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# ANALYSIS OF A LIGHT CATERPILLAR VEHICLE LOADED WITH BLAST WAVE FROM DETONATED IED

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### *Abstract*

*More and more impudent attacks on the military convoys in Afghanistan proved a huge danger of the improvised explosive devices – IED. Huger and more clever charges are a serious problem for vehicles protection. Additionally, hitherto defence standards and STANAG didn't predict such huge charges. Majority investigations were based on a 3 kg anti-tank mine.*

*The article presents the results of numerical calculations for the elements of the combat vehicle supporting structure loaded with an impact generated by explosion of a huge explosive charge under the bottom of the vehicle with consideration of the wave reflected from the ground. Such an approach allows obtaining a good approximation of numerical simulations to real conditions of terroristic attacks. Additionally, the analysis of IED side influence on the vehicle shell was conducted. The explosive charge – IED – was simulated with the use of concentrated energy of properly selected (on the base of literature investigations) density and initial energy. During analyses of side explosive on the vehicle structure, the obstacle in the form of a building increasing the pressure impulse was taken into account.*

*The paper presents the results of a numerical analysis in which Euler and Lagrange domains(describing a vehicle) were coupled. A perfect gas model was used to describe air parameters.. Additionally, the ground was described with a gas model. Every kind of material data were selected on the base of experimental investigations. A bilinear material model with a Cowper and Symonds strain rate model was used to describe a vehicle. Such an approach fully describes the phenomena occurring in the system.*

***Keywords:*** *IED, vehicle shell, FE analysis, ground*

## 1. Introduction

High mobility, great fire force in any climatic and terrain conditions determine that armoured vehicles are the fundamental equipment used by stabilization forces of different countries. These type vehicles are subjected to destruction by different kind of weapons which are at the opponent disposal. These weapons include barrel artillery, rocket systems, anti-tank mines and ABC.

Due to these reasons, modern tactic-technological requirements determine forming the frames of armoured combat vehicles regarding assurances of high ability to survive on the battlefield and in situations of danger. These activities are related to, among others, assurances of proper: vehicles geometry, suspension strength to outer dynamic loads, protection of a crew and equipment against different classes mine means. Protection of the crew and the equipment against the opponent fire means is realized mainly through basic armour with determined efficiency. A fundamental problem appears while creating effective protection of a crew and outside equipment against mines [1], especially against improvised explosive devices.

A huge development of numerical methods and the increase of calculation abilities of modern computers allow modelling a number of physical phenomena, starting from explosive charge combustion and ending with an influence of a blast wave on the construction. The above mentioned development, in relation with increasingly greater care about passive protection [2, 3], causes the search for more and more modern constructional solutions not only using classic experimental methods but also using a computer experiment.

The coupling between the medium described with the use of continuum mechanics Euler equations and the medium described with the use of Lagrange equations for description of the reaction between the construction and the blast wave loading it and coming from explosion were applied in the present paper. Euler equations usually describe liquid – in this case, it is air in which explosive material detonation and blast wave propagation occur. However, Lagrange equations, expressing conservation laws of mass, momentum and energy, are used to describe the construction behaviour. A complex character of an explosive material detonation process and blast wave propagation cause significant calculation problems. It results in developing a special calculation method of modelling this phenomenon. This phenomenon and the manners of its modelling are widely described in literature [1, 4-6].

For coupling of the interaction between liquid and a structure there was selected a general coupling which is included in a standard implementation of MSC Dytran software [7]. During calculations, the explicit procedure of motion integration was applied for both the liquid and the construction.

The numerical investigations presented in the present paper aimed at initial examination of the influence of IED charge localization on the vehicle.

## 2. General description of numerical models

The numerical analysis was conducted for an exemplary shell numerical model of the vehicle loaded with the influence of the pressure wave coming from detonation of a huge explosive material charge. The changes induced by deformation of the vehicle (construction) frame were taken into account in calculations.

The pressure wave induced by detonation (simulated in approximation of point detonation) was propagating in the cubic-shaped area with the given proper boundary conditions. The theoretical solution of the strong propagation of spherical shaped discontinuity originated from the point source exists in the form of analytical Taylor similarity equations which after transformation can be written as [8, 9]:

$$p(r) = 0.155\, E_o\, r^{-3},$$

where:

$E_o$ - initial internal energy,

r - current radius of a sphere.

It allows for a computer simulation of the propagation process of a blast wave through giving the proper initial conditions (density, energy, pressure) to the certain, selected elements from the Euler domain, and next solving the conservation laws of mass, momentum and energy. Typical values for explosive substances: density - 1600 kg/m3 and specific internal energy – 4.2 MJ/kg.

The layer, in which the blast wave was spreading, was modelled using the Euler elements type Hex 8 characterised by ideal gas properties of $\gamma = 1.4$ and density corresponding to atmospheric air in regular conditions ($\rho = 1.2829$ kg/m3). The ground was described by a Mie-Gruneisen material model [8] with the following parameters: $\gamma = 2$ and density corresponding to the ground density ($\rho = 2.35 \cdot 103$ kg/m3). It was assumed that under the ground there was a rock which was modelled as a rigid body. Lagrange elements types Shell Quad 4 were used to model the behaviour of the vehicle steel plates. To describe the steel behaviour the bilinear model of elastic-plastic material DYMAT 24 was used. The maximum deformation was assumed as a fracture criterion [7].

Developing of a full-scale model of a special vehicle was preceded by additional laboratory tests on mechanical properties of armoured steel used for building such vehicles. These tests were executed in the Department of Mechanics and Computer Science Military University of Technology.

A general view of the numerical model of the vehicle and the cross section of the whole system is presented in Fig. 1 and 2.

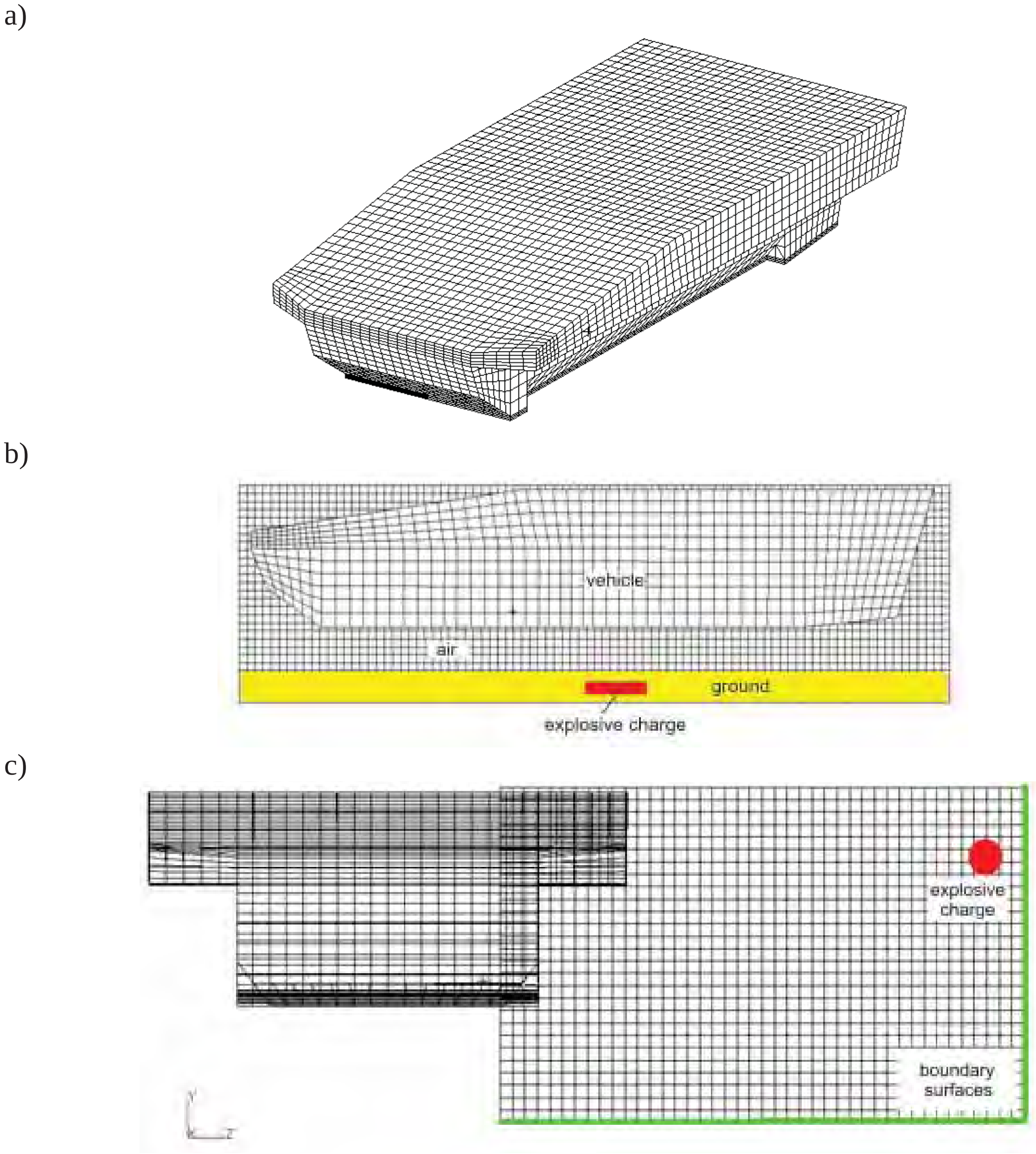

*Fig. 1. A draft of a numerical model of the vehicle: a) a general view of the numerical model of the vehicle shell; b) a cross-section of the numerical model presenting the vehicle, the ground and the charge location in the ground; c) a cross-section of the second numerical model presenting the vehicle, the ground and the side location of IED charge*

In all the models used in the present paper, the nodes of the structural elements (Lagrange domain nodes) didn't have any initial conditions. That's means that all the velocities and displacements for time t = 0 were zeroed.

Any kinds of tests of military armoured vehicle are conducted according to a standard NATO STANAG 4569. The other of the possible tests of anti-mine resistance is investigation of the detonation results of the anti-tank mine TM57 of the TNT charge mass 6.34 kg. Due to the necessity of protection against improvised explosive devices of mass significantly greater than anti-tank mines, there was also executed the analysis of models of the vehicles loaded with IED significantly exceeding the mass of TM 57 mine.

## 3. Results of numerical analysis

Pressure maps and graphs of displacements, acceleration and velocity of characteristic points were, among the others, obtained as a result of numerical analysis. At the first stage of numerical analyses the model was loaded with the pressure wave coming from the detonation of an explosive material charge. Fig. 2a presents the pressure distribution for moment t = 2.38 μs. The next figure shows the pressure distribution for the moment of time t = 23.44 μs, for which the approach of the wave front to the construction and reflection occurred. As a result of reflection of the blast wave from the frame, strengthening of the pressure impulse occurred.

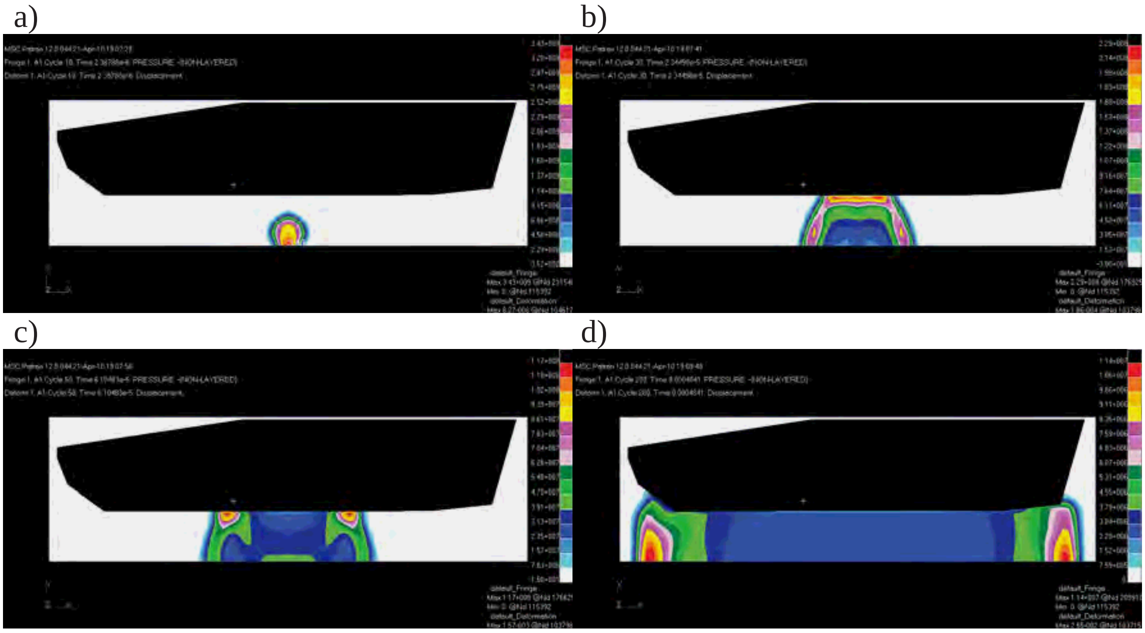

*Fig. 2. The manner of pressure wave distribution at different moments of time*

For moment of time t = 61 μs, shown in Fig. 2c, the weakening of the pressure impulse to value 117 MPa occurred. The subsequent pressure propagation is illustrated in Fig. 2d. The maximum velocity (the component of velocity read in the direction of spreading of the blast wave) was equal to 70 m/s for the point on the bottom of the vehicle. However, the maximum velocity for the point on the roof of the vehicle shell was equal to 3 m/s. Comparison of the velocity graphs for the point on the vehicle shell is presented in Fig. 3.

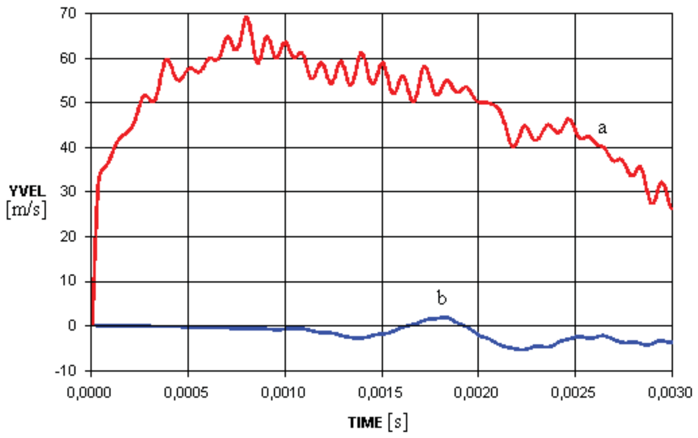

*Fig. 3. The measurement of the bottom (a) and roof (b) velocity of the vehicle shell*

As a result of the numerical analysis of a computer model of the vehicle shell, the acceleration values presented in fig. 4 were also obtained. The highest acceleration value for the point on the construction bottom amounted $1{,}5\cdot10^6$ m/s$^2$. A lower acceleration value was recorded for the point on the vehicle roof - $30\cdot10^3$ m/s$^2$.

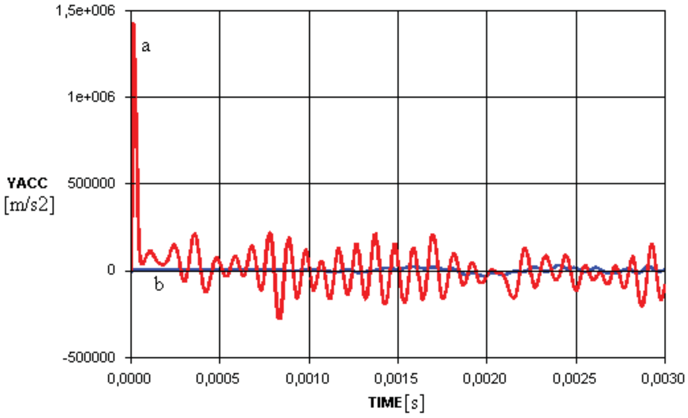

*Fig. 4. Acceleration values of the bottom (a) and the roof (b) of the shell vehicle*

Figure 5. Presents the displacement of the bottom plate centre in the function of time. The maximal displacement amounted 15 cm.

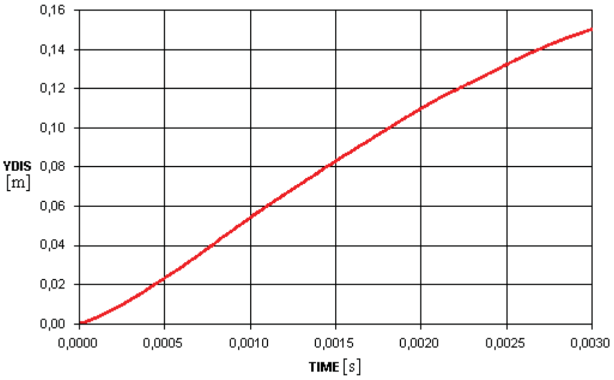

*Fig. 5. Displacements of the node of the vehicle bottom in the function of time*

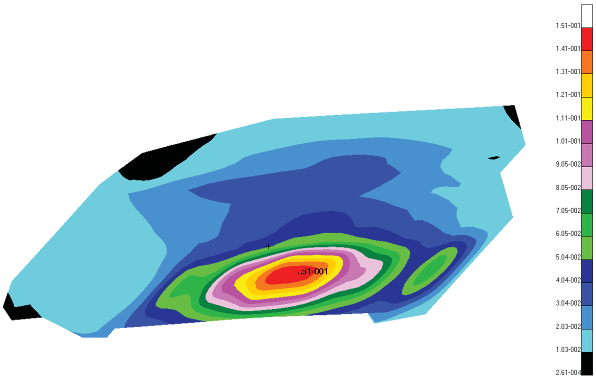

*Fig. 6. The final deformation of the shell model*

Figure 6 presents the final map of the vehicle deformation.

For case 2 – the case of the side detonation – the model was loaded with a charge of an approximate mass 8 kg. Similarly as in case of the first model, as the result of the numerical analysis, the pressure maps and the graph of displacements, accelerations and velocities of characteristic points were obtained.

During the additional numerical investigations, the influence of the charge location on the results of its activity was analysed.

Figure 7a presents the pressure distribution for the moment t = 2.38 μs. The next Fig. 7b shows the pressure distribution for the moment of time t = 60 μs, for which the approach of the wave front to the ground occurred. In the result of the pressure wave reflection from the bottom of the frame strengthening of the pressure impulse occurred in this case too.

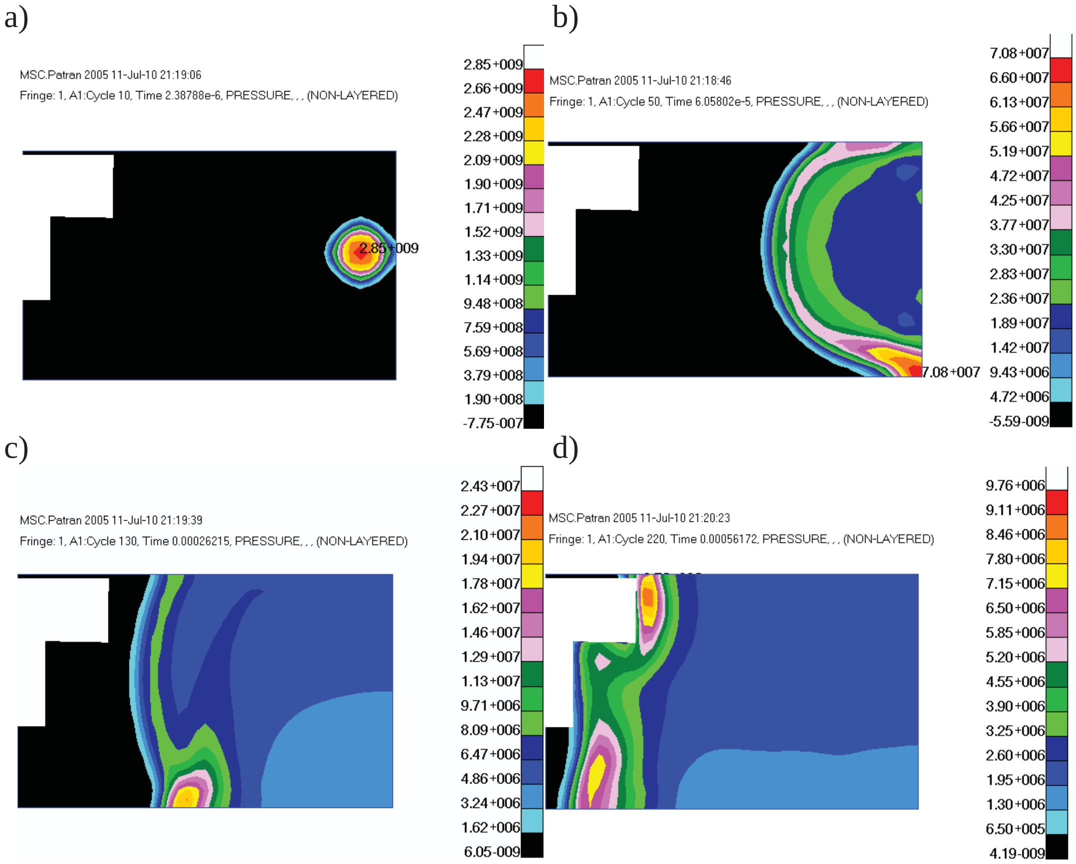

*Fig. 7. The manner of the pressure wave distribution at different moments of time*

For the moment of time t = 0,2 ms, shown in picture 7c, the weakening of the pressure impulse in relation value 24,3 MPa occurred. Accumulation of pressure occurs in the result of Mach wave origination. Strengthening of the pressure impulse as the result of reflection from the upper vehicle side was presented in picture 7d.

The maximum velocity (the component of velocity read out in the direction of the blast wave propagation) of the metering point located on the vehicle roof amounted 12 m/s.

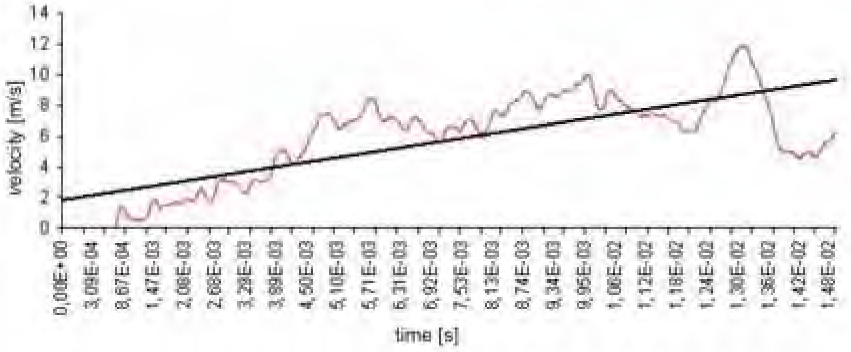

*Fig. 8. Velocity of the point located on the roof of the shell vehicle*

An additional trend line marked in Fig. 8 indicates the motion of the stiff frame. As a result of the numerical analysis of the computer model of the vehicle shell the acceleration values presented in Fig. 9 were obtained. The highest acceleration value for a point located on the construction roof amounted 15 000 m/s$^2$. Fig. 10 presents displacement of the bottom plate centre in the function of time.

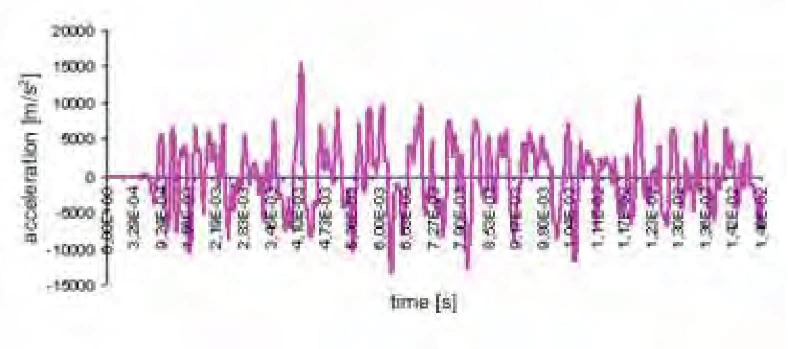

*Fig. 9. Accelerations of the roof central node in the function of time*

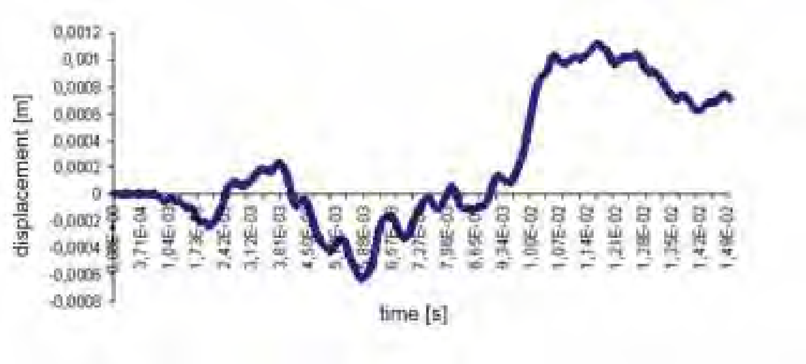

*Fig. 10. Displacements of the roof central node in the function of time*

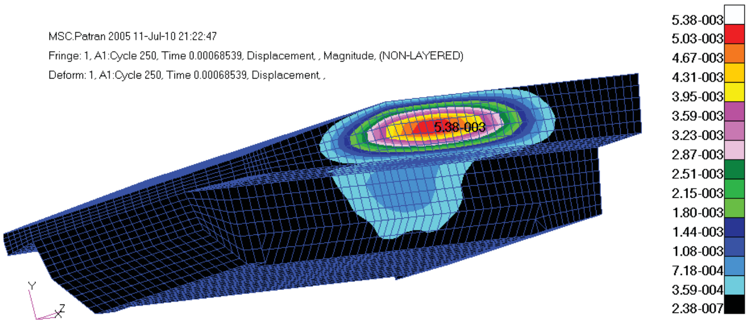

*Fig. 11. The final deformation of the side of the shell model*

The last of the figures (Fig. 11) presents the final map of the vehicle deformation. The side deformation of the vehicle caused by IED explosion is especially interesting. In order to avoid excessive deformation of the vehicle sides (Fig. 11), it is advisable to give the streamlined shapes to the shell.

## 4. Conclusions

Application of the ground model caused transmitting the strengthen pressure impulse onto the vehicle bottom. Multiple reflections contributed to originating of the Mach wave phenomenon. Such a description of the initially boundary conditions caused the 40% increase of displacement of the node placed on the vehicle bottom.

An additional analysis of the side influence of IED on the vehicle frame enabled full cognition of the phenomena of a dynamic influence of the huge charge on the vehicle shell.

Since the influence of the mesh shape on the pressure values on the front of the blast wave is relatively insignificant [1], the analysis was based on the cubic, but properly thick, mesh of Euler elements.

The paper presented the part of the investigations conducted on blast wave propagation. The model of the whole vehicle was modelled in order to determine the shape and values of the pressure impulse.

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