

STRUCTURAL EVALUATION OF A 1400 DWT INLAND NAVIGATION BARGE

Teodora Tămoanu

“Dunarea de Jos” University of Galati,
Faculty of Naval Architecture, Galati, 47
Domneasca Street, 800008, Romania,
E-mail:
teodora.tamoanu@bureauveritas.com

Alina Modiga

“Dunarea de Jos” University of Galati,
Faculty of Naval Architecture, Galati, 47
Domneasca Street, 800008, Romania,
E-mail: alina.modiga@ugal.ro

Răzvan Bidoae

“Dunarea de Jos” University of Galati,
Faculty of Naval Architecture, Galati, 47
Domneasca Street, 800008, Romania,
E-mail: razvan.bidoae@ugal.ro

Dumitru-Silviu Perijoc

“Dunarea de Jos” University of Galati,
Faculty of Naval Architecture, Galati, 47
Domneasca Street, 800008, Romania,
E-mail: silviu.perijoc@ugal.ro

ABSTRACT

Structural Finite Element Method (FEM) analysis provides a solid basis for evaluating the structural behavior of ships and contributes directly to the identification of critical areas in terms of strength and design validation. Inconsistent and non-compliant design can result in operational risks, high maintenance costs, early degradation, or even structural collapse. The present study aims to evaluate the overall structural behavior of a 1400 TDW inland navigation barge under real operating conditions, during ballast and full load navigation, both in calm water and under design-equivalent wave loads. The wave height of 1.2m was considered as imposed by the navigation area. To enable an effective evaluation that accurately reflects the barge's actual condition, the 3D FEM model represents the idealized structure of the barge with average element size of 200mm. The model equilibrium was achieved using Orca3D software. The results were assessed based on the Von Mises criterion and the maximum deformation values, allowing the identification of regions with increased risk in terms of structural strength.

Keywords: FEA, stress distribution, maximum deformation, structural strength

1. INTRODUCTION

Inland navigation represents one of the main components of transportation; therefore, inland vessels, particularly barges, play a crucial role in ensuring the continuity of cargo flow, as they are designed to transport significant amounts of cargo while requiring less energy than other modes of transport (such as road or rail). In this context, the robustness of barges becomes especially

significant, as they are subjected to considerable loads during operation. The topic is closely related to current concerns regarding the constructive optimization of barges based on their structural response to operational loads, as well as the possibility of reducing material consumption while increasing durability and adapting to the various conditions of inland waterways.

This analysis involves the estimation of the stress and strain states for the overall barge

structure subjected to the main loads, the verification of the consistency between the analyzed model and the safety and structural stability requirements by comparing the obtained results with applicable standards (e.g., class requirements, IACS rules), and the demonstration of the efficiency of the Finite Element Method (FEM) in the evaluation of naval structures.

2. THE 1400 TDW INLAND BARGE DESCRIPTION

The analyzed vessel is a non-propelled, flat-bottomed barge with a carrying capacity of 1400 TDW, intended for bulk dry cargo transport on inland waterways such as the Danube River. In Table 1 are presented the dimensions of the barge, and the 3D CAD model is illustrated in Fig.1. The scantling calculations were developed in the MARS Inland software [8], under Bureau Veritas Classification Society rules [9], according to the main characteristics of the barge. The midship characteristics are presented in Figs. 2-6.

Table 1. Main characteristics of the barge

Length overall	L_{OA}	70	[m]
Breadth	B	9.5	[m]
Depth	D	4	[m]
Draught	T	2.5	[m]
Lightship	Δ_0	216	[t]
Deadweight	Δ_{wt}	1400	[tdw]
Displacement (full load)	Δ	1616	[t]

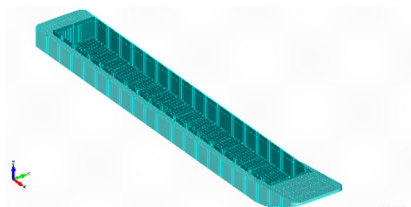


Fig.1 The 3D CAD model of the 1400 tdw inland barge

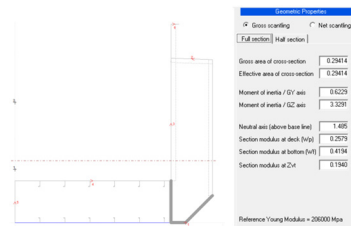


Fig.2 Geometric characteristics of the midship section



Fig.3 Shell thickness

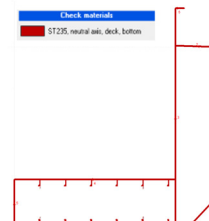


Fig.4 Material used

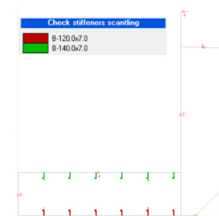


Fig.5 Stiffeners scantling



Fig.6 Transverse stiffeners scantling

3. THE 3D-FEM MODEL OF THE 1400 TDW INLAND BARGE

A simplified 3D-CAD representation of the hull structure shown in Figs. 7-10 was created using the 3D modeling capabilities of Femap/NX Nastran [7]. To reduce the complexity of the analysis, local structural details, such as equipment and secondary components, were neglected.

Based on the 3D-CAD representation of the 1400 tdw inland barge, a three-dimensional finite element model (3D-FEM) was generated using the meshing capabilities of the Femap/NX Nastran [7] software. The hull is constructed from steel, with its properties listed in Table 2.

Table 2. Grade A steel - material properties

Density	ρ	7850	kg/m ³
Young Modulus	E	2.1e5	[N/mm ²]
Poisson's coefficient	ν	0.3	-
Yielding stress	σ_c	235	[MPa]

The 3D-FEM model consisted of 144879 finite elements and 113826 nodes, using 1D-BEAM elements – for stiffeners, girders, and longitudinal profiles, and 2D-PLATE elements (QUAD) – for shell plating, decks, bulkheads, and double bottom structures.

Mesh quality was verified using the Jacobian criterion, ensuring numerical stability and element validity ($0 < J < 2$).

The vessel operates in inland waters under moderate wind conditions and significant wave heights up to 1.2 m.

Two operational cases were modeled: ballast condition – the barge carries only ballast water for immersion and stability, and full load condition – the barge transports dry bulk cargo at maximum capacity.

Details of the 3D-FEM structural model for the 1400 tdw inland barge are illustrated in Figs. 11-15.

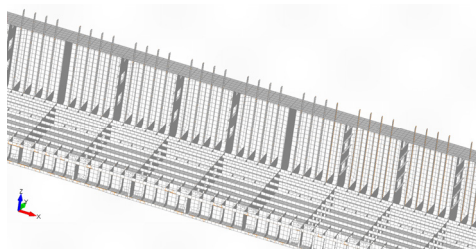


Fig.11 Discretized cylindrical part detail – 1D & 2D elements

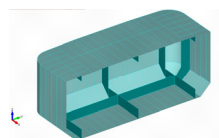


Fig.7 Geometry - Aft ballast tank

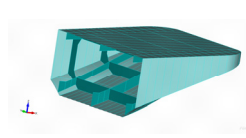


Fig.8 Geometry – Fore detail

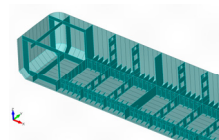


Fig.9 Geometry - Aft structure detail

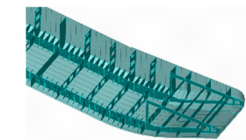


Fig.10 Geometry - Fore structure detail

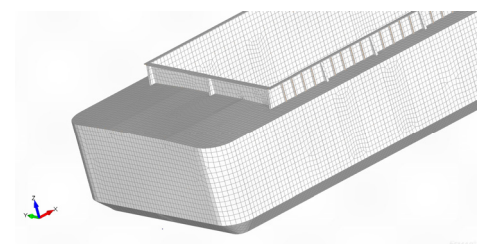


Fig.12 Discretized aft detail – 2D elements

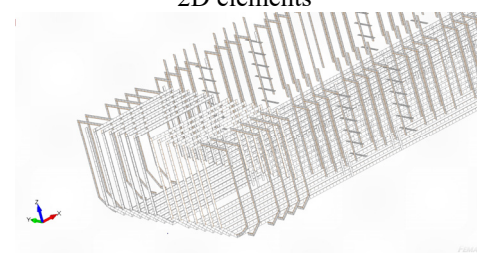


Fig.13 Discretized aft detail – 1D elements

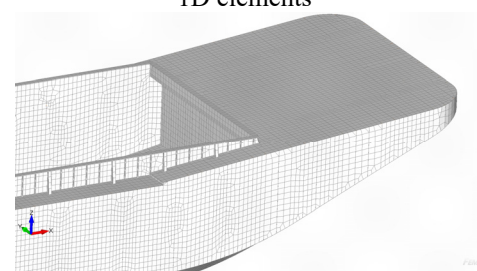


Fig.14 Discretized fore detail – 2D elements

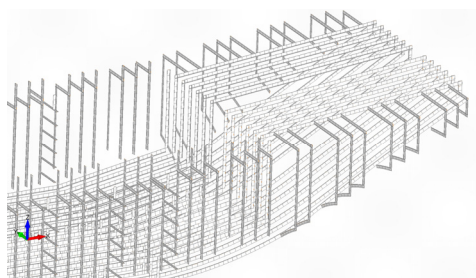


Fig.15 Discretized fore detail –
1D elements

3.1 Boundary Conditions

Constraints are located at the intersection between the reinforced frames at the stern and bow, the deck, and the outer shell of the barge, as shown in Figs. 16-17 and followed IACS [13] recommendations as shown in Table 3:

Table 3. Boundary conditions

Location	Direction	Description
Aft end	PS & SB	Z translation
	CL	Y translation
Fore end	CL	X, Y, Z translation

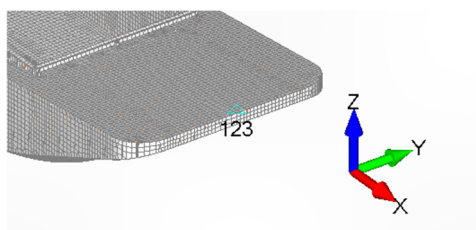


Fig.16 Fore Boundary Conditions

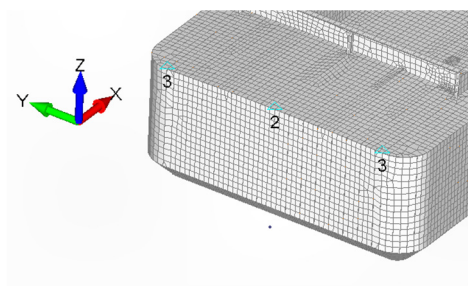


Fig.17 Aft Boundary Conditions

The load cases considered in the analysis include: calm water pressure at both ballast and full-load drafts; equivalent design wave loads – hogging (wave crest amidships) and sagging (wave trough amidships); cargo pressure on the inner hull plating and transverse bulkheads and on the inner bottom plating (modeled as non-structural mass) during full-load navigation; water ballast pressure (modeled as non-structural mass) on the bottom plating at the aft end during ballast operation; and the effect of gravitational acceleration ($g = 9.81 \text{ m/s}^2$).

Equilibrium and trim conditions were computed using Orca3D [12] hydrostatics to ensure accurate draft and buoyancy alignment between Femap and the hydrostatic data.

For all load cases, the total reaction forces at the constraints were verified to remain within $\pm 5\%$ of the vessel's total mass, thus confirming both the static equilibrium and stability of the model.

4 NUMERICAL RESULTS AND DISCUSSION

Results from static linear analysis indicate that maximum stresses occur near the bow and stern strengthened frames and in the hatch coaming region near midship.

The Figs. 18-32 present the global strain and Von Mises stress distributions for the ballast and full load conditions under still-water loads, hogging, and sagging.

In ballast condition, in all cases, the hatch coaming frame and its reinforcing flange exhibit the highest stresses (see Figs. 18-23).

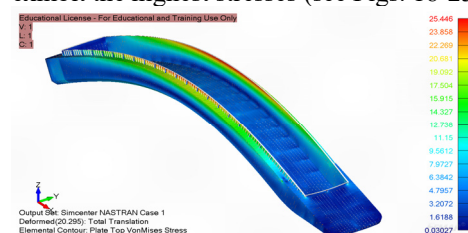


Fig.18 Ballast condition results:
2D elements – still-water loads

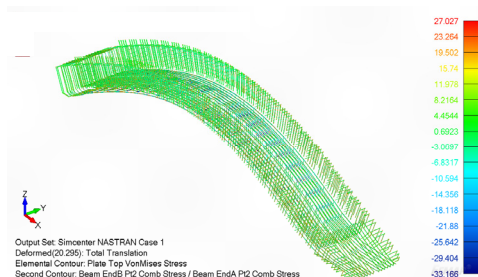


Fig.19 Ballast condition results:
1D elements – still-water loads

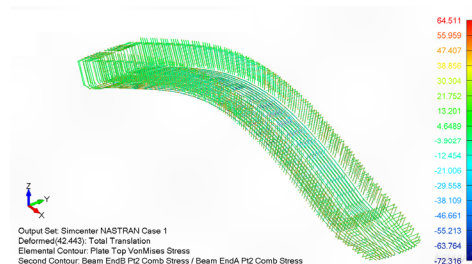


Fig.23 Ballast condition results:
1D elements – hogging

The information regarding the maximum Von Mises stress values and the displacements obtained from the analyses is summarized in Table 4:

Table 4. Ballast condition analysis results

Load case	Von Mises stress [MPa]		Total translation [mm]
	1D elements	2D elements	
Still-water	27.027	25.446	20.295
Sagging	46.92	46.92	12.745
Hogging	64.511	60.522	42.443

In full-load condition, high stress values are registered in the aft bottom longitudinal profiles under hydrostatic pressure in calm water, as shown in Figs. 24-26.

For the sagging condition, in Figs. 27-29, it is observed that high stress values occur at the hatch coaming frame for PLATE-type elements and in the aft bottom bulb sections for BEAM-type elements.

In hogging condition, significant stress values are identified in the side shell profiles (Figs. 30-32).

The maximum Von Mises stress values and the total translations obtained from the analyses are summarized in Table 5.

Table 5. Full-load condition analysis results

Load case	Von Mises stress [MPa]		Total translation [mm]
	1D elements	2D elements	
Still-water	97.309	53.969	15.809
Sagging	120.33	96.461	63.795
Hogging	123.58	123.58	43.979



Fig.20 Ballast condition results:
2D elements – sagging

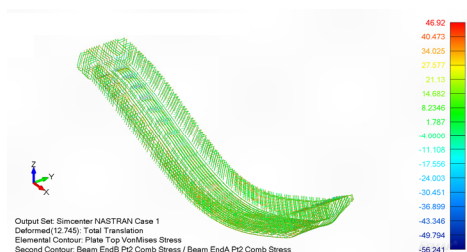


Fig.21 Ballast condition results:
1D elements – sagging

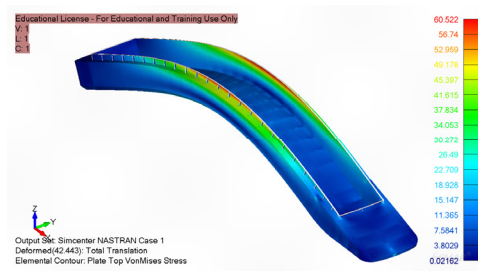


Fig.22 Ballast condition results:
2D elements – hogging

The maximum computed Von Mises stress did not exceed 75% of the yield strength ($\sigma = 235 \text{ MPa}$) for any load case, meeting the safety criteria. Deflections were within allowable limits, ensuring adequate stiffness for all structural members.

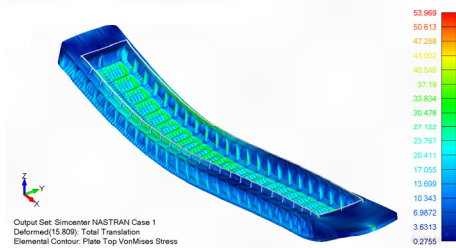


Fig.24 Full-load condition results:
2D elements – still-water loads

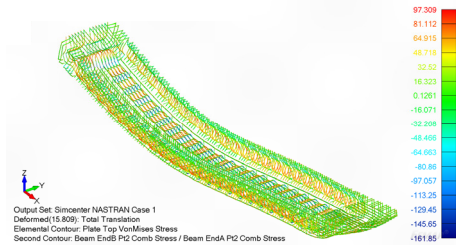


Fig.25 Full-load condition results:
1D elements – still-water loads

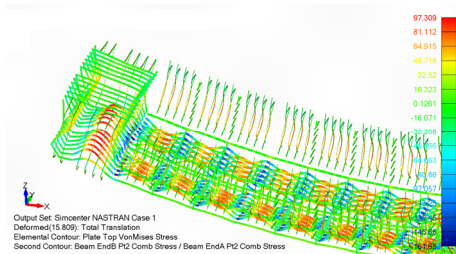


Fig.26 Full-load condition results:
1D elements – still-water loads

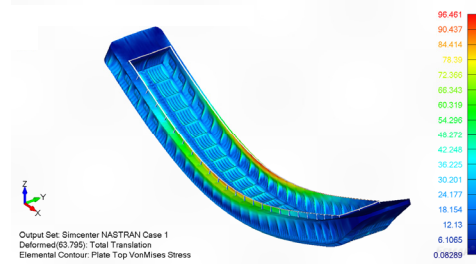


Fig.27 Full-load condition results:
2D elements – sagging

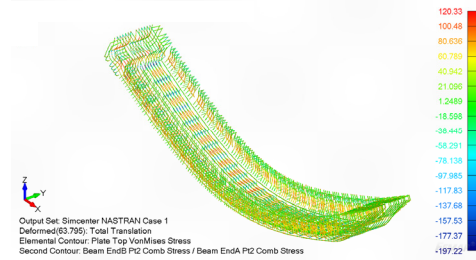


Fig.28 Full-load condition results:
1D elements – sagging

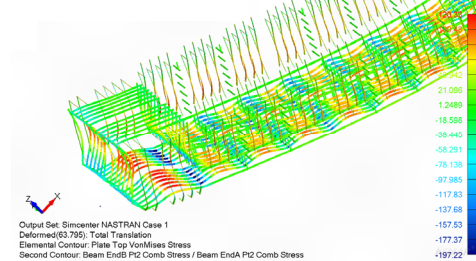


Fig.29 Full-load condition results:
1D elements – sagging

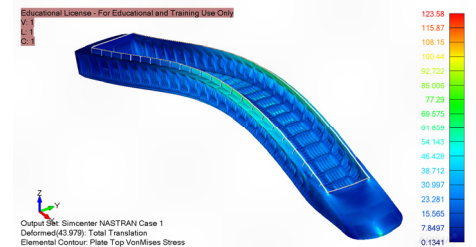


Fig.30 Full-load condition results:
2D elements – hogging

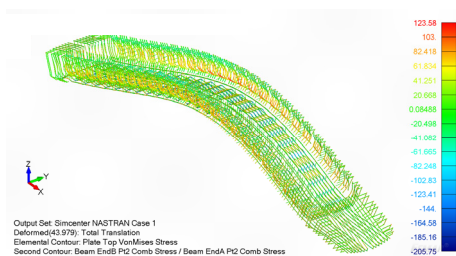


Fig.31 Full-load condition results:
1D elements – hogging

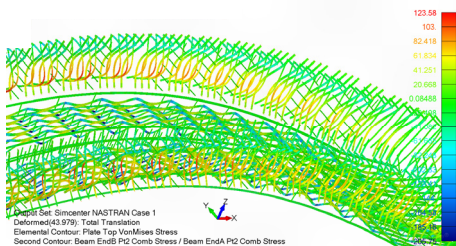


Fig.32 Full-load condition results:
1D elements – hogging

5 CONCLUDING REMARKS

This study demonstrates the importance of finite element structural analysis in the design and verification of inland navigation barges. Through the global FEM model developed in Femap [7], the 1400 TDW barge was evaluated under realistic ballast and loading conditions, including calm water and design-wave scenarios.

Femap provides a clear visualization of the structural response and critical areas of the structure, offering high accuracy in assessing structural behavior. This software enables flexible modeling of ship structures, featuring advanced tools for geometry creation and the assignment of element properties.

Consequently, it contributes to enhanced reliability and safety; however, it should be noted that results obtained using Femap require proper validation and careful interpretation.

Key findings:

- The structural configuration satisfies Bureau Veritas strength and stiffness requirements.

- The most critical stress regions were generally observed at the hatch coaming frame, in the bottom or side shell profiles, or in the forepeak reinforcement.

- The use of FEM significantly enhances the accuracy and reliability of naval structural assessments, providing a foundation for design optimization.

Acknowledgements

Support was provided by the Research Centre of the Faculty of Naval Architecture of "Dunarea de Jos" University of Galati.

REFERENCES

- [1] Domnişoru L., *Metoda Elementului Finit în Construcții Navale*, Editura Tehnică, Bucharest, 2001.
- [2] Domnisoru, L., "Structural analysis and hydroelasticity of ships", The University Found."Dunarea de Jos" Publish, Galati, 2006.
- [3] Domnisoru, L., "Special chapters on ships' structure analysis. Applications", The University Foundation "Dunarea de Jos" Publishing House, Galati, 2017.
- [4] D. C. Obreja, *Teoria Navei*, Lecture Notes.
- [5] E. Găvan, *Construcția Navei*, Lecture Notes.
- [6] F. D. Păcuraru, *Arhitectura Navei*, Lecture Notes.
- [7] FNN, "Femap/NX Nastran users' manual", Siemens PLM Software Inc., 2019.
- [8] MARS Inland, Bureau Veritas Software
- [9] NR217 Rules for the classification of inland navigation vessels.
- [10] NR467 Rules for the classification of steel ships.
- [11] The European Standard laying down Technical Requirements for Inland Navigation vessels – ESTRIN 2023.
- [12] Orca3D – Marine Design for Rhinoceros.
- [13] International Association of Classification Societies (IACS).

Paper received on November 17th, 2025

