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Mechanical response of V shaped plates under blast loading

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ABSTRACT

An assessment of structural response of blast resistant structures is important for the efficient design of armored personal vehicles (APV). A rigid design of these structures will transfer the blast forces into the crew cabin whereas softer design will lead to excessive structure deformation which is dangerous to the crew. An optimal design should absorb the energy as much as possible and transmit less vibration to the crew in the cabin. For this purpose the effectiveness of different V-shaped plates are investigated here for finding its response under different plate angles, mass and eccentricity of the TNT charge. The assumed geometry is similar to that of plates used in the armored personal carrier CASSIPIR and the material under consideration is mild steel. Three-dimensional (3D) numerical analyses was performed using the non-linear finite element (FE) code ABAQUS/Explicit to predict the maximum central deflection, impulse transmitted and damage mode of V shaped plates. Results of the numerical simulation for failure in V shaped plates with different included angles(145,160,180 degrees), subjected to localized blasts are presented here. It is seen that primary variables like mass of the charge, the V-angle and eccentricity of the explosive affect the response variables of the plate.

1. Introduction

Blast loading is a major threat for military vehicles and civil infrastructure. The blast loading due to landmines and improvised explosive devices (IED) pose a major threat to the life of soldiers in the military vehicles. Blast loading has the potential to induce substantial damage on structural elements like columns and plates. Response of vehicles to blast loading is difficult to predict as there are many variables involved, such as the angle of the V-shaped plate, position and shape of the charge etc. The design of blast protected vehicles becomes important as it is the only means of mobility in many combat situations. The identification and optimization of the important design parameters for an efficient and safe design of military vehicles is essential for the above purpose. Experiments and numerical study on beams and plates (both circular and quadrangular shapes) have been widely reported in literature Refs. [1–6]. Flat plate structures have been traditionally used for the blast mitigation. Flat plates absorb most of the energy and either deforms or fractures in the process. The explosion creates a shock wave which travels toward the target plate and gets reflected from target surface. The reflected pressure on the flat surface is many times higher than the incident pressure considering the dissociation and ionization of real gases [7]. This implies that the capability of flat plate to resist the loads is mainly dependent on the thickness of the plate, for any given material. As compared to the flat plate, V shaped plates are more advantageous, since the plate structure is capable of deflecting a major part of the blast load [6,9]. As result the effect of the reflected overpressure is reduced considerably. This can result in reducing the thickness of the plate, and the hence the vehicle weight itself.

While flat plates have received considerable attention in open literature [2–5], very little data is available for V-plates. The armored personnel vehicles (APV) like South African Cassipir have been using the V shaped plates for blast deflection [8]. As of now various vehicles are available which utilizes the blast mitigation property of the V shaped plate to offer enhanced protection against blast loads. Comprehensive review of the various design parameters and their influence on the impact loading and vehicle response with V shaped hull is still not available. It is seen from literature [9,13,14] that experimental and numerical studies on scaled down models have brought out certain features of the V shaped hulls.

Genson [9] made an experimental study for finding the transmitted impulse due to blast loading on dihedral plates. The effect of variables like standoff distance, mass of the charge and the depth of burial were studied for dihedral plates of varying included angles. The experiment was conducted by subjecting various dihedral plates to blast loads generated from 0.636 g of explosive. The transmitted impulse was found from the high speed video recordings. The standoff distance was varied from 0 to 1.5 in. (0–38.1 mm), depth of burial was varied from 0.04 to 0.5 in. (0–12.7 mm) and the angle of the plate is varied from 180° to 140°. He found a roughly inverse relation between standoff

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distance and the transmitted impulse. Similarly the reduction in imparted impulse with the decreasing plate angle was also noticed. He found that below a certain minimum limiting value of angle there was negligible reduction in the impulse transmitted provided the other variables are held constant. Similarly he has also identified a certain maximum standoff distance beyond which there was no significant reduction in transmitted impulse. Genson has found the maximum reduction in impulse to occur in the range of 170–150° included angle, after which it stagnates. Similarly there is not much difference between the flat plate and 170° plate in reducing the impulse transmitted. The significance of the standoff distance in affecting the plate response was also found. It was seen that the mitigation effects of the plate angle is maximum when the standoff distance is minimum. At larger standoff distances variation in plate angle did not have much effect on the impulses. Further, as compared to the depth of burial of the mine standoff distant is a more important parameter in reducing the blast effect for all the plates under consideration.

Benedetti [10] conducted experimental study to find the effect of a protective hull during blast loading on a scaled down model of vehicle floor board. The hull was made with aluminum plate 0.228 cm (2.28 mm) thick. The depth of burial of the explosive is 0.76 cm (7.6 mm). The standoff distance was fixed at 8.10 cm (81.0 mm). The maximum mitigation was observed for hull included angle of 155°. It was seen that the transmitted impulse has a nonlinear variation with included angle and drops off suddenly with reduction in included angle before stagnating. Similar observation was made by Genson who suggested that no further mitigation is possible after a certain minimum cutoff angle is reached. Similarly for flat plate and 168° plates the midpoint velocity levels are almost same, indicating that nearly the same impulse is transmitted. The velocity levels are almost the same for 154° plates and 140° plates. Similar results were also reported by Genson, who suggested that the impulse stagnates after a certain cutoff angle is reached.

Gurumurthy [11] conducted 2D and 3D numerical simulations of blast loading on simplified vehicle structures, resistant to landmine explosions. He has considered the propagation and interaction of the blast waves with the structure. The explosive standoff distance was assumed as 0.3 m (300 mm) for flat plate and 1.3 m (1300 mm) for every other plate. The width of the vehicle exposed to the blast load was taken as 2 m (2000 mm). A comparison of the impulse acting on flat plate, V plate, convex and concave shaped plates was made. He has concluded that for a given loading (energy intensity 0.8–40 MJ/m) V shape experienced the least head on impulse. The side on impulse was not minimum for V plate, but it was seen that its magnitude is comparatively smaller. The study also showed that the minimum impulse for a V plate is generated for the combination of maximum stand off and maximum floor height (that is, for steeper plates). Specifically the author has shown an impulse reduction of 30% for a 68° V shaped plate by conducting 3D numerical simulation.

Anderson et al. [12] conducted blast loading experiments with V shaped plates. The experiment set up consisted of steel plates weighing 300 kg, placed 20 cm above the ground. The cylindrical explosive (625 g of Comp B) was buried at about 5 cm below the ground. The authors have calculated the imparted velocity of the plates based on the experimental observations. It was observed that the V shaped plates offered considerable reduction in the imparted momentum when compared with flat plates under the same situations. The reduction in transmitted impulse for 90° and 120° plates were 60% and 40% respectively.

Experimental and numerical study exclusively for V plates has been conducted by Yuen et al. [13]. Here V- Shaped plates mounted on a ballistic pendulum were subjected to blast loads. The explosive is centrally positioned throughout the experiment. The mass of the charge and its standoff distance were varied during the experiment. The plate included angle was varied from 180° to values as low as 60°. It was found that there is a linear trend in the transmitted impulse with the variation in included angles. However for a given charge, midpoint deflection seemed to decrease gradually for plate angles from 180° to 150°. A sudden drop in the mid-point deflection was observed from 150° to 90° and thereafter the variation is again gradual up to 60°. The experiments with variations in mass of charge showed that the impulse changes almost linearly for all the plates. Plates with angles less than 150° showed a lesser rate of decrease in deflection with decrease in the mass of the charge.

Sahu and Gupta [14] conducted numerical analysis of blast response of various shapes of hull plates used in APV. The numerical simulations using LS-DYNA used the built in blast load function Conwep. They analyzed various shapes like flat shape, parabolic, triangular and wavy (convex-concave) shapes. They have concluded that the structure with triangular cross section produced the least mid-point deflection. The authors have concluded that both the triangular shape and parabolic shape is preferable from the point of view of energy dissipation.

The literature review shows that scaled down models have been used in the experimental and numerical investigations. From the experimental point of view this could be the feasible option, as full scale model experiments are economically prohibitive. These experiments on the V shaped plates are focused on the deformation and impulse transmitted. It is seen that the V shaped hull is more capable of mitigating the blast load compared with other shapes (like parabolic or convex). Hence in this paper we focus only on the characteristics of the V shaped plates. Further it is seen that experimental and numerical results are available for scaled down models of flat plates which undergo deformation and failure. Hence possibility exists for carrying out numerical simulation of full scale model, based on validation with experimental results from scaled models. A more accurate picture of the failure modes for full-scale models could be simulated and verified based on the above results. Further no systematic set of experiments or numerical simulations are available which can be useful in designing V shaped plates for vehicles.

In the present paper the objectives are,

1) To develop a numerical model that would simulate the mechanical response of scaled down V shaped hulls and validate the published experimental results.
2) To use the numerical models developed above to simulate the mechanical response of full scale model of V shaped hull subjected to variation in blast parameters.

The mechanical response parameters monitored in the study are a) transmitted impulse at the supports and b) deflected profile of the hull. The design parameters that are varied in the study are a) plate included angle b) mass of the charge and c) eccentricity of the charge with respect to the centerline of the hull.

In this paper we are attempting a numerical solution for the case of blast loading on the V shaped plate. The commercial software ABAQUS Explicit is utilized for the 3D simulation. Section 2 covers the modelling aspects including the geometric part modelling and meshing, material selection and blast load modelling. A full scale model study is presented here, by taking the target plate dimensions to be the same as that of the hull of APV Cassipir. Section 3 studies the deformation as well as the impulse generated due to the blast loading. The initial part of the section is aimed at studying the impulse generated on both the scaled down model and full scale model. The latter part of the section deals with the midpoint deflection of the models. The plate response with respect to each of the design parameter is studied numerically to assist in finding an optimum design configuration of the blast resistant vehicle. Section 3.1 gives the concluding remarks of the investigation.

2. Problem description and numerical modelling

The APV Cassipir employs a V shaped hull to provide adequate protection to its crew from the land mine blasts. The hull employs a