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External explosion in an industrial site

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ABSTRACT

The scenario of an intentional explosion in an industrial site is studied here with the objective of understanding the propagation and interaction of shock waves in a complex environment standing for a gas storage warehouse. We conducted a small-scale experimental study supported by numerical simulations in order to lead a discussion. We are interested in the effects of an explosive charge located at the entrance of the gas storage infrastructure. The walls of the gas storage infrastructure and bottles of gas are assumed to be undeformable in this study. The propagation and reflection of the shock waves with overpressure effects are assessed in this study.

1. Introduction

It is necessary to estimate and evaluate the effects of explosions in real-world scenarios in varied and complex environments to protect the stored goods and people working on sites that store, transport or handle flammable and dangerous materials.

Explosions in complex geometries have mainly been studied in urban environments. Remennikov and Rose (2005), Smith, Whalen, Feng, and Rose (2001) and Smith and Rose (2002, 2006) highlight the interaction between two buildings as well as the influence of the density of buildings on focusing and reflecting explosive waves, leading to overpressures and impulses that are quite higher than those obtained in a free field. Studies relating to industrial facilities are often limited to the case of deflagrations (Dadashzadeh, Abbassi, Khan, & Hawboldt, 2013; Hansen, Hinze, Engel, & Davis, 2010).

In this work, we are interested in the effects and analysis of the phenomena of the reflection of consecutive shock waves relative to the detonation within a gas storage warehouse. The scenario studied is more related to a terrorist scenario with detonation of explosive charges. Here, we propose a two-pronged approach consisting of a small-scale experimental study and a work supported by numerical simulations. The use of a Computational Fluid Dynamics-based explosion model allows for an analysis of the dynamics of blast waves in the presence of interactions with multiple objects, supplementing the experimental results.

2. Experimental description

This experimental study is carried out on a small scale (1:20) on the bench using a detonation, as previously described by the PRISME laboratory (Sauvan & Sochet, 2012; Sauvan, Sochet, & Trélat, 2012; Trélat, Sochet, Autrusson, Horse, & Loiseau, 2007). The explosive load consists of a hemisphere (a soap half-bubble) filled with a stoichiometric propane–oxygen gaseous mixture with a radius of 0.05 m; detonation is ensured by an explosive wire releasing a nominal energy of 200 J. The detonation was checked by placing a pressure gauge inside the confinement of gaseous charge at 3.5 cm from the center of the ignition source. The maximum pressure measured is 30 bar and the time for the pressure rise is of 3 μs. Consequently, the detonation can propagate until the boundary of the bubble and this measure confirms that a detonation is really created inside the hemispherical gaseous charge.

The resulting shock wave is characterized by the arrival time, overpressure, duration of positive phase and impulse via pressure gauges and the acquisition system. However, only overpressures will be discussed in this article.

The configuration studied here represents the detonation of an explosive load at the entrance of a gas storage warehouse with a "U-shape" which is a standard shape for storage bottles of high-pressure gas (Fig. 2a). The gas storage warehouse is open on one side and does not have a roof. The bottles of gas are stored

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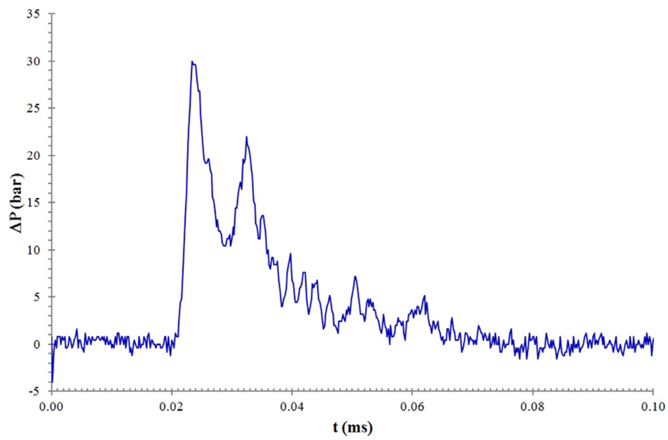

Fig. 1. Pressure profile inside the hemispherical confinement at 3.5 cm from the center of ignition source.

horizontally within a metal bottle crate (Fig. 2b). The model is a 1/20 scale reproduction representing an enclosure of 800 × 550 mm on its sides and 250 mm in height. The warehouse is made entirely out of transparent plexiglass with a thickness of 25 mm.

Fig. 2a presents the exact positions of the pressure gauges placed on the surface of the bench for the explosion tests, with the charge centered at the entrance of the warehouse. The sensors inside are named IG (Interior Gauge) and those outside are named EG (Exterior Gauge).

Tests were carried out in a free field before model testing. Thus, the evolution of overpressure relative to distance was reduced for a spherical gas load, described by $Z_G = R/M_G^{1/3}$ (R, distance between the center of the explosive charge and the point of measurement, M_G, mass explosive load), and can be expressed as the following law:

$$\ln(\Delta P) = 1.486 - 1.782 \times \ln(Z_G) - 0.104 \ln(Z_G)^2 + 0.115 \ln(Z_G)^3 - 0.017 \ln(Z_G)^4$$

(Sauvan et al. 2012) with ΔP (bar) and $0.84 < Z_G(\text{kg m}^{-1/3}) < 14$.

3. Experimental analysis of pressure profiles

3.1. Pressure profiles obtained inside storage warehouses

The presence of the structure and bottle crates generates the appearance of significant overpressure peaks at the pressure gauges located inside the structure. For sensor IG1 (Fig. 3), the

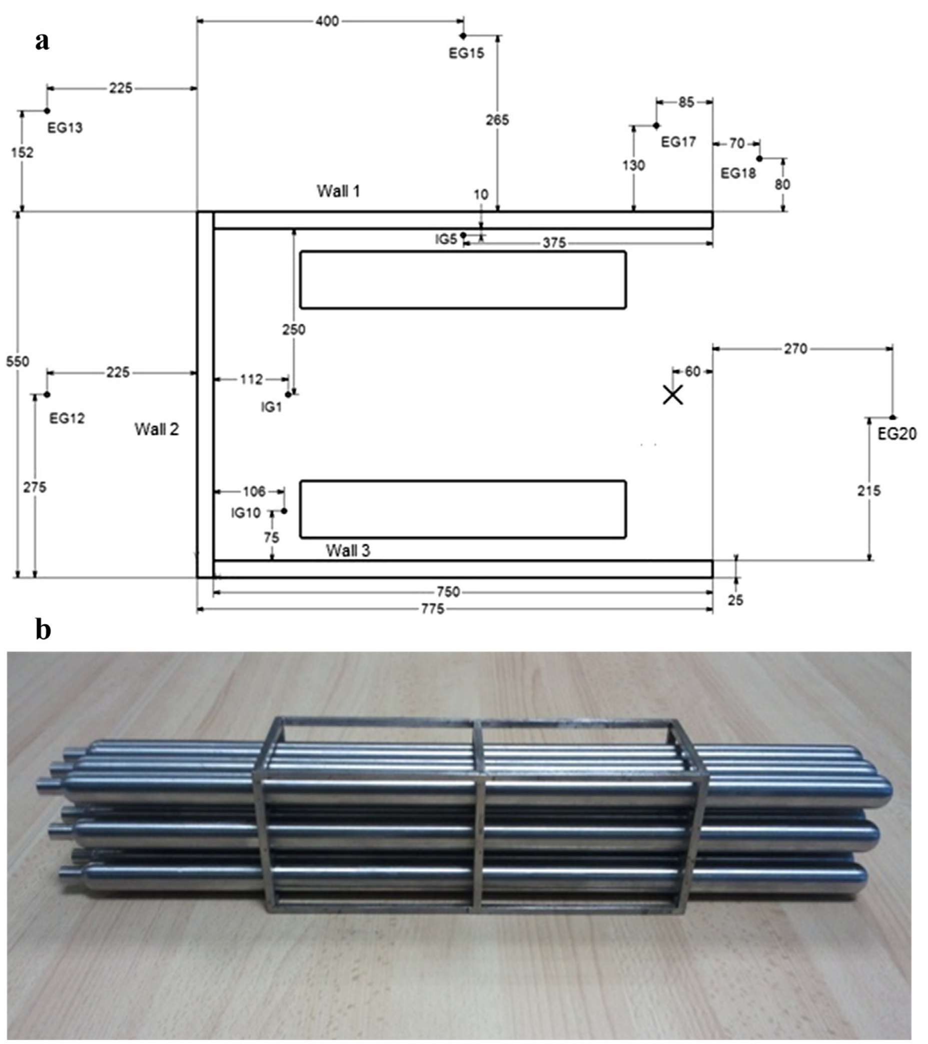

Fig. 2. a: Diagram of the model with the charge centered at the entrance of the gas storage warehouse and the positions of the pressure gauges (distances provided in millimeters). b: Photograph of the bottles arrangement at a reduced scale.