International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 12; Issue: 3; March 2025
Website: www.ijrrjournal.com
Research Paper E-ISSN: 2349-9788; P-ISSN: 2454-2237

Effect of Bulkhead Numbers and Thickness on Containership Displacement and Stresses Using Coupled BEM and FEM

OLUSEGUN, Samuel Dare[1], BAYO-PHILIP, Patrick[2]

[1,2]Marine Engineering Department, Nigeria Maritime University, Okerenkoko, Delta State, Nigeria

Corresponding Author: Olusegun Samuel Dare

DOI: https://doi.org/10.52403/ijrr.20250353

ABSTRACT

This study investigates the influence of bulkhead number and plating thickness on containership stress distribution and displacement through a coupled Boundary Element Method (BEM) and Finite Element Method (FEM) analysis. The primary objective was to quantify the structural response to hydrodynamic loads across varying configurations. BEM-derived hydrodynamic pressures were applied to FEM models to simulate vessel behavior. Results indicate that configurations with 20 bulkheads, regardless of 15mm or 25mm plating, exhibit superior structural integrity, evidenced by lower critical stress values around 90 Pa and more uniform stress distribution compared to the 10-bulkhead, 20mm configuration, which showed critical stress values of 120 Pa. Displacement analyses further support these findings, with the 20-bulkhead configurations demonstrating reduced and more evenly distributed displacements, reflecting enhanced rigidity. Conversely, the 10-bulkhead and 5-bulkhead configurations showed increased localized displacements, indicating greater susceptibility to deformation. Specifically, the 5-bulkhead, 25mm configuration displayed critical displacement values reaching 2.5×10^−5 mm, while the 10-bulkhead, 20mm configuration peaked at 0.5×10^−5 mm. The coupled BEM-FEM approach effectively captured the intricate interplay between structural design and hydrodynamic response, highlighting a critical trade-off between rigidity and flexibility. The study underscores the importance of optimizing bulkhead design to minimize stress concentrations and ensure vessel integrity, providing valuable insights for naval architects aiming to enhance containership safety and operational longevity.

KEYWORD: Bulkheads, Containership, Displacements, Stresses, Finite Element Method, Boundary Element Boundary

I. INTRODUCTION

The global maritime industry relies heavily on efficient and safe transportation of goods, with containerships playing a pivotal role in this process. As these vessels continue to increase in size and capacity, ensuring their structural integrity under various hydrodynamic loads becomes paramount. A critical aspect of containership design involves the optimization of internal structural elements, specifically bulkheads, which significantly influence the vessel's displacement, stress distribution, and overall structural performance.

Bulkheads serve multiple functions, including providing transverse strength, compartmentalizing cargo spaces, and limiting flooding in case of damage [1]. The number and thickness of these structural members directly affect the vessel's stiffness and resistance to hydrodynamic forces, particularly in challenging sea states. Understanding the intricate relationship between bulkhead configuration and vessel response is crucial for mitigating potential structural failures and ensuring safe operations.

Traditional design methodologies often rely on empirical formulas and simplified analytical models, which may not accurately capture the complex hydrodynamic phenomena and structural interactions experienced by large containerships [2]. In recent years, numerical methods, such as the Boundary Element Method (BEM) and the Finite Element Method (FEM), have emerged as powerful tools for analyzing these complex problems.

BEM is particularly effective for modeling hydrodynamic interactions, as it focuses on discretizing the fluid domain boundaries, thereby reducing computational effort [3]. This method is well-suited for analyzing wave-induced pressures and vessel motions, providing accurate predictions of hydrodynamic loads on the hull. On the other hand, FEM is widely used for structural analysis, allowing for detailed modeling of complex geometries and material behaviors [4]. FEM can accurately predict stress distributions and displacements within the vessel's structure under various loading conditions, including those obtained from BEM hydrodynamic analyses.

Previous studies have investigated the impact of structural modifications on vessel performance using numerical methods. For example, researchers have explored the effects of hull form variations on wave resistance and ship motions using BEM [5]. Similarly, FEM has been employed to analyze the structural response of containerships under slamming loads and wave-induced bending moments [6]. However, there is a need for a comprehensive study that integrates BEM and FEM to specifically examine the influence of bulkhead thickness and numbers on containership displacements and stresses.

This paper aims to address this gap by employing a coupled BEM-FEM approach to analyze the hydrodynamic pressures, displacements, and stresses in a containership with varying bulkhead configurations. The results of this study will provide valuable insights for optimizing bulkhead design and enhancing the structural integrity of large containerships, ultimately contributing to safer and more efficient maritime transportation.

II. METHODOLOGY

The core equation in FEM for structural analysis is derived from the principle of virtual work or the principle of minimum potential energy. It relates the nodal displacements to the applied forces and material properties.

The Fundamental FEM Equation:

The general form of the FEM equation for static structural analysis is:

$$[K]\{u\} = \{F\} \quad (1)$$

Where:

[K] is the global stiffness matrix. It represents the stiffness properties of the entire structure.

{u} is the vector of nodal displacements. It contains the unknown displacements at each node of the finite element mesh.

{F} is the vector of nodal forces. It represents the external forces applied to the structure.

Global Stiffness Matrix [K]:

1. This matrix is assembled from the element stiffness matrices, which are derived from the material properties (Young's modulus, Poisson's ratio) and the element geometry.
2. The element stiffness matrix relates the nodal forces and displacements within a single element.
3. The assembly process involves combining the element stiffness matrices based on the connectivity of the elements in the mesh.

Nodal Displacement Vector {u}:

4. This vector contains the unknown displacements at each node of the finite element mesh.
5. The displacements can include translations and rotations, depending on the type of element used.
6. Solving the FEM equation for {u} yields the displacements at all nodes.

Nodal Force Vector {F}:

7. This vector contains the external forces applied to the nodes of the finite element mesh.
8. The forces can include concentrated loads, distributed loads, and boundary conditions.
9. It is very important to include the hydrodynamic pressures from the BEM analysis within this vector.

Calculating Stresses:

Once the nodal displacements {u} are obtained, the stresses within each element can be calculated using the following equation:

{σ} = [D] [B] {u_e} (2)

Where:

{σ} is the stress vector, containing the stress components (e.g., normal stresses, shear stresses).

[D] is the material constitutive matrix, which relates stresses to strains based on the material properties.

[B] is the strain-displacement matrix, which relates strains to nodal displacements within the element.

{u_e} is the element nodal displacement vector, containing the displacements of the nodes belonging to the element.

1. The accuracy of the FEM solution depends on the mesh quality, material properties, and boundary conditions.
2. Various types of finite elements can be used, depending on the geometry and loading conditions.
3. The solution of the FEM equation typically involves solving a large system of linear equations.

This provides the core equations for the FEM side of your analysis. When you combine this with the hydrodynamic pressures obtained from BEM, you can perform a coupled analysis to accurately predict the vessel's structural response.

in a matrix form

$$\sigma = D\varepsilon \tag{3}$$

where

$$\sigma = [\sigma_{11} \quad \sigma_{22} \quad \sigma_{33} \quad \sigma_{12} \quad \sigma_{23} \quad \sigma_{31}]^T \tag{4}$$

$$\varepsilon = [\varepsilon_{11} \quad \varepsilon_{22} \quad \varepsilon_{33} \quad 2\varepsilon_{12} \quad 2\varepsilon_{23} \quad 2\epsilon_{31}]^T \tag{5}$$

$$D = \begin{bmatrix} \lambda + 2\mu & \lambda & \lambda & 0 & 0 & 0 \\ \lambda & \lambda + 2\mu & \lambda & 0 & 0 & 0 \\ \lambda & \lambda & \lambda + 2\mu & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu & 0 & 0 \\ 0 & 0 & 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu \end{bmatrix} \tag{6}$$

Therefore, we can write

$$\varepsilon : \sigma = \varepsilon^T \sigma = \varepsilon^T D \varepsilon \tag{7}$$

However, we can also write the strain with respect to the displacement in a matrix form as

$$\begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ 2\varepsilon_{12} \\ 2\varepsilon_{23} \\ 2\varepsilon_{31} \end{bmatrix} = \begin{bmatrix} \partial/\partial x_1 & 0 & 0 \\ 0 & \partial/\partial x_2 & 0 \\ 0 & 0 & \partial/\partial x_3 \\ \partial/\partial x_2 & \partial/\partial x_1 & 0 \\ 0 & \partial/\partial x_2 & \partial/\partial x_3 \\ \partial/\partial x_3 & 0 & \partial/\partial x_1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} \quad (8)$$

Define the strain matrix as

$$B = \begin{bmatrix} \partial/\partial x_1 & 0 & 0 \\ 0 & \partial/\partial x_2 & 0 \\ 0 & 0 & \partial/\partial x_3 \\ \partial/\partial x_2 & \partial/\partial x_1 & 0 \\ 0 & \partial/\partial x_2 & \partial/\partial x_3 \\ \partial/\partial x_3 & 0 & \partial/\partial x_1 \end{bmatrix} \emptyset \quad (9)$$

Therefore, we can now rewrite the stress and strain in a matrix form.

$$\varepsilon = Bd \quad (10)$$

$$\sigma = DBd \quad (11)$$

Hence, the bilinear form equation can be written as

$$\left(\int_\Omega B^T DBdx\right)dx = \int_\Omega \emptyset^T fdx + \int_{\Gamma_N} \emptyset^T gnds \quad (12)$$

Or, in a matrix form, solve for d in the following linear system

$$Md = F \quad (13)$$

$$M = \int_\Omega B^T DBdx \quad (14)$$

The BEM equations and containership model use for the simulation in this paper can be found in recently published paper [7]; [8].

III. RESULTS AND DISCUSSION

Figure 1 shows the deformed shape of the vessel, displayed with displacement color mapping, represents the structural response of the vessel to hydrodynamic pressure forces. This result was obtained by coupling the hydrodynamic pressure calculated through the Boundary Element Method (BEM) with the structural analysis conducted using the Finite Element Method (FEM). The coupling process involves mapping the pressure distribution from the BEM analysis as a load input into the FEM model, allowing for the computation of structural deformation.

In this visualization, the color gradient from blue to yellow represents the range of displacement values across the vessel, with blue areas indicating lower displacement and yellow areas indicating higher displacement. The displacement scale, measured in meters, shows that the highest displacements are close to 3×10^−5meters (in Tensile) and up to -0.5×10^−5 meters (Compression). These values provide a detailed picture of how different regions of the vessel structure respond to the applied hydrodynamic forces. The structural response illustrated here is significant because it provides insight into areas of high and low deformation within the vessel. The areas with greater displacement, such as sections towards the vessel's ends and internal walls, indicate regions where the vessel experiences more structural stress under hydrodynamic loading. Conversely, regions with minimal displacement demonstrate stability under pressure, revealing the structural robustness of these sections.

This coupled BEM-FEM approach is essential for accurately modeling the vessel's behavior under wave loads, as it accounts for both the hydrodynamic forces from the surrounding fluid and the vessel's material properties and structural integrity. Such analysis is crucial in designing vessels that can withstand real-world wave forces while minimizing deformation, ensuring both safety and operational efficiency. This displacement mapping can further aid in identifying structural reinforcements, optimizing the vessel's design, and enhancing durability in response to hydrodynamic forces.

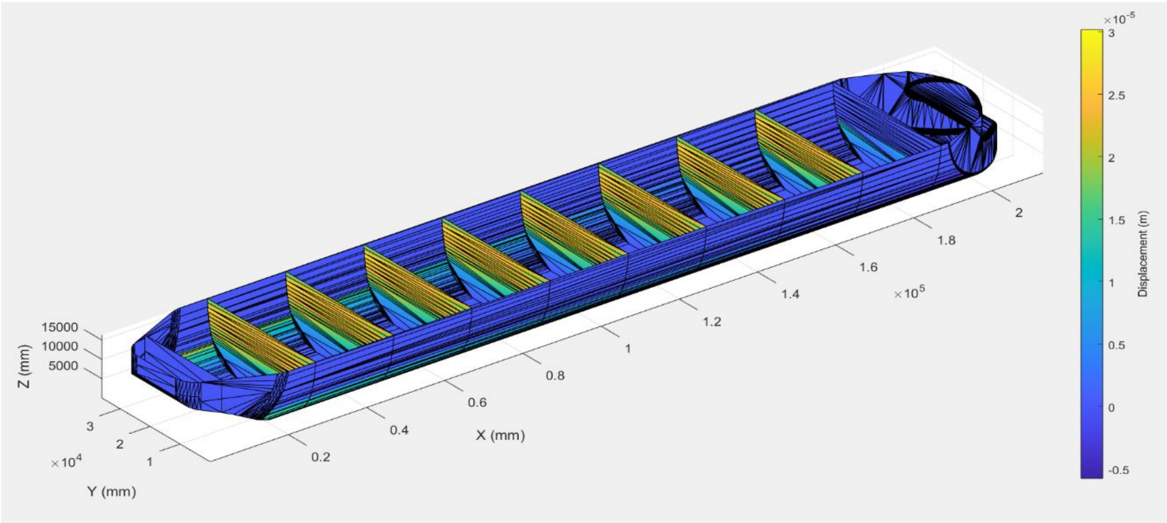

Figure 1: Deformation on the Vessel due to Coupled BEM and FEM

The stress distribution on the vessel, shown in Figure 2 with a node-based color mapping, visualizes the structural stress response resulting from hydrodynamic pressures applied to the vessel. This visualization is a direct outcome of coupling the hydrodynamic forces computed through the Boundary Element Method (BEM) with the vessel's structural response analyzed via the Finite Element Method (FEM). This coupled approach allows for an accurate representation of how the vessel's structure distributes and bears the applied wave-induced pressures.

In this plot, the color gradient from blue to yellow represents stress levels across the vessel in Pascals (Pa). Blue areas indicate regions under less stress, while yellow areas highlight zones experiencing higher stress. The scale shows that stress values range from about 50 Pa to close to 0 Pa, with negative values indicating compressive stresses in the vessel's structure. The stress distribution is crucial for identifying potential points of structural weakness. High-stress regions, typically located around structural features such as internal bulkheads and near the vessel's ends, show where the structure is under significant load and may be more susceptible to material fatigue over prolonged use. In contrast, areas displaying lower stress levels reflect stability and structural integrity, suggesting they are well-positioned to resist hydrodynamic forces.

This node-based stress analysis is essential for improving vessel design. Understanding where the highest stresses occur allows engineers to reinforce specific areas, enhance material choices, or modify the design to distribute stress more evenly. This process ultimately contributes to the vessel's durability and safety in harsh marine environments by reducing the risk of structural failure and enhancing load-bearing capacity under various wave conditions. Through this coupled BEM-FEM approach, designers can ensure the vessel's structural resilience, maximizing its operational lifespan and reliability.

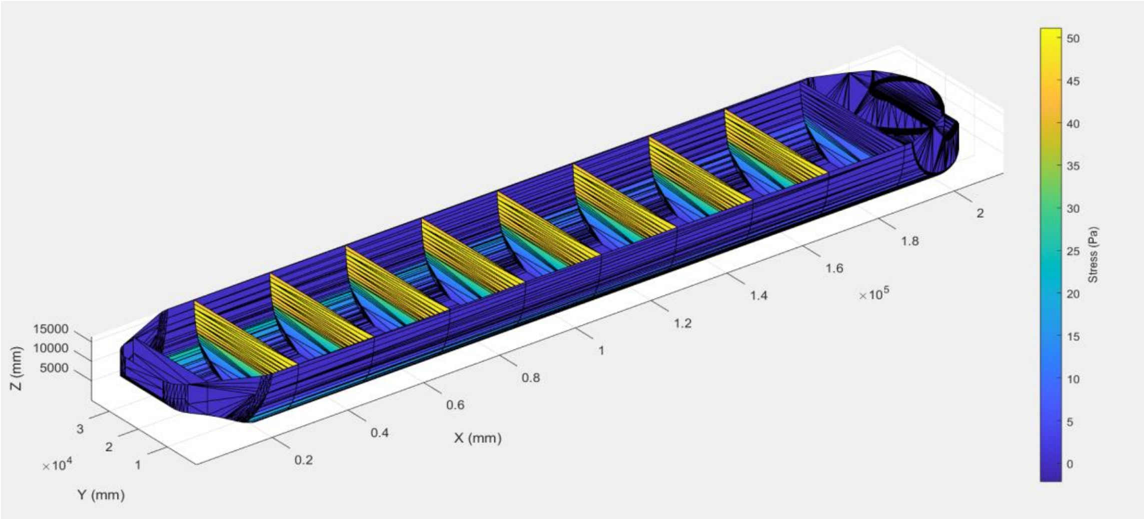

Figure 2: Stress Distribution on the Vessel due to Coupled BEM and FEM

Figure 3 with 20 bulkheads and 25 mm thickness, the container vessel shows a displacement distribution with a broader range, reaching values closer to the upper color limit on the scale. The additional bulkheads and increased thickness contribute to structural rigidity, which distributes the displacement more evenly along the vessel's length. The critical displacement value is slightly lower in this setup, indicating a more resilient structure.

Figure 1 with 10 bulkheads and 20 mm thickness, the vessel experiences higher critical displacement values, suggesting that it is more susceptible to deformation under the same load conditions. The reduced number of bulkheads and thinner structure likely lead to increased flexing, particularly in regions between bulkheads. The lower structural support results in higher localized displacements, as evidenced by the slightly greater spread of displacement values toward the higher end of the color scale. Overall, the configuration with 20 bulkheads and 25 mm thickness provides a sturdier structure with more evenly distributed displacement, whereas the configuration with 10 bulkheads and 20 mm thickness exhibits increased localized displacement, indicating areas of potential structural vulnerability.

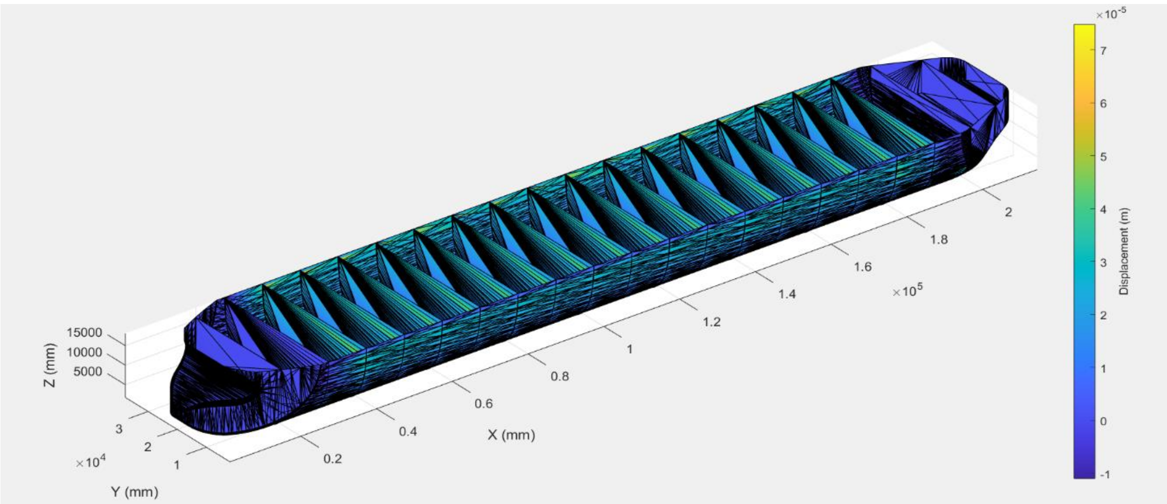

Figure 3: Deformation Distribution at Twenty Bulkhead and 25mm Thickness

In the stress distribution visualizations, the vessel with 20 bulkheads and 25mm thickness (Figure 4) displays a more uniform stress distribution across its structure compared to the vessel with 10 bulkheads and 20mm thickness (Figure 2). This configuration in Figure 4 results in higher structural integrity, as evidenced by the broader spread of stress with a lower concentration of critical values in any single area. In contrast, Figure 2, with fewer bulkheads and thinner structure, shows localized areas of higher stress concentrations, indicating weaker support and increased vulnerability to stress points.

The critical stress values in Figure 4 reach approximately 90 Pa, while in Figure 2, the critical stress values are around 120 Pa. The stress values are lower in Figure 4, as to when compared with Figure 2. The distribution suggests that Figure 4 has a more robust design due to the added bulkheads. This reinforces the importance of structural reinforcements in maintaining uniform stress across the vessel, minimizing the risk of high-stress concentrations that could lead to structural failure under heavy loading conditions.

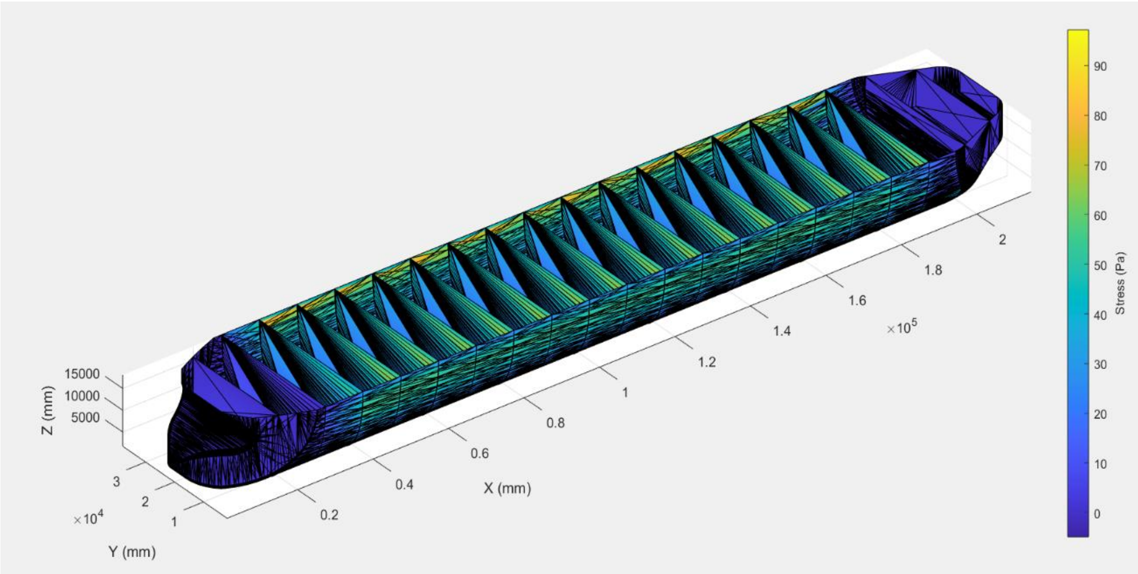

Figure 4: Stress Distribution at Twenty Bulkhead and 25mm Thickness

Figure 5 with 20 bulkheads and 15 mm thickness, the container vessel shows a displacement distribution with a broader range, reaching values closer to the upper color limit on the scale. The additional bulkheads and increased thickness contribute to structural rigidity, which distributes the displacement more evenly along the vessel's length. The critical displacement value is slightly lower in this setup, indicating a more resilient structure.

Figure 1 with 10 bulkheads and 20 mm thickness, the vessel experiences higher critical displacement values, suggesting that it is more susceptible to deformation under the same load conditions. The reduced number of bulkheads structure likely lead to increased flexing, particularly in regions between bulkheads. The lower structural support results in higher localized displacements, as evidenced by the slightly greater spread of displacement values toward the higher end of the color scale. Overall, the configuration with 20 bulkheads and 15 mm thickness provides a sturdier structure with more evenly distributed displacement, whereas the configuration with 10 bulkheads and 20 mm thickness exhibits increased localized displacement, indicating areas of potential structural vulnerability.

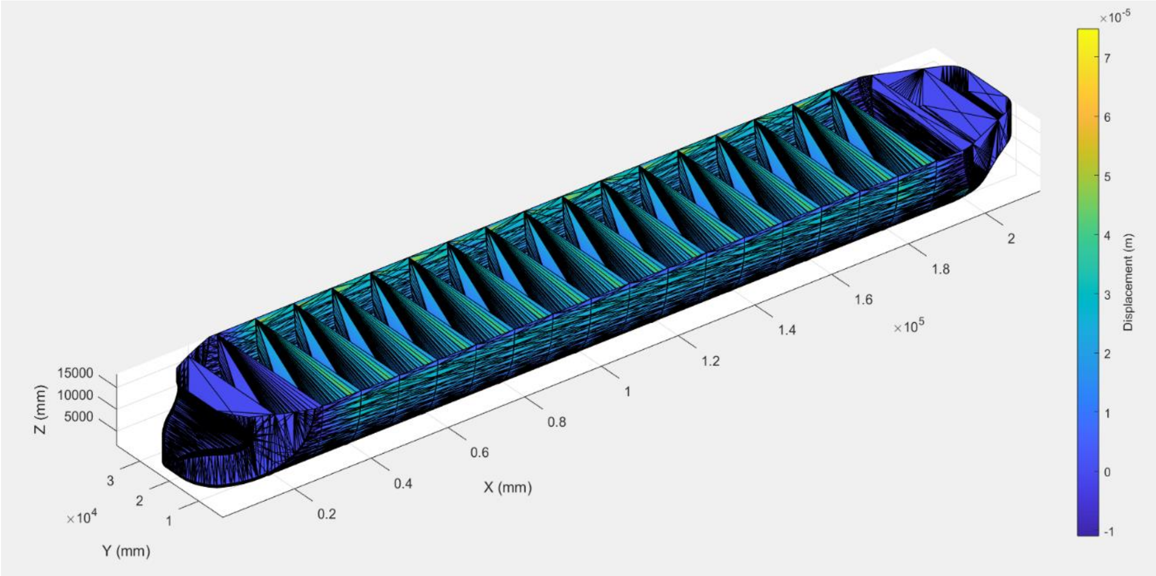

Figure 5: Deformation Distribution at Twenty Bulkhead and 15mm Thickness

Figure 6 shows the stress distribution visualizations, the vessel with 20 bulkheads and 15mm thickness and compared with Figure 4 with 20 bulkheads and 25mm thickness; though the stress mapping shows a maximum stress value 90pa for both case but the high stress value stress are more concentrated across the vessel. Also, when compared to the vessel with 10 bulkheads and 20mm thickness (Figure 2). This configuration in Figure 6 results in higher structural integrity, as evidenced by the broader spread of stress with a lower concentration of critical values in any single area. The Figure 2, with fewer bulkheads and thinner structure, shows localized areas of higher stress concentrations, indicating weaker support and increased vulnerability to stress points.

The critical stress values in Figure 2 and Figure 6 reach approximately 90 Pa, while in Figure 2, the critical stress values are around 120 Pa. The stress values are lower in Figure 6, as to when compared with Figure 1. The distribution suggests that Figure 6 has a more robust design due to the added bulkheads. This reinforces the importance of structural reinforcements in maintaining uniform stress across the vessel, minimizing the risk of high-stress concentrations that could lead to structural failure under heavy loading conditions.

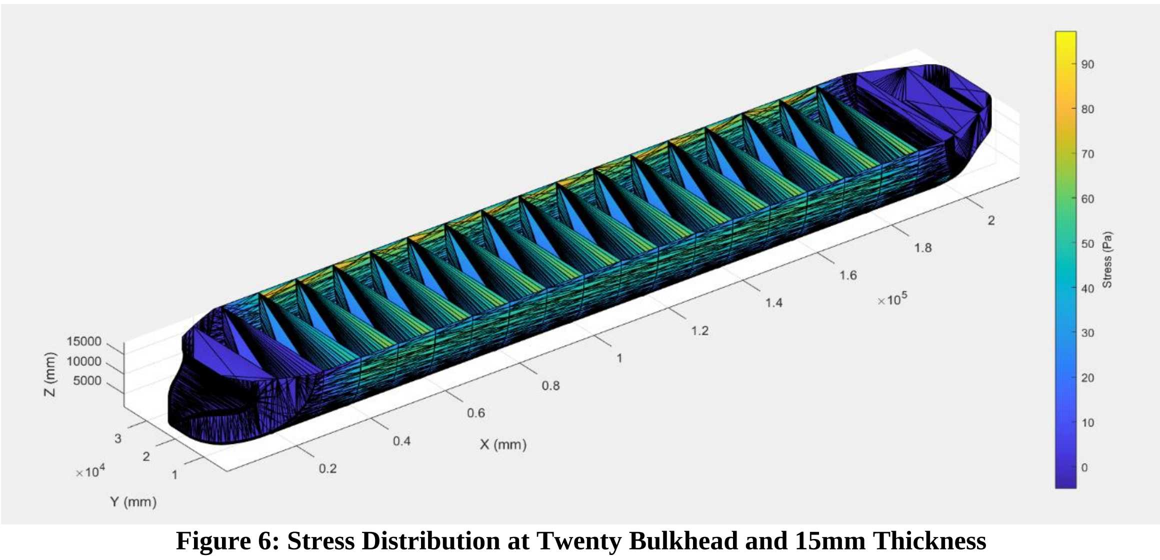

Figure 6: Stress Distribution at Twenty Bulkhead and 15mm Thickness

The two visualizations of the container vessel's deformation distribution display the effects of differing structural configurations. In Figure 7, with 5 bulkheads at 25mm thickness, the color mapping indicates a higher deformation, with critical values reaching up to approximately 2.5×10^−5mm. This suggests that the fewer bulkheads provide less structural reinforcement, leading to a more pronounced displacement.

In contrast, Figure 1, with 10 bulkheads at 20mm thickness, shows a reduced maximum deformation, peaking around 0.5×10 ^−5mm. The increase in bulkheads enhances the vessel's structural integrity, distributing stresses more evenly and thus limiting overall displacement. However, the decreased thickness partially offsets the reinforcement effect, resulting in a moderate level of displacement. The critical displacement values reveal the structural trade-off between bulkhead count and thickness: increasing bulkheads improves stability, while reducing thickness slightly lowers rigidity.

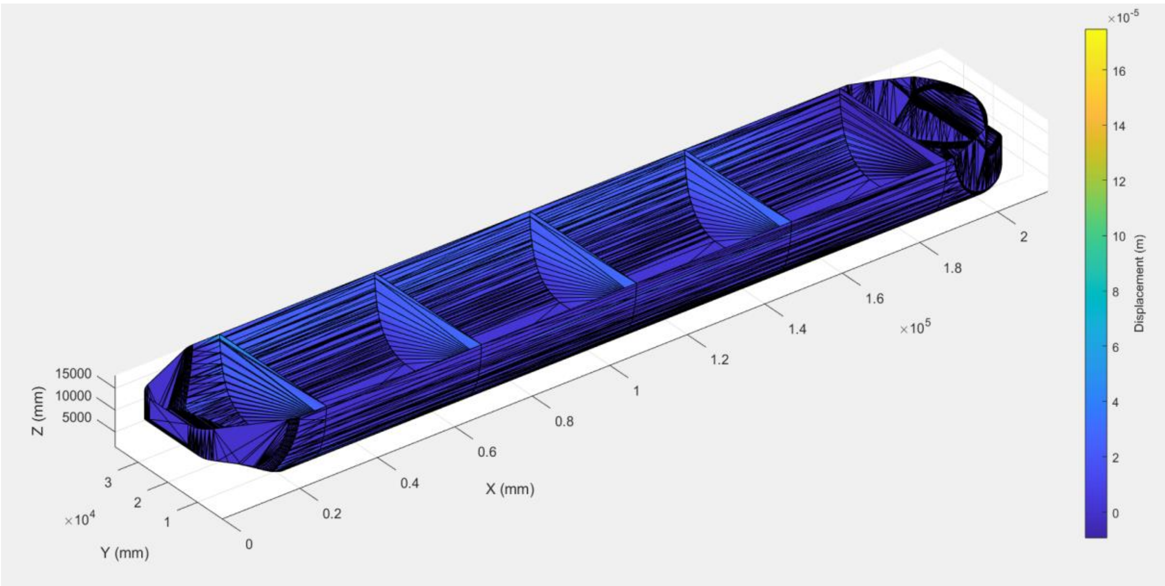

Figure 7: Deformation Distribution at Five Bulkhead and 25mm Thickness

In comparing the shear stress distribution visualizations of the container vessel, Figure 8 with 5 bulkheads and 25mm thickness differs significantly from Figure 2, which has 10 bulkheads and 20mm thickness. In Figure 2, the structure appears to experience lower stress intensities across the vessel length, as evidenced by the predominantly blue and green color gradients. This indicates that the more bulkheads and thicker walls effectively distribute the stress over a larger area, reducing localized stress peaks. The critical stress values are lower in magnitude, suggesting enhanced structural integrity due to the thicker material and fewer structural discontinuities from bulkheads.

In contrast, Figure 2 displays a higher distribution of stress along the vessel, as shown by the shift toward yellow and green hues. This increased stress concentration is due to the increased number of bulkheads, which introduce more structural interfaces, and the reduced wall thickness, which makes the material more susceptible to deformation under load. Consequently, Figure 2 reaches higher critical values, reflecting a less robust distribution of stress under similar conditions.

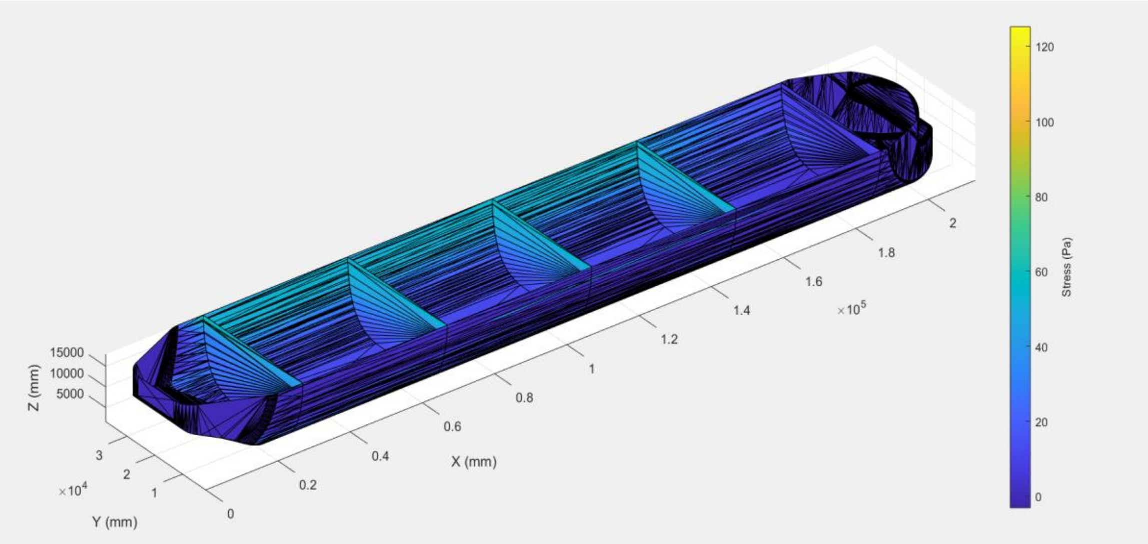

Figure 8: Stress Distribution at Five Bulkhead and 25mm Thickness

IV. CONCLUSION

The coupled Boundary Element Method (BEM) and Finite Element Method (FEM) analysis effectively visualized the impact of varying bulkhead numbers and thicknesses on containership stress distribution and displacement. The results consistently demonstrated that increasing bulkhead numbers and plating thicknesses significantly enhanced structural rigidity, leading to a more uniform stress distribution and reduced critical stress values. Specifically, configurations with 20 bulkheads, regardless of 15mm or 25mm plating, displayed lower critical stress values (around 90 Pa) compared to the 10-bulkhead, 20mm configuration (120 Pa), indicating a more robust design. Furthermore, these configurations exhibited more evenly distributed displacements, suggesting greater resistance to deformation. Conversely, vessels with fewer bulkheads and thinner plating showed localized areas of higher stress concentration and increased displacement, highlighting potential structural vulnerabilities. The 5-bulkhead, 25mm configuration, while having thicker plating, demonstrated higher deformation due to the reduced number of bulkheads. The analysis revealed a clear trade-off between structural rigidity and flexibility, emphasizing the importance of optimizing bulkhead design to minimize stress concentrations and ensure vessel integrity under hydrodynamic loads. The coupled BEM-FEM approach proved invaluable in accurately predicting the structural response, providing critical insights for enhancing vessel design and operational safety.

Declaration by Authors

Acknowledgement: None
Source of Funding: None
Conflict of Interest: No conflicts of interest declared.

REFERENCES

1. Rawson, K. J., & Tupper, E. C. (2001). *Basic ship theory*. Butterworth-Heinemann.
2. Faltinsen, O. M. (1990). *Sea loads on ships and offshore structures*. Cambridge University Press.
3. Newman, J. N. (1977). Marine hydrodynamics. MIT press.
4. Zienkiewicz, O. C., & Taylor, R. L. (2000). *The finite element method: solid mechanics*. Butterworth-Heinemann.
5. Kim, Y. H., & Kim, D. J. (2010). Numerical study on the effects of hull form variations on wave resistance and ship motions. *Ocean Engineering, 37*(1), 1-13.
6. Jensen, J. J., & Pedersen, P. T. (1981). Wave-induced bending moments in ships—a quadratic theory. *Transactions of the Royal Institution of Naval Architects, 123*, 151-163.
7. Olusegun, S.D. Eferebo, S.I., Orji, C.U. & TAMUNODUKOBIPI, D. (2024).

Simulation of Containership Hydrodynamic Forces and Response Amplitude Operator in Time Domain International Journal of Engineering and Modern Technology (IJEMT), Vol 10(11), pp 81-91.

8. Olusegun, S.D. & Elakpa, A.A. (2024). Simulation of a Container Vessel Using Boundary Element Method for the Computation of Hydrodynamic Pressure and Forces. International Journal of Advances in Engineering and Management (IJAEM), 2024 Volume 6, Issue 12, Page 241-248.

How to cite this article: OLUSEGUN, Samuel Dare, BAYO-PHILIP, Patrick. Effect of bulkhead numbers and thickness on containership displacement and stresses using coupled BEM and FEM. *International Journal of Research and Review*. 2025; 12(3): 428-438. DOI: *https://doi.org/10.52403/ijrr.20250353*

******