International Journal of Impact Engineering 90 (2016) 46–60

Contents lists available at ScienceDirect

International Journal of Impact Engineering

journal homepage: www.elsevier.com/locate/ijimpeng

Prediction of the quasi-static pressure in confined and partially confined explosions and its application to blast response simulation of flexible structures

V.R. Feldgun [a,*], Y.S. Karinski [a], I. Edri [b], D.Z. Yankelevsky [c]

[a] National Building Research Institute, Technion, Haifa, Israel
[b] Faculty of Civil & Environmental Engineering, Technion, Haifa, Israel
[c] Faculty of Civil & Environmental Engineering, National Building Research Institute, Technion, Haifa, Israel

ARTICLE INFO

Article history:
Received 24 July 2014
Received in revised form 1 October 2015
Accepted 1 December 2015
Available online 14 December 2015

Keywords:
Confined explosion
Gas pressure
Afterburning
Detonation products
Blast response

ABSTRACT

The paper aims at understanding some characteristics of an interior explosion within a room with limited venting. Internal explosions may occur as a result of an ammunition storage explosion, or a charge explosion within a room in a terrorist action or a warhead explosion following its penetration into a closed space. The paper deals with one of the basic aspects of internal blast – residual blast pressure (gas pressure, quasi-static pressure). The article presents different models for the prediction of the gas pressure. The sensitivity of the gas pressure to the heat capacity ratio and internal energy of explosion is studied. It is demonstrated that the heat capacity ratio has a much stronger effect on the gas pressure than the internal energy of explosion. It is shown that a thermodynamic model based on accounting for the afterburning energy release shows best agreement with experimental data. This method takes into account the variation of the total energy released and the heat capacity ratio depending on the ratio between the charge weight divided by the confined air volume. It is demonstrated that the proposed simplified approach based on using the developed gas pressure as well as on the Bernoulli equation for the quasi-stationary phase is well suited for simulation of partially confined explosions and properly describes the pressure relief and gas outflow from the vented room. The developed gas pressure can be successfully applied to simulation of confined blast response of flexible structures. An analytical solution of the SDOF blast response of a flexible structure is implemented. It is shown that the simplified approach based on the quasi-static gas pressure properly describes the elastic-plastic shell behaviour. It shows a good agreement with test data and with a solution using pressure time history obtained by AUTODYN simulation.

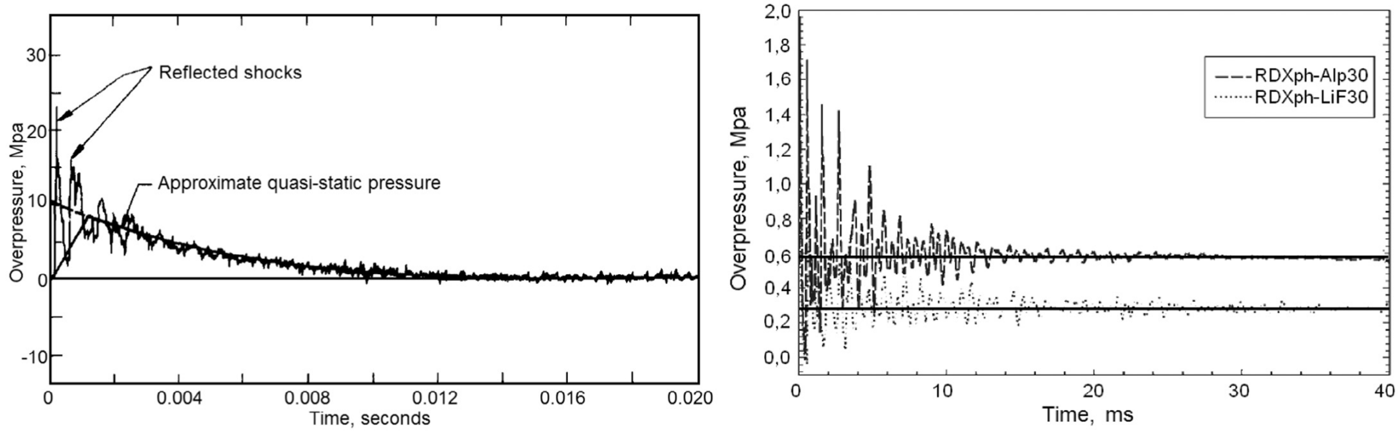
1. Introduction

Confined explosions may occur due to various reasons and their effects may be extremely severe and may lead to serious damage to structural elements and even to structural collapse [1]. The confined explosion causes more damage than a similar external free-air explosion, and this damage depends on the geometrical parameters of the space where the explosion occurs (geometrical dimensions, the charge location, the openings' size and location, etc.) as well as on the charge characteristics. The analysis of an internal explosion in a confined space aims at both assessment of the pressures acting on the inner space boundary and the response analysis of the boundary structural elements to predict the elements' response and assess the induced damage. The damages occur shortly after the shock waves' arrival at the structural components and may lead to further collapse of the entire structure [2,3]. Such an analysis may be performed either without coupling of the pressure prediction and the structural dynamic response [4–6] or with coupling [7–11]. The first stage of the analysis of this general problem is the prediction of the contact pressures acting on the inner sides of the surrounding structural elements (walls, ceiling, floor, dividing partitions etc.) depending on the charge properties and location, the confined space geometry, the presence of openings in the elements, their size and location, etc. The basis of the analysis is the problem of the shock wave interaction with the boundaries of the confined space. This is a well known problem that has been studied in many books [12–14], handbooks [15,16], manuals [17–20], papers [21–28], reports [29,30].

Typical time histories of pressures acting on the wall of a vented- and fully confined structure are shown in Fig. 1a and Fig. 1b respectively [31,32]. It can be seen that the loading from an explosive charge detonated within a vented structure consists of two almost distinct phases (Fig. 1a). The first phase presents the reflected blast

* Corresponding author. National Building Research Institute, Technion-IIT, 32000 Haifa, Israel. Tel.: +972 4 8292244; Fax: +972 4 8324534.
E-mail address: aefeldgo@technion.ac.il (V.R. Feldgun).

http://dx.doi.org/10.1016/j.ijimpeng.2015.12.001
0734-743X/



a) vented structure [31] b) fully confined structure [32]

Fig. 1. Typical pressure–time history of an explosion.

loading. It consists of the initial high pressure, short duration reflected wave, plus several following reflected shocks. The second phase is characterized by a slowly decaying pressure. Its magnitude and variation with time is a function of the volume and the venting area of the structure.

In the case of a fully confined structure (Fig. 1b), the above first phase includes the following reflected shocks occurring during the process; however, the second phase is not characterized by a decaying pressure. The residual quasi-static gas pressure that is developed in the explosion process remains rather constant in that case for a rather long time. It should be noted that the partially confined explosion may be modelled by the above mentioned second (quasi-stationary) phase that starts at a pressure which is a result of the same explosion, but in fully confined space. Anderson et al. [31] reviewed test results and prediction methods for gas pressures for many types of internal explosions including high explosives, high explosives plus combustibles, gas mixtures and dust suspensions. It should be noted that all these methods are based on various empirical relationships [33–39]. Various computerized approaches for blast loads from confined explosions are presented in different papers [40–42]. Different sources present (Figs. 2, 3) graphs of the peak gas pressure as a function of W/V (W/V is the ratio between the charge weight (W) and the free volume of the structure (V)).

In earlier recent papers that were written by the authors, a full scale experimental study was presented [6,43,44], in which TNT charges were detonated at the centre of a cubicle room with rigid boundaries that had limited venting in its roof. 2-D and 3-D numerical models were presented by the authors in Reference 6. The models aim at studying and validating the developed blast pressures and at gaining a new insight regarding the pressure distribution on the walls as well as the pressure attenuation. Furthermore, investigation of the influence of TNT afterburning in a confined explosion scenario was presented [45] including a comparison to the full-scale experimental data to quantify and evaluate the results.

The present paper deals with one of the basic aspects of the internal blast – the residual blast pressure (gas pressure, quasi-static pressure). This paper presents different models developed by the authors for the prediction of the gas pressure and shows that a thermodynamic model that accounts for the afterburning energy release is in best agreement with experimental data. The predicted gas pressure is applied in simulation of a partially confined explosion and analysis of the blast response of flexible structures.

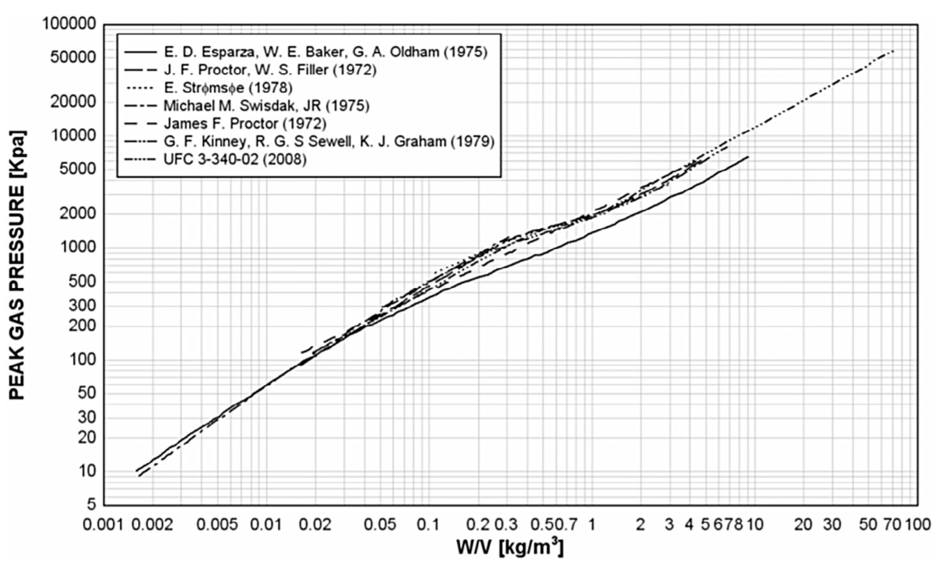


Fig. 2. Comparison of different proposed experimental relationships for the peak gas pressure as a function of W/V.