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ANALYSIS OF THE IMPACT OF LOCAL DISCRETIZATION IN THE AREA OF TECHNOLOGICAL CUTOUTS ON STRESS CONCENTRATORS

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ABSTRACT

This study aims to analyze and compare the influence of steel flat bar beveling around technological cutouts on the stress state of a chemical tanker with a deadweight of 35,622 tons (TDW). Technological cutouts, which are essential for the installation of equipment, passage of cables, and other functional purposes, can cause stress concentration in the ship's structure, increasing the risk of cracking and localized failure. To assess the impact of beveling, two structural models are compared: one with steel plate beveling and one without. Using finite element analysis (FEM) through FEMAP/NX Nastran software, stresses and displacements around the cutouts are examined at four representative points along the cutout's circumference. The results reveal significant differences in stress distribution between the two models, demonstrating the effectiveness of beveling in reducing local stress concentrations. This study provides insights into improving structural integrity and safety in ship design by addressing the risks associated with technological cutouts.

Keywords: finite element method, technological cutouts, stress concentration

1. INTRODUCTION

The vessel analyzed in this study is a chemical tanker with a deadweight of 35622 tons (TDW), specialized in the transportation of chemical substances and petroleum derivatives. The primary purpose of this vessel is to ensure the safe and efficient transport of bulk chemicals, while complying with strict international standards and regulations. Due to the sensitive and often hazardous nature of the transported cargo, the structural integrity of the ship becomes essential for preventing accidents and protecting the surrounding environment.

This study focuses on the influence of steel plate beveling around technological cutouts, analyzing the impact of this solution on the stress state within the ship's structure and evaluating its effects on the vessel's strength and durability under operating conditions.

The main dimensions of the vessel were obtained from the "JSEA_SEA" database, which contains essential information about ships built between 1993 and 1999. These data are illustrated in **Table 1.1**.

Based on this information, the vessel's sampling was carried out using the Poseidon ND v.21.4 program package belonging to the DNV classification company.

Table 1.1 Dimensions and characteristics of the simplified structure

Description	Symbol	Value	Unit
Length Between Perpendiculars	Lpp	167	[m]
Overall Length	LOA	174.92	[m]
Beam	B	30	[m]
Depth of Construction	D	14.2	[m]

2. GENERATION AND ANALYSIS OF THE SIMPLIFIED MODEL

To assess the impact of steel plate beveling on the stress state, two distinct 3D models were created: one with beveling and one without. The process of generating these models was carried out using Rhino, due to its speed and efficiency in handling geometry.

After creating the models in Rhino, they were imported into FEMAP, where they were finalized and prepared for generating the necessary 3D-FEM models for structural analysis. It is important to note that the structure was simplified by avoiding the use of framing elements, such as braces or stiffeners.

2.1 3D-CAD Model - Rhino

The 3D-CAD model of the ship was initially created in Rhino (a powerful software application for 3D modeling and design. This model serves as the foundation for subsequent analyses and modifications in structural engineering applications), where the double bottom and the shell were modeled along the length of 5 frames, using the master section. The geometry was imported into FEMAP, where it was copied and modified to create the final model. The length of the model reflects the length of 3 holds, each measuring 21600 mm, resulting in a total length of 64800 mm **(Figure 1**).

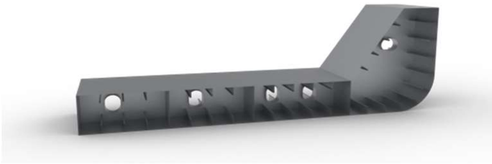

Fig. 1 3D-CAD - Rhino

2.2 3D-CAD model of the shed in FEMAP/NX Nastran

The 3D-CAD model of the shed created in FEMAP/NX Nastran (**Figure 2)** provides a solid platform for evaluating structural performance. It allows engineers to optimize the design and ensure compliance with safety and efficiency standards. The analyses conducted on this model significantly contribute to preventing structural failures and protecting the environment.

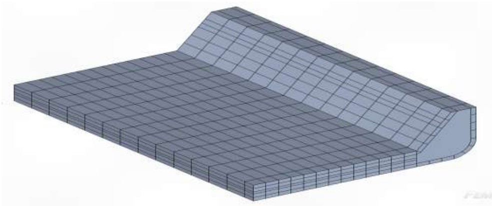

Fig. 2 3D-CAD Model (FEA)

2.3 Complete 3D-CAD model

The complete 3D-CAD model represents a comprehensive and detailed depiction of the structure, created using advanced modeling software such as FEMAP/NX Nastran or Rhino. This model (**Figure 3)** serves as a vital tool in the design and analysis phases of engineering projects, particularly for chemical tankers and similar structures.

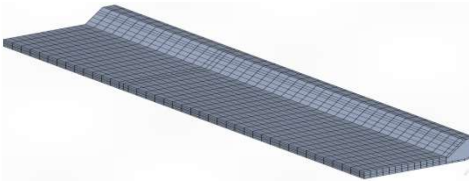

Fig. 3 Complete 3D-CAD model

3. MATERIAL CHARACTERISTICS AND MESHING PROCESS

The material used is high-strength steel with the following characteristics (**Table 1.2**):

Table 1.2 Material characteristics

Description	Symbol	Value	Unit
Yield strength	σ_c	235	MPa
Longitudinal elastic modulus (Young's modulus)	E	210	GPa
Poisson's ratio	ν	0.3	-
Density	ρ	7800	kg/m³

The meshing process was conducted in FEMAP, utilizing a varied discretization of quad elements with sizes of 50 mm, 100 mm, and 200 mm. This approach was adopted to highlight the differences and impacts of these element sizes in subsequent analyses.

By employing a variety of mesh sizes, the aim was to achieve a detailed and precise analysis of structural behavior, allowing for clearer identification of stress concentrations and displacements around the technological cutouts. This method also ensures an adequate evaluation of the effectiveness of steel plate beveling and its impact on the structural integrity of the ship (**Table 1.3**).

Table 1.3 The characteristics of 3D-FEM

Discretization	Fine mesh	Medium mesh	Coarse mesh
Element size	50 mm	100 mm	200 mm
Number of nodes	1701956	426969	118136
Number of elements	1719968	437405	124989

These characteristics of the 3D-FEM **(Figure 4)** models highlight the impact of discretization on the complexity and accuracy of structural analysis. The choice of mesh sizes is essential for balancing precision and efficiency in the simulations performed.

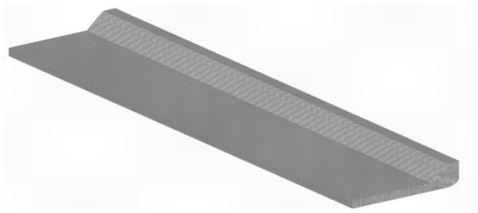

Fig. 4 Complete 3D - FEM model

4. BOUNDARY CONDITIONS

For the structural simulations, suitable boundary conditions (**Table 1.4 and Figure 5)** were defined and applied in the 3D-FEM models. These conditions reflect the real constraints encountered during the operation of the vessel, ensuring an accurate simulation of the structural behavior.

Table 1.4 Boundary conditions

Boundary condition	Blocked degrees of freedom					
	Ux	Uy	Uz	Rx	Ry	Rz
Symmetry in the diametral plane (PD)	-	x	-	x	-	-
Intersection of the central support with the lower pedestal of the longitudinal wall	-	x	x	x	-	-
Intersection of the inner shell with the watertight transverse bulkheads	-	-	x	-	-	-
Intersection of the tank section with the double bottom section	-	-	x	-	-	-
Continuity of the longitudinal elements at the stern and bow ends of the model	x	x	x	x	-	x

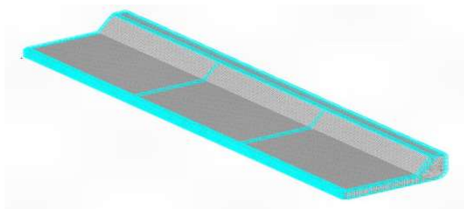

Fig. 5 Boundary conditions applied to the entire model

5. LOADS APPLIED UPON THE MODEL

A) The case of static placement on still water

The FEM model is subjected to the following types of loads (**Figure 6**):

To simulate real operating conditions, the 3D-FEM model was subjected to the following loads:

a) Gravitational load: this represents the weight of the structural elements and other components onboard the vessel, taking into account the density of steel (ρ = 7.8 t/m³) and gravitational acceleration (g = 9.81 m/s²).

b) Hydrostatic pressure of the cargo: this pressure is applied to the inner shell of the hold at a height H = 11200 mm, which represents the maximum height at which the pressure acts. The density of the cargo (oil) is equal to ρ = 0.9 t/m³.

c) Hydrostatic pressure generated by seawater (ρ = 1.025 t/m³) is applied to the external shell of the model at a height of T = 10500 mm, which corresponds to the draft at full load of the ship.

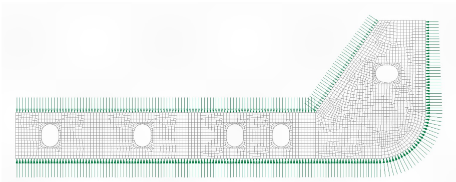

Fig. 6 Applied loads to the model for the static settlement case on stillwater

B) The case of static settling on waves

a) Gravitational loading: similar to that in the static settling case on calm water presented earlier.

b) Hydrostatic pressure of the cargo: Similar to that presented in the previous case.

c) Quasi-static equivalent wave loading: this loading has an equivalent hydrostatic pressure [N/mm²]. This loading is calculated using the balancing parameters represented in the following table (**Table 1.5, Figure 7 and Figure 8)**:

Table 1.5 Balancing parameters from the simplified 1D analysis

Description	Variables	Value	U.M.
Length of the ship	LOA	174920	mm
Wave height	HW	9351	mm
Aft end of the model	XPP	55060	mm
Aft draft	DPP	7000	mm
Forward draft	DPV	7000	mm

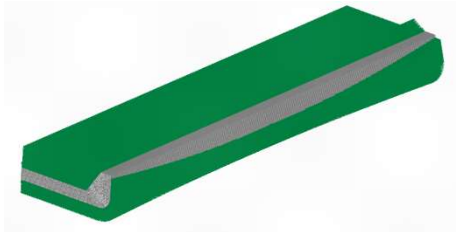

Fig. 7 Applied loads on the model for the case of static settling in a wave trough

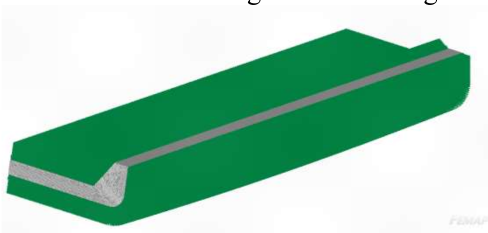

Fig. 8 Applied loads on the model for the case of static settling at the crest of a wave

6. VON MISES STRESSES AND MAXIMUM DISPLACEMENTS OF THE SIMPLIFIED MODEL

The following table summarizes the Von Mises stresses and maximum displacements observed for the simplified model under various loading conditions and mesh discretizations:

Table 1.7 Von Mises stresses and maximum displacements of the simplified model

Ship positioning case		Mesh discretization			UM.
Von Mises Stress	Still water	200	100	50	[mm]
		94.12	119.66	144.38	[MPa]
	Sagging	200	100	50	[mm]
		154.47	194.83	254.28	[MPa]
	Hogging	200	100	50	[mm]
		84.43	134.39	163.27	[MPa]
Displacements	Still water	200	100	50	[mm]
		3.89	3.919	3.925	[mm]
	Sagging	200	100	50	[mm]
		6.566	6.614	6.654	[mm]
	Hogging	200	100	50	[mm]
		4.931	4.949	4.997	[mm]

7. INTERPRETATION OF RESULTS

a) Still water condition:

The Von Mises stress values show an increasing trend with finer mesh refinement, suggesting that as the mesh becomes more detailed, the stress distribution is captured more accurately. This is crucial for identifying areas that may be susceptible to failure.

The maximum displacement remains relatively low across all discretizations, indicating that the vessel performs stably when floating on calm water, which is essential for safe operation in such conditions.

b) Sagging condition:

In this scenario, the Von Mises stresses are significantly elevated, especially with the finer meshes reaching up to 254.28 MPa. This increase signals higher loading conditions that could potentially lead to structural concerns, highlighting the need for careful monitoring and design considerations.

The maximum displacements also increase considerably, illustrating the ship's heightened response to wave impacts during trough conditions. This emphasizes the importance of designing for dynamic loads when the vessel is subjected to waves.

c) Hogging condition:

The Von Mises stresses are lower when the ship is positioned at the crest of the wave compared to the trough. This decrease underscores the dynamic effects of the vessel's positioning within the wave cycle, indicating that different wave positions can lead to varied stress responses.

The maximum displacements observed at the crest are also less than those at the trough, suggesting that the structural integrity of the vessel may be better preserved when it is situated at the wave crest. This finding is essential for understanding how wave patterns affect vessel behavior.

8. ANALYSIS OF THE IMPACT OF STEEL PLATE REINFORCEMENT AROUND TECHNOLOGICAL CUTOUTS

Steel plate reinforcement around technological cutouts is a commonly used solution in naval engineering to improve the structural integrity of ships. This process aims to strengthen vulnerable areas, thus helping to prevent failures and increase the durability of the ship's structure.

This analysis intends to investigate the impact of reinforcement on the distribution of stresses and deformations in critical areas, particularly around technological cutouts.

To conduct this comparison, the stresses will be examined to highlight areas with an increased risk of failure, and the displacements around the technological cutouts will be evaluated to assess the impact of different mesh sizes on structural stability. Four representative elements from the circumference of the cutout were considered for each type of mesh (200 mm - **Figure 9a**, 100 mm - **Figure 9.b**, 50 mm - **Figure 9.c**).

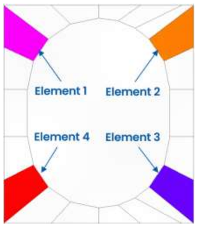

Fig. 9.a 3D-FEM model of a cutout - mesh 200 mm

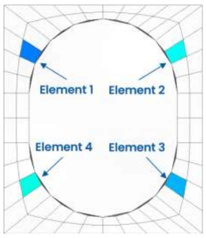

Fig. 9.b 3D-FEM model of a cutout - mesh 100 mm

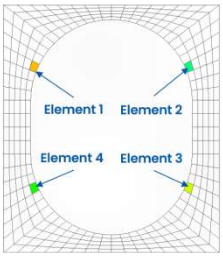

Fig 9.c 3D-FEM model of a cutout - mesh 50 mm

9. COMPARATIVE ANALYSIS OF STRESSES

Next, the stresses of the four elements will be compared for both the unbordered and bordered cases across all conditions of the ship's positioning on water, based on the size of the discretization.

a) <u>Case of static positioning on calm water</u>

In this section, we analyze the results obtained from the finite element analysis (FEM) of the model positioned on calm water. The primary focus is on the Von Mises stresses and displacements experienced by the vessel in various configurations, particularly comparing bordered and unbordered elements under different mesh sizes (200 mm - **Tabel 1.8a**, 100 mm - **Table 1.8b**, and 50 mm - **Table 1.8c**).

Table 1.8a Von Mises stresses of elements - mesh 200 mm - still water

Table 1.8a Von Mises stresses of elements - mesh 200 mm - still water

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 1	33.148	38.994	17.64%
Element 2	62.449	44.540	-27.08%
Element 3	36.985	43.313	17.11%
Element 4	64.634	49.621	-24.40%

Table 1.8b Von Mises stresses of elements - mesh 100 mm - still water

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 1	23.620	36.032	52.55%
Element 2	77.448	48.729	-37.08%
Element 3	24.717	40.821	64.15%
Element 4	81.351	50.419	-38.02%

Table 1.8c Von Mises stresses of elements - mesh 50 mm - still water

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 1	30.408	27.383	-9.95%
Element 2	84.632	51.540	-39.10%
Element 3	26.862	32.360	20.47%
Element 4	88.727	53.383	-39.83%

b) <u>Sagging condition</u>

In this section, we analyze the Von Mises stress values for the unbordered and bordered configurations of the model under wave trough conditions. This investigation helps to assess the impact of structural modifications, particularly the addition of steel plates around technological cutouts (**Table 1.9a, Table 1.9c** and **Table 1.9a**).

Table 1.9a Von Mises stresses of elements - mesh 200 mm - sagging

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 1	149.332	89.833	-39.84%
Element 2	124.428	96.663	-22.93%
Element 3	136.780	79.732	-41.71%
Element 4	132.936	93.206	-29.89%

Table 1.9a Von Mises stresses of elements - mesh 200 mm - sagging

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)

Table 1.9b Von Mises stresses of elements - mesh100 mm - sagging

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 1	161.945	109.812	-32.19%
Element 2	109.283	117.291	7.33%
Element 3	149.211	107.156	-28.19%
Element 4	124.655	113.767	-8.73%

Table 1.9c Von Mises stresses of elements - mesh50 mm - sagging

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 1	240.475	122.143	-49.21%
Element 2	198.251	117.840	-40.56%
Element 3	226.905	118.685	-47.69%
Element 4	217.849	118.208	-44.74%

c) Hogging condition

Table 1.10a Von Mises stresses of elements - mesh 200 mm - hogging condition

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 1	47.918	43.680	-8.85%
Element 2	84.537	56.407	-34.06%
Element 3	50.301	50.469	0.33%
Element 4	91.639	63.086	-31.16%

Table 1.10b Von Mises stresses of elements - mesh 100 mm - hogging condition

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 1	21.894	46.075	110.45%
Element 2	74.211	66.087	-10.95%
Element 3	23.569	52.579	123.08%
Element 4	77.358	69.295	-10.42%

Table 1.10c Von Mises stresses of elements - mesh 50 mm - hogging condition

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 1	69.035	39.180	-43.25%
Element 2	124.950	72.455	-42.47%

Table 1.10a Von Mises stresses of elements - mesh 200 mm - hogging condition

Element	Unbordered (MPa)	Bordered (MPa)	Difference (%)
Element 3	62.427	44.427	-28.83%
Element 4	133.879	74.872	-43.33%

The interpretation of the results is not complete, as the analyzed model includes only the stresses and deformations caused by local loads, without considering the global bending of the ship, which introduces additional stresses, especially in the structural elements of the double bottom.
It is recommended to use steel plates around the technological cutouts, as this significantly reduces the stresses.
As observed in the tables presented earlier, in some cases, there is an increase in stresses in the bordered model compared to the unbordered one. This phenomenon is due to the fact that bordering adds additional rigidity to the structure, leading to a redistribution of stresses. Thus, instead of the stresses being concentrated in certain areas, they become more uniform across a larger surface. This phenomenon can be considered beneficial for the structure, as it reduces the risk of stress concentrations that could lead to cracks or other types of structural damage.

10. COMPARISON OF STRESSES IMPLIFIED AND COMPLETE MODELS

In this section, we analyzed and compared the stress distribution around technological cutouts for both the simplified model, which includes only the double bottom and keel, and the complete ship model. This comparison is essential for understanding the impact these cutouts have on the structural integrity of the vessel, depending on the complexity of the model used.
Through this analysis, we highlight differences in stress behavior and identify poten-

tial risk areas, thus providing valuable insights for optimizing ship design.

a) Case of the ship's positioning on still water

Element	Simplified model unbordered (MPa)	Complete model unbordered (MPa)	Simplified model bordered (MPa)	Complete model bordered (MPa)
Element 1	30.408	34.693	27.383	32.475
Element 2	84.362	76.822	51.540	45.713
Element 3	26.862	30.226	32.360	34.994
Element 4	88.727	82.688	53.383	46.662

b) Case of the ship's positioning in a sagging

Element	Simplified model unbordered (MPa)	Complete model unbordered (MPa)	Simplified model bordered (MPa)	Complete model bordered (MPa)
Element 1	240.475	156.162	122.143	90.941
Element 2	198.251	115.534	117.840	82.831
Element 3	226.905	145.269	118.685	87.506
Element 4	217.849	127.629	118.208	85.656

c) The case of the ship's position on a hogging

Element	Simplified model unbordered (MPa)	Complete model unbordered (MPa)	Simplified model bordered (MPa)	Complete model bordered (MPa)
Element 1	69.035	52.083	39.180	42.008
Element 2	125.950	95.272	72.455	56.761
Element 3	62.427	45.808	44.427	43.455
Element 4	133.879	102.343	75.872	43.455

11. CONCLUSIONS

The analysis of stress distribution around technological cutouts has revealed important insights into how different model complexities affect the structural integrity of the vessel. Comparing the simplified model (with only the double bottom and keel) to the full ship model, we observed several key findings:

- ✓ Stress concentration differences: the simplified model and the full model exhibit notable differences in stress concentration around the cutouts. These variations highlight the importance of including complete structural elements in simulations to more accurately capture stress distribution, especially in critical areas.
- ✓ Identification of high-risk zones: the analysis allowed us to pinpoint specific high-stress zones that could present potential risks for structural failure. This information is crucial for reinforcing these areas in the design phase to ensure enhanced durability and safety.
- ✓ Impact of model complexity on integrity assessment: the simplified model provides a general overview but may underestimate certain stresses due to its limited scope. The complete model offers a more comprehensive assessment of how cutouts affect overall integrity, making it essential for precise evaluations in final design stages.
- ✓ Design optimization potential: the findings contribute valuable data for ship design optimization, enabling more targeted adjustments to reinforce areas with significant stress concentrations and improve overall structural performance.

In summary, the comparison underscores the need for detailed modeling to accurately assess the effects of structural cutouts, providing insights that can inform both design enhancements and risk management strategies for improved vessel integrity.

The impact of local discretization on stress concentrators, particularly around technological cutouts, is profound. Properly refining the mesh in these regions is crucial to obtaining accurate stress predictions, which in turn affects the design's reliability, safety, and performance. The balance between computational cost and accuracy is essential, and techniques such as adaptive mesh refinement can help optimize the analysis. Ultimately, addressing local discretization challenges leads to more accurate fatigue analysis, better understanding of stress concentrations, and safer, more durable designs.

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