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INFLUENCE OF THE SHAPE OF THE EXPLOSIVE CHARGE ON BLAST PROFILE

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Abstract

When an explosive charge is fired, the nature and mass of the explosive are the only parameters of importance usually considered. The shape however, also plays a major role in the effect of an explosive charge. Knowledge of shape effect can be important before the use of the explosive (in order to create a maximum effect with a given mass of explosive), or in post-explosion damage assessment. The shape effect however is only significant within a certain range from the charge. At longer distance, the produced blast wave tends to be spherical. The shock wave parameters studied in this work are the peak overpressure and the first positive impulse. A series of numerical test has been performed in order to determine the range of influence of the charge shape. Different locations of initiation were compared. A hemispherical charge was point detonated at its centre whereas a cylindrical shape was detonated at the centre of an upper or lower plane.

Numerical simulations of near field burst were conducted using LS-DYNA software. During numerical tests a pressure fields were determined for different shapes of explosive charges as well as the pressure waveforms at points located 1000 mm from a centre. Additionally, reference pressure history curves from LOAD_BLAST_ENHANCED procedure were calculated.

Keywords: *cylindrical and rectangular charge, blast overpressure, blast impulse, LS-DYNA, ALE*

1. Introduction

A large part of the work on the impact load is associated with the blast of explosives. With the powerful computational aids now available, it is possible to develop solutions to detonation problems with high conformity with the results of experimental research [1, 3, 4]. When faced with the task of simulating an air blast against a structure the analyst has at his disposal two main techniques. One commonly used approach involves applying the air blast pressures directly to the Lagrangian structure. The blast pressure is computed with empirical equations, which were derived using a compilation of results from air blast experiments. In this approach, there is no need to model the air or explosive. The required input for the empirical equations consists of the explosive charge weight (its equivalent of TNT weight) and its position relative to the structure [6]. As results, a computational cost is less than in other simulation techniques. A disadvantage of this approach is that reflections cannot be accounted for, e.g. as would occur when waves merge after reflecting off structures. Similarly, this method cannot consider shadowing of the blast wave due to the presence of intervening structures. Another commonly used approach involves explicit modelling of the air and explosive with the multi-material arbitrary Lagrangian-Eulerian (MM-ALE) formulation in which appropriate equations of state are assigned to the materials and a burn model controls the explosive's detonation behaviour. The structure of interest is usually treated as Lagrangian and fluid-structure interaction (FSI) [2, 5] is used for communication between it and the ALE domain. The nature of explosive air blast involves a strong shock wave propagating through the air and accordingly the ALE elements must be small enough to capture the nearly discontinuous shock front. The main disadvantage of the MM-ALE solver is the large air domain that typically needs to be included in the air blast model to mitigated boundary effects. The large domain increases the computation time.

When an explosive charge is fired, the nature and mass of the explosive are the only parameters of importance usually considered. Frequently, it is assumed that the explosive is spherical. The shape however, also plays a major role in the effect of an explosive charge [6]. Moreover, offered on the military and civilian market explosives usually have a cylindrical or rectangular shape (Fig. 1). Knowledge of this shape effect can be important before the use of the explosive (in order to create a maximum effect with a given mass of explosive), or in post-explosion damage assessment [4].

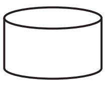
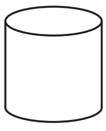
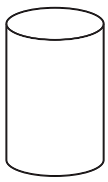
The basic purpose of this paper was to assess an influence of explosive shape and its point of detonation on blast profile. The considerations were worked out on the basis of numerical models.

Fig. 1. Example shape of explosives

2. Research object and methodology

In comparative studies assumed explosive charge shape and their dimension shown in Tab. 1. For comparison, the hemispheric shape of a specified radius was considered as well as pressure waveforms received from LS-DYNA LOAD_BLAST_ENHANCED (LBE) procedure.

Tab.1. Mass and dimensions of explosive charge

2 kg TNT	**4 kg TNT**	**8 kg TNT**
Energy E = 9.372 MJ	Energy E = 18.74 MJ	Energy E = 37.49 MJ
 H R	 H R	 H R
R = 68.4 mm H = 85 mm	R = 68.4 mm H = 170 mm	R =68.4 mm H = 340 mm
Equivalent hemisferical charge radius		
R = 84.2 mm	R = 114.3 mm	R = 133.7 mm

Numerical simulation of near field burst was conducted using LS-DYNA software [2]. Multi-material arbitrary Lagrangian-Eulerian (MM-ALE) algorithm of LS-DYNA software was adopted. The structure model was discretised into finite numbers of elements over which the conservation and constitutive equations are solved. There are two materials in this study: air and explosive, both are modelled with Eulerian meshes.

The air was treated as an ideal gas using the linear polynomial equation of state (EOS) while the Jones-Wilkins-Lee EOS is used to characterize the explosive. Initially the entire ALE mesh were occupied only by air but at the start of the calculation the explosive charge was represented by appropriately initializing the volume fractions of the elements enclosed by its shape (INITIAL_VOLUME_FRACTION function was used). The control of mass of charges was realised by defining initial volume fraction of different materials in multi-material ALE. Different locations of initiation were compared. A hemispherical charge was point detonated at its centre whereas a cylindrical shape was detonated at the centre of an upper or lower plane.

Due to the symmetry, developed model (Fig. 2) represented quarter of complete structure. The air box with dimension 1.2x1.2x1.8 m was discretized into 2 592 000 Eulerian hexahedra elements. Virtual pressure sensors were placed at every 25° angles one meter from the centre.

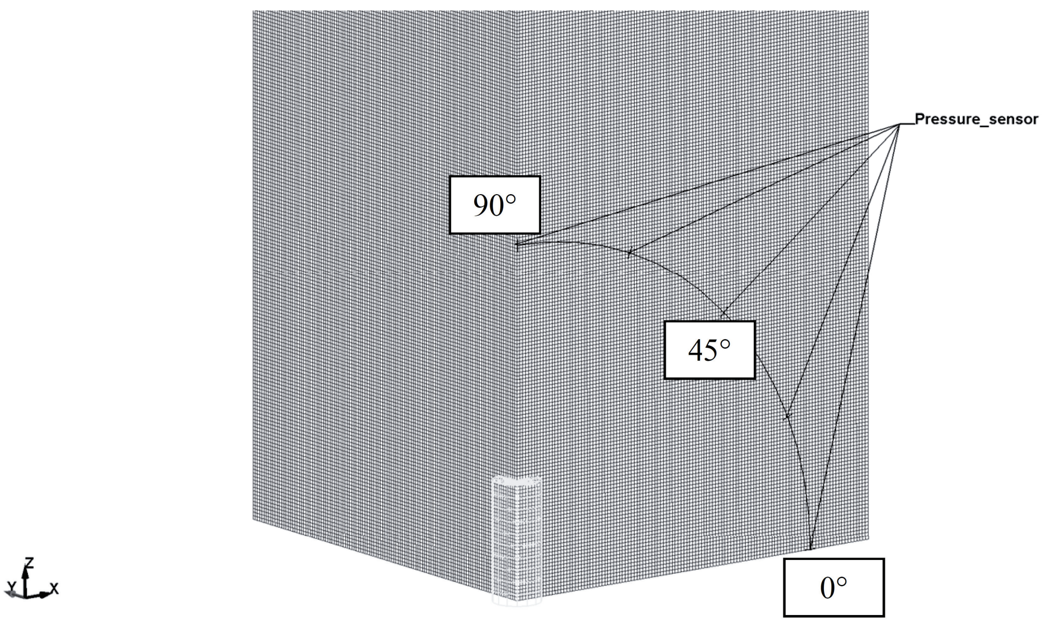


Fig. 2. Air blast model

3. Test results

The main aim of this study was investigation of the airblast propagation of near-field burst. During numerical tests a pressure fields were determined for different shapes of explosive charges as well as the pressure waveforms at points located 1000 mm from a centre.

Figure 3 compares pressure wave propagation for cylindrical and hemispherical explosives weighing 8 kg TNT. For a spherical charge, the gas propagates proportionately in all directions. The energy expands into an increasing volume. To cylindrical charge, in the first phase burning is mainly observed toward the ground. The results show clearly the details of the main shock shape, the reflection from the ground and the second shock. After reaching the ground plane pressure wave propagates largely in a direction parallel to this plane. A smaller part of the energy of explosion propagates in the vertical direction. For a cylindrical shape of charge the shock front faster reach the height of 1000 mm, but as a consequence a smaller pressure impulse is observed.

The pressure profile over time of a blast wave can be characterized by its arrival time, the peak overpressure, the duration of the positive phase and the total duration. In the most common case, by considering spherical explosions in air from explosives, these quantities can be measured precisely in terms of the energy released, which is typically related to the mass of the explosive and is most commonly related to TNT.

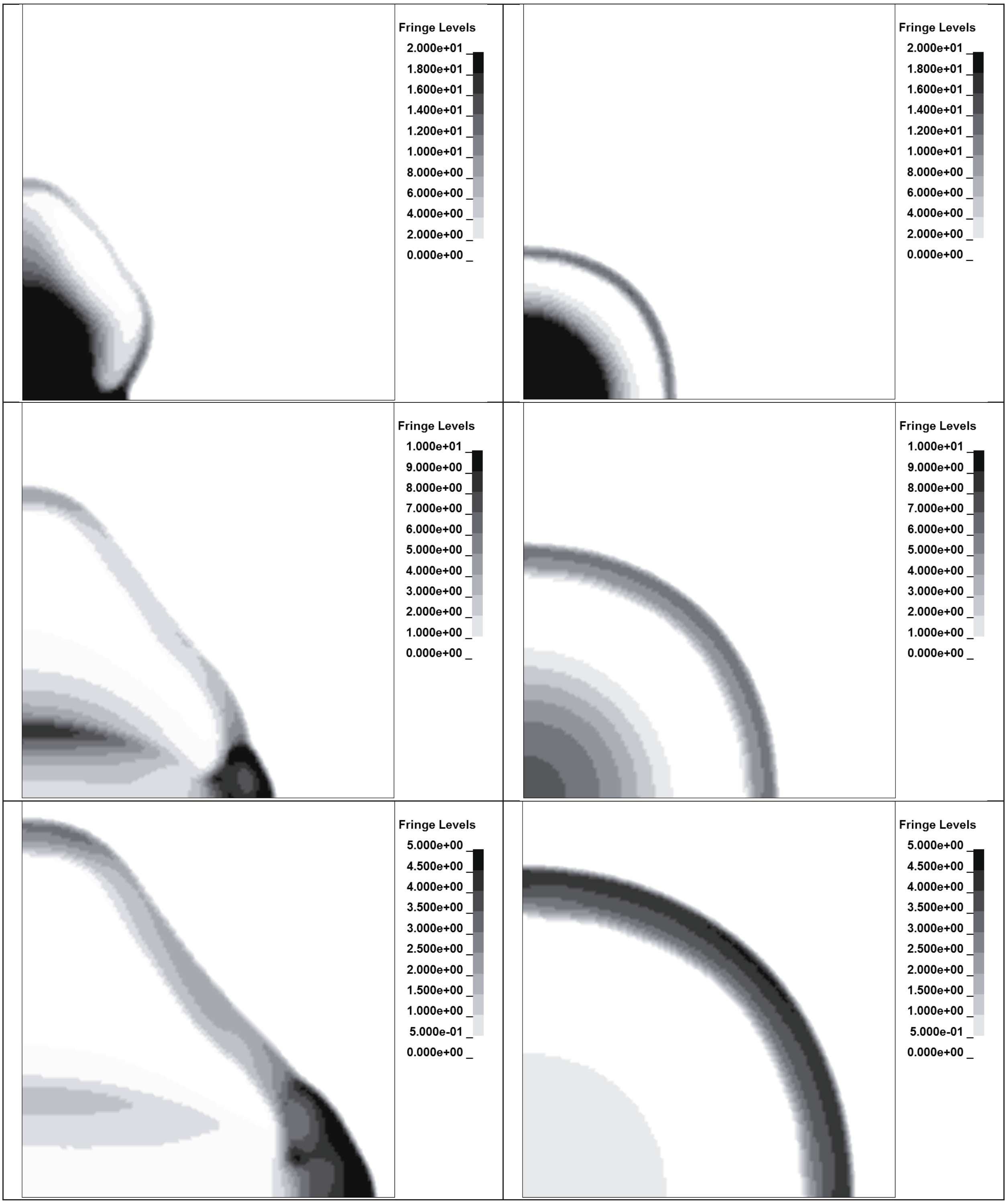


Fig. 3. Pressure wave propagation - cylindrical (left) and hemispherical shape (right) [MPa], t = 0.1; 0.2; 0.3 ms

Figure 4 compares the pressure history recorded at pressure sensors located at every 22.5° angles one meter from the centre. The maximum pressure value has received for parallel to ground direction (0°). It amounts to 8.5 MPa and is almost twice as high as the pressure at a point located above charge (4.7 MPa). Additionally, there is also a longer duration which increases the pressure impulse. Although damage is most often associated with the peak pressure, the duration and impulse of blast waves are also important parameters. The smallest value of pressure has been registered for 45° direction. The magnitude of the overpressure amounts to 2.1 MPa. For this direction the longest arrival time is observed.

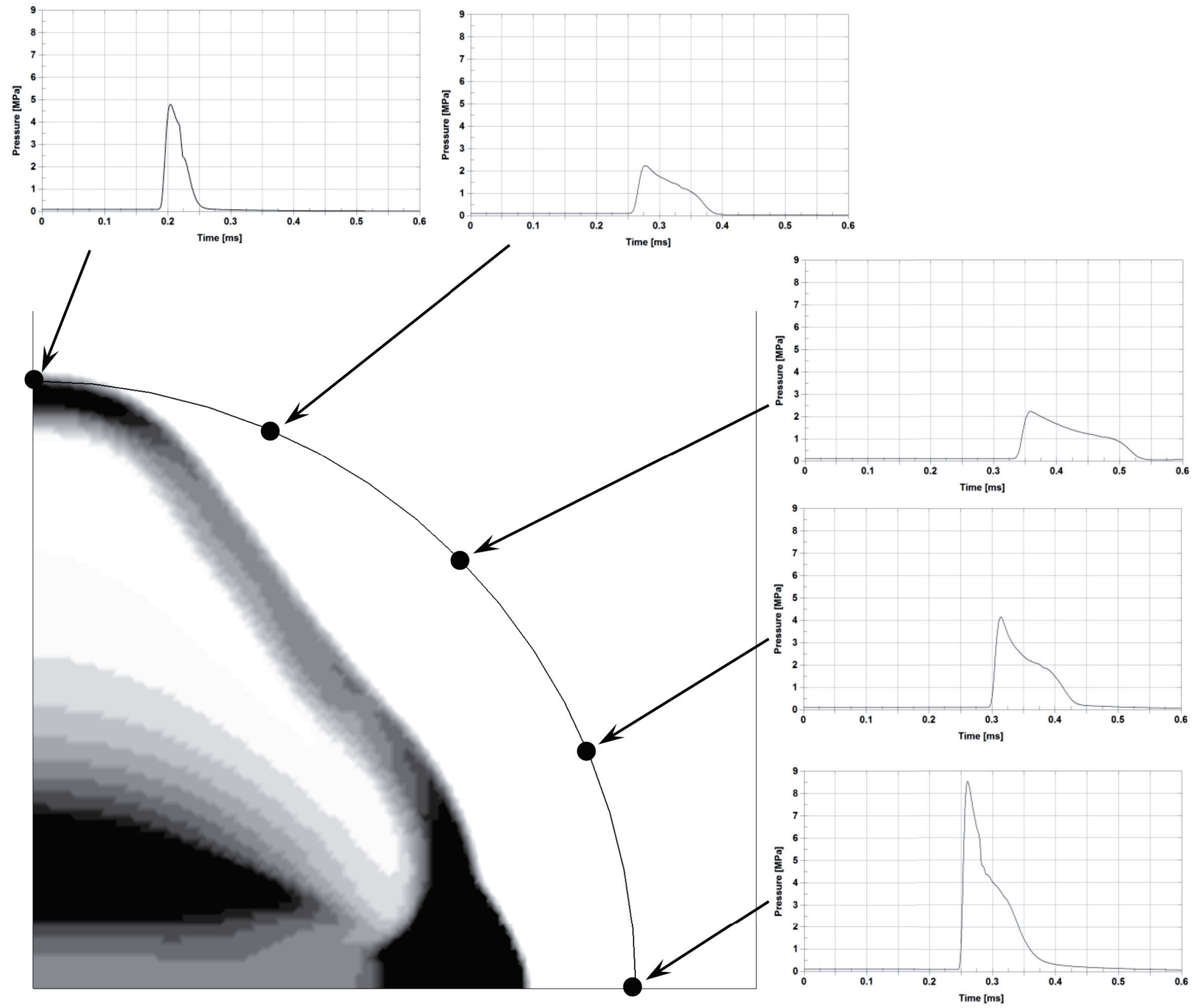


Fig. 4. The pressure history for different direction – 8 kg TNT – cylindrical shape

Figure 5 and 6 compares the waveforms of pressure and pressure impulse for a payload of 8 kg TNT. Additionally, they shows reference pressure history curve from LOAD_BLAST_ENHANCED procedure. As should be expected, pressure histories for hemispherical shape charge is very similar to pressure from LBE procedure – on both the pressure wave arrival time, reached the maximum value and the duration.

An arrival time is the shortest for cylindrical shape of explosive, which was detonated at the bottom plane. The magnitude of the overpressure for this case is the biggest too (10.5 MPa). The duration of the positive phase is very short, thus a pressure impulse is the smallest.

As shown in Fig. 5 and 6, maximum overpressure for cylindrical shape of explosive, which was detonated at the upper plane, is very similar to pressure from hemispherical shape. Nonetheless, a significant difference with duration is observed. As a result, a pressure impulse is almost two times less.

In Tab. 2, overpressure and impulse values are given for analysed cases. Values of pressures and impulses for hemispherical charge in all the variants do not differ significantly from the values obtained from the LBE procedure.

The location of the initiation influences the pressure distribution, certainly at the direction above the charge (90°). For cylindrical shape of explosive, which was detonated at the upper plane, increasing the ratio of H/R causes the value of the pressure in 90° direction is getting smaller in relation to parallel to ground direction. A smaller is also the ratio of pressure impulse.

This pattern is not observed for charge detonated at the bottom plane. For all masses of charge, the pressure values for 90° direction are greater than for 0°. At the same time, the value of the pressure impulse is significantly less. This is the effect of the short duration of positive phase.

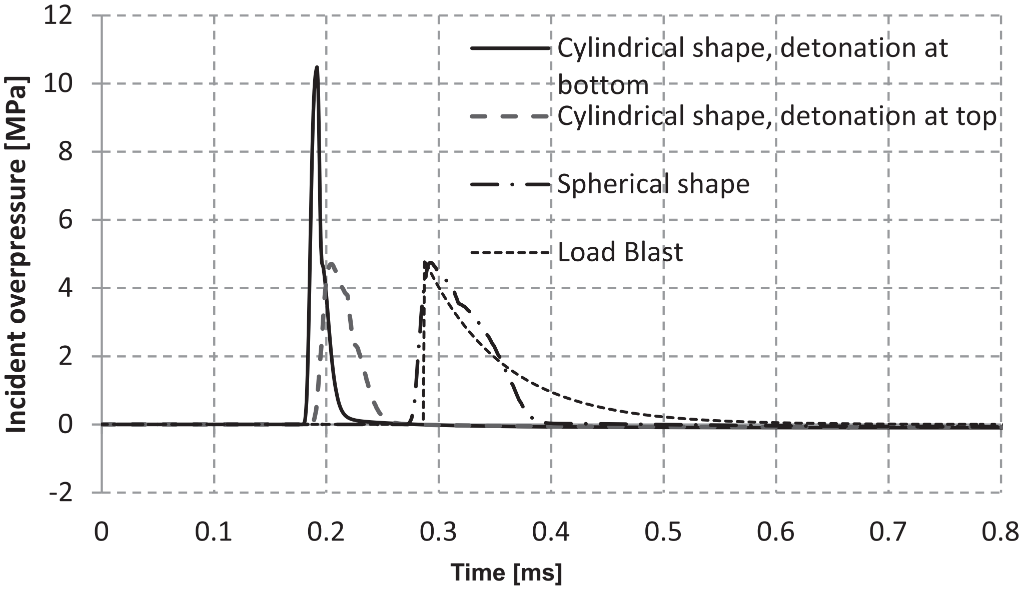


Fig. 5. The view of a test track with a rigid retaining wall and a personnel carrier prepared for a crash test

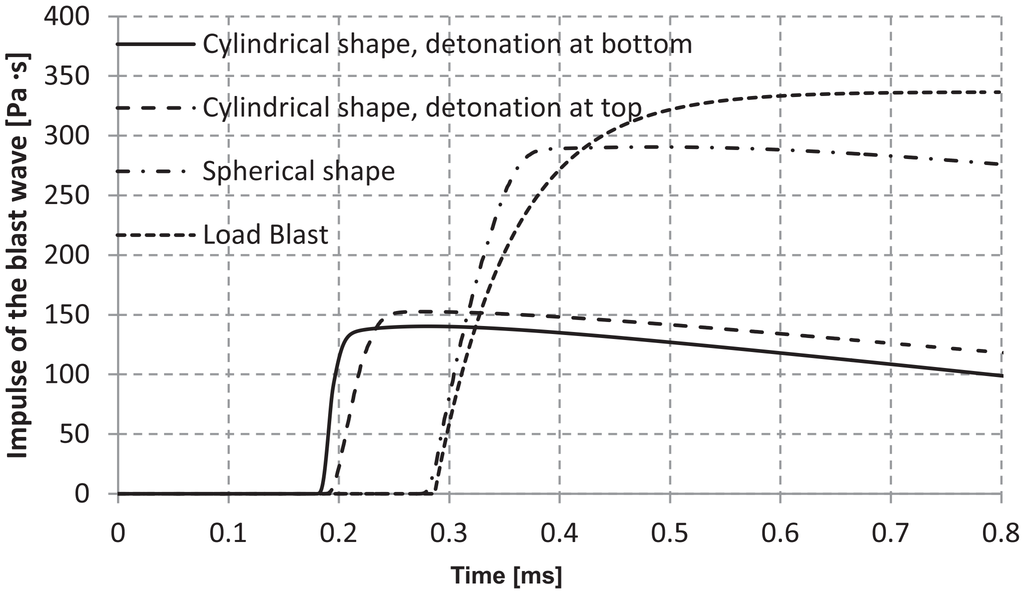


Fig. 6. A dummy located in the driver compartment (left) and in the landing troop compartment (right)

4. Summary

Knowledge of the blast properties, especially at the short range, is important for the prediction of its effects. Issues related to the air detonation require including basic factors, such as dimensions, shape of charges and the type of explosive. These elements have a significant impact on pressure values and impulse of blast wave in air in different directions, especially close to explosion. Using computers models is possible very detailed analysis and quantitative assessment of the impact explosion on environment.

The majority of experimental test results are related to spherical shape of explosive charge. Unfortunately, there is a lack of a sufficient number of test results for other shapes. For this reason, there are some difficulties in accurately defining the impact of charge shape on structure.

Tab. 2. Magnitude of overpressures and impulses

		Overpressure [MPa] / Impulse [Pa·s]			
Explosive charge shape		Cylindrical		Hemispherical	LOAD_BLAST
Charge mass	Detonation point / Direction	Top	Bottom	Centre	---
2 kg TNT	90°	2.96 / 179	4.90 / 176	1.97 / 244	2.16 / 256
	67.5°	2.15 / 153	2.52 / 189		
	45°	1.94 / 249	1.53 / 259		
	22.5°	4.05 / 272	5.53 / 282		
	0°	3.89 / 169	2.94 / 205		
4 kg TNT	90°	3.27 / 172	6.96 / 159	3.24 / 256	3.31 / 280
	67.5°	1.78 / 146	1.89 / 165		
	45°	2.07 / 276	1.98 / 288		
	22.5°	2.42 / 239	2.80 / 214		
	0°	4.94 / 214	4.83 / 304		
8 kg TNT	90°	4.70 / 153	10.47 / 140	4.75 / 291	4.82 / 336
	67.5°	1.69 / 147	1.54 / 153		
	45°	2.13 / 232	2.74 / 294		
	22.5°	1.68 / 236	1.65 / 228		
	0°	8.46 / 472	5.50 / 470		

The use of numerical models of blast wave has many advantages. These include more precise estimates of the energy and resulting pressure of the blast wave, as well as the ability to evaluate non-symmetrical effects caused by realistic geometries and ignition locations. This knowledge can be important before the use of the explosive (in order to create a maximum effect with a given mass of explosive), or in post-explosion damage assessment.

The shape of the charge can play an important factor on blast profile. Often, in actual applications, explosive charges have a non-spherical or even unsymmetrical shape. Spherical charges lead to symmetrical effects, whereas elongated charges lead to asymmetry in the pressure field. It should, however, be stressed that the shape effect is only significant within a certain range from the charge. For far field of explosion this effect is less important. At longer distance, the produced blast wave tends to be spherical.

Further numerical test would be used to simulate the other (e.g. rectangular) shapes of the explosive and evaluate the influence of the position of ignition point and the orientation of the plate on the pressure waves.

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