International Journal of Offshore and Coastal Engineering
Vol.8 | No. 1 | pp. 12 – 16 | May 2024
e-ISSN: 2580-0914

Submitted: January 16, 2024 | Revised: March 21, 2024 | Accepted: April 25, 2024

Factors in an Effort to Acquire the Efficiency of the Cargo Compartment Design on Tankers

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ABSTRACT

Tankers are one of the popular modes of transportation associated with liquid cargo. Efficiency with respect to the volume of cargo transported by tankers is an essential consideration in the transportation business process, especially fuel oil, which has become a benchmark for the global economy recently. Various studies have been carried out to optimize cargo space. This study aims to define the factors that influence cargo compartment efficiency to increase the effectiveness in the transportation business. In this study, it is known that the transverse bulkhead arrangement affects the payload capacity, which is related to the criteria in the naval architect principle. The hopper design also influences the optimization of cargo volume, which can provide benefits in terms of payload. Excess cargo volume on existing ships due to hopper design optimization, the future ship design can reduce the length of the cargo compartments that still meet the desired payload. Reducing the length of the cargo hold will undoubtedly provide an opportunity to optimize the scantling analysis for longitudinal and transverse ship structures. This study is expected to be a reference and a more detailed discussion regarding the efficiency of cargo space on tankers in the future.

Keywords: *Tankers, Cargo Compartment, Efficiency*.

1. INTRODUCTION

The sea transportation business is an attractive business model, especially in Indonesian waters. It is very commonly known that Indonesia is one of the maritime countries consisting of thousands of islands. The unique geographical condition certainly requires consideration in choosing the most appropriate mode of transportation so that transportation business costs can be minimized with the maximum quantity of cargo. In the process of delivering cargo, especially petroleum commodities, tankers are a mode of transportation widely used worldwide in the oil transportation process. Tankers are a solution that is able to answer various requirements in the oil transportation business by being able to select the capacity of the cargo space when carrying out the design process for a new tanker. Based on the type of tanker according to its capacity, it can be divided into Coastal Tanker (DWT < 50,000), Aframax (around 80,000 DWT), Suezmax (125,000 < DWT < 180,000), Very Large Crude Carrier (around 320,000 DWT) and Ultra Large Crude Carrier (around 320,000 DWT).

In the tanker design process, a naval architect needs to consider cargo space, which is an essential consideration for prospective ship owners in the transportation business in the future. The efficient cargo arrangement design on tankers will positively impact business processes and provide significant advantages to prospective owners when considering tanker design options. Efficient cargo space design in terms of capacity should comply with existing regulations such as MARPOL, Class Society, etc. The design of the cargo space will also influence the ship's dimensions, which may provide the opportunity to get dimensions that are shorter than the existing ship design. In cargo compartment design, two important considerations must be considered carefully. Adequate cargo space and structural member configurations, both longitudinal and transverse members, will have a significant effect on the ship production process in the shipyard industry. Material requirements resulting from cargo design arrangement will provide losses or profits if seen from the ship weight and will influence people's hours which has an impact on production costs.

In general, this research will discuss what factors influence the design of cargo compartments on tankers. In the next chapter, we will discuss the literature study, which includes regulations relating to compartment arrangements and research carried out. Next, we will discuss the relationship between cargo space and ship structure due to design changes that may be made that still comply with applicable regulations.

2. LITERATURE STUDY

2.1 Regulations Related to Compartment Arrangement

In the ship design process, especially the cargo compartment, it must comply with existing regulations. Several requirements must be met so that the compartment design is efficient and safe during ship operation. There are several rules and regulations of the arrangement of the compartments. It is conducted to ensure that the compartment design complies with existing regulations. The MARPOL 73/78 Chapter 4 Part A Regulation 19 discusses the regulations in the design process for double hulls and double bottoms. In this regulation, it should be applied to oil tankers of more than 600 DWT. For tankers above 5,000 DWT, the specifics can be explained as follows:

$$w = 0.5 + \frac{DW}{20.000}(m)\ or w = 2\ m, whichever\ is\ the\ lesser \quad (1)$$

$$h = \frac{B}{15}(m)\ or\ h = 2\ m, whichever\ is\ the\ lesser \quad (2)$$

The minimum value of wing space (w) and double bottom space is 1 meter. DW and B are defined as deadweight (tons) and breadth (m), respectively. The bilge part can be explained in detail according to Fig. 1.

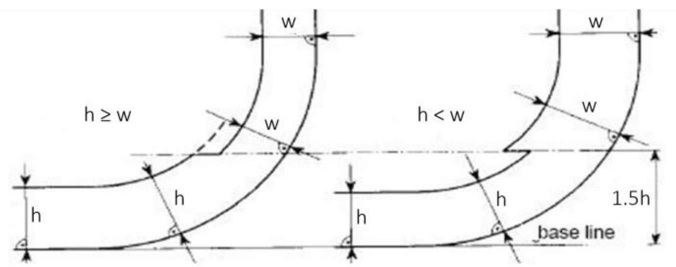

Figure 1: Cargo Tank Boundary Lines (DWT ≥ 5,000)

For tankers with a capacity of less than 5,000 dwt, it can be explained as follows:

$$w = 0.4 + \frac{DW}{20.000}(m)\ or\ minimum\ value\ of\ w = 0.76\ m \quad (3)$$

$$h = B/15\ (m)\ or\ minimum\ value\ of\ h = 0.76\ m \quad (4)$$

In the bilge area and in locations where the bilge does not turn, the cargo tank boundary line should be parallel to the flat bottom line amidships, as shown in Fig. 2

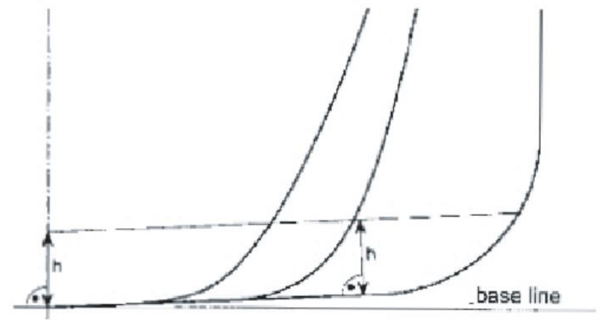

Figure 2: Cargo Tank Boundary Lines (DWT < 5,000)

Other regulations governing cargo compartments and several other regulations from class society relating to cargo compartments can be listed as follows:

- KR Class Part 10, Chapter 7 (Double Bottom) and Chapter 24 (Double Hull Tankers)
- MARPOL 73/78 Chapter 4 Part A, Regulation 23 (Accidental outflow performance)
- MARPOL 73/78 Chapter 4 Part A, Regulation 29 (Slop Tanks)
- KR Class Part 10, Hull Structure and Equipment of Small Steel Ships
- Intact Stability Code (IS Code)
- Unified Requirements, UR S1 Requirements for Loading Conditions, Loading Manuals and Loading Instruments

Fig. 3 illustrates the design of a double hull and double bottom with a bilge area.

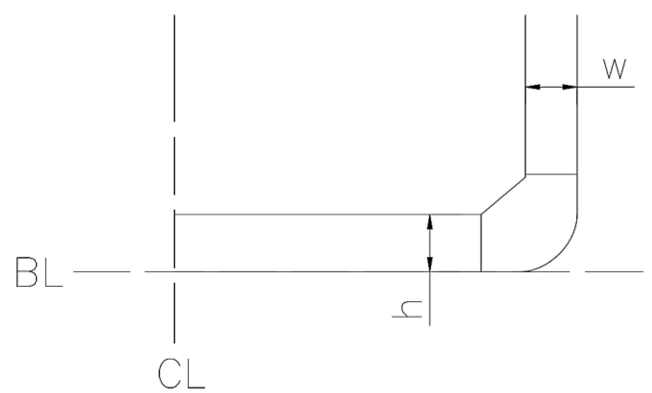

Figure 3: Illustration of Double Hull and Double Bottom Design

2.2 Previous Research Related to Cargo Compartment Design

The design of the cargo compartment is a crucial aspect of ship design. In the case of tankers, the ship's length significantly influences the choice of regulations. For oil tankers exceeding 150 meters in length, the procedure of ship design compartment is based on the CSR-OT (Common Structural Rule for Oil Tankers) as outlined in the Common Structural Rules for Bulk Carriers and Oil Tankers, 2022, by the International Association of Classification Societies (IACS). In the other case, ships with a length of less than 150 meters are subject to regulations set by classification societies. The KR class regulates tankers with a length of less than 90 m (KR, Part 10: Hull Structure and Equipment of Small Steel Ships, 2021) and ships with a length of 90 m but less than 150 m (KR, Part 3: Hull Structures, 2022).

Several previous studies were carried out in an effort to optimize various factors to make compartment design efficient, both in terms of cargo space and structure member effects. In 1985, the finite element method was utilized to reduce the weight of the transverse strength member. However, the method has weaknesses in terms of processing time and costs because the iteration process is long and requires hardware and software components that are not cheap [1]. A method was developed for optimizing the structural design of the double-hull tanker, which involved creating a multi-objective function based on Pareto optimal points. This approach aimed to streamline the quest for the best solutions across the entire design spectrum [2] [3]. The implementation of composite materials as a cost and weight-reduction option for ships aligns with DNV regulations. Research findings indicate that utilizing alternative materials, such as carbon fiber, results in a weight reduction of 20% to 30% compared to glass fiber. It is essential to acknowledge that carbon fiber is associated with a higher cost. Additionally, the adoption of sandwich materials offers lighter-weight advantages over single-skin panels. Nevertheless, when using sandwich materials, it is imperative to carefully consider compliance with critical design parameters as per the relevant regulations [4].

Efforts to minimize the weight of oil tankers and bulk carriers involve the creation of algorithms aimed at automatically arranging compartments. However, this particular study has a limitation, as it is only applicable to ships that share similar dimensions and structures. Subsequently, an algorithm was devised to establish a connection between the automated compartmentalization control algorithms used in bulk carriers and the structural design of the hull [5] [6]. An optimization system for configuring the compartments of an oil tanker was developed to achieve design outcomes that aim to lower the expenses associated with ship production [7]. In the other research, an algorithm for design automation of longitudinal strength members that can be interlocked with automation of compartment arrangement of an oil tanker was performed. This algorithm is designed to identify reinforcement shapes that can effectively reduce weight by analyzing the specific characteristics of these reinforcements on an oil tanker. Furthermore, a dimensioning algorithm for longitudinal strength members was developed, grounded in this analysis [8].

The creation of an Automated Compartment Arrangement System was undertaken to reduce the weight of ship structures in accordance with CSR-H guidelines. This research has the capability to achieve weight reduction through the reduction of still water bending moment [9]. The study primarily focuses on tankers of 318,000 DWT (Very Large Crude Carriers, VLCC) and bulk carriers of the Supramax class with 63,000 DWT. The ship's length determines compliance with the Common Structural Rules (CSR). The research findings indicate an increase in cargo capacity by approximately 4%, enabling a reduction in ship length by about 3.26 meters. For the 318,000 DWT VLCC Tanker, a decrease in the cross-sectional area of the longitudinal component was noted at approximately 0.8%. At the same time, in the case of the 63,000 DWT Supramax Bulk Carrier, it was around 1.9% [9].

In an effort to reduce the weight of the ship, new ultra-high strength materials were applied to address the weight reduction problem. Specifically, the integration of high-strength materials has been employed as a method to reduce the ship's weight. This study was conducted with a focus on 158,000 Suezmax tankers. The application of high-strength materials has demonstrated a remarkable potential for weight reduction, achieving nearly a 30% reduction compared to previous ship structures. Moreover, this investigation extended to ships with a 12-foot length that incorporated the use of titanium materials, leading to a substantial weight reduction of approximately 67% compared to conventional ships. In the case of ships measuring 32 feet in length, the ship's weight savings can reach as high as 64% when compared to the existing ship. The incorporation of titanium material has proven to yield a significant impact, as its material properties offer approximately 2-3 times the yield strength compared to the previously used materials, contributing to the outstanding results achieved [10].

Research on the methodology of hull weight reduction considering the variations of compartment arrangement and ship length was carried out to determine the factors related to the design of a coastal tanker ship. In this research, it was possible to obtain an increase in cargo space volume of 1.98% from existing conditions. In the structural optimization design, the reduction in the cross-section area of the midship structure shows a reduction of around 13.5% when compared to the existing ship. However, this research has not considered transverse members, which will undoubtedly provide more benefits in the future [11].

3. DISCUSSION

3.1 Cargo Space Determination

The design stage for the cargo boundary line can be illustrated in Fig. 4.

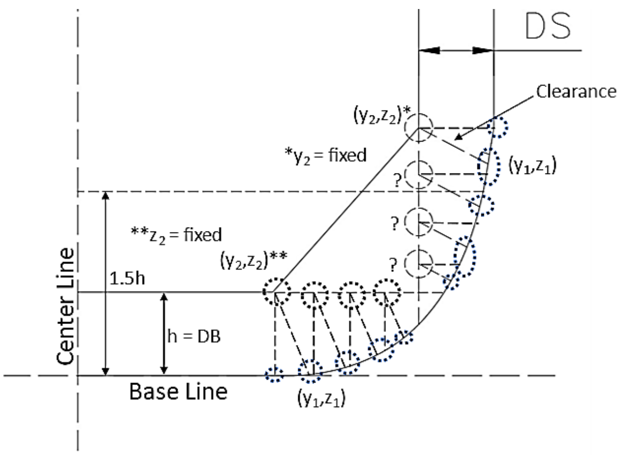

Figure 4: Illustration of Cargo Tank of Boundary Line

Initial double skin (DS) and double bottom (DB) should be predefined as initial points. In the next stage, the landing point coordinates (y, z) can be determined and can be defined for the hopper angle. By varying the landing point, variations in the volume of the cargo space will be defined. Furthermore, the double skin and double bottom, including the landing point, are varied in such a way as to obtain many variations in the volume of the cargo compartment that should comply with clearance and regulations in MARPOL.

Fig. 5 illustrates the cargo tank of the boundary line in the longitudinal direction. The landing point in the hopper area plays an important role in optimizing cargo space on tankers. Determining landing points took many iterations, so meeting the specified requirements takes a lot of time.

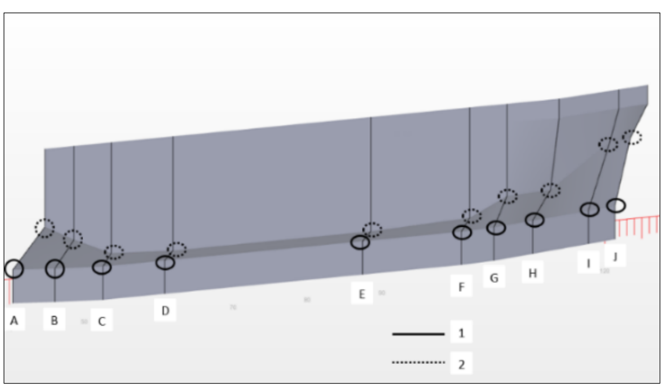

Figure 5: Illustration of Cargo Tank of Boundary Line (Longitudinal)

3.2 Structure Member Calculation

Fig. 6 shows the hull structure optimization algorithm adapted to the KR class rule.

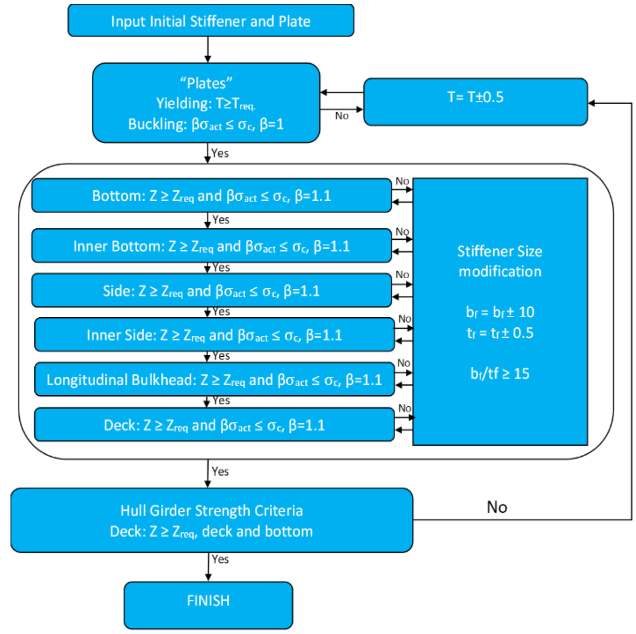

Figure 6: General Algorithm of Hull Structure Calculation

Plates are required to maintain a specific thickness to prevent yielding. In terms of buckling criteria, a safety factor denoted as β with a value of 1 is applied to both panels and web panels. When it comes to stiffeners, the modulus should comply with the minimum required value. For stiffener buckling criteria, a safety factor (β) of 1.1 is employed. The ratio between the breadth and thickness of the flange must be greater than 15. In the calculation of hull girder strength, it is necessary to ensure that the modulus for the deck and bottom meets the specified requirements.

In general, the calculation process starts with selecting the plate and stiffener as initials. Then, calculation and verification are conducted on the ratio and minimum value requirements, which are regulated by the class rule. In the end, recommendations are given for the appropriate plate and stiffener specifications that meet the criteria.

4. CONCLUSION

Previous studies regarding regulations and recent research have been carried out on cargo compartment arrangements on tanker ships. It can be informed and concluded that cargo boundary line arrangements have an essential influence related to cargo space volume. For structural design, the configuration of the profile size and arrangement in the bottom, sides, and deck has a positive effect by reducing the weight of the material, which will provide benefits to production costs. In the future, more detailed research regarding various types and sizes of tankers will be carried out more comprehensively in order to obtain various variations of cargo compartments.

ACKNOWLEDGEMENTS

The authors thank the Ship Design Laboratory, Department of Naval Architecture, Sepuluh Nopember Institute of Technology (ITS), for supporting this research study.

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