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Evaluation of Plate Structure Response to Buried Explosive Charges

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Abstract. An interaction of the blast pressure wave after detonation of a burried mine under the multilayer mine protection mounted to the bottom of a vehicle is described in this paper. The main focus was applied to absorbing capability of the multilayer sandwich. Results from numerical simulations were compared with experimental tests. The test procedure is provided according to STANAG 4569/AEP-55 standard with threat level 3B.

Introduction

A reasonable protection level against many ballistic threats can be achieved by using simple rules. But in the case of blast and landmine protection this is not possible since there are many parameters playing a role as important as the material or the landmine charge: the distance between the vehicle and the landmine, the landmine burial conditions, the vehicle's plates boundary conditions…etc. Therefore it is very difficult to design an optimised protection configuration for a given case. On the other hand, the experimental approach has also many problems. While armour design to defeat a given projectile can be performed by testing a few plates, in the case of blast protection full scale testing is necessary. That means actual vehicle testing (and destruction) or at least full scale mock-ups testing. Obviously, such testing is very time and money consuming, thus protection design based exclusively on experimental tests is not affordable. Therefore the numerical approach appears as the most suitable one. Although the experimental work can not be fully avoided, it can be considerably reduced. One reasonable approach could be to perform simple experimental tests to adjust the numerical parameters needed for the simulations besides an extensive numerical simulation work to optimize the protection. Finally, only a few full scale experimental tests for verification and for comparison between the best proposals would be performed to confirm the results.
Another issue where the numerical approach becomes very helpful is the occupants' safety analysis. When analysing landmine protection, although many injury causes can be found in the literature, depending on the authors (see for example [1-3]), all of them can be classified into three major categories: overpressure inside the vehicle, accelerations suffered by the occupants and debris and loose objects ejection during the explosion. The overpressure can be avoided by ensuring the vehicle integrity. However, occupants protection against the two other threats requires further analysis and numerical simulations arise as a helpful tool for such purpose.

When facing the accelerations problem, the DRI index is one of the preferred tools. This index was first developed for the study and design of ejection seats on the aircraft industry and is related with the maximum deflection measured in a simple onedimensional oscillator model, whose frequency and damping parameters are set to approach the thora-columbar spine behaviour of the human body subjected to a sudden vertical acceleration. The DRI is obtained as:

$$DRI = \frac{\varpi^2 Z_{\max}}{G} \quad , \tag{1}$$

where ω, is the angular frequency of the oscillator, G the acceleration of gravity and Z_{max} the maximum deflection of the oscillator given by:

$$\frac{d^2 Z}{dt^2} + 2\varsigma\varpi \frac{dZ}{dt} + \varpi^2 Z = a(t) \quad , \tag{2}$$

where ů and ć are the angular frequency and the damping coefficients respectively (having values of 52.9 s-1 and 0.224 respectively), *Z* the spine deflection and *a(t)* is the vertical acceleration history suffered by the occupant. More detail information about the DRI can be found e.g. in [3].

Experimental Details

A case of 8 kg and 6 kg TNT cylindrical landmine explosion has been investigated through both experiments and numerical simulations. The landmine studied was buried in sand (100 mm below the sand surface) and square plate (dimensions 1 000 x 1 000 mm) clamped on two opposite sides was situated above the sand (at height of 450 mm). View on the experimental set up is shown in the Fig. 1.

Fig. 1. Experimental equipment – stand and testing plate.

During the experiments, dynamic and static plate deformation was monitored at the centre of the plate.

The following problems have been studied:

A) Charge (8 kg), composite target: 8 mm ARMOX 440T/30 mm air/ 12 mm ARMOX 440 T.

B) Charge (8 kg), composite target: 8 mm ARMOX 440T/30 mm air/ 12 mm ARMOX 500 T.
C) Charge (8 kg), composite target: 8 mm ARMOX 440T/30 mm of balsa (fibres parallel to the plate surface)/ 12 mm ARMOX 500 T.
D) Charge (8 kg), composite target: 8 mm ARMOX 440T/30 mm of balsa (fibres perpendicular to the plate surface)/ 12 mm ARMOX 500 T.
E) Charge (8 kg), composite target: 8 mm ARMOX 440T/30 mm of aluminium honeycomb (cell size about 6 mm, density of 92 kg/m^3)/ 12 mm ARMOX 500 T.
F) Charge (6 kg), composite target: 600 of the steel ARMOX 440 T/40 mm of the air/ 6 mm of the steel ARMOX 500 T.
G) Charge (6 kg), composite target: 600 of the steel ARMOX 440 T/30 mm of the balsa (fibres parallel to the plate surface)/ 6 mm of the steel ARMOX 500 T.

The charge of 8 kg TNT has a form of a cylinder (270 mm in diameter, 90 mm in height). The same diameter to height ratio was used for the 6 kg TNT cylindrical charge (250 mm in diameter, 70 mm in height).

Numerical Model

The main problem in the use of numerical simulation of the plate loading by the blast wave consists in the description of the behaviour of the explosive, sand, air and single component of the targets.

For the TNT charge, the JWL equation was used.

$$p = A\left(1-\frac{\omega}{R_1}\frac{\rho}{\rho_o}\right)e^{-\frac{R_1\rho}{\rho_o}} + B\left(1-\frac{\omega}{R_2}\frac{\rho}{\rho_o}\right)e^{-\frac{R_2\rho}{\rho_o}} + \frac{\omega E\rho}{\rho_o} \tag{3}$$

The parameters of this equation can be found e.g. in our previous paper [4]. The detonation point was supposed to be at the centre of charge surface.

For the sand, the material type 147 was used. This is an isotropic material model with damage. It has a modified Mohr-Coulomb surface to determine the pressure dependent peak shear strength. The model is discussed in [5] in details.

For the steel, the Johnson-Cook constitutive model was used.

$$\sigma = \left(A + B\varepsilon^n\right)\left(1 + C\ln\dot{\varepsilon}\right)\left(1 - T^{*m}\right) \tag{4}$$

The parameters of this equation can be found e.g. in [6]

For the air, the ideal gas state equation was used. The balsa has been considered as orthotropic material. The behaviour of the honeycomb material has been described in terms of model used in LS DYNA .The sand has been described as a fluid with a bulk modulus K and limit pressure p_k in terms of model *MAT_ELASTIC_FLUID* [6]:

ρ_0 = 1560 kg/m^3

K = 13.75 MPa

p_k = 0.0 MPa

The numerical simulation was performed using of the LS-DYNA3D 970 [7] code . An *Arbitrary Lagrangian-Eulerian* (ALE) mesh was used for both explosive load and air, while *Lagrangian* meshes were used for all the vehicle parts. Both kind of meshes (ALE and *Lagrangian*) were coupled by using the so called *Fluid Structure Interaction* technique.

Results and Discussion

The geometry of the solved problem is shown in the Fig. 2:

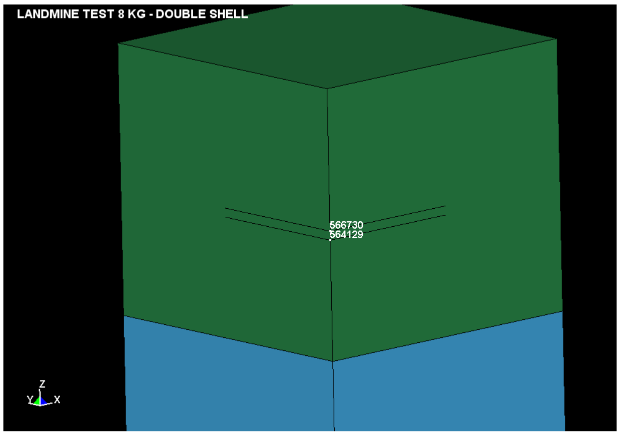

Fig. 2. Schematic of the numerical model.

In this Figure the two points are denoted. The point with the lower number is denoted as position one. The next point is called as the position two.

In these points the displacement, velocity and acceleration as functions of the time have been evaluated. The displacement increases up to some nearly constant value. The velocity exhibits a peak at the beginning. Results for the all versions are shown in the Fig. 3.

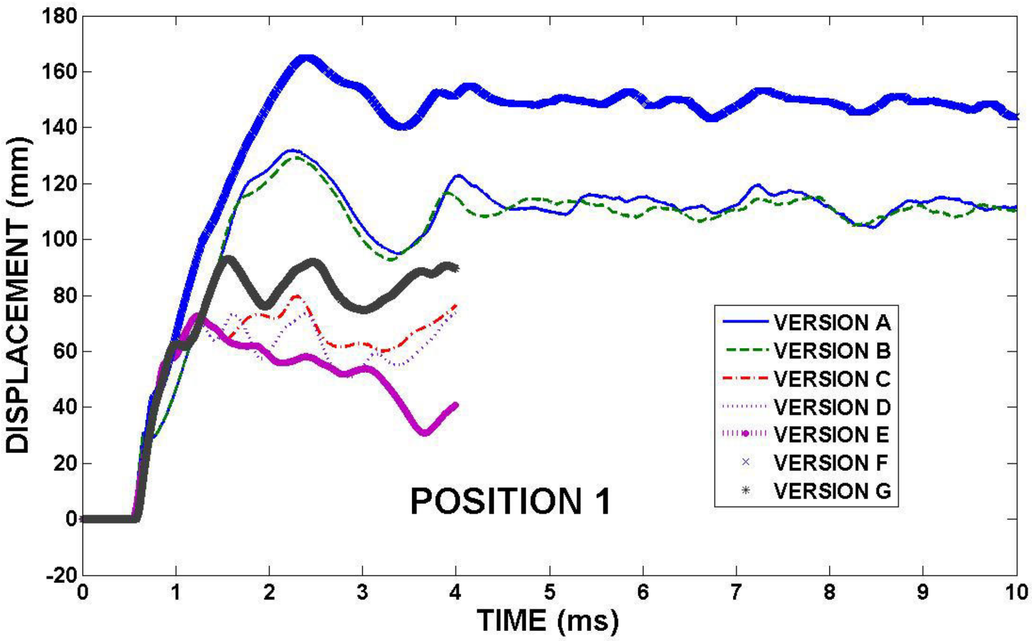

Fig. 3. The displacements for the single versions of the targets.

The difference between maximum of target deflection obtained experimentally and from the numerical analysis was lower than 13 %. It means our material models and their parameters are reliable and they can be applied for the numerical simulation of some other structures including the whole vehicle.

The survey of the velocities and acceleration are shown in the Figs. 4 -5.

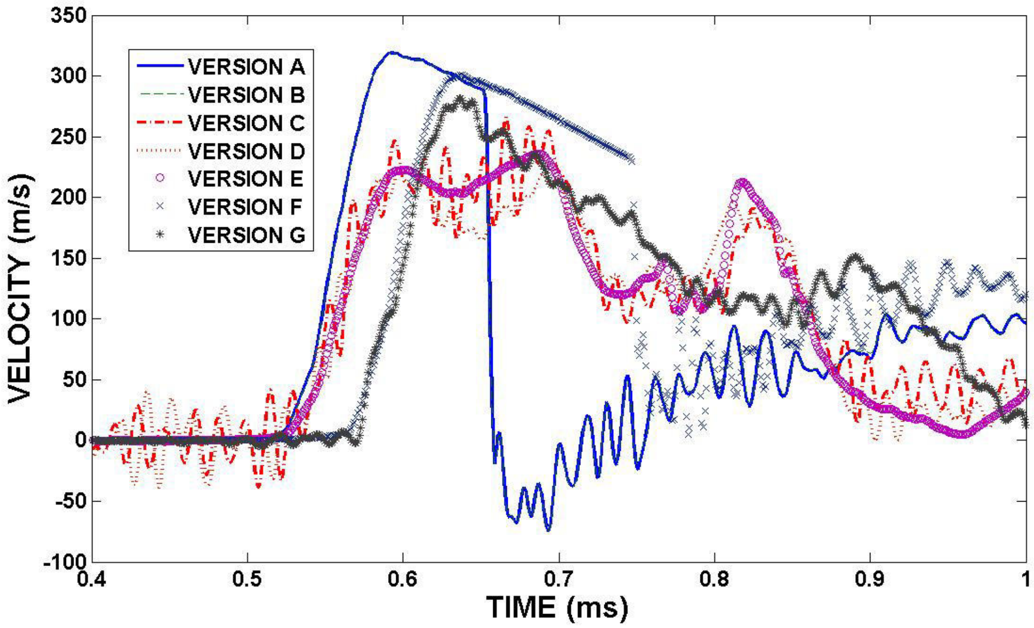

Fig. 4. Velocities found for the different versions.

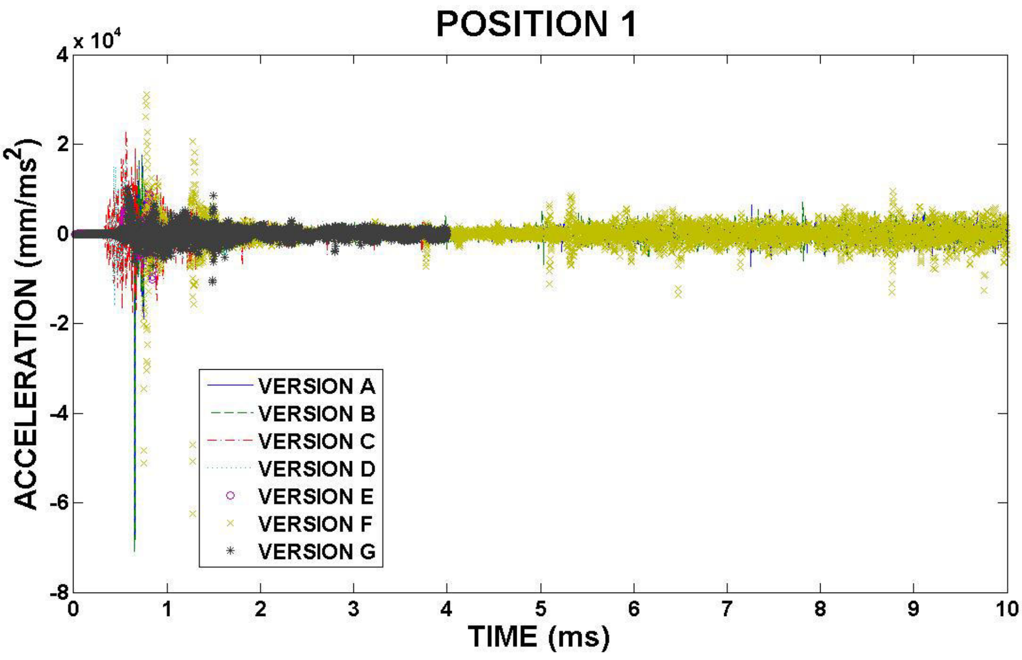

Fig. 5. Accelerations found for the different versions.

The peak values of the velocities and accelerations are displayed in Figs. 6 and 7.

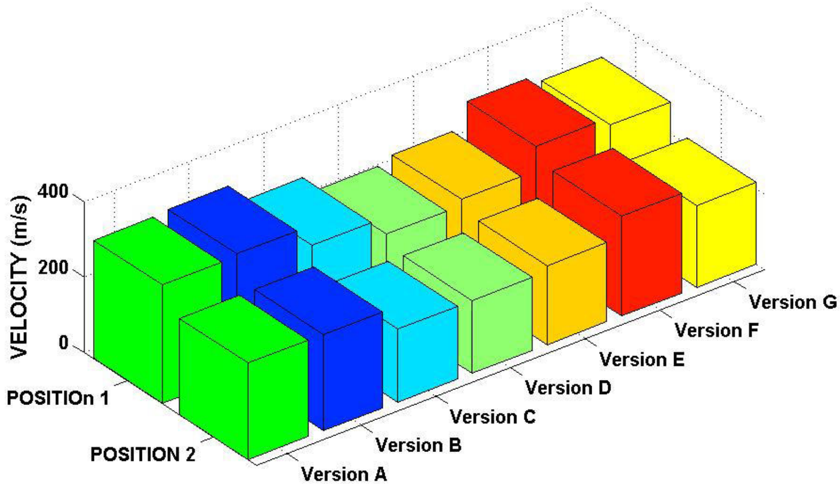

Fig. 6. Peak values of the velocities.

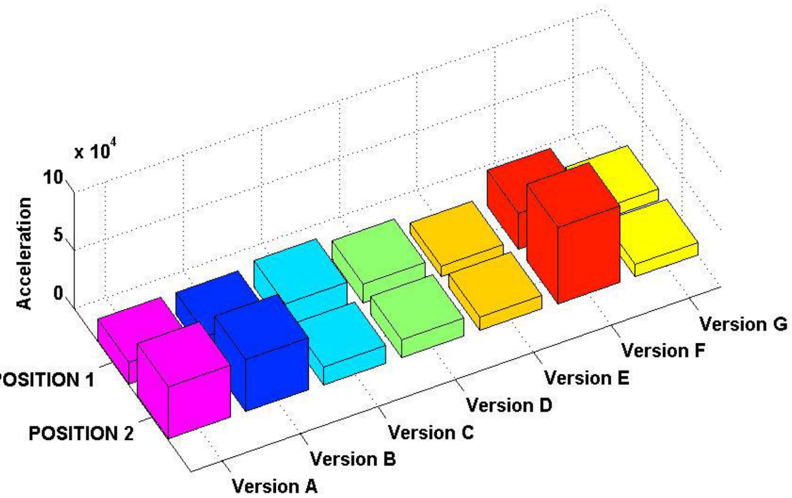

Fig. 7. Peak values of the accelerations.

Namely the vulnerability of human occupants is caused by the acceleration – see Eqs. (1) and (2). This quantity is then used for the evaluation of the targets efficiency.

Conclusions

Results of this work show the reliability of material parameters in the numerical simulation of the mentioned mine test.

The obtained numerical results also have shown that the best efficiency against mine explosion can be expected for the following targets:

- Version C: charge (8 kg), composite target: 8 mm ARMOX 440T/30 mm of balsa One of objectives of this work was to validate material parameters and numerical simulation setup that is able to describe mentioned mine test. (fibres parallel to the plate surface)/ 12 mm ARMOX 500 T.

- Version D: charge (8 kg), composite target: 8 mm ARMOX 440T/30 mm of balsa (fibres perpendicular to the plate surface)/ 12 mm ARMOX 500 T.
- Version E: charge (8 kg), composite target: 8 mm ARMOX 440T/30 mm of aluminium honeycomb (cell size about 6 mm, density of 92 kg/m^3)/ 12 mm ARMOX 500 T

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