EXPERIMENTAL INVESTIGATION OF SELECTED EXPLOSION PARAMETERS FOR NUMERICAL MODEL VALIDATION

Wiesław Barnat, Roman Gieleta, Tadeusz Niezgoda

Military University of Technology
Department of Mechanics and Applied Computer Science
Gen. Sylwestra Kaliskiego Street 2, 00-908 Warsaw, Poland
tel. +48 22 6837201, +48 22 6839226, +48 22 6839849, fax: +48 22 6839355
e-mail: wbarnat@wat.edu.pl, rgieleta@wat.edu.pl, tniezgoda@wat.edu.pl

Abstract

The aim of presented work is examination of blast wave, especially incident and reflected wave pressure. Due to many difficulties and complexity of phenomenon a complete study for different charges should be done. In presented paper two cylindrical TNT charges were used, weighting respectively 100 g and 200 g. Pressure wave was examined using original test stand designed and developed on Department of Mechanics and Applied Computer Science. A test steel test plate with 5 mm thickness was equipped with pressure gauge to measure reflected wave. Additionally, the plate was placed on four special electroresistance strain gauges. To measure force Vishay EA-06-120-060LZ strain gauges were used. For amplification of the dynamometers with strain gauges, MS1001 INFEL bridge was used. The system was used to validate the results from reflected wave pressure gauge. Shock wave pressures was measured using a special sensor model 137A21 amd M350B21 made by PCB Piezotronics At specific distance there was also incident wave pressure gauge. In order to fully examine the dynamic response of the plate an accelerometer was used. As a result, pressure versus time and acceleration versus time plots were obtained. The results will be used to validate numerical model of blast wave impact on a plate.

Keywords: *IED, Improvised Explosive Device, numerical model, validation*

1. Introduction

Numerical examination of rapid phenomena is very complicated task that requires much experience from the researchers involved. Blast wave comes with great energies and very short duration. It is often difficult to even estimate incident and reflected wave pressure values. Many works present analytical and numerical solutions to the problem [1–6]. However, the numerical simulation without validation and evaluation are under risk of major mistake.

Presented work concerns different charge weights influence on the response of steel plate. Both incident and reflected wave pressures were measured. Additionally, the acceleration of plate's middle point was registered. To estimate the values some canonic formulas were used.

2. Analytical solutions

Available literature allows for estimation of loads applied to the structure using mathematical expressions. Such an approach has many limitations and allows only coarse estimation of force impulse. Best results are obtained for ideal conditions as approximation of real state.

Modern literature provides many simplifications that allow estimating the pressure peak value for both air and water. All the descriptions base on general physics laws. For one-dimensional ideal gas the conservation laws are [4]:

– mass:

$$\frac{\partial \ln \rho}{\partial t} + u\frac{\partial \ln \rho}{\partial r} + \frac{\partial u}{\partial r} + \frac{Nu}{r} = 0\,, \tag{1}$$

– momentum:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial r} + \frac{1}{\rho}\frac{\partial p}{\partial r} = 0\,, \tag{2}$$

– energy:

$$\frac{\partial (p/\rho^{\gamma})}{\partial t} + u\frac{\partial (p/\rho^{\gamma})}{\partial r} = 0\,, \tag{3}$$

where p, ρ, u are pressure, density and mass velocity of medium, respectively.

The overpressure values as time function can be described with Friedlander formula:

$$P_s(t) = P_{so}\left(1 - \frac{t - t_A}{t_o}\right)\exp\left(-\beta\frac{t - t_A}{t_o}\right). \tag{4}$$

Typical pressure plot generated by an explosive is presented in Fig. 1. The β coefficient to semtex model equals to 1.24 and for B composition 1.148.

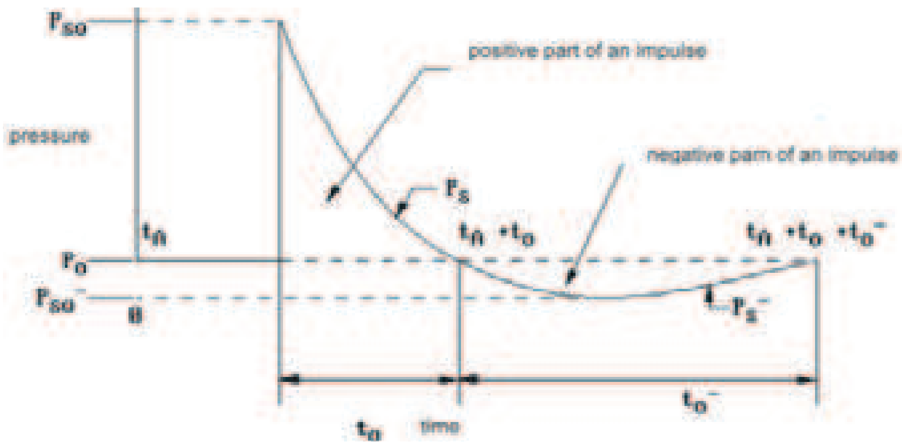

Fig. 1. Pressure impulse caused by the detonation: P_{s0} – pressure in undisturbed area, t_0 – time of positive part of an impulse, β – decay coefficient, t_A – initiation of explosive charge

Pressure wave generated by the charge deflects of any approached obstacle. Pressure wave value can be determined using Rankine-Hugoniot equation. It depends on pressure in undisturbed area, specific heats ratio and dynamic pressure. In case of perpendicular load on flat surface the maximum pressure value is described as:

$$p_r = 2p + (\gamma + 1)q\,, \tag{5}$$

$$q = \frac{5p^2}{2(p + 7p_0)}\,. \tag{6}$$

For air ($\gamma = 1.4$) reflected wave pressure value:

$$p_r = 2p\frac{7p_0 + 4p}{7p_0 + p}\,. \tag{7}$$

For weak waves $p_r = 2p$, whereas for strong $p_r = 8p$. Basing on literature, in real situations amplifications above 10 can occur.

In general, the pressure wave can be described using the formula:

$$P(t) = P_r\cos^2\theta + P_i(1 + \cos^2\theta - 2\cos\theta)\,, \tag{8}$$

where θ is aincident pressure angle, p_r is reflected wave pressure, p_i is incident wave pressure. The formula was developed in 1991 for United States Army [7].

3. Experimental approach

Due to safety regulations, experimental research was done with charges 100 g and 200 g of TNT. Test plate was made of St3 steel 6 mm thick. Additionally, the total force affecting the plate was measured using electroresistance force gauges mounted in test stand base. Test stand was designed in Department of Explosives and Department of Mechanics and Applied Computer Science. It allows for measurements of:

– incident wave pressure,
– reflected wave pressure,
– force affecting base plate,
– acceleration of test plate middle point.

Figure 2 shows test equipment used.

To condition and strengthen the signals from incident wave pressure transducers and accelerometers LTT 500 amplifier produced by Tasler GmbH was used. For amplification of the dynamometers with strain gauges MS1001 INFEL bridge was used. Registration runs were carried out using National Instruments NI-USB measuring card model 6833 with a fast 16-bit analog-to-digital converter (2 MHz sampling rate on each channel) and Toshiba Satellite laptop computer with a program to support measurement card. Measuring equipment used in the study is shown in Fig. 3.

To measure force Vishay EA-06-120-060LZ strain gauges were used. Shock wave pressure was measured using a special sensor model 137A21 made by PCB Piezotronics (serial number 9080) with a sensitivity of 143.3 mV/MPa and 6.894 MPa range. Sensor was placed at 700 mm distance from the axis of the load. Base plate acceleration measurement was done using acceleration sensor M350B21 model made by PCB Piezotronics (serial number 39486) with a sensitivity of 0.046 mV/g and measuring range of $100 \cdot 10^3$ [g].

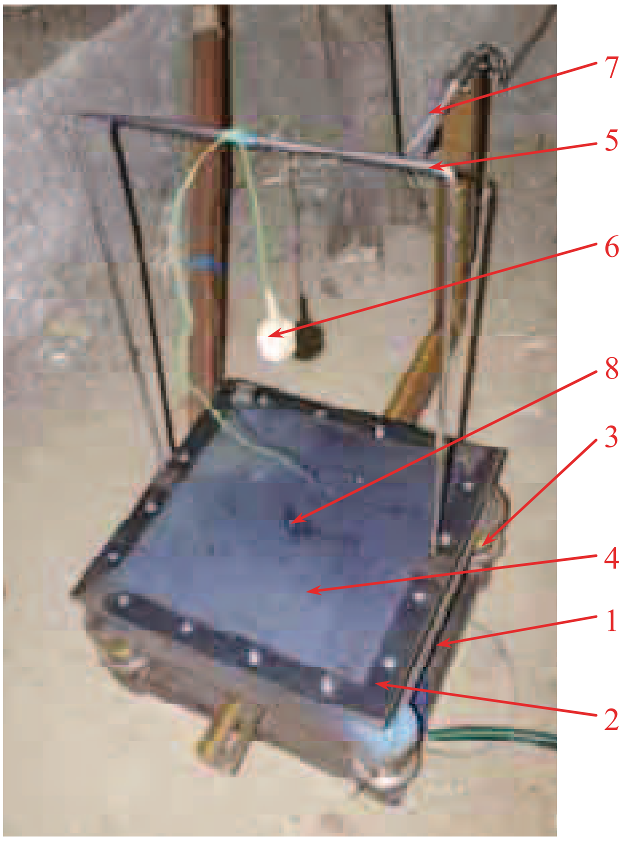

Fig. 2. Test stand: 1 – base, 2 – mounting frame, 3 – strain gauge force transducer (4 pieces), 4 – base plate, 5 – explosive charge mount, 6 – explosive charge, 7 – incident wave pressure gauge, 8 – reflected wave pressure gauge

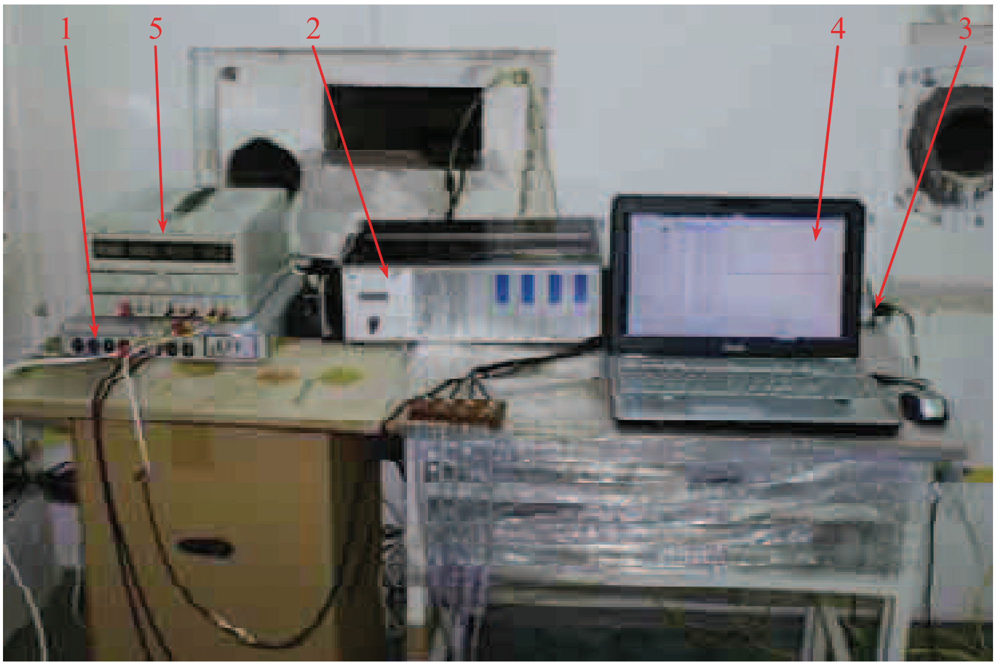

Fig. 3. Test equipment: 1 – LTT 500 amplifier, 2 – strain gauge amplifier MS1001, 3 – measurement card NI-USB 6833, 4 – computer with software supporting the equipment, 5 – power supply

4. Test results

After tests, the obtained force, incident wave pressure and acceleration plots were scaled In order to provide time plots. Fig. 4–9 show reach plot for respectively 100 g and 200 g of TNT. The aim is to determine the influence of chare mass on response of each system.

In case of 100 g charge, incident pressure wave versus time plot is shown in Fig. 4a, reaching 0.43 MPa for time 0.7 ms. Such an offset is caused by the distance between the charge and pressure gauge (which could be damaged). Maximum force reached 3200 kN for time 1.2 ms. Maximum acceleration of test plate reached $30 \cdot 10^3$ g for time 0.4 ms. Acceleration versus time plot is presented in Fig. 4b.

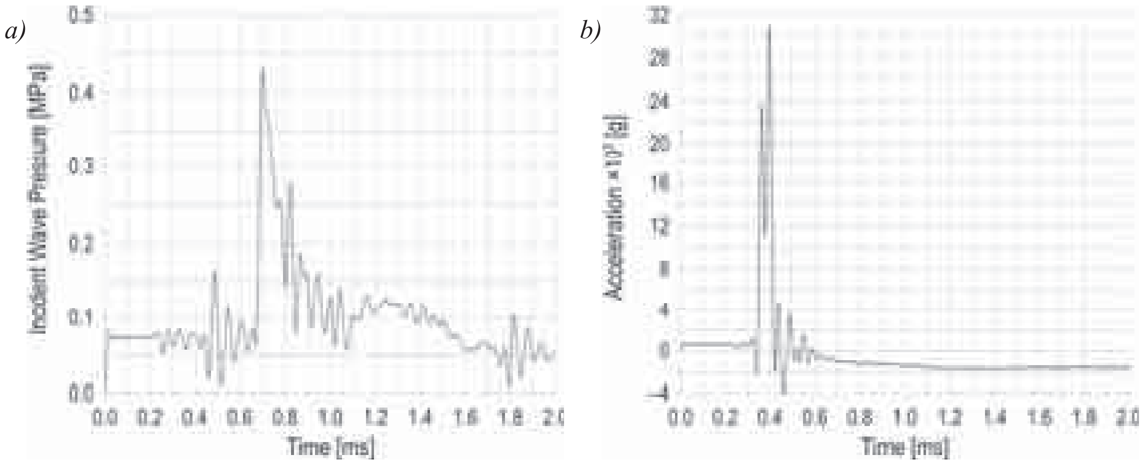

Fig. 4. Incident wave pressure vs. time (a) and acceleration vs. time (b) plots – 100 g TNT

In case of 200 g charge, incident pressure wave versus time plot is shown in Fig. 5a, reaching 1.02 MPa for time 0.53 ms. Pressure value was 2.3 times higher than in case of 100 g TNT. Maximum value of acceleration for 200 g charge reached $32 \cdot 10^3$ g. Acceleration versus time plot is shown in Fig. 5b.

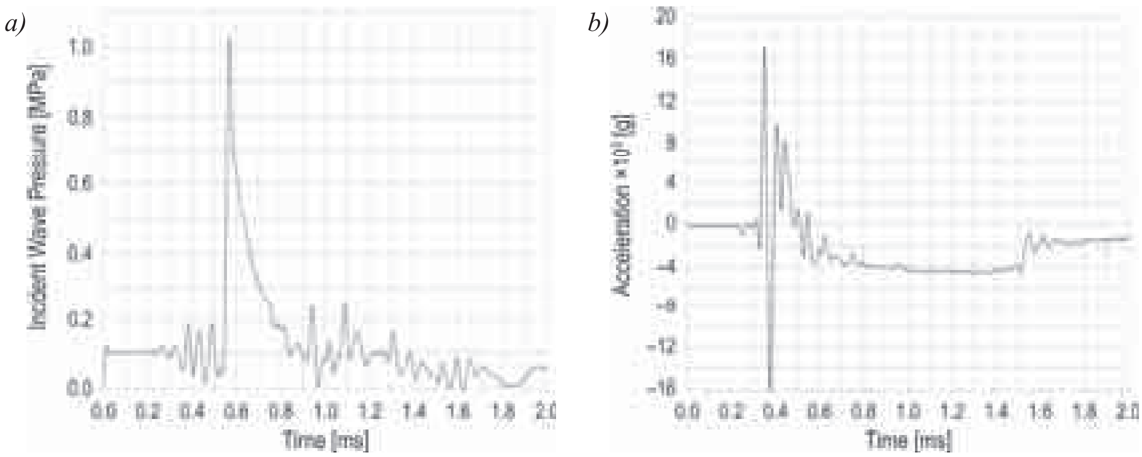

Fig. 5. Incident wave pressure vs. time (a) and acceleration vs. time (b) plots – 200 g TNT

5. Conclusions

The paper presents some work concerning blast wave propagation caused by detonation of 100 g and 200 g charges of TNT. As a result incident wave pressure and reflected wave pressure plots were obtained. What is more, force affecting the test stand's base and plate acceleration was also measured. Further study will include numerical modelling of presented experiments.

Acknowledgements

The paper is a part of a development project No. O R00 0081 12, entitled: *Group of modular wheeled armoured vehicles for reconnaissance and mine clearance of roads*, supported by Ministry of Science and Higher Education, Poland. This support is gratefully acknowledged.

References

[1] Małachowski, J., Niezgoda, T., *Research of Elastomeric Protective Layers Subjected to Blast Wave*, Applied Mechanics and Materials, Vol. 82, pp. 680-685, 2011.
[2] Baranowski, P., Małachowski, J., Niezgoda, T., *Numerical Analysis of Vehicle Suspension System Response Subjected to Blast Wave*, Applied Mechanics and Materials, Vol. 82, pp. 728-733, 2011.
[3] Włodarczyk, E., *Podstawy fizyki wybuchu*, Wydawnictwo WAT, 2012.
[4] Staniukowicz, K. P., *Fizyka wzrywa*, Moskwa 1975.
[5] Le Blanc, G., Adourn, M., Lapoujade, V., *External Blast Load on Structures – Empirical Approach*, 5th European LS-DYNA Users Conference, UK 2005.
[6] Ergonenc, C., *Development and Design of Closed-Cell Aluminum Foam-Based Lightweight Sandwich Structures for Blast Protection*, Doctoral Thesis, Turkey 2008.
[7] Baker, W. E., *Explosions in Air*, University of Texas Press, Austin & London 1973.