Preprint
UCRL-JC-139827

Effect of Multiple and Delayed Jet Impact and Penetration on Concrete Target Borehole Diameter

M. J. Murphy, D. W. Baum, R. M. Kuklo, S. C. Simonson

This article was submitted to
19th International Symposium on Ballistics, Interlaken, Switzerland,
May 7-11, 2001

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

January 26, 2001

This work was performed under the auspices of the United States Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

EFFECT OF MULTIPLE AND DELAYED JET IMPACT AND PENETRATION ON CONCRETE TARGET BOREHOLE DIAMETER[1]

M.J. Murphy, D.W. Baum, R.M. Kuklo, S.C. Simonson

Lawrence Livermore National Laboratory, 7000 East Ave, Livermore, CA 94551, USA

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 <u>entrance crater</u> 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 <u>borehole volume</u> and enhanced <u>borehole diameter</u> 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.

---

[1] Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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.

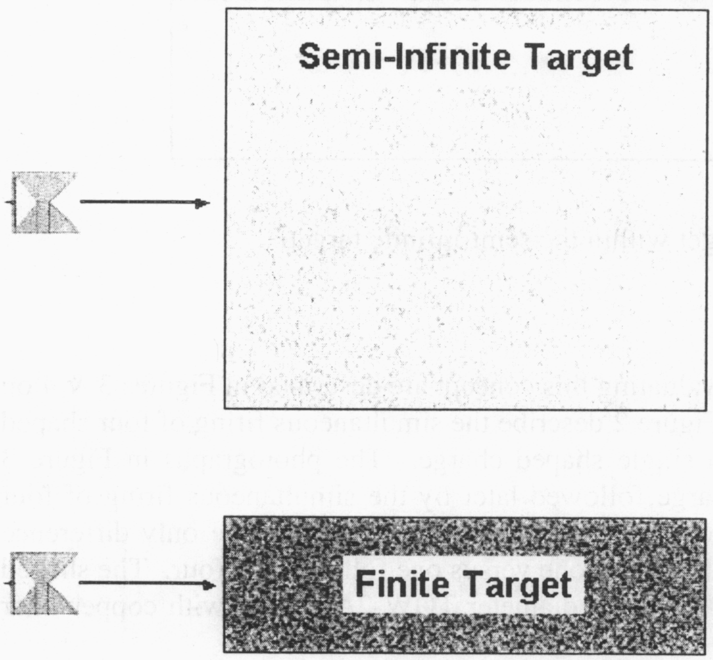
Concrete is a brittle material that fails at a lower stress in tension than in compression. It is much stronger in compression and exhibits a high confined compressive strength after failure due to coulomb type pressure-dependent strength. By taking the fundamental properties of concrete into consideration, 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 surface 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 larger 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.

Semi-infinite target penetration

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 overmatched, 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 overmatched finite target resulting in a higher proportionality of borehole diameter to energy in the jet. This is described in Figure 1.



The damage to a semi-infinite target is the hole size created by the jet which is proportional to the energy in the jet.

The damage to a finite target is the whole target which results in a higher proportionality to the energy in the jet.

Figure 1. Target Damage Comparison

Finite target penetration

The question we are now addressing is how does one 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 as shown in Figure 2. 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.

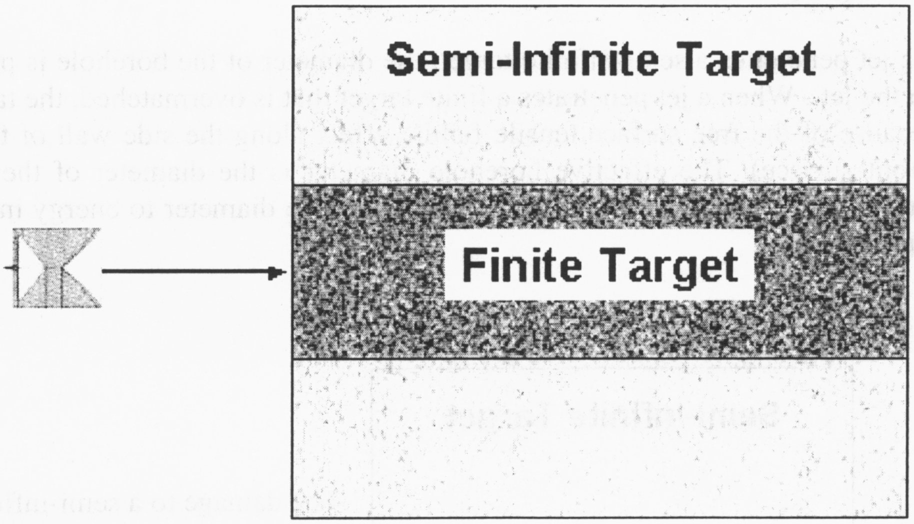


Figure 2 - Finite target within the semi-infinite target.

EXPERIMENTAL RESULTS

The test setups and test results for evaluating this concept are described in Figures 3 & 4 on the following pages. The photographs in Figure 2 describe the simultaneous firing of four shaped charges followed later by the firing of a single shaped charge. The photographs in Figure 3 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 Figure 3a. 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 Figure 3b. 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 simultainity effects here. The setup for firing the single shaped charge into the center of the four boreholes is shown in Figure 3c. 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 Figure 3d. 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.

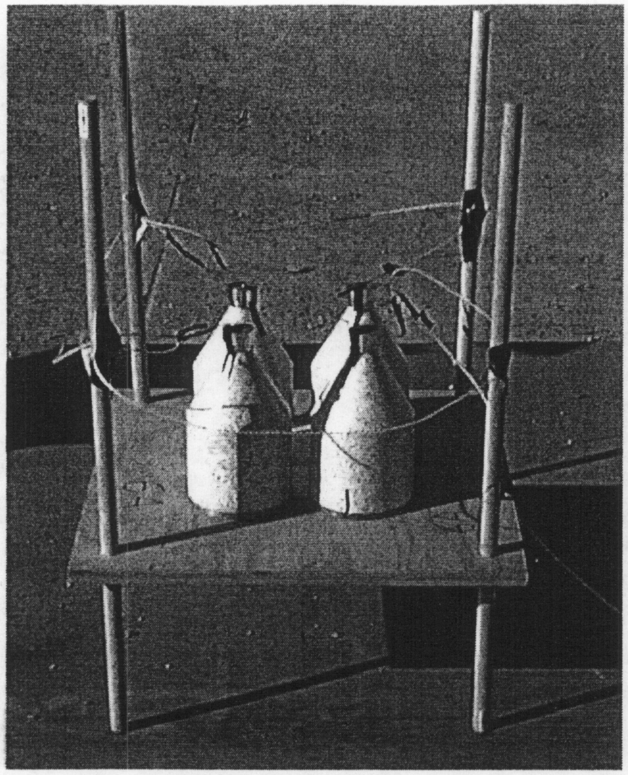


Figure 3a. Test setup for firing 4 charges.

Figure 3b. Target damage from 4 charges.

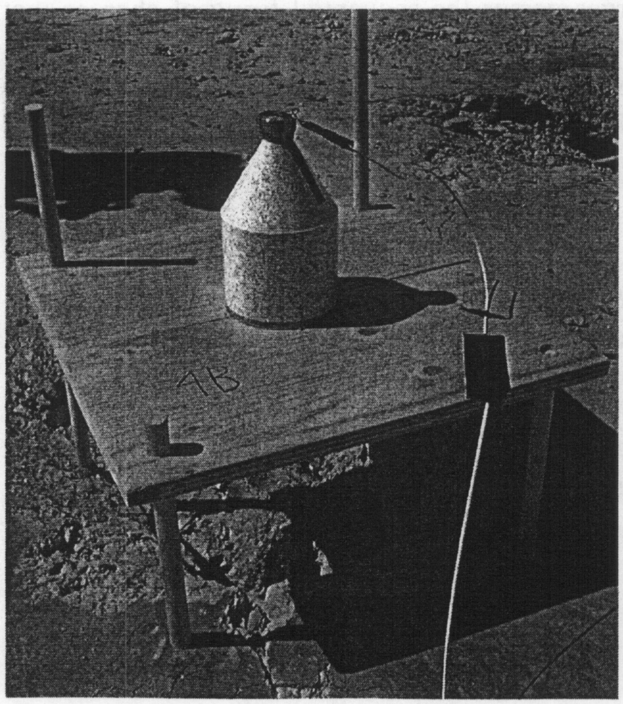


Figure 3c. Setup for firing second charge.

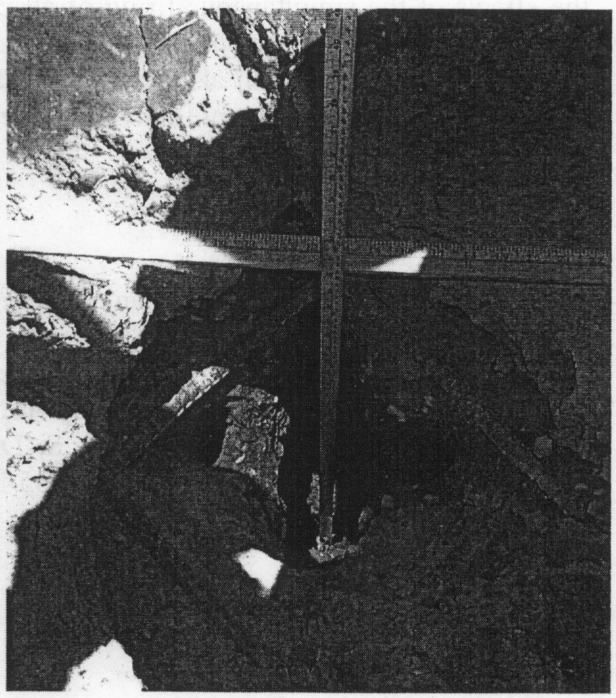


Figure 3d. Target damage from 4 + 1 charge.

Figure 3. Test setups and target damage from the 4 + 1 test series

One shaped charge plus four shaped charges

The test setup for initially firing the single shaped charge is shown in Figure 4a. This charge was fired at 292 mm (2 CD's) from the target. The result of the single shaped charge firing is shown in Figure 4b. 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 Figure 4c. These charges were also fired at 2 CD's standoff to the target face. The resulting target damage is shown in Figure 4d. Comparing these results to the results shown in Figure 3d, 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.

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.

FUTURE WORK

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.

ACKNOWLEDGEMENTS

The authors would like to thank Tommy Rambur for his support for setting up & running the tests as well as the crew at the Supersonic Naval Ordnance Research Track (SNORT) located at the Naval Air Weapons Center China Lake for their test support. This work was supported in part by the Joint DoD/DOE Munitions Technology Development Program. This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

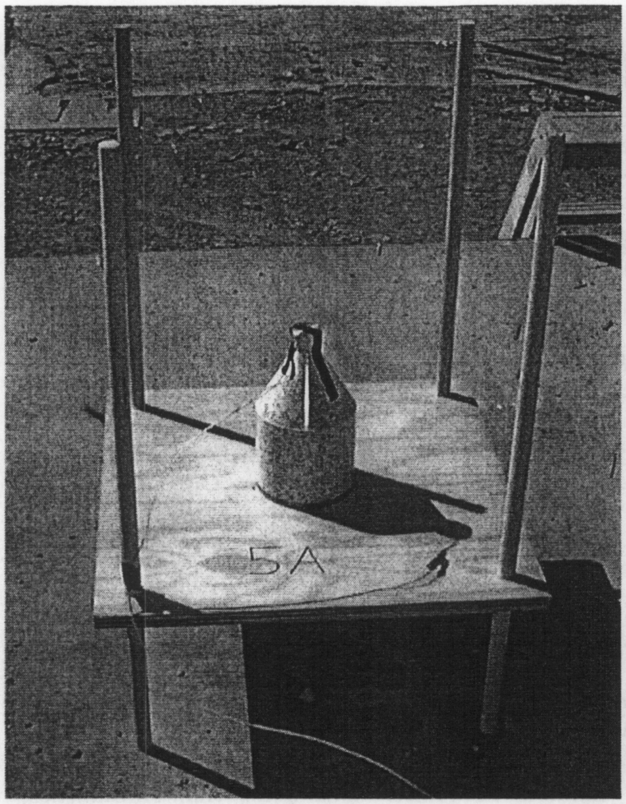


Figure 4a. Test setup for firing 1 charge.

Figure 4b. Target damage from 1 charge.

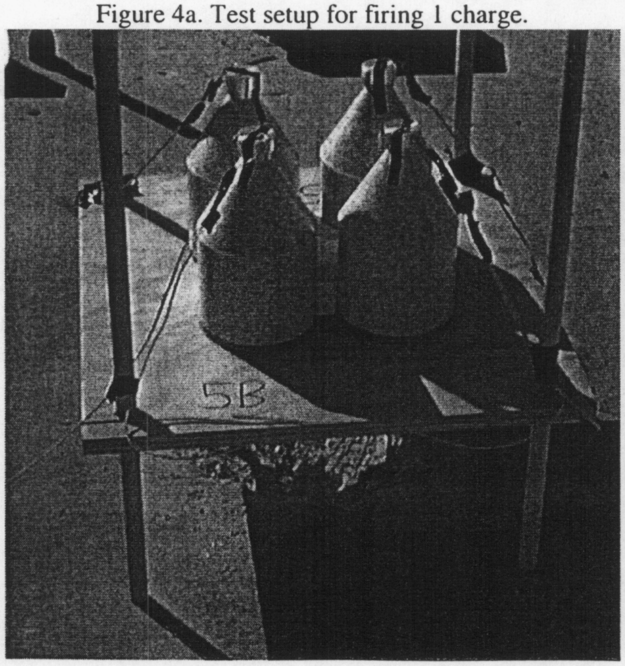


Figure 4c. Setup for firing 4 more charges.

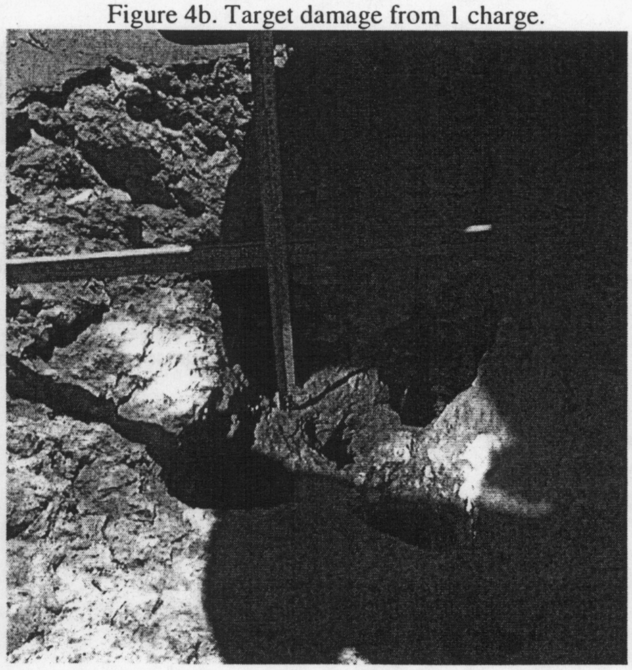


Figure 4d. Target damage from 1+ 4 charges.

Figure 4. Test setups and target damage from the 1 + 4 test series

REFERENCES

1. J.B. Feldman, "Volume-Energy Relation from Shaped-charge Jet Penetrations", Proceedings of the 4th Symposium on Hypervelocity Impact", APGC-TR-60-39 (II), 1960.

2. C. Riparbelli, "A Method to Calculate the Profile of a Crater Produced be a High Velocity Projectile Impacting a Bulky Target", General Dynamics Report TM 6-122-44.34-21, 1968.

3. Szendrei, T., "Analytical Model of Crater Formation by Jet Impact and Its Application to Calculation of Penetration Curves and Hole Profile", 7th 8th International Symposium on Ballistics, The Hague, NL, May 1983.

4. M.J. Murphy, "Survey of the Influence of Velocity and Material on the Projectile Energy/Target Hole Volume Relationship", 10th International Symposium on Ballistics, San Diego, Oct. 1987.

5. D.W. Baum, R.M. Kuklo, J.W. Routh, S.C. Simonson, "Simultaneous Multiple-Jet Impacts in Concrete – Experiments and Advanced Computational Simulations", 18th International Symposium On Ballistics, San Antonio, TX, November 1999.

6. F.E. Walker, R.E. Varosh, "Hard Structure Munition Project" , LLNL 1975-1980

7. F.E. Walker, R.E. Varosh, M.J. Murphy, "Tomahawk Airfield Attack Munition Project", LLNL 1979-1982.

8. M.J. Murphy & J.M. Henderson, "Computer Simulation of Concrete Penetration by Shaped Charge Jets", 7th International Symposium on Ballistics, The Hague, Netherlands, April 1983.

9. M.J. Murphy, "Performance Analysis of Two-Stage Munitions", 8th International Symposium on Ballistics, Orlando, Florida, October 1984.

10. E.N. Folsom, "Projectile Penetration into Concrete with an Inline Hole", Masters Thesis, UCRL-53786, June 1987.

11. E.J. Mostert, "Penetration of Steel Penetrators into Concrete Targets with Pre-Drilled Cavities of Different Diameters", 18th International Symposium On Ballistics, San Antonio, November 1999.

12. M. J. Murphy and R. M. Kuklo, "Fundamentals of Shaped-charge Penetration in Concrete", 18th International Symposium On Ballistics, San Antonio, November 1999.

13. S.C. Simonson, K.A. Winer, R.D. Breighaupt, G.R. Avara, D.W. Baum, "Fabry-Perot Measurements and Analysis of TOW-2A Liner Collapse and Jet Formation", 16th International Symposium On Ballistics, San Francisco, September 1996.