23^{RD} INTERNATIONAL SYMPOSIUM ON BALLISTICS
TARRAGONA, SPAIN 16-20 APRIL 2007

INVESTIGATION OF PRE-CURSOR CHARGE CONFIGURATIONS AND DESIGNS TO ALLOW FOR OFF-AXIS MOTION OF A FOLLOW-THROUGH PENETRATOR IN A TARGET

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Various design options are considered for pre-cursor charges in an anti-bunker munition where the second charge is a follow-through penetrator with predetermined off-axis motion. The potential performance of multiple shaped charges and single shaped charges with special features to enhance the cavity in a specific plane of a concrete target are compared with the performance of a conventional axis-symmetric shaped charge. Experimental firings with selected conceptual configurations provide insight into the practical application of the designs against a specific target.

INTRODUCTION

The use of pre-cursor shaped charges in opening up a path for follow-through explosively filled penetrators into a target is well known and has been demonstrated previously [1, 2]. There have also been a number of studies on the performance of various types and configurations of shaped charge warheads against concrete targets [3-7].

In this study various pre-cursor charge configurations and design options were considered for a fixed cylindrical geometrical space allocation and a concrete target of specified type and thickness. The mass of the pre-cursor arrangement could vary within a specified margin. A design requirement was to take into consideration cases where the dynamic characteristics of the missile, or munition, results in off-axis motion of the follow-through penetrator relative to the shot-line of the pre-cursor charge(s). Such off-axis motion is typically brought about when the missile is in the final stage of a trajectory and has a nose-up attitude or when the missile is manoeuvring prior to engaging the target.

ANALYTICAL CONSIDERATIONS

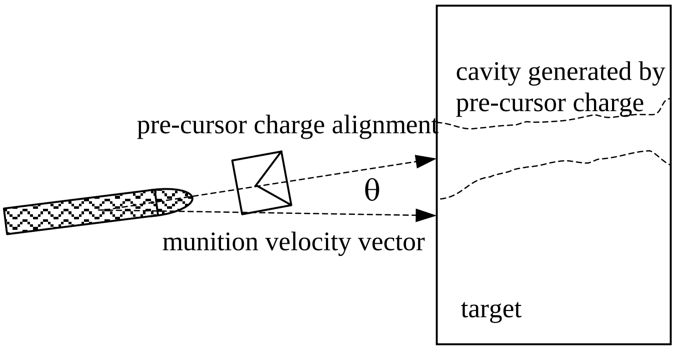

Figure 1. Schematic representation of dynamic munition/target interaction

The dynamic interaction scenario of the pre-cursor charge/penetrator arrangement is shown schematically in Figure 1. To compensate for the fact that the eventual penetrator path is not aligned with the symmetry-axis of the pre-cursor charge at time of initiation, there is a requirement to enlarge the cavity in the direction of the off-axis motion (if this direction is a priori known).

It has been established that the volume of the penetration cavity of a shaped charge is proportional to the jet energy deposited in the target [4]:

$$\frac{E_{jet}}{V} = c\ . \qquad [1]$$

It is generally assumed that the cavity expansion is axis-symmetric in the target and then the proportionality constant (for ductile materials) can be estimated theoretically from the flow stress in the target, σ, and the jet and target densities [8]:

$$\frac{E_{jet}}{V} = \sigma\left(\sqrt{\frac{\rho_t}{\rho_j}} + 2 + \sqrt{\frac{\rho_j}{\rho_t}}\right) \qquad [2]$$

Within the assumptions and constraints of eq. 2 it predicts that if similar jet mass and jet velocities are assumed for an aluminium jet and a copper jet, the cavity resulting from the aluminium jet in a target with the density of concrete will have approximately 10% higher volume than for the copper jet. However, it has also been experimentally established [4, 6-7] that the cumulative hole-volume in a target from the penetration of multiple charges fired simultaneously into concrete is more than the sum of the individual hole-volumes. Specifically for a finite concrete target, this opens up the possibility of using multiple sub-calibre charges with higher density liners (to achieve equal penetration) as a substitute to a single pre-cursor charge. In the context of producing a non-symmetric cavity in the target, the charges can be aligned in a preferred direction.

If the penetration cavity expansion is not axis-symmetric (as for planar jets [9-10]), or in cases where the cavity in the target is created from jets with a lateral velocity component, the extent of the energy-volume relationship is not obvious.

For a fixed geometrical space allocation the following pre-cursor options are possible:

a) mono-shaped charge with a liner choice and design that maximises the (symmetric) cavity volume;
b) mono-shaped charge with a lateral jet velocity gradient to induce a cutting action in the target in a preferred direction;
c) mono-shaped charge with an induced asymmetry to generate a planar jet in order to enhance the cavity diameter in the target in a preferred direction;
d) multiple (parallel or angled) sub-calibre charges with higher density liner material.

NUMERICAL SIMULATIONS

To evaluate trends in the performance of the various options discussed above, the numerical tool Autodyn^{TM} was employed. The first set of simulations performed was the evaluation of the effect of two parallel jets impinging simultaneously into a concrete target. The 3-D Autodyn solver was used with symmetry specified in the x-plane, with the concrete simulated with a SPH grid together with the RHT material model for 35 MPa concrete (resident in Autodyn). The two jets were modelled in Lagrange as tapered copper rods with diameter 6 mm at the front and 10 mm at the rear and with velocity gradients of 6-2 mm/μs from tip to tail. The jets impacted the target 40 mm apart. The initial configuration of the model as well of as a damage plot in the target around the cavities (jet removed from the simulation) at 20 μs are shown in Figure 2.

In Figure 2 it can be observed that a coalescing of the damaged area in the target between the penetration cavities is predicted. This indicates a loss of target strength between the cavities and thus confirms an added effect from the use of two charges. However, it is also observed from Figure 2 that the cavities do not physically coalesce, and that a follow-through penetrator would still have to negotiate the inertial effect of the remaining material, irrespective of the loss of target strength.

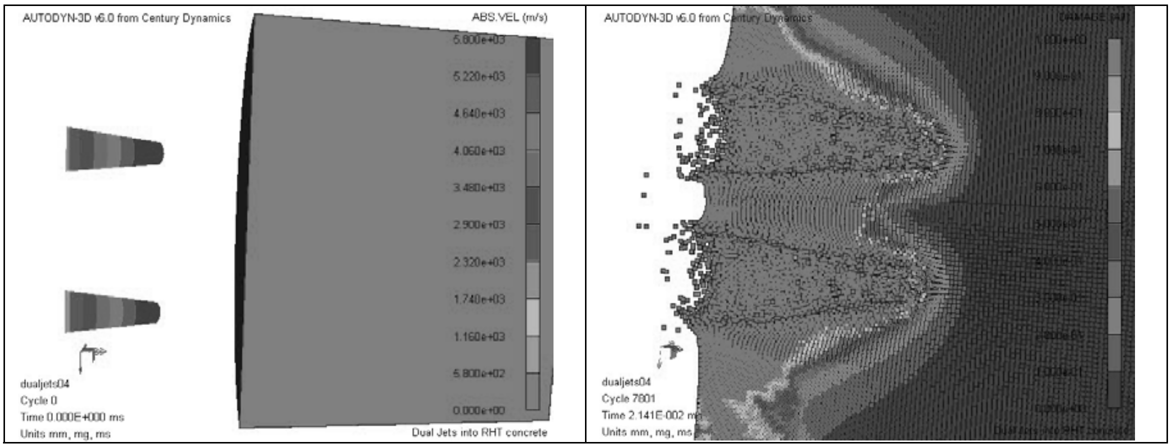

Figure 2. Simulation of two jets impinging simultaneously onto a concrete target

The second set of simulations performed concerned the modelling of a jet with a lateral velocity gradient caused by asymmetric confinement on the base of a shaped charge. For this purpose the Euler-Godunov processor in Autodyn-3D was used to model the formation of a jet from a charge as well as the penetration into a section of concrete. The concrete was modelled with the porous EOS model resident in Autodyn. The initial configuration and the penetration cavity in a short section of the target are shown in Figure 3.

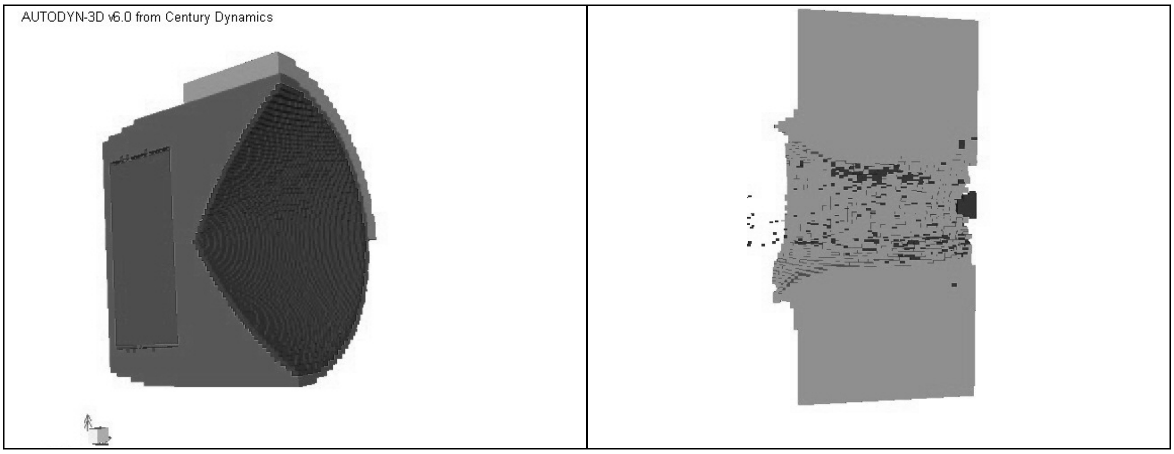

Figure 3. Simulation of the penetration of a jet with a lateral velocity gradient

The crater formed by the jet with the lateral velocity gradient indicated an enlargement in the lateral direction in the front of the target but a lot of the jet energy is expended in the front section of the target and acute reduction in penetration occur.

A further set of simulations with the Euler-Godunov processor was performed with jets formed by initiating a waveshaped shaped charge at two points on the rear of the charge. The resulting jet formed was non-symmetric (planar jet) as shown in Figure 4 with corresponding non-symmetric penetration cavity in the target.

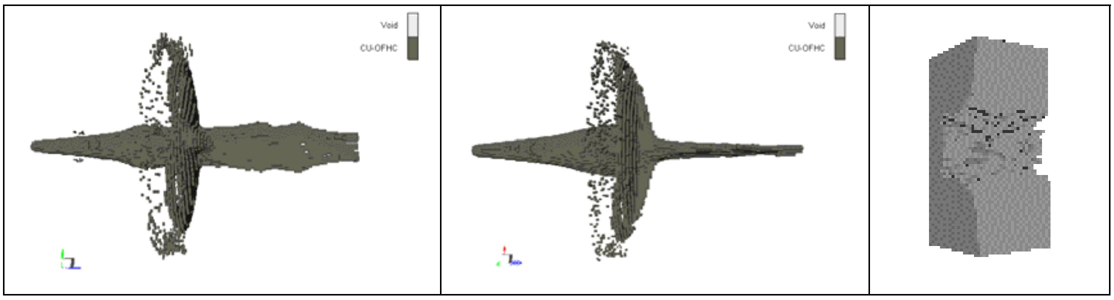

Figure 4. Orthogonal views of the jet formed by two initiation points and penetration in the front target section

EXPERIMENTAL

A 120 mm diameter waveshaped shaped charge with a L/D of 1 and an aluminium liner was used as base-line for the experimental study. The target was lightly reinforced concrete of compressive strength 20-30 MPa and thickness of over half a meter. The jet from the base line charge had a tip velocity of 9.2 mm/μs and a scaled break-up time of approximately 1. The standoff of the charge was 200 mm. The shaped charge was aligned in the centre of the target in such a way that no reinforcing bars would be in the jet path. The setup for the firing and the cavity generated by the aluminium jet in the target after the firing are shown in Figure 5. The average cavity diameter in the centre of the target was 75 mm and the diameter in the frontal (spalled) area was approximately 250 mm for a depth of 50 mm. The concrete around the hole in the target was delaminated and clearly weakened. The E/V value (not taking the spall sections in consideration) is approximately 600 J/cc.

Figure 5. Setup and Result of the Aluminium lined base-line charge

Copper lined 57 mm diameter shaped charges were utilised for the multiple sub-calibre tests. The charges were non-waveshaped trumpet designs of L/D 1.4 with a tip velocity of 9 mm/μs and a scaled average break-up time of 1.6. Two charges were tested in a parallel configuration and two charges were tested in a slightly angled configuration (with impact points 40 mm apart on the target). Shown in Figure 6 is the setup of the angled configuration and the resultant cavities in the target (front and rear) after the test.

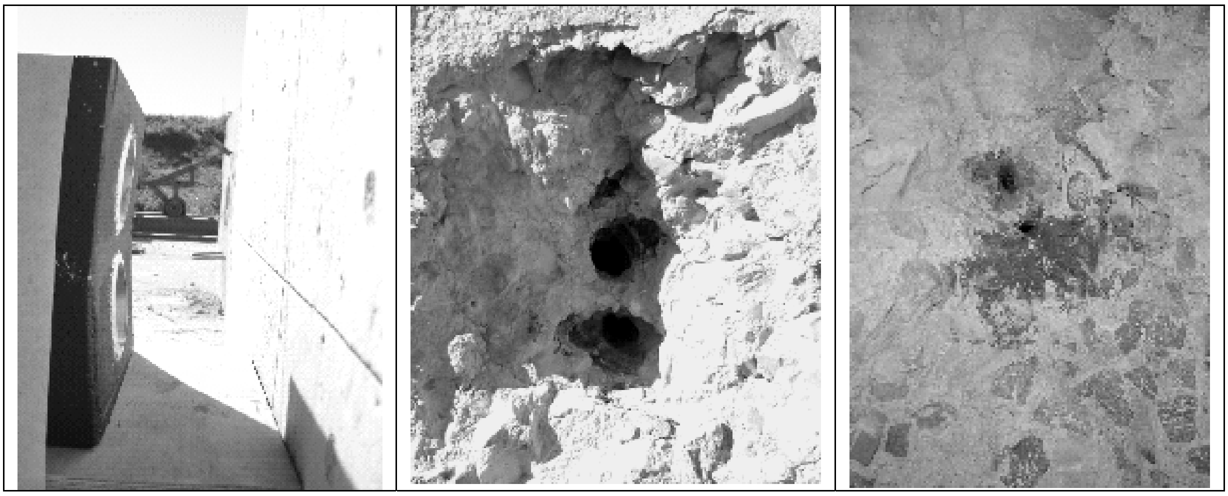

Figure 6. Setup and Entry and Exit cavities in the target for the sub-calibre firings

A novel method to estimate the cavity volume was devised by injecting a polymer compound into the cavities. Shown in Figure 7 are the recovered mouldings of the cavities for the angled sets of tests. It can be seen that for the angled sub-calibre firings there is a coalescing of the cavities towards the rear of the penetration cavity. The summed E/V value was estimated at 1200 J/cc.

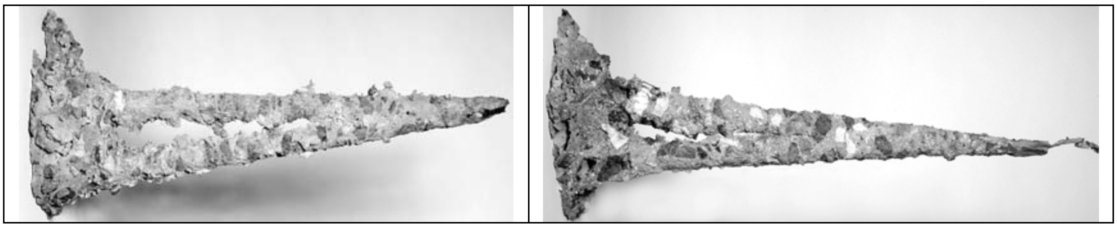

Figure 7. Polymer mouldings extracted from the sub-calibre test cavities

In Figure 8 the oblong cavity is shown that was generated by a planar jet from a 124 mm diameter copper lined shaped charge with two initiation points. In this case the target was perforated with considerable residual penetration into steel target at the rear of the concrete target, which prohibited a reliable estimate of the E/V value.

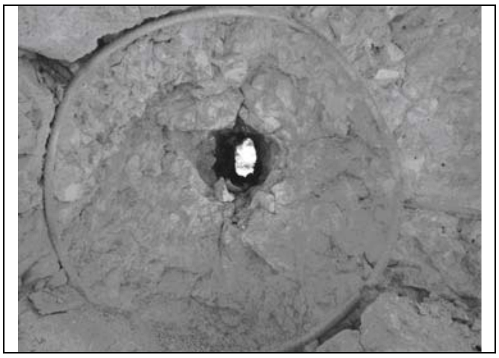

Figure 8. Cavity resulting from the 124 mm diameter copper shaped charge with two initiation points

DISCUSSION

For a fixed geometrical space allocation it appears from analytical and numerical considerations that it will be beneficial to use multiple sub-calibre charges as pre-cursor charge for a follow-through penetrating munition with off-axis motion. For arbitrary sub-calibre charges in this volume it was however experimentally found that, although the target strength between the separate cavities might be reduced, the cavities did not physically coalesce all along the depth of the target. This implies that a penetrator with off-axis motion would need substantial kinetic energy in order to breach the residual material in the target. Although the aluminium lined mono-charge produces a symmetric cavity in the target, it appears that multiple sub-calibre charges (in a fixed geometry allocation) will be hard pressed to deliver the same penetration and cavity diameter (even taking into account the asymmetric positioning of the charges).

From the simulations and experiments it could also be ascertained that jets with lateral velocity gradients would be an inefficient option. Planar jets from mono-charges formed by multiple initiation points, however, hold promise depending on how effectively the planarity of the jet can be optimised whilst still attaining the required penetration.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the management and personnel of Denel Land Systems Western Cape who contributed to, and supported, this work.

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