

# NUMERICAL-EXPERIMENTAL INVESTIGATION OF SQUARED-BASED METAL PYRAMIDS LOADED WITH A BLAST WAVE FROM A SMALL EXPLOSIVES CHARGE

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**Abstract:** The paper presents the results of computer simulation and experimental investigation of blast wave action arising from a small explosive charge on a metal pyramid with a square base. The explicit finite element method has been used to perform numerical analyses. This method is included in the Ls-Dyna software for modelling the behaviour of the pyramid exposed to the action of a pressure wave arising from the detonation of an explosive charge. The detonation process was described in programming burn approximation. The fluid-structure interaction was used to describe an influence of a blast wave on the structure.

**Key:** FEM, Blast Wave, Blast Wave Interaction with Structure, Fluid Structure Interaction

## 1. INTRODUCTION

Threats in the form of terrorist attacks during actions of Polish Army in Chad, Iraq and Afghanistan revealed the necessity of improving mine resistance and shrapnel resistance of different of military equipment.

The works on different solutions allowing meeting the requirements included in various documents and standards, for example in STANAG 4569, are carried out worldwide.

One of typical elements, which can be utilized in new solutions for dispersion of explosion energy, are metal pyramids. A simple construction of geometrical energy absorbers can assure the maximum protection at relatively low costs. The main advantage of this solution is using the streamlined shape of the construction and energy dispersion through great system deformations.

## 2. EXPERIMENTAL INVESTIGATIONS

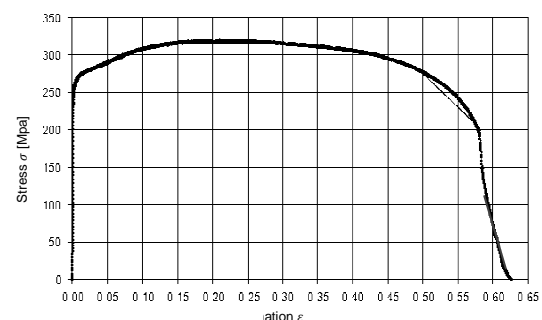
In the initial part of investigations, the basic parameters characterizing mechanical properties of the applied material were determined. A universal strength machine INSTRON was used for the investigations. In order to obtain information about the boundary strength, plasticity boundary  $R_e$  and strength  $R_m$ , the manufactured oblong samples were cut out of the examined pyramids. Part of the samples were subjected to the examination till the moment of breaking. The remaining samples were used to determine Young modulus and Poisson ratio.

The strength characteristic of the examined steel, presented in Fig. 1, was also obtained from the tensile stress test. The below characteristic was initially simplified to the form of the multi-linear one, possible to be used in LS-DYNA software (a thin line in Fig. 1).

The graph of a tensile stress static test does not have a clear

moment in which the material undergoes breaking (Fig. 1), what is characteristic for, among others, constructional steel. The examined material did not undergo failure till the end of the test. Deformations were recorded till the moment when stress reached the value of 0 MPa. This situation occurred at deformation  $\varepsilon = 0.624$ . In the presented Fig., only the change of the stress-deformation curve course at deformation  $\varepsilon = 0.58$  is observed.

The collected data describing the examined material are presented in Tab. 1.

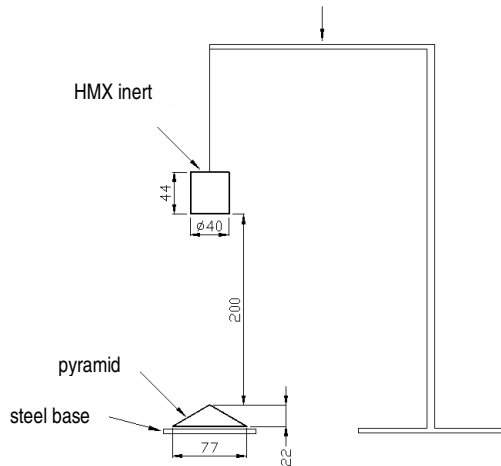


**Fig. 1.** Graph of dependencies of stresses from deformations in static tensile stress test along with simplified numerical multi-linear characteristic (a thin line)

In the further part of tests, a metal pyramid was loaded with the use of a pressure wave coming from detonation of an explosive charge. The scheme of the utilized experimental testing stand is presented in Fig. 2. The metal pyramid was set freely, below the explosive charge, on the thick flat plate selected so as not to undergo permanent deformation resulting from explosion. The explosive charge in the shape of cylinder was freely and symmetrically hung over the examined element.

**Tab. 1.** Properties of the examined steel

properties	low-carbon steel
density, $\rho$ [kg/m <sup>3</sup> ]	7865
Young's modulus, E [GPa]	94.62
Poisson ratio, $\nu$	0.284
yield point, $R_e$ [MPa]	253
ultimate tensile strength, $R_m$ [MPa]	319.4
stress at fracture, [MPa]	200
strain failure, $\epsilon_f$ [mm/mm]	0.58



**Fig. 2.** Scheme of the experimental testing stand (dimensions in mm)

HMx inert, which properties are presented in Tab. 1, was used for the examinations.

**Tab. 2.** Properties of HMx inert [3 ÷ 7]

HMx inert $C_4H_8N_8O_8$	
explosion energy [kJ/cm <sup>3</sup> ]	16.23
Chapman – Jouguet pressure [GPa]	38.6
detonation velocity $V_{det}$ [km/s]	9.12
density corresponding to $V_{det}$ [g/cm <sup>3</sup> ]	1.894
detonation temperature [°C]	279
gas products volume [cm <sup>3</sup> /g]	755
equivalent of TNT according to Berthelot approximation	1.73
JWL coefficients for HMx inert	
A [GPa]	858.08
B [GPa]	7.55
$R_1$	4.306
$R_2$	0.80
$\omega$	0.30

As a result of the conducted experiment, the metal pyramid underwent permanent deformation and its height was reduced from 22 mm to 12 mm. Changes of the dimensions of the base are possible to be ignored due to their size. The deformed pyramid is presented in Figs. 3 and 4.

Despite the symmetric structure of the pyramid before explosion, its deformations are asymmetric. One of the edges was "pushed" under the vertex, where the rest three edges meet.

The opposite edge, especially its end, stuck up significantly higher, at the height of approximately 5 mm, than the others. It can result from imperfections in manufacturing and setting the pyramid, or result from the fact that during the process of the pyramid extrusion, the material underwent strengthening to a different degree.



**Fig. 3.** Side view on undeformed and deformed pyramid



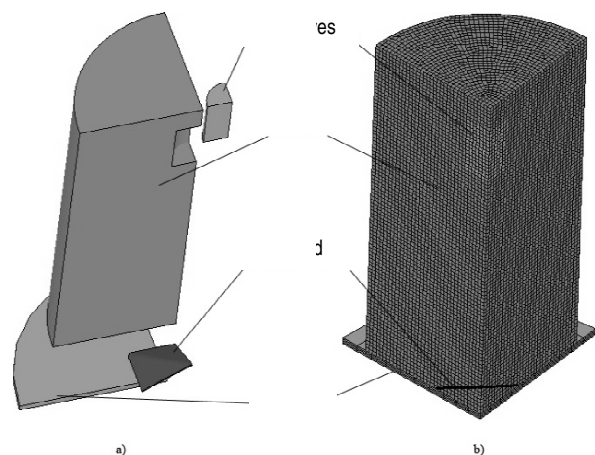
**Fig. 4.** Top view on deformed and undeformed pyramid

### 3. NUMERICAL INVESTIGATION

In order to reproduce accurately the experimental research consisting in loading the metal pyramid with a pressure wave coming from detonation of explosive material, the 3D model was developed (Fig. 5).

The following assumption and simplifications were applied in respect to the conducted experiment:

- it was assumed that the system was symmetric, what allowed modelling of only the one quarter of the whole system. It enabled over threefold shortening of calculations time with simultaneous maintenance of very good agreement with the results of the conducted experiment,



**Fig. 5.** Full model in decomposed view (a) and in state ready to conduct simulation, along with superimposed mesh (b)

- behaviour of the examined element was described with properties of an isotropic body. Any effects of material strengthening on the edges, caused by plastic deformation of the steel plate during formation of the pyramid were ignored. Its behaviour was described with the multi-linear model,
- the air was described with the use of equation of perfect gas,
- approximation of detonative optics was used to describe detonation (Jach et al., 2001),
- behaviour of detonation products was described with JWL equation (Włodarczyk, 1994),
- in this case, to model the influence of a pressure wave on the structure, the algorithm included in LS-Dyna software was applied.

Based on the obtained results, it is possible to distinct three stages of the described phenomenon:

- stage I (0-35  $\mu$ s): detonation of explosive material and expansion of gas explosion products until the moment of reaching the pyramid by the front of the pressure wave;
- stage II (35-50  $\mu$ s): interaction of the wave with the structure (pyramid) (Fig. 6). The characteristic feature of this stage is the phenomenon of originating of the wave reflected from the pyramid with the intensity significantly greater than intensity of an incident wave. The value of the pressure at the front of a reflected wave is possible to be higher even eighth times than the pressure of an incident wave. After approximately 15  $\mu$ s from the moment of reaching the pyramid vertex by a blast wave, deformations in the examined object start to be visible;
- stage III (50-250  $\mu$ s): structure deformation. The pressure of the reflected wave decreases quickly and progressive deformation of the element occurs only as an effect of interaction of inertia forces (Fig. 7).

Owing to the character of the conducted examinations, it is only possible to compare the final shapes of the considered elements. The final form of the element deformation obtained through the experiment and numerical calculations is presented in Figs. 8 and 9. A very good agreement of calculations and the experiment was obtained. The difference in the final form of deformation was amounted to less than 7.5 %.

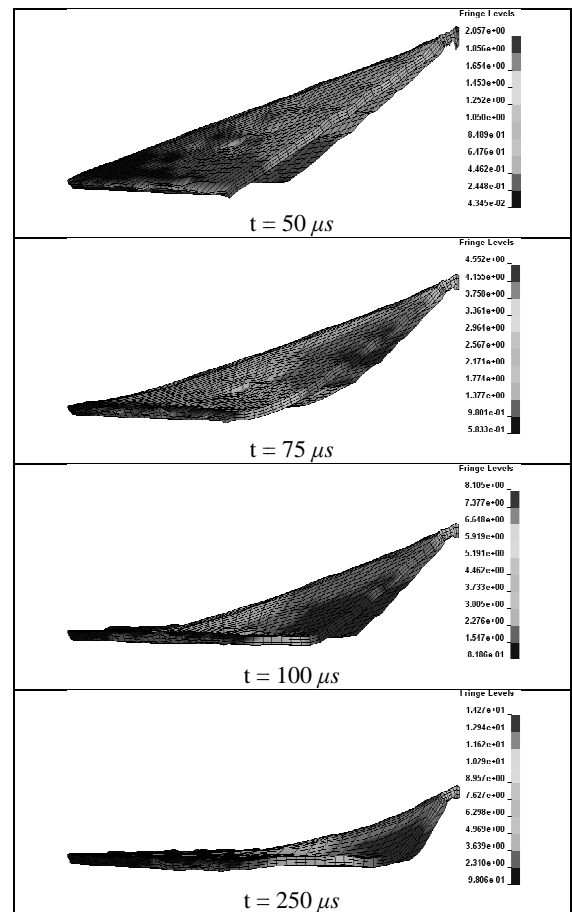


Fig. 7. The course of deformation process of the object (deformations in mm)

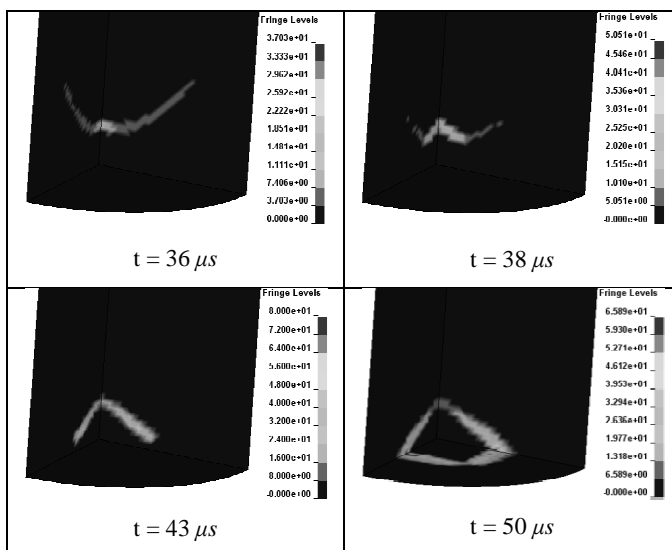


Fig. 6. The course of process of pressure wave reflection from the considered object (pressure values in MPa)

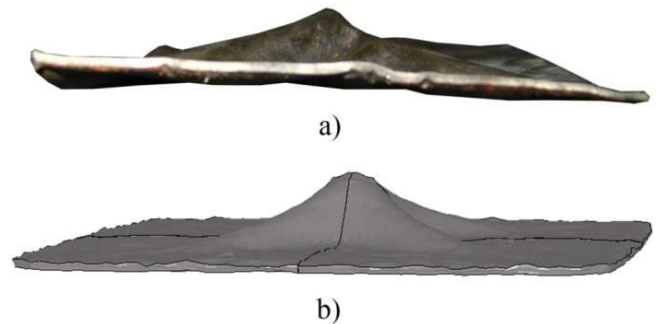


Fig. 8. Comparison of deformed pyramid from the experimental research (a) with the result obtained in full simulation of influence of pressure wave on the element (b) – side view



Fig. 9. Comparison of deformed pyramid from the experimental research (a) with the result obtained in full simulation of influence of pressure wave on the element (b) – top view

Comparing visually both of the models, it is possible to observe mainly the difference in the form of the edge between the pyramid walls. In the real model they are maintained on the whole length – from the pyramid vertex to the corners of the base. In the numerical model, the edges between the pyramid walls are maintained more or less to the half length, viewing from the vertex, and subsequently they undergo complete flattening. It results, first of all, from ignoring the material strengthening effect at the edges.

#### 4. SUMMARY AND CONCLUSIONS

The paper presents the numerical-experimental results of research of dynamic loading the constructional element in the form of a metal pyramid with a square base with the pressure wave (coming from detonation of explosive material). A very good agreement between numerical calculations and the experiment was obtained in the aspect of the final form of deformation of the considered objects. The calculated intensity of the falling and reflected pressure wave corresponds to literature data. There was depicted the course of deformation in the examined element during the course of the considered phenomenon.

The presented constructional element is possible to be applied in energy absorbing panels. Due to their mass, such panels can be used for protection of stationary objects, not the mobile ones. They can be used particularly for protection of objects of critical infrastructure.

The paper presents the narrow part of a wide range of work on the problem of energy absorption and impact energy dispersion carried out by the Department of Mechanics and Applied Computer Science, Military University of Technology.

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