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NUMERICAL ANALYSIS OF EFFECTS OF IED SIDE EXPLOSION ON CREW OF LIGHTARMOURED WHEELED VEHICLE

Robert Panowicz, Kamil Sybilski, Damian Kołodziejczyk

Military University of Technology, Department of Mechanics and Applied Computer Science
Gen. Sylwestra Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: (22) 683 7348
e-mail: rpanowicz@wat.edu.pl
ksybilski@wat.edu.pl, dkolodziejczyk@wat.edu.pl

Tadeusz Niezgoda, Wiesław Barnat

Military University of Technology, Department of Mechanics and Applied Computer Science
Gen. Sylwestra Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: (22) 683 9461, (22) 683 7201
e-mail: tniezgoda@wat.edu.pl, wbarnat@wat.edu.pl

Abstract

The article presents numerical simulation of interaction of a pressure wave coming from detonation of an improvised explosive device on the crew of the ligtharmoured wheeled vehicle. There was analysed one of the typical scenario, namely the explosion on the side of the vehicle, which the army deals with during the stabilization missions of different kind. The objective of the presented numerical investigations was to examine the influence of dynamics impulse, according to mass of detonated charge, on the crew in the characteristic anthropometric points of the body. The numerical investigations presented in the present paper aimed at testing the influence of the mass of the detonated charge on the load to which the vehicle crew is subjected to. In order to meet this target, there were used capability of coupling between the compressed air, described with the use of equations of continuum mechanics by Euler, and the vehicle with the crew described with the same equations but formulated by Lagrange. Interaction of both of the centres was executed with the use of general coupling. To perform the analyses, Ls-Dyna software based on the finite element method with the algorithm of explicit integration in time was used. Development of a full-scale model of the special vehicle was preceded with the laboratory tests on the mechanical properties of armour steel applied for constructing the vehicles of this type.

***Keywords**: numerical analysis, detonation, IED, ligtharmoured wheeled vehicle, Head Injury Criterion,*

1. Introduction

In the literature there is a great number of works dedicated to the process of interacting of the blast wave coming from the detonation of explosive charge on the elements of constructions, vehicles and armours [3-6]. However, there is a small number of works dedicated to interaction of the blast wave (coming from detonation of improvised explosive device) on the crew of a wheeled ligtharmoured vehicle. Situations of this type take place during various stabilization missions as, for example, in Iraque and Afghanistan. Improvised explosive devices (IED) and mines are the most common reasons of death of soldiers taking part in the above mentioned missions [11, 12], Fig. 1 presents a percentage share of these charges in the in the soldiers death in years 2001-2011.

2. Evaluation of the influence of the effects of IED side explosion on wheeled ligtharmoured vehicles and their crew

The structure of the vehicle in the zone of the explosion of IED is subjected to a strong influence of the blast wave. In the moment of the explosion, there originates a blast wave which

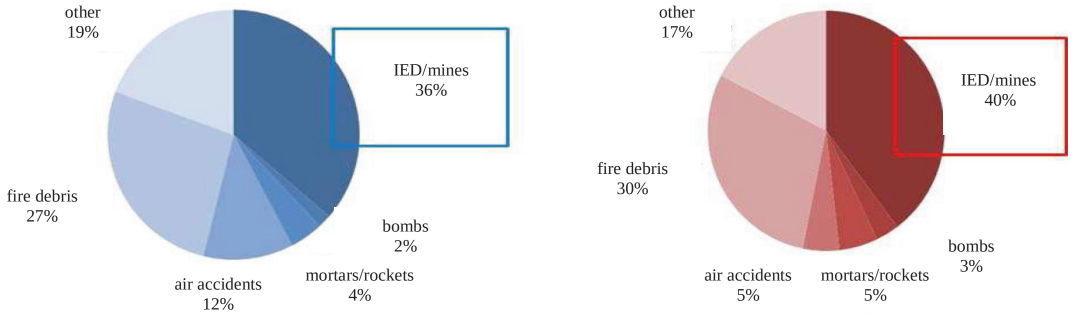


Fig. 1. Percentage distribution of the reasons of death of the soldiers taking part in stabilization missions in years 2001-2010: blue – in Iraque, red – in Afghanistan [15]

dispears in all possible directions at velocity greater than the speed of sound. This wave, surrounding the vehicle body, interacts on its elements causing overloadings inside the cat. After detonation of explosive charge, according to its mass and the initiation kind, the originating blast wave causes pulse loadings of the vehicle armour. This impulse in a few miliseconds induces high accelarations causing injuries and even death of the crew.

The degree of the crew threat depends on its distance from the place of detonation, vehicle construction as well as the arrangment of the inside of crew compartment. During the side explosion, a head and the body of the passanger arethe most subjected to the injuries.

There are various standards and documents, developed on the basis of experimental reasearch, determining allowed values of overloadings to which the human body can be subjected. The best known standards in this scope are:

- standard NATO – *STANAG 4569,*this is a military standard in the field of ballistic protection against missisles and shrapnels as well as in the field of protection agaist a blast wave coming from detonation of mine or improvised explosive device.
- American standard – *UFC 3-340-02 STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS* .It allows to establish the parameters of loading with detonation required in the process of protective construction designing.

Evaluation of the threat of life and health of the crew in the effect of the dynamic impulse transmissble through mutual interaction of the soldier body and the seat is based on the complex analysis of the examined phenomena.

It is essentials to take into consideration two kinds of shocks:

- impacts causing accelerations of the body
- Vibrations resulting from vibrating motion of the structure.

The investigations showed that velocity safe for the impact equals 10 fps (3 m/s). At value 18 fps (5.5 m/s), the probability of breaking the skull is almost 50%, while at 23 fps (7 m/s) the probability is almost 100%. Allowed horizontal acceleration required assuring protection of the personnel in the standing, sitting or laying position (not fastened with the belts) is 0.50g.

Tolerations of vibrations for the personnel with limited movement (fastened with the belts) are considered as allowed: at acceleration 2g less than 10 Hz, 5g for 10-20 Hz, 20-40 Hz to 7g and 10g above 40 Hz. However, application of toleration for accelerations greater than 2g requires usually too complicated holding appliances for most of production centres and research laboratories.

3. Finite Element Method numerical calculations

To perform the analyses, Ls-Dyna software based on the finite element method with the algorithm of explicit integration in time was used. The detonation process was modelled with the approximation of geometrical optics, in which it is assumed that the front of the detonation wave moves at the given constant velocity and originates a surface of strong nonlinearity. It results in the fact that there can be considered only the cells with the overreacted explosive material through which the front has already passed. In the cells on the front of the detonation wave there are given the values of pressure, density and energy (temperature) corresponding to the values at the Chapman-Joguet point. Such an approach allows applying not very trick calculation meshes (larger time step) without a significant increase of calculation inadequacy.

In the analyses there was applied the possibility of coupling between air described with the use of Euler equations of continuum mechanics and a vehicle with a crew described with the use of the same equations, however, in Lagrange's approach. The interaction of both the centres was implemented with the use of the general coupling [1].

The chase of explosive material detonation is described by a JWL (Jones, Wilkins, Lee):

$$p_{PD} = A\left(1-\frac{\delta}{R_1\,V}\right)^{-R_1\,V} + B\left(1-\frac{\delta}{R_1\,V}\right)^{-R_2\,V} + \delta\rho E\,, \tag{1}$$

where:

A, B, R1, R2, δ - empiric constants,
V= ρ0/ρ - relative volume of explosive material,
E - inner energy on the volume unit.

The equation of the state:

$$p = C_0 + \left(C_1 + C_2\mu\right)E\,, \tag{2}$$

where:

μ=(1/V)-1, V= ρ0/ρ - relative volume,
E - inner energy on the volume unit,
C0, C4, C5 - empiric constants was applied to describe the air surrounding the explosive charge.

3.1. Finite Element Method analysis

The analysis was conducted for Tyree values of the charge mass 5, 10 and 15 kg. Fig. 2 presents a numerical model of a lightarmoured vehicle in which a model of a human was placed.

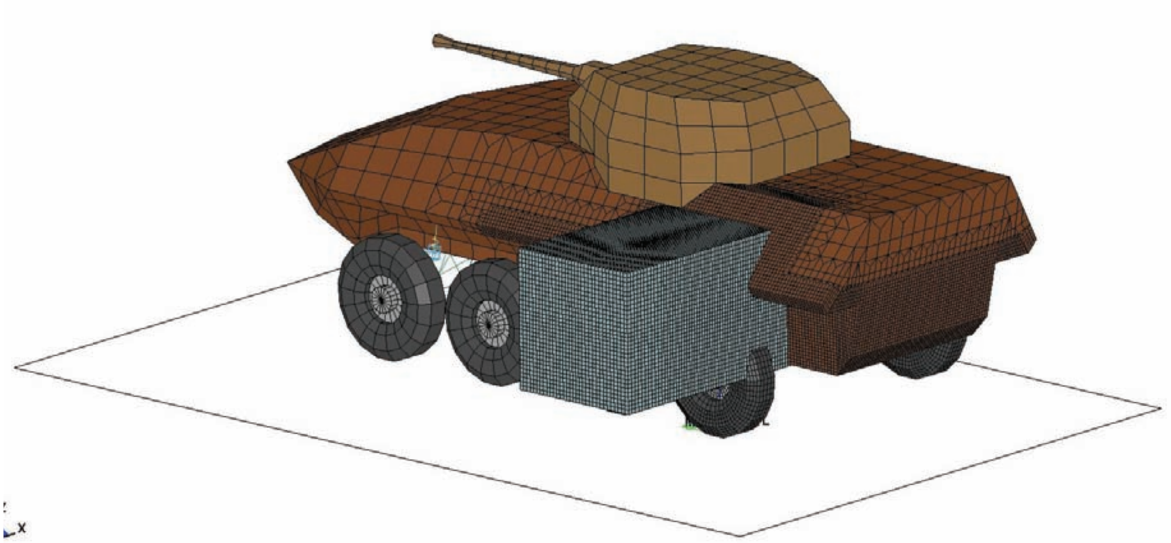


Fig. 2. Numerical model of the vehicle with an air model in the shape of cuboid used in numerical analyses

During the calculation process there was applied the model of a human Hybrid III Male which was verified in numerous crash tests. It is applied mainly in modelling of the effects of car crashes both on a driver and passengers. A dummy model was placed in the back part of the vehicle (Fig. 3), explosive charge (of 5, 10 and 15kg) is located in the distance of 1.5 m from the dummy at 1.5 m attitude.

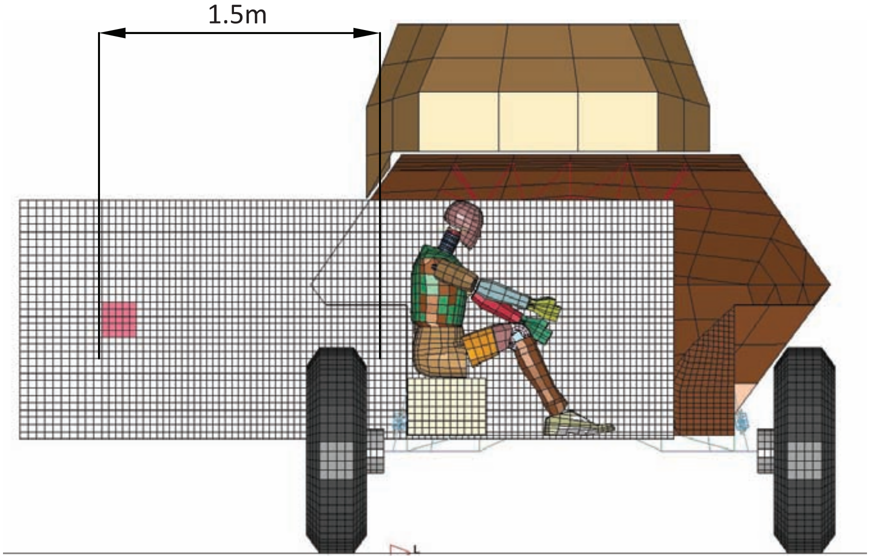


Fig. 3. Sectional picture presenting arrangement of the charge and the vehicle passenger supposed to be influenced by a blast wave

3.2. Results of analysis of IED side explosion

Standard criteria of evaluation of crew life threat concerns lower extremities, breast-loins section of the spine - DRI (Dynamic Response Index), neck section, spine, chest, inner organs and head [5, 7]. The paper will concentrate on the evaluation of effects of blast wave influence on the head using HIC criterion accessible in LS-DYNA.

Head Injury Criterion is a measure of the likelihood of head injury arising from an impact. The HIC can be used to assess safety related to vehicles, personal protective gear, and sport equipment. Normally the variable is derived from the acceleration/time history of an accelerometer mounted at the centre of gravity of a dummy's head, when the dummy is exposed to crash forces [14]. It is defined as:

$$HIC = \max\left\{ (t_2 - t_1)\left(\frac{1}{t_2 - t_1}\left(\int_{t_1}^{t_2} a(\tau) d\tau \right) \right)^{\frac{5}{2}} \right\}, \tag{3}$$

where: $a = \sqrt{a_x^2 + a_y^2 + a_z^2}$.

Apart from the condition $0 \le t_1 \le t_2 \le T$, the starting point t_1 and the time period $\Delta t = t_2 - t_1$ are arbitrary at first. To be able to evaluate the measured curve practically, one makes some simplifying model assumption [15]:

- We demand $t_2 - t_1 \le 36$ ms. Longer deceleration times do not increase the injury risk, according to experience.
- Peak acceleration values must last 3ms. This requirement has reasons of measurement technique and is supported by the assumption that decelerations of shorter duration do not have any effect on the brain.

The head injury criteria are comprised of four different injury criterions [14]:

- Head Injury Criterion. (HIC) – Brain Injury and concussion plus skull fracture on Flat object impacts,
- Blunt Object Skull Fracture Injury Criterion (KN) – Depressed skull fracture from blunt object impacts Facial Injury Criterion (KN/mm) – Facial fracture and injury from blunt object impacts,
- Facial Injury Criterion (KN/mm) – Facial fracture and injury from blunt object impacts,
- Facial Laceration Criterion – Facial Laceration.

HIC levels as shown Tab. 2.

Tab. 2. Levels Of Consciousness In Relation To Head Injury Criteria[14]

Head Injury Criteria	**AIS Code**	**Level Of Brain Concussion And Head Injury**
135 – 519	1	Headache or dizziness
520 – 899	2	Unconscious less than 1 hour – linear fracture
900 – 1254	3	Unconscious 1 – 6 hours – depressed fracture
1255 – 1574	4	Unconscious 6 – 24 hours – open fracture
1575 – 1859	5	Unconscious greater than 25 hours – large haematoma
> 1860	6	Non survivable

Tab. 3. Head Injury Criteria Tolerance Levels [14]

Injury Criteria		**Tolerance Levels**				
Criterion	**Units**	**Level 0**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
		No Injury Egress	**Minor Injury Egress**	**Major Injury Egress Assisted**	**Severe Injury Medical Assistance**	**Potentially Non Survivable**
HIC Brain Injury (Brain Injury in all head impacts)	HIC (15msec)	<150 (No concussion)	<150 (No concussion)	150 – 500 (Mild concussion)	500 – 1800 (Severe concussion)	1800 (Life threatening coma)
HIC Skull Fracture (Flat Impacts)	HIC (15msec)	<500 (No Fracture)	<500 (No Fracture)	500 – 900 (Minor Fracture)	900 – 1800 (Major Fracture)	1800 (Life threatening fracture)
Blunt Object Skull Fracture	KN	<2.2 (No Fracture)	<2.2 (No Fracture)	2.2 – 5.5 (Minor depressed fracture)	>5.5 (Major depressed fracture)	>5.5
Facial Injury	KN/mm	>0.25/12 (Very minor injury)	0.25/12 – 0.90/20 (Minor facial injury)	0.90/20 – 3.3/40 (Major facial facture)	>3.3/40 (Severe facial injury)	>3.3/40
Facial Laceration	Cuts to chamoios leather thin layer	0	0	Moderate	Major	N/A

The above tables will be used for evaluation of injuries suffered by a dummy in the conducted numerical analyses. Fig. 4 presents results of simulation, interesting for us values of criterion HIC.

Comparing results of numerical analysis with allowed values of HIC parameters (Tab. 4), it can be concluded that only at loading with explosion of a 5kg-charge a vehicle passenger has a chance to avoid more serious injuries.

There was also recorded a dislocation of a dummy influenced by a blast wave (Fig. 6).

Exemplary runs of accelerations of the selected parts of dummy body are presented in Fig. 6 and 7.

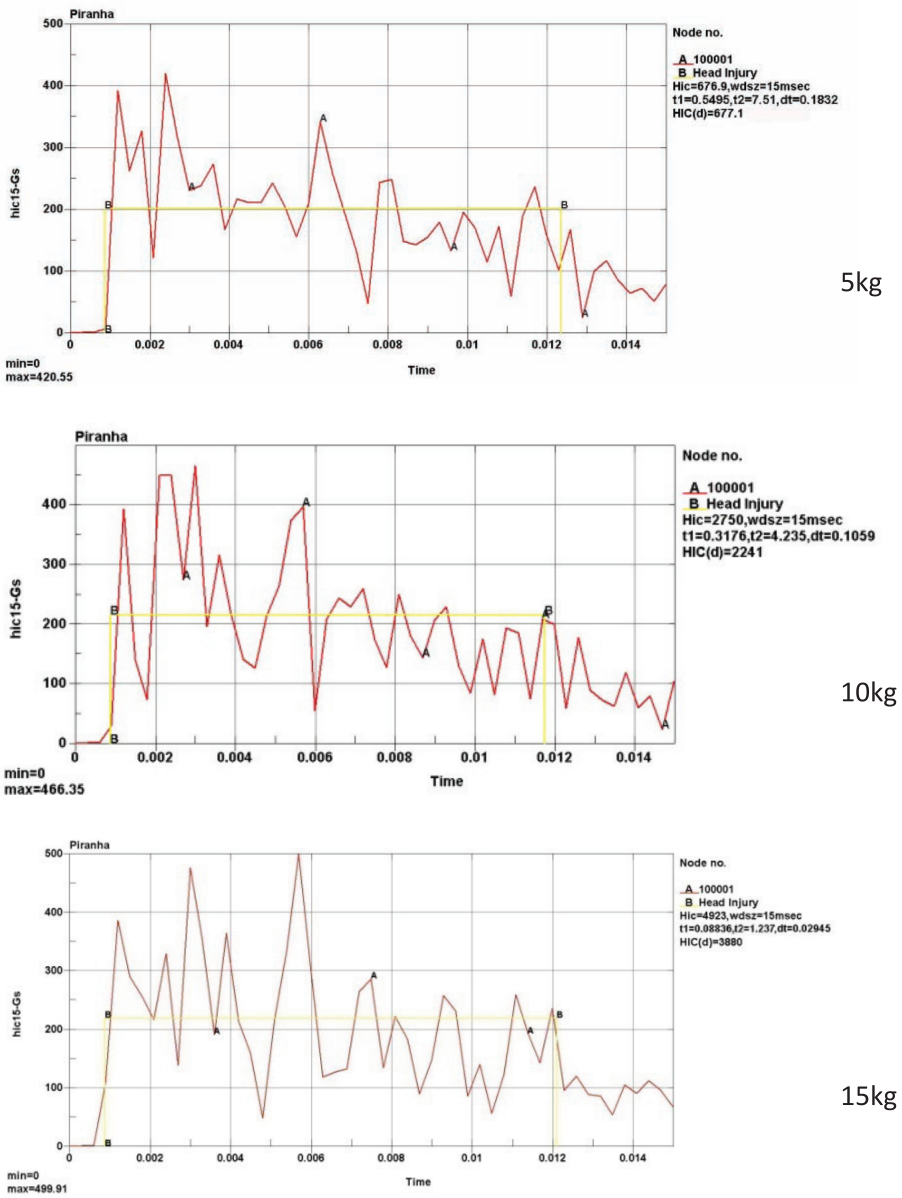


Fig. 4. HIC15 runs for subsequent options of loadings: 5, 10 and 15g of C4 charge in the distance of 1.5m from the vehicle

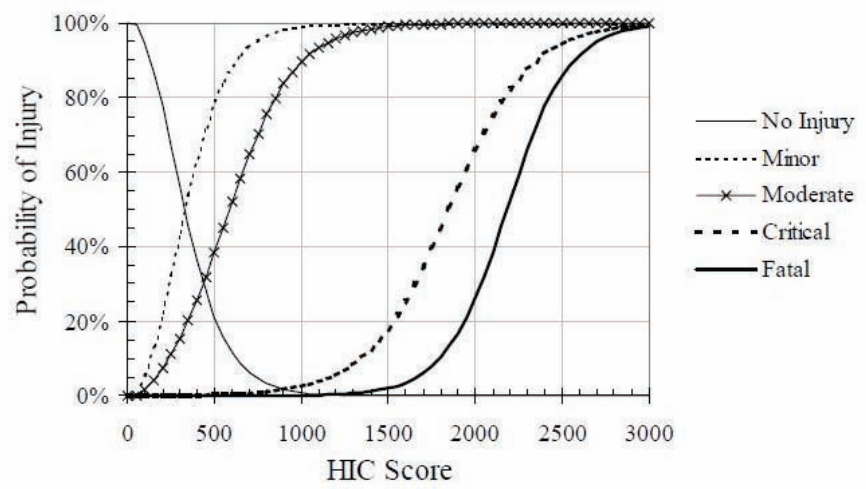


Fig. 5. Probability of specific head injury levels for a given HIC score

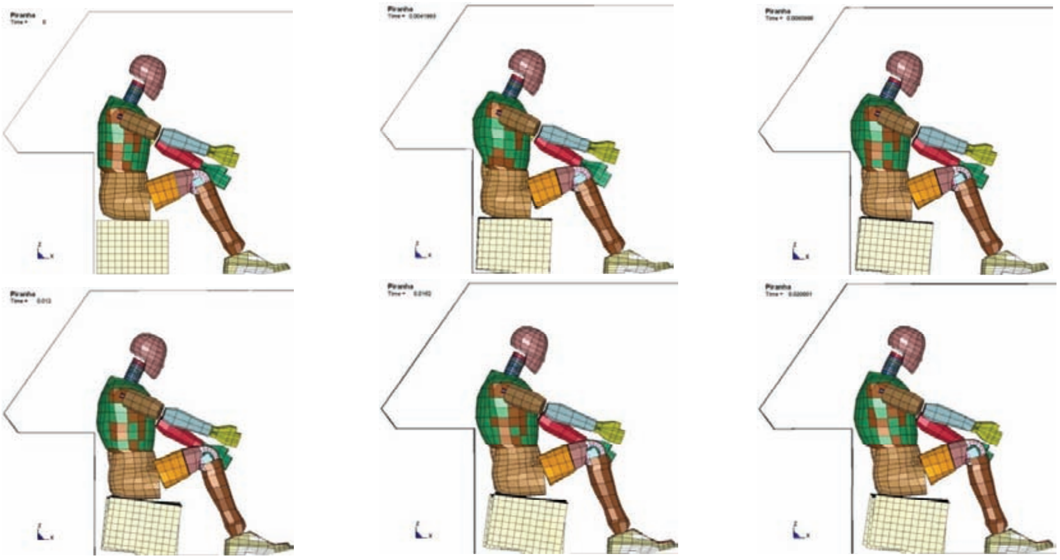


Fig. 6. Dislocation of a dummy for a selected time steps under an influence of a blast wave coming from detonation of a 15kg-charge

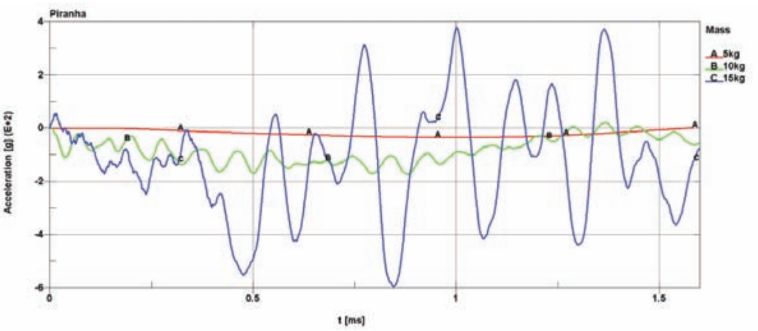


Fig. 7. Agreed accelerations (a/g) of the head resulted from IED side explosions of various masses located at the attitude of loins part of human spine

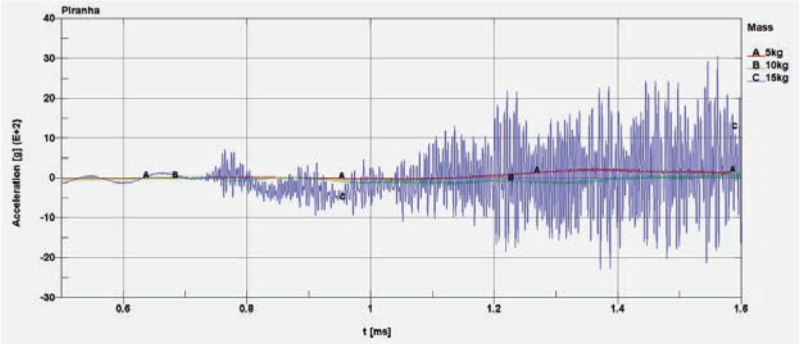
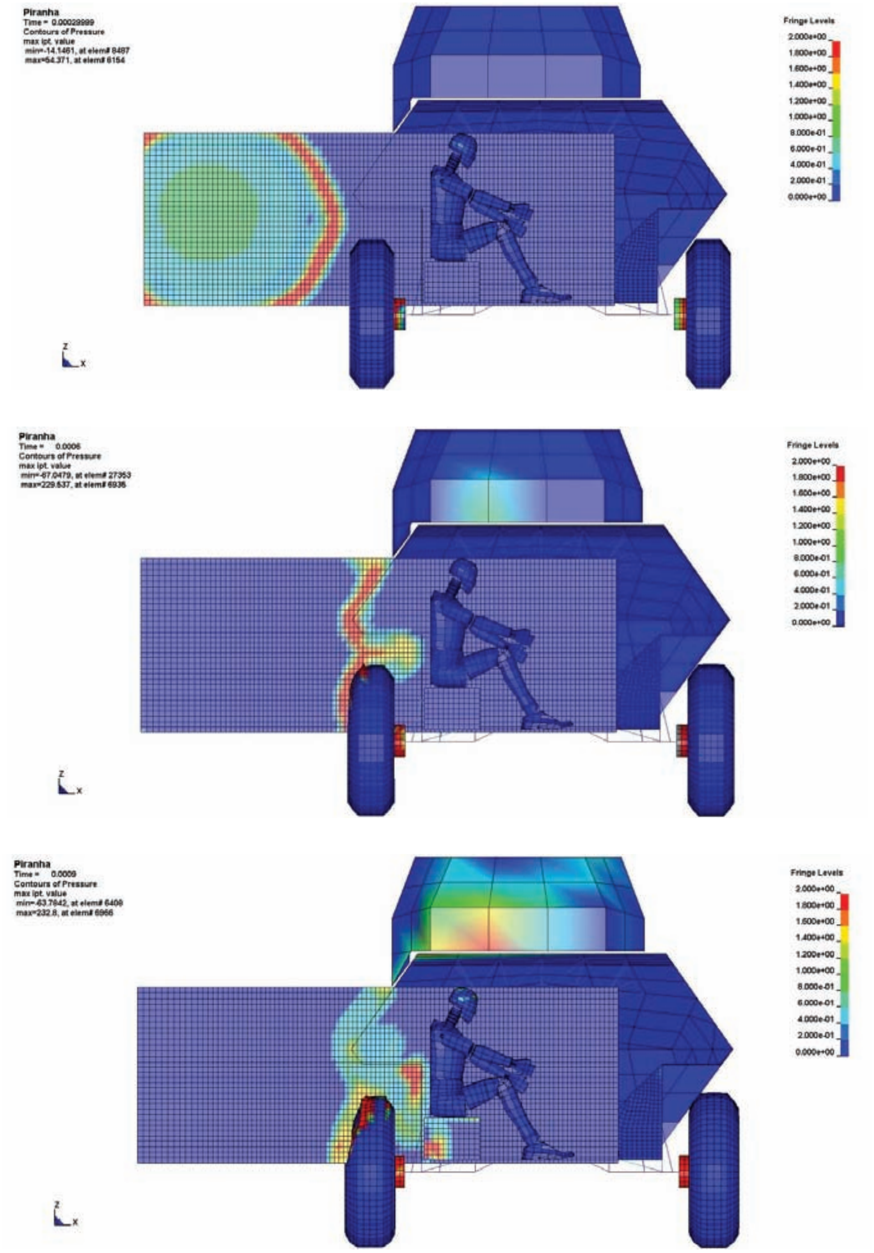


Fig. 8. Agreed accelerations of the pelvis resulted from IED side explosions of various masses located at the attitude of loins part of human spine

Capabilities of LS-DYNA calculation code allow also observing the manner of blast wave dispersion (fig. 9). Thanks to such capabilities of the program, it is possible to take a better look at the phenomena of the influence of a blast wave on a human being. There is visible the moment when the blast wave reaches the dummy. In this type of case (side explosion), the most threaten parts of body, according to DRI criterion, are: neck section, chest, inner organs and head.



t=0.3ms

t=0.6ms

t=0.9ms

Fig. 9. Pressure wave propagation

4. Conclusions

In the paper, there were presented the results of modelling the influence of interacting of a blast wave coming from explosion of mine or IED on a human in a ligtharmoured wheeled vehicle. The obtained results show that forces and overloadings operating on the selected human organs are so significant that they can result in serious injuries. The body structure, built of certificated standard materials, nowadays is not sufficient to meet all the requirements of ballistic protection. There is a need to assure additional protection of passengers, especially against side explosion.

The results of conducted numerical studies can constitute data for calculation of evaluation coefficients of vehicle crew life threat in various types of model investigations. The aim of such a complex analysis comprising the influence of a blast wave explosion on specific vehicles and their crew is development of modern and effective protective means. Meeting the criteria and assumptions presented in the paper will be an evidence of safety and reliability of wheeled armoured vehicles of the contemporary battlefield.

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