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INFLUENCE OF DIMENSIONAL PROPORTIONS OF CYLINDRICAL EXPLOSIVE ON RESULTING BLAST WAVE

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Abstract

Explosives are broadly used today in many applications, both civilian and military. Many experiments involving explosives use either ball or cylinder charges. However, there can be raised a question whether an exact shape influences the resulting blast wave, and, additionally, if the length to diameter ratio of the cylinder influences the wave. To answer the question, numerical analysis was conducted. A 3D model of the charge was constructed in LS-Prepost software and calculated with use of an explicit FEM method in LS-DYNA software. To determine the change of character of the blast wave, the dimensions of the charge change, whereas the mass and distance from the centre of the charge are constant. Several length to diameter ratios was tested, starting from 0.25, to 2, in 0.25 increments. Two explosives, HMX and TNT, were used. As expected, the resulting Blast wave was different in each case, with 100% difference in pressure values between 0.25 and 2 L to D ratios, especially along the length axis of the cylinder. The results show that the exact diameters of the charges need to be taken into consideration while determining a type of charge to be used as well as determining the goal to be achieved during a particular conducted experiment.

Keywords: *materials engineering, mechanical engineering*

1. Introduction

Values and course of impulse loads emerging from the detonation of the explosive material or an improvised explosive device are described in the literature based on experimental studies and numerical analyses. Henrych [3], Sadowski [11] and Kingery and Bulmash [6] describe, based on the experimental data, the equations describing the values of the peak pressure and an impulse for both the reduced mass and distance. For given parameters of the charge, the values of the peak pressure and the pressure impulse can vary significantly. In numerical analyses of the influence of the pressure impulse on the structure, different models can be used – a triangular wave load, point detonation load or ConWep approximation. In the case of ConWep approximation, there are used both pressure distribution determined based on experimental tests and implemented in ConWep software and an influence of this load on the considered element of the setup depending on its distance and arrangement in respect to the charge[2, 4]. In the triangular wave method, the peak values are equal to the peak pressure, and the area under the experimental curve is equal to the pressure impulse [13]. In the point detonation model approximation, the detonation process is not considered. It is only assumed that, in the initial time, in the small part of the volume, an emanation of energy occurs. The assumptions and conclusions regarding this model are presented in the studies of Taylor [15], Sedov [12] and von Neumann [7], who developed it independently. This model was then further developed by, among others, Staniukowicz [14].

None of the described methods considers the influence of the shape of the explosive charge and its orientation in regards to the object to be impacted by the blast wave. Therefore, in this study, an analysis of the influence of the typical, cylindrical charges on the resulting blast wave's parameters along the given direction of propagation is presented. Blast waves created by the charges made of TNT and HMX are analysed. The heat of explosion is equal to 6 GJ/m^3 and 10.5 GJ/m^3 for the TNT and HMX, respectively [8].

A finite elements method with explicit integration as implemented by LS-Dyna software was used [4]. Calculations were carried out using the ALE approach, which allows for modelling fluid behaviour [8]. The used ALE method minimizes the problems caused by the advective members, which cause the artificial numerical dissipative processes [10].

2. Description of the case

A scheme of the investigated case is shown in Fig. 1. It presents an explosive material surrounded by the air domain. The edges of the domain were constrained with non-reflecting boundaries with constant pressure applied equal to atmospheric pressure. The domain was big enough for the wave to not reach the edge at the end of the numerical analysis. The detonation process was approximated using the program burn algorithms [1, 5]. This method is based on assessing the initial values characterizing the explosion as a velocity of detonation, a point of initiation, the blast wave front parameters (D – velocity of detonation, p_{CJ} – pressure at Chapman–Jouguet point, ρ_{CJ} – density in that point) and the equation detailing the behaviour of detonation results.

To calculate the pressure of the results of detonation, JWL equation was used (Jones, Wilkins, Lee) [9, 16]:

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

where:
$V = \rho_0/\rho$,
ρ_0 – initial density,
ρ – density of the results of detonation,
A, B, R_1, R_2, ω – constants.

The air domain properties were represented with Mie-Gruneisen equation of state [16]:

$$p = p_0 + \gamma \rho E \tag{2}$$

where:
p – pressure,
p_0 – initial pressure,
γ –Gruneisen parameter,
ρ – density,
E – internal energy.

In the experiment, the following values were used for the Euler's air domain: $\gamma = 1.4$, $\rho = = 1.185$ kg/m^3, $p_0 = 1013$ hPa [16].

The blast wave resulting from detonation of an explosive charge with the mass of 50 g made of TNT and HMX and with variable L/D ratio (from 0.25 to 2) was analysed. The results are shown in the next chapter for pressure values in the 20 cm and 35 cm distance from the centre of the charge.

Parameters characterising the materials, their detonation process and the propagation process used in the calculations are presented in Tab. 1 and 2.

3. Results

Figures 2-6 show the shape of the blast wave resulting from detonation of explosive charges with different L/D ratios and with two different explosive materials – TNT and HMX. The pressure distributions are shown 0.2 ms after initiating the detonation of the charge.

Tab. 1. Constants for JWL formula [16]

parameter	A	B	R_1	R_2	ω
explosive	[GPa]	[GPa]	[–]	[–]	[–]
TNT	373.8	3.747	4.15	0.9	0.35
HMX	778.3	7.071	4.2	1	0.3

Tab. 2. Parameters of TNT and HMX [16]

parameter	ρ_0	D	p_{CJ}	ρ_{CJ}
explosive	[kg/m^3]	[m/s]	[GPa]	[kg/m^3]
TNT	1630	6930	21	2230
HMX	1890	9110	42	2621

In the case of the TNT, the influence of geometrical parameters of the charge on the blast wave is more pronounced, with greater pressure gradients of the wave depending on the direction of propagation. With the HMX charges, the influence is smaller. This leads to significant discrepancies with the classic, spherical distribution of pressure used in calculations with simpler models, which leads to significant divergences in the results. The most significant differences in peak pressure values (50.3% and 53% for 20 cm, respectively) occurred for the charge with L/D = 0.25 for both TNT and HMX.

A non-spherical shape of the blast wave resulting from detonation of charges with low L/D ratio also results in higher velocity of the blast wave propagation along the axis of the charge than in the transverse direction (Fig. 1-4). For the charge made of TNT and L/D = 0.25, it reaches 20 cm after 0.063 ms and 35 cm after 0.127 ms. With L/D = 2, the values are 0.080 ms and 0.215 ms, respectively. For HMX, the values are 0.049 ms, 0.215 ms for the L/D = 0.25, and 0.068 ms, 0.182 ms for L/D = 2.

The blast wave resulting from detonation of the charges with a higher L/D ratio also blurs more rapidly, which leads to higher differences between peak pressures of the wave as the distance from the centre rises for both materials used in the experiment. The values of the drop between the 20 cm and 35 cm distance in the case of L/D = 0.25 is equal to 55% and 53% for TNT and HMX, respectively. With L/D = 1, the values are 67% and 68%. The highest drop occurs for L/D = 2, with 69% and 71% for TNT and HMX, respectively.

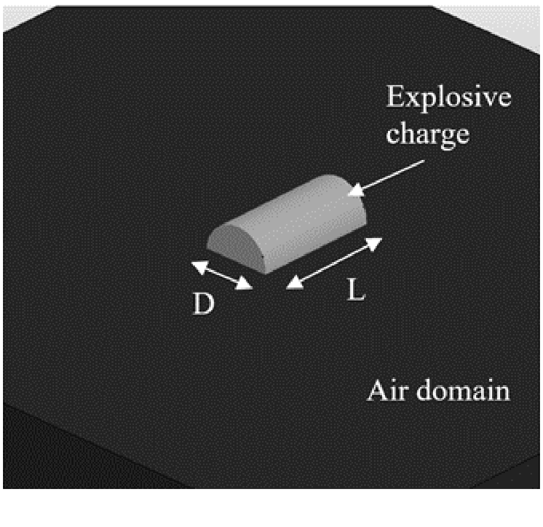

Fig. 1. Scheme of the model used in analyses

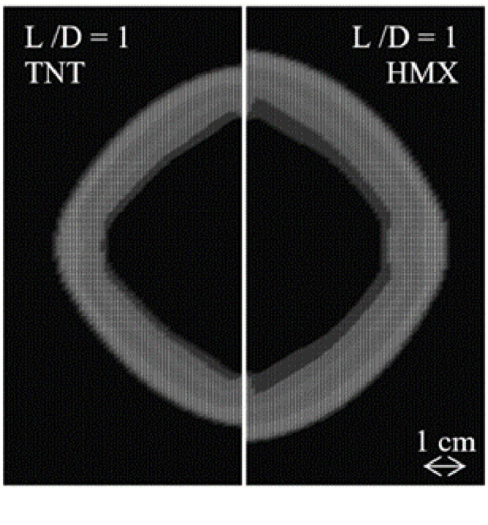

Fig. 2. Shape of the blast wave 0.2 ms after initiating the detonation for charge with L/D ratio of 1

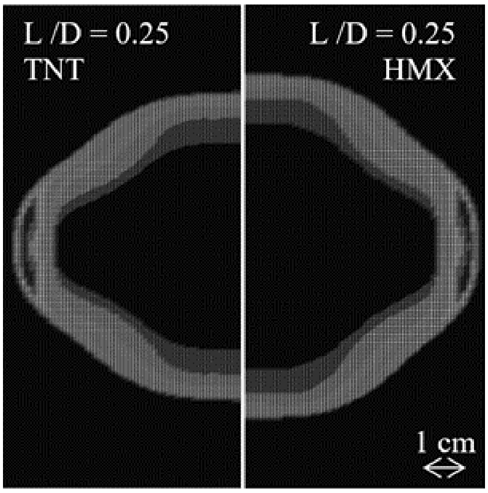

Fig. 3. Shape of the blast wave 0.2 ms after initiating the detonation for charge with L/D ratio of 0.25

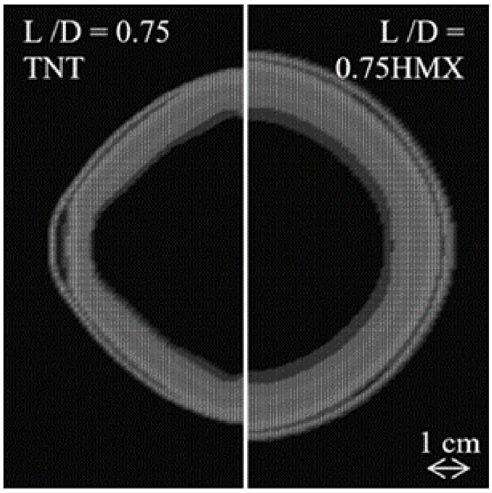

Fig. 4. Shape of the blast wave 0.2 ms after initiating the detonation for charge with L/D ratio of 0.75

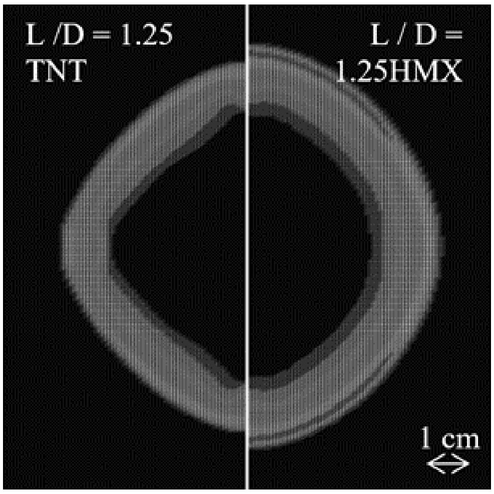

Fig. 5. Shape of the blast wave 0.2 ms after initiating the detonation for charge with L/D ratio of 1.25

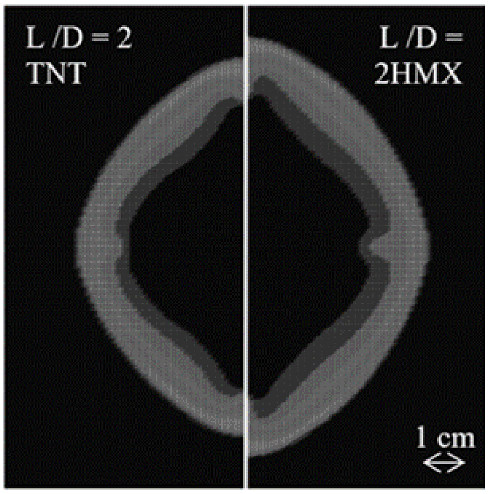

Fig. 6. Shape of the blast wave 0.2 ms after initiating the detonation for charge with L/D ratio of 2

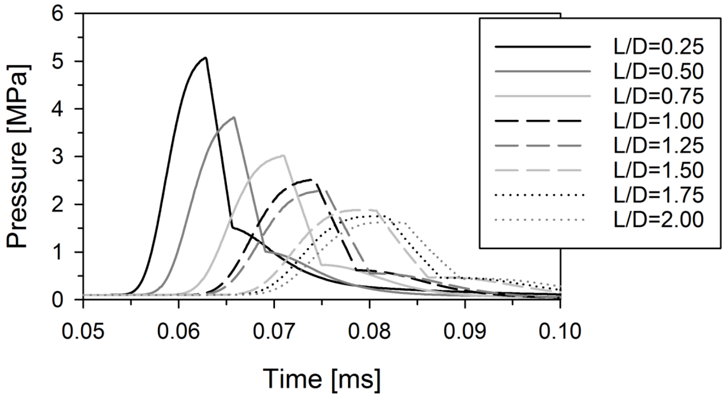

Fig. 7. Pressure valuesat the distance of 20 cm from the centre of the TNT charge

4. Conclusion

The results of the experiments show a definitive need to accommodate the geometrical parameters of explosive charges during simplified modelling of blast wave impact resulting from explosive material detonation on structures. The conducted numerical analyses of explosive charges

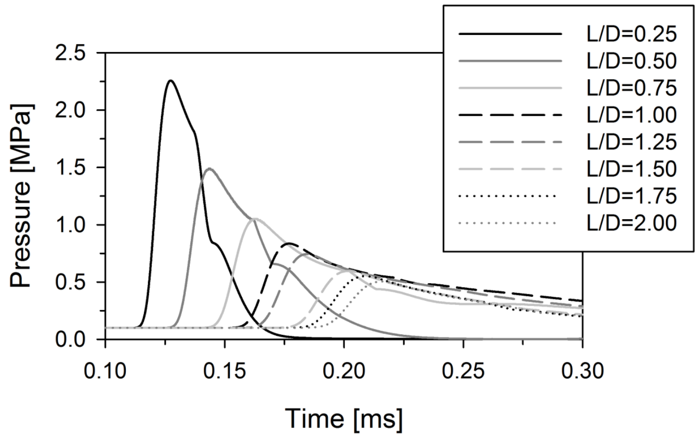

Fig. 8. Pressure values at the distance of 35 cm from the centre of the TNT charge

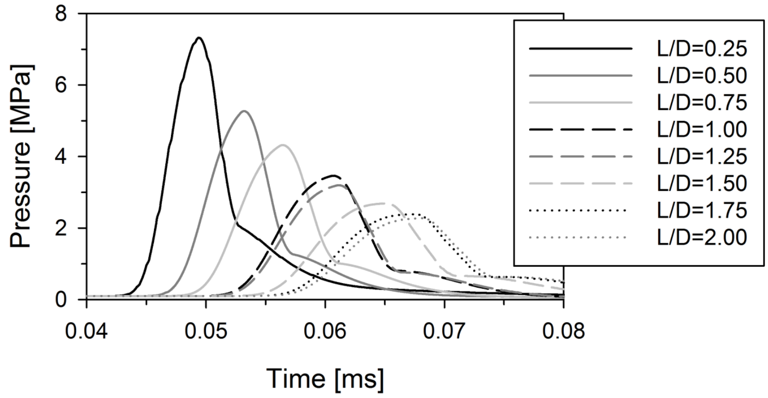

Fig. 9. Pressure values at the distance of 20 cm from the centre of the HMX charge

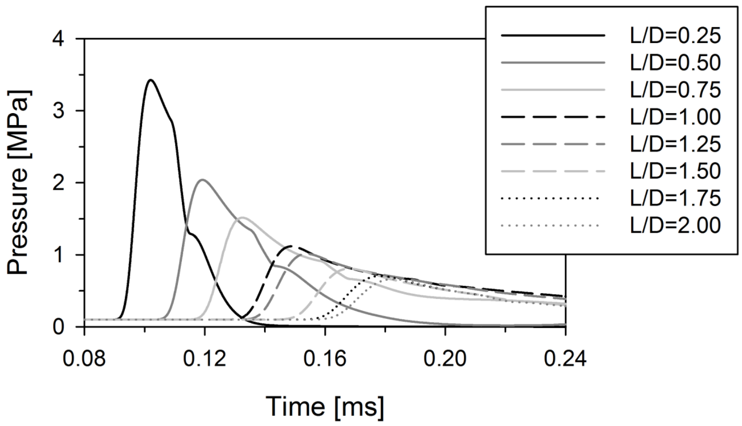

Fig. 10. Pressure values at the distance of 35 cm from the centre of the HMX charge

with a mass of 50 g, made of TNT and HMX and with L/D ratio from 0.25 to 2, suggest that the difference between pressure peaks can reach 300%. The velocity of wave propagation in air also changes depending on the angle and the analysed geometrical parameters. This also causes less dispersion of the pressure impulse, resulting in more severe damage caused to the structure during the impact.

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References

[1] Bdzil, J.B., Stewart, D.S., Jackson, T.L., *Program burn algorithms based on detonation shock dynamics: discrete approximations of detonation flows with discontinuous front models*, Journal of Computational Physics, Vol. 174, pp. 870-902, 2001.

[2] *CONWEP: Conventional Weapons Effects Program*, US Army Waterways Experimental Station, Vicksburg 1991.

[3] Henrych, J., *The Dynamic of Explosion and its Use*. Academia, Prague 1979.

[4] Hallquist, J. O., *LS-DYNA Theory Manual*, Livermore Software Technology Corporation, Livermore, CA 2005.

[5] Jach, K., Panowicz, R. i in., *Komputerowe modelowanie dynamicznych oddziaływań metodą punktów swobodnych*, PWN, Warszawa 2001.

[6] Kingery, C.N., Bulmash, G., *Air blast parameters from TNT spherical air burst and hemispherical surface burst*, BRT Technical Report ARBRL-TR-02555, Aberdeen, US Army Armament Research and Development Center, Ballistic Research Laboratory, 1984.

[7] Von Neumann, J., *The point source solution*, National Defence Research Committee, Div. B Report AM-9, 1941.

[8] Panowicz, R., Barnat, W., Niezgoda, T., Szymańczyk, L., Grzymkowski, J., *Numerical-experimental investigation of squared-based metal pyramids loaded with blast wave from a small explosives charge*, Acta Mechanica et Automatica, Vol. 6, No. 1, 2012.

[9] Panowicz, R., Konarzewski, M., Borkowski, J., Milewski, E., *Selected aspects of modelling a phenomena occurring with very large strain rates on the example of the shaped charge jet stream forming process and explosive formed projectiles*, Journal of KONES, Vol. 22, No. 3, pp. 187-192, 2015.

[10] Panowicz, R., Konarzewski M., Borkowski, J., Milewski, E., *Analysis of the influence of the finite elements mesh density on the determined shaped charge jet parameters*, Journal of KONES, Vol. 22, No. 3, pp. 329-336, 2015.

[11] Sadovsky, M.A., *Mechanical effects of air shockwaves from explosions according to experiments*, in: Geophysics and Physics of Explosion (ed. M.A. Sadovsky), Nauka Press, Moscow 2004.

[12] Sedov, L.I., *Propagation of intense (strong) blast waves*, Prikl. Mat. Mek., Vol. 10, pp. 241-250, 1946.

[13] Syeda, Z.I., Mohameda, O.A., Rahmanb, S.A., *Non-linear finite element analysis of offshore stainless steel blast wall under high impulsive pressure loads*, Procedia Engineering, Vol. 145, pp. 1275-1282, 2016.

[14] Staniukowicz, K.P., *Fizyka wzrywa*, Moscow 1975.

[15] Taylor J.L., *The formation of a blast wave by a very intense explosion* I, Proc. Roy. Soc., Ser. A, Vol. 201, pp. 159-174, 1950.

[16] Włodarczyk, E., *Wstęp do mechaniki wybuchu*, PWN, Warszawa 1994.