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Blast wave dynamics: The influence of the shape of the explosive

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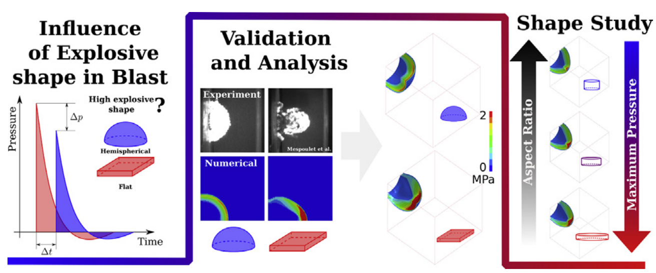
HIGHLIGHTS

- The authors proposed a numerical model to analyse blast wave dynamics.
- Study influence of pre-detonation shape of the high-explosive.
- Study influence of mass of explosive.
- Shape of explosive strongly influences blast wave dynamics and resulting pressure/impulse.

GRAPHICAL ABSTRACT



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ABSTRACT

A numerical model is developed to analyse the influence of the shape of a high-explosive on the dynamics of the generated pressure wave. A Multi-Material Arbitrary Lagrangian Eulerian (MM-ALE) technique is used as the CONWEP approach is not adequate to model such situations. Validation and verification of the proposed numerical model is achieved based on experimental data obtained from the bibliography. The numerical model provides relevant information that cannot be obtained from the experimental results. The influence of the mass and shape of the high-explosive is studied and correlated to the dynamics of the generated blast wave through the analysis of peak pressures, time of arrival and impulse. Tests are done with constant mass hemispherical, cylindrical and flat-shaped Formex F4HV samples. A detailed analysis of the generated blast wave is done, along with a thorough comparison between incident and reflected waves. It is concluded that the dynamic effects of the reflected pressure pulses should always be considered in structural design, most relevantly when analysing closed structures where the number of reflections can be significant. The model is proved reliable, concluding that the frontal area of the high-explosive is a determinant driving parameter for the impulse generated by the blast.

1. Introduction

Anticipating the effects of an explosion is a major task when designing blast protection structures, both for defence or accident mitigation, or in accident/attack reconstruction. From this perspective, the most relevant physical parameters are directly related to the generated pressure pulse (overpressure, time of arrival, etc.), the induced impulse on the structure and the configuration of the blast wave. This paper focuses on this latter aspect and the novel contribution proposed by the authors is the assessment of which geometrical factors — initial shape of the high-explosive (HE) — are most relevant and determinant for the shape of the blast wave, and how this will affect the generated pressure and impulse.

In the past, authors have studied the evolution of the shape of a blast wave when it interacts with structures. Benselama et al. [1] studied the interaction of a blast wave and quadrangular cross-section tunnel structures. These authors performed a set of parametric analyses looking into the effect of the aspect ratio of the cross section of the tunnel and the relative initial position

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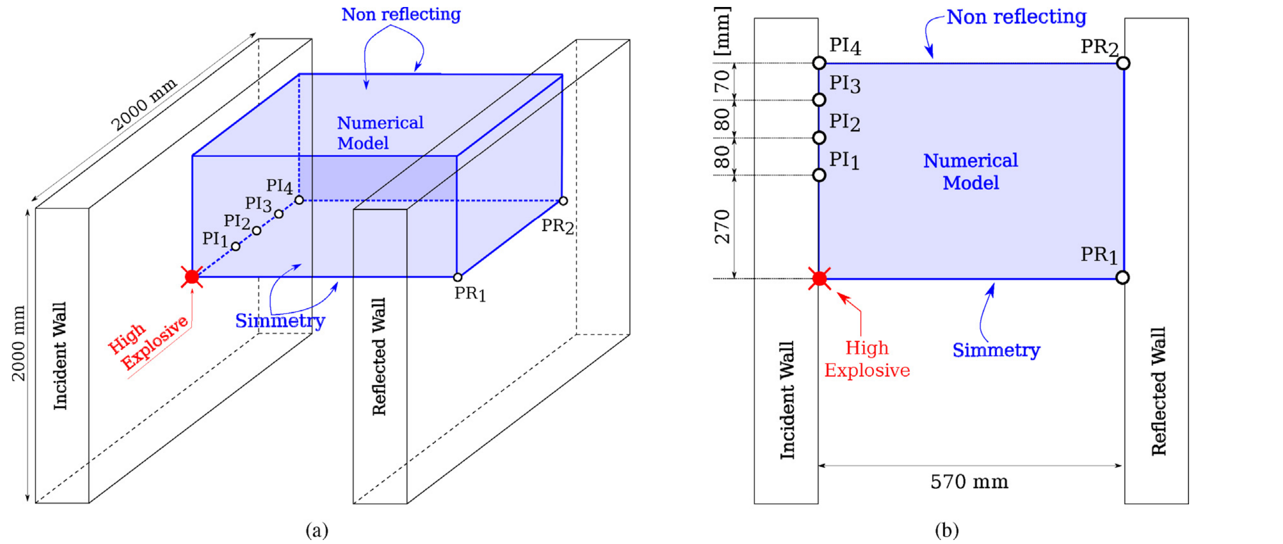

Fig. 1. (a) 3D and (b) top views of the experimental setup according to Lefrancois et al. [5]. Highlighted in blue is the physical region that is numerically modelled in the present paper (not to scale).

of the explosive on the development of the blast wave. They concluded that geometrical aspects, namely the ratio of the HE mass to the hydraulic diameter of the tunnel, are highly relevant parameters. However, all observations and analyses were based on the assumption that the initial blast wave (i.e. before it interacts with the structure) is spherical.

Other studies, such as the ones by Larcher et al. [2] and Clutter and Stahl [3], adopt a larger scale approach, and discuss the effect of a HE generated blast wave on complex structures such as train carriages and large offshore structures or clusters of structures, but again assuming that the initial shape of the blast wave is spherical. Larcher et al. [2] developed a complex numerical model to analyse the effects of venting on the evolution of pressure and impulse after a detonation. They thoroughly analysed the effect of different venting areas and mass of explosive, both on simple tunnel-like structures and realistic train carriages, effectively contributing to the knowledge that venting areas have a drastic influence on the effects (including injury levels) of an explosion. The earlier study by Clutter and Stahl [3] analyses the interaction of a blast wave generated by a HE detonation on different scenarios with highly complex configurations and geometries, such as industrial sites, urban environments and off-shore facilities. They proposed a novel approach to represent the explosive source term, using an enthalpy formulation, validate this using several shock-tube experiments and further expand their model to study the relevance of the geometrical detailing when modelling complex environment and blast waves.

Most of the publications on this topic, however, are mostly concerned with the interaction effects and the geometry and configuration of surrounding structures, not specifically with the shape of the blast wave front, almost always assuming an initially spherical blast wave, as can be additionally substantiated by the work of Vanderstraeten et al. [4]. Conversely, in the present work the authors are mostly concerned with the relation between the pre-detonation shape of the high-explosive and the post-detonation configuration and shape of the blast wave and the generated pressure and impulse. A numerical model is developed to analyze this and is validated using the experimental results obtained by Lefrancois et al. [5] and Mespoulet et al. [6]. The influence of the mass and shape of the high-explosive is analysed and correlated to the dynamics of the generated blast wave through the analysis of peak pressures, time of arrival and impulse.

2. Numerical modelling

A numerical model is developed to study the influence of the pre-detonation shape of the high-explosive on the blast wave formation and dynamics. For validation purposes, the obtained results are compared to experimental observations by Lefrancois et al. [5] and Mespoulet et al. [6]. These authors used a 14.2 g hemispherical (13.5 [mm] of radius) and a 15 g flat explosive ($120 \times 60 \times 1.5$ [mm^3]) to study the influence of different HE shapes on the profile of the blast wave. The composition of the HE used is PETN/rubber with a 89/11 ratio, commercially known as Formex F4HV. The following sections describe in detail the setup of the numerical model was setup in these sections.

2.1. Geometry, domain, boundary conditions and discretisation

The diagram in Fig. 1 is an overview of the whole experimental and numerical setup. As can be seen, the high-explosive is positioned at the centre of a 2000×2000 [mm^2] high density concrete wall, designated by incident wall (IW). Four pressure transducers (PI_i with $i = 1, \ldots, 4$) are located along this wall spaced as indicated. A second parallel concrete wall is positioned 570 mm from the incident wall, with two additional pressure transducers (PR_1 and PR_2), designated by reflected wall (RW). The pressure transducers used in the experimental setup were PCB piezoelectric gauges and the explosions were recorded at 30, 000 fps using a Photron high speed video camera.

The commercial finite element analysis (FEA) package LS-Dyna [7] is used to reproduce the experimental tests and ultimately better understand how the initial (pre-detonation) shape of the high-explosive influences the development and propagation of the resulting blast wave. The CONWEP approach is often used to model blast waves and is implemented in LS-Dyna [8–16]. However, this method cannot be used in the scope of the work here presented as it is only suited for spherical HE, which will ultimately generate spherical blast wave fronts, regardless of the shape of the HE.

Additionally, adopting a finite element (FE) Lagrangian technique is also not adequate as this approach will fail to accurately reproduce the generation and propagation of the blast wave. This is mostly due to the high levels of deformation and strain that will develop, leading to severe element distortions and ultimately numerical instabilities (e.g. time integration instabilities) [17,18].