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Optimization of Double Bottom Design in Cargo Hold Areas: Case Study of Tanker with Lengths 150 M And Above

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Abstract

The shipping industry is keep advancing to produce the most efficient ship designs, including tankers, to reduce production and operational cost while increasing the profit for shipbuilders and the shipowners. According to MARPOL Annex 1 Regulation 19, oil tankers with a deadweight of over 600 tonnes and built after 6 July 1996 must have double side and double bottom structures. These structures are intended to prevent oil spill in the event of hull damaged. However, they significantly reduce the cargo hold volume. Therefore, the objective of this research is to optimize the cargo hold volume by optimizing the double bottom design along the cargo oil tank. One of the optimization methods that can solve this problem is the brute force search method. Unlike heuristic algorithms, it provides exact rather than approximate results, making it ideal for solving small-scale problems with shorter iteration times. In this research, the variables are the locations of two cargo landing points at each knuckle of the ship's cargo oil tank. The constraints are the regulations governing clearance, stability, freeboard, and longitudinal strength of ship. The research resulted in a new design that increased the cargo oil tank volume by 375.996 m³, equivalent to 0.865%. A new ship with the same payload can be constructed using an optimized cargo oil tank configuration, reducing both the cargo tank length and the overall ship length by 1.011 m.

1. Introduction

The shipping industry is keep advancing to produce the most efficient ship designs. In the 1930s, welding began to replace the riveting method for joining ship hulls because it significantly reduced the ship's weight. Some researchers have developed a new type of material that is both stronger and lighter than mild steel. Others have designed ship hulls with minimal resistance to lower operational costs. Additionally, some have attempted to design ships with maximum cargo hold capacity without increasing their overall main dimensions.

Several studies have been conducted to optimize ship design. Earlier studies on regulations and recent research concerning tanker cargo compartment layouts indicate that the arrangement of cargo boundary lines plays a crucial role in determining cargo space volume [1]. One study successfully increased the cargo capacity of tankers by 2.0% and bulk carriers by 1.94% using the Parametric Inner Shell Optimization Method (PISOM) [2]. Another study reduced the total and residual resistance coefficients by 2.4% and 6.8%, respectively, using Sequential Quadratic Programming (SQP) [3]. A combination of dynamic programming and a genetic algorithm was used to solve voyage planning in three dimensions, achieving an average fuel saving and emission reduction of 3.4% on a medium-size chemical tanker [4]. A CFD-based adjoint solver tool for modifying the hull form of a trimaran ship is presented, resulting in a 6.67% reduction in total resistance [5]. Multi-objective optimization design for composite panels of the superstructure in large passenger ships is performed using the Neighbourhood Cultivation Genetic Algorithm (NCGA), with structural mass reduced by 4.1% and ultimate strength increased by 9.2% [6]. A route for a container ship was optimized using Dijkstra's algorithm, resulting in a fuel consumption decrease of around 6 tons and total costs that were 4.76% less than those of the great circle arc path [7]. A Japan Bulk Carrier (JBC) was optimized using the Dung Beetle Optimizer algorithm which resulting in a 4.7% decrease in resistance[8]. The optimization of the ship structure reduced the steel weight of OSV vessels by 121.9 tonnes (42.4%) using the blind search method [9]. The optimization of the Sectional Area of Curve (SAC) and the cross-sectional shape of the design load waterline (DLWL) reduced wave-making resistance by 13.2% and added resistance by 13.8% on bulk carriers, as determined by a study using Particle Swarm Optimization (PSO) [10]. Another study found that the production costs and construction weight of chemical tankers could be reduced by 3% and 2.18%, respectively, based on Common Structural Rules (CSR) [11]. Another study produced an optimal structural layout and scantling configuration using a semi-automatic design method with VBA [12]. A multi-fidelity deep neural network (MFDNN)-based framework is proposed to improve hull form optimization by combining high- and low-fidelity data, achieving enhanced computational efficiency and accuracy while reducing resistance [13]. A data-driven hull shape optimization pipeline using reduced-order models, dynamic mode decomposition, and machine learning is developed to efficiently minimize ship drag, enabling genetic algorithm-based optimization with reduced computational cost [14]. A nonlinear programming-based hull form optimization method using B-spline parameters is developed to minimize total resistance by considering both wave-making and viscous effects and is validated through experimental testing on an improved Series60 model [15]. Another study successfully reduced the structural profile cross-sectional area by 4,425% and the ship's VCG by 1,267% using the Dominated Artificial Bee Colony (D-ABC) algorithm [16]. A design of a small coastal tanker was successfully optimized to increase its cargo capacity by 1.98% [17]. Recently, research shows that the cargo oil tank volume of a tanker can be increased by 0.960% by converting the conventional sloped hopper into a rounded inner bilge [18].

Tankers have become the backbone of the global economy by transporting the world's most widely used energy source: oil. By 2025, tankers accounted for 27.5% of the total deadweight (DWT) of commercial vessels worldwide [19]. Oil tankers are designed to transport crude or refined oil in bulk. They differ from other types of cargo vessel, such as bulk carriers, container ships and general cargo ships. They have no large hatch openings, only have one deck in their cargo hold area and double bottom and double side (wing tank) structures. At the intersection of double bottom and double side, in the bilge area, there is a hopper structure connecting two cargo landing points.

The design of double bottom, double side, and hopper structures must comply with MARPOL 73/78 regulations, which regulates that there must be a space or clearance between the ship's hull and the cargo oil tanks. This space is intended to prevent oil spill when the hull is damaged. However, these structures significantly reduce the volume of the cargo hold.

Despite the extensive research on ship design optimization, most studies have focused on improving hydrodynamic performance, structural efficiency, routing, or material selection. Only a limited number of studies have addressed the optimization of cargo hold design. For example, previous approaches, such as Parametric Inner Shell Optimization Method (PISOM), have demonstrated improvements in cargo hold capacity. Therefore, this research aims to investigate the potential for increasing cargo hold capacity through the optimization of the double bottom design within the cargo hold area. Specifically, this study focuses on maximizing cargo hold volume by modifying the double bottom configuration. The increased cargo hold volume will increase the revenue for every trip, which will be a benefit for the shipowner. The increased cargo hold volume can be also used to reduce the ship's length to maintain the initial volume. This has wide-ranging economic and technical benefits. The cost of shipbuilding materials will be reduced, as will the ship's resistance and the engine power requirements. This reduction will lower fuel consumption, reducing operational costs, and carbon footprint.

2. Methods

2.1. Basic Theory

2.1.1. MARPOL 73/78

MARPOL 73/78 is an international convention that addresses the prevention of pollution at sea caused by ship operations or accidents [20]. According to MARPOL Annex 1 Regulation 19, oil tankers over 600 DWT and built after 6 July 1996 must have wing tank and double bottom structures. A wing tank or double side tank is a tank or compartment structure that separates the cargo oil tank from the side shell of the ship, extending from the inner bottom to the main deck. According to Regulation 19.3.1, the minimum width of the wing tanks (w) can be calculated using Eq. (1), where DWT is the ship's deadweight while the value of w being limited to the range $1 \leq w \leq 2\,m$. A double bottom is a tank or compartment located at the bottom of the ship that separates the cargo oil tank from the ship's bottom. The minimum height of the double bottom (h) is determined using Eq. (2) with a value limit of $1 \leq h \leq 2\,m$ where B is the ship's breadth, based on Regulation 19.3.2 [21]. The value of h and w is called as minimum clearance.

$$w = 0.5 + DWT/20000\ (m) \tag{1}$$

$$h = B/15\ (m) \tag{2}$$

The double bottom and double side structures are intersected at the inner bilge area. The values of w and h on tankers can vary, resulting in changes to the minimum clearance at the inner bilge area. According to Regulation 19.3.3, the minimum clearance between the hull shell and the cargo tanks in the bilge area must be h from baseline up to a height of $1.5h$. Above $1.5h$, the minimum clearance is w, as illustrated in Figure 1 [21].

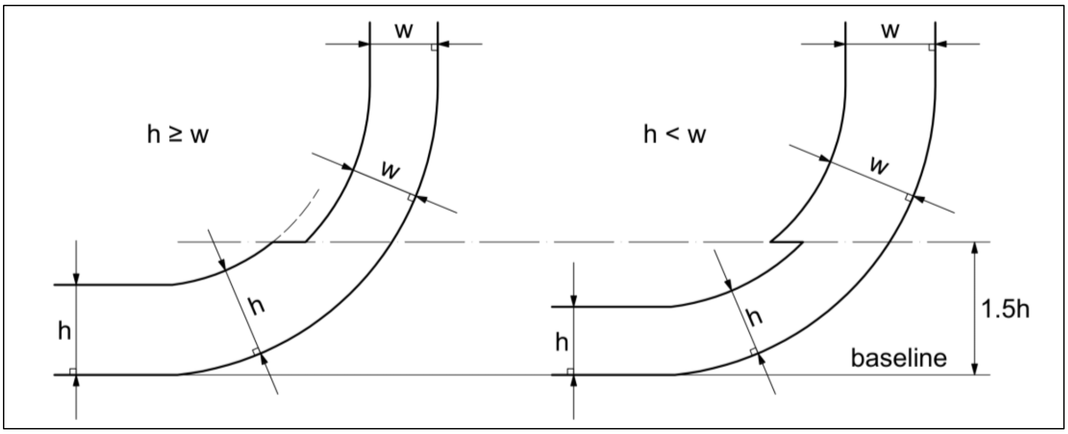


Figure 1. The Minimum Clearance between Hull Shell and Cargo Tank

2.1.2. Common Structural Rules

The Common Structural Rules (CSR) is a classification regulation developed by the International Association of Classification Societies (IACS) for bulk carriers and oil tankers. IACS establishes principles that must be adhered to in terms of ship design, construction and safety. The CSR provides guidelines to help shipowners and builders ensure that their ships meet international safety standards. The CSR also regulates the use of double bottoms and double sides on tankers in accordance with MARPOL 73/78 regulation. According to the CSR, the purpose of double bottoms and double sides is to protect the cargo oil, and these tanks must not be filled with oil. The regulations regarding double bottoms are outlined in Part 1, Chapter 2, Section 3.2, and the regulations regarding double sides are outlined in Part 1, Chapter 2, Section 3.3 [22].

2.1.3. Brute Force Search Optimization Method

The brute force search method is a numerical algorithm used to find the optimal solution to an optimization problem. It is easy to implement this method in various cases without requiring sophisticated intelligence [23]. This method ensures that all possible solutions are examined without any being missed. Unlike heuristic algorithms, it provides exact results rather than approximate results. It is ideal for solving small-scale problems and requires shorter iteration times than heuristic algorithms [24]. However, in complex problem spaces involving many variables, a large domain, and multiple objective functions, this method can take a very long time to find a solution. Figure 2 illustrates the brute force search algorithm.

In this research, the brute force optimization method was chosen to determine the optimal combination. This method offers high accuracy, easy to implement, and guarantees identification of the global optimum without the risk of becoming trapped in local optima. Although it requires relatively high computational effort due to its exhaustive search approach, it is considered suitable for this study because the optimization problem involves a relatively small design space, making the computational cost manageable.

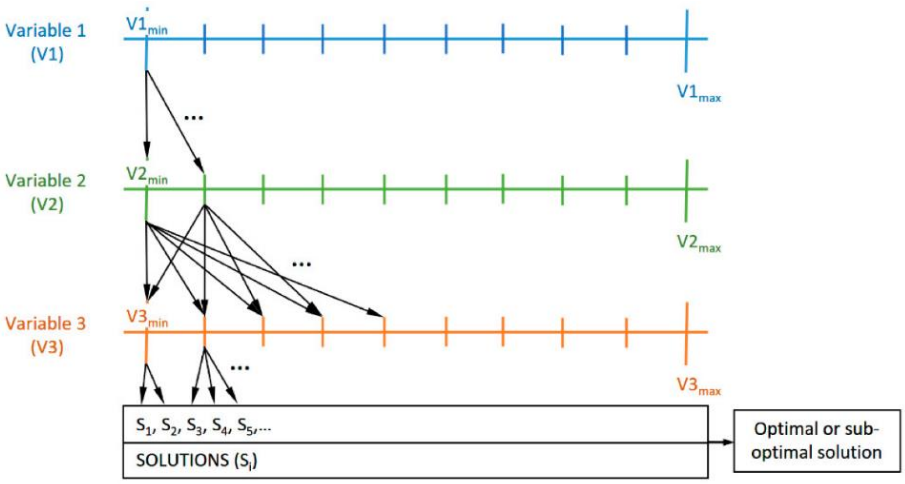


Figure 2. Brute Force Search Optimization Method [25]

2.1.4. Ship Stability

Ship stability is a fundamental aspect of vessel operations and a key factor in assessing maritime safety [26]. Stability is the ability of a ship to return to its original position after being subjected to external forces such as waves and wind [27]. If a ship returns to its equilibrium position after being subjected to an external force, it is said to have positive stability or to be stable. When the ship stops at a new position after being subjected to an external force, it is said to be indifferent. If the ship continues to move, it has negative stability. Ship stability is influenced by the dynamic arm (GZ) which forms a couple moment that balances the upward pressure and the gravity.

One of the regulations about ship stability is the Intact Stability (IS) Code 2008. This applies to all ships over 24 metres long and the stability criteria required by the code are explained in Part A Chapter 2 [28].

a. The area under the GZ curve shall not be less than 0.055 meter-radians up to 30°.
b. The area under the GZ curve shall not be less than 0.09 meter-radians up to 40°.
c. The area under the GZ curve between angles of heel 30° to 40° shall not be less than 0.03 meter-radians.
d. The maximum value of GZ at angles of heel 30° shall not be less than 0.2 m.
e. The maximum GZ should not occur at angles of heel of less than 25°.
f. The initial metacentric height GM0 must not be less than 0.15 m.

2.2. Data Collection and Ship Modelling

A tanker design is generated using ship modelling software based on data from the existing ship. The collected data include lines plan, general arrangement, construction profile, midship section, and stability booklet. The hull form is created from surfaces based on the lines plan, ensuring that its shape is as similar as possible to the existing ship. The general arrangement, construction profile and midship section are used for modelling the cargo oil tanks. The stability booklet provides details on load distribution and loading conditions of the ship.

2.3. Double Bottom Optimization

2.3.1. Design Variables

The design variables are varied to minimise or maximise the objective function while satisfying the constraints. In this research, the variables are the locations of two cargo landing points at each knuckle of the ship's cargo oil tank. Figure 3 shows an example of the variables at one of the knuckle points in the ship's cargo oil tank. These variables will be varied, then the combination of variables that produces the most optimum objective function value will be selected as the optimum solution. The cargo landing point at the double bottom will be varied by adjusting its vertical and transverse coordinate, while the cargo landing point at the double side will be varied by adjusting its vertical coordinate only. Therefore, there are three variables, the vertical and transverse coordinates of the cargo landing point at the double bottom, and the vertical coordinate of the cargo landing point at the double side. One parameter that needs to be considered in this research is the width of the cargo landing point on the double side (DS), which remains unchanged.

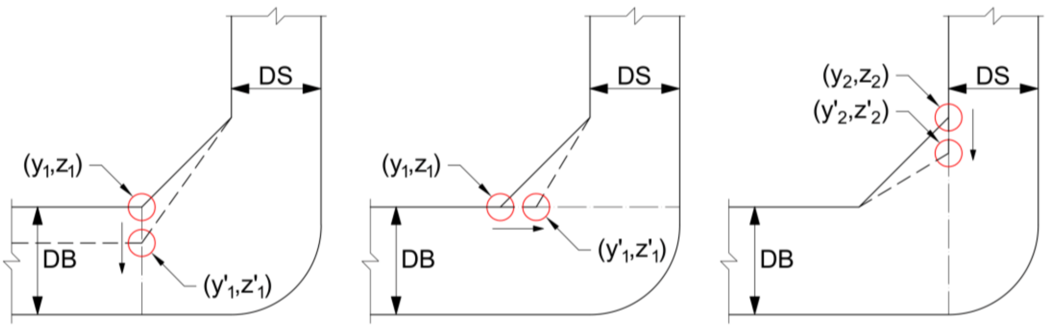


Figure 3. Illustration of the Design Variables at Any Cargo Oil Tank Knuckle

2.3.2. Objective Function

The objective function of this research is to maximise the volume of cargo oil tank. The volume of the cargo oil tank increases if its cross-sectional area increases. Therefore, the objective function could be focused on maximising the cross-sectional area of the cargo oil tank at every knuckle. The equation to obtain the volume of the cargo oil tank is defined by Eq. (3), whereas the equation to obtain the cross-sectional area is given by equation (4) as illustrated by Figure 4.

$$V_{CH} = \int_0^{l_{CH}} A_{CH}\, dx \tag{3}$$

Where, V_{CH} is the volume of cargo oil tank in (m^3), A_{CH} is the cross-sectional area of each knuckle of the cargo oil tank in (m^2), and l_{CH} is the length of cargo oil tank in (m).

$$Cross\ sectional\ area = 2 \cdot (Area\ of\ rectangle - Area\ of\ triangle$$
$$- Area\ of\ longitudinal\ bulkhead\ lower\ stool)$$

$$A_{CH} = 2 \cdot \left[\left((H - z_0) \cdot y_2 \right) - \left(\frac{1}{2} (z_2 - z_1) \cdot (y_2 - y_1) \right) - A_{stool} \right] \tag{4}$$

Where,
H = ship height (m)

z_0 = vertical coordinate of double bottom at centerline measured from baseline (m)
y_1 = transverse coordinate of cargo landing point at double bottom measured from centerline (m)
z_1 = vertical coordinate of cargo landing point at double bottom measured from baseline (m)
y_2 = transverse coordinate of cargo landing point at double side measured from centerline (m)
z_2 = vertical coordinate of cargo landing point at double side measured from baseline (m)
A_{stool} = cross-section area of longitudinal bulkhead lower stool (m^2)

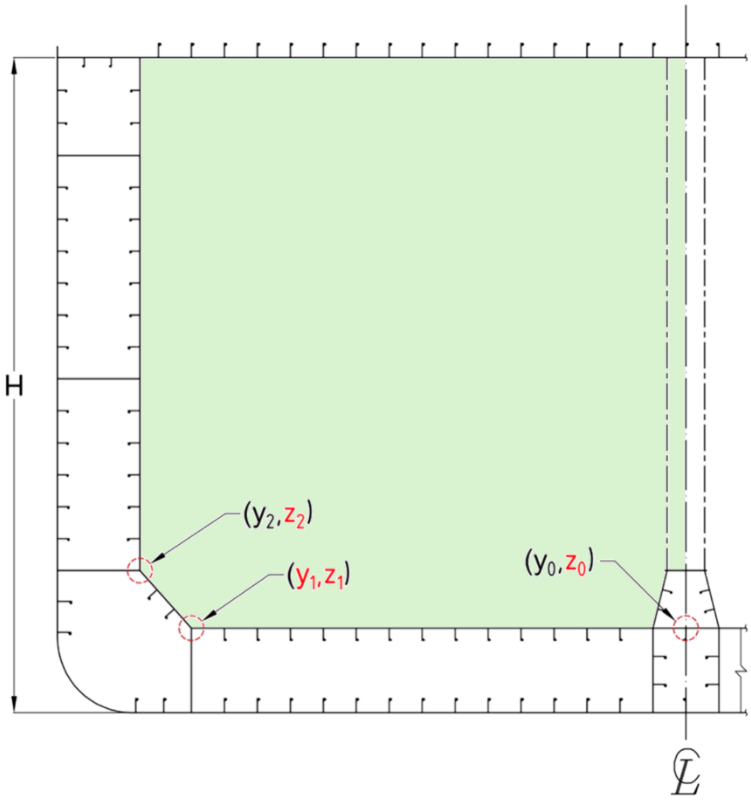


Figure 4. The Illustration of Calculating Cross-Sectional Area

2.3.3. Constraints

Constraints are criteria that must be met during the optimization process. In this study, the constraints include regulatory requirements related to clearance, stability, freeboard, still water bending moment (SWBM) and still water shear force (SWSF). The minimum clearance value is specified by MARPOL Regulation 19.3 and CSR Part 1 Chapter 2 Section 3. The constraints relating to stability and freeboard are governed by IS Code 2008 Part A Chapter 2 and the International Convention on Load Lines (ICLL) 1966, respectively. CSR also sets the maximum and minimum SWBM and SWSF for ships. In addition to these regulatory constraints, geometric constraints are also applied to ensure that the double-bottom configuration maintains a practical and realistic shape.

The geometric constraint relates to the combination of the cargo landing point coordinates. The cargo landing point at the double bottom (y_1, z_1) must not be adjusted transversely passing the transverse coordinate of the cargo landing point at the double side (y_2, z_2). Similarly, the cargo landing point at the double side (y_2, z_2) must not be adjusted vertically passing the vertical coordinate of the cargo landing point at the double bottom (y_1, z_1). This constraint is shown by Figure 5.

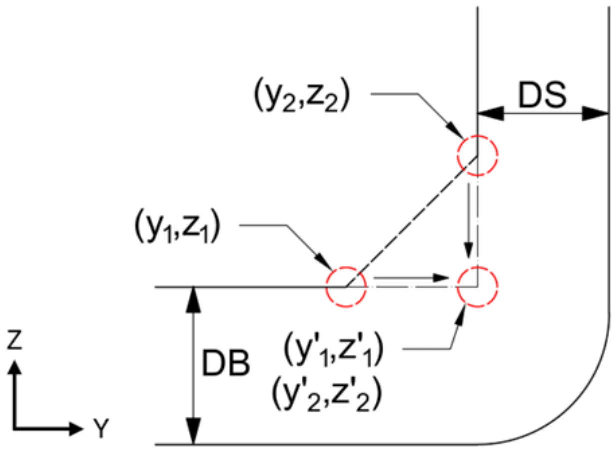


Figure 5. The Geometric Constraints of Double Bottom Optimization

2.4. Optimization Method

The optimization is performed using the brute force search method, where every possible variable combination must be examined. To calculate the total combination of all variables, the number of variations of each variable must be multiplied together. Equation (5) shows that the total combination can be obtained by multiplying the number of variations of the three variables.

$$t = \sum_{i=1}^{n} \left(\frac{z_{1,i} - h}{m}\right) \cdot \left(\frac{y_{2,i} - y_{1,i}}{m}\right) \cdot \left(\frac{z_{2,i} - z_{1,i}}{m}\right) \quad (5)$$

Where, t is the total number of combinations, i is the knuckle point, and m is the precision or step increment.

Each variable combination must comply with the minimum clearance requirement set by MARPOL 73/78. To examine the clearances of the double bottom and hopper, the outer hull line is discretized into points, as illustrated in Figure 6, using data from ship-modelling software. The distances from two cargo landing points and from a hopper point located at a height of $1.5h$ are then measured to all points on the outer hull. Any design variation that results in a distance below the minimum clearance limit is neglected.

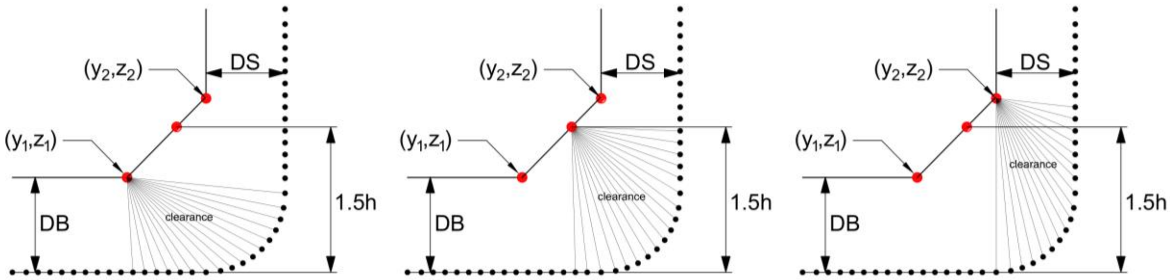


Figure 6. Illustration of Clearance Examination

The flowchart of clearance examination and the optimization process is shown in Figure 7. Following are the detail of the process.

i. Collect the data of cargo landing point coordinates at the double bottom and double side at every knuckle along the cargo oil tank ((y_0, z_0); (y_1, z_1); and (y_2, z_2)). Then calculate the minimum clearance h and w value according to equation (1) and (2).

ii. Examine the clearance for cargo landing point at the double bottom $[(y_0, z_0); (y_1, z_1)]$. If the clearance is greater than the minimum value of h, then the optimization process can be continued. Otherwise, there is no more variation that can satisfy the clearance constraint, so the examination can be terminated and move to process (x).

iii. Examine the clearance for cargo landing point at the double bottom (y_1, z_1). If the clearance is greater than the minimum value of h, then the optimization process can be continued. Otherwise, there is no more variation that can satisfy the clearance constraint, so the examination can be terminated and move to process (vi).

iv. Examine the hopper clearance with the following conditions: For the hopper part below $1.5h$, the clearance value must be greater than or equal to h; for the part above $1.5h$, it must be greater than or equal to w; and for the point at $1.5h$, it must be greater than or equal to h or w, whichever is the greater. If these requirements are met, proceed to the next step by changing the shape of the cargo oil tank design, as shown in Figure 8 and explained in steps (v) to (vii). If the requirements are not met, the optimization process can be ended by going to step (vii).

v. Vary the height of the double bottom by reducing the values of z_0 and z_1 by m.

$$[z_0, (z_0 - m), (z_0 - 2m), (z_0 - 3m), \ldots, h] \quad (5)$$

$$[z_1, (z_1 - m), (z_1 - 2m), (z_1 - 3m), \ldots, h] \quad (6)$$

vi. Vary the transverse cargo landing point coordinate at the double bottom by increasing the values of y_1 by m.

$$[y_1, (y_1 + m), (y_1 + 2m), (y_1 + 3m), \ldots, (B/_2 - w)] \quad (7)$$

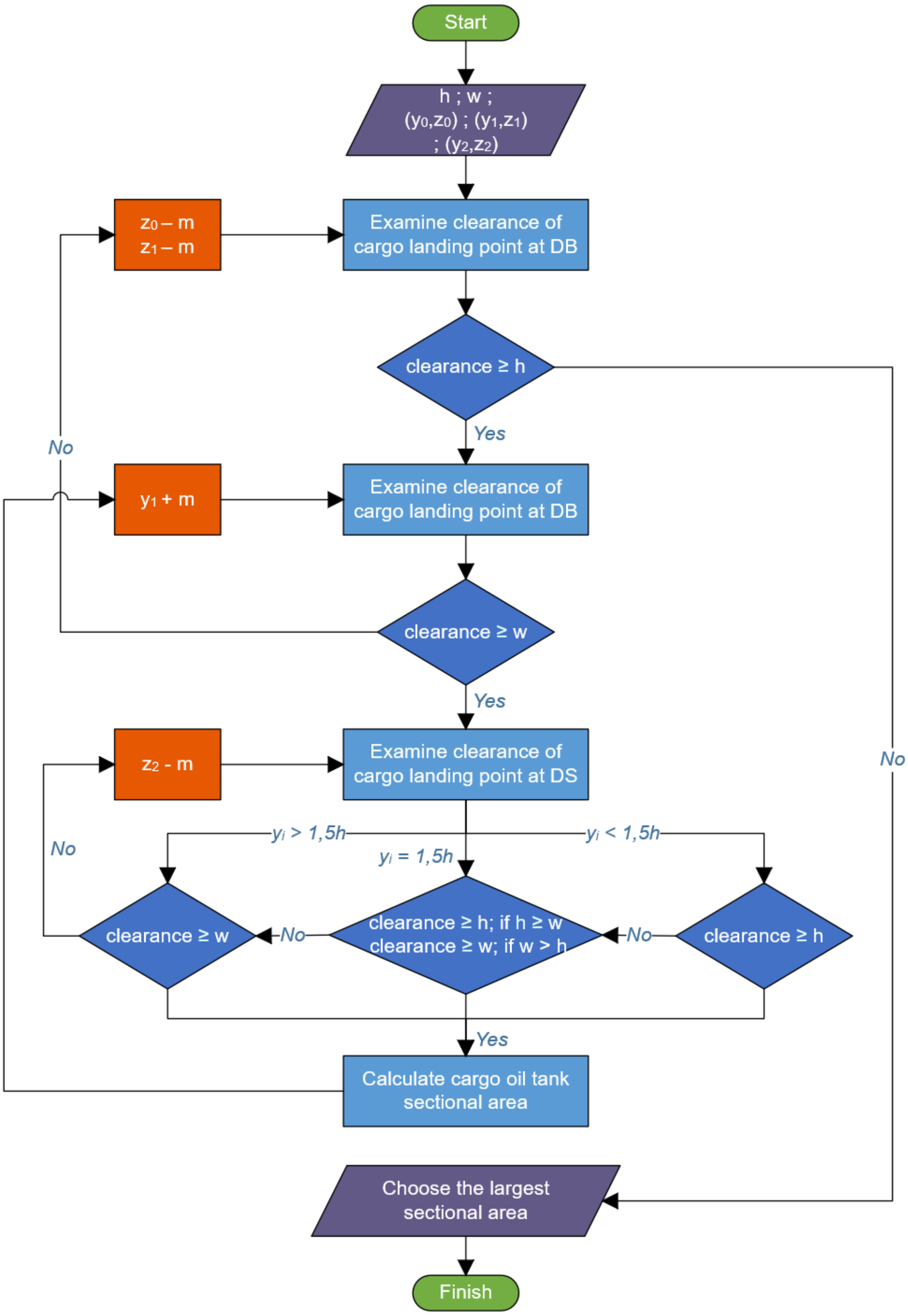


Figure 7. The Flowchart of Optimization Process

vii. Vary the vertical cargo landing point coordinate at the double side by reducing the values of z_2 by m.

$$[z_2, (z_2 - m), (z_2 - 2m), (z_2 - 3m), \dots, h] \tag{8}$$

viii. Calculate the cross-sectional area of the cargo oil tank using equation (4).
ix. Repeat step (ii) to (viii) until all the variations have been evaluated.
x. Choose the variation that results the largest cross-sectional area to achieve the most optimal volume.

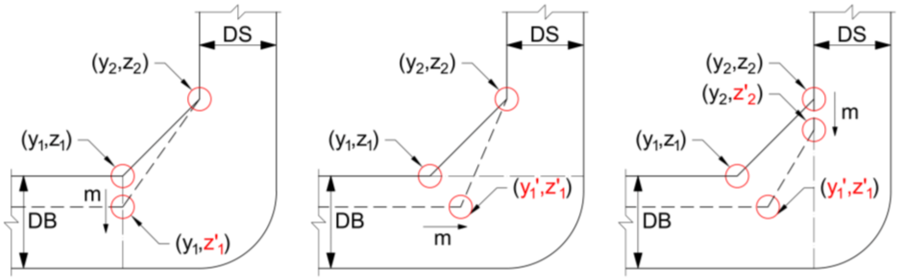


Figure 8. The Adjustment Process of The Cargo Landing Points

2.5. Reducing the Length of the Parallel Middle Body

The volume of the cargo oil tank must satisfy the contractual agreement. Optimizing the double bottom design increases the cargo oil tank volume. This additional volume may be utilised either to enhance cargo capacity or to reduce the principal dimensions of the ship. One option is to shorten the ship′s length. To preserve the original hull′s streamlined form, the reduction is applied within the parallel midbody section. The result is a new tanker design that maintains the same payload as the existing ship but with a reduced overall length, as shown in Figure 9.

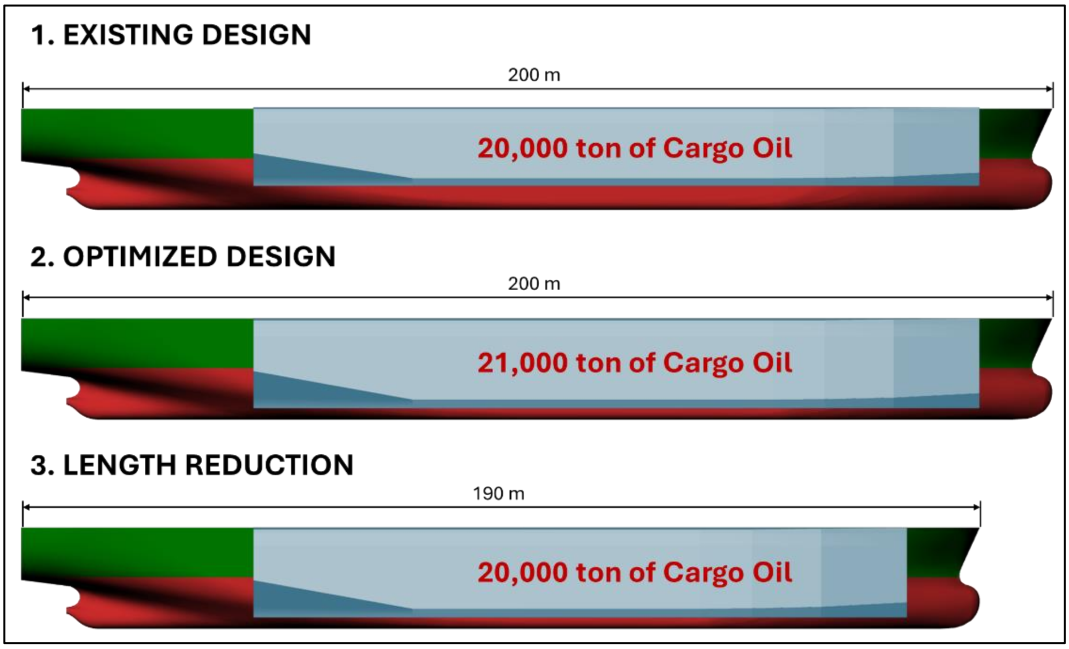


Figure 9. Illustration of Ship Length Reduction

2.6. Regulation Checking

The ship design was checked for compliance with regulations concerning freeboard, stability, and longitudinal strength, both before and after optimization. All calculations required to obtain stability, hydrostatic, and longitudinal strength data were carried out using ship-modelling software. Freeboard, stability, and longitudinal strength assessments were performed for each loading condition in both before and after optimization. The applicable stability criteria are defined in the IS Code 2008 Part A Chapter 2. Freeboard verification was conducted by determining the ship' s actual draft and comparing it with the allowable maximum draft based on ICLL 1966. The maximum permissible draft was calculated by subtracting the height of the ship with the minimum required freeboard, as specified in ICLL 1966.

For longitudinal strength, the criteria evaluated were Still Water Bending Moment (SWBM) and Still Water Shear Force (SWSF). The calculated bending moment and shear force values were compared against the allowable SWBM and SWSF specified by Common Structural Rules (CSR). Bending moments with positive values in the ship will be compared with the maximum hogging criteria, while those with negative values will be compared with the minimum sagging criteria. These criteria were examined because the optimization modifies both the payload and buoyancy distributions, which directly influence the bending moment and shear force. The payload distribution is changed due to the increased volume of cargo oil tank. Furthermore, the increase of payload leads to higher ship displacement, thereby altering the buoyancy distribution.

3. Results and Discussion

3.1. Existing Ship Data

The research focuses on a 30,000 DWT product oil tanker, with the principal dimensions outlined in Table 1.

Table 1. Principal Dimension of 30,000 DWT Product Oil Tanker

Item	Dimensions (m)
Length overall (Loa)	180.00
Length between perpendiculars (Lpp)	173.00
Breadth (B_{mld})	30.50
Depth (H_{mld})	15.90
Designed draft (T_{mld})	9.00
Summer load draft	9.016

3.2. Ship Model

The ship hull and cargo oil tank was remodelled using a ship modelling software, as shown in Figure 10. The difference in moulded volume displacement between the ship model and the actual ship is 0.048%. The height of the double bottom and the width of the double side of the existing cargo oil tank at midship are 2.05 m and 2.00 m, respectively. The cargo oil tank has six knuckle points and consists of 14 separate tanks with 37 different loading conditions.

The parallel middle body of the ship is located between 69.20 m and 121.10 m from the AP, but there are no knuckle points within this range. Therefore, two more knuckle points were added at 85.80 m and 115.80 m from AP to ensure that the cargo hold cross-sectional area remains consistent along the parallel middle body.

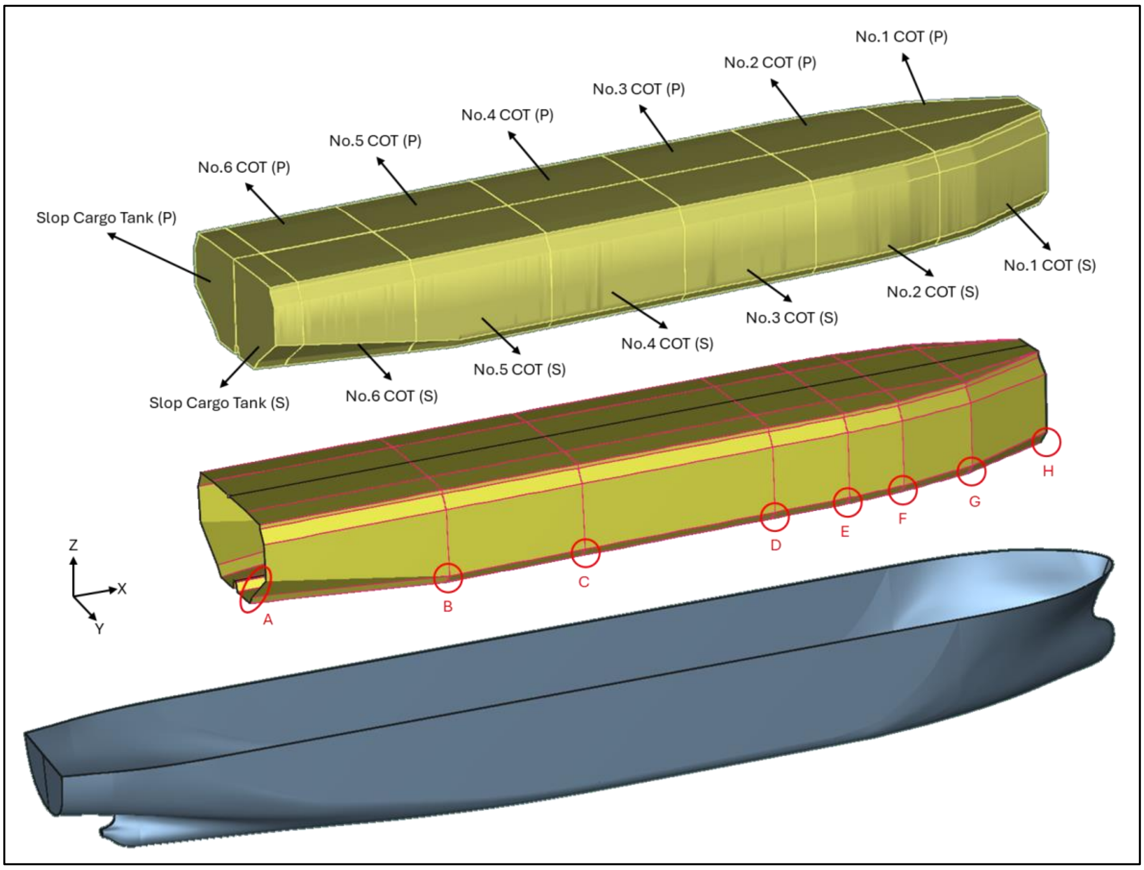


Figure 10. Existing Ship and Cargo Oil Tank Model

3.3. Optimized Design

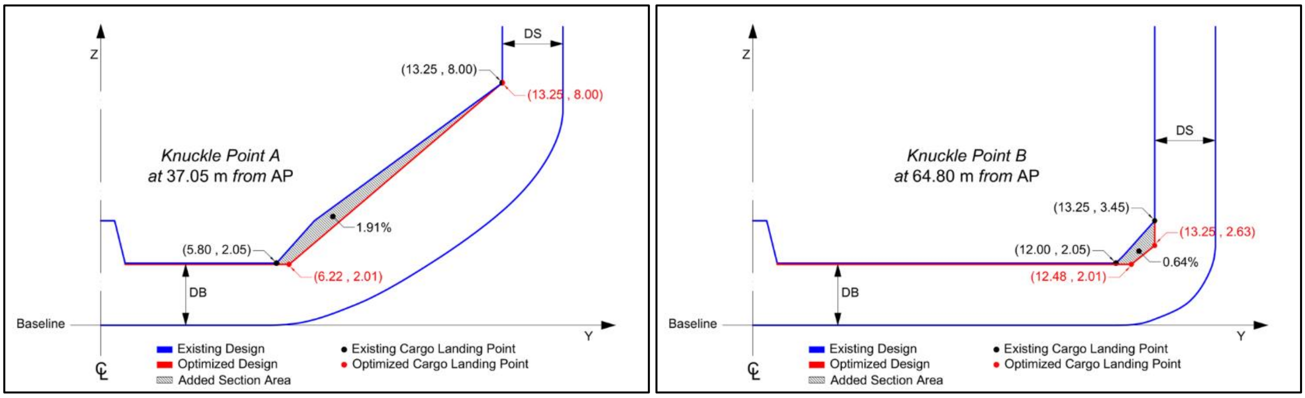
In this research, the first design variable was the cargo landing point at the double bottom. The coordinate was shifted by 0.02 m increments in a vertical direction until the minimum clearance was met. The second variable, also the cargo landing point at the double bottom, was shifted transversely by 0.02 m until the minimum clearance was met. Meanwhile, the third design variable, the cargo landing point at the double side was shifted vertically by 0.02 m increments. Table 2 shows the optimization results for the cargo landing points at each knuckle point. This data represents the combination resulting in the largest cargo hold cross-sectional area.

The new double bottom design results after optimization are shown in Figure 11 to Figure 14. The optimization process resulted in a higher volume of cargo oil tank compared with the existing design, indicating potential for further improvement to the original configuration. The results also vary among the knuckles. While the sectional area of some knuckles can be increased by more than 1.00%, others show only a slight improvement of around 0.23%, suggesting that these regions are already close to their optimal configurations. It is also noteworthy that the optimized hopper design at Knuckles C and D is almost right-angled. Although this configuration complies with the MARPOL requirements, it may lead to stress concentration and reducing the efficiency of cargo loading and unloading operations. Therefore, future studies should incorporate additional geometric constraints for the hopper, such as a minimum hopper angle and length, to ensure that the optimized design is not only compliant with regulations but also structurally robust and operationally practical.

Table 2. Design Variables Optimization Results

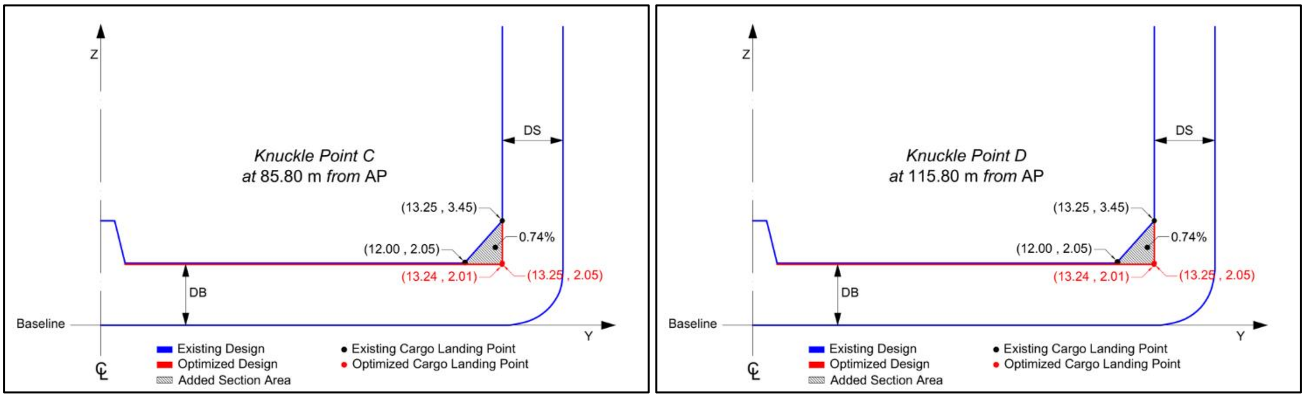
No.	Cargo Landing Point	X (m)	Y (m)		Z (m)	
			Existing Ship	Optimized	Existing Ship	Optimized
1	A1	37.05	5.80	6.22	2.05	2.01
	A2	37.05	13.25	13.25	8.00	8.00
2	B1	64.80	12.00	12.48	2.05	2.01

No.	Cargo Landing Point	X (m)	Y (m)		Z (m)	
			Existing Ship	Optimized	Existing Ship	Optimized
	B2	64.80	13.25	13.25	3.45	2.63
3	C1	85.80	12.00	13.24	2.05	2.01
	C2	85.80	13.25	13.25	3.45	2.05
4	D1	115.80	12.00	13.24	2.05	2.01
	D2	115.80	13.25	13.25	3.45	2.05
5	E1	127.80	12.00	13.22	2.05	2.01
	E2	127.80	13.25	13.25	3.45	3.41
6	F1	136.80	11.50	12.18	2.05	2.01
	F2	136.80	12.80	12.80	3.51	3.09
7	G1	148.80	9.40	9.44	2.05	2.03
	G2	148.80	10.93	10.93	3.74	3.58
8	H1	163.80	3.15	3.33	2.05	2.01
	H2	163.80	5.30	5.30	4.46	3.58



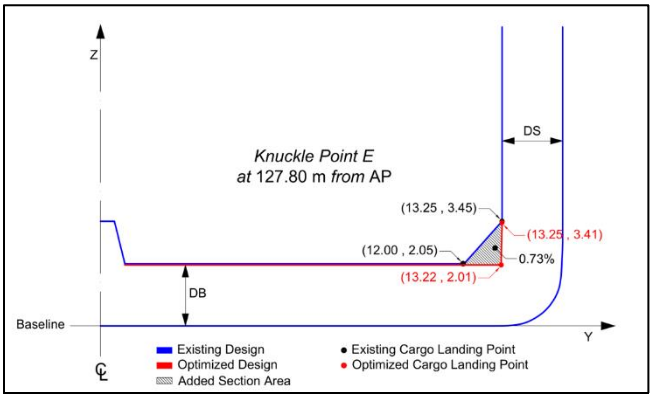
(a) (b)

Figure 11. (a) Double Bottom Optimization Result at Knuckle Point A; (b) Double Bottom Optimization Result at Knuckle Point B

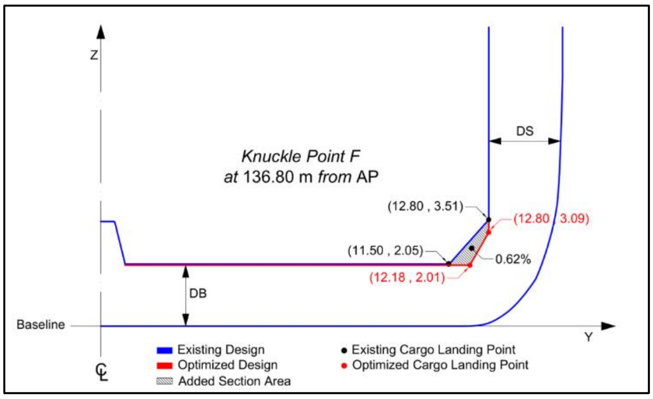


(a) (b)

Figure 12. (a) Double Bottom Optimization Result at Knuckle Point C; (b) Double Bottom Optimization Result at Knuckle Point D

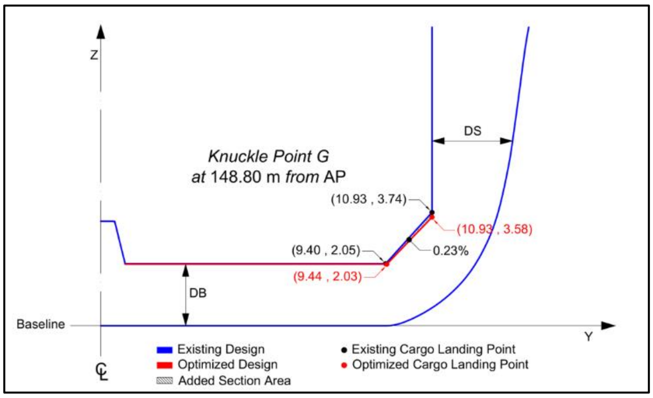


(a)

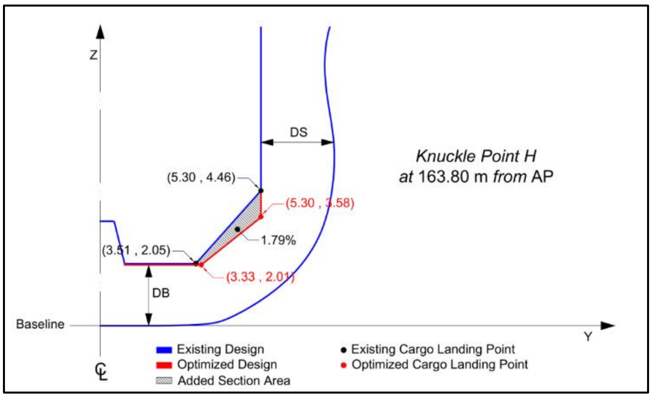


(b)

Figure 13. (a) Double Bottom Optimization Result at Knuckle Point E; (b) Double Bottom Optimization Result at Knuckle Point F



(a)



(b)

Figure 14. (a) Double Bottom Optimization Result at Knuckle Point G; (b) Double Bottom Optimization Result at Knuckle Point H

3.4. Existing and Optimized Design Comparison

The objective function of this research is to maximise the cargo oil tank volume. The analysis results indicate that the cargo oil tank volume increased by 375.996 m³, representing 0.865% benefit. Table 3 shows the extent of the increase in cargo oil tank volume in each compartment and Figure 15 illustrates the additional volume after optimization.

Table 3. Cargo Oil Tank Volume After Optimization

Tank Name	Existing Volume (m^3)	Optimized Volume (m^3)	Additional Volume (m^3)	Additional Volume (%)
No.1 COT (S)	2689.418	2704.780	15.362	0.571%
No.1 COT (P)	2690.579	2705.946	15.367	0.571%
No.2 COT (S)	3764.589	3789.580	24.991	0.664%
No.2 COT (P)	3775.420	3800.495	25.075	0.664%
No.3 COT (S)	3864.170	3893.054	28.884	0.747%
No.3 COT (P)	3866.015	3894.913	28.898	0.747%
No.4 COT (S)	3870.627	3899.510	28.883	0.746%
No.4 COT (P)	3868.782	3897.650	28.868	0.746%
No.5 COT (S)	3862.503	3891.424	28.921	0.749%
No.5 COT (P)	3866.863	3895.884	29.021	0.750%
No.6 COT (S)	2992.031	3039.749	47.718	1.595%
No.6 COT (P)	2991.681	3039.340	47.660	1.593%
Slop Cargo Tank (S)	692.026	705.265	13.239	1.913%
Slop Cargo Tank (P)	685.182	698.291	13.109	1.913%
Total	**43479.886**	**43855.881**	**375.996**	**0.865%**

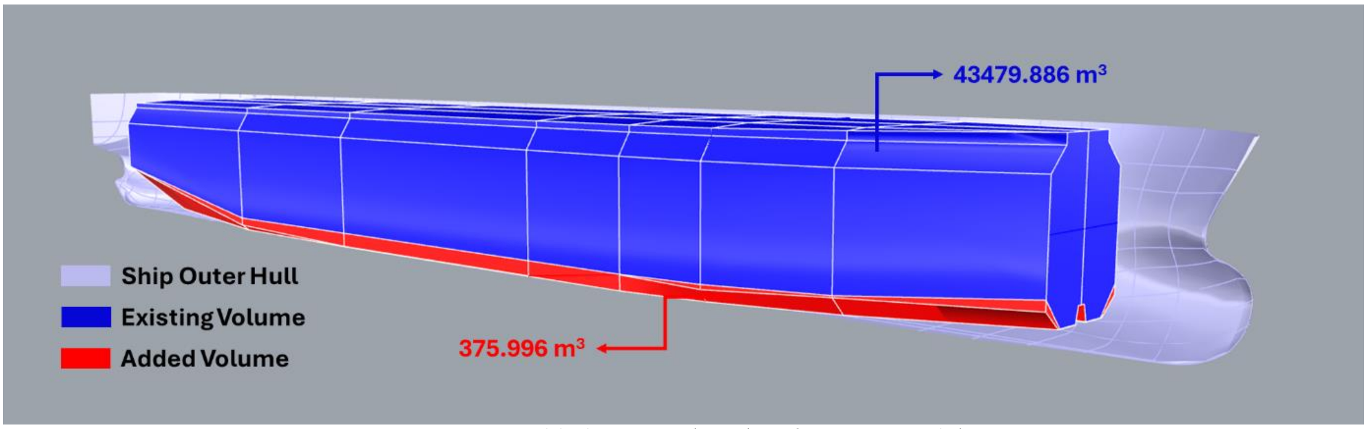


Figure 15. Added Cargo Oil Tank Volume 3D Model

3.5. Length reduction

A ship is designed and built according to the owner's requirements, so an additional cargo oil tank may not be necessary. Therefore, the optimized design of the cargo oil tank can be reduced to the required volume by reducing its dimensions. The length of the cargo oil tank and the ship's parallel middle body can be easily reduced without interrupting the streamlined shape of the ship. This reduction in length can be achieved by dividing the additional cargo volume by the optimized cargo oil tank cross-sectional area at midship. The calculation results below show that the ship's length can be reduced by 1.011 metres along the parallel middle body. The reduced part of the hull and the cargo oil tank are located at the parallel middle body between 86.500 m to 87.511 m, measured from AP, as shown in igure 16.

Length reduction = (Added volume)/(Cargo oil tank cross-sectional area at midship)

$$l = \frac{375.996 \text{ m}^3}{371.905 \text{ m}^2} = 1.011 \text{ m} \quad (8)$$

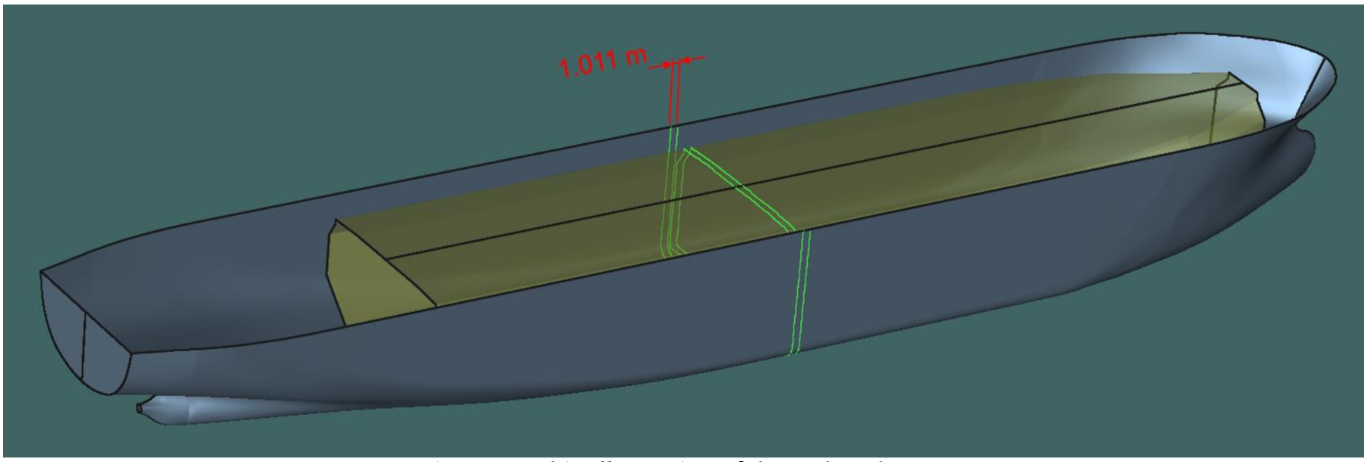


Figure 16. Ship Illustration of the Reduced Parts

3.6. Regulation Checking

Based on ICLL 1966, the minimum freeboard for a tanker with principal dimension listed in Table 1 is 4.187 m making the maximum draft 11.713 m. According to the freeboard analysis, all the 37 loading conditions both optimized, and length reduction design passed the criteria. For example, the initial draft of 9.014 m at the Full Load Departure Condition with Full Bunker increased by 0.588% to 9.067 m and further increased by 0.650% to 9.072 m after the length reduction.

According to the stability analysis, all the criteria required by IS Code 2008 are met for all loading conditions. As shown in Table 4, the additional cargo oil tank volume causes the stability criteria to have a higher value than that of the existing ship. However, the length reduction lowers the value. This is due to the change in the ship's centre of gravity and centre of buoyancy. Increasing the payload on the double bottom shifts the centre of gravity towards the bottom of the ship. Furthermore, the increase in draft due to the added mass caused the centre of buoyancy to shift upwards.

The SWBM and SWSF values for the ship also change slightly due to the additional cargo oil tank volume and length reduction, as shown in Table 5. This is because the SWBM and SWSF values are affected by changes in payload and buoyancy distribution. The payload distribution is changed due to the increased volume of cargo oil tank. Furthermore, the increase of payload leads to higher ship displacement, thereby altering the buoyancy distribution. The length reduction also alters the lightweight, payload, and buoyancy distribution along the ship.

Table 4. Intact Stability Analysis at Full Load Departure Condition with Full Bunker

Criteria	Required Value	Existing Ship	Optimized Ship	Length Reduction
Area under GZ curve between heel angles of 0 to 30 degrees shall not be less than (m.rad)	0.055	0.605	0.611	0.610
Area under GZ curve between heel angles of 0 to 40 degrees shall not be less than (m.rad)	0.090	1.087	1.133	1.131
Area under GZ curve between heel angles of 30 to 40 degrees shall not be less than (m.rad)	0.030	0.481	0.522	0.521
The righting lever GZ shall be at least 0.2 m at an angle of heel equal to or greater than (m)	0.200	2.855	3.288	3.281
The maximum righting lever shall occur at an angle of heel not less than (degrees)	25.0	39.1	42.7	42.7
The initial metacentric height GM0 shall not be less than (m)	0.150	4.325	4.345	4.340

Table 5. SWBM and SWSF Analysis at Full Load Departure Condition with Full Bunker

FR No.	Long. Pos.	Existing Ship SWSF	Optimize d-Ship SWSF	Length Reductio n SWSF	Allowable SWSF	Existing Ship SWBM	Optimize d-Ship SWBM	Length Reductio n SWBM	Allowable SWBM
55	40.8	-0.636	-0.669	-0.645	-2.377	4.106	3.079	3.623	81.658
61	58.8	-0.274	-0.265	-0.234	-2.887	-4.225	-5.411	-4.364	-67.200
68	79.8	0.252	0.266	0.301	3.326	-4.279	-5.210	-3.469	-67.200
75	100.8	0.826	0.846	0.755	3.326	7.493	6.913	9.232	111.800
82	121.8	-0.917	-0.909	-0.879	-2.887	5.753	5.452	5.916	111.800
89	142.8	-0.099	-0.089	-0.080	-2.388	-4.247	-4.334	-3.437	-17.359
96	163.8	0.289	0.293	0.181	2.377	-1.299	-1.312	-0.604	-1.711

4. Conclusion

The double bottom optimization using the brute force search method resulted in a new cargo oil tank design that increased the cargo tank volume by 375.996 m³ (0.865%) compared to the existing ship design. Although the percentage increase is relatively modest, it demonstrates that the original design still has room for improvement through systematic optimization of the double bottom design. The increased cargo tank volume provides greater flexibility in the subsequent ship design process. In this study, it enables the design of a sister ship with the same payload while reducing the cargo oil tank and the overall ship length by 1.011 m at the parallel middle body. This reduction contributes to a more compact hull form without compromising the required cargo carrying capacity. The optimization also influenced several key ship performance characteristics, including freeboard, intact stability, and longitudinal strength, due to the changes in payload and buoyancy distribution. Nevertheless, the optimized design satisfied all applicable regulatory requirements, demonstrating that the proposed optimization approach can improve cargo tank capacity while maintaining compliance with safety and classification standards. Future research should extend the optimization framework by considering the stress concentration around hopper knuckles and the practical design constraints related to cargo loading and unloading operations and shipyard manufacturability.

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References

[1] A. N. Yulianto *et al.*, "Factors in an Effort to Acquire the Efficiency of the Cargo Compartment Design on Tankers," *International Journal of Offshore and Coastal Engineeing*, vol. 8, no. 1, p. 12, May 2024, doi: 10.12962/j25800914.v8i1.20461

[2] Y. Y. Yu, Y. Lin, M. Chen, and K. Li, "A New Method for Ship Inner Shell Optimization Based on Parametric Technique," *International Journal of Naval Architecture and Ocean Engineering*, vol. 7, no. 1, pp. 142–156, 2015, doi: 10.1515/ijnaoe-2015-0011.

[3] J. H. Park, J. E. Choi, and H. H. Chun, "Hull-Form Optimization of KSUEZMAX to Enhance Resistance Performance," *International Journal of Naval Architecture and Ocean Engineering*, vol. 7, no. 1, pp. 100–114, 2015, doi: 10.1515/ijnaoe-2015-0008.

[4] H. Wang, X. Lang, and W. Mao, "Voyage optimization combining genetic algorithm and dynamic programming for fuel/emissions reduction," *Transportation Research Part D: Transport and Environment*, vol. 90, p. 102670, Jan. 2021, doi: 10.1016/j.trd.2020.102670.
[5] A. Nazemian and P. Ghadimi, "Shape optimisation of trimaran ship hull using CFD-based simulation and adjoint solver," *Ships and Offshore Structures*, vol. 17, no. 2, pp. 359–373, Feb. 2022, doi: 10.1080/17445302.2020.1827807.
[6] B. Liu, J. Jiang, and D. K. Kim, "Structural analysis and optimisation of GFRP sandwich panel with steel stiffeners in upper decks of large passenger ships," *Ships and Offshore Structures*, pp. 1–13, Mar. 2025, doi: 10.1080/17445302.2025.2478367.
[7] N. Bahrami and S. M. Siadatmousavi, "Ship voyage optimisation considering environmental forces using the iterative Dijkstra's algorithm," *Ships and Offshore Structures*, vol. 19, no. 8, pp. 1173–1180, 2024, doi: 10.1080/17445302.2023.2231200.
[8] Y. Wei, H. Zhang, D. Jiang, Y. Zhang, and S. Xiao, "Optimising ship principal dimensions with a Dung Beetle Optimizer and random forest proxy model," *Ships and Offshore Structures*, vol. 20, no. 11, pp. 1789–1800, Nov. 2025, doi: 10.1080/17445302.2024.2397928.
[9] A. M. H. Elhewy, A. M. A. Hassan, and M. A. Ibrahim, "Weight Optimization of Offshore Supply Vessel Based on Structural Analysis Using Finite Element Method," *Alexandria Engineering Journal*, vol. 55, no. 2, pp. 1005–1015, 2016. doi: 10.1016/j.aej.2016.02.032.
[10] J. W. Yu, C. M. Lee, I. Lee, and J. E. Choi, "Bow Hull-Form Optimization in Waves of a 66,000 DWT Bulk Carrier," *International Journal of Naval Architecture and Ocean Engineering*, vol. 9, no. 5, pp. 499–508, 2017, doi: 10.1016/j.ijnaoe.2017.01.006.
[11] M. Sayebani, A. Mohammadrahimi, and H. K. Looyeh, "Weight and Cost Optimization of Midship Section Using Common Structural Rules," *Journal of Ship Production and Design*, vol. 36, no. 3, 2020. doi: 10.5957/JSPD.01190002
[12] M. Aguiari, M. Gaiotti, and C. M. Rizzo, "Ship Weight Reduction by Parametric Design of Hull Scantling," *Ocean Engineering*, vol. 263, no. August, p. 112370, 2022, doi: 10.1016/j.oceaneng.2022.112370.
[13] Y. Wei, G. Pan, P. Paladaechanan, and D. Wan, "A novel hull form optimization framework based on multi-fidelity deep neural network," *Journal of Hydrodynamics*, vol. 37, no. 1, pp. 149–159, Feb. 2025, doi: 10.1007/s42241-025-0007-4.
[14] N. Demo, G. Ortali, G. Gustin, G. Rozza, and G. Lavini, "An efficient computational framework for naval shape design and optimization problems by means of data-driven reduced order modeling techniques," *Bollettino dell'Unione Matematica Italiana*, vol. 14, no. 1, pp. 211–230, Mar. 2021, doi: 10.1007/s40574-020-00263-4.
[15] B.-J. Zhang and Z.-X. Zhang, "Research on theoretical optimization and experimental verification of minimum resistance hull form based on Rankine source method," *International Journal of Naval Architecture and Ocean Engineering*, vol. 7, no. 5, pp. 785–794, Sep. 2015, doi: 10.1515/ijnaoe-2015-0055.
[16] C. Jiang, S. Yang, P. Nie, and X. Xiang, "Multi-objective structural profile optimization of ships based on improved Artificial Bee Colony Algorithm and structural component library," *Ocean Engineering*, vol. 283, p. 115124, Sep. 2023, doi: 10.1016/j.oceaneng.2023.115124.
[17] A. N. Yulianto, "Research on The Methodology of Hull Weight Reduction Considering The Variations of Compartment Arrangement and Ship Length for Small Coastal Tanker," Mokpo National University, 2023.
[18] A. N. Yulianto, R. R. Winarko, S. L. A. Pasaribu, R. F. Ahmad, B. A. Adietya, and H. Hasanudin, "Optimization of Inner Bilge Design to Enhance Cargo Tank Capacity in Tankers," *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*, vol. 23, no. 1, pp. 48–62, Apr. 2026, doi: 10.14710/kapal.v23i1.82683.
[19] United Nations Conference on Trade and Development, Review of Maritime Transport 2025: staying the course in turbulent waters. United Nations, 2026.
[20] H. A. Kurniawati, Statutory Regulations. Surabaya: Departemen Teknik Perkapalan Fakultas Teknologi Kelautan ITS, 2020.
[21] IMO, International Convention for the Prevention of Pollution from Ships (MARPOL). London, 1973.
[22] IACS, Common Structural Rules for Bulk Carriers and Oil Tankers. London, 2023.
[23] M. Mahoor, F. R. Salmasi, and T. A. Najafabadi, "A Hierarchical Smart Street Lighting System With Brute-Force Energy Optimization," *IEEE Sensor Journal*, vol. 17, no. 9, pp. 2871–2879, May 2017, doi: 10.1109/JSEN.2017.2684240.
[24] Z. Xing, Z. Zhang, J. Guo, Y. Qin, and L. Jia, "Rail train operation energy-saving optimization based on improved brute-force search," *Applied Energy*, vol. 330, p. 120345, Jan. 2023, doi: 10.1016/j.apenergy.2022.120345.
[25] J. J. Cartelle Barros, M. Lara Coira, M. P. de la Cruz López, A. del Caño Gochi, and I. Soares, "Optimisation Techniques for Managing the Project Sustainability Objective: Application to a Shell and Tube Heat Exchanger," *Sustainability*, vol. 12, no. 11, p. 4480, Jun. 2020, doi: 10.3390/su12114480.
[26] Hasanudin, A. Dwi Saputra, and A. Nugroho Yulianto, "A Study on Stability and Passenger Capacity of Traditional River and Lake Boats," *BIO Web of Conferences*, vol. 157, p. 03005, Feb. 2025, doi: 10.1051/bioconf/202515703005.
[27] K. J. Rawson and E. C. Tupper, Basic Ship Theory, 5th ed. Oxford: Butterworth-Heinemann, 2001.
[28] IMO, Intact Stability (IS) Code 2008. London, 2008.