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# STRUCTURAL EVALUATION OF A 1400 DWT INLAND NAVIGATION BARGE

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## 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 for 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 them 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 DESCRIPTION OF THE 1400 TDW INLAND BARGE

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 | $\Delta_0$ | 216 | [t] |
| Deadweight | $\Delta_{wt}$ | 1400 | [tdw] |
| Displacement (full load) | Δ | 1616 | [t] |

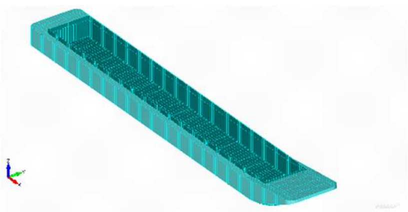

**Fig.1** The 3D CAD model of the 1400 tdw inland barge

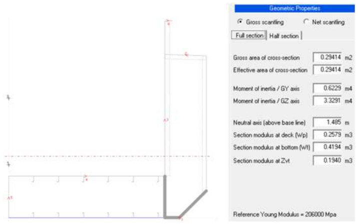

**Fig.2** Geometric characteristics of the midship section

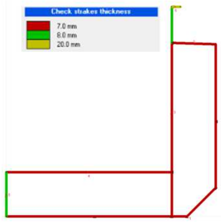

**Fig.3** Shell thickness

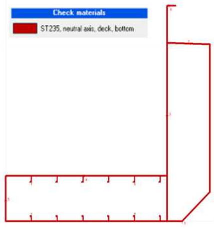

**Fig.4** Material used

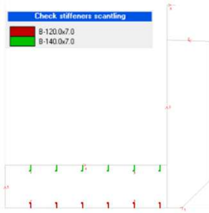

**Fig.5** Stiffeners scantling

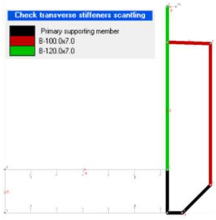

**Fig.6** Transverse stiffeners scantling

## 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 | $\rho$ | 7850 | $kg/m^3$ |
| Young Modulus | E | 2.1e5 | $[N/mm^2]$ |
| Poisson's coefficient | $\upsilon$ | 0.3 | - |
| Yielding stress | $\sigma_c$ | 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 modelled: 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.

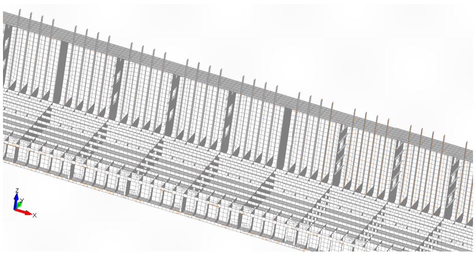

**Fig.11** Discretized cylindrical part detail – 1D & 2D elements

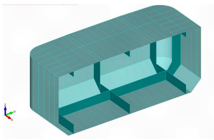

**Fig.7** Geometry - Aft ballast tank

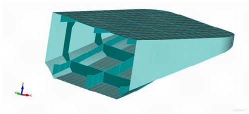

**Fig.8** Geometry – Fore detail

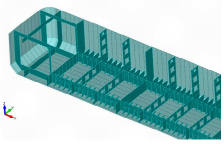

**Fig.9** Geometry - Aft structure detail

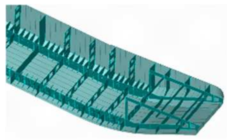

**Fig.10** Geometry - Fore structure detail

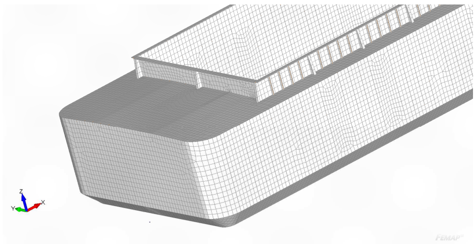

**Fig.12** Discretized aft detail – 2D elements

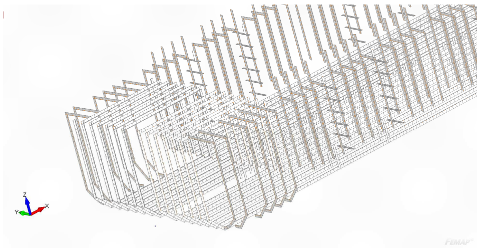

**Fig.13** Discretized aft detail – 1D elements

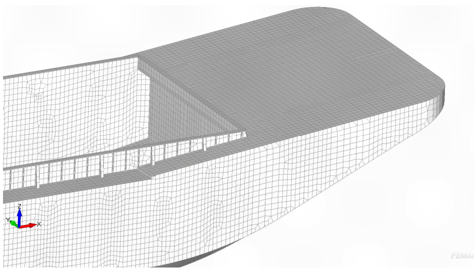

**Fig.14** Discretized fore detail – 2D elements

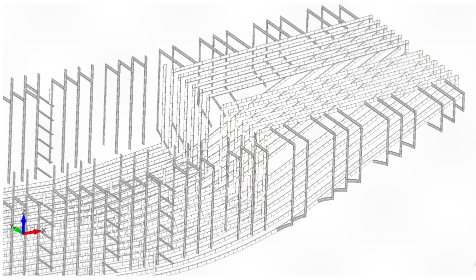

**Fig.15** Discretized fore detail – 1D elements

### 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 |

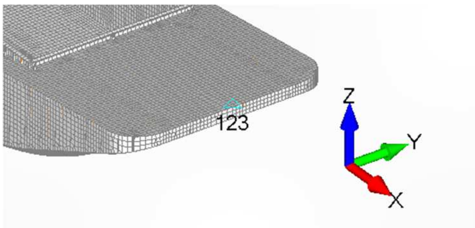


**Fig.16** Fore Boundary Conditions

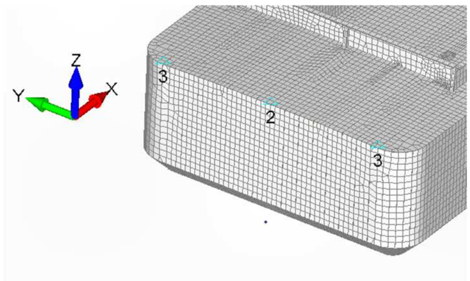


**Fig.17** Aft Boundary Conditions

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 (modelled as non-structural mass) during full-load navigation; water ballast pressure (modelled as non-structural mass) on the bottom plating at the aft end during ballast operation; and the effect of gravitational acceleration (g = 9.81 m/s²).

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 ±5% of the vessel's total mass, thus confirming both the static equilibrium and the 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.

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).

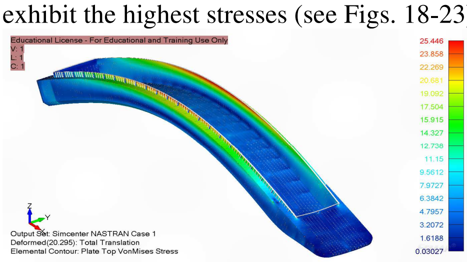


**Fig.18** Ballast condition results: 2D elements – still-water loads

 

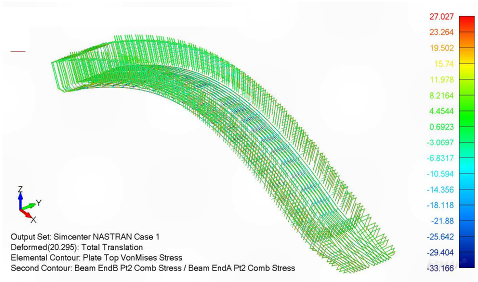

**Fig.19** Ballast condition results: 1D elements – still-water loads

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

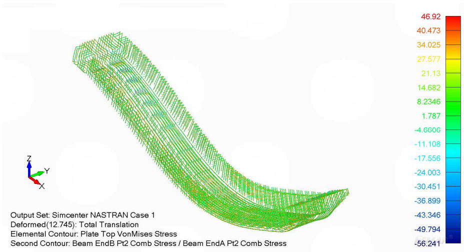

**Fig.21** Ballast condition results: 1D elements – sagging

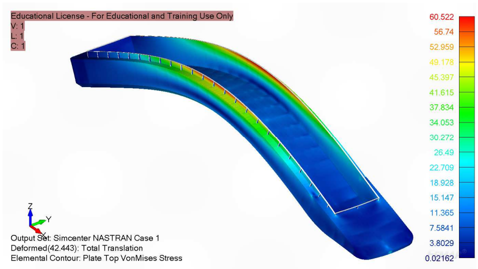

**Fig.22** Ballast condition results: 2D elements – hogging

**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 |

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

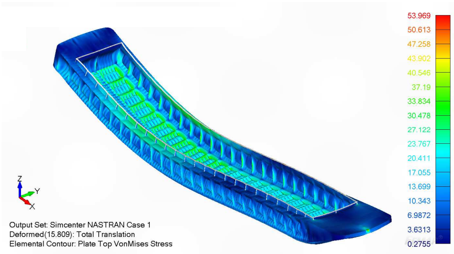


**Fig.24** Full-load condition results: 2D elements – still-water loads

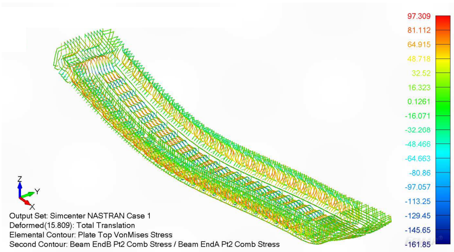


**Fig.25** Full-load condition results: 1D elements – still-water loads

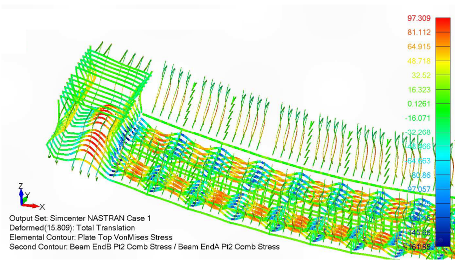


**Fig.26** Full-load condition results: 1D elements – still-water loads

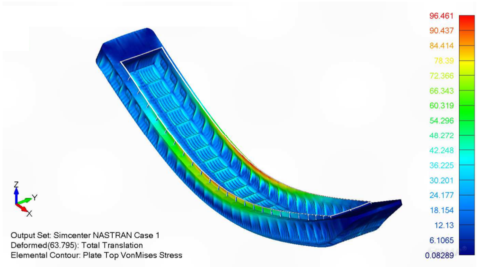


**Fig.27** Full-load condition results: 2D elements – sagging

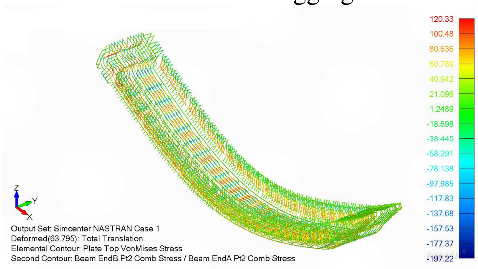


**Fig.28** Full-load condition results: 1D elements – sagging

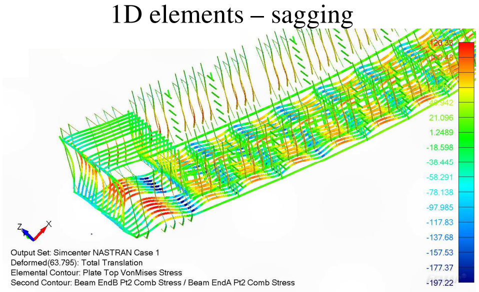


**Fig.29** Full-load condition results: 1D elements – sagging

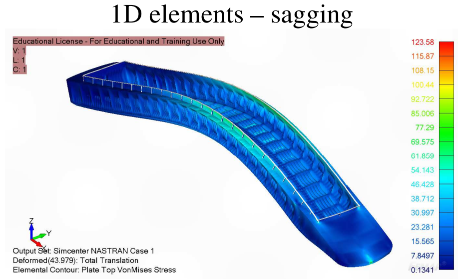


**Fig.30** Full-load condition results: 2D elements – hogging

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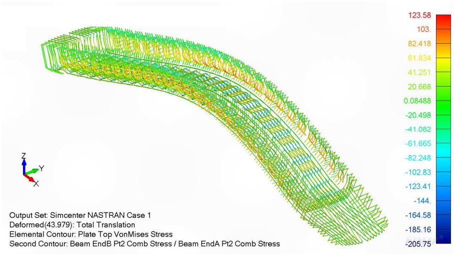


**Fig.31** Full-load condition results: 1D elements – hogging

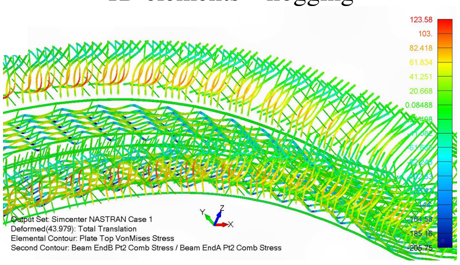


**Fig.32** Full-load condition results: 1D elements – hogging

## 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

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