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Transient response of steel plates subjected to close proximity explosive detonations in air

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ABSTRACT

The permanent deformation and failure of steel plates subjected to air-blast loading has been the subject of numerous investigations. The transient deformation of such intensely loaded plates has been difficult to obtain due to experimental difficulties. In recent times, high speed imaging and digital image correlation techniques have enabled reliable non-contact measurement of deformation and strain in various applications, such as tensile testing and far-field impulsive loading response of large plated structures. This paper investigates the transient deformation and strain evolution of a deformable plate subjected to air blast loading arising from explosives detonated in close proximity to the plates. The experiments made use of a blast pendulum to measure the impulse imparted on the plates. The pendulum modifications required to accommodate the high speed camera system are described. Results from blast experiments are used to show the influence of stand-off distance on the transient response and permanent deformation of thin steel plates subjected to air blast loading. The difference between maximum transient mid-point deflection and final deformation decreased with an increase in charge mass and global deformation.

1. Introduction

Due to the current global social and political climate, explosive threats loom larger in the public consciousness than ever before. Explosive threats can be either accidental (such as a gas explosion aboard an offshore platform) or deliberate (such as terrorist activity or military action). The common thread in deliberate explosions is an explosive substance connected to a detonation device, with examples being pipe bombs, improvised explosive devices (IEDs) and landmines.

In the interests of public safety and security, the need to protect people, equipment and structures from explosions has greatly increased. A great deal of effort has gone into preventing an explosive detonation, such as improving screening at airports and active mitigation methods in military systems. However, active mitigation techniques are not practicable for everyday situations and screening methods will not always work perfectly. Hence, there is a need to understand the loading arising from an explosive detonation and the damage that is sustained by structures subjected to blast loading from close proximity explosive detonations. This improved understanding will assist in efforts made to prevent injury or loss of life during explosions.

There is little full-scale explosion test data available as full scale tests are prohibitively expensive and time consuming to perform, and often the findings are classified by the military. Small scale testing offers a number of advantages such as reducing the expense, allowing better control of the test process variables (explosive size and geometry, accurate positioning of the explosive, stand-off distance to target structure) and potentially improved measurement of parameters such as impulse, pressure and structural response. The link between the small scale experimental and the full scale testing is being able to scale the work.

Extensive laboratory scale experimental studies were performed by Nurick and Martin [1] with the aim of understanding the large permanent ductile deformation and rupture of plates, beams and shells due to air-blast loading. Jones [2] and Nurick and Martin [1,3] present overviews of theoretical and experimental studies of plates subjected to uniformly distributed impulsive loading. Further studies were reported, examining the influence of boundary conditions (clamped or built-in) [4,5] and the spatial distribution of the loading. In each case, the loading was assumed to be impulsive and reported on the permanent deformation and failure of the structures. Many of these make use of a blast pendulum in order to measure the impulse imparted on the plates outlined by Nurick [1].

Menkes and Opat [6] were the first to define the failure modes of blast loaded clamped beams. Three modes were observed as the applied uniform impulse was increased:

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Fig. 1. Photograph of the modified pendulum hanging in blast chamber. Clearly showing the 300 mm circular exposed test area on the plate.

- Mode I - Large inelastic deformation
- Mode II - Tensile tearing at the supports
- Mode III - Transverse shear failure at supports

Understanding the transient deformation history of plates prior to failure would add valuable insight to the mechanisms which may influence and drive the different modes of deformation.

Capturing transient test data by placing instrumentation on or in close proximity to a test plate poses a problem where the instrumentation itself may influence the plate response. Simple tools such as the deformation combs described by Neurberger [7] have yielded valuable insight into maximum transient deflection of plates but were unable to provide information about transient deformation profiles or time to peak deflection. Non-contact measurement techniques such as light interference and high speed filming have proved the most successful in previous works when trying to extract richer data.

The use of 3D Digital Image correlation for displacement measurement has become a well established technique [8] used in many different applications [9,10]. Fourney et al. [11] used a 3D DIC system to measure the transient response of test plates under blast conditions. Velocity and acceleration profiles were both reported. An issue noted in this work was the constraint of camera resolution and lighting of the specimen as the experimental setup tracked an

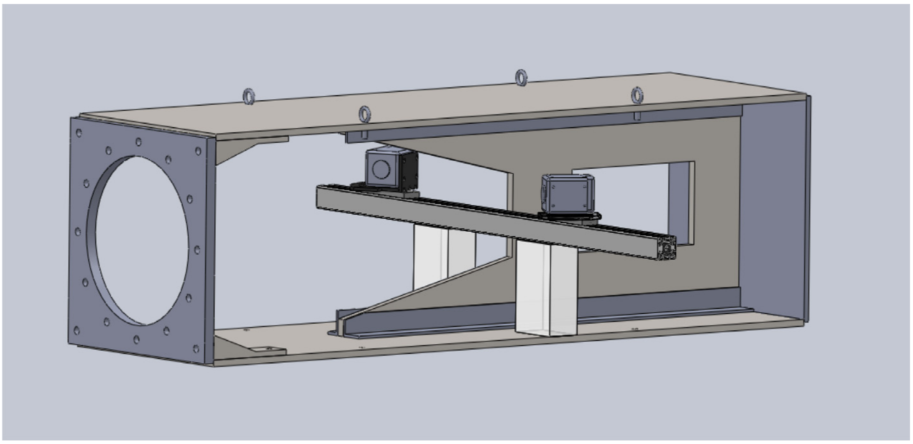

Fig. 2. Schematic drawing of modified pendulum, showing internal arrangement (shroud removed for clarity).

Fig. 3. The Modified pendulum with shrouds removed to show the inside.