The Static Behavior of a Ship Deck Panel Made of Composite Materials

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Abstract: A study on the static analysis of a naval panel made of composite sandwich materials is presented. By using FEM, the modeling of a naval floor with a length of 5 m and a width of 2.5 m is performed. Two distinct cases, have been performed: the first model consists of the plate and stiffeners made of steel and the second model concerns a panel made of composite material sandwich type steel / SANFoam103 / steel, and the stiffeners made of steel. A parametric study has been performed. The thickness of the steel faces have 6 mm, and for the core of SANFoam have been selected the thicknesses 5 mm, 10 mm, 20 mm, 40 mm.

Keywords: static analysis, ship deck panel, FEM analysis, composite materials, sandwich

1. Introduction

Composites represent the most important material used to build performing structures in all industrial domains. The basic feature of composite materials is the high strength/weight ratio, which makes them more efficient than some of the best steel categories. A sandwich panel made of composite materials is performant if it has thin and rigid faces with high strength, and the core has low density.

Sandwich panels with metal faces and foam cores are very often used as lightweight structures in shipbuilding applications [1-5], especially because of their performance on light weight and high rigidity. In the shipbuilding industry, the application of polymeric sandwich-type composites is constantly evolving, introducing into their composition new basic materials such as: fibers, resins, adhesives, cure accelerators, additives, etc.

As an alternative to panels with a classic stiffened metal structure [6-8], sandwich structures justify their use in the shipbuilding, making these materials less complex, eliminating the need for secondary stiffening (stiffeners). At the same time, other advantages of sandwich-type composite materials are related to corrosion resistance, increased tensile strength, for easier durability, and thermal insulation [9, 10].

The faces of sandwich panels can be made of metal materials (aluminum alloys or stainless steel), non-metallic (polymeric laminates with glass fibers or carbon fibers), various composite materials (reinforced polymeric) or hybrid. The core consists of a light, porous or non-porous material, granulated or special types, consisting of cells (honeycomb type) - [19] or profiles (U, I, T, etc.). As a rule, the core is a composite material that, at a long time load, slowly deforms.

As an alternative solution in shipbuilding, the concept of SPS (sandwich plate system) material has developed. This material allows the replacement of the classic panels with a stiffened steel structure with a polyurethane elastomer [5, 11-14].

In the case of naval decks, in the classical system, longitudinal structures are used as stiffening elements, whose welded joints are the sensible to corrosion and fatigue.

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In the case of SPS, the space between two steel plates is filled with an elastomer and thus the need for longitudinal welds on the coating is eliminated. In the case of decks repair, the process is much simplified, the main stiffeners (currents, longitudinal or transverse frames) are welded, and the remaining spaces are stiffened with elastomer, with an important financial and time advantage versus the classical methods.

In order to obtain answers such as stresses and strains for various cases of loading, of the natural vibration modes or of behavior of the structural elements to the buckling in the structural analyses that are applied in the ship structures, analytical calculations or the finite elements method are often used [15-18]. In general, in order to correctly define a structural analysis, various stages are taken, starting from the setting of objectives, type and size of the analysis, modeling of the structure and boundary conditions, modeling itself and evaluation of the results. In certain cases, linear analyses of ship structures are often sufficient.

In the work a study on the static analysis of a ship deck structure made of sandwich-type composite materials, by using the FEM is performed.

2. Materials and methods
2.1. Materials

The ship deck structure has length of 5 m and a width of 2.5 m. Two cases are considered: a first case in which the floor and stiffeners are made entirely of steel, and the second where the deck panel is made of steel / SANFoam103 / steel sandwich composite material and the stiffeners are of steel. The thickness of the steel faces is 6 mm, and the core of SANFoam has thicknesses of 5 mm, 10 mm, 20 mm, 40 mm respectively.

The dimensions are chosen so that the weights of the resulting structures are approximately the same with the initial one. In the case of analysis of the static behaviour of a ship deck panel using FEM, when defining the geometry of the model, for the steel panel and stiffeners, steel is considered as materials used in modeling, steel having the characteristics of Figure 1.

Label	Name	Temp/BH_Cr	Value		Label	Name	Temp/BH_Cr	Value
1	EX	0	2.100000e+005		1	EX	0	2.100000e+005
1	NUXY	0	2.800000e-001		1	NUXY	0	2.800000e-001
1	MPERM_R	0	1.000000e+000		1	MPERM_R	0	1.000000e+000
1	RK	0	8.500000e-001		1	RK	0	8.500000e-001
2	EX	0	8.500000e+001					
2	NUXY	0	3.000000e-001					
2	MPERM_R	0	1.000000e+000					
2	RK	0	8.500000e-001					
a.					**b.**			

Figure 1. The characteristics of the steel used in FEM analysis: a. - panel; b. - stiffeners

The core of the sandwich is SAN Foam whose characteristics are presented in Table 1.

Table 1. SAN Foam 103 kg/m^3 characteristics

Characteristics	Value	Measure unit
Density	103	kg/m^3
Elastic Isotrop	-	-
Young's Modulus	85	MPa
Poisson ratio	0.3	-
Bulk modulus	70.833	MPa
Shearing Modulus	32.692	MPa

The analyzed cases have been described in Table 2.

Table 2. Analysed models

Model	Material		Thickness [mm]	Mass [kg]
M1	Steel		12	1179
M2	Face1	Steel	6	1185.4
	Core	SAN Foam 103 kg/m^3	5	
	Face 2	Steel	6	
M3	Face 1	Steel	6	1191.87
	Core	SAN Foam 103 kg/m^3	10	
	Face 2	Steel	6	
M4	Face 1	Steel	6	1204
	Core	SAN Foam 103 kg/m^3	20	
	Face 2	Steel	6	
M5	Face 1	Steel	6	1230.5
	Core	SAN Foam 103 kg/m^3	40	
	Face 2	Steel	6	

The structure of the ship deck panel (Figure 2) was modeled using COSMOS/M, static analysis: extensive library of 1D, 2D and 3D elements supports isotropic, orthotropic, anisotropic, multi-layer composite materials, and temperature-dependent material properties. Capabilities include linear gap/contacts, stress stiffening, sub-structuring, multi-point constraints, constraint equations and much more.

Figure 2. Ship deck panel structure

2.2. Methods

For the structure FEM models SHELL 4L elements are used. In Figures 3, 4 and 5 the steps of FEM model defining are presented.
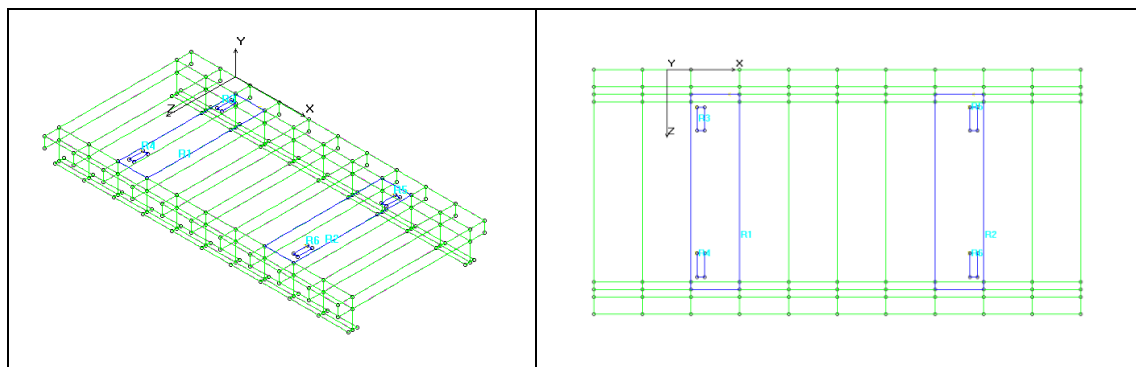
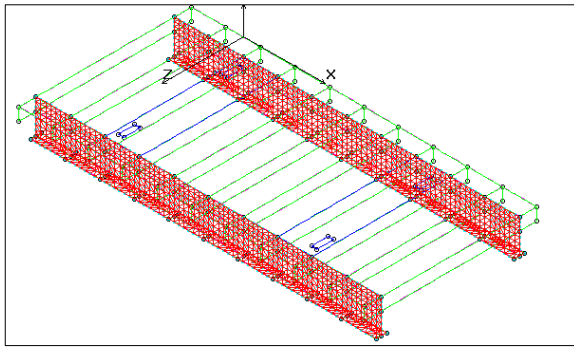**Figure 3.** Ship deck structure geometry: regions defining
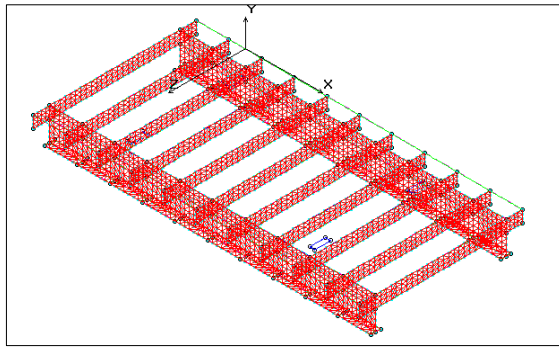
Figure 4. FEM model of transverses

Figure 5. FEM model of longitudinals

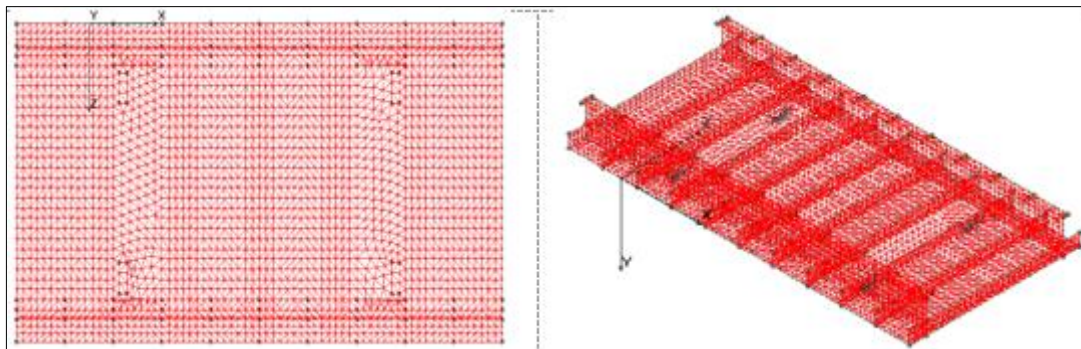In Figure 6 the FEM model of the deck panel structure is presented.

Figure 6. FEM model of the deck structure

The ship deck pane model is simple supported on all sides. The loading is produced by the tires pressure of the vehicles having the masses 1.5 t, 2 t, 2.5 t, 3 t and 3.5 t, as are presented in the Table 3.

Table 3. Loads acting on the ship deck panel

Case	Mass, m [tons]	Pressure, p [N/mm^2]
M1	m1=1.5	0.195
M2	m2=2	0.26
M3	m3=2.5	0.32
M4	m4=3	0.39
M5	m5=3.5	0.45

According to calculus of contact area of the tire car placed on the ship deck panel, the resulted pressure (**m1÷m5**) is presented in the Table 3. In Figures 7 and 8, the boundary conditions of the ship deck panel model are illustrated. The real contact area is an ellipse, but in FEM calculus was approximated with a rectangle.
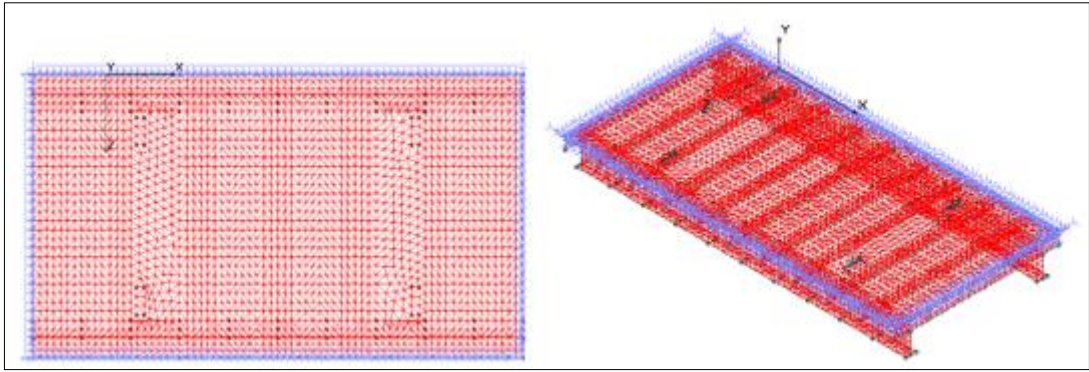
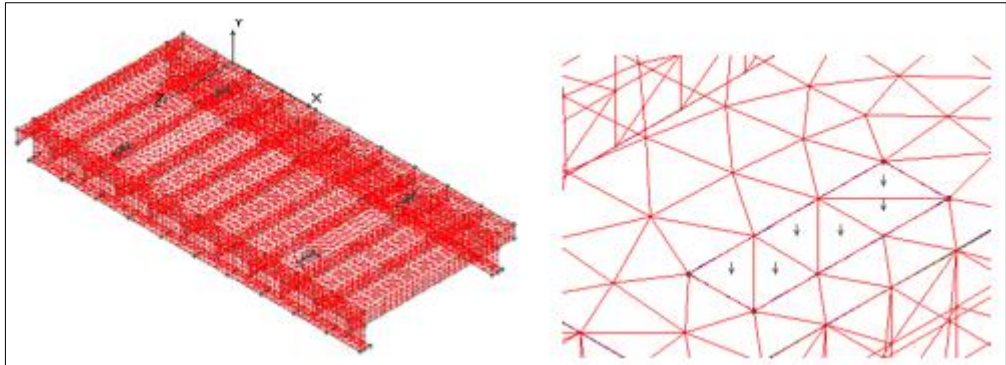**Figure 7.** Boundary conditions of the panel model

Figure 8. Details of the model loading conditions

3. Results and discussions
3.1. Results

According to the FEM analysis of the ship deck panel, the results obtained for the all five models **M1÷M5** and five analysed cases **(m1÷m5)** are illustrated in the Figures 9÷13.

M1	Panel material: steel / thickness: 12 mm. Panel mass: 1179 kg		
m1		m2	
m3		m4	
m5			

Figure 9. Model **M1** - displacements map [mm] and equivalent stresses map [MPa]

M2	Panel material: Face 1 - steel / thickness: 6 mm; Core - SAN Foam 103 kg/m³ / thickness: 5 mm; Face 2 - steel / thickness: 6 mm. Panel mass: 1185.4 kg		
m1		m2	
m3		m4	
m5			
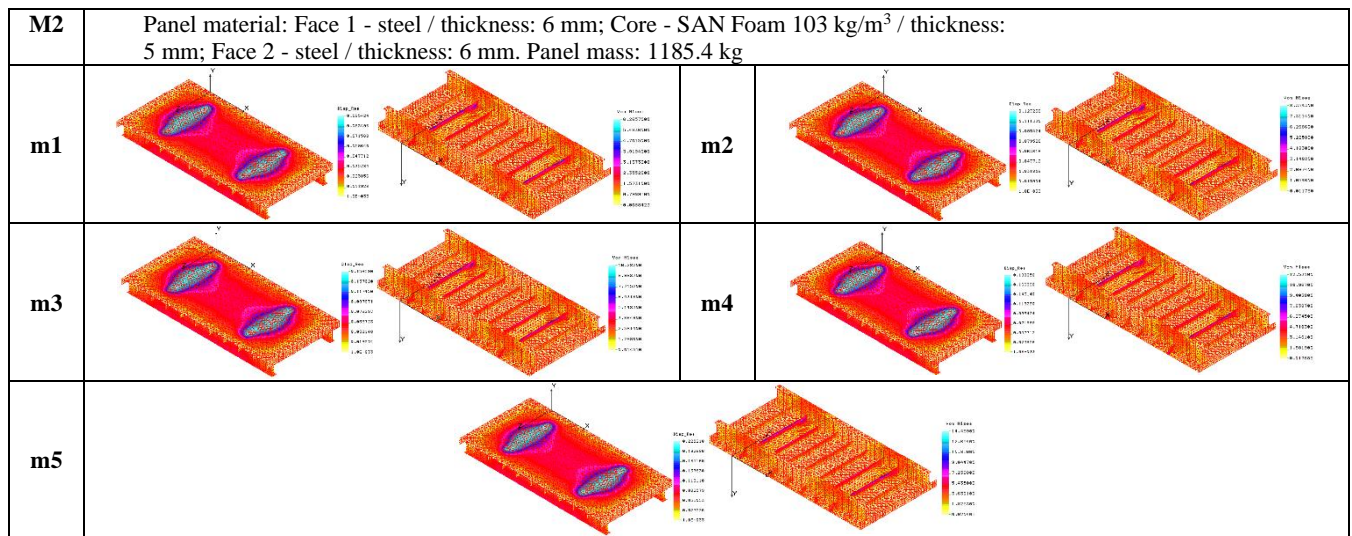
Figure 10. Model **M2** - displacements map [mm] and equivalent stresses map [MPa]

M3	Panel material: Face 1 - steel / thickness: 6 mm; Core - SAN Foam 103 kg/m³ / thickness: 10 mm; Face 2 - steel / thickness: 6 mm. Panel mass: 1191.87 kg		
m1		m2	
m3		m4	
m5			
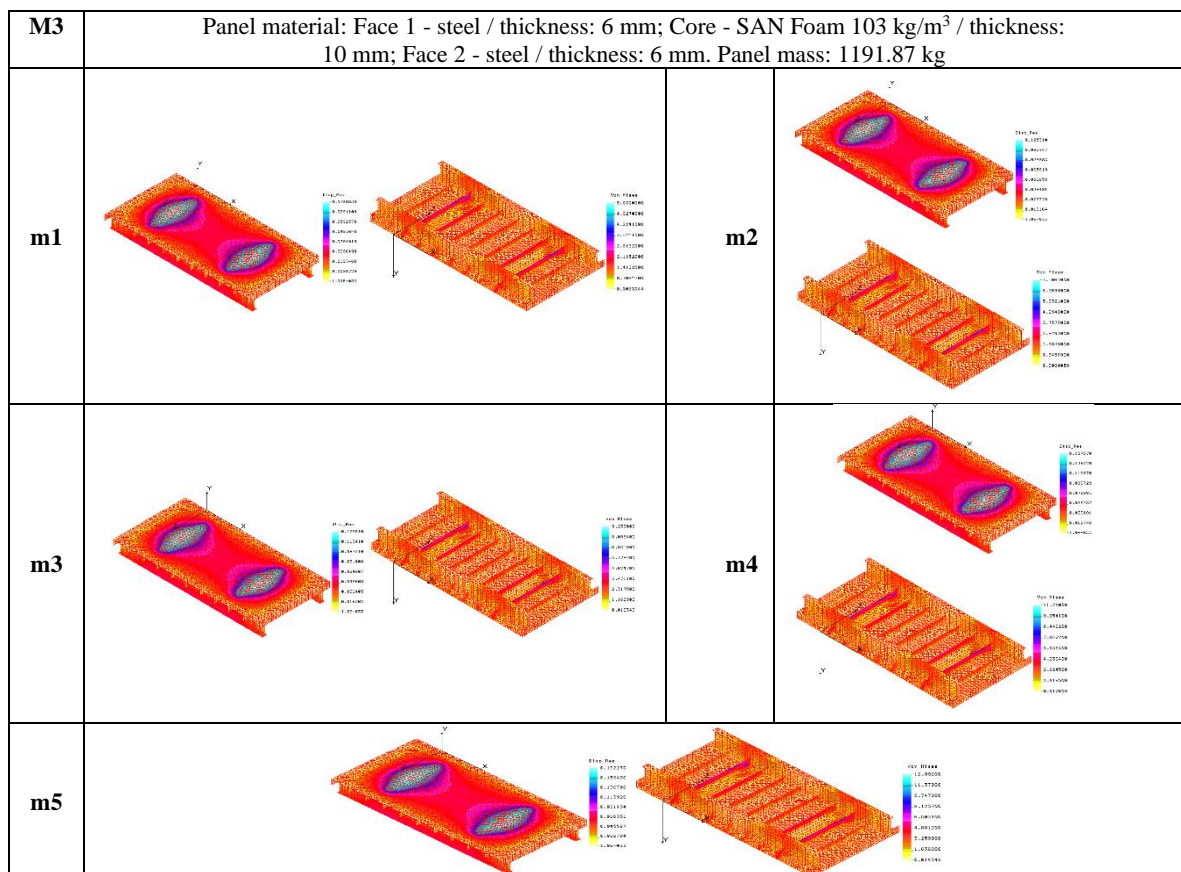
Figure 11. Model **M3** - displacements map [mm] and equivalent stresses map [MPa]

M4	Panel material: Face 1 - steel / thickness: 6 mm; Core - SAN Foam 103 kg/m³ / thickness: 20 mm; Face 2 - steel / thickness: 6 mm. Panel mass: 1204 kg		
m1		m2	
m3		m4	
m5			
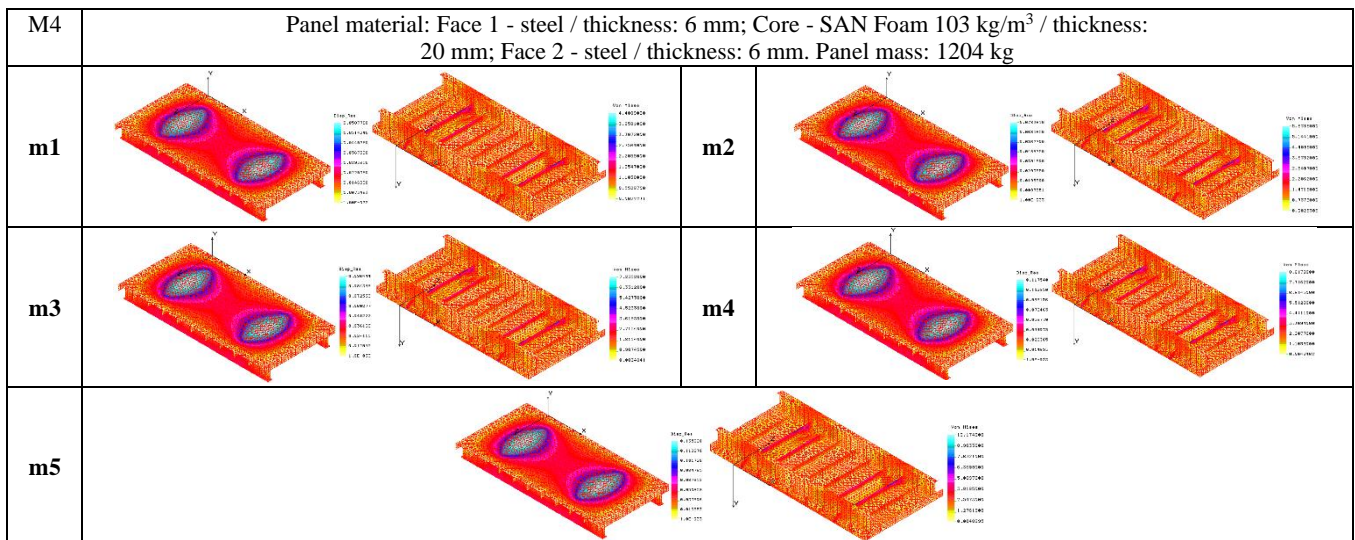
Figure 12. Model **M4** - displacements map [mm] and equivalent stresses map [MPa]

M5	Panel material: Face 1 - steel / thickness: 6 mm; Core - SAN Foam 103 kg/m³ / thickness: 40 mm; Face 2 - steel / thickness: 6 mm. Panel mass: 1230.5 kg		
m1		m2	
m3		m4	
m5			
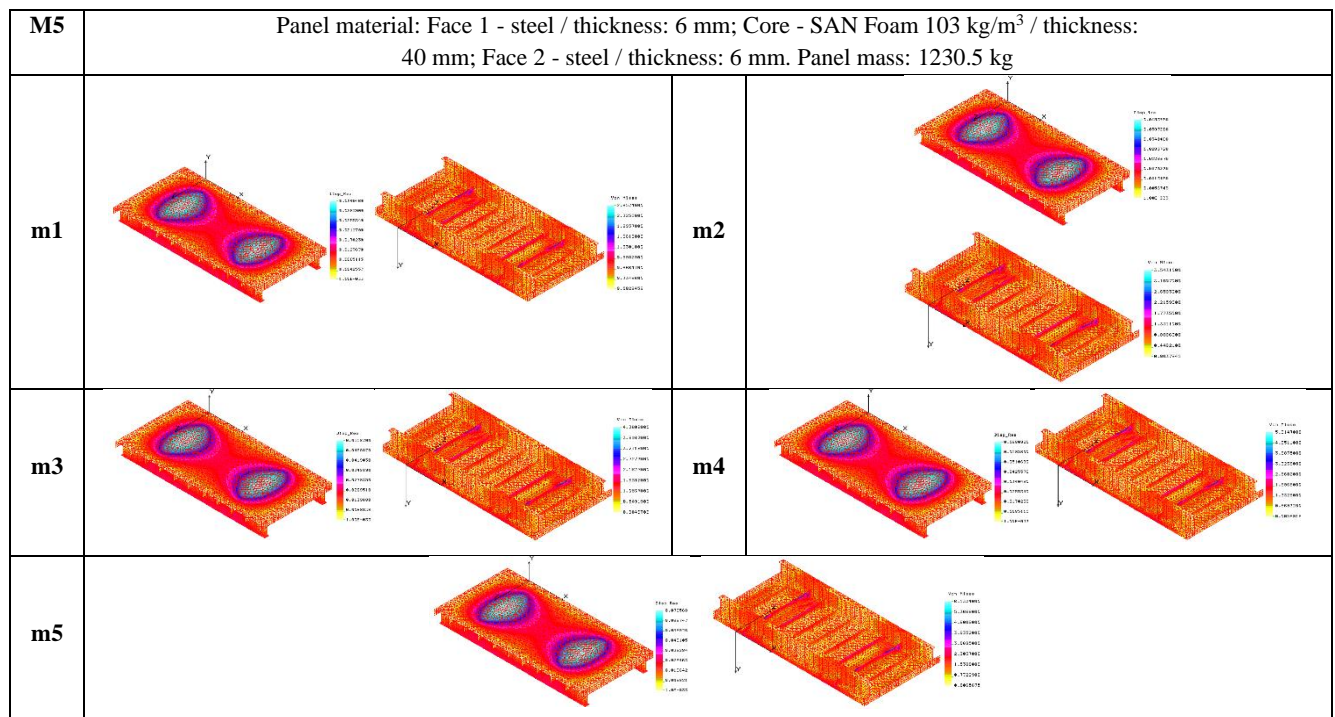
Figure 13. Model **M5** - displacements map [mm] and equivalent stresses map [MPa]

3.2. Discussions

In the case of the deck panel made of steel **(M1)** it can be seen that with the increase of the mass of the vehicle, the value of the maximum displacement increases, but also increase the values of the equivalent stresses, as are illustrated in Figure 14.
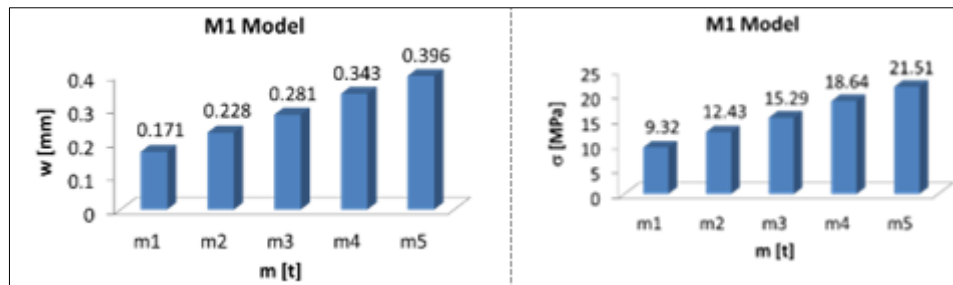
Figure 14. Model **M1** - influence of mass on maximum
displacements and equivalent stresses

In the case of the other models of the deck panel made of sandwich composite material with a core thickness of 5 mm **(M2)**, 10 mm **(M3)**, 20 mm **(M4)** and 40 mm **(M5)** and steel faces of 6mm, it can be seen that since the mass of the vehicle increases, the value of the maximum displacement also increases. The same can be seen in the case of the equivalent stress (Figures 15÷18).
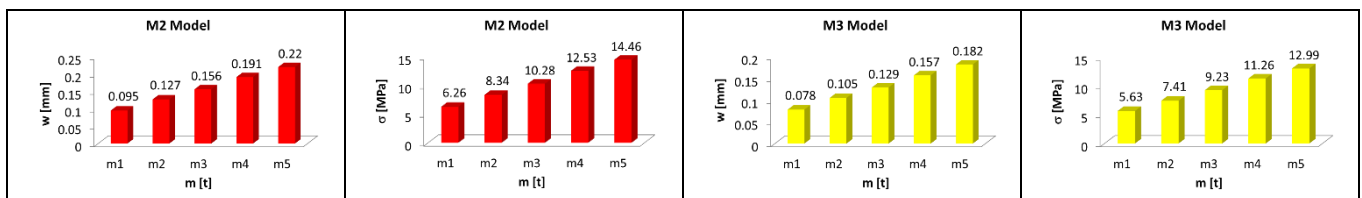

Figure 15. Model **M2** - influence of mass on
maximum displacements and
equivalent stresses
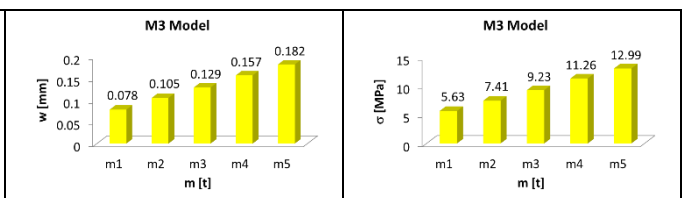
Figure 16. Model **M3** - influence of mass on
maximum displacements and
equivalent stresses
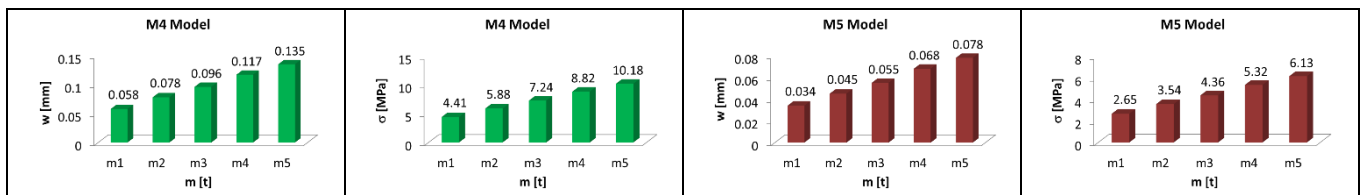
Figure 17. Model **M4** - influence of mass on
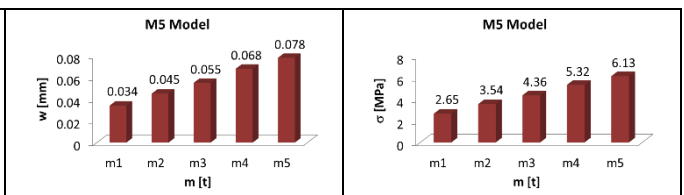maximum displacements and
equivalent stresses

Figure 18. Model **M5** - influence of mass on
maximum displacements and
equivalent stresses

If the forces produced by the vehicle masses **(m1, m2, m3, m4, m5)**, are applied to the deck panel, but the thickness of the sandwich core varies, it can be seen that the maximum displacement decreases with the increase of this thickness. The same situation can be seen in the case of the equivalent stress (Figures 19÷23).
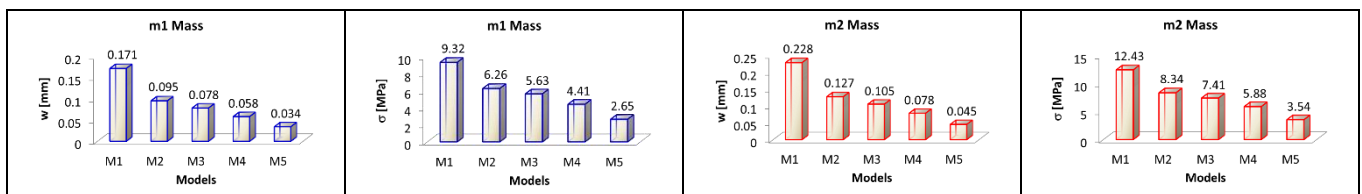

Figure 19. Models **M1÷M5** - influence of mass
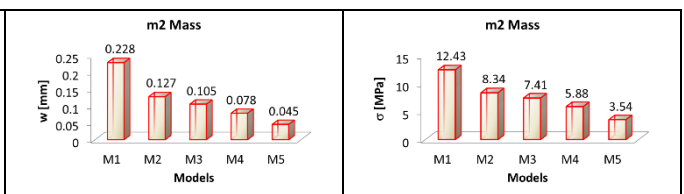**m1** on maximum displacements and
equivalent stresses

Figure 20. Models **M1÷M5** - influence of mass
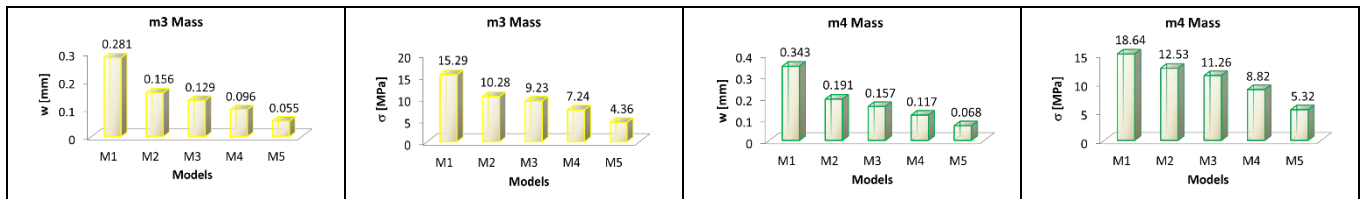**m2** on maximum displacements and
equivalent stresses

Figure 21. Models **M1÷M5** - influence of mass **m3** on maximum displacements and equivalent stresses

Figure 22. Models **M1÷M5** - influence of mass **m4** on maximum displacements and equivalent stresses
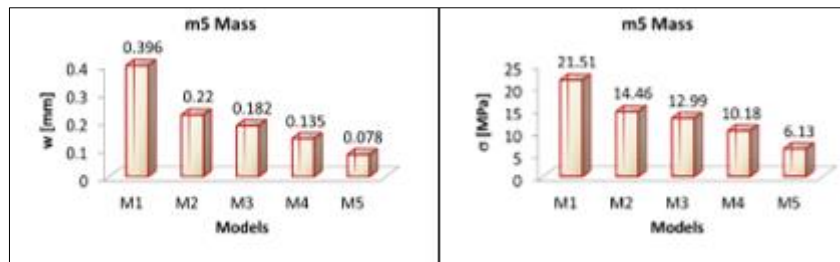

Figure 23. Models **M1÷M5** – influence of mass **m5** on maximum displacements and equivalent stresses

4. Conclusions

In the case of the deck panel made of sandwich composite material with a core thickness that varies between 5 mm and 40 mm and the steel faces of 6mm, it can be seen that with the increasing of forces produced by the vehicle masses, the value of the maximum displacement increases (e.g. from 0.095 mm (model **M2**, mass **m1**) to 0.22 mm, (model **M2**, mass **m5**)) (Figure 24).

Similarly, in the case of the deck panel made of sandwich composite material with a core thickness that varies between 5 mm and 40 mm and the steel faces of 6mm, it can be seen that with the increasing of forces produced by the vehicle masses, the value of the equivalent stress (e.g. from 2.65 MPa (model **M5**, mass **m1**) to 6.13 MPa, (model **M5**, mass **m5**)) (Figure 25).
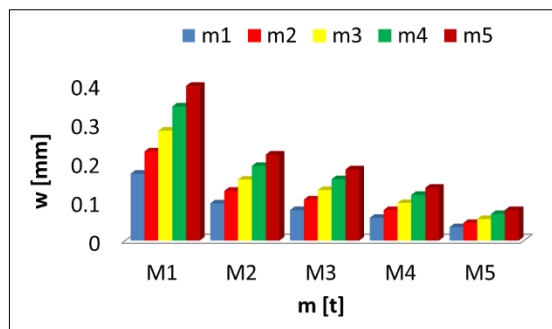

Figure 24. Models M1÷M5 - influence of mass on the maximum displacement
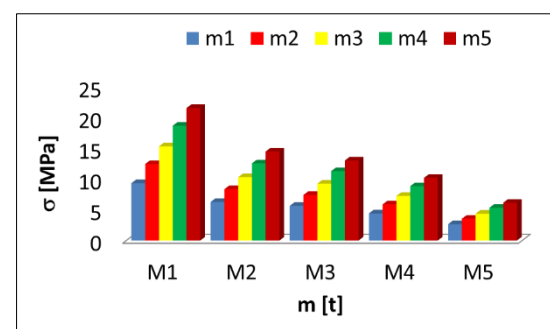
Figure 25. Model*s* M1÷M5 - influence of mass on the maximum equivalent stress

If a single mass type is applied to the ship deck panel, but the thickness of the core of the sandwich composite varies, it can be seen that the maximum displacement decreases with the increase of core thickness, the lowest displacement value, 0.034 mm, being recorded in the case of the model **M5** - deck material: face 1 - steel with a thickness of 6mm, core - SAN Foam 103 kg/m^3 with a thickness of 40 mm, face 2 - steel with a thickness of 6mm, at a load produced by the **m1** mass of the vehicle (1.5 t) (Figure 26).

Similarly, if a single mass type is applied to the ship deck panel, but the thickness of the core of the composite sandwich varies, it can be seen that the equivalent stress decreases with the increase of core thickness, recording a minimum value of 2.65 MPa (model **M5**, mass **m1**) (Figure 27).
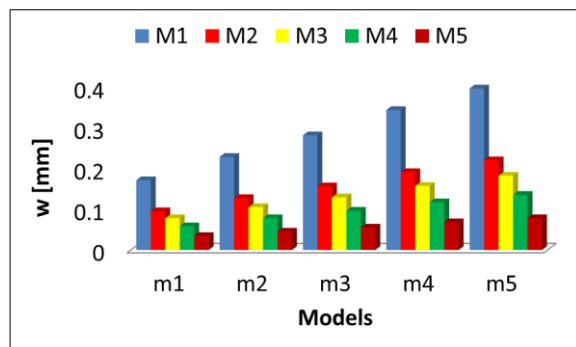
Figure 26. Masses m1÷m5 - influence of the case model on the maximum displacement
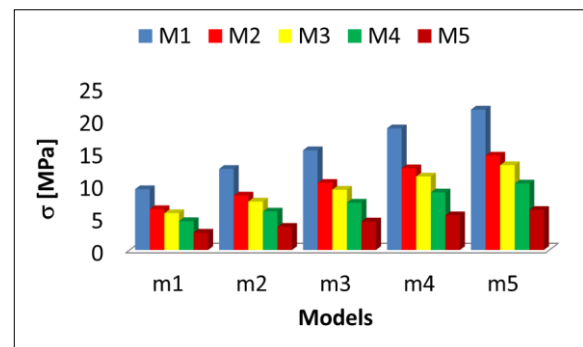

Figure 27. Masses m1÷m5 - nfluence of the case model on the maximum equivalent stress

Even in these upper conditions, both in the case of displacements and equivalent stresses obtained by FEM modeling, it is observed that the highest values of displacements and stresses are recorded on the ship deck panel made of steel, with a thickness of 12 mm, these varying upwards with the increase in the values of the loading, which demonstrates that the composite panels have a better behavior compared to the metal ones, even if their weight is approximately equal. This observation is provided by the metal stiffeners, which exist in all the analyzed constructive models.

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