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Deflections Analysis of Ship Hull and Deckhouse by Numerical Approach *

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***Abstract*—In modern marine vessels, there is usually a long deckhouse or superstructure in the area of main deck. If the ship hull bends due to the sea and other external loads, then the deckhouse or superstructure bends in response to the loads transmitted to it by its connection to ship hull. These loads consist of the distributed longitudinal shear forces and distributed vertical forces acting on the lower edges of the sides of deckhouse. Depending on the rigidity of the substructure (bulkheads, frames, supports, etc.), the deckhouse is forced more or less into the bending curve of hull by additional vertical forces. The presence of the deckhouse influences the structural behavior of the ship hull. The rigidity can then be considerably greater than that of the ship hull alone if the deckhouse is long enough and the ship hull and the deckhouse are made of the same material and effectively connected together. In addition to these influences on the overall bending stiffness and the corresponding stress curves, local stress concentrations can be expected at the ends of the deckhouse, because here the structure is transformed abruptly from that of a beam consisting only of the main hull alone to that of hull plus deckhouse. In this paper, deflections for the inclination of the deckhouse forward bulkhead 90o, without main deck supports and those with main deck supports will be analyzed by Finite Element Method.**

Keywords*—Bending Stiffness, Deckhouse, Deflection, Finite Element Method, Forward Bulkhead, Hull, Local Stress Concentrations, Main Deck Supports, Superstructure

I. Introduction

A long deckhouse or superstructure in the area of main deck of modern marine vessels, contributes to the longitudinal strength of the entire ship. Extremely high stress peaks occur at the ends of the deckhouse or superstructure, which have led to damages. The problem statement is to investigate the influence of stiffness of the main deck on the effective contribution of deckhouse to the longitudinal strength of ship by numerical approach. The stiffness of the main deck plays an important role in the deflection of deckhouse together with the ship hull. The aim of this paper is to highlight the influence of stiffness of the main deck through its supports on the deflection of ship hull and deckhouse by using Finite Element Analysis. The objective of this research is firstly to conduct a detailed study of the literature on this problem; then to create a finite element calculation model, based on the model studies by Paulling and Payer [1]. Another objective is to document and comment on the calculated results.

II. Summary of Influencing Factors

In the past, many researchers have investigated the interaction between ship hull and deckhouse. There were previous conducted studies using simple beam theory. In view of these studies, the specific physical factors to be considered for assessing the validity of the simple beam theory applied to the discontinuous beam structure are as follows: A. Stiffness of the main deck B. Shear effects C. Geometry of the deckhouse D. Side openings E. 3-dimensional effects F. Slips G. Other factors Out of the above-mentioned factors, stiffness of the main deck which is closely linked to the deflections and curvatures of the

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ship hull and deckhouse, will be described. Other factors will be examined in the future work.

III. Stiffness of The Main Deck

Here, the main deck is defined as a deck that forms the upper flange of the ship hull support and to which the deckhouse is assumed to be rigidly connected. According to Fig. 1, two types of forces, namely normal forces N(x) and shear forces S(x), are involved in the connection between the ship hull and deckhouse [2]. These forces are defined for the unit length.

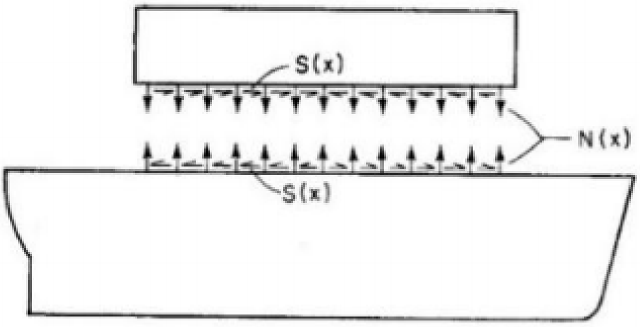


Figure I: **Normal Forces N(x) and Shear Forces S(x) at the Connection between Ship Hull and Deckhouse**

In the extreme case, in which the normal forces N(x) are zero, only the shear forces S(x) act in the connection between the ship hull and deckhouse. When the ship hull is in "hogging", the free-body diagram of the deckhouse, as in Fig. 2, clearly shows that the acting shear forces S(x) cause the deformation of the deckhouse into the form of "sagging" with a concave upward curvature while the ship hull deforms with the opposite curvature. Since there are no axial forces acting, the integration of all shear forces acting on the base of the deckhouse must be zero. Therefore, near the middle of the deckhouse length S(x) is zero, as in Fig. 2, and an increase in the magnitude of S(x), but with opposite sign, expected towards the ends of the deckhouse.

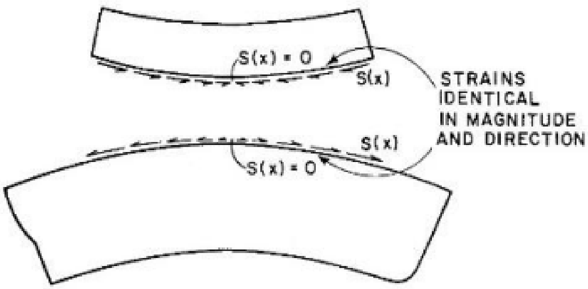


Figure II: **Free Body Diagram of the Ship Hull and Deckhouse under the Shear Forces S(x)**

This extreme case is obviously not possible in practice, since the deckhouse's own weight creates a normal force N(x). However, the example shows the theoretical possibility that the curvature of the deck and that of the deckhouse could arise with opposite signs. This indicates the strain distribution, which is linear through the height of the ship hull and linear through the height of the deckhouse (the validity of the application of the simple beam theory is assumed to be independent for the ship hull and the deckhouse), but not collinear through the entire cross-section. Therefore, as shown in Fig. 3, the strain distribution is interrupted in the middle of the deckhouse length on the main deck and assumption (a) (Any cross-section of the beam that are plane and normal to the neutral axis before bending remain plane and normal to the neutral axis after bending.) of the simple beam theory cannot be applied to the entire ship cross-section. This is correct in the middle of the deckhouse length for a long deckhouse.

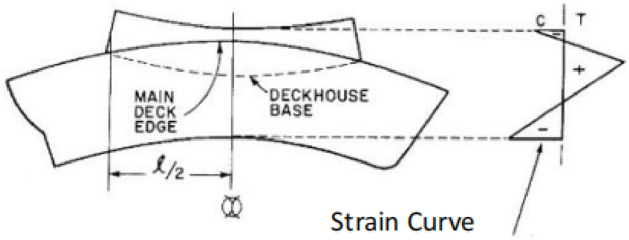


Figure III: **Strain Distribution at the Deckhouse Midlength under the Shear Forces S(x)**

It is assumed that the shear forces $S(x)$ are zero and that only the normal forces $N(x)$ act [2]. It is better to express the normal forces $N(x)$ in terms of the vertical stiffness $k(x)$ as follows.

If $k(x)$, defined as the force per unit length at a location x, produces a relative vertical unit deflection between the edge of the main deck and the base of the deckhouse, then $N(x)$ can be expressed by the product:

$$N(x) = k(x) \cdot \Delta v(x) \tag{1}$$

where $\Delta v(x)$ is the relative vertical deflection between the deckhouse side and the edge of the deck at a point x.

The deflection of the deckhouse is measured at the base of its sides, while the deflection of the hull is measured at the edges of the deck.

If $N(x) = 0$, the stiffness of the deck $k(x)$ must be zero, or in other words, the deck is so weak that no forces are transmitted through the deck and the relative deflection can take any value.

In the other extreme case, where the deck is very vertically stiff, k(x) can be considered infinite. If this is the case, the deck forming the upper flange of the hull will, under the bending stress, assume the same curvature as the neutral axis of the hull. At the same time, if the connection between deckhouse and deck is a slip connection, then the strain curve in the middle of the deckhouse length will be, as for a pair of simple beams shown in Fig. 4.

The two shear and vertical forces are transmitted more realistically through the connection. As shown in Figure 5, the strain distribution in the area of the middle of the deckhouse length is linear throughout the entire cross-section, as with a simple beam, and assumption (a) of the simple beam theory applies. Since the stiffness effect, as mentioned here, is closely linked to the deflections and curvatures of the ship hull and deckhouse, this factor is sometimes also referred to as the differential deflection or curvature factor. In a realistic situation, the vertical stiffness lies between the extreme values assumed above and all normal forms of the connection transmit a certain amount of shear [2]. Therefore, the hull-deckhouse combination behaves in a certain middle form. The strain curve could then take the shape shown in Figure 6, which runs linearly through the hull and the deckhouse, but not continuously through the entire cross-section. Although the vertical stiffness k(x) (also called the foundation modulus) provides good physical insight into the problem, it is nonetheless difficult to measure or calculate in practice. Their value can be influenced by many factors of a local condition: for example, the detailed arrangement of the deck's structures and the supporting structure of the deck. For the rigid transverse bulkheads, k(x) can be assumed to be infinite, while k(x) assumes some finite value at the points far from the rigid transverse bulkheads. These wide variations in magnitude again make the problem more difficult to solve and the application of stiffness or the concept of foundation unclear. In the two cases discussed above, another extreme case is missing, which can arise when the curvature of the deckhouse and that of the deck have the same sign, but that of the deckhouse has a larger amount [2]. As shown in Figure 7, the strain curve can show an interruption on the deck, but with a greater strain in the deckhouse than the strain in the deckhouse calculated using simple beam theory. This situation can occur, for example, if the deckhouse had an initial curvature when it was connected to the main deck, or because of the arrangements of the bulkheads supporting the main deck. In the summary it can be described that in a ship hull-deckhouse combination the strain curve is not necessarily linear throughout the entire cross-section. If the ship hull and deckhouse can be assumed to be individual simple beams, then the strains are linear through each beam. But there may be a discontinuity on the deck. In the deckhouse, the strains can be less than, equal to, or greater than the strains calculated by simple beam theory. The strains in the deckhouse depend significantly on the vertical stiffness of the deck and the supporting system as well as the shear strength of the connection.

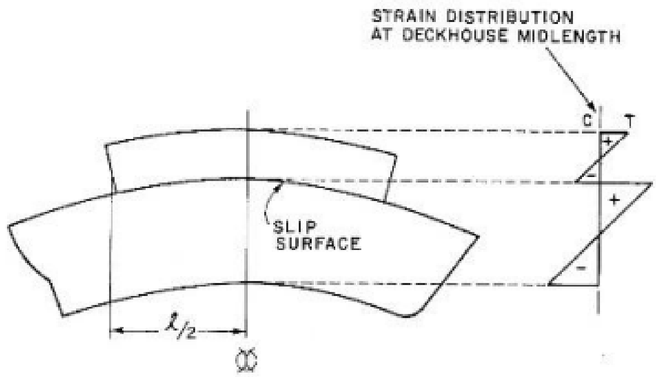


Figure IV: **Strain Distribution at the Deckhouse Mid-length under the Normal Forces N(x)**

From a design standpoint it can be summarized that the supported deck should be made as rigid as possible if the deckhouse as a whole is to contribute to the longitudinal strength of the ship. For this purpose, the ship hull-deckhouse connection should be made strong enough to ensure sufficient rigidity and to be able to withstand the large shear forces that occur particularly at the ends of the deckhouse. On the other hand, if the deckhouse is to be free from the stress transmitted by the hull, then the elastic supports and/or the shear-eliminating knee plates or the slip connections can be introduced in the design. These help to reduce the magnitude of the normal force N(x) and that of the shear force S(x), but it is difficult to make them fully effective in practice.

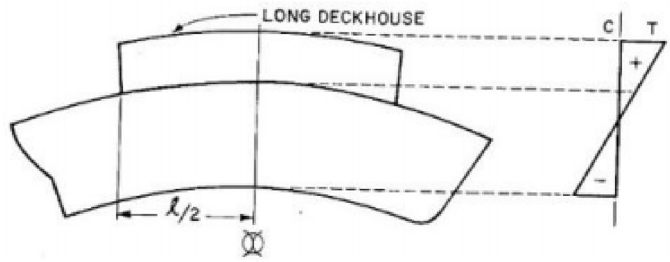


Figure V: **Ideal Strain Distribution at the Deckhouse Mid-length under the Normal Forces N(x) and Shear Forces S(x)**

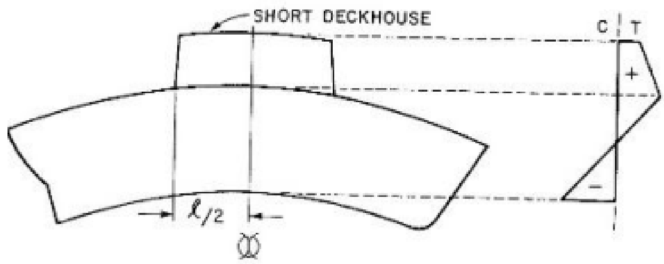


Figure VI: **Real Strain Distribution at the Deckhouse Mid-length under the Normal Forces N(x) and Shear Forces S(x)**

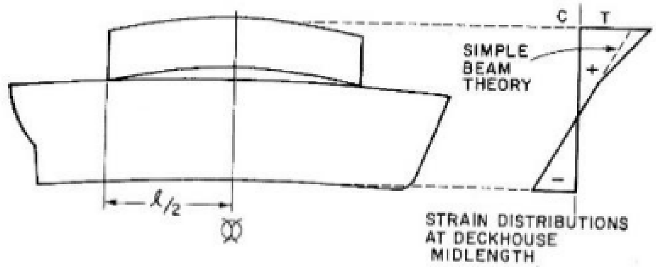


Figure VII: **Strain Distribution at the Deckhouse Mid-length (Deckhouse with Initial Curvature**

IV. Description of Hull-Deckhouse Mathematical Model (Procedure of Research)

In this paper, a finite element mathematical model is built based on the model researches of Paulling and Payer [1]. Due to the symmetrical conditions, a quarter of the ship hull-deckhouse model is generated. The calculation is done by using Ansys Structural Analysis software. The ship hull-deckhouse calculation model with the inclination of deckhouse forward bulkhead 90o without main deck supports is shown in Fig. 8 and that with main deck supports in Fig. 9 and the midship section of hull-deckhouse model in Fig. 10.

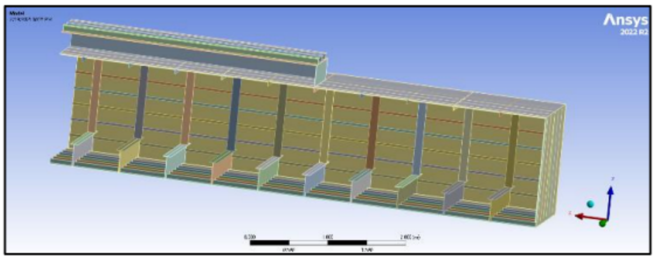


FIGURE VIII: **Ship Hull-Deckhouse Calculation Model for the Inclination of Deckhouse Forward Bulkhead 90o without Main Deck Supports**

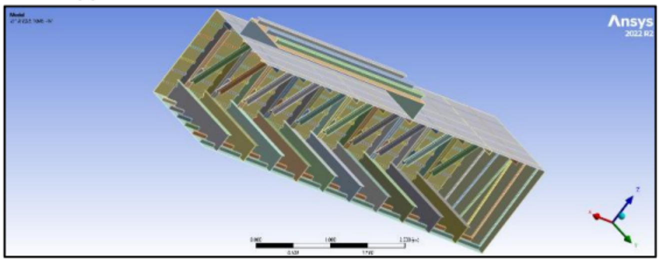


FIGURE IX: **Ship Hull-Deckhouse Calculation Model for the Inclination of Deckhouse Forward Bulkhead 90o with Main Deck Supports**

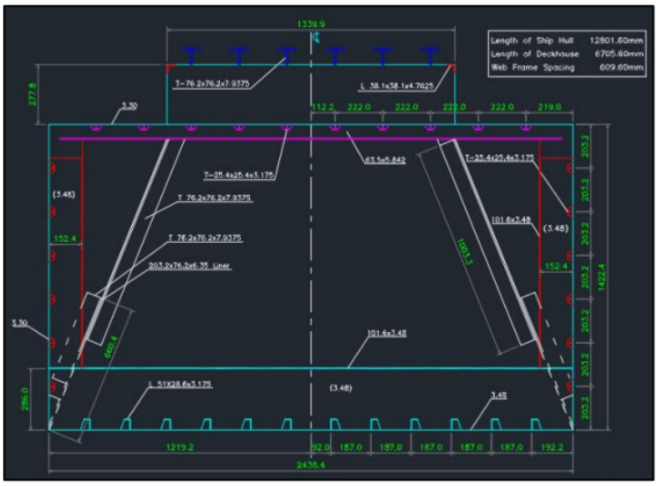


FIGURE X: **Midship Section of Hull-Deckhouse Model**

The calculation procedure in the Ansys Static Structural Analysis software is shown in Fig. 11.

FIGURE XI: **Calculation Procedure in Ansys Static Structural Analysis Software**

As the pre-processing, the steps as shown in Fig. 12 are undertaken. Under Model (A4), there are Geometry Imports, Geometry, Materials, Coordinate Systems, Connections and Mesh. The geometry of ship hull-deckhouse model is drawn by AutoCAD and then imported to the Design Modeler of Ansys in which the naming of solid parts and some other necessary preparations for the geometry of Model (A4) have been performed.

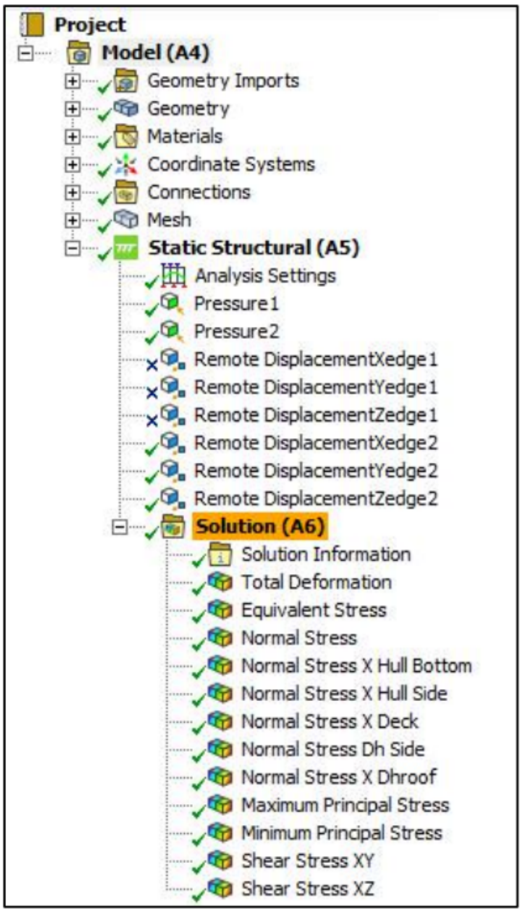
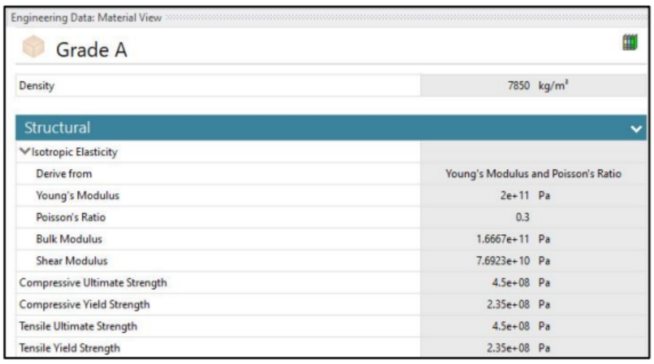


FIGURE XII: **Pre-processing Steps for the Calculation of Ship Hull-Deckhouse Model**

The material of the ship hull-deckhouse model is shipbuilding quality grade A mild steel and the respective engineering data are mentioned in Fig. 13.



Engineering Data: Material View

Grade A

Density	7850 kg/m³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	2e+11 Pa
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+11 Pa
Shear Modulus	7.6923e+10 Pa
Compressive Ultimate Strength	4.5e+08 Pa
Compressive Yield Strength	2.35e+08 Pa
Tensile Ultimate Strength	4.5e+08 Pa
Tensile Yield Strength	2.35e+08 Pa

FIGURE XIII: **Pre-processing Steps for the Calculation of Ship Hull-Deckhouse Model** he global coordinating system is used for the Coordinate System. For connections, there are contacts including 444 contact regions using bonded type, automatic scope mode and pinball region radius 50 mm as mentioned in Fig. 14.

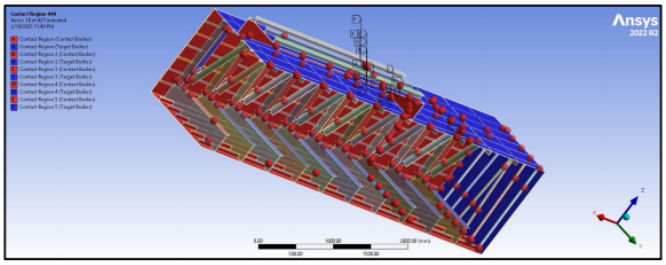


FIGURE XIV: **Contacts including 444 Contact Regions for Connection in Ship Hull-Deckhouse Calculation Model**

The meshing of ship hull-deckhouse calculation model is generated by Automatic Method, element size 50 mm, use adaptive sizing – No, resulting 212593 nodes and 28458 elements as shown in Fig. 15.

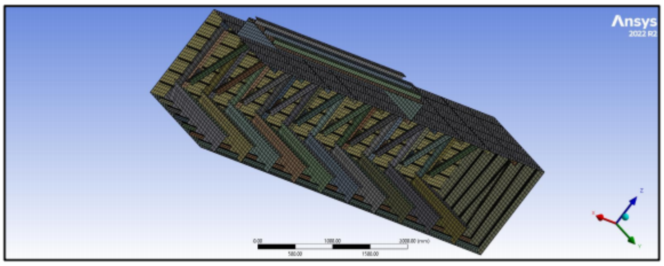


FIGURE XV: **Meshing of Ship Hull-Deckhouse Calculation Model**

Under Static Structural (A5), Pressure1 0.005671 MPa, Pressure2 0.005671 MPa, Remote Displacement X, Y and Z including translational and rotational dispacements X, Y and Z are specified for the boundary conditions as described in Fig. 16.

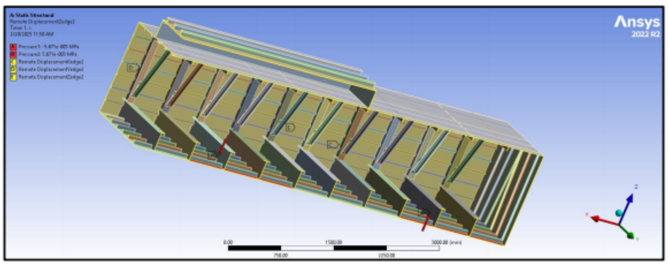


FIGURE XVI: **Boundary Conditions of Ship Hull-Deckhouse Calculation Model**

Under Solution (A6), the required results such as Total Deformation, Equivalent Stress, Normal Stress for all bodies, Normal Stress X Hull Bottom, Normal Stress X Hull Side, Normal Stress X Main Deck, Normal Stress X Deckhouse Side, Normal Stress X Deckhouse Roof, Shear Stress XY and Shear Stress XZ are selected and solved. As the post-processing, the results are presented in tables and figures for the discussions and conclusion.

V. RESULTS AND DISCUSSIONS

The calculations were carried out on the desktop computer with the Ansys software [3]. The deflections of ship hull and deckhouse are calculated by numerical approach. As the preprocessing steps, the load case of the model studies by Paulling and Payer [1] was used as the basis for the load on the ship hull-deckhouse calculation model; the conditions of symmetry were applied to the boundary conditions of the calculation model, meshing of hull-deckhouse geometry was done, loads and boundary conditions were entered and the required deflections calculated as described above. As the post-processing steps of numerical approach, from the calculated results, the comparison between the deflections of the ship hull without main deck supports and those of the ship hull with main deck supports is shown in Table I and the comparison between the deflections of the deckhouse without main deck supports and those of the deckhouse with main deck supports for the inclination of forward bulkhead 90° in Table II.

TABLE I: DEFLECTION MEASUREMENTS WITH AND WITHOUT SUPPORTS

S. No.	Position X (mm)	Without Supports (mm)	With Supports (mm)
1	-3356.3	2.9557	2.1795
2	-3047.0	3.2706	2.4631
3	-2747.1	3.7177	2.8225
4	-2447.9	4.1971	3.2326
5	-2147.1	4.7724	3.6895
6	-1847.7	5.3361	4.1515
7	-1498.3	6.0643	4.7180
8	-1148.5	6.7728	5.2893
9	-798.3	7.5247	5.8836
10	-398.4	8.3819	6.5532
11	-0.5	9.2286	7.2291

TABLE II: UPDATED DEFLECTION MEASUREMENTS WITH AND WITHOUT SUPPORTS

S. No.	Position X (mm)	Without Supports (mm)	With Supports (mm)
1	-3356.3	2.9823	2.5456
2	-3047.0	3.6502	3.1623
3	-2747.1	4.3526	3.7829
4	-2447.9	5.0917	4.4189
5	-2147.1	5.8435	5.0716
6	-1847.7	6.6085	5.7234
7	-1498.3	7.5085	6.5038
8	-1148.5	8.4277	7.2855
9	-798.3	9.3447	8.0745
10	-398.4	10.3960	8.9780
11	-0.5	11.4470	9.8789

The decrease in deflections of Ship Hull and Deckhouse between without and with main deck supports (Deckhouse Forward Bulkhead 90o) is mentioned in Table III and Table IV respectively as the post-processing steps.

TABLE III: DEFLECTION MEASUREMENTS WITH AND WITHOUT SUPPORTS AND DECREMENT VALUES

S. No.	Position X (mm)	Without Supports (mm)	With Supports (mm)	Decrement (mm)
1	-3356.3	2.9557	2.1795	0.7762
2	-3047.0	3.2706	2.4631	0.8075
3	-2747.1	3.7177	2.8225	0.8952
4	-2447.9	4.1971	3.2326	0.9645
5	-2147.1	4.7724	3.6895	1.0829
6	-1847.7	5.3361	4.1515	1.1846
7	-1498.3	6.0643	4.7180	1.3463
8	-1148.5	6.7728	5.2893	1.4835
9	-798.3	7.5247	5.8836	1.6411
10	-398.4	8.3819	6.5532	1.8287
11	-0.5	9.2286	7.2291	1.9995

Table IV: Updated Deflection Decrease With Supports Compared to Without Supports

S. No.	Position X (mm)	Without Supports (mm)	With Supports (mm)	Decrement (mm)
1	-3356.3	2.9823	2.5456	0.4367
2	-3047.0	3.6502	3.1623	0.4879
3	-2747.1	4.3526	3.7829	0.5697
4	-2447.9	5.0917	4.4189	0.6728
5	-2147.1	5.8435	5.0716	0.7719
6	-1847.7	6.6085	5.7234	0.8851
7	-1498.3	7.5085	6.5038	1.0047
8	-1148.5	8.4277	7.2855	1.1422
9	-798.3	9.3447	8.0745	1.2702
10	-398.4	10.3960	8.9780	1.4180
11	-0.5	11.4470	9.8789	1.5681

The differential deflections between the ship hull and deckhouse for the inclination of deckhouse forward bulkhead 90o without main deck supports are presented in Table V and those with main deck supports in Table 6 also as the post-processing steps.

Table V: Ship Hull vs Deckhouse Deflection and Differential Deflection

S. No.	Position X (mm)	Ship Hull (mm)	Deckhouse (mm)	Differential Deflection (mm)
1	-3356.3	2.9557	2.9823	0.0266
2	-3047.0	3.2706	3.6502	0.3796
3	-2747.1	3.7177	4.3526	0.6349
4	-2447.9	4.1971	5.0917	0.8946
5	-2147.1	4.7724	5.8435	1.0711
6	-1847.7	5.3361	6.6085	1.2724
7	-1498.3	6.0643	7.5085	1.4442
8	-1148.5	6.7728	8.4277	1.6549
9	-798.3	7.5247	9.3447	1.8200
10	-398.4	8.3819	10.3960	2.0141
11	-0.5	9.2286	11.4470	2.2184

Table VI: Ship Hull vs Deckhouse Deflection and Differential Deflection (With Supports)

S. No.	Position X (mm)	Ship Hull (mm)	Deckhouse (mm)	Differential Deflection (mm)
1	-3356.3	2.1795	2.5456	0.3661
2	-3047.0	2.4631	3.1623	0.6992
3	-2747.1	2.8225	3.7829	0.9604
4	-2447.9	3.2326	4.4189	1.1863
5	-2147.1	3.6895	5.0716	1.3821
6	-1847.7	4.1515	5.7234	1.5719
7	-1498.3	4.7180	6.5038	1.7858
8	-1148.5	5.2893	7.2855	1.9962
9	-798.3	5.8836	8.0745	2.1909
10	-398.4	6.5532	8.9780	2.4248
11	-0.5	7.2291	9.8789	2.6498

From Table V and Table VI, it can be seen that the differential deflection between the hull and deckhouse in the case with main deck supports is larger than that in the case without main deck supports. By using the above-mentioned data of Table I, Table II, Table III, Table IV, Table V and Table VI, the respective curves are plotted as follows: Ship Hull and Deckhouse Deflection.

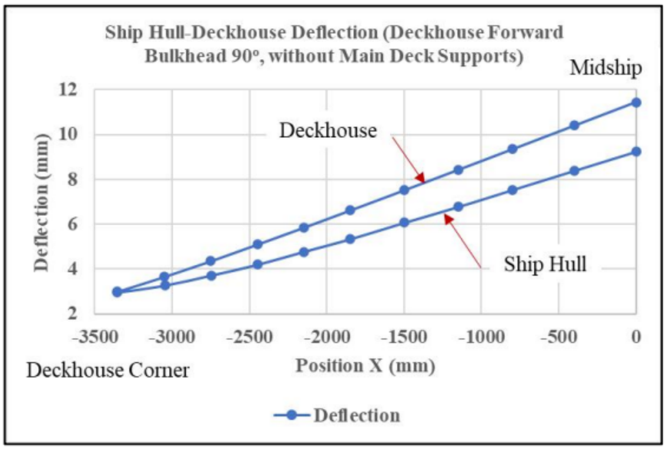


Figure XVII: **Curves of Ship Hull and Deckhouse Deflection (Deckhouse Forward Bulkhead 90o) without Main Deck Supports**

The curves of ship hull and deckhouse deflection (deckhouse forward bulkhead 90o) without main deck supports are shown in Fig. 17 and those with main deck supports in Fig. 18. The curves of ship hull deflection (deckhouse forward bulkhead 90o) without and with main deck supports are shown in Fig. 19 and those of deckhouse in Fig. 20.

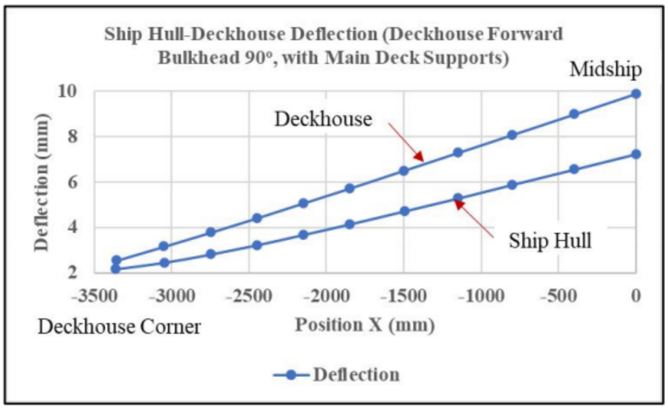


Figure XVIII: **Curves of Ship Hull and Deckhouse Deflection (Deckhouse Forward Bulkhead 90o) with Main Deck Supports**

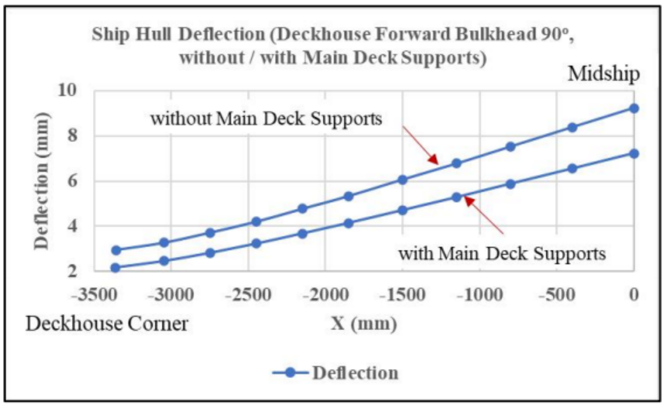


Figure XIX: **Curves of Ship Hull deflection (Deckhouse Forward Bulkhead 90o) without and with Main Deck Supports**

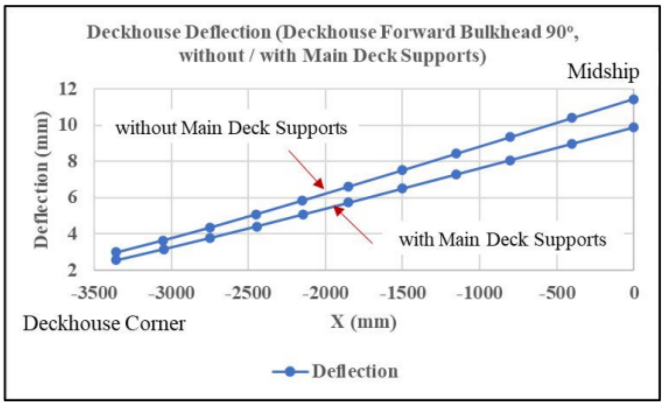


Figure XX: **Curves of Deckhouse Deflection (Deckhouse Forward Bulkhead 90o) without and with Main Deck Supports**

Decrease in Deflections of Ship Hull and Deckhouse and Differential Deflections between Ship Hull and Deckhouse. The curves of decrease in deflections of ship hull and deckhouse between without and with main deck supports (deckhouse forward bulkhead 90o) is shown in Fig. 21. The curves of differential deflections between ship hull and deckhouse (deckhouse forward bulkhead 90o, without / with main deck supports) is mentioned in Fig. 22.

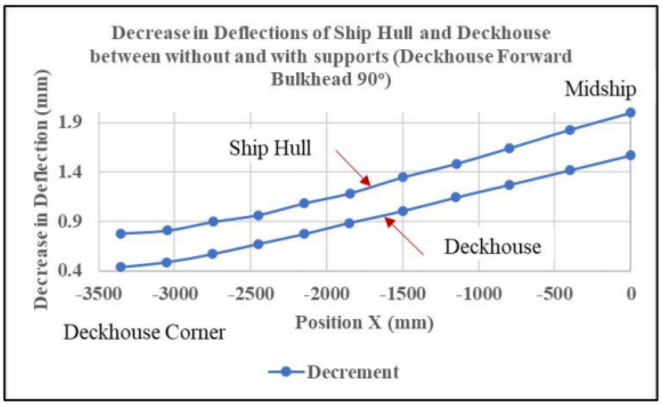


FIGURE XXI: **Curves of Decrease in Deflections of Ship Hull and Deckhouse between without and with Main Deck Supports (Deckhouse Forward Bulkhead 90o)**

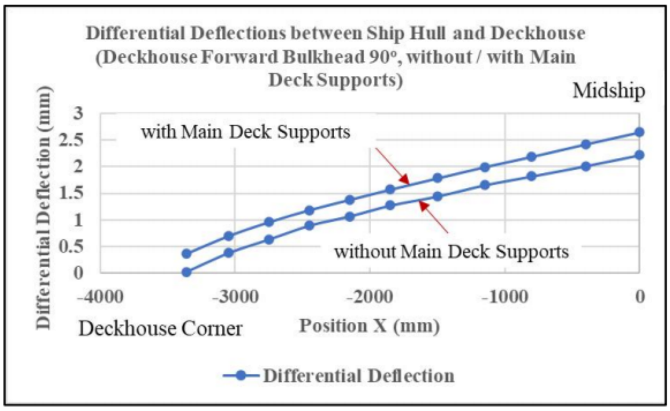


FIGURE XXII: **Curves of Differential Deflections between Ship Hull and Deckhouse (Deckhouse Forward Bulkhead 90o, without / with Main Deck Supports)**

The deflections of ship hull and deckhouse in the calculation by Ansys static structural software for deckhouse forward bulkhead 90o without main deck supports are illustrated in Fig. 23 and those with main deck supports in Fig. 24.

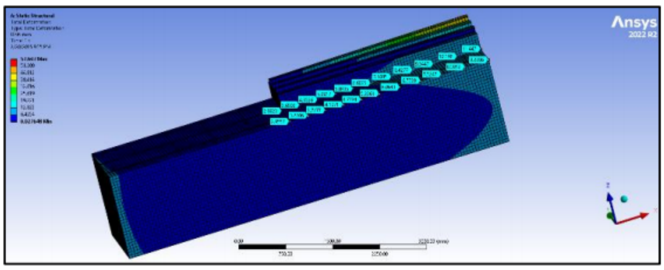


FIGURE XXIII: **Deflections of Ship Hull and Deckhouse in the Calculation by Ansys Static Structural Software for Deckhouse Forward Bulkhead 90o without Main Deck Supports)**

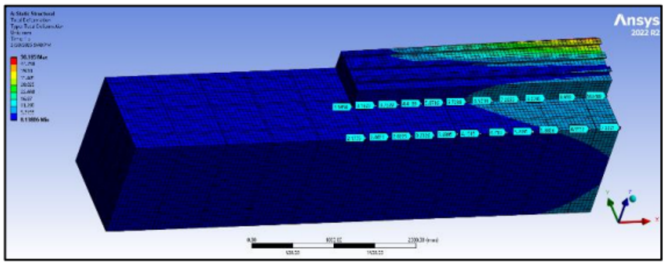


FIGURE XXIV: **Deflections of Ship Hull and Deckhouse in the Calculation by Ansys Static Structural Software for Deckhouse Forward Bulkhead 90o with Main Deck Supports)**

From Fig. 17 and Fig. 18, it is found that the deflections of deckhouse are larger than those of ship hull for both cases without and with main deck supports. Therefore, it leads to the fact that the deckhouse structure is strong and the connection between the ship hull and deckhouse is sufficient enough so that the deckhouse could contribute to the longitudinal strength of ship for both cases. From Fig. 19 and Fig. 20, it is found that the deflections of ship hull and those of deckhouse (deckhouse forward bulkhead 90o, with main deck supports) are smaller than those (deckhouse forward bulkhead 90o, without main deck supports). This is because of the increase in stiffness of main deck due to its supports, both ship hull and deckhouse deflect lesser, but the decrement in deflections of ship hull is larger as compared to that of deckhouse as shown in Fig. 21. It means that the deckhouse takes more load from the ship hull and the deckhouse with main deck supports contributes better to the longitudinal strength of ship. In this case, the ship hull and deckhouse work together better and bend into the same curvature as well. Again, from the point of view of decrease in deflections between the two cases without and with main deck supports, it also means that the stress on main deck is transmitted more to the deckhouse which is now able to better contribute to the longitudinal strength of ship which can be seen in Fig. 17, Fig. 18, Fig. 19, Fig. 20 and especially in Fig. 21. In addition to this, it is also noted that the connection between the ship hull and deckhouse is sufficient enough due to the good contacts which enable the efficient transmission of stresses from the ship hull to deckhouse through the main deck. On the other hand, from the differential deflection (between the ship hull and deckhouse) standpoint, it is found that the differential deflection with main deck supports is greater than that without main deck supports as presented in Fig. 22. It also highlights that the deckhouse deflects more than the ship hull does and the deckhouse take parts better in the longitudinal strength of ship.

VI. Conclusion

From the above-mentioned discussions, it is concluded that in the case with main deck supports, the deckhouse contributes better to the longitudinal strength of ship than without main deck supports and the Von Mises equivalent stress in the deckhouse corner will decrease consequently. In the future research, the calculation of Von Mises equivalent stresses in the deckhouse corner for the inclination of deckhouse forward bulkhead 90o, 60o and 45o without and with supports of main deck will be conducted by numerical approach in order to find out the optimum inclination from the point of view of stress reduction.

Competing interests

The authors declare no competing interests.

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Ethical Statement

In this article, the principles of scientific research and publication ethics were followed. This study did not involve human or animal subjects and did not require additional ethics committee approval.

Declaration Of AI Usage

No AI tools were used in the creation of this manuscript.

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