ANALYSIS OF IED SIDEBAR EXPLOSION INFLUENCE ON HULL OF LIGHT FIGHTING VEHICLE

Wiesław Barnat

Military University of Technology
Department of Mechanics and Applied Computer Science
Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 22 6837201, fax: +48 22 6839355
e-mail: wbarnat@wat.edu.pl

Abstract

This paper shows preliminary numerical analysis of impact of IED sidebar blast on the hull of the light fighting vehicle in order to meet the current standards. Numerical analysis was carried out using a 3-dimensional shell FE model of the vehicle. The problem of the modelling method and computer simulations required several specific features for applied material models, e.g. physical state, plasticity, crispness, hardness. All necessary material properties were taken from the available literature or they were based on the experimental tests carried out in the Department of Mechanics and Applied Computer Science at the Military University of Technology. The STANAG 4569 is a legal basis that regulates the level of ballistic protection for such vehicles. Companies producing that kind of armoured vehicles for army, constantly look for the best and the newest energy consuming materials to ensure appropriate protection of the vehicle and the crew inside it against the effect of IED blast. The connection between a detonation wave and a formed shrapnel shell after detonation of the IED is created depending on the mass and kind of the charge. It is caused by impulsive load on a side bar or the bottom of a light vehicle. Both, safety of people and equipment endurance, is compatible with main rules that are common in Polish Army and it will be common rule in future. It is the fact that motivates the research centres and the arms industry to develop a product using advance computation method to construct new energy absorbing construction which will increase safety of the crew in the armed vehicle.

Keywords: *blast, IED, protection, numerical analysis*

1. Introduction

Most of the armies in European countries have light armour vehicles which are designed to patrol dangerous zones. A part of this kind of equipment based on American HMMWV (High Mobility Multi-Purpose Wheeled Vehicle) or equipment which is built on its automobile platform. Swiss EAGLE or Turkish OTOCAR are the examples of such constructions. Many incidents that took place in the Afghanistan missions show that the level of crew protection in light vehicle was not acceptable.

Therefore, new constructions like MRAP [2], which are entered by U.S. Army, are being built in the whole world. However despite the fact that their construction is armour-piercing and anti-tank mine resistant, they need a lot of improvement to protect the crew of the vehicle from the IED blast [3, 5, 6].

That is why research centers are focused on detailed module of applied improvised explosive devices in the aspect of their place and mass of explosion materials.

2. Formulation of physics model

The results of computing analysis of the influence of sidebar explosion of IED on the hull of the light armoured vehicle, in order to meet the current standards, are presented in this paper.

It was decided that the Finite Element Analysis (FEA) would be applied from among the computing methods for solution of the explosion phenomena. Commercial MSC.Dytran [7] software with the explicit integration of the equations of motion was used. In this numerical algorithm equation of equilibrium, a discrete model is solved by direct time-integration. These equations are coupled, which is associated with the large expense of numerical solutions and large demand for memory during calculation. Due to the relatively short duration of the phenomenon, it is possible to omit the damping.

Basic equation of explicit approach is as follows [8]:

$$[M]\{\ddot{x}\}_n = \{F\}_n - \{F_{\text{int}}\}_n, \tag{1}$$

where:
$[M]$ – matrix of mass,
$\{F\}$ – matrix of external force,
$\{F_{\text{int}}\}$ – matrix of internal force.

Assuming that matrix of mass occurs in the form of a diagonal the equation of motion may be resolved by an explicit Euler method. In this case, the vector of nodal accelerations $\{\ddot{x}\}$ can be determined from the formula [8]:

$$\{\ddot{x}\}_n = [M]^{-1}(\{F\}_n - \{F_{\text{int}}\}_n). \tag{2}$$

The damping can be also taken into account in equation (2) but only in the form of a diagonal matrix. An additional advantage of this approach is that the differential equations of motion are not coupling. Therefore, they can be solved separately.

Vector of velocity $\{\dot{x}\}_{n+1/2}$ and displacement $\{x\}_{n+1}$ for the next time steps are calculated by integrating the central finite difference method for time.

$$\{\dot{x}\}_{n+1/2} = \{\dot{x}\}_{n-1/2} + \{x\}_n \Delta t_n, \tag{3a}$$

$$\{x\}_{n+1} = \{x\}_n + \{\dot{x}\}_{n+1/2} \Delta t_{n+1/2}. \tag{3b}$$

Unfortunately, this method is conditionally unstable. The length of the time step for integrating must be limited (4) in order to ensure the stability:

$$\Delta T \le 2/\omega_{\max}, \tag{4}$$

where $\omega_{\max}$ is the highest frequency of undamped vibration of its own discrete model. This means that the step must be shorter than the time wave propagation through the smallest element in the computational model. The consequence of this is that the more accurate the model is (small items), the shorter the step of integration is, and the calculation time is longer. At the same time disappears problem selection length.

The mechanics problem dealt with modelling method and computer simulations require the adoption of a suitable description of the behaviour of the materials used. This description must take into account several specific features e.g. physical state, plasticity, crispness, hardness. Material data, necessary to build the model, were taken from the available literature. Some of data were based on the experimental tests carried out in the Department of Mechanics and Applied Computer Science at the Military University of Technology.

3. Spatial discretisation the geometrical model

Numerical analysis was carried out for the 3D numerical shell model of the vehicle. The model was loaded by the wave of pressure after the detonation of the large explosive charge placed on the side of the vehicle. Vehicle was designed according to the latest standards.

The pressure wave which was created by detonation propagate in the area of the cube-shaped with appropriate boundary condition. Theoretical solution of propagation of strong discontinuity of spherical-shaped launched charge with point source exists in the form of analytical equations, the similarity Taylor equations, which restated can be written as [7, 8]:

$$p(r) = 0.155 \cdot E_0 \cdot r^{-3}, \qquad (5)$$

where:
E_0 – the initial internal energy,
r – the current radius of the sphere.

It allows for computer simulation of the process of shock wave propagation by giving the appropriate initial conditions (density, energy, pressure) for some selected elements with the Euler's domain, then the solution law of conservation of mass, momentum and energy. Typical values for explosive substances is: density – 1600 kg/m^3 and the internal energy of the competent – 4.2 MJ/kg.

The shock wave was spread in the area modelled using Hex 8 type Euler's elements. Euler's elements were characterised by the properties of the ideal gas $\gamma = 1.4$ and density corresponding to the density of air at standard conditions (ρ = 1.2829 kg/m^3). The ground was modelled as a rigid body. The calculation must include changes caused deformation of the hull of the vehicle. Therefore, the vehicle was modelled by using Quad 4 type Shell Lagrange elements. These elements were described by the following mechanical properties: E = 2.1E+9 MPa, $\nu = 0.31$. For description behaviour of steel was used bilinear model of elastoplastic material DYMAT 24. Maximum strain failure criterion has been adopted [7].

Development of the special vehicle model was preceded by additional laboratory research of mechanical properties of steel used in the construction of this type of vehicles. Laboratory research was carried out in the Department of Mechanics and Applied Computation Science on Military University of Technology.

Overall view of the numerical model of the vehicle and the cross-section of the entire system was presented in Fig. 1.

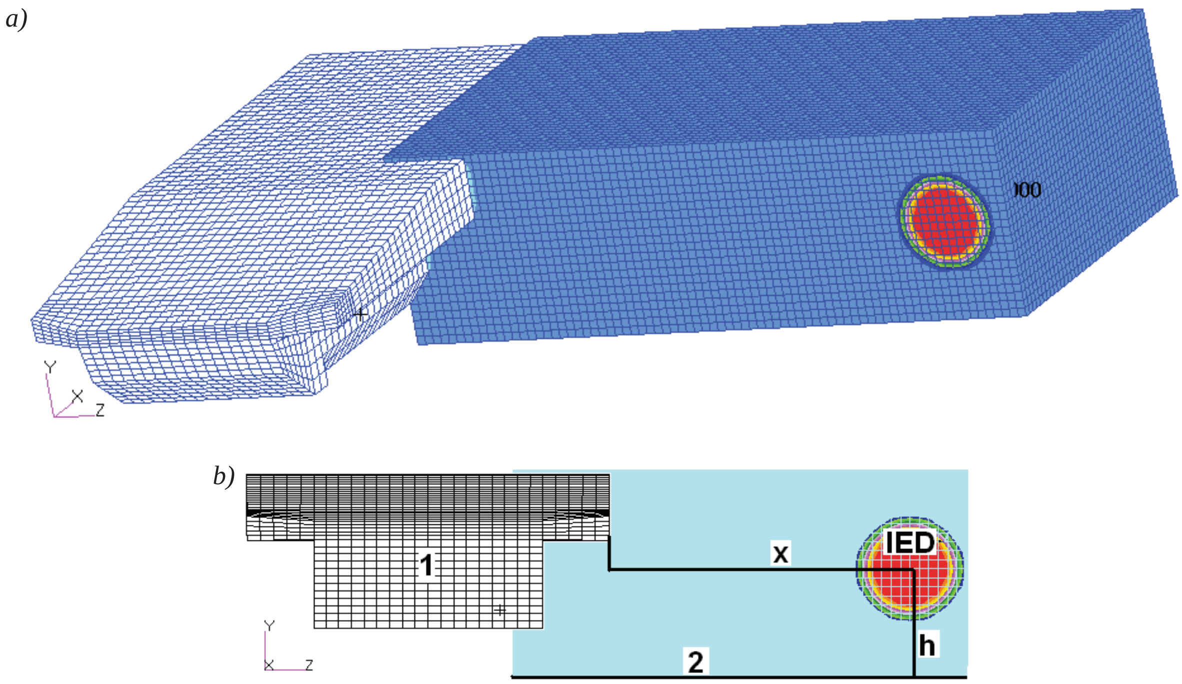

Fig. 1. Position of the IED relative to the hull of special vehicle (a – numerical model, b – schematic diagram): 1 – hull, 2 – ground, x – the distance of the charge, h – height of the charge placement, IED – charge

Load of the explosion wave has been carried out in accordance with the provisions to be included in the new standard. The IED charge was located in x distance equal to 5 m and height h equal to 1 m over ground. Such placement of the charge allows the effect of Mach wave the schema creation showed in Fig. 2. The propagation of pressure wave created by the detonation of the explosive is shown in Fig. 2.

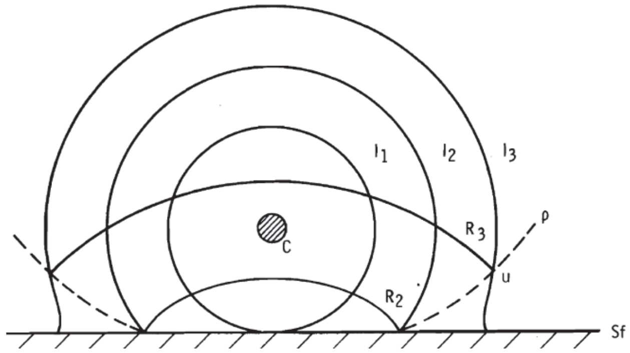

Fig. 2. Propagation of pressure wave created by the detonation of the explosive [9]

The General coupling included in the standard software implementations of the MSC Dytran [7] was selected to describe the interaction of the fluid and the structure. Such approach allows connection of two different mediums.

During the numerical analysis, the considered vehicle model was loaded with pressure wave of blast created by the explosive charge. The following explosive charges were used: 25, 50, 100, 250 and 500 kg.

4. The results of numerical analysis

The selected results of numerical simulation are depicted in Fig. 3 and 4. The results show deformation of the hull of the special vehicle, contours of total displacements and time histories of the following values: internal energy, displacements, velocity and displacement of the characteristic point on the cabin of the vehicle.

Figure 3 shows the pressure wave propagation for a charge of weight equal to 500 kg. For the first moment of time (Fig. 3a) the initial state developed, the pulse pressure can be observed.

For the next time t = 1.6E–5 s, we have pulse pressure amplification by reflection from a rigid ground. The amplification is tenfold and pressure value reflected from the ground is equal to 2.13E+9 Pa. The phenomenon of amplification the pulse pressure from the ground is shown in Fig. 3b.

The formation of the front of Mach wave in accordance with scheme presented in Fig. 3b. Despite the pressure pulse travelled half distance between the charge and hull the vehicle pressure value droped slightly. The front of Mach wave is depicted in Fig. 3c.

As a result of reaching front of pressure pulse to structure appeared strengthening of the pulse by reflect form the side wall of vehicle. The increase of the pressure wave due to the reflection is shown in Fig. 3d. (pressure pulse before reflection) and Fig. 3e. (pressure pulse after amplification due to reflections from the walls of the hull). Further strengthening of the pressure pulse was due to a rebound from the bottom wall of the hull of the vehicle (Fig. 3f).

The individual contours for the hull of the special vehicle caused by the explosion of 500 kg IED charge are shown in Fig. 4.

The displacement contour for the vehicle hull is depicted in Fig. 4a. The maximum displacement reaches 0.344 m. This value includes the value of displacement around the hull of the vehicle 0.0351 m.

The energy deflection contour for individual items is shown in Fig. 4b. The maximum value of the energy of deformation was 17.7kJ and it was the biggest for the area of the second rebound (rebound from Hull) pulse pressure.

The contour of the plastic strains is presented in Fig. 4c. The maximum value is equal to 3.925E-2.

Huber – von Misses stress contour is shown in Fig. 4d. The maximum value of the stress significantly exceeded the value of yield stress and was equal to 2160 MPa. Such a high value of stress is caused by the dynamic strengthening yield strength.

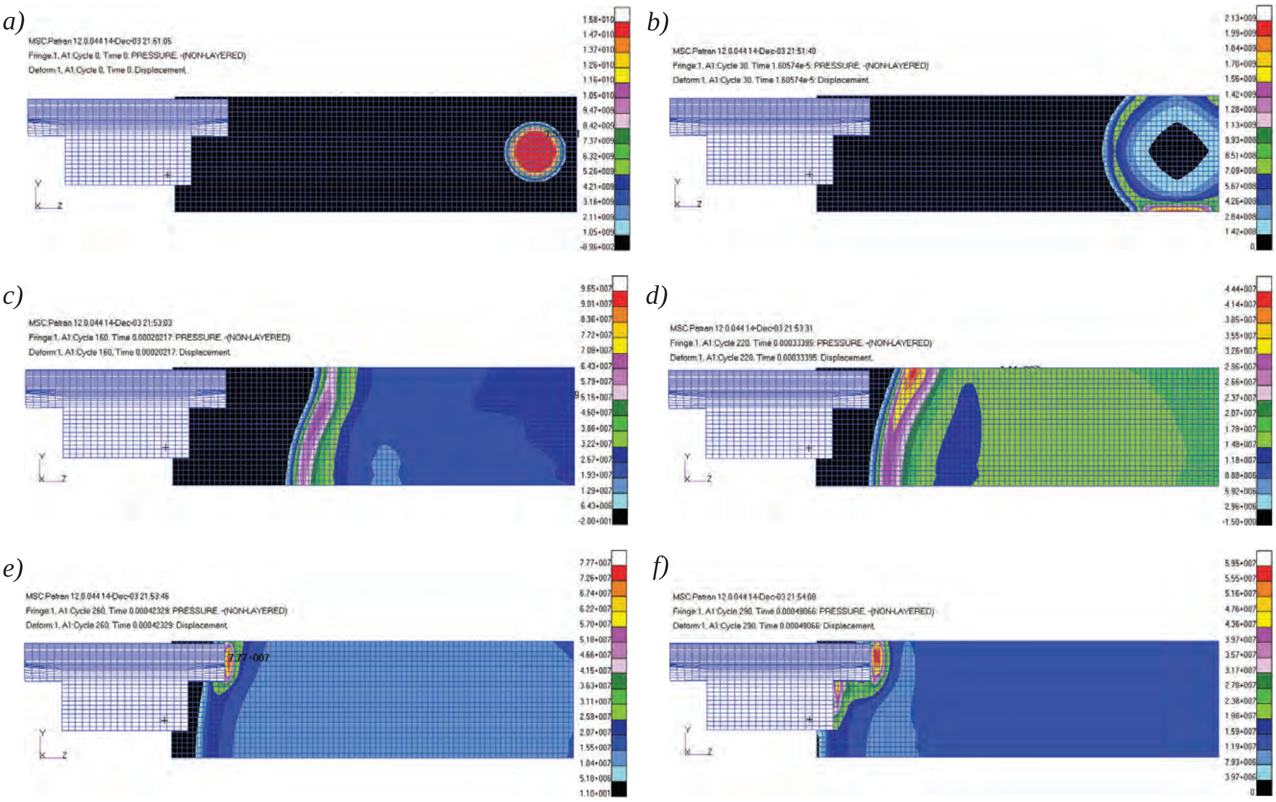

Fig. 3. Propagation of the pressure wave for different moments of time

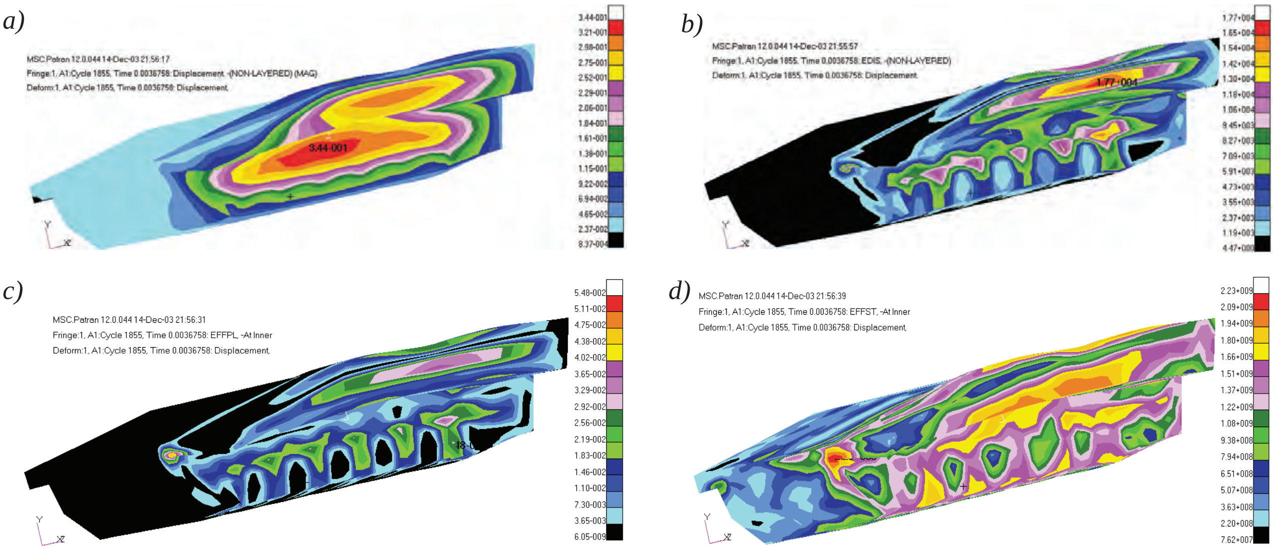

Fig. 4. Results of the FE analysis for the IED charge of 500 kg: a) contour of total displacement, b) contour of the strain energy, c) contour of the plastic deformation, d) contour of the equivalent stress

For the considering cases, the pressure wave reflected from the first vehicle plane is depicted in Fig. 5 in the form of time histories. The largest pressure value has been reported for the charge of weight equal to 500 kg. This value was 1.1E+8 Pa. For charges 250, 150, 100, 50, 25 kg the maximum pressure values for reflected wave were equal to: 5.8E+7 Pa, 3.6E+7 Pa, 2.5E+7 Pa, 1.4E+7 Pa, 6.3E+6 Pa, respectively.

Time history of deformation energy for entire hull is shown in Fig. 6. Similarly, as in the case of the pressure charts for the reflected wave, the highest values of the deformation energy equal 6 MJ, which was noted for explosive charge equal to 500 kg, and the minor equal 0.5 MJ for the charge of 25 kg.

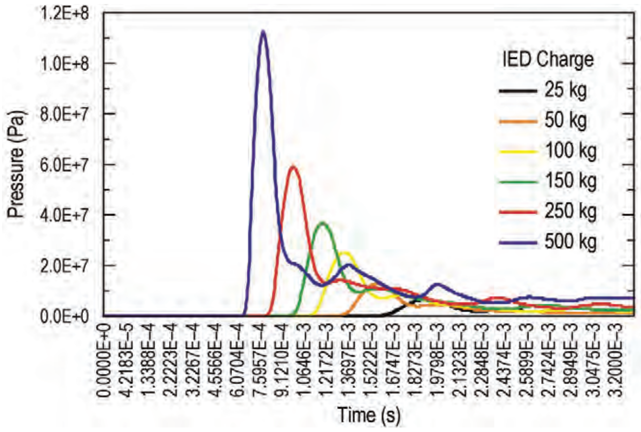

Fig. 5. The pressure wave reflected from the first vehicle plane for each value of charge

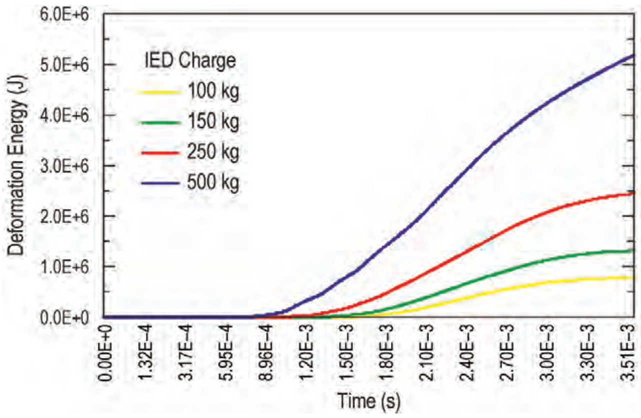

Fig. 6. Time history of deformation energy for entire hull

Figure 7 shows a time history of the node displacement. Selected node was located on the side of the vehicle.

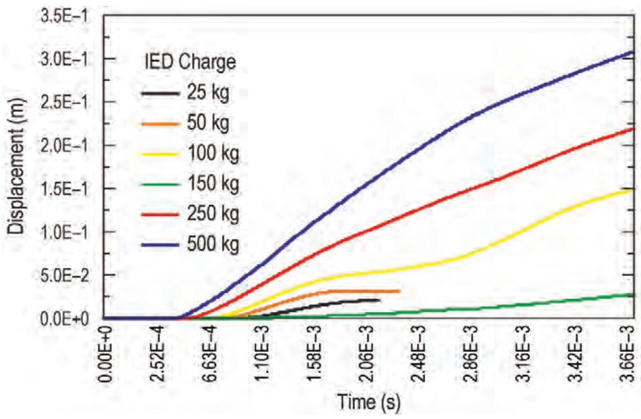

Fig. 7. Time history of the displacement of selected node located on the side of the vehicle

The maximum value of displacement which equals 0.3 m, was noted for the time 3.66E–3 s, for the charge of 500 kg. The minor displacement was 0.025 m for the charge of 25 kg. From the observation of the results of particular charges, it is confirmed that for the charge of 500 kg, all the physical values, which are obtained from the numerical analysis, are critical.

The maximum velocity of the node (Fig. 8) was obtained for the model, which was loaded with the charge of 500 kg and it was equal to 75 m/s, and minimum velocity of the node was equal to 15 m/s for the charge of 25 kg.

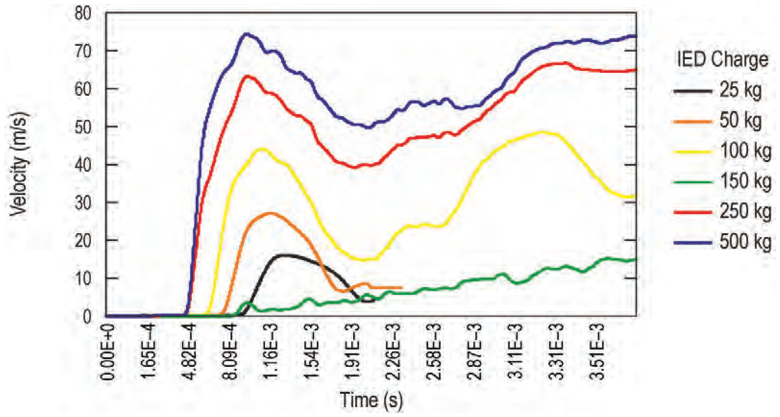

Fig. 8. Time history of the velocity of selected node located on the side of the vehicle

As with the previous physical values, all the extremes were noted for the model loaded with the charge of 500 kg. The maximum value of the node acceleration (Fig. 9) was obtained for the model loaded with the charge of 500 kg and was equal to 7.5E+5 m/s^2. The minimum value of nodal acceleration was obtained for the charge of 25 kg and was equal to 4.0E+4 m/s^2.

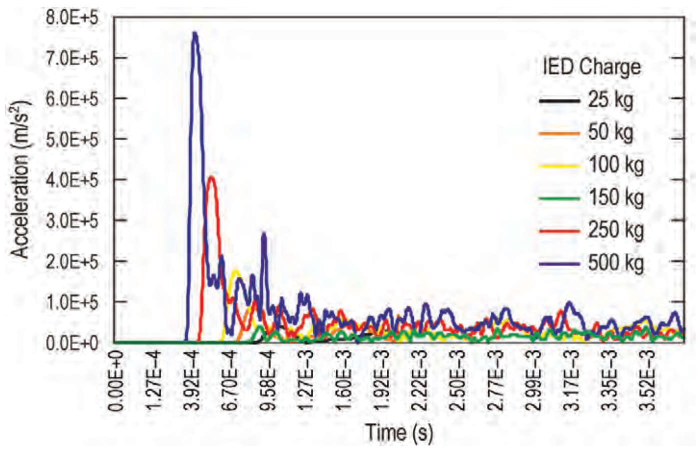

Fig. 9. Time history of the acceleration of selected node located on the side of the vehicle

From the analysis of the obtained results it can be seen that the explosion of charges larger than 100 kg are the most dangerous for the crew inside the vehicle. The pressure peak operates on the hull in a very short time after the shock wave reaches the hull. As it is known, that kind of action like large value of pressure in short time causes most serious injuries in human being.

5. Summary

As it is known, a safe structure loaded with a pressure peak should provide the life zone which is a measure of reliability of such a structure. In the analysed cases, it can be seen that the reliability is retained for the charge of small masses, but for the largest charges there is a risk that the cabin will not provide the required level of safety. To improve the level of safety it is necessary to apply the modification, which increases the hull stiffness and, at the same time, increases the level of protection of the crew inside the vehicle.

One of the safest ways to obtain information about the loads, which are influence on vehicle and the same for the crew of the vehicle in the case of the shock wave generated by explosion are numerical simulations. Their relatively low cost in comparison to experimental research gives the ability to select the best design solutions as well as modifying and optimizing the construction already in the design phase.

The company producing armoured vehicles for the army is constantly looking for the most durable ballistic material and energy-intensive to protect the vehicle and the crew located inside from the effects of the attack on them by using mine or IED. After the detonation, depending on the weight and type of the load applied, resulting from the combination of shock wave pulse load causes the body of the vehicle. Impulse this within just a few milliseconds generates high acceleration which cause the inertia forces of causing serious injuries and even death of the crew.

It follows that provide of adequate protection for the primary purpose of anti-mine is becoming the main aim for the modern structure of the armed vehicle which were created by using numerical simulations.

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