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NUMERICAL STUDY OF THE RESPONSE OF THE BODY OF A HEAVY VEHICLE TO AN IMPACT LOAD AS EXEMPLIFIED BY THE KRAB SELF-PROPELLED GUN-HOWITZER

Abstract. The paper presents results of numerical analyses of the response of the body of a gun-howitzer to gun shot in different positions of the gun in relation to the body. Shots at several different barrel elevation angles were analyzed, including the worst cases in terms of structure strength. Numerical analysis was performed using the explicit method of computing fast-changing phenomena. The adopted main criterion of body response assessment was material effort.

Keywords: shot, tracked vehicles, numerical analysis.

1. INTRODUCTION

The continuing "armour-missile" race forces design engineers to develop new vehicle designs. The fashion of the 1960s gave the impression that rocket missiles will supplant traditional artillery. However, economic conditions (price of a single missile and continuously improving performance of artillery munitions, of propellant explosives in particular) have caused the barrel artillery to become the main component of military actions support. The range of modern barrel artillery of ca. 40 km allows to position the gun far from the enemy. There are situations, however, when a gun needs to be mounted on a heavily armoured chassis able to perform tasks at contact distance from the enemy. An example of that is the recent KRAB gun-howitzer. In order to study the response of the body to a gun shot, a number of simulations were carried out using the Finite Element Method (FEM) [1]. In view of the nature of the phenomenon, it was decided to solve the problem using the explicit method. The problems of dynamic response of structures were studied by many researchers [2]. Continuous development of computational methods enables the application of numerical analysis to describe such problems as modelling of the destruction of materials [3, 4, 5]. In addition, advanced software enables to conduct numerical analysis of the effect of selected aspects of dynamic response of a structure: penetrating capability [6] of explosions in various environments [7].

The paper presents results of numerical analyses of an armoured vehicle. The response of the body was assessed in the aspect of its resistance to loads associated with gun shots performed at extreme positions of the gun.

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2. CHOICE OF THE SOLVING METHOD

The main object of the study was a heavy gun-howitzer. The vehicle model was subjected to a pressure impulse generated by a shot fired under different turret and gun positions (zenith position and elevation). The results obtained are presented in the form of maps of reduced tension.

The Finite Element Method (FEM) has recently become the basic method for analyzing the process of the effect of the shot on the vehicle body. The following assumptions were made for the numerical analysis performed using LS-DYNA [1]:

- explicit algorithm for solving the equations of structure dynamics within a non-linear range;
- elastic-plastic model of the material;
- rigid material model;
- deformable shell elements (type 2) [1];
- deformable solid elements (type 1) [1];
- initial boundary conditions with gravity accounted for;
- large deformations and displacements.

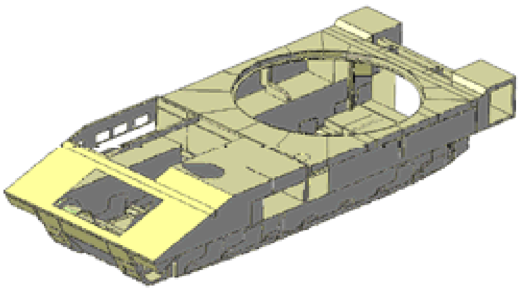
Note that the phenomena discussed in this paper:

- change rapidly with time (duration of gunshot);
- are characterized by high geometrical nonlinearities (large deformations, displacements, contact) and physical nonlinearities (material nonlinearities);
- require small time steps Δt.

Simulation of phenomena of this type is handled using an explicit type algorithm.

3. NUMERICAL MODEL

The major difficulty in modelling vehicles of any type is the proper division of the geometry (Fig. 1) into finite elements while maintaining the optimum number of nodes and Gauss points. The elements are then assigned appropriate properties taking into account thickness, type of defined material, connections between individual vehicle parts, etc. Upon completing the above tasks we get a numerical model of the vehicle (Figs. 2 - 8). An elastic-plastic model of material (with dynamic reinforcement) of the following properties was applied in numerical analyses: E = 210 GPa – Young's modulus, $\nu = 0.3$ – Poisson number, Re = 1000 MPa – yield point.



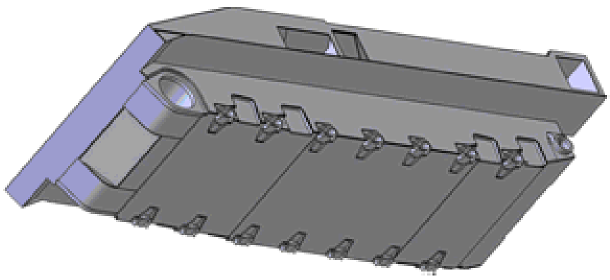


Fig. 1. Geometrical model of the vehicle

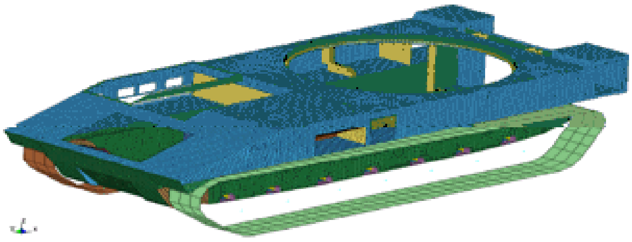


Fig. 2. Numerical model of the KRAB vehicle – general view

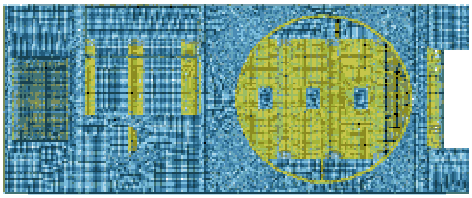


Fig. 3. Numerical model of the KRAB vehicle – top view

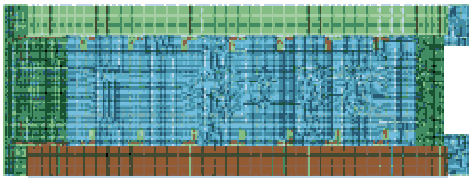


Fig. 4. Numerical model of the KRAB vehicle – bottom view

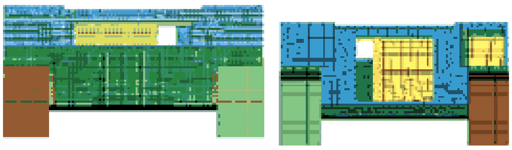


Fig. 5. Numerical model of the KRAB vehicle – front and rear views

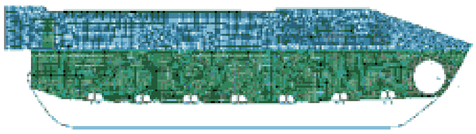


Fig. 6. Numerical model of the KRAB vehicle – right side view

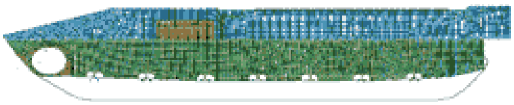


Fig. 7. Numerical model of the KRAB vehicle – left side view

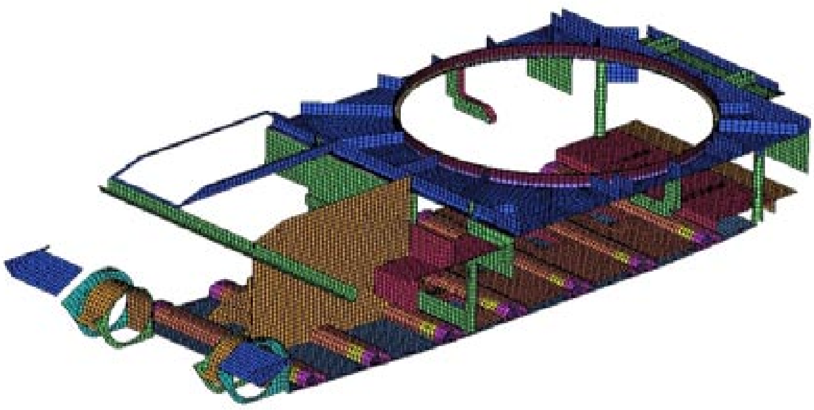


Fig. 8. Interior of the KRAB vehicle

Main mass elements, such as: turret, tanks, batteries, etc. are represented by concentrated masses. Schematic arrangement of concentrated masses is shown in Fig. 9.

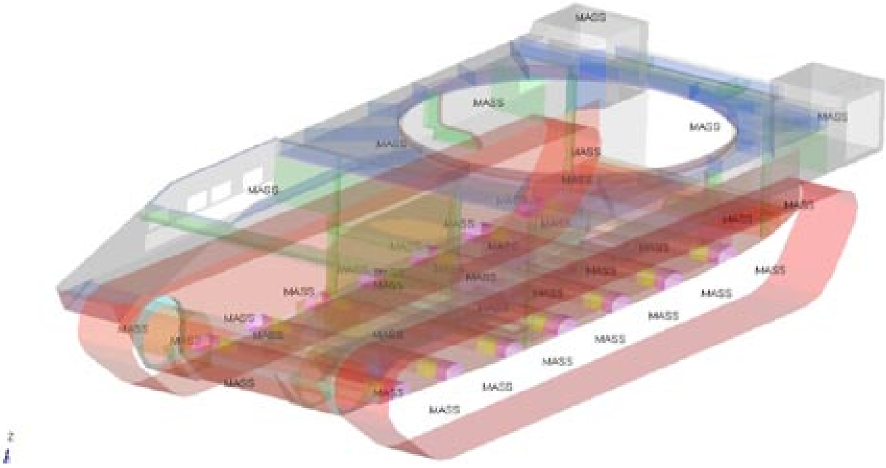


Fig. 9. Arrangement of concentrated masses in the numerical model

The body was linked to nondeformable tracks, the mass of which corresponded to that of real tracks, by means of elastic damping elements. The modelled elastic damping elements represent the suspension in the real vehicle (Fig. 10). In addition, the numerical analysis took into account the interaction of the vehicle tracks with the ground, by the use of the contact function (including friction). Based on the available literature, the coefficients of static and kinetic friction of 0.8 were adopted.

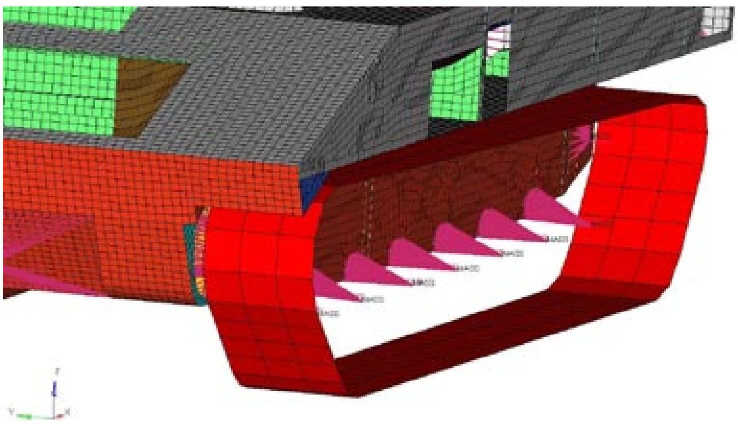


Fig. 10. Connection between suspension and body effected by means of interpolation constraints

The turret in the adopted model is defined by means of mass element (point mass connected to thrust bearing on the body by means of constraint equations). Gravitational load is accounted for in numerical analysis to ensure real behaviour of the vehicle during the shot phenomenon. Gravitational load is effected in the initial phase of analysis by means of DYNAMIC_RELAXATION [1]. This approach eliminates instabilities arising during sudden application of gravitational load on the model.

Additionally, in order to quicken the numerical analysis, mass scaling of selected elements was performed. The time step in the explicit type solution algorithm depends in the first place on the size of elements that form the model. Scaling is possible when the Courant's stability criterion is satisfied [1].

4. CALCULATION VARIANTS

In the numerical analysis the vehicle model was subjected to gravitational load during the first phase. After appropriate stabilization period the vehicle was loaded with a time-varying force impulse (shot simulation). Six shot direction configurations were studied in the numerical analysis:

1) 0° azimuth 0° elevation - shot towards the front,
2) 0° azimuth 70° elevation - shot towards the front,
3) 90° azimuth 0° elevation - shot to the side,
4) 90° azimuth 70° elevation - shot to the side,
5) 180° azimuth 0° elevation - shot to the rear,
6) 180° azimuth 70° elevation - shot to the rear.

The results obtained for every load type are presented in the form of maps of reduced tension according to Huber's hypothesis. Due to the limited size of this paper, only the most strenuous results obtained from numerical analysis are presented here.

5. RESULTS FOR VARIANT No. 2 - 70° SHOT TOWARDS THE FRONT

The most likely way to use a gun-howitzer in combat is a shot towards the front with the barrel elevated at an angle of 70 degrees. In such case the most affected component of the vehicle is the suspension and bottom. In addition, stress distribution is uneven and the rear of the vehicle is subject to main load. In practical terms such a shot "drives" the vehicle body into the ground. In the case of evaluating material effort, the maximum value of reduced tension was lower than the yield strength of the adopted material and was equal to 628 MPa. Exceedance of yield strength has also not been observed in other main stress directions. The stress pattern is shown in Figs. 11 and 12 and in Table 1.

Table 1. Maximum reduced tensions in analyzed models

Item	Variant	Max. reduced tension [MPa]
1.	0° shot towards the front	581
2.	70° shot towards the front	628
3.	0° shot to the side	515
4.	70° shot to the side	506
5.	0° shot to the rear	451
6.	70° shot to the rear	357

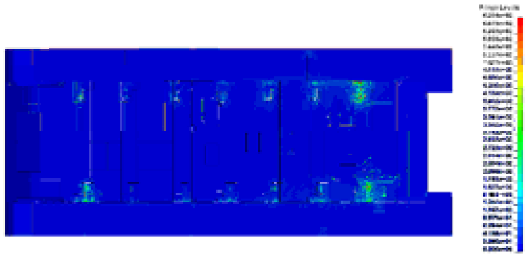


Fig. 11. Map of reduced tensions [MPa]

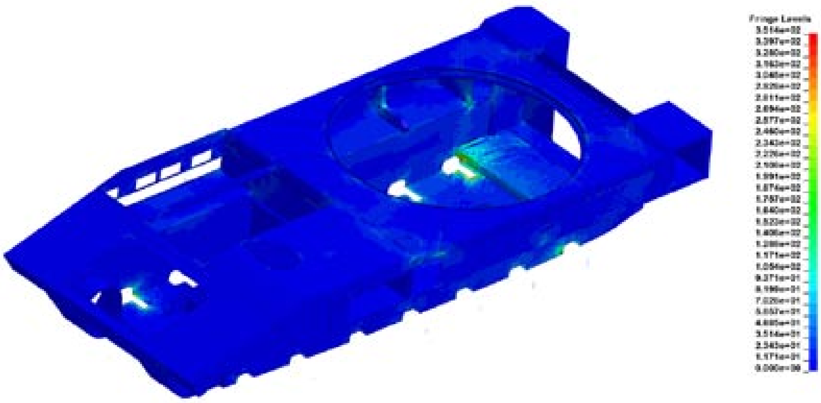


Fig. 12. Map of reduced tensions [MPa]

6. RESULTS FOR VARIANT No. 4 - 70° SHOT TO THE SIDE

The other interesting case of numerical analyses is the shot to the side. In this variant of load application, due to certain eccentricity of the turret, there is a kind of stress concentration on the side opposite to that from which the shot is fired. The map of reduced tension according to Huber's hypothesis is shown in Figs. 13 and 14. It is worth noting that, as was the case with the shot towards the front at gun elevation angle 70°, the tension did not exceed the material yield strength. This means that all body strains were within the elastic range.

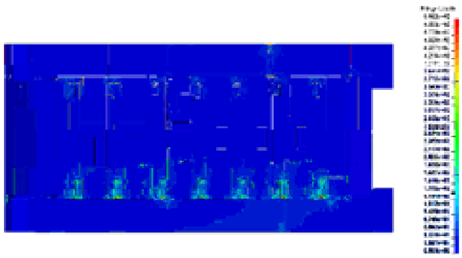


Fig. 13. Map of reduced tensions [MPa]

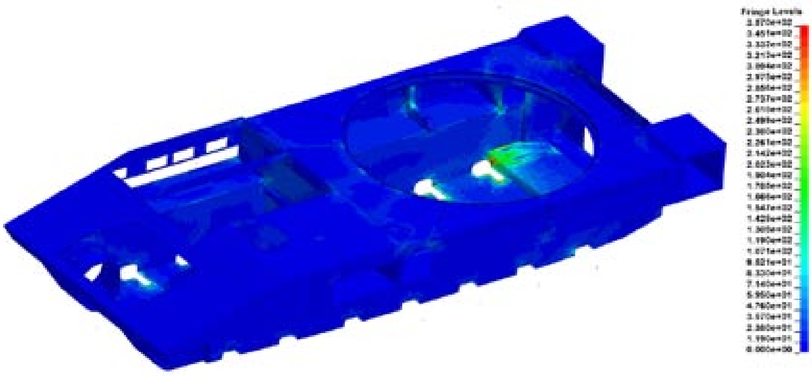


Fig. 14. Map of reduced tensions [MPa]

7. SUMMARY

The paper presents the problem, important from the engineering point of view, of the response of the body of a military vehicle structure to gun shot impulse. The simulations presented were made using the most advanced numerical methods with account taken of both physical and geometrical nonlinearities.

Calculation results indicate that the vehicle bottom meets strength criteria in terms of dynamic loads.

The numerical methods presented in this paper have only recently been applied in engineering calculations of military vehicles.

The advantage of the presented methods is that the computer methods provide approximate accuracy. In order to ascertain the validity of the obtained results it is advisable to verify calculations experimentally. Essentially in no load scenario has the yield strength in the bottom and sides of the vehicle been exceeded. Further studies are planned to subject the bottom of the vehicle to high explosives in order to assess the level of protection against mines.

8. REFERENCES

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