COMPUTER MODELLING OF COMPLEX ACTION SYSTEM OF BLAST WAVE ARISING FROM MINE OR IED EXPLOSION ON LIGHT ARMOURED VEHICLE

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Abstract

In this paper the results of computer simulation of blast wave action arising from mine or IED explosion on wheeled light armoured vehicle will be presented. In the last years the NATO STANG 4569 international standard has been prepared. It describes the test standards concerning the ballistic resistance of vehicles not only to missiles but also to fragments and pressure wave arising from mine or IED explosion. In accordance with this standard the explosive charge is placed under ground surface (independently to the charge position in relation to the vehicle-under the wheel or under the vehicle centre). This case is of frequent occurrence during the different stabilization missions conducted by our troops both in Iraq and in Afghanistan.

In the calculations the possibility of coupling between the medium described with the aid of Eulerian equations and the medium described with the aid of Lagrange equations has been used. The coupling enables the complex description of the issue. The detonation process has been described approximately of detonation optics and the behaviour of detonation of explosive device has been described with the aid of JWL equation in common use. Such approach to the subject is sufficient to resolve mast engineer problems. The vehicle has been described with the aid of Lagrange elements with corresponding material properties. The effect of high masses has been taken into account, in particular the effect of engine on behaviour of the object.

The adequate coupling of the mediums above- mentioned has been very difficult during the numerical work, but additional taking the ground in consideration has improved considerably the quality of the results obtained which are nearer of the real results.

Keywords: *explosion, finite element method, light armoured vehicle*

1. Introduction

During the operations of our troops within the frame work of the NATO and UN forces the weak sides of the equipment utilized with threats arising from the present asymmetrical conflicts have been noticed. There are the following threats: the projectile being shot by machine gun, missiles with shaped charge jet heads and improvised explosive devices – IED. The modern projectile made of tungsten reach a speed of 1400 m/s and enables to pierce the armour of light armoured vehicles. The most popular (the oldest) missiles of rocket propelled grenades of the first generation are equipped with the heads with shaped charge jet enabling to pierce the RHA armour plate of thickness of circa 300 mm, but the modern tandem (arrangement in series) missiles of the third generation enable to pierce the RHA steel up to 900 mm. The different improvised explosive devices-IED are able to cause inconsiderable destructions and they are also able to damage the vehicle completely killing the whole crew depending on the vehicle's weight and detonation place in relation to the vehicle. These threats have appeared particularly during the patrols and the escorting which have been executed by our troops within the framework of stabilization missions in Iraq and Afghanistan.

In this situation the military hardware (transport equipment) should meet the requirements higher and higher. It is essential that to ensure a corresponding safety for the soldiers using these transport facilities, it regards the equipment being used by the troops just now (modernization - additional screens) and the equipment to be in future (new construction solutions, materials). At present the light armoured vehicles being the base of each mission are in danger most of all.

The prospects of the present software and particularly the finite element methods and the hard wave being used in the calculations advanced enable to design and to test different equipment minimizing the costs and design life cycle.

In this paper the possibilities of the open finite element method have been used. This method is included in the Ls-Dyna software for modelling the behaviour of the wheeled light armoured vehicle exposed to the action of pressure wave arising from the detonation of explosive charge. The explosive charge has been placed under the surface in accordance with the NATO-STANG 4569 standard. Generally this place of explosive charge is in Iraq and Afghanistan of frequent occurrence. This place forces to take in account the influence of ground on the whole phenomena in the calculation process.

According to the standard above-mentioned, two situations of place of the vehicle in relation to the explosive charge have been examined. In the first case the mine is situated under the wheel of the vehicle in the second case the mine is situated under the vehicle.

The behaviour of air, explosive charge and ground has been described with the aid of the equations of continuous medium mechanics in ALE formulation (Arbitrary Lagrange-Euler method) [1]. The ALE method ensures the higher calculation quality as compared with classical solving the equations of continuous medium mechanics in Euler formulation. The behaviour of the wheeled vehicle has been described with the aid of the equations of continuous medium mechanics in Lagrange formulation as usually in these issues.

2. Numerical model

In Figure 1 the complete model of the system examined has been shown.

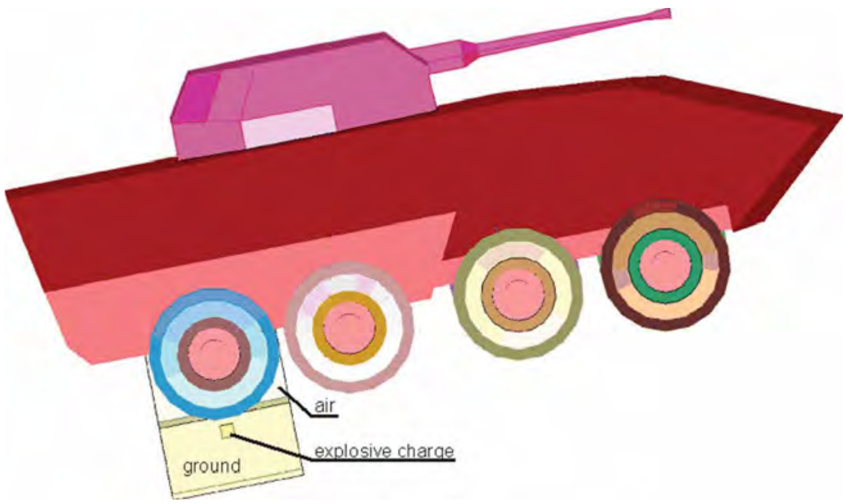

Fig. 1. Model of the system examined

There are two approaches concerning the construction of this model of the system examined and the determination of coupling between the domain described with the aid of the ALE equations and the part described with the aid of the Lagrange equations. One of them consist in location the whole vehicle model in the medium described with the aid of the equations of continuous medium mechanics in ALE formulation. Whichever disturbance is arising from the air and the ground is being transferred on the vehicle. In consideration of limited computer store and calculation time this approach forces the use of big calculation cells. As a result there is a small space resolution of the calculation results.

The alternative approach limits the domain occupied by ALE elements in preserving comparable number of calculation cells and comparable calculation time. There is a problem in this case corresponding selection of the Euler domain size (air, ground). This size should be enough big that the disturbance (perturbation) arising from the explosive charge detonation has enough low intensity after reaching the boundary of calculation domain so that not to influence the vehicle really.

In the initial tests the first approach has been used to estimate the wave intensity and the changes arising from it. But at the end the second approach has been used. It ensures more exact results.

The behaviour of air has been described with the aid of the Mie-Gruneisen equation [2]:

$$p = p_0 + \gamma \rho E\,, \tag{1}$$

where:
p - pressure,
p_0 - initial pressure,
γ - Gruneisen coefficient,
ρ - density,
E - specific internal energy.

The following values constant in the equation (1) [2, 3]: $\gamma = 1.4$; $\rho = 1.185$ kg/m^3; $p_0 = 1013$ hPa.

To describe the behaviour of ground exposed to the action of heavy and quick-variable load the model has been used which remain as a real body with non-linear consolidation growing with deformation. This type of consolidation is characteristic to the bodies in which voids (e.g. boiling) are and when all the voids are almost closed. This type was prepared in 1972 by Krug. The data for this model have been taken from [4].

If we are not interested in the phenomena occurring during the reaction of explosive and the processes occurring in front of shock wave, we can use the approximation of detonation optics [5]. You should know approximately: speed of explosive detonation, place of initiation, parameters in front of detonation wave-parameters in the Chapman-Jouguet point and the equation describing the behaviour of detonation products. In this approach the front of detonation wave moves at a given, constant speed and creates the surface of strong discontinuity. For that reason you can take into account only the cells with explosive reacted, in which the front has penetrated. In the cells situated in the front of detonation wave the values of pressure, density and energy (temperature) corresponding with the values in the Chapman-Jouguet point have been given. This approach enables to use not very fine calculation net (screen) (higher time step) without large increasing the calculation inaccuracy.

The behaviour of detonation products has been described with the aid of the JWL (John, Wilkins, Lee) equation [2, 5]:

$$p = A\left(1 - \frac{\omega}{R_1 V}\right)^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)^{-R_2 V} + \omega \rho E\,, \tag{2}$$

where:
$V = \rho_0/\rho$,
ρ_0 - initial density,
ρ - density of detonation products,
A, B, R_1, R_2, ω - constants.

The trinitrotoluene (TNT) is being used most often as an explosive in mines and improvised explosive devices. Therefore in these calculations the TNT has been accepted. The values constant of the JWL equation for TNT have been presented in Tab. 1 [2].

Tab. 1. The values constant of the JWL equation for TNT [2]

A	B	R_1	R_2	ω
[GPa]	[GPa]	[-]	[-]	[-]
373.8	3.747	4.15	0.9	0.35

The other parameters describing the explosive (D - detonation speed, P_{CJ} - pressure in the Chapman-Jouguet point, ρ_{CJ} - density in this point) have been given in Tab. 2.

Tab. 2. The other parameters describing TNT used in the calculations [2]

ρ_0	D	p_{CJ}	ρ_{CJ}
[kg/m^3]	[m/s]	[GPa]	[kg/m^3]
1630	6930	21	2230

During designing the vehicle model the geometry of object has been simplified. Only these elements have been remained which may matter during the action of the blast wave arising from the mine detonation. The number of finite elements has been limited by circa 3 500. Then the concentration of finite elements net has been made in the area exposed to the greatest load (Fig. 2).

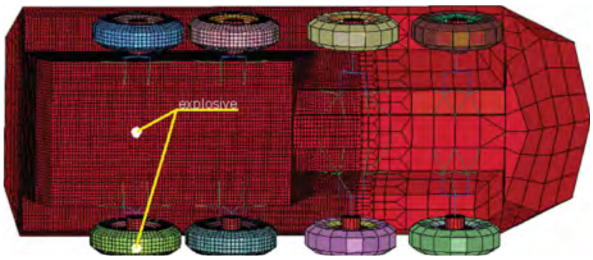

Fig. 2. The finite elements net of vehicle with places adequate to location of explosives

Body, tower, tires and elements of wheels have been described by the finite elements of coat type. The suspension system has been simplified and modelled by beam elements. The engine block has been described with the aid of solid elements. The air inside tires has been characterized with the aid of the perfect gas model under adequate pressure. The material of the body has been described with the aid of the model of bilinear elastic-plastic body with plastic consolidation and the data adequate to armour steel [5]. The simplified suspension system has been modelled with the aid of finite elements of discrete type. The non linear properties of spring and suppressor have been taken into account. The vehicle model constructed has been put on the numerical test in order to eliminate errors and inaccuracies.

3. Calculation results

The destructions in the vehicle in the case of mine detonation under the wheel have been presented in Fig. 3. The destruction of the tire and deformation of the wheel band under which the explosive have been situated are visible. The model has not taken into account the mass inserts used in a part of the military hardware. The mass inserts enable to leave from the place of event in spite of the destruction of tire. The process of vehicle body deformation due to the action of blast wave in selected time moments has been presented in Fig. 4a, and the normal speed distributions of the vehicle bottom elements have been presented on the right side of the figure.

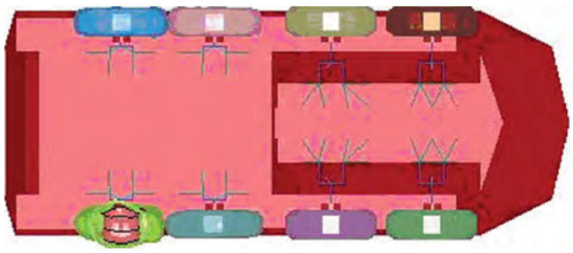

Fig. 3. Destructions due to mine detonation of 2 kg weight. The mine have been situated 10 cm under ground surface, under back wheel

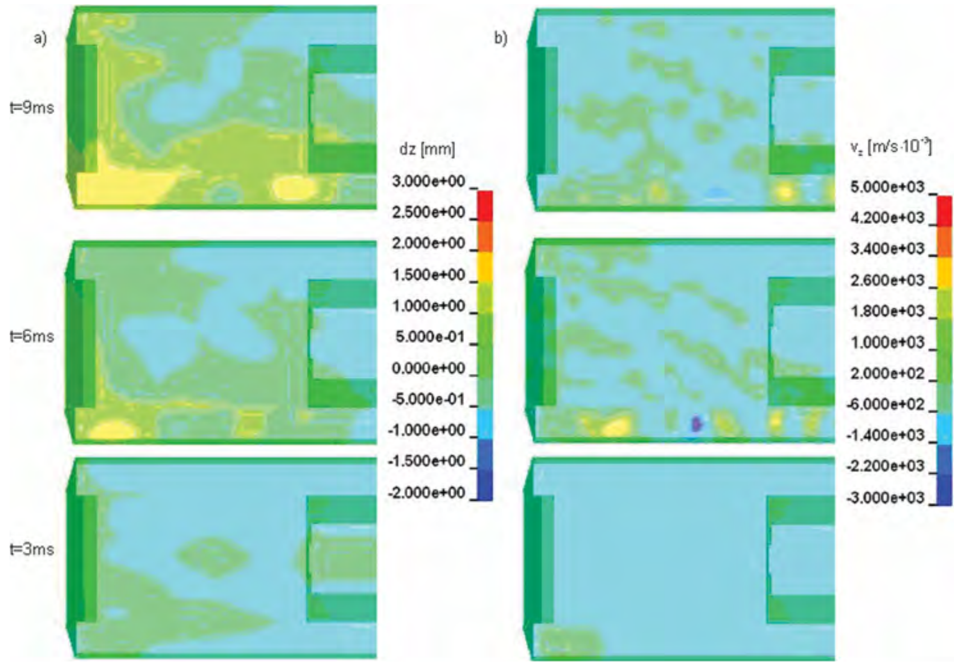

Fig. 4. Vertical component of displacement (a) and vertical component of speed (b) of vehicle bottom elements due to mine detonation of 2 kg weight. The mine have been situated 10 cm under ground surface, under back wheel in time moments chosen

The vehicle bottom elements speed (3-5 m/s) is enough to make a few injuries of down parts of legs.

The deformation levels of the object under examination (Fig. 5a) and the normal speeds of the chassis elements (Fig. 5b) change completely in case of mine or IED detonation situated under vehicle. The lack in possibility of free propagation of blast wave in the air causes this difference principally. In consequence the action of wave on the vehicle body is longer and more intensive. As result of it the speeds and deformations of elements of the vehicle under examination are much higher.

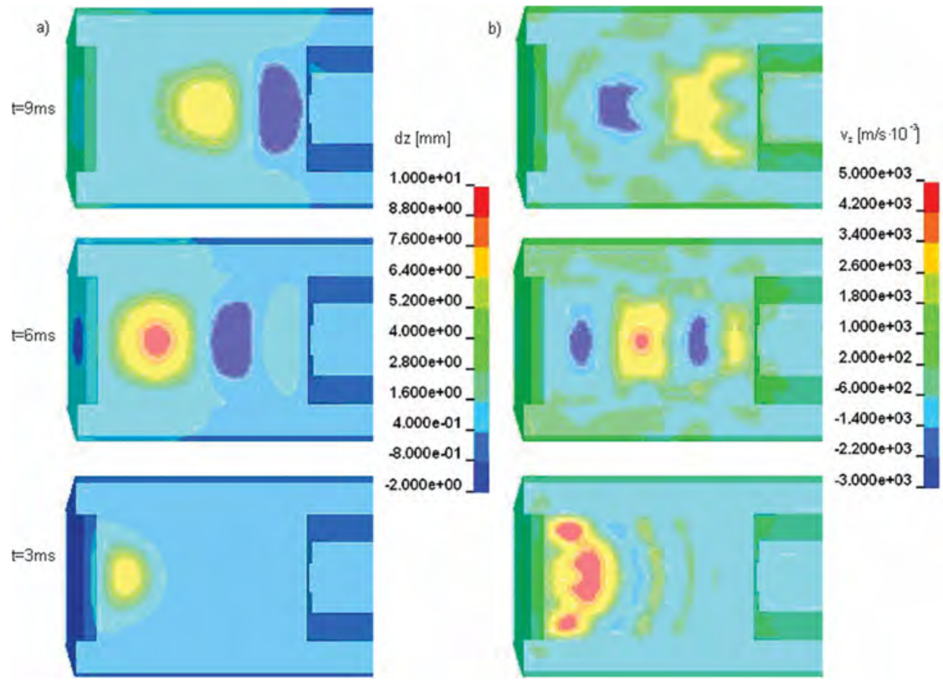

Fig. 5. Vertical component of displacement (a) and vertical component of speed (b) of vehicle bottom elements due to mine detonation of 2 kg weight. The mine have been situated 10 cm under ground surface, on the symmetry axis of vehicle under the axle of back wheels in time moments chosen

4. Recapitulation and conclusions

The results of simulation of pressure wave action arising from a little mine or IED of 2 kg weight on light armoured vehicle have been presented in this paper. Two cases of mine location have been examined: under vehicle wheel and on summitry axis of vehicle bottom.

The mine detonation under vehicle wheel causes its destruction. The almost free possibility of propagation of detonation products and pressure wave causes only small deformations of vehicle body. There is other situation in case of mine detonation under vehicle. In this case the deformation in the places exposed most of all to the ware pressure action has been five times higher and the speed circa three times higher.

This behaviour of vehicle bottom exposed to dynamic loads does not cause a threat for life of soldiers, but may cause many contusions (shell-shocks) of legs of soldiers which are (excluded) from later (subsequent) fights. The longer and most intensive action of pressure wave on vehicle body causes it.

One should notice that we have examined the impact of action of pressure wave arising from detonation of mine relatively small. In case of detonation of mine of higher weight the deformations and the speeds will be much higher. The greater mines may cause the destruction of vehicle killing the crew.

In the paper the heavy impact of location of explosive on effects has been shown. Therefore the vehicles should be equipped with a deflector (V-shaped bottom). In order to improve the security level against mines you may also use energy-consuming panels on the vehicle bottom as an additional (supplementary) layer.

Acknowledgements

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