A comparative study of the barge’s geometry under impact loads

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Abstract. The main objective of the present paper is to study the naval structure’s geometry for improving its behavior during critical accidents that can affect structural safety. Increasing and decreasing the geometry’s curvature of the barge’s board is considered for generating four models used in numerical structural analyses under impact loads. Three values of friction coefficient and two values of velocity are chosen as input data. The area and the volume values of collided structure are compared for impact assessing. This study is focusing particularly on the bow of the barge. The results presented at the end of the paper show that increasing the geometry’s curvature diminish the collision’s effects.

1. Introduction
The statistical data published by the European Commission presents Romania at the third place, with 9.1% (values expressed in tons-kilometres), as seen in figure 1, between the EU Member States, in 2018 [1]. The volume of goods includes the goods registered in national, international transport and in transit by inland waterways, from Romania.

![Figure 1: Inland waterway transport in EU Member States, in 2018 [1].](image1)

![Figure 2: Evolution of inland waterway transport indicators (thousands tons) [1].](image2)

The comparative volume’s analysis of the inland waterway transport, during 2019 compared to 2018, in thousands tons, is presented in figure 2. It can be observed that the total values (national, international, transit) registered an increase of 11.9%, as a result of the international transport trend, which increased by 32.1% and of the national transport, by 6.5%, while the transit transport recorded a 4.9% decrease.
Galati port, which operated 17.8% of the Romanian port's goods, is considered the second port, after the Constanta port, which achieved 43.8% of this activity. According to the NTS 2007 classification, the most significant quantity is the ores, mining products, quarry exploitation, peat, uranium, thorium, in proportion of 59.8% in national transport and 74.4% in inland transit.

In 2019, Galati port operated, 25.9% of the Romanian ports activity, for this indicator, as can be seen in figure 3, and represents 75% of its activity.

Figure 3. Structure of inland waterway transport from Romania, % thousands tons-kilometres [1].

Figure 4. Structure of loaded and unloaded goods - total depends on the cargo's type [1].

The city of Galati, located in Romania, on the left bank of the Danube river, is included also among the seaports. Figure 4 shows that the solid bulk cargo was transported in the largest quantity, 56.7%, in 2019, and totaled 30084 thousand tons, of which 3.9% represents the activity of the Galati port. The activities carried out for this indicator in the Galati port represent 67% of the total merchandise operated in 2019, with an increase of 160% compared to 2018.

In the Romanian ports, freight traffic is carried out on different types of ships (oil tanker, bulk carrier, container ships, specialized carriers, barges). Due to the collisions of the ships, due to the high energies involved, the ships can be seriously damaged with the loss of safety regarding their navigation.

In the naval field, the impact phenomenon is regulated by the norms included in DNV GL-RP-204 [2] issued in 2017, which standardizes design that ensures the safety of the ships operations in case of accidental loads of their structure. This phenomenon is verified, both for objects falling in the air, on deck or in water (drop test) and for collisions of ships.

Even if the barges represent only 0.7% of the total ship traffic, of the Romanian seaports that carry solid freight in bulk, it is necessary, also for this type of ships, to ensure the safety of traffic and the protection of the environment, without causing negative effects. In order to avoid accidents, an impact resistance analysis is required, starting from the design stage.

Nechita and Mocanu work [3] about a barge under impact loads shows that barge's structure curvature influences the Von Mises stress values. In the present paper, four redesign models of a barge's structure, with different curvature, are analysed. Conclusions show that the structure's curvature may diminish the collision's effects. Our future paper will deal on hydrodynamic behaviour of a ship under impact loads, considering Nechita and Popescu studies [4].

2. Impact scenarios on the starboard of a B2000T barge's structure
It can be observed that an analysis of the structure of the board's barge under impact loads may be useful in order to improve the design of the structure's barge. In this paper is performed the structural analysis of a ship structure under impact loads to determine the influence of the structure's geometry on its safety.
Impact scenarios (18) were realized, in 3 different points of the naval structure, already described in [3, 5]. The impact energies of 100kJ and 400kJ were simulated and generated by a striking object with a mass of 2000kg moving with 10m/s, respectively 20m/s, with different values of the friction coefficient. Values of fiction coefficient used are comparative with those used in other research paper [6]. In order to analyse the damage diminishing, 24 collision scenarios are done with 4 redesigned models. Nastran NX Femap 11.4.2 FE software is used for simulation, analysis and pre-post processing.

2.1. The analysis of the unmodified structure geometry’s influence on the effects due to the impact depending on the friction coefficients between the elements of the structure and the striking object

Numerical simulations were performed using the nonlinear Finite Element Method (FEM) to produce virtual experimental data for 18 collision scenarios of the ship structure.

In figure 5 and figure 6 are presented variations of the plastic strain and Von Mises stress during the impact, T = 100ms, for the three variants of the coefficient of friction, Cf, for the impact of the structure on the frames C121 and C125, with the energy E = 100kJ.

![Figure 5](image1.png)

**Figure 5.** Variation of the plastic strain and Von Mises stress, for the impact on the structure at the frame C121 (x=64.62 m, y=3.19 m, z= 5.49 m), with E= 100 kJ (v=10m/s), T=100 ms; (a) Variation of the plastic strain on the board for the element 4807, (b) Von Mises stress variation on the board, μ=0.0, (c) Von Mises stress variation on the board, μ=0.4, (d) Von Mises stress variation on the board, μ=0.6.

In figure 5 (a) and figure 6 are shown diagrams of the plastic strain during the impact, T = 100ms, for the three values of the coefficient of friction, Cf, for the impact of the structure at the frames C121 and C125, with the energy E = 100kJ. We observe a different behaviour depending on the structure's curvature. Thus for a small curvature of the frame C121, located near of the cylindrical area, the constant value of the plastic strain, being constant, illustrates an impact at which the board does not break, for all 3 values of the coefficient of friction. It is observed in the figure 5(a), a decrease of the variation of the plastic strain by
25% for the cases in which the influence of friction was considered, at impact, compared to the case where the coefficient of friction was ignored. In figures 5(b), (c) and (d), the behaviour of the impact shell, at the end of the analysis, is illustrated for the three values of the friction coefficient.

![Image](image_url)

Figure 6. Variation of the plastic strain and Von Mises stress, for the impact on the structure at the frame C125 (x=66.62 m, y=3.19 m, z= 5.29 m), with E= 100 kJ (v=10m/s), T=100 ms; (a) Variation of the plastic strain on the board for the element 4620, (b) Von Mises stress variation on the board, μ=0.0, (c) Von Mises stress variation on the board, μ=0.4, (d) Von Mises stress variation on the board, μ=0.6, (e) Von Mises stress variation on the frame, μ=0.0, (f) Von Mises stress variation on the frame, μ=0.4, (g) Von Mises stress variation on the frame, μ=0.6.

The impact of the shell at the frame C125, located towards the bow, due to its curvature, determines the rupture of the shell, illustrated by the null value of the plastic strain at time T = 40ms, a phenomenon illustrated in figure 6 (a) and figures 6(b), (c) and (d), for the end of the analysis. It is observed in the variant figure 6(a), a decrease of the plastic strain variation by 10% for the cases in which the influence of friction was considered, at impact, compared to the case where the friction coefficient was ignored. In the figures 6(e), (f) and (g) of the same damage of the impacted area is observed for all 3 values of the friction coefficient.

An increase in damage is observed for the case where the friction is neglected, compared to the cases in which the influence of the friction is considered. Thus, two broken elements are identified, for
the analyzes that consider the influence of the coefficient of friction, against three broken elements, for the analysis in which the friction phenomenon was ignored. This causes a decrease in the variation of Von Mises stress by 6.60%, for the case of neglecting the friction compared to the case $\mu = 0.4$. Similarly, a decrease in the variation of Von Mises stress by 14.51% is identified, for the case of neglecting the friction, compared to the case $\mu = 0.6$.

To study the influence of impact requests on the structure geometry, the impact speed was doubled, which resulted in an increase of energy from $E = 100\text{kJ}$ to $E = 400\text{kJ}$. It is observed that increasing of the impact energy by 4 times leads to a failure of the shell, twice faster, along the frame C125.

Also is observed, the influence of the coefficient of friction on the mode of rupture the structure, impacted with $E = 400\text{kJ} (v=20\text{m/s})$, the surface affected more being that without friction, where an extension of the effect on the frame C126 (1 broken element) is observed.

2.2. Redesign the curvature of the frame

The structure at frame C125 was modified by moving 6 points, towards the interior and exterior of the ship along the Z direction, symmetrically on both sides. The positioning of the points on the starboard, at frame C125 is shown on the curves and on the mesh elements illustrated in figure 7, the nodes S and T being fixed. The modifications made do not affect the surface of the shell, which has, in the end, a single curvature. The contact was evaluated in the structure's modification area. The visualizations carried out showed that no detachments appeared after the transformations made. In order to study the behavior of the new impact geometries, another 24 collision scenarios (6 for each model) were performed.

![Figure 7](image.png)

Figure 7. Curvature's structure changing at frame C125, start from initial structure (initial model), M0, to new models M1, M2, M3 and M4.

Similar data were obtained from the numerical analysis for models 1 and 2, for an impact of the structure in the area of the C125 frame with the energy $E = 100\text{kJ} (v=10\text{m/s})$, for the three values of the coefficient of friction. The contact between the elements of the barge- striking object assembly, evidenced by the friction coefficients, causes an increase of the variation of the plastic strain by 0.06%, of the friction coefficient $\mu = 0.6$ compared to $\mu = 0.4$. As a result of the impact, the shell remains deformed in the plastic field without entering the rupture stage.

The structural analysis for the model 3, on the board's shell, shows an increase of the plastic strain, with a value of 21.97% for the case where the influence of the friction with $\mu = 0$ is considered, compared to the case where the friction is neglected. The analysis on the impacted frame with the same energy shows a decrease of the variation of the damaged areas with a value of 26.79%, for the case of the curvature modification according to model 3 (see figure 7) compared to the unmodified structure, only for $\mu = 0.0$. There are no modifications of the redesigned frame damage to the unmodified structure, in cases where the influence of friction is considered.

3. Evaluation the influence of frame’s curvature on the effects due to the impact loads

The analysis of the data determines the influence of the curvature of the structure on the area and the volume damaged due to the impact with the energy $E=100\text{kJ} (v=10\text{m/s})$, for four models. It can be observed that both the damaged areas and volumes have the same growth or decrease trends compared to the similar values of the initial geometry, as a percentage having identical values for all new models. A
decrease of 42.84% of the damaged area on the shell is identified only for μ=0 compared to the initial geometry, while the damaged area on the frame is unchanged, for the first two new models. For the other values of the coefficient of friction no changes are observed. For model 3 and model 4, a decrease of 26.79% of the damaged area on the frame is observed only for μ=0. In these models, on the shell, the damage is zero. It can be observed that the modification of the curvature of the frame in the model 2 compared to the model 1 did not generate changes of the effects due to the impact, both for the shell and for the frame.

Similarly, the influence of the structure’s curvature on the area and the damaged volume is determined, due to the impact with energy E = 400kJ, for the four models. The damaged areas and volumes of the four modified structures were compared with the similar values of the unmodified geometry. We observe a tendency to increase the variation of the damage on the shell with a maximum value of 52%, for μ = 0.6, for models 1 and 2 compared to the initial geometry, as can be seen in figure 8. For models 3 and 4, there is a tendency to decrease the variation of the damage on the shell, with a maximum value of 11.54%, for model 3 with respect to the initial geometry, for μ = 0.6.

![Figure 8](image1.png)

**Figure 8.** The influence of friction coefficient on the damage's area on starboard for four models, impacted at the frame C125 with E=400 kJ (v=20m/s).

In figure 9 are presented the variations of the damaged volume of the impacted shell at the C125 frame area with the same energy depending on the friction coefficient. We observe a tendency similar to that of the variation of the damaged areas, shown in figure 8. The decrease of the variation of the damage on the frame is registered only for model 3, having the value 2.87, for μ = 0.6.

![Figure 9](image2.png)

**Figure 9.** The influence of friction coefficient on the damage's volume on starboard for four models, impacted at the frame C125, with E=400 kJ (v=20m/s).

In figure 10, one clearly observes the dependence of the variation of the structure geometry damage on the impact velocity. Thus, when impacting the structure of the boarding with the speed v = 10m/s, there are no visible changes of the damage for the 4 redesigned models, according to figure 7.
compared to the initial structure, unchanged. When impacting the structure with $v = 20$ m/s, we observe a varied behavior of the redesigned models with respect to the unmodified structure. Thus, from the graph in figure 10, it can be quickly identified that model 3 is the one with the best impact behavior, from the proposed ones.

Figure 10. The influence of geometry on damage area of the shell impacted at C125 frame depending on the friction coefficients, for 4 redesign models.

4. Conclusions
The following conclusions were drawn from analysing the 42 scenarios of this paper, considering the influence the velocity and the friction coefficient.

The effects are local for all the variants of the ship's structure side collision, the frames yielding faster than the board, which ensures the buoyancy of the ship for a period of time.

The modification of the frame’s curvature causes a decrease of the damage compared to the initial geometry, with maximum relative variation’s values of 11.54% for the board, and 2.87% for the damages of the frame at $\mu = 0.6$, at the impact with the energy $E = 400$ kJ ($v=20$ m/s).

The modification of the frame’s curvature, when double the impact speed for model 3, causes a decrease with 2.87%, compared to initial model, $\mu = 0.6$.

In the numerical analyzes performed in this paper it was observed that the impact with the energy with $v=20$ m/s ($E = 400$ kJ), causes the reaching of the rupture stage when the value of the damaged area becomes dependent on the structure’s curvature, the model 3 (with increased curvature), having the best behavior under impact loads compared to initial structure.

A broader approach of the ship structure's behaviour in the plastic field, using a coupled method that considers simultaneously the hydrodynamic behaviour of the model (includes inertia forces, global, local and impact demands), will be studied in the future work using a CFD analysis.

5. References
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