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NUMERICAL ANALYSIS OF MINE BLAST ACTION ON A VEHICLE

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Abstract:

The main objective of the present research is development of a preliminary numerical model of dynamics and possible damage of a vehicle under the action of blast wave generated by the activation of a landmine. Such a model should provide a valuable insight into complex phenomena accompanied by detonation of a mine – pressure distribution in time, vehicle motion, damage, etc. Numerical simulation has been performed using Abaqus/Explicit, FEM-based software suitable for nonlinear processes with high strains, strain rates and energy densities, which is typical for explosion effects. A representative case study of an explosion of 8 kg explosive substance Composition B was analyzed. The explosion takes place under a vehicle with the mass of 8 tons, with specific V-shaped body consisted from 10 mm thick armor steel plates. The numerical model based on usage of Abaqus build-in CONWEP blast relations is described. The results obtained show the displacement, and stress-stain field in the loaded vehicle, on the basis of which the degree of damage to the target structure can be predicted. The guidelines for the further work and model improvement are suggested.

Key words: landmine, explosive device, detonation, blast, vehicle

1. Introduction

It is known that commercial vehicles, as well as light armored vehicles and their passengers, are very vulnerable to the demolition of the mine explosion. The development of a mine protection system, whose main goal is to reduce the sensitivity of vehicles and passengers, usually involves a large number of experimental tests. The use of experimental testing is generally expensive, requires a lot of time and involves destruction of testing vehicles. Consequently, the use of appropriate engineering computer analyzes and simulations should contribute to significant cost reduction. In the last few decades, great progress has been made in modeling of detonation, dynamic behavior of materials, and ballistic interactions between detonation products and the structure of a vehicle. These models are usually created by coupling Eulerian and Lagrangian approach in treatment of computational mesh [1-6].

Anti-tank (or more general anti-vehicle) mines can disable heavy vehicles or completely destroy lighter vehicles. The most common form of anti-tank mine is an explosive mine that uses a large quantity of explosives to directly damage the target. Unlike standard mines, improvised explosive devices (IED) can be of different sizes, shapes, types, and based on various technical solutions, and therefore the problem of their description and modeling increases. Explosives, especially mines, pose a major threat to armored vehicles. The increase in the number of attacks by IED in the last decade brought a large number of victims and the need to increase vehicle protection. An explosion is an extremely complex process, because changes of physical quantities take place quickly in space and time. An explosion is a continuous event that takes place over a relatively short period of time (usually several hundred ms).

In order to achieve greater survival of the passengers by reducing the acceleration that affects them, a lot of efforts have been made to direct the explosion products away from the vehicle. Geometry of V-shaped hull allows more explosion energy to be routed away from the vehicle, and therefore a lower vertical impulse is transmitted to the vehicle. In the case where it is not possible to simply introduce a V-shaped hull due to the height and problems that can arise with the control, it is possible to introduce "double V-shape". In this case, instead of blasting exclusively on the exterior of the vehicle, one part of the explosion is directed towards the center of the explosion. A flat hull offers a high degree of mobility and load capacity, but does not provide enough blast protection.

2. Definition of the problem and numerical model

Principles of numerical approach to the problem of mine blast loading of a vehicle will be demonstrated using a representative example illustrated in Fig. 1. Typical vehicle structure is consisted from a V-shaped hull and the upper structure which will be termed as the "cabin".

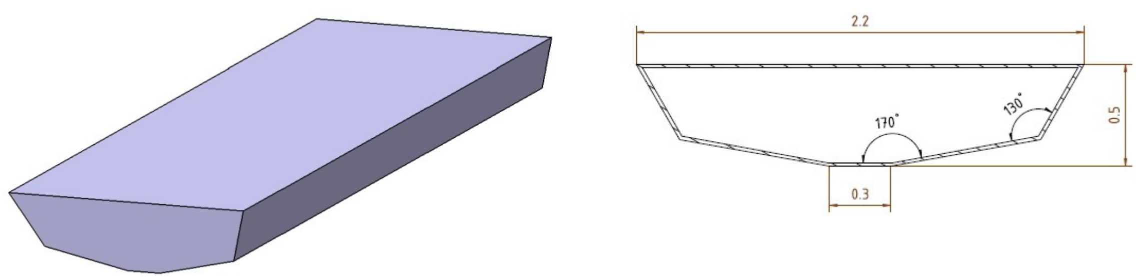

Figure 1. 3D model of the V-shaped hull and geometry used in numerical model

The problem analyzed here can be summarized as follows: A vehicle of a total weight of 8000 kg is exposed to the explosion action of 8 kg explosive Composition B, which consists from 60% hexogen (RDX) and 40% of trinitrotoluene (TNT). The vehicle has two main parts - the cabin with mass of 6 t and a V-hull of mass 2 t. These figures are typical for a representative V-shaped hull armored vehicles. The V-shaped hull is made of 10 mm thick plates of Hardox 400 steel. The position of the explosive charge is 0.6 m bellow the center of the vehicle.

The effect of the mine explosion on the target structure is analyzed using the overpressure function according to an empirical model, known as "CONWEP". To use this approach, one needs to know the following information on explosive charge: mass, position and TNT equivalent (TNT mass that will give the same explosion performance as the real mass of the explosive used). For explosive Composition B, the relevant data are shown in Table 1.

Explosive	**Density (g/cm³)**	**Detonation velocity (m/s)**	**TNT equivalent factor, q_{TNT}**
Composition B, 60% RDX + 40% TNT	1.751	8000	1.148

Table 1. The main properties of Composition B used in the numerical model

TNT equivalent W represents the mass of TNT which provides the same amount of released energy as the mass of the used explosive. The equivalent mass of TNT W corresponding to the mass of used explosive M_E is determined as:

$$W = q_{\mathrm{TNT}} \cdot M_{\mathrm{E}} \tag{1}$$

Based on eq. (1) and data from Table 1, the equivalent mass of explosive substance Composition B can be simply calculated:

$$W = q_{\mathrm{TNT}} \cdot M_{\mathrm{E}} = 1.148 \cdot 8 = 9.184\,\mathrm{kg} \tag{2}$$

Very important parameter for calculation of blast effect is scaled distance from the center of explosion, which is defined as:

$$Z = \frac{R}{W^{1/3}} \tag{3}$$

where R is the actual distance from the center of explosion.

For example, if a real distance from the center of explosion is assumed to be 1 m, it is obtained that the scaled distance from the center of explosion is $0.478\ \mathrm{m/kg^{1/3}}$, according to the eq. (3).

The overpressure produced by the rapid expansion of detonation products can be determined by different empirical relationships, which are explained in detail in [7]. One of empirical formulas that is excessively used is Henrych's equation:

$$p_{\max} = \begin{cases} \dfrac{14.072}{Z} + \dfrac{5.540}{Z^2} - \dfrac{0.357}{Z^3} + \dfrac{0.00625}{Z^4}, & 0.05 < Z \le 0.3 \\ \dfrac{6.193}{Z} - \dfrac{0.326}{Z^2} + \dfrac{2.132}{Z^3}, & 0.3 \le Z \le 1 \\ \dfrac{0.662}{Z} + \dfrac{4.05}{Z^2} + \dfrac{3.288}{Z^3}, & 1 \le Z \le 10 \end{cases} \tag{4}$$

For previously determined scaled distance of 0.478, it can be calculated from eq. (4) that the value of the overpressure in free air is 49.2 bar.

In the presence of a rigid obstacle, it can be shown that the value of overpressure behind reflected normal shock wave can be expressed as:

$$p_{\mathrm{r}} = 2 p_{\max} \frac{7 p_0 + 4 p_{\max}}{7 p_0 + p_{\max}} \tag{5}$$

In the present study, the option in Abaqus for calculation of overpressure on a part of designated surface using this simplified empirical model (CONWEP) is used for simulation of explosive loading on a vehicle. The target structure is modeled with common 3D homogenous finite elements, as well as with elements of continuum shell type (Fig. 2). In the analysis, the cabin was considered to be relatively rigid, i.e. it is not a subject of significant plastic deformation, and the main objective is to analyze the behavior of the V-shaped hull section.

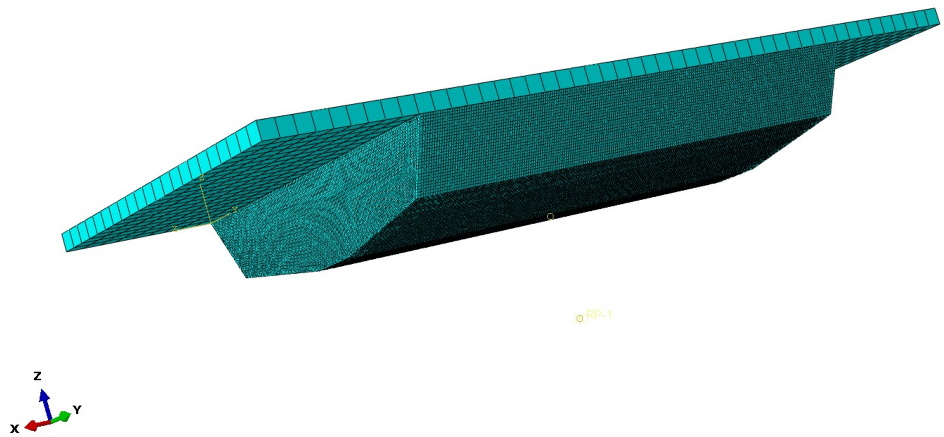

Figure 2. FEM model of the vehicle and center of explosive charge

3. Results and discussion

In this section the main results obtained by numerical simulation will be presented, especially concerning the deformation of the target structure.

Figure 3 shows a spatial change in the position of the vehicle material (steel) from the initial position to the final moment after detonation. Material displacement is indicated in legend. The degree of deformation of the target structure is clearly visible. From the simulation results, it is clearly noticed that after the detonation, which acts on the vehicle with the V-shaped hull of the geometry shown in Fig. 1, the target structure is deformed, but there is no fracture and destruction of the V-shaped hull. As the model is made so that the explosive material is in the central position in relation to the vehicle, it is clear why the greatest deformations can be seen in the middle of the V-hull, as shown in Fig. 3.

Figure 4 shows the distribution of the von Mises stress on the vehicle body surface for four different moments after detonation. From this figure, it is noted that in the central part of the V-shaped hull the greatest stress is obtained immediately after detonation, and after a certain time the pressure is distributed over the surface of the V-shaped hull (target structure). Also, from this analysis, it can be concluded that the vehicle velocity initially has a sudden increase, reaches its maximum value, and then gradually decreases under the influence of gravity. Acceleration reaches a maximum much earlier than speed, and then rapidly decreases, resulting from the transfer of a pulse to a vehicle under the influence of an explosion.

At the end of this section, it should be mentioned that significant improvement of the model is still possible. Advanced treatment of material fracture, mesh improvement, modeling of blast wave and fluid-structure interaction in coupled Eulerian-Lagrangian analysis are some of directions of future work in this field.

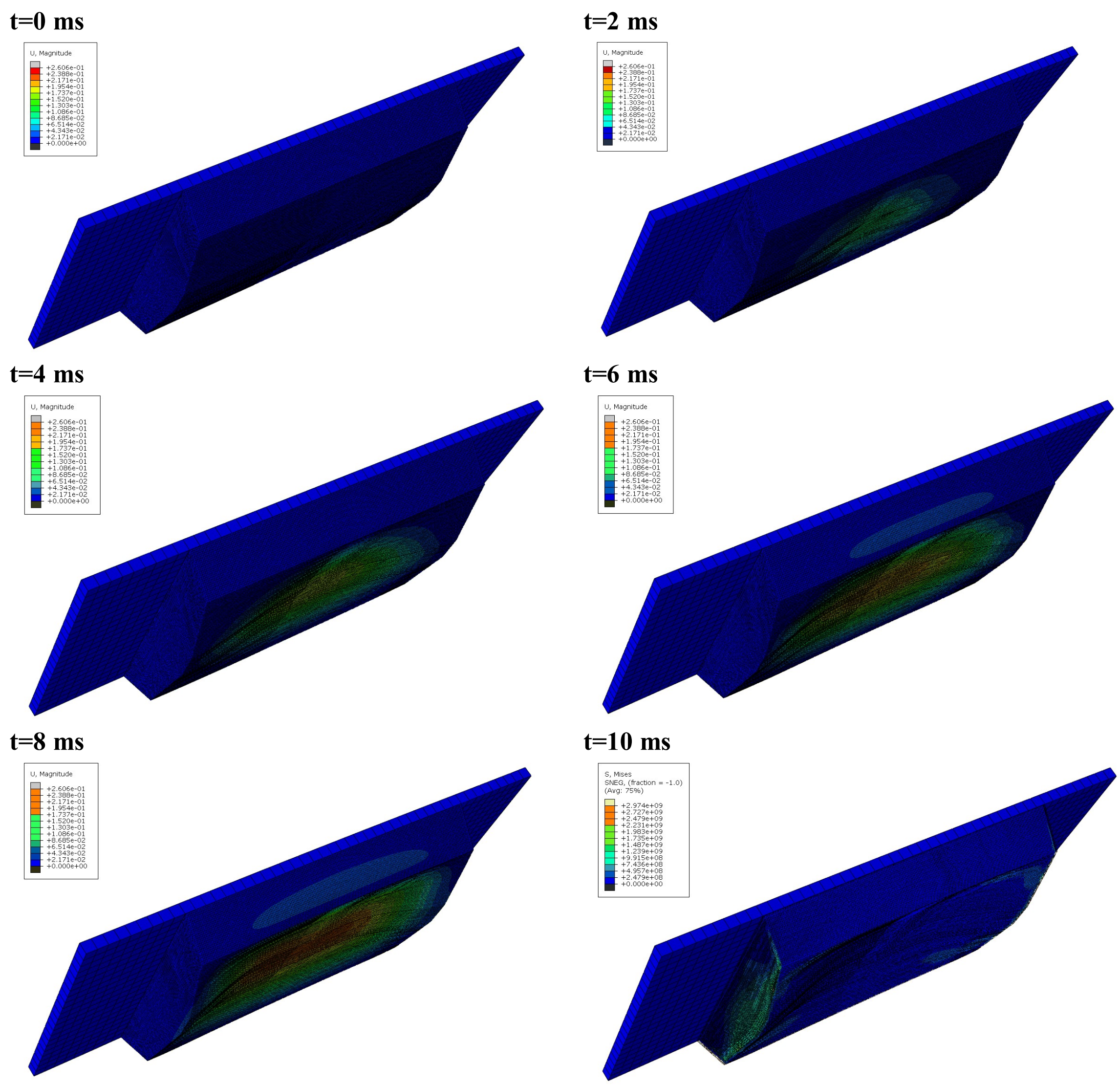

Figure 3. Evolution of vehicle material position after the mine detonation in terms of material displacement in six moments

3. Conclusions

The main objective of this paper is to point out a possible solution to alleviate the degrading effects of mines on the armored combat vehicle. In introduction, a brief overview of the impact of anti-tank mines on a vehicle is presented.

The following section describes the problem that is being analyzed and the relations used for analysis within the "CONWEP" model are presented. The properties of the explosive used in this analysis are given. Also, the model for calculation of overpressure is shown, and typical values are presented. The developed numerical model is briefly explained.

The numerically obtained results are presented concerning the deformation of the target structure, as well as the spatial distribution of pressure over the V-shaped hull surface. The obtained results show that the V-shaped hull of the analyzed geometry has a favorable effect on the reduction of the impact of mine detonation, i.e. to reduce the impulse transfer to the target vehicle.

The analysis shows that in the case of the adopted geometry and detonation of 8 kg of Composition B there will be no fracture of the V-shaped hull, and thus there is no damage of the floor of the cabin. However, this important conclusion should be tested with improved numerical model, and finally by experimental approach.

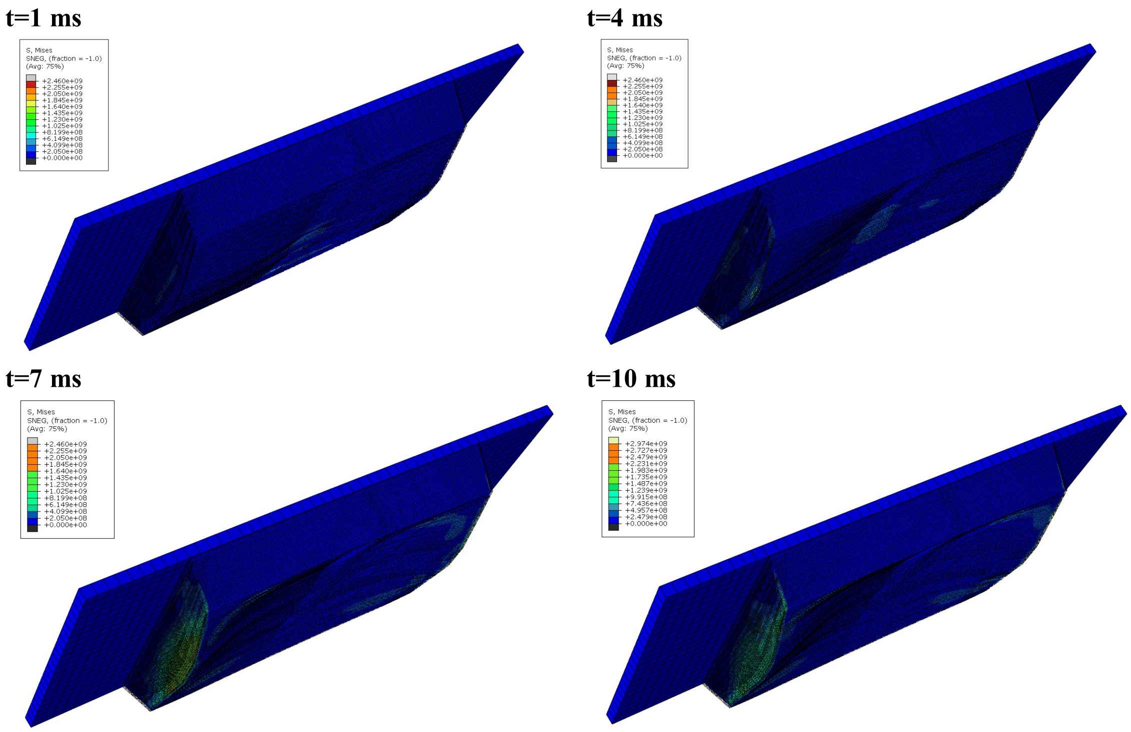

Figure 4. Evolution of von Mises stress in loaded structure – 1 ms, 4 ms, 7 ms and 10 ms after detonation of the explosive charge

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