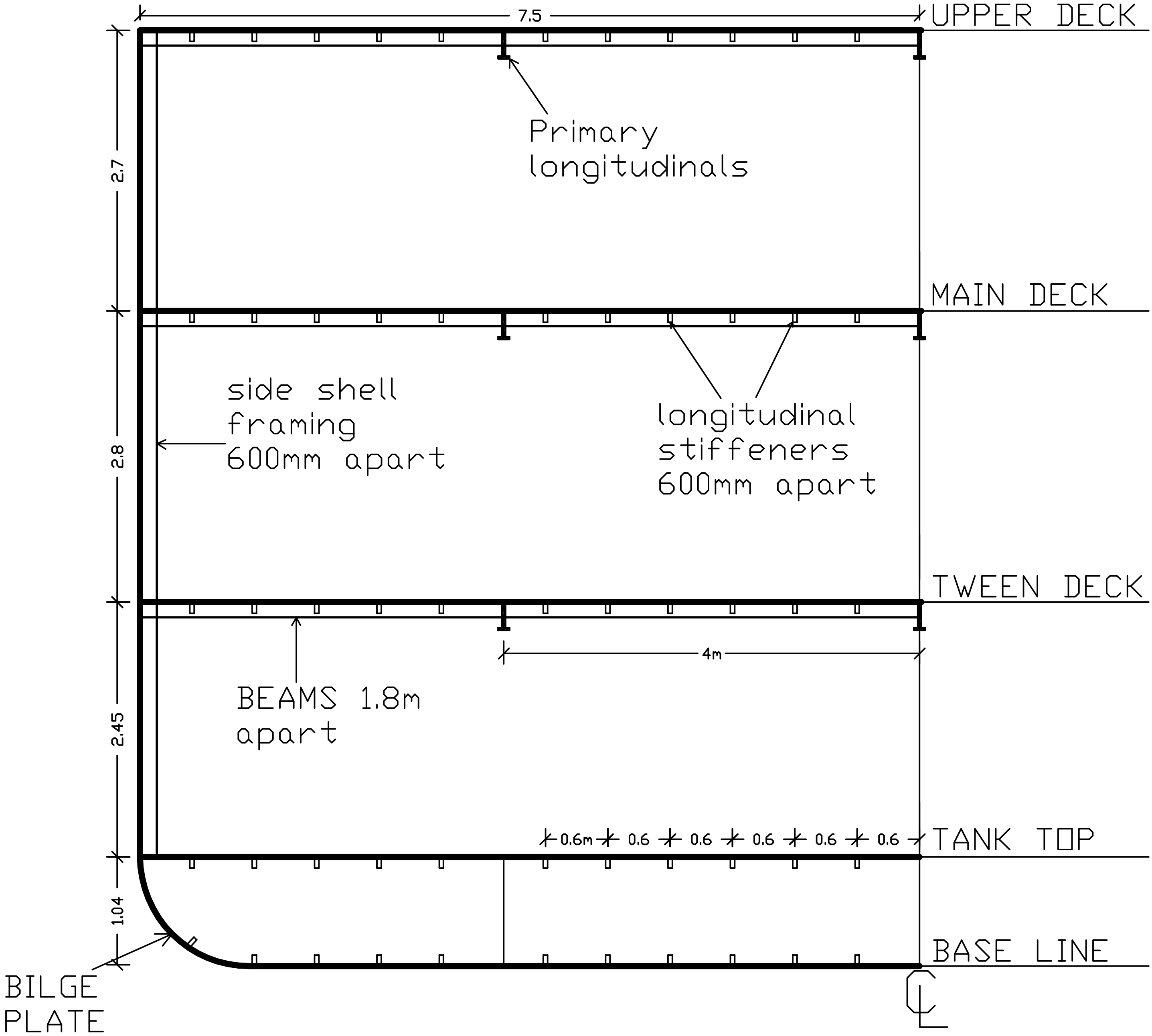


Fig. A.1
An ordinary frame at midship

TWEEN DECK, MAIN DECK, UPPER DECK, TANK TOP

k_L, k are to be taken as defined in A.1

s_1=s as defined in A.1=600mm

L_1=L as defined in A.1=80.42m

T=scantling draft=3.5m

F_D=stress reduction factor=0.75 (As defined in LR-Part3, Chapter-3, Sec.-5)

Table A.1 Scantling of Deck plates (As per LR-part4, chapter-1, section-4, table-1.4.1)

Location	Minimum thickness in, mm
Outside the line of opening	Longitudinal framing
	The greater of following
	(a) $t = 0.001s_1(0.059L_1 + 7)\sqrt{\frac{F_D}{k_L}}$ $t = 0.001 \times 600(0.059 \times 80.42 + 7)\sqrt{\frac{0.75}{1}}$
	=6.10
	(b) $t = 0.00083s_1\sqrt{Lk} + 2.5$ $t = 0.00083 \times 600\sqrt{80.42 \times 1} + 2.5$
	=6.97
	Ans. 7.0mm
Tank top	$t = 0.00136(s + 660)\sqrt[4]{LTk^2}$ $t = 0.00136(600 + 660)\sqrt[4]{80.42 \times 3.5 \times 1^2}$
	=7.02
	Ans. 8.0mm

BOTTOM SHELL AND BILGE PLATING

k_L, k are to be taken as defined in A.1

$s_{1=}$s as defined in A.1=600mm

L_1=L as defined in A.1=80.42m

T=scantling draft=3.5m

C_W=wave head in meters as defined in A.1

$=7.71 \times 10^{-2} Le^{-0.0044L} = 7.71 \times 10^{-2} \times 80.42 \times e^{-0.0044 \times 80.42} = 4.35$ m

h_{T2} = $(T+0.5C_W)$, in meters but need not be taken greater than 1.2T m

= $(3.5+0.5 \times 4.35)$ or 1.2×3.5

=5.68 or 4.2

=4.2

F_B=stress reduction factor=0.67 (As defined in LR-Part3, Chapter-3, Sec.-5)

Table A.2 scantling of bottom plates (As per LR-part4, chapter-1, section-5, table-1.5.2)

Location	Minimum thickness in, mm
Bottom shell	Longitudinal framing
	The greater of following
	(a) $t = 0.001s_1(0.043L_1 + 10)\sqrt{\frac{F_B}{k_L}}$ $t = 0.001 \times 600(0.043 \times 80.42 + 10)\sqrt{\frac{0.67}{1.0}}$
	=6.61
	(b) $t = 0.0052s_1\sqrt{\frac{h_{T2}k}{1.8 - F_B}}$ $t = 0.0052 \times 600\sqrt{\frac{4.2 \times 1.0}{1.8 - 0.67}}$
	=6.02
	(c) Basic requirement $t = (6.5 + 0.033L)\sqrt{\frac{ks_1}{s_b}}$ $t = (6.5 + 0.033 \times 80.42)\sqrt{\frac{1.0 \times 600}{600}}$
	=9.15
	Ans. 10mm
Bilge plating	t as for bottom shell

SIDE SHELL

k_L, k are to be taken as defined in A.1

$s_{1=}$s as defined in A.1=600mm

L_1=L as defined in A.1=80.42m

F_D=stress reduction factor=0.75 (As defined in LR-Part3, Chapter-3, Sec.-5)

F_B=stress reduction factor=0.67 (As defined in LR-Part3, Chapter-3, Sec.-5)

T=scantling draft=3.5m

C_W=wave head in meters as defined in A.1

$=7.71 \times 10^{-2} \mathrm{L} e^{-0.0044L} = 7.71 \times 10^{-2} \times 80.42 \times e^{-0.0044 \times 80.42} = 4.35 \text{ m}$

h_{T1}=T+C_W m but need not be greater than 1.36T

(As defined in LR-Part4, Chapter-1, Sec.-5, table-1.5.3)

=7.85m or 4.76m

= 4.76m

h_{T2} = (T+0.5C_W), in meters but need not be taken greater than 1.2T m

(As defined in LR-Part4, Chapter-1, Sec.-5, table-1.5.3)

= (3.5+0.5 × 4.35) or 1.2 × 3.5

=5.68 or 4.2

=4.2

Table A.3 scantling of side shell plates (As per LR-part4, chapter-1, section-5, table-1.5.3)

Location	Minimum thickness in, mm
Side shell	Longitudinal framing
	(a) Above $\frac{D}{2}$ from base
	The greater of following
	(i) $t = 0.001s_1(0.059L_1 + 7)\sqrt{\frac{F_D}{k_L}}$ $t = 0.001 \times 600(0.059 \times 80.42 + 7)\sqrt{\frac{0.75}{1}}$
	=6.10
	(ii) $t = 0.0042s_1\sqrt{h_{T1}k}$ $t = 0.0042 \times 600 \times \sqrt{4.76 \times 1}$
	=5.50
	(b) At upper turn of bilge
	The greater of following
	(i) $t = 0.001s_1(0.059L_1 + 7)\sqrt{\frac{F_B}{k_L}}$ $t = 0.001 \times 600(0.059 \times 80.42 + 7)\sqrt{\frac{0.67}{1}}$
	=5.77
	(ii) $t = 0.0054s_1\sqrt{\frac{h_{T2}k}{2 - F_B}}$ $t = 0.0054 \times 600 \times \sqrt{\frac{4.2 \times 1}{2 - 0.67}}$
	=5.76
	(c) Between upper turn of bilge and $\frac{D}{2}$ from base
	(i) t from (b)(i) (ii) t from interpolation between (a)(ii) and (b)(ii)

DECK LONGITUDINALS

k is to be taken as defined in A.1

s=spacing between stiffener=600 mm

l_e=spacing between transverses=1.8 m

h_{T1}= weather head (As per LR-part4, chapter-1, section-4, table-1.4.3)

=the greater of $\frac{L_1}{70}$ or 1.2 m

h_2=cargo head (As per LR-part3, chapter-3, section-5, table-3.5.1)

h_3=accommodation head (As per LR-part3, chapter-3, section-5, table-3.5.1)

Table A.4 Scantling of longitudinal stiffeners (As per LR-part4, chap.-1, sec.-4, tab.-1.4.3 and tab.-1.4.4)

Location	Section modulus in, cm^3
Upper deck	$z = 0.043skh_{T1}l_e^2F_1$ $z = 0.043 \times 600 \times 1 \times 1.2 \times 1.8^2 \times 0.1$
	=14.86
Cargo deck	$z = 0.005skh_2l_e^2$ $z = 0.005 \times 600 \times 1 \times 1.2 \times 1.8^2$
	=11.66
Accommodation deck	$z = 0.00425skh_3l_e^2$ $z = 0.00425 \times 600 \times 1 \times 1.2 \times 1.8^2$
	=9.91

DECK BEAMS

k is to be taken as defined in A.1

T=scantling draft in meters=3.5m

D=molded depth of midship in meters=6.3m

B_1=B=molded breadth of midship in meters=16m

s= spacing between stiffeners in mm=600mm

h_1=weather deck head (As per LR-part3, chapter-3, section-5, table-3.5.1)

h_2=cargo head (As per LR-part3, chapter-3, section-5, table-3.5.1)

h_3=accommodation head (As per LR-part3, chapter-3, section-5, table-3.5.1)

l_e =effective length of beam in meter=1.8m

K_1, K_2, K_3 are as defined in LR-part4, chapter-1, section1, table-1.4.5

K_1=factor dependent on number of deck=20

K_2=factor dependent on location of beam short bridge, poop or elsewhere=530

K_3=factor dependent on location of beam span adjacent to the ship side or elsewhere=3.3

Table A.5 scantling of deck beams (As per LR-part4, chapter-1, section-4, table-1.4.5)

Location	Section modulus in, cm^3
Upper deck	The lesser of the following
	(a) $z = (K_1K_2TD + K_3B_1sh_1l_e^2)k \times 10^{-4}$ $z = (20 \times 530 \times 3.5 \times 6.3 + 3.3 \times 16 \times 600 \times 1.2 \times 1.8^2)1 \times 10^{-4}$
	=35.31
	(b) $z = 2K_3B_1skh_1l_e^2 \times 10^{-4}$ $z = 2 \times 3.3 \times 16 \times 600 \times 1 \times 1.2 \times 1.8^2 \times 10^{-4}$
	=23.86
	Ans. 23.86
Cargo deck	$z = (400K_1TD + 38.8sh_2l_e^2)k \times 10^{-4}$ $z = (400 \times 20 \times 3.5 \times 6.3 + 38.8 \times 600 \times 1.2 \times 1.8^2)1 \times 10^{-4}$
	=26.69
Accommodation deck	$z = (530K_1TD + 38.8sh_3l_e^2)k \times 10^{-4}$ $z = (530 \times 20 \times 3.5 \times 6.3 + 38.8 \times 600 \times 1.2 \times 1.8^2)1 \times 10^{-4}$
	=32.42

DECK PRIMARY GIRDER/TRANSVERSES

k is to be taken as defined in A.1

S=spacing between transverses in meters=1.8m

l_e=effective length of transverse in meter=4.0m

H_g=deck head in meter=1.2m (As per LR-4, chapter-1, section-4, table-1.4.6)

Table A.6 Scantling of primary deck girder (As per LR-part4, chapter-1, section-4, table-1.4.6)

Location	Section modulus in, cm^3
Girders and transverses in way of dry cargo spaces and clear of hatch openings: supporting four or more point loads or a uniformly distributed load	$z = 4.75kSH_gl_e^2$ $z = 4.75 \times 1 \times 1.8 \times 1.2 \times 4^2$
	=164.16

A.2 EXTERNAL SEA PRESSURES ON SIDE SHELL AND BOTTOM

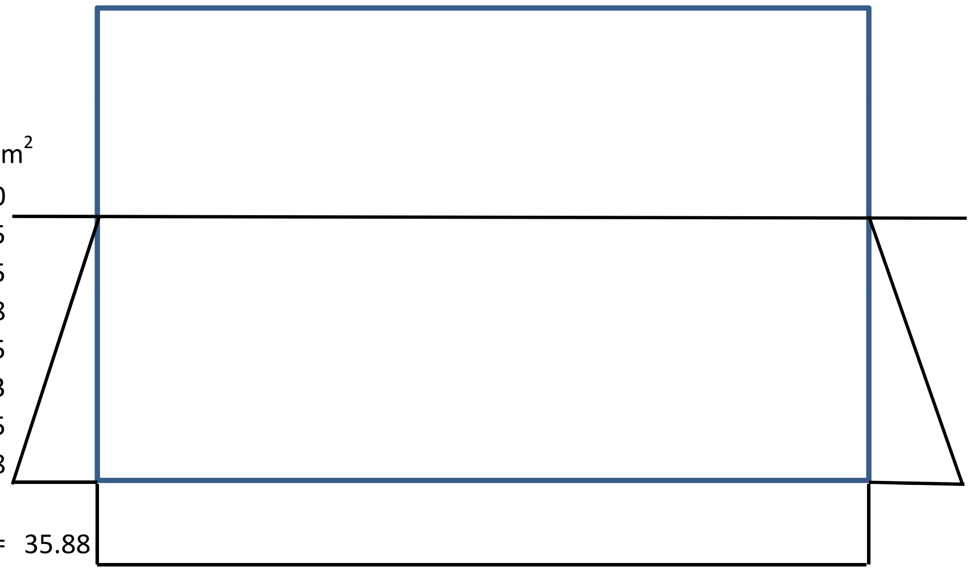
Hydrostatic pressure

Ps=Hydrostatic pressure, Table 4.6

T_{LCi} in mtr.= 3.5

ρg in KN/m^3= 10.25

z in mtr.=	P_s in KN/m^2
3.5	0
3	5.125
2.5	10.25
2	15.38
1.5	20.5
1	25.63
0.5	30.75
0	35.88



P_s= 35.88

Hydrodynamic pressure

L=	85.2	m	Rule length L
L_i=	80.1	m	Length between perpendicular
B_i=	15	m	Moulded breadth breadth at the waterline, in m
T_{LC}=	3.5	m	Draught in considered cross section, in m
T_s=	3.6	m	Scantling draught in m
Δ=	3756.45	m^3	Moulded displacement in tonnes, at draught T
C_B=	0.893276		Block coefficient
f_p=	1		As defined in Chapter 4, Section 4.12.2
f_{nl}=	0.9		As defined in Chapter 4, Section 4.12.4
C=	7.601879		Wave parameter
λ=	100.82	m	Wave length as per Equation 4.9

x,y,z= X, Y, and Z co-ordinats in m, of the load point with reference to co-ordinate system.

Hydrodynamic pressure P_{HF} in kN/m^2 as defined in Chapter4, Section4.12.4

	y	0	1	2	3	4	5	6	7	7.5
z	0	17.37	19.69	22	24.32	26.63	28.95	31.27	33.58	34.74
	0.5	19.85	22.17	24.48	26.8	29.12	31.43	33.75	36.06	37.22
	1	22.33	24.65	26.96	29.28	31.6	33.91	36.23	38.54	39.7
	1.5	24.81	27.13	29.45	31.76	34.08	36.39	38.71	41.03	42.18
	2	27.3	29.61	31.93	34.24	36.56	38.88	41.19	43.51	44.67
	2.5	29.78	32.09	34.41	36.73	39.04	41.36	43.67	45.99	47.15
	3	32.26	34.57	36.89	39.21	41.52	43.84	46.15	48.47	49.63
	3.5	34.74	37.06	39.37	41.69	44	46.32	48.64	50.95	52.11

Amplitude coefficient in the longitudinal direction of the ship k_l as defined in Chapter4, Seciton4.12.4

	x	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	84.6	85.2
y	0	2.679	2.065	1.622	1.323	1.14	1.043	1.006	1	1.005	1.05	1.17	1.42	1.828	2.45	3.31	3.41	3.52
	1	2.066	1.676	1.395	1.205	1.089	1.028	1.004	1	1.004	1.04	1.14	1.35	1.685	2.2	2.91	3	3.09
	2	1.812	1.515	1.301	1.156	1.068	1.021	1.003	1	1.004	1.04	1.13	1.32	1.626	2.09	2.75	2.83	2.91
	3	1.617	1.391	1.229	1.119	1.051	1.016	1.002	1	1.004	1.03	1.12	1.29	1.581	2.01	2.62	2.69	2.77
	4	1.453	1.287	1.168	1.087	1.038	1.012	1.002	1	1.003	1.03	1.11	1.27	1.543	1.95	2.52	2.58	2.65
	5	1.308	1.195	1.114	1.059	1.026	1.008	1.001	1	1.003	1.03	1.11	1.26	1.509	1.89	2.42	2.48	2.55
	6	1.177	1.112	1.066	1.034	1.015	1.005	1.001	1	1.003	1.03	1.1	1.24	1.479	1.84	2.34	2.4	2.46
	7	1.057	1.036	1.021	1.011	1.005	1.001	1	1	1.003	1.03	1.09	1.23	1.451	1.79	2.26	2.31	2.37
	7.5	1	1	1	1	1	1	1	1	1.003	1.03	1.09	1.22	1.438	1.76	2.22	2.28	2.33

Phase coefficient in the longitudinal direction of the ship k_p as defined in Chapter4, Section 4.12.4

kp=	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Hydrodynamic pressure on side shell P_w in KN/m^2 as defined in table 4.7

	x	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	84.6	85.2
z	0	34.74	34.74	34.74	34.74	34.74	34.74	34.74	34.74	34.83	35.6	37.9	42.4	49.94	61.3	77.2	79.1	81
	0.5	37.22	37.22	37.22	37.22	37.22	37.22	37.22	37.22	37.32	38.2	40.6	45.4	53.51	65.7	82.7	84.7	86.8
	1	39.7	39.7	39.7	39.7	39.7	39.7	39.7	39.7	39.81	40.7	43.3	48.5	57.08	70	88.2	90.4	92.6
	1.5	42.18	42.18	42.18	42.18	42.18	42.18	42.18	42.18	42.3	43.3	46	51.5	60.65	74.4	93.7	96	98.4
	2	44.67	44.67	44.67	44.67	44.67	44.67	44.67	44.67	44.79	45.8	48.7	54.5	64.21	78.8	99.3	102	104
	2.5	47.15	47.15	47.15	47.15	47.15	47.15	47.15	47.15	47.28	48.4	51.4	57.6	67.78	83.2	105	107	110
	3	49.63	49.63	49.63	49.63	49.63	49.63	49.63	49.63	49.76	50.9	54.1	60.6	71.35	87.5	110	113	116
	3.5	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.25	53.4	56.8	63.6	74.92	91.9	116	119	121

Hydrodynamic pressure on bottom shell P_w in KN/m^2

	x	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	84.6	85.2
y	0	93.08	71.74	56.36	45.97	39.6	36.25	34.96	34.74	34.92	36.4	40.7	49.2	63.5	85	115	119	122
	1	76.56	62.11	51.7	44.66	40.34	38.08	37.2	37.06	37.21	38.5	42.3	49.9	62.46	81.4	108	111	114
	2	71.35	59.65	51.22	45.53	42.03	40.2	39.49	39.37	39.52	40.8	44.5	51.8	64.04	82.4	108	111	114
	3	67.42	58.01	51.22	46.64	43.83	42.35	41.78	41.69	41.84	43.1	46.7	53.9	65.91	84	109	112	115
	4	63.93	56.64	51.39	47.84	45.66	44.52	44.08	44	44.15	45.4	49	56	67.89	85.7	111	114	117
	5	60.59	55.37	51.61	49.07	47.51	46.69	46.37	46.32	46.47	47.7	51.2	58.2	69.91	87.5	112	115	118
	6	57.26	54.1	51.83	50.3	49.35	48.86	48.67	48.64	48.78	50	53.5	60.4	71.93	89.3	114	117	119
	7	53.85	52.79	52.03	51.51	51.19	51.03	50.96	50.95	51.09	52.3	55.7	62.5	73.93	91.1	115	118	121
	7.5	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.25	53.4	56.8	63.6	74.92	91.9	116	119	121

Total pressure on side shell in kN/m^2 as defined in Chapter 4, Section 4.12.4

	x	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	84.6	85.2
z	0	34.74	34.74	34.74	34.74	34.74	34.74	34.74	34.74	34.83	35.6	37.9	42.4	49.94	61.3	77.2	79.1	81
	0.5	42.35	42.35	42.35	42.35	42.35	42.35	42.35	42.35	42.45	43.3	45.7	50.6	58.64	70.8	87.8	89.8	91.9
	1	49.95	49.95	49.95	49.95	49.95	49.95	49.95	49.95	50.06	51	53.6	58.7	67.33	80.3	98.5	101	103
	1.5	57.56	57.56	57.56	57.56	57.56	57.56	57.56	57.56	57.67	58.6	61.4	66.9	76.02	89.8	109	111	114
	2	65.17	65.17	65.17	65.17	65.17	65.17	65.17	65.17	65.29	66.3	69.2	75	84.71	99.3	120	122	125
	2.5	72.77	72.77	72.77	72.77	72.77	72.77	72.77	72.77	72.9	74	77	83.2	93.41	109	130	133	136
	3	80.38	80.38	80.38	80.38	80.38	80.38	80.38	80.38	80.51	81.6	84.9	91.3	102.1	118	141	144	146
	3.5	87.99	87.99	87.99	87.99	87.99	87.99	87.99	87.99	88.13	89.3	92.7	99.5	110.8	128	152	154	157

Total pressure on bottom shell in kN/m^2 as defined in Chapter 4, Section 4.12.4

	x	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	84.6	85.2
y	0	129	107.6	92.24	81.85	75.47	72.12	70.83	70.62	70.79	72.3	76.6	85.1	99.38	121	151	154	158
	1	112.4	97.98	87.57	80.54	76.22	73.95	73.08	72.93	73.09	74.4	78.2	85.7	98.33	117	144	147	150
	2	107.2	95.52	87.1	81.4	77.91	76.07	75.37	75.25	75.4	76.7	80.4	87.7	99.91	118	144	147	150
	3	103.3	93.88	87.1	82.52	79.7	78.23	77.66	77.56	77.71	79	82.6	89.8	101.8	120	145	148	151
	4	99.81	92.52	87.27	83.72	81.54	80.39	79.95	79.88	80.03	81.3	84.8	91.9	103.8	122	147	150	153
	5	96.47	91.25	87.49	84.94	83.38	82.56	82.25	82.2	82.34	83.6	87.1	94.1	105.8	123	148	151	154
	6	93.13	89.98	87.71	86.17	85.23	84.73	84.54	84.51	84.66	85.9	89.3	96.3	107.8	125	150	152	155
	7	89.73	88.67	87.9	87.39	87.07	86.9	86.84	86.83	86.97	88.2	91.6	98.4	109.8	127	151	154	157
	7.5	87.99	87.99	87.99	87.99	87.99	87.99	87.99	87.99	88.13	89.3	92.7	99.5	110.8	128	152	154	157