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Measurement of the spatial specific impulse distribution due to buried high explosive charge detonation

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ABSTRACT

Buried high explosive (HE) charges represent a high threat to military vehicles. The detonation of these charges can lead to significant momentum transfer onto vehicles and their occupants. A detailed understanding of the physical processes involved in the loading of vehicle structures is necessary for an optimization of effective countermeasures and protection systems. A quantitative description of the local momentum distribution on the vehicle underbody due to the detonation process is of special importance. In the following, a new test setup is presented that allows the experimental determination of the specific impulse distribution. It is based on a ring arrangement where the elements are nested into each other and the velocity of each ring is correlated with the local specific impulse at its position.

The momentum transfer to a vehicle depends on a number of influencing factors such as: charge mass, embedding material (e.g. sand, gravel, clay), density, water content, saturation, depth of burial, ground clearance and vehicle shape. The presented technology is applied to quantify the influence of the embedding material (alluvial sand, quartz sand), the burial depth and the water content on the local specific impulse distribution. The obtained data can be used as initial condition for the numerical simulation of occupant safety assessment and as input for empirical modeling of momentum transfer on structures.

1. Introduction

Military operations during the last two decades were characterized by asymmetric threat scenarios. Special attention has been given to the effects of land mines and improvised explosive devices (IEDs) on vehicles. A detailed review about anti-tank mines and their effects is given in Ref. [1]. The detonation of mines or IEDs leads to a complex sequence of loading phenomena on vehicle structures. Important effects in this context are the interaction of the blast wave or detonation products with the vehicle as a whole, but also local impacts of primary or secondary fragments onto the vehicle surface. Thus, loading effects can be classified into local and global phenomena. Local effects are related to the impact of projectiles and the development of protective systems with threat adapted material combinations. This paper deals with the physical effects that are caused by the detonation of buried high explosive charges below the military vehicle. In this case, a large momentum transfer on the vehicle structure as a whole takes place and leads to high accelerations of the vehicle and the occupants.

First, most research concentrated on the analysis of low buried mines, and techniques were developed to measure momentum transfer [2,3] and the local deformation of vehicle floor structures [4,5] due to mine detonation. Simulation models for the assessment of mine effects on vehicles were developed [6–8]. Special attention was given to modeling the charge detonation in a sand environment (with adequate material models) and the following interaction with a momentum trapping structure [9,10]. It was realized that the burial conditions and the embedding material properties show a significant influence on the momentum transfer [6,11–16].

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With the appearance of IEDs, phenomena in connection with deeply buried charges of large masses became of interest [17–19]. It turned out and was partially unexpected that this type of threat caused a significantly increased momentum transfer. Hence, there was the need for a better understanding of this loading process. Influencing factors are: charge mass, embedding material (e.g. sand, gravel, clay), density, water content, saturation, depth of burial, ground clearance and vehicle shape, to mention only the most significant parameters. In most test setups, only the global momentum transfer on a large-area structure was examined. For a better understanding of the loading process, locally resolved information about the specific impulse distribution on a structure is necessary [20–26]. We therefore developed a new test technology based on a ring arrangement with each individual ring used as a momentum trap at the corresponding local position. The HE charge is placed in a barrel structure and embedded within the selected material that is prepared under highly reproducible conditions. After detonation of the charge, the detonation products and the accelerated embedding material interact with the ring arrangement and transfer locally different amounts of impulse on each ring. From the different ring velocities, the corresponding impulse can be derived. For the determination of the ring velocities, redundant measurement techniques are used. In the following, the development of the test design with numerical simulations is shown. The method is used to quantify the influence of several burial parameters on the local momentum distribution. Parameters varied are the embedding material, the water content and the burial depth. The detailed local momentum distribution can be used as initial conditions for numerical simulations of loading processes of vehicles. Additionally, they provide validation material for the empirical description of momentum transfer on structures that is used in several commercial simulation tools.

2. Experimental arrangement

2.1. Description of the experimental setup

In order to characterize the effects of a buried HE charge, most of the tests presented in the literature use large area steel plates as a momentum trap. This approach delivers no information about the spatial momentum distribution. Therefore, a new experimental method has been developed by which the local distribution of the momentum transfer from a HE detonation on a vehicle structure can be obtained. The principle idea is to measure the velocity and thus the momentum transfer of different rigid bodies at different spatial positions that are exposed to the detonation of the buried HE charge. The local specific impulse is determined from the mass, the gained velocity and the surface area of the corresponding body hit by the detonation products. The exposed surface areas of the objects determine the local resolution of the specific impulse measurement.

Our test technology is based on an arrangement with concentric rings where each individual ring is used as a momentum trap at the corresponding local position (see Fig. 1). The arrangement is placed above a sand filled barrel that contains the HE charge. The rings are fixed with wires at the ceiling of the experimental hall and precisely aligned with respect to the sand barrel and its surface.

The ring velocities are determined with redundant measuring techniques: X-ray diagnostic and high-speed camera.

The experimental setup is shown in Fig. 1. The explosive charge is embedded in an accurately prepared sand environment. The sand barrel has a diameter of 63 cm and a height of 80 cm, which is replaced for each test and is filled with sand again.

2.2. Charge definition

A PETN charge (with a density of 1.54 g/cm^3) has a mass of 84 g with a diameter of 59.2 mm. The depth of burial of the explosive charge (distance from the top of the charge to the top of the soil) varies from 46.4 mm to 116 mm. The initiation of the charge occurs at the center of the bottom of the explosive charge. The distance between the sand surface and the ring structure is 139 mm.

2.3. Sand definition

A defined and reproducible preparation of the embedding material is of great importance. For our tests we used loose sand material which is a heterogeneous material consisting of the quartzite grains, water and the air voids. The effects of buried HE charges depend strongly on the actual composition between these three components. It is therefore necessary to prepare a largely homogeneous mixture of the components within the test barrel. Special attention was given to an exact determination of the water content and the water saturation. The intention was to determine the local momentum distribution as a function of these parameters.

Two different sand types have been chosen for the experiments: an alluvial sand, with 5% water content, and a dry quartz sand. The grain size distributions for the materials are shown in Fig. 2. It can be seen that 80% of the sand particles have a size between 0.1 mm and 0.3 mm which corresponds to a rather fine-grained particle distribution.

As mentioned before, the two parameters water content and the saturation are of special importance for the preparation of defined test conditions. Both parameters have to be prepared in the sand barrel as homogeneous as possible connected with a precise experimental determination of their actual values at the time of testing.

Therefore, we determined the following parameters for each experiment: wet density ρ_{wet}, water content w, dry density ρ_{dry} and saturation S. In the following we give a short summary of the measurements and formulae used for the determination of these parameters.

Shortly before the test, the selected amount of water and sand was mixed and evenly distributed in the test barrel. Afterwards, sand samples (with mass m_{sample}) were taken from the prepared sand in the test barrel with help of a core cutter (height 120 mm, diameter 96 mm, volume $V_{sample} = 868$ mm^3).

The wet sand density ρ_{wet} results from Equ.1

$$\rho_{wet} = \frac{m_{sample}}{V_{sample}} \tag{1}$$

The taken sand sample is then heated at a temperature of 105 °C until the complete water fraction has disappeared from the sample. The sand sample is then weighed and the mass of the dry sand m_{dry} is determined.

The water content w is calculated from Equ.2

$$w = \frac{m_{water}}{m_{dry}} \tag{2}$$

with m_{water} being the evaporated water mass.

The dry density ρ_{dry} is calculated from Equ.3

$$\rho_{dry} = \frac{\rho_{wet}}{1 + w} \tag{3}$$

which finally gives the saturation ratio S with Equ.4