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The influence of orientation of blast loading on quadrangular plates

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ABSTRACT

This paper presents the results of experiments and numerical simulations carried out to characterise and assess the effects of orientation of blast loading onto a quadrangular plate. The study was carried out in two distinct arrangements. In one configuration, the explosive was tilted at different angles (0° (use as baseline for comparison), 15°, 30° and 45°) with respect to the target plate to provide different impact angles of the shock wave front with respect to the plate. In the other configuration, the target plate was tilted at two different angles (15° and 45°) with respect to the explosive. The blast load was achieved by detonating a 38 mm cylindrical disc of explosive. The stand-off distance, defined as the distance between the plate and the centre of the nearest face of the explosive cylinder, was kept constant at 40 mm. The mass of explosive was varied between 8 and 28 g of PE4 to achieve different responses of the plate ranging from large inelastic deformation to tearing of the structure. For all the different loading scenarios, the target plate consisted of a 2 mm thick DOMEX steel quadrangular plates with an exposed area of 300 × 300 mm. Each loading scenario was quantified in terms of impulse imparted onto the target in the axial direction of a horizontal ballistic pendulum. The damage was evaluated in terms of maximum deflection/tearing of the target plate. Numerical simulations was carried out in ANSYS® AUTODYN® using a coupled Eulerian and Lagrangian solver approach to provide insights in the mechanism of the blast load in terms of load distribution on the target plate.

1. Introduction

The response of structural components subjected to blast loading has been an ongoing subject of research for the past few decades. The peak pressures produced by blast waves resulting from the detonation of an explosive are generally greater than the static collapse pressure of the structures. Structures subjected to these high peak pressures usually undergo large plastic deformation, which converts the energy associated with the blast loading into plastic strain energy within the structure, resulting in a stable deformation profile or fracture of the material. Insights into the relationship between explosive loading and the deformation/fracture behavior of a structure provide a better understanding to design and build structures with significantly enhanced energy absorption and blast resistance. Numerous authors have reported on the large permanent ductile deformation and rupture of basic elements of structures; such as plates, beams and shells, to blast load resulting from the detonation of explosives in air. Jones [1], Zhao [2], Nurick and Martin [3,4] and Rajendran and Lee [5] have presented overviews of the theoretical and experimental results of plates that were loaded uniformly over the entire plate area. The results also discussed the geometrical effects (circular or quadrangular) of the target plates. Further studies have been carried out to investigate different boundary conditions (clamped or built-in) and loading conditions (localised and uniform loading), for instance Refs. [6–17]. In most studies the impulsive load is achieved by detonating either a spherical or cylindrical charge set up at a stand-off distance from a target plate with the shock wave front impacting the target plate in the normal direction.

In real-life scenarios, a blast load can impact a structural target in any direction. The ongoing conflicts are proofs that any targets may be hit using any asymmetrical and unconventional weapons such as Improvised Explosive Device (IED) detonated from any direction and stand-off distance. In cases where the blast loading condition is not perpendicular to the plate (oblique blast loading), few studies have been published in the open literature. Chennamsetty et al. [18,19] reported on the dynamic response of Hastelloy X plates to normal and oblique shock loading. A shock tube was used to impart the simulated blast load onto the plate set at different incident angles. Lower angles of shock incidence were found to cause more deformation on the specimens. Their study highlights the advantages in presenting an angled

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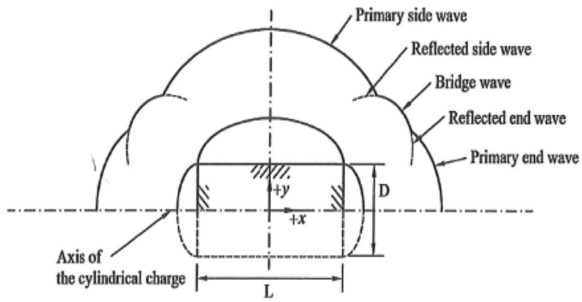

Fig. 1. Schematic showing the propagation of blast waves from a cylindrical charge [29].

surface to the blast wave, which is identical to the concept of the 'V' shape hull.

The "V" shape hull, often used as blast deflector on landmine vehicles such as the Casspir armoured personnel carrier, would be an oblique target to a charge detonated in the normal direction to the ground. Numerous authors have carried out studies to investigate the mitigation effects of the "V" shaped hulls, for examples Refs. [20–25]. In these studies, the experiments were carried to evaluate the effect of the included angle in the "V" shape plates for blast loads resulting from the detonation of explosives in air or buried under sand. In all the studies, the explosive charge was detonated in the central position to emulate the loading condition of a charge detonated in the central position underneath a vehicle hull. While these studies have provided a better understanding of how these structures respond to loading directly underneath the 'V', in some circumstances the charge will detonate under the wheel, resulting in an oblique loading on one side of the 'V'. This condition essentially represents an oblique loading on a flat plate from a cylindrical charge.

Numerous authors [26,27] have shown how the impulse imparted onto a target structure and the subsequent damage to the structure are influenced by the geometry of the charges. Unlike spherical charges which produce a roughly uniform flow-field in all directions, landmines are typically cylindrical in shape, resulting in a non-uniform flow-field. Fig. 1 shows the main features of the flow-field from a cylindrical charge. There is a primary 'side' wave that propagates from the large flat face of the charge and a primary 'end' wave that propagates from the circumference of the charge. Both primary waves are propagated by the expansion of the detonation products in these directions. The regions between these primary waves are connected by bridge waves. Whilst these waves coalesce at larger distances from the explosion, at closer distances, there is a significant difference in loading from each region. Adhikary et al. [28] investigated the influence of cylindrical charge orientation on high strength concrete panels. Pressure sensors, mounted on a steel plate, were also used to measure the reflected blast wave parameters for the two loading conditions. The experimental results showed significant difference in the blast response of the panels (i.e., maximum mid-span displacement and failure mode) when the orientation of the cylindrical charge was changed from perpendicular to parallel with respect to the longitudinal axis of the test panels. This highlighted the difference in loading from the primary 'side' wave and the primary 'end' wave, with the 'side' wave from the flat face of the charge producing significantly higher loadings and a greater level of associated damage. One limitation of their study is that no charge angles were evaluated that resulted in an asymmetrical loading across the plate.

This paper focuses on providing insights into the effect of cylindrical charge orientation on the response of a plate structure, through the use of small-scale blast experiments. The explosive, located in the centre of the target plate, was tilted to different specified angles with respect to the target plate to impulsively load the target plate. Additionally, experiments were conducted where the target plates were angled with respect to the explosives. In these cases, the experiments represent the small-scale version of the loading on an angled plate structure from a 'V' Shape hull. Numerical simulations were also performed to provide some preliminary insights into the effect of the charge/plate orientation on the spatial distribution of loading on the plate structure.

2. Experimental arrangements

The experiments were conducted on a horizontal ballistic pendulum, shown in Fig. 2 that was suspended to the ceiling via four adjustable steel cables. The impulse imparted onto the target was determined from the axial displacement of the pendulum measured using a laser displacement sensor and single degree of freedom motion theory as presented by Curry and Langdon [30]. The target plates, made from 2 mm thick Domex steel, were 400 × 400 mm in size and clamped between two 20 mm thick clamping frames leaving a deformable area of 300 × 300 mm (clamping width of 50 mm). The Domex steel had a yield strength of 222 MPa determined from uni-axial tensile tests. The experimental set-up was similar to previous studies such as Nurick et al. [13–17].

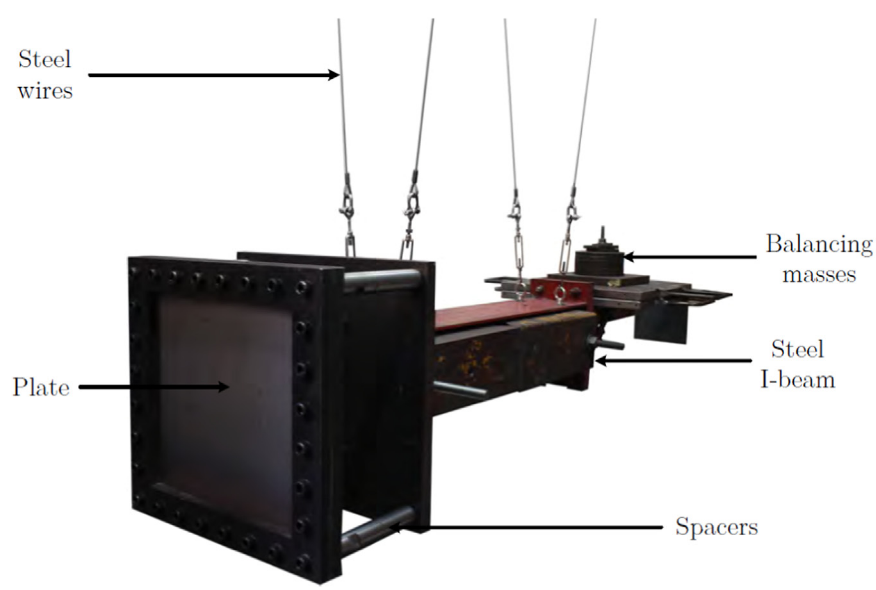

Fig. 2. Photograph showing the horizontal ballistic pendulum set up for an angle of tilt of 0°.