International Journal of Impact Engineering 36 (2009) 122–131

Contents lists available at ScienceDirect

International Journal of Impact Engineering

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

Numerical simulation on the interaction of blast waves with a series of aluminum cylinders at near-field

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ARTICLE INFO

Article history:
Received 1 November 2006
Received in revised form 2 November 2007
Accepted 19 December 2007
Available online 11 May 2008

Keywords:
Blast loading
Near-field
Close-in
Cylindrical charges
Fluid-structure interaction

ABSTRACT

This paper demonstrates the application of numerical simulation in predicting the interaction of blast waves with a series of aluminum cylinders at near-field. The results from the experiments performed by Held [Held M. Impulse method for the blast contour of cylindrical high explosive charges. Propellants Explos Pyrotech 1999;24:17–26] are used as a benchmark for comparison. This numerical simulation, performed using the fluid-structure coupling feature in AUTODYN-3D®, predicts the initial velocities of the aluminum cylinders in the vicinity of the blast field. Results from the numerical simulation yield relatively good agreement with those obtained from experiments, and also provide insight and explanations to some of the surprising results observed in the experiments. An understanding of these results from the experiments is crucial in determining the effects of close-in explosions from high explosive. The paper also includes the study of the momentum transfer to these cylinders when the explosive charge is initiated at two ends simultaneously. The results from this simulation are then compared with a case when it is initiated at two ends with different initiation times. In an effort to investigate the effects of high length-to-diameter ratios on the momentum transfer, simulation for a cylindrical charge with $L/D = 3.0$ is also included.

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1. Introduction

Structural elements are vulnerable to damage when exposed to blast waves and more so when they are inside the fireball. Since the last decade there have been numerous experiments conducted to study the effects of blast wave loading on structures, but only a few are related to the research on the effects of blast wave loading on structural elements located inside the fireball [1–3]. The study of structural damage inside a fireball remains a challenge to experimentalists. Measuring the peak pressure and obtaining the pressure–time plots inside a fireball using pressure gauges is expensive, risky and difficult. Recording pressure in near-field which encompasses the fireball and reacted products is not a trivial exercise [4]. At the near-field, pressure gauges are exposed to a variety of stimuli and are subjected to many forms of interference. In addition these gauges are also sensitive to light, heat and mechanical stresses as well as electromagnetic effects from electrical noise, firing pulse and the explosion. Furthermore when assessing the survivability of structural elements, structural engineers and ballisticians are more concerned about the magnitude of the impulse rather than that of the peak pressure. Confronted with these concerns and challenges, some ballisticians and engineers have designed novel systems to measure the impulse of blast wave in the proximity of the fireball [1–3].

In 1998, Held [1] designed a novel system to measure the momentum transfer of blast waves in the vicinity of the fireball. In his system, the momentum transfer from a 775 g cylindrical high explosive (HE) charge was obtained using 70 mm diameter aluminum cylinders. After the blast had occurred, the displacements of the aluminum cylinders were measured, and later used to calculate the initial velocity of the cylinders. In the publication Held reported that the use of high-speed photography to capture the motion of the cylinders during the blast was not possible because the reacted products from the HE had obscured the aluminum cylinders. However, the initial velocities obtained (i.e. the aluminum cylinders) from the displacements of the cylinders revealed surprising results about the blast contours of the cylindrical charge. Held observed that at near distances the momentum transferred of a cylindrical charge was different from that of a spherical charge. The momentum gauges normal to the radial expansion have higher momentum than that of gauges lying $+45°$ and $-45°$ from the normal. Moreover Held also noticed that the momentums of the gauges in the vicinity of the two ends of the cylindrical charge were different. The momentum in the direction of the detonation wave was much higher than that in the opposite direction. In 2002, Held [2] reported a new test set-up. In this new set-up the momentum

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doi:10.1016/j.ijimpeng.2007.12.011

gauges (i.e. cylindrical or rectangular) were arranged in 2 semi-circles with different radii. With this new set-up the variation in the distance and projected surface area of each momentum gauges in relation to the expanding reacted products were minimized. In the experiments the momentum transferred at 4 different radii (i.e. 0.25, 0.5, 0.75 and 1 m) were measured. For the smallest radius, steel rectangular cubes were used to measure the momentum. Steel which has a higher density than aluminum was able to attenuate the initial velocities of the gauges, hence reducing their range. The impulse density captured from the two momentum gauges – cylindrical and rectangular – was in close agreement.

There have been several publications on the blast wave characteristics from cylindrical charges. Since most warheads are cylindrical rather than spherical, the study of blast wave from cylindrical charges has practical relevance. Plooster [5] published experimental results of free-air blast wave properties for end-initiated cylindrical charges. These cylindrical charges, oriented at 22.5° increment, were cast Pentolite with length/diameter (L/D) ratios ranging from 1/4 to 6/1. The pressure from the blast waves was measured and the experimental results also included peak pressure, positive impulse, positive duration and time of arrival. For calibration, Plooster also captured the blast wave pressure from spherical charges. From these measurements he observed substantial differences between blast wave from cylindrical and spherical charges. Ismail and Murray [6] reported blast wave measurements from cylindrical tetryl charges. Blast wave pressure for charges with different configurations and orientation were measured. They discovered that multiple shocks were present when the warhead axis was in line with the pressure transducer array.

With the advent of cheaper and faster computing power, hydrocode simulations have been used to predict blast wave pressure of cylindrical charges. Zimmerman et al. [7] investigated the variations between spherical and cylindrical C4 charges. For both spherical and cylindrical charges, the peak overpressure and impulse are dependent on the point of initiation. Schraml et al. [8] performed 2D hydrocode simulations to characterize the blast environment of cylindrical charges. The simulation results were validated against experimental data. The simulations were able to reproduce the dominant characteristics observed in the static overpressure recorded in the experiments. The variations in shock arrival time with respect to charge orientation were also captured by the simulations. Baum et al. [9] applied a coupled Computational Fluid Dynamics (CFD) and Computational Structural Dynamics (CSD) methodology to study the interaction of blast wave from bare cylindrical charges with rigid and deformable walls. Very good agreement between the measured and predicted pressure and impulse time histories for the rigid and deformable walls was noted. Both measurements and predictions were able to identify the presence of a strong jet with a maximum velocity of 5000 m/s propagating from the nose-end of the cylindrical charge.

The objective of this paper is twofold. First it aims to provide insight and explanation to the results observed in Held's experiments on cylindrical charges (i.e. $L/D = 1.35$) [2], using numerical simulations. The impulses on the aluminum cylinders from the simulations are compared with those obtained from the experiments. The second purpose of this paper is to determine the impulse of a cylindrical charge with $L/D = 3$ and also to investigate the impulse when a cylindrical charge is initiated simultaneously at the two ends. Result from the latter case is then compared with result when a cylindrical charge is initiated at the two ends with different initiation times. The simulation work in this area is useful in understanding the influence of initiation position and timing, and also the effect of charge geometry on blast wave contours and intensity. The results from such simulations are necessary in studying the position and timing of initiators for a given charge geometry to produce a particular set of blast wave characteristics that will inflict maximum damage on structural elements. Combining such simulations with full-scale testing, ballisticians can decide on the position and timing of the initiator as well as the charge geometry to produce blast wave contours and intensity that will achieve multiple functions from a single warhead. In the research on blast wave propagation, reliable and accurate prediction of near-field blast loading of structures using hydrocode simulations remains a challenge to both ballisticians and scientists. Nevertheless simulations could still be used to explain some of the phenomena observed in experiments. The simulations presented in this paper are initial attempts to demonstrate that there is still a role for hydrocode for near-field explosions.

2. Numerical approach

A computer program that is capable of computing strains, stresses, velocities and propagation of shock waves as a function of time and position is known as a hydrocode. In a hydrocode simulation, the response of a continuum subjected to dynamic loading is governed by the conservation of mass, momentum and energy, and also the equation of state (EOS) and constitutive relation of the continuum. The equation of state takes into account the effects of compressibility of the continuum, whereas the constitutive relation represents the continuum's resistance to shear. In this paper the hydrocode simulations are performed using AUTODYN-2D and 3D® [10], a fully integrated and interactive hydrocode developed by Century Dynamics, a subsidiary of ANSYS®. One unique feature of AUTODYN® is it allows different parts of a single problem to be modeled with their appropriate numerical formulation which have been made available in the hydrocode. Hence this allows a user to couple different numerical solution techniques in a single problem.

2.1. Hydrocode model

The air and high explosive are first modeled using the multi-material Euler formulation in AUTODYN-2D®. The remapping capability unique to AUTODYN® is utilized to reduce the computational cost associated with the initial stages of the calculation which involves the detonation and expansion of the cylindrical high explosive charge. The publication by Chapman et al. [11] demonstrated this unique capability by remapping solution from a 1D detonation calculation to a 2D axis-symmetric computational domain. In this publication, however, the capability on remapping solution from a 2D detonation calculation to a 3D computational domain will be demonstrated. Fig. 1 shows the set-up for the 2D numerical model. For this 2D detonation calculation the axial-symmetry condition is imposed on the x-axis. The 2D computational domain consists of 246,051 (i.e. IMAX = 751, JMAX = 501) nodes. The high explosive charge in the numerical simulation is

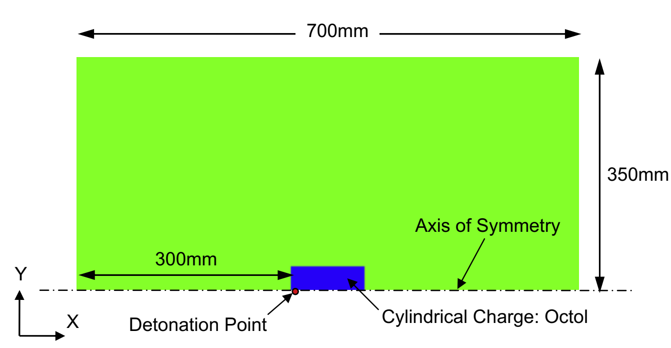

Fig. 1. Initial 2D set-up for simulating the detonation of cylindrical charge.

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