Probabilistic Damage Stability Verification of a Monohull and a Multihull

A Thesis for the degree of

Bachelor of Science

by

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Declaration

We declare that the content of this written submission reflects our original ideas expressed in our own words. Whenever we have incorporated the ideas and words of others, we have appropriately acknowledged and referenced the original source. We confirm that we have maintained the highest standards of academic honesty and integrity, refraining from misrepresenting, fabricating, or falsifying any ideas, data, facts, or sources in our work. We acknowledge that failure to comply with these guidelines may result in disciplinary measures from the Institute and may also lead to legal consequences from sources that have not been accurately cited or from whom proper permission was not obtained when necessary.

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Abstract

This thesis focuses on the verification of the probabilistic damage stability of a monohull vessel and a multihull vessel. The primary objective is to determine whether the vessels meet the criterion of probabilistic damage stability. To achieve this, a comprehensive analysis of the damage stability characteristics of monohull and multihull designs is conducted. The study includes examining various damage scenarios and their effects on the stability of the vessels. The hand calculations are performed in Excel, considering relevant parameters such as compartment flooding, weight redistribution, and stability criteria. The MaxSurf software, renowned for its capabilities in naval architecture, is also utilized to obtain comparative results. The obtained results are thoroughly analyzed and compared, focusing on key aspects and relevant stability indicators. Any discrepancies or differences between the two methods are investigated and discussed.

Keywords: probabilistic damage stability, monohull, multihull, hand calculations, Excel, MaxSurf, comparative analysis.

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Symbols

R	Required Index
L_s	Length of Subdivision
s_i	A probability factor
$J_{\max}$	Normalised maximum damage length
p_k	Cumulitive probability at J_{kn}
A	Attain Index
p_i	A probability factor
v_i	A probability factor
J_{kn}	Knuckle point
$L*$	Length where normalised distribution ends

Chapter 1

Introduction

1.1 Before formal Science

Before the development of modern science and analysis methods, the construction of boats and other watercraft was often based on empirical knowledge and practical experience. Early boat builders relied on trial and error, observation of natural materials and structures, and the accumulated knowledge passed down through generations.

1.2 Introduction of Science

Archimedes of Syracuse who lived during the 3rd century BC, made significant contributions to various scientific disciplines, including hydrodynamics. But significant advancements in hydrodynamics as a scientific discipline occurred during the 17th and 18th centuries. The application of analysis and science in boat building has evolved over time, with significant advancements occurring in the past few centuries. During the 19th century, the emergence of naval architecture as a formal discipline led to the application of scientific principles in boat design and construction. Engineers and naval architects began utilizing mathematical models, empirical data, and physical experiments to study the behavior of boats and ships in various conditions. This included analyzing the hydrodynamics, structural strength, stability, and other factors influencing vessel performance.

1.3 Damage Stability

The analysis of damage stability in ships used earlier methods such as floodable length calculation and the deterministic approach.

The floodable length calculation involved determining the maximum allowable length of a compartment that could be flooded while still maintaining the ship's stability. This method helped in assessing the effects of potential flooding scenarios on the vessel's stability.

On the other hand, the deterministic approach relied on established rules and regulations to determine the required subdivision and placement of watertight bulkheads. These rules, often based on factors such as ship size and type, aimed to ensure adequate compartmentalization and minimize the risk of flooding.

1.4 Probabilistic approach

The previously employed methods provide a measure of safety within specific damage cases, ensuring a certain level of survivability for the ship. However, if the damage exceeds those predefined cases, the ship's survival cannot be guaranteed. Conversely, the probabilistic method introduces a fundamental shift by establishing that the ship possesses a probability of survival across a wide spectrum of potential damage scenarios.

The probabilistic damage stability (PDS) approach is based on accident statistics and introduces uncertainties through the use of random variables. It calculates the probability of various damage scenarios and the survivability of the vessel after each scenario. The attained index represents the ship's ability to withstand damage, and regulations require it to meet or exceed the required index. PDS regulations, which came into force in 2009, apply to specific types of ships and aim to improve safety by considering a wider range of potential damage cases. The deterministic damage stability (DDS) method, which preceded PDS, focused on predefined damage cases and lacked the flexibility and risk quantification offered by probabilistic rules. Efforts are ongoing to enhance and refine probabilistic regulations for damage stability.

Chapter 2

Literature review

Since the 1970s, passenger vessels have been required to comply with probabilistic damage stability regulations, as stated in IMO Resolution A.265(VIII). Subsequently, the regulations were extended to dry cargo ships built after 1992. A harmonization process called HARDER was initiated in 2003 to unify damage stability regulations for all ship types. However, large passenger ships faced delays in adopting the harmonized regulations. Eventually, IMO mandated that all dry cargo and passenger vessels constructed after January 1, 2009, must adhere to the probabilistic damage stability criteria outlined in SOLAS Chapter II-1, Part B-1.

According to SOLAS, certain vessel types that comply with other instruments covering damage stability regulations are exempt from the application of probabilistic damage stability regulations. Resolution MSC.235(82) specifically addresses damage stability for platform supply vessels using a deterministic approach. Therefore, platform supply vessels are not obligated to follow probabilistic damage stability regulations, unless the ship owner requests the special purpose ship (SPS) notation.

The SPS notation allows a ship to carry more than 12 special personnel without being classified as a passenger vessel in terms of safety requirements. This personnel are involved in specialized operations unrelated to normal ship activities, and they receive safety drills and have knowledge of the vessel layout. SPS vessels follow the same probabilistic damage stability approach as passenger vessels, but the required safety level is lower and dependent on the certified number of personnel (IMO, 2008c).

When designing vessels based on deterministic damage stability regulations, bulkhead placement is determined by the specified damage extents. In contrast, probabilistic damage stability requirements offer more flexibility to designers regarding bulkhead placement. However, designers may wonder how to leverage this flexibility effectively.

Probabilistic damage stability calculations necessitate a detailed general arrangement of the ship to assess compliance with the regulations. Typically, ship designers follow a top-down design approach, starting with main dimensions and progressively incorporating bulkheads and equipment. Damage stability calculations are performed in the later stages of the design process, where designers can verify if the ship possesses adequate stability to meet the damage stability regulations. Given the unique nature of each offshore vessel, minor modifications to the arrangement can significantly impact the attained index. If designers could understand how the placement of specific bulkheads affects the attained index, it would streamline the design process, reducing the need for iterations.

The complexity of regulations pertaining to probabilistic damage stability poses a significant challenge, requiring substantial time and effort to grasp the intricacies of the calculations involved. Understanding the effects of arrangement changes on the attained index is further complicated by the multitude of factors influencing the results. As offshore vessels have relatively new probabilistic damage stability requirements, research on how changes in the arrangement affect the attained index for these vessel types is limited. At NTNU, probabilistic damage stability has not been extensively covered in the curriculum until 2014, and only one master's thesis has been written on the subject since 2002. The most available research on the impact of arrangement changes on damage stability focuses on Ro-Ro or passenger ships. These studies employ computer software to optimize the subdivision and maximize the attained index. This emphasis on Ro-Ro and passenger ships could be attributed to their long-standing compliance with probabilistic damage stability requirements. Numerous papers have been published on subdivision optimization to enhance the attained index. For instance, a 2004 publication by Boulougouris, Papanikolaou, and Zaraphonitis explored the use of genetic algorithms to optimize the arrangement of Ro-Ro passenger ships. Genetic algorithms consider parameters such as attained subdivision index, lane meters, and steel weight as objective functions. However, this approach has drawbacks in terms of computational time and the need for calculations to converge to an optimal solution. Input variables in the arrangement include ship depth, minimum double bottom margin, and the number of bulkheads in front of the machinery room. Through genetic algorithms, computer programs optimize the internal arrangement of the vessel, resulting in an optimal subdivision. The conducted case studies demonstrated the applicability of this optimization method to realistic design problems. In 2003, Erik Sonne Ravn's Ph.D. thesis focused on optimizing the subdivision of Ro-Ro vessels.

The objective was to maximize the attained index and deck area while minimizing the lightship weight—a multi-objective optimization problem. Ravn employed genetic algorithms for subdivision optimization and investigated ways to simplify the calculations for the attained index due to their computational demands. His findings revealed that the most critical parameters influencing the attained index were KG position, Ro-Ro deck position, the presence of side casings, and the number of transverse bulkheads. Interestingly, the position of the double bottom had minimal significance for the attained index. An article published in the Journal of Shipping and Ocean Engineering in 2012 addressed reducing uncertainty in subdivision optimization. The study explored the relationship between bulkhead placement and the attained subdivision index, aiming to identify optimal optimization strategies for time reduction. The analysis aimed to understand the topology of the attained index and leverage it during the optimization process. The findings indicated that the attained index topology generally exhibited characteristics of non-convexity, multimodality, and high irregularity. Moreover, as the attained index increased, the irregularity decreased, implying that improving the attained index became easier when the initial index was high. The study concluded that optimization techniques such as genetic algorithms and other heuristics should be employed for effective subdivision optimization. The previous research primarily focuses on optimization techniques and their practical applications, mainly concerning passenger and Ro-Ro vessels. However, since the internal subdivision requirements for offshore vessels differ significantly, the existing literature offers limited guidance for naval architects when designing offshore vessels. Consequently, given the scarcity of available information, it would be intriguing to explore how arrangement changes impact the damage stability properties of offshore vessels.

Chapter 3

Historical Background

3.1 Ancient Shipbuilding

Boats have been used since pre-historic times. The earliest boats are believed to be dugouts, and archaeological discoveries indicate that boats have been used for approximately 7,000 to 10,000 years. The **Pesse canoe**, the oldest recovered boat in the world, was found in the Netherlands and dates back to the period between 8200 and 7600 BC. It is a dugout crafted from the hollowed trunk of a Pinus sylvestris tree [1]. Ancient boat-building methods encompassed various techniques such as hide, log, sewn, lashed-plank, clinker, shell-first, and frame-first construction. While the modern shipbuilding industry favors the frame-first technique, ancient civilizations primarily relied on other methods to construct their watercraft. These techniques often required significant labor and raw material resources. Despite their differences, vessels from the ancient world, especially those utilized in the Mediterranean Sea and Southeast Asian trade, were seaworthy and enabled large-scale maritime commerce [2].

3.2 Damage Stability in Ancient Boats

In ancient shipbuilding, the analysis of damage stability was not conducted using formal scientific methods or sophisticated calculations as we know them today. Instead, shipbuilders relied on practical knowledge and empirical observations to assess the stability of a vessel in the event of damage.

Ancient shipbuilders had an understanding of the basic principles of buoyancy and stability. They recognized that a ship needed to maintain sufficient buoyancy to stay afloat even if it suffered damage. To achieve this, they employed various design features and construction techniques that aimed to minimize the risk of capsizing or sinking.

One common method used in ancient shipbuilding was the incorporation of multiple watertight compartments within the hull. These compartments served as a means to limit the spread of water in case of damage, thus helping to maintain the overall stability of the vessel. By dividing the ship into smaller compartments, the risk of flooding and loss of buoyancy was reduced.

Another approach was the use of resilient materials and construction techniques that provided inherent strength and resistance to damage. This included techniques such as overlapping planks or the use of strong timbers and structural reinforcements.

Additionally, shipbuilders in ancient times relied on their experience and intuition to ensure the seaworthiness and stability of their vessels. They learned through trial and error, studying the behavior of ships in various conditions and making adjustments to their designs accordingly.

While the analysis of damage stability in ancient shipbuilding was not conducted using formal calculations or scientific methods, it was an essential consideration in ensuring the safety and functionality of the vessels. The knowledge and practices developed during this era formed the foundation for subsequent advancements in ship design and stability analysis.

3.3 Damage Stability Calculation in Modern Ship

The introduction and explanation of modern ship stability principles occurred centuries later. In 1746, Pierre Bouguer published "Traité du Navire," followed by Leonhard Euler's "Scientia Navalis" in 1749. These works addressed specific ship theory problems based on Newtonian mechanics.

During the nineteenth century's industrial revolution, a practical and systematic approach to ship stability became necessary. Classification societies established rules for bulkhead positioning in merchant ships, resulting in the inclusion of fore and aft peak tanks and separated machinery and cargo spaces.

The loss of the Titanic in 1914 on its maiden voyage prompted the establishment of the International Convention for the Safety of Life at Sea (SOLAS). This convention, which remains in effect today, governs global maritime safety.

It was after World War II, in the 1948 SOLAS convention, that explicit requirements for damage stability were introduced, such as maintaining a positive metacentric height in damaged conditions. This convention also laid the groundwork for the International Maritime Organization (IMO), a United Nations agency responsible for enhancing maritime safety and preventing pollution at sea.

Following the Andrea Doria accident, the 1960 SOLAS convention mandated a minimum metacentric height of 0.05 m in damage conditions, which was further reinforced by the 1974 SOLAS convention. An implicit requirement for a righting arm of at least 0.03 m in damage conditions was also introduced. In response to the Herald of Free Enterprise accident in 1987, SOLAS 90 implemented a comprehensive damage stability criterion.

3.4 Deterministic Approach

Early deterministic assessments of damaged stability focused on the fundamental principles involved in determining the extent to which a ship could be flooded without compromising its integrity. These methods considered the waterline level at which the loss of the ship occurred, typically when the damaged waterline was tangent to the uppermost weathertight deck called the bulkhead deck.

To ensure a safety margin, a line known as the margin line was established 76 mm below the bulkhead deck at the ship's side. The floodable length at any point along the ship's length was defined as the distance, centered at that point, which could be flooded without submerging any part of the margin line, assuming the ship had no list or tilt.

These early deterministic assessments provided a basic framework for understanding the limitations and boundaries of damaged stability. They aimed to determine the maximum floodable length while maintaining the structural integrity of the ship, accounting for a safety margin to ensure the vessel's stability and buoyancy in damaged conditions.

3.5 Probabilistic Approach

Two major accidents involving Ro-Ro Passenger ships in Europe, namely the losses of the Herald of Free Enterprise in 1987 and Estonia in 1994, temporarily halted the International Maritime Organization's (IMO) efforts to harmonize existing damage stability rules. In response, IMO's SLF (Stability, Load Lines, and Fishing Vessels) and MSC (Maritime Safety Committee) committees urgently revised the deterministic SOLAS (Safety of Life at Sea) damage stability regulations for passenger ships. These revisions aimed to address the water-on-deck issue specific to Ro-Ro passenger ships. The enhanced deterministic requirements were adopted in the SOLAS Convention of 1995.

Following this, IMO's relevant committees resumed the harmonization of damage stability rules and proposed revisions to SOLAS Chapter II-1 Parts A, B, and B-1. Concurrently, the HARDER research project (2000-2003) funded by the European Commission brought together industry stakeholders, classification societies, universities, research establishments, and administrations to generate knowledge on ships' damage stability. The project evaluated the harmonized damage stability concept known as the SLF42 proposal, which was under development at IMO. An improved proposal, the HARDER-SLF46, was introduced for discussion at IMO. Both concepts underwent extensive deliberation in IMO-SLF 46/INF.5.

In September 2003, concerns were raised regarding the potential impact of the proposed harmonized damage stability regulations on the design and economy of very large passenger ships. Consequently, the approval process was temporarily halted. The IMO-MSC instructed the SLF subcommittee to reconsider the concerns, leading to further studies focusing on the damaged stability of large passenger ships. Proposed amendments addressing these concerns were submitted to IMO-SLF46 and

MSC78.

Based on the work of the International Correspondence Group of IMO-SLF46/47, the HARDER-SLF46 proposal was revisited and evolved into the SLF47 proposal. It was approved as IMO-SLF47 and subsequently at IMO-MSC79 in September 2004. However, revisions were made to the large ship assessment method during the transition from MSC79 to MSC80 in May 2005. The final version of the probabilistic damage stability assessment concept was adopted at MSC80. It stipulated that the concept would apply to all new dry cargo and passenger ships constructed after January 1, 2009

3.6 Damage Stability Calculation

The calculation of stability for damaged ships is a complex and laborious process. Currently, two different analysis concepts are utilized: the deterministic concept and the probabilistic concept. In both concepts, damage stability calculations typically employ the method of lost volume or lost buoyancy. However, these calculations do not account for collision resistance, and vessels with strengthened side structures are treated the same as single-hulled ships.

The deterministic approach is characterized by its predictability. It follows a set rule or fixed procedure, ensuring that a given input consistently produces the same output. In this approach, the system's states are represented by known quantities, such as physical characteristics, or observables like length or mass.

It is important to note that the current damage stability regulations, which are outlined in Table 3.1, adhere to either the deterministic or probabilistic concept. However, these regulations do not consider collision resistance and treat different

TABLE 3.1: Current damage stability regulations

A	Passenger vessels pre-2009	Deterministic
B	The Stockholm agreement	Probabilistic
C	Safe return to port regulations	Deterministic
D	Damaged stability requirements - Type A/B vessels (pre-2009)	Deterministic
E	SOLAS damaged stability rules post-2009	Probabilistic

types of vessels uniformly. The deterministic approach is commonly used for deterministic damage stability (DS) regulations in ship design, as it focuses on ensuring that a ship can withstand a predetermined level of damage [3]. This approach has been dominant for a significant period and continues to be utilized for several reasons. Firstly, the probabilistic damage stability (PS) regulations do not encompass all ship types. Secondly, despite the known conservatism of DS regulations, they have a proven track record and are trusted by society.

Deterministic damage stability calculations are based on assumptions about the extent of damage, such as damage length, transverse extent, and vertical extent. Compliance with required compartment conditions must be demonstrated, considering the ship type and potential environmental risks associated with the cargo carried. The deterministic concept is relevant for chemical and liquefied gas tankers, bulk carriers, offshore supply vessels, high-speed craft, and special-purpose ships.

Chapter 4

Ship Stability

4.1 Intact Stability

Imagine a ship floating upright in still water. The center of gravity (G) is where all the weight of the ship is concentrated, and the center of buoyancy (B) is where the water pushes back up against the ship in Figure 4.1(a). Now, if an external force causes the ship to tilt to one side, a wedge of buoyancy (WOW_1) will be lifted out of the water, while an equal wedge (LOL_1) becomes immersed. This transfers a wedge of buoyancy with its center of gravity at point g to a new position with its center of gravity at point g1. The center of buoyancy (B) will shift to a new position, B1, that is parallel to GG_1 in Figure 4.1(b). The point where the verticals through the centers of buoyancy at two consecutive angles of the heel intersect is called the metacenter. The height of the initial metacenter above the keel (KM) depends on a ship's underwater shape. The vertical distance between G and M is referred to as the metacentric height. If G is below M, the ship is said to have a positive metacentric height, and if G is above M, the metacentric height is said to be negative. If the ship has positive metacentric height, it is in stable equilibrium in Figure 4.1(c). When

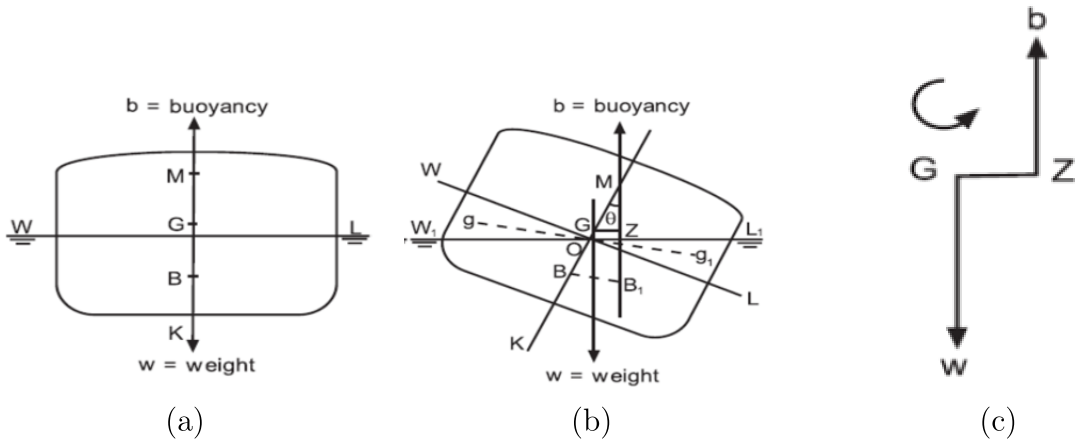
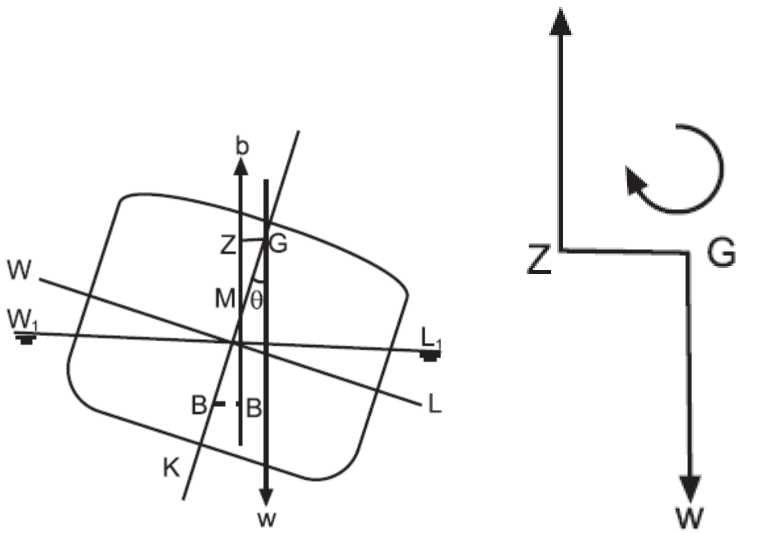


Figure 4.1: Stable equilibrium

inclined, it tends to return to the initial position. This is because the center of gravity is below the metacenter. The moment of statical stability is the product of the force 'W' and the length of the lever GZ, which is the perpendicular distance between the center of gravity and the vertical through the center of buoyancy.

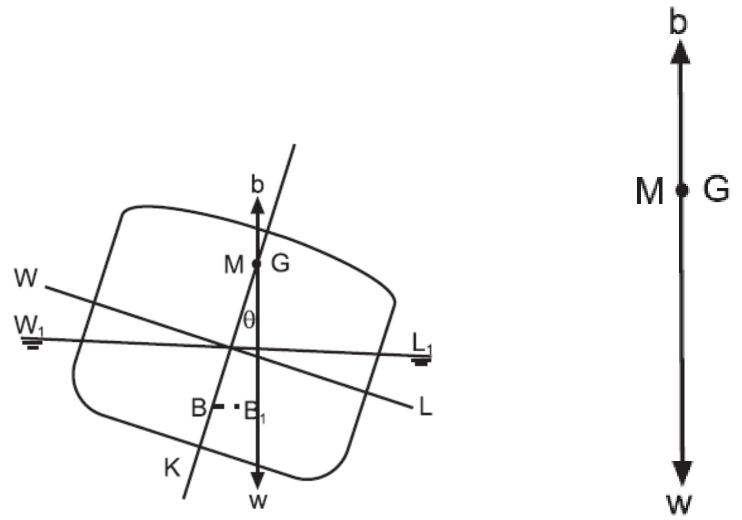
If the ship has negative metacentric height, it is in unstable equilibrium. When inclined, it tends to heel over still further. The moment of statical stability in this case is a capsizing moment that will tend to heel the ship still further in Figure 4.2.

When G coincides with M, the ship is said to be in neutral equilibrium. If inclined to a small angle, it will tend to remain at that angle of the heel until another external force is applied. The ship has zero GM, and there is no moment to bring the ship back to the upright or to heel her over still further in Figure 4.3. The ship will move vertically up and down in the water at the fixed angle of the heel until further external or internal forces are applied [4].



(a) (b)

Figure 4.2: Unstable equilibrium



(a) (b)

Figure 4.3: Nutral equilibrium

4.2 Damage Stability

In order to ensure a minimum level of safety following flooding, it is necessary to perform damage stability calculations. The loss of stability resulting from flooding may be attributed, in part, to the presence of a free surface. To assess these calculations, two approaches have been devised: deterministic and probabilistic. Both methods share a common objective of achieving the most effective subdivision of the ship, enabling it to remain stable and afloat during damaged conditions.

4.2.1 Deterministic Approach

When performing damage stability calculations, the deterministic method relies on presumed damage scenarios in which one or more compartments may become flooded. A range of deterministic methods have been developed, depending on the type of ship, the level of freeboard reduction, and the cargo being carried. These methods include the floodable length approach, the SOLAS90 damage stability criterion, the Stockholm Agreement, and stability criteria specific to certain types of vessels. The floodable length approach refers to the furthest longitudinal extent of the flooded area located around any point of the ship, which must retain a positive metacentric height without causing immersion of the margin line. The SOLAS 90 two-compartment standard is a deterministic approach based on rules which ensure the ship remains afloat in the event of flooding occurring in up to two adjacent compartments. The number of compartments that become flooded can vary depending on the length of the ship, with smaller ships experiencing flooding in only one compartment, while larger ships may have 2 or more compartments flooded. The standard used for damage stability calculations is based on empirical analysis

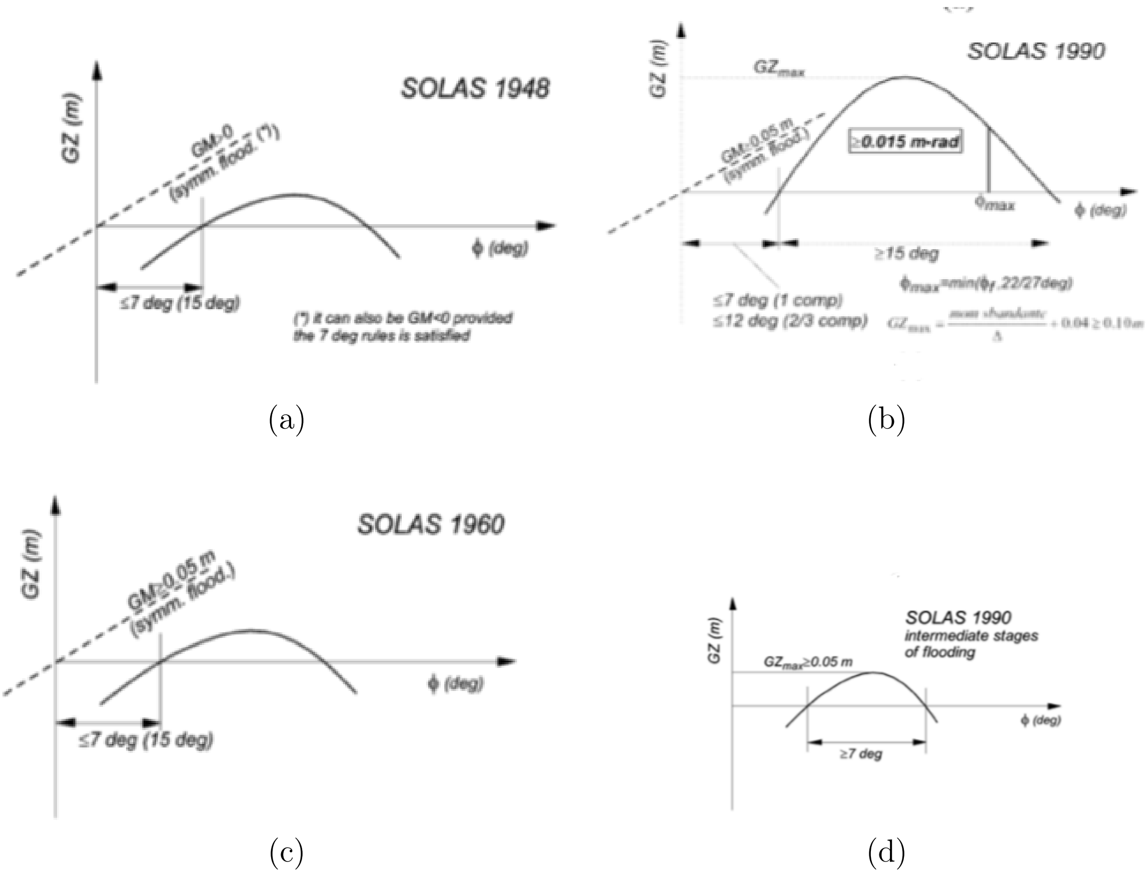


FIGURE 4.4: Evolution of damage stability standards for passenger ships in SOLAS

of stability data from previous cases where a ship has capsized or sunk due to damage. The SOLAS90 damage stability criterion requires that a ship in a damaged condition meets the following demands [5]:

- A range of stability of at least 15º from the equilibrium angle.
- A minimum reserve of stability of 0.015 m-rad.
- A minimum metacentric height in damage condition of 0.05 m.
- A minimum righting arm of 0.10 m, including the effects of passengers crowded on one side, launching of lifeboats, and wind pressure.
- The maximum heeling angle before equalization should not exceed 15º.

4.2.2 Probabilistic Approach

Probabilistic damage stability (PDS) is a methodology that involves some degree of uncertainty and randomness. The method is based on accident statistics from ship-ship collisions, where the size and location of damage and whether the vessel has enough buoyancy to remain afloat after damage have occurred are noted. The idea behind PDS is that two different ships with the same attained index of subdivision are equally safe. The attained index is the sum of the probability and survivability of all possible damage cases that a ship can encounter. Survivability is defined as the vessel's capability to stay afloat after being rammed by an arbitrary ship. The required index is easily calculated for each vessel based on the ship length and the number of passengers the vessel can carry. The PDS regulations were adopted in 2009 as part of SOLAS Chapter II-1, Part B-1 Stability and apply to dry cargo ships with a length of 80 m or above and all passenger ships with keel laying on or after this date. In addition, Special Purpose Ships (SPSs) are also covered by the 'Code of Safety for Special Purpose Ships, 2008' (SPS code) adopted in 2008. All ships that are applicable to the PDS regulations are required to have double bottom and automatic cross-flooding arrangements that stabilize the ship within 10 minutes. If the ship is carrying over 36 passengers, there are additional deterministic requirements. Before PDS, deterministic damage stability (DDS) was the dominant method for damage stability calculations. DDS calculates if a ship can withstand certain damage scenarios depending on its beam and length, and the method gives a rapid impression of the ship's capabilities to withstand damage. However, the method gives little flexibility in the design, and deterministic rules cannot be used as a quantification of risk. It has been demonstrated in several accidents that the concept of rule damages of a predefined size, such as in DDS, is not sufficient in real life.

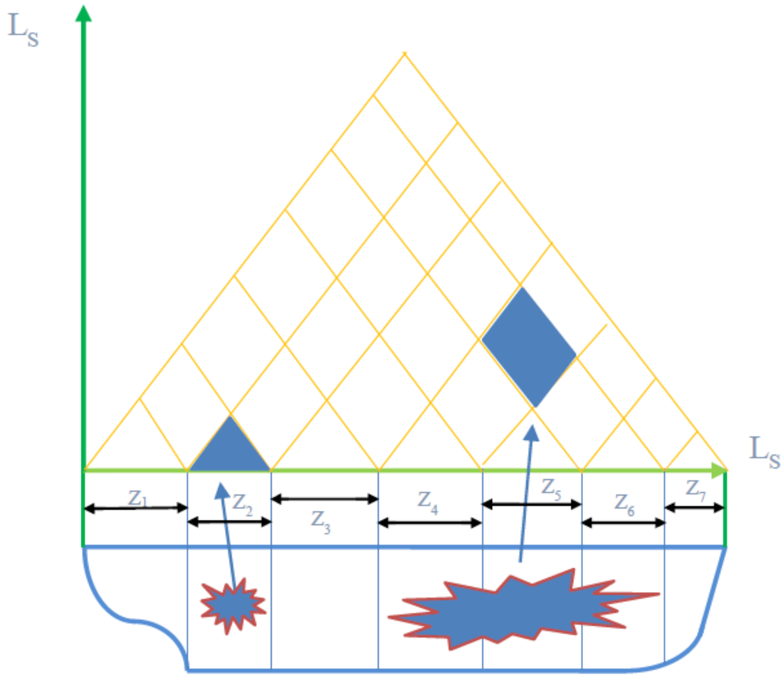


FIGURE 4.5: Possible single and multi-zone damages for a ship with 7 zones

Figure 4.5 illustrates a seven-zone division of a ship with the corresponding possible single- and multi-zone damages. The bottom-line triangles indicate single-zone damages, while the parallelograms indicate multi-zone damages [6]. The regulations for probabilistic damage stability, taken from SOLAS Chapter II-1 Part B: Stability, provide a single measure called the attained index. Applying these regulations in the conceptual design process to determine the most suitable subdivision can be challenging. The calculation of the required and attained index is described in detail in the subsequent sub-chapters, with support from the explanatory notes. Examining a calculated damage case can aid in understanding and applying the regulations effectively.

To assess the probability of a ship surviving damage, two key factors must be considered:

1. The probability of flooding in each individual compartment, as well as groups of two or more adjacent compartments.
2. The probability that the ship will remain buoyant and stable after flooding, so as to prevent dangerous tipping, sinking, or capsizing.

To determine the ship's safety factors in a probabilistic manner, two indices must be taken into account:

1. The Attained Subdivision Index (A), which measures the ship's likelihood of survival in the event of damage.
2. The Required Subdivision Index (R), represents a mandated survival level based on the ship's size and number of passengers, as outlined in regulations.

It is required that:

$$A \geq R$$

The general formula for the index A is:

$$A = p_i s_i v_i$$

where:

- $p_i$is the probability that the compartment or a group of compartments is flooded
- $s_i$is the probability of survival after flooding the compartment or a group of compartments
- v_i is the probability that the space above an existing horizontal boundary is not flooded

The regulation for the required subdivision index R for passenger ships, which became effective on January 1st, 2009, applies to all newly constructed vessels. As per SOLAS 2009 [7], R is calculated using equation 4.1.

$$R = 1 - \frac{5000}{L_s + 2.5N + 15252} \tag{4.1}$$

where:

- L_s is subdivision length
- $N = N_1 + 2N_2$
- N_1 number of persons for whom lifeboats are provided
- N_2 number of persons the ship is permitted to carry

The required index for cargo ships is only dependent on ship length. For cargo ships greater than 100 m in length, the required index R is calculated using equation 4.2.

$$R = 1 - \frac{128}{L_s + 152} \tag{4.2}$$

In the case of cargo ships less than 100 m in length and not greater than 80 m in length, R is calculated using the equation 4.3.

$$R = 1 - \frac{1}{1 + \frac{L_S}{100} \times \frac{R_0}{1-R_0}} \tag{4.3}$$

Where R_0 is the Required index calculated using equation 4.2 [8].

Chapter 5

Vessels for calculation

Two vessels have been selected for the verification of damage stability using the probabilistic approach. The first vessel is a monohull cargo vessel, and the second vessel is a catamaran hull passenger vessel.

5.1 Monohull

Table 5.1 provides details of the monohull cargo vessel.

Table 5.2 provides Principal Particulars of the monohull cargo vessel.

Table 5.1: Vessel Information

NAME	**VESSEL**	O. T. GOLDEN TOUCH
	Name of the Shipping Lines	AASSIAN MARINE AND FUEL SERVICES. 385, Agrabad Access Road, Chittagong
	Owner of the Vessel	MD. SIRAZUL ISLAM
DESIGNED BY	**DESIGNER**	MD. SHAMSUL ALAM
	Enlisted Firm	B. F. INTERNATIONAL LTD. 89, Bijoy Nagar(2nd Floor), Dhaka-1000.
	Authorized Person of the Firm	MIR FAKHRUL ISLAM

Table 5.2: Principal Particulars

Particular	:	Value
Length O.A	:	27.10 m
Length LWL	:	25.56 m
Length LBP	:	24.92 m
Breadth MLD	:	5.48 m
Depth MLD	:	3.00 m
Draft DESIGN	:	2.60 m

5.2 Catamaran

Table 5.3 provides details of the catamaran passenger vessel.

Table 5.4 provides Principal Particulars of the catamaran passenger vessel.

TABLE 5.3: Vessel Information

NAME	**VESSEL**	MV ADVENTURE 06
	Name of the Shipping Lines	M/S. NIZAM SHIPPING LINES
	Owner of the Vessel	MD. NIZAM UDDIN
DESIGNED BY	**DESIGNER**	MD. ABU ELIAS
	Enlisted Firm	FLEUVE NAVAL ARCHITECTS
	Authorized Person of the Firm	MD. ABU ELIAS

TABLE 5.4: Principal Particulars

Particular	:	Value
Length O.A	:	47.25 m
Length LWL	:	46.49 m
Length LBP	:	45.61 m
Breadth MLD	:	13.00 m
Depth MLD	:	3.00 m
Draft LOADED	:	2.10 m

Chapter 6

Hull Design

The vessels were designed using Rhinoceros software. This chapter provides a concise overview of the hull construction process.

6.1 Monohull

The offset table, which is presented in Table 6.1, was collected. From the coordinates provided in the table, control points were created. Lines were then generated using these control points. A surface was constructed using Rhinoceros software for further analysis. The constructed surface was then prepared for import into Maxsurf Software. Figure 6.1 illustrates a 3D model of the vessel's surface.

6.2 Catamaran

The same process was applied to the catamaran hull. The offset table for a single hull, as shown in Table 6.2, was utilized. Control points were created from the coordinates

Table 6.1: Offset Table for a monohull cargo vessel

	HALF BREADTH					ABOVE BASE LINE			
STATION	WL-1	WL-2	WL-3	W.L-4	Deck At Side	KEEL	B.T.K-A	B.T.K-B	DECK
0	—	—	—	—	—	2600	—	—	3200
$\frac{1}{2}$	—	1974	2673	2713	2727	1205	1238	1282	3152
1	—	2636	2740	2740	2740	0782	0815	0849	3110
$1\frac{1}{2}$	2436	2730	2740	2740	2740	0417	0450	0483	3073
2	2690	2740	2740	2740	2740	0093	0118	0149	3042
3	2740	2740	2740	2740	2740	—	0033	0066	300
4	2740	2740	2740	2740	2740	—	0033	0066	3000
5	2740	2740	2740	2740	2740	—	0033	0066	3000
6	2740	2740	2740	2740	2740	—	0033	0066	3000
7	2622	2712	2740	2740	2740	—	0039	0106	3038
8	2212	2506	2614	2671	2705	—	0111	0335	3143
$8\frac{1}{2}$	1626	2128	2383	2516	2596	—	0229	0826	3213
9	0790	1395	1797	2081	2306	—	0754	1956	3296
$9\frac{1}{2}$	—	0258	0781	1282	1790	0968	2096	3412	3391
10	—	—	—	—	0896	2600	3503	—	3499

of the table. Lines were subsequently generated using the control points. The surface was then constructed using Rhinoceros software. Another surface was derived from this surface, and a 3D model of the surface was created using Rhinoceros software, employing an appropriate hull separation ratio. Figure 6.2 presents a view of the model. The detailed procedures of hull generation are illustrated in Appendix A.

6.3 Summary

During the process of creating the 3D model, special attention was given to the number of surfaces involved. This consideration arose from the fact that MaxSurf, the analysis software being utilized, can handle a maximum of 10 surfaces in a design. Therefore, the model was structured and organized to adhere to this limitation.

Additionally, great care was taken to ensure the precision of the surfaces. Any surfaces that were not smooth or contained imperfections were meticulously updated and refined. This was crucial as the vessels being analyzed were already in service, necessitating the utmost accuracy in replicating the original hull surface.

By prioritizing the fidelity of the created hull model, we aimed to faithfully capture and represent the intricate details and characteristics of the original vessel's surface. This meticulous approach ensured that the resulting 3D model aligned precisely with the surface of the original hull, enabling accurate analysis and evaluation of the design.

TABLE 6.2: Offset Table for a multihull passenger vessel

	HALF BREADTH					ABOVE BASE KEEL				
Station	WL-1	WL-2	WL-3	WL-4	Dk.At.Side-6	Keel	BTK-1	BTK-2	BTK-3	BTK-4 (-)
0	-	-	-	1791	2172	1618	1627	1665	2013	3000
$\frac{1}{2}$	-	-	1482	1889	2172	1388	1395	1426	1799	3000
1	-	1158	1748	1923	2172	962	968	1008	1620	3000
$1\frac{1}{2}$	-	1604	1793	1931	2172	560	563	654	1523	3000
2	1286	1639	1802	1932	2172	227	252	441	1493	3000
3	1380	1678	1814	1932	2172	-	61	346	1436	3000
4	1380	1678	1814	1932	2172	-	61	346	1436	3000
5	1380	1678	1814	1932	2172	-	61	346	1436	3000
6	1380	1678	1814	1932	2172	-	62	346	1436	3000
7	1271	1559	1704	1839	2116	-	77	428	1858	3000
8	856	1091	1232	1389	1829	-	236	1380	2945	3000
$8\frac{1}{2}$	621	820	943	1087	1609	6	469	2279	-	3000
9	421	576	680	806	1388	37	1110	2858	-	3000
$9\frac{1}{2}$	164	314	423	550	1004	120	2146	-	-	3000
10	-	-	-	-	407	2000	-	-	-	3000

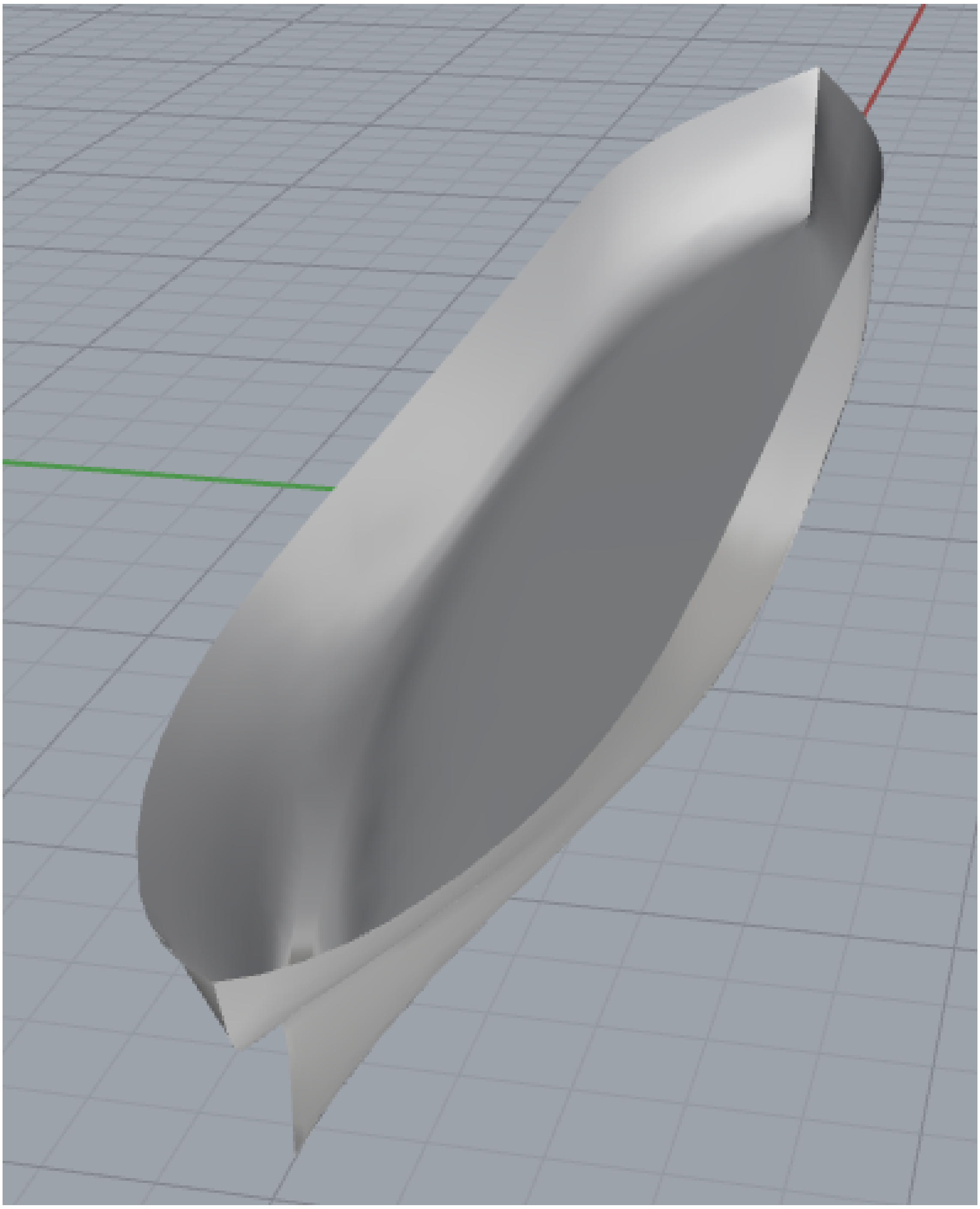


Figure 6.1: A 3D model of the monohull.

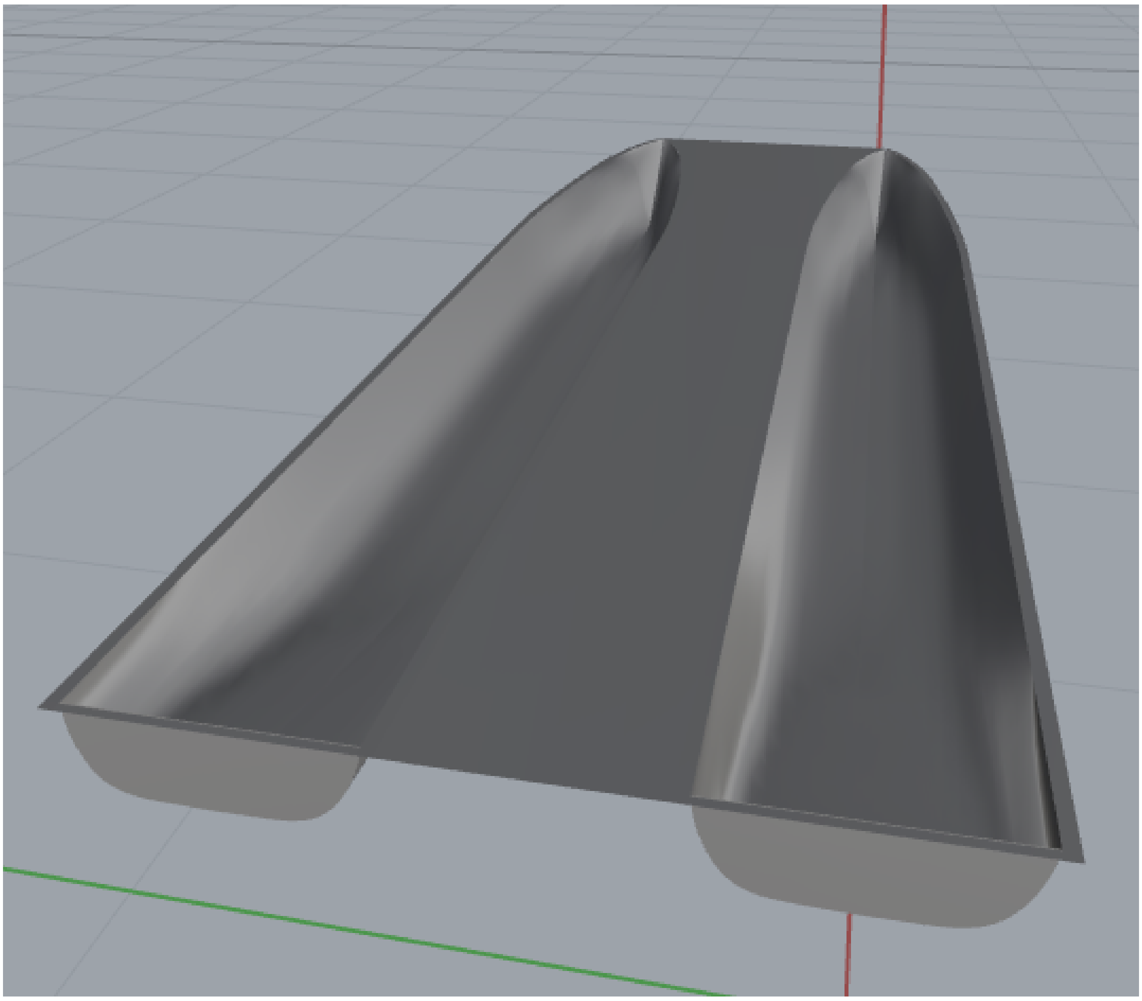


FIGURE 6.2: A 3D model of the catamaran hull.

Chapter 7

Manual Calculation of Probabilistic Approach for Damage Stability

The safety assessment of ships through DS calculations hinges primarily on ship size, encompassing length, beam, and depth. These parameters collectively ascertain the ship's vulnerability to damage, as expounded in preceding book chapters. Although calculation parameters are generally consistent across ship types, their impact varies due to factors like ship type, size, cargo, and passengers.

Moreover, the ship must withstand specific damage scenarios aligned with predetermined extents. The primary objective involves identifying the most critical damage scenarios by examining all potential conditions within these bounds. These scenarios must adhere to SOLAS-defined requirements. Failing to meet these standards in the calculations results in disapproval from the flag state or classification societies, as noted by Djupvik et al. [9] and Patterson and Ridley [10].

7.1 Monohull

7.1.1 Calculation of the Required Index

The Required Index of a Cargo Ship can be obtained by the equation 7.1.

$$R = 1 - \frac{128}{L_s + 152} \tag{7.1}$$

Here, L_s represents the length of the subdivision. Specifically, for the designated cargo ship, L_s equates to 27.1 meters. By plugging this value into equation 7.1, we can subsequently determine the R-factor.

$$\boxed{R \approx 0.285}$$

7.1.2 Calculation of the Attained Index

The probability of survival following hull damage from a collision is denoted by the index A. Computation of index A involves assessing diverse damage scenarios determined by the extent of damage and the ship's initial loading conditions prior to the damage event. It's crucial to account for three distinct loading conditions, and the final outcome is obtained by applying the weighting equation 7.2.

$$A = 0.4A_s + 0.4A_p + 0.4A_l \tag{7.2}$$

The A-index for a specific loading condition can be calculated using the equation 7.3.

$$A_c = \sum p_i s_i v_i \tag{7.3}$$

Where,

- p_i is known as the p-factor and depends on the ship geometry and the watertight arrangement of the ship.
- v_i is the probability of the survivability of the ship after a certain damage case.
- s_i is the probability that the spaces above the horizontal subdivision will not be flooded.

7.1.2.1 Calculation of p_i Factor

The parameters used in the calculation of p_i index are shown in the table 7.1. The pi

TABLE 7.1: Description of Symbols

Symbol	Description
j	The aftmost zone number involved in the damage starting with No.1 at the stern
n	The number of adjacent damage zones involved in the damage
k	The number of a particular longitudinal bulkhead as a barrier for the transverse penetration in the damage zone counted from the shell towards the centerline. The shell has $k = 0$
x1	The distance from the aft terminal of ls to the after end of the zone in question
x2	The distance from the aft terminal of ls to the forward end of the zone in question
b	The mean transverse distance in meters measured at right angles to the centerline at the deepest subdivision load line between the shell and an assumed vertical plane extended between the longitudinal limits with all or part of the outermost portion of the longitudinal bulkhead under consideration

factor depends upon the watertight arrangements and the zone division of the ship. This factor is for the probability of specific damage to the ship as shown in figure 7.1, without any horizontal subdivision and $\sum p = 1$. For single-zone damage, p_i

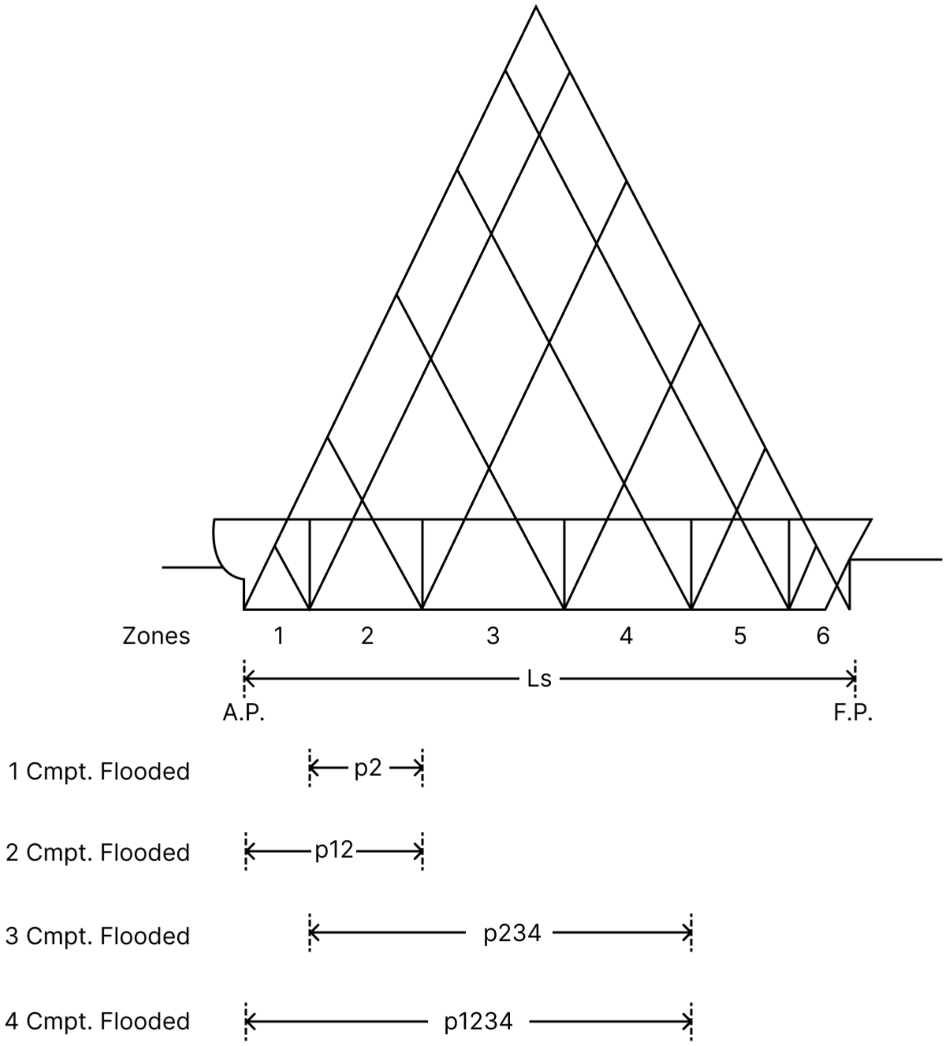


FIGURE 7.1: Probabilistic subdivision of cargo ships. Calculation of pi.

is calculated using equation 7.4, equation 7.5 for two-zone damage, equation 7.6 for three-zone damage, and equation 7.7 for four-zone damage.

$$p_i = p(x1_j, x2_j)\left[r(x1_j, x2_j, b_k) - r(x1_j, x2_j, b_{k-1})\right] \tag{7.4}$$

$$\begin{aligned} p_i = p(x1_j, x2_{j+1})[r(x1_j, x2_{j+1}, b_k) - r(x1_j, x2_{j+1}, b_{k-1})] - p(\text{single compartment}) \\ -p(x1_{j+1}, x2_{j+1})[r(x1_{j+1}, x2_{j+1}, b_k) - r(x1_{j+1}, x2_{j+1}, b_{k-1})] \end{aligned} \tag{7.5}$$

$$p_i = p(x1_j, x2_{j+2})\left[r(x1_j, x2_{j+2}, b_k) - r(x1_j, x2_{j+2}, b_{k-1})\right] - p(\text{single compartment})$$
$$-p(\text{two compartment}) - p(x1_{j+2}, x2_{j+2})\left[r(x1_{j+2}, x2_{j+2}, b_k) - r(x1_{j+2}, x2_{j+2}, b_{k-1})\right] \tag{7.6}$$

$$p_i = p(x1_j, x2_{j+3})\left[r(x1_j, x2_{j+3}, b_k) - r(x1_j, x2_{j+3}, b_{k-1})\right] - p(\text{single compartment})$$
$$-p(\text{two compartment}) - p(\text{three compartment})$$
$$-p(x1_{j+3}, x2_{j+3})\left[r(x1_{j+3}, x2_{j+3}, b_k) - r(x1_{j+3}, x2_{j+3}, b_{k-1})\right] \tag{7.7}$$

The formula to calculate $p(x_1, x_2$ varies when the zone does not coincide with aft or fwd and when coincides. The formula when do coincides with aft or fwd is given by the equation 7.8.

$$p(x_1, x_2) = \begin{cases} \frac{1}{6}J^2\left(b_{11}J + 2b_{12}\right), & \text{if } J \le J_k \\ -\dfrac{1}{3}b_{11}J_k^3 + \dfrac{1}{2}\left(b_{11}J - b_{12}\right)J_k^2 + b_{12}JJ_k - \dfrac{1}{3}b_{12}\left(J_n^3 - J_k^3\right) \\ \qquad + \dfrac{1}{2}\left(b_{21}J - b_{22}\right)\left(J_n^2 - J_k^2\right) + b_{22}J\left(J_n - J_k\right), & \text{if } J > J_k \end{cases} \tag{7.8}$$

But when it coincides, the formula is given by the equation 7.9 where p_1 and p_2 can be found using the equation 7.8 with corresponding cases.

$$p(x_1, x_2) = \begin{cases} \frac{1}{2}\left(p_1 + J\right), & \text{if } J \le J_k \\ \frac{1}{2}\left(p_2 + J\right), & \text{if } J < J_k \end{cases} \tag{7.9}$$

To find the coefficients, the equations in 7.10 can be used.

TABLE 7.2: Values of the Coefficients

Parameters		**Value**
J_{max}	:	0.303
J_{kn}	:	0.152
p_k	:	0.917
1_{max}	:	60
L^*	:	260
1_8	:	26.223
$1_8 < L^*$?	:	TRUE
J_m	:	0.303
b_0	:	11
J_k	:	0.152
b_{12}	:	11
b_{11}	:	-65.34
b_{21}	:	-7.26
b_{22}	:	2.2

$$\begin{aligned} J_m &= \min\left(J_{\max}, \frac{l_{\max}}{l_s}\right), \; b_0 = 2\left[\frac{p_k}{J_{kn}} - \frac{1-p_k}{J_{\max}-J_{kn}}\right] \\ J_k &= \frac{J_m}{2} + \frac{1-\sqrt{1+(1-2p_k)\,b_0 J_m + \frac{1}{4}b_0^2 J_m^2}}{b_0} \\ b_{12} &= b_0, \; b_{11} = 4\frac{1-p_k}{(J_m-J_k)\,J_k} - 2\frac{p_k}{J_k^2} \\ b_{21} &= -2\frac{1-p_k}{(J_m-J_k)^2}, \; b_{22} = -b_{21}J_m \end{aligned} \tag{7.10}$$

The r factor is calculated using equation 7.11 where C is calculated using equation 7.12.

$$r(x_1, x_2, b) = 1 - (1-C)\left[1 - \frac{G}{p(x_1, x_2)}\right] \tag{7.11}$$

$$C = 12J_b(-45J_b + 4), \; J_b = \frac{b}{15B} \tag{7.12}$$

The definition of G is evaluated from the following equation where compartments or groups extend over the entire L_s:

$$G = G_1 = \frac{1}{2}b_{11}J_b^2 + b_{12}J_b$$

But where neither end of the compartment is aft or forward terminals, G is calculated using the following equation with $J_0 = \min(J, J_b)$:

$$G = G_2 = -\frac{1}{3}b_{11}J_0^3 + \frac{1}{2}(b_{11}J - b_{12})J_0^2 + b_{12}JJ_0$$

If the compartment or group coincides with either terminal then the following equation is used:

$$G = \frac{1}{2}(G_2 + G_1 J)$$

Using the formulas, the required coefficients are obtained which are shown in the table 7.2. Now, the p factor is calculated for different damage scenarios. The damage case for at most four-compartment flooding is shown in table 7.3.

TABLE 7.3: Calculation of p factor

							Do not Coincide		Coincide with Aft/Fwd		
							$J \leq J_k$	$J > J_k$	$J \leq J_k$	$J > J_k$	
	Compt.	**x1 (m)**	**x2 (m)**	**Damage (m)**	**J**	**Jn**	**p(x1,x2)**	**p(x1,x2)**	**p(x1,x2)**	**p(x1,x2)**	**p(x1,x2) (pi)**
1 compt. flooded	1	0	1.6	1.6	0.061	0.061	0.0112	0.0306	0.0361	0.0458	0.0361
	2	1.6	6.394	4.794	0.183	0.183	0.0560	0.0932	0.1194	0.1380	0.0932
	3	6.394	7.454	1.06	0.040	0.040	0.0053	0.0107	0.0228	0.0256	0.0053
	4	7.454	12.784	5.33	0.203	0.203	0.0600	0.0910	0.1316	0.1471	0.0910
	5	12.784	18.114	5.33	0.203	0.203	0.0600	0.0910	0.1316	0.1471	0.0910
	6	18.114	21.845	3.731	0.142	0.142	0.0429	0.0853	0.0926	0.1138	0.0429
	7	21.845	22.91	1.065	0.041	0.041	0.0053	0.0109	0.0230	0.0258	0.0053
	8	22.91	26.223	3.313	0.126	0.126	0.0366	0.0782	0.0815	0.1023	0.0815
2 compt. flooded	1,2	0	6.394	6.394	0.244	0.244	0.0601	0.0725	0.1520	0.1582	0.0289
	2,3	1.6	7.454	5.854	0.223	0.223	0.0616	0.0844	0.1424	0.1538	0.0000
	3,4	6.394	12.784	6.39	0.244	0.244	0.0602	0.0727	0.1519	0.1582	0.0000
	4,5	7.454	18.114	10.66	0.407	0.303	-0.1256	0.0758	0.1404	0.2412	0.0000
	5,6	12.784	21.845	9.061	0.346	0.303	-0.0115	0.0352	0.1670	0.1903	0.0000
	6,7	18.114	22.91	4.796	0.183	0.183	0.0560	0.0932	0.1195	0.1380	0.0899
	7,8	21.845	26.223	4.378	0.167	0.167	0.0515	0.0919	0.1092	0.1294	0.0427
3 compt. flooded	1,2,3	0	7.454	7.454	0.284	0.284	0.0461	0.0331	0.1652	0.1587	0.2229
	2,3,4	1.6	12.784	11.184	0.426	0.303	-0.1779	0.0891	0.1243	0.2578	0.0000
	3,4,5	6.394	18.114	11.72	0.447	0.303	-0.2398	0.1028	0.1036	0.2748	0.0000
	4,5,6	7.454	21.845	14.391	0.549	0.303	-0.6956	0.1707	-0.0734	0.3597	0.0000
	5,6,7	12.784	22.91	10.126	0.386	0.303	-0.0803	0.0622	0.1529	0.2242	0.0000
	6,7,8	18.114	26.223	8.109	0.309	0.303	0.0286	0.0110	0.1689	0.1601	0.0329
4 compt. flooded	1,2,3,4	0	12.784	12.784	0.488	0.303	-0.3903	0.1298	0.0486	0.3087	0.0857
	2,3,4,5	1.6	18.114	16.514	0.630	0.303	-1.2656	0.2246	-0.3179	0.4272	0.0000
	3,4,5,6	6.394	21.845	15.451	0.589	0.303	-0.9547	0.1976	-0.1827	0.3934	0.0000
	4,5,6,7	7.454	22.91	15.456	0.589	0.303	-0.9560	0.1977	-0.1833	0.3936	0.0000
	5,6,7,8	12.784	26.223	13.439	0.512	0.303	-0.5028	0.1465	0.0048	0.3295	0.0508

7.1.2.2 Calculation of s_i Factor

The factor s_i for any damage case at any flooding condition, d_s , shall be obtained from:

$$s_i = \min(\mathrm{s_{intermediate,i}}, \mathrm{s_{final,i}}, \mathrm{s_{mom,i}})$$

Where the variables are defined for a cargo ship as follows:

$$s_{\text{intermediate },i} = 1$$

$$s_{\text{mom },i} = 1$$

$$s_{\text{final },i} = K\left[\frac{GZ_{\max}}{0.12}\frac{\text{Range}}{16}\right]^{\frac{1}{4}}$$

Where,

$$K = \begin{cases} 1 & \text{if } \theta_e \leq \theta_{\min} \\ 0 & \text{if } \theta_e > \theta_{\min} \\ \sqrt{\frac{\theta_{\max}-\theta_e}{\theta_{\max}-\theta_{\min}}} & \text{otherwise} \end{cases}$$

The summary of the calculation of s_i factor is shown in table 7.4.

Table 7.4: Calculation of s_i Factor

	Compt.	**x1 (m)**	**x2 (m)**	**Damage (m)**	**Heel**	**GZmax**	**Stability Range (∘)**	**sinter,i**	**sfinal,i**	**smom,i**	**p(x1,x2) (pi)**
1 compt. flooded	1	0	1.6	1.6	10	0.120	16	1	0.3635	1	0.3635
	2	1.6	6.394	4.794	10	0.120	16	1	0.3635	1	0.3635
	3	6.394	7.454	1.06	10	0.120	16	1	0.3635	1	0.3635
	4	7.454	12.784	5.33	10	0.120	16	1	0.3635	1	0.3635
	5	12.78	18.114	5.33	10	0.120	16	1	0.3635	1	0.3635
	6	18.11	21.845	3.731	10	0.120	16	1	0.3635	1	0.3635
	7	21.85	22.91	1.065	10	0.120	16	1	0.3635	1	0.3635
	8	22.91	26.223	3.313	10	0.120	16	1	0.3635	1	0.3635
2 compt. flooded	1,2	0	6.394	6.394	10	0.120	16	1	0.3635	1	0.3635
	2,3	1.6	7.454	5.854	20	0.120	16	1	0.3635	1	0.3635
	3,4	6.394	12.784	6.39	10	0.120	16	1	0.3635	1	0.3635
	4,5	7.454	18.114	10.66	20	0.120	16	1	0.3635	1	0.3635
	5,6	12.78	21.845	9.061	10	0.120	16	1	0.3635	1	0.3635
	6,7	18.11	22.91	4.796	20	0.120	16	1	0.3635	1	0.3635
	7,8	21.85	26.223	4.378	10	0.120	16	1	0.3635	1	0.3635
3 compt. flooded	1,2,3	0	7.454	7.454	10	0.120	16	1	0.3635	1	0.3635
	2,3,4	1.6	12.784	11.184	20	0.120	16	1	0.3635	1	0.3635
	3,4,5	6.394	18.114	11.72	10	0.120	16	1	0.3635	1	0.3635
	4,5,6	7.454	21.845	14.391	20	0.120	16	1	0.3635	1	0.3635
	5,6,7	12.78	22.91	10.126	10	0.120	16	1	0.3635	1	0.3635
	6,7,8	18.11	26.223	8.109	20	0.120	16	1	0.3635	1	0.3635
4 compt. flooded	1,2,3,4	0	12.784	12.784	20	0.120	16	1	0.3635	1	0.3635
	2,3,4,5	1.6	18.114	16.514	20	0.120	16	1	0.3635	1	0.3635
	3,4,5,6	6.394	21.845	15.451	20	0.120	16	1	0.3635	1	0.3635
	4,5,6,7	7.454	22.91	15.456	20	0.120	16	1	0.3635	1	0.3635
	5,6,7,8	12.78	26.223	13.439	20	0.120	16	1	0.3635	1	0.3635

7.1.2.3 Calculation of v_i Factor

The v_i factor is the probability that the spaces above the horizontal boundary under consideration remain intact after a collision. If there are watertight subdivisions above the waterline, the s_i value for lower compartments or a group of compartments should be scaled by a reduction factor v_i. This factor considers the possibility of spaces above the specified horizontal boundary remaining undamaged after a collision. If these areas flood due to a ship collision, it reduces the vessel's residual stability, causing adverse changes in the GZ curve due to alterations in buoyancy.

The v_i factors should be calculated for $i = 1, 2, \ldots, n+1$ when n compartments flooded using equation 7.13.

$$V_i = \begin{cases} 0.8\dfrac{H_{m-n+1} - d}{7.8}, & \text{for } i = 1 \\ 0.8\dfrac{H_{m+i-n} - H_{m+i-n-1}}{7.8}, & \text{for } 1 < i < n+1 \\ 1 - \sum_1^n V_i, & \text{for } i = n+1 \end{cases} \tag{7.13}$$

Where H_m is the least height to the m^{th} horizontal boundary above the waterline measured from the baseline which is illustrated in figure 7.2. The calculation is shown in the tables 7.5, 7.30, 7.7, 7.8.

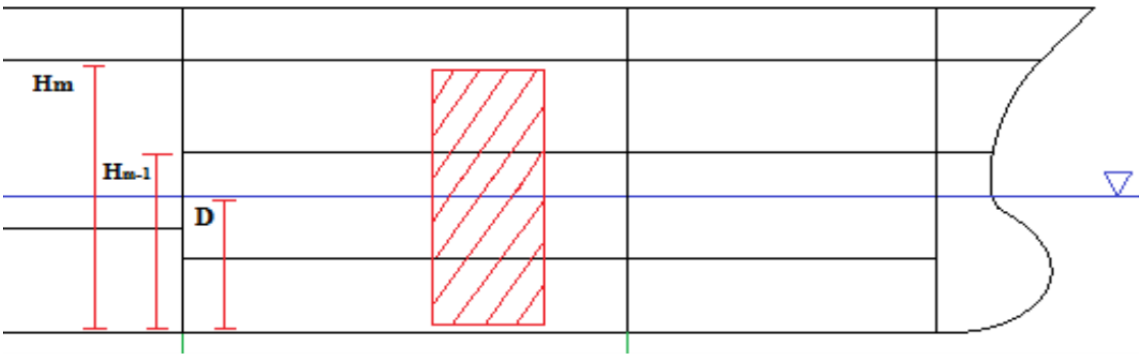


FIGURE 7.2: The illustration of H_m

Table 7.5: Height of the main deck

Cases	**Compartment**	**Height of main deck**	
1 compartments flooded	1	1.675	
	2	2.612	
	3	3.000	
	4	3.000	
	5	3.000	
	6	3.150	
	7	3.254	
	8	2.814	
2 compartments flooded	1 & 2	2.612	1.675
	2 & 3	3.000	2.612
	3 & 4	3.000	3.000
	4 & 5	3.000	3.000
	5 & 6	3.150	3.000
	6 & 7	3.254	3.150
	7 & 8	2.814	3.254
3 compartments flooded	1,2 & 3	3.000	2.612
	2,3 & 4	3.000	3.000
	3,4 & 5	3.000	3.000
	4,5 & 6	3.150	3.000
	5,6 & 7	3.254	3.150
	6,7 & 8	2.814	3.254
4 comp. flooded	1,2,3 & 4	3.000	3.000
	2,3,4 & 5	3.000	3.000
	3,4,5 & 6	3.150	3.000
	4,5,6 & 7	3.254	3.150
	5,6,7 & 8	2.814	3.254

TABLE 7.6: Calculation of V_i for the deepest subdivision draft, $d = 2.6$ m

Cases	Comp.	x1	x2	l	v1	v2	v3	v4	v5
1 compartments flooded	1	0.000	1.600	1.600	0.000	1.000			
	2	1.600	6.394	4.794	0.001	0.999			
	3	6.394	7.454	1.060	0.041	0.959			
	4	7.454	12.784	5.330	0.041	0.959			
	5	12.784	18.114	5.330	0.041	0.959			
	6	18.114	21.845	3.731	0.056	0.944			
	7	21.845	22.910	1.065	0.067	0.933			
	8	22.910	26.223	3.313	0.022	0.978			
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.000	0.096	0.904		
	2 & 3	1.600	7.454	5.854	0.001	0.040	0.959		
	3 & 4	6.394	12.784	6.390	0.041	0.000	0.959		
	4 & 5	7.454	18.114	10.660	0.041	0.000	0.959		
	5 & 6	12.784	21.845	9.061	0.041	0.015	0.944		
	6 & 7	18.114	22.910	4.796	0.056	0.011	0.933		
	7 & 8	21.845	26.223	4.378	0.067	0.000	0.933		
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.000	0.096	0.040	0.864	
	2,3 & 4	1.600	12.784	11.184	0.001	0.040	0.000	0.959	
	3,4 & 5	6.394	18.114	11.720	0.041	0.000	0.000	0.959	
	4,5 & 6	7.454	21.845	14.391	0.041	0.000	0.015	0.944	
	5,6 & 7	12.784	22.910	10.126	0.041	0.015	0.011	0.933	
	6,7 & 8	18.114	26.223	8.109	0.056	0.011	0.000	0.933	
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.000	0.096	0.040	0.000	0.864
	2,3,4 & 5	1.600	18.114	16.514	0.001	0.040	0.000	0.000	0.959
	3,4,5 & 6	6.394	21.845	15.451	0.041	0.000	0.000	0.015	0.959
	4,5,6 & 7	7.454	22.910	15.456	0.041	0.000	0.015	0.011	0.944
	5,6,7 & 8	12.784	26.223	13.439	0.041	0.015	0.011	0.000	0.933

TABLE 7.7: Calculation of V_i for the partial subdivision draft, $d = 2.3$ m

Cases	Comp.	x1	x2	l	v1	v2	v3	v4	v5
1 compartments flooded	1	0.000	1.600	1.600	0.000	1.000			
	2	1.600	6.394	4.794	0.032	0.968			
	3	6.394	7.454	1.060	0.072	0.928			
	4	7.454	12.784	5.330	0.072	0.928			
	5	12.784	18.114	5.330	0.072	0.928			
	6	18.114	21.845	3.731	0.087	0.913			
	7	21.845	22.910	1.065	0.098	0.902			
	8	22.910	26.223	3.313	0.053	0.947			
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.000	0.096	0.904		
	2 & 3	1.600	7.454	5.854	0.032	0.040	0.928		
	3 & 4	6.394	12.784	6.390	0.072	0.000	0.928		
	4 & 5	7.454	18.114	10.660	0.072	0.000	0.928		
	5 & 6	12.784	21.845	9.061	0.072	0.015	0.913		
	6 & 7	18.114	22.910	4.796	0.087	0.011	0.902		
	7 & 8	21.845	26.223	4.378	0.098	0.000	0.902		
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.000	0.096	0.040	0.864	
	2,3 & 4	1.600	12.784	11.184	0.032	0.040	0.000	0.928	
	3,4 & 5	6.394	18.114	11.720	0.072	0.000	0.000	0.928	
	4,5 & 6	7.454	21.845	14.391	0.072	0.000	0.015	0.913	
	5,6 & 7	12.784	22.910	10.126	0.072	0.015	0.011	0.902	
	6,7 & 8	18.114	26.223	8.109	0.087	0.011	0.000	0.902	
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.000	0.096	0.040	0.000	0.864
	2,3,4 & 5	1.600	18.114	16.514	0.032	0.040	0.000	0.000	0.928
	3,4,5 & 6	6.394	21.845	15.451	0.072	0.000	0.000	0.015	0.928
	4,5,6 & 7	7.454	22.910	15.456	0.072	0.000	0.015	0.011	0.913
	5,6,7 & 8	12.784	26.223	13.439	0.072	0.015	0.011	0.000	0.902

TABLE 7.8: Calculation of V_i for the light service draft, $d = 1.85$ m

Cases	Comp.	x1	x2	l	v1	v2	v3	v4	v5
1 compartments flooded	1	0.000	1.600	1.600	0.000	1.000			
	2	1.600	6.394	4.794	0.078	0.922			
	3	6.394	7.454	1.060	0.118	0.882			
	4	7.454	12.784	5.330	0.118	0.882			
	5	12.784	18.114	5.330	0.118	0.882			
	6	18.114	21.845	3.731	0.133	0.867			
	7	21.845	22.910	1.065	0.144	0.856			
	8	22.910	26.223	3.313	0.099	0.901			
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.000	0.096	0.904		
	2 & 3	1.600	7.454	5.854	0.078	0.040	0.882		
	3 & 4	6.394	12.784	6.390	0.118	0.000	0.882		
	4 & 5	7.454	18.114	10.660	0.118	0.000	0.882		
	5 & 6	12.784	21.845	9.061	0.118	0.015	0.867		
	6 & 7	18.114	22.910	4.796	0.133	0.011	0.856		
	7 & 8	21.845	26.223	4.378	0.144	0.000	0.856		
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.000	0.096	0.040	0.864	
	2,3 & 4	1.600	12.784	11.184	0.078	0.040	0.000	0.882	
	3,4 & 5	6.394	18.114	11.720	0.118	0.000	0.000	0.882	
	4,5 & 6	7.454	21.845	14.391	0.118	0.000	0.015	0.867	
	5,6 & 7	12.784	22.910	10.126	0.118	0.015	0.011	0.856	
	6,7 & 8	18.114	26.223	8.109	0.133	0.011	0.000	0.856	
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.000	0.096	0.040	0.000	0.864
	2,3,4 & 5	1.600	18.114	16.514	0.078	0.040	0.000	0.000	0.882
	3,4,5 & 6	6.394	21.845	15.451	0.118	0.000	0.000	0.015	0.867
	4,5,6 & 7	7.454	22.910	15.456	0.118	0.000	0.015	0.011	0.856
	5,6,7 & 8	12.784	26.223	13.439	0.118	0.015	0.011	0.000	0.856

7.1.2.4 Calculation of Attain Index

The sum of the attained subdivision index A is determined using equation **??**.

$$A = 0.4A_s + 0.4A_p + 0.2A_l \tag{7.14}$$

The calculation of the attained index is calculated in the subsequent tables. The summary of the calculation is shown in 7.9.

TABLE 7.9: Summary of the calculation of the attained index

Attained Index for Deepest subdivision draught	As	0.5460316
Attained Index for Partial subdivision draught	Ap	0.5460316
Attained Index for Light service draught	Al	0.5460316

Substituting these values into equation 7.14, the attained index is obtained as:

$$\boxed{\mathbf{A = 0.55}}$$

TABLE 7.10: Calculation of V_1 for the deepest subdivision draft, $d = 2.6$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	1.600	1.600	0.036	0.546	0.000	0.000
	2	1.600	6.394	4.794	0.093	0.546	0.078	0.004
	3	6.394	7.454	1.060	0.005	0.546	0.118	0.000
	4	7.454	12.784	5.330	0.091	0.546	0.118	0.006
	5	12.784	18.114	5.330	0.091	0.546	0.118	0.006
	6	18.114	21.845	3.731	0.043	0.546	0.133	0.003
	7	21.845	22.910	1.065	0.005	0.546	0.144	0.000
	8	22.910	26.223	3.313	0.081	0.546	0.099	0.004
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.029	0.547	0.000	0.000
	2 & 3	1.600	7.454	5.854	0.000	0.547	0.078	0.000
	3 & 4	6.394	12.784	6.390	0.000	0.547	0.118	0.000
	4 & 5	7.454	18.114	10.660	0.000	0.547	0.118	0.000
	5 & 6	12.784	21.845	9.061	0.000	0.547	0.118	0.000
	6 & 7	18.114	22.910	4.796	0.090	0.547	0.133	0.007
	7 & 8	21.845	26.223	4.378	0.043	0.547	0.144	0.003
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.000	0.000
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.078	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.118	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.118	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.118	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.133	0.002
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.000	0.000
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.078	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.118	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.118	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.118	0.003

TABLE 7.11: Calculation of V_2 for the deepest subdivision draft, $d = 2.6$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	1.600	1.600	0.036	0.546	1.000	0.020
	2	1.600	6.394	4.794	0.093	0.546	0.922	0.047
	3	6.394	7.454	1.060	0.005	0.546	0.882	0.003
	4	7.454	12.784	5.330	0.091	0.546	0.882	0.044
	5	12.784	18.114	5.330	0.091	0.546	0.882	0.044
	6	18.114	21.845	3.731	0.043	0.546	0.867	0.020
	7	21.845	22.910	1.065	0.005	0.546	0.856	0.002
	8	22.910	26.223	3.313	0.081	0.546	0.901	0.040
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.029	0.547	0.096	0.002
	2 & 3	1.600	7.454	5.854	0.000	0.547	0.040	0.000
	3 & 4	6.394	12.784	6.390	0.000	0.547	0.000	0.000
	4 & 5	7.454	18.114	10.660	0.000	0.547	0.000	0.000
	5 & 6	12.784	21.845	9.061	0.000	0.547	0.015	0.000
	6 & 7	18.114	22.910	4.796	0.090	0.547	0.011	0.001
	7 & 8	21.845	26.223	4.378	0.043	0.547	0.000	0.000
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.096	0.012
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.040	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.000	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.000	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.015	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.011	0.000
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.096	0.004
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.040	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.000	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.000	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.015	0.000

Table 7.12: Calculation of V_3 for the deepest subdivision draft, $d = 2.6$ m

Cases	**Compartment**	**x1**	**x2**	**Damage length**	**p(x1,x2) (pi)**	**s(x1,x2) (si)**	**v(x1,x2) (vi)**	**Attained Index**
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.029	0.547	0.904	0.014
	2 & 3	1.600	7.454	5.854	0.000	0.547	0.882	0.000
	3 & 4	6.394	12.784	6.390	0.000	0.547	0.882	0.000
	4 & 5	7.454	18.114	10.660	0.000	0.547	0.882	0.000
	5 & 6	12.784	21.845	9.061	0.000	0.547	0.867	0.000
	6 & 7	18.114	22.910	4.796	0.090	0.547	0.856	0.042
	7 & 8	21.845	26.223	4.378	0.043	0.547	0.856	0.020
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.040	0.005
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.000	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.000	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.015	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.011	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.000	0.000
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.040	0.002
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.000	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.000	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.015	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.011	0.000

Table 7.13: Calculation of V_4 for the deepest subdivision draft, $d = 2.6$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.864	0.105
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.882	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.882	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.867	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.856	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.856	0.015
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.000	0.000
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.000	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.015	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.011	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.000	0.000

Table 7.14: Calculation of V_5 for the deepest subdivision draft, $d = 2.6$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.864	0.040
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.882	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.867	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.856	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.856	0.024

Sum, A_s=0.54603

TABLE 7.15: Calculation of V_1 for the partial subdivision draft, $d = 2.3$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	1.600	1.600	0.036	0.546	0.000	0.000
	2	1.600	6.394	4.794	0.093	0.546	0.032	0.002
	3	6.394	7.454	1.060	0.005	0.546	0.072	0.000
	4	7.454	12.784	5.330	0.091	0.546	0.072	0.004
	5	12.784	18.114	5.330	0.091	0.546	0.072	0.004
	6	18.114	21.845	3.731	0.043	0.546	0.087	0.002
	7	21.845	22.910	1.065	0.005	0.546	0.098	0.000
	8	22.910	26.223	3.313	0.081	0.546	0.053	0.002
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.029	0.547	0.000	0.000
	2 & 3	1.600	7.454	5.854	0.000	0.547	0.032	0.000
	3 & 4	6.394	12.784	6.390	0.000	0.547	0.072	0.000
	4 & 5	7.454	18.114	10.660	0.000	0.547	0.072	0.000
	5 & 6	12.784	21.845	9.061	0.000	0.547	0.072	0.000
	6 & 7	18.114	22.910	4.796	0.090	0.547	0.087	0.004
	7 & 8	21.845	26.223	4.378	0.043	0.547	0.098	0.002
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.000	0.000
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.032	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.072	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.072	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.072	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.087	0.002
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.000	0.000
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.032	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.072	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.072	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.072	0.002

Table 7.16: Calculation of V_2 for the partial subdivision draft, $d = 2.3$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	1.600	1.600	0.036	0.546	1.000	0.020
	2	1.600	6.394	4.794	0.093	0.546	0.968	0.049
	3	6.394	7.454	1.060	0.005	0.546	0.928	0.003
	4	7.454	12.784	5.330	0.091	0.546	0.928	0.046
	5	12.784	18.114	5.330	0.091	0.546	0.928	0.046
	6	18.114	21.845	3.731	0.043	0.546	0.913	0.021
	7	21.845	22.910	1.065	0.005	0.546	0.902	0.003
	8	22.910	26.223	3.313	0.081	0.546	0.947	0.042
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.029	0.547	0.096	0.002
	2 & 3	1.600	7.454	5.854	0.000	0.547	0.040	0.000
	3 & 4	6.394	12.784	6.390	0.000	0.547	0.000	0.000
	4 & 5	7.454	18.114	10.660	0.000	0.547	0.000	0.000
	5 & 6	12.784	21.845	9.061	0.000	0.547	0.015	0.000
	6 & 7	18.114	22.910	4.796	0.090	0.547	0.011	0.001
	7 & 8	21.845	26.223	4.378	0.043	0.547	0.000	0.000
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.096	0.012
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.040	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.000	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.000	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.015	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.011	0.000
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.096	0.004
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.040	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.000	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.000	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.015	0.000

Table 7.17: Calculation of V_3 for the partial subdivision draft, $d = 2.3$ m

Cases	**Compartment**	**x1**	**x2**	**Damage length**	**p(x1,x2) (pi)**	**s(x1,x2) (si)**	**v(x1,x2) (vi)**	**Attained Index**
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.029	0.547	0.904	0.014
	2 & 3	1.600	7.454	5.854	0.000	0.547	0.928	0.000
	3 & 4	6.394	12.784	6.390	0.000	0.547	0.928	0.000
	4 & 5	7.454	18.114	10.660	0.000	0.547	0.928	0.000
	5 & 6	12.784	21.845	9.061	0.000	0.547	0.913	0.000
	6 & 7	18.114	22.910	4.796	0.090	0.547	0.902	0.044
	7 & 8	21.845	26.223	4.378	0.043	0.547	0.902	0.021
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.040	0.005
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.000	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.000	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.015	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.011	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.000	0.000
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.040	0.002
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.000	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.000	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.015	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.011	0.000

TABLE 7.18: Calculation of V_4 for the partial subdivision draft, $d = 2.3$ m

Cases	**Compartment**	**x1**	**x2**	**Damage length**	**p(x1,x2) (pi)**	**s(x1,x2) (si)**	**v(x1,x2) (vi)**	**Attained Index**
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.864	0.105
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.928	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.928	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.913	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.902	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.902	0.016
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.000	0.000
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.000	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.015	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.011	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.000	0.000

TABLE 7.19: Calculation of V_5 for the partial subdivision draft, $d = 2.3$ m

Cases	**Compartment**	**x1**	**x2**	**Damage length**	**p(x1,x2) (pi)**	**s(x1,x2) (si)**	**v(x1,x2) (vi)**	**Attained Index**
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.864	0.040
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.928	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.928	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.913	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.902	0.025

Sum, A_p=0.546

TABLE 7.20: Calculation of V_1 for the light service draft, $d = 1.85$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	1.600	1.600	0.036	0.546	0.000	0.000
	2	1.600	6.394	4.794	0.093	0.546	0.078	0.004
	3	6.394	7.454	1.060	0.005	0.546	0.118	0.000
	4	7.454	12.784	5.330	0.091	0.546	0.118	0.006
	5	12.784	18.114	5.330	0.091	0.546	0.118	0.006
	6	18.114	21.845	3.731	0.043	0.546	0.133	0.003
	7	21.845	22.910	1.065	0.005	0.546	0.144	0.000
	8	22.910	26.223	3.313	0.081	0.546	0.099	0.004
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.029	0.547	0.000	0.000
	2 & 3	1.600	7.454	5.854	0.000	0.547	0.078	0.000
	3 & 4	6.394	12.784	6.390	0.000	0.547	0.118	0.000
	4 & 5	7.454	18.114	10.660	0.000	0.547	0.118	0.000
	5 & 6	12.784	21.845	9.061	0.000	0.547	0.118	0.000
	6 & 7	18.114	22.910	4.796	0.090	0.547	0.133	0.007
	7 & 8	21.845	26.223	4.378	0.043	0.547	0.144	0.003
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.000	0.000
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.078	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.118	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.118	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.118	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.133	0.002
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.000	0.000
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.078	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.118	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.118	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.118	0.003

TABLE 7.21: Calculation of V_2 for the light service draft, $d = 1.85$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	1.600	1.600	0.036	0.546	1.000	0.020
	2	1.600	6.394	4.794	0.093	0.546	0.922	0.047
	3	6.394	7.454	1.060	0.005	0.546	0.882	0.003
	4	7.454	12.784	5.330	0.091	0.546	0.882	0.044
	5	12.784	18.114	5.330	0.091	0.546	0.882	0.044
	6	18.114	21.845	3.731	0.043	0.546	0.867	0.020
	7	21.845	22.910	1.065	0.005	0.546	0.856	0.002
	8	22.910	26.223	3.313	0.081	0.546	0.901	0.040
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.029	0.547	0.096	0.002
	2 & 3	1.600	7.454	5.854	0.000	0.547	0.040	0.000
	3 & 4	6.394	12.784	6.390	0.000	0.547	0.000	0.000
	4 & 5	7.454	18.114	10.660	0.000	0.547	0.000	0.000
	5 & 6	12.784	21.845	9.061	0.000	0.547	0.015	0.000
	6 & 7	18.114	22.910	4.796	0.090	0.547	0.011	0.001
	7 & 8	21.845	26.223	4.378	0.043	0.547	0.000	0.000
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.096	0.012
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.040	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.000	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.000	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.015	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.011	0.000
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.096	0.004
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.040	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.000	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.000	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.015	0.000

TABLE 7.22: Calculation of V_3 for the light service draft, $d = 1.85$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
2 compartments flooded	1 & 2	0.000	6.394	6.394	0.029	0.547	0.904	0.014
	2 & 3	1.600	7.454	5.854	0.000	0.547	0.882	0.000
	3 & 4	6.394	12.784	6.390	0.000	0.547	0.882	0.000
	4 & 5	7.454	18.114	10.660	0.000	0.547	0.882	0.000
	5 & 6	12.784	21.845	9.061	0.000	0.547	0.867	0.000
	6 & 7	18.114	22.910	4.796	0.090	0.547	0.856	0.042
	7 & 8	21.845	26.223	4.378	0.043	0.547	0.856	0.020
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.040	0.005
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.000	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.000	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.015	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.011	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.000	0.000
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.040	0.002
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.000	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.000	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.015	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.011	0.000

Table 7.23: Calculation of V_4 for the light service draft, $d = 1.85$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
3 compartments flooded	1,2 & 3	0.000	7.454	7.454	0.223	0.545	0.864	0.105
	2,3 & 4	1.600	12.784	11.184	0.000	0.545	0.882	0.000
	3,4 & 5	6.394	18.114	11.720	0.000	0.545	0.882	0.000
	4,5 & 6	7.454	21.845	14.391	0.000	0.545	0.867	0.000
	5,6 & 7	12.784	22.910	10.126	0.000	0.545	0.856	0.000
	6,7 & 8	18.114	26.223	8.109	0.033	0.545	0.856	0.015
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.000	0.000
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.000	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.015	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.011	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.000	0.000

Table 7.24: Calculation of V_5 for the light service draft, $d = 1.85$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
4 comp flooded	1,2,3 & 4	0.000	12.784	12.784	0.086	0.546	0.864	0.040
	2,3,4 & 5	1.600	18.114	16.514	0.000	0.546	0.882	0.000
	3,4,5 & 6	6.394	21.845	15.451	0.000	0.546	0.867	0.000
	4,5,6 & 7	7.454	22.910	15.456	0.000	0.546	0.856	0.000
	5,6,7 & 8	12.784	26.223	13.439	0.051	0.546	0.856	0.024

Sum, A_l=0.546

7.2 Catamaran

7.2.1 Calculation of the Required Index

The R-index formulation for passenger ships originated from computations conducted on sample vessels within the HARDER project, as detailed by Hjort and Olufsen [11]. A pivotal goal in formulating regulations for passenger ships was to establish parity in safety standards between new and pre-existing ships under these regulations. With this principle at heart, an initial scientific formulation for the R-index concerning passenger ships was methodically devised. This entailed executing numerous trial iterations utilizing existing ships to derive the formula.

The Required Index of a Cargo Ship can be obtained by the equation 7.15.

$$R = 1 - \frac{500}{L_s + 2.5N + 15225} \tag{7.15}$$

Here, L_s represents the length of the subdivision. Specifically, for the designated passenger ship, L_s equates to 47.25 meters. N is obtained using the equation $N = N_1 + 2N_2$ where N_1 is the number of people for Whom lifeboats are provided and N_2 is the number of people exceeds N_2. For our ship, $N_1 = 150$ and $N_2 = 50$. By plugging this value into equation 7.15, we can subsequently determine the R-factor.

$$\boxed{R \approx 0.685}$$

7.2.2 Calculation of Attain Index

The calculation of the attained index is similar to the monohull. A summary of the calculation of p_i, s_i, and v_i are shown in the subsequent tables.

TABLE 7.25: Calculation of p_i Factor for the catamaran Hull

	Compt.	x_1 (m)	x_2 (m)	Damage (m)	J	Jn	p	$p(x_1,x_2)$	$r(x_1,x_2,b)$	p_i
1 compt. flooded	1	0	2	2	0.042	0.042	0.0057	0.0240	0.4378	0.0240
	2	2	14	12	0.254	0.254	0.1396	0.1396	0.4509	0.1396
	3	14	15	1	0.021	0.148	0.0015	0.0015	0.4365	0.0015
	4	15	22	7	0.148	0.148	0.0451	0.0451	0.4443	0.0451
	5	22	31.5	9.5	0.201	0.201	0.0879	0.0879	0.4476	0.0879
	6	31.5	33	1.5	0.032	0.032	0.0033	0.0033	0.4371	0.0033
	7	33	38	5	0.106	0.106	0.0282	0.0282	0.4417	0.0282
	8	38	41	3	0.063	0.063	0.0120	0.0120	0.4391	0.0120
	9	41	44	3	0.063	0.069	0.0120	0.0120	0.4391	0.0120
	10	44	47.25	3.25	0.069	0.069	0.0138	0.0413	0.4394	0.0413
2 compt. flooded	1,2	0	14	14	0.296	0.296	0.1818	0.2391	0.2429	0.0754
	2,3	2	15	13	0.275	0.275	0.1607	0.1607	0.2411	0.0195
	3,4	14	22	8	0.169	0.169	0.0577	0.0577	0.2321	0.0111
	4,5	15	31.5	16.5	0.349	0.303	0.2347	0.2347	0.2475	0.1018
	5,6	22	33	11	0.233	0.138	0.1143	0.1143	0.2375	0.0231
	6,7	31.5	38	6.5	0.138	0.138	0.0410	0.0410	0.2294	0.0095
	7,8	33	41	8	0.169	0.169	0.0577	0.0577	0.2321	0.0176
	8,9	38	44	6	0.127	0.132	0.0368	0.0368	0.2285	0.0128
	9,10	41	47.25	6.25	0.132	0.132	0.0390	0.0856	0.2289	0.0323
3 compt. Flooded	1,2,3	0	15	15	0.317	0.303	0.2030	0.2602	0.2448	0.0001
	2,3,4	2	22	20	0.423	0.303	0.3088	0.3088	0.2538	0.0919
	3,4,5	14	31.5	17.5	0.370	0.303	0.2559	0.2559	0.2493	0.0085
	4,5,6	15	33	18	0.381	0.303	0.2665	0.2665	0.2502	0.0053
	5,6,7	22	38	16	0.339	0.303	0.2241	0.2241	0.2466	0.0721
	6,7,8	31.5	41	9.5	0.201	0.233	0.0876	0.0876	0.2348	0.0170
	7,8,9	33	44	11	0.233	0.233	0.1187	0.1187	0.2375	0.0362
	8,9,10	38	47.25	9.25	0.196	0.303	0.0813	0.1385	0.2343	0.0281
4 compt. Flooded	1,2,3,4	0	22	22	0.466	0.303	0.3511	0.4084	0.2574	0.0000
	2,3,4,5	2	31.5	29.5	0.624	0.303	0.5099	0.5099	0.2710	0.0029
	3,4,5,6	14	33	19	0.402	0.303	0.2876	0.2876	0.2520	0.0000
	4,5,6,7	15	38	23	0.487	0.303	0.3723	0.3723	0.2592	0.0000
	5,6,7,8	22	41	19	0.402	0.265	0.2870	0.2870	0.2520	0.0163
	6,7,8,9	31.5	44	12.5	0.265	0.302	0.1501	0.1501	0.2402	0.0015
	7,8,9,10	33	47.25	14.25	0.302	0.303	0.1871	0.2443	0.2434	0.0239

TABLE 7.26: Calculation of s_i factor of the Catamaran Hull

	Compt.	x_1 **(m)**	x_2 **(m)**	**Damage (m)**	**GZmax**	**Stability Range (°)**	**sinter,i**	$s_{\text{final,i}}$	$s_{\text{mom,i}}$	$s(x_1, x_2)$
1 compt. flooded	1	0	2	2	2.838	30	1	0.9379	1	0.9379
	2	2	14	12	2.838	30	1	0.9379	1	0.9379
	3	14	15	1	2.838	30	1	0.9379	1	0.9379
	4	15	22	7	2.838	30	1	0.9379	1	0.9379
	5	22	31.5	9.5	2.838	30	1	0.9379	1	0.9379
	6	31.5	33	1.5	2.838	30	1	0.9379	1	0.9379
	7	33	38	5	2.838	30	1	0.9379	1	0.9379
	8	38	41	3	2.838	30	1	0.9379	1	0.9379
	9	41	44	3	2.838	30	1	0.9379	1	0.9379
	10	44	47.25	0	2.838	30	1	0.9379	1	0.9379
2 compt. flooded	1,2	0	14	14	2.838	30	1	0.9379	1	0.9379
	2,3	2	15	13	2.838	30	1	0.9379	1	0.9379
	3,4	14	22	8	2.838	30	1	0.9379	1	0.9379
	4,5	15	31.5	16.5	2.838	30	1	0.9379	1	0.9379
	5,6	22	33	11	2.838	30	1	0.9379	1	0.9379
	6,7	31.5	38	6.5	2.838	30	1	0.9379	1	0.9379
	7,8	33	41	8	2.838	30	1	0.9379	1	0.9379
	8,9	38	44	0	2.838	30	1	0.9379	1	0.9379
	9,10	41	47.25	6.25	2.838	30	1	0.9379	1	0.9379
3 compt. Flooded	1,2,3	0	15	15	2.838	30	1	0.9379	1	0.9379
	2,3,4	2	22	20	2.838	30	1	0.9379	1	0.9379
	3,4,5	14	31.5	17.5	2.838	30	1	0.9379	1	0.9379
	4,5,6	15	33	18	2.838	30	1	0.9379	1	0.9379
	5,6,7	22	38	16	2.838	30	1	0.9379	1	0.9379
	6,7,8	31.5	41	0	2.838	30	1	0.9379	1	0.9379
	7,8,9	33	44	11	2.838	30	1	0.9379	1	0.9379
	8,9,10	38	47.25	9.25	2.838	30	1	0.9379	1	0.9379
4 compt. Flooded	1,2,3,4	0	22	22	2.838	30	1	0.9379	1	0.9379
	2,3,4,5	2	31.5	29.5	2.838	30	1	0.9379	1	0.9379
	3,4,5,6	14	33	19	2.838	30	1	0.9379	1	0.9379
	4,5,6,7	15	38	23	2.838	30	1	0.9379	1	0.9379
	5,6,7,8	22	41	19	2.838	30	1	0.9379	1	0.9379
	6,7,8,9	31.5	44	12.5	2.838	30	1	0.9379	1	0.9379
	7,8,9,10	33	47.25	14.25	2.838	30	1	0.9379	1	0.9379

TABLE 7.27: Height of the main deck

Cases	**Compartment**	**Height of main deck**		**Cases**	**Compartment**	**Height of main deck**	
1 compartments flooded	1	1.417		3 compartments flooded	1,2 & 3	2.833	2.167
	2	2.167			2,3 & 4	2.833	2.833
	3	2.833			3,4 & 5	2.833	2.833
	4	2.833			4,5 & 6	2.833	2.833
	5	2.833			5,6 & 7	2.833	2.833
	6	2.833			6,7 & 8	2.833	2.833
	7	2.833			7,8 & 9	2.750	2.833
	8	2.833			8,9 & 10	1.750	2.75
	9	2.75		4 comp. flooded	1,2,3 & 4	2.833	2.833
	10	1.75			2,3,4 & 5	2.833	2.833
2 compartments flooded	1 & 2	2.167	1.417		3,4,5 & 6	2.833	2.833
	2 & 3	2.833	2.167		4,5,6 & 7	2.833	2.833
	3 & 4	2.833	2.833		5,6,7 & 8	2.833	2.833
	4 & 5	2.833	2.833		6,7,8 & 9	2.75	2.833
	5 & 6	2.833	2.833		7,8,9 & 10	1.75	2.75
	6 & 7	2.833	2.833				
	7 & 8	2.833	2.833				
	8 & 9	2.75	2.833				
	9 & 10	1.75	2.75				

Table 7.28: Calculation of V_i for the deepest subdivision draft, $d = 2.1$ m

Cases	Comp.	x1	x2	l	v1	v2	v3	v4	v5
1 compartments flooded	1	0.000	2.000	2.000	0.000	1.000			
	2	2.000	14.000	12.000	0.007	0.993			
	3	14.000	15.000	1.000	0.075	0.925			
	4	15.000	22.000	7.000	0.075	0.925			
	5	22.000	31.500	9.500	0.075	0.925			
	6	31.500	33.000	1.500	0.075	0.925			
	7	33.000	38.000	5.000	0.075	0.925			
	8	38.000	41.000	3.000	0.075	0.925			
	9	41.000	44.000	3.000	0.067	0.933			
	10	44.000	47.250	3.250	0.000	1.000			
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.000	0.077	0.923		
	2 & 3	2.000	15.000	13.000	0.007	0.068	0.925		
	3 & 4	14.000	22.000	8.000	0.075	0.000	0.925		
	4 & 5	15.000	31.500	16.500	0.075	0.000	0.925		
	5 & 6	22.000	33.000	11.000	0.075	0.000	0.925		
	6 & 7	31.500	38.000	6.500	0.075	0.000	0.925		
	7 & 8	33.000	41.000	8.000	0.075	0.000	0.925		
	8 & 9	38.000	44.000	6.000	0.067	0.000	0.933		
	9 & 10	41.000	47.250	6.250	0.000	0.000	1.000		
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.077	0.068	0.855	
	2,3 & 4	2.000	22.000	20.000	0.007	0.068	0.000	0.925	
	3,4 & 5	14.000	31.500	17.500	0.075	0.000	0.000	0.925	
	4,5 & 6	15.000	33.000	18.000	0.075	0.000	0.000	0.925	
	5,6 & 7	22.000	38.000	16.000	0.075	0.000	0.000	0.925	
	6,7 & 8	31.500	41.000	9.500	0.075	0.000	0.000	0.925	
	7,8 & 9	33.000	44.000	11.000	0.075	0.000	0.000	0.925	
	8,9 & 10	38.000	47.250	9.250	0.067	0.000	0.000	0.933	
4 compartments flooded	1,2,3 & 4	0.000	22.000	22.000	0.007	0.068	0.000	0.000	0.925
	2,3,4 & 5	2.000	31.500	29.500	0.075	0.000	0.000	0.000	0.925
	3,4,5 & 6	14.000	33.000	19.000	0.075	0.000	0.000	0.000	0.925
	4,5,6 & 7	15.000	38.000	23.000	0.075	0.000	0.000	0.000	0.925
	5,6,7 & 8	22.000	41.000	19.000	0.075	0.000	0.000	0.000	0.925
	6,7,8 & 9	31.500	44.000	12.500	0.075	0.000	0.000	0.000	0.925
	7,8,9 & 10	33.000	47.250	14.250	0.067	0.000	0.000	0.000	0.933

Table 7.29: Calculation of V_i for the partial subdivision draft, $d = 1.9$ m

Cases	Comp.	x1	x2	l	v1	v2	v3	v4	v5
1 compartments flooded	1	0.000	2.000	2.000	0.000	1.000			
	2	2.000	14.000	12.000	0.027	0.973			
	3	14.000	15.000	1.000	0.096	0.904			
	4	15.000	22.000	7.000	0.096	0.904			
	5	22.000	31.500	9.500	0.096	0.904			
	6	31.500	33.000	1.500	0.096	0.904			
	7	33.000	38.000	5.000	0.096	0.904			
	8	38.000	41.000	3.000	0.096	0.904			
	9	41.000	44.000	3.000	0.087	0.913			
	10	44.000	47.250	3.250	0.000	1.000			
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.000	0.077	0.923		
	2 & 3	2.000	15.000	13.000	0.027	0.068	0.904		
	3 & 4	14.000	22.000	8.000	0.096	0.000	0.904		
	4 & 5	15.000	31.500	16.500	0.096	0.000	0.904		
	5 & 6	22.000	33.000	11.000	0.096	0.000	0.904		
	6 & 7	31.500	38.000	6.500	0.096	0.000	0.904		
	7 & 8	33.000	41.000	8.000	0.096	0.000	0.904		
	8 & 9	38.000	44.000	6.000	0.087	0.000	0.913		
	9 & 10	41.000	47.250	6.250	0.000	0.000	1.000		
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.077	0.068	0.855	
	2,3 & 4	2.000	22.000	20.000	0.027	0.068	0.000	0.904	
	3,4 & 5	14.000	31.500	17.500	0.096	0.000	0.000	0.904	
	4,5 & 6	15.000	33.000	18.000	0.096	0.000	0.000	0.904	
	5,6 & 7	22.000	38.000	16.000	0.096	0.000	0.000	0.904	
	6,7 & 8	31.500	41.000	9.500	0.096	0.000	0.000	0.904	
	7,8 & 9	33.000	44.000	11.000	0.096	0.000	0.000	0.904	
	8,9 & 10	38.000	47.250	9.250	0.087	0.000	0.000	0.913	
4 compartments flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.077	0.068	0.000	0.855
	2,3,4 & 5	2.000	31.500	29.500	0.027	0.068	0.000	0.000	0.904
	3,4,5 & 6	14.000	33.000	19.000	0.096	0.000	0.000	0.000	0.904
	4,5,6 & 7	15.000	38.000	23.000	0.096	0.000	0.000	0.000	0.904
	5,6,7 & 8	22.000	41.000	19.000	0.096	0.000	0.000	0.000	0.904
	6,7,8 & 9	31.500	44.000	12.500	0.096	0.000	0.000	0.000	0.904
	7,8,9 & 10	33.000	47.250	14.250	0.096	0.000	0.000	0.000	0.904

TABLE 7.30: Calculation of V_i for the light service draft, $d = 1.6$ m

Cases	Comp.	x1	x2	l	v1	v2	v3	v4	v5
1 compartments flooded	1	0.000	2.000	2.000	0.000	1.000			
	2	2.000	14.000	12.000	0.058	0.942			
	3	14.000	15.000	1.000	0.126	0.874			
	4	15.000	22.000	7.000	0.126	0.874			
	5	22.000	31.500	9.500	0.126	0.874			
	6	31.500	33.000	1.500	0.126	0.874			
	7	33.000	38.000	5.000	0.126	0.874			
	8	38.000	41.000	3.000	0.126	0.874			
	9	41.000	44.000	3.000	0.118	0.882			
	10	44.000	47.250	3.250	0.015	0.985			
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.000	0.077	0.923		
	2 & 3	2.000	15.000	13.000	0.058	0.068	0.874		
	3 & 4	14.000	22.000	8.000	0.126	0.000	0.874		
	4 & 5	15.000	31.500	16.500	0.126	0.000	0.874		
	5 & 6	22.000	33.000	11.000	0.126	0.000	0.874		
	6 & 7	31.500	38.000	6.500	0.126	0.000	0.874		
	7 & 8	33.000	41.000	8.000	0.126	0.000	0.874		
	8 & 9	38.000	44.000	6.000	0.126	0.000	0.874		
	9 & 10	41.000	47.250	6.250	0.118	0.000	0.882		
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.077	0.068	0.855	
	2,3 & 4	2.000	22.000	20.000	0.058	0.068	0.000	0.874	
	3,4 & 5	14.000	31.500	17.500	0.126	0.000	0.000	0.874	
	4,5 & 6	15.000	33.000	18.000	0.126	0.000	0.000	0.874	
	5,6 & 7	22.000	38.000	16.000	0.126	0.000	0.000	0.874	
	6,7 & 8	31.500	41.000	9.500	0.126	0.000	0.000	0.874	
	7,8 & 9	33.000	44.000	11.000	0.126	0.000	0.000	0.874	
	8,9 & 10	38.000	47.250	9.250	0.126	0.000	0.000	0.874	
4 compartments flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.077	0.068	0.000	0.855
	2,3,4 & 5	2.000	31.500	29.500	0.058	0.068	0.000	0.000	0.874
	3,4,5 & 6	14.000	33.000	19.000	0.126	0.000	0.000	0.000	0.874
	4,5,6 & 7	15.000	38.000	23.000	0.126	0.000	0.000	0.000	0.874
	5,6,7 & 8	22.000	41.000	19.000	0.126	0.000	0.000	0.000	0.874
	6,7,8 & 9	31.500	44.000	12.500	0.126	0.000	0.000	0.000	0.874
	7,8,9 & 10	33.000	47.250	14.250	0.126	0.000	0.000	0.000	0.874

Table 7.31: Calculation of V_1 for the deepest subdivision draft, $d = 2.1$ m

Cases	**Compartment**	**x1**	**x2**	**Damage length**	**p(x1,x2) (pi)**	**s(x1,x2) (si)**	**v(x1,x2) (vi)**	**Attained Index**
1 compartments flooded	1	0.000	2.000	2.000	0.024	0.738	0.000	0.000
	2	2.000	14.000	12.000	0.140	0.738	0.007	0.001
	3	14.000	15.000	1.000	0.002	0.738	0.075	0.000
	4	15.000	22.000	7.000	0.045	0.738	0.075	0.003
	5	22.000	31.500	9.500	0.088	0.738	0.075	0.005
	6	31.500	33.000	1.500	0.003	0.738	0.075	0.000
	7	33.000	38.000	5.000	0.028	0.738	0.075	0.002
	8	38.000	41.000	3.000	0.012	0.738	0.075	0.001
	9	41.000	44.000	3.000	0.012	0.738	0.067	0.001
	10	44.000	47.250	3.250	0.041	0.738	0.000	0.000
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.075	0.738	0.000	0.000
	2 & 3	2.000	15.000	13.000	0.020	0.738	0.007	0.000
	3 & 4	14.000	22.000	8.000	0.011	0.738	0.075	0.001
	4 & 5	15.000	31.500	16.500	0.102	0.738	0.075	0.006
	5 & 6	22.000	33.000	11.000	0.023	0.738	0.075	0.001
	6 & 7	31.500	38.000	6.500	0.010	0.738	0.075	0.001
	7 & 8	33.000	41.000	8.000	0.018	0.738	0.075	0.001
	8 & 9	38.000	44.000	6.000	0.013	0.738	0.067	0.001
	9 & 10	41.000	47.250	6.250	0.032	0.738	0.000	0.000
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.000	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.007	0.000
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.075	0.000
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.075	0.000
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.075	0.004
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.075	0.001
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.075	0.002
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.067	0.001
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.000	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.058	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.126	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.126	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.126	0.002
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.126	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.126	0.002

TABLE 7.32: Calculation of V_2 for the deepest subdivision draft, $d = 2.1$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	2.000	2.000	0.024	0.738	1.000	0.018
	2	2.000	14.000	12.000	0.140	0.738	0.993	0.102
	3	14.000	15.000	1.000	0.002	0.738	0.925	0.001
	4	15.000	22.000	7.000	0.045	0.738	0.925	0.031
	5	22.000	31.500	9.500	0.088	0.738	0.925	0.060
	6	31.500	33.000	1.500	0.003	0.738	0.925	0.002
	7	33.000	38.000	5.000	0.028	0.738	0.925	0.019
	8	38.000	41.000	3.000	0.012	0.738	0.925	0.008
	9	41.000	44.000	3.000	0.012	0.738	0.925	0.008
	10	44.000	47.250	3.250	0.041	0.738	0.933	0.028
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.075	0.738	0.077	0.004
	2 & 3	2.000	15.000	13.000	0.020	0.738	0.068	0.001
	3 & 4	14.000	22.000	8.000	0.011	0.738	0.000	0.000
	4 & 5	15.000	31.500	16.500	0.102	0.738	0.000	0.000
	5 & 6	22.000	33.000	11.000	0.023	0.738	0.000	0.000
	6 & 7	31.500	38.000	6.500	0.010	0.738	0.000	0.000
	7 & 8	33.000	41.000	8.000	0.018	0.738	0.000	0.000
	8 & 9	38.000	44.000	6.000	0.013	0.738	0.000	0.000
	9 & 10	41.000	47.250	6.250	0.032	0.738	0.000	0.000
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.077	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.068	0.005
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.000	0.000
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.000	0.000
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.000	0.000
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.000	0.000
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.000	0.000
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.000	0.000
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.077	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.068	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.000	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.000	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.000	0.000
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.000	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.000	0.000

TABLE 7.33: Calculation of V_3 for the deepest subdivision draft, $d = 2.1$ m

Cases	**Compartment**	**x1**	**x2**	**Damage length**	**p(x1,x2) (pi)**	**s(x1,x2) (si)**	**v(x1,x2) (vi)**	**Attained Index**
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.075	0.738	0.923	0.051
	2 & 3	2.000	15.000	13.000	0.020	0.738	0.925	0.013
	3 & 4	14.000	22.000	8.000	0.011	0.738	0.925	0.008
	4 & 5	15.000	31.500	16.500	0.102	0.738	0.925	0.069
	5 & 6	22.000	33.000	11.000	0.023	0.738	0.925	0.016
	6 & 7	31.500	38.000	6.500	0.010	0.738	0.925	0.007
	7 & 8	33.000	41.000	8.000	0.018	0.738	0.925	0.012
	8 & 9	38.000	44.000	6.000	0.013	0.738	0.933	0.009
	9 & 10	41.000	47.250	6.250	0.032	0.738	1.000	0.024
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.068	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.000	0.000
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.000	0.000
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.000	0.000
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.000	0.000
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.000	0.000
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.000	0.000
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.000	0.000
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.068	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.000	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.000	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.000	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.000	0.000
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.000	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.000	0.000

TABLE 7.34: Calculation of V_4 for the deepest subdivision draft, $d = 2.1$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.855	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.925	0.063
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.925	0.006
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.925	0.004
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.925	0.049
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.925	0.012
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.925	0.025
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.933	0.019
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.000	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.000	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.000	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.000	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.000	0.000
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.000	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.000	0.000

TABLE 7.35: Calculation of V_5 for the deepest subdivision draft, $d = 2.1$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.855	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.874	0.002
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.874	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.874	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.874	0.011
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.874	0.001
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.874	0.015

Sum, A_s=0.737

Table 7.36: Calculation of V_1 for the partial subdivision draft, $d = 1.9$ m

Cases	**Compartment**	**x1**	**x2**	**Damage length**	**p(x1,x2) (pi)**	**s(x1,x2) (si)**	**v(x1,x2) (vi)**	**Attained Index**
1 compartments flooded	1	0.000	2.000	2.000	0.024	0.738	0.000	0.000
	2	2.000	14.000	12.000	0.140	0.738	0.027	0.003
	3	14.000	15.000	1.000	0.002	0.738	0.096	0.000
	4	15.000	22.000	7.000	0.045	0.738	0.096	0.003
	5	22.000	31.500	9.500	0.088	0.738	0.096	0.006
	6	31.500	33.000	1.500	0.003	0.738	0.096	0.000
	7	33.000	38.000	5.000	0.028	0.738	0.096	0.002
	8	38.000	41.000	3.000	0.012	0.738	0.096	0.001
	9	41.000	44.000	3.000	0.012	0.738	0.087	0.001
	10	44.000	47.250	3.250	0.041	0.738	0.000	0.000
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.075	0.738	0.000	0.000
	2 & 3	2.000	15.000	13.000	0.020	0.738	0.027	0.000
	3 & 4	14.000	22.000	8.000	0.011	0.738	0.096	0.001
	4 & 5	15.000	31.500	16.500	0.102	0.738	0.096	0.007
	5 & 6	22.000	33.000	11.000	0.023	0.738	0.096	0.002
	6 & 7	31.500	38.000	6.500	0.010	0.738	0.096	0.001
	7 & 8	33.000	41.000	8.000	0.018	0.738	0.096	0.001
	8 & 9	38.000	44.000	6.000	0.013	0.738	0.087	0.001
	9 & 10	41.000	47.250	6.250	0.032	0.738	0.000	0.000
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.000	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.027	0.002
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.096	0.001
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.096	0.000
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.096	0.005
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.096	0.001
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.096	0.003
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.087	0.002
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.000	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.027	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.096	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.096	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.096	0.001
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.096	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.096	0.002

Table 7.37: Calculation of V_2 for the partial subdivision draft, $d = 1.9$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	2.000	2.000	0.024	0.738	1.000	0.018
	2	2.000	14.000	12.000	0.140	0.738	0.973	0.100
	3	14.000	15.000	1.000	0.002	0.738	0.904	0.001
	4	15.000	22.000	7.000	0.045	0.738	0.904	0.030
	5	22.000	31.500	9.500	0.088	0.738	0.904	0.059
	6	31.500	33.000	1.500	0.003	0.738	0.904	0.002
	7	33.000	38.000	5.000	0.028	0.738	0.904	0.019
	8	38.000	41.000	3.000	0.012	0.738	0.904	0.008
	9	41.000	44.000	3.000	0.012	0.738	0.904	0.008
	10	44.000	47.250	3.250	0.041	0.738	0.913	0.028
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.075	0.738	0.077	0.004
	2 & 3	2.000	15.000	13.000	0.020	0.738	0.068	0.001
	3 & 4	14.000	22.000	8.000	0.011	0.738	0.000	0.000
	4 & 5	15.000	31.500	16.500	0.102	0.738	0.000	0.000
	5 & 6	22.000	33.000	11.000	0.023	0.738	0.000	0.000
	6 & 7	31.500	38.000	6.500	0.010	0.738	0.000	0.000
	7 & 8	33.000	41.000	8.000	0.018	0.738	0.000	0.000
	8 & 9	38.000	44.000	6.000	0.013	0.738	0.000	0.000
	9 & 10	41.000	47.250	6.250	0.032	0.738	0.000	0.000
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.077	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.068	0.005
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.000	0.000
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.000	0.000
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.000	0.000
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.000	0.000
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.000	0.000
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.000	0.000
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.077	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.068	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.000	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.000	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.000	0.000
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.000	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.000	0.000

Table 7.38: Calculation of V_3 for the partial subdivision draft, $d = 1.9$ m

Cases	**Compartment**	**x1**	**x2**	**Damage length**	**p(x1,x2) (pi)**	**s(x1,x2) (si)**	**v(x1,x2) (vi)**	**Attained Index**
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.075	0.738	0.923	0.051
	2 & 3	2.000	15.000	13.000	0.020	0.738	0.904	0.013
	3 & 4	14.000	22.000	8.000	0.011	0.738	0.904	0.007
	4 & 5	15.000	31.500	16.500	0.102	0.738	0.904	0.068
	5 & 6	22.000	33.000	11.000	0.023	0.738	0.904	0.015
	6 & 7	31.500	38.000	6.500	0.010	0.738	0.904	0.006
	7 & 8	33.000	41.000	8.000	0.018	0.738	0.904	0.012
	8 & 9	38.000	44.000	6.000	0.013	0.738	0.913	0.009
	9 & 10	41.000	47.250	6.250	0.032	0.738	1.000	0.024
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.068	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.000	0.000
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.000	0.000
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.000	0.000
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.000	0.000
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.000	0.000
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.000	0.000
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.000	0.000
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.068	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.000	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.000	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.000	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.000	0.000
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.000	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.000	0.000

Table 7.39: Calculation of V_4 for the partial subdivision draft, $d = 1.9$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.855	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.904	0.061
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.904	0.006
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.904	0.004
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.904	0.048
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.904	0.011
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.904	0.024
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.913	0.019
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.000	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.000	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.000	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.000	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.000	0.000
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.000	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.000	0.000

Table 7.40: Calculation of V_5 for the partial subdivision draft, $d = 1.9$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.855	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.904	0.002
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.904	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.904	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.904	0.011
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.904	0.001
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.904	0.016

Sum, A_p=0.7366

TABLE 7.41: Calculation of V_3 for the light service draft, $d = 1.6$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	2.000	2.000	0.024	0.738	0.000	0.000
	2	2.000	14.000	12.000	0.140	0.738	0.058	0.006
	3	14.000	15.000	1.000	0.002	0.738	0.126	0.000
	4	15.000	22.000	7.000	0.045	0.738	0.126	0.004
	5	22.000	31.500	9.500	0.088	0.738	0.126	0.008
	6	31.500	33.000	1.500	0.003	0.738	0.126	0.000
	7	33.000	38.000	5.000	0.028	0.738	0.126	0.003
	8	38.000	41.000	3.000	0.012	0.738	0.126	0.001
	9	41.000	44.000	3.000	0.012	0.738	0.118	0.001
	10	44.000	47.250	3.250	0.041	0.738	0.015	0.000
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.075	0.738	0.000	0.000
	2 & 3	2.000	15.000	13.000	0.020	0.738	0.058	0.001
	3 & 4	14.000	22.000	8.000	0.011	0.738	0.126	0.001
	4 & 5	15.000	31.500	16.500	0.102	0.738	0.126	0.010
	5 & 6	22.000	33.000	11.000	0.023	0.738	0.126	0.002
	6 & 7	31.500	38.000	6.500	0.010	0.738	0.126	0.001
	7 & 8	33.000	41.000	8.000	0.018	0.738	0.126	0.002
	8 & 9	38.000	44.000	6.000	0.013	0.738	0.126	0.001
	9 & 10	41.000	47.250	6.250	0.032	0.738	0.118	0.003
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.000	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.058	0.004
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.126	0.001
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.126	0.000
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.126	0.007
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.126	0.002
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.126	0.003
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.126	0.003
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.000	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.058	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.126	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.126	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.126	0.002
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.126	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.126	0.002

TABLE 7.42: Calculation of V_2 for the light service draft, $d = 1.6$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
1 compartments flooded	1	0.000	2.000	2.000	0.024	0.738	1.000	0.018
	2	2.000	14.000	12.000	0.140	0.738	0.942	0.097
	3	14.000	15.000	1.000	0.002	0.738	0.874	0.001
	4	15.000	22.000	7.000	0.045	0.738	0.874	0.029
	5	22.000	31.500	9.500	0.088	0.738	0.874	0.057
	6	31.500	33.000	1.500	0.003	0.738	0.874	0.002
	7	33.000	38.000	5.000	0.028	0.738	0.874	0.018
	8	38.000	41.000	3.000	0.012	0.738	0.874	0.008
	9	41.000	44.000	3.000	0.012	0.738	0.882	0.008
	10	44.000	47.250	3.250	0.041	0.738	0.985	0.030
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.075	0.738	0.077	0.004
	2 & 3	2.000	15.000	13.000	0.020	0.738	0.068	0.001
	3 & 4	14.000	22.000	8.000	0.011	0.738	0.000	0.000
	4 & 5	15.000	31.500	16.500	0.102	0.738	0.000	0.000
	5 & 6	22.000	33.000	11.000	0.023	0.738	0.000	0.000
	6 & 7	31.500	38.000	6.500	0.010	0.738	0.000	0.000
	7 & 8	33.000	41.000	8.000	0.018	0.738	0.000	0.000
	8 & 9	38.000	44.000	6.000	0.013	0.738	0.000	0.000
	9 & 10	41.000	47.250	6.250	0.032	0.738	0.000	0.000
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.077	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.068	0.005
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.000	0.000
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.000	0.000
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.000	0.000
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.000	0.000
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.000	0.000
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.000	0.000
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.077	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.068	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.000	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.000	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.000	0.000
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.000	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.000	0.000

Table 7.43: Calculation of V_3 for the light service draft, $d = 1.6$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
2 compartments flooded	1 & 2	0.000	14.000	14.000	0.075	0.738	0.923	0.051
	2 & 3	2.000	15.000	13.000	0.020	0.738	0.874	0.013
	3 & 4	14.000	22.000	8.000	0.011	0.738	0.874	0.007
	4 & 5	15.000	31.500	16.500	0.102	0.738	0.874	0.066
	5 & 6	22.000	33.000	11.000	0.023	0.738	0.874	0.015
	6 & 7	31.500	38.000	6.500	0.010	0.738	0.874	0.006
	7 & 8	33.000	41.000	8.000	0.018	0.738	0.874	0.011
	8 & 9	38.000	44.000	6.000	0.013	0.738	0.874	0.008
	9 & 10	41.000	47.250	6.250	0.032	0.738	0.882	0.021
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.068	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.000	0.000
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.000	0.000
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.000	0.000
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.000	0.000
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.000	0.000
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.000	0.000
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.000	0.000
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.068	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.000	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.000	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.000	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.000	0.000
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.000	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.000	0.000

TABLE 7.44: Calculation of V_4 for the light service draft, $d = 1.6$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
3 compartments flooded	1,2 & 3	0.000	15.000	15.000	0.000	0.738	0.855	0.000
	2,3 & 4	2.000	22.000	20.000	0.092	0.738	0.874	0.059
	3,4 & 5	14.000	31.500	17.500	0.009	0.738	0.874	0.005
	4,5 & 6	15.000	33.000	18.000	0.005	0.738	0.874	0.003
	5,6 & 7	22.000	38.000	16.000	0.072	0.738	0.874	0.046
	6,7 & 8	31.500	41.000	9.500	0.017	0.738	0.874	0.011
	7,8 & 9	33.000	44.000	11.000	0.036	0.738	0.874	0.023
	8,9 & 10	38.000	47.250	9.250	0.028	0.738	0.874	0.018
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.000	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.000	0.000
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.000	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.000	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.000	0.000
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.000	0.000
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.000	0.000

TABLE 7.45: Calculation of V_5 for the light service draft draft, $d = 1.9$ m

Cases	Compartment	x1	x2	Damage length	p(x1,x2) (pi)	s(x1,x2) (si)	v(x1,x2) (vi)	Attained Index
4 comp flooded	1,2,3 & 4	0.000	22.000	22.000	0.000	0.738	0.855	0.000
	2,3,4 & 5	2.000	31.500	29.500	0.003	0.738	0.874	0.002
	3,4,5 & 6	14.000	33.000	19.000	0.000	0.738	0.874	0.000
	4,5,6 & 7	15.000	38.000	23.000	0.000	0.738	0.874	0.000
	5,6,7 & 8	22.000	41.000	19.000	0.016	0.738	0.874	0.011
	6,7,8 & 9	31.500	44.000	12.500	0.001	0.738	0.874	0.001
	7,8,9 & 10	33.000	47.250	14.250	0.024	0.738	0.874	0.015

Sum, A_l=0.739

7.2.3 Summary

The sum of the attained subdivision index A is determined using equation 7.16.

$$A = 0.4A_s + 0.4A_p + 0.2A_l \tag{7.16}$$

The calculation of the attained index is calculated in the previous tables. The summary of the calculation is shown in 7.46.

TABLE 7.46: Summary of the calculation of the attained index

Attained Index for Deepest subdivision draught	As	0.7373
Attained Index for Partial subdivision draught	Ap	0.7366
Attained Index for Light service draught	Al	0.7394

Substituting these values into equation 7.16, the attained index is obtained as:

$$\boxed{\mathbf{A = 0.74}}$$

Chapter 8

Probabilistic Approach for Damage Stability Using Maxsurf

8.1 Monohull

8.1.1 Preparation for Analysis

The tanks were defined in MaxSurf based on the tank capacity plan depicted in Figure 8.1. Each tank was assigned its aftmost and foremost ends, as well as its starboard or portside breadth and vertical height. The tank definition details, including dimensions and the density of the fluid it contains, are presented in Table 8.1 below.

For the probabilistic damage analysis, the necessary data was entered in MaxSurf. Three loading conditions, namely Lightship, Partially loaded, and deepest subdivision conditions, were considered, and the corresponding data were provided.

TABLE 8.1: Room definition details

Name	**Sp. Gravity**	**Aft** (m)	**Fore**(m)	**F.Port** (m)	**F.Stbd** (m)
APT	1	-0.645	1.221	-2.172	2.172
FPT	1	26.858	30.993	-2.172	2.172
Engine Room		1.221	5.525	-2.172	2.172
Copper Dam (A)		5.525	6.774	-2.172	2.172
Tank 01	0.95	6.774	13.61	-2.172	2.172
Tank 02	0.95	13.61	20	-2.172	2.172
Tank 03	0.95	20	24.991	-2.172	2.172
Copper Dam (F)		24.991	26.858	-2.172	2.172

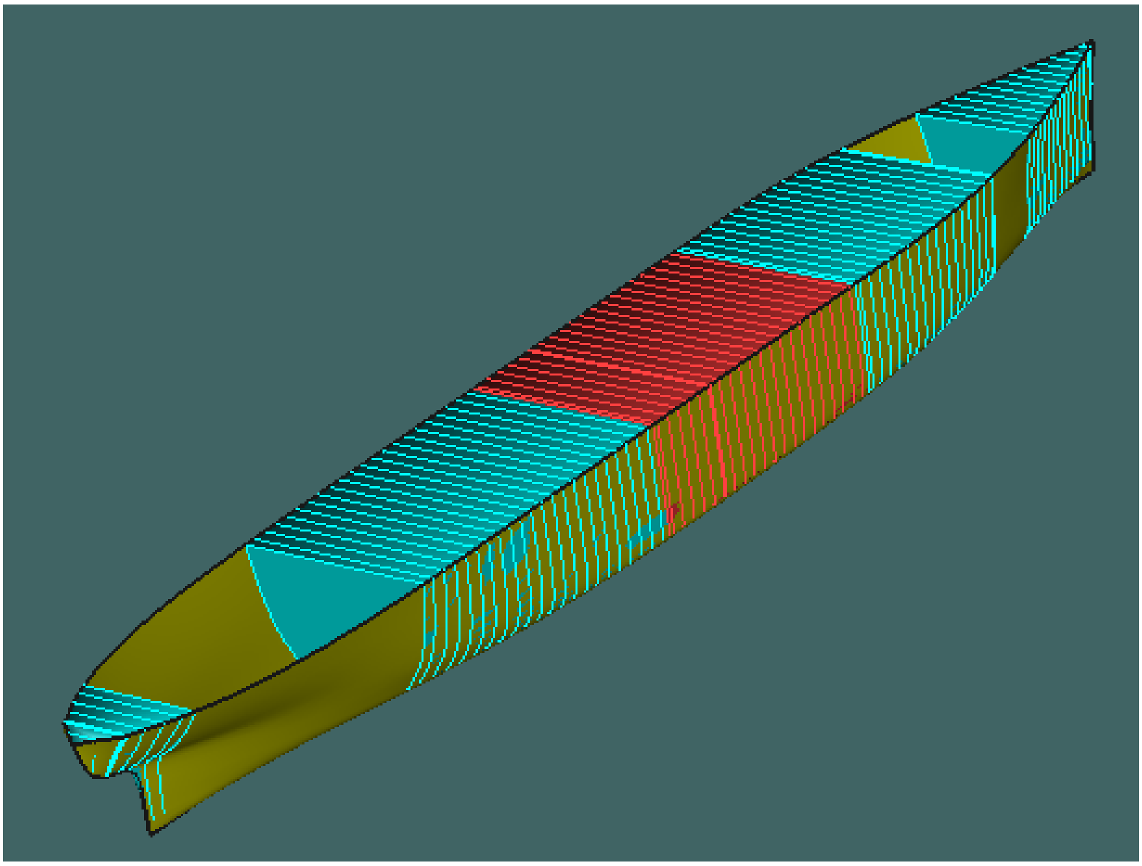


FIGURE 8.1: The hull of the cargo vessel with tanks.

The division of the ship into zones was performed. Considering that the ship was already in service, the zones were selected based on the positions of the bulkheads. The details of the zone division are presented in Table 8.2 and Figure 8.2. By performing these steps, the required information for the probabilistic damage analysis was prepared in MaxSurf.

Name	**Aft** (m)	**Fwd** (m)	**Length** (m)	**Center** (m)
Zone 1	-0.645	1.221	1.866	0.288
Zone 2	1.221	5.525	4.304	3.373
Zone 3	5.525	6.744	1.219	6.134
Zone 4	6.744	12.690	5.946	9.717
Zone 5	12.690	13.610	0.920	13.150
Zone 6	13.610	20.000	6.390	16.805
Zone 7	20.000	26.858	6.858	23.429
Zone 8	26.858	30.993	4.135	28.926

Table 8.2: Division of zones for monohull

8.1.2 Result of analysis

After all the relevant data was entered, the analysis was conducted. The summary of the MaxSurf report is presented in table 8.3 and 8.4. Due to the relatively shorter length of our ship, the required index is also small. The requirements were successfully met by the vessel, indicating that the attained index surpasses the required index.

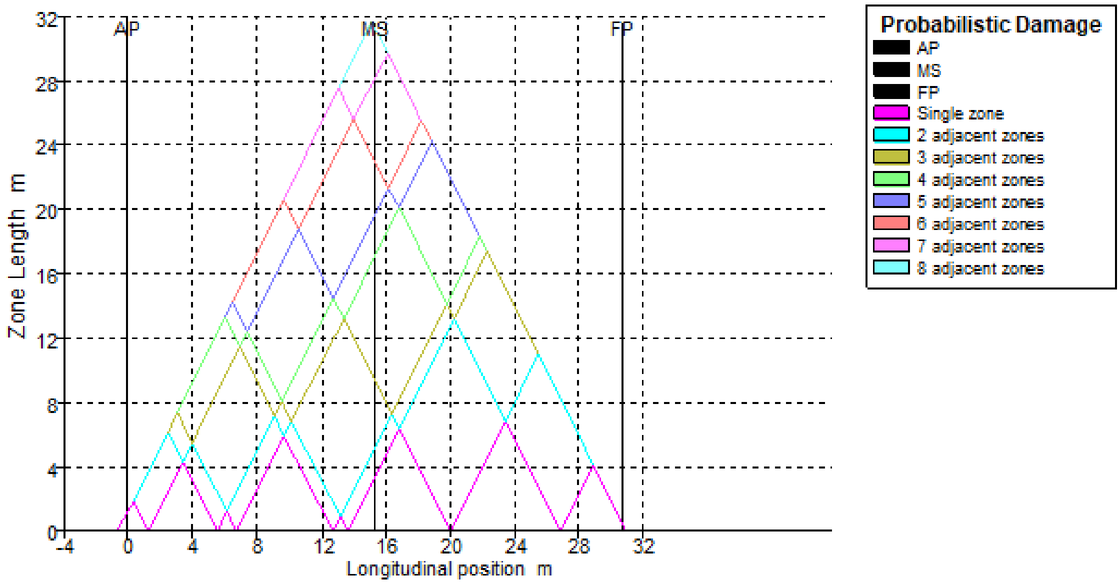


FIGURE 8.2: Damage Cases

TABLE 8.3: Result for Deepest subdivision draft (summer load-line)

Depest	$\mathbf{p_i}$	$\mathbf{r_i}$	$\mathbf{v_i}$	$\mathbf{s_i}$	$\mathbf{p_i r_i v_i s_i}$
Z1	0.015576	1	1	1	0.015576
Z2	0.037725	1	0.79	1	0.029803
Z3	0.004349	0.8	0.89	1	0.003096
Z4	0.200493	1	0.9	0.89	0.160595
Z5	0.008711	1	0.8	0.78	0.005436
Z6	0.146266	1	1	0.56	0.093613
27	0.164203	1	1	1	0.164203
Z8	0.11337	1	1	1	0.11337
$\mathbf{A_s}$					**0.585692**

Table 8.4: Result for partial subdivision draft and Conclusion

Partial	$\mathbf{p_i}$	$\mathbf{r_i}$	$\mathbf{v_i}$	$\mathbf{s_i}$	$\mathbf{p_i r_i v_i s_i}$
Z1	0.025576	1	1	1	0.025576
Z2	0.047725	1	0.78	1	0.037226
Z3	0.004349	0.8	0.85	1	0.002957
Z4	0.200493	1	0.9	0.88	0.15879
Z5	0.008711	1	0.8	0.71	0.004948
Z6	0.626266	1	1	0.56	0.350709
Z7	0.154203	1	1	1	0.154203
Z8	0.01337	1	1	1	0.01337
$\mathbf{A_p}$					**0.584837**
A					**0.585692**
R					**0.284916**
Pass/Fail					Pass

8.2 Catamaran

8.2.1 Preparation for Analysis

The tanks were defined in MaxSurf based on the tank capacity plan depicted in Figure 8.3. Each tank was assigned its aftmost and foremost ends, as well as its starboard or portside breadth and vertical height. The tank definition details, including dimensions and the density of the fluid it contains, are presented in Table 8.1 below.

For the probabilistic damage analysis, the necessary data was entered in MaxSurf. Three loading conditions, namely Lightship, Partially loaded, and deepest subdivision conditions, were considered, and the corresponding data were provided.

TABLE 8.5: Room definition of the catamaran vessel

Item	**Quantity**	**Unit Mass**	**Total mass**	**Unit volume**	**Total volume**	**Long. Arm (m)**	**Trans. Arm(m)**	**Vertical arm. (m)**
Lightship	1	360	360			21	0	2.5
AP TK (P)	90 %	7.683	6.914	7.683	6.914	0.127	-4.328	2.41
FP TK (S)	90 %	7.683	6.914	7.683	6.914	0.127	4.328	2.41
FOS TK (P)	90 %	4.372	3 .935	4.372	3.935	13.4	-4.328	2.411
FOS TK (S)	90 %	4.372	3.935	4.372	3.935	13.4	4.328	2.411
FOR TK (P)	90 %	3.08	2.772	3.08	2.772	13.5	-4.328	0.785
FOR TK (S)	90 %	3.08	2.772	3.08	2.772	13.5	4.328	0.785
FPT (P)	90 %	5.192	4.673	5.192	4.673	43.14	-4.328	2.05
FPT (S)	90 %	5.192	4.673	5.192	4.673	43.14	4.328	2.05
Passenger M/DK	315	0.065	20.475			24.5	0	3.8
Passenger U/DK	192	0.065	12.48			20.877	0	6.55
Passenger B/DK	141	0.065	9.165			24.8	0	9.3
Total Loadcase			438.71	40.655	36.59	20.822	0	2.782
FS correction								0.099
VCG fluid								2.881

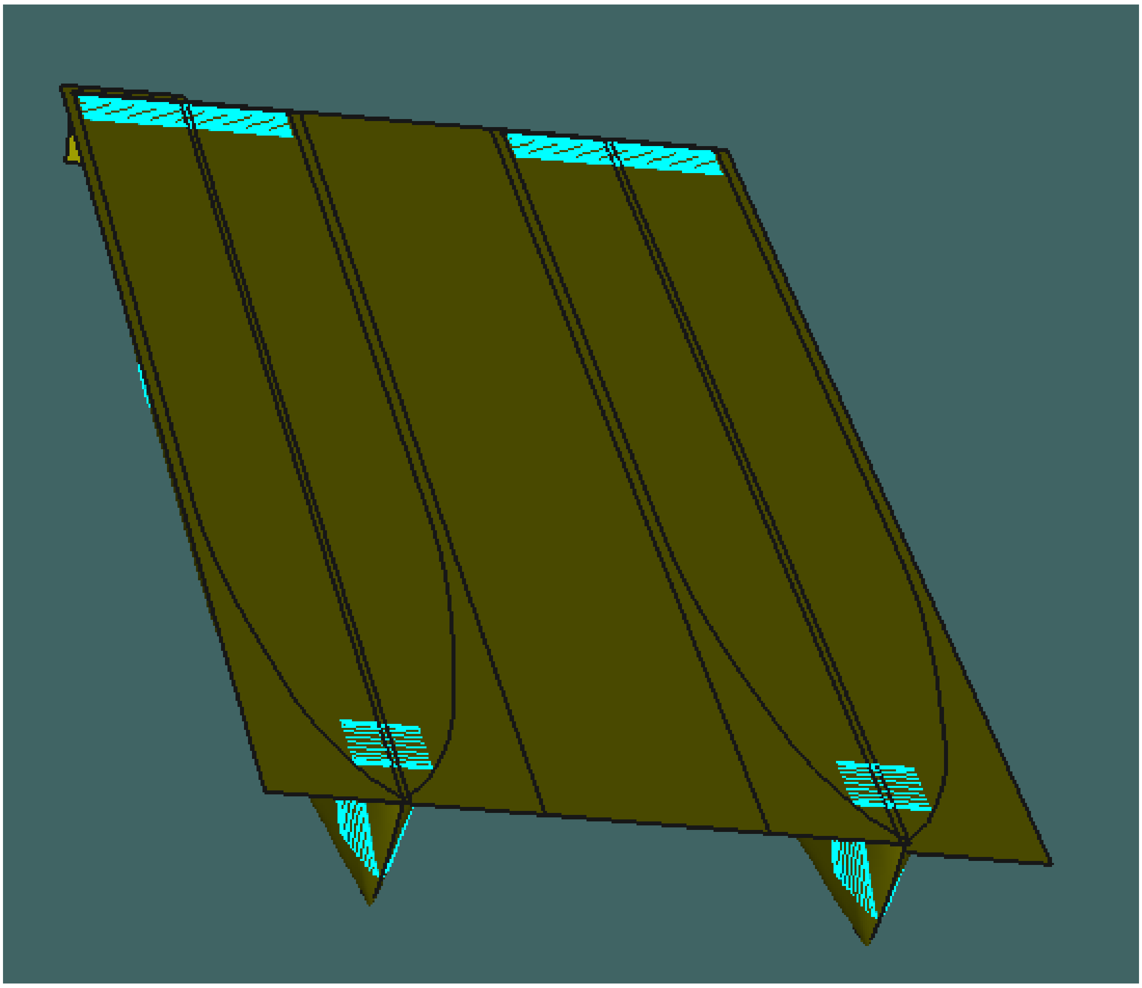


FIGURE 8.3: The hull of the catamaran passenger vessel with tanks.

The division of the ship into zones was performed. Considering that the ship was already in service, the zones were selected based on the positions of the bulkheads. The details of the zone division are presented in Table 8.6 and Figure 8.4. By performing these steps, the required information for the probabilistic damage analysis was prepared in MaxSurf.

TABLE 8.6: Division of zones for Catamarn

Name	**Aft** (m)	**Fwd** (m)	**Length** (m)	Center (m)
Zone 1	0.000	2.000	2.000	1.000
Zone 2	2.000	15.000	13.000	8.500
Zone 3	15.000	22.000	7.000	18.500
Zone 4	22.000	31.500	9.500	26.750
Zone 5	31.500	33.000	1.500	32.250
Zone 6	33.000	38.000	5.000	35.500
Zone 7	38.000	41.000	3.000	39.500
Zone 8	41.000	44.000	3.000	42.500
Zone 9	44.000	47.250	3.250	45.625

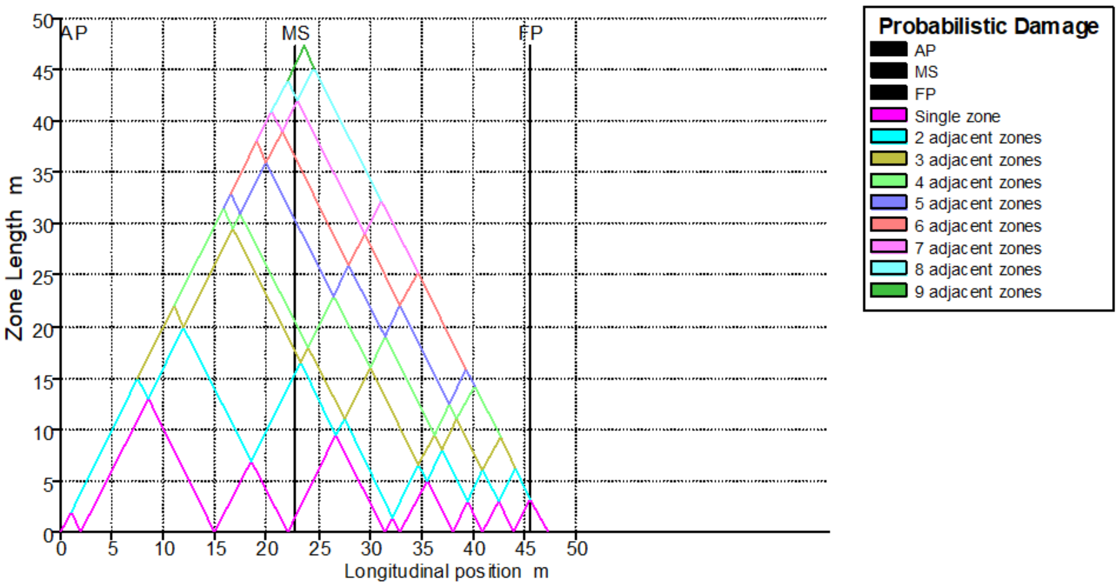


FIGURE 8.4: Damage Cases

8.2.2 Result of analysis

After all the relevant data was entered, the analysis was conducted. The summary of the MaxSurf report is presented in table 8.7, 8.8, and 8.9. Due to the relatively shorter length of our ship, the required index is also small. The requirements were successfully met by the vessel, indicating that the attained index surpasses the required index.

TABLE 8.7: Result for Deepest subdivision draft (summer load-line)

Depest	$\mathbf{p_i}$	$\mathbf{r_i}$	$\mathbf{v_i}$	$\mathbf{s_i}$	$\mathbf{p_i r_i v_i s_i}$
Z1	0.025678	1	0.65	1	0.115576
Z2	0.025678	1	0.45	1	0.029803
Z3	0.207818	0.8	0.90	0.76	0.003096
Z4	0.135001	1	0.9	0.89	0.160595
Z5	0.048684	1	0.8	0.78	0.105436
Z6	0.045630	1	1	0.56	0.093613
27	0.207818	1	1	0.84	0.164203
Z8	0.045630	1	1	1	0.11337
Z8	0.207818	1	1	1	0.11337
$\mathbf{A_s}$					**0.753253**

TABLE 8.8: Result for partial subdivision draft

Partial	p_i	r_i	v_i	s_i	$p_ir_iv_is_i$
Z1	0.025678	1	0.65	1	0.115576
Z2	0.025678	1	0.45	1	0.029803
Z3	0.207818	0.8	0.90	0.76	0.103096
Z4	0.135001	0.93	0.67	0.89	0.160595
Z5	0.048684	1	0.8	0.78	0.005436
Z6	0.045630	1	1	0.56	0.093613
27	0.207818	1	1	0.84	0.164203
Z8	0.045630	1	1	1	0.14453
Z8	0.207818	1	1	1	0.13434
$\mathbf{A_s}$					**0.738798**

TABLE 8.9: Result for Light service draft and Conclusion

Lightship	p_i	r_i	v_i	s_i	$p_ir_iv_is_i$
Z1	0.025576	1	1	1	0.025576
Z2	0.047725	1	0.78	1	0.137226
Z3	0.004349	0.8	0.85	1	0.002957
Z4	0.200493	0.48	0.9	0.88	0.15879
Z5	0.008711	0.98	0.8	0.71	0.004948
Z6	0.626266	1	1	0.56	0.350709
Z7	0.154203	1	1	1	0.2324564
Z8	0.01337	1	1	1	0.02743
$\mathbf{A_p}$					**0.754376**
A					**0.743287**
R					**0.685**
Pass/Fail					Pass

Chapter 9

Comparison of Results

In this section, a comparative analysis is presented between the results obtained from our monohull vessel, O. T. GOLDEN TOUCH, and the Passenger Yacht Code (PYC) monohull vessel. The comparison aims to highlight the similarities and differences in various aspects of the two vessels.

Comparison	**Passenger Yacht Code**	**O. T. GOLDEN TOUCH**
Length of Subdivision (L_s)	92.65 m	27.10 m
Deepest subdivision draft (d_s)	4.2 m	2.60 m
Partial subdivision draft (d_p)	4.114 m	2.30 m
Light service Draft (d_d)	3.985 m	1.85 m
Required Index "R"	0.68	0.28
Attained Index "A"	0.815	0.55

The chosen vessel is an inland vessel with a relatively shorter length. The required index is dependent on the length of the vessel's subdivision. Due to the small length of the chosen vessel, the required index is also small. The percentage difference between the required index is calculated as follows:

$$\frac{0.68005 - 0.28531}{0.68005} \times 100\% = 58\%$$

The percentage difference between the attained index is calculated as:

$$\frac{0.81504 - 0.55}{0.81504} \times 100\% = 33\%$$

It is observed that a 58% difference in the required index corresponds to a 33% difference in the attained index, which indicates a favorable outcome. The smaller difference in the attained index suggests a higher probability of survival for our chosen ship compared to the passenger yacht code.

Chapter 10

Conclusions

Damage stability calculations are essential for ensuring a minimum level of safety following a flooding incident. Both deterministic and probabilistic methods share the common objective of determining the most efficient ship subdivision. The deterministic approach relies on predefined damage scenarios but the probabilistic approach ensures safety for any probable damage case.

Nevertheless, the deterministic approach is gradually being superseded by the probabilistic method, which employs statistical evidence, making it a more realistic approach. Moreover, the probabilistic approach is now mandatory, reflecting its increasing acceptance and effectiveness in ship design and safety assessments.

We performed manual calculations and compared them with software analysis. For the monohull, we selected the vessel O.T. GOLDEN TOUCH. The obtained result indicates a required index, R=0.285, significantly lower than the typical value. This is attributed to the ship being an inland vessel with a subdivision length of 27.1 meters, which is comparatively lower. The achieved index is 0.55, higher than the required index. The software analysis yields a similar result, validating the accuracy of our calculations. These results affirm the ship's safety, indicating a high probability of survival after any potential collision and damage.

For the catamaran vessel, we chose MV ADVENTURE 06, which is already in service. The calculations reveal a required index of 0.685 and an attained index of 0.74. The larger required index is due to the presence of two hulls, contributing to increased transverse stability. The calculation breadth considers the total breadth of the ship, accounting for both hulls. With a greater breadth, the attained index is also higher, ensuring enhanced safety.

Furthermore, the obtained results demonstrate a resemblance to the findings presented in ASCIC's (2015) thesis titled "Probabilistic damage stability verification of PYC motor yachts" conducted at the University of Genoa. This alignment of results further supports the validity and consistency of the probabilistic approach in assessing the damage stability of our ships.

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Appendix A

Hull Design in Rhino 3D

The hull of the ships is crafted using Rhino 7 software, and this appendix elaborates on the procedures for designing the catamaran hull specified in Table 5.3. Since catamaran vessel hulls are symmetric, modeling a single hull and mirroring it while preserving the hull spacing to length ratio is sufficient. The initial step involves generating coordinate points from the offset table provided in Table 6.2. For illustration, the process of obtaining coordinate points for station 4 will be explained.

The x-coordinate represents the distance of the station from the aft. Given a station spacing of 4.640 meters, the distance of station 4 from the aft is calculated as $4 \times 4.640 = 18.560$ meters, which remains constant for all station 4 coordinates. The y-coordinate corresponds to the distance of waterlines from the midship, obtained from the offset table for station 4. The z-coordinate denotes the height of the waterline from the baseline. Taking Waterline 2 as an example, from Table 6.2, WL2 is 1678 mm or 1.687 meters from the midship. With a waterline spacing of 0.5 meters, WL2 is positioned $2 \times 0.5 = 1$ meter above the baseline. Consequently, the coordinate becomes $(18.560, 1.687, 1)$. Following the same methodology, the coordinates for station 4 are detailed in Table A.1.

TABLE A.1: Coordinates of Station 4

x	y	z
18.560	1.380	0.500
18.560	1.678	1.000
18.560	1.814	1.500
18.560	1.932	2.000
18.560	2.172	3.000

All coordinate points are identified and stored in a text file. Subsequently, in the Rhino 3D software, these points are imported as depicted in figure A.1. The application of the *CurveThroughPt* command to the points generates the curves, illustrated in figure A.2(a). Following this, the *NetworkSrf* command is used to create a surface from the generated curves, as shown in figure A.2(b). To obtain a complete single hull, the surface is mirrored about the midship, resulting in figure A.2(c). Subsequently, this single hull is duplicated, maintaining a hull separation ratio of 0.4. The final outcome is the generation of a complete catamaran hull, illustrated in Figure A.2(d).

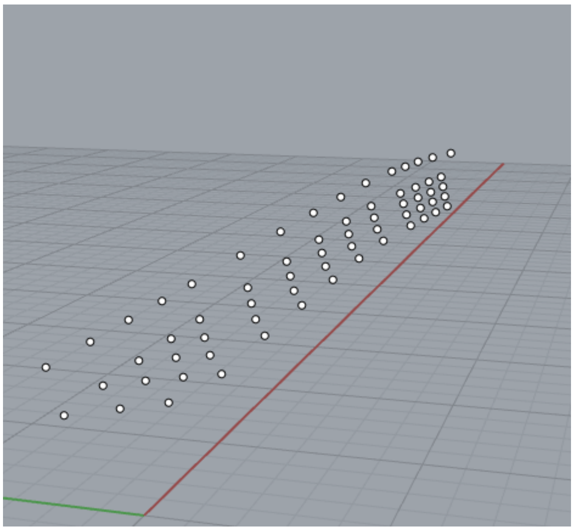
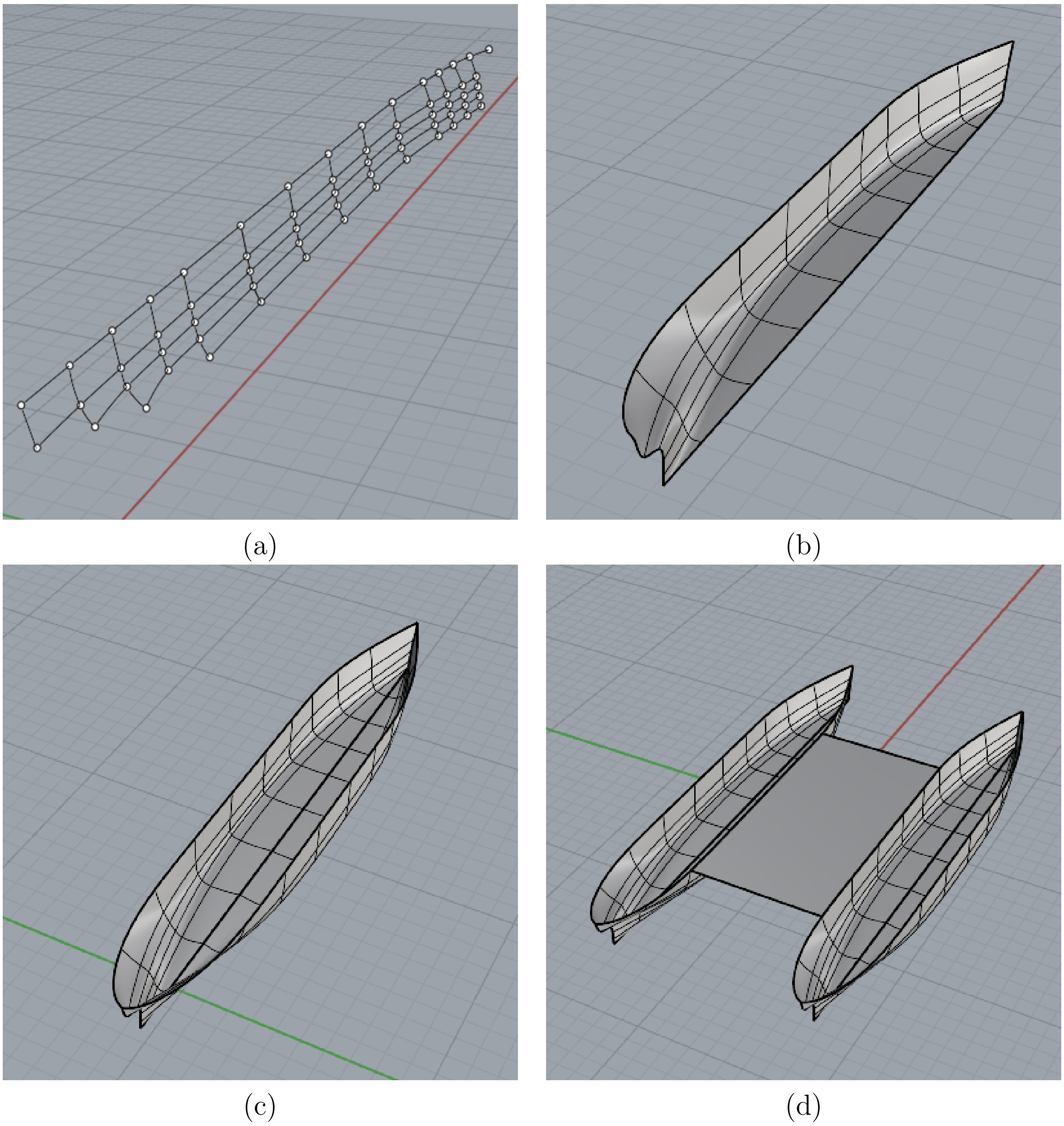


FIGURE A.1: Imported points in Rhino



(a) (b) (c) (d)

FIGURE A.2: Hull generation process

Appendix B

MAXSURF Modeling

The Rhino-modeled hull is exported in the form of an IGS surface file, which is subsequently imported into the MAXSURF modeler. The primary objective is to establish reference points and a design grid encompassing Waterline (WL), Station, and BTK. Within the MAXSURF modeler's `Data` tab, the frame of reference is configured, as illustrated in Figure B.1. Subsequently, the process involves designing grids for the Waterline, BTK line, and Station. Aligning with the specified spacing requirements for WL, BTK, and ST of the vessel, corresponding values are input into the `Design grid` section of the `Data` tab, as depicted in Figure B.2. After the completion of the grid design, the Lines Plan and the 3D view are illustrated in Figure B.3 and Figure B.4.

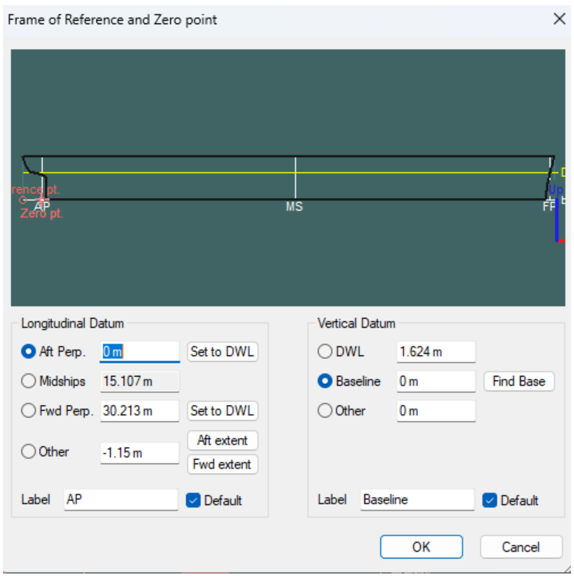


FIGURE B.1: Setting Up the frame of reference

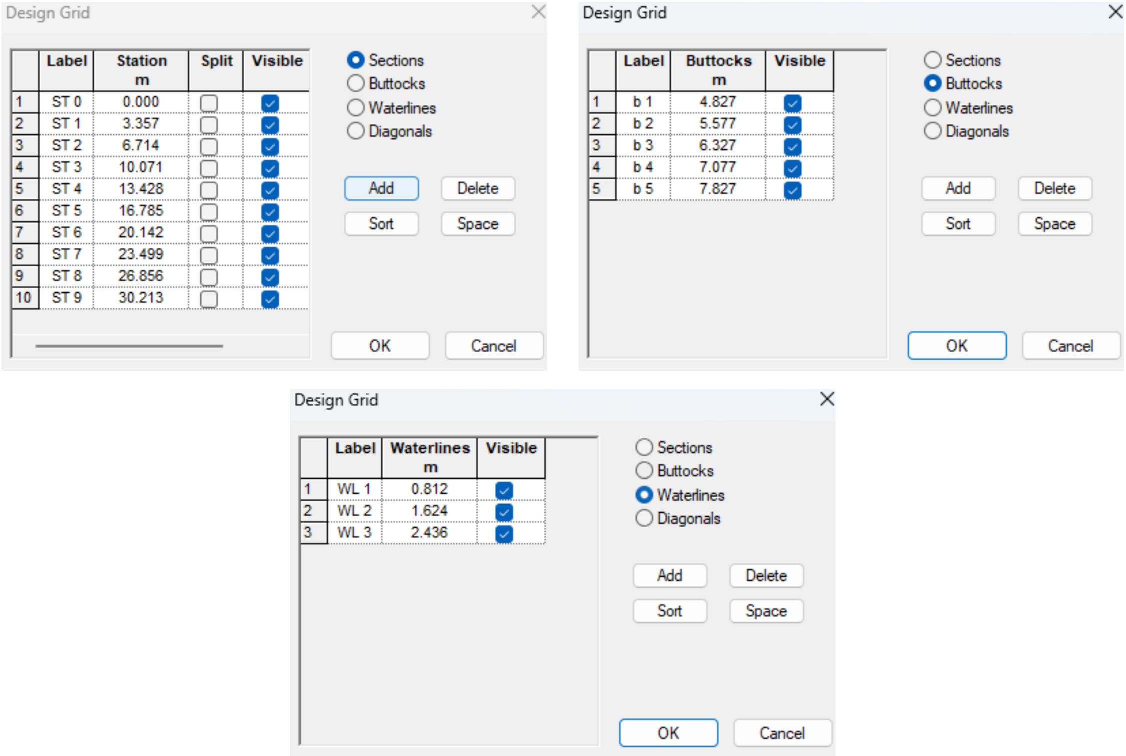
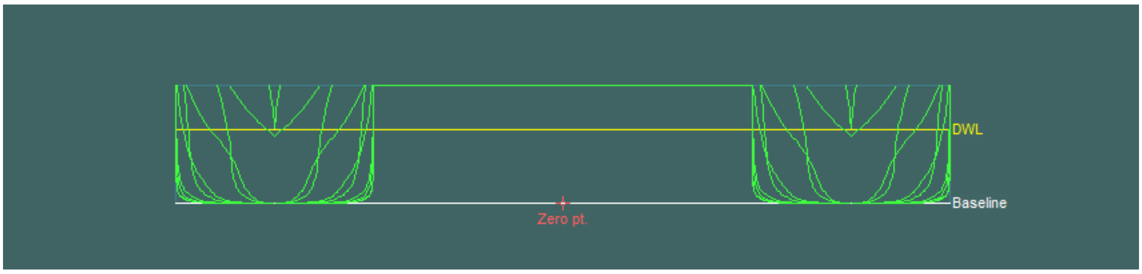
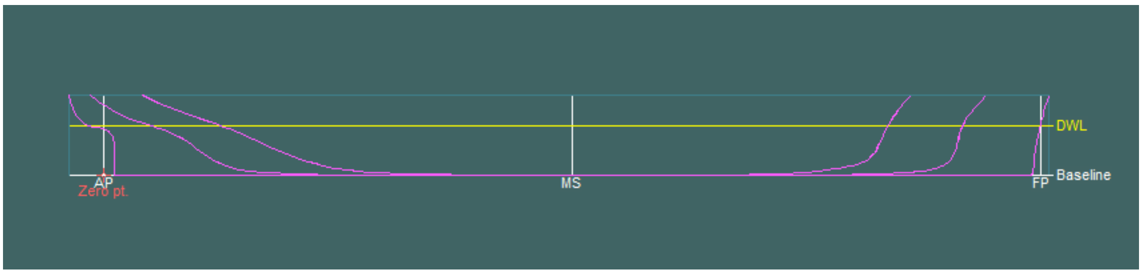


FIGURE B.2: Grid Design

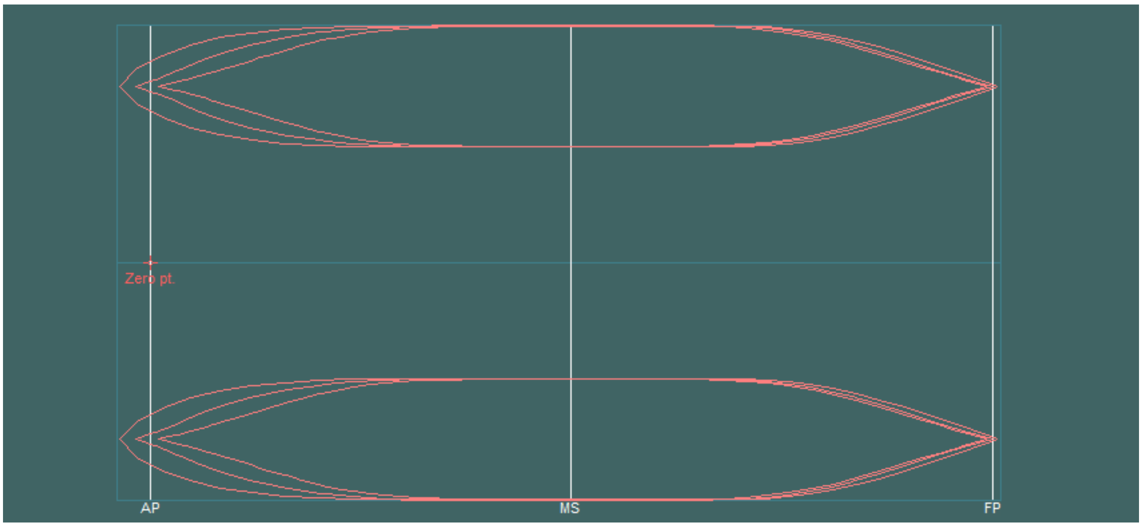


(a)

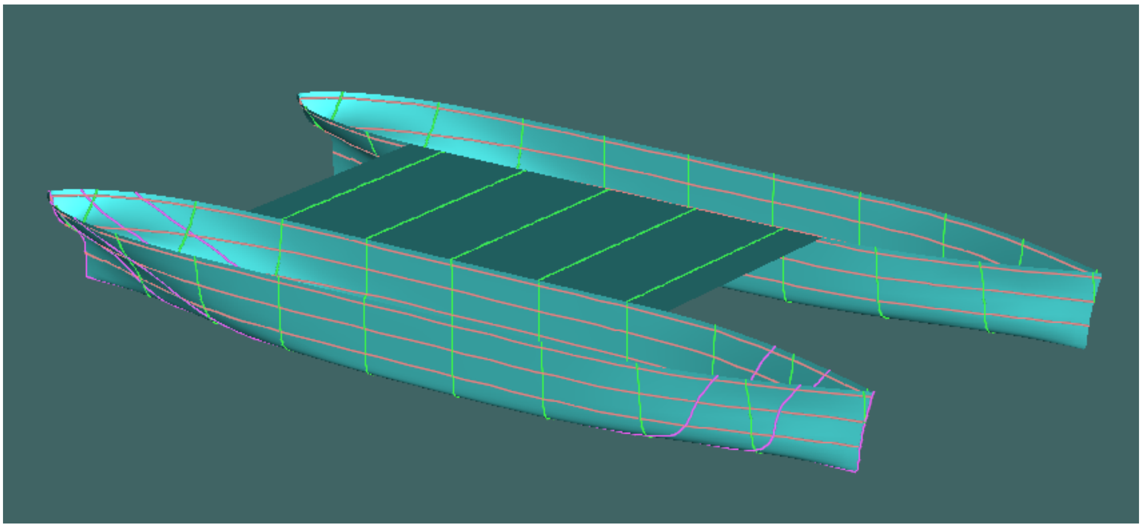


(b)

FIGURE B.3: Lines Plan in MAXSURF Modeler. (a) Station, (b) BTK



(a)



(b)

FIGURE B.4: (a) Waterline, (b) 3D View

Following the completion of the initial setup, the model is imported into Maxsurf Stability. Subsequently, tank and compartment definitions are established within Maxsurf Stability, and the requisite data for conducting probabilistic damage stability calculations is incorporated. A comprehensive explanation of these procedures is provided in Chapter 8.