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COMPARATIVE STATIC FEA OF EQUIPMENT FOUNDATIONS ON MARINE VESSELS: STANDARD, STIFFENED, AND STRUCTURAL INTEGRATED

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ABSTRACT

This study case presents a comprehensive static finite element analysis (FEA) of an equipment foundation aboard a marine vessel, conducted in three distinctive scenarios. The initial analysis adheres to a generalized standard, providing a baseline for structural performance. Subsequently, the same foundation is re-evaluated with the addition of stiffening brackets, aimed at enhancing rigidity and load distribution capabilities. The final analysis transitions from the theoretical models to practical application, examining the foundation as it is truly mounted and integrated within the ship's structure. Each scenario is meticulously compared to assess the impact of design modifications and integration on the foundation's performance.

Keywords: equipment foundations, ship integrated foundation, static FE analysis

1. INTRODUCTION

The present paper analyzes the building of a foundation for naval equipment, which should be simple enough, but at the same time able to provide the necessary rigidity to fix the equipment in place [2].

It is common knowledge that foundations must be capable of supporting the attached equipment as well as various additional loads, redistributing those into the hull structure. The foundation evaluation should include the weights of machinery and any existing equipment, not to mention any liquids at operating levels; it is also important that it supports half of the lengths of connected piping and cables which are otherwise unsupported, and the additional dynamic effects of the ship motion and vibration [3].

The ever higher cost of materials and human manufacture on vessel construction requires that shipboard foundations be lighter and of simple design. The most expensive processes in hull structure fabrication are the cutting, fit-up, and welding operations which go into building the foundation. Foundation designs that reduce cutting, fitting and welding to a minimum, also decreasing the requirement for jigs and fixtures obviously lead to a considerable reduction of manual labour.

Even if foundations represent only around 10% of the steel weight of ships, their cost represents close to 50% of the steel construction; however, when speaking of commercial ships, the portion of the steel weight taken by the foundation is lower, but still quite significant in absolute value [3].

Developing standard foundations for various equipment provides numerous benefits, such as:

- Shorter welding time
- Less amount of material used
- Reduced manufacturing/fit up
- Shorter time for the installation of the foundation
- 45% to 50% savings in weight
- 50% savings in welding
- 50% reduction in the number of parts.

The computer models allow engineers to obtain a ready representation of the foundation type by carrying out tests showing the deflection characterization of foundations under each orthogonal direction when a load is applied, thus providing the required parameters to compute the structural stiffness, load distribution and stress development.

The main objective of every design/engineering team is to produce foundation drawings for shipyards so they can be easily manufactured while meeting all specifications for the parameters, like structural adequacy, vibration and acoustic limit, weight and cost effectiveness, as well as maintenance requirements.

From a more conservative point of view, these designs would allow the foundation to be loaded up to 50% of the material yield strength in order to withstand the most severe ship motions. Since ship motions typically produce 2-3 times the static load, a foundation designed according to these criteria would be able to cope with at least 4-6 times the static load successfully [3].

2. EQUIPMENT DESCRIPTION

The evolution of new technological solutions can be noticed both in the axis line as well as in specific local areas.

Firstly, we should focus on the presentation of the the equipment that needs the foundation, which is an electric piece of equipment, a switchboard.

In order to perform the modelling of a foundation, we should take into account the following:

- The type of equipment;
- The weight of the equipment;
- The gauge;
- The number and size of the mounting holes;
- The equipment placement on the section structure and the compartment;
- The check-up of the maintenance space – not only for the equipment, but also for the adjoining pieces;
- The check-up in order to see whether the equipment position in the compartment is "production friendly".

The main dimensions of the equipment are 812x608x2036 mm and it has 4 mounting holes. In operation the equipment weight is about 1500 kg.

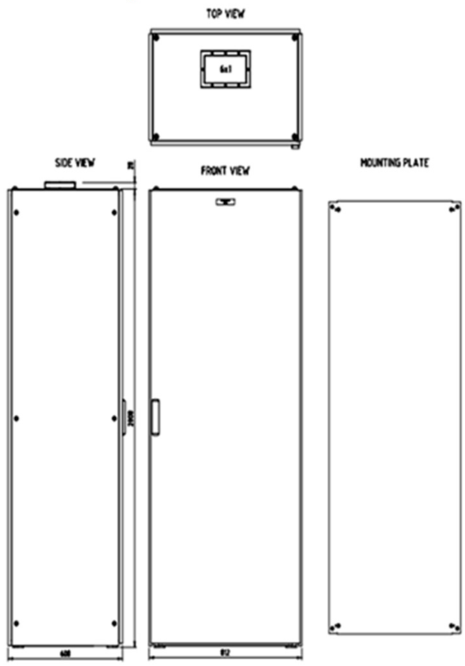

Fig.1. Switchboard

The mounting system and the number of mounting holes are shown in Figure 2.

The present paper deals with a comparative study in three distinct scenarios aimed at building a foundation for a switchboard.

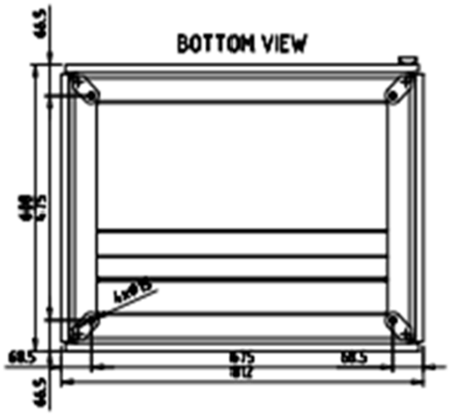

Fig.1. Equipment footprint

3. FINITE ELEMENT ANALYSIS

The characteristics and design features that result in the manufacture of a producible foundation are the following:

- Foundations should be originally designed by the hull design engineer in order to make sure that the equipment has an adequate support;
- Foundations should be designs which need the least number of pieces and operations for each piece;
- Foundations should be rectilinear in configuration, i.e. they should consist of straight lines and right angles in the highest proportion possible;
- Foundations should provide enough access to enable ease of installation, welding and inspection and maintenance of the equipment;
- Foundations should be built to avoid liquid-containing pockets.

The present paper assessed 3 versions for the foundation geometry [1]. The initial model was designed considering the equipment footprint and weight, resulting in the standard case. The second foundation model considered the same geometry and added vertical stiffening brackets. The third geometry analysed considered the real integrated foundation on-board of the ship, taking into account surrounding structure.

Considering the weight of the equipment, AE100x10 has been used for the foundation structure, according the standard.

Fig.3. CAD Geometry - case 1

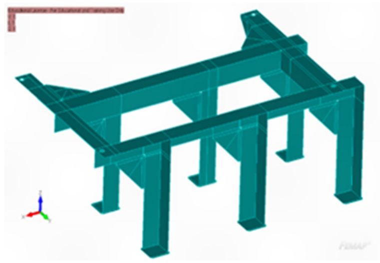

Fig.4. CAD Geometry – case 2

Case 2 is the version of standard foundation to which stiffening brackets were added on the main directions.

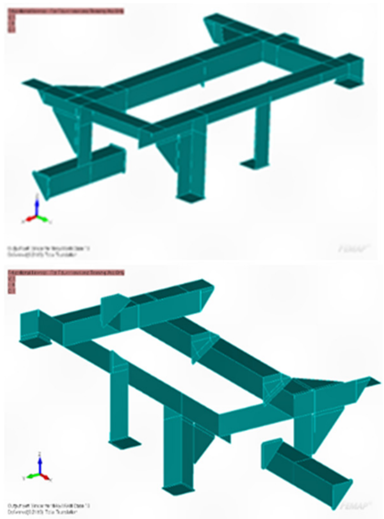

Fig.5. CAD Geometry - case 3

Case 3 is the final version of the foundation which corresponds to the real foundation mounted on the vessel.

The next figures show the foundation structural model in the 3D software used for designing the manufactured version.

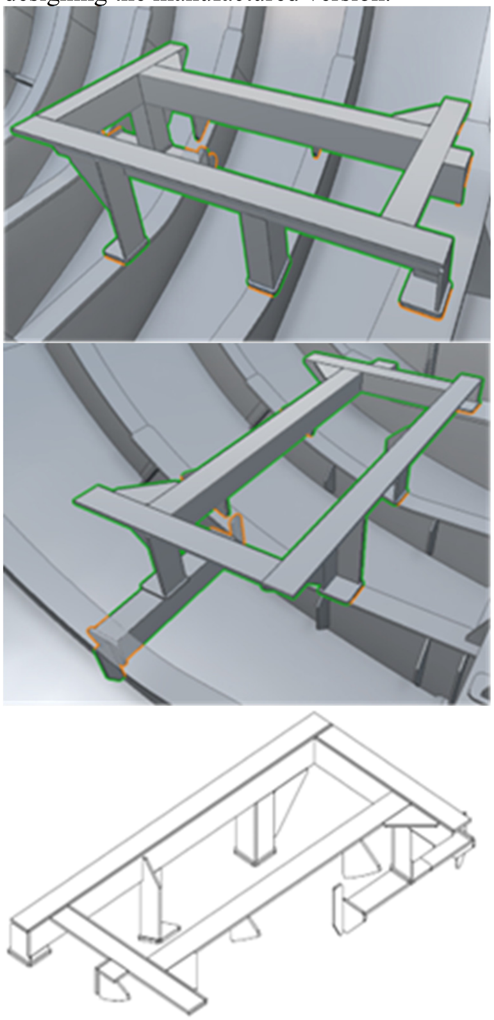

Fig.6. Details of the foundation mounted onboard the ship

The structural CAD and finite element model was generated and analysed using the FEMAP software [4].

After meshing, a network of quadrilateral quad type was obtained, whose size varies in accordance with the body surface, having an average element size of 15 mm.

Discretised model of the foundation variants for the analysis performed in this study are presented in the following figures.

Fig.7. Structural discretization - case 1

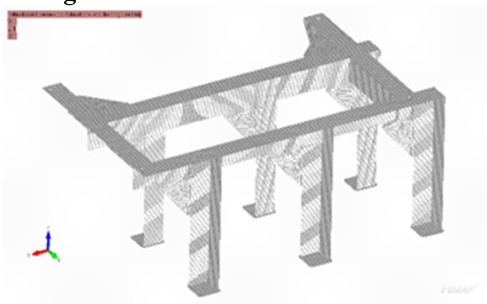

Fig.8. Structural discretization - case 2

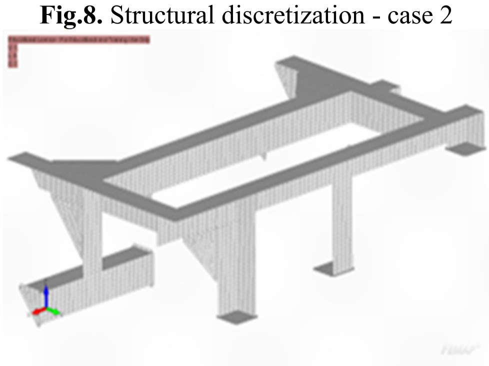

Fig.7. Structural discretization - case 3

The FE model of the foundation has been loaded with the force exerted by the equipment previously presented. The equivalent force of the equipment has been applied at it's center of gravity and the acting force has been translated to the equipment foundation's footprint through rigid 2D elements [1].

The material model used in assessing the integrity of the foundation structure is a linear model of industrial steel, having the yielding strength of 235 MPa, Poisson ratio of 0.3, and density of 7850 kg/m^3.

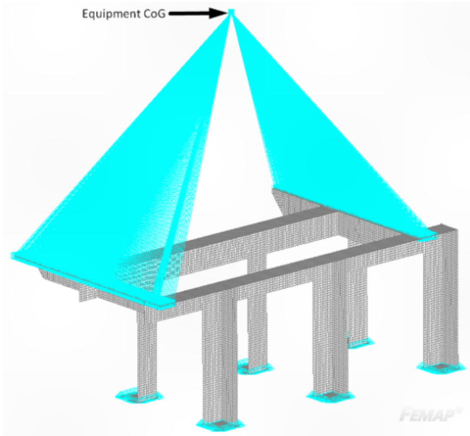

Fig.10. Loading point and constraints on foundation

As a result, a number of 54 distinct loading cases have been identified. The first 6 for the main orthogonal directions (3 positive/ 3 negative), and the remaining 48 are combinations of the above, with the resulting force, all being presented in matrix loading Table 1. The model has been considered fixed at contact with ship's structure.

Table 1. FEA loading matrix

Load case	Direction and loading factor X+	X-	Y+	Y-	Z+	Z-	Resulting force [N]	Load case	Direction and loading factor X+	X-	Y+	Y-	Z+	Z-	Resulting force [N]
LC 1	1							LC 28		0.7		0.7	0.7		
LC 2		1						LC 29		0.7		0.7		0.7	17841.0
LC 3			1				14715	LC 30		0.7	0.7			0.7	
LC 4				1				LC 31	0.8		0.8		0.8		
LC 5					1			LC 32	0.8			0.8	0.8		
LC 6						1		LC 33	0.8			0.8		0.8	
LC 7	0.5		0.5		0.5			LC 34	0.8		0.8			0.8	20389.7
LC 8	0.5			0.5	0.5			LC 35		0.8	0.8		0.8		
LC 9	0.5			0.5		0.5		LC 36		0.8		0.8	0.8		
LC 10	0.5		0.5			0.5	12743.6	LC 37		0.8		0.8		0.8	
LC 11		0.5	0.5		0.5			LC 38		0.8	0.8			0.8	
LC 12		0.5		0.5	0.5			LC 39	0.9		0.9		0.9		
LC 13		0.5		0.5		0.5		LC 40	0.9			0.9	0.9		
LC 14		0.5	0.5			0.5		LC 41	0.9			0.9		0.9	
LC 15	0.6		0.6		0.6			LC 42	0.9		0.9			0.9	22938.4
LC 16	0.6			0.6	0.6			LC 43		0.9	0.9		0.9		
LC 17	0.6			0.6		0.6		LC 44		0.9		0.9	0.9		
LC 18	0.6		0.6			0.6	15292.3	LC 45		0.9		0.9		0.9	
LC 19		0.6	0.6		0.6			LC 46		0.9	0.9			0.9	
LC 20		0.6		0.6	0.6			LC 47	1		1		1		
LC 21		0.6		0.6		0.6		LC 48	1			1	1		
LC 22		0.6	0.6			0.6		LC 49	1			1		1	
LC 23	0.7		0.7		0.7			LC 50	1		1			1	25487.1
LC 24	0.7			0.7	0.7			LC 51		1	1		1		
LC 25	0.7			0.7		0.7	17841.0	LC 52		1		1	1		
LC 26	0.7		0.7			0.7		LC 53		1		1		1	
LC 27		0.7	0.7		0.7			LC 54		1	1			1	

4. RESULTS AND DISCUSSIONS

The results calculated for the 3 foundation models of the loaded with the equivalent force values shown above, the state of von Mises stress and total displacements were calculated and are presented in the following.

Table 2. FEA Results, Case 1

Load case	Results vM[MPa]	Displ.[mm]	Load case	Results vM[MPa]	Displ.[mm]
LC 1	59.6	0.46	LC 28	83.7	0.72
LC 2	59.6	0.46	LC 29	82.0	0.70
LC 3	99.7	0.83	LC 30	78.3	0.55
LC 4	99.7	0.83	LC 31	93.7	0.79
LC 5	38.6	0.16	LC 32	89.5	0.63
LC 6	38.6	0.16	LC 33	102.9	0.77
LC 7	58.6	0.50	LC 34	95.6	0.82
LC 8	55.9	0.39	LC 35	102.9	0.77
LC 9	64.3	0.48	LC 36	95.6	0.82
LC 10	59.8	0.51	LC 37	93.7	0.79
LC 11	64.3	0.48	LC 38	89.5	0.63
LC 12	59.8	0.51	LC 39	105.4	0.89
LC 13	58.6	0.50	LC 40	100.6	0.71
LC 14	55.9	0.39	LC 41	115.8	0.87
LC 15	70.3	0.60	LC 42	107.6	0.92
LC 16	67.1	0.47	LC 43	115.8	0.87
LC 17	77.2	0.58	LC 44	107.6	0.92
LC 18	71.7	0.62	LC 45	105.4	0.89
LC 19	77.2	0.58	LC 46	100.6	0.71
LC 20	71.7	0.62	LC 47	117.2	0.99
LC 21	70.3	0.60	LC 48	111.8	0.79
LC 22	67.1	0.47	LC 49	128.6	0.97
LC 23	82.0	0.70	LC 50	119.5	1.03
LC 24	78.3	0.55	LC 51	128.6	0.97
LC 25	90.0	0.68	LC 52	119.5	1.03
LC 26	83.7	0.72	LC 53	117.2	0.99
LC 27	90.0	0.68	LC 54	111.8	0.79

Table 2 shows the results corresponding to the case 1 foundation, considering the structural model without reinforcements.

Table 3. FEA Results, Case 2

Load case	Results vM[MPa]	Displ.[mm]	Load case	Results vM[MPa]	Displ.[mm]
LC 1	56.4	0.31	LC 28	68.0	0.46
LC 2	56.4	0.31	LC 29	65.1	0.54
LC 3	72.8	0.66	LC 30	68.0	0.46
LC 4	72.8	0.66	LC 31	80.0	0.64
LC 5	26.3	0.10	LC 32	74.6	0.49
LC 6	26.3	0.10	LC 33	80.3	0.60
LC 7	50.0	0.40	LC 34	83.2	0.57
LC 8	46.6	0.31	LC 35	74.4	0.61
LC 9	50.2	0.37	LC 36	77.7	0.53
LC 10	52.0	0.36	LC 37	74.4	0.61
LC 11	46.5	0.38	LC 38	77.7	0.53
LC 12	48.6	0.33	LC 39	90.0	0.72
LC 13	46.5	0.38	LC 40	83.9	0.55
LC 14	48.6	0.33	LC 41	90.3	0.67
LC 15	60.0	0.48	LC 42	93.6	0.64
LC 16	55.9	0.37	LC 43	83.7	0.69
LC 17	60.2	0.45	LC 44	87.4	0.59
LC 18	62.4	0.43	LC 45	83.7	0.69
LC 19	55.8	0.46	LC 46	87.4	0.59
LC 20	58.3	0.40	LC 47	100.0	0.80
LC 21	55.8	0.46	LC 48	93.2	0.61
LC 22	58.3	0.40	LC 49	100.3	0.75
LC 23	70.0	0.56	LC 50	104.0	0.71
LC 24	65.2	0.43	LC 51	93.0	0.77
LC 25	70.2	0.52	LC 52	97.1	0.66
LC 26	72.8	0.50	LC 53	93.0	0.77
LC 27	65.1	0.54	LC 54	97.1	0.66

Table 3 lists the results corresponding to the second variant of the foundation, the model with stiffening brackets, while table 4 presents the results calculated for the real case foundation to be manufactured and mounted on-board the ship.

Table 4. FEA results, Case 3

Load case	Results		Load case	Results	
	vM[MPa]	Displ.		vM[MPa]	Displ.[mm]
LC 1	45.8	0.07	LC 28	101.3	0.30
LC 2	45.8	0.07	LC 29	139.9	0.30
LC 3	124.2	0.36	LC 30	66.2	0.20
LC 4	124.2	0.36	LC 31	159.8	0.40
LC 5	32.6	0.06	LC 32	75.7	0.20
LC 6	32.6	0.06	LC 33	96.0	0.30
LC 7	99.9	0.24	LC 34	115.8	0.30
LC 8	47.3	0.12	LC 35	96.0	0.30
LC 9	60.0	0.18	LC 36	115.8	0.30
LC 10	72.4	0.18	LC 37	159.8	0.40
LC 11	60.0	0.18	LC 38	75.7	0.20
LC 12	72.4	0.18	LC 39	179.8	0.40
LC 13	99.9	0.24	LC 40	85.2	0.20
LC 14	47.3	0.12	LC 41	108.0	0.30
LC 15	119.9	0.29	LC 42	130.3	0.30
LC 16	56.8	0.15	LC 43	108.0	0.30
LC 17	72.0	0.22	LC 44	130.3	0.30
LC 18	86.8	0.22	LC 45	179.8	0.40
LC 19	72.0	0.22	LC 46	85.2	0.20
LC 20	86.8	0.22	LC 47	199.8	0.50
LC 21	119.9	0.29	LC 48	94.6	0.20
LC 22	56.8	0.15	LC 49	120.1	0.40
LC 23	139.9	0.33	LC 50	144.7	0.40
LC 24	66.2	0.17	LC 51	120.1	0.40
LC 25	84.0	0.25	LC 52	144.7	0.40
LC 26	101.3	0.26	LC 53	199.8	0.50
LC 27	84.0	0.25	LC 54	94.6	0.20

Figures 11, 12, and 13 present the calculated von Mises stress distribution and the scaled deformations for the highest stress registered loading case for each loading scenario.

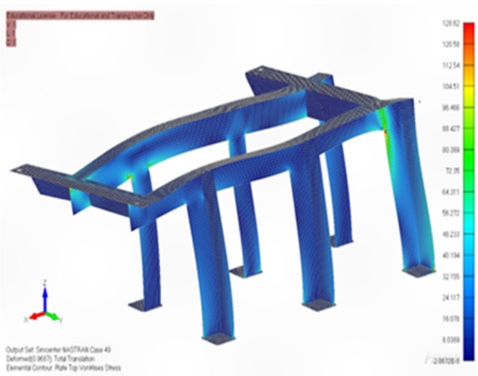

Fig.11. Case 1, von Mises stress distribution

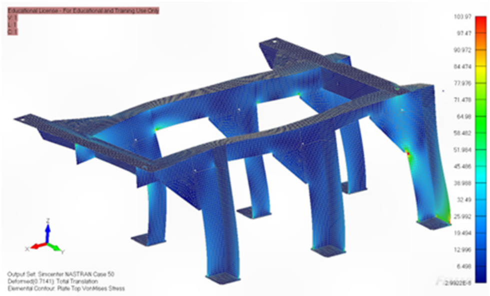

Fig.12. Case 2, von Mises stress distribution

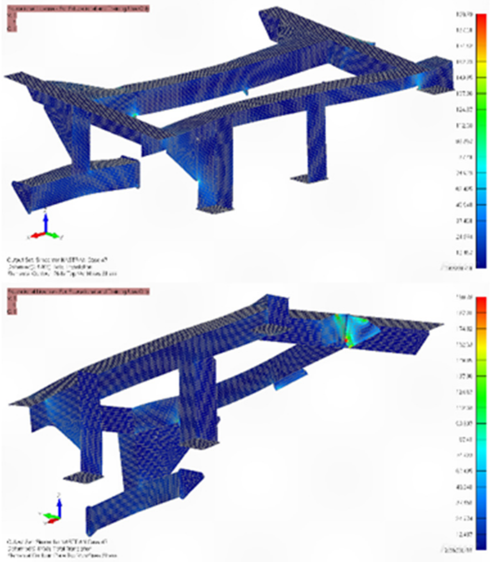

Fig.13. Case 3, von Mises stress distribution

4. CONCLUDING REMARKS

The current study on the comparative static finite element analysis of equipment foundations on marine vessels in three distinct scenarios – standard, stiffened, and structural integrated – leads to the following key conclusions:

- The addition of stiffening brackets to the standard foundation improves the rigidity and load distribution, a crucial factor in the challenging marine environment.

- Across all design scenarios, the stress levels remained within safe limits, indicating robust structural design, without any risk of plastic deformations. This highlights the reliability of the foundation designs under study.

- Analyzing the integrated foundation within the ship's structure, described as Case 3, provides practical insights, and highlights the concentrated stress levels at the connections with ship's transverse stiffened frame, close to yielding strength(aprox. 200 MPa). The real case scenario emphasizes the necessity for designs that are viable both theoretically and in real-world applications.

- The purpose of the current study was to point out that large deviations from any standard of designing an equipment foundation can be overlooked and can lead to negative consequences throughout the ship's operation lifetime.

- Finite element analysis proves to be an indispensable tool in the design and optimization of marine equipment foundations, allowing for fast, low cost, detailed modeling, and analysis of complex conditions.

Marine vessels are subjected to cyclic loading due to waves, vessel motion, and operational loads, which can lead to fatigue damage over time. Unlike static loads, these dynamic effects can cause failure at stress levels, significantly lower than the material's yield strength. Fatigue analysis would provide insight into the lifespan of the foundation under realistic service conditions, which is critical for ensuring long-term structural integrity and safety.

This study contributes to the advancement in the field of the naval architecture, offering insights into optimizing foundation designs for marine vessels, balancing performance, safety, and cost-effectiveness.

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REFERENCES

[1]. **Domnişoru L**., *"Analiza structurilor navale prin metoda elementului finit . Aplicatii numerice"*, Editura Fundaţiei Universitare "Dunărea de Jos", Galaţi, 2009

[2]. **DNVGL, 2021**, "*Modeling and Analysis of Marine Operations"*, Recommended Practice, DNV-RP-H103, https://rules.dnvgl.com.

[3]. **Germanischer Lloyd, 2023,** *"Rules and Guidelines, Part I Sea Going Ships"*

[4]. **FEMAP** 2023. "*NX NASTRAN 5.0 User's Guide"*

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