Paper presented at the 12th Annual DIVK Conference
November 17-19, 2024, Belgrade, Serbia

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EVALUATING THE STRUCTURAL INTEGRITY OF NOVEL DECKHOUSES ON TANKER SHIPS UNDER EXTREME CONDITIONS

PROCENA INTEGRITETA KONSTRUKCIJA NOVIH NADGRAĐA NA TANKERIMA U EKSTREMNIM USLOVIMA

Originalni naučni rad / Original scientific paper
Rad primljen / Paper received: 27.01.2025
https://doi.org/10.69644/ivk-2025-01-0019

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Keywords
- thin-walled superstructure
- finite element analysis (FEA)
- deckhouse
- tanker
- extreme conditions
- environmental loads

Abstract

This paper assesses the structural integrity of atypical superstructures mounted on the decks of two sister sea-going tankers under extreme load conditions. Namely, each tanker features a pair of deckhouses which are welded onto the existing deck structure girders, exposing them directly to harsh environmental loads. These deckhouses, designed as 'ad hoc' solutions resembling land-based structures with similar applications, serve as storage for ballast water treatment systems, added due to insufficient internal technical space within the existing ship structure. Given the lack of fully developed regulations for assessing the structural integrity of novel and atypical ship structures, classification rules typically require a direct structural assessment to ensure their structural integrity. Therefore, this study uses the finite element method to analyse extreme design load scenarios faced by these structures, including seawater loads from waves, wind loads, accelerations due to ship motions, and static loads from the structures' and internal equipment weights. Besides identifying critical areas, the findings reveal that the initially proposed deckhouse structures failed to meet the criteria for certain scantling arrangements and demonstrate how variations in scantlings affect the overall structural response. Based on these insights, general recommendations for modifying the deckhouse structure are proposed.

Ključne reči
- tankozido nadgrađe
- metoda konačnih elemenata (MKE)
- kućica
- tanker
- ekstremni uslovi
- spoljnja opterećenja

Izvod

U radu se daje procena integriteta atipičnih konstrukcija nadgrađa postavljenih na palube dva 'sestrinska' morska broda - tankera, u ekstremnim uslovima opterećenja. Tankeri imaju po dva nadgrađa koja su zavarena na postojeće nosače na palubi, što ih direktno izlaže ekstremnim spoljašnjim opterećenjima. Ova nadgrađa, projektovana kao 'ad hoc' rešenja nalik konstrukcijama za kopnene primene, služe kao skladišta za sisteme za tretman balastnih voda, a dodata su zbog nedovoljnog unutrašnjeg prostora u postojećoj konstrukciji broda. S obzirom na nedostatak potpuno razvijenih propisa za procenu integriteta konstrukcija novih i atipičnih brodskih konstrukcija, propisi i pravila klasifikacionih društava obično zahtevaju direktnu analizu konstrukcije kako bi se pokazao njen integritet. Stoga, ova studija primenjuje metodu konačnih elemenata u analizi scenarija ekstremnih projektnih opterećenja kojima su izložene ove konstrukcije, uključujući opterećenja od talasa u oluji, opterećenja vetrom, ubrzanja uzrokovana kretanjem broda i statička opterećenja od težine samih konstrukcija i unutrašnje opreme. Pored identifikacije kritičnih zona, rezultati otkrivaju da predložene konstrukcije nadgrađa nisu zadovoljile kriterijume za dimenzije elemenata konstrukcije i pokazuju kako varijacije u dimenzijama utiču na ukupni odziv konstrukcije. Na osnovu ovih uvida, predložene su opšte preporuke za modifikovanje strukture nadgrađa.

INTRODUCTION

Rules and regulations for the classification of ships prescribe standardized formulas and calculation procedures to evaluate the structural integrity of conventional ship structures. These procedures generally focus on assessing the buckling or yielding of critical elements in relation to the corresponding permissible stress criteria /1-3/. However, for non-standard ship structures or their arrangements, these standardized procedures are often not applicable. In such instances, rules and regulations require the proof of structural integrity of the particular structure by employing finite element analysis (FEA), conducted in accordance with recommended practices, /1-4/.

To evaluate the structural response of an atypical structural solution, this paper presents a finite element analysis conducted for two superstructure units (deckhouses) mounted on the decks of two identical tanker ships. Design of deckhouses is based on land-based objects with a similar purpose. These deckhouses were installed to accommodate storage for a ballast water treatment system (BWTS) added post-construction, after the ships had already entered service. This is driven by increasing environmental concerns in recent years, particularly the need to prevent the invasion of harmful organisms and pathogens into new ecosystems through ballast water discharge. Ballast water has been identified as one of the most significant threats to global marine biodiversity. As a result, emerging research and regulations /5, 6/ advocate and mandate the installation of advanced BWTS onboard ships to mitigate the spread of invasive aquatic species.

For ships already in service, internal technical space for such systems is often unavailable onboard of ships, as these requirements were not accounted for during the ship design phase. This limitation necessitates the installation of deckhouses on the main deck, which is an ‘ad hoc’ solution and unconventional structural arrangement. Unlike systems installed within the ship's internal structures, these externally mounted units are exposed to environmental loads such as waves and wind. This unique configuration raises additional challenges in assessing the structural performance of the ship, making detailed analysis of these installations essential.

Although various types of deckhouses are commonly found onboard ships, they remain sparsely investigated in the literature. This lack of research interest can be attributed to their relatively minor influence on the overall hull girder strength of ships /7/. The structural integrity of a ship is primarily ensured by its hull structure, which extends from the keel to the strength deck. Consequently, early research primarily concentrated on examining the impact of superstructures and deckhouses on the overall hull girder strength of ships /8-10/. Nevertheless, despite their smaller size compared to the hull, deckhouses are susceptible to extreme wave-induced loads acting on ships /11/. These loads include not only global hull girder loads but also localised ones, such as green water impacts on the ship deck, which can significantly affect structures mounted on the deck and pose considerable structural challenges /12, 13/. A novel development in this field is the use of movable deckhouses on large containerships to optimise deck cargo space. The impact of this innovative concept on the ship’s structural response has been explored in /14/.

Studies on deckhouses can also be categorised into those addressing impact loads. The effects of blast loading on deckhouses for military purposes have been investigated using the finite element method, as presented in /15/. Similarly, the impact of underwater explosions is explored in /16/, while recent research has increasingly focused on the interaction between ship deckhouses and bridge girders during collisions, as discussed in /17/.

In naval architecture, superstructures are primarily recognised for their aerodynamic influence on overall ship resistance /18, 19/. Their aerodynamic effects can be also relevant in contexts such as helicopter operations on military ships, as examined in /20/. More broadly, various structures mounted on the deck can significantly impact ship's aerodynamics and, consequently, its overall energy consumption /21, 22/.

From a general structural perspective, deckhouses are evaluated similarly to other ship structures, based on their scantlings and a range of structural integrity assessment methodologies /23/. For further insights into general approaches for assessing structural integrity of structures, see /24-26/. It should be noted that corrosion is not directly considered in such structural assessments. However, in ships, it is indirectly accounted for through the criteria for renewing structural elements during maintenance /27-30/. This approach acknowledges that modern coatings significantly extend the lifespan of structures and delay the onset of corrosion, /31/.

To conclude, there is a notable lack of studies on the structural integrity of superstructures (deckhouses) on ships, particularly non-typical structures installed post-construction. While these structures have been investigated in a broader context, the focus has predominantly been on their aerodynamic characteristics or response to impact loads. Similar structures have been studied, but their direct relevance to deckhouses is limited.

Given the increasing need for novel, non-typical, post-installed structures on ships - driven by emerging regulations requiring additional systems like water ballast systems or similar equipment - this study makes the following contributions:

- To the best of the authors' knowledge, this is one of the first studies to apply a standard FEA approach to evaluate non-standard deckhouse structure arrangements under extreme conditions, specifically for installations on existing ships.
- The analysis includes multiple scenarios of extreme load variations, such as wave pressures, wind pressures, accelerations due to ship motions (heave, pitch, roll), in addition to static loads from equipment and structural weights.
- Various scenarios involving scantling variations of the existing structural arrangement are assessed to determine their structural integrity.
- Practical recommendations for structural modifications are provided to enhance the performance and safety of such structures.

DECKHOUSES

Deckhouses are installed on two sister tanker ships, each designed for a deadweight of 46655 t. The main particulars of the vessels are as follows: length overall 183.2 m, breadth 32.2 m, height 18.8 m, and design draught 11 m (see the general arrangement in Fig. 1). A 3D model illustrating the deckhouses and their positions is provided in Fig. 2. In this figure, ‘PS’ denotes the port side (left deckhouse, when facing forward toward the bow), while ‘SB’ denotes the starboard side (right deckhouse, when facing forward toward the bow).

The deckhouses are constructed from mild structural steel (grade A), characterised by a minimum yield stress of 235 MPa, a modulus of elasticity of 206000 MPa, Poisson’s ratio of 0.3, and density of 7850 kg/m^3. The overall dimensions of deckhouses (length × breadth × height, excluding foundations below the structures and overhangs) are as follows: 7.0×4.38×4.4 m for the PS deckhouse and 5.3×3.65×2.7 m for the STB deckhouse (see Fig. 2). Figure 3 shows the internal technical space within one of the deckhouses, along the general steel stiffeners arrangements.

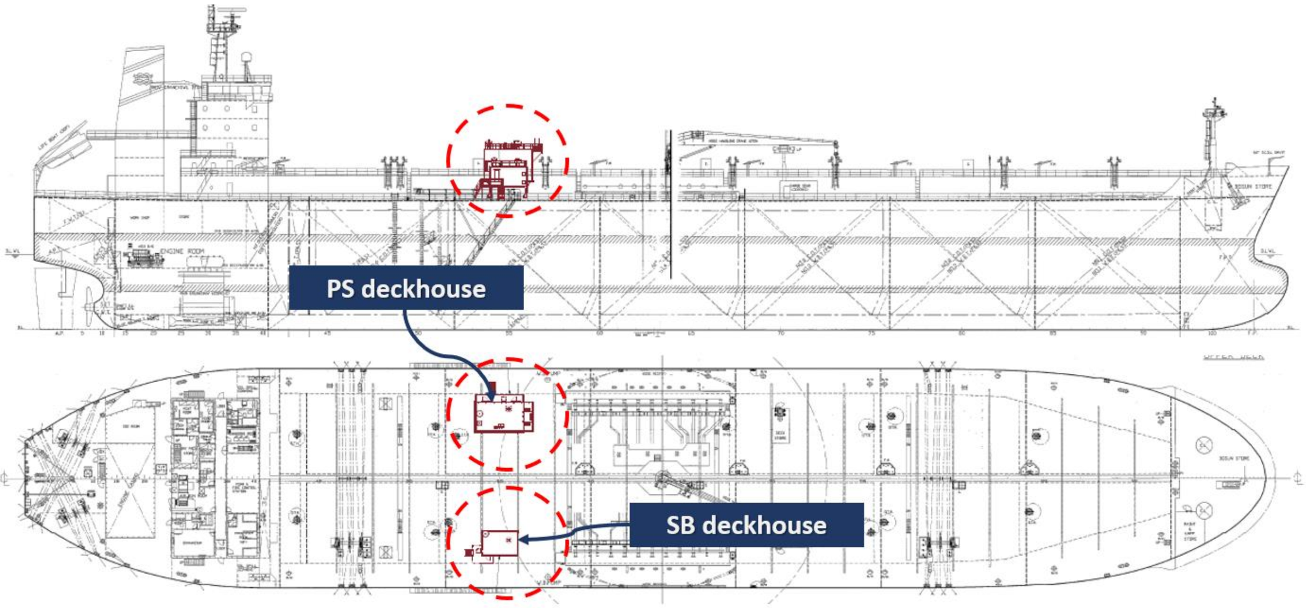

Figure 1. The extract from the general arrangement plan of one of the ships with marked locations for the deckhouses.

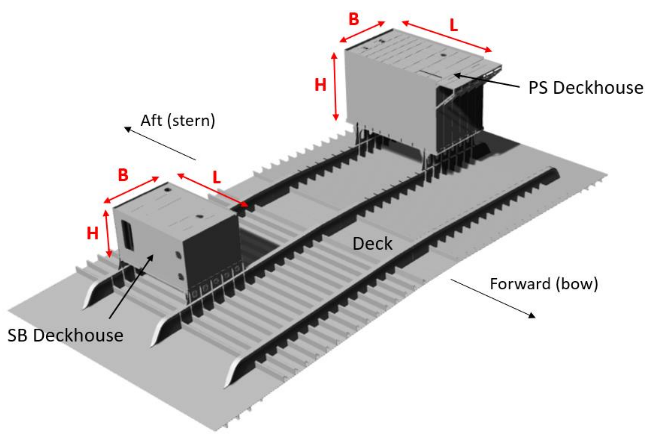

Figure 2. 3D model of deckhouses and part of the deck.

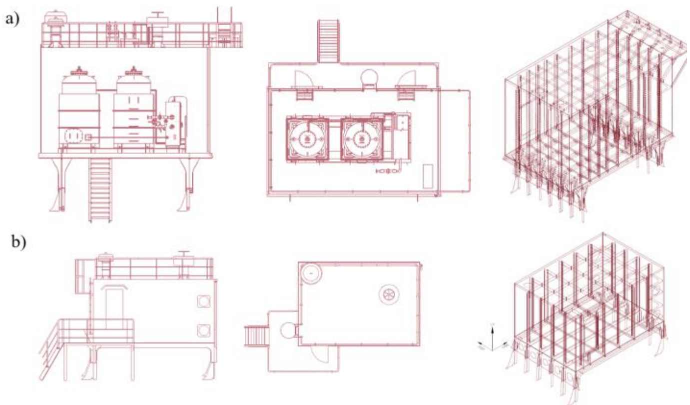

Figure 3. General overview of deckhouses: a) PS deckhouse, b) SB deckhouse.

METHODOLOGY

Finite element modelling

Rules, regulations, and relevant literature /1-4/, recommend applying the thin-plate theory of small deformations to analyse thin-walled structures, such as shell plating, girders, and stiffeners in ship structures, due to their inherent slenderness. Furthermore, as suggested in the literature, a linear-elastic material model is employed, assuming a linear stress-strain relationship. In that context, the von Mises stress yield criterion is used, along with 90 %, 80 % and 70 % share of yield stress. Multiple criteria are introduced here due to absence of definitive rule-based stress requirements for such structures.

Furthermore, the bottom nodes of the foundation structure in both deckhouses are constrained and simulated as clamped, with no translations or rotations allowed in any of the three global axis directions. This boundary condition corresponds to the intersection between the ship's deck structure and the deckhouses' structures. Two finite element models are developed, one for each deckhouse. Average dimensions of thin-plate elements are in the range between 100 and 150 mm. The PS deckhouse model comprises 22357 finite elements and 22313 nodes, while the SB deckhouse model contains 13927 finite elements and 12652 nodes (see Figs. 4 and 5, respectively). To summarise, the FE models are created based on the following principles:

1. All structural members from the 3D model influencing the structural integrity of the deckhouses are considered: shells, girders, stiffeners, brackets. This means that the global model is produced with a refined mesh to acquire stress concentrations.
2. All structural members are modelled as thin-plate elements to account for the thin-plate theory, by dominantly using four-node plate elements. In addition, three-node plate elements are employed in regions in which four-node plate elements are found to be insufficient to retain the geometry.
3. 6 elements are modelled in between the stiffeners in order to properly acquire the tertiary response of the structure, i.e., bending between the stiffeners.
4. All plate FE element aspect ratios are kept as minimum as possible to keep the validity of calculations.

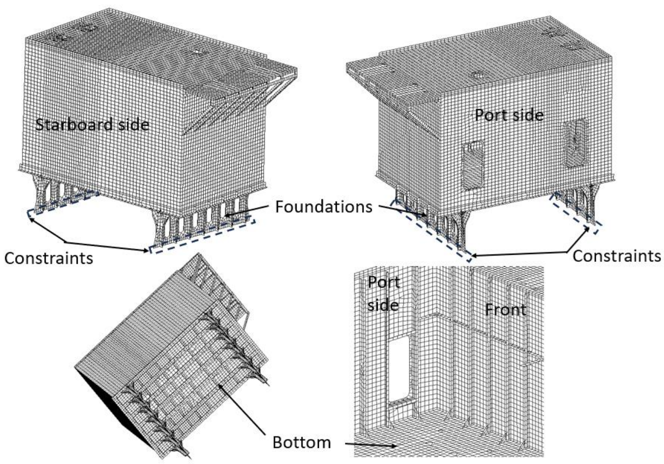

Figure 4. PS deckhouse FE model.

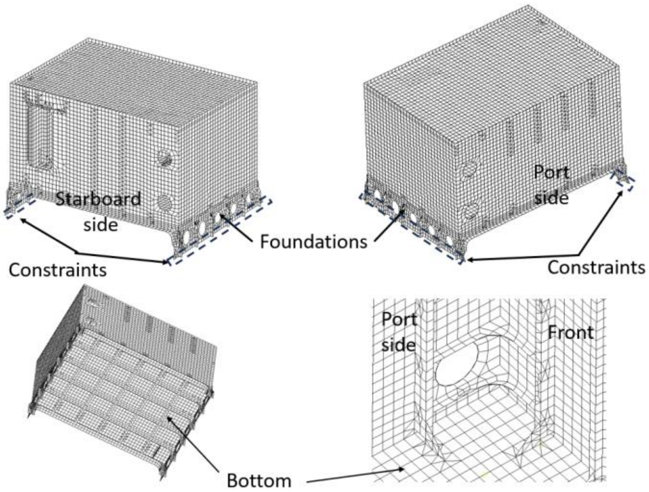

Figure 5. SB deckhouse FE model.

Loads

The loads considered include design pressures, wind pressures, accelerations due to deckhouse (ship) motion, and the weights of the structure and internal equipment. All load calculations are performed in accordance with /1/, which provides a detailed calculation procedure and application. The walls of the deckhouse are labelled as follows: aft wall, front wall, starboard-side wall, and port-side wall. Design pressures account for the impact of large waves during extreme sea state conditions (e.g., severe storms), with green water loads resulting from wave splashing against the walls of the deckhouses. The design pressure h is calculated according to Eq.(1). Coefficients α, δ, β, λ and γ depend on the ship's particulars and position of the deckhouse wall (unprotected front, sides, or aft end walls), see /1, 32/. It is important to note that the pressure head must not fall below the minimum value defined by Eq.(2). Input L_2 represents the ship length between perpendiculars, which is 174 m. The surface areas of the walls subjected to design pressures are as follows: for the PS deckhouse, 19.87 m^2 (front and aft ends) and 31.8 m^2 (sides); for the SB deckhouse, 10.25 m^2 (front and aft ends) and 13.27 m^2 (sides). The water column height can then be converted into the design pressure applied to the structure, as shown in Eq.(3). Wind pressure is calculated based on a wind velocity of 63 m/s, assumed for extreme conditions, along with the density of air (ρ_{air}), see Eq.(4). The resulting wind loads are applied to the walls of the deckhouses. The summary of load cases is provided in Appendix A.

$$h = \alpha\delta(\beta\lambda - \gamma) \ \ [\text{m}], \tag{1}$$

$$h_{\min} = 1.25 + 0.005 L_2 \ \ [\text{m}], \tag{2}$$

$$p = h \cdot 1.025 \cdot 9.81 \ \ [\text{Pa}], \tag{3}$$

$$P = \frac{1}{2}\rho_{air} V_{wind}^2 \ \ [\text{m}]. \tag{4}$$

Scantlings

In most rules and regulations addressing direct calculations, particularly in the context of FEA, net scantlings are used /2/. This approach evaluates the structure based on net scantlings, excluding corrosion additions. In shipbuilding, gross scantlings represent the as-built dimensions of structural elements as mounted on a ship. By subtracting the corrosion addition from the gross scantlings, net scantlings are obtained. Thus, in the present models, net scantlings are applied, excluding corrosion additions which typically range between 1 and 3 mm for ship structures exposed to maritime conditions. This methodology incorporates a safety margin, ensuring that the structure maintains sufficient structural integrity even without the added strength provided by corrosion additions. Therefore, in addition to the four load cases mentioned earlier, three scantling cases are also considered, as detailed in Appendix B.

RESULTS AND DISCUSSION

Based on four loading scenarios and three scantling cases, a total of 12 FE simulations are conducted. Across all cases, the stress plots reveal consistent structural response characteristics, including the nature of response, locations of maximal stresses, and stress gradients. This consistency suggests that structural behaviour of deckhouses is not significantly influenced by specific load or scantling case examined. The primary reason for this lies in the dominance of green water loads-design loads caused by waves splashing against the walls of deckhouses during storms. While wind pressures and ship motion-induced accelerations can be significant during storms, their contribution to the structural response is comparatively smaller than that of green water, which acts uniformly on all walls across all loading scenarios. Representative Von Mises stress plots (in MPa) for both deckhouses are shown in Figs. 6 and 7, with critical areas highlighted. These stress plots are consistent across all scantling cases, differing only in stress magnitudes. Similarly, they are broadly representative across all loading scenarios, with minor variations observed in walls exposed to specific wind pressures in certain cases, where slightly higher stresses are evident.

Figure 6 illustrates the structural response of the PS deckhouse, highlighting relatively low stress levels in the outer walls. Instead, the internal grillage structure experiences higher stresses. Two critical areas are identified: one at the aft wall vertical stiffeners and the other at the front wall transverse stiffener, as marked in Fig. 6. The aft wall vertical stiffeners exhibit higher stresses, particularly at mid-span and their flanges, resulting from bending induced by lateral pressures, primarily from green water loads. The shell and stiffeners of the aft wall are constructed from elements with thicknesses ranging from 4 to 6 mm. However, the primary cause of this stress concentration is the unusually large span of 4.4 m, which is atypical for stiffeners in ship structures. Maximum Von Mises stress occurs in the front transverse stiffener at the corner connection between the front and side walls (90° angle), identified as a hot-spot stress. In ship structures, such areas typically feature brackets to mitigate hot-spot stresses. The absence of intersecting girders to support the long spans of stiffeners exacerbates the structural vulnerability of this region.

For the SB deckhouse, the starboard wall (sea side) and its vertical stiffeners exhibit higher stress levels, with notable stresses also present in the aft wall and its stiffeners. Similar to the PS deckhouse, this behaviour is primarily attributed to significant lateral pressures from green water, which dominate the bending response of the wall structure. Additionally, the stress concentrations are intensified by unusually large stiffener spans and the smaller scantling sizes used in the design. Maximal stress is again recorded at wall connections, where brackets are absent in the original design.

Poor structural performance of deckhouses can be attributed to their design, which mimics land-based structural arrangements. While these land-based structures are adequate for static loads and equipment storage, their structural integrity is not sufficient to withstand dynamic ship loads, such as wind pressures, vessel motions, and accelerations. Adapting such designs to a marine environment without modification is inherently unsafe. Ship structures require arrangements tailored to dynamic loads, including transverse girders placed at 1 to 3 m intervals, depending on structural calculations. Stiffeners should be supported by girders in both directions, with the stiffeners aligned in the direction of maximal loads. This fundamental design principle ensures adequate structural integrity under the diverse and extreme conditions experienced at sea.

To summarise, the maximal Von Mises stresses across all loading and scantling cases are presented for the PS deckhouse in Fig. 8, and for the SB deckhouse in Fig. 9. Minor variations in stress results across scantling cases are attributed to the non-symmetrical and non-standard features of the deckhouse structures. Consequently, the critical load case for one deckhouse is not necessarily critical for the other.

As expected, scantling case 1 exhibits the highest stresses due to the smallest scantlings, while scantling cases 2 and 3 follow a decreasing trend in stress, with scantling case 3 showing the lowest stress levels. Given the absence of consistent criteria for deckhouse design in existing regulations, a range of yield stress-based criteria is evaluated: σ_y (235 MPa), $0.9\sigma_y$, $0.8\sigma_y$, and $0.7\sigma_y$ (90 %, 80 %, and 70 % of yield stress, respectively).

The PS deckhouse fails to meet almost all criteria except for scantling case 3 under the σ_y criterion. While some load cases pass the $0.9\sigma_y$ criterion, this is insufficient since the deckhouse must satisfy all load cases to be considered structurally safe under a particular criterion.

The SB deckhouse demonstrates a milder structural response. Only scantling case 1 fails to meet the σ_y criterion, while scantling cases 2 and 3 satisfy even the $0.8\sigma_y$ criterion; with scantling case 3 also meeting the more stringent $0.7\sigma_y$ criterion. This improved performance, compared to the PS deckhouse, is largely due to the SB deckhouse's smaller size and shorter stiffener spans, which significantly reduce stress levels.

In conclusion, while both deckhouses are subject to similar loads (pressures and accelerations), the structural deficiencies in the PS deckhouse are predominantly due to its larger dimensions and greater stiffener spans, which lead to higher stresses and a weaker structural response.

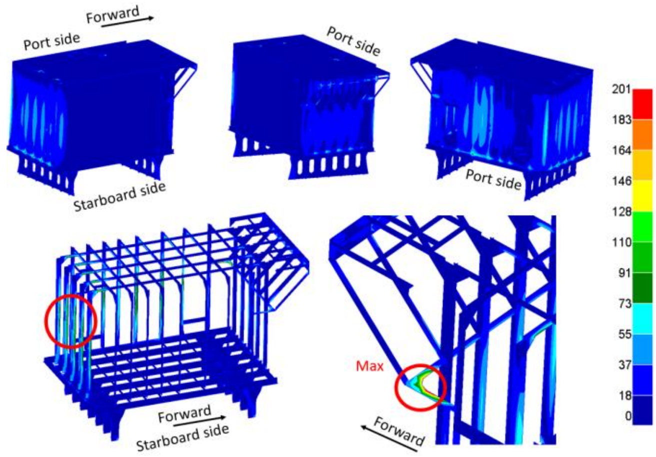

Figure 6. PS deckhouse Von Mises stress results for loading case 1 and scantling case 3.

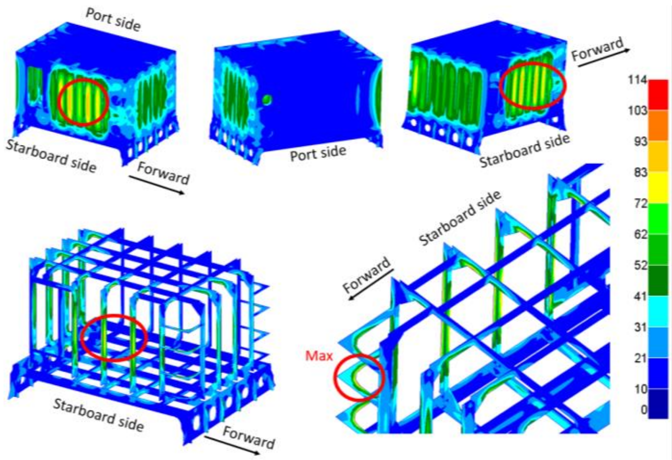

Figure 7. SB deckhouse Von Mises stress results for loading case 1 and scantling case 3.

Limitations of this analysis include its specificity to the deckhouses studied, meaning the results cannot be directly applied to other deckhouses on different ships. This is because such structures often exhibit unique and atypical features that deviate from standard designs. Additionally, the internal equipment stored within these deckhouses varies by ship and the purpose of mounted deckhouses, influencing their size and arrangement. Moreover, the analysis does not account for the bending of the ship or deck structure, as the boundary conditions do not consider the interaction between the deckhouses and the underlying deck structure. This omission may affect the accuracy of the structural response predictions. Finite element size can also influence results, although the particular mesh is generated according to the literature recommendations and the classification societies guidelines. Lastly, no optimisation analysis is performed to improve the structural response of the deckhouses. The primary objective of this research is to evaluate the structural response under various scenarios and identify critical regions, structural features, and key design considerations.

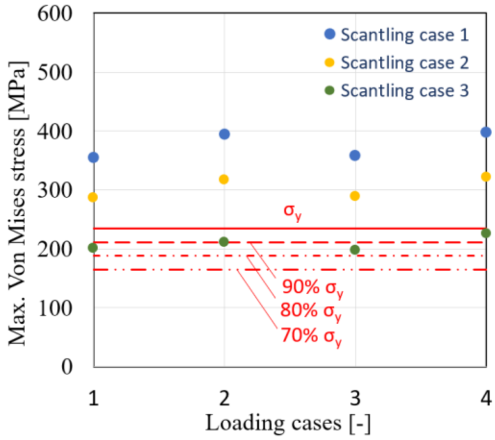

Figure 8. PS deckhouse maximum stress results.

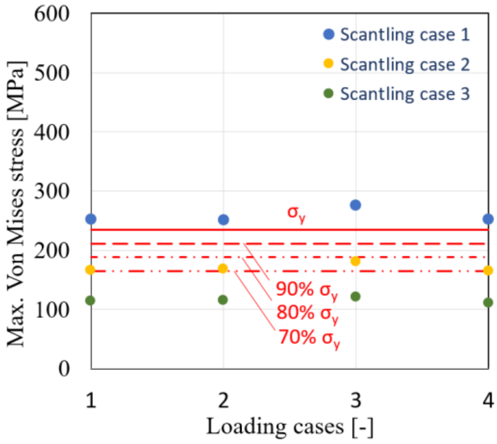

Figure 9. SB deckhouse maximum stress results.

CONCLUSIONS

This study evaluates the structural integrity of atypical deckhouses with designs based on existing land-based objects of similar purpose. Deckhouses here are installed on two sister tanker ships under extreme environmental conditions. Using FEA, the structural response of deckhouses is assessed across four loading scenarios and three scantling cases.

The findings highlight that green water loads dominate the structural response, significantly influencing stress distribution and critical regions. While wind pressures and ship motions contribute to the loads, their effect on structural response is secondary compared to green water loads. Both deckhouses demonstrate stress concentrations at specific locations, particularly at stiffeners with unusually large spans and at hot-spot stress areas where brackets are absent. The PS deckhouse exhibits higher stress levels than the SB deckhouse due to its larger size and longer stiffener spans, underscoring the influence of general structural arrangement on performance. The evaluation of various scantling cases reveals that increased scantling dimensions improve structural performance, with the highest scantlings meeting stricter criteria.

This analysis emphasizes the importance of adapting land-based structural designs to meet the dynamic loading conditions unique to marine environments. While certain land-based and ship structures may serve similar purposes, such as equipment storage, the structural requirements differ significantly. Land-based designs cannot simply be transferred to ship environments without substantial modifications to accommodate the dynamic forces at sea. The absence of transverse girders and insufficient stiffener support underscores the critical need for optimised deckhouse design. Large stiffener spans should be reduced by incorporating equidistant transverse girders, which effectively lower bending stresses at midspan and enhance overall structural integrity. Furthermore, stiffeners alone cannot function solely as beams supporting the outer shell. A robust structure must integrate both vertical (longitudinal, depending on plating position) and transverse girders, with stiffeners providing additional strength in the direction of the dominant loads.

Future research should include the interaction between deckhouses and the ship's deck structure, as well as optimisation to enhance structural performance. Developing guidelines specific to post-installed structures on ships would provide essential support for meeting the growing demands of emerging regulations.

ACKNOWLEDGEMENTS

This work was supported by Ministry of Education, Science and Technological Development of Serbia (Project no. 451-03-65/2024-03/200105 from February 5, 2024). The authors would like to acknowledge the Ocean Pro Marine Engineers Ltd. for providing data and certain figures.

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Appendix A

Table A1. Summary of four loading cases for the PS deckhouse.

Type of load		Region of applied load	Load cases			
			1	2	3	4
Design pressures [kPa]	Unprotected front	Front wall	21.22	21.22	21.22	21.22
	Sides	Port side wall	21.22	21.22	21.22	21.22
	Aft end	Aft wall	21.22	21.22	21.22	21.22
Wind pressures [kPa]	P_x	Aft wall (+), front wall (-)	2.43	-2.43	0	0
	P_y	Starboard side (+), port side (-)	0	0	2.43	-2.43
Accel. m/s^2]	a_x	Aft (+), front (-)	+0.5g	-0.5g	0	0
	a_y	Starboard side (+), port side (-)	0	0	+0.5g	-0.5g
	a_z	Downwards	-2g	-2g	-2g	-2g
Weights [kg]	Foundation of tanks and generators	Total weight is divided into a nodal force (260 nodes in total) and distributed on the bottom panel along the line of foundations	935	935	935	935
	Acid & Purate tank + generator		14518	14518	14518	14518
	Fill station	Total weight is divided into a nodal force (4 nodes in total) and distributed on the deck panel	64.48	64.48	64.48	64.48
	Vent station	Total weight is divided into a nodal force (4 nodes in total) and distributed on the deck panel	70.49	70.49	70.49	70.49
	Tote cradle	313.06 (+1000 t) divided into a nodal force (6 nodes in total) and distributed onto its foundations	313.06	313.06	313.06	313.06
	Ventilation inlet	Total weight is divided into a nodal force (12 nodes in total) and distributed on the deck panel around the edge of the hole	186.28	186.28	186.28	186.28
	Ventilation outlet (8)	Total weight is divided into a nodal force (12 nodes in total) and distributed on the deck panel around the edge of the hole	150.50	150.50	150.50	150.50
	Ventilation outlet (30)	Total weight is divided into a nodal force (12 nodes in total) and distributed on the deck panel around the edge of the hole	163.84	163.84	163.84	163.84

Table A2. Summary of loading cases for the SB deckhouse.

Type of load		Region of applied load	Load cases			
			1	2	3	4
Design pressures [kPa]	Unprotected front	Front wall	21.22	21.22	21.22	21.22
	Sides	Port side wall	21.22	21.22	21.22	21.22
	Aft end	Aft wall	21.22	21.22	21.22	21.22
Wind pressures [kPa]	P_x	Aft wall (+), front wall (-)	2.43	-2.43	0	0
	P_y	Starboard side (+), port side (-)	0	0	2.43	-2.43
Accel. [m/s^2] Note: applied to all nodes	a_x	Aft (+), front (-)	+0.5g	-0.5g	0	0
	a_y	Starboard side (+), port side (-)	0	0	+0.5g	-0.5g
	a_z	Downwards	-2g	-2g	-2g	-2g
Weights [kg]	Ventilation outlet 1	Total weight is divided into a nodal force (12 nodes in total) and distributed on the deck panel	150.5	150.5	150.5	150.5
	Ventilation inlet 2	Total weight is divided into a nodal force (12 nodes in total) and distributed on the deck panel	186.3	186.3	186.3	186.3
	Local weights (top)	Total weight is divided into a nodal force (8 nodes in total) and distributed on the deck panel positions	5040	5040	5040	5040
	Local weights (bottom)	Total weight is divided into a nodal force (10 nodes in total) and distributed on the bottom panel positions	4980	4980	4980	4980

Appendix B

Table B1. Scantling cases for the PS deckhouse.

PS deckhouse	Case 1	Case 2	Case 3
Bottom/sides/aft/front	4	5	6
Stiffeners	5	6	7
Brackets/front plating/transverse/deck stiffeners/front console stiffeners/webs of bottom girders/foundation brackets	6	7	8
Bottom stiffeners/flanges of bottom girders/foundation platings	8	9	10

Table B2. Scantling cases for SB deckhouse.

SB deckhouse	Scantling case 1	Scantling case 2	Scantling case 3
Bottom/deck/sides/aft/front platings/deck stiffeners/sides/edge brackets	4	5	6
Foundation platings and brackets/bottom flat stiffener	6	7	8
Sides stiffeners/brackets	5	6	7
Bottom girders/flanges of bottom girders/bottom transverse/flanges of bottom transverse	8	9	10