

## EFFECT OF MULTIPLE AND DELAYED JET IMPACT AND PENETRATION ON CONCRETE TARGET BOREHOLE DIAMETER

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The effect of multiple and delayed jet impact and penetration on the borehole diameter in concrete targets is discussed in this paper. A first-order principle of shaped-charge jet penetration is that target hole volume is proportional to the energy deposited in the target by the jet. This principle is the basis for the relation that target borehole diameter at any depth along the penetration path is proportional to the jet energy deposited in the target at that location. Our current research shows that the “jet energy per unit hole volume constant” for concrete can be substantially altered by the use of multiple and delayed jet impacts. It has been shown that enhanced entrance crater formation results from the simultaneous impact and penetration of three shaped-charge jets. We now demonstrate that enhanced borehole diameter is also observed by the simultaneous impact and penetration of multiple shaped-charge jets followed by the delayed impact and penetration of a single shaped-charge jet.

### INTRODUCTION

This paper describes the results and evaluation of several experiments that investigate the effect of multiple and delayed jet impact and penetration on the borehole diameter in concrete targets. One of the first-order principles of shaped-charge jet penetration is that the target hole volume is proportional to the energy deposited in the target by the jet [1-3]. This principle is the basis for the relation that the target borehole diameter at any depth along the penetration path is proportional to the jet energy deposited in the target at that location. The proportionality constant between jet energy deposited and the resulting borehole diameter is a fundamental property of the target material that is mildly dependent on the penetrator material and penetration velocity [4].

Our current research shows that “jet energy per unit hole volume” for concrete can be substantially altered by the use of multiple and delayed jet impacts. In previous work it was shown that an enhanced entrance crater formation could be obtained from the simultaneous impact and penetration of three Viper shaped-charge jets into a concrete target [5]. Our current work shows that in addition to the enhanced *entrance crater* formation

from multiple jet impacts, enhanced *borehole volume* and enhanced *borehole diameter* can be obtained from the subsequent delayed impact and penetration of a second shaped-charge jet. The basis for these enhancements is the combination of stress wave interactions, free-surface effects, and the tensile failure characteristics of concrete.

## BACKGROUND AND REVIEW

The issue of creating large diameter boreholes in concrete has been studied for many years [6–8]. One motivation has been to create a pilot borehole in the concrete target for the subsequent penetration by a “low-velocity” projectile [9]. In this context we use the term “low velocity” to mean a velocity that provides much less than one projectile body length of penetration into an intact undamaged concrete target. The size of the pilot hole should be at least 80% of the diameter of the projectile to obtain a significant improvement in the penetration depth at low velocity [9–11].

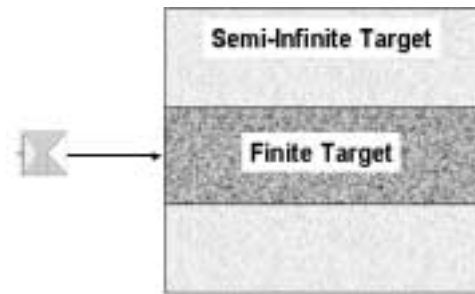
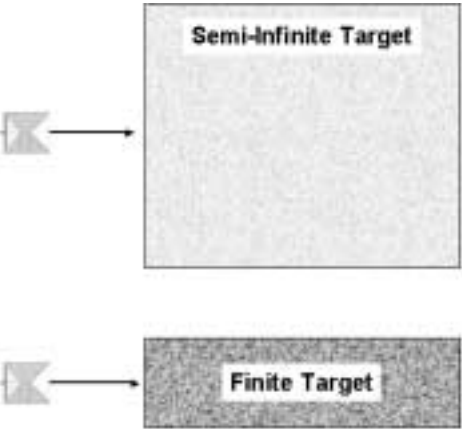
The target borehole volume is proportional to the jet kinetic energy (from classical jet penetration theory). With an “efficient” jet for hole drilling in concrete, the jet kinetic energy is primarily a function of the size of the shaped charge, while the hole shape is controlled by the liner density, liner geometry, and standoff distance [12]. Fundamental shaped charge principles guide how to make a large-diameter borehole with corresponding shallower depth of penetration (a constant-volume hole). Assuming one has an efficient shaped-charge design, it appears that the only way to increase the total borehole volume with a single shaped charge is to increase the size of the charge.

Concrete is a brittle material that fails at a lower stress in tension than in compression. It is much stronger in compression and exhibits a high confined compressive strength after failure due to coulomb type pressure-dependent strength. By taking the fundamental properties of concrete into consideration, we show that it is possible to increase the ratio of target borehole volume divided by jet kinetic energy using multiple and delayed shaped-charge jet penetrations to damage the concrete in tension. The key to our approach is to use stress-wave interactions combined with free-surface effects to generate tensile stresses that exceed the tensile failure strength of the concrete target. An example of this type of effect in concrete is observed when comparing projectile penetration to projectile perforation. Stress waves reflecting off the rear free surface cause target material failure ahead of the projectile. The rear surface target material failure reduces the apparent or effective thickness of the target. This results in a greater perforation thickness than penetration depth. The following section describes a similar effect for creating large diameter boreholes in concrete using stress wave interactions, free-surface effects, and tensile failure.

## ENHANCEMENT OF BOREHOLE DIAMETER

In previous work [5] it was shown that an enhanced entrance crater could be formed from the simultaneous impact and penetration of three shaped-charge jets. The primary mechanism for the creation of the enhanced crater was the free-surface tensile failure effect at the front face of the target. The three Viper shaped charge jets provided a much lar-

ger spatial pressure field with the same pressure levels as a single jet. This resulted in a larger spall crater from tensile failure at the front face. Discussions of how to extend this free-surface tensile failure effect to a greater depth in the target led to a new concept of enhancing the diameter of the borehole. When a jet penetrates a semi-infinite target, the diameter of the borehole is proportional to the energy in the jet. When a jet penetrates a finite target that is over-matched, the target is totally destroyed because of the free-surface tensile failure effect along the side wall of the target (not just at the front surface). The effective borehole diameter is the diameter of the over-matched finite target, resulting in a higher proportionality of borehole diameter to energy in the jet. How do you make a semi-infinite target react like a finite target in the region of the jet penetration? The approach we have examined is to create a finite target within the semi-infinite target. We first use a cluster of shaped charges to create the finite target in



the semi-infinite target by drilling holes and creating free-surfaces around the path of jet penetration. This is followed by the impact and penetration of a second shaped-charge jet that links the boreholes from the cluster of charges, creating a single large hole. The net effect is a substantial increase in the diameter of the borehole in the target. The following pages describe an experimental evaluation of this concept.

## EXPERIMENTAL RESULTS

The test setups and test results for evaluating this concept are described in Figs. 1 & 2 on the following pages. The photographs in Fig. 1 describe the simultaneous firing of four shaped charges followed later by the firing of a single shaped charge. The photographs in Fig. 2 describe the firing of a single shaped charge followed later by the simultaneous firing of four shaped charges. Both tests used the same number of shaped charges, with the only difference being the order of the test firings: four followed by one versus one followed by four. The shaped charge used in the tests was an uncased 146 mm diameter TOW-2A charge with copper liner and LX-14 explosive [13].

## Four shaped charges plus one shaped charge

The test setup for firing the first four shaped charges is shown in Fig 1a. The four charges were spaced 25 mm apart and 292 mm (2 charge diameters, CD's) from the target. The result of the simultaneous firing of the four charges is shown in Fig 1b. An enhanced surface crater is observed along with four distinct boreholes into the target. Note that the surface crater has a 300-mm square by 300-mm deep box-like structure resulting mainly from the shock wave interactions with the free-surface, although there may also be simultaneity effects here. The setup for firing the single shaped charge into the center of the four boreholes is shown in Fig. 1c. The standoff was 2 CD's to the concrete target face making the effective standoff to the bottom of the surface crater about 4 CD's. The resulting target damage from this second test is shown in Fig. 1d. In the region just below the bottom of the initial surface crater, two of the holes (vertical in the figure) were completely connected while the other two holes (horizontal in the figure) were only partially connected. However, deeper into the target, all four of the initial boreholes were connected, resulting in a total target damage diameter at least four times greater than the borehole diameter from a single jet.

## One shaped charge plus four shaped charges

The test setup for initially firing the single shaped charge is shown in Fig. 2a. This charge was fired at 292 mm (2 CD's) from the target. The result of the single-shaped charge firing is shown in Fig. 2b. Note that, as expected, an enhanced surface crater is *not* observed. The test setup for the simultaneous firing of the four TOW charges into the region surrounding the single borehole is shown in Fig. 2c. These charges were also fired at 2 CD's standoff to the target face. The resulting target damage is shown in Fig. 2d. Comparing these results to the results shown in Fig. 1d, we see less enhancement to the entrance crater and no enhancement to the borehole diameter in the target. There was no linking of the four boreholes and the center borehole diameter became smaller.



Figure 1a. Test setup for firing 4 charges.



Figure 1b. Target damage from 4 charges.



Figure 1c. Setup for firing second charge.



Figure 1d. Target damage from 4 + 1 charge.



Figure 2a. Test setup for firing 1 charge.



Figure 2b. Target damage from 1 charge.



Figure 2c. Setup for firing 4 more charges.



Figure 2d. Target damage from 1+4 charges.

## CONCLUSIONS

These test results show that an enhanced borehole diameter can be obtained from the simultaneous impact and penetration of multiple shaped-charge jets followed by the delayed impact and penetration of a single shaped charge jet. The two sets of experiments demonstrate that stress-wave interactions, free-surface effects, and the tensile failure

characteristics of concrete can either work to increase or decrease resulting target damage from multiple and delayed jet impacts.

In our future work, we plan to study the effects of using different liner materials along with the effects of the simultaneous firing of all charges versus the sequential firing of charges that was tested here. Since the enhancement in target damage is derived from stress-wave reflections from free-surfaces, we will also examine the use of constant energy deposition jets that should create a constant enhancement to the borehole diameter.

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