DESIGN AND ANALYSIS OF AN OCEAN GOING LIQUIFIED NATURAL GAS CARRIER

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DEPARTMENT OF
NAVAL ARCHITECTURE AND MARINE ENGINEERING
MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY

بسم الله الرحمن الرحيم

"In the name of Allah, the Merciful,
The Compassionate"

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SUPERVISOR'S APPROVAL

The project is titled:

"DESIGN AND ANALYSIS OF AN OCEAN GOING LIQUIFIED NATURAL GAS CARRIER"

It was submitted by Fatin Israk Kabya and Md. Rokibul Hasan for the academic session 2021-2022 as part of the course NAME 300 (Ship Design Project) in the Naval Architecture and Marine Engineering Program.

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Lec. Amreen Tahiat Rashed

Department of
Naval Architecture and Marine Engineering
Military Institute of Science and Technology

PREFACE

The transportation of liquefied natural gas (LNG) plays a crucial role in the global energy supply chain, ensuring the safe and efficient delivery of natural gas across vast distances. The design of an LNG carrier is a complex engineering challenge that requires a deep understanding of ship structure, hydrodynamics, cargo containment systems, and safety regulations.

This project booklet presents a comprehensive study on the design of an LNG carrier, focusing on key aspects such as structural integrity, cargo containment, propulsion systems, and environmental considerations. The design follows international maritime regulations and classification society standards to ensure operational efficiency, safety, and sustainability.

The aim of this project is to apply theoretical knowledge to a practical ship design scenario, integrating principles of naval architecture, marine engineering, and safety management. Through detailed calculations, structural analysis, and design optimizations, this booklet provides insights into the technical and economic feasibility of LNG carrier development.

We extend our gratitude to our faculty and supervisor, who have provided valuable guidance and resources throughout this project. Their support has been instrumental in shaping our understanding of LNG carrier design.

We hope that this booklet serves as a useful reference for students, researchers, and professionals interested in LNG transportation and ship design.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to all those who contributed to the successful completion of our **NAME-300 Ship Design project**.

First, we are deeply thankful to **Lt Col Muhammad Rabiul Islam** for his exceptional guidance throughout the course. Your leadership and expertise have been invaluable. A special thanks to **Asst. Prof. Dr. S M Ikhtiar Mahmud** and **Asst. Prof. Md Mezbah Uddin** for your insightful teaching and support, which greatly enhanced our understanding of ship design.

We would also like to thank **Lec. Umme Tasnim Sarah** for your clear explanations and enthusiastic approach, making complex topics more accessible. Our heartfelt thanks go to our **supervisors, Lec. Fatema Akter** and **Lec. Amreen Tahiat Rashed**, for your continuous guidance, encouragement, and constructive feedback throughout this project. Your support was crucial to our progress.

Lastly, we are grateful to our fellow classmates for their collaboration and teamwork, and to everyone who offered their assistance and encouragement during this journey.

Thank you all for your contributions to the success of this project.

OBJECTIVES

Objectives for NAME 300 – Ship Design Project Course focus on ensuring that each design stage is approached methodically, with clear goals and expected outcomes. They highlight both the technical calculations and the design visualizations that contribute to a comprehensive ship design project.

1. **Displacement Calculation:** Determine the ship's displacement based on design parameters.
2. **Principal Particulars Calculation:** Compute the ship's main dimensions (length, breadth, depth).
3. **GA Plan:** Develop the general arrangement layout of the ship.
4. **3D Model, Lines Plan, Offset Table:** Create a 3D model and develop lines plan with offset table.
5. **Hydrostatic Comparison:** Compare Maxsurf hydrostatic data with empirical formulas.
6. **Scantling Calculation:** Calculate structural dimensions for hull strength.
7. **Midship Section Drawing:** Create a cross-sectional view of the ship at midship.
8. **Shell Expansion Drawing:** Develop a flat pattern of the ship's hull for fabrication.
9. **Longitudinal Drawing:** Generate a longitudinal view of the ship's structure.
10. **Resistance and Power Calculation:** Calculate water resistance and required engine power.
11. **Shaft Diameter Calculation:** Determine the optimal shaft diameter for safe power transmission.
12. **Engine Selection & Foundation Drawing:** Select the engine and design its foundation.
13. **Propeller and Rudder Drawing:** Design and draw the ship's propeller and rudder.
14. **Final Weight Estimation:** Estimate the total weight of the ship.
15. **Ship Stability:** Analyze stability using hydrostatic curves, cross curves, and conditional analysis.

The primary aim of this project is to design a ship, covering all critical aspects of naval architecture. The objectives outlined here represent the key stages and calculations involved in the ship design process. Each objective plays a vital role in ensuring the vessel's structural integrity, performance, and stability. From displacement and principal particulars calculations to stability analysis and the final weight estimation, these steps provide a comprehensive approach to developing a seaworthy, efficient, and reliable ship. This process integrates theoretical knowledge with practical application, ensuring a well-rounded understanding of ship design principles.

ABSTRACT

This project focuses on the design of a Liquefied Natural Gas (LNG) carrier with a capacity of 156,000 m^3, designed to operate at a speed of 19.5 knots along the route from the USA to Japan. The design process involved completing a comprehensive set of objectives, including displacement calculation, principal particulars determination, hydrostatic analysis, structural calculations, and stability assessments. The project also encompassed the creation of detailed engineering drawings, such as the midship section, shell expansion, and longitudinal views. Additionally, the ship's resistance and power requirements were calculated to ensure optimal performance.

The stability of the vessel was analyzed through hydrostatic curves, cross curves, and conditional analysis to ensure safe operation under various loading conditions.

A key aspect of the project was the development of a real-life 3D model based on the design, providing a visual representation of the LNG carrier. This model facilitated the integration of all design elements and allowed for a more realistic assessment of the ship's features and functionality.

Through this project, a holistic approach to ship design was applied, combining theoretical knowledge with practical skills to create a fully functional LNG carrier that meets the operational demands of its intended route.

Contents

CHAPTER 1:INTRODUCTION

1.1 What is Ship Design?

Ship design is a process of joining together a wide range of disciplines and analysis methods. In the past, ship design was a process of evolution, that starts from a basic design and some changes were made. After inventing computer and other modem equipment, the naval architects became much more innovative than before. Complex design and analysis can be done in the design process that saves time and money.

Though designer can review design several times before production, there are no criteria that the designer has to 'get it right' at the first approach. There are three distinct phases -concept, contract and detail design. The designer will establish a good connection between the owner and their requirements.

The safety of the ship, the people on board and the environment in Which it sails are all important.

It has been said that the problem for a naval architect is to design a ship that will carry a certain deadweight at a reasonable rate of stowage in a vessel at predetermined speed on a given radius of action as cheaply as possible all in conjunction with a general arrangement suited to the ship's trade.

The naval architect must therefore keep in mind all the followings:

- Main dimensions
- hull form
- displacement
- freeboard
- depth
- capacities
- trim & stability
- Economic considerations
- Longitudinal & transverse strength
- Structural Scantlings
- Resistance and powering
- Machinery
- Endurance
- Wood and outfit
- Lightweight & deadweight
- Material costs

In determining the main dimensions for a new ship, guidance can be taken from a similar ship for which basic details are known. This is known as Basis Ship and must similar in type, size, speed and power to the new vessel. It is constantly referred to as the new design is being developed.

When a ship-owner makes an initial enquiry, he usually gives the shipbuilder four items of operations:

1. Type of vessel
2. Deadweight of the new ship
3. Required Service Speed
4. Route on which the vessel will operate

1.2 Design Philosophy

The **design philosophy** in naval architecture refers to the guiding principles, goals, and approach that influence how a naval architect designs a vessel. It encompasses the ideas, values, and constraints that must be taken into account throughout the entire design process. The design philosophy helps define the overall purpose and functionality of the ship and ensures the design decisions are aligned with the requirements, safety standards, and operational goals.

Key elements of design philosophy in naval architecture include:

1. **Functionality**: The primary purpose of the ship, such as cargo transport, passenger transport, military use, or offshore work. The design must ensure that the ship meets its operational requirements efficiently.
2. **Safety**: Ensuring the ship adheres to international safety standards, such as those set by the International Maritime Organization (IMO), to prevent accidents, minimize risks, and protect passengers, crew, and the environment.
3. **Performance**: The design must ensure the ship performs as expected under various conditions, including speed, maneuverability, stability, and fuel efficiency.
4. **Cost and Budget**: The design should balance performance, safety, and environmental goals within the constraints of a set budget, considering construction, maintenance, and operational costs.
5. **Sustainability and Environmental Considerations**: Modern designs prioritize reducing environmental impacts, such as emissions and fuel consumption, and include eco-friendly technologies and sustainable materials.
6. **Regulatory Compliance**: The design must meet local, national, and international regulatory standards governing ship construction, operation, and safety.

1.3 Concept of Design Process

The life of a ship may be divided into two distinct parts:

- The period of Construction
- The period of Operation.

The owner is most concerned with the second period, but the Naval Architect is more concerned with the first.

The first period can be further divided into two stages:

- Design
- Build.

Naval Architects are concerned in both stages, but the Designer is most involved in the first stage.

The actual design process is not a single activity but for most ships consists of three or four distinct phases:

- Basic Design (Concept Design/Feasibility Design)
- Contract Design (Contract Design)
- Detailed Design (Detailed Design)

The three or four phases are conveniently illustrated in the Design Spiral as an iterative process working from owner's requirements to a detailed design.

1.4 Design Spiral

The design spiral is one of the most important pieces of the technical know- how of a Naval Architect. Designing a ship is perhaps the most rigorous of all engineering problems. It takes a lot of technical expertise, often across many disciplines to design such structures. A ship not only floats on the surface of the ocean but also makes its way around the world, along different routes through rough weather - "in one piece". The Design Spiral is a systematic approach to achieving near perfect designs for a given ship design problem. A naval architect traces his way along the design spiral through the different stages of design (1.1.2).

The most common design spirals are –

- Buxton (1972)
- Taggart (1980)
- Rawson & Tupper (1994)

Taggart shows the process starting at the outside of the spiral, where many concept, designs may exist, and converging in to the single, final, detailed design.

Rawson & Tupper and Buxton show the process starting at the center of the spiral where very little information is known and proceeding outwards to represent the ever-increasing amount of information generated by the design process.

In either representation it is clear that a series of characteristics of the ship are guessed, estimated, calculated, checked, revised etc. on a number of occasions throughout the design process in the light of the increased knowledge the designer(s) have about the ship.

1.4.1 Key Characteristics of the Design Spiral:

Iterative Process: The design process is not a one-time effort but involves revisiting and refining design elements repeatedly. Each iteration brings more detailed information, improved understanding, and design adjustments.

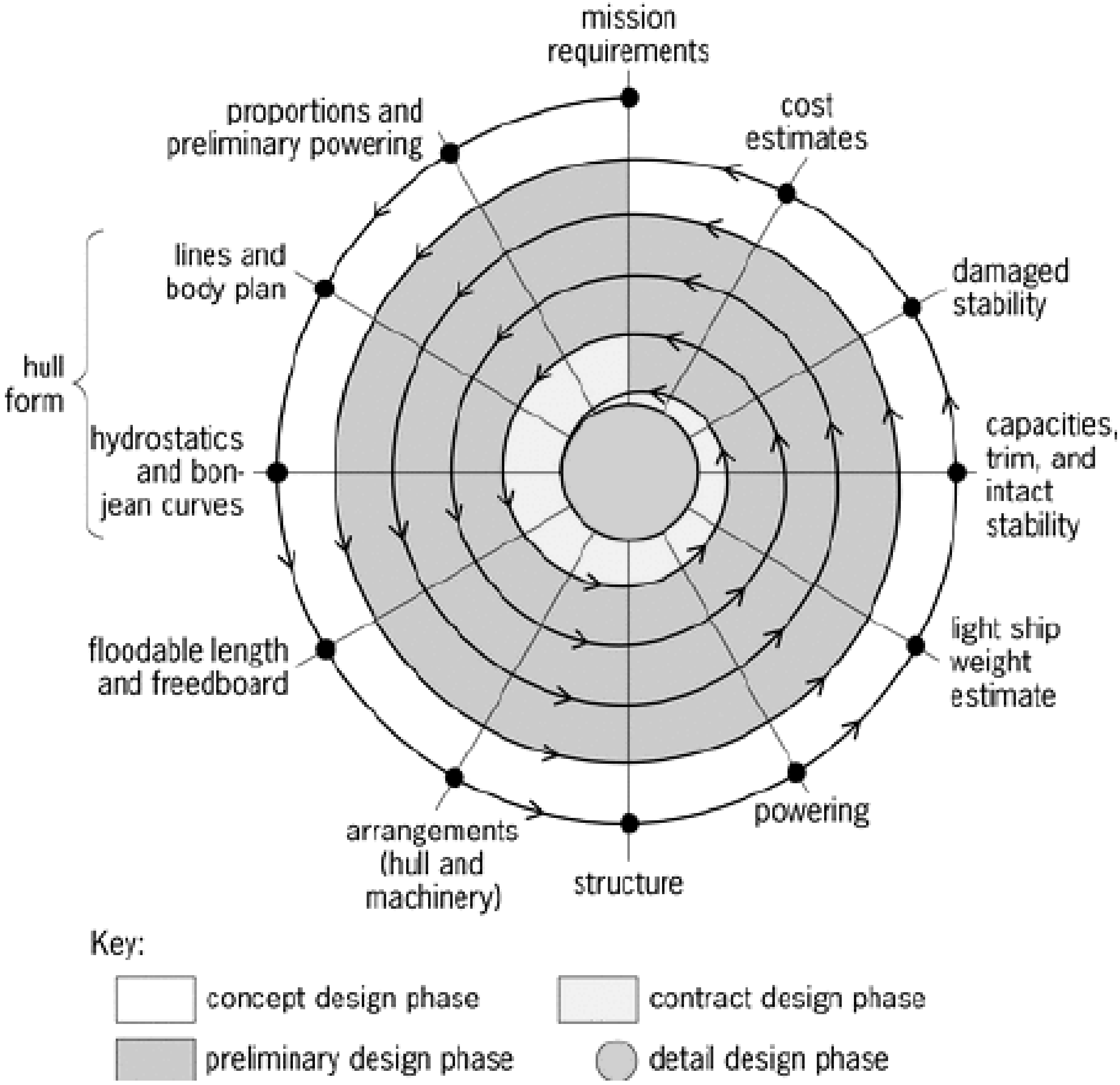
Feedback Loops: The design spiral incorporates feedback from various stages, such as initial concept development, model testing, performance evaluations, and regulatory checks. Feedback helps the design evolve to meet the intended goals.

Initial Concept to Final Design: The process begins with a broad concept or initial idea. As more detailed calculations, simulations, and testing are done, the design evolves in the spiral, moving toward the final, optimized design.

Risk Management: As each iteration is tested, the design spiral helps to identify and mitigate risks at an early stage, ensuring that safety and performance standards are met before moving forward.

Balance of Competing Factors: The design spiral helps to balance competing factors such as safety, performance, aesthetics, and cost. Each iteration helps refine these factors based on ongoing feedback.

Flexibility: The design spiral allows flexibility to make necessary changes to the design as new technologies, regulations, or market conditions emerge during the design process.



1.4.2 The Phases of the Design Spiral

1. **Conceptual Design**: Initial ideas and concepts are created, exploring different types of ships, hull shapes, and design approaches based on the project goals.
2. **Preliminary Design**: Basic design parameters like the ship's dimensions, structural layout, and hull form are developed, along with the selection of systems such as propulsion, navigation, and power.
3. **Detailed Design**: This phase involves more detailed calculations, structural analysis, and system integration, with the goal of refining the ship's design for construction.
4. **Production and Testing**: After finalizing the design, the ship is constructed, and prototype testing or simulations are conducted to ensure that it meets the design expectations.
5. **Operational Feedback**: After the ship is put into operation, feedback from real-world performance and operational conditions is gathered to further refine future designs.

CHAPTER 2:LNG Carrier

An LNG carrier (Liquefied Natural Gas carrier) is a specialized type of ship designed to transport liquefied natural gas (LNG) over long distances by sea. LNG is natural gas (primarily methane) that has been cooled to a liquid state at around -162°C (-260°F) to make it more energy-dense for efficient transportation. LNG carriers are essential for global energy trade, allowing countries to import and export natural gas, especially when pipelines are not feasible.

2.1 Key Characteristics and Design Elements of an LNG Carrier

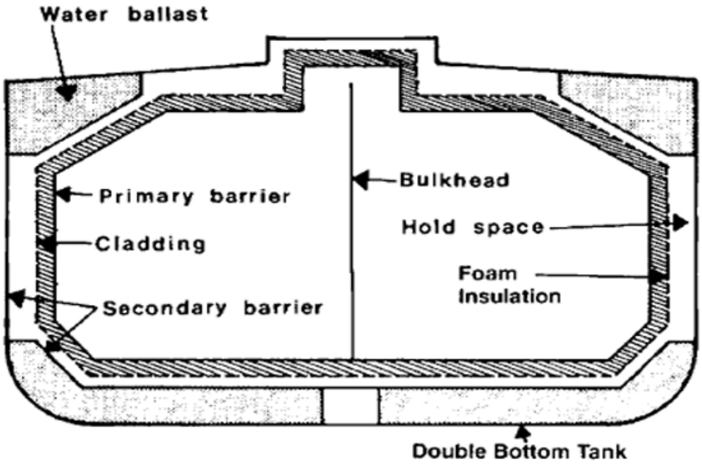
1. **Cargo Tanks and Containment Systems:**
   - LNG carriers feature specialized **cryogenic tanks** (membrane or Moss-type) that store LNG at temperatures around -162°C. These tanks are insulated to minimize boil-off gas (BOG) and prevent LNG from vaporizing during transit.
2. **Double-Hull Structure:**
   - The ship has a **double-hull design** for safety, with an inner hull for containing LNG and an outer hull for protection against external damage, ensuring the LNG remains secure.
3. **Insulation Systems:**
   - Advanced **insulation systems** like **perlite insulation** are used to minimize heat transfer and maintain the LNG's cryogenic temperature, preventing gas evaporation during the journey.
4. **Propulsion and Power Systems:**
   - LNG carriers use **dual-fuel engines**, allowing the vessel to run on both **LNG and marine diesel**, improving fuel efficiency and reducing emissions.
5. **Safety Features:**
   - LNG carriers are equipped with **fire suppression**, **gas detection systems**, and **safety relief valves** to prevent accidents like leaks or explosions, ensuring compliance with international safety standards.
6. **Size and Capacity:**
   - Typically large, with capacities ranging from **125,000 to 266,000 cubic meters** of LNG, the size of the ship is optimized for transport efficiency and port infrastructure compatibility.
7. **Energy Efficiency and Sustainability:**
   - Incorporating technologies like **reliquefaction plants**, LNG carriers aim to reduce boil-off gas and improve energy efficiency, minimizing environmental impact.
8. **Dynamic Positioning and Mooring Systems:**
   - Some LNG carriers are equipped with **dynamic positioning systems** for safe docking and loading at offshore or deep-water terminals, ensuring stable operation during cargo transfer

2.2 Types of LNG Carrier

Today there are four containment systems in use for new build LNG carriers. Two of the designs are of the self-supporting type, while the other two are of the membrane type. There is a trend towards the use of the two different membrane types instead of the self-supporting storage systems. This is most likely because prismatic membrane tanks utilize the hull shape more efficiently and thus have less void space between the cargo-tanks and ballast tanks. As a result of this, Moss type design compared to a membrane design of equal capacity will be far more expensive to transit the Suez Canal. However, self-supporting tanks are more robust and have greater resistance to sloshing forces, and will possibly be considered in the future for offshore storage where bad weather will be a significant factor.

2.2.1 Type A tanks

Type A tanks are constructed primarily of flat surfaces as shown in Figure 4.5. The maximum allowable tank design pressure in the vapor space for this type of system is 0.7 bars; this means cargoes must be carried in a fully refrigerated condition at or near atmospheric pressure.

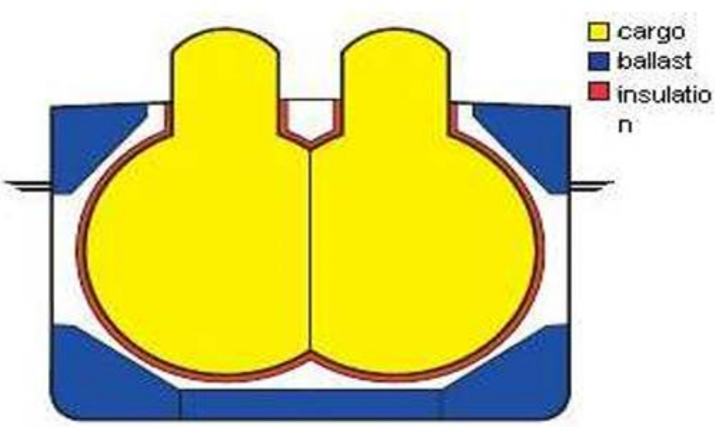


2.2.2 Membrane tanks

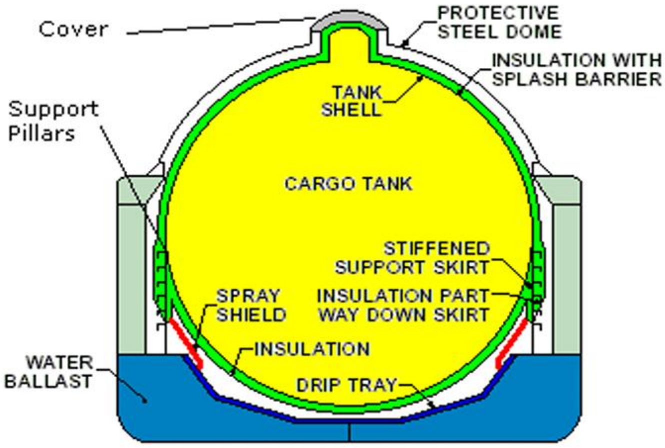
A liquefied gas tank design where the cargo is contained by a thin Stainless Steel or Nickel alloy flexible membrane. There are two membrane systems in use. In both cases the insulation is fitted directly into the inner hull and the primary barrier consists of a thin metal membrane less than one millimeter thick.

2.2.3 Type C tanks

Type C tanks are normally spherical or cylindrical pressure vessels having design pressures higher than 2 bars. The cylindrical vessels may be vertically or horizontally mounted as shown in Figure 4.8. This type of containment system is always used for semi-pressured and fully pressurized gas carriers. In the case of the semi pressurized ships, it can also be used for fully refrigerated carriage. Type C tanks are designed and built to conventional pressure vessel codes and as results, can be subjected to accurate stress analysis.



2.2.4 Type B tanks



Type B tanks can be constructed of flat surfaces or they may be of the spherical type. This type of containment system is the subject of much more detailed stress analysis compared to type A systems, these controls must include an investigation of fatigue life and crack propagation analysis. This design is owned by the Norwegian company Moss Maritime and it is a spherical tank. This is to have from four to six tanks all along the center line of the vessel. Surrounding the tanks is a combination of ballast tanks, cofferdams and voids. These areas give the vessel a double-hull type design. The outside of the tank has a thick layer of foam insulation that is either fitted in panels or in more modern designs wound round the tank.

2.3 Design Challenges for Naval Architects

1. **Cryogenic Temperature Management:**
   - Maintaining LNG at -162°C requires highly effective **insulation** and **cargo containment systems** to prevent evaporation or temperature fluctuations during transit.
2. **Structural Integrity:**
   - The vessel must withstand dynamic forces like waves and collisions, requiring robust materials and design for both the **hull** and **cargo tanks**.
3. **Safety and Environmental Concerns:**
   - Strict safety regulations must be followed to prevent gas leaks, fires, or explosions. The design must also minimize **emissions** and **fuel consumption**.
4. **Cost and Operational Efficiency:**
   - Balancing **construction costs**, **fuel efficiency**, and operational performance presents a challenge, especially while meeting environmental standards.
5. **Regulatory Compliance:**
   - The vessel design must adhere to international regulations like those from the **IMO**, ensuring safety, environmental sustainability, and structural integrity throughout the ship's life.

CHAPTER 3: Owner's Requirement

A design begins with the preparation of a set of "Owner's Requirements" for a merchant ship or "Staff Requirements" for a warship. In general, the stages leading up to the request for a new design are the same for merchant ships as for warships with the important difference that warships are built for a government whereas merchant ships are normally built for a private owner.

3.1 Owner's Requirement

Type: LNG Carrier	
LNG Capacity	**156,000 m^3**
Speed, V	**19.5 knots**
Route	**USA - Japan**

The LNG carrier must be designed to transport **156,000 cubic meters** of liquefied natural gas (LNG) efficiently and safely. The vessel should be capable of achieving a maximum speed of **19.5 knots** to ensure timely and reliable transportation. The design must focus on maintaining LNG at cryogenic temperatures, optimizing fuel efficiency, and meeting international safety and environmental standards. The carrier should incorporate **dual-fuel propulsion** for enhanced operational flexibility and sustainability, while ensuring structural integrity and stability during transit.

3.2 Operational Route

The route from the **USA to Japan** for an LNG carrier typically involves a long ocean voyage across the Pacific Ocean, covering significant distances depending on the specific ports of departure and arrival.

3.2.1 Key Aspects of the Route:

1. **Port of Departure (USA):**
    - LNG carriers departing from the USA often start from Gulf Coast ports such as Sabine Pass (Texas), Cove Point (Maryland), or Corpus Christi (Texas). These ports serve as key LNG export terminals.
2. **Distance and Duration:**
    - The journey from the Gulf Coast (USA) to Japan is approximately 9,000 to 10,000 nautical miles depending on the specific departure and destination ports.
    - Voyage Duration: With a ship speed of 19.5 knots, the journey would typically take around 30 to 40 days, depending on weather conditions, navigational routes, and port handling times.
3. **Route Considerations:**
    - The route typically passes through the Panama Canal (if departing from the Gulf Coast) or may go around the Cape of Good Hope if starting from the West Coast ports like California.
    - From the Panama Canal or the west coast, the LNG carrier would cross the Pacific Ocean towards Japan, passing through key maritime routes such as the Pacific Great Circle Route, which is the most efficient path between the Americas and Asia.
4. **Weather and Environmental Factors:**
    - The route would pass through varying weather conditions, including possible tropical storms, especially in the Pacific. The ship would need to be designed to withstand the effects of high winds, large waves, and varying sea conditions.
    - Depending on the time of year, the route may encounter seasonal challenges such as typhoons or hurricanes in the Pacific region.

5. **Ports of Arrival (Japan):**
   - Key LNG import terminals in Japan include Kashiwazaki-Kariwa, Sakai (Osaka), and Toranomon (Tokyo). These ports are major entry points for LNG cargoes, supporting Japan's energy needs.
   - The LNG carrier will need to be designed for safe docking and efficient cargo unloading at these terminals.

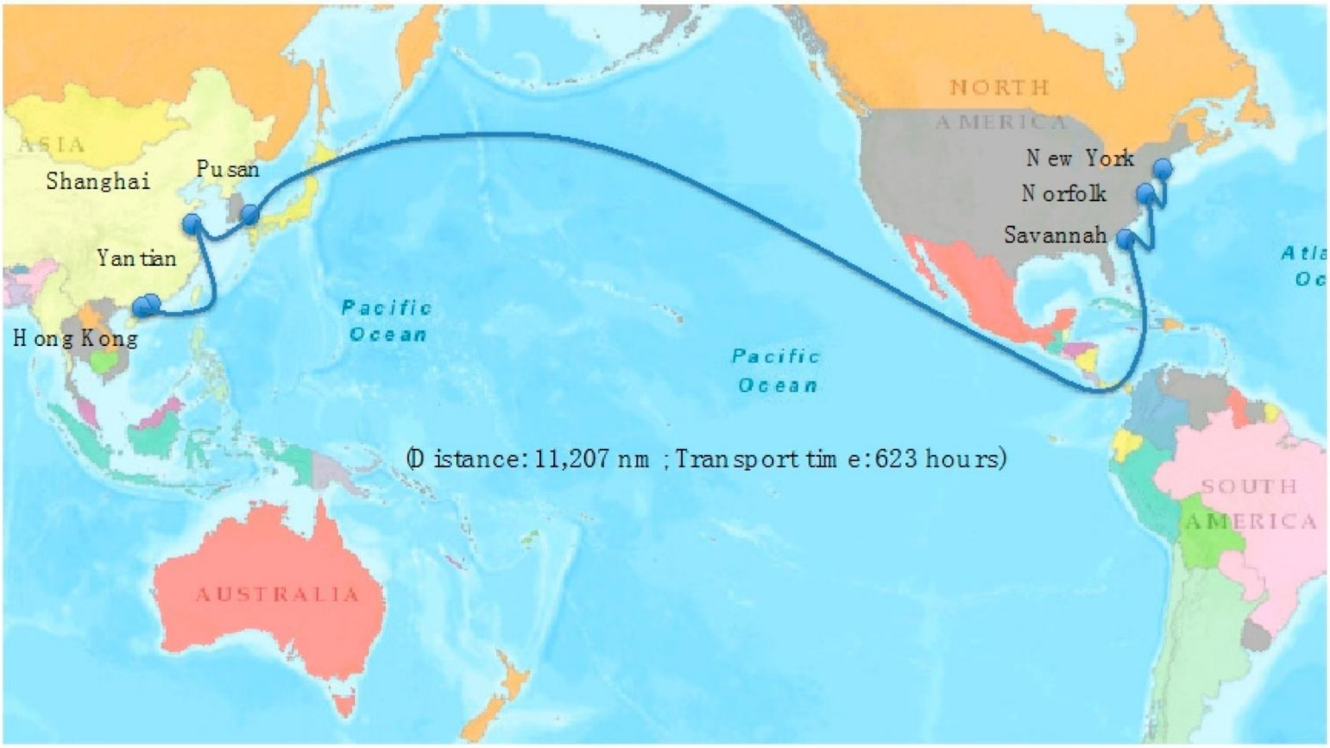


Figure 1: Route USA- Japan

CHAPTER 4: DIMENSION ESTIMATION

Dimension estimation of a ship refers to the process of determining the key physical measurements and proportions of a ship's structure, which are essential for design, construction, and operational purposes.

4.1 Basis Ship

ARCTIC VOYAGER is a LNG carrier built in 2006 by KAWASAKI SHIPBUILDING CORPORATION - SAKAIDE, JAPAN. Currently sailing under the flag of Bahamas. Formerly also known as ARCTI, ARBDIC VCQAFER, AZCUIC VOYAGER.

Figure 2: Basis Ship

Gross tonnage	118571 tons
Deadweight	75485 tons
Length	289 m
Breadth	48 m
Draught	11.5 m
Depth	26.5 m
Engine power	27000 KW
Year of build	2006

4.2 Deadweight & Lightweight Estimation

- **Lightweight**: The light ship weight is the actual weight of a vessel when complete and ready for service but empty.
- **Deadweight**: Deadweight is the actual amount of weight in tonnes that a vessel can carry when loaded to the maximum permissible draught (includes fuel, fresh water, gear supplies, catch and crew). This weight depends on the

Deadweight tonnage is a measure of a vessel's weight carrying capacity, not including the empty weight of the ship. It is distinct from the displacement (weight of water displaced), which includes the ship's own weight, or the volumetric measures of gross tonnage or tonnage.

It is the difference between the displacement and the mass of empty vessel (lightweight) at any given draught. It is a measure of ship's ability to carry various items: cargo, stores, ballast water, provisions and crew etc.

SOLAS Convention defines deadweight as follows:
"Deadweight is the difference in tones between the displacement of a ship in water of a specific gravity of 1.025 at the load waterline corresponding to the assigned summer freeboard and the lightweight of the ship."

Estimation of Deadweight is a very important step of the designing steps of a ship. The Deadweight/Displacement Ratio is used to obtain the first approximation to Displacement for a given Deadweight. It is often based on total deadweight rather than the more logical choice of cargo deadweight because total deadweight is a more readily available figure being independent of the amount of fuel etc. carried. Then considering the ratios of model ships we determine other principal particulars.

4.2.1 Calculation

Items	Capacity	Unit Weight	Weight	unit
LNG Weight	156,000 m^3	0.47	73320	ton
Lube	80	0.95	76	ton
Fuel	4000	0.94	3480	ton
Fresh Water	1000	1	1100	ton
Crew	45	0.075	3.375	ton
Supply			500	ton
Total Deadweight, dwt			78479	ton

We know,
Dead Weight Coefficient, $C_d = \frac{Dwt}{Displacement\ in\ Tonne, \Delta}$

Let,
$C_d = 0.62$ [For LNG Tankers range is 0.62]

So,
$\therefore$ Displacement in ton, $\Delta = \frac{Dwt}{Cd}$

$\therefore$ Lightweight= Displacement in ton – Deadweight

Displacement in ton	126579.64	ton
Displacement in m^3	123492.33	m^3
Lightweight	48100	ton

4.3 Preliminary Dimension Estimation

Basis Ship (Arctic Voyager)		
LOA	290	m
LBP (L)	277	m
Breadth, B	48	m
Draft, d	11.56	m
Depth, D	26.5	m
Deadweight, Dwt	75485	ton
Speed	19.3	kn

Ratio		
L/B	5.77	
B/d	4.15	
d/D	0.436	
Dead Weight Coefficient, C_d	0.62	
Displacement in ton	121750	ton
Displacement in m3	118780.49	m3
Block coefficient	0.772	

4.3.1 Cubic Root Method

Length, $L = [\frac{dwt \times (L/B)^2 \times (B/d)}{\rho \times C_b \times C_d}]^{1/3}$

$=[\frac{78320 \times (5.77)^2 \times (4.15)}{1.025 \times 0.772 \times 0.62}]^{1/3}$

$=280.425$ m

Breadth, $B = \frac{L}{L/B} = \frac{280.425}{5.77} = 48.59$ m

Draft, $d = \frac{B}{B/d} = \frac{48.59}{4.15} = 11.7$ m

Depth, $D = \frac{d}{d/D} = \frac{11.7}{0.436} = 26.82$ m

Block Coefficient, $C_b = \frac{\nabla}{L \times B \times d} = \frac{123241.54}{280.42 \times 48.59 \times 11.7} = 0.772$

4.3.2 Geosim Method

For Geosim,

$$(\frac{L}{L_b})^3 = (\frac{W}{W_b})$$

⇨ $(\frac{L}{L_b}) = (\frac{W}{W_b})^{1/3}$

⇨ $k = (\frac{W}{W_B})^{1/3} = (\frac{78320}{75485})^{1/3} = 1.01237$

According to this method,

$$\frac{L}{L_b} = \frac{B}{B_b} = \frac{d}{d_b} = \frac{D}{D_b} = k$$

∴ Length, $L = L_b \times k = 277 \times 1.01 = 280.42\ m$

∴Breadth, $B = B_b \times k = 48 \times 1.01 = 48.59\ m$

∴Draft, $d = d_b \times k = 11.56 \times 1.01 = 11.7\ m$

∴Depth, $D = D_b \times k = 26.5 \times 1.01 = 26.82\ m$

∴Block Coefficient, $C_b = \frac{\nabla}{L \times B \times d} = \frac{123241.54}{280.42 \times 48.59 \times 11.7} = 0.772$

4.3.3 Graphical Intersection Method

We know,

Block Coefficient, $C_b = \dfrac{\nabla}{L \times B \times d}$

$$= \frac{123241.54}{L \times \frac{L}{5.77} \times 11.7} \qquad \textbf{[let, draft, d = 11.7m]}$$

$$= \frac{123241.54}{L^2 \times \frac{11.7}{5.77}} \quad \text{..................(i)}$$

Empirical Formula of Block Coefficient for LNG Carrier:

Block Coefficient, $C_b = 1 - 0.182 \left(\frac{V}{\sqrt{L}}\right)$

$$= 1 - 0.182 \left(\frac{19.5}{\sqrt{L}}\right) \quad \text{..................(ii)}$$

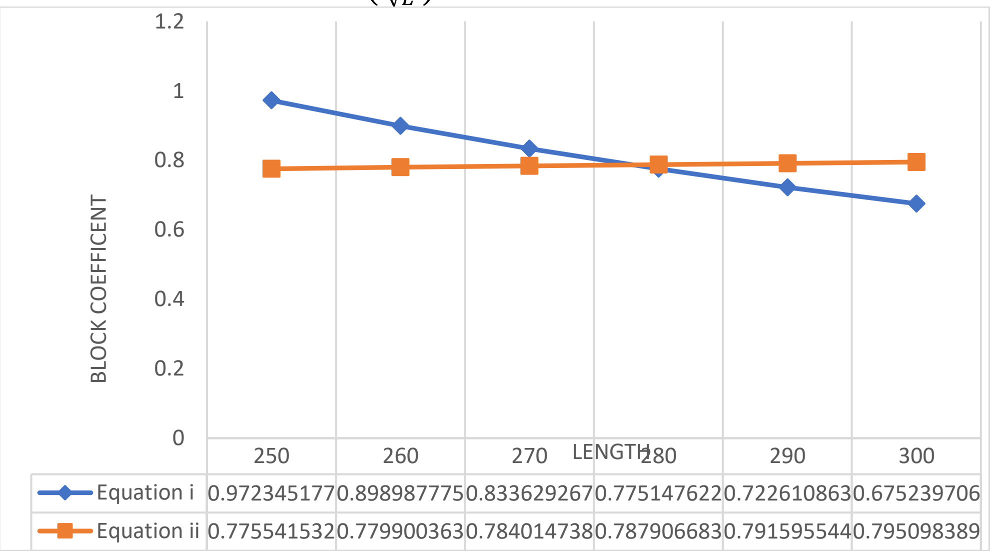


Figure 3: C_b vs L Graph

By solving equation (i) and (ii),

Length, L = 277.88m ≈ 278 m

From Ratio of Mother Vessel,

Breadth, B = 278 / 5.77 = 48.18 m

Depth, D = d/0.43= 11.7/0.43= 27.44m = 26.59 m

∴ Block Coefficient, $C_b = \frac{\nabla}{L \times B \times d} = \frac{123241.54}{278 \times 48.17 \times 11.7} = 0.786$

4.4 Principal Particulars

Summary of Estimated Principal Particulars			
Particulars	**Cubic Root**	**Geosim**	**Intersection**
LBP	280.43	280.43	278.00
Breadth	48.59	48.59	48.17
Draft	11.70	11.70	11.70
Depth	26.83	26.83	26.83
Cb	0.77	0.77	0.786

Principal Particulars		
Length, LBP	280.43	m
Breadth, B	48.59	m
Draft, d	11.70	m
Depth, D	26.83	m
Block Coefficient, C_b	0.77	
Dead Weight Coefficient, C_d	0.62	
Deadweight, Dwt	78320	tonnes
Displacement in tonne, Δ	126322.58	tonnes
Displacement in m^3, ∇	123241.54	m^3
Lightweight	48002.58	tonnes

CHAPTER 5:HULL DESIGN

5.1 Definition of Hull

A hull is the watertight body of a ship or boat. The hull may be open at the top (such as a dinghy), or it may be fully or partially covered with a deck. Atop the deck may be a deckhouse and other superstructures, such as a funnel, derrick, or mast. The type of hull to be made mostly depend on the type of vessel we are going to design.

5.2 General Features

There is a wide variety of hull types that are chosen for suitability for different usages, the hull shape being dependent upon the needs of the design. Shapes range from a nearly perfect box in the case of scow barges, to a needle-sharp surface of revolution in the case of a racing multihull sailboat. The shape is chosen to strike a balance between cost, hydrostatic considerations (accommodation, load carrying and stability), hydrodynamics (speed, power requirements, and motion and behavior in a seaway) and special considerations for the ship's role, such as the rounded bow of an icebreaker or the flat bottom of a landing craft.

In a typical modern steel ship, the hull will have watertight decks, and major transverse members called bulkheads. There may also be intermediate members such as girders, stringers and webs, and minor members called ordinary transverse frames, frames, or longitudinal, depending on the structural arrangement. The uppermost continuous deck may be called the "upper deck", "weather deck", "spar deck", "main deck", or simply "deck". The particular name given depends on the context—the type of ship or boat, the arrangement, or even where it sails.

5.3 Hull Shapes

Hulls come in many varieties and can have composite shape but are grouped primarily as follows:

- **Displacement hull**: Here the hull is supported exclusively or predominantly by buoyancy. Vessels that have this type of hull travel through the water at a limited rate that is defined by the waterline length. They are often, though not always, heavier than planning types.
- **Planning hull:** Here, the planning hull form is configured to develop positive dynamic pressure so that its draft decreases with increasing speed. The dynamic lift reduces the wetted surface and therefore also the drag. They are sometimes flat- bottomed, sometimes V-bottomed and more rarely, round-bilged.
- **Semi-displacement, or semi-planning:** Here the hull form is capable of developing a moderate amount of dynamic lift; however, most of the vessel's weight is still supported through buoyancy.

For our design we have adopted the displacement hull type.

A **bulbous bow** is a specialized hull shape used at the front (bow) of a ship, extending forward below the waterline. This protruding structure is designed to improve a vessel's hydrodynamic efficiency by reducing wave resistance, improving fuel economy, and enhancing stability.

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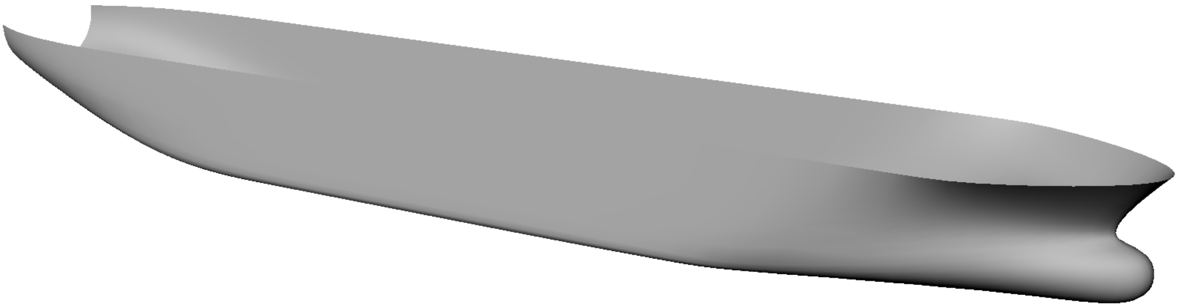
5.4 3D Designed Hull:

Obtained principal particulars is used and a 3D hull is generated using **MAXSURF MODELLER V24 Minor**



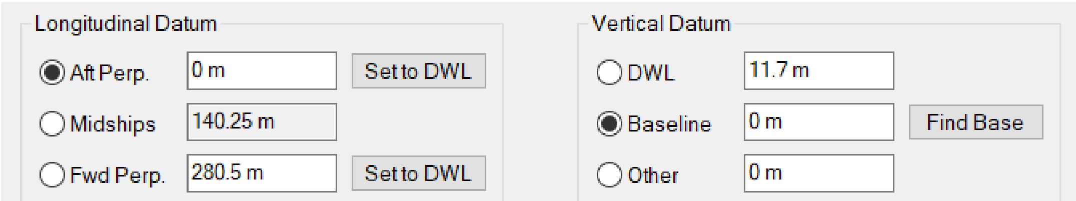


Figure 4: Frame of Reference

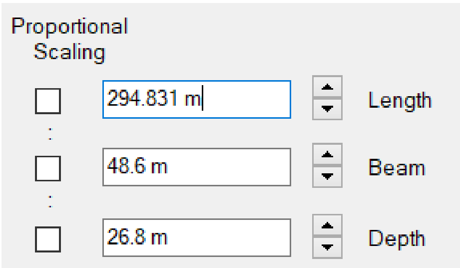
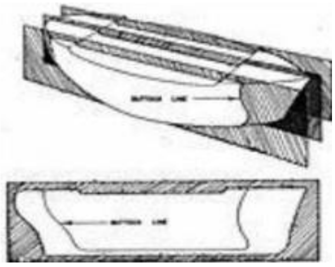


Figure 5: Frame of Reference

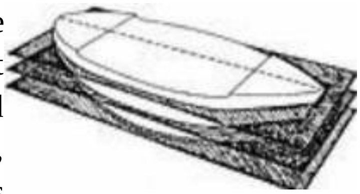
CHAPTER 6:LINES PLAN & OFFSET

A **Lines Plan** is a graphical representation of a ship's shape, showing the outlines of the hull at various sections and elevations. It is a crucial document in ship design, as it provides the basic geometric shape of the vessel. The lines plan typically consists of three views:

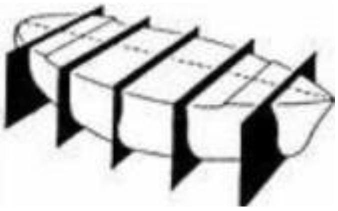
- **Profile View**: The centerline plane is a plane that passes through the middle of the ship and parallel to the sides of the hypothetical box from bow to stem. At regular intervals from the centerline, one imagines a set of planes parallel to one side of the centerline plane. At the spots where each plane intersects the ship's hull, a curved line is formed. These lines are projected onto a single plane known as the Profile Plan and are referred to as buttock or butt lines. Each buttock line shows the true shape of the hull from the side view for some distance from the centerline of the ship. The centerline plane shows a special butt line called the profile of the ship.



- **Half-Breadth Plan**: A reference plane known as the base plane sits at the bottom of the box. Typically, the base plane and the keel are level. At regular intervals, often every meter, a sequence of planes above and parallel to the base plan are envisaged. At the spots where they intersect, each plane will form a line with the ship's hull. The Ralf-Breadth Plan is the single plane onto which all of these lines—known as waterlines—are projected. For a certain elevation above the base plane, each waterline displays the hull's actual shape from the top view.

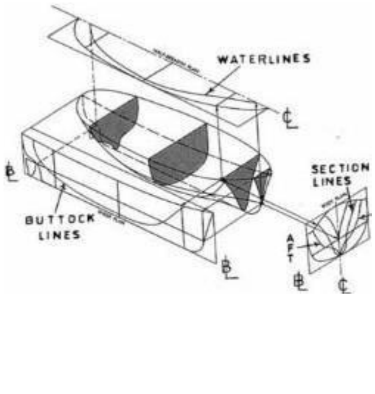


- **Body Plan**: Stations are planes that run parallel to the front and rear of the hypothetical box. Three stations are significant. Forward Perpendicular (FP) is the junction of the ship's stem at the design water line. The Aft Perpendicular (AP) is the point where the rudder stock or the stern intersect at the design waterline (immersed transom). The midships stations are those that are situated halfway between the perpendiculars. At the spots where they intersect, each station plane will create a curved line with the ship's hull. All of these lines—known as sectional lines—are projected onto the Body Plan, a single plane. The ship's symmetry is used by the body plan.



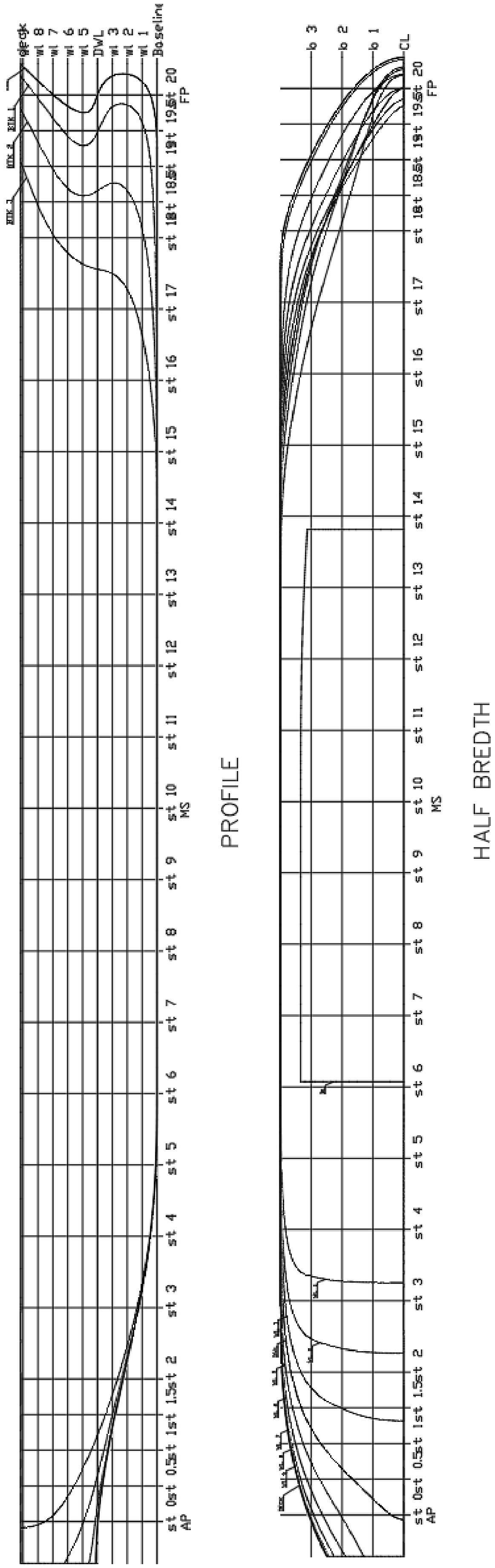
An **Offset Table** is a table of numerical values that defines the shape of the ship's hull. These values represent the **horizontal (X), vertical (Y), and depth (Z) positions** of points along the length of the ship, typically at regular intervals. These offsets allow the designer to construct the exact shape of the hull. The components of an Offset Table:

- **Stations**: These are the specific longitudinal positions along the ship's length (usually in meters or feet).
- **Waterlines**: Horizontal planes at different heights, usually denoted by their distance from the keel or baseline.
- **Buttocks**: Planes that run along the ship's length and intersect the hull at an angle.

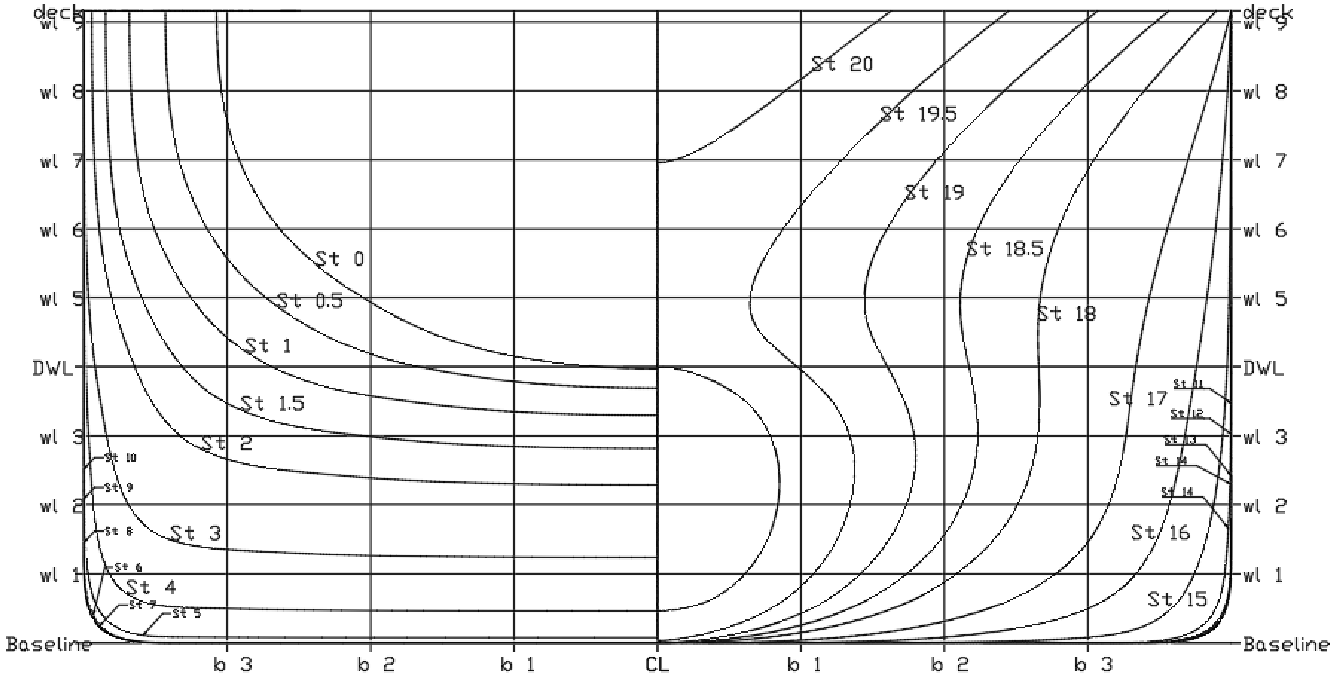


6.1 Designed Lines Plan

6.1.1 Profile & Half Breadth Plan



6.1.2 Body Plan



6.2 Offset Table

6.2.1 What is Offset Table?

A Table of Offsets are basically the dimensions of the bull lines (stations, waterlines, buttocks, and diagonals) with respect to the three reference lines: centerline, baseline, and station 0.

Offset data also called as half breadth data, because it represents the half breadth of the ship at every station and waterlines. In the offset table it is also a standard practice to indicate the data of height above based for deck, chine, and bulwark and knuckles lines. The height above base of buttock lines may also be included whenever necessary.

6.2.2 Purpose of Offset Table

Offset table and Lines' plan have the same purpose of existence; give the correct perspective of a vessel to viewer. However, both work in different manner.

Offset table shows the measurement of a vessel for calculation purposes as well as preparation of lines plan, whereby lines plan makes sure the measurement from the offset table is able to produce a smooth and fair hull form.

6.2.3 Offset Table of Designed Vessel

Station		Waterline Half-Breadths											Buttock Heights			
		BL	WL1	WL2	WL3	DWL	WL5	WL6	WL7	WL8	WL9	DECK	CL	BTK 1	BTK 2	BTK 3
		0	2.93	5.85	8.78	11.70	14.63	17.55	20.48	23.40	26.33	26.80	0.00	6.07	12.15	18.22
0	0.00	-	-	-	-	2.48	12.47	16.00	17.72	18.47	18.67	18.67	11.62	12.15	14.43	22.09
0.5	7.01	-	-	-	-	10.08	16.58	19.07	20.26	20.72	20.84	20.84	10.80	11.08	12.24	16.29
1	14.03	-	-	-	-	16.32	19.76	21.31	22.04	22.30	22.37	22.37	9.64	9.80	10.47	12.94
1.5	21.04	-	-	-	12.42	20.13	21.84	22.78	23.18	23.33	23.37	23.37	8.24	8.32	8.75	10.14
2	28.05	-	-	-	20.21	22.15	23.12	23.64	23.85	23.93	23.95	23.95	6.70	6.74	6.99	7.78
3	42.08	-	-	22.41	23.33	23.82	24.09	24.21	24.27	24.29	24.30	24.30	3.61	3.62	3.70	3.96
4	56.10	-	23.22	23.90	24.09	24.21	24.26	24.28	24.29	24.30	24.30	24.30	1.35	1.35	1.37	1.45
5	70.13	-	24.11	24.25	24.28	24.29	24.30	24.30	24.30	24.30	24.30	24.30	0.23	0.23	0.23	0.24
6	84.15	-	24.27	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	0.00	0.00	0.00	0.00
7	98.18	20.26	24.29	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	0.00	0.00	0.00	0.00
8	112.20	20.26	24.29	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	0.00	0.00	0.00	0.00
9	126.23	20.26	24.29	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	0.00	0.00	0.00	0.00
10	140.25	20.26	24.29	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	0.00	0.00	0.00	0.00
11	154.28	20.22	24.29	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	0.00	0.00	0.00	0.00
12	168.30	20.03	24.29	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	0.00	0.00	0.00	0.00
13	182.33	19.55	24.26	24.29	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	0.00	0.00	0.00	0.00
14	196.35	-	24.02	24.22	24.28	24.29	24.30	24.30	24.30	24.30	24.30	24.30	0.00	0.00	0.00	0.00
15	210.38	-	22.74	23.56	23.94	24.12	24.21	24.25	24.27	24.29	24.30	24.30	0.00	0.00	0.02	0.23
16	224.40	-	20.26	21.67	22.33	22.83	23.27	23.64	23.93	24.14	24.28	24.30	0.00	0.02	0.24	1.45
17	238.43	-	16.86	19.10	19.83	20.26	20.83	21.59	22.47	23.37	24.18	24.30	0.00	0.11	0.91	4.27
18	252.45	-	12.68	15.24	16.11	16.15	16.21	16.97	18.49	20.63	23.22	23.68	0.00	0.43	2.56	20.05
18.5	259.46	-	10.56	12.89	13.56	13.20	12.83	13.56	15.35	17.92	21.10	21.66	0.00	0.74	4.60	23.70
19	266.48	-	8.60	10.55	10.88	9.74	8.76	9.72	11.85	14.68	18.06	18.65	0.00	1.25	20.82	26.46
19.5	273.49	-	6.60	8.15	8.15	5.92	3.92	5.32	7.81	10.83	14.28	14.88	0.10	2.39	24.56	-
19.5	273.49	-												11.57		
19.5	273.49	-												18.53		
20	280.50	-	3.71	5.09	4.77	0.00	-	-	0.74	5.43	9.27	9.90	1.35	23.89		
20	280.50	-											11.70			
20	280.50	-											20.37			

CHAPTER 7:GENERAL ARRANGEMENT

7.1 Introduction

The general arrangement of a ship refers to the layout and design of its various parts, compartments, and spaces, organized to ensure safe, efficient operation.

The general arrangement of a ship can be defined as the drawing which indicates the assignment of spaces for all the required functions and equipment, properly coordinated for location and access. Four consecutive steps characterize general arrangement:

- Allocation of main spaces
- Setting individual space boundaries,
- Choosing and locating equipment and furnishing within boundaries
- Providing interrelated access

GA Plans are prepared and modified for the conceptual, preliminary, contract and working plan stages. The data in the early stages comes from past experience and the degree of detail increases as the design progresses.

What GA Plan Depicts?

GA plan depicts the division and arrangement of the ship:

- Side view: Elevation
- Plan views of the most important decks: Main Deck, Under Deck, Bottom Deck, Poop Deck, Bridge Deck etc.
- Cross Section

7.2 Components of a General Arrange Plan

7.2.1 Hull Structure

- FRAMES: Transverse supports forming the shape of the hull.
- BULKHEADS: Vertical partitions dividing the ship into compartments (including watertight bulkheads).
- DECKS: Horizontal layers dividing the ship into separate levels, like the MAIN DECK, CARGO DECK, and TANK TOP.

7.2.2 Compartments

- CARGO HOLDS: Spaces for storing cargo.
- BALLAST TANKS: For stability, holding water or other materials.
- FUEL TANKS: Storage for fuel oil.
- FRESHWATER TANKS: For storing freshwater.
- ENGINE ROOM: Contains the main engines and auxiliary machinery.
- ACCOMMODATION: Sleeping quarters, mess rooms, and sanitary facilities for crew and passengers.

7.2.3 Bridge and Navigation

- BRIDGE: Command center for navigation and control.
- WHEELHOUSE: The area from which the ship is steered.
- NAVIGATIONAL EQUIPMENT: Instruments like radar, GPS, and communication systems.

7.2.4 Steering and Propulsion

- MAIN ENGINE: Powers the ship's movement.
- AUXILIARY ENGINE: Supports smaller functions.
- RUDDER: For steering the ship.
- PROPELLER: Propels the ship through water.

7.2.5 Safety Features

- LIFEBOATS: Emergency evacuation boats.
- LIFE RAFTS: Smaller emergency rafts.
- FIRE EXTINGUISHING SYSTEMS: For fire suppression.
- ESCAPE ROUTES: Marked evacuation paths.

7.2.6 Deck Equipment

- CARGO HANDLING GEAR: Cranes, winches for loading/unloading.
- ANCHORING EQUIPMENT: Includes anchors, windlasses, and chains.
- VENTILATION SYSTEMS: For air circulation in enclosed spaces.

7.2.7 Superstructure

- SUPERSTRUCTURE: Above the main deck, including the bridge and cabins.
- DECKHOUSES: Small buildings for equipment or crew facilities.

7.2.8 Service Spaces

- PUMP ROOMS: For ballast, bilge, and cargo systems.
- ELECTRICAL ROOMS: Contain electrical panels and distribution systems.
- WORKSHOPS: Maintenance and repair spaces.

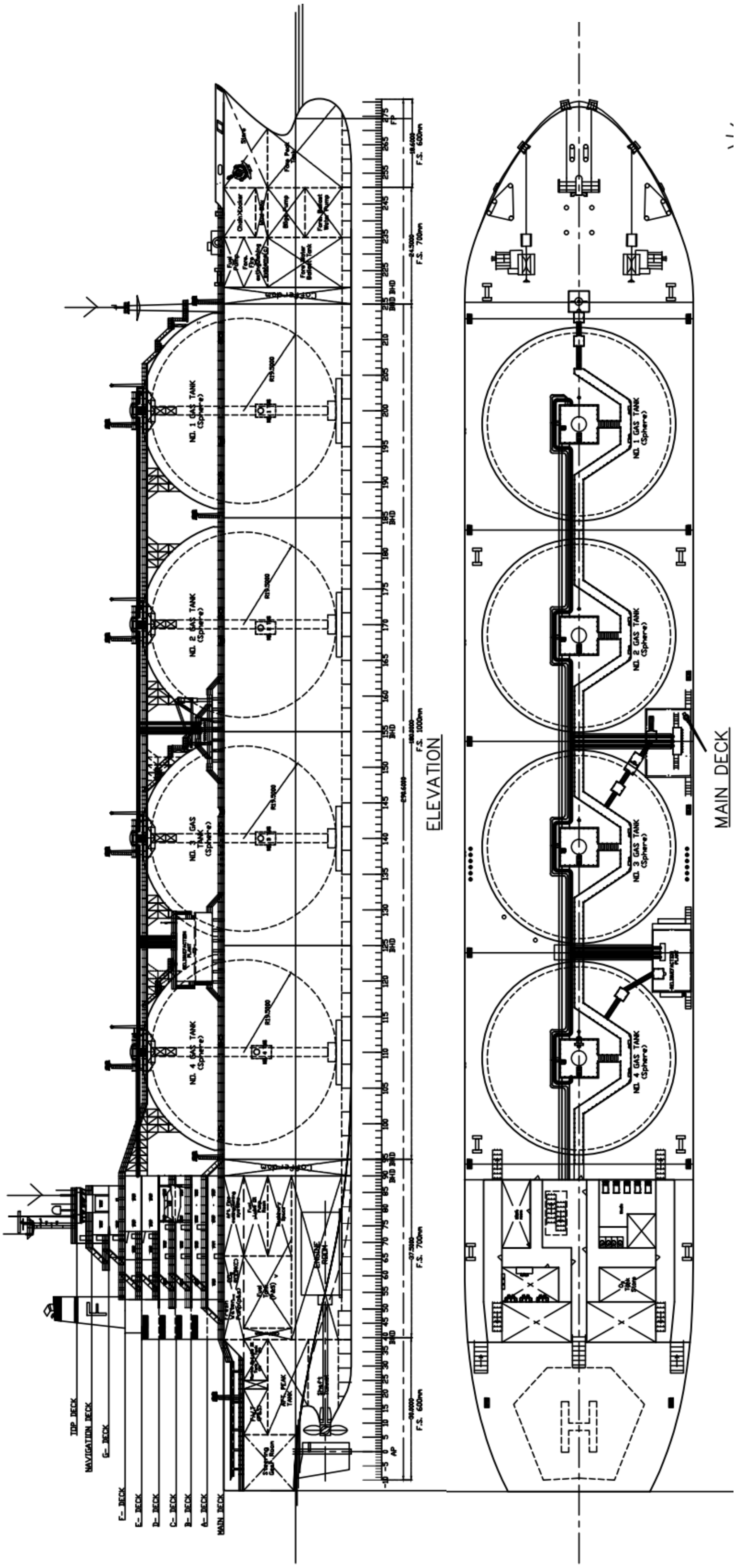
7.2.9 Specialized Compartments

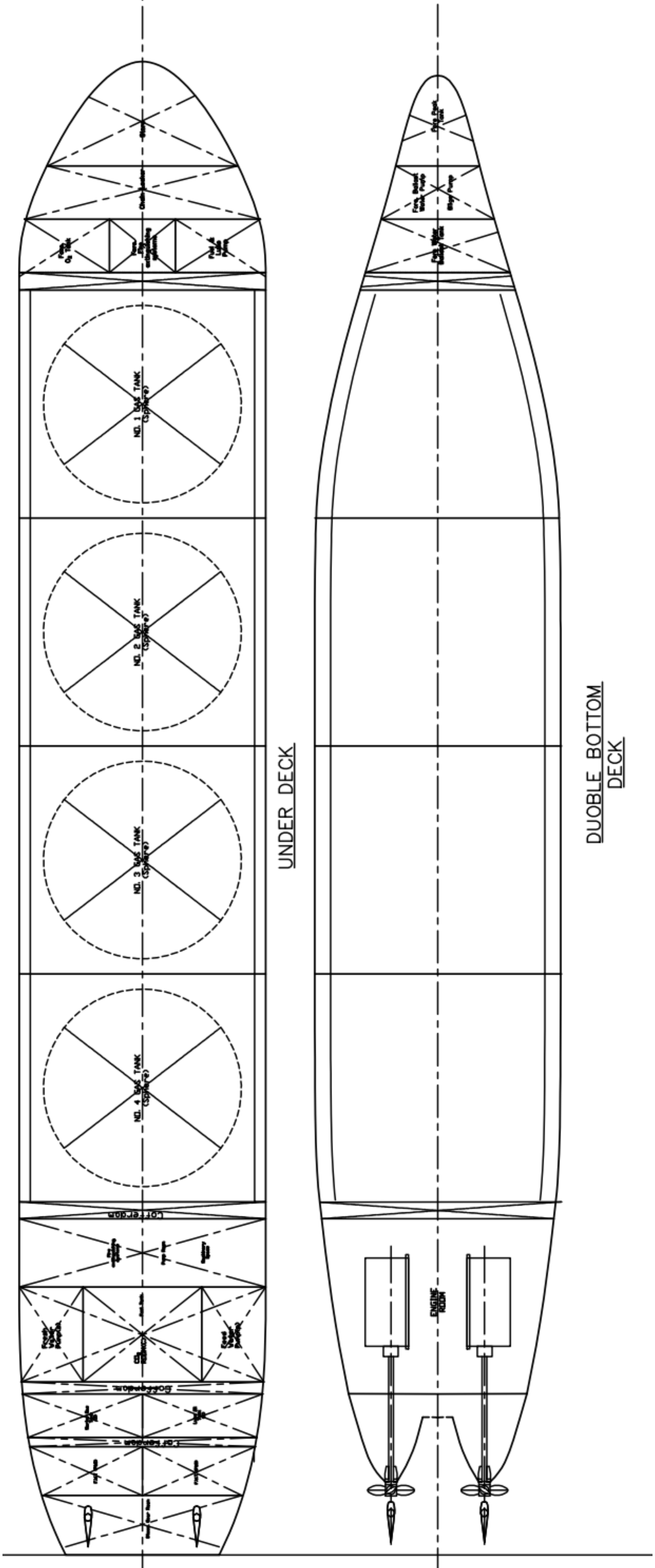
- TANKER: Tanks for liquid cargo.
- CONTAINER SHIP: Spaces for containers.
- RO-RO SHIP: Spaces for vehicles with ramps.
- PASSENGER SHIP: Luxury amenities for passengers.

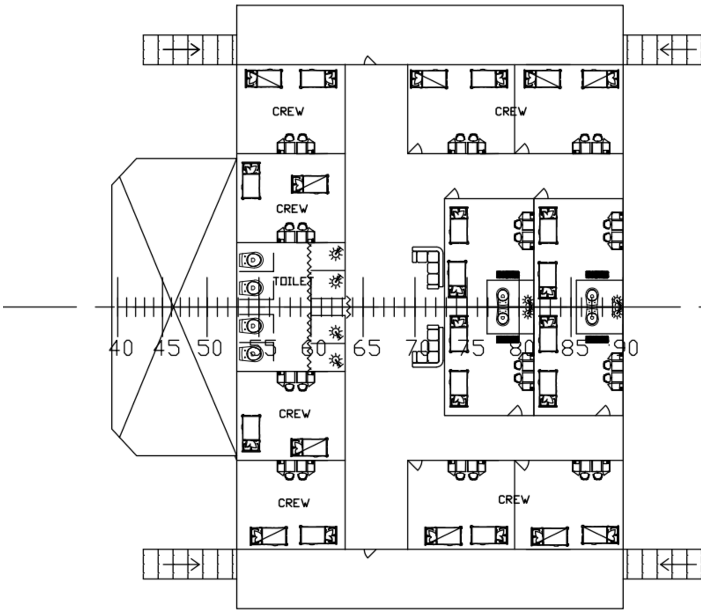
7.2.10 External Features

- BOW: Front of the ship, containing anchors.
- STERN: Rear of the ship, housing rudder and propeller.

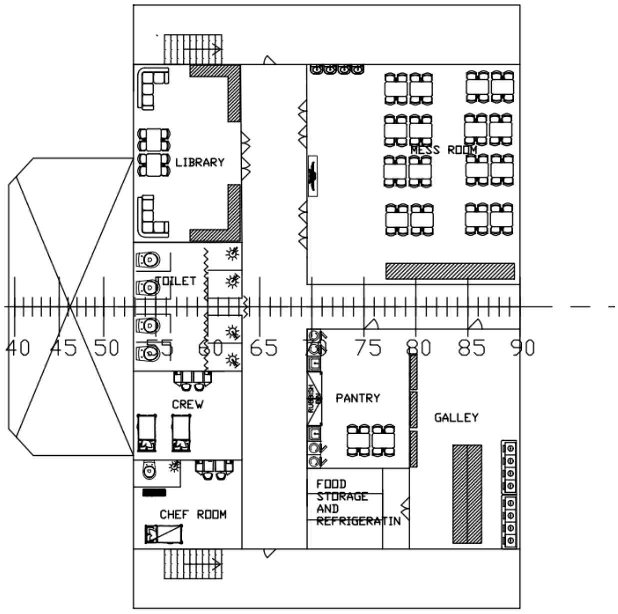
7.3 General Arrangement Drawing



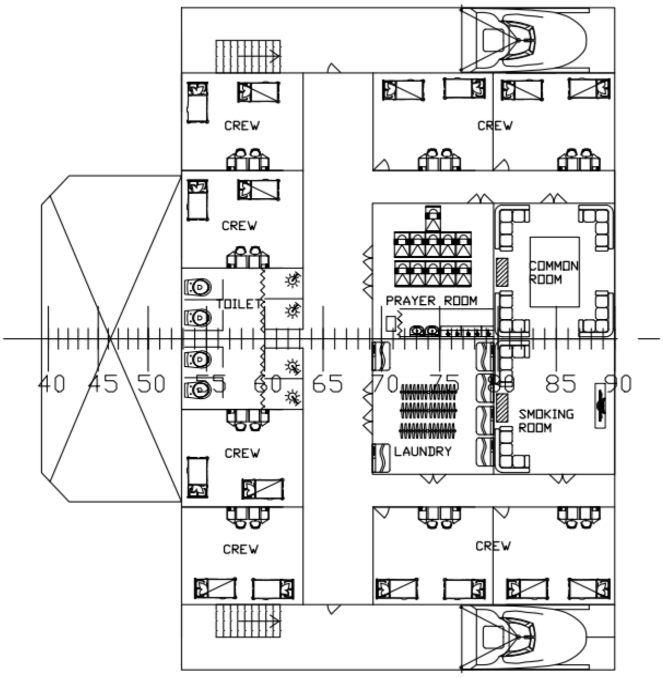

NO. 1 GAS TANK
NO. 2 GAS TANK
NO. 3 GAS TANK
NO. 4 GAS TANK
UNDER DECK
DUOBLE BOTTOM
DECK



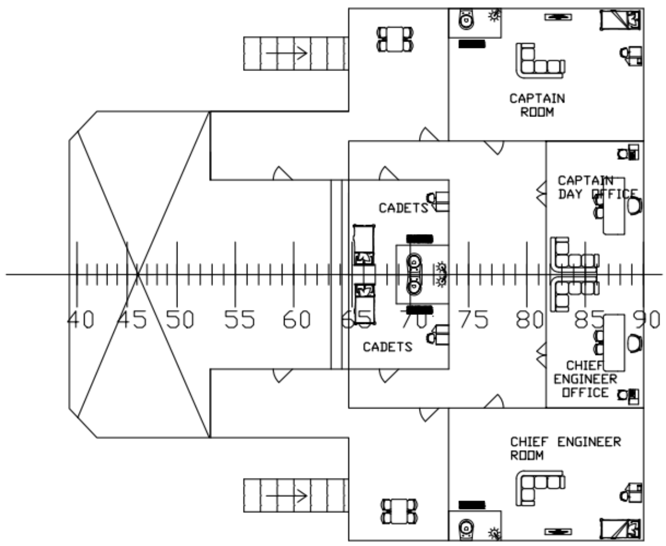
A-DECK



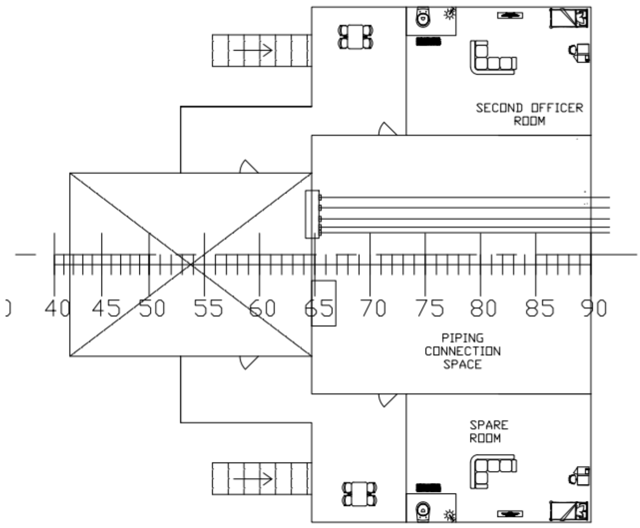
B-DECK



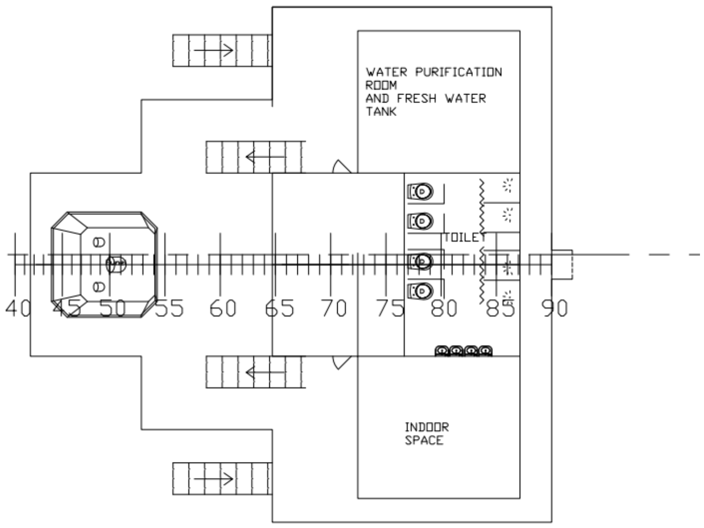
C-DECK



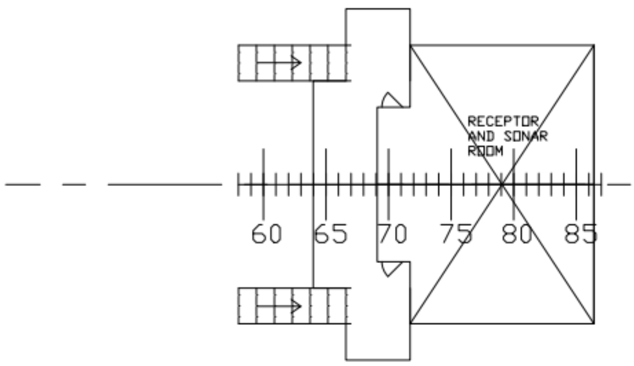
D-DECK



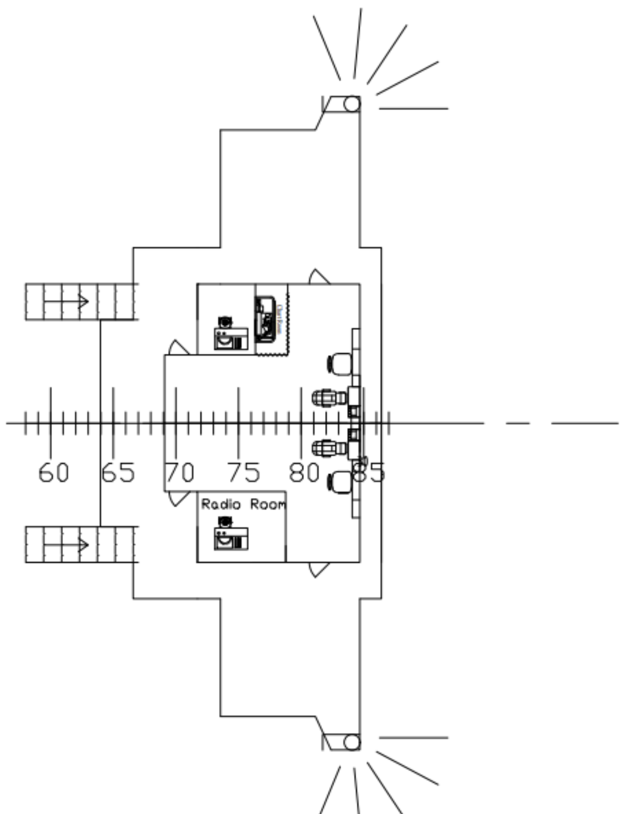
E-DECK



F-DECK



G-DECK



NAVIGATION DECK

CHAPTER 8:SCANTLING

8.1 Introduction

Scantling calculation is meant for the construction of the structures and plating of a ship during construction. The structure's dimensions and the plate thickness are determined to withstand the load that is going to apply on the vessel during operation. The design is one of the key parts because midship represents the structural integrity of a ship, because the longitudinal strength of hull girder depends on the section modulus of that element. Either the ship can withstand the cyclic load of waves or not, it depends greatly at the construction of the middle portion of the hull.

Basically, midship drawing is the cross section of a ship's amidships that represents main frames, web frames, keelsons, girder, longitudinal, holes, brackets etc. The design helps in the production sector in order to construct a block. Also, in times of tender, choosing right material is important. Midship helps in that section too.

Two locations of the structures are generally shown in the midship drawing are web frame no 14 and corresponding ordinary frame. Depending on different types of ship, the midship block structural arrangement differs greatly.

Midship Elements Dimensions are found by using DNV-GL rulebook, a Norwegian and German Based Classification Society.

8.2 Scantling Elements of an LNG Carrier

Longitudinal members: all longitudinal elements which are extend over the ship length and contribute to the longitudinal strength, such as shell, inner bottom, decks, stringers, longitudinal bulkheads (inner skin), and longitudinal girders.

Transverses members: all elements which are not contribute to the longitudinal strength such as web frames, floors and, transverse bulkheads may be also considered as transverse members. The model prepared is from the aft part, till the collision bulkhead.

8.3 Framing system

Frame is the special coordinate value to represent the position of the hull section, structure member and compartment arranged along the longitudinal direction of ship. Framework play the role of a rib cage and the hull is like the skin. The ribs hold the hull in its place, not allowing it to flex. Because the hull curves produce the classic boat shape, every rib has a unique shape framing spacing is in longitudinal and transversal directions, marine architects and engineers vary the number and the spacing of the frames based on the requirements of the hull and construction system.

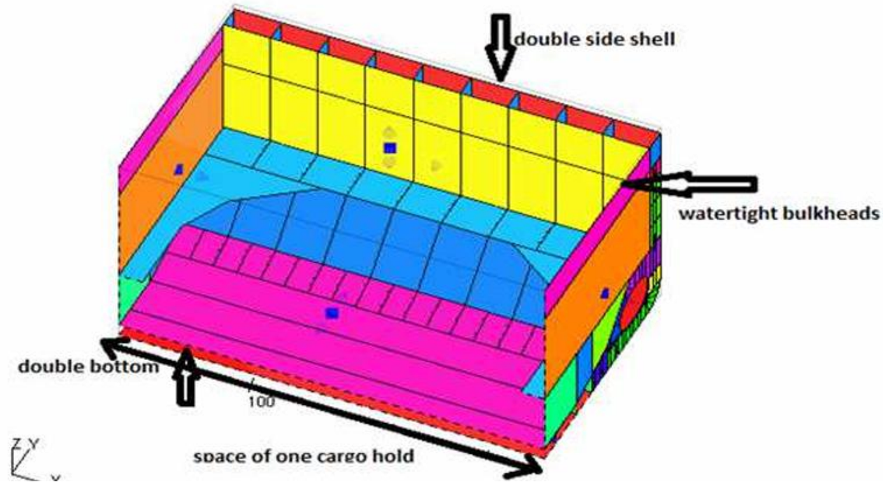
Frame spacing is necessary to know the location of all structural elements such as web frames, longitudinal girders, floors and longitudinal stiffeners. The spacing of the primary structural elements is based on the elementary framing spacing in the longitudinal direction and the stiffener spacing in the transversal direction. In the developed design the framing spacing in both longitudinal and transversal direction is selected as assumption as follow:

- The longitudinal framing spacing is taken equal to 600 mm, along the aft part and Bow part
- The longitudinal framing spacing is taken equal to 700 mm along Engine Room and Fwd collision area.
- The longitudinal framing spacing is taken equal to 1000 mm in tank area.

The selection of framing system shows the importance of transversal framing according to the distribution of ship and cargo weight. It is combination between transversal system in the aft part and longitudinal system in the mid and for part.

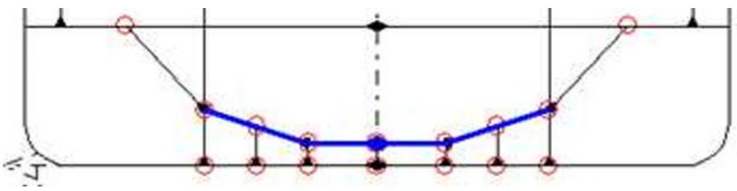
8.4 Structural topology selection

The selection of the structural topology of LNG carrier is based on the typical LNG ships spherical tanks type B. This selection should obey the classification rules in every part, therefore, an initial structural topology of one cargo hold is defined, starting by the identification of the arrangement of the primary structural members, the location of watertight barriers and bulkheads, besides of other construction notes such as the inner hull spaces, and the arrangement of the elements of each structure.



8.5 Double bottom structure

The double bottom of a ship is not only an important strength member of the bottom construction but also a principal structural member for longitudinal hull strength. Every part of the structure must serve its mission and support the rigidity of the ship body, even the double bottom, will follow the spherical tank in order to provide sufficient space to the ballast tanks and to facilitate the access during the fabrication process, inspection and in case of reparation. The double bottom occupies all void space under the spherical tank with sloped part make connection with the foundation deck. The mid part of double bottom has high assumed to be 2100 mm, after that this double bottom follow the tank curve to be higher and inclined to connect the slop part.



8.6 Scantling Calculation of Plates

8.6.1 Bottom Shell Plating: -

(Chapter-1; section-6; paragraph –B; page-6-2)

The thickness t_B of the bottom shell plating is not to be less than determined by the following formulae:

For ships without proven longitudinal strength:

$t_B = t_{B1}$ [within 0.4 L amidships]

$t_B = \max [t_{B1}; t_{B2}]$ [within 0.1 L forward of the aft end of the length L and within 0.05 L aft of F.P.]

$t_{B1} = 1.9 \cdot n_f \cdot a \cdot \sqrt{P_B \cdot K} + t_K$ [mm]

$t_{B2} = 1.21 \cdot a \cdot \sqrt{P_B \cdot K} + t_K$ [mm]

Where,

n_f = factor to take the framing system into account, defined as

n_f = 1.00 [for transverse framing]

n_f = **0.83** [for longitudinal framing]

a = frame spacing = 1 m

P_B = Load on bottom

$= 10 \cdot T + P_0 \cdot C_F$ [KN / m^2]

$= 10 \times 11.7 + 32.916 \times 1$

= **149.916** KN / m^2

Where,

T = Draft

P_0 = Basic External dynamic load [KN / m^2] for wave directions with or against the ship's heading's:

$P_0 = 2.1 \cdot (C_B + 0.7) \cdot C_0 \cdot C_L \cdot f$

$= 2.1 \times (0.77 + 0.7) \times 10.663 \times 1 \times 1$

= **32.916** KN / m^2

C_B = block co-efficient [from principal particulars]

C_0 = wave co-efficient

$C_0 = [\frac{L}{25} + 4.1] \cdot C_{RW}$ [for L < 90 m]

$C_0 = [10.75 - (\frac{300-L}{100})^{1.5}] \cdot C_{RW}$ [for $90 \le L \le 300$ m]

$= [10.75 - (\frac{300-280.43}{100})^{1.5}] \cdot 1$

= **10.663**

$C_0 = 10.75 \cdot C_{RW}$ [for L > 300 m]

Where,

L = length between perpendiculars

C_{RW} = Service range co-efficient

C_{RW} = 1.00 for unlimited service range

C_L = length co-efficient

$C_L = \sqrt{\frac{L}{90}}$ for L < 90 m

C_L = 1.0   for $L \geq 90$ m

f = probability factor

Defined as,

f = 1.00 for plate panels of the outer hull (shell plating, weather decks)

f = 0.75 for secondary stiffening members of the outer hull (frames, deck beams),

f = 0.60 for girders and girder systems of the outer hull (web frames. stringers, grillage systems)

C_F = Distribution factor = **1.00**

K = Material factor = **1.00**   for **R_{eH} = 235 N/mm²**

[**Normal strength hull structural steel** is a hull structural steel with yield strength, ReH of 235 N / mm2 and a tensile strength Rm of 400 – 520 N / mm2]

t_K = Corrosion addition

= **1.5 mm**   for t` ≤ 10 mm

$= \frac{1.5 \cdot t`}{\sqrt{K}}$   for t` > 10 mm

where, t`= required rule thickness excluding t_K [mm]

Therefore,

$t_{B1} = 1.9 \cdot n_f \cdot a \cdot \sqrt{P_B \cdot K} + t_K$

$= 1.9 \times 0.83 \times 1 \times \sqrt{149.916 \times 1} + 1.5$

= 20.8 mm

And,

$t_{B2} = 1.21 \cdot a \cdot \sqrt{P_B \cdot K} + t_K$

$= 1.21 \times 1 \times \sqrt{149.916 \times 1} + 1.5$

= 16.31 mm

Therefore, we take the thickness of bottom plate as 21 mm.

8.6.2 Inner Bottom Plating:

(Chapter-1; section-8; paragraph –C; page-8-6)

The thickness t of the inner bottom plating is not to be less than determined by the following formula:

$$t_{IB} = 1.1 \times a \times \sqrt{p \times k} + t_K$$
(In this case $p = p_B$)
$$t_{IB} = 1.1 \times 1 \times \sqrt{149.916 \times 1} + 1.5$$
$$= 14.968 \text{ mm}$$
So we take the thickness of Inner Bottom plating as 15 mm.

8.6.3 Flat Keel Plating:

(Chapter-1; section-6; paragraph –B; page-6-4)

The thickness t_{FK} of the flat plate keel is not to be less than be determined by the following formula:

$t_{FK} = t_B + 2.0$ [within 0.7 L amidships and in way of the engine seating]
$= 21 + 2$
$=$ **23** mm

Therefore, we take the thickness of flat keel plate as 23 mm.

8.6.4 Bilge Plating:

(Chapter-1; section-6; paragraph –C; page-6-4)

Bilge plating is considered to be same as flat keel plating.

Therefore, we take the thickness of Bilge plating as 23 mm.

8.6.5 Side Shell Plating: -

(Chapter-1; section-6; paragraph –B; page-6-4)

For ships without proven longitudinal strength:

$t_s = t_{s1}$ Within 0.4 L amidships

$t_s = \max[t_{s1}; t_{s2}]$ Within 0.1 L forward of the aft end of the length L and within 0.05L aft of F.P

$$t_{s1} = 1.9 . n_f . a \sqrt{P_s . k} + t_k \text{ [mm]}$$
$$t_{s2} = 1.21 . a \sqrt{P_s . k} + t_k \text{ [mm]}$$

Where, Ps = loads on Ship's sides

For elements having the load center located above the load waterline:

$$P_s = P_o . c_f . \frac{20}{10 + z - T} \quad \text{kN/mm}^2$$
$$32.916 \times 1 \times \frac{20}{10+14-11.7}$$

= 53.521 KN/mm^2 [for wave directions with or against the ship's heading]

here,

Z = vertical distance (m) between load center of element and base line
= 14 m

So,

$$t_{s1} = 1.9 . n_f . a \sqrt{P_s . k} + t_k \text{ [mm]}$$
$$= 1.9 \times 0.83 \times 1 \times \sqrt{53.521 \times 1} + 1.5$$
$$= 13.03 \text{ mm}$$
$$t_{s2} = 1.21 . a \sqrt{P_s . k} + t_k \text{ [mm]}$$
$$= 1.21 \times 1 \times \sqrt{53.521 \times 1} + 1.5$$
$$= 10.35 \text{ mm}$$

Therefore, we take the thickness of Side Shell plating as 14 mm.

8.6.6 Inner Side Shell Plating:

(Chapter-1; section-8; paragraph –C; page-8-6)

The thickness of inner bottom plating should not be less than

$$t_{IB} = 1.1 \times a \times \sqrt{p \times k} + t_K$$

(In this case $p = p_s$)

$$t_{IB} = 1.1 \times 1 \times \sqrt{53.521 \times 1} + 1.5$$
$$= 9.62 \text{ mm}$$

So we take the thickness of Inner Side Shell plating as 10 mm.

8.6.7 Deck Plating: -

(Chapter-1; section-7; paragraph –B; page-7-6)

The thickness of strength deck plating tE for 0.1 L from the ends and between hatchways is not to be less than determined by the following formula:

$$t_E = \max(t_{E1}; t_{E2})$$
$$t_{E1} = 1.21 \times a \times \sqrt{p_D \times k} + tK$$
$$t_{E2} = 1.10 \times a \times \sqrt{p_L \times k} + tK$$

Where, a=1m

Acceleration addition ,a_v = F× m *(Chapter-1; section-4; paragraph –A; page-4-1)*

And,

F = Co-efficient = $0.11\frac{v_0}{\sqrt{L}}$

p_L = load on cargo deck = $p_c \times (1 + a_v)$ *(Chapter-1; section-4; paragraph –C; page-4-10)*

And,

Static load on cargo p_c = 7× H = 7× 26.83 = **187.81** [KN / m^2]

Here, V_0 = Velocity of the ship = 19.5 knot

So,

$$F = 0.11\frac{19.5}{\sqrt{280.43}} = \mathbf{0.12808}$$

Now,

a_v = F× m
= 0.12808 x 1.0
= **0.12808**

And, $P_L = P_c \times (1 + av)$
= 187.81 x (1 + 0.12808)
= **211.86** [KN / m^2]

Load on weather decks, $p_D = p_0 \frac{20 \times T}{(10+z-T) \times H} \times c_D$ [kN / m^2]

$$= 32.916\frac{20 \times 11.7}{(10+26.83-11.7) \times 26.83} \times 1$$
$$= 11.423 \text{ kN / m}^2$$

So, $t_{E1} = 1.21 \times a \times \sqrt{p_D \times k} + tK$

$$= 1.21 \times 1 \times \sqrt{11.423 \times 1} + 1.5$$
$$= 5.589 \text{ mm}$$

And, $t_{E2} = 1.10 \times a \times \sqrt{p_L \times k} + tK$

$$= 1.10 \times 1 \times \sqrt{211.86 \times 1} + 1.5$$
$$= 17.51 \text{ mm}$$

We can take Thickness of Deck Plate as 18 mm.

8.6.8 Shear strake: -

(Chapter-1; section-6; paragraph –C; page-6-5)

The width b of the sheer strake is not to be less than determined by the following formula:

$b = 800 + 5 \cdot L$ [mm] [with $b \leq b_{max}$]

$= 800 + 5 \times 280.43$

$= 2202.15$mm

b_{max} = maximum width of the sheer stake [mm]

= **1800mm**

So, the thickness t of the sheer strake is, in general, not to be less than determined by the following Formula:

$$t = 0.5.(t_D + t_s) \quad [\text{mm}] \quad \text{with } t \geq t_s$$

Where,

t_D = required thickness of strength deck = 18 mm

t_s = required thickness of side shell = 14 mm

$t = 0.5 \times (18+14) = 16$ mm

Therefore, we take the thickness of shear strake as 16 mm.

8.7 Scantling Calculation of Transverse Stiffeners

8.7.1 Main Frame:

[*Section-3; paragraph –B; page-3-6*]

$m_{k3} = 1.0 - \left(\frac{l_{ku}}{l} + 0.4 \times \frac{l_{ko}}{l}\right)$ [with $m_{k3} \geq 0.6$]

l_{ku}, l_{ko} = Length of lower/ upper bracket connection of main frames within the length l (m) (= unsupported span)

Here we assume $l_{ku} = 0m$, $l_{ko} = 0m$,

l =10m

So,

$m_{k3} = 1.0 - \left(\frac{0}{10} + 0.4 \times \frac{0}{10}\right)$ [with $m_{k3} \geq 0.6$]

$= 1$

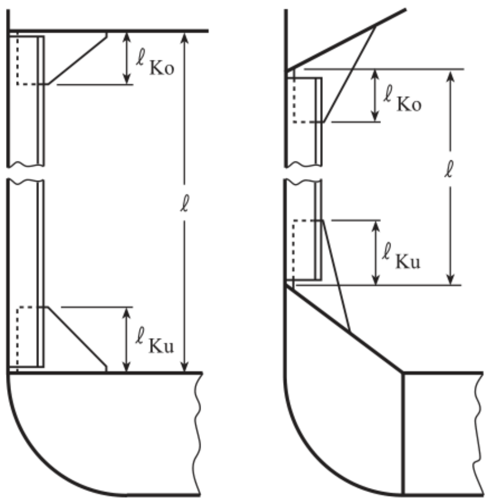


Fig. 3.3 End attachment of main frames

<u>Section modulus:</u> *(Chapter-1; section-9; paragraph –B; page-9-2)*

The section modulus W_R of the main frames including end attachments are not to be less than determined by the following formulae:

$W_R = n \cdot m_{k3} \cdot (1 - m_a^2)\, m_c \cdot a \cdot l^2 \cdot p \cdot k$

Where,

$m_c = 1$

$m_{k3} = 1$

n = factor, defined as

$= 0.9 - 0.0035L$ for $L < 100$ m

$= 0.55$ for $L \geq 100$ m

m_a = Factor to take the load distribution into account.

$= 0.204 \times \frac{a}{l} \times \left[4 - \left(\frac{a}{l}\right)^2\right]$ [with $\frac{a}{l} \leq 1$]

$= 0.204 \times \frac{1}{10} \times \left[4 - \left(\frac{1}{10}\right)^2\right]$

$= 0.081$

l = Unsupported span [m] = 10 m

$p = p_s = 53.521$ KN / m^2

Therefore,

W_R = $n \cdot m_{k3} \cdot (1 - m^2_a)\, m_c \cdot a \cdot l^2 \cdot p \cdot k$
$= 0.55 \times 1 \times \{1 - (0.081)^2\} \times 1 \times 1 \times 10^2 \times 53.521 \times 1$
$= 2924.34\ cm^3$

Therefore, the dimension of Ordinary frame L Sec is - 450×200×20mm.

8.7.2 Web Frame:

[*Section-9; paragraph –B; page-9-5*]

Where web frames and supporting stringers are fitted instead of tiers of beams, their section modulus W to be determined by the following formula:

$W = 0.55 \times e \times l^2 \times p \times n_c \times K\ [cm^3]$

where,

l = unsupported span [m], without consideration of cross ties, if any
= 10
l_1 = Similar to l
p = Design pressure = $p_s = 53.521\ KN / m^2$
n_c = co-efficient according to the following Table = 1

Table of reduction co-efficient, n_c

Number of cross ties	n_c
0	**1.0**
1	0.5
3	0.3
≥3	0.2

Therefore,

Section modulus is,

$W = 0.55 \times e \times l^2 \times p \times n_c \times K$
$= 0.55 \times 5 \times (10)^2 \times 53.521 \times 1 \times 1$
$= 14718.27\ cm^3$

Therefore, the dimension of Web Frame Plate I -section is 2200×18mm.

8.7.3 Deck Beam:

We take the dimension of Deck Beam same as that of the Deck Longitudinal. (later in the calculation)
Therefore, the dimension of Deck Beam s is L -Section is 150×70×8mm.

8.7.4 Deck Web:

We take the dimension of Deck Web Frame same as that of the Deck Girders. (later in the calculation)
Therefore, the dimension of Deck Web s is T -Section is 2200×1700×18mm.

8.7.5 Plate floors:

[Section-8; paragraph –C.5.1; page-8-6]

The thickness of plate floors is not to be less than determined by the following formula:

$t_{pf} = t_m - 2.0 \times \sqrt{k}$ [mm] with $t_{pf} \leq 16$ mm

t_m: thickness of centre girder according to C.2.2.2

$$\begin{aligned} t_{pf} &= t_m - 2.0 \times \sqrt{k} \\ &= 19 - 2.0 \times \sqrt{1} \\ &= 17 \text{ mm} \end{aligned}$$

Plate floor height = Depth of Center Girder = 2200 mm

The Dimension of Plate floors I- Section is 2200 X 17 mm.

8.7.6 Bracket floors:

[Section-8; paragraph –C.5.3; page-8-7]

<u>Bottom & Inner Bottom Frames:</u>

We take the dimension of Bracket Floor Transverse Frames same as that of the Main Frame.

Therefore, the Dimension of Bracket Floor Frame L Sec is - 450×200×20mm

<u>Struts:</u> *Section 8, C.8*

The cross-sectional area of the struts in double bottom is to be determined according to *Section 10, C.2* analogously. The design force P is to be determined by the following formula:

$P = 0.5 \times p \times a \times l$ **[kN]**

p : load according to C.5.3.3

l : unsupported span according to C.5.3.3

$P = 0.5 \times p \times a \times l = 0.5 \times 149.916 \times 1 \times 2.2 = 164.9076$ **[kN]**

The sectional area $A_{s,req}$ of pillars is not to be less than determined by the following formula: *[Section 10 ,C.2]*

$$A_{s,req} = \frac{P_s}{\sigma_p} \times 10 \quad [\text{cm}^2]$$

$$piller\ load, P_s = p.A + P_i = 149.916 \times 0.76 + 164.9076 = 278.84[\text{kN}]$$

$$A_{s,req} = \frac{278.84*100}{150} = 185.893[\text{cm}^2]$$

Therefore, the Dimension of Bracket Floor Struts L Sec is - 450×450×20mm

8.8 Scantling Calculation of Longitudinal Stiffeners

8.8.1 Center Girder:

(Chapter-1; section-8; paragraph –C.2; page-8-4)

The depth h of the center girder is not to be less than determined by the following formula:

$h = 350 + 45\, l\ (mm)$ $\qquad\qquad h \geq hmin$

h_{min} : minimum depth [mm], defined as:

h_{min} =600mm

l : unsupported span [m] of the floor plates, defined as,

$l = B$ In general

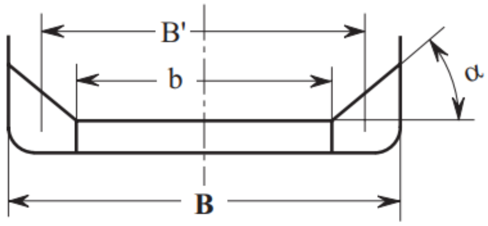
$l = 0.8B$ In case of longitudinal side bulkheads, the distance between the bulkhead can be used as unsupported span

$\boldsymbol{l = B'}$ in case of double bottoms with hopper tanks the fictitious breadth B' can be used as unsupported span

B' : fictitious breadth [m], defined as:

$\boldsymbol{B' = \frac{1}{3}(2B + b)}$ for α ≥ 35°

$B' = B$ for α < 35 °



∴ unsupported span [m] : $l = B' = \frac{1}{3}(2B + b) = \frac{1}{3}(2 \times 48.59 + 24)$

$= 40.393m$

∴ The depth h of the centre girder , $h = 350 + 45\, l = 350 + 45 \times 40.393$

$= 2167.68mm$

∴ The depth of the centre girder is 2.2 m

The thickness t_m of the center girder is not to be less than determined by the following formula:

$t_m = \frac{h}{h_a}\left(\frac{h}{100} + 1.0\right)\sqrt{k}$ **[mm] ; for h ≤ 1200 mm**

$t_m = \frac{h}{h_a}\left(\frac{h}{120} + 3.0\right)\sqrt{k}$ **[mm] ; for h > 1200 mm**

However, $t_m \geq t$

h_a: depth [mm] of center girder as built

t: plate thickness of the longitudinal girders

so, $t_m = \frac{h}{h_a}\left(\frac{h}{120} + 3.0\right)\sqrt{k}$

$t_m = \frac{2167.68}{2200}\left(\frac{2167.68}{100} + 1.0\right)\sqrt{1}$ **mm [h_a is taken as 2200 mm]**

t_m = 18.78mm

∴ The thickness of the centre girder is 19mm

Hence the dimension of the center girder is 2200 x 19 mm.

8.8.2 Side girders:

[Section-8; paragraph –C.3; page-8-5]

The distance of the side girders from each other and from centre girder and ship's side respectively is not to be greater than: [C.3.1]

1.8 m; in the engine room within the engine seatings
4.5 m; where one side girder is fitted in the other parts of double bottom
4.0 m; where two side girders are fitted in the other parts of double bottom
3.5 m; where three side girders are fitted in the other parts of double bottom
3m ; For Four side Girders

We took 4 Side Girders at distance 3m.

The thickness tm of the side girders is not to be less than determined by the following formula:

$t_m = \frac{h^2}{120 \times h_a} \times \sqrt{k}$ [mm] [C.3.2]

Where,

h = depth of the centre girder according to C.2.2.1
= 2167.68 mm

h_a = as built depth [mm] of side girders. ha need not be taken less than h to calculate t.

t = plate thickness of the longitudinal girders according to C.6.4

in case 1st and 2nd side girder ($h = h_a$):

$$t_m = \frac{h^2}{120 \times h} \times \sqrt{k}$$
$$= \frac{2200^2}{120 \times 2167.68} \times \sqrt{1}$$
$$= 18.606 \text{ mm}$$

The thickness of the 1st and 2nd side girder is 19 mm.

Hence the dimension of the 1st and 2nd side girder is 2200 x 19 mm.

in case of 3rd side girder (h_a= 3.35 m = 3350 mm):

$$t_m = \frac{h^2}{120 \times h_a} \times \sqrt{k}$$
$$= \frac{2200^2}{120 \times 3350} \times \sqrt{1}$$
$$= 12.039 \text{ mm}$$

The thickness of the 3rd side girder is 13 mm.

Hence the dimension of the 3rd side girder is 3350 x 13 mm.

in case of 4th side girder (h_a= 4.5 m = 4500 mm):

$$t_m = \frac{h^2}{120 \times h_a} \times \sqrt{k}$$
$$= \frac{2200^2}{120 \times 4500} \times \sqrt{1}$$
$$= 8.9629 \text{ mm}$$

The thickness of the 4th side girder is 9 mm.

Hence the dimension of the 4th side girder is 4500 x 9 mm.

8.8.3 Deck girders: -

[Section-8; paragraph –C.3; page-8-5]

The section modulus of deck girder should not be less than

$W_{DG} = c \times e \times p \times l^2 \times k$ Here,

$P = P_D = 11.423\ KN/m^2$

So,

$W_{DG} = c \times e \times p \times l^2 \times k$

$W_{DG} = 0.75 \times 5 \times 11.423 \times (5)^2 \times 1$

$= 1070.90\ cm^3$

Hence the dimension of the deck girder T-section is 400×300×18mm.

8.8.4 Side Stringers: -

We take the dimension of side stringer same as that of the web frame.

Therefore, the dimension of Side Stringers is I -Section is 2200×18mm.

8.8.5 Longitudinal:

[Section-9; paragraph –C; page-9-7]

$$W_l = \frac{83}{\sigma_{p_r}} \times \left(m_{k1}^2 - m_a^2\right) \times a \times l^2 \times p \qquad [cm^3] \qquad \{With\left(m_{k1}^2 - m_a^2\right) \geq \frac{m_{k1}^2}{2}\}$$

Where,

σ_{p_r} = permissible local stress $[KN/mm^2]$, defined as :

$= \sigma_{perm} - |\sigma_L| \qquad \{ With\ \sigma_{p_r} \leq \frac{150}{k} \}$

Here,

σ_L = design longitudinal hull girder bending stress

σ_{perm} = total permissible stress $[N/mm^2]$

$\sigma_{perm} = (0.8 + \frac{L}{450}) \times \frac{230}{k} \qquad \{ With\ \sigma_{perm} \leq \frac{230}{k} \}$

$\sigma_{perm} = (0.8 + \frac{280.43}{450}) \times \frac{230}{1}$

$= 327.33\ KN/mm^2$

So , $\sigma_{p_r} = 327.33 - |175| = 152.33\ KN/mm^2$

8.8.5.1 Bottom Longitudinal

[Section-9; paragraph –C.3; page-9-8]

The section modulus of bottom longitudinal should not be less than

$W_{BL} = \frac{83.3}{\sigma_{p_r}} \times \left(m_{k1}^2 - m_a^2\right) \times a \times l^2 \times p \qquad (P=P_B)$

$W_{BL} = \frac{83.3}{152.33} \times \{(1)^2 - (0.081)^2\} \times 1 \times (5)^2 \times$ **149.916**

$= 2036.05\ cm^3$

Hence the dimension of the bottom longitudinal is 450×180×14mm.

8.8.5.2 Side Longitudinal

[Section-8; paragraph –C.3; page-9-8]

The section modulus of side longitudinal should not be less than

$$W_{SL} = \frac{83.3}{\sigma_{pr}} \times \left(m_{k1}^2 - m_a^2\right) \times a \times l^2 \times p \qquad (p=ps)$$

$$W_{SL} = \frac{83.3}{152.33} \times \{(1)^2 - (0.081)^2\} \times 1 \times (5)^2 \times \mathbf{53.521}$$

$$= 726.88\ cm^3$$

Hence the dimension of the Side longitudinal is – 450×100×8mm.

8.8.5.3 Deck Longitudinal

[Section-8; paragraph –C.3; page-9-8]

The section modulus W_d transverse deck beams and of deck longitudinal not contributing to the longitudinal strength are to be not less than determined by the following formulae:

$$W_{DL} = \frac{83}{\sigma_{pr}} \times \left(m_{k1}^2 - m_a^2\right) \times a \times l^2 \times p \qquad (P=PD)$$

$$= \frac{83}{152.33} \times \{(1)^2 - (0.081)^2\} \times 1 \times (5)^2 \times 11.423$$

$$= 155.14\ cm^3$$

Hence the dimension of the Deck longitudinal is 150×70×8mm.

8.9 SUMMARY OF SCANTLING CALCULATION

Plates		
Serial	**Items**	**Thickness**
1.	Bottom plating	**21mm**
2.	Inner Bottom plating	**15mm**
3.	Flat keel plate	**23mm**
4.	Bilge plating	**23mm**
5.	Side Shell plating	**14mm**
6.	Inner Side Shell plating	**10mm**
7.	Shear Strake	**16mm**
8.	Deck plate	**14mm**

Stiffeners				
Serial	**Items**		**Section**	**Dimension**
1.	Main Frame		**L**	450×200×20
2.	Web Frame		**I**	2200×18
3.	Plate Floor		**I**	2200 X 17
4.	Bracket Floor	Transvers Frame	**L**	450×200×20
		Struts	**L**	450×450×20
5.	Centre Girder		**I**	2200 x 19
6.	Side Girders	**1st & 2nd**	**I**	2200 x 19
		3rd	**I**	3350 x 13
		4th	**I**	4500 x 9
7.	Deck Girder		**T**	450×300×18
8.	Side Stringer		**I**	2200×18
9.	Deck Web		**T**	400×300×18
10.	Deck Beam		**L**	150×70×8
11.	Bottom Longitudinal		**L**	450×180×14
12.	Side Longitudinal		**L**	450×100×8
13.	Deck Longitudinal		**L**	150×70×8

CHAPTER 9:MIDSHIP DRAWING

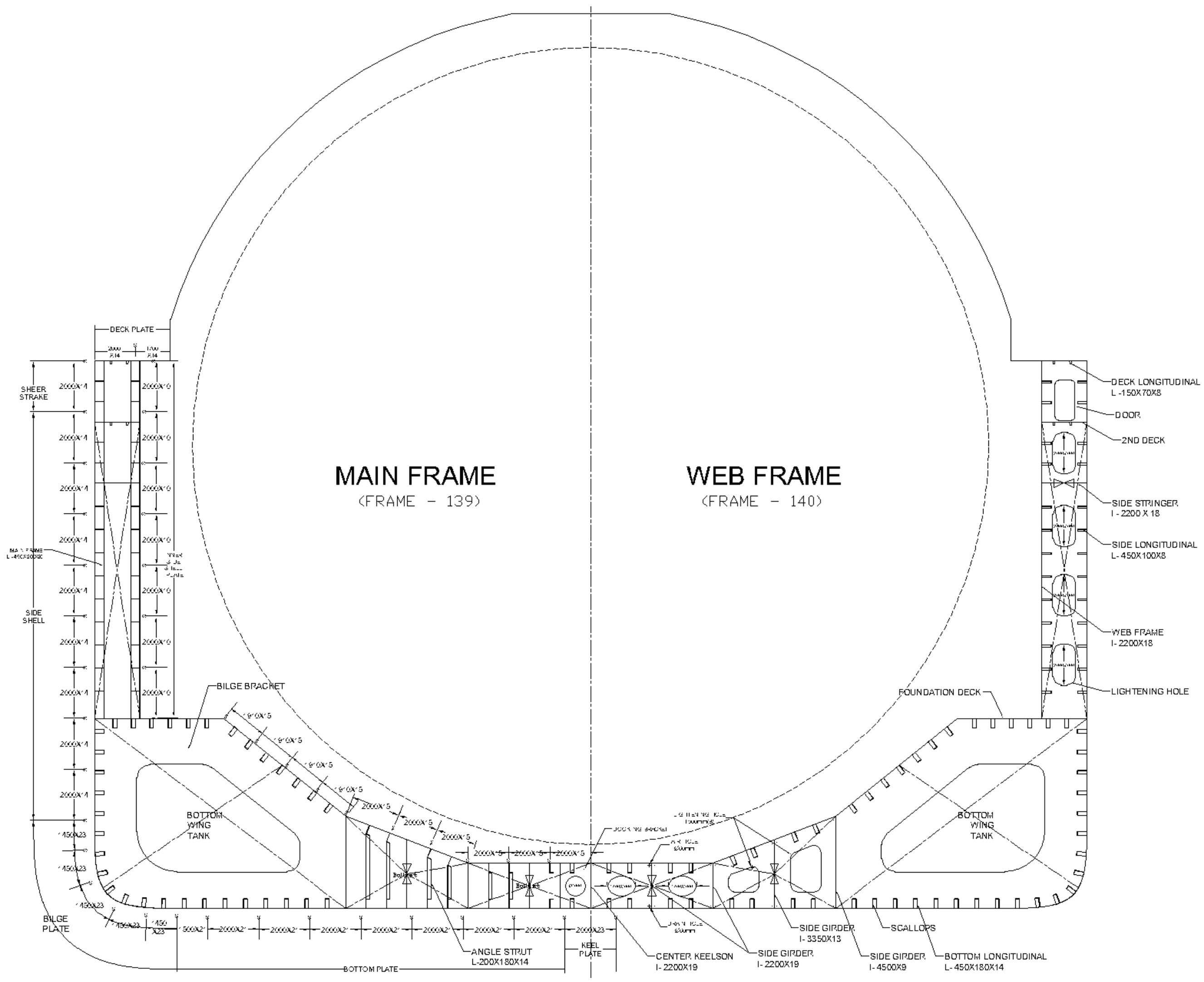
The **midship section** of a ship refers to the cross-sectional area of the vessel taken at the midpoint of its length. This section is typically used as a reference point in ship design and construction, as it represents the broadest, most stable part of the ship's hull. The midship drawing is done wholly based on the scantling calculation results.

Key points about the midship section:

- **Location**: It is located at the midpoint of the ship, which is halfway between the bow (front) and the stern (rear).
- **Shape**: The shape of the midship section is critical for the ship's stability, strength, and hydrodynamic efficiency. It is often designed to minimize resistance when moving through the water.
- **Structure**: It includes the ship's main structural components like the hull, decks, bulkheads, and internal arrangements, such as engine rooms or cargo holds, depending on the type of vessel.

In shipbuilding and naval architecture, the midship section is an essential reference for designing the overall geometry and ensuring the strength of the ship's hull.

9.1 Midship Drawing



CHAPTER 10: SHELL EXPANSION

10.1 Introduction

A **shell expansion drawing** is a detailed, flat, and scaled-out drawing used in shipbuilding to represent the various curved sections of a ship's hull (the "shell"). It is a type of drawing that "unwraps" or "unrolls" the complex 3D surfaces of the ship's hull into 2D to show how the plates and sections that make up the hull are laid out and connected. The drawing provides information on:

- **Plate sizes and shapes**: How the individual steel plates or sections that make up the hull are arranged.
- **Location of seams**: The places where different plates or sections are welded together.
- **Cut lines**: Where the plates need to be cut to fit together.
- **Curvatures and angles**: How curved parts of the hull (such as the bow, stern, and sides) are translated into flat plates.
- **Stiffeners**: Where stiffeners and plate are welded, to avoid double welding.

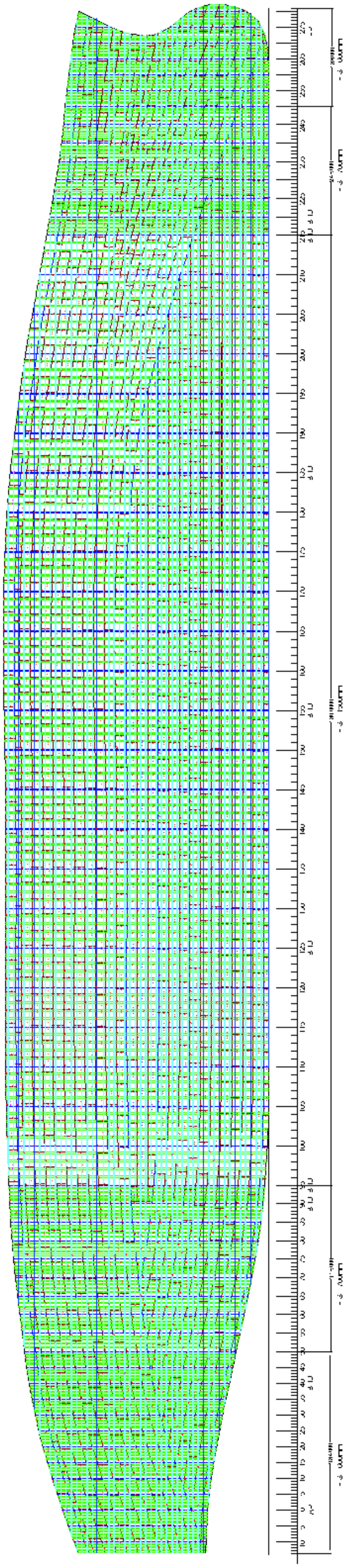
10.2 Usefulness of Shell Expansion Drawing

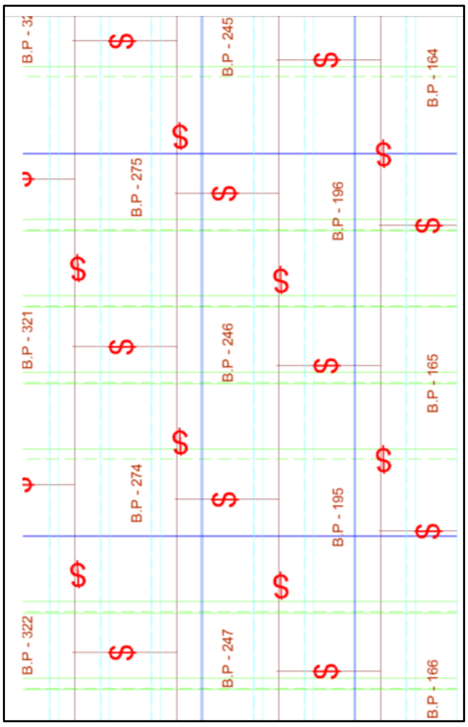
- In case of rough sea condition or naval warfare or any general damage occurs, identifying the correct strake number is important for quick repairing.
- Following Rectangular Beam theory, where the shear connection occurs, there are higher stress distribution in Keel, Bilge Keel, Sheer Strake. So, the thickness of these area is higher than standard location in order to cope up with the higher stress. If the plate number is mentioned, identifying a particular plate will be very easy.
- Painting scheme greatly depends on the strake number. Identifying Boot Top, Underwater portion is important in order to paint according to the scheme. This becomes useful in solving disputes concerning areas of preparation and painting.
- Quality of different types of steel used and their welding types are mentioned in the shell expansion drawing.
- Buying different types of plates in times of tender is made easier

10.3 Shell Expansion Drawing Summary

Abbreviation	Full form	Number of plates
K.P	Keel Plate	49
B.P	Bottom Plate	400
Bi.P	Bilge Plate	82
S.Sh	Side Shell Plate	608
SS	Shear Strake	49
		total=1188

10.4 Shell Expansion Drawing





CHAPTER 11: LONGITUDINAL CONSTRUCTION

11.1 Introduction

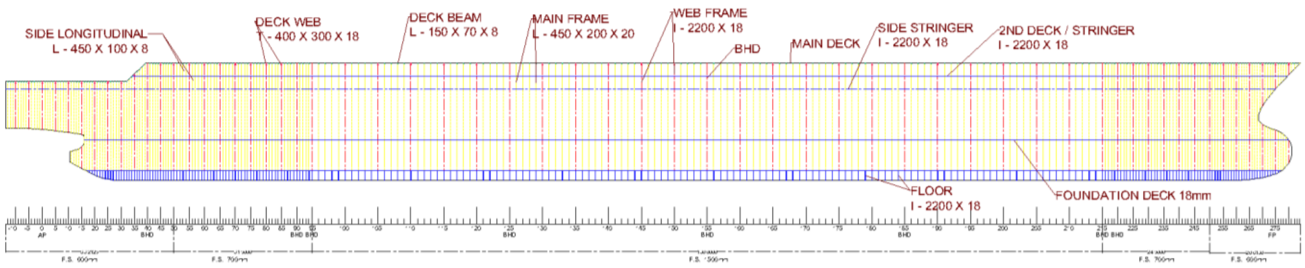
longitudinal drawing refers to a type of technical drawing or plan that shows the side profile of a ship. It typically depicts the ship's structure and key components along its length, viewed from the side (along the longitudinal axis).

This type of drawing is used to:

1. Show the overall shape and proportions of the ship, including the hull, deck, and superstructure.
2. Illustrate the internal arrangement of the ship, such as bulkheads, decks, and internal spaces.
3. Provide a guide for shipbuilding by showing how the ship will be constructed, including material specifications and structural details.

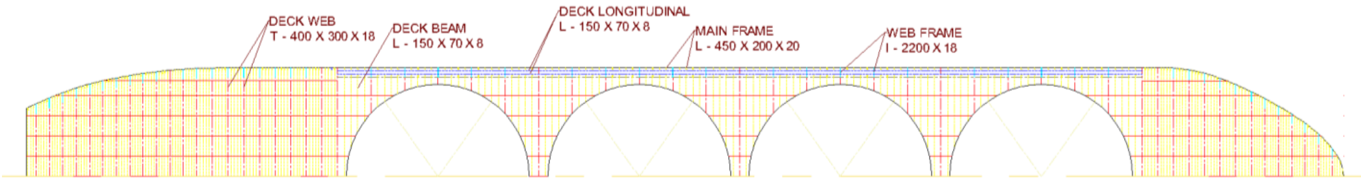
11.2 Longitudinal Drawing

11.2.1 Profile



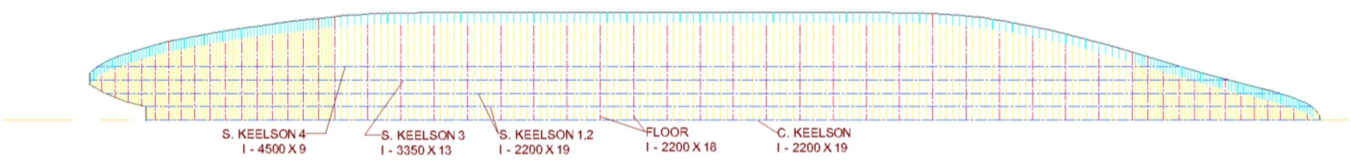
PROFILE

11.2.2 Main Deck



MAIN DECK

11.2.3 Underdeck



DOUBLE BOTTOM DECK

CHAPTER 12: DETAILED LIGHTSHIP CALCULATION

12.1 Introduction

Lightship:

- **Definition**: The **lightship** refers to the weight of a ship when it is empty, without any cargo, fuel, passengers, or other supplies. Essentially, it's the weight of the ship in its "unladen" or "light" condition.
- **Components**: The lightship weight includes the structure, equipment, machinery, and everything that is a permanent part of the ship but excludes things like fuel, cargo, and ballast.
- **Importance**: Lightship weight is crucial for calculating a ship's displacement, stability, and the load it can safely carry.

LCG (Longitudinal Center of Gravity):

- **Definition**: **LCG** refers to the position of the **center of gravity** along the length of the ship (from bow to stern). It is the point where the ship's total weight is considered to act along the length of the hull.
- **Calculation**: LCG is typically measured in meters from the forward perpendicular (FP) of the ship.
- **Importance**: The LCG is critical for the ship's stability and trim. If the LCG is too far forward, it can cause the ship to trim by the bow, while if it's too far aft, it can cause a stern-heavy condition, affecting the ship's performance and stability.

VCG (Vertical Center of Gravity):

- **Definition**: **VCG** refers to the vertical position of the **center of gravity** of the ship, essentially the height at which the total weight of the ship acts in the vertical direction. It is measured from the keel or baseline of the ship.
- **Importance**: The VCG is a key factor in determining the ship's stability. A low VCG increases stability, while a high VCG can make the ship prone to tipping or capsizing. It's crucial in balancing the ship to avoid excessive roll or pitch.

12.2 Plates

Name	L (m)	B (m)	T (m)	Density (ton/m3)	Weight (ton)	longitudinal lever (m)	longitudinal moment (ton-m)	vertical lever (m)	vertical moment (ton-m)
Keel plate	295	2	0.023	7.85	106.52	140.25	14940.06	0.01	1.23
Bottom plate	295	40	0.021	7.85	1945.23	140.25	272818.51	0.01	20.42
Bilge plate	295	12	0.023	7.85	639.15	140.25	89640.37	1.00	639.15
Side shell plate	295	42	0.014	7.85	1361.66	140.25	190972.96	14.30	19471.75
Shear strake	295	4	0.016	7.85	148.21	140.25	20786.17	25.80	3823.77
inner bottom	295	52.8	0.015	7.85	1834.07	140.25	257228.88	3.50	6419.26
inner side shell	295	35.02	0.01	7.85	810.98	140.25	113739.33	18.05	14638.11
deck plate	295	48.6	0.014	7.85	1575.64	140.25	220982.99	26.79	42216.02
					8421.46		1181109.27		87229.71

Total Weight	8421.46	Ton
LCG	140.25	m fwd AP
VCG	10.36	m above keel

12.3 Bulkheads

Name	H(m)	B(m)	t(m)	density(ton/m3)	weight(ton)	longitudinal lever (m)	longitudinal moment (ton-m)	vertical lever (m)	vertical moment (ton-m)
BHD 1	26.80	48.60	0.02	7.85	184.04	23.57	4337.83	13.40	2466.14
BHD 2	26.80	48.60	0.02	7.85	184.04	58.00	10674.34	13.40	2466.14
BHD 3	26.80	48.60	0.02	7.85	184.04	61.50	11318.49	13.40	2466.14
BHD 4	26.80	48.60	0.02	7.85	184.04	106.50	19600.31	13.40	2466.14
BHD 5	26.80	48.60	0.02	7.85	184.04	151.50	27882.12	13.40	2466.14
BHD 6	26.80	48.60	0.02	7.85	184.04	196.50	36163.94	13.40	2466.14
BHD 7	26.80	48.60	0.02	7.85	184.04	241.50	44445.76	13.40	2466.14
BHD 8	26.80	48.60	0.02	7.85	184.04	245.00	45089.90	13.40	2466.14
					1472.32		199512.70		19729.13

Total Weight	1472.32	Ton
LCG	135.51	m fwd AP
VCG	13.40	m above keel

12.4 Web Frame

Web Frame +Floor	Web (mm)	thickness (mm)	quantity	area (m2)	Length(m)	density (ton/m3)	weight (ton)	longitudinal lever (m)	longitudinal moment (ton-m)	vertical lever (m)	vertical moment (ton-m)
in frame spacing 600mm (fwd)	2200	18	11	2200	100.00	7.85	341.9	15.00	5129.19	18.0	6158
in frame spacing 700mm (fwd)	2200	18	8	2200	100.00	8.85	280.3	45.75	12826	18.0	5049
in frame spacing 1500mm	2200	18	25	2200	100.00	9.85	975.1	151.50	147735	18.0	17562
in frame spacing 700mm (aft)	2200	18	6	2200	100.00	10.85	257.8	253.75	65415	18.0	4642
in frame spacing 600mm (aft)	2200	18	6	2200	100.00	11.85	281.	275.30	77512	18.0	5070
							2136		308619		38484

Total Weight	2136.82	Ton
LCG	144.43	m fwd AP
VCG	18.01	m above keel

12.5 Main Frame

MAINFRAME	web(mm)	flange (mm)	Thickness (mm)	quantity	web area (m2)	flange area (m2)	total area (m2)	Length(m)	density (ton/m3)	weight(ton)	longitudinal lever (m)	longitudinal moment (ton-m)	vertical lever (m)	vertical moment (ton-m)
in frame spacing 600mm (fwd)	450	200	20	40.00	0.01	0.00	0.01	70.00	7.85	276.95	15.00	4154.22	18.01	4987.83
in frame spacing 700mm (fwd)	450	200	20	36.00	0.01	0.00	0.01	70.00	8.85	281.01	45.75	12855.99	18.01	5060.90
in frame spacing 1500mm	450	200	20	96.00	0.01	0.00	0.01	70.00	9.85	834.02	151.50	126353.91	18.01	15020.69
in frame spacing 700mm (aft)	450	200	20	28.00	0.01	0.00	0.01	70.00	10.85	267.95	253.75	67992.72	18.01	4825.81
in frame spacing 600mm (aft)	450	200	20	24.00	0.01	0.00	0.01	70.00	11.85	250.84	275.30	69056.47	18.01	4517.64
										1910.76		280413.31		34412.87

Total Weight	1910.76	Ton
LCG	146.75	m fwd AP
VCG	18.01	m above keel

12.6 Longitudinal

Longitudinals		web (mm)	flange(mm)	thickness(mm)	web area(m2)	flange area(m2)	total area(m2)	Length(m)	density(ton/m3)	weight (ton)	longitudinal lever (m)	longitudinal moment (ton-m)	vertical lever (m)	vertical moment (ton-m)
Bottom	1	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	2	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	3	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	4	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	5	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	6	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	7	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	8	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	9	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	10	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	11	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	12	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	13	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	14	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	15	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	16	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
	17	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.26	5.11
Bilge	18	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.28	5.59
	19	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.45	9.07
	20	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	0.90	17.99
	21	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	1.71	34.21
	22	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	2.73	54.60
	23	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	3.72	74.25
	24	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	4.72	94.22
	25	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	5.72	114.19
	26	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	6.72	134.17
	27	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	7.72	154.14
	28	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	8.72	174.11
Inner Bottom	29	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	1.91	38.11
	30	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	1.91	38.11

	31	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	1.91	38.11
	32	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	1.91	38.11
	33	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	2.30	45.97
	34	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	2.69	53.64
	35	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	3.85	76.94
	36	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	4.88	97.46
	37	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	5.51	109.98
	38	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	6.13	122.50
	39	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	6.76	135.02
	40	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	7.39	147.55
	41	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	8.02	160.07
	42	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	8.64	172.59
	43	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	9.00	179.68
	44	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	9.00	179.68
	45	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	9.00	179.68
	46	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	9.00	179.68
	47	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	9.00	179.68
	48	450	180	14	0.0063	0.0023	0.0086	295	7.85	19.97	140.25	2800.94	9.00	179.68
Side Shell	49	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	10.62	106.65
	50	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	11.75	118.00
	51	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	14.01	140.69
	52	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	15.14	152.04
	53	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	16.27	163.38
	54	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	17.40	174.73
	55	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	18.53	186.08
	56	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	19.66	197.42
	57	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	20.79	208.77
	58	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	21.79	218.81
	59	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	22.79	228.85
	60	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	24.79	248.93
	61	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	25.79	258.98
Inner Side Shell	62	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	10.62	106.65
	63	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	11.75	118.00
	64	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	14.01	140.69

	65	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	15.14	152.04
	66	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	16.27	163.38
	67	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	17.40	174.73
	68	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	18.53	186.08
	69	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	19.66	197.42
	70	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	20.79	208.77
	71	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	21.79	218.81
	72	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	22.79	228.85
	73	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	24.79	248.93
	74	450	100	8	0.0036	0.0007	0.0043	295	7.85	10.04	140.25	1408.26	25.79	258.98
										1219.68		171059.80		8112.40

Total Weight	1219.68	Ton
LCG	140.25	m fwd AP
VCG	6.65	m above keel

12.7 Girder & Stringer

GIRDER & STRINGER	web(mm)	thickness(mm)	area(m2)	Length(m)	density(ton/m3)	weight(ton)	longitudinal lever (m)	longitudinal moment (ton-m)	vertical lever (m)	vertical moment (ton-m)
center keelson	2200	19	0.04	295.00	7.85	96.80	140.25	13575.97	1.10	106.48
side girder 1	2200	19	0.04	295.00	7.85	96.80	140.25	13575.97	1.10	106.48
side girder 2	2200	19	0.04	295.00	7.85	96.80	140.25	13575.97	1.10	106.48
side girder 3	3350	13	0.04	295.00	7.85	100.85	140.25	14144.34	1.68	168.93
side girder 4	4500	9	0.04	295.00	7.85	93.79	140.25	13153.75	2.25	211.02
side stringer	2200	18	0.04	295.00	7.85	91.70	140.25	12861.44	20.79	1906.61
						576.74		80887.44		2605.99

Total Weight	576.74	Ton
LCG	140.25	m fwd AP
VCG	4.52	m above keel

12.8 Assumptions

Assumptions	
Paint	1%
Weld	2%
Superstructure	15%

12.9 Total Steel Weight, LCG & VCG

Items	Weight(ton)	LCG(m)	LCG moment(ton-m)	VCG(m)	VCG moment(ton-m)
Plates	8421.46	140.25	1181109.27	10.36	87229.71
Bulkheads	1472.32	135.51	199512.70	13.40	19729.13
Web frame & Floors	1740.82	133.80	232921.18	18.01	31352.10
Mainframes	3279.06	136.18	446526.58	18.01	59055.95
Longitudinal	2533.62	140.25	355339.61	7.40	18743.43
Girder & Stringers	1153.48	140.25	161774.88	4.52	5211.99
Deck Girder	335.64	140.25	47072.88	26.72	8968.18
Deck Web	798.69	133.80	106864.24	26.72	21340.90
Superstructure	18948.30	150.00	2084313.00	30.00	568449.00
Mechinary	1600.00	150.00	236000.00	13.40	21440.00
Outfitting	4034.00	150.00	595015.00	13.40	54055.60
Paint Weight	1263.22	150.00	186324.95	13.40	16927.15
Weld Material Weight	1566.40	150.00	231044.00	13.40	20989.76
Total	**47146.99**		**6063818.30**		**933492.89**

LIGHTSHIP		**47147**	**Ton**
LCG		**147.39**	**m fwd. AP**
VCG		**19.80**	**m above keel**

CHAPTER 13: STABILITY

13.1 GENERAL DEFINATION

13.1.1 Nomenclature:

Symbol	Description	Unit
AP	Aft perpendicular	
BGL	Distance between LCB and LCG	m
BML	Distance of longitudinal metacenter from center of buoyancy	m
BMT	Distance of transverse metacenter from center of buoyancy	m
CB	Block coefficient	
FP	Fore perpendicular	
FSM	Free surface moments	ton-m
g	Gravitational acceleration	ms^{-2}
GM0	Initial metacentric height	m
GMT	Transverse metacentric height	m
GML	Longitudinal metacentric height	m
GZ	Righting Lever	m
KB	Distance of center of buoyancy above keel	m
KG	Distance of center of gravity above keel	m
KGF	Corrected center of gravity above keel	m
KM	Metacentric height above keel	m
KMT	Transverse metacentric height above keel	m
KML	Longitudinal metacentric height above keel	m
KN	Offset from the keel to the vertical line passing through the center of buoyancy	m
L	Waterline length of the ship	m
LF	Distance from FP to draft mark forward	m
LCB	Longitudinal centre of buoyancy	m
LCG	Longitudinal centre of gravity	m
LCF	Longitudinal centre of floatation	m
LPP	Length between perpendiculars	m
lW1	Steady wind heeling lever	m
lW2	Gust wind heeling lever	m
MTC	Moment to change trim one centimeter	tonne-m
OG	Distance between the centre of gravity and the waterline	m
P	Wind pressure	Pa
RM	Righting moment	tonne-m
s	Factor depending on rolling period TR	
SG	Specific Gravity	
T	Moulded Draft	m
t	Trim	m
Ta	Draught at aft draft mark	m
TAP	Draught at AP	m
TCG	Transverse center of gravity	m
Tf	Draught at forward draft mark	m
TFP	Draught at FP	m
TPC	Tonnes per centimeter immersion	tonne/cm
TR	Rolling period	sec
θ	Angle of heel	degrees
θ_0	Angle of heel under action of steady wind	degrees
θ_1	Angle of roll to windward due to wave action	degrees
θ_2	Angle of down flooding (θ_f) or 50° or θ_c, whichever is less	degrees
θ_c	Angle of second intercept between gust wind heeling lever and GZ curve	degrees
θ_f	Angle of heel at which openings in the hull, superstructure, or deckhouses which cannot be closed weather tight, immerse	degrees
VCG	Vertical center of gravity	m
Z	Vertical distance from the center of A to the center of the underwater lateral area or approximately to a point at one half of the draft	m
Δ	Displacement	tonne

13.1.2 Unit conversions:

Multiply by	To convert from	To obtain	
0.039370	mm	inches	25.4
0.39370	cm	inches	2.54
3.2808	m	feet	0.3048
2.2046	KG	lbs	0.45359
0.00098421	KG	Tons (2240 lbs)	1016.0
0.98421	Tonnes (1000 KG)	Tons (2240 lbs)	1.016
2.4999	Tonnes per cm	Tons per inch	0.40002
8.2017	Tonnes metres units (MCTC)	Ton feet units (MCTI)	0.12193
187.98	Metre Radians	Foot Deg	0.0053198

13.1.3 Relationships between Weight and Volume:

10mm cubed = 1 cubic cm

1 cubic cm of fresh water (S.G. = 1.0) = 1 gram

1000 cubic cm of fresh water (S.G. 1 = 1.0) = 1 kg (1000grams)

1 cubic meter of fresh water (S.G. 1 = 1.0) = 1 tonnes (1000kg)

1 cubic meter of salt water (S.G. 1 = 1.025) = 1.025 tonnes (1025kg)

1 Tonne of salt water (S.G. 1 = 1.025) = 0.975 cubic metres

1 cubic metre = 35.316 cubic feet

1 cubic foot = 0.0283 cubic metres

13.2 GENERAL NOTES

The intact stability of this cargo vessel and cross curves of stability have been calculated using the computer program **Maxsurf Stability Advance V.24 Minor** The results and corresponding graphs are presented in the following sections of this booklet.

The calculation of the stability curve and metacentric height GM (Figure 01) takes the actual floating position including trim and heel into account. Therefore, small deviations may be expected when compared to manual calculations.

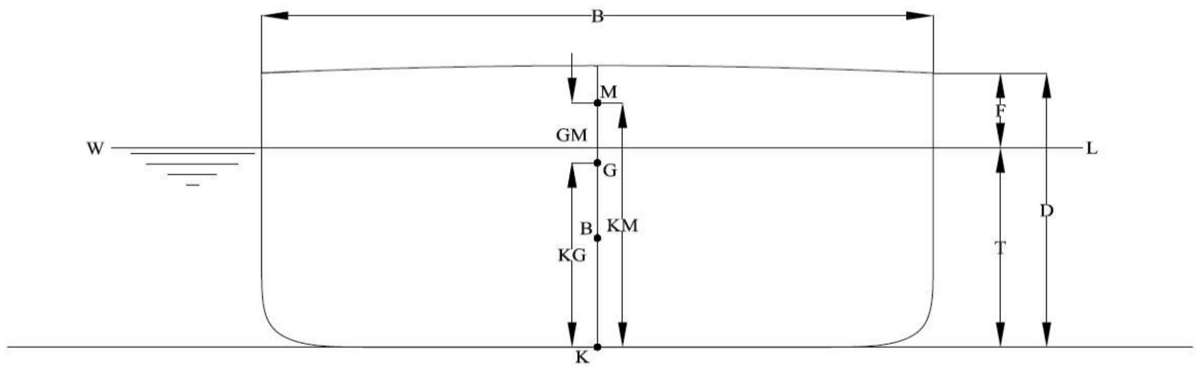


Figure. 01

The Cross curves and Hydrostatic data are presented in tabular form. KN (Figure 03) values in cross curve table are presented at 10 degrees of spacing up to 90 degrees of inclination. KN is defined as the offset from the keel to the vertical line passing through the centre of buoyancy. Righting arm GZ is obtained from the following formula,

$$GZ = KN - KG \sin \theta$$

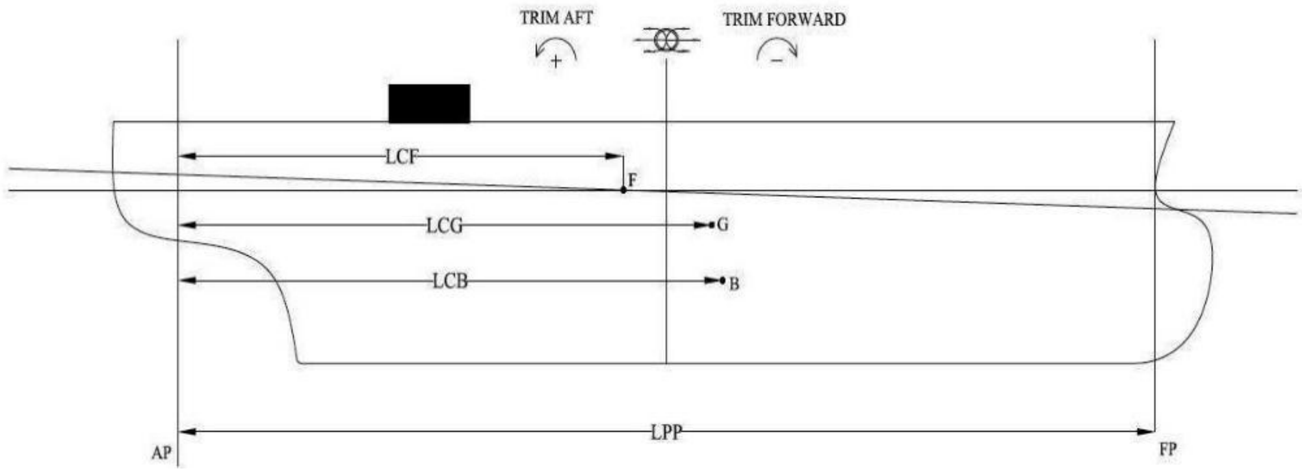
KG = Centre of gravity above keel

θ = Angle of inclination

Sign Convention:

The following sign conventions are adopted in the calculations:

LCG & LCB (Figure 02) are considered negative if located at aft of amidships and positive if located at the forward side of amidships.



Sign convention of trim lever:

Trim by stern is taken as positive.

The trim lever BG_L will be positive when G is situated aft of B and negative when G is situated forward of B.

Correction of displacement for trim:

Because a ship trims about the center of floatation, the draught at that position does not alter with trim. It does alter everywhere else, including amidships where the mean draught between perpendiculars occurs. The displacement of a ship is recorded for different means draughts but at a specified designed trim. Should the ship be floating at a different trim, it is necessary to imagine the ship being trimmed about the center of floatation until it is brought to the designed trim; the revised mean draught is calculated and so the displacement pertinent to that draught can be found.

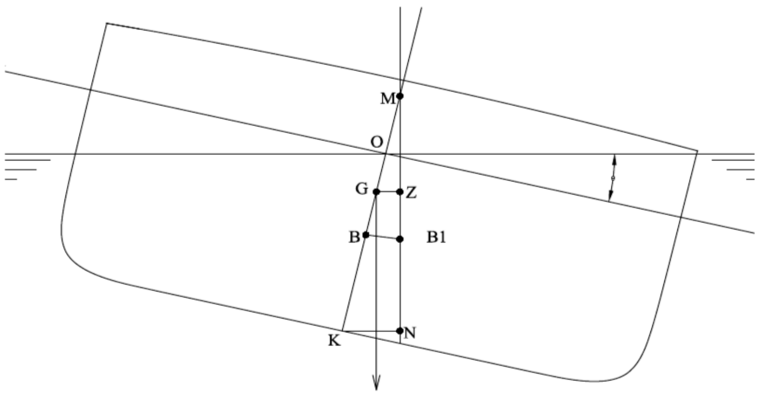
Whether the trim correction is positive or negative depends upon the position of the LCF (Figure 02) and whether the excess trim is by bow or by stern. When the LCF is abaft amidships and there is an excess trim by the bow, the trim correction is negative, i.e. the displacement given by the hydrostatic data for the actual meaning draught to waterline WL is too great. Accordingly, if the LCF is forward of amidships, the trim correction is positive.

Hog and Sag:

Deviation of the keel from a straight line, which may be permanent or temporary in nature or a combination of both, is known as Hog when the keel is concave downward or Sag when the keel is concave upward. Hog or Sag is measured by the difference of calculated and actual drafts amidships. If the actual reading is less than the calculated one, then the ship is hogging and vice versa. The draft should be increased at the center of floatation or at amidships by 75 percent for sag and to decrease it by 75 percent for hog.

Curves of Righting Lever GZ:

Let us consider a symmetrical ship heeled to a very small angle dθ. The center of buoyancy has moved off the ship's centerline as the result of the inclination, and the lines along which the resultants of weight and buoyancy act are separated by a distance GZ, called the righting arm. A vertical line through the center of buoyancy will intersect the original vertical through the center of buoyancy, which is in the ship's centerline plane, at a point M, called the transverse metacenter. The location of this point will vary with the ship's displacement and draft, but for any given draft it will always be in the same location.



When small angles of inclination are considered, the position of the metacenter is assumed to remain unchanged up to about 10 and the initial stability is measured by the distance or the transverse metacentric height. When inclined the righting lever is,

$$GZ = GM \times \sin\theta \text{ (For small angles of inclination)}$$

Use of Cross Curves (KN):

The purpose of the Cross-Curves of KN is to enable Statical Stability Curves to be drawn for the ship in any sailing condition.

$$GZ = KN - KG_F \sin\theta$$

KN = Cross-curve ordinate

KG_F = Center of gravity above keel (Corrected for free surface effects)

θ = Angle of inclination

13.3 VESSEL GENERAL INFORMATION & PARTICULARS

13.3.1 Principal Particulars:

Length, LBP	280.43	m
Breadth, B	48.59	m
Draft, d	11.70	m
Depth, D	26.83	m
Block Coefficient, C_b	0.77	
Dead Weight Coefficient, C_d	0.62	
Deadweight, Dwt	78320	tons
Displacement in tonne, Δ	126322.58	tons
Displacement in m^3, ∇	123241.54	m^3

13.3.2 Frame of Reference:

Aft Perpendicular	0 m
Midships	140.25 m
Fwd Perpendicular	280.5 m
Length Between Perpendiculars	280.5 m
Baseline	0 m
Dead WL	11.7 m

13.3.3 Room definitions:

Steering Gear Room	Compartment		
A.P. T	Tank	1.025	Water Ballast
F.W. T	Tank	1	Fresh Water
Cofferdam	Compartment		
Marine Gas	Tank	0.8524	Gasoil
Lube Oil	Tank	0.92	Lube Oil
Cofferdam	Compartment		
Fuel Tank	Tank	0.9443	Fuel Oil
Engine Room	Compartment		
Machinery Space	Compartment		
Fuel Lube Oil Pump Room	Compartment		
Cofferdam	Compartment		
Fire Ext. Room	Compartment		
Co2 room	Compartment		
Feed Water Pump	Compartment		
Fresh Water Pump	Compartment		
Cofferdam	Compartment		
Fore. W.B.T	Tank	1.025	Water Ballast
F.P.T	Tank	1.025	Water Ballast
F.B.W.Pump	Compartment		
Bilge Pump	Compartment		
Store	Compartment		
Chainlocker	Compartment		
Mud Box	Compartment		
O2 room	Compartment		
Fire ext. Room	Compartment		
Fuel pump	Compartment		
Ballast 1	Tank	1.025	Water Ballast
Ballast 2	Tank	1.025	Water Ballast
Ballast 3	Tank	1.025	Water Ballast
Ballast 4	Tank	1.025	Water Ballast
TANK 1	Tank	0.48	LNG
TANK 2	Tank	0.48	LNG
TANK 3	Tank	0.48	LNG
TANK 4	Tank	0.48	LNG

13.3.4 Key Points:

Name	Long. Pos. m	Offset m	Height m	Type	Linked to	Flood from	Intact (use for intact case)	Damage (use for final damage cases)	Int'md. (used for intermediate damage cases)	Flow into Tank when immersed	Opening cross-sect. area cm^2
Engine Room Vent P	40.000	-20.000	26.800	Down flooding point	None	Sea	1	1	1	0	0.00
Engine Room Vent S	40.000	20.000	26.800	Down flooding point	None	Sea	1	1	1	0	0.00

13.3.5 Hull:

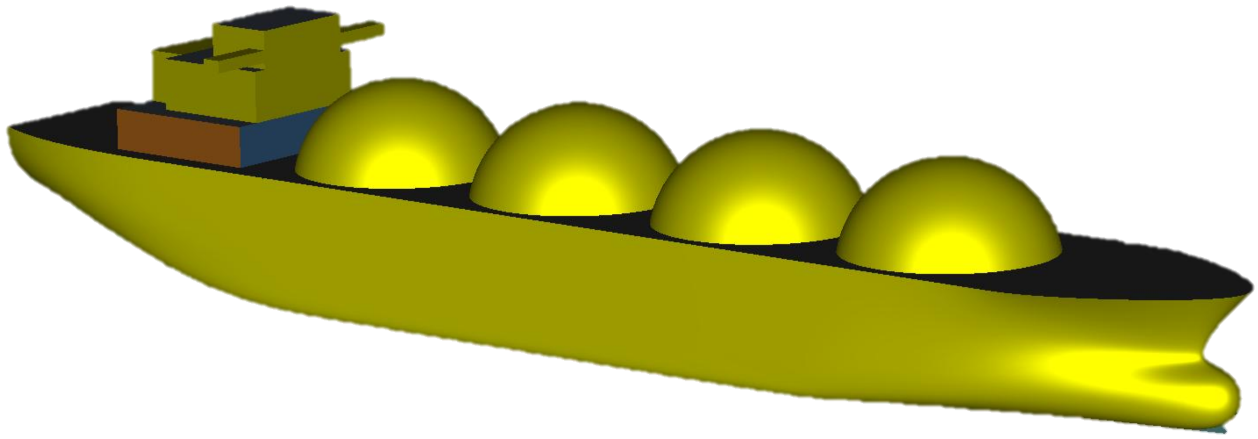


Fig: Maxsurf 3d Hull

13.3.6 Tanks & Compartments:

Fig: Compartments

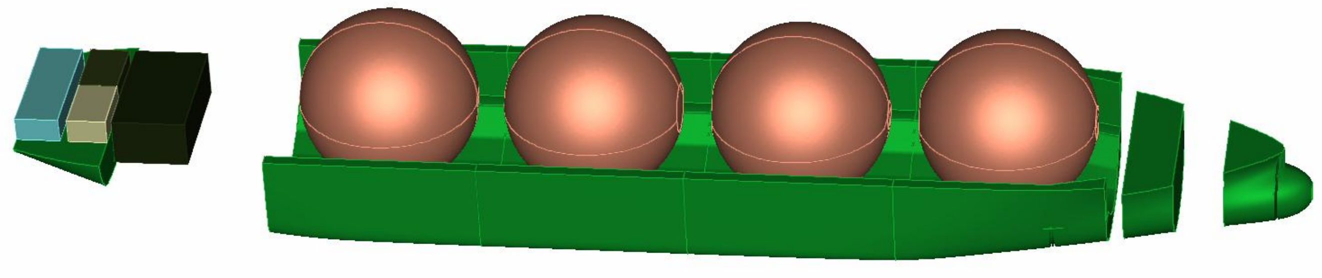


Fig: Tanks

13.4 UPRIGHT HYDROSTATICS

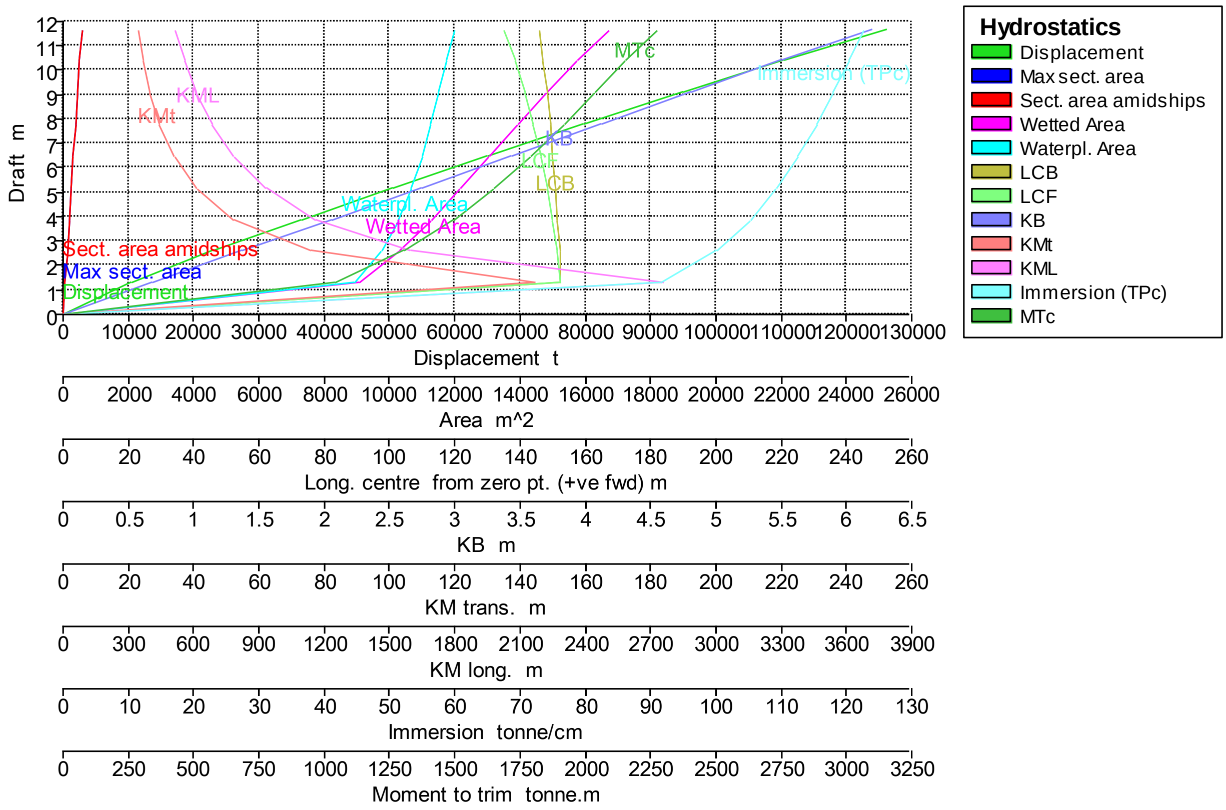
13.4.1 Hydrostatic Data:

Damage Case - Intact

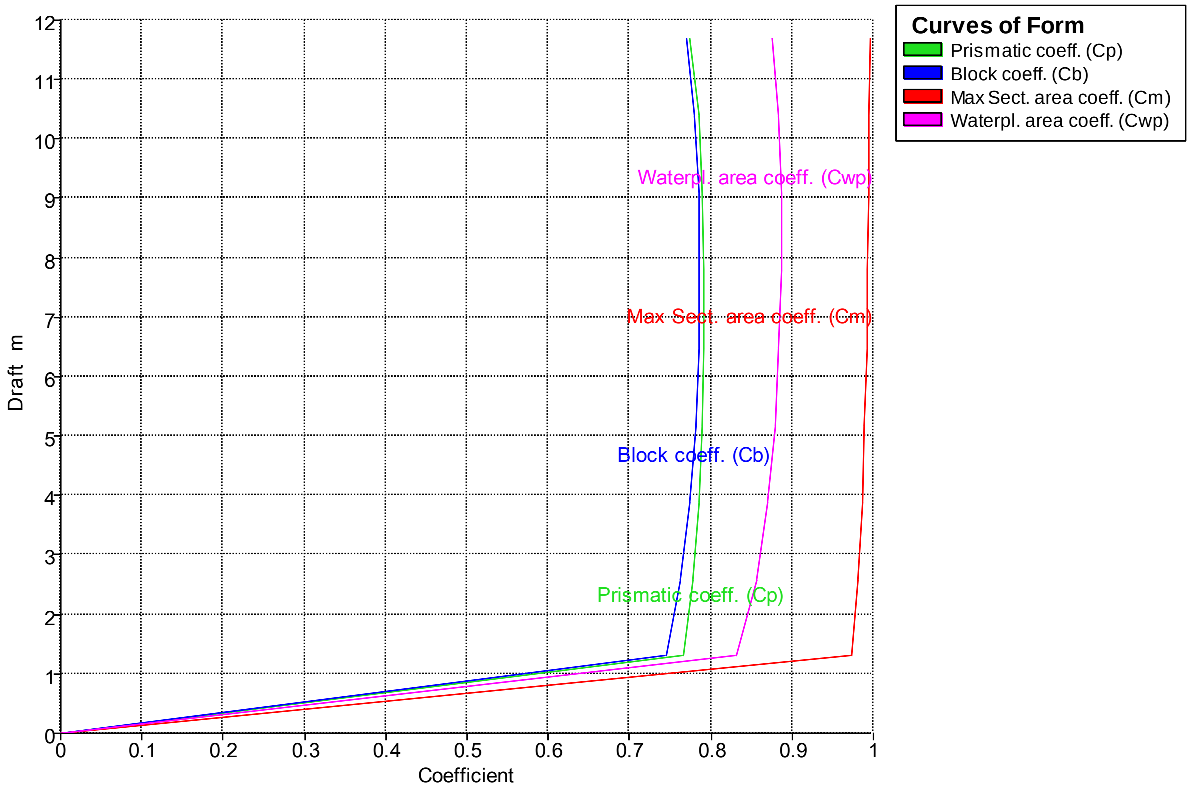
Fixed Trim = 0 m (+ve by stern)
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)

Draft Amidships m	0.000	1.300	2.600	3.900	5.200	6.500	7.800	9.100	10.400	11.700
Displacement t	0.0000	10688	23222	36614	50590	65027	79857	95033	110524	126315
Heel deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Draft at FP m	0.000	1.300	2.600	3.900	5.200	6.500	7.800	9.100	10.400	11.700
Draft at AP m	0.000	1.300	2.600	3.900	5.200	6.500	7.800	9.100	10.400	11.700
Draft at LCF m	0.000	1.300	2.600	3.900	5.200	6.500	7.800	9.100	10.400	11.700
Trim (+ve by stern) m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WL Length m	185.004	223.856	235.286	243.236	249.814	255.779	261.490	267.227	273.327	281.428
Beam max extents on WL m	0.000	48.045	48.540	48.600	48.600	48.600	48.600	48.600	48.600	48.600
Wetted Area m^2	0.000	9105.722	10300.091	11280.825	12192.576	13080.483	13964.753	14858.673	15777.259	16747.951
Waterpl. Area m^2	0.000	8950.989	9780.349	10289.332	10672.141	10987.717	11262.587	11510.547	11737.419	11969.655
Prismatic coeff. (Cp)	0.000	0.766	0.778	0.786	0.790	0.792	0.792	0.789	0.785	0.774
Block coeff. (Cb)	0.000	0.746	0.763	0.775	0.782	0.785	0.786	0.785	0.781	0.770
Max Sect. area coeff. (Cm)	0.000	0.974	0.980	0.986	0.989	0.992	0.993	0.994	0.995	0.995
Waterpl. area coeff. (Cwp)	0.000	0.832	0.856	0.870	0.879	0.884	0.886	0.886	0.884	0.875
LCB from zero pt. (+ve fwd) m	0.000	152.379	152.154	151.601	150.908	150.107	149.207	148.206	147.091	145.836
LCF from zero pt. (+ve fwd) m	0.000	152.501	151.338	149.916	148.245	146.337	144.169	141.667	138.751	135.215
KB m	0.000	0.683	1.372	2.061	2.750	3.439	4.128	4.819	5.510	6.203
KG m	11.700	11.700	11.700	11.700	11.700	11.700	11.700	11.700	11.700	11.700
BMt m	0.000	143.992	74.465	50.204	37.893	30.458	25.474	21.899	19.212	17.126
BML m	0.000	2754.628	1591.671	1157.676	926.518	781.586	682.082	609.389	553.452	512.057
GMt m	-11.700	132.976	64.137	40.565	28.942	22.197	17.903	15.018	13.022	11.629
GML m	-11.700	2743.612	1581.344	1148.037	917.567	773.325	674.511	602.508	547.262	506.560
KMt m	0.000	144.676	75.837	52.265	40.642	33.897	29.603	26.718	24.722	23.329
KML m	0.000	2755.312	1593.044	1159.737	929.267	785.025	686.211	614.208	558.962	518.260
Immersion (TPc) tonne/cm	0.000	91.748	100.249	105.466	109.389	112.624	115.442	117.983	120.309	122.689
MTc tonne.m	0.000	1045.413	1309.183	1498.560	1654.893	1792.772	1920.300	2041.295	2156.352	2281.146
RM at 1deg = GMt.Disp.sin(1) tonne.m	0.000	24804.223	25993.953	25921.397	25553.704	25191.027	24951.062	24907.726	25118.315	25635.563
Max deck inclination deg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Trim angle (+ve by stern) deg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

13.4.2 Hydrostatic Curve:



13.4.3 Curves of Form:



13.5 STABILITY

13.5.1 Loading Conditions:

13.5.1.1 Lightship:

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m
Lightship	1	47147.000	47147.000			147.390	0.000	19.800
A.P.T	0%	5709.227	0.000	5569.978	0.000	23.417	0.000	7.692
F.W.T	0%	1457.557	0.000	1457.557	0.000	8.349	0.000	17.586
Marine Gas	0%	70.579	0.000	82.800	0.000	19.288	12.000	17.586
Lube Oil	0%	76.176	0.000	82.800	0.000	19.288	-12.000	17.586
Fuel Tank	0%	3479.934	0.000	3685.200	0.000	33.081	0.000	12.586
Fore. W.B.T	0%	5835.446	0.000	5693.118	0.000	249.454	0.000	0.000
F.P.T	0%	3360.007	0.000	3278.055	0.000	267.810	0.000	0.000
Ballast 1	0%	15155.252	0.000	14785.611	0.000	95.058	0.000	0.000
Ballast 3	0%	15003.236	0.000	14637.303	0.000	173.704	0.000	0.000
Ballast 2	0%	15040.684	0.000	14673.838	0.000	128.999	0.000	0.000
Ballast 4	0%	11945.063	0.000	11653.720	0.000	205.781	0.000	0.000
TANK 1	0%	14895.841	0.000	31033.001	0.000	0.000	0.000	3.124
TANK 2	0%	14892.040	0.000	31025.083	0.000	0.000	0.000	3.163
TANK 3	0%	14890.505	0.000	31021.885	0.000	0.000	0.000	3.164
TANK 4	0%	14897.054	0.000	31035.528	0.000	0.000	0.000	3.164
Total Load case			47147.000	199715.479	0.000	147.390	0.000	19.800

13.5.1.2 Ballast Departure:

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m
Lightship	1	47147.000	47147.000			147.390	0.000	19.800
A.P.T	100%	5709.227	5709.227	5569.978	5569.978	14.986	0.000	13.917
F.W.T	100%	1457.557	1457.557	1457.557	1457.557	8.349	0.000	20.293
Marine Gas	100%	70.579	70.579	82.800	82.800	19.288	12.000	18.793
Lube Oil	100%	76.176	76.176	82.800	82.800	19.288	-12.000	18.793
Fuel Tank	100%	3479.934	3479.934	3685.200	3685.200	33.081	0.000	17.543
Fore. W.B.T	100%	5835.446	5835.446	5693.118	5693.118	250.059	0.000	9.533
F.P.T	100%	3360.007	3360.007	3278.055	3278.055	272.374	0.000	8.350
Ballast 1	100%	15155.252	15155.252	14785.611	14785.611	83.699	0.000	5.874
Ballast 2	100%	15040.684	15040.684	14673.838	14673.838	129.000	0.000	5.749
Ballast 3	100%	15003.236	15003.236	14637.303	14637.303	173.965	0.000	5.759
Ballast 4	100%	11945.063	11945.063	11653.720	11653.720	216.821	0.000	5.925
TANK 1	0%	14895.841	0.000	31033.001	0.000	0.000	0.000	3.124
TANK 2	0%	14892.040	0.000	31025.083	0.000	0.000	0.000	3.163
TANK 3	0%	14890.505	0.000	31021.885	0.000	0.000	0.000	3.164
TANK 4	0%	14897.054	0.000	31035.528	0.000	0.000	0.000	3.164
Total Load case			124280.161	199715.479	75599.981	144.414	-0.001	12.252

13.5.1.3 Ballast Arrival:

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m
Lightship	1	47147.000	47147.000			147.390	0.000	19.800
A.P.T	100%	5709.227	5709.227	5569.978	5569.978	14.986	0.000	13.917
F.W.T	10%	1457.557	145.756	1457.557	145.756	8.349	0.000	17.857
Marine Gas	10%	70.579	7.058	82.800	8.280	19.288	12.000	17.707
Lube Oil	10%	76.176	7.618	82.800	8.280	19.288	-12.000	17.707
Fuel Tank	10%	3479.934	347.993	3685.200	368.520	33.081	0.000	13.082
Fore. W.B.T	100%	5835.446	5835.446	5693.118	5693.118	250.059	0.000	9.533
F.P.T	100%	3360.007	3360.007	3278.055	3278.055	272.374	0.000	8.350
Ballast 1	100%	15155.252	15155.252	14785.611	14785.611	83.699	0.000	5.874
Ballast 2	100%	15040.684	15040.684	14673.838	14673.838	129.000	0.000	5.749
Ballast 3	100%	15003.236	15003.236	14637.303	14637.303	173.965	0.000	5.759
Ballast 4	100%	11945.063	11945.063	11653.720	11653.720	216.821	0.000	5.925
TANK 1	0%	14895.841	0.000	31033.001	0.000	0.000	0.000	3.124
TANK 2	0%	14892.040	0.000	31025.083	0.000	0.000	0.000	3.163
TANK 3	0%	14890.505	0.000	31021.885	0.000	0.000	0.000	3.164
TANK 4	0%	14897.054	0.000	31035.528	0.000	0.000	0.000	3.164
Total Loadcase			119704.339	199715.479	70822.460	148.956	0.000	12.002

13.5.1.4 Full Load Departure:

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m
Lightship	1	47147.000	47147.000			147.390	0.000	19.800
A.P.T	0%	5709.227	0.000	5569.978	0.000	23.417	0.000	7.692
F.W.T	100%	1457.557	1457.557	1457.557	1457.557	8.349	0.000	20.293
Marine Gas	100%	70.579	70.579	82.800	82.800	19.288	12.000	18.793
Lube Oil	100%	76.176	76.176	82.800	82.800	19.288	-12.000	18.793
Fuel Tank	100%	3479.934	3479.934	3685.200	3685.200	33.081	0.000	17.543
Fore. W.B.T	0%	5835.446	0.000	5693.118	0.000	249.454	0.000	0.000
F.P.T	0%	3360.007	0.000	3278.055	0.000	267.810	0.000	0.000
Ballast 1	0%	15155.252	0.000	14785.611	0.000	95.058	0.000	0.000
Ballast 2	0%	15040.684	0.000	14673.838	0.000	128.999	0.000	0.000
Ballast 3	0%	15003.236	0.000	14637.303	0.000	173.704	0.000	0.000
Ballast 4	0%	11945.063	0.000	11653.720	0.000	205.781	0.000	0.000
TANK 1	100%	14895.841	14895.841	31033.001	31033.001	84.003	0.000	22.624
TANK 2	100%	14892.040	14892.040	31025.083	31025.083	128.992	0.000	22.663
TANK 3	100%	14890.505	14890.505	31021.885	31021.885	174.014	0.000	22.663
TANK 4	100%	14897.054	14897.054	31035.528	31035.528	219.005	0.000	22.663
Total Loadcase			111806.685	199715.479	129423.855	144.044	-0.001	21.255

13.5.1.5 Full Load Arrival:

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m
Lightship	1	47147.000	47147.000			147.390	0.000	19.800
A.P.T	0%	5709.227	0.000	5569.978	0.000	23.417	0.000	7.692
F.W.T	10%	1457.557	145.756	1457.557	145.756	8.349	0.000	17.857
Marine Gas	10%	70.579	7.058	82.800	8.280	19.288	12.000	17.707
Lube Oil	10%	76.176	7.618	82.800	8.280	19.288	-12.000	17.707
Fuel Tank	10%	3479.934	347.993	3685.200	368.520	33.081	0.000	13.082
Fore. W.B.T	0%	5835.446	0.000	5693.118	0.000	249.454	0.000	0.000
F.P.T	0%	3360.007	0.000	3278.055	0.000	267.810	0.000	0.000
Ballast 1	0%	15155.252	0.000	14785.611	0.000	95.058	0.000	0.000
Ballast 2	0%	15040.684	0.000	14673.838	0.000	128.999	0.000	0.000
Ballast 3	0%	15003.236	0.000	14637.303	0.000	173.704	0.000	0.000
Ballast 4	0%	11945.063	0.000	11653.720	0.000	205.781	0.000	0.000
TANK 1	100%	14895.841	14895.841	31033.001	31033.001	84.003	0.000	22.624
TANK 2	100%	14892.040	14892.040	31025.083	31025.083	128.992	0.000	22.663
TANK 3	100%	14890.505	14890.505	31021.885	31021.885	174.014	0.000	22.663
TANK 4	100%	14897.054	14897.054	31035.528	31035.528	219.005	0.000	22.663
Total Loadcase			107230.864	199715.479	124646.334	149.098	0.000	21.360

13.5.2 Equilibrium:

13.5.2.1 Lightship:

Damage Case - Intact

Free to Trim
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)
Fluid analysis method: Simulate fluid movement

Draft Amidships m	5.009
Displacement t	48000
Heel deg	0.0
Draft at FP m	4.127
Draft at AP m	5.891
Draft at LCF m	4.969
Trim (+ve by stern) m	1.764
WL Length m	251.516
Beam max extents on WL m	48.600
Wetted Area m^2	12097.597
Waterpl. Area m^2	10689.425
Prismatic coeff. (Cp)	0.721
Block coeff. (Cb)	0.712
Max Sect. area coeff. (Cm)	0.987
Waterpl. area coeff. (Cwp)	0.874
LCB from zero pt. (+ve fwd) m	144.927
LCF from zero pt. (+ve fwd) m	146.608
KB m	2.643
KG solid m	13.500
BMt m	39.893
BML m	983.375
GMt corrected m	29.036
GML m	972.518
KMt m	42.536
KML m	985.999
Immersion (TPc) tonne/cm	109.567
MTc tonne.m	1664.213
RM at 1deg = GMt.Disp.sin(1) tonne.m	24324.316
Max deck inclination deg	0.3603
Trim angle (+ve by stern) deg	0.3603

Key point	Type	Freeboard m
Margin Line (freeboard pos = -8.213 m)		20.781
Deck Edge (freeboard pos = -8.213 m)		20.857
Engine Room Vent P	Downflooding point	21.160
Engine Room Vent S	Downflooding point	21.160

13.5.2.2 Ballast Departure:

Damage Case - Intact
Free to Trim
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)
Fluid analysis method: Simulate fluid movement

Draft Amidships m	11.138
Displacement t	119533
Heel deg	0.0
Draft at FP m	10.870
Draft at AP m	11.406
Draft at LCF m	11.145
Trim (+ve by stern) m	0.536
WL Length m	280.032
Beam max extents on WL m	48.600
Wetted Area m^2	16354.579
Waterpl. Area m^2	11929.113
Prismatic coeff. (Cp)	0.766
Block coeff. (Cb)	0.762
Max Sect. area coeff. (Cm)	0.994
Waterpl. area coeff. (Cwp)	0.877
LCB from zero pt. (+ve fwd) m	145.375
LCF from zero pt. (+ve fwd) m	136.389
KB m	5.908
KG solid m	10.053
BMt m	18.005
BML m	536.902
GMt corrected m	10.173
GML m	529.069
KMt m	23.913
KML m	542.809
Immersion (TPc) tonne/cm	122.273
MTc tonne.m	2254.599
RM at 1deg = GMt.Disp.sin(1) tonne.m	21221.540
Max deck inclination deg	0.1094
Trim angle (+ve by stern) deg	0.1094

Key point	**Type**	**Freeboard m**
Margin Line (freeboard pos = -8.213 m)		15.303
Deck Edge (freeboard pos = -8.213 m)		15.379
Engine Room Vent P	Downflooding point	15.471
Engine Room Vent S	Downflooding point	15.471

13.5.2.3 Ballast Arrival:

Damage Case - Intact
Free to Trim
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)
Fluid analysis method: Simulate fluid movement

Draft Amidships m	10.998
Displacement t	117840
Heel deg	0.0
Draft at FP m	10.663
Draft at AP m	11.332
Draft at LCF m	11.006
Trim (+ve by stern) m	0.668
WL Length m	279.665
Beam max extents on WL m	48.600
Wetted Area m^2	16257.188
Waterpl. Area m^2	11918.364
Prismatic coeff. (Cp)	0.764
Block coeff. (Cb)	0.760
Max Sect. area coeff. (Cm)	0.994
Waterpl. area coeff. (Cwp)	0.877
LCB from zero pt. (+ve fwd) m	145.245
LCF from zero pt. (+ve fwd) m	136.668
KB m	5.834
KG solid m	9.458
BMt m	18.240
BML m	543.468
GMt corrected m	13.856
GML m	539.083
KMt m	24.074
KML m	549.300
Immersion (TPc) tonne/cm	122.163
MTc tonne.m	2264.720
RM at 1deg = GMt.Disp.sin(1) tonne.m	28495.107
Max deck inclination deg	0.1365
Trim angle (+ve by stern) deg	0.1365

Key point	Type	Freeboard m
Margin Line (freeboard pos = -8.213 m)		15.373
Deck Edge (freeboard pos = -8.213 m)		15.449
Engine Room Vent P	Downflooding point	15.564
Engine Room Vent S	Downflooding point	15.564

13.5.2.4 Full Load Departure:

Damage Case - Intact

Free to Trim
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)
Fluid analysis method: Simulate fluid movement

Draft Amidships m	11.012
Displacement t	117994
Heel deg	0.0
Draft at FP m	10.739
Draft at AP m	11.284
Draft at LCF m	11.019
Trim (+ve by stern) m	0.546
WL Length m	279.143
Beam max extents on WL m	48.600
Wetted Area m^2	16260.045
Waterpl. Area m^2	11906.090
Prismatic coeff. (Cp)	0.767
Block coeff. (Cb)	0.763
Max Sect. area coeff. (Cm)	0.994
Waterpl. area coeff. (Cwp)	0.878
LCB from zero pt. (+ve fwd) m	145.471
LCF from zero pt. (+ve fwd) m	136.731
KB m	5.841
KG solid m	18.012
BMt m	18.208
BML m	540.884
GMt corrected m	5.635
GML m	528.311
KMt m	24.048
KML m	546.723
Immersion (TPc) tonne/cm	122.037
MTc tonne.m	2222.377
RM at 1deg = GMt.Disp.sin(1) tonne.m	11604.764
Max deck inclination deg	0.1114
Trim angle (+ve by stern) deg	0.1114

Key point	Type	Freeboard m
Margin Line (freeboard pos = -8.213 m)		15.424
Deck Edge (freeboard pos = -8.213 m)		15.5
Engine Room Vent P	Downflooding point	15.593
Engine Room Vent S	Downflooding point	15.593

13.5.2.5 Full Load Arrival:

Damage Case - Intact

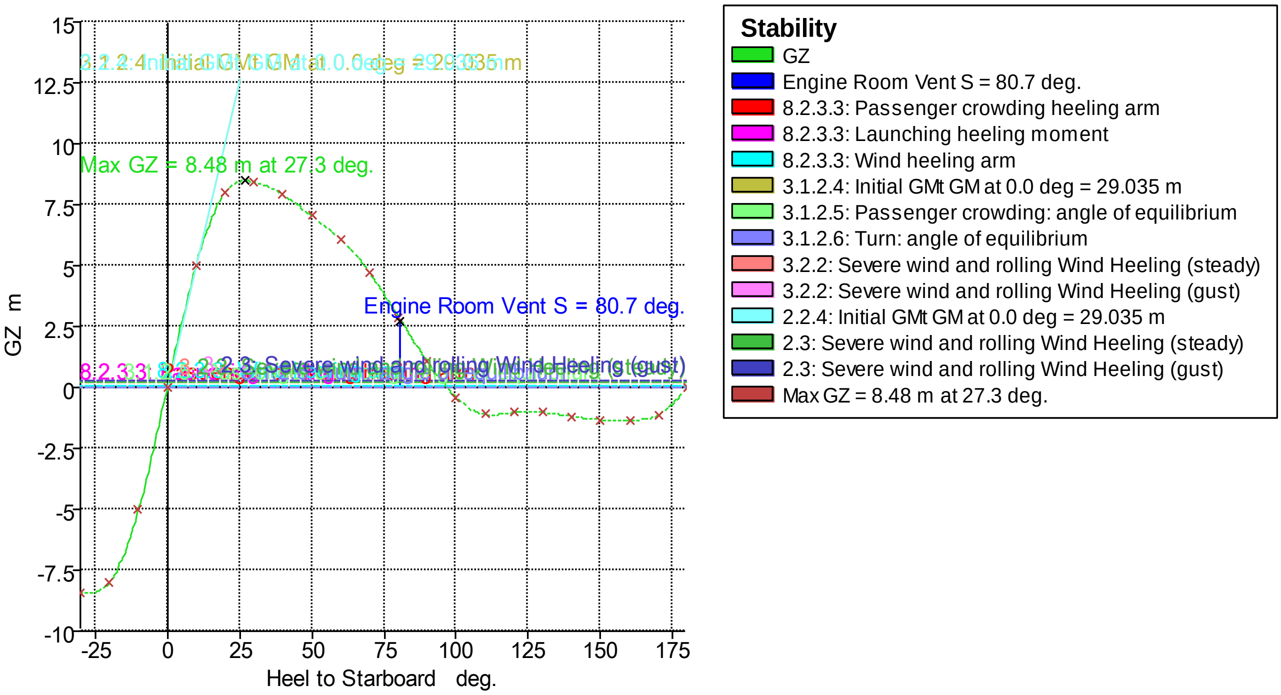
Free to Trim
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)
Fluid analysis method: Simulate fluid movement

Draft Amidships m	10.169
Displacement t	107758
Heel deg	0.0
Draft at FP m	10.086
Draft at AP m	10.252
Draft at LCF m	10.170
Trim (+ve by stern) m	0.166
WL Length m	272.742
Beam max extents on WL m	48.600
Wetted Area m^2	15619.258
Waterpl. Area m^2	11714.156
Prismatic coeff. (Cp)	0.782
Block coeff. (Cb)	0.777
Max Sect. area coeff. (Cm)	0.994
Waterpl. area coeff. (Cwp)	0.884
LCB from zero pt. (+ve fwd) m	146.964
LCF from zero pt. (+ve fwd) m	139.187
KB m	5.388
KG solid m	18.479
BMt m	19.654
BML m	564.822
GMt corrected m	6.109
GML m	551.276
KMt m	25.042
KML m	570.210
Immersion (TPc) tonne/cm	120.070
MTc tonne.m	2117.812
RM at 1deg = GMt.Disp.sin(1) tonne.m	11488.151
Max deck inclination deg	0.0339
Trim angle (+ve by stern) deg	0.0339

Key point	Type	Freeboard m
Margin Line (freeboard pos = 84.55 m)		16.395
Deck Edge (freeboard pos = 84.55 m)		16.471
Engine Room Vent P	Downflooding point	16.571
Engine Room Vent S	Downflooding point	16.571

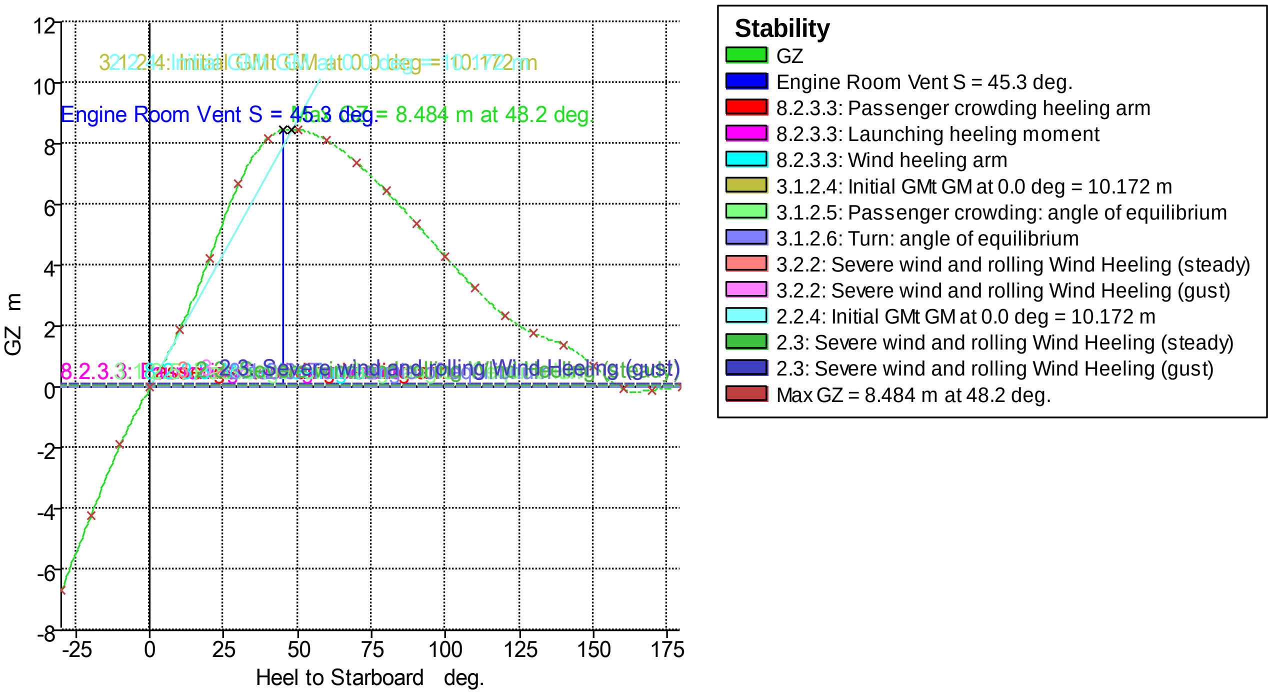
13.5.3 Large Angle Stability:

13.5.3.1 Lightship:



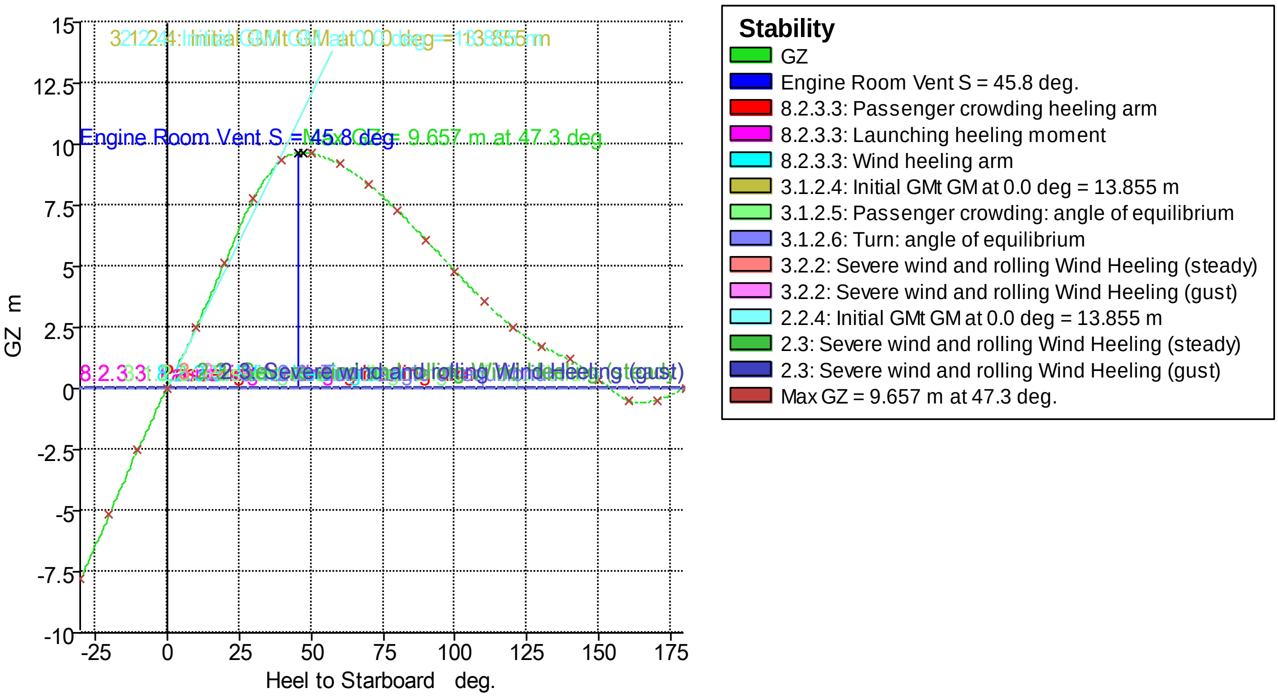
Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle	34.0	deg			
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	8.480	Pass	+21100.00
	8.2.3.3: Launching heeling moment	0.040	m	8.480	Pass	+21100.00
	8.2.3.3: Wind heeling arm	0.040	m	8.427	Pass	+20967.50
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	8.480	Pass	+16860.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	96.8	Pass	+1282.83
SOLAS, II-1/8	8.6.3: Margin line immersion - GZ based (EquilAngle ratio)	100.00	%	0.00	Pass	+100.00
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30	3.1513	m.deg	177.2270	Pass	+5523.93
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 40	5.1566	m.deg	259.4572	Pass	+4931.56
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 30 to 40	1.7189	m.deg	82.2302	Pass	+4683.88
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.2: Max GZ at 30 or greater	0.200	m	8.436	Pass	+4118.00
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.3: Angle of maximum GZ	25.0	deg	27.3	Pass	+9.09
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.4: Initial GMt	0.150	m	29.035	Pass	+19256.67
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.5: Passenger crowding: angle of equilibrium	10.0	deg	0.0	Pass	+100.00
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.6: Turn: angle of equilibrium	10.0	deg	0.0	Pass	+100.00
A.749(18) Ch3 - Design criteria applicable to all ships	3.2.2: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.3	Pass	+97.83
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	0.65	Pass	+99.19
	Area1 / Area2 shall not be less than (>=)	100.00	%	230.66	Pass	+130.66
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30	3.1513	m.deg	177.2270	Pass	+5523.93
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40	5.1566	m.deg	259.4572	Pass	+4931.56
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40	1.7189	m.deg	82.2302	Pass	+4683.88
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater	0.200	m	8.436	Pass	+4118.00
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ	25.0	deg	27.3	Pass	+9.09
267(85) Ch2 - General Criteria	2.2.4: Initial GMt	0.150	m	29.035	Pass	+19256.67
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.3	Pass	+97.83
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	0.65	Pass	+99.19

13.5.3.2 Ballast Departure:



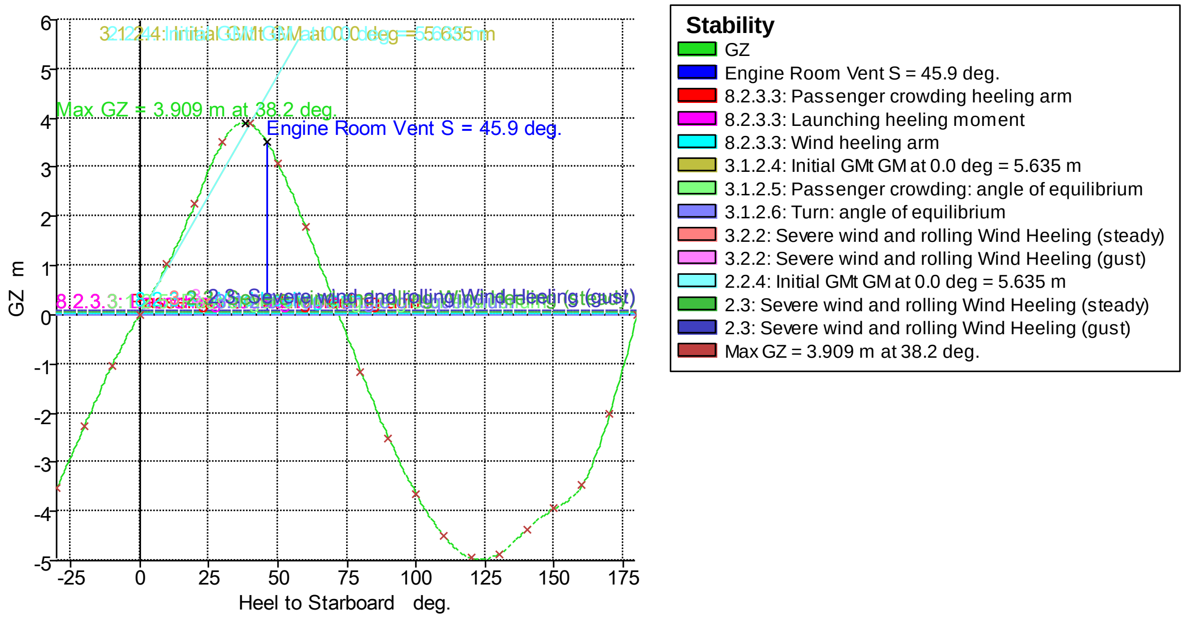
Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle	22.0	deg			
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	8.454	Pass	+21035.00
	8.2.3.3: Launching heeling moment	0.040	m	8.454	Pass	+21035.00
	8.2.3.3: Wind heeling arm	0.040	m	8.435	Pass	+20987.50
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	8.484	Pass	+16868.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	158.7	Pass	+2166.59
SOLAS, II-1/8	8.6.3: Margin line immersion - GZ based (EquilAngle ratio)	100.00	%	0.03	Pass	+99.97
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30	3.1513	m.deg	94.1680	Pass	+2888.23
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 40	5.1566	m.deg	169.6442	Pass	+3189.85
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 30 to 40	1.7189	m.deg	75.4762	Pass	+4290.96
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.2: Max GZ at 30 or greater	0.200	m	8.484	Pass	+4142.00
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.3: Angle of maximum GZ	25.0	deg	48.2	Pass	+92.73
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.4: Initial GMt	0.150	m	10.172	Pass	+6681.33
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.5: Passenger crowding: angle of equilibrium	10.0	deg	0.0	Pass	+100.15
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.6: Turn: angle of equilibrium	10.0	deg	0.0	Pass	+100.15
A.749(18) Ch3 - Design criteria applicable to all ships	3.2.2: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.3	Pass	+97.91
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	1.00	Pass	+98.75
	Area1 / Area2 shall not be less than (>=)	100.00	%	328.59	Pass	+228.59
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30	3.1513	m.deg	94.1680	Pass	+2888.23
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40	5.1566	m.deg	169.6442	Pass	+3189.85
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40	1.7189	m.deg	75.4762	Pass	+4290.96
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater	0.200	m	8.484	Pass	+4142.00
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ	25.0	deg	48.2	Pass	+92.73
267(85) Ch2 - General Criteria	2.2.4: Initial GMt	0.150	m	10.172	Pass	+6681.33
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.3	Pass	+97.91
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	1.00	Pass	+98.75
	Area1 / Area2 shall not be less than (>=)	100.00	%	429.95	Pass	+329.95

13.5.3.3 Ballast Arrival:



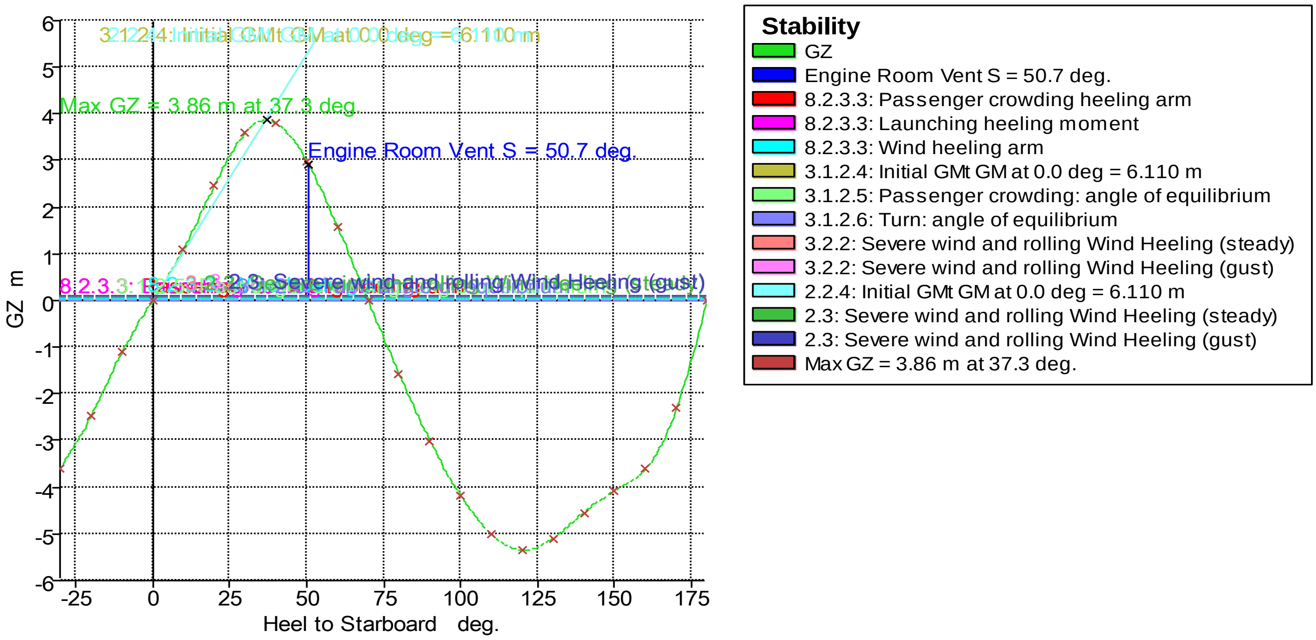
Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle	20.9	deg			
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	9.644	Pass	+24010.00
	8.2.3.3: Launching heeling moment	0.040	m	9.644	Pass	+24010.00
	8.2.3.3: Wind heeling arm	0.040	m	9.625	Pass	+23962.50
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	9.657	Pass	+19214.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	153.9	Pass	+2098.64
SOLAS, II-1/8	8.6.3: Margin line immersion - GZ based (EquilAngle ratio)	100.00	%	0.00	Pass	+100.00
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30	3.1513	m.deg	115.5796	Pass	+3567.68
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 40	5.1566	m.deg	202.4392	Pass	+3825.83
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 30 to 40	1.7189	m.deg	86.8597	Pass	+4953.21
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.2: Max GZ at 30 or greater	0.200	m	9.657	Pass	+4728.50
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.3: Angle of maximum GZ	25.0	deg	47.3	Pass	+89.09
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.4: Initial GMt	0.150	m	13.855	Pass	+9136.67
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.5: Passenger crowding: angle of equilibrium	10.0	deg	0.0	Pass	+100.01
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.6: Turn: angle of equilibrium	10.0	deg	0.0	Pass	+100.01
A.749(18) Ch3 - Design criteria applicable to all ships	3.2.2: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.3	Pass	+98.40
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	0.76	Pass	+99.05
	Area1 / Area2 shall not be less than (>=)	100.00	%	315.40	Pass	+215.40
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30	3.1513	m.deg	115.5796	Pass	+3567.68
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40	5.1566	m.deg	202.4392	Pass	+3825.83
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40	1.7189	m.deg	86.8597	Pass	+4953.21
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater	0.200	m	9.657	Pass	+4728.50
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ	25.0	deg	47.3	Pass	+89.09
267(85) Ch2 - General Criteria	2.2.4: Initial GMt	0.150	m	13.855	Pass	+9136.67
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.3	Pass	+98.40
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	0.76	Pass	+99.05
	Area1 / Area2 shall not be less than (>=)	100.00	%	451.75	Pass	+351.75

13.5.3.4 Full Load Departure:



Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle	20.9	deg			
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	3.909	Pass	+9672.50
	8.2.3.3: Launching heeling moment	0.040	m	3.909	Pass	+9672.50
	8.2.3.3: Wind heeling arm	0.040	m	3.889	Pass	+9622.50
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	3.909	Pass	+7718.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	72.1	Pass	+929.79
SOLAS, II-1/8	8.6.3: Margin line immersion - GZ based (EquilAngle ratio)	100.00	%	0.06	Pass	+99.94
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30	3.1513	m.deg	50.7077	Pass	+1509.10
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 40	5.1566	m.deg	88.7459	Pass	+1621.02
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 30 to 40	1.7189	m.deg	38.0381	Pass	+2112.94
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.2: Max GZ at 30 or greater	0.200	m	3.909	Pass	+1854.50
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.3: Angle of maximum GZ	25.0	deg	38.2	Pass	+52.73
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.4: Initial GMt	0.150	m	5.635	Pass	+3656.67
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.5: Passenger crowding: angle of equilibrium	10.0	deg	0.0	Pass	+100.27
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.6: Turn: angle of equilibrium	10.0	deg	0.0	Pass	+100.27
A.749(18) Ch3 - Design criteria applicable to all ships	3.2.2: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.6	Pass	+96.18
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	1.81	Pass	+97.74
	Area1 / Area2 shall not be less than (>=)	100.00	%	306.10	Pass	+206.10
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30	3.1513	m.deg	50.7077	Pass	+1509.10
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40	5.1566	m.deg	88.7459	Pass	+1621.02
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40	1.7189	m.deg	38.0381	Pass	+2112.94
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater	0.200	m	3.909	Pass	+1854.50
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ	25.0	deg	38.2	Pass	+52.73
267(85) Ch2 - General Criteria	2.2.4: Initial GMt	0.150	m	5.635	Pass	+3656.67
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.6	Pass	+96.18
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	1.81	Pass	+97.74
	Area1 / Area2 shall not be less than (>=)	100.00	%	446.99	Pass	+346.99

13.5.3.5 Full Load Arrival:



Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.3: IMO roll back angle	22.0	deg			
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	3.860	Pass	+9550.00
	8.2.3.3: Launching heeling moment	0.040	m	3.860	Pass	+9550.00
	8.2.3.3: Wind heeling arm	0.040	m	3.839	Pass	+9497.50
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	3.860	Pass	+7620.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	69.9	Pass	+899.01
SOLAS, II-1/8	8.6.3: Margin line immersion - GZ based (EquilAngle ratio)	100.00	%	0.01	Pass	+99.99
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30	3.1513	m.deg	54.0269	Pass	+1614.43
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 40	5.1566	m.deg	91.9385	Pass	+1682.93
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 30 to 40	1.7189	m.deg	37.9117	Pass	+2105.58
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.2: Max GZ at 30 or greater	0.200	m	3.860	Pass	+1830.00
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.3: Angle of maximum GZ	25.0	deg	37.3	Pass	+49.09
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.4: Initial GMt	0.150	m	6.110	Pass	+3973.33
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.5: Passenger crowding: angle of equilibrium	10.0	deg	0.0	Pass	+100.06
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.6: Turn: angle of equilibrium	10.0	deg	0.0	Pass	+100.06
A.749(18) Ch3 - Design criteria applicable to all ships	3.2.2: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.7	Pass	+95.77
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	1.92	Pass	+97.60
	Area1 / Area2 shall not be less than (>=)	100.00	%	322.02	Pass	+222.02
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30	3.1513	m.deg	54.0269	Pass	+1614.43
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40	5.1566	m.deg	91.9385	Pass	+1682.93
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40	1.7189	m.deg	37.9117	Pass	+2105.58
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater	0.200	m	3.860	Pass	+1830.00
267(85) Ch2 - General Criteria	2.2.3: Angle of maximum GZ	25.0	deg	37.3	Pass	+49.09
267(85) Ch2 - General Criteria	2.2.4: Initial GMt	0.150	m	6.110	Pass	+3973.33
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Angle of steady heel shall not be greater than (<=)	16.0	deg	0.7	Pass	+95.77
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	1.92	Pass	+97.60
	Area1 / Area2 shall not be less than (>=)	100.00	%	418.70	Pass	+318.70

13.6 CROSS CURVES OF STABILITY

13.6.1KN Values:

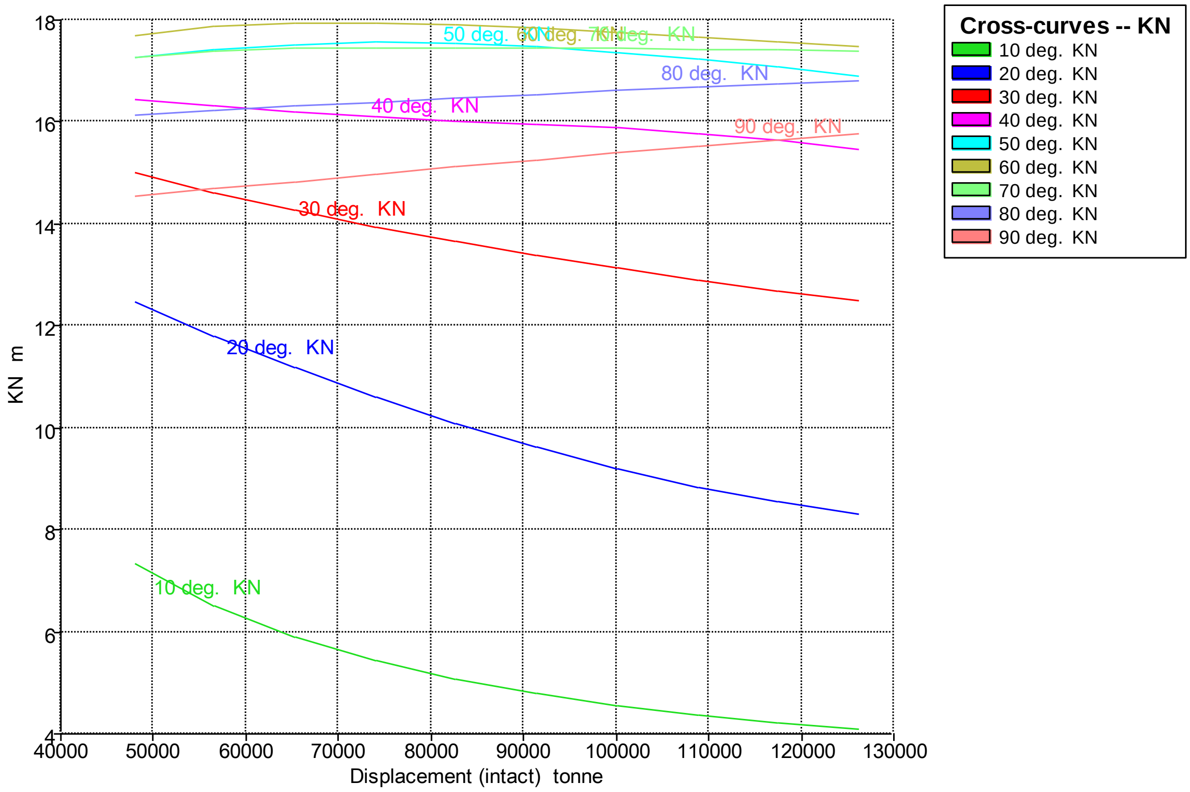
Damage Case - Intact

Initial Trim = 0 m (+ve by stern)
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)
VCG = 0 m; TCG = 0 m

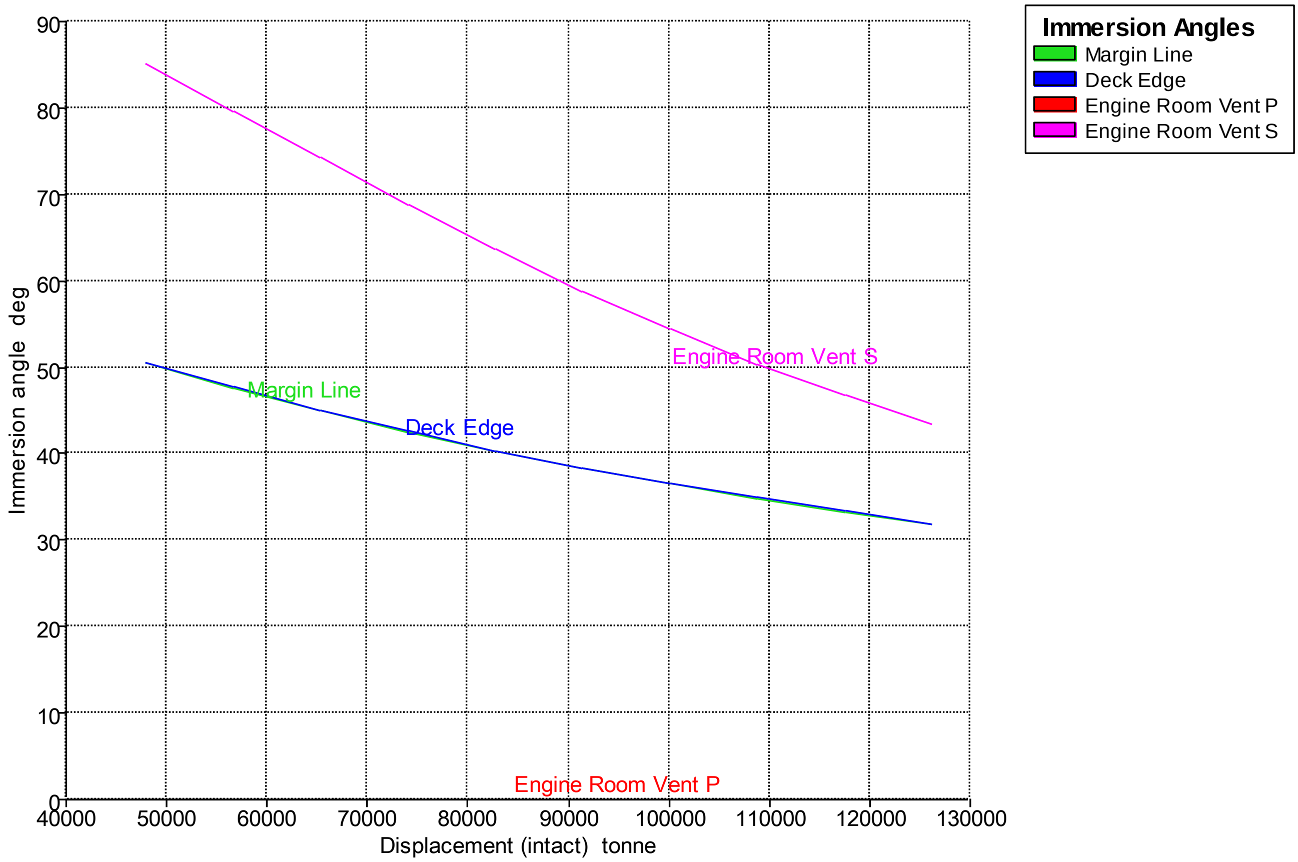
Displacement (intact) tonne	Draft Amidships m	Trim (+ve by stern) m	LCG m	TCG m	Assumed VCG m	KN 10.0 deg. Starb.	KN 20.0 deg. Starb.	KN 30.0 deg. Starb.	KN 40.0 deg. Starb.	KN 50.0 deg. Starb.	KN 60.0 deg. Starb.	KN 70.0 deg. Starb.	KN 80.0 deg. Starb.	KN 90.0 deg. Starb.
15735	1.837	0.000	152.356	0.000	0.000	13.022	16.194	17.242	17.272	16.660	15.680	14.784	14.618	14.546
28022	3.074	0.000	151.974	0.000	0.000	10.303	14.441	16.182	16.876	16.928	16.665	16.372	15.673	14.405
40308	4.248	0.000	151.426	0.000	0.000	8.280	13.153	15.408	16.583	17.144	17.396	17.077	16.012	14.462
52595	5.383	0.000	150.802	0.000	0.000	6.863	12.104	14.792	16.365	17.349	17.795	17.350	16.180	14.623
64882	6.487	0.000	150.116	0.000	0.000	5.933	11.207	14.277	16.200	17.509	17.944	17.438	16.305	14.823
77168	7.567	0.000	149.376	0.000	0.000	5.296	10.418	13.832	16.073	17.559	17.936	17.456	16.420	15.030
89455	8.625	0.000	148.584	0.000	0.000	4.845	9.718	13.441	15.977	17.494	17.852	17.452	16.527	15.230
101742	9.666	0.000	147.736	0.000	0.000	4.516	9.129	13.092	15.867	17.340	17.736	17.440	16.628	15.420
114028	10.691	0.000	146.824	0.000	0.000	4.273	8.662	12.777	15.699	17.137	17.608	17.423	16.720	15.596
126315	11.700	0.000	145.836	0.000	0.000	4.091	8.301	12.491	15.465	16.910	17.475	17.402	16.804	15.760

Key point	Type	Immersion angle at 15735 t deg	Immersion angle at 28022 t deg	Immersion angle at 40308 t deg	Immersion angle at 52595 t deg	Immersion angle at 64882 t deg	Immersion angle at 77168 t deg	Immersion angle at 89455 t deg	Immersion angle at 101742 t deg	Immersion angle at 114028 t deg	Immersion angle at 126315 t deg
Margin Line		69.0	59.9	53.8	48.9	45.1	41.7	38.8	36.2	33.9	31.8
Deck Edge		68.9	59.9	53.8	49.0	45.2	41.7	38.8	36.3	34.0	31.8
Engine Room Vent P	Downflooding point	Not immersed in positive range	Not immersed in positive range	Not immersed in positive range	Not immersed in positive range	Not immersed in positive range	Not immersed in positive range	Not immersed in positive range	Not immersed in positive range	Not immersed in positive range	Not immersed in positive range
Engine Room Vent S	Downflooding point	Not immersed in positive range	Not immersed in positive range	89.6	82.2	74.5	66.9	59.9	53.6	48.1	43.5

13.6.2 Graphs:



Cross-curves -- KN
10 deg. KN
20 deg. KN
30 deg. KN
40 deg. KN
50 deg. KN
60 deg. KN
70 deg. KN
80 deg. KN
90 deg. KN
KN m
Displacement (intact) tonne



Immersion Angles
Margin Line
Deck Edge
Engine Room Vent P
Engine Room Vent S
Immersion angle deg
Displacement (intact) tonne

CHAPTER 14: RESISTANCE & POWER CALCULATION

14.1 INTRODUCTION TO RESISTANCE

The movement of a ship through water requires energy to overcome resistance, i.e. the force working against movement. The total resistance to calm water can be divided into three main components:

1. Frictional resistance
2. Residual resistance
3. Air resistance.

In mathematical terms, total resistance can be written as:

$R_T = R_V + R_W + R_{TR} + R_B + R_{App} + R_{AA}$

Where:

R_T = Total hull resistance
R_V = Viscous (Friction) resistance
R_W = Wave making resistance
R_{App} = Appendage Resistance
R_B = Additional Pressure Resistance of Bulbous Bow
R_{TR} = Additional Pressure Resistance of Immersed Transom
R_{AA} = Air resistance caused by vessel moving through calm air

The resistance of an LNG carrier is a crucial factor influencing its power requirements, fuel consumption, and operational efficiency. Resistance is the total force opposing the vessel's forward motion through water, and minimizing it is essential for improving performance and reducing costs. It can be divided into several components, each contributing to the overall resistance experienced by the ship.

Modern LNG carrier designs employ a range of techniques to minimize resistance.

- Hull optimization, such as streamlining the hull form.
- Increasing waterline length relative to beam, reduces both frictional and wave-making resistance.
- The use of appendages like bulbous bows and energy-saving devices, such as ducts or fins near the propeller, further enhances efficiency.
- Operational strategies, including speed optimization and route planning, also play a vital role in minimizing resistance and fuel consumption.

LNG carriers, being large vessels with a significant wetted surface area and heavy displacement, are particularly sensitive to resistance. Their design must consider the challenges of long-distance voyages, which often include navigating canals and open seas. By addressing all resistance components, ship designers and operators can achieve optimal propulsion efficiency, reduce operational costs, and improve the environmental sustainability of these vessels.

Taking all these conditions into consideration, we have designed our hull with bulbous bow and calculated the total resistance for our ship to calculate the total resistance and effective power **"Maxsurf Resistance Module"** software has been used. For validation, we calculated resistance manually using “**Holtrop & Mennen’s Method”**.

14.2 Used Method:

- Holtrop Method
- Using ITTC Formula

14.3 Input Data:

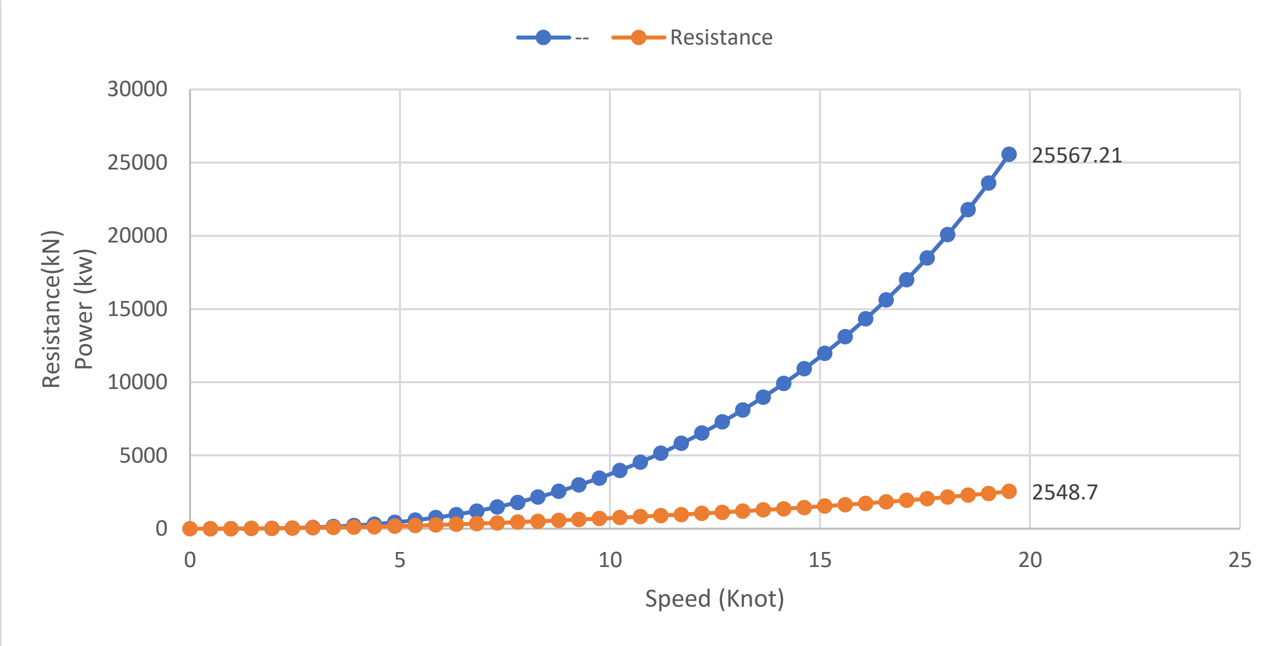
	Items	Value	Unit	Holtrop
1	LWL	281.428	m	281.428
2	Beam	48.6	m	48.6 (high)
3	Draft	11.7	m	11.7 (low)
4	Displaced volume	123231.7	m^3	123231.736
5	Wetted area	16727.56	m^2	16727.555
6	Prismatic Coeff. (Cp)	0.774		0.774
7	Waterplane. area Coeff. (Cwp)	0.875		0.875
8	1/2 angle of entrance	25.1	deg.	25.1
9	LCG from midships (+ve for'd)	5.574	m	5.574
10	Transom area	343.367	m^2	343.367
11	Transom wl beam	0	m	--
12	Transom draft	0	m	--
13	Max sectional area	565.962	m^2	--
14	Bulb transverse area	84.487	m^2	84.487
15	Bulb height from keel	6.537	m	6.537
16	Draft at FP	11.7	m	11.7
17	Deadrise at 50% LWL	0	deg.	--
18	Hard chine or round bilge	Round bilge		--
20	Frontal Area	2597.006	m^2	
21	Headwind	19.5	kn	
22	Drag Coefficient	0		
23	Air density	0.001	tonne/m^3	
24	Appendage Area	0	m^2	
25	Nominal App. length	0	m	
26	Appendage Factor	1		
28	Correlation allowance	0.0004		Calculated by method
29	Kinematic viscosity	1.19E-06	m^2/s	
30	Water Density	1.0259	tonne/m^3	

14.4 RESULT

14.4.1 Maxsurf Calculated Resistance & Effective Power:

Speed (Knot)	Froude No. LWL	Froude No. Vol.	Holtrop Resistance (KN)	Holtrop Power (kW)	Holtrop Power (Hp)
0	0	0	--	--	--
0.487	0.005	0.011	1.7	0.435	0.584
0.975	0.01	0.023	6.6	3.304	4.431
1.462	0.014	0.034	14.6	11.022	14.78
1.95	0.019	0.045	26.1	26.192	35.124
2.438	0.024	0.057	41.1	51.596	69.192
2.925	0.029	0.068	59.9	90.137	120.876
3.413	0.033	0.079	82.5	144.766	194.134
3.9	0.038	0.091	108.9	218.416	292.901
4.388	0.043	0.102	139.1	313.939	421
4.875	0.048	0.114	173.1	434.056	582.079
5.363	0.053	0.125	210.7	581.323	779.566
5.85	0.057	0.136	251.9	758.109	1016.64
6.337	0.062	0.148	296.5	966.593	1296.222
6.825	0.067	0.159	344.3	1208.767	1620.982
7.313	0.072	0.17	395.1	1486.443	1993.352
7.8	0.076	0.182	448.9	1801.277	2415.551
8.287	0.081	0.193	505.4	2154.786	2889.615
8.775	0.086	0.204	564.5	2548.378	3417.43
9.262	0.091	0.216	626.1	2983.374	4000.77
9.75	0.095	0.227	690	3461.05	4641.344
10.238	0.1	0.238	756.2	3982.667	5340.843
10.725	0.105	0.25	824.6	4549.514	6100.997
11.213	0.11	0.261	895.1	5162.958	6923.64
11.7	0.115	0.272	967.7	5824.496	7810.776
12.188	0.119	0.284	1042.4	6535.805	8764.657
12.675	0.124	0.295	1119.3	7298.808	9787.862
13.163	0.129	0.307	1198.5	8115.736	10883.38
13.65	0.134	0.318	1280.1	8989.186	12054.695
14.138	0.138	0.329	1364.3	9922.185	13305.868
14.625	0.143	0.341	1451.2	10918.253	14641.615
15.113	0.148	0.352	1541.1	11981.452	16067.389
15.6	0.153	0.363	1634.4	13116.446	17589.44
16.087	0.158	0.375	1731.3	14328.54	19214.885
16.575	0.162	0.386	1832.3	15623.724	20951.755
17.063	0.167	0.397	1937.7	17008.701	22809.04
17.55	0.172	0.409	2048.1	18490.905	24796.708
18.038	0.177	0.42	2163.8	20078.546	26925.769
18.525	0.181	0.431	2285.5	21780.67	29208.354
19.013	0.186	0.443	2413.6	23606.887	31657.352
19.5	0.191	0.454	2548.7	25567.21	34286.187

14.4.2 Effective Power & Resistance vs Speed:



14.4.3 Final Effective Power & Resistance:

Speed (Knot)	Holtrop Resistance (KN)	Holtrop Power (kW)	Holtrop Power (Hp)
19.5	2548.7	25567.21	34286.187

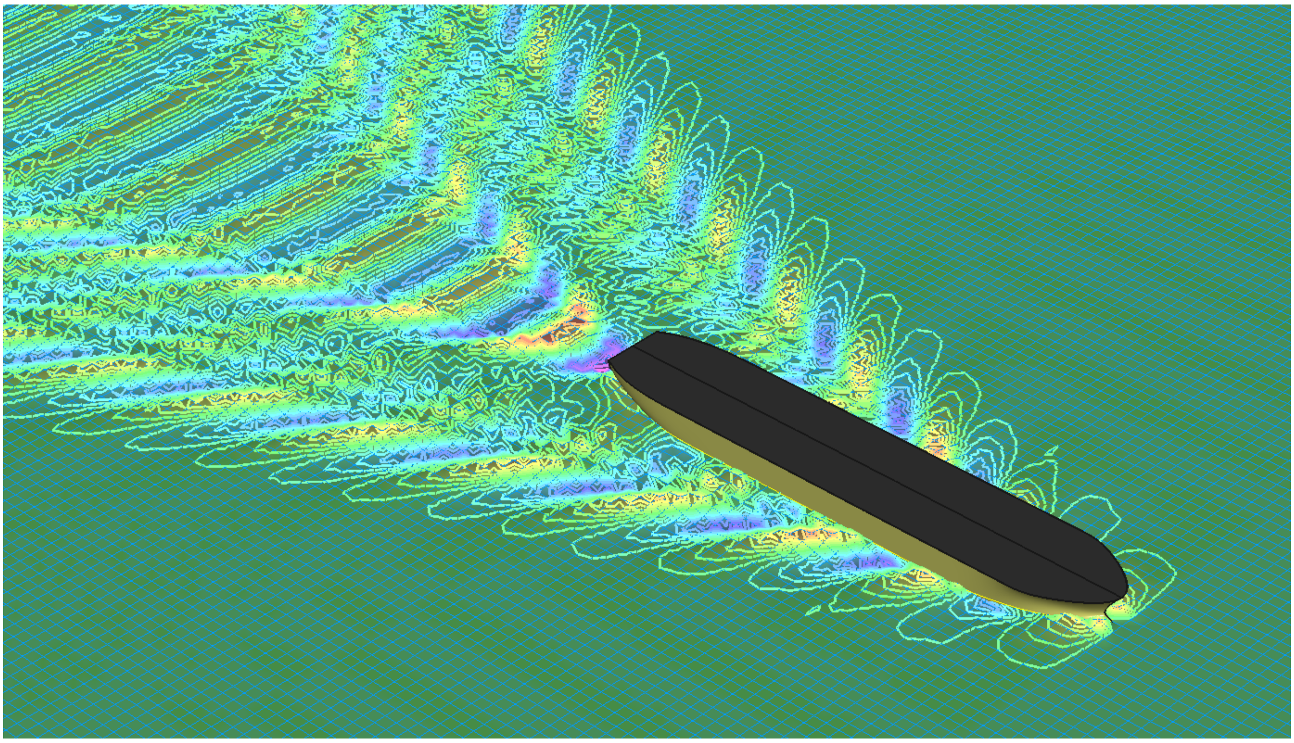
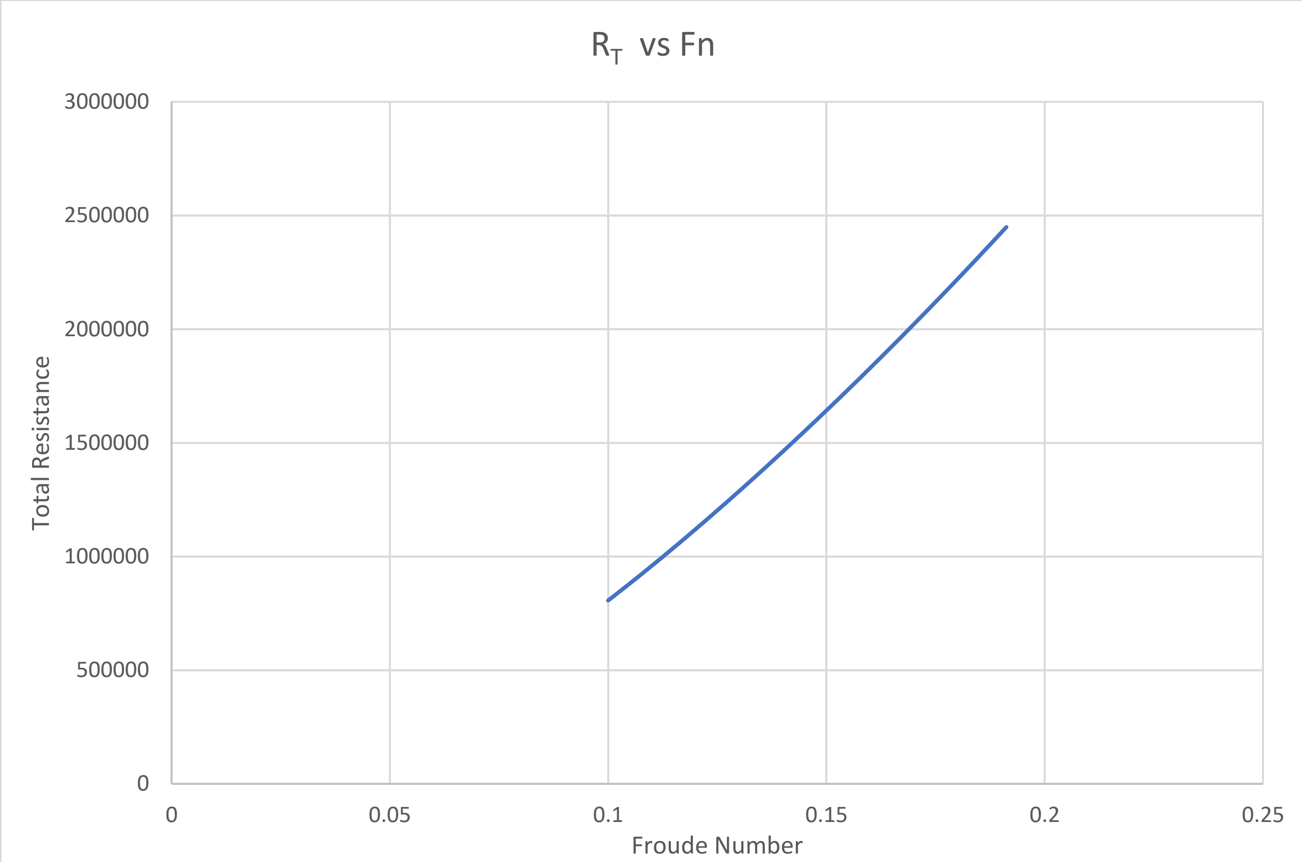


Figure: Free Surface Calculated by Maxsurf

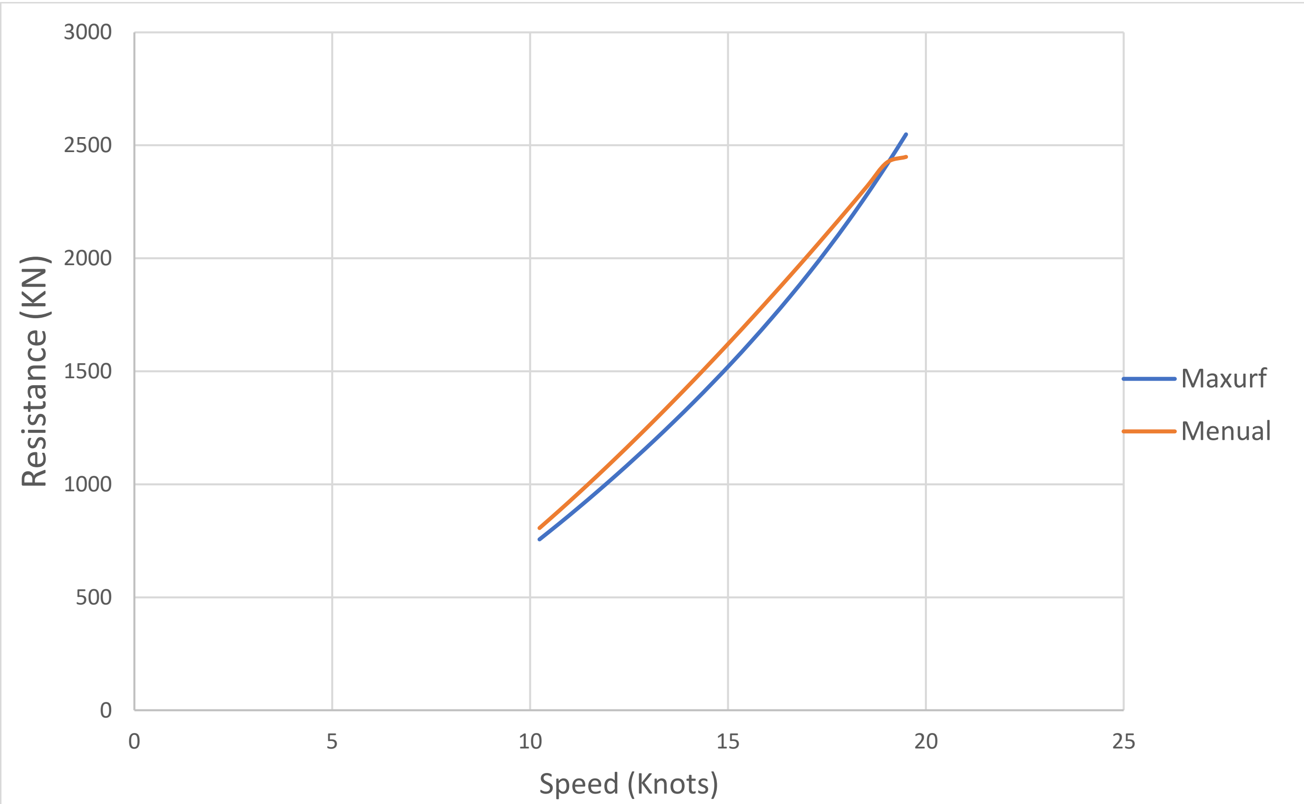
14.5 PREDICTION OF RESISTANCE BY HOLTROP & MENNEN'S METHOD

Table for Fixed Parameters & Coefficients				
Description	Symbol	Equation & Conditions	Value	Unit
Wetted Surface Area of Bare Hull	S_{BH}	$L_{WL}(2T+B)\sqrt{C_M}(0.4530+0.4425C_B-0.2862C_M-0.003467\frac{B}{T}+0.3696C_{WP})+2.38\frac{A\_BT}{C_B}$	16501.16449	m^2
Waterline area coeffiecient	C_{WP}	$0.67C_B+0.32$	0.8359	
Transverse Area of Bulbous Bow	A_{BT}		84.487	m^2
Form Factor	$1+k_1$	$0.93+0.487118*C_{14}\left(\frac{B}{L_{WL}}\right)^{1.06806}*\left(\frac{T}{L_{WL}}\right)^{0.46106}*\left(\frac{L_{WL}}{L_R}\right)^{0.121563}*\left(\frac{L_{WL}^3}{\nabla}\right)^{0.36486}*(1-C_P)^{-0.60247}$	1.285025279	
	C_{14}	$1+0.011C_{STERN}$	1.11	
	C_{STERN}	-25 for pram stern with gondola shape -10 for V shaped section stern 00 for normal section stern 10 for U shaped section stern	10	
Length of the Run	L_R	$L_{WL}(1-C_P+\frac{0.06C_P\times lcb}{4C_P-1})$	97.42730862	m
Longitudinal centre of buoyancy	lcb	$1.5\%\ of\ L_{BP}$	5.425	m
Equivalent Appendage Resistance Factor	$(1+k_2)_{eq}$	$\frac{\sum S_{APP,i}(1+k_2)_i}{\sum S_{APP,i}}$	1.598776224	
Coefficient for the emergence of Bulbous bow	P_B	$0.56\sqrt{A_{BT}}/(T_F-1.5h_B)$	3.431560915	
Vertical Position of the Centroid of A_{BT}	h_B	Above the Baseline	6.8	m
Immersed Area of Transom	A_T		1	m^2
For Fn<0.4	C_1	$2{,}223{,}105C_7^{3.78613}(T/B)^{1.07961}(90-i_E)^{-1.37565}$	3.547599626	
	C_7	$0.229577(B/L_{WL})^{0.33333}$ when $B/L_{WL}<0.11$ B/L_{WL} when $0.11\le B/L_{WL}<0.25$ $0.5-0.0625(L_{WL}/B)$ when $0.25\le B/L_{WL}$	0.172695615	
Half Angle of Entrance	i_E	$1+89e^{\left\{\begin{array}{l}-(L_{WL}/B)^{0.80856}\cdot(1-C_{WP})^{0.30484}\cdot(1-C_P-0.0225lcb)^{0.6367}\\\cdot(L_R/B)^{0.34574}\cdot(100\nabla/L_{WL}^3)^{0.16302}\end{array}\right\}}$	47.39353191	degree
	C_2	$e^{-1.89\sqrt{C_3}}$	0.552253269	
	C_3	$0.56A_{BT}^{1.5}/\left\{B\cdot T\left(0.31\sqrt{A_{BT}}+T_F-h_B\right)\right\}$	0.09869189	
	C_5	$1-0.8A_T/(B\cdot T\cdot C_M)$	0.000353496	
For Fn<0.4	m_1	$0.0140407L_{WL}/T-1.75254\nabla^{1/3}/L_{WL}$ $-4.79323B/L_{WL}-C_{16}$	-1.984716991	
	C_{16}	$8.07981C_P-13.8673C_P^2+6.984388C_P^3$ when $C_P<0.8$ $1.73014-0.7067C_P$ when $0.8\le C_P$	1.184761046	
	C15	-1.69385 when $L_{WL}^3/\nabla<512$ $-1.69385+(L_{WL}/\nabla^{1/3}-8.0)/2.36$ when $512\le L_{WL}^3/\nabla\le 1,726.91$ 0 when $1,726.91<L_{WL}^3/\nabla$	-1.69385	
	λ	$1.446C_P-0.03L_{WL}/B$ when $L_{WL}/B<12$ $1.446C_P-0.36$ when $12\le L_{WL}/B$	0.945487951	
	C_A	$0.006(L_{WL}+100)^{-0.16}-0.00205$ $+0.003\sqrt{L_{WL}/7.5}C_B^4C_2(0.04-C_4)$	0.000268071	
	C_4	T_F/L_{WL} when $T_F/L_{WL}<0.04$ 0.04 when $0.04\le T_F/L_{WL}$	0.04	
For Fn>0.55	C_1	$6{,}919.3C_M^{-1.3346}(\nabla/L_{WL}^3)^{2.00977}(L_{WL}/B-2)^{1.40692}$	1.319712662	
For Fn>0.55	m_1	$-7.2035(B/L_{WL})^{0.326869}\cdot(T/B)^{0.605375}$	-1.713326175	

Froude Number	**Speed**	**Frictional Resistance Coefficient**	**Frictional Resistance**	**Appendage Resistance**	**Additional Pressure Resistance of Bulbous Bow**	**Wave Resistance**	**Correlation Resistance**	**Total Resistance**	**Total Resistance Coefficient**
Fn	v	Cf	Rf	RApp	RB	Rw	RA	RT	CT
0.1	5.245669643	0.00144	335083.039	4642.603	308683.5243	0.122146339	62382.08	806298.504	0.003464859
0.105	5.507953125	0.001432	367269.274	5088.546	335767.9782	0.240448845	68776.243	881583.309	0.003436168
0.11	5.770236607	0.001424	400839.34	5553.662	362809.7839	0.446377751	75482.316	958934.893	0.003405598
0.115	6.032520089	0.001416	435786.27	6037.855	389708.5876	0.787295322	82500.3	1038243.9	0.003373598
0.12	6.294803571	0.001409	472103.459	6541.033	416378.7894	1.327460987	89830.195	1119416.22	0.003340556
0.125	6.557087053	0.001402	509784.624	7063.108	442748.0972	2.150935648	97471.999	1202371.48	0.003306803
0.13	6.819370535	0.001396	548823.782	7603.999	468756.098	3.364229752	105425.71	1287041.61	0.00327262
0.135	7.081654018	0.001389	589215.22	8163.626	494352.8958	5.098565689	113691.34	1373369.41	0.003238243
0.14	7.3439375	0.001383	630953.474	8741.913	519497.8412	7.511654988	122268.88	1461307.31	0.003203872
0.145	7.606220982	0.001378	674033.313	9338.787	544158.3691	10.78892398	131158.32	1550816.11	0.003169669
0.15	7.868504464	0.001372	718449.714	9954.18	568308.948	15.14415488	140359.68	1641864	0.003135771
0.155	8.130787946	0.001367	764197.855	10588.02	591930.1398	20.8195384	149872.95	1734425.49	0.003102287
0.16	8.393071428	0.001362	811273.093	11240.26	615007.7648	28.08515164	159698.12	1828480.66	0.003069305
0.165	8.65535491	0.001357	859670.96	11910.81	637532.164	37.23804578	169835.21	1924014.34	0.003036897
0.17	8.917638393	0.001352	909387.142	12599.63	659497.5505	48.60020485	180284.21	2021015.46	0.003005117
0.175	9.179921875	0.001348	960417.478	13306.66	680901.4416	62.51689658	191045.12	2119476.48	0.002974008
0.18	9.442205357	0.001343	1012757.94	14031.85	701744.1619	79.36003815	202117.94	2219392.86	0.0029436
0.185	9.704488839	0.001339	1066404.65	14775.12	722028.4109	99.51415891	213502.67	2320762.65	0.002913915
0.19	9.966772321	0.001335	1121353.82	15536.45	741758.8854	123.350227	225199.31	2423586	0.002884967
0.19122	10.03099978	0.001334	1135007.77	15725.63	746506.7318	129.7929991	228111.1	2448986.92	0.002877992



14.6 Comparison Between Maxsurf & Manual Calculation



Fn	Speed (knot)	Speed (m/s)	Maxsurf Calculated R_T (KN)	Manual Calculated R_T (KN)

0.1	10.238	5.246	756.2	806.299
0.105	10.725	5.508	824.6	881.583
0.11	11.213	5.770	895.1	958.935
0.115	11.7	6.033	967.7	1038.244
0.119	12.188	6.295	1042.4	1119.416
0.124	12.675	6.557	1119.3	1202.371
0.129	13.163	6.819	1198.5	1287.042
0.134	13.65	7.082	1280.1	1373.369
0.138	14.138	7.344	1364.3	1461.307
0.143	14.625	7.606	1451.2	1550.816
0.148	15.113	7.869	1541.1	1641.864
0.153	15.6	8.131	1634.4	1734.425
0.158	16.087	8.393	1731.3	1828.481
0.162	16.575	8.655	1832.3	1924.014
0.167	17.063	8.918	1937.7	2021.015
0.172	17.55	9.180	2048.1	2119.476
0.177	18.038	9.442	2163.8	2219.393
0.181	18.525	9.704	2285.5	2320.763
0.186	19.013	9.967	2413.6	2423.586
0.191	19.5	10.031	2548.7	2448.987

Speed (knot)	Speed (m/s)	Maxsurf Calculated R_T (KN)	Manual Calculated R_T (KN)
19.5	10.031	2548.7	2448.987

The comparison between the Maxsurf-calculated and manually-calculated total resistance values shows a consistent trend across varying Froude numbers and speeds. The total resistance increases as the Froude number and speed increase, which aligns with expectations for hydrodynamic performance.

While both methods produce similar trends, there are notable differences in the resistance values. The manually calculated resistance is generally higher than the Maxsurf-calculated resistance for most data points, with the differences becoming more pronounced as the speed increases. This discrepancy may stem from differences in the assumptions, methods, or accuracy of the computational approaches used in Maxsurf and the manual calculations.

14.7 Engine Power

14.7.1 Engine Power Losses:

Ship power losses refer to the energy lost at various stages in the propulsion system from the engine to the propeller thrust. These losses occur due to friction, inefficiency in energy transfer, and environmental factors. Understanding these losses helps optimize fuel efficiency and propulsion performance.

Propeller Loss

- **Description**: Propeller loss is the reduction in energy as the propeller converts the mechanical power transmitted by the engine into thrust.
- Key Factors:
  - **Blade Resistance**: Friction between the blades and water.
  - **Cavitation**: Formation of bubbles on the propeller surface leading to energy loss.
  - **Design**: Efficiency is influenced by blade shape, number, and pitch.

Shaft Loss

- **Description**: Shaft loss occurs during the transmission of mechanical power from the engine to the propeller via the rotating shaft. It results from friction and misalignment.
- Key Factors:
  - **Bearing Friction**: Resistance in bearings that support the rotating shaft.
  - **Shaft Misalignment**: Improper alignment of the shaft, causing increased friction.

Mechanical Loss

- **Description**: Mechanical losses are energy losses within the ship's propulsion machinery, such as the engine, gearbox, and transmission system.
- Key Factors:
  - **Engine Friction**: Internal friction within engine parts, including pistons and cylinders.
  - **Gearbox Friction**: Losses due to friction in gear meshes and bearings in the gearbox.

Auxiliary Power Loss

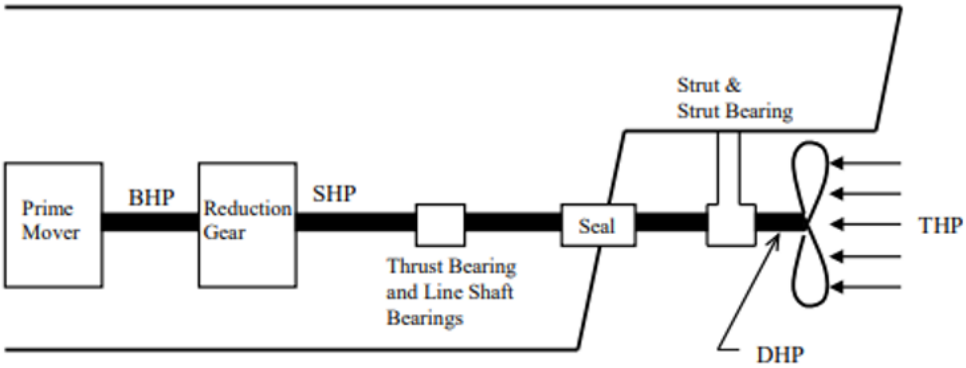
- **Description**: Auxiliary power losses occur as energy is used for non-propulsion systems, like generators, pumps, lighting, and other onboard equipment.
- Key Factors:
  - **Energy Demand**: Consumption of energy by various systems reduces the power available for propulsion.
  - **Inefficient Systems**: Poorly maintained or inefficient auxiliary equipment may consume more energy.

Environmental Loss

- **Description**: Environmental losses refer to the energy required to overcome resistance from the ship's interaction with water and atmospheric conditions.
- **Key Factors:**
  - **Hull Resistance**: Drag created as the hull moves through water.
  - **Wave-Making Resistance**: Energy required to form waves as the ship moves.
  - **Wind Resistance**: Additional drag from wind on the ship's superstructure.

14.7.2 Assumed Losses & Efficiency:

Loss Type	Loss	Efficiency
Propeller Loss	25%	75.0%
Shaft Loss	3%	97.0%
Mechanical Loss	5%	95.0%
Auxiliary Power Loss	3%	97.0%
Environmental Loss	2%	98.0%
Overall		65.7%



14.7.3 Power Calculation

Number of Engines: **2**

Required Engine Power $= \frac{Effective\ Power\ (kW)(maxsurf)}{Overall\ Efficiency \times Number\ of\ Engines}$

$= \frac{25567.21}{65.7\% \times 2}$

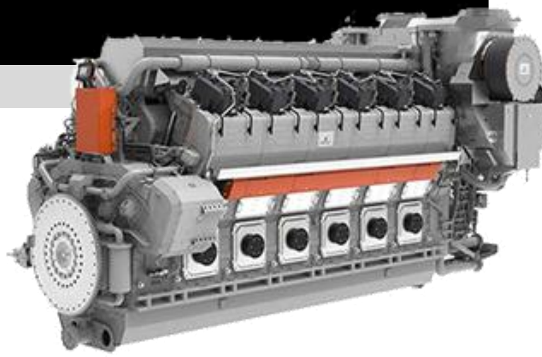
= 19458.03 kW =**19500 kW**

= 26093.64 HP =**26100 HP**

The calculated effective power requirement of 25,567 kW, considering a system efficiency of 65.7%, underscores the energy demands of high-speed LNG carriers

CHAPTER 15: ENGINE SELECTION, FOUNDATION & DESIGN

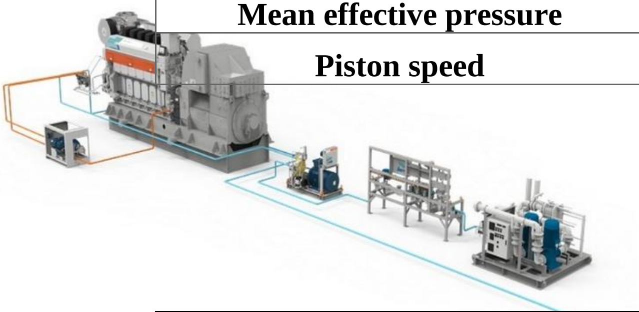
15.1 Engine Selection



16V46TS WÄRTSILÄ

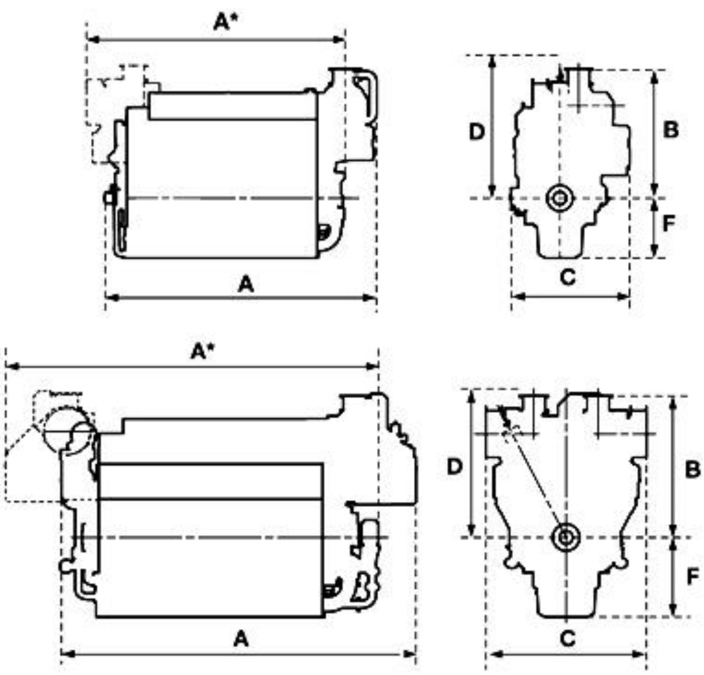
The Wärtsilä 46TS-DF represents the next generation of medium-speed engines and is designed to set a new benchmark for fuel efficiency and emissions performance while offering future-fuel flexibility

Main technical data		IMO Tier III
Cylinder bore	460 mm	Fuel specification: Dual Fuel
Piston stroke	580 mm	700 cSt/50°C 7200sR1/100°F
Cylinder output	1300 kW/cyl	ISO 8217, category ISO-F-DMX. DMA. DMB Natural Gas
Speed	600 rpm	
Mean effective pressure	27 bar	Engine efficiency up to 52%
Piston speed	11.6 m/s	



Rated power	
Engine type	kW
16V46TS	20800

Dimensions (mm) and weights (tonnes)						
Engine type	A mm	A* mm	B* mm	F mm	C mm	Weight t
Wartsila 16V46TS	13456	11550	4363	1505	5733	252



15.2 Engine Foundation

An **Engine Foundation Drawing** in naval architecture is a detailed technical illustration showing how the ship's engine is mounted and supported within the hull. It depicts the structure that provides a stable and secure base for the engine, ensuring proper alignment, minimizing vibrations, and maintaining the vessel's overall stability and safety. Importance of Engine Foundation Drawing:

1. **Stability & Safety**: Ensures the engine is securely anchored, preventing any misalignment or shifting during the ship's operation, which could affect performance or safety.
2. **Vibration Control**: Helps in the design of vibration isolation systems, reducing the impact of engine vibrations on the hull and other ship systems.
3. **Structural Integrity**: Provides detailed information on how the engine foundation integrates with the ship's overall structure, ensuring that all forces are properly distributed.
4. **Alignment**: Ensures the engine and shaft are correctly aligned to optimize efficiency and reduce wear on mechanical components.
5. **Maintenance**: Assists in understanding the engine mounting system, which is critical for repairs and regular maintenance.

Main Components of an Engine Foundation Drawing:

1. **Engine Bed/Baseplate**: The main support structure, usually a thick steel plate, that holds the engine.
2. **Frames**: Vertical structural supports of the ship's hull that are connected to the engine foundation to provide stability.
3. **Engine Mounting Plates**: Plates where the engine's mounting brackets are fixed, providing a connection point for the engine.
4. **Vibration Isolation System**: Typically, chock fast, rubber or composite material between the engine and foundation to absorb vibrations and reduce noise.
5. **Foundation Bolts**: Heavy-duty bolts securing the foundation to the ship's hull structure.
6. **Stiffeners**: Reinforcements to prevent the foundation from bending or warping under stress.

These components ensure that the engine remains securely mounted, properly aligned, and operates smoothly within the ship's structure.

15.3 Engine Foundation Calculation

15.3.1 Plate floors

Plate floors are to be fitted at every frame. The floor thickness t is to be determined by the following formula:

$$t = c.t_{pf} \qquad [\text{mm}]$$

c : coefficient, defined as:

$$c = 1.0 + \left(3.6 + \frac{P}{500}\right).10^{-3} \qquad \text{with } 1.05 \leq c \leq 1.15$$

P : single engine output [kW]

t_{pf}: thickness of floor plates according to scantling.

$$c = 1.0 + \left(3.6 + \frac{19500}{500}\right).10^{-3} = 1.0426$$

$$t = 1.0452 * 17 = 17.7684 \;\approx 18\,mm$$

The thickness of the plate floors below engine is **18 mm.**

15.3.2 Inner bottom

Between the foundation girders, the thickness of the inner bottom plating required according to scantling is to be increased by 2 mm. The strengthened plate is to be extended beyond the engine seating by three to five frame spacings.

$$t_{be} = t_b + 2 = 15 + 2 = 17\,mm$$

The thickness of the inner bottom plating is **17 mm**

15.3.3 Longitudinal girders

The thickness t of the longitudinal girders above the inner bottom is not to be less than determined by the following formula:

$$T = \sqrt{\frac{P}{15}} + 6 \qquad [\text{mm}] \qquad \text{for P < 1500kW}$$

$$T = \frac{P}{750} + 14 \qquad [\text{mm}] \qquad \text{for } 1500 \leq \text{P < 7500kW}$$

$$T = \frac{P}{1875} + 20 \qquad [\text{mm}] \qquad \text{for 7500kW} \leq \text{P}$$

P : single engine output [kW]

$$T = \frac{P}{1875} + 20 = \frac{19500}{1875} + 20 = 31mm$$

So, we take the thickness of longitudinal girder as **31 mm.**

15.3.4 Foundation Bolts

The foundation bolts for fastening the engine at the seating shall be spaced no more than apart, $S = 3 \times d$ From the longitudinal foundation girder where the distance of the foundation bolts from the longitudinal foundation girder is greater, proof of equivalence is to be provided.

Where, d = diameter of the foundation bolt

Let, d = 50mm

$$S = 3 \times 50 = 150\ mm$$

Therefore, we take the spacing of foundation bolt from the foundation girder **150 mm**

15.3.5 Top Plate

The thickness of the top plate is approximately to be equal to the diameter of the fitted-in bolts. The cross-sectional area A_T of the top plate is not to be less than determined by the following formulae:

$$A_T = \frac{P}{75} + 30 \quad [\text{cm}^2] \quad \text{for } P \leq 750\text{kW}$$

$$A_T = \frac{P}{75} + 70 \quad [\text{cm}^2] \quad \text{for } P > 750\text{kW}$$

$$A_T = \frac{P}{75} + 70\ cm^2 = \frac{19500}{75} + 70 = 330\ cm^2$$

The thickness of top plate should approximately be equal to the diameter of the fitted in bolts. So, we have the thickness of the top plate as, t_T = 50 mm

So, the width of top plate will be

$$b_T = \frac{A_T \times 100}{t_T} = \frac{330 \times 100}{50} = 660\ mm$$

Therefore, we take the width of top plate **660 mm**

15.3.6 Web frame

The longitudinal girders of the engine seating are to be supported transversely by means of web frames.

The section modulus W of web frames are not to be less than determined by the following formulae:

$$W = 0.8 \times e.l^2.p_s.k \qquad [\text{cm}^3]$$

here,

l = unsupported span [m], without consideration of cross ties, if any
= 10
p = Design pressure = p_s =53.521 KN / m^2
k = 1
e = 700mm = .7m

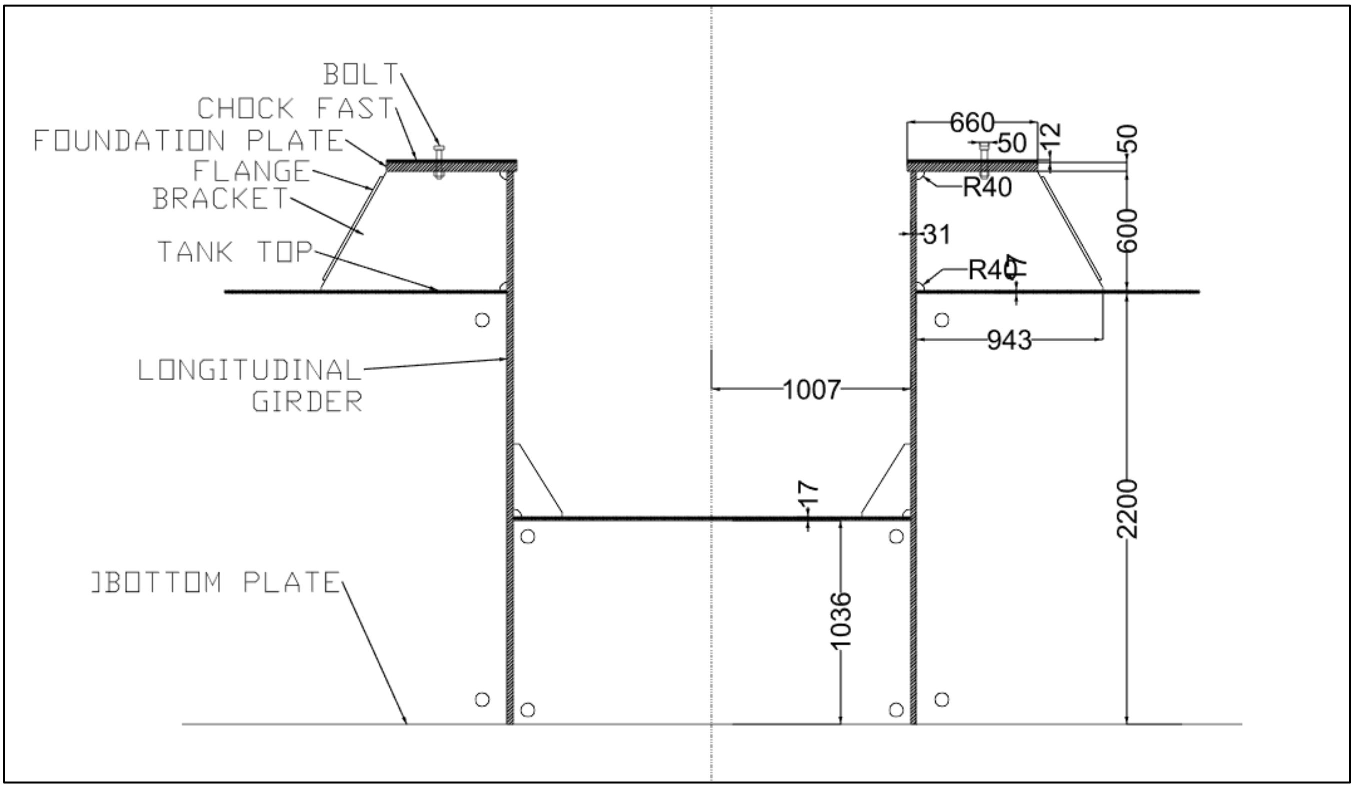
$$W = 0.8 \times 5 \times 10^2 \times 53.52 \times 1 = 2997.176 \qquad [\text{cm}^3]$$

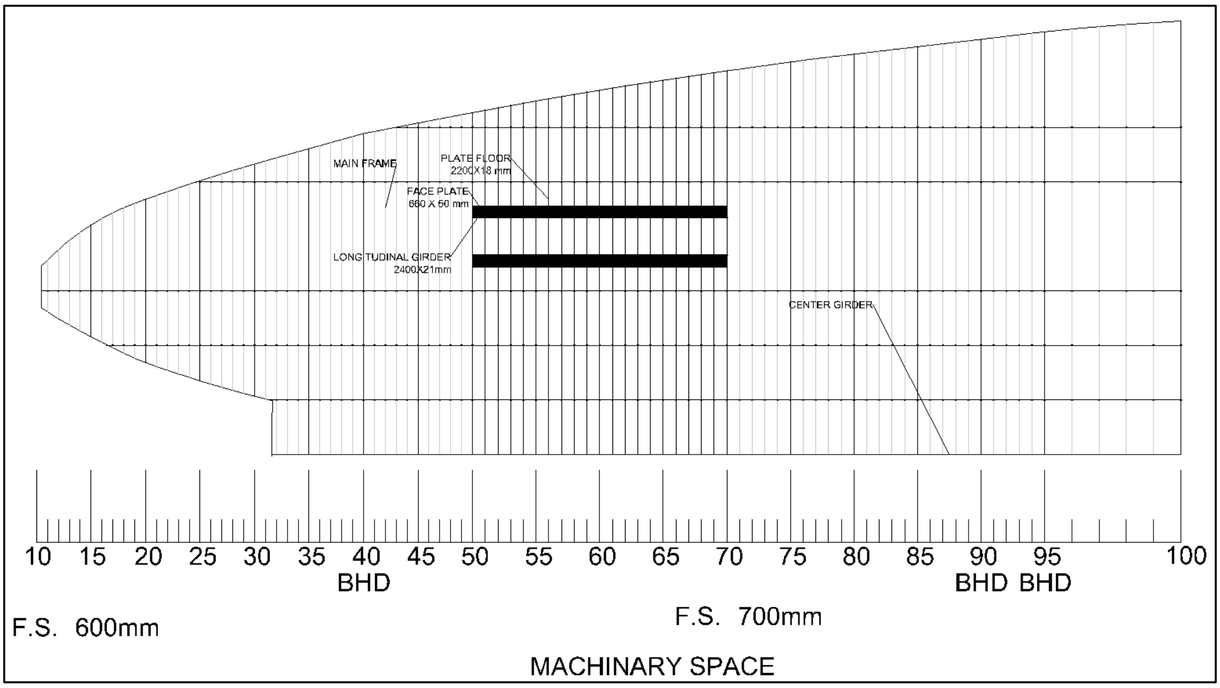
Hence, the dimension of the web frame **I – section 2200 X 17 mm**

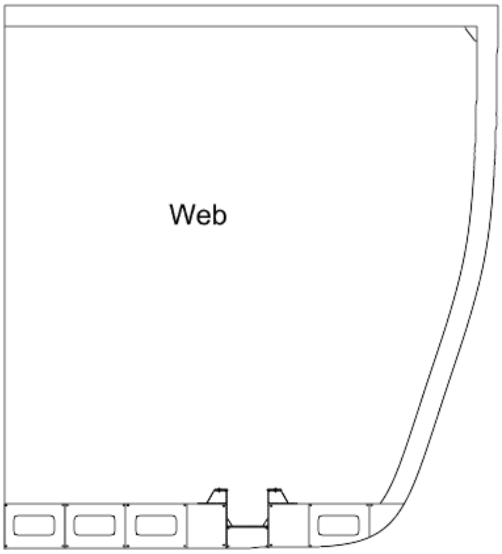
15.3.7 Calculation Summary

Title	Dimension
Floor Plate	18 mm thick
Inner bottom Plate	17 mm thick
Longitudinal Girder	31 mm thick
Foundation bolt	Dia 50 mm and spacing 150 mm
Face plate width	660 mm & 50mm thick
Web Frame	I – 2200 X 17 mm

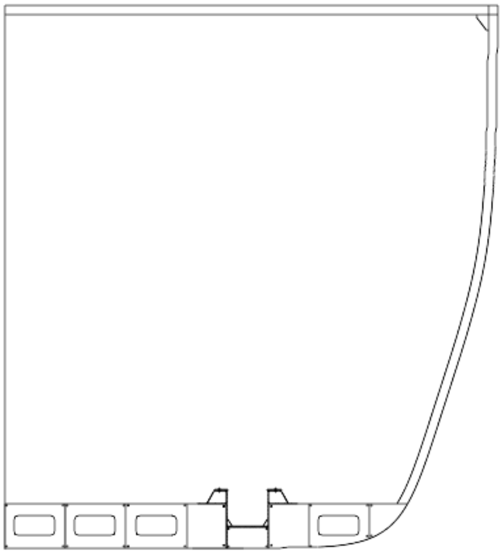
15.4 Engine foundation Drawing



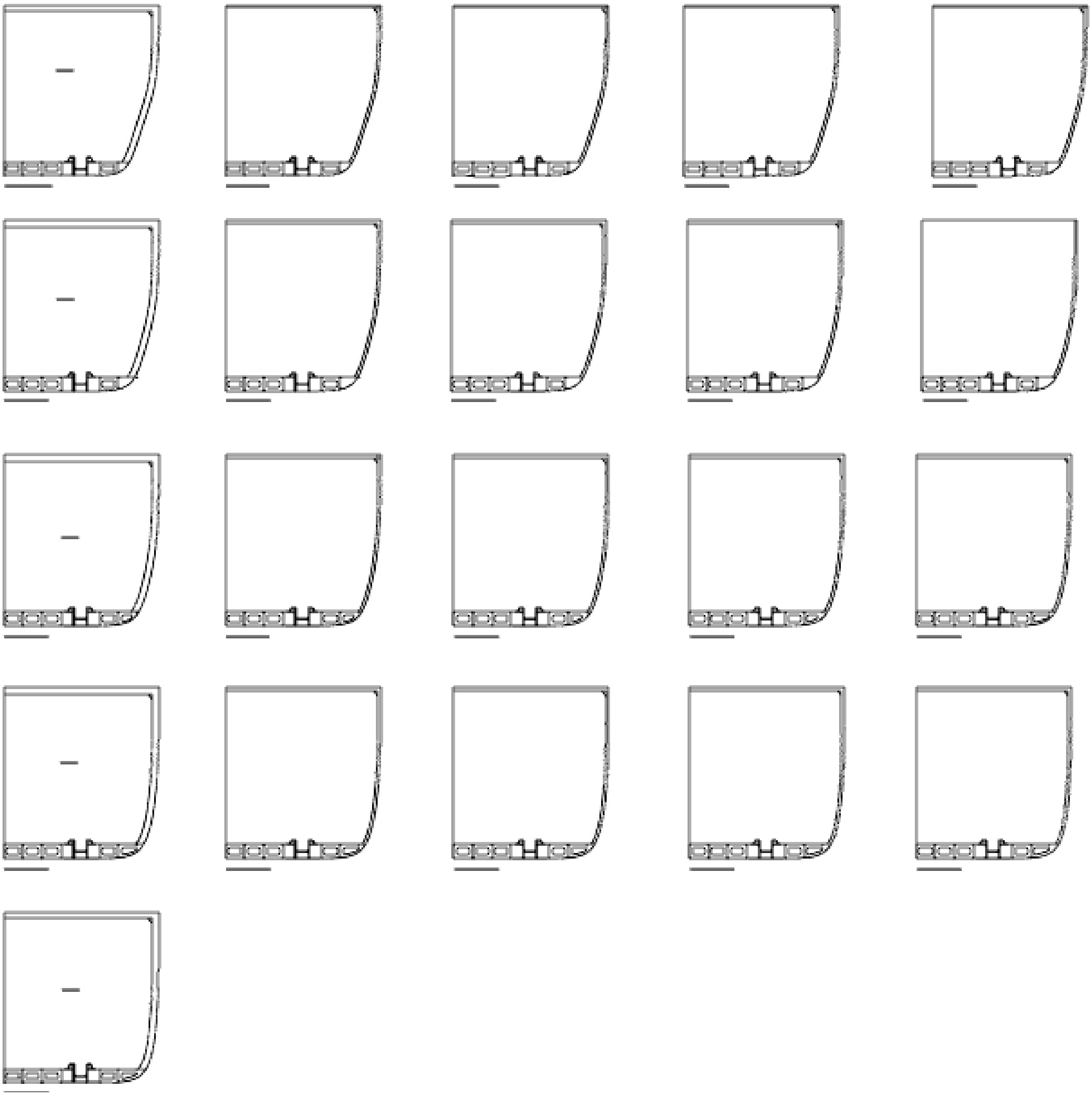




FRAME - 50



Station - 51



CHAPTER 16: DESIGN & CALCULATION OF PROPELLER SHAFT

16.1 Introduction

Shafting system of a ship consists of the equipment necessary to convert engine power into thrust power and to transmit the developed thrust of the propeller to the ship's hull.

There are basically two purposes of Shafting system;

- Transmit the torque developed by the main engine to the propeller
- Transmit the thrust developed by the propeller to ships' Hull

Components of shafting system

I. Thrust block	8. Eddy Plate
2. Plummer block	9. Rope guard
3. Bulkhead gland	11. Stem Tube
4. Shaft locking gear	12. Stem Tube bushes
5. Loose coupling	13. Eddy Plate
6. Stem gland	14. Rope guard
7. *NP* bracket	15. Propeller

The propeller shaft is divided into three section.

- **Thrust Shaft:** This shaft connects Gear Box or Main Engine to the thrust block. This shaft is the forward most section in a shaft arrangement.
- **Intermediate Shaft:** This is the shaft in the middle that connects Thrust shaft with Tail Shaft.
- **Tail Shaft:** This is the after most shaft with whom the propeller is attached at the back.

Thrust Block:

Another important element in shafting arrangement is Thrust Block. Thrust block transmits propeller thrust to the ship's hull. Thrust is taken against heavy collar mounted on thrust shaft. Thrust absorbed with pad to collar to thrust block body which is rigidly fitted with ship's hull.

Thrust block can be categorized in two types:

- Thrust Block with meter ring
- Thrust block without thrust meter.

16.2 CALCULATION OF SHAFT DIAMETER:

Name	Value
Engine RPM	600
Gearbox Ratio	**3.5:1**
Shaft RPM	175

Shaft speed, $f = \frac{Engine\ speed}{Gear\ ratio}$

$= \frac{600}{3.5}$

$= 171.42\ RPM$

$\approx 175\ RPM$

Torque, $T = P \times \frac{60}{2\pi f}$

$= 20800 \times \frac{60}{2\pi \times 175}$

=1135 Nm

$c = \frac{d}{2}$

$J = \frac{\pi d^4}{32}$

Now,

Shear Stress, $\tau = \frac{Tc}{J}$

Or, $60 \times 10^6 = \frac{1135 \times d/2}{\frac{\pi d^4}{32}}$

Or, $d = 458.4$mm

Therefore, diameter of the shaft ≈ 460 mm

16.2.1 TWISTING ANGLE:

TH, $\theta = \frac{TL}{J}$

Where, $J = \frac{\pi (460)^4}{32}$

And, $G = 8.3 \times 10^{10}$

$L = 20\ m$

Therefore, $\theta = \frac{1135 \times 20}{\frac{\pi (460)^4}{32}}$

$= 5.16 \text{x} 10^{-6\ \text{o}}$

16.3 CALCULATION OF SHAFT DIAMETER <u>(using BVrulebook):</u>

the shaft dia should not be less than,

$$d = F \times K \times \sqrt[3]{[\frac{P}{n} \times \left\{1 - \left(\frac{d_i}{d_a}\right)^4\right\} \times C_w]}$$

Here,
d=outside diameter of shaft
d_i=Actual diameter of shaft bore
d_a= Actual shaft diameter
The expression $\left\{1 - \left(\frac{d_i}{d_a}\right)^4\right\}$ can be taken equal to 1.
P=Power transmitted by shaft = 20800 KW
n= shaft speed = 175RPM

Now,
R_m = tensile strength of shaft material = 760 N/mm
C_W = material factor

Hence, $C_W = \frac{560}{160+R_m}$

$= \frac{560}{160+760}$

$= 0.6086$

F= Factor for type of propulsion installation = 100
k = Factor for shaft type = 1.4 [for intermediate propeller shaft]

$$\therefore d = 100 \times 1.4 \times \sqrt[3]{\frac{20800}{175} \times 1 \times 0.6086}$$

$$= 583.329\ mm$$

Therefore, we take the shaft diameter to be 585 mm

16.3.1 MINIMUM WALL THICKNESS:

Wall thickness, $s = (0.03 \times d) + 7.5$
Hence, $s = (0.03 \times 585) + 7.5 \quad mm$
= **25mm**

16.3.2 COUPLING:

The thickness of coupling flanges on the intermediate and thrust shafts and on the forward end of the propeller shaft must be equal to at least 20% of the calculated diameter of the shaft.

Thickness of coupling flange $= 0.2 \times d$

$= 0.2 \times 585\ m$ = **117mm**

16.3.3 SHAFT BEARING DISTANCE:

$l_{max} = k1 \times \sqrt{d}$

where,
l_{max} = maximum permissible distance between bearings
d=diameter of shaft bearing
k_1=280 [for water lubricated rudder bearings in stern tubes and shaft brackets]

Hence, $l_{max} = 280 \times \sqrt{585}$
$= 6772.3\ mm$
$\approx \mathbf{6770mm}$

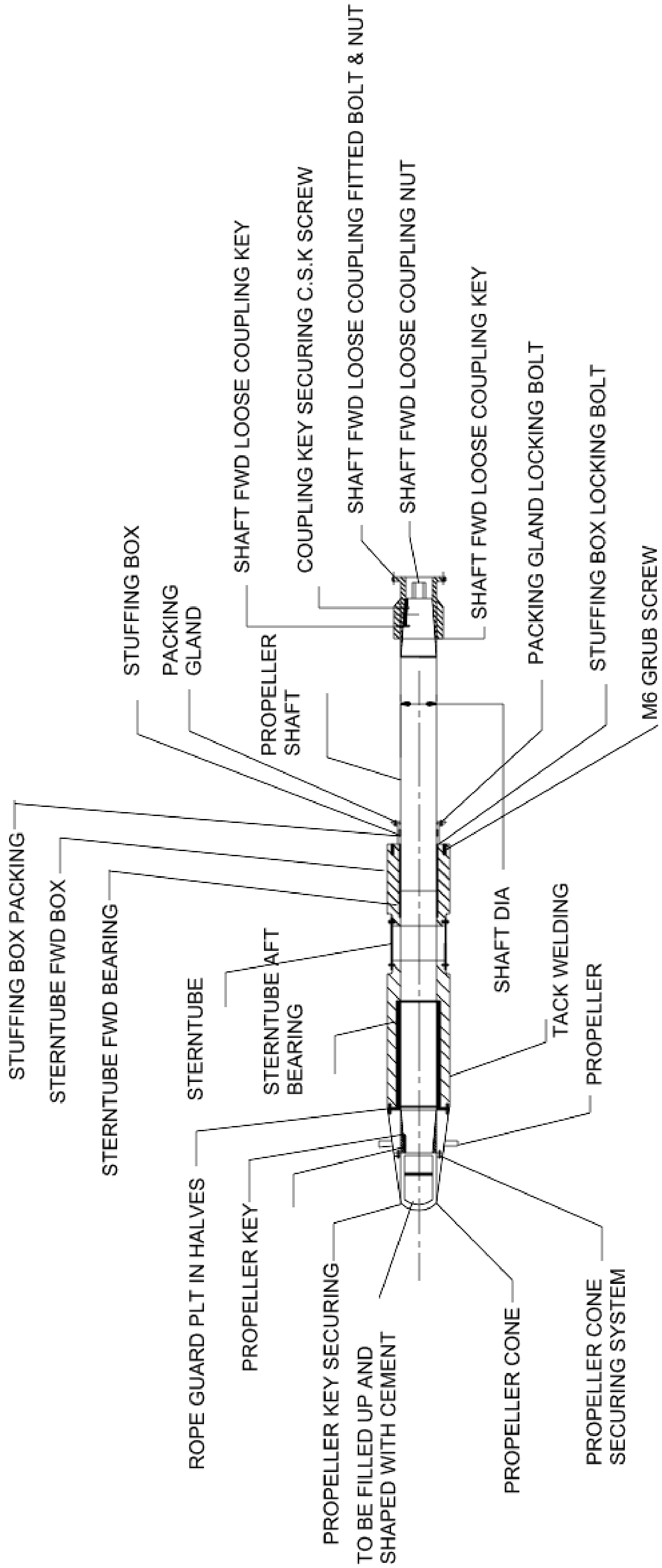
16.3.4 SHAFT BEARING LENGTH:

For water lubricated aft and forward rudder bearings inside stern tube,
Length of after stern tube bearing $= 4 \times d$
$= 4 \times 585\ mm$
$= \mathbf{2340\ mm}$
Length of forward stern tube bearing $= 1.5 \times d$
$= 1.5 \times 585\ mm$
$= \mathbf{877.5\ mm}$

16.3.5 SUMMARY

Name	**Value**	**Unit**
Shaft Diameter	585	mm
Minimum Wall Thickness	25	mm
Thickness Of Coupling Flange	117	mm
Shaft Bearing Distance	6770	mm
Shaft Bearing Length	877.5	mm

16.4 PROPELLER SHAFT DRAWING



CHAPTER 17: RUDDER

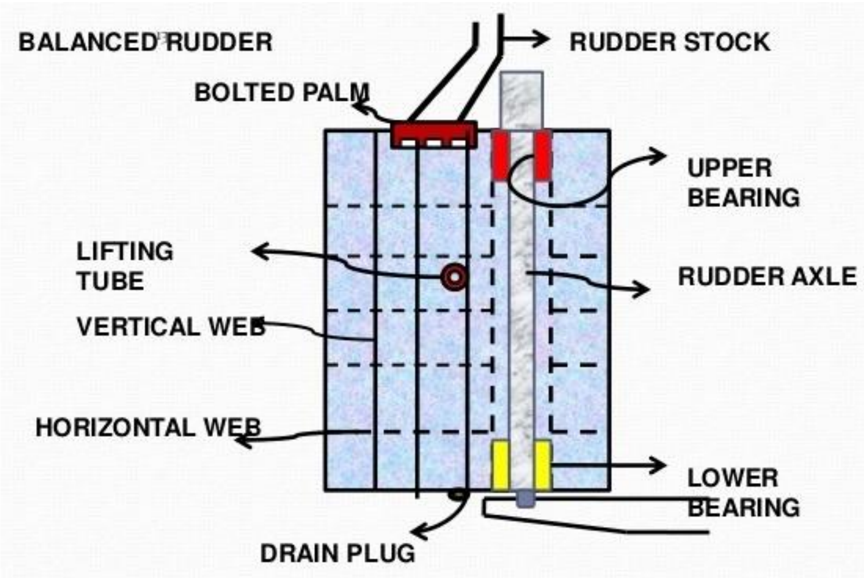
17.1 Introduction to Rudder

A RUDDER is a flat, vertical blade attached to the stern (rear) of a ship, used to steer the vessel. It works by deflecting water flow, generating a force that causes the ship to change direction. The rudder is controlled by the ship's steering system, allowing the captain to navigate the vessel.

17.1.1 Types of Rudders Based on Balance

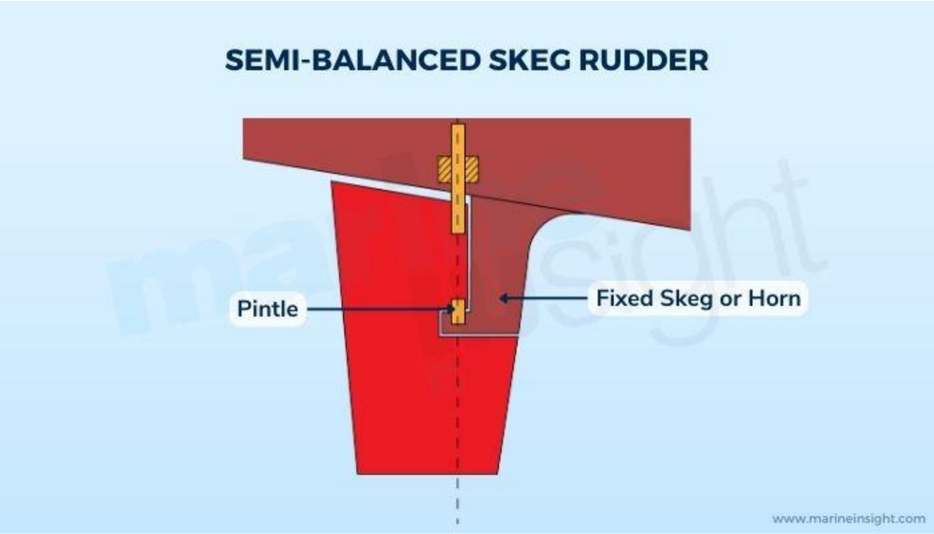
Balanced rudder:

- Description: in a balanced rudder, the center of resistance is placed forward of the rudder stock (pivot point). This makes it more efficient by reducing the amount of force needed to turn the rudder.
- Advantages:
  - Requires less torque (turning force) to move, reducing strain on the steering gear.
  - Provides better maneuverability and quicker response.
  - Particularly useful on large ships that require high steering power.
- Common use: found on larger vessels like cargo ships, container ships, and tankers.

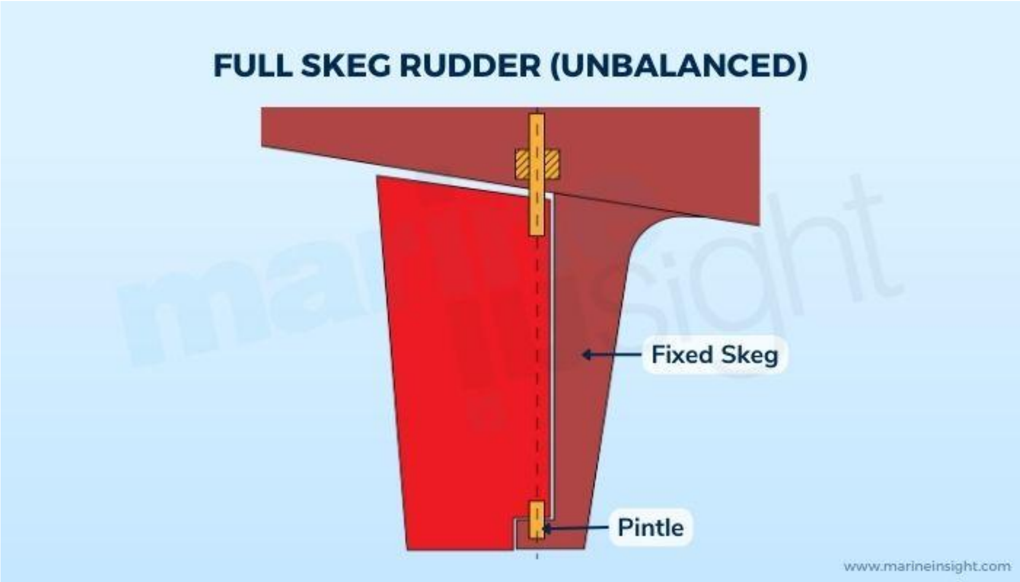


Semi-balanced rudder:

- Description: a semi-balanced rudder has part of its area forward of the rudder stock and part behind it. This design provides some balance but not as much as a fully balanced rudder.
- Advantages:
  - Requires moderate steering effort compared to unbalanced rudders.
  - Offers a good balance of maneuverability and simplicity.
- Common use: used on mid-sized vessels or ships where some reduction in torque is needed, but full balance is not required.



2. **Unbalanced rudder:**
   - Description: in an unbalanced rudder, the entire surface of the rudder is located behind the rudder stock. This requires more force to turn because all of the resistance is behind the pivot point.
   - Advantages:
     - Simple and cost-effective design, easy to construct.
     - Typically has fewer moving parts, making it easier to maintain.
   - Disadvantages: requires more effort to steer, putting additional strain on the steering mechanism.
   - Common use: mostly used in smaller vessels, boats, and older ships.



17.2 Rudder Calculation

17.2.1 Rudder Area:

$= \frac{length \times Draft}{55}$ m^2

$= \frac{280.43 \times 11.70}{55}$ m^2

=59.65 m^2

≈ **6**0 m^2

- Aspect Ratio: $\frac{Rudder\ Height}{Rudder\ Breadth} = 1.67$

Or, $Rudder\ Height = 1.67 \times Rudder\ breadth$
$= 1.67 \times 6$
$= 10\ m$

17.2.2 Rudder Force:

$=196 \times Rudder\ area\ \times (speed, ms^{-1})^2 \times Angle, N$
$= 196 \times 60\ \times (10.031)^2 \times 0.6545\ N$
= 774471.5 N

17.2.3 Center of Pressure:

Center of Pressure from the leading edge for rectangular rudder,
X = (0.195+0.305 sin(angle)) × rudder breadth, m
= (0.195+.305 sin(37.5)) × 6 m
= 2.284 m

Turning axis from the leading edge,
= 0.18 × rudder breadth
= 0.18 × 6 m
= 1.08 m

Center of pressure from turning axis,
$r = x - (0.18 * Rudder\ Breadth)$
$= (2.284\ - 1.08)$ m
$= 1.204$ m

Torque,
$T = Rudder\ Force * r$
$= 774471.5 \times 1.204$
$= 932463.686\ Nm$

Rudder Stock Diameter**:**

$$d^3 = \frac{16\times T}{3.1416\times f}\ \text{m}$$

Or, $d = \sqrt[3]{\frac{16\times 932463.686}{3.1416\times 235\times 10\text{^}6}}$
$= 0.2723\ m$
$= 272.3mm \approx 275mm$

Where, f= allowable stress of the material = 235 MPa.

17.2.4 Rudder Area:

$A = C_1 \times C_2 \times C_3 \times C_4 \times \frac{1.75 \times lengt \times draft}{100}$, m^2

Where, C_1= factor for ship type

= 1.0 in General

= 0.9 for bulk carriers & tankers having displacement more than 50,000 tonnes

=1.7 for tug and trawlers

C_2=factor for rudder type

=1.0 in general

= 0.9 for semi-spade rudders

= 1.7 for high lift rudders

C_3=Factor for rudder profile

= 1.0 for NACA-Profile & Plate Rudders

= 0.8 for hollow profiles & mixed Profiles

C_4=factor for Rudder Arrangement

=1.0 for rudders in the propeller jet

=1.5 for rudders outside the propeller jet

Therefore, $A = 0.9 \times 1 \times 1 \times 1.5 \times 1.75 \times 280.43 \times \frac{11.7}{100}$

$= 77.51\, m^2$

17.2.5 Material Factor:

$$K_r = \left(\frac{235}{R_{eH}}\right)^{0.75}$$
$$= \left(\frac{235}{350}\right)^{0.75}$$
$$= 0.7417$$

Where, R_{eH} = minimum nominal upper yield point of material used (N/mm^2)

=350 N/mm^2

17.2.6 Rudder Force:

$$C_R = 132\,.K_1.K_2.K_3.A.V^2.K_t$$

Where, A= Rudder Area, m^2

K_1=coefficient, depending on the aspect ratio , κ

= $\frac{\kappa+2}{3}$,where κ need not be taken greater than 2

K_2=coefficient, depending on the type of the rudder profile according to table 14.1

K_3=coefficient. Depending on the location of the rudder

=0.8 for rudders outside the propeller jet

=1.0 elsewhere, including rudders within the propeller jet

=1.5 for rudders aft of the propeller nozzle

K_t=coefficient, depending on the thrust coefficient, C_{TH}

=1.0 Normally

Thus, $C_R = 132 \times 1.1333 \times 0.8 \times 0.8 \times 77.51 \times (10.031)^2 \times 1$

$= 746698.00\, N$

17.2.7 Rudder Torque:

$$Torque, T = Rudder\ Force * r$$

Where, r = c (α -K_b)

c= mean breadth of the Rudder Area, $\frac{x_1+x_2}{2}$
α =0.33 for ahead condition
=0.66 for astern condition (general)
= 0.75 for astern condition (hollow profile)
K_b= balance factor
= 0.08, for unbalanced condition

$$c = 6$$
$$r = 6 \times (0.33 - 0.08)$$
$$= 1.5 \text{ m}$$

Therefore, $T = 746698.00 \times 1.5\ Nm$
$= 1120047\ Nm$

17.2.8 Rudder Stock Diameter:

$$D_t = 4.2 * (torque * material\ factor)^{\frac{1}{3}}$$
$$= 4.2 \times \sqrt[3]{(1120047 \times 0.7417)}$$
$$= 394.82\ mm$$
$$\approx 395\ mm$$

Hence, we take the rudder stock diameter to be 395mm.

17.2.9 Coupling Bolt:

$$Coupling\ Bolt\ Diameter, d_b = 0.62 * \left(\frac{D^3 * K_b}{K_r . n . e}\right)^{0.5}, mm$$

Where,
D=Rudder Stock Diameter, mm
n= Total Number of Bolts = 50
e=Mean distance of the bolt axes from the center of bolt system = 225 mm
K_r=Material factor of the Coupling Flanges =0.7417
K_b=Material factor of the Bolts

Hence,

$$K_b = \left(\frac{235}{R_{eH}}\right)^{0.75}$$
$$= \left(\frac{235}{450}\right)^{0.75}$$
$$= 0.6143$$

$$Coupling\ Bolt\ Diameter, d_b = 0.62\left(\frac{395^{\ 3} \times 0.6143}{0.7417 \times 50 \times 225}\right)^{0.5} mm$$

= 41.76 mm

17.2.10 Coupling Bolt Thickness:

$$Coupling\ Bolt\ Thickness, t_f = 0.62\left(\frac{D^3 * K_f}{K_r . n . e}\right)^{0.5}, mm$$

Where,
K_f= Material factor of the coupling flanges

$$K_f = \left(\frac{235}{R_{eH}}\right)^{0.75}$$
$$= \left(\frac{235}{450}\right)^{0.75}$$
$$= 0.6143$$

Therefore, $t_f = 0.62\left(\frac{395^{\,3} \times 0.6143}{0.7417 \times 50 \times 225}\right)^{0.5}$
$= 41.76\text{mm}$

17.2.11 Rudder Plating:

$$Thickness\ of\ Rudder\ Plate, t = 1.74 * a * (P_r * k)^{0.5} + 2.5\ , mm$$

Where,

$$P_r = 10 * T + \frac{Rudder\ Force}{Rudder\ Area * 10^3}$$
$$= 10 \times 11.7 + \frac{746698.00}{77.51 \times 1000}$$
$$= 126.63\ MPa$$

T= draft ,m
a= The Smaller unsupported width of a Plate panel, m
k= Material Factor=0.7417

Therefore, $t = 1.74 \times 0.5 \times \sqrt[2]{126.63 \times 0.7417} + 2.5$
$= 10.93\ mm$
$\approx 12mm$

17.2.12 Pintles:

$$Pintle\ diameter. d = 0.35 * (B_1 * K_r)^{0.5}$$

Where,

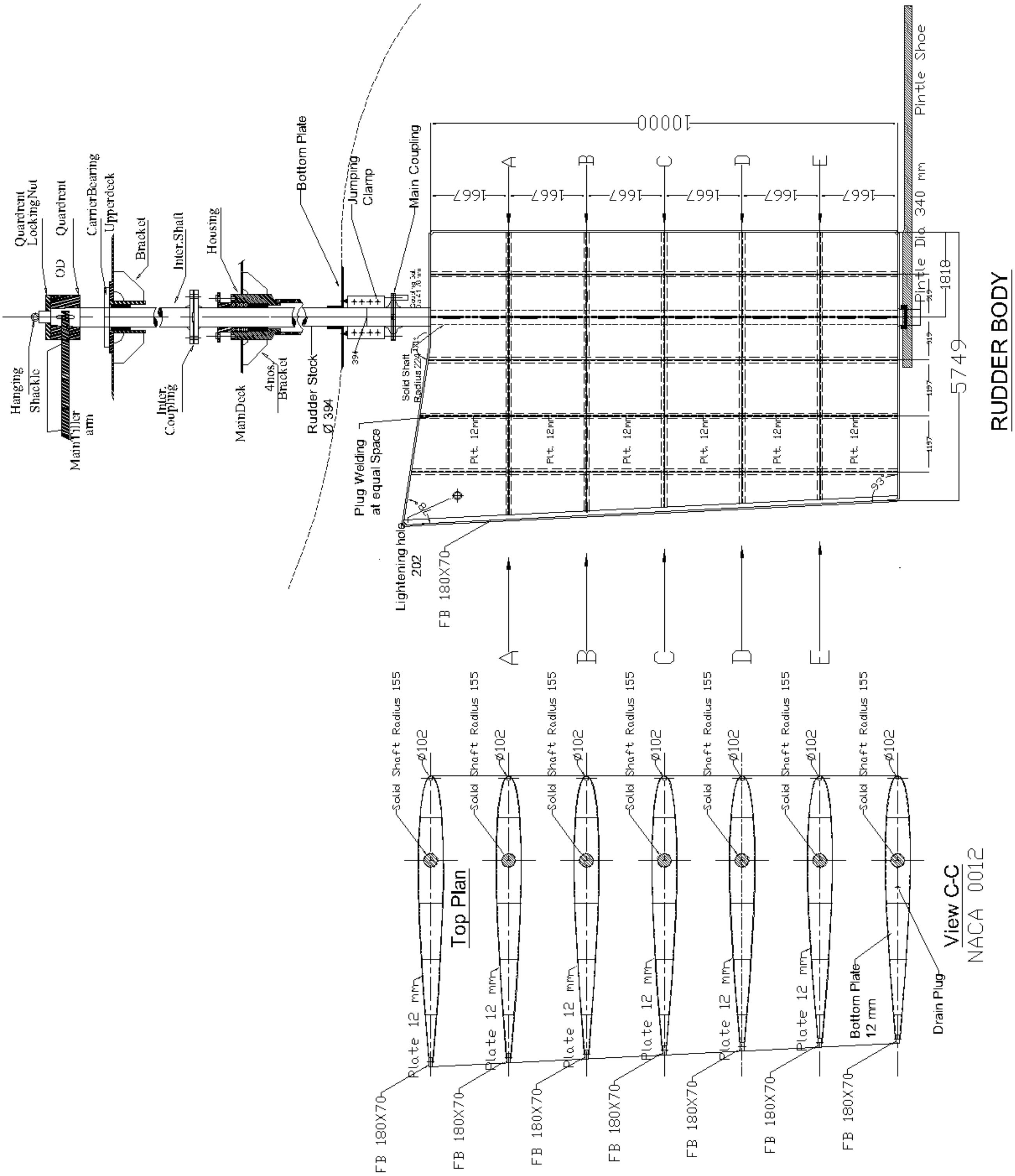
$$B_1 = Support\ force = Rudder\ Force * \frac{Rudder\ Height}{Rudder\ Breadth}$$
$$= 746698.00 \times \frac{10}{6}$$
$$= 1244496.66\ N$$

K_r=Material Factor =0.7417
Therefore, $d = 0.35 \times \sqrt[2]{1244496.66 \times 0.7417}$
$= 336.26mm$
$\approx 340\ mm$

17.3 Calculation Summary

Name	Value	Unit
Rudder Area	60	m^2
Height	10	m
Breadth	6	m
Rudder Stock Diameter	395	mm
Coupling Bolt Dia	41.76	mm
Coupling Bolt Thickness	41.76	mm
Rudder Plating Thickness	12	mm
Pintles	340	mm

17.4 Rudder Drawing



CHAPTER 18: PROPELLER

18.1 Introduction

A **ship's propeller** is a mechanical device that converts rotational energy into thrust, propelling a vessel through water. It consists of multiple blades attached to a central hub, which rotates when driven by the ship's engine. The blades are designed with a helical shape to create a pressure difference between the front and back, generating forward motion.

Types of Ship Propellers

1. **Fixed Pitch Propeller (FPP)** – Blades are fixed and cannot change their angle.
2. **Controllable Pitch Propeller (CPP)** – Blades can rotate on their axis to adjust thrust direction and speed.
3. **Ducted (Kort Nozzle) Propeller** – A propeller enclosed in a duct to increase efficiency, often used on tugboats.
4. **Contra-Rotating Propeller (CRP)** – Two propellers rotating in opposite directions to reduce energy loss.
5. **Voith Schneider Propeller (VSP)** – A vertical blade system that provides highly maneuverable thrust control, used in ferries and tugs.

Factors Affecting Propeller Performance:

- **Diameter & Pitch** – Determines thrust and efficiency.
- **Number of Blades** – More blades reduce vibration but may increase resistance.
- **Material** – Common materials include bronze, stainless steel, and composite alloys for durability.
- **Cavitation** – Formation of vapor bubbles that can damage the blades and reduce efficiency.

The **"Propeller Handbook"** by **Dave Gerr** is a well-known reference book on marine propellers. It provides in-depth knowledge about propeller design, selection, and performance, making it valuable for boat owners, engineers, and naval architects. According the book we have designed the propeller.

18.2 Calculation

Break Hhorse Power	**BHP**	26100	Hp
Engine RPM		600	
Block Coefficient	**C_b**	0.77	
Ship Speed	**V_s**	19.5	Knots
		10.0308	m/s

Transmission Loss		5%
Gear Box Ratio	**1:05**	0.2

Shaft Hhorse Power	**SHP**	24795	Hp
Shaft RPM	**Engine RPM X Gear Box Ratio**	120	

Formula 5-3 DIA-HP-RPM Formula

$$D = \frac{632.7 \times SHP^{0.2}}{RPM^{0.6}}$$

Where:

D = Propeller diameter in inches

SHP = Shaft horsepower at the propeller

RPM = Shaft RPM at the propeller

\

Propeller Diameter	**D**	270.7459129	inch
		6.876946187	m

Formula 6-4b—Twin Screw:

$$Wf = 1.06 - (0.4 \times Cb)$$

Where:

Wf = Wake factor (percent of V "seen" by the propeller)

Cb = Block coefficient of hull

Wake Fraction	**W_f**	0.752	
Velocity of Advance	**V_a**	14.664	Knots
		7.5431616	m/s

Formula 6-7 Power Factor Formula

$$Bp = \frac{(SHP)^{0.5} \times N}{Va^{2.5}}$$

Where:

Bp = Power factor

SHP = Shaft horsepower at the propeller

N = Shaft RPM

Va = Speed of advance of the propeller through the wake

Formula 6-8 Advance Coefficient Formula

$$\delta = \frac{N \times Dft}{Va} \text{ or } \frac{N \times D}{12 \times Va}$$

This may also be restated as:

$$D = \frac{\delta \times Va \times 12}{N}$$

Where:

δ = Advance coefficient

N = Shaft RPM

Dft = Propeller diameter in feet

D = Propeller diameter in inches

Va = Speed of advance of the propeller through the wake

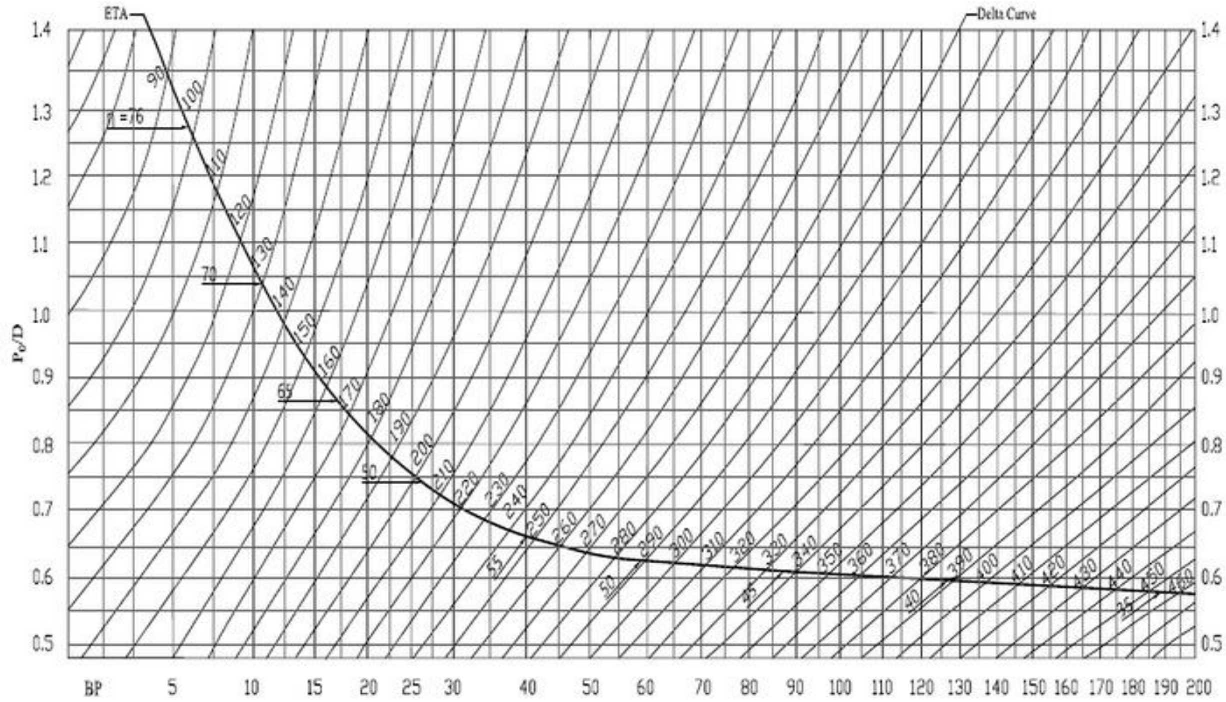
Power Factor	**Bp**	120.9148865
Advance Coefficient	**δ**	358.9289574

No of Blade	**n**	4	
Blade Area Ratio (BAR)	**Ae/Ao**	0.55	
From Bp-δ Diagram			
Pitch Ratio	**P/D**	0.7	
Propeller Efficiency	**n**	0.43	

Bp-δ Diagram

REQUIRED CALCULATIONS	
V_A	V_S (1-W_t)
W_t	-0.20 + 0.55 X C_b for twin screw ship
P_d	P_b (1-0.03)
N	Engine RPM / Gear Ratio
Bp	N X $P_d^{1/2}$ / $V_A^{2.5}$
D_0	(δ X V_A) / (3.28 X N)

ADDITIONAL INFORMATION					
V_A	Velocity of advance	Knot	P_0	Propeller pitch	Higher RPM typically causes the propeller's diameter and efficiency to decline. Thus, gearboxes with higher reduction ratios are recommended.
A_e/A_0	Expanded blade area ratio	Meter	D_0	Propeller diameter	
W_t	Taylor's wake fraction	-0.05 + 0.55 X C_b for Single screw ship			
P_d	Delivered Power	HP	Screw series B.4.55		
P_b	Break Horse Power	HP	Type B	4 Blades	
N	Speed Of the Shaft	RPM	A_e/A_0 = 0.55	t/D = 0.045	



*Notes: 1) Efficiency curves has been removed, efficiencies are indicated at ETA curve which got highest possible efficiency at each BP station. 2) Curves were taken by tracing the image of original Bp-δ diagram but the aspect ratio was kept same. 3)Average Error for δ is more or less 0.55%-1%.

PREPARED BY:	MD. YASIN ARAFAT
DATE:	21-12-2022

Formula 4-6 Developed Area vs Mean-Width Ratio Formula

Ad = π × $(D/2)^2$ × MWR × 0.51 × No. of Blades

Where, for both of the above formulas:

Ad = Developed area

D = Diameter

DAR = Disc-area ratio

MWR = Mean-width ratio

π≈3.14

Formula 4-4 Disc-Area Ratio vs Mean-Width Ratio

DAR = No. of Blades × 0.51 × MWR

or

$$\text{MWR} = \frac{\text{DAR}}{\text{No. of Blades} \times 0.51}$$

Where:

DAR = Disc-area ratio

MWR = Mean-width ratio

Disc-Area Ratio	**DAR**	0.55	
Mean-Width Ratio	**MWR**	0.269607843	
Developed Area	**Ad**	31648.72108	in^2

18.3 Checking For Cavitation

Formula 5-6 Allowable Blade Loading Formula

$$PSI = 1.9 \times Va^{0.5} \times Ft^{0.08}$$

Where:

PSI = The pressure, in pounds per square inch, at which cavitation is likely to begin.

Va = The speed of water at the propeller (see next chapter regarding wake factor) in knots.

Ft = The depth of immersion of the propeller shaft centerline, during operation, in feet.

Formula 5-7 Actual Blade Loading Formula

$$PSI = \frac{326 \times SHP \times e}{Va \times Ad}$$

Where:

PSI = Blade loading in pounds per square inch.

SHP = Shaft horsepower at the propeller.

e = Propeller efficiency in open water.

Va = Speed of water at the propeller, in knots (see "Wake Fraction," next chapter).

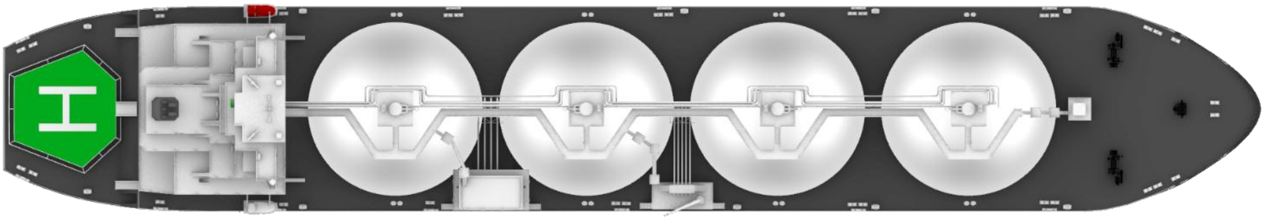
Ad = Developed area of propeller blades, in square inches.

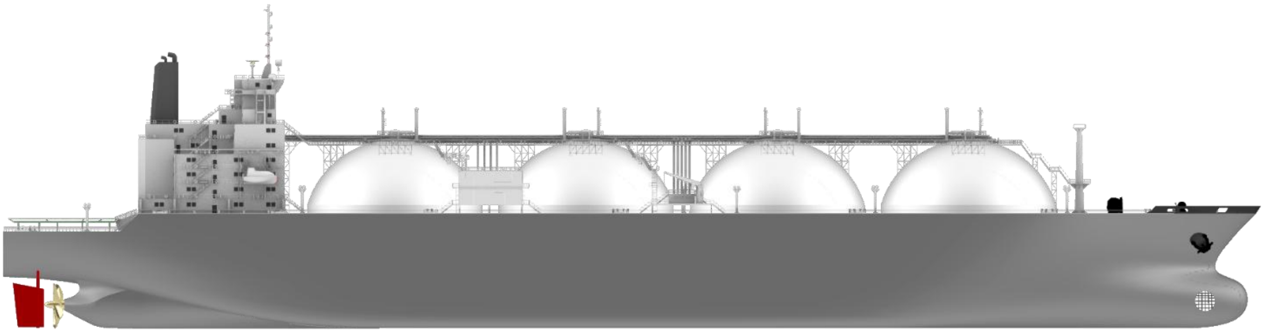
Checking For Cavitation			
The depth of immersion of the propeller shaft centerline, during operation, in feet.	**Ft**	20.58	ft
Allowable Blade Loading	**PSI**	10.68677181	psi
Actual Blade Loading	**PSI**	7.489305584	psi

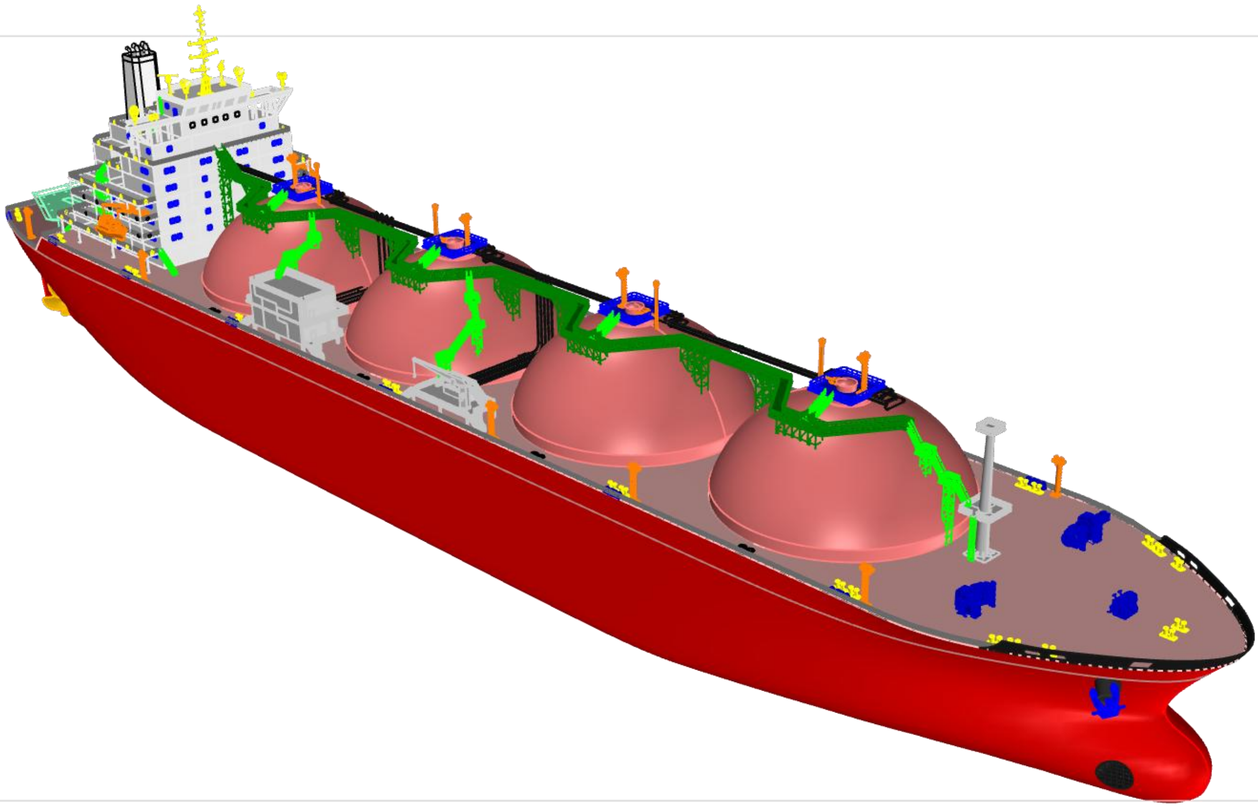
18.4 Calculation Summary

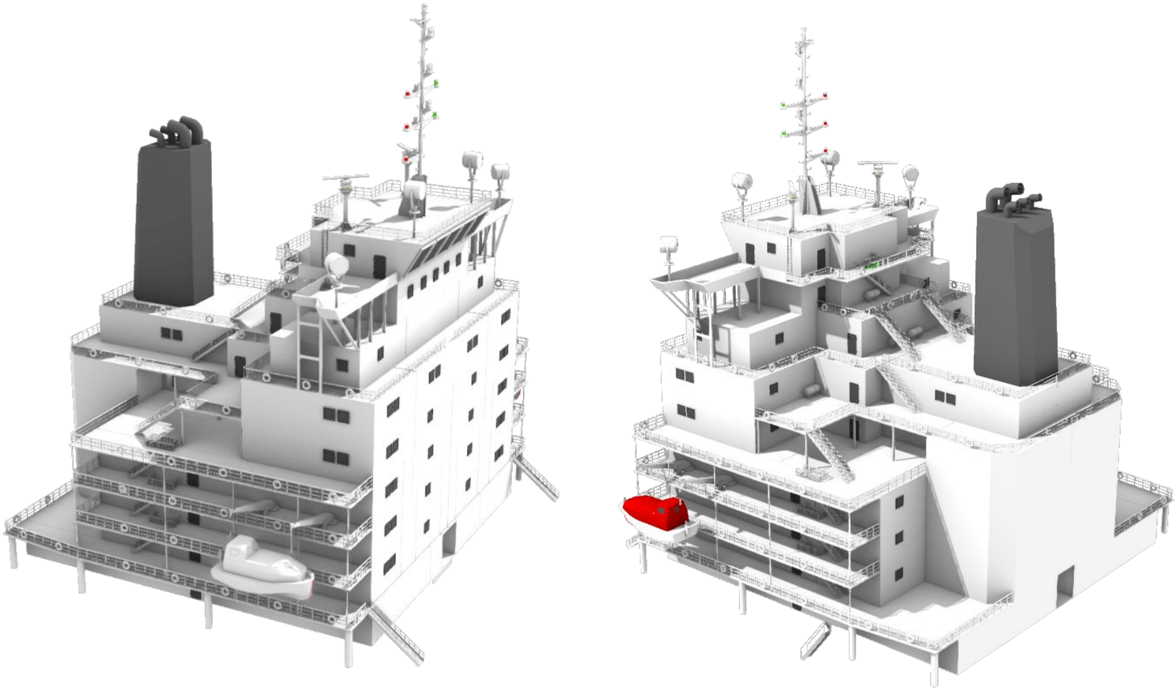
Summary	
Propeller Diameter	6.87 m
Pitch Ratio	0.7
Propeller Efficiency	0.43
No of Blade	4
Blade Area Ratio (BAR)	0.55

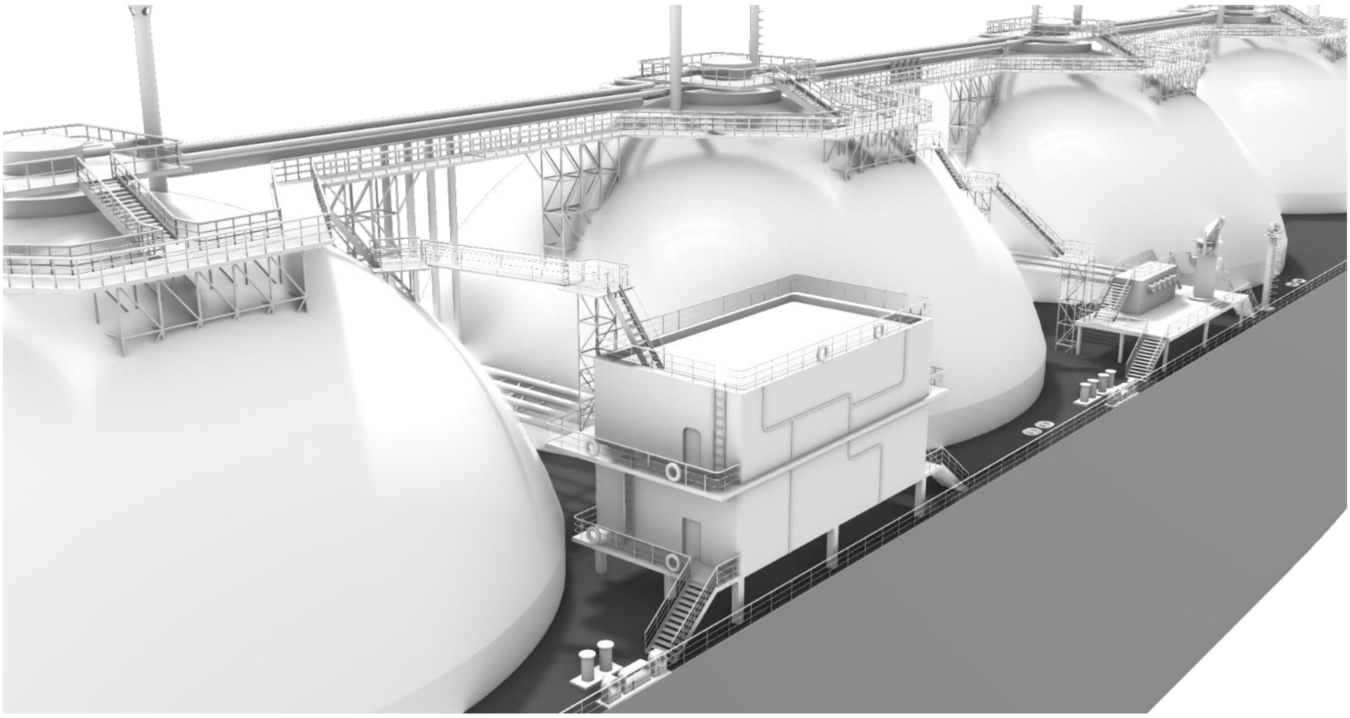
CHAPTER 19: 3D MODEL OF SHIP











CHAPTER 20: CONCLUSION

In conclusion, the **NAME 300 – Ship Design Project Course** provides students with a comprehensive, hands-on approach to ship design, guiding them through essential stages of the process from initial calculations to final design visualizations. By working through key objectives such as displacement calculation, hydrostatic comparison, resistance and power calculation, and stability analysis, students gain a deep understanding of the technical and practical aspects of naval architecture. This course emphasizes a methodical, structured approach to ship design, ensuring students are equipped with the skills and knowledge necessary to create seaworthy, efficient, and safe vessels. The integration of theoretical principles with real-world applications prepares students to tackle the challenges of ship design and contribute to the advancement of the maritime industry.

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THE END