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FEM Simulation to Determine Optimum Stiffener Distance on Barge Deck Sandwich Plate

Pratama Yuli Arianto[1)], Risalah Alifatus Zharo[1) *)], Hery Indria Dwi Puspita[1)], Muammar Kadhafi[2)], Syafiuddin[3)]

[1)] Department of Naval Architecture, University of Jember, Jember, Indonesia
[2)] Department of Mechanical Engineering, Kunsan National University, Gunsan, South Korea
[3)] Department of Marine Engineering, Shipbuilding Institute of Polytechnic Surabaya (PPNS), Surabaya, Indonesia
[*)] Corresponding Author: 211910701008@mail.unej.co.id

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Abstract

The application of sandwich plates in marine structures provides a lightweight yet strong alternative to conventional steel plates. This study investigates the extent to which stiffener spacing on barge decks can be increased when using 5–15–5 mm sandwich plates, without exceeding the allowable stress limit. The analysis was conducted using the finite element method (FEM) in ANSYS Student R2 2024. The stiffener spacing configurations examined were 610 mm (32 stiffeners), 762 mm (24 stiffeners), 1016 mm (16 stiffeners), 1524 mm (8 stiffeners), and a model without stiffeners. The simulation results indicate that all models with stiffeners, up to a spacing of 1524 mm, satisfy the allowable stress limit of 175 MPa specified by Lloyd's Register. In contrast, the model without stiffeners exceeds this limit and is therefore considered unsafe. Deformation analysis further shows that the maximum deflection tends to occur on the port side, particularly in regions not supported by beams or girders. As the stiffener spacing increases, the magnitude of deformation also increases, and its location shifts due to edge effects and asymmetrical support conditions. In addition, the use of sandwich plates leads to a substantial reduction in structural weight compared with conventional steel construction, ranging from 23.13% to 32.83%, depending on the stiffener spacing. Based on these results, a stiffener spacing of up to 1524 mm is considered optimal for maintaining structural safety while achieving significant weight reduction.

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1. Introduction

In recent years, material development in the maritime industry has progressed rapidly. Innovation in this field is no longer focused solely on structural strength, but also on weight efficiency. One of the main challenges in modern ship design is achieving lightweight structures without compromising strength and safety. Excess structural weight can adversely affect fuel consumption, cargo capacity, and ship stability [1]. One alternative solution to address this challenge is the use of sandwich plates, which are composite materials offering an optimal balance between strength and weight.

Sandwich plates consist of faceplate layers with high strength and stiffness, combined with a core layer that is lightweight and relatively flexible. This configuration produces a structure that is lightweight while maintaining adequate strength, making it well suited for application in ship structures [2,3]. The use of sandwich plates in ship construction offers several advantages: (a) reduction in structural weight, (b) simplification of structural geometry, (c) an improved strength-to-weight ratio, and (d) reduced production costs due to lower material usage [4].

Numerous studies have demonstrated the benefits of sandwich plates in marine applications. Sujiatanti's research [4] on ship decks incorporating sandwich plates reported significant reductions in stress and deformation. Ismail [5] showed that sandwich plates exhibit good resistance to dynamic loads, based on vibration test results. Furthermore, Tuswan [6] reported that the use of sandwich plates on ship side structures resulted in a weight reduction of up to 17%. Similarly, Wahid [7] found that the application of sandwich plates on Ro-Ro ship decks reduced structural weight by more than 5%. Panagian [8] also investigated the use of sandwich plates with polyurethane elastomer cores on ship decks and side shells. Yuwantoro [9] evaluated sandwich plate systems (SPS) on the tank decks of 7,000 DWT landing ships and confirmed comparable strength performance. In addition to deck and side-shell applications, sandwich plates have been tested on the inner-bottom structures of container ships. Pambudi et al. [10] investigated the application of a 6–15–7 mm SPS in container ship double bottoms and found that it satisfied the Lloyd's Register allowable stress limit (<175 MPa), achieving a total weight reduction of 2.8% and up to 5.7% for the inner-bottom structure alone.

Research has also focused on the development of sandwich plate core materials. Utomo studied three different core materials–polyurethane foam, polyresin, and synthetic resin combined with talc–and concluded that a synthetic resin composition of 50% resin, 50% talc, and 0.3% catalyst satisfies Lloyd's Register requirements [11]. Building on this work, Arianto [12] reported that a core composition of 90% resin and 10% talc produced a maximum stress of 28.6 MPa, which remained within safe limits. Abdullah [13] investigated sandwich plate cores made from shell powder and resin, demonstrating that shell-based cores are feasible and efficient for ship construction. Furthermore, Mula [14] examined the use of eggshell powder as a sandwich plate core and found that compositions containing 20–30% eggshell exhibited sufficient strength and material characteristics for ship deck applications.

Yudiono [15] reported that sandwich panels using epoxy rice husk cores (0–20%) experienced only a slight reduction in tensile strength while still meeting Lloyd's Register stress requirements (≥20 MPa), confirming their suitability for ship deck structures. Although many studies have investigated the application of sandwich plates in ship construction, one important aspect remains insufficiently explored: the extent to which stiffener spacing can be increased without compromising structural strength. This issue is particularly important for thin sandwich plate configurations, such as those with 5 mm faceplates and a 15 mm core (5–15–5 mm). While closely spaced stiffeners ensure structural safety, they also increase overall ship weight.

Therefore, this study aims to determine the maximum allowable stiffener spacing for a 5–15–5 mm sandwich plate system applied to a barge deck structure. Finite element analysis using ANSYS Student R2 2024 is employed to evaluate five stiffener configurations: 610 mm, 762 mm, 1016 mm, 1524 mm, and a configuration without stiffeners. The sandwich plate model incorporates a synthetic resin core composed of 50% resin and 50% talc with 0.3% catalyst, as validated in Utomo's previous study [11]. The objective of this research is to identify an optimal balance between structural safety and weight efficiency for lightweight ship deck applications.

2. Method

This study was conducted to determine the extent to which stiffener spacing can be increased in a sandwich plate system with a 5 mm faceplate and a 15 mm core configuration. The object of the study is the deck structure of a barge in the midship region, spanning frame 15 to frame 32, where a sandwich plate configuration consisting of 5 mm faceplates and a 15 mm core is applied. This region was selected because it represents the central part of the ship's cross-section, which generally experiences the most significant load distribution due to both cargo weight and environmental loading [9]. The midship region is widely recognised as the most critical section of a vessel's hull, as it is subjected to the highest global bending moments.

In accordance with the *BKI Analysis Techniques for Strength* (2005) [16], as well as international standards including DNV-RU-SHIP Part 3 Chapter 7 (2021), DNV Class Guideline CG 0127, and Lloyd's Register Guidance Notes GN 032, finite element analysis (FEA) is recommended or required for structural assessment in this region. These guidelines emphasise that the midship section should serve as the primary location for structural evaluation–particularly for composite structures such as sandwich panels–due to its exposure to maximum stresses and deformations under global loading conditions [17-19]. Accordingly, this study employs numerical analysis based on the finite element method (FEM) using ANSYS Student Version R2 2024.

A linear static analysis was performed to evaluate stresses and deformations under uniformly distributed loading. The reliability of the FEM results was assessed by comparing the maximum von Mises stress with the allowable stress limit of 175 MPa, in accordance with Lloyd's Register requirements. A mesh size of 150 mm was adopted, resulting in a model with 78,516 nodes and 76,077 elements. Although a comprehensive mesh sensitivity analysis was not conducted, it is well established that finer meshes yield results that more closely approximate the true solution. This has been demonstrated by Manet [20] in his study of sandwich structures using ANSYS, which explicitly highlighted the influence of mesh refinement on stress accuracy. Furthermore, the ANSYS Student Version imposes a strict limitation on model size, with a maximum combined total of 128,000 nodes and elements for structural analyses [21]. The selected mesh size therefore represents a balance between computational efficiency and software licensing constraints.

The sandwich plate was modelled as a three-layer structure comprising a 5 mm top faceplate, a 15 mm core layer, and a 5 mm bottom faceplate. The faceplates were modelled as conventional steel with linear elastic behaviour (yield strength = 292.74 MPa; Young's modulus = 199,877.63 MPa), while the core material was modelled as a resin–talc composite (50% resin, 50% talc, and 0.3% catalyst) with an elastic modulus of 2,792.06 MPa, based on experimental data reported by Utomo [11]. All materials were assumed to exhibit ideal linear elastic behaviour, without plastic deformation or material imperfections. This simplification is acknowledged as a limitation of the present study.

2.1. Barge Deck Profile Constructions

In this study, the sandwich plates were applied in the construction of a barge deck. The mechanical properties are shown in Table 1. The deck is modelled in the midship region, spanning frame 15 to frame 32, with overall dimensions of 31,091.1 mm × 24,400 mm × 2,300 mm. The faceplate layers are made of conventional steel with a thickness of 5 mm, while the core layer consists of a synthetic resin composite with a composition of 50% resin, 50% talc, and 0.3% catalyst, as previously investigated by Utomo [11].

Based on the available data, the barge deck is subjected to a uniformly distributed static load of 8 tonnes per square metre. This load represents the combined effect of the cargo weight acting on the deck and the self-weight of the supporting structural components beneath the deck. Accordingly, the total applied load in this study is 59,536.53 kN. The two-dimensional deck models corresponding to each configuration are shown in Figures 1 - 7.

Table 1. Mechanical Properties Sandwich Plate [11]

Mechanical properties faceplate at Room temperature		**Mechanical properties core at Room temperature (composition ratio of 50% resin, 50% talc, and 0.3% catalyst)**	
Tensile strength, σtk	447.28 MPa	Force yield	2,140.63 Newton
Yield strength, σy	292.74 MPa	Yield strength	8.84556 MPa
Flexural strength, σlt	482.27 MPa	Yield displacement	1.87900 mm
Shear stress, τ	110.23 MPa	Elongation at yield	1,99894 %
Modulus elasticity, Ef	199,877.63 MPa	Force max	5,989.38 Newton
Shear Modulus, Gf	60,573.26 MPa	Tensile strength	24.7495 MPa
Poisson ration, υ	0.30	Max displacement	4.25350 mm
Max. Deflection, Δ	3.82 mm	Max elongation	4.52500 %
Density	7,850 kg/m^3	Elasticity modulus	2,792.06 MPa
		Shear modulus	1,396.03 MPa
		Poisson ratio	0
		Density	1,728 kg/m^3

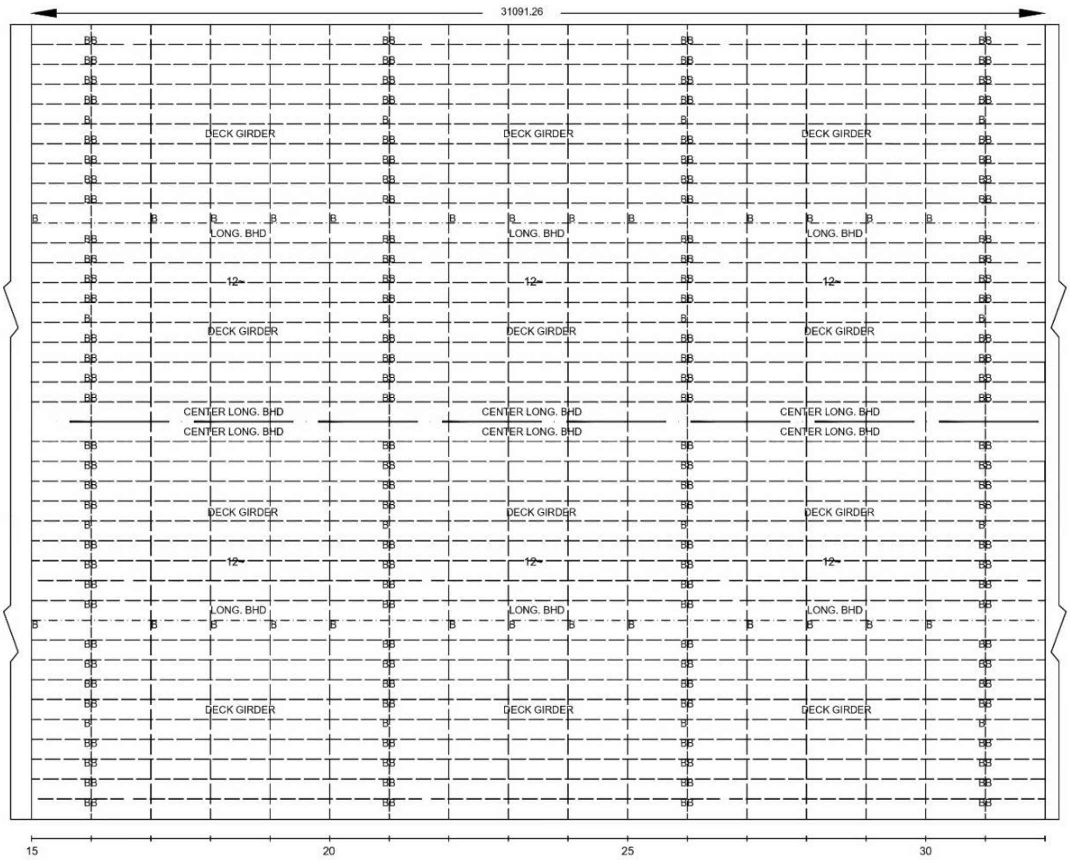

Figure 1. 2D from of the main deck

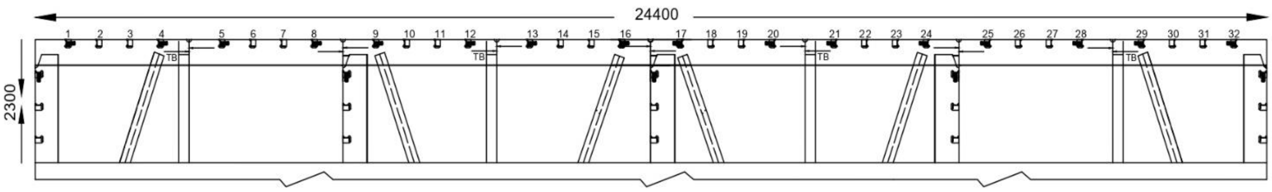

Figure 2. 2D from front view of the midship section

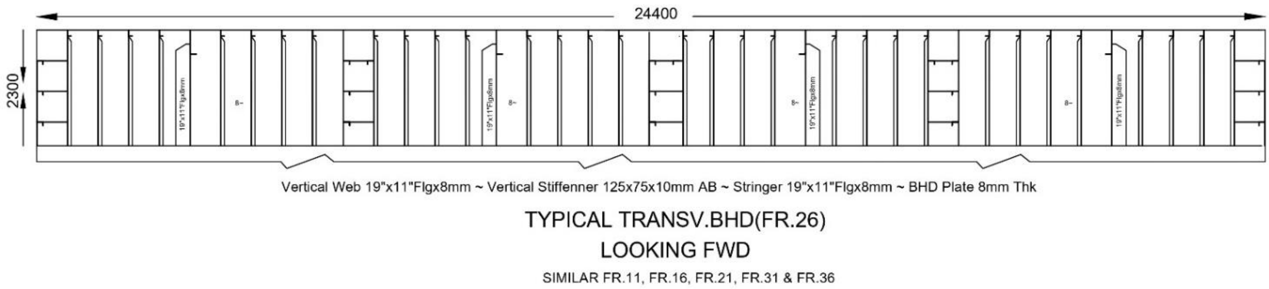

Figure 3. 2D from front view of the transversal bulkhead

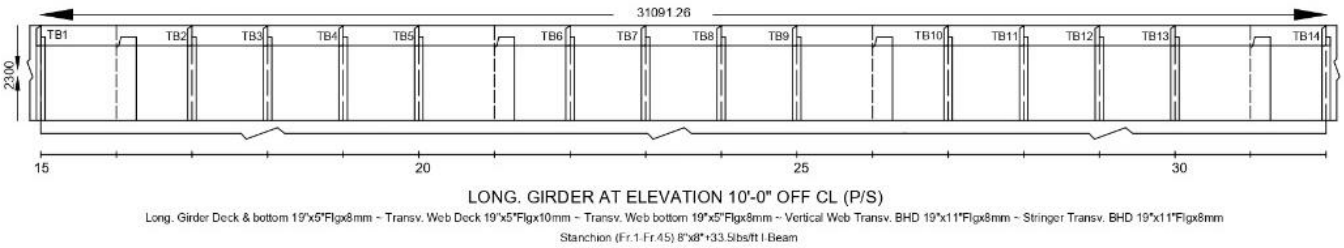

Figure 4. 2D from side view of the long girder

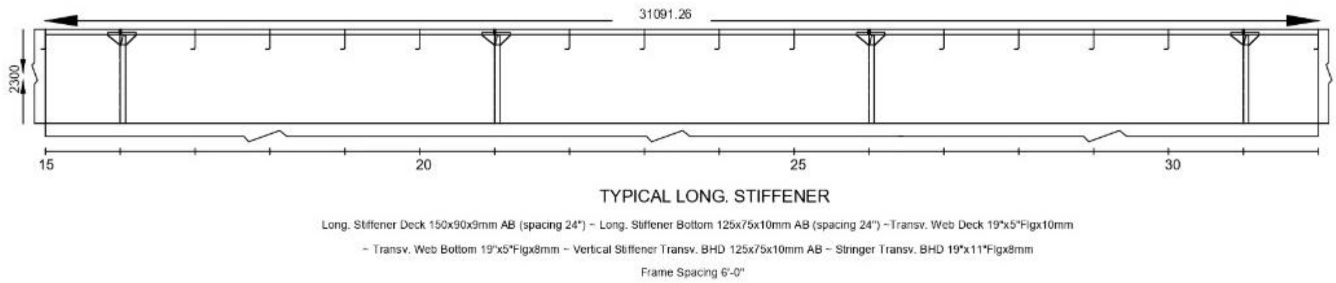

Figure 5. 2D from side view of the long girder

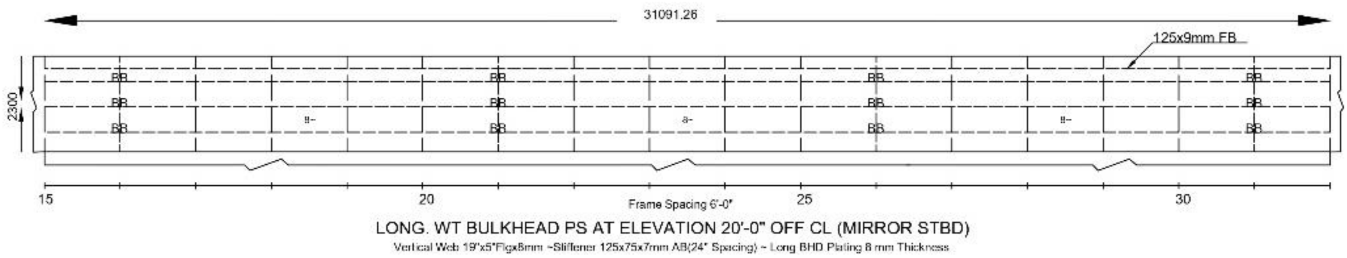

Figure 6. 2D from side view of the longitudinal watertight bulkhead

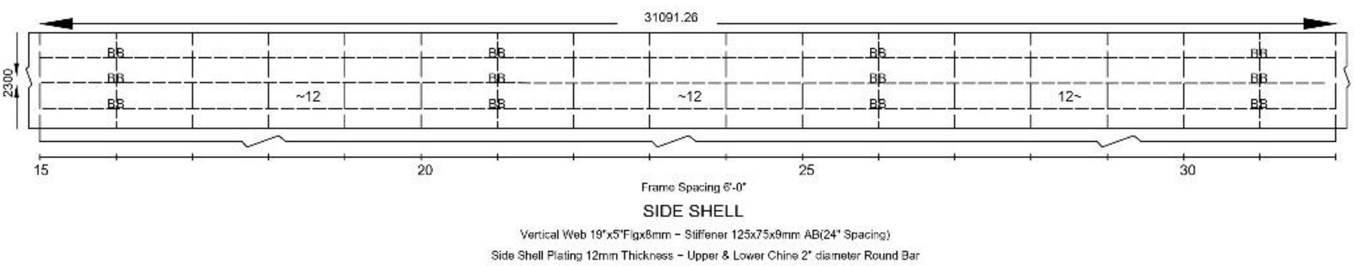

Figure 7. 2D from of the side shell

The influence of stiffener spacing on structural strength is reflected in both stress levels and deformation behaviour. Therefore, five variations of stiffener spacing were examined to determine the maximum spacing that can be optimally applied to the 5–15–5 mm sandwich plate configuration. The investigated stiffener spacings were 610 mm (32 stiffeners), 762 mm (24 stiffeners), 1,016 mm (16 stiffeners), 1,524 mm (8 stiffeners), and a final configuration without stiffeners.

The analysis was performed numerically using the finite element method (FEM) with the assistance of ANSYS Student Version R2 2024. This method was selected because it provides detailed insight into stress distribution and deformation behaviour and has been widely applied in sandwich plate research. The analysis procedure began with geometric modelling of the barge deck using SpaceClaim, which is integrated within the ANSYS environment. Subsequently, the sandwich plate lay-up was defined using ANSYS Composite PrepPost (ACP), where three layers were assigned to the deck structure: a 5 mm thick top faceplate, a 15 mm thick core layer, and a 5 mm thick bottom faceplate. Material properties were assigned in accordance with the synthetic resin data reported by Utomo [11].

The next stage involved the application of boundary conditions and mesh generation. Boundary conditions were applied along the transverse bulkheads and longitudinal girders at the deck edges, where translational degrees of freedom were constrained (Ux = Uy = Uz = 0) while rotational degrees of freedom were permitted. This approach represents the actual structural continuity of the deck. A mesh size of 150 mm was adopted, resulting in a total of 78,516 nodes and 76,077 elements.

Following meshing, the model was subjected to a uniformly distributed static load of 8 tonnes/m² acting vertically downwards along the negative Z-axis. The total applied load of 59,536.53 kN represents the combined effects of cargo loading and the self-weight of the supporting structures. Identical loading and boundary conditions were applied to all five stiffener-spacing configurations to ensure consistent comparison. Finally, the solver was executed to obtain the required outputs, namely the von Mises stress distribution and deck deformation [22].

3. Results and Discussion

3.1. Von Mises Stress

Table 2 presents the maximum stress values for the 5–15–5 mm sandwich plate configurations. Details of Von Mises Stress location for each configuration are shown in Figure 8–12. The results show that sandwich plates with this configuration and stiffener spacings ranging from 610 mm to 1,524 mm can withstand the applied load of 59,536.53 kN. However, the sandwich plate model without stiffeners (Sandwich E) exceeds the allowable von Mises stress limit specified by Lloyd's Register, which is 175 MPa [21].

Table 2. maximum stress of sandwich plate 5 - 15 -5

Model	Type	Stiffener Distance (mm)	Allowable Stress (MPa)	Maximum Stress (Mpa)
1	Sandwich A	610	175	96.73
2	Sandwich B	762	175	95.80
3	Sandwich C	1,016	175	101.40
4	Sandwich D	1,524	175	99.02
5	Sandwich E	Without stiffener	175	178.46

For Sandwich A, with a stiffener spacing of 610 mm, the maximum stress occurs in the region of Longitudinal Bulkhead 1 on the port side, near Deck Beam 7. This is attributed to the higher stiffness of the bulkhead–deck beam connection compared with surrounding areas, as well as its proximity to the midship region. This finding is consistent with the work of Sujiatanti [4], who reported that the intersection between longitudinal beams and transverse girders is often a critical stress location due to the combined bending moments acting in two directions.

Sandwich B exhibits a similar stress location to Sandwich A; however, the maximum stress value is reduced. This reduction is associated with the decreased number of stiffeners, which promotes stress diffusion. As the structure becomes more flexible, both the faceplates and the core contribute more effectively to bending resistance, resulting in a more uniform stress distribution and a lower peak stress. Zhao [24] reported a similar phenomenon, where moderate increases in stiffener spacing led to reduced peak stresses before increasing again at excessive spacing.

In Sandwich C, the maximum stress shifts to the region of Transverse Bulkhead 2 near Stiffener 5. This change in stress location, compared with Sandwiches A and B, is caused by the wider stiffener spacing. The increased spacing allows loads to be transferred not only through the deck but also towards the ship's side structures, directing force flow towards connections with higher stress concentrations. Zhao [24] explained that such local stress increases occur at connection nodes due to changes in local stiffness and force-flow direction.

For Sandwich D, the stiffener spacing is further increased, resulting in pronounced bending effects due to the reduced support from longitudinal stiffeners. Consequently, the maximum von Mises stress occurs at the deck beam rather than at the stiffener. A similar observation was reported by Panangian [8], who found that sandwich plates with wide stiffener spacing exhibited stress peaks at plate–beam connections instead of at stiffener locations.

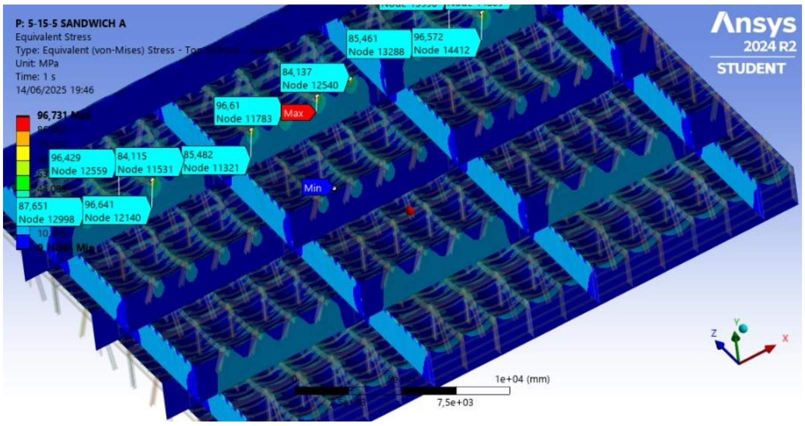

Figure 8. Von mises stress location sandwich A

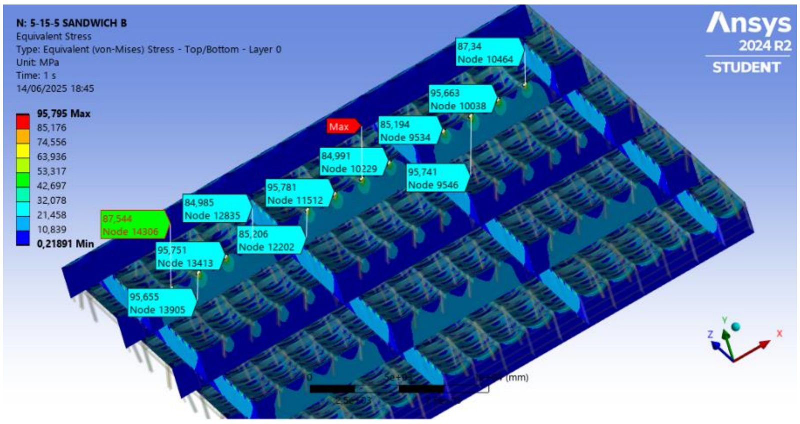

Figure 9. Von mises stress location sandwich B

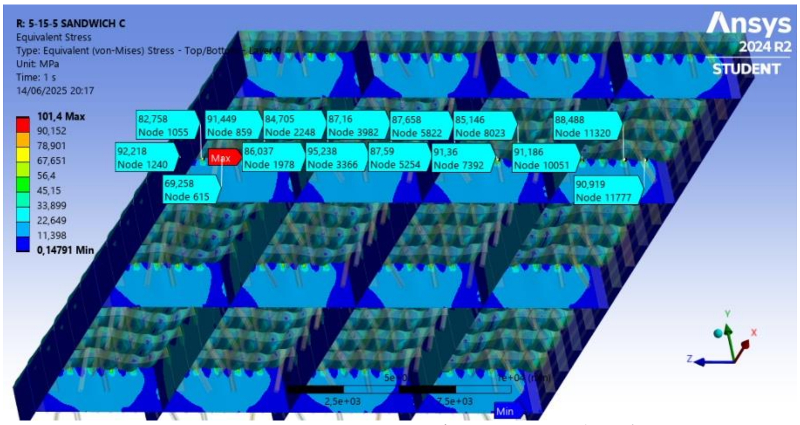

Figure 10. Von mises stress location sandwich C

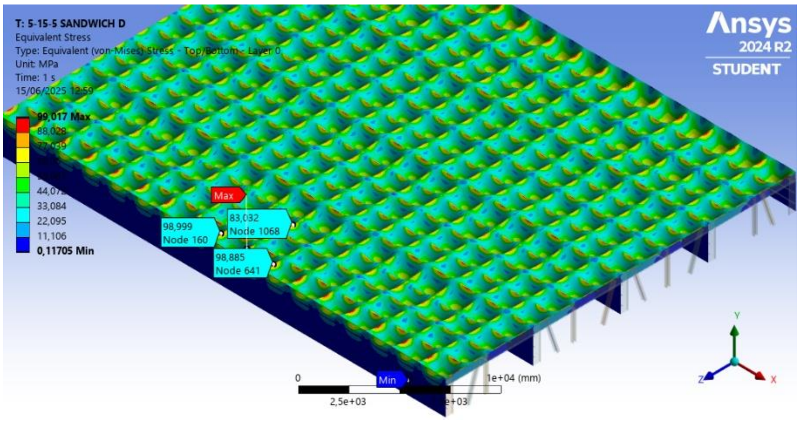

Figure 11. Von mises stress location sandwich D

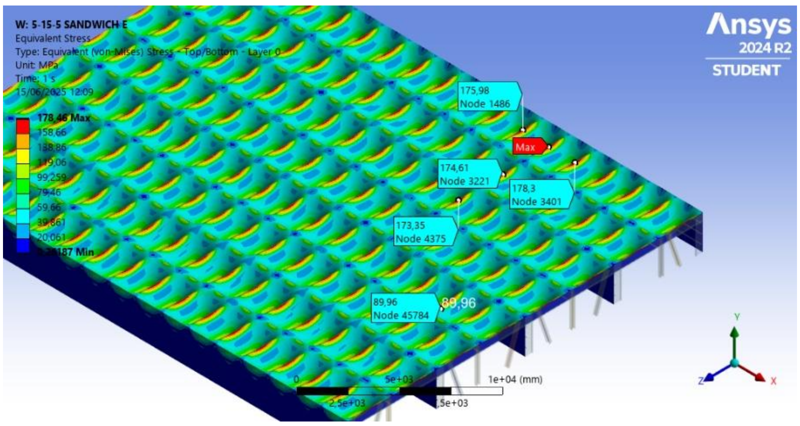

Figure 12. Von mises stress location sandwich E

Sandwich E, which does not include any stiffeners, shows the maximum von Mises stress at Deck Beam 6 on the starboard side. In the absence of stiffeners, the applied load is transferred directly to the deck beam supports. For the 5–15–5 mm sandwich plate configuration, the resulting maximum von Mises stress reaches 178 MPa, exceeding the allowable limit specified by Lloyd′s Register. Therefore, this configuration is considered unsafe for application in ship structures.

3.2. Deformation

Deformation refers to a change in the shape or dimensions of a structure resulting from applied forces or stresses. In numerical structural analysis, deformation is a key parameter that must be carefully considered. Materials with high ductility are generally capable of sustaining high stress levels but also tend to undergo greater deformation. Therefore, controlling or limiting deformation is an essential aspect of evaluating structural performance.

In this study, deformation of the sandwich plate predominantly occurs on the port side of the vessel. This behaviour is attributed to the asymmetric structural configuration of the deck, where the starboard side is comparatively stiffer due to support from the central longitudinal bulkhead. As shown in Table 3, deformation increases as the stiffener spacing increases. This trend is caused by the reduction in structural support associated with wider stiffener spacing, which leads to greater flexibility of the sandwich plate [6, 25]. Details for deformation contour for each sandwich configuration are shown in Figure 13-17.

Table 3. maximum deformation of sandwich plate 5 - 15 -5 mm

Model	Type	Stiffener Distance (mm)	Maximum Deformation (mm)
1	Sandwich A	610	2.71
2	Sandwich B	762	3.14
3	Sandwich C	1,016	4.06
4	Sandwich D	1,524	6.93
5	Sandwich E	Without stiffener	14.14

Sandwich A exhibits maximum deformation in the second lane of the port-side region, with a magnitude of 2.706 mm. This occurs because, despite the relatively close stiffener spacing, areas not directly supported by stiffeners, beams, or girders still experience dominant bending. Sujiatanti [4] reported similar findings, noting that closer stiffener spacing generally results in lower deformation values.

For Sandwich B, the maximum deformation remains on the port side but increases to 3.14 mm. This increase is primarily due to the wider stiffener spacing, which reduces overall structural stiffness. Sandwich C shows a further increase in deformation, reaching 4.05 mm. However, the location of maximum deformation remains in the same lane, as the pressure distribution is still partially restrained by the stiffeners and the supporting longitudinal girder system.

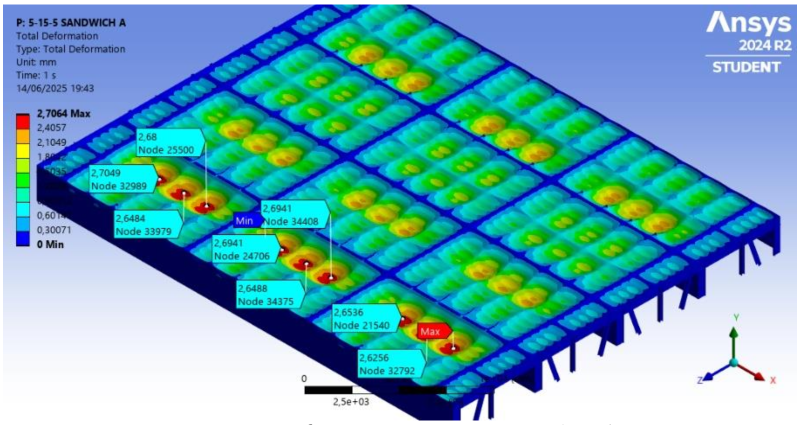

Figure 13. Deformation contour Sandwich A

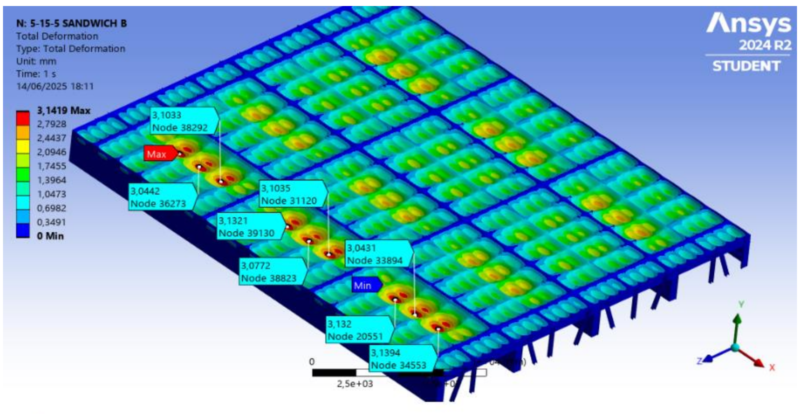

Figure 14. Deformation contour Sandwich B

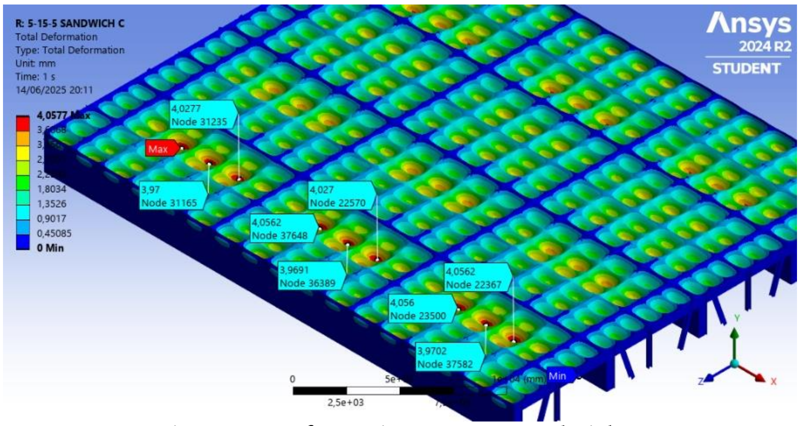

Figure 15. Deformation contour Sandwich C

In Sandwich D, the stiffener spacing becomes sufficiently wide to cause a significant increase in deformation, reaching 6.92 mm. The location of maximum deformation also shifts. This behaviour results from the substantial reduction in plate stiffness, which makes the sandwich plate more flexible. Consequently, the applied deck load is no longer distributed uniformly but instead concentrates in the most flexible region of the structure [24].

Sandwich E, which does not include any stiffeners, exhibits a pronounced increase in deformation to 14.13 mm. Despite the absence of stiffeners, the maximum deformation does not occur in the outermost lane but rather in the second lane from the edge. This is because the first lane still receives support from the main longitudinal girder, whereas the second lane lacks both vertical and transverse support, making it the most vulnerable region under compressive loading. This observation is consistent with Zhao [24], who noted that in unstiffened plate structures, deformation tends to accumulate in regions located between major support points.

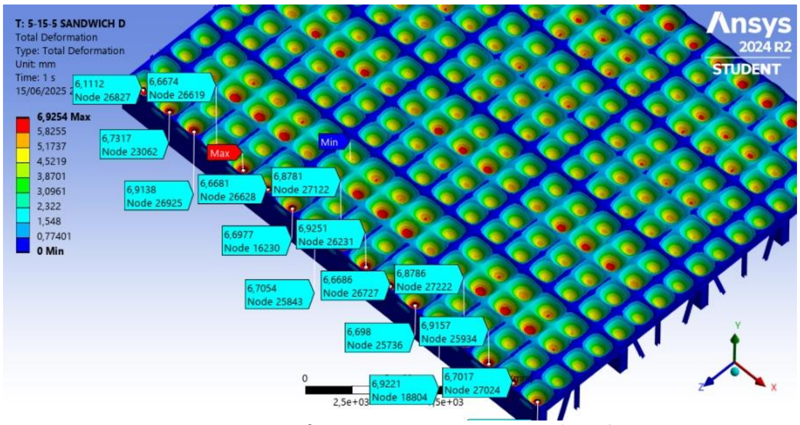

Figure 16. Deformation contour Sandwich D

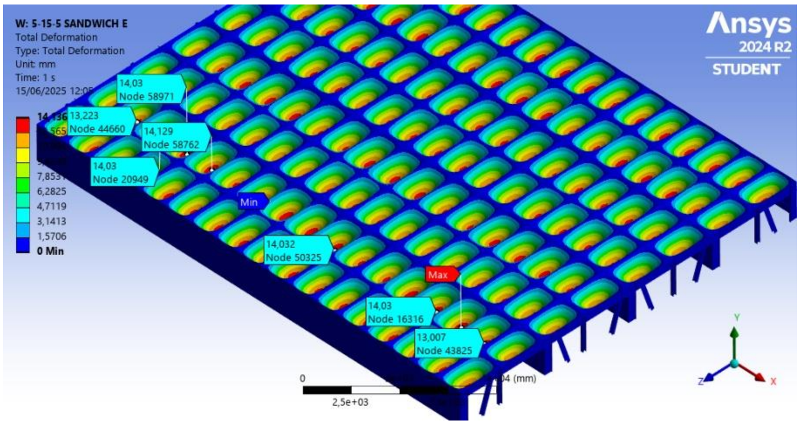

Figure 17. Deformation contour Sandwich E

3.3. Weight of Sandwich Plate Structure

Reduction in structural weight is one of the principal advantages of applying sandwich plates in ship construction. Based on the analyses conducted, each increase in stiffener spacing results in a lighter overall structure. This weight reduction is primarily due to the decreased number of stiffeners, which directly lowers the total structural mass of the vessel.

As shown in Table 4, the weight reduction between successive models is approximately 4.06 tonnes. This reduction is significant and can contribute to improved cargo capacity and enhanced fuel efficiency. However, reductions in stiffener quantity must be carefully controlled. Although Sandwich E represents the lightest configuration, it does not satisfy the allowable stress criteria and is therefore not recommended. In contrast, Sandwich D, with a structural weight of 116.42 tonnes, is proven to be safe with respect to both stress and deformation limits for the 5–15–5 mm sandwich plate configuration.

Table 4. sandwich plate construction weight

Model	Type	Stiffener Distance (mm)	Weight (ton)	Weight Reduction (tons)	Weight Reduction (%)
Existing	Conventional steel	610	167.29		
1	Sandwich A	610	128.60	38.69	23.13%
2	Sandwich B	762	124.54	42.75	25.55%
3	Sandwich C	1016	120.48	46.81	27.98%
4	Sandwich D	1524	116.42	50.87	30.41%
5	Sandwich E	Without stiffener	112.36	54.93	32.83%

For comparison, a conventional steel plate deck constructed with the same stiffener spacing of 610 mm has a total structural weight of 167.29 tonnes. Relative to this baseline, Sandwich A achieves a weight reduction of 38.69 tonnes, equivalent to 23.13%. As stiffener spacing increases, the structural mass continues to decrease, reaching a maximum reduction of 32.83% in Sandwich E. These results are consistent with previous studies by Wahid et al. [7] and Pambudi et al. [10], which reported substantial weight savings through the application of sandwich plate systems in ship deck and bottom structures.

4. Conclusion

The findings of this study demonstrate that sandwich plates with a 5–15–5 mm thickness configuration can provide satisfactory structural performance and represent a viable alternative to conventional steel plates for barge deck applications. Finite element simulations indicate that all stiffener spacing variations up to 1,524 mm comply with the Lloyd′s Register allowable stress limit of 175 MPa. However, the configuration without stiffeners exceeds both stress and deformation limits and is therefore unsuitable for practical implementation.

Deformation analysis reveals that the maximum deformation generally occurs on the port side of the deck, particularly in regions that lack direct support from stiffeners or underlying girders. As stiffener spacing increases, deformation magnitude also increases, and the location of maximum deformation may shift due to edge effects and asymmetric support conditions. Among all configurations examined, a stiffener spacing of 1,524 mm represents the maximum spacing that remains acceptable in terms of both stress and deformation performance.

This study was conducted under the assumption of ideal plate conditions, without accounting for initial imperfections. In practical ship construction, imperfections such as welding-induced distortion, residual stresses, and geometric deviations are unavoidable and may reduce buckling resistance, increase deformation, and lead to higher local stress concentrations. Consequently, the omission of geometric imperfections and nonlinear material behaviour should be regarded as a limitation of this study. Future research is recommended to incorporate these factors to obtain results that more closely represent actual ship structural performance.

Acknowledgment

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