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COMPARATIVE NUMERICAL ANALYSIS OF AN ARMOR PLATE UNDER EXPLOSION

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Abstract: *This paper presents, in a very synthetic manner, some aspects regarding developing of the blast wave calculus. So, essential aspects are presented starting with experimental formulas and finishing with the newest numerical procedures. These procedures are used for numerical analysis of the behavior of some armor plates. The armor plates are made in many constructive solutions, depending on the aim. Our work is referring to the behavior of the armor plates under explosion, especially the behavior of the armor personnel carrier plates under mine explosion. Two constructive solutions are analyzed and compared with the plane armor plate. Finally, this work presents numerical solutions, models and conclusion which can be used for the improving of the protection against mines, available for armor personnel carrier as well as for others structures having such requirements.*
Keywords: *blast wave, armor plate, explosion effects, blast wave parameters*

1. INTRODUCTION

Calculus of the blast wave effects upon structures and as well as the blast wave parameters is a problem of a large theoretical and practical interesting, especially in the last twenty years. Probably, the interesting for the calculus of the blast wave effects upon structures and human beings started just together with the first explosions used in military aims, but in a real and consistence sense, the interesting of the researchers began after the Second World War (WW2); the terrorist threats, of the last twenty years, determined an intension of the researching, using specially experimental and numerical methods.
The vulnerability of the light armored vehicles as well as of the personnel to the blast mines is studied by all researching ways. Such studies involve an improving of the calculus, but in the same time, an improving of the constructive solutions of the armor plates. This aspect is referring to the materials, but in the last time, different shapes and constructive solutions are taken into account.
This paper presents, in a very synthetic manner, some aspects regarding developing of the blast wave calculus. A numerical study of a new constructive solution is carried out and the results are presented in a comparative way with respect to a common constructive solution of a plane plate having a constant thickness.

2. CALCULUS OF THE BLAST WAVE PARAMETERS

Blast wave calculus or explosion calculus is referring to two aspects, which can be solved separately or together: blast wave parameter calculus and blast wave effect calculus. Blast wave parameter calculus all times is made, but some times this calculus is not directly invocated (in some blast effect calculus). No matter the subject of calculus, the experimental way is a very necessary one, being a truth criterion. The experimental approaching ways are not presented in this paper, being a too important and a large subject.
Experimentally and analytically, determination of the blast wave profile is presented in the Figure 1, in a point at a standoff distance of the explosion initiation place [2], [3]. Friedlander first time modeled the ideal blast wave profile in 1946, but nowadays the modified Friedlander ecuation, relation (1), is mostly used.
Some notations used in relation (1) can be watched in the Figure 1; t_a is arrival time and a and b are decay parameters, being different for positive and negative pressure.

$$P(t) = P_{max}\left(1 - \frac{t}{t_+}\right)e^{\left(-a\frac{t}{t_+}\right)} + P_{min}\left(1 - \frac{t}{t_-}\right)e^{\left(-b\frac{t}{t_-}\right)} \quad (1)$$

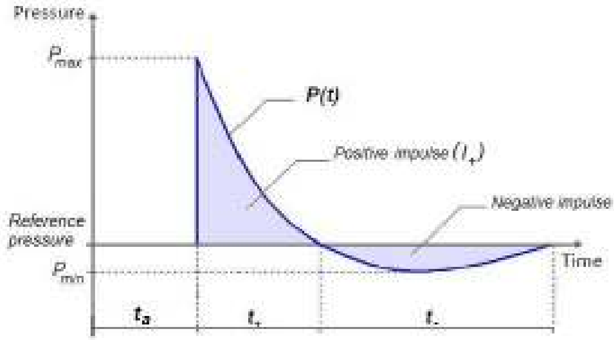


Figure 1: Blast wave profile, in time

2.1. Empirical Calculus of the Blast Wave Parameters

Almost all researchers are referring to spherical charge detonated in air, when the explosive has a spherical shape and is placed somewhere above the ground at a distance h. In the case of an explosion at ground level (surface explosion), the explosive is considered like a hemispherical charge and the parameters could multiplied with a factor grater 1 and less 2. An universal normalized description of the blast effects and parameters can be given by scaling distance Z *(Hopkinson-Cranz)* relative to the ratio:

$$Z = \left(\frac{E}{P_0}\right)^{\frac{1}{3}} \quad (2)$$

where E is the released energy [J/kg] and P_0 is the ambient pressure [Pa]. Experimentally, and from the above relation, all air blast effects and parameters follow the same scaling law, expressed by the scaled distance Z:

$$Z = \frac{R}{W^{1/3}} \quad (3)$$

where R is the is the distance [m] from the explosion point to a considered point (where the parameters or effects of blast waves are calculated) and W is the charge weight [kg]. So, the scaled distance Z is independent of the type of explosion: nuclear *(Glasstone & Dolan-1977)* or non-nuclear *(Friedlander-1946, Brode-1955, Newmark & Hansen-1961, Baker-1983, Bulmash & Kingery-1984, Mills-1987, Beshara-1994, Mays & Smith-1995, Randers-Pehrson & Bannister-1997, Henrych, Held, Kinney & Grahm, Sadovskiy, Bajic and many others)*.

The main parameters of an explosion are: peak positive over pressure (P_{pos}; P_{max}), positive duration (t_{pos}; t_+), negative (under) pressure (P_{neg}; P_{min}), negative duration (t_{neg}; t_-), wave decay parameter (b), the impulse (I) which can be referred to positive (I_+), negative (I_-) or total time period. All these parameters and others, can be referring to the incident (direct) pressure (P_i) or to the reflected pressure (P_r). By the mechanism of wave formation, the reflected pressure parameters are higher than incident pressure parameters, they occur practically instantaneously and they influence the damage characteristics of the blast wave. Practically, $P_r = P_{max}$. A very important parameter, specially for blast wave effect evaluation, is the impulse corresponding to the positive duration I_+, which has the expression:

$$I_+ = \int_{t_+} P(t)dt \quad (4)$$

Therefore, the impulse, applied on the surface unit, is defined by the area under pressure-time curve (Figure 1) on the t_+ domain. Many empirical formulas for I_+ calculus exist. One of them, by Kinney, has the form of relation (5), where I_+ [Pa*s], Z [m/kg$^{1/3}$], W [kg].

$$I_+ = \frac{0.067\sqrt{1+(Z/0.23)^4}}{Z^2\sqrt[3]{1+(Z/1.55)^3}}100 \cdot \sqrt[3]{W} \quad (5)$$

The literature [3], [4], [5] presents some nomogrames for calculus of all blast wave parameters, for those two main cases: explosion in free air and explosion on the surface.

Practically, for all blast wave parameters, empirical formulas exist and many authors exist too. For maximum pressure P_{max}, Brode proposed the relations (6) and (7).

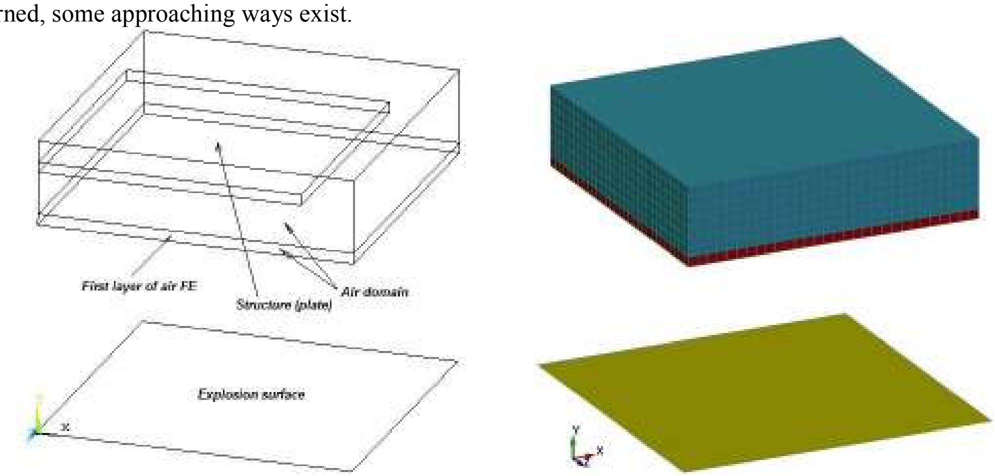
$$P_{max} = \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.85}{Z^3} \qquad 0.10 < P_{max} < 10 \tag{6}$$

$$P_{max} = \frac{6.7}{Z^3} + 1 \qquad 10 < P_{max} \tag{7}$$

All these wave blast parameters can be plotted, versus scaled distance Z or real distance R and so, a value can easily determined and some useful conclusions can be obtained.

2.2 Numerical Calculus of the Blast Wave Effects and Parameters

There are some numerical approaching ways, each of them having advantages and disadvantages regarding calculus facilities and/or spent computer time. Regardless of the way, for a right numerical modeling, adequate material models must be used. Some professional programs contain, in their material library, dedicated material models. Mat_High_Explosive_Burn with Jones-Wilkins-Lee (JWL) or Jones-Wilkins-Lee-Baker (JWLB) equations of state (EOS) for modeling of the charge, Mat_Null with Linear_Polynomial or Gruneisen equations of state for modeling of the air; these material models with their EOS are available in LS-DYNA code [6]. When the blast wave effects, upon a structure, are the aim of the numerical calculus, a properly material models for structure modeling have to be used. Next to these aspects, a maximum importance has the finite element formulation. Thus, for explosive and air modeling Arbitrary Lagrangian Eulerian (ALE) formulation is used. Structure modeling, no matter the aim study, Lagrangian formulation is used. As finite element calculus model is concerned, some approaching ways exist.



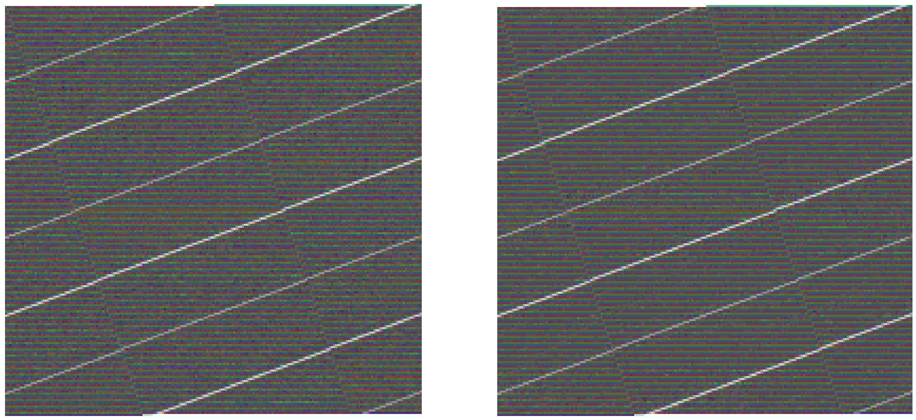
a) b)

Figure 2: Domains and FE model (1/4 simplified model)

We used the most recent way and perhaps the most efficient way, when using the procedures Load_Blast, Load_Brode or Load_Blast_Enhanced (LBE), the modelling of the charge is avoided. We also used a new concept – Multi-Material Arbitrary Lagrange Eulerian (MM-ALE) – in which the user can model the action of more material (resulting or moved by explosion), upon a structure [1]. In the Figure 2, we can see the specific domains of modelling as well as the finite element model. Taking into account the symmetry, only 1/4 of model is used (Figure 2). The air domain includes the structure, but it has smaller dimensions, being around the structure (one or more structures). The fluid-structure interaction (FSI) is modelled by a special procedure, named Constrained_Lagrange_in_Solid, available in LS-DYNA code [6].

3. COMPARATIVE NUMERICAL ANALYSIS OF AN ARMOUR PLATE

The vulnerability of light and heavy armoured vehicles to anti-vehicular blast mines is strong closed by all characteristics of the armour plate, especially of the hull or floor plate. Among all characteristics of an armour plate, an important aspect is the constructive solution of the armour plate. In this work, such a constructive solution is discussed in a comparative way.



Upper face Lower face (to blast wave)

Figure 3: Finite element model of the armour plates

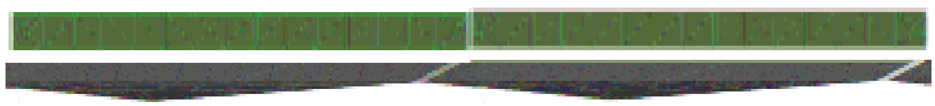


Figure 4: The side profile of those two versions of armour plates

Reference constructive solution is a plane armour plate with a thickness of 2 cm; the analysed constructive solution is represented by an armoured plate having the same maximum thickness (2 cm), but the face exposed to mine explosion has a number of pyramids. The mesh (Figures 3 and 4) was the same for both constructive solutions (made by parametric describing of the geometry). In the modelling version presented in the Figures 3 and 4, the average dimension of the finite elements (4-node tetrahedron element) is 3 cm. The height of pyramids is 1 cm and their square base is 25 cm. The finite elements of air (8-node solid element) have a cube-shaped of 2 cm dimension. The results of our numerical analysis are synthetically presented in the following figures.

4. COMPARATIVE NUMERICAL RESULTS

The results presented here are referring to a square armor plate with 1m side length, placed at standoff distance of 50 cm above an explosive (Pentolite). This charge is placed just under the plate center and at the level of soil. The numerical calculus model is presented in the Figure 2. The calculus time was the same for those two constructive solutions, namely 0.001 second. In this paper, the charge mass was 27.84 kg for whole structure (only 6.96 kg for 1/4 simplified model). The explosive was not in a spherical or semispherical shape; it was in solid brick form with dimension of 0.16x0.16x0.16 m. The armor plate was clamped on its sides.

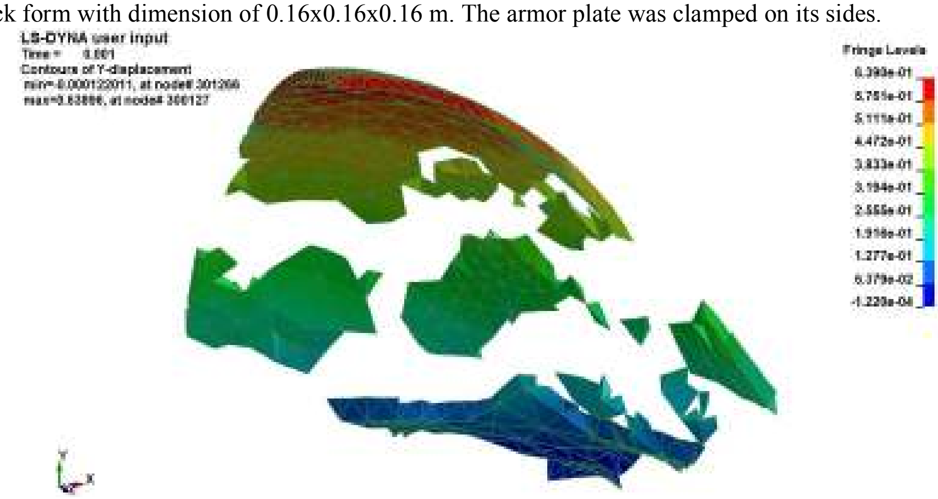


Figure 5: UY displacement for the plane armor plate

As is shown in the figures 5 to 10, the armor plate, for both constructive solutions, was broken by explosion, but some important parameters tell us which the constructive solution is better.

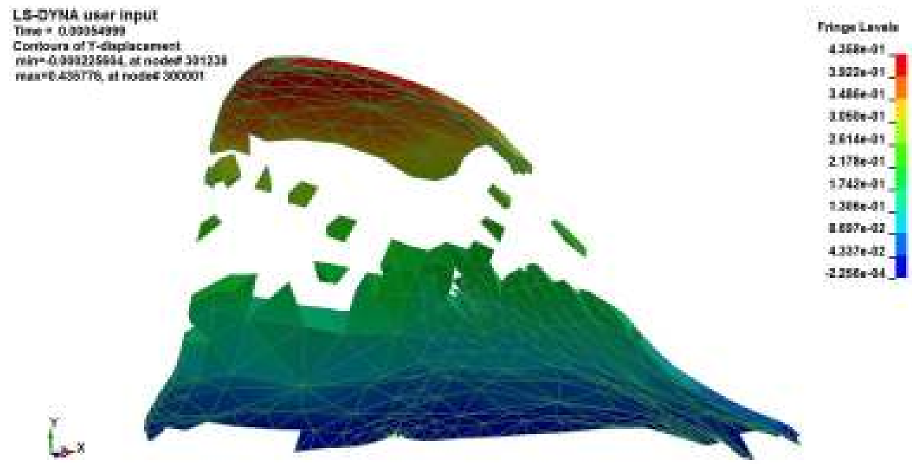


Figure 6: UY displacement for the pyramided armor plate

The studied parameters for a comparative analysis of the blast wave effect were: the maximum displacement (UY), the maximum velocity (VY), the pressure field, total energy of the plate, kinetic and internal energy etc.

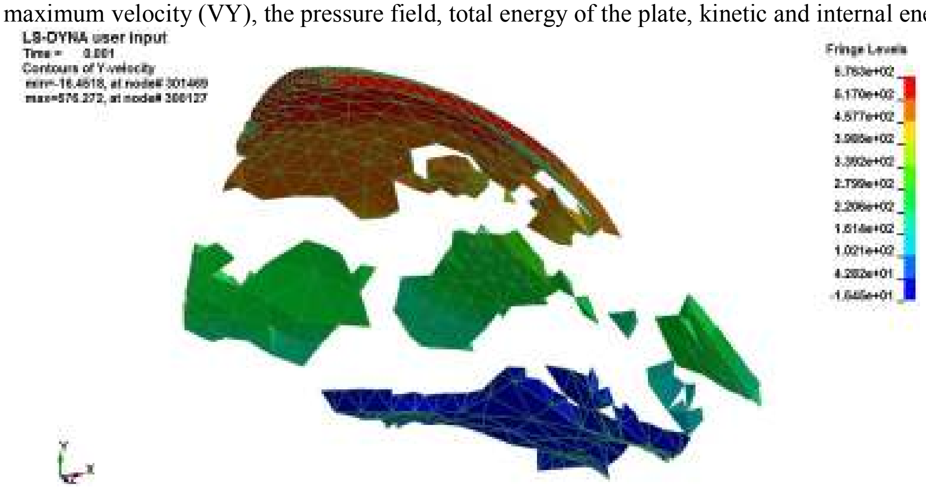


Figure 7: VY velocity for the plane armor plate

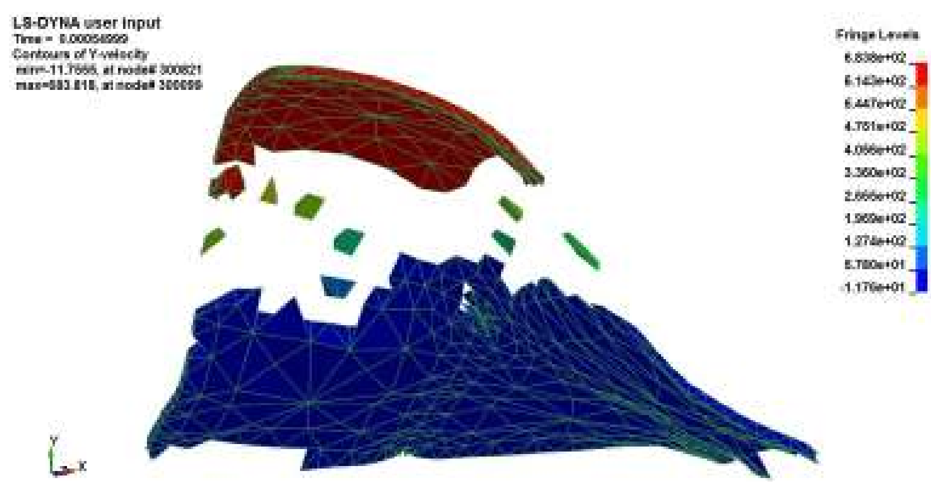


Figure 8: VY velocity for the pyramided armor plate

Our results consist in more analyzed parameters, but not of all are presented in this paper. For an easily comparing of the results, next to above presented parameters, only the pressure field is also presented in the following figures.

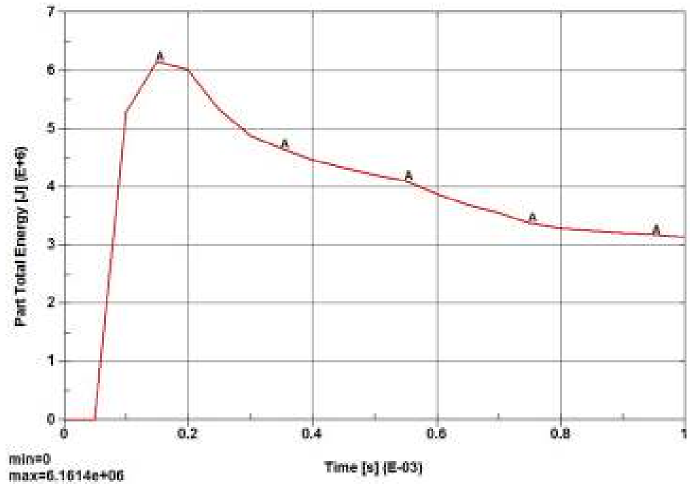


Figure 9: Total energy of the plane armor plate

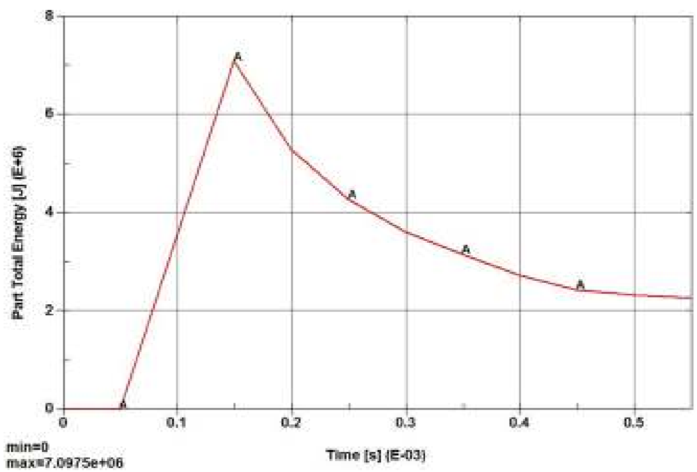


Figure 10: Total energy of the pyramided armor plate

5. CONCLUSION

The results presented in this paper clearly show that the pyramided armor plate can be o better constructive solution (comparatively with a plane armor plate) for the floor of the personnel armor vehicles and just for others parts of such vehicles. This conclusion is based on our numerical results and on our understanding of the phenomena. Therefore, if we calculate the armor plates mass, we will see that the pyramided armor plate is easier with 33%. The maximum UY displacement of the pyramided armor plate is less (31%) than maximum UY displacement of the plane armor plate, having a lower mass. This aspect can be explained by an increasing of the energy absorbing capacity (15%). The maximum VY velocity of the pyramided armor plate is greater (18%) than maximum VY velocity of the plane armor plate. The results seem to be very important and useful and we will continue our researching, including the optimizing the pyramid height.

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