International Journal of Impact Engineering 73 (2014) 1–14

Contents lists available at ScienceDirect

International Journal of Impact Engineering

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

The response of partially confined right circular stainless steel cylinders to internal air-blast loading

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ARTICLE INFO

Article history:
Received 23 August 2013
Received in revised form
7 April 2014
Accepted 11 May 2014
Available online 20 May 2014

Keywords:
Blast loading
Plastic deformation
Cylinders
Confined explosions
Modelling

ABSTRACT

This article presents the results of an experimental and numerical investigation into the response of partially confined right-circular stainless steel cylinders to air-blast loading. The blast loading was generated by detonating spheres of plastic explosive at two axial positions along the centre line of the cylinders. Partial confinement was created by closing one end of the cylinder and leaving the other end free to vent to air. Numerical simulations were performed to gain insight into the blast wave propagation and the transient response of the cylinders. As expected, the diametric deflection of the cylinders increased with increasing charge mass, and was a maximum in the same axial location as the charge. For the centrally located charges ($L = 150$ mm), the diametric deflections increased linearly with increasing charge mass. The numerical simulations showed that the reflected pressure from the closed end of the cylinder (that is, the axial component) interacted with the radially developed pressure reflected from the cylinder walls. This caused the pressure to be driven out of the open end of the cylinder when $L = 150$ mm, meaning that the expected quasi-static pressure accumulation had little effect on the deformation of the cylinder.

When the charges were placed closer to the open end, at $L = 225$ mm, the experimental diametric deflections increased exponentially with increasing charge mass, and were significantly higher than the deflections measured when $L = 150$ mm. The simulations predicted linear increases similar to those for $L = 150$ mm, but at slightly higher magnitudes. This eliminates the lower mechanical support at the open end from being the main cause of the higher experimentally observed deflections, as this would also have been observed in the numerical simulations. Since the numerical simulation results were unable to fully predict the response and pressure accumulation when $L = 225$ mm, there must be some physical phenomena must be present in the experiments that did not affect the response when $L = 150$ mm (that was also not captured by the numerical simulations). One possible explanation is that afterburning of the explosive products was a significant factor when $L = 225$ mm, but this requires further investigation to confirm.

1. Introduction

Confined space explosions are a particularly devastating threat as the energy concentrations from confined blast events are typically hundreds of times greater than those generated in free air blasts [1]. Not surprisingly, confined space explosions are associated with a greater number of fatalities, and a higher incidence of primary blast injuries and serious injuries than open air explosions [2]. In civil infrastructure, partially confined spaces that allow significant long term quasi-static pressure accumulation are commonplace, with examples such as pipeline systems, underground transport tunnels (for trains and metro systems), and litter bins. Prevention of confined space explosions is clearly the best alternative – such as the removal of litter bins from high-risk public areas such as train stations [3,4]. Even with effective prevention methods, there will still be a requirement for better understanding the response of common structural components, such as tunnel-like structures (with "rigid" walls) and thin-walled cylindrical structures (which are deformable), to confined explosion loading.

The pressure accumulation within rigid walled tubular structures such as tunnels has been examined by various research teams

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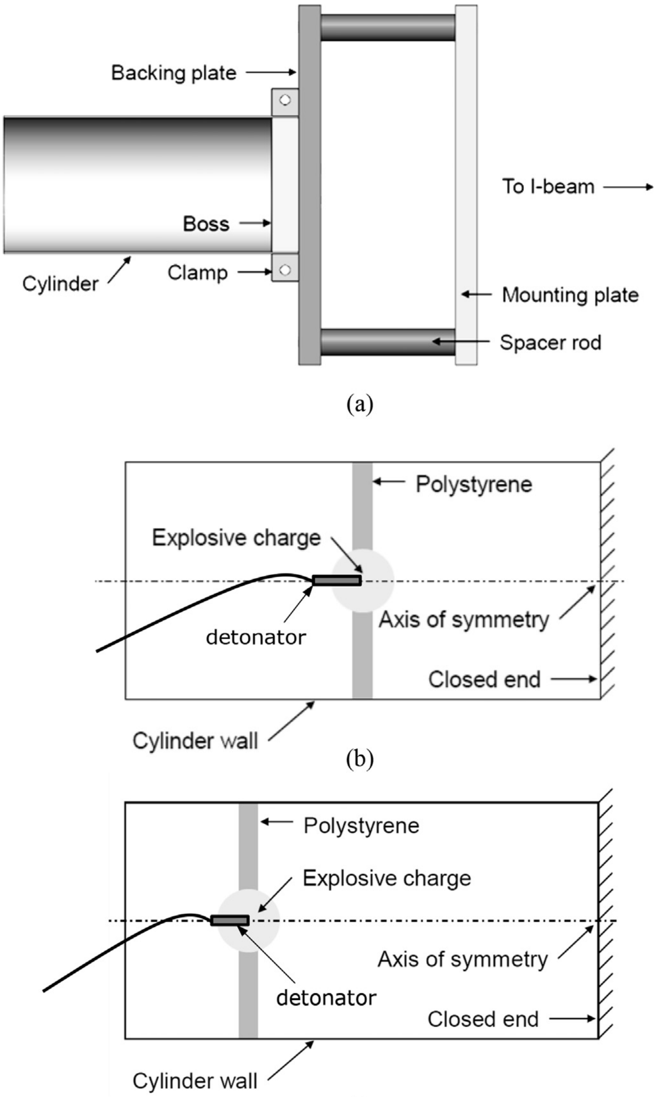
http://dx.doi.org/10.1016/j.ijimpeng.2014.05.002

[1,5–9]. Experimentally determined pressure-time histories from confined explosion tests at scales ranging from very small (0.5 g PETN detonations [6]) to very large (16,000 kg of TNT [7]) have been reported. For example, side-on blast pressures of the order of 1 MPa for a 100 g TNT blast have been recorded at a distance of 10 m from detonation of the charge in a 188 m long straight type underground mining tunnel [8]. The peak side on pressure increased to 7 MPa for a 22 kg TNT detonation in the same tunnel structure. The pressure decreased appreciably at the waves propagated along the tunnel, with the magnitude halving during the first 30 m of travel [8]. Work by Jacob et al. [9] also showed that increasing the stand-off distance reduced the destructive effect of a blast wave propagating along a rigid walled tube.

The response of thin-walled, deformable, cylindrical structures has been investigated experimentally, analytically and numerically by various researchers [10–16]. Early work by Duffey and co-workers [10,11] reported results from experiments on 267 mm diameter mild steel cylinders loaded internally by detonating centrally located spheres of C4. The charge mass ranged from 90 g to 315 g. The cylinders were 533 mm long (hence radius/length = 1/4) and had a wall thickness of 6.35 mm. Open and closed ended cylinders were both investigated and analytical models were developed to predict the radial strain in the cylinders. Quasi-static gas pressure accumulation was incorporated into the simplified modelling and was shown to increase the radial strain predictions, improving the experimental correlation [11].

Analytical modelling of the response of cylinders to internal blast [10,11] and external blast loading [12] can provide useful predictions regarding the likely damage to a structure in the event of an explosion, but it cannot provide information about the blast wave propagation, or account for non-idealised geometry. Numerical modelling offers the potential to overcome both of these limitations. For example, Liu et al. [13] modelled the response of foam filled sandwich cylinders to internal blast loading using LS-DYNA. The structure investigated was a 596 mm inner diameter, 800 mm long cylinders with varying density foam layers combined to produce a total wall thickness of 100 mm [13]. Spheres of 20–40 g TNT explosive were detonated at the centre of cylinders, resulting in relatively small deformations of the overall cylindrical structure [13].

Whenhui et al. [14] and Rushton et al. [15] present some experiments on cylindrical structures subjected to internal blast loading. Whenhui et al. [14] highlighted the strain growth phenomenon that was present both experimentally and in the numerical solution, whereby the post-shock vibration of the cylinder caused the magnitude of the hoop and radial strains to increase. Similar observations were made by Karpp et al. [16] and subsequently by Dong et al. [17] for spherical vessels. Rushton et al. [15] presented preliminary findings from two explosion tests where 600 g and 800 g of PE4 were detonated in the centre of 324 mm

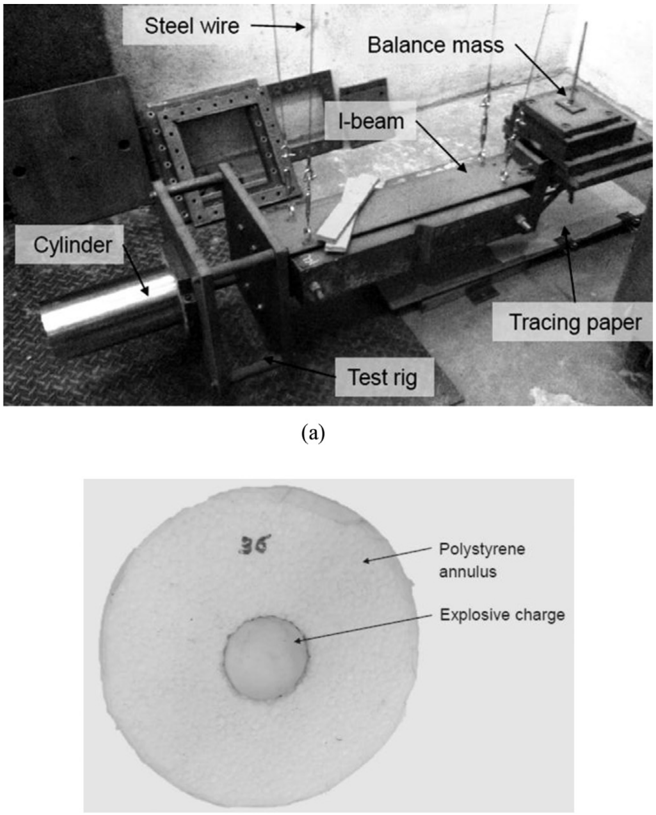


(a)

(b)

(c)

Fig. 1. Schematics showing details of the test arrangement (a) mounting to pendulum, (b) cross-section showing charge location, $L = 150$ mm from the closed end, (c) cross-section showing charge location, $L = 225$ mm from the closed end.



(a)

(b)

Fig. 2. Photographs of blast test arrangement (a) blast pendulum, (b) PE4 charge.