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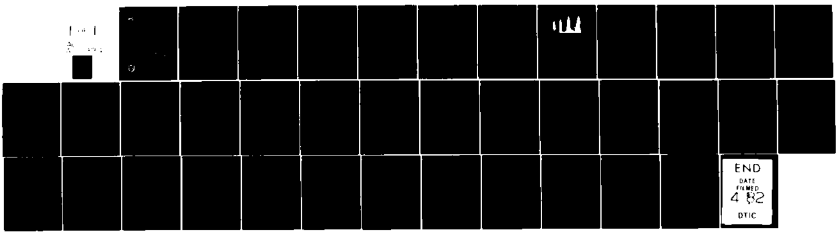

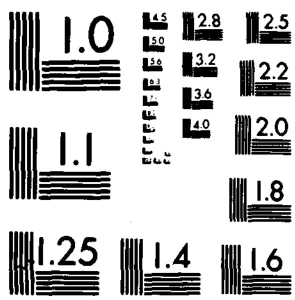

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AN ANALYSIS OF CRATERS PRODUCED BY ARTILLERY MUNITIONS DURING DUSTY INFRARED TEST SERIES

JANUARY 1982

By

Bruce W. Kennedy

Approved for public release; distribution unlimited.

US Army Electronics Research and Development Command
Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002

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Dusty Infrared Tests (DIRT) I, II, and III provided important data on the craters produced by artillery munitions and other explosives. This paper compares the crater dimensions produced in various soils by static detonations and by live firings. A battlefield standard, the 155-millimeter high explosive projectile, is suggested as a comparison base. The paper contains recommendations for future tests to help compute more accurate munition equivalences.

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INTRODUCTION

It is known that an explosive charge of constant size, configuration, and placement with respect to the earth's surface will produce different size craters depending on soil type and moisture.[1] It is desirable to do an analysis of artillery munitions and resultant cratering so that an accurate estimate of ejecta can be calculated for modeling purposes. Dusty Infrared Tests (DIRT) I, II, and III, conducted between October 1978 and May 1980, addressed this subject. DIRT-I,[2] performed at White Sands Missile Range (WSMR), New Mexico, included static detonations and live artillery firings of 155-mm high explosive (HE) ammunition. The soil type was a brown silty sand with low-to-moderate moisture content (3 to 13 percent). DIRT-II,[3] also conducted at WSMR, included static detonations of 105- and 155-mm and 4.2-in ammunition, and live firings of 105- and 155-mm projectiles. The soil was an alluvial deposit of silty clay with varying amounts of sand. Moisture content varied from 10 to 15 percent near the surface to 18 to 24 percent at depths of up to 1 m. DIRT-III, conducted at Fort Polk, LA, during April and May 1980, utilized static firings of 105- and 155-mm HE US Army ammunition, and 122- and 152-mm Soviet HE projectiles (figure 1). Also included in the tests were various sizes and placements of uncased HE, including composition four (C-4) and M118 demolition block. Surface soil was sandy loam, below which was a heavy yellow clay. Moisture content was high, ranging up to 30 percent by weight.

The thread of commonality throughout the DIRT series was the 155-mm HE projectile. Therefore, comparisons of craters formed by the various munitions can be related to the 155. Only those tests where the projectiles were placed at elevated angles of up to 30° with the nose tangent to the surface (ST) are used for comparison. The rationale for detonating the static munitions in this manner is that the elevation angle and burst position approximates an incoming round containing a superquick point detonating fuze. As will be seen, this assumption is not entirely correct, because the craters produced by live fire were generally smaller than static detonations and the crater shapes were different. Those craters produced by tube-delivered rounds generally had pronounced elongation along the flight path, while craters made with statically detonated projectiles had lateral troughs normal to the projectiles' long axis.

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[1] Cratering from High Explosive Charges: Analysis of Crater Data, Technical Report No. 2-547, Report 2, US Army Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, MI, June 1961.

[2] Lindberg, James D., Compiler, Measured Effects of Battlefield Dust and Smoke on Visible, Infrared, and Millimeter Wavelength Propagation: A Preliminary Report on Dusty Infrared Test-I (DIRT-I), ASL-TR-0021, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, January 1979.

[3] Kennedy, Bruce W., Compiler, Dusty Infrared Test-II (DIRT-II) Program, ASL-TR-0058, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, May 1980.

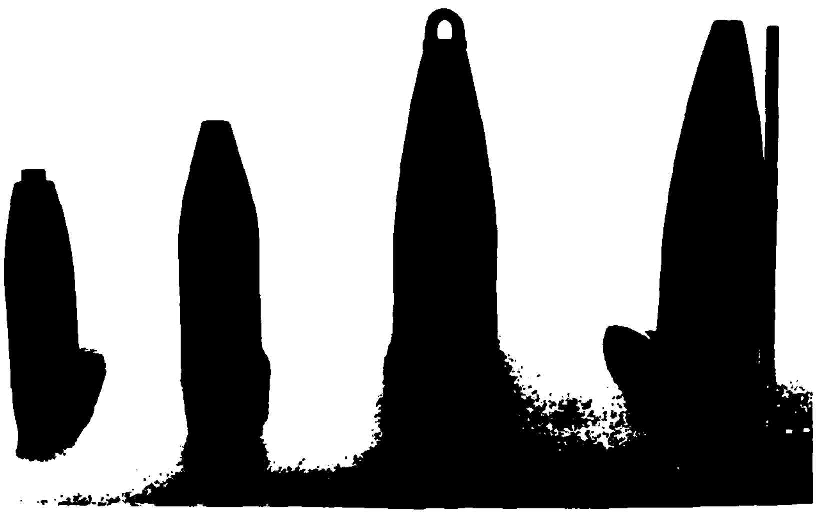

Figure 1. The four types of projectiles used during the DIRT-III test including (left to right) US 105-mm, USSR 122-mm, US 155-mm, and USSR 152-mm.

ANALYSIS

Table 1 summarizes the tests to be compared from DIRT-I, II, and III. The table includes the mean crater depth and diameter, number of samples, and the standard deviation. Unfortunately, samples are limited in some cases to only three. Therefore, results of any analysis can only be construed as indicators of trends. It can also be observed that the standard deviation of crater depth is generally smaller than crater diameter, although on a percentage basis the variation of depth is larger in three out of seven cases. Diameters were usually measured across two axes, major and minor, and the values averaged. Methods of measurement will not be discussed here, but there was some subjectivity in the determination of crater diameter, and this can lead to uncertainties. Most of the variability, however, is not attributable to this uncertainty.

First, we will examine the differences in craters due to soil. Referring to table 2, the ratio of static 155-mm depth between DIRT-I and DIRT-II is 0.7, while the ratio of diameters of 0.86. This shows that craters at the DIRT-II site were larger. A test of significance at 95 percent confidence shows that the values are different. Comparing DIRT-II with DIRT-III the depth ratio is 1.1 and the diameter ratio is 0.85. Again, differences are statistically significant. DIRT-I/DIRT-III ratios are 0.77 for depth and 0.73 for diameter. The conclusion is that crater size increases as a function of moisture and soil cohesiveness. This agrees well with data in reference one.

TABLE 1. STATISTICAL SUMMARY OF CRATER DEPTH AND DIAMETERS FOR VARIOUS MUNITIONS USED DURING DIRT-I, II, AND III

	DIRT-I		DIRT-II		DIRT-III	
	DEPTH (n)	DIAMETER (n)	DEPTH (n)	DIAMETER (n)	DEPTH (n)	DIAMETER (n)
155-mm live fire	0.37(50)	1.44(59)	0.55(10)	1.73(10)	-	-
105-mm live fire	-	-	0.3(10)	1.05(11)	-	-
155-mm static (11°-30°)	0.40(5)	1.72(5)	0.57(9)	2.01(9)	0.52(3)	2.37(3)
σ	0.10	0.12	.13	0.1	0.02	0.31
105-mm static	-	-	0.30(6)	1.45(6)	0.29(3)	1.31(3)
σ			0.02	0.17	0.02	0.28
152-mm static	-	-	-	-	0.35(4)	2.05(4)
σ					0.06	0.19
122-mm static	-	-	-	-	0.35(3)	1.76(3)
σ					0.05	0.37

(n) denotes sample size. Units are meters.

TABLE 2. RATIOS OF CRATER DEPTHS AND DIAMETERS FOR VARIOUS TESTS CONDUCTED AT DIRT-I, II, AND III

Test Comparison	Ratio: Depth	Ratio: Diameter
155 ST DIRT-I/155 ST DIRT-II	0.70	0.86
155 ST DIRT-II/155 ST DIRT-III	1.10	0.85
155 ST DIRT-I/155 ST DIRT-III	0.77	0.73
155 FIRE DIRT-I/155 FIRE DIRT-II	0.67	0.83
155 FIRE DIRT-I/155 ST DIRT-I	0.93	0.84
155 FIRE DIRT-II/155 ST DIRT-II	0.96	0.86
105 FIRE DIRT-II/105 ST DIRT-II	1.00	0.72
152 ST DIRT-III/155 ST DIRT-III	0.67	0.86
105 ST DIRT-III/122 ST DIRT-III	0.83	0.74
122 ST DIRT-III/155 ST DIRT-III	0.67	0.74

Craters can also be compared between DIRT-I and DIRT-II for live artillery firings of 155-mm ammunition. The depth ratio between DIRT-I and DIRT-II is 0.67, while the diameter ratio is 0.83. This compares favorably with the 0.7 and 0.86 ratios derived from the static detonations.

To further compare data, live artillery firings and static detonations from both DIRT-I and DIRT-II are examined. For DIRT-I, the ratio of 155-mm tube-delivered projectiles vs static detonations is 0.93 for depth and 0.84 for diameter. DIRT-II 155-mm results are 0.96 and 0.86, respectively, a good correlation. DIRT-II 105-mm results are 1.00 for depth and 0.72 for diameter.

One important factor that can be determined from this data is the relative strength of the foreign ammunition compared with that of the United States. Comparing DIRT-III static detonations of 152- with 155-mm, the depth ratio is 0.67, and the diameter ratio is 0.86. In other words, the 155 round produces a larger crater, a somewhat interesting statistic because the Soviet round contained approximately 0.17 kg more explosive.

A comparison can also be made between the 105- and 122-mm rounds for DIRT-III. The depth and diameter ratios are 0.83 and 0.74, which is not surprising, because the Soviet round contains 1.38 kg more explosive. The 122/155 mm ratios are 0.67 for depth and 0.74 for diameter. In this case the 155 round contains about 3 kg more explosive material.

Even though there were no tube-delivered tests of Soviet ammunition, an approximation of crater size can be computed based on comparison between static and dynamic US ammunition. The average ratios between 155-mm dynamic and static firings for DIRT-I and DIRT-II are 0.945 for depth and 0.85 for diameter. Table 3 shows simulated live fire crater values computed for both US and Soviet ammunition. It also shows actual values of crater parameters for live firings at DIRT-II. Agreement is good between computed vs actual value for 105 and 155 rounds, with the exception of 105-mm crater diameter.

TABLE 3. CRATER PARAMETERS (METERS). COMPUTED VALUES REPRESENT SIMULATED LIVE FIRINGS. ACTUAL VALUES WERE TAKEN AT DIRT-II.

	Computed		Actual	
Projectile	Depth	Diameter	Depth	Diameter
DIRT-II 105-mm	.28	1.23	.03	1.05
DIRT-II 155-mm	.54	1.71	.55	1.73
DIRT-III 122-mm	.33	1.5	-	-
DIRT-III 152-mm	.33	1.74	-	-
DIRT-III 105-mm	.27	1.11	-	-
DIRT-III 155-mm	.49	2.01	-	-

It has been common practice for explosives to be expressed in terms of TNT equivalence. C-4, for example, has a TNT equivalence of about 1.3 One of the objectives of DIRT-I, II, and III was to determine the bare charge equivalence for the various military munitions. However, Mason and Carnes[3] show that craters formed by cased munitions are irregular in shape and have "troughs" on each side of the crater. DIRT-II revealed that for a ST detonation, approximately twice the projectile charge of C-4 was required to produce an equivalent crater. Carnes attributed this to the work exerted on the soil by the shell fragments. Further studies have indicated that there are different equivalences for crater depth than for diameter:[4] a single uncased charge will simulate either depth or diameter, but not both. The reason for needing equivalence is because some tests cannot tolerate the presence of fragment hazard for either safety reasons or equipment protection.

For the purposes of modeling battlefield obscuration from HE dust, it is probably safe to assume that the adversaries will not be hurling uncased charges at one another. It seems sensible, then, to create an equivalence more akin to the battlefield. This author proposes using the 155-mm TNT filled fragment projectile as the standard. This standard would provide a proportionality constant, K, to denote both depth and diamater equivalences. Table 4 reflects the K-factors for each of the munitions discussed here. These K-factors are for low angle of fire (<30° angle of fall) and surface detonation. The values for the 105-mm were calculated from table 1, while those for the 122- and 152-mm were computed from table 3.

TABLE 4. K-FACTORS FOR TUBE-DELIVERED ARTILLERY MUNITIONS USING THE 155-MM HE FRAGMENT ROUND AS A STANDARD

Projectile	Explosive Type	Explosive Charge-Kg	Projectile Weight-Kg	K-FACTOR Depth	K-FACTOR Diameter
105-mm	COMP B	2.3	15	0.55	0.61
155-mm	TNT	6.76	44	1.0	1.0
122-mm	Amatol/TNT	3.68	21.76	0.67	0.75
152-mm	TNT	6.93	40	0.67	0.86

[3] Kennedy, Bruce W., Compiler, Dusty Infrared Test-II (DIRT-II) Program, ASL-TR-0058, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, May 1980.

[4] Kennedy, Bruce W., B. I. Carnes, and James B. Mason, "Dusty Infrared Test II (DIRT-II)," presented to Smoke/Obscurant Symposium IV, Adelphi, MD, April 1980.

RECOMMENDATIONS

Because of the limited quantity of data, additional research and field experiments are needed to:

1. Verify, through repetitive tests, the accuracy of the findings of this report.

2. Conduct low angle firings into soil similar to Fort Polk, LA.

3. Conduct high angle tests, i.e. quadrant elevation greater than 45° in various soil types.

4. Fire projectiles containing time delay fuzes.

5. Test comparability of US and Soviet superquick point detonating fuzes and craters using live fire.

Items 4 and 5 are of particular importance. According to Terlecky,[5] a surface tangent bare charge produces 32 to 36 percent of the true crater mass in fallback, 62 to 66 percent ejecta, and 2 percent in cloud and crater compaction. Noting the latter figure, a partially buried charge produces 18 to 22 percent of crater mass as dust cloud and compaction. At projectile impact, a few milliseconds delay between contact and detonation would yield a significantly larger dust cloud.

It is desirable to compare craters between live firings of United States and Soviet ammunition. However, because live firings of the foreign rounds were not conducted, an indirect approach using the results from a combination of tube-delivered and static detonation craters is necessary. Using the averaged ratios of 0.945 and 0.85 for depth and diameter of 155-mm craters, a simulation of crater size can be calculated for the 122- and 152-mm rounds. Table 3 shows these simulated values for both Soviet and United States ammunition. These comparisons assume that the fuze for the Soviet ammunition is equivalent to the US fuze. This assumption should be tested.

SUMMARY AND CONCLUSIONS

DIRT-I, II, and III have produced important data on craters formed by the detonation of military artillery projectiles in different types of soil. Even with limited testing, strong correlative trends are apparent between projectiles and soil types. Crater sizes generally increase as soil moisture content increases, and as soil type progresses from sand to silt to clay.

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[5]Terlecky, P. Michael, Jr., "Mass Partition in Soil Cratering," <u>Journal of Geophysical Research</u>, 78:32, November 1973.

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