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The response of plates subjected to loading arising from the detonation of different shapes of plastic explosive

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ABSTRACT

The response of circular steel plates subjected to loading arising from the detonation of plastic explosive PE4 was investigated experimentally. The shape of the explosive charge, the charge dimensions and the charge mass were varied during the experiments. Cylindrical, truncated cone and the inverted truncated cone shaped explosives were detonated in close proximity to fully clamped circular plates fixed to a ballistic pendulum. The impulse, for the detonation of a given charge mass, was found to be highest for the inverted truncated cone. However, the maximum permanent displacement of the circular plates was greatest for the truncated cone shape. An analytical approach, combining the ZND detonation model with the concept of effective mass of explosive, was developed to gain understanding of the shape and intensity of the shock wave resulting from the explosion. The distribution of the shock wave obtained from the analytical approach was used to explain some of the experimental observations.

1. Introduction

The response of circular metal plates subjected to localised airblast loading has been an ongoing subject of research for the last twenty years. Nurick and co-workers [1–5] have performed various investigations on steel plates by detonating centrally located disks of plastic explosive (PE4). The mass of explosive has been varied by altering the dimensions of the PE4 disk (diameter, charge height) to produce failure modes including plastic deformation, partial tearing, capping [1,2] and petalling [3] in the central region. The plate profiles were different compared to uniformly loaded plates. Instead of a global dome, the locally loaded plates exhibited a secondary inner dome atop the outer global dome [1]. The inner dome diameter increased with increased charge diameter, as might be expected. The influence of load to plate diameter ratio on the response of locally blast-loaded circular plates with built-in boundaries has also been investigated [3]. For load to plate diameter ratios above 0.4, the loading was less localised – tearing failure occurred at the plate boundary rather than in the central region [3].

In some cases, the explosive charges used in these investigations are referred to as disks (with a low charge height to diameter ratio), and in other cases, the charges are called cylinders (higher charge height to diameter ratio). However, in all these investigations, the charge had a constant cross-section throughout the explosive thickness used in each test.

In order to more fully understand the localised blast loading response of structures, attempts have been made to describe the spatial and temporal distribution of the blast loading impinging upon the surface of the target structure. Different approaches to this can be summarised into the following types:

- Experimental measurements: often employing pressure transducers in the far-field [6] or Hopkinson bars in the near field [7]. These give a smeared 'global' pressure [6] or force [7] distribution across the area of the measuring instrument.
- Simple detonation mechanisms: modelling the formation of detonation and subsequent blast waves using theories such as the ZND model [8,9] and the Gurney model [10].
- Empirical approaches: scaling laws such as TNT equivalence method, Hopkinson-Cranz scaling [11,12] and equations based upon large scale field tests. Pressures at range are most often empirically predicted using equations developed by Kingery and Bulmash [13] which are based on experimental data from TNT detonations. The US Conventional Weapons Effects Programme (CONWEP) software is based on these equations. Spranghers et al. [14] and Henchie et al. [15] have employed the Conwep approach to obtain blast loading pressures; the Conwep predictions were used with commercial numerical modelling codes to predict

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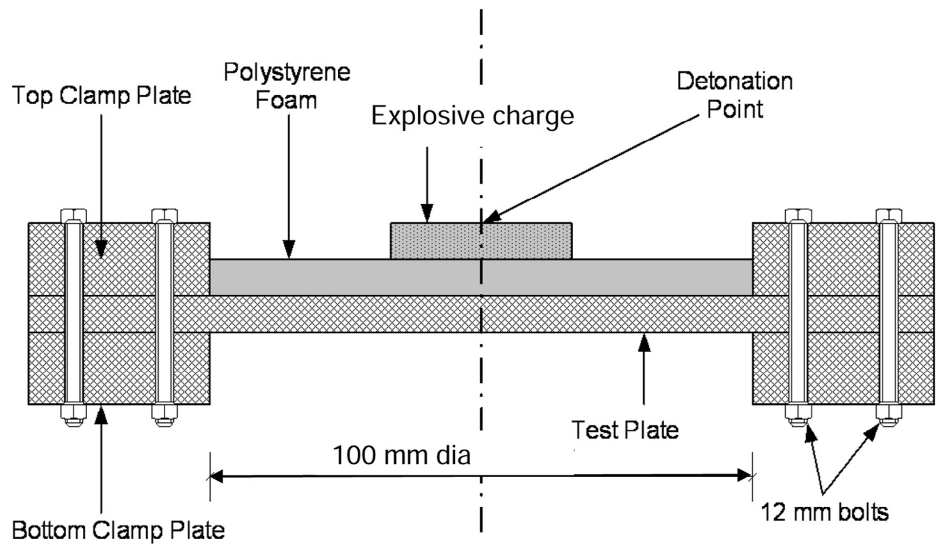

Fig. 1. Schematic of clamping arrangement (showing cylindrical charge shape).

the structural response. Empirical approaches do not work in near-field explosions, only in the far-field.

- Gas dynamics approach: incorporating equations of state (for example, the JWL equation of state) to describe explosive detonation and development of blast waves [16]. This approach has been incorporated into several commercial modelling codes such as LS Dyna [17] and Autodyn [18]. This can provide accurate simulations of the pressure development resulting from the combustion products generated during the detonation process, and a number of researchers (for examples, see work by Chung Kim Yuen et al. [19], Li et al. [20] and Langdon et al. [21]) have been using these codes to model the response of structures to explosion loading.
- Manual estimations based on the assumption of impulsive loading (which are subsequently used in Lagrangian modelling approaches) [2,22,23].

In addition to these approaches, Kennedy [10] reported on the practice of discounting some of the explosive mass due to side losses. Explosive material within 30° of the normal of the charge edge is assumed not to count. The remaining explosive, known as the effective mass of explosive, was considered to be the only part of the explosive that contributed to the axial impulse imparted due to the charge detonation. This approach leads to a maximum effective charge height h_{eff} for a given explosive diameter – any additional explosive above this height is completely redundant.

This paper reports results from an investigation into the response of plates where the charge diameter is varied through the explosive. Simple models of the detonation mechanism at the CJ state and the work by Kennedy [10] on the effective mass of explosive concept are described and used to interrogate the experimental observations.

2. Experimental method

Mild steel plates with a side length of 245 mm were clamped between two frames, giving the plates an exposed circular area with a diameter of 100 mm. All the plates were 1.6 mm thick. Quasi-static tensile tests on standard dog-bone specimens were performed at a nominal strain rate of $10^{-3}\,s^{-1}$. The yield stress of the steel was 289 MPa.

The clamped assembly was mounted to a ballistic pendulum, used to measure the impulse. A sectional view of the test rig is shown in Fig. 1. The plates were loaded by detonating three different shapes of plastic explosive (PE4), shown in Fig. 2: (1) cylindrical (CY), (2) truncated cone (TC) and (3) inverted truncated cone

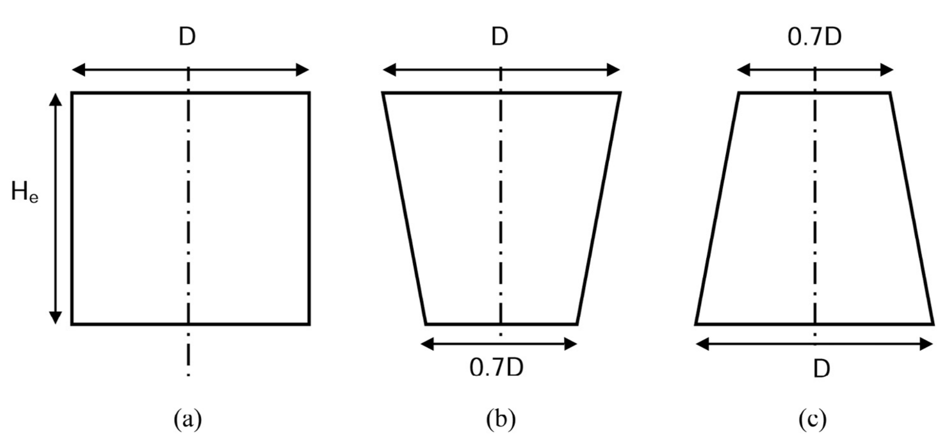

Fig. 2. Geometry of explosive charges: (a) cylindrical (CY), (b) inverted truncated cone (ITC), and (c) truncated cone (TC).