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Design and Strength Analysis of an Amphibious Multipurpose Dredger for the Eastern Surabaya Shipping Lane and the Porong River in Sidoarjo

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***Abstract*— This study investigates the problem of sedimentation in the Porong River and the Eastern Surabaya Shipping Lane by taking a close look at the Amphibious Multipurpose Dredger. The study examines the vessel's parameters (length: 14.30 m, breadth: 4.70 m, height: 1.60 m, draft: 1.10 m) in light of the requirements of coastal reclamation. For stability and pressure studies, manual calculations and Finite Element Method simulations are utilised. The results show that the hollow Spud design is superior to the alternatives in terms of material efficiency (Safety Factor: 12.4032). The research makes a substantial contribution by offering an effective way to address sedimentation issues through improved dredger design. Moreover, it emphasizes the crucial part that an adaptable amphibious multipurpose dredger plays in reducing sedimentation. The study highlights the strategic significance of the recommended spud design, satisfying safety regulations and improving operational efficiency, as coastal ecosystems face rising challenges. For practitioners in environmental and maritime engineering looking for sustainable approaches to the development of coastal infrastructure, this paper is an invaluable resource.**

Keywords—Amphibious, Dredger, Sedimentation, Vessel Design, Spud Strength

I. Introduction

Due to ongoing sedimentation problems in key waterways like the Porong River and the Eastern Surabaya Shipping Lane, Indonesia's vast maritime infrastructure [1]—which is essential to the country's economic activity and trade [2]—affects both the safety of navigation [3] and the movement of goods [4]. The Amphibious Multipurpose Dredger presents a revolutionary answer to these problems by improving navigational efficiency [5] and revolutionizing silt removal [6] thanks to its unique ability to operate on land and water [7]. A detailed investigation of the design elements [8] and spud strength [9] of this unique watercraft is necessary given the economic importance of these waterways [10].

The Amphibious Multipurpose Dredger is a relatively unexplored market [11] despite extensive study in dredging technology, with most prior studies concentrating on traditional dredging vessels [12]. Though they add to our knowledge of these traditional boats, the complex dynamics of a boat changing from land to water require specific consideration [13]. By focusing on spud strength analysis and proposing parametric design variations [14] for the most appropriate design concept, our research aims to close this gap [15]. By doing this, it hopes to advance our knowledge of the particular difficulties presented by the amphibious multipurpose dredger [16] and offer insightful contributions to the domains of maritime engineering and vessel design [17].

The results of the study have the potential to impact maritime engineering techniques worldwide [18], going beyond only resolving sedimentation issues in the Porong River and the Eastern Surabaya Shipping Lane. This study not only establishes a standard for creating inventive boats with broader applications [19], but it also emphasizes how crucial it is to pay particular attention to boats that move between land and sea in the changing context of developing maritime infrastructure [20].

II. Method

The design process of the Amphibious Multipurpose Dredger vessel employs both quantitative and qualitative methods, with the outcomes presented in the form of drawings, figures, or numerical data. This phase addresses the key issues to be explored in this research, specifically focusing on how to devise a vessel that aligns with operational requirements in the Eastern Surabaya Shipping Lane, accompanied by meticulous calculations regarding the weight and stability of the Amphibious Multipurpose Dredger vessel. The goal is to derive a well-suited vessel design that can serve as a practical reference for actual vessel construction. Data is meticulously collected from various sources through direct and indirect means, involving observation of diverse information sources. This collected data serves as a foundation for problem formulation and design, commencing with the selection of a comparable vessel, formulation of a preliminary design, overall planning, weight calculation, and stability testing of the vessel to ensure compliance with the standards outlined in IMO A.749 Chapter 3 for the Amphibious Multipurpose Dredger vessel [21].

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The design process of the Amphibious Multipurpose Dredger vessel involves the utilization of Maxsurf software, a tool that yields the hull shape of the vessel in accordance with its primary data [22]. In determining the engine power for the Amphibious Multipurpose Dredger vessel, the Hullspeed software comes into play, aiding in identifying the necessary power to attain the specified speed based on the vessel's hull design [23]. Given that this vessel is dedicated to dredging sediments in the Eastern Surabaya Shipping Lane, a speed of 6 knots is selected for optimal performance [24].

For the Linesplan design of the vessel, careful consideration is given to the spacing between sections, Buttock Line, and Water Line. Additionally, a General Arrangement plan is developed. The vessel is specifically engineered for the effective dredging of sediments in the Eastern Surabaya Shipping Lane, ensuring optimal stability. Its unique feature lies in its ability to seamlessly transition between land and water, facilitated by the deployment of four spuds. The weight calculation for the vessel encompasses the total displacement derived from the calculations of LWT (Lightweight Tonnage) and DWT (Deadweight Tonnage). The stability analysis is systematically conducted using specialized software, aligning with the regulations outlined by the International Maritime Organization (IMO) in Chapter 3 of regulation 749 [21].

Data for this research were meticulously gathered from a combination of primary and secondary sources. Primary data was acquired through direct measurements and observations conducted during the vessel design and spud strength analysis processes. Concurrently, secondary data sources, such as literature reviews, maritime engineering databases, and pertinent previous research publications, were extensively explored. This comprehensive approach ensured the collection of detailed and varied information encompassing vessel design parameters, materials, spud strength components, and environmental factors.

The primary dimensions of the vessel were determined using a linear regression approach, employing the least squares quadratic regression method. This statistical method played a crucial role in defining key vessel parameters such as length, breadth, height, draft, speed, and block coefficient. The utilization of this approach ensured the accurate calculation of the vessel's design attributes, providing a data-driven foundation for well-informed decisions regarding the Amphibious Multipurpose Dredger.

The collection of primary data encompassed direct measurements and instrumentation conducted during both the design and analysis phases. Parameters such as length (L), breadth (B), height (H), draft (T), speed, and block coefficient (Cb) were precisely measured in the vessel design phase. Additionally, spud strength data was acquired through instrumented testing involving various design concepts. To supplement this primary data, secondary data was obtained through a comprehensive review of scholarly articles, books, and official maritime documents. This dual-sourced data approach ensured a robust foundation for the subsequent analysis and conclusions.

The data analysis process involved employing data retrieval techniques, which included selecting representative samples from the gathered data. For determining the vessel's primary dimensions (length, breadth, etc.), a linear regression approach utilizing the least squares quadratic regression method was applied. This statistical method proved instrumental in accurately establishing the main vessel parameters. In the case of spud strength analysis, Finite Element Method (FEM) software played a crucial role in analyzing and comparing different spud design concepts. Furthermore, a research framework was developed, incorporating a flowchart that outlined the sequential steps in the research process. This framework served as a guide throughout the research, from initial data collection to the final determination of the preferred spud design concept based on safety [3] and material efficiency.

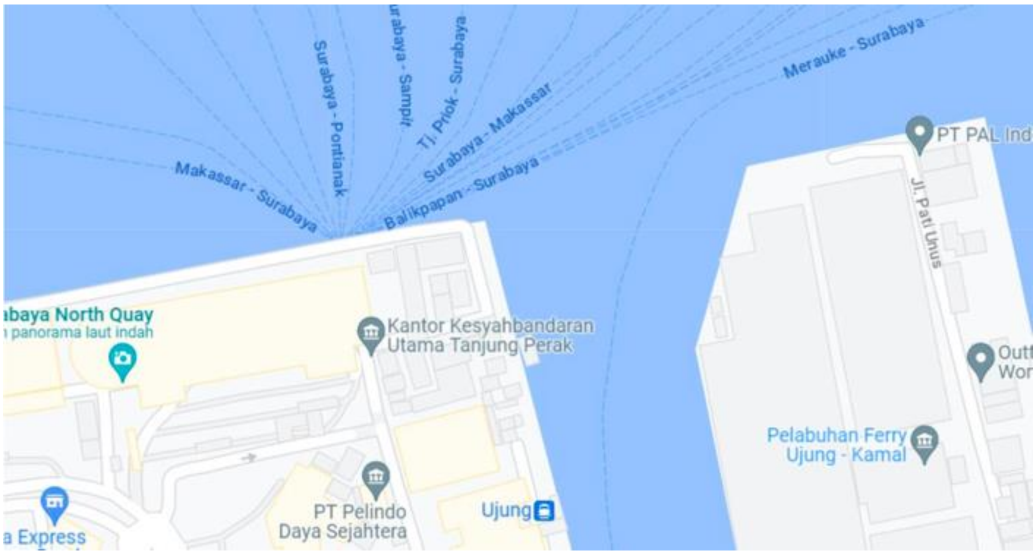

Figure 1. Dredging Zone in Tanjung Perak Port

TABLE 1.
VESSEL MAIN DIMENSION VALIDATION

Parameter	Standard	Result	Remark
L/T	10<L/T>30	13.00	Pass
B/T	1.8<B/T>5	4.27	Pass
L/H	4<L/H>10	8.93	Pass
H	H>L/16	1.60	Pass

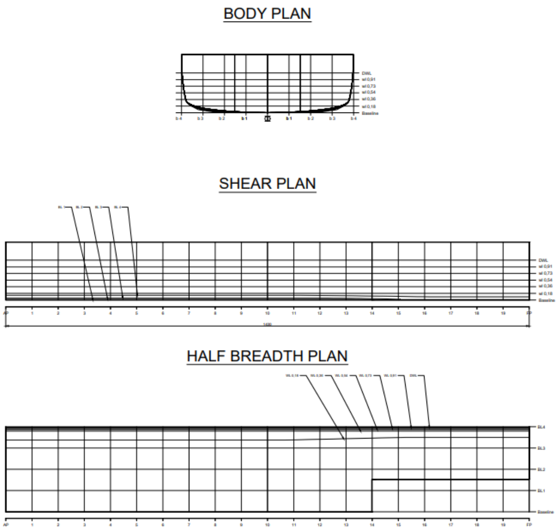

Figure. 2. Lines Plan

III. RESULTS AND DISCUSSION

The selected Amphibious Dredger is a specialized Cutter Suction Dredger designed for areas prone to sedimentation, such as mud and sand. The planning process for this Amphibious Cutter Suction Dredger initiates with data collection on a comparable vessel, determination of its primary dimensions, and the creation of a Linesplan model facilitated by Maxsurf Modeller software. Subsequently, a General Arrangement or a comprehensive plan drawing of the vessel is generated. The subsequent step involves calculating the weight of the empty vessel using steel material. This entails determining the weight of each section, with the goal of achieving the weight and center of gravity of the vessel that closely approximates the actual values post-construction.

Once the weight and center of gravity calculations are finalized, the analysis shifts to assessing the vessel's speed utilizing Maxsurf Resistance software. Further, stability analysis is conducted under diverse conditions, employing Maxsurf Stability software to ensure compliance with regulations outlined in IMO A. 749 Chapter 3 [21].

In its operational role, the Amphibious Cutter Suction Dredger is assigned the task of dredging at the Tanjung Perak Port in Surabaya, specifically in the Eastern Surabaya Shipping Lane area. To execute efficient dredging operations, the vessel must be designed not only from a technical perspective but also with meticulously planned scenarios to ensure seamless operations. The subsequent section delineates the scenarios during dredging operations until reaching the dumping area. Two dredging zones exist along the navigational route of Tanjung Perak Port in Surabaya, extending from the estuary of the Kalimas River to the entrance of the Jamrud Terminal Port, as illustrated in Figure 1.

To determine the vessel's main dimensions, linear regression with the least squares quadratic regression method is employed. Least squares quadratic regression is a regression where the sum of the squares of the vertical distances of each data point from the regression curve is minimized. In this regression, the displacement weight of 40 tons is used as a locking variable or variable X, and L (length), B (breadth), T (draft), and H (height) are used as Y variables or independent variables to obtain values for L (length), B (breadth), T (draft), and H (height).

The linear curve generated by the distribution of the linear regression data results in Loa with an R^2 value of 0.9742, B with an R^2 value of 0.905, H with an R^2 value of 0.7352, and T with an R^2 value of 0.709. The minimum standard set at the beginning is 0.6. From the linear regression performed, the results are as follows.

$$Loa = 0.4616x + 1.4031 \quad (1)$$
$$B = 0.1489x + 0.5862 \quad (2)$$
$$H = 0.0416x + 0.4739 \quad (3)$$
$$T = 0.0397x + 0.0064 \quad (4)$$

Where:
Loa = Length over all (m)
B = Breadth (m)
H = Depth (m)
T = Draft (m)
x = The initially set number of passengers, which is 6 people

The main dimensions of the vessel obtained are as follows:
L = 14.3 m
B = 4.7 m
H = 1.6 m
T = 1.1 m

The obtained main dimensions are validated for the Amphibious Multipurpose Dredger vessel according to the Rules Principles of Naval Architecture Volume I, as shown in the Table 1.

The design of the Amphibious Multipurpose Dredger vessel is conducted using Maxsurf software, which allows us to obtain the vessel's hull shape that aligns with the primary data of the vessel. In determining the engine power to be used in the Amphibious Multipurpose Dredger vessel, Hullspeed software is utilized. This software provides the required power to achieve the desired speed in accordance with the hull design. Since the Amphibious Multipurpose Dredger vessel is intended for sediment dredging in the Eastern Surabaya Shipping Lane, a speed of 6 knots is selected.

In the design of a Linesplan for the Amphibious Multipurpose Dredger vessel, the spacing between sections, Buttock Line, and Water Line must be carefully planned. Figure 2 shows the Linesplan for the Amphibious Multipurpose Dredger vessel.

This vessel is designed to efficiently dredge sediments in the Eastern Surabaya Shipping Lane while maintaining good stability. It is also capable of transitioning between land and water, utilizing four spuds for this purpose. The design showcased in Figure 3 is an adapted version of a Cutter Suction Dredger from previous studies, customized to fulfill specific needs. It integrates Spuds as the pivotal axis for the vessel dredger during operations or sediment suction, also doubling as anchors or moorings when the vessel is above water. The General Arrangement depicted in Figure 3 outlines the placement of four spuds, two on each side (left and right) at the vessel's front and rear. These four spuds are strategically positioned to facilitate the vessel's transition between land and water, aiding in its movement from one environment to the other.

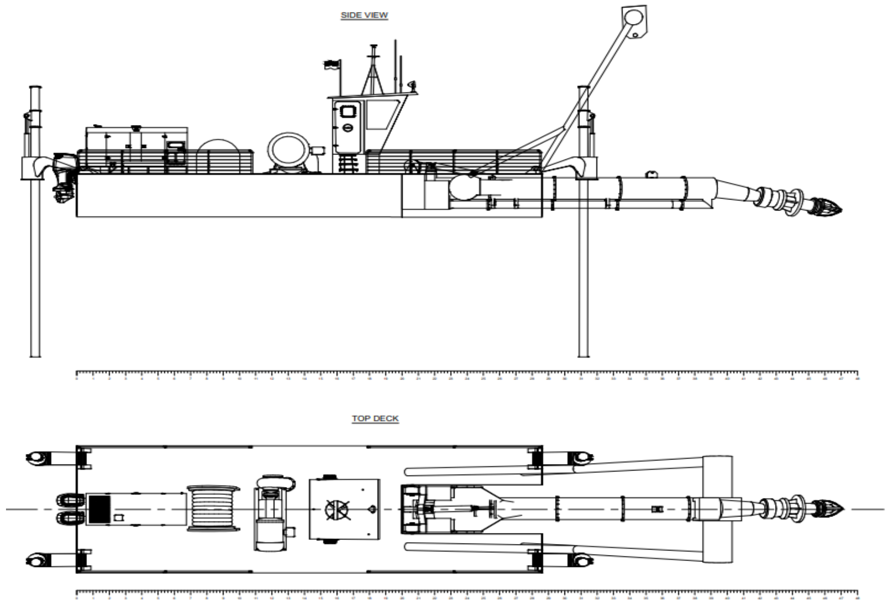

Figure. 3. General Arrangement

TABLE 2.
PIPE SCHEDULE FOR SPUD

ASME B36.10 Carbon Steel Schedule 40 Pipes	
Density	0.00000785 kg/mm^3
Young's Modulus	210,000 Mpa
Yield Tensile Strength	240 N/mm^2
Ultimate Tensile Strength	415 N/mm^2

The Spud on the Amphibious Cutter Suction Dredger vessel utilizes pipes, specifically designated as Schedule 40 pipes or ASME B36.10 Carbon Steel Pipes for Pressure Sch 40. The term "Sch" or "Schedule" in the context of piping refers to the indication of the pipe's thickness or serves as a parameter for determining the wall thickness of the pipe. Sch 40 iron pipes are recognized as an optimal type, possessing an appropriate thickness suitable for various construction pipeline applications, ranging from ship construction to other structural projects. The subsequent section provides the dimensions for ASME B36.10 Carbon Steel Schedule 40 Pipes, While the size data for the spud used on the Amphibious Cutter Suction Dredger vessel can be observed in the following Table 2 and Table 3.

The design of the Spud structure for the Amphibious Multipurpose Dredger vessel involves the application of support points or fixed supports to address the loads affecting the structure. This includes the specification of the direction or force load that will undergo analysis using Ansys software. The following Figure 4 is the application of support points or fixed supports for the loading that occurs on the structure of the Spud of the Amphibious Multipurpose Dredger vessel. This involves specifying the direction or force load that will be analyzed using Ansys software.

Simultaneously, the Spud structure design aims to determine its weight and assess the maximum load it can bear. This evaluation is achieved through the application of an equation to calculate the maximum load, providing insights into the structural integrity.

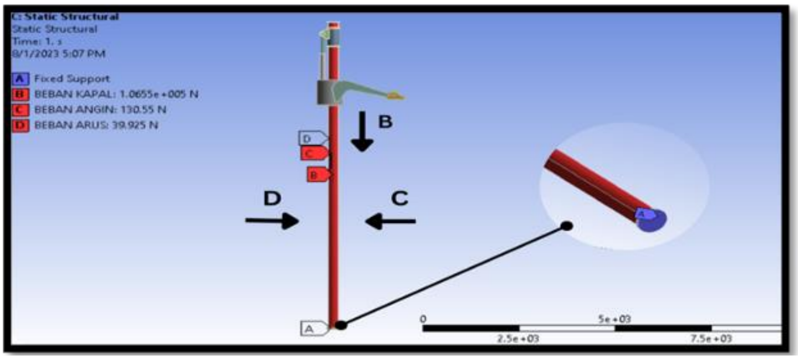

Figure 4. The direction of the load and fixed support applied to the Spud

Furthermore, the calculation extends to determining the maximum bending moment on the Spud, focusing on the Cantilever profile. The corresponding formula for the maximum bending moment (M_max) guides this calculation, contributing to a comprehensive understanding of the structural performance.

To ensure the Spud's structural adequacy, the required cross-sectional modulus for the profile is computed using a specific equation. This calculation lays the foundation for assessing the actual cross-sectional modulus for the Spud, considering its hollow cylindrical profile with steel material ASME B36.10, as outlined in the provided specifications. The Spud, designed as a hollow cylindrical pipe, undergoes a moment of inertia calculation based on the cross-sectional area of the hollow cylindrical (pipe), providing critical insights into its structural stability.

The allowable deformation (δ) is 17.5 mm, and upon calculation, the deformation for the hollow spud is 1.637 mm, and for the solid concrete spud, it is 1.5950 mm (within the safe limit). The calculated actual deformations indicate that the actual deformation values are smaller than the allowable deformation. Comparison between Spud Hollow and Spud Solid Concrete could be seen in following table 4.

TABLE 3.
SPUD DIMENSION DETAILS

Nominal Size	10 inches
Outside Diameter	273 mm
Inside Diameter	254.46 mm
Wall Thickness	9.27 mm
Weight per Meter	60.29
Spud Height	10.534 mm

TABLE 4.
DEFORMATION FOR EACH VARIATION IN THE SPUD STRUCTURE

	Calculation	Simulation	allow.δ	Remark
Hollow	1.637 mm	1.066 mm	17.5 mm	Pass
Solid	1.595 mm	1.371 mm	17.5 mm	Pass

Normal Stress (σ) indicates the value of normal stress on the Spud structure, which can be calculated by dividing the force or load received by the surface area of the Spud. Additionally, Shear Stress (τ) is also an evaluation parameter that provides insight into the level of deformation in the structure. At the same time, the

The maximum allowable Equivalent Stress is 170 N/mm², and after calculating, the stress on the hollow spud is 19.32 N/mm², while on the Solid Concrete spud, it is 5.7522 N/mm² (Von Mises stress within the safe limit).

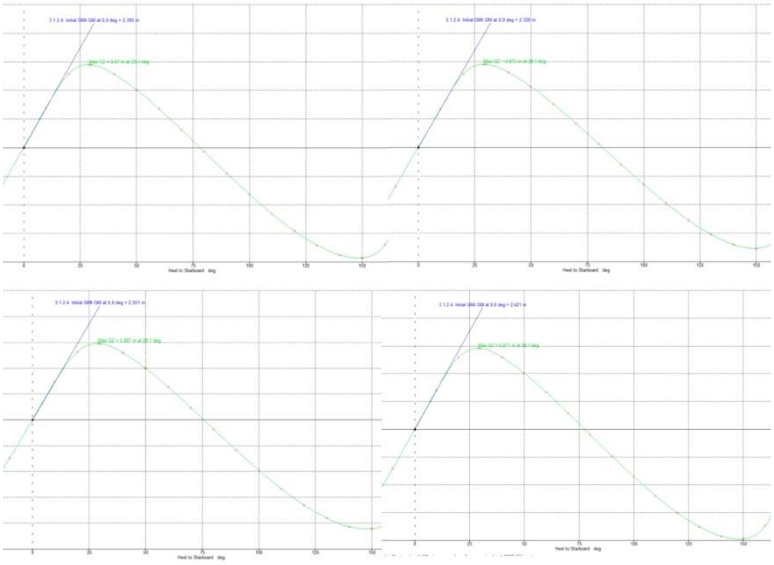

Figure 5. GZ Curve for Loadcase 1,2,3, and 4

TABLE 5.
EQUIVALENT STRESS OF EACH SPUD VARIATIONS

	Calculation	Simulation	allow.δ	Remark
Hollow	19.349 N/mm^2	19.32 N/mm^2	170 N/mm^2	Pass
Solid	5.556 N/mm^2	5.75 N/mm^2	170 N/mm^2	Pass

TABLE 6.
STABILITY RESULT CRITERIA

No	Loadcase	Status
1.	Full Load Condition	Pass
2.	Departure Condition	Pass
3.	Operational Condition	Pass
4.	Empty Load Condition	Pass

Equivalent Von Mises Stress (σ_vm) is calculated to offer a comprehensive overview of the stress occurring in the Spud structure. The Equivalent Von Mises Stress is a method to combine the effects of normal and shear stress, providing a more holistic picture of the stress level experienced by the material.

In addition to Normal Stress and Shear Stress, it is important to note that an analysis is also conducted on the deformation generated by the applied load on the Spud. Deformation provides information about how much the structure can flex or undergo a change in shape. The results of the analysis on stress and deformation provide a deep understanding of the Spud structure's performance in handling the given load, and these findings will serve as the basis for optimizing the design and ensuring structural safety [3] and efficiency. Equivalent Stress from Each Variation of the Spud Structure could be seen in following table 5.

Stability analysis is conducted using stability software based on the regulations of the International Maritime Organization (IMO) Chapter 3 [21], as these regulations provide the necessary guidelines for stability calculations on vessels. The stability calculations are performed under several conditions: Loadcase 1: Full Load Condition. Passengers 100%, Fuel Tanks 100%, and Ballast Tanks 100%. Loadcase 2: Departure Condition. Passengers 100%, Fuel Tanks 100%, Ballast Tanks 50%. Loadcase 3: Operational Condition. Passengers 100%, Fuel Tanks 50%, Ballast Tanks 50%. Loadcase 4: Empty Load Condition. No Passengers, Fuel Tanks 10%, Ballast Tanks 100%. GZ Curve for all Loadcase could be seen in Figure 5, while the stability load criteria could be seen in following Table 6.

IV. CONCLUSION

Here are the conclusions drawn from the completion of the Amphibious Multipurpose Dredger Vessel Design: Key Vessel Dimensions:

- Length (L): 14.30 meters
- Breadth (B): 4.70 meters
- Height (H): 1.60 meters
- Draft (T): 1.10 meters
- Speed: 6 Knots
- Block Coefficient (Cb): 0.8

The required speed of the vessel for optimal operation in the designated area is 6 knots. Given its primary function in coastal reclamation and sediment dredging, a high-speed performance is unnecessary, as a powerful engine would not significantly enhance its efficiency in these tasks. Stability analysis results affirm the vessel's robust stability, meeting 100% of the criteria outlined in IMO 749 Chapter 3 [21].

Further analysis indicates that the vessel experiences an air pressure of 130,547 Newton, a river current pressure of 39,294 Newton, and internal vessel pressure of 106,548,233 Newton. Simulation results for the Spud design concepts reveal that the hollow material ASME B36.10 Carbon Steel Sch 40 experiences an equivalent stress of 19,349 N/mm^2 and a deflection of 1.6370 mm. Conversely, the Spud design concept with the ASME B36.10 Carbon Steel Sch 40 pipe filled with Portland cement experiences an equivalent stress of 5,5567 N/mm^2 and a deflection of 1.5950 mm in its construction. Based on the analysis and calculations, the safety factor is determined to be 12.4032 for the hollow material ASME B36.10 Carbon Steel SCH 40 Spud design and 44 for the design concept filled with Portland cement. Therefore, the Hollow Spud design is selected.

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