ANALYSIS OF A PROTECTIVE COMPOSITE PANEL WITH ENERGY ABSORBENT IN THE FORM OF FOAMED ALUMINIUM

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Abstract

The article presents the results of the investigations into modelling a blast wave for huge charges of 1kg TNT equivalent. Modelling of huge charges is a very interesting problem due to a scale effect. During numerical analyses a detonation phenomenon was ignored (for the reason of the analysis time).

The paper considers the effects of the influence of a pressure wave coming from a huge TNT charge (modelled with energy) on a 6 mm thick steel plate as well as on a protective panel made of foamed aluminium with composite layer. A panel of foamed aluminium was used for the protection of the described plate. The particular elements of a panel, subjected to an experimental analysis, were jointed with the use of a glueing method. In the numerical model the particular component layers were jointed with contact. The ALE (Arbitrary-Lagrange-Euler) function was used for coupling between the Euler domain and the Lagrange domain. The method requires absolute location compatibility of the nodes from both jointed areas.

In the results of the conducted investigations, the permanent deformation of the steel plate was obtained.. Additionally, the possibility of the steel plate deformation evaluation was considered on the basis of accessible literature. Due to a huge charge, the analysis was performed with the use of the finite element method with the experimental verification.

***Keywords**: blast wave, analytical model, FE analysis, aluminium panel*

1. Introduction

During modelling a pressure impulse wave coming from explosion, the scale effect related to the charge size and its distance from the selected point in space is often ignored. A tenfold difference in the charge mass and in the distance from the considered point causes significant differences in the effects of the pressure impulse influence. This fact is related, among others, with the impulse duration time. In the case of bigger charges, the influence of the wave on the object is significantly longer.

The present paper aims at examining the possibility of modelling the pressure wave induced by the explosion of a huge sphere-shaped charge and its influence on a selected object. In the paper, the analysis of the above mentioned phenomenon was performed with the use of numerical methods used in MSC Dytran software [1]. The results of the presented experiments served, among others, to validate the numerical structures models loaded with a pressure impulse (blast wave). In the present paper, the explosion was modelled with the use of a point detonation model. The pressure wave, propagating itself in the air, was considered using the Euler equations of continuum mechanics and the structure, which is influenced by it, was considered using the Lagrange conservation laws. The connection between the two calculation domains (the Euler domain and the Lagrange domain) was obtained with the use of ALE coupling [1].

2. Description of an analytic approach to the phenomenon of blast wave propagation

The solution of a comprehensive question of explosive material detonation, blast wave propagation and its interaction with the structure is a very complex problem. The correct description of the process of detonation and propagation of blast waves requires not only the solution of confounding partial differential equations expressing laws of conservation of mass, momentum and energy for geometry of the considered system, but also consideration of the course of the energy releasing process – complex exothermal reactions and real properties of the considered elements. There are some well-known solutions concerning the process of pressure waves propagation in gases. The best-known one is the point detonation model developed independently by Taylor [2], Siedov [3] and von Neumann [4] assuming that at the initial moment, at the certain point the finite amount of energy is released (the influence of a charge shape and a detonation process is ignored). In later years, this theory was developed, among others, by Staniukowicz [5]. The model allows determining the distribution of pressure, density and velocity of the medium behind the front of the propagating blast wave.

Optical detonation approximation [6] (sometimes call programming burn model) and equation of state JWL [6, 7] are used in numerous publications to describe the propagation of detonation products or an empiric formula determining the pressure change of the propagating blast wave in the function of charge mass and distance from the detonation point. Optical detonation approximation depends on setting the initial values describing the explosion, such as: explosive material detonation velocity, place of explosion initiation, parameters on the front of the detonation wave (in the form of parameters at the Chapman-Jouguet point). In this approach, the detonation wave front moves with assigned, constant velocity and forms the surface of strong continuity. Due to this fact, during calculations, only cells with overreacted explosive material, through which the front has already come, can be considered. In the cells on the detonation wave front the values of pressure, density and energy (temperature) corresponding to the values at the Chapman-Jouguet point are assumed. This method allows applying huger elements enabling extension of the time step (without influencing the obtained results).

In an empiric approach the pressure changes are expressed in the function of parameter Z joining together influence of the charge mass and distance from the explosion place [8, 9, 10]:

$$Z = \frac{R}{\sqrt[3]{W}}, \tag{1}$$

where:
W - charge mass,
R - its distance from the examined object.

The approximated value of maximal pressure on the blast wave front can be determined from experimental data using the formula:

$$p = p\left(\frac{1}{Z}\right) = p\left(\frac{\sqrt[3]{W}}{R}\right). \tag{2}$$

It indicates that maximal pressure p, which is a detonation effect of a 100 g explosive charge in the distance of 0,4 m, has the same value as the pressure induced by the detonation of a 100 kg charge in the distance of 4 m. The effect of the wave action is, however, significantly greater in the other case since the pressure impulse duration time is about ten times longer [11].

Different function developments are applied in the calculations (2). One of the simplest evaluations was presented in paper [11]:

$$p = \frac{1}{2\pi} Q \frac{1}{Z^3} \approx 0{,}159 \cdot Q \frac{1}{Z^3}, \tag{3}$$

where Q - unit internal specific energy of an explosive material (for TNT 4.2 MJ/kg).

More exact approximation of pressure distribution can be obtained applying formula [11]:

$$p = \frac{a_1}{Z} + \frac{a_2}{Z^2} + \frac{a_3}{Z^3}, \tag{4}$$

where: a_1 = 82400, a_2 = 264870, a_3 = 686700 – parameters values calculated for TNT assuming that Z is expressed in m/kg$^{1/3}$. In such a case, pressure is expressed in Pascals.

In actual fact, the form of the function (2) is much more complex than it is expressed in the presented formulae (3) and (4). Pressure equivalent to action of blast wave for given parameter Z can be determined more precisely on the base of tables developed by U.S. Department of Defence [12] or solving complex models describing the explosion process considering the process of detonation initiation and blast wave propagation with the use of advanced numerical methods.

MSC Dytran software enables modelling the propagation of the pressure wave coming from the explosion on the basis of the instantaneous detonation model. In such a case, the explosion is described with the use of mass, momentum and energy conservation laws assuming that detonation of the explosive material takes place at the initial moment, and the explosive material is substituted with the sphere of hot gas of homogeneous density and determined specific internal energy corresponding to energy supplied to the system by the detonating explosive material. Such an approach is right in the case when the system is not influenced by the detonation (combustion) process of the explosive material.

3. Description of numerical models of the analysed systems

The base object model in the form of a square plate of side length 0.75 m and thickness 0.06 m was taken into consideration for the numerical investigations. The plate was placed on the frame consisted of square profile of 0.12 x 0.12 m dimensions and thickness 0.06 m. The joint between the frame and the plate edge was obtained through the elements simulating a welded joint, type PWELD. The joint parameters were selected on the base of the accessible literature. An additional frame was placed on the stiff plate described with the underformable material RIGID simulating the ground. All the panel component elements were jointed with contact.

Additionally, the same system with the panel of 50 mm thickness made of foamed aluminium was examined.

The values of material constants were selected on the base of an experiment conducted in the Department of Mechanics and Applied Computer Science, Military University of Technology.

The significant difficulty in the modelling process of particular protective layers is the right description of the Lagrange and Euler domain coupling in order to enable the influence of pressure on the construction. In the case of simple structures the simple ALE coupling model (node to node) was applied. The coupling of this type doesn’t cause the occurring of flows between the Euler and Lagrange cells.

The right description of initial boundary conditions for the explosion was an additional problem. This problem was solved through modelling the explosion as concentrated initial energy (in the shape of sphere) placed in the Euler domain.

The following assumptions concerning the blast wave source were taken into account: 1 kg TNT charge placed in the distance of 0.4 m from the examined object. The explosive material density ρ = 1520 kg/m3 and specific internal energy Q = 1520 J/kg were considered for analysis [5]. The geometrical parameters for the sphere-shaped charge were calculated on the base of the mass.

In order to obtain the pressure distribution of the blast wave generated by an explosion, the Eulerian Solid type mesh of elements were defined. The simplest state equation of perfect gas was considered for the description of both the gas (air) medium and detonation products. The centre density (for the air ρ = 1.29 kg/m3), isentropic index (γ = 1.4) and specific internal energy (Q = 193800 J/kg) are defined in this model. Fig. 2 presents the impulse of the blast wave,

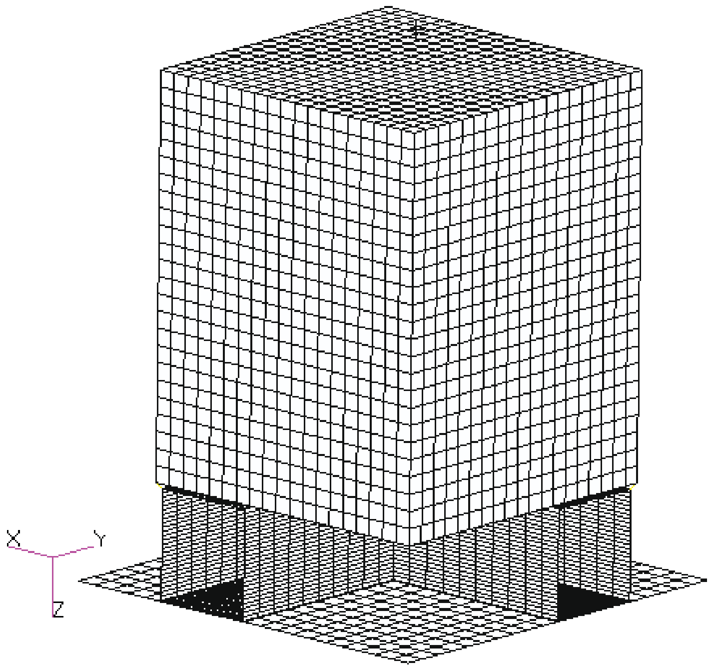

Fig. 1. A general draft of a a numerical stand model with the use of ALE coupling

reflected from the plate obtained in a numerical manner. The results obtained in a numerical manner can differ from the results obtained in an analytical and experimental manner. The difference is caused by the Euler elements size. However, comparison of energy graphs (of the Euler domain and the system described by Lagrange elements) resulted in obtaining a great agreement of the results.

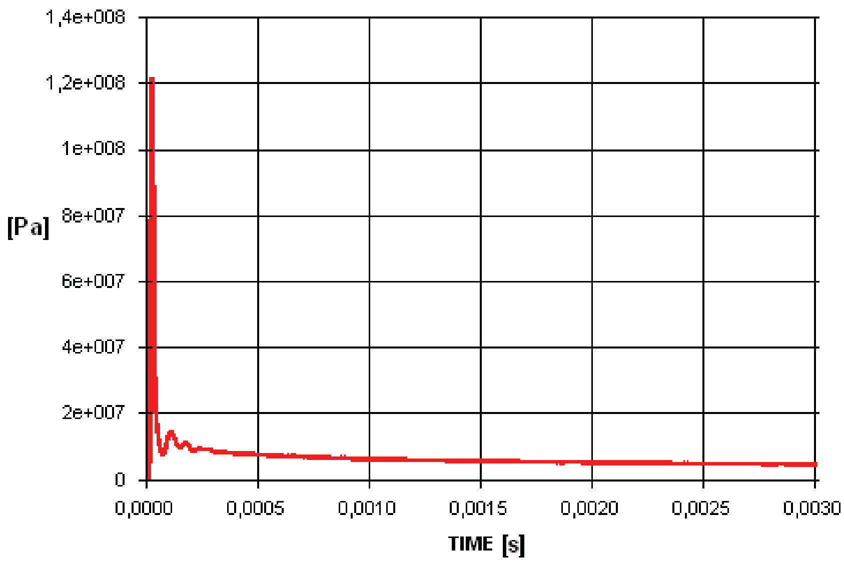

Fig. 2. The graph of the pressure impulse obtained from numerical calculations

Figure 3 presents the subsequent phases of pressure wave propagation in the air for a 1 kg charge.

Cubic elements were applied for modelling the Euler domain coupled with the Lagrange structure. Such a match of elements shape results from the necessity of adjusting elements of the Euler mesh to the mesh of finite elements defining the examined object. A spherical blast wave propagating in the mesh of cubic elements undergoes slight deformation.

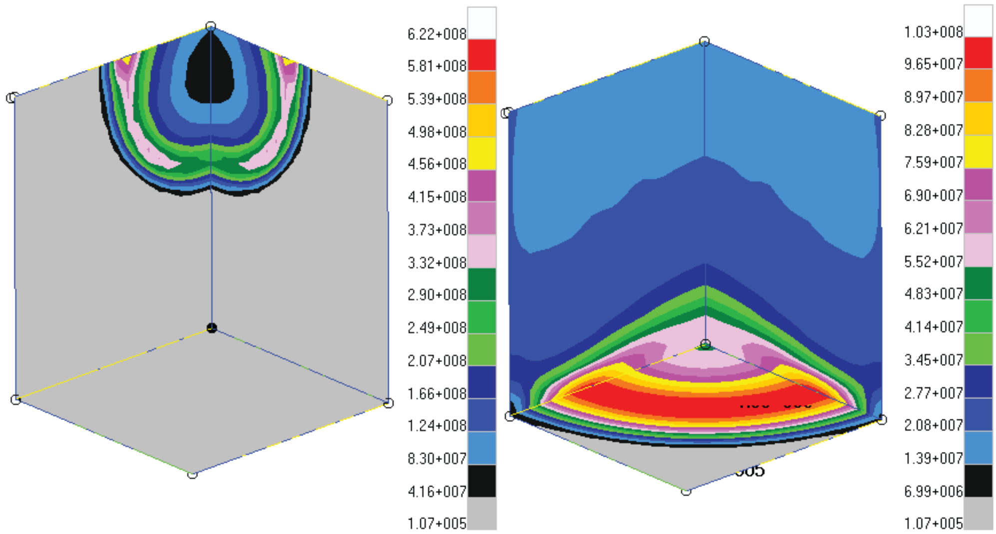

Fig. 3. Subsequent phases of the pressure wave freely spreading in the air [Pa]

At the significant changes (gradients) of pressure, the elements mesh size significantly influences on the calculated pressure values. Due to this fact, the Euler elements are very sensitive to the change of mesh parameters. On the other hand, the concentration of mesh elements requires (on this calculation level) more and more outer and operational memory. The mesh elements size is determined by comparison of the pressures values obtained numerically and evaluated analytically or experimentally. From the comparison of numerical and analytical results it is found that the mesh parameters should be adjusted to each change of the charge size.

Since the influence of the mesh shape on the pressure at the front of the blast wave is slight, the further analysis was based on the cubic, but appropriately dense, Euler elements mesh.

To evaluate the results, the evaluation of the displacement of the plate central point (in the symmetry plane) was applied.

4. Results of numerical investigations for a steel plate

Figure 4 presents the displacement change of the medium of the examined steel plate in the time function. In this case, the initial range of approximately 0.0005 s corresponds to the approach of the wave to the object and is characterised by the lack of displacements. The movement time amounts to 4.5E-4 s. Next, the displacement level stabilises, the disappearing vibrations occur around the fixed level 0.025 m. The final plate deformation is presented in Fig. 5.

The graphs of the steel plate equivalent stress are shown in Fig. 7.

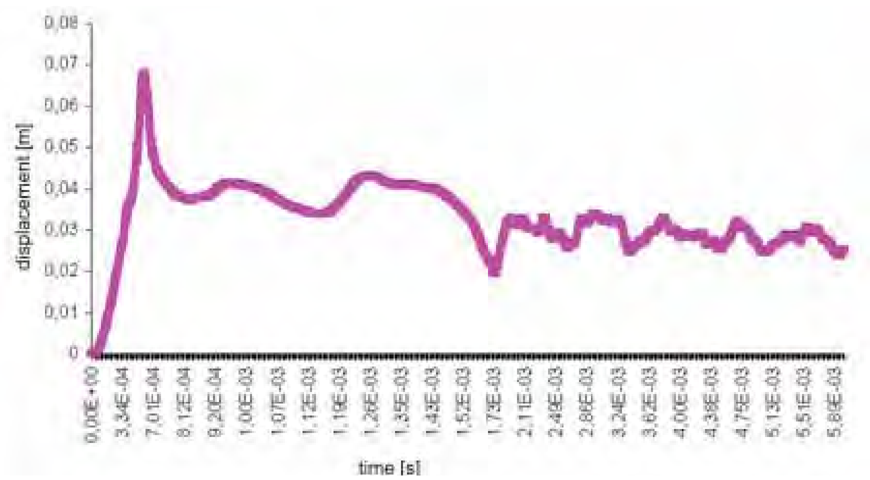

Fig. 4. Displacements of the steel plate central node in the time function

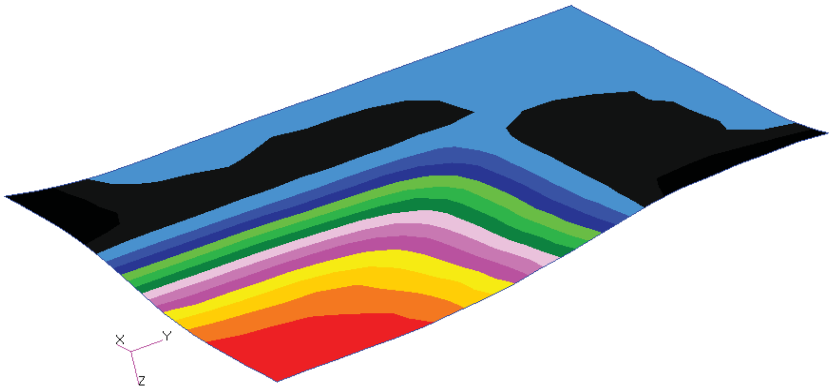

Fig. 5. The final form of the plate deformation

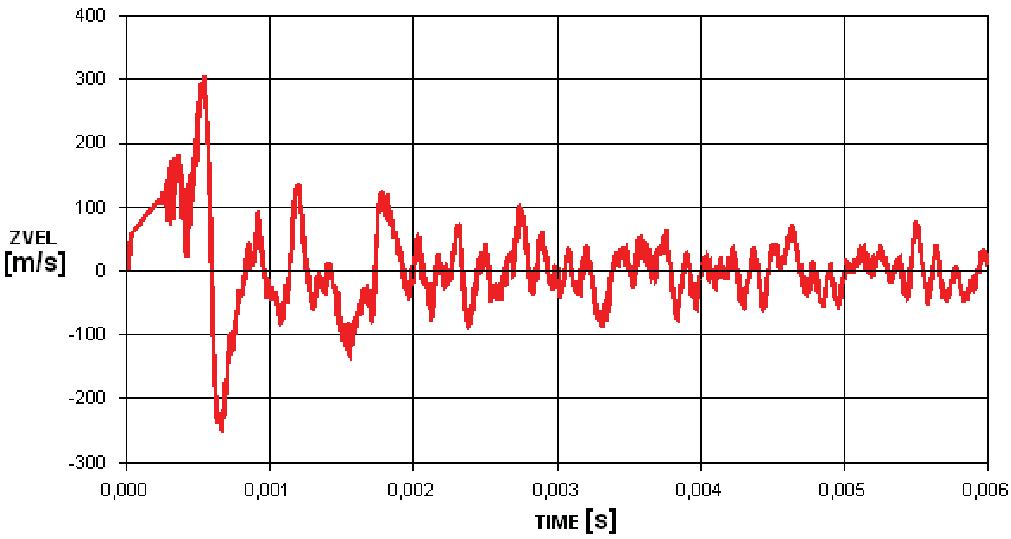

Fig. 6. Velocity of the central point

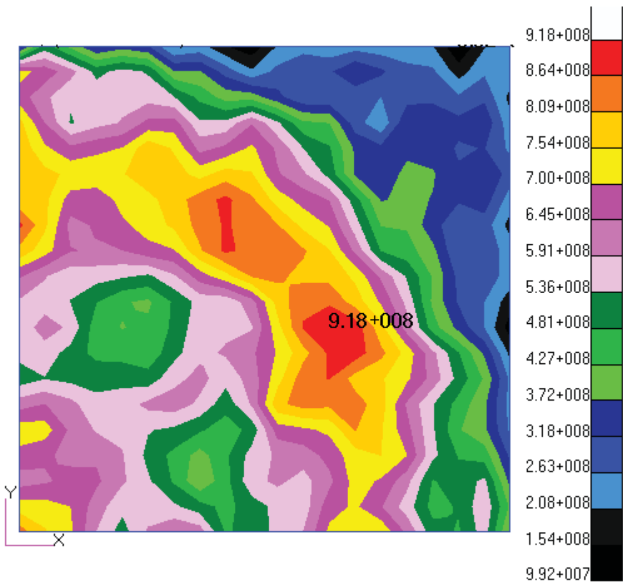

Fig. 7. Map of the plate equivalent stress

As the result of the numerical analysis the maximal equivalent stress value 9.18 E8 Pa was obtained (for Re = 315 MPa – obtained experimentally).

5. Results of numerical investigations for a composite panel with aluminium foam core

Figure 8 presents the displacement change of the examined plate centre in the time function. The duration time of the pressure equals to approximately 7.5E-4 s. Next, the displacements level stabilises at the level 0.0125 m. The final plate deformation is shown in Fig. 9.

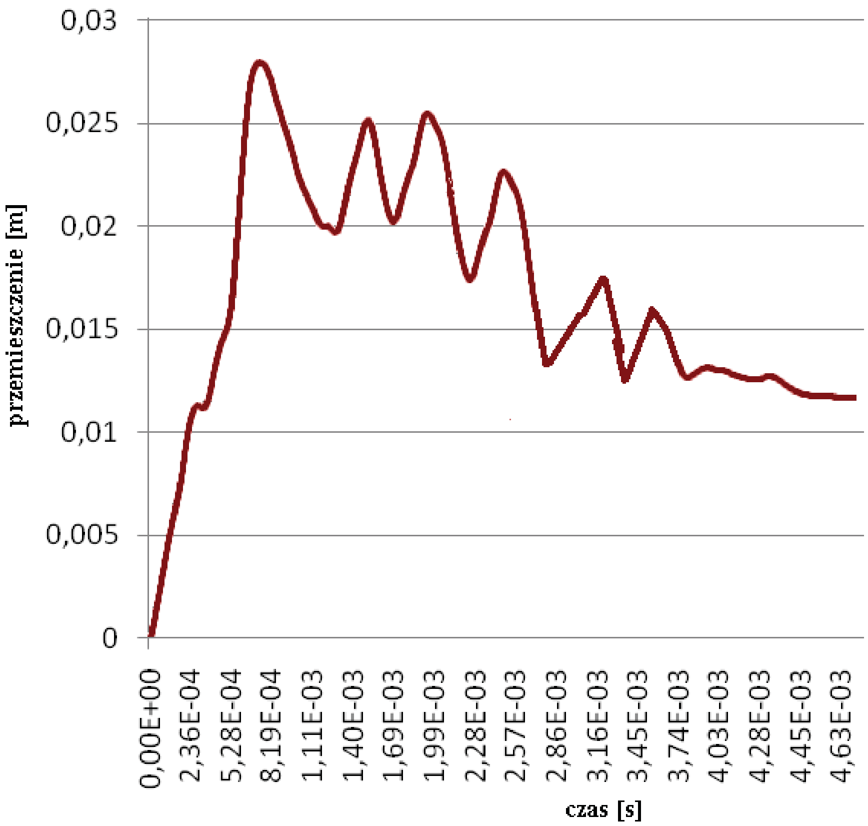

Fig. 8. Displacements of the central point of the steel plate with the composite panel in the time function

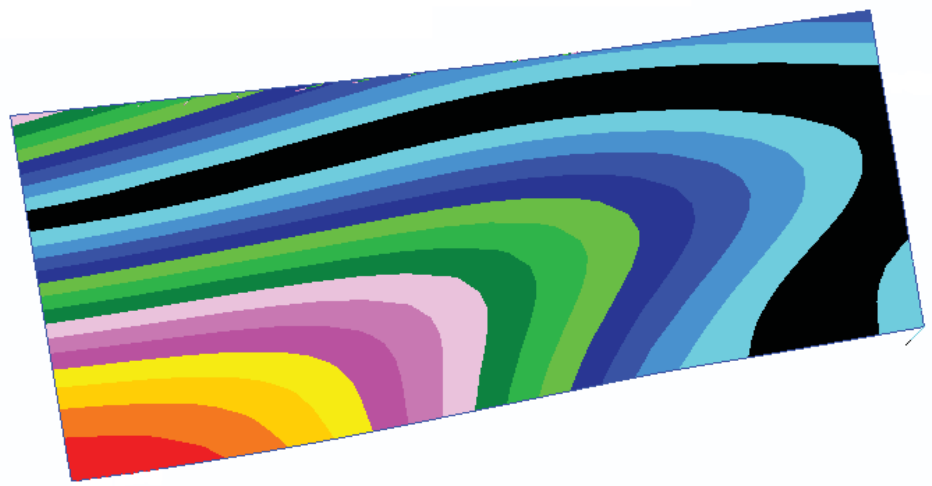

Fig. 9. The final form of plate deformation

The graphs of the equivalent stress of the steel plate are presented in Fig. 10.

As the result of the numerical analysis the maximum equivalent stress value 3.15 E8 Pa was obtained. This value is three times as great as in the case of model 1.

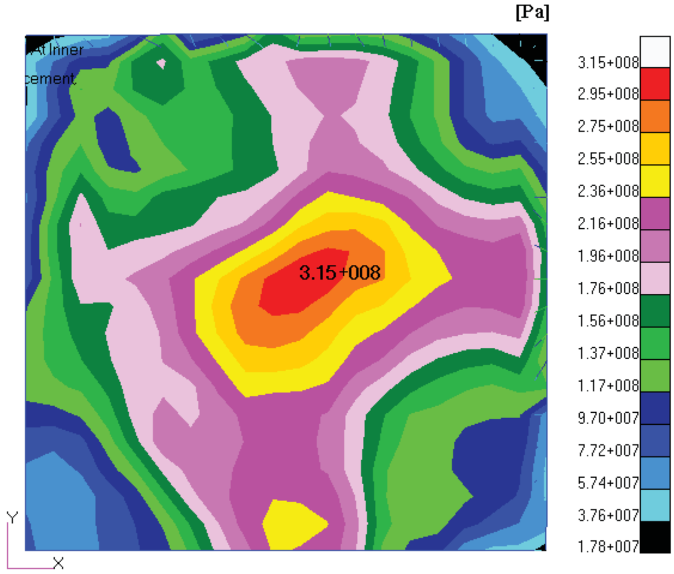

Fig. 10. The comparison map of the plate model equivalent stress

6. A stand for experimental investigations

Experimental investigations were performed in the firing ground conditions. The presented below stand was made on the base of the numerical simulations and analysis of the accessible literature.

While designing and performing the stand the possibility of changing some initial parameters of the experiment were taken into consideration in order to carry out the investigations for different values of an explosive charge. The general view of the stand is presented in Fig. 11.

The source of the pressure impulse was a huge TNT charge placed in the distance of 0.4 m from the examined object. An explosive material was placed freely over the centre of the object. The impulse load induced by detonation is characterised by a short duration time and a great amplitude. The duration time of such a pressure impulse is shorter by an order or even two orders than the stroke time and equals to a few tenth of a millisecond.

Fig. 11. The general view of a stand for testing the panels loaded with huge explosive charges

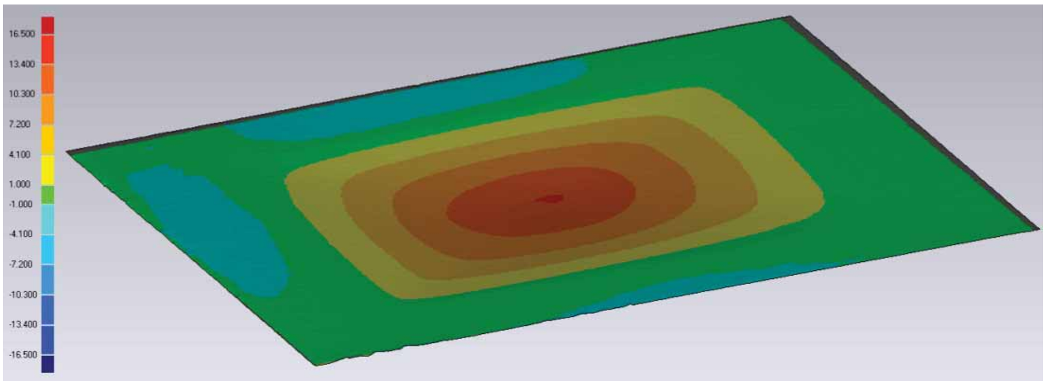

Fig. 12. The scan of final deformation of the plate loaded with a 1 kg charge [mm]

As a result of experimental investigations of the same plate the permanent plate deformation was obtained (Fig. 12).

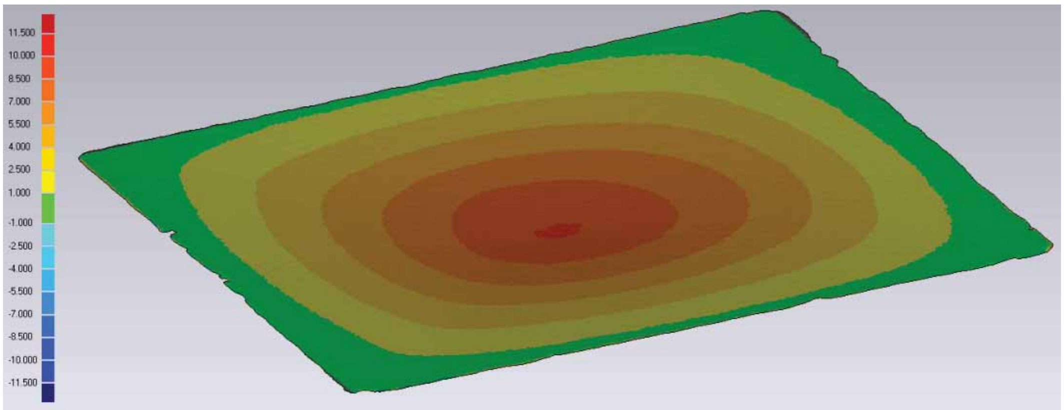

Fig. 13. The deformation scan of the steel plate with an aluminium foam layer loaded with a 1 kg charge [mm]

Application of a foam panel decreased the permanent deformation of the plate (Fig. 13) by 30% - the central plate node displaced permanently by 16.5 mm.

7. Results

The presented investigations are the stage of the research works on the conception of protective structures of the objects loaded with a blast wave induced by a huge TNT charge. Computer simulating technologies play more and more significant role in the analysis of phenomena accompanying the collisions and explosions. They enable a significant cost decrease and an increase of investigations efficiency by supplying data which cannot be measured experimentally. The essential thing is calibration and verification of calculation models on the base of experimental data and analytical investigations. Numerical models verified for the selected states of structures confirmed the correctness of the accepted technology enabling conducting the analyses for other states. The correctness of modelling huge charges was confirmed during the investigations.

Acknowledgements

This research work has been supported by Ministry of Science & Higher Education, Poland, as a part of the research project No. R00-O0064/3 realized in the period of 2008 - 2010. This support is gratefully acknowledged.

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