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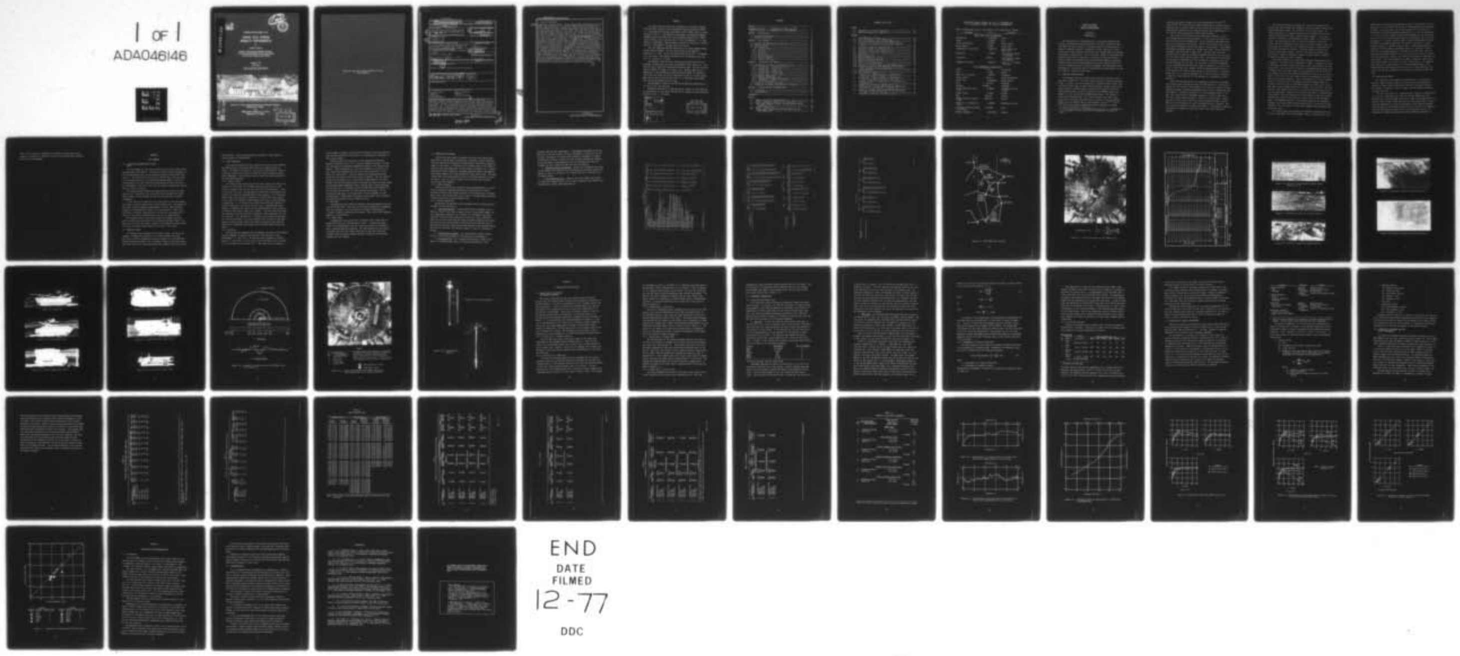

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EVENT DICE THROW MOBILITY EXPERIMENTS

by

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Final Report

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Event DICE THROW, a 2.5-terajoule (600-ton) charge of ammonium nitrate-fuel oil (ANFO), was detonated on 6 October 1976 at the Giant Patriot Site on the White Sands Missile Range in New Mexico. The soil is predominately loose silty sand with random lenses of hard silty clay. Field tests were conducted to determine the degree to which the crater and its associated ejecta field constituted a physical barrier to the movement of military vehicles. Four terrain units in the crater and ejecta area were delineated as significant to ground mobility and described in terms of soil

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strength, soil moisture content, surface configuration, ejecta depth, and areal extent. The test vehicles, i.e., an M60A1 tank, an M551 Sheridan tank, an M577A1 command post carrier, an M109 self-propelled howitzer, an M35A2C 2-1/2-ton cargo truck, and an M715 1-1/4-ton cargo truck, could operate with ease in all the terrain units except the crater wall. The crater wall was too steep for the vehicles to make a safe entry into the crater; therefore, a D7F bulldozer was used for 10 minutes to make an entrance lane into the crater. By entering the crater by way of the entrance lane the M577A1 and the M109 were able to exit the crater by way of the crater wall. The M60A1 was not tested on the crater wall due to the mechanical condition of its track system. No engineering effort (bulldozing) was done to ensure passage of all the test vehicles across the crater due to the short time the test vehicles were available and the unavailability of a bulldozer operator. The total time required by a D7F bulldozer to make the crater passable for all the test vehicles, except the M109 and M577A1, was estimated to be 20 minutes. Degradation in terms of drawbar-pull coefficient and speed increased for all the vehicles tested in each terrain unit from the original surface to ground zero (GZ). The degraded area per gigajoule (0.24 ton) of explosive was 0.73 m^2 (7.85 ft^2), which indicates that large-scale surface explosives in this type of material (silty sand) are not an efficient means of creating barriers to military vehicles. The effective no-go width for the crater was 48 metres (160 ft). Comparison of measured values and values predicted by AMM-74X (Army Mobility Model) for four vehicle performance parameters revealed that the overall accuracy of the predictions for go-no go, drawbar pull, motion resistance, and speed was acceptable in every case.

PREFACE

The study reported herein was performed by the Mobility Systems Division (MSD), Mobility and Environmental Systems Laboratory (MESL), U. S. Army Engineer Waterways Experiment Station (WES), under the sponsorship of the U. S. Army Materiel Development and Readiness Command (DARCOM) under Intra-Army Order for Reimbursable Services No. 76N603 dated 29 October 1975, and the Office, Chief of Engineers, U. S. Army (Project 4A762719AT40, "Effectiveness of Craters as Barriers to Ground Mobility - DICE THROW," Task A2, Work Unit 035 Q6.

The DICE THROW Program was conducted by the Field Command Defense Nuclear Agency (FCDNA). The test group Director was LCDR E. W. Edgerton, U. S. Navy, and the Technical Director was CPT T. Y. Edwards, U. S. Air Force. The program coordinator for the mobility tests was CPT V. A. Alvarez, U. S. Army.

The mobility field work was conducted from 6-10 October 1976 by personnel of MESL under the direct supervision of Mr. Charles E. Green, Projects Group, Mobility Investigations Branch, MSD. The test data was taken by Messrs. M. Hodge, C. M. May, and L. Jackson, MSD, and B. G. Palmertree of Instrumentation Services Division (ISD). All phases of this study were under the direct supervision of Mr. A. A. Rula, Chief, MSD, and the general supervision of Mr. W. G. Shockley, Chief, MESL. This report was prepared by Mr. Green.

Acknowledgment is made to the Fort Bliss Military Reservation for the loan of the test vehicles.

Commander and Director of WES during the conduct of this study and the preparation of this report was COL John L. Cannon, CE, and Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
Metric (SI) to U. S. Customary		
millimetres	0.03937007	inches
metres	3.280839	feet
square millimetres	0.00155	square inches
square metres	10.7607	square feet
kilograms per cubic metre	0.06242797	pounds (mass) per cubic foot
gigajoules	0.238095	tons (nuclear energy equivalent)
terajoules	238.095	tons (nuclear energy equivalent)
kilometres per hour	0.6213711	miles (U. S. statute) per hour
U. S. Customary to Metric (SI)		
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square inches	645.16	square millimetres
square feet	0.09290304	square metres
tons	907.1847	kilograms
kilotons	907184.7	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (force)	4.4482	newtons
kips	4448.222	newtons
pounds (force) per square inch	6894.757	pascals
miles (U. S. statute) per hour	1.609344	kilometres per hour
horsepower (550 foot-pounds per second)	745.6999	watts
degrees (angular)	0.01745329	radians

EVENT DICE THROW
MOBILITY EXPERIMENTS

CHAPTER 1
INTRODUCTION

The possibility of creating barriers to vehicular mobility with surface or near-surface explosives such as the atomic demolition munition (ADM) has been a subject of military interest for several years. A number of questions need to be answered, the most important of which concerns the actual mobility restriction for a combat vehicle attempting to traverse a crater field. Once a sufficient number of tests have been conducted with tactical vehicles in a variety of sizes and shapes of craters formed in consolidated and unconsolidated sediments, pertinent relations will be established between craters and vehicle characteristics for estimating tactical vehicle performance and engineering effort requirements. The results will be incorporated in field manuals for use by troops in a theater of operations.

1.1 PREVIOUS INVESTIGATIONS

Six programs have been conducted with military vehicles to determine their capability to traverse craters typical of those produced with an ADM. In 1964, tests were conducted in conjunction with Project Tank Trap using an M60 tank, an M113 armored personnel carrier, and an articulated two-unit, general-purpose tracked vehicle called the Polecat. Trafficability-type tests were conducted in the SCOOTER crater, the JANGLE U crater, and the PRE-SCHOONER BRAVO crater. The results of these tests indicated that: (1) craters formed in dry soil by the detonation of low-yield explosives at the surface or at very shallow depths of burial (DOB's) down to approximately 4.0 $m/TJ^{1/3.4}$ (20 $ft/kt^{1/3.4}$)* do not present signigicant mobility problems to tracked

* A table of factors for converting metric (SI) to U. S. customary and U. S. customary to metric (SI) units of measurement is given on page 4.

vehicles; (2) craters formed at or near optimum DOB 32.0 $m/TJ^{1/3.4}$ (160 $ft/kt^{1/3.4}$) in dry soil are mobility obstacles to tracked tactical vehicles; and (3) craters formed in hard rock, such as basalt, cannot be negotiated by tracked tactical vehicles without major modification of the craters and/or assistance by heavy-duty equipment.

The second military vehicle test program was conducted in July 1970 during Event Dial Pack (Reference 1). The crater was formed in a lean clay soil by the detonation of a 2.1-TJ (500-ton) TNT sphere tangent to and resting on the surface. An M37 3/4-ton cargo truck and an M113 armored personnel carrier were used as test vehicles. Four vehicle performance parameters (go-no go, drawbar pull (DBP), motion resistance, and speed) were evaluated in this study. The Dial Pack crater was divided into four units for mobility purposes--the outer lip, the inner lip, the crater wall, and the crater floor. The units were established on the basis of differences in type of material, strength, slope, and size and spacing of soil clods. On the basis of go-no go performance, it was concluded that the M37 truck could not negotiate the soft crater floor or the crater wall, whereas the M113 armored personnel carrier could negotiate all terrain units except the crater floor. It was estimated that 3 or 4 hours of bulldozer (D7 or D8) time would be required to make the crater passable for 100 passages of conventional military vehicles.

The third military vehicle test program was conducted in November 1971 during Project Diamond Ore Phase IIA (Reference 2). Craters were formed in a clay shale by the detonation of a series of 58.8-GJ (14-ton) spherical charges of aluminized ammonium nitrate slurry (simulating low-yield ADM's). The series consisted of a fully stemmed charge at a 12-metre (39.4-foot) DOB, an unstemmed charge at a 12-metre (39.4-foot) DOB, and a fully stemmed charge at a 6-metre (19.7-foot) DOB. An M48 was able to climb out of the first crater (unstemmed charge, 12-metre DOB) on the 13th attempt; the total crossing time was 15 minutes. The tank could not negotiate the other two craters. A D9 bulldozer required a minimum of 50 minutes to make the 6-metre (19.7-foot) DOB crater passable.

The fourth military test program was conducted in November 1972 during Event Mixed Company III (Reference 3) with an M60A1 tank, an M113 armored personnel carrier, and an M561 1-1/4-ton cargo truck. The crater was formed in a layered sandstone by the detonation of a 2.1-TJ (500-ton) TNT spherical charge, again surface tangent. It was asymmetrical, resulting in two predominant slope classes, i.e. shallow and steep. The test vehicles could negotiate the shallow (31 percent) slopes but were immobilized on the steep (66 percent) slopes. Thus, the crater and ejecta field were not considered barriers to mobility when the vehicles entered the crater on the steep slopes and exited the crater on the shallow slopes. When the direction was reversed, the crater was a barrier to mobility; however, a TD20 bulldozer required 12 minutes to make the crater passable.

The fifth military test program was conducted intermittently from 23 August to 31 October 1973 during ESSEX I, Phase I (Reference 4), with an M60 tank, an M113A1 armored personnel carrier, and an M715 1-1/4-ton cargo truck. Four craters were formed in interfingering lenticular beds of sands, silts, and clays, three by the detonation of 51.67-GJ (12.4-ton) charges of gelled nitromethane (Reference 5) and one by the detonation of a 41.25-GJ (9.9-ton) charge of gelled nitromethane at different DOB's and stemming conditions. The series consisted of a fully stemmed charge at a 6-metre (19.7-foot) DOB, a partially stemmed charge at a 12-metre (39.4-foot) DOB, an unstemmed charge at a 6-metre (19.7-foot) DOB, and a fully stemmed charge at a 12-metre (39.4-foot) DOB. The test vehicles could operate with ease in the crater ejecta area but at some cost in performance. However, the vehicles were unable to negotiate the crater walls. The time required for a D8 bulldozer to make the craters passable was between 2 and 3 hours for each of the craters discussed above. The engineering effort on the crater formed by the unstemmed charge at the 6-metre DOB was discontinued after 1.5 hours due to rain; therefore, the time shown (3.0 hour) was estimated from the amount done before the rain.

The sixth military test program was conducted intermittently from 20 July to September 1974 during ESSEX I, Phase 2, (Reference 6), with an M60 tank, an M113A1 armored personnel carrier, and an M715 1-1/4-ton cargo truck. Four craters were formed in interfingering lenticular beds of sands, silts, and clays, one by the detonation of a 48.3-GJ (11.5-ton) charge of gelled nitromethane (Reference 5), one by the detonation of a 42.0-GJ (10-ton) charge of gelled nitromethane, one by the detonation of a 37.8-GJ (9-ton) charge of gelled nitromethane, and one by the detonation of a 33.6-GJ (8-ton) charge of gelled nitromethane at different DOB's and stemming conditions. The series consisted of a fully stemmed charge at a 3-metre (9.8-foot) DOB, a water-stemmed charge at a 6-metre (19.7-foot) DOB, an unstemmed charge at a 3-metre (9.8-foot) DOB, and an unstemmed charge at a 12-metre (39.4-foot) DOB. The test vehicles could operate with ease in the crater ejecta area but at some cost in performance. However, the vehicles were unable to negotiate the crater walls. The time required for an HD21 to make the craters passable varied from 0.3 to 10 hour for each of the craters. The engineering effort on the crater formed by the water-stemmed charge at the 6-metre DOB was discontinued after 6 hour due to rain; therefore, the time of 10 hour was estimated from the amount of work done before the rain.

1.2 OBJECTIVE AND SCOPE

The objective of the mobility experiments was to determine the degree to which craters formed in a layered natural unconsolidated material by large surface explosions constitute a physical barrier to the movement of military vehicles (tanks, armored personnel carriers, and cargo carriers).

The study was limited to: describing the craters for ground mobility purposes; conducting tests with six vehicles (M60A1 tank, M551 Sheridan tank, M577A1 command post carrier, M109 self-propelled howitzer, M35A2C 2-1/2-ton cargo truck, and M715 1-1/4-ton cargo truck) to determine the degradation of vehicle performance as the vehicles traveled from the natural, undisturbed terrain across the crater; and comparing measured performance parameters with those predicted with the U. S. Army Materiel Command Ground Mobility Model (AMM-74X) (Reference 7).

Also, if the crater was impassable, the amount of engineering effort required to construct a passable route for the vehicles under consideration was to be determined.

CHAPTER 2

TEST PROGRAM

2.1 LOCATION AND DESCRIPTION OF TEST SITE

The DICE THROW test site was the Giant Patroit Site at White Sands Missile Range in New Mexico. This site is located 13 miles southeast of the Stallion Range Center in the northern portion of White Sands (Figure 2.1). The site is at an elevation of 4729.46 feet above sea level in the northern portion of the Jornada del Muerto Basin. The soil is predominantly loose silty sand with random lenses of hard silty clay. The topography of the area is even and the nearest mountains are approximately 8 miles to the east.

The apparent crater formed was symmetrical and circular in shape (Figure 2.2). Generally, the cratered area was available for vehicle tests, except for the northern 1/4 section which was used for other experiments.

At the time of the mobility tests, the surface of the area beyond the ejecta was fairly smooth, with a sparse grass cover. The surface in the ejecta area was composed predominantly of loose, sandy material (Figure 2.3) sprinkled with clods of the same material. These clods were small, scattered, and golf-ball size near the outer edge of the ejecta of the crater, increasing near the crest to baseball size.

The steepest parts of the crater slopes were smooth; the more gentle portions near the bottoms of the slopes contained clods of the same size as on the outer edge. Figures 2.4-2.8 show the surface conditions from beyond the ejecta field to the floor of the crater.

2.2 VEHICLES TESTED

Six vehicles were furnished by Fort Bliss, Texas, for use in the program. An M60A1 tank (Figure 2.9), an M551 Sheridan tank (Figure 2.10), an M577A1 command post carrier (Figure 2.11), an M109 self-propelled howitzer (Figure 2.12), an M35A2C 2-1/2-ton cargo truck (Figure 2.13), and an M715 1-1/4-ton cargo truck (Figure 2.14) were used as test vehicles. Vehicle characteristics pertinent to this study are shown in Table 2.1 (Reference 8).

2.3 TESTS CONDUCTED

Go-no go and speed tests were conducted with the six test vehicles. Also DBP and motion resistance (MR) tests were conducted with the M577A1, the M35A2C, and the M715. The areas in which specific types of tests were conducted are shown in Figure 2.15 and discussed in subsequent paragraphs. The procedures used in these tests are discussed in the following paragraphs.

2.3.1 Go-No Go Tests

The vehicles were positioned near the outer edge of the ejecta and driven at a slow speed in a straight line toward the center of the crater to determine the terrain units that they could negotiate. Prior to the start of a test, the appropriate terrain data were measured (see section 2.4) along the intended paths of the vehicles. The terrain and vehicle data were examined to identify the terrain units (see section 3.1) in which the vehicle(s) would definitely not go or would experience a marginal go. If an obvious no-go condition was indicated because of terrain conditions or for safety reasons (i.e., traveling down steep slopes), a bulldozer was used to do the minimum amount of work required to make the particular terrain unit passable. The time spent bulldozing was recorded as the time required to make the crater negotiable for the test vehicles. If a marginal go or definite go condition was indicated, the test was conducted. If it was estimated that a vehicle could negotiate all crater terrain units, the course was laid out such that the vehicle had to negotiate the steepest wall available while exiting the crater.

2.3.2 DBP Tests

DBP and slip were measured with the M577A1, the M715, and the M35A2C on short segments of nearly level terrain in Terrain Units 1 and 2 (paragraphs 3.1.1 and 3.1.2). No DBP tests were conducted in Terrain Units 3, 4, and 5 due to a lack of area in Terrain Units 3 and 5 and due to a no-go condition in Terrain Unit 4. DBP tests were not conducted with the M60A1, the M551, and the M109 due either to the short time the vehicles were available for testing or to the mechanical conditions of their track systems.

DBP data taken in Terrain Unit 2 were compared with DBP data obtained in Terrain Unit 1 (i.e., the area beyond the ejecta) to determine the amount of performance degradation caused by the ejecta on the surface. DBP was measured by a load cell attached to a 21-metre- (70-foot) long cable extending from the rear of the test vehicle to the front of a load vehicle. Slip was computed from measured distances traveled by the vehicle and by the traction elements. The test vehicle pulled the load vehicle at a steady speed of approximately 3.2 km/hr (2 mph), and the load vehicle driver increased the load in several stages (by applying brakes gradually) from no load-no slip to high load-high slip or stall out. A continuous record of DBP and of the distances the test vehicle and the wheel or track traveled was obtained. As the record was being made, it was examined by the test engineer for any irregularities. Measurements were made in this manner until sufficient data had been obtained to plot a DBP-slip curve.

2.3.3 MR Tests

Towed MR tests were conducted using the same instrumentation as was used in the DBP tests. With the test vehicle's transmission disengaged, the force required to tow the vehicle at a speed of approximately 3.2 km/hr (2 mph) was measured and recorded. These tests were conducted adjacent to the DBP tests.

2.3.4 Speed Tests

Straight-line test courses 76 to 91 metres (250 to 300 feet) in length were laid out in Terrain Units 1 and 2. A vehicle was positioned at the beginning of the test course and allowed to accelerate until a maximum speed was achieved. The time required for the vehicle to traverse the last 30.5 metres (100 feet) of the test course was recorded, and the maximum average speed was calculated from distance traveled and time elapsed.

2.4 TERRAIN DATA OBTAINED

Terrain data were taken to describe the crater for mobility purposes and to relate vehicle performance to specific terrain attributes. Data for description purposes were taken along a line drawn through the center of the crater. A schematic of the terrain units of the crater is shown in plan view along with a profile sketch in Figure 2.15. Surface composition (type of material, strength, moisture content, and density) and surface geometry data were measured for each terrain unit. The same terrain data also were measured in each of the areas selected for vehicle tests. The test areas in Figure 2.16 are those areas in which terrain data were measured.

2.4.1 Surface Geometry

Elevation profiles were measured along and perpendicular to crater radii by standard surveying techniques to characterize the crater. Microprofiles were taken roughly parallel to the crater wall in Terrain Units 2 and 3 and along various test courses. The approximate locations of these profiles are given in Figure 2.16.

2.4.2 Surface Composition

Specialized instrumentation and procedures used in evaluating soil strength are described below.

1. Cone penetrometer. A hand-operated field instrument used to obtain an index of the shear strength of soil at prescribed depths, the cone penetrometer (Figure 2.17), consists of a 30-degree cone with a 322.6-mm^2 (1/2-$in.^2$) base mounted on one end of a 9.5-mm (3/8-inch) shaft and a proving ring with dial gage and handle mounted on the other. The force per unit area required to vertically penetrate the soil is indicated on the dial inside the proving ring and is read visually while the cone is forced into the ground by hand at a rate of 1.83 m/min (6 ft/min).

2. Trafficability sampler. The trafficability sampler (Figure 2.18) is a piston-type sampler for obtaining soft soil samples.

3. Cone index (CI). Soil strength was measured in terms of CI, which is a dimensionless index of the shearing resistance of soil

obtained with the cone penetrometer. Measurements were made at the surface and at 25.4-mm (1-inch) vertical increments to a depth of 152.4 mm (6 inch), and then at 76.2-mm (3 inch) vertical increments to a depth of 610 mm (24 inches), or until the soil strength exceeded the capacity of the instrument. Approximately 20 sets of readings were made and averaged for each terrain unit and test lane as required.

4. Moisture content and density. Three sets of samples were taken in each terrain unit and test area to determine the moisture content and density of the 0- to 152-mm (0- to 6-inches) and 152- to 305-mm (6- to 12-inches) depths.

5. Soil classification. Composite bulk soil samples were taken for laboratory identification of soil type according to the Unified Soil Classification System (USCS)(Reference 9).

TABLE 2.1

SUMMARY OF VEHICLE CHARACTERISTICS

No.	Vehicle Characteristics: Identification	Units	Vehicle: M60A1	M551	M577A1	M109	M35A2C	M715
1	Vehicle Type (NVEH = 0 for track and 1 for wheeled)	--	0	0	0	0	1	1
2	Gross Vehicles Weight	kips	100	36	22	45	14	6
3	Grouser Height for tracks; Number of tires for wheeled	--	1.5	1	1	1	10	4
4	Gross rated horsepower	bhp	750	300	210	405	141	116
5	Winch capacity (use 0 for no winch)	kips	0	0	0	0	0	0
6	Number of tracks or tires	--	2	2	2	2	10	4
7	Number of axles	--	NA	NA	NA	NA	3	2
8	Vehicle width	in.	143	110	106	124	96	85
9	Vehicle length	in.	273	248	192	240	278	210
10	Track width or nominal tire width	in.	28	17	15	15	9	9
11	Wheel rim diameter	in.	NA	NA	NA	NA	20	16
12	Recommended tire pressure (cross-country)	psi	NA	NA	NA	NA	50	27
13	Area of one track shoe (tracked) or number of wheels (wheeled)	in^2	194	82	90	90	10	4
14	Number of bogies (tracked) or chain indicator (wheeled) (0 = no chains, 1 = chains)	--	12	10	10	14	0	0
15	Vehicle ground clearance at the center of greatest wheel span	in.	NA	NA	NA	NA	19.1	15.5
16	Minimum vehicle ground clearance	in.	18	17.5	16	17.7	12.87	10
17	Rear end clearance (vertical clearance of vehicle is trailing edge)	in.	40	25.9	24.5	31	32	26.5
18	Vehicle departure angle	deg	43	38	40	80	40	25
19	Vertical clearance of vehicle's leading edge	in.	45	43	30	44	35	19
20	Vehicle approach angle	deg	90	38.5	70	75	40	45
21	Length of track on ground or wheel diameter	in.	171	143	108	159	38	34
22	Height of vehicle pushbar	in.	45	43	30	44	35	19
23	Distance between first and last wheel center lines	in.	167	140	105	156	178	126
24	Horizontal distance from the center of gravity to the front wheel center lines	in.	109	74.8	54	94	88	81
25	Vertical distance from the center of gravity to the road wheel center lines	in.	24	27.1	30.5	30	22.3	15.3
26	Maximum span between adjacent wheel	in.	NA	NA	NA	NA	130	126
27	Angle between a line parallel to the ground surface and the line connecting the center of gravity and the center of the rear wheel (road wheel or idler). The wheel is the one used to determine departure angle	deg.	25.9	31.7	18.5	8.7	NA	NA
28	Distance from the center of gravity to the center of the rear wheel (road wheel or idler). The wheel is the one used to determine departure angle	in.	110	75	108	94	NA	NA
29	Vertical distance from the ground to the center of the rear wheel (road wheel or idler)	in.	18	27.5	20.8	30	20.1	15.7
30	Track thickness plus radius of the rear wheel (road wheel or idler). The wheel is the one used to determine departure angle (wheeled = RW)	in.	18	17.0	11.0	8.0	20.1	15.7
31	Rolling radius of tire or sprocket pitch radius	in.	12	11.1	9.8	9.8	17.7	15.7
32	Height or rigid point used to determine approach angle	in.	45	29	28	45	35	19
33	Maximum braking force the vehicle develops	--	0.8	0.41	0.8	0.35	0.8	0.8
34	Loaded wheel radius	in.	NA	NA	NA	NA	17.7	15.7
35	Total ground contact area	$in.^2$	9576	4862	3240	4770	NA	NA
36	Distance vehicle spans before significant motion begins	in.	67	70	66	94	19	17
37	Maximum force the pushbar can withstand	kips	200	72	49	106	19	6
38	Maximum axle load/gross vehicle weight	--	NA	NA	NA	NA	0.47	0.5
39	Vehicle rated horsepower per ton	hp/ton	15	16.7	19.3	15.7	30.7	38.7
40	Transmission type (0 = automatic; 1 = manual)	--	0	0	0	0	1	1
41	Final drive gear ratio	--	5.08	2.22	3.93	4.36	6.27	5.87
42	drive gear efficiency	--	0.95	0.97	0.95	0.9	0.9	0.9
43	Number of gears in transmission	--	2	4	3	4	10	8
44	Gear ratios for transmission	--	3.497	6.16	3.81	4.69	9.94	12.54
			1.256	4.18	1.94	3.18	5.5	6.40
				2.24	1.0	1.59	5.02	6.06
				1.1		0.79	3.21	3.31
							2.78	3.09
							1.98	1.96
							1.62	1.69
							1.56	1.0
							1.0	
							0.79	
45	Transmission efficiency	--	0.95	0.95	0.95	0.95	0.9	0.9
46	Number of points in array TTE (see item 47)	--	17	27	30	24	34	29

TABLE 2.1 (Continued)

No.	Vehicle Characteristics Identification	M60A1 Vehicle Speed mph	M60A1 Tractive Force lb	M551 Vehicle Speed mph	M551 Tractive Force lb	M577A1 Vehicle Speed mph	M577A1 Tractive Force lb	M109 Vehicle Speed mph	M109 Tractive Force lb	M35A2C Vehicle Speed mph	M35A2C Tractive Force lb	M715 Vehicle Speed mph	M715 Tractive Force lb
47	Array containing vehicle speed versus tractive force	0	72,790	0	36,869	0	17,950	0	41,104	0	14,013	0	7,460
		1.4	62,800	2.0	26,400	1.0	16,330	0.8	41,015	2.2	13,899	2.8	7,450
		2.3	52,850	3.4	25,818	1.5	15,850	1.5	37,033	3.2	12,991	3.6	7,350
		3.5	42,910	4.0	18,400	1.9	14,250	2.2	28,128	4.3	11,174	4.3	6,950
		4.5	38,000	4.4	14,343	2.0	12,750	3.7	20,711	4.4	7,824	5.0	6,160
		5.5	33,020	6.0	14,000	2.5	11,250	4.3	19,932	5.4	7,484	5.1	3,920
		6.8	28,100	8.0	9,620	3.2	9,750	5.5	15,015	6.6	6,973	6.3	3,910
		8.0	23,200	10.0	8,850	3.9	8,770	5.6	14,312	8.0	6,325	8.1	3,830
		12.0	14,600	12.0	5,910	4.8	8,030	6.4	13,356	8.1	6,098	9.3	3,580
		16.0	10,800	13.0	5,520	5.8	7,380	7.4	11,532	8.6	5,769	10.3	3,290
		20.0	9,100	15.0	5,240	5.9	6,990	8.2	10,312	8.7	4,633	10.4	3,190
		24.0	7,100	16.0	5,960	7.5	6,975	8.3	8,634	10.6	4,486	11.0	3,040
		26.0	6,700	18.0	4,490	8.0	6,650	10.3	6,780	12.2	4,168	11.1	2,140
		28.0	6,000	20.0	3,670	9.5	6,050	12.0	6,718	13.8	3,736	12.8	2,100
		30.0	3,000	22.0	3,430	10.8	5,300	14.1	6,293	13.9	3,736	15.0	2,060
		31.0	2,000	24.0	3,200			16.0	5,155	15.9	3,248	17.5	1,970
		31.0	0	25.0	2,990			16.1	4,452	16.0	2,850	20.1	1,730
				26.0	2,890			20.2	3,362	18.4	2,714	20.2	1,630
				28.0	2,710			24.0	3,355	21.1	2,521	21.0	1,540
				30.0	2,460			28.2	3,142	23.1	2,351	21.1	1,290
				32.0	2,430			32.0	2,576	23.2	2,181	25.0	1,260
				35.0	2,400			35.0	2,000	25.0	2,124	30.8	1,130
				37.0	2,390			35.0	0	28.2	1,840	33.9	1,020
				40.0	2,380					28.3	1,783	34.0	890
				42.0	2,250					29.1	1,385	39.4	840
				43.0	2,080					29.2	1,385	39.5	530
				43.0	0					36.0	1,374	50.0	520
										42.0	1,272	60.0	500
										45.0	1,102	60.0	0
										45.1	1,090		
										51.0	1,034		
										53.0	1,011		
										58.0	919		
										58.0	0		

No.	Vehicle Characteristics Identification	Vehicle: M60A1	M551	M577A1	M109	M35A2C	M715
48	Number of points in vehicle velocity versus obstacle height array (see item 49)	16	14	19	13	14	23

No.	Vehicle Characteristics Identification	M60A1 Obstacle Magnitude in.	M60A1 Vehicle Speed mph	M551 Obstacle Magnitude in.	M551 Vehicle Speed mph	M577A1 Obstacle Magnitude in.	M577A1 Vehicle Speed mph	M109 Obstacle Magnitude in.	M109 Vehicle Speed mph	M35A2C Obstacle Magnitude in.	M35A2C Vehicle Speed mph	M715 Obstacle Magnitude in.	M715 Vehicle Speed mph
49	Array containing vehicle velocity versus obstacle height at 2.5-g's vertical acceleration	0	31.0	0	45.0	0	100.0	0	35.0	0	100.0	0	60.0
		8.0	31.0	4.5	45.0	5.1	100.0	4.0	35.0	3.7	100.0	2.0	60.0
		8.5	25.0	4.6	40.0	5.3	80.0	5.0	20.0	4.2	80.0	3.0	48.4
		9.0	19.8	4.65	32.0	5.5	60.0	7.5	14.5	4.8	56.0	4.0	27.2
		10.0	15.0	5.0	28.0	6.0	40.0	10.0	11.0	5.0	52.0	5.0	17.4
		12.6	10.0	5.4	25.0	6.45	31.5	12.5	8.5	5.8	40.0	6.0	12.1
		14.0	9.0	6.0	21.0	6.7	26.8	15.0	6.2	6.7	30.0	7.0	8.9
		15.0	8.4	7.0	18.2	7.1	20.0	20.0	3.5	8.4	20.0	8.0	6.8
		16.0	8.0	8.0	16.0	8.0	15.0	25.0	2.5	10.0	13.0	9.0	5.4
		20.0	6.9	9.0	14.5	10.0	10.0	30.0	2.1	11.5	10.0	10.0	4.4
		25.0	5.0	10.0	13.2	11.0	8.3	40.0	2.0	15.0	6.0	11.0	3.6
		30.0	4.9	12.0	12.0	12.4	6.8	50.0	2.0	20.0	3.2	12.0	3.0
		35.0	4.8	18.0	10.2	13.7	5.5	60.0	2.0	25.0	2.0	13.0	2.6
		40.0	4.7	40.0	2.0	14.0	4.8			50.0	0.6	14.0	2.2
		50.0	4.6			18.0	3.0					15.0	1.9
		60.0	4.5			20.0	2.8					16.0	1.7
						30.0	2.0					17.0	1.5
						40.0	1.2					18.0	1.3
						50.0	1.2					19.0	1.2
												20.0	1.1
												21.0	1.0
												30.0	0.5
												40.0	0.5

(Continued)

(Sheet 2 of 3)

TABLE 2.1 (Concluded)

Item	Description	Vehicle: M60A1	M551	M577A1	M109	M35A2C	M715
50	Number of points in rms versus speed array (see item 51)	16	11	22	16	12	8

51 Array containing ride dynamic speed curve

M60A1 rms in.	M60A1 Speed mph	M551 rms in.	M551 Speed mph	M577A1 rms in.	M577A1 Speed mph	M109 rms in.	M109 Speed mph	M35A2C rms in.	M35A2C Speed mph	M715 rms in.	M715 Speed mph
0	31.0	0	45.0	0	100.0	0	35.0	0	100.0	0	60.0
1.4	31.0	0.1	45.0	0.4	100.0	0.85	35.0	0.23	80.0	0.5	60.0
1.5	30.0	0.5	30.0	0.4	80.0	1.0	30.0	0.24	60.0	1.0	30.0
1.6	25.0	1.0	23.0	0.4	70.0	1.25	22.5	0.25	40.0	1.5	13.0
1.72	23.0	2.0	15.0	0.43	60.0	1.5	19.0	0.35	30.0	2.0	7.6
2.0	18.5	2.4	13.0	0.48	50.0	1.75	17.0	0.46	25.0	3.0	4.0
2.5	14.0	3.0	11.0	0.50	43.0	2.0	15.5	0.72	20.0	6.0	2.0
2.8	12.2	4.0	9.0	0.55	40.0	2.5	13.0	1.0	16.6	8.0	1.2
3.0	11.2	5.0	8.0	0.66	35.0	2.75	12.0	1.17	15.0		
3.5	9.8	6.0	7.8	0.75	30.0	3.0	11.4	2.0	10.0		
4.0	8.8	8.0	7.6	1.0	24.0	3.5	9.8	3.0	8.0		
5.0	7.2			1.23	20.0	4.0	9.0	8.0	6.0		
6.0	6.3			1.5	16.0	5.0	8.0				
7.0	6.0			1.8	14.0	6.0	7.1				
8.0	5.5			2.0	13.0	7.0	6.6				
20.0	5.5			2.5	11.0	8.0	5.5				
				3.0	10.0						
				3.5	9.0						
				4.0	8.0						
				5.0	7.0						
				6.0	6.0						
				8.0	5.0						

(Sheet 3 of 3)

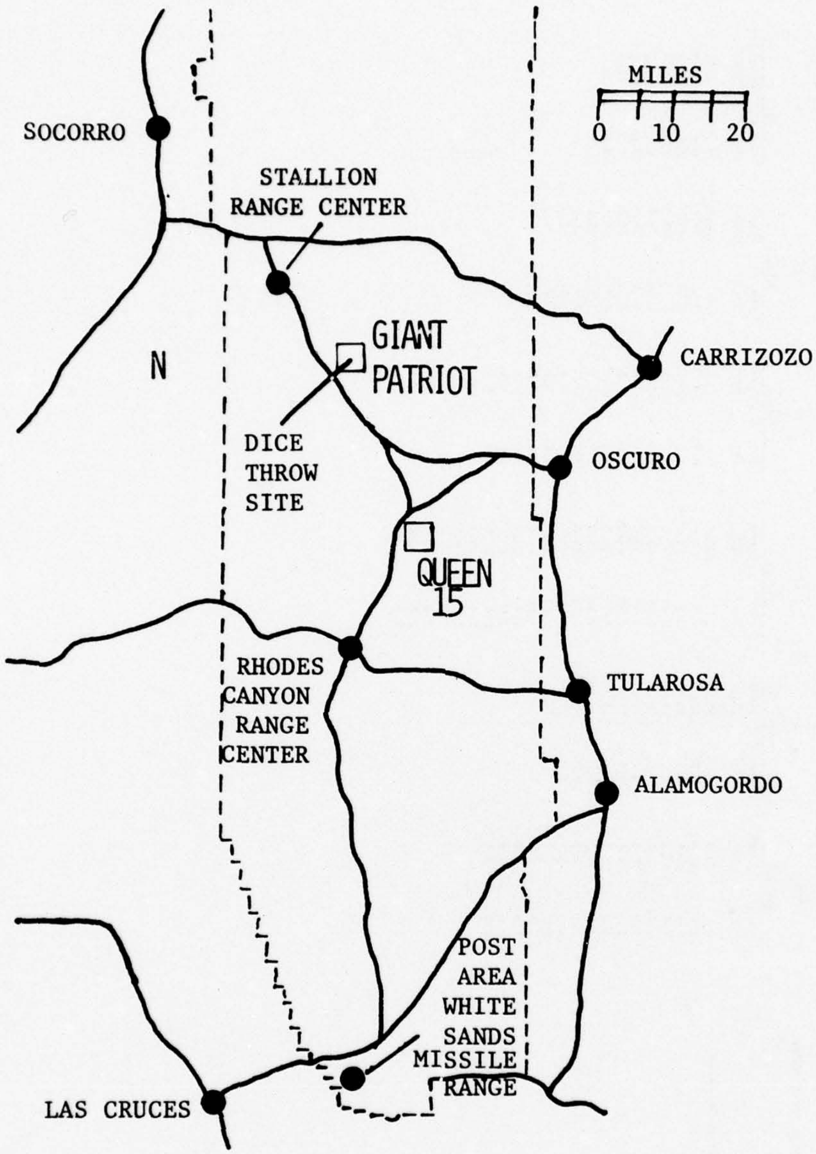
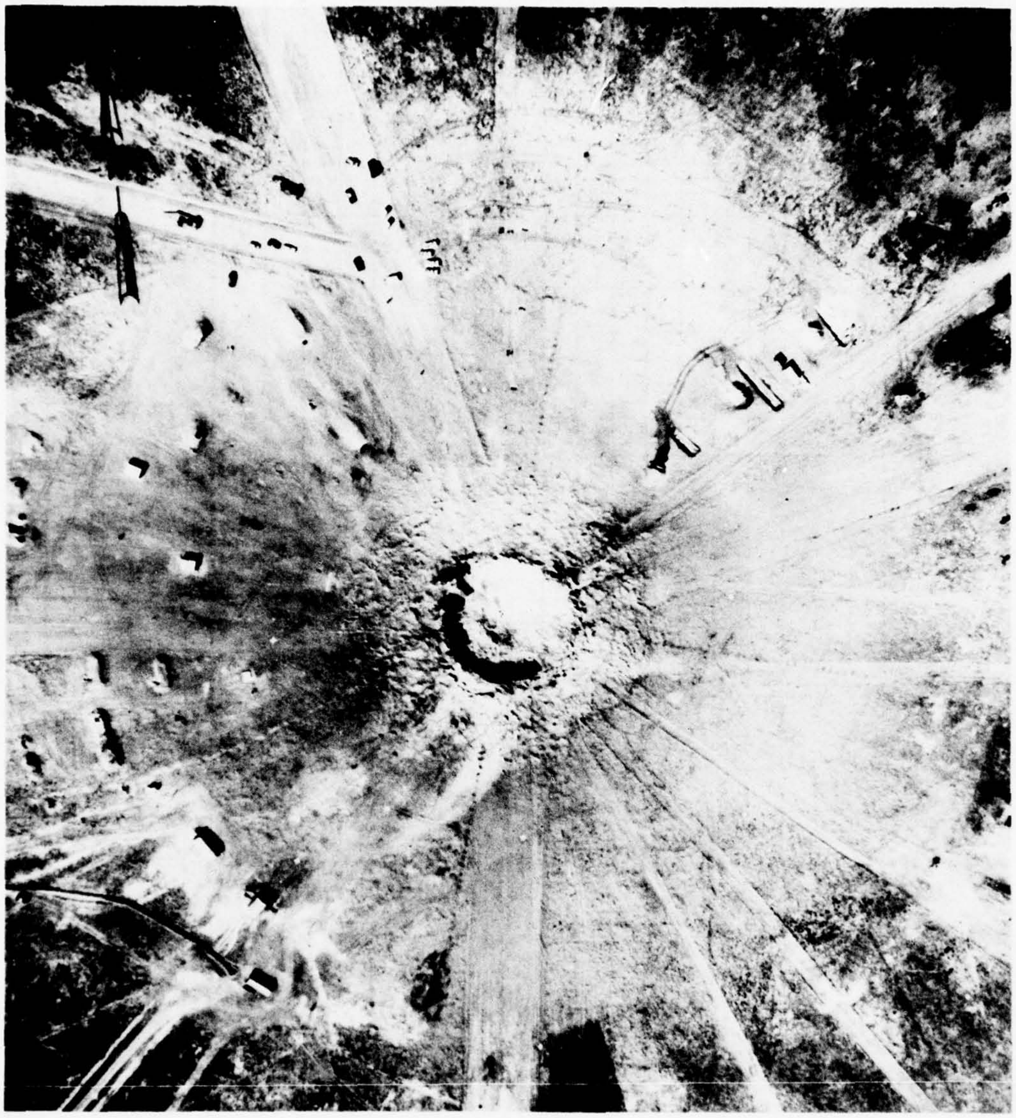


Figure 2.1. DICE THROW site location.



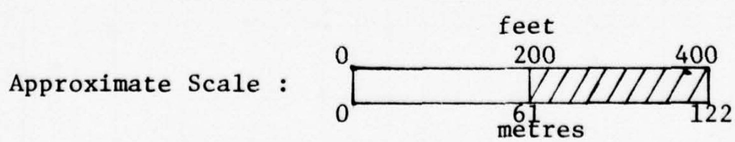
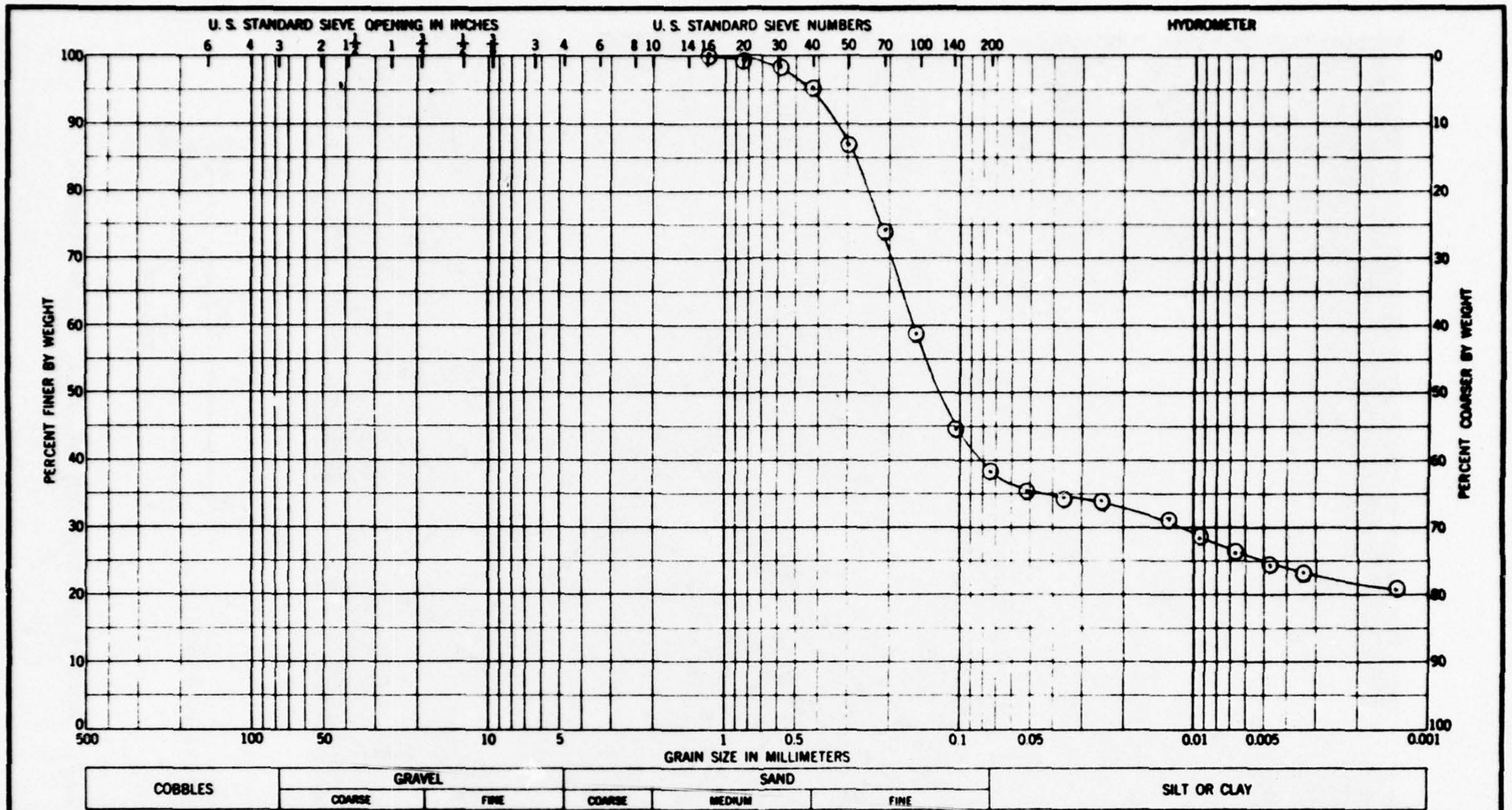


Figure 2.2. Aerial photograph of DICE THROW crater.



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	0-12	SILTY SAND(SM) Grayish Brown Gs= 2.70(est)		29	26	3

Project DICE THROW
Area NEW MEXICO
Boring No. 3
Date 1 Nov., 1976

GRADATION CURVES

ENG FORM 1 MAY 63 2087

Figure 2.3. Soil classification data for DICE THROW crater.

Figure 2.4. Overview of area beyond the ejecta field (Terrain Unit 1).

Figure 2.5. Overview of outer lip (Terrain Unit 2).

Figure 2.6. Overview of inner lip (Terrain Unit 3).

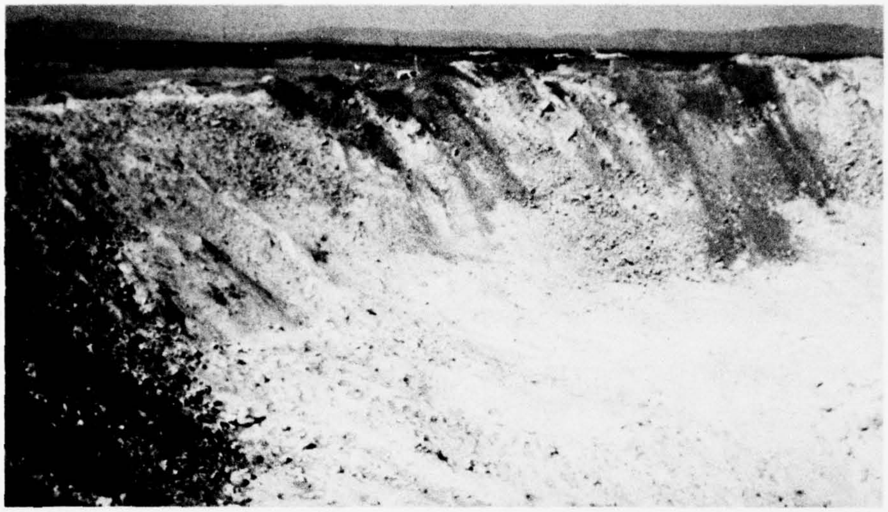


Figure 2.7. Overview of crater wall (Terrain Unit 4).

Figure 2.8. Overview of crater floor (Terrain Unit 5).

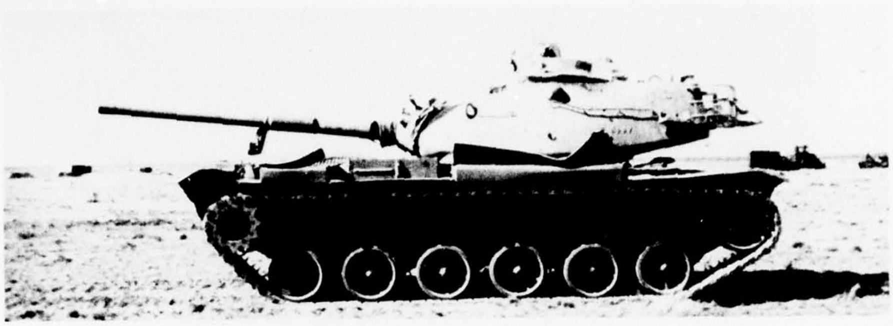


Figure 2.9 M60A1 tank.

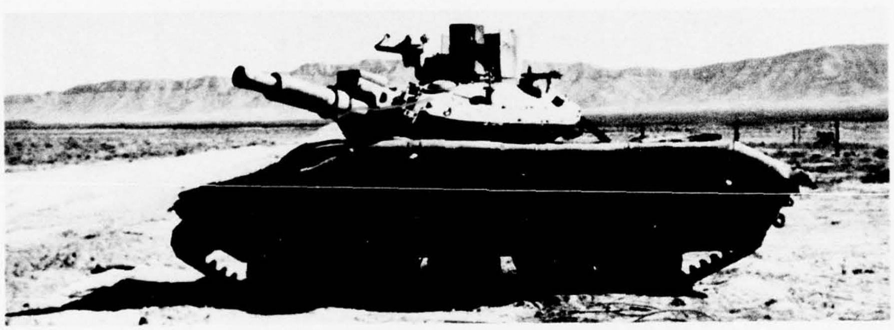


Figure 2.10. M551 Sheridan tank.

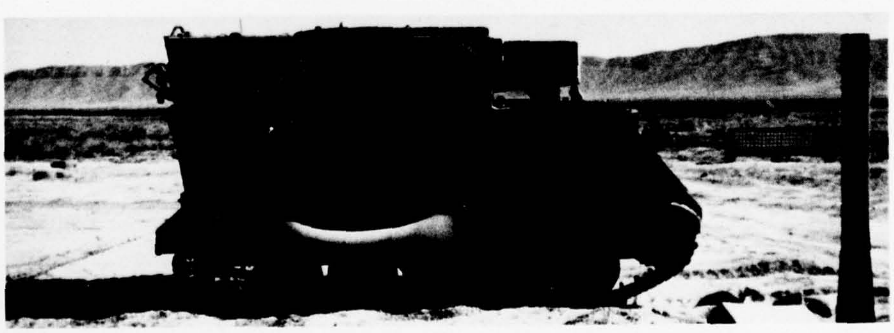


Figure 2.11. M577A1 command post carrier.

Figure 2.12. M109 self-propelled howitzer.

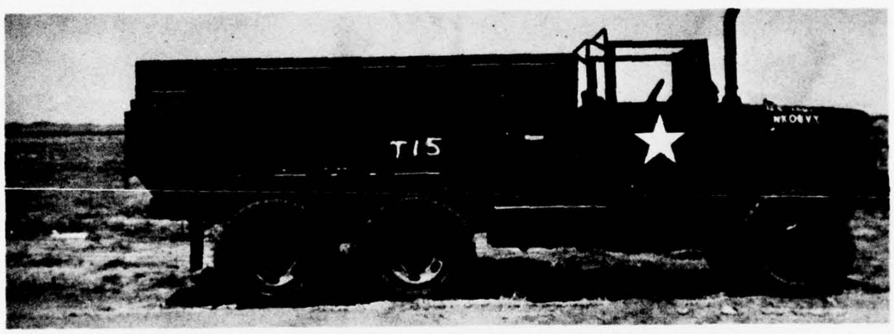


Figure 2.13. M35A2C 2-1/2-ton cargo truck.

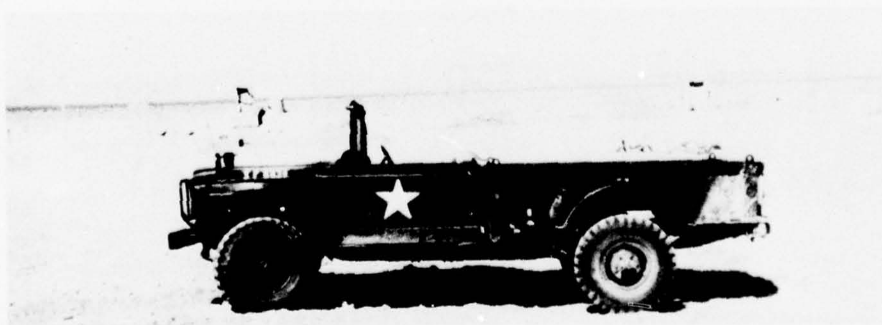
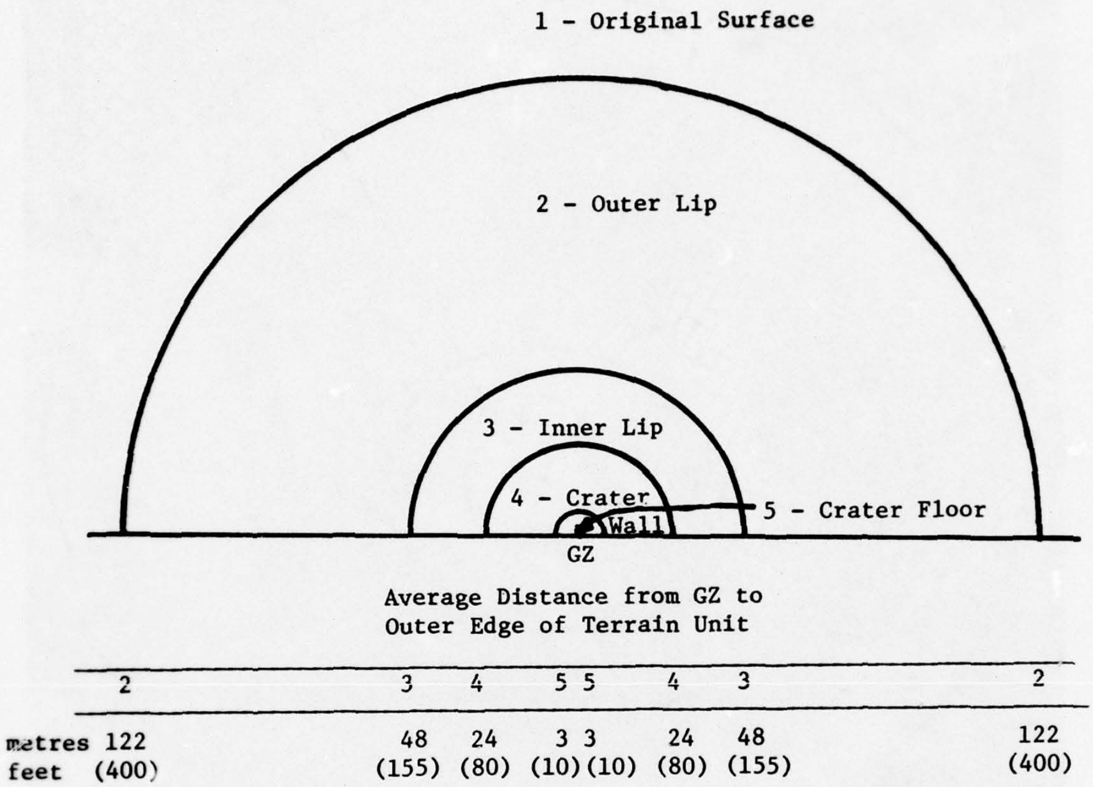
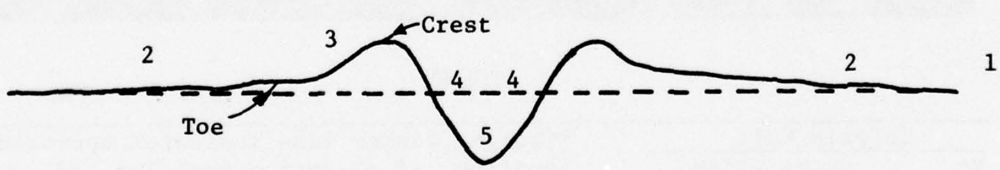


Figure 2.14. M715 1-1/4-ton cargo truck.

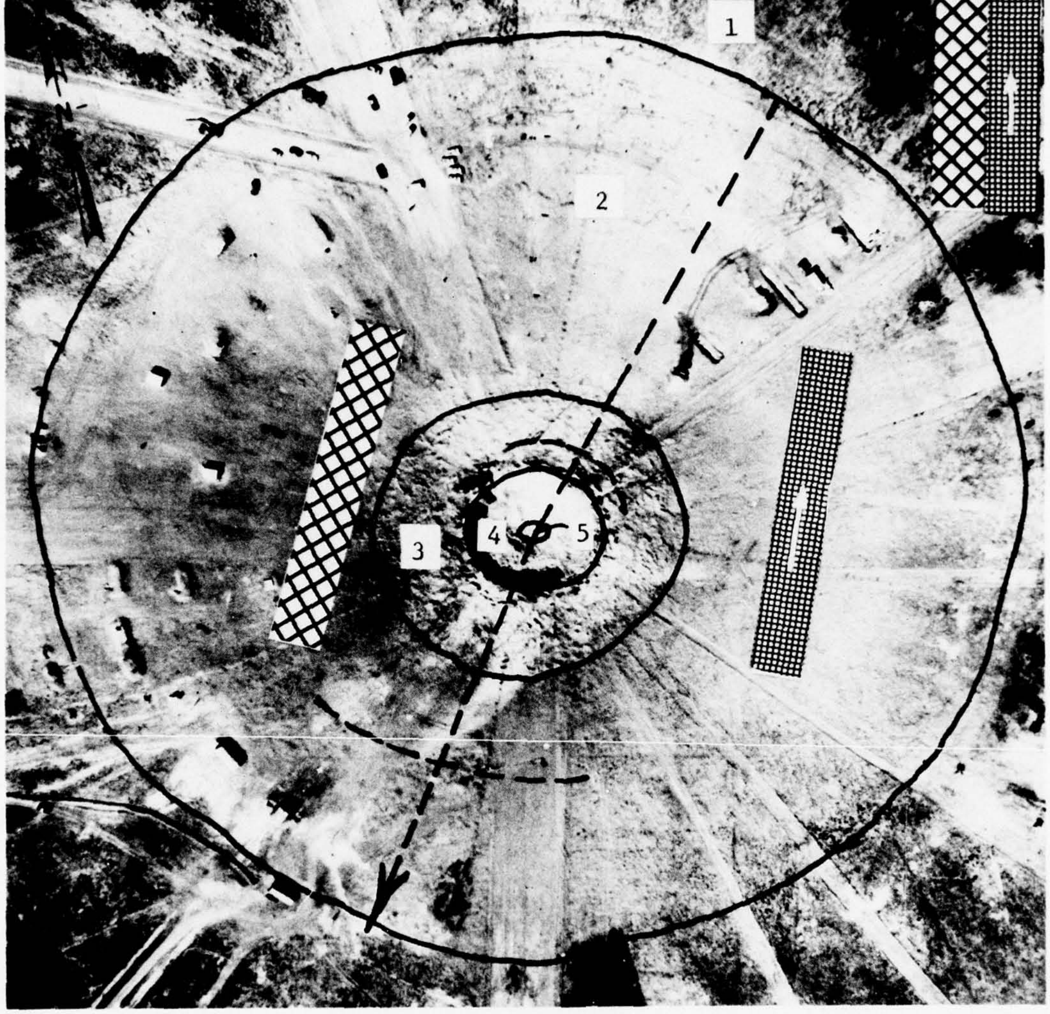


a. Plan View



b. Profile Sketch

Figure 2.15. Schematic of terrain units for DICE THROW crater. GZ = ground zero.



LEGEND

Terrain Unit	
No.	Description
1	Original Surface
2	Outer Lip
3	Inner Lip
4	Crater Wall
5	Crater Floor

Straight dashed line indicates approximate locations of elevation profiles and go-no go vehicle tests. Arrow indicates direction of go-no go tests. Curved dashed line indicates locations of microprofiles.

⊠ - DBP and MR test areas

▦ - Speed test areas

Figure 2.16. Aerial photograph of DICE THROW crater with terrain units and test locations identified

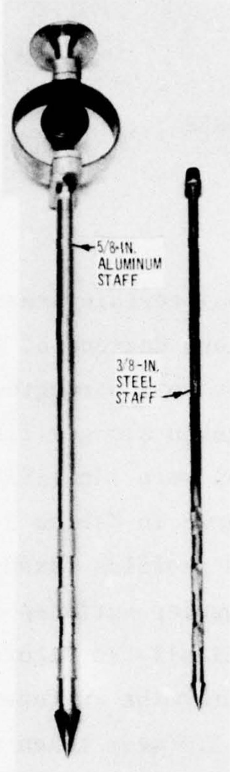


Figure 2.17 Cone penetrometer.

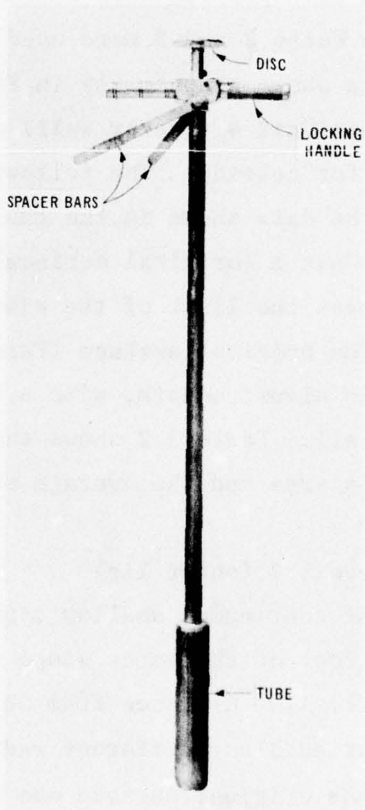


Figure 2.18 Trafficability sampler.

CHAPTER 3

TEST RESULTS AND ANALYSES

3.1 DESCRIPTION OF THE CRATER FOR MOBILITY PURPOSES

The crater, associated ejecta, and natural terrain areas were divided into five terrain units offering various degrees of impedance to vehicle mobility as a result of differences in soil strength, slope, and surface geometry. Surface composition data taken along a line through the center of the crater and in the test areas were identified as to terrain unit and averaged. These data are shown in Tables 3.1 and 3.2. The surface geometry data, microprofiles, and profiles taken in the terrain units that exhibited significant irregular surfaces are given in Table 3.3. The microprofile data shown graphically in Figures 3.1 and 3.2 for Terrain Units 2 and 3 were used to determine surface roughness. The profile data shown graphically in Figure 3.3 were taken along a radius in Terrain Unit 4 (crater wall) that had the maximum slope in the area available for testing. The following sections present a brief discussion of the data shown in the tables and figures identified above.

3.1.1 Terrain Unit 1 (original surface)

The area past the limit of the ejecta field of the crater was identified as the original surface (Terrain Unit 1). This area was level, firm, and almost smooth, with a sparse cover of grass about 203 mm (8 inches) tall. Table 3.2 shows that the average soil strength was greatest in this area and the average slope (approximately 1.6 percent) was the least.

3.1.2 Terrain Unit 2 (outer lip)

The area of continuous shallow ejecta extending from the natural terrain to the foot of the outer slope was identified as the outer lip (Terrain Unit 2). The distance from GZ to the outer and inner boundaries of this area varied along different radii of the crater. In this terrain unit, the original surface was covered with ejecta ranging from individual grain particles to clods several inches in size. The average soil strength in the 0- to 152.4-mm (0- to 6-inches) layer was lower in Terrain Unit 2 than in Terrain Unit 1 as a result of a 100- to 180-mm- (4- to 7-inches-) thick layer of soft ejecta. The soil was relatively dry, and the ejecta clods disintegrated when pressure was applied. The depth of the ejecta gradually increased from the outer edge of the ejecta toward GZ, resulting in a slight average slope of approximately 3 percent. A typical microprofile of the outer lip of the crater is shown in Figure 3.1.

3.1.3 Terrain Unit 3 (inner lip)

The area of continuous ejecta extending from the foot of the outer slope to the crest was identified as the inner lip (Terrain Unit 3). The distances from GZ to the outer and inner boundaries of this area varied along different radii of the crater. The ejecta depth averaged more than 610 mm (24 inches) in this terrain unit, resulting in a lower average soil strength and a higher average slope (approximately 13.7 percent) than in Terrain Units 1 and 2, as can be seen in Table 3.2. The surface of the inner lip was relatively rough because of undulating ejecta or the presence of clods. A typical microprofile of the inner lip of the crater is shown in Figure 3.2.

3.1.4 Terrain Unit 4 (crater wall)

The sloping sides of the craters extending from the lip crest to the toe of the slope at the edge of the crater floor were identified as the crater wall (Terrain Unit 4). The distances from GZ to the outer and inner boundaries of this area varied along different radii of the crater. The loose, dry material on the slopes was greater than 610 mm (24 in.) deep, and the average soil strength was similar to that in Terrain Unit 3. The overall slope of the crater walls varied in magnitude at the upper and lower ends and along different crater radii. The minimum and maximum slopes were 50 and 56 percent, respectivvely. An elevation profile of the crater wall of maximum slope of the crater is given in Figure 3.3.

3.1.5 Terrain Unit 5 (crater floor)

The area extending from the toe of the slope of the crater wall to GZ was identified as the crater floor (Terrain Unit 5). The outer boundaries of this area varied along different radii of the crater. Due to the impact of the explosion which compacted the soil, the average soil strength was higher in this terrain unit than any other terrain unit except Terrain Unit 1 (Table 3.2).

3.2 PERFORMANCE DEGRADATION

3.2.1 Measured Performance Data

Four first-pass vehicle performance parameters commonly measured, shown in Table 3.4, are go-no go, DBP, MR, and speed. Of these performance parameters, only DBP and speed were considered in the analysis of degradation of vehicle performance of the various terrain units; however, all vehicle performance parameters measured in the crater and ejecta areas are given in Table 3.4. Results of the go-no go tests and DBP tests are discussed in the following paragraphs.

1. Go-no go. All the test vehicles could operate with ease in Terrain Units 1, 2, 3, and 5; however, none of the vehicles could make a safe entry into the crater because of the steep slopes (50 percent) of Terrain Unit 4 (crater wall). A D7F bulldozer was used for 10 minutes to do the minimum amount of work required for the vehicles to make a safe entry into the crater. The vehicles then entered the crater, crossed the crater floor, and attempted to exit by way of the crater wall. A summary of the exiting test results on the crater wall (Terrain Unit 4) is shown in the following tabulation:

Vehicle	Performance	No. of Attempts
M60A1	not tested	0
M551	no go	5
M577A1	go[a]	3
M109	go	3
M35A2C	no go	6
M715	no go	6

[a] Go after entrance lane was constructed.

The M60A1 tank was not tested in Terrain Units 4 or 5 due to the mechanical condition of its track system. Several attempts were made before two of the vehicles (M577A1 and M109) could negotiate Terrain Unit 4. On the fifth attempt to exit the crater the M551 threw a track. All the vehicles tested were able to climb onto the crater wall

(Terrain Unit 4); however, only the M577A1 and the M109 were able to negotiate the wall. The other vehicles were turned around on the crater floor and driven out of the crater by way of the entrance lane. No additional engineering effort (bulldozing) was done to ensure passage of all the test vehicles across the crater due to the short time the test vehicles were available and the unavailability of a bulldozer operator. The test engineer estimated that it would take approximately the same amount of time (10 minutes) to make an exit lane as it did the entrance lane. The total time required by a D7F bulldozer to make the crater passable for the test vehicles that could not negotiate the crater wall was estimated to be 20 minutes.

2. DBP tests. As previously mentioned, DBP tests were conducted in Terrain Units 1 and 2 with the M715, the M35A2C, and the M577A1. DBP tests were not conducted with the M60A1, M551, and the M109 due either to the short time the vehicles were available for testing or to the mechanical condition of their track systems. No DBP tests were conducted in Terrain Units 3, 4, and 5 due to the small size of the area in Terrain Units 3 and 5 and due to a no-go condition in Terrain Unit 4.

DBP, in terms of DBP coefficient (DBP/W, where W is the vehicle weight), was plotted versus wheel or track slip for each test, and curves of best visual fit were drawn through the data points (Figure 3.4).

DBP/W is a performance parameter often used in evaluating the traction capabilities of a vehicle. A high DBP/W at a low slip indicates that a vehicle can do efficient useful work, i.e. move forward and tow a load, whereas a high DBP/W at a high slip (near 100 percent) indicates that very little useful work can be done, i.e. the vehicle can barely move itself forward. In these tests the maximum DBP/W for the M715 and M35A2C occurred near 30 percent slip and for the M577A1 at 100 percent slip. A more meaningful performance parameter is the optimum DBP/W value, which is the value of DBP/W when the vehicle's work output coefficient (WOC) is at a maximum (Reference 10). WOC is an arbitrary index of efficiency defined as the ratio of work output to work input, where work output is DBP times the distance the vehicle travels (S) in the time interval (t), and work input is the weight of the vehicle (W) times the distance the wheel or tracks travel (L) in the same time interval (t), or

$$WOC = \frac{DBP\left(\frac{S}{t}\right)}{W\left(\frac{L}{t}\right)} \tag{1}$$

Since

$$Slip = 1 - \frac{S/t}{L/t}$$

or

$$\frac{S/t}{L/t} = 1 - slip$$

then

$$WOC = \frac{DBP}{W}\ (1 - slip)$$

An example of the determination of optimum DBP/W at maximum WOC for each test vehicle in Terrain Unit 1 of the crater is shown in Figure 3.5. Figure 3.5 shows that the optimum slip was 20 percent for the M715 and 18 percent for the M35A2C and the M577A1; the optimum DBP coefficients for the three vehicles in Terrain Unit 1 of the crater were 0.52, 0.43, and 0.59, respectively. Past studies at the U. S. Army Engineer Waterways Experiment Station (WES) have shown that optimum DBP generally occurs at or near 20 percent slip, as was found in the tests in this program.

3.2.2 Degradation of Vehicle Performance

The effectiveness of the craters as barriers to mobility is shown as the degradation of speed and DBP. Degradation is expressed in percent and is obtained from the following expression:

$$\text{Percent degradation} = \left(1 - \frac{T}{N}\right) \times 100 \tag{2}$$

where

T = performance in a given terrain unit

N = performance in natural terrain

Degradation in performance in each of the terrain units tested is shown in Table 3.5.

The degradation in speed for the tracked vehicles (M60A1, M551, M577A1, and M109) varied from 10 percent for the M109 to 37 percent for the M577A1 in Terrain Unit 2. The degradation in optimum DBP coefficient in Terrain Unit 2 for the M577A1 was 8 percent. The degradation in speed of the wheeled vehicles (the M35A2C and the M715) was somewhat higher than the degradation in optimum DBP coefficient. It may be noted that the degradation in optimum DBP coefficient of the M577A1 was about half that of the M35A2C and the M715. This possibly is a result of the configuration of the traction elements of the vehicles and the surface of the terrain units. Due to the undulating surface of Terrain Unit 2, each traction element of the wheeled vehicles encountered each undulation, whereas the tracks of the M577A1, in some cases, spanned several undulations.

3.2.3 Areal Effectiveness

Using the dimensions given in Figure 2.15, the areas occupied by Terrain Units 2 through 5, inclusive, are shown in the following tabulation along with the speed degradation in percent.

Terrain Unit No.	Terrain Unit Description	Area m^2 (ft^2)	Speed Degradation, pct M60A1	M551	M577A1	M109	M35A2C	M715
2	Outer Lip	39,686 (426,962)	14	19	37	10	16	19
3	Inner Lip	5,144 (55,342)	NM[a]	NM	NM	NM	NM	NM
4	Crater Wall	1,839 (19,782)	100	100	100	100	100	100
5	Crater Floor	29 (314)	NM	NM	NM	NM	NM	NM
	Total	46,698 (502,400)						

[a] NM means not measured.

The areal extent of 100 percent degradation (i.e. complete barrier to mobility) was approximately 1,839 m^2 (19,782 ft^2) for all the test vehicles. The degraded area per gigajoule (0.24 ton) of explosive was 0.73 m^2 (7.85 ft^2), which indicates that large-scale surface explosives in this type of material (silty sand) are not an efficient means of creating barriers to the movement of military vehicles.

In a combat situation, the major concern may be the width of the no-go area rather than the areal effectiveness, for example, how wide a pass could be blocked with a particular charge. Using the dimensions shown in Figure 2.15 the effective no-go width was approximately 48 metres (160 feet), which indicates that a similar charge in the same soil conditions would be effective in combat conditions for creating obstacles in this width range.

Although the results discussed in the previous paragraphs are, as would be expected, for craters in this type of material, it is cautioned that this single crater cannot be considered definitive of all craters formed in unconsolidated materials in which the explosive material varies in amount and depth of charge.

3.3 PREDICTION OF VEHICLE PERFORMANCE

Vehicle performance was predicted for the terrain units identified for ground mobility purposes in the DICE THROW crater, using the Army Mobility Model AMM-74X (Reference 7). The basic premises of AMM-74X (Reference 10) are given in the following paragraphs.

The performance of a vehicle at any moment is the result of a complex interplay among many different characteristics of the vehicle, numerous features of the particular terrain in which it is operating, its immediate past operating history, and elections and constraints imposed on the driver. AMM-74X postulates that the maximum practical speed of a sound vehicle at any moment, including zero (no go), is an appropriate measure of its mobility at that time and place. Accordingly, each of the many system parameters potentially involved must be quantified in engineering terms that will permit calculation of probable vehicle speed as limited by one or more of the number of possible specific terrain-vehicle-driver interactions. The following tabulation outlines off-road system attributes considered in AMM-74X.

Terrain	Vehicle	Driver
Surface material	Geometry	Reaction time
Type	Mechanical components	Recognition distance
Strength	Inertial components	V-ride limit
		Vertical acceleration limit
Surface geometry		
Slope		
Discrete obstacles		
Roughness		
Vegetation	Geometry	Reaction time
Stem size and spacing	Mechanical components	Recognition distance
Visibility	Inertial components	V-ride limit
		Vertical acceleration limit
Hydrologic geometry[a]		
Stream cross section		
Water velocity and depth		

[a] These terrain attributes are necessary for linear features such as streams. In this study, linear features were not considered.

The endless variability of real terrain can be represented by a mosaic of pieces, each of which, to some feasible resolution, can be considered uniform in terms of measurable factors affecting vehicle responses. Such a subclass of terrain is called a terrain unit. An areal terrain unit is currently characterized by the 13 measurements listed below:

1. Surface factors
   (1) Type
   (2) Strength in cone index or rating cone index
   (3) Slope, percent
   (4) Roughness, root mean square (rms) elevation in inches. A measure of the rms of the deviations of the terrain elevations from the mean can be expressed as:

$$rms = \sum_{j=1}^{N} \frac{(xj - \bar{x})^2}{N} \qquad (3)$$

where

N = number of elevation points
xj = terrain elevation
x = mean value of terrain elevation in a given profile

2. Obstacle factors

(5) Approach angle, deg

(6) Height, mm (in.)

(7) Base width, mm (in.)

(8) Length, m (ft)

(9) Spacing, m (ft)

(10) Type

3. Vegetation factors

(11) Stem diameter, mm (in.)

(12) Stem spacing, m (ft)

(13) Visibility, m (ft)

Maximum practical speeds for a vehicle in each areal unit within an area, calculated from validated engineering relations, can be combined by suitable procedures to predict the performance of the vehicle along any given path in the real terrain and/or to accumulate a statistical representation of vehicle performance in the area as a whole.

3.4 COMPARISON OF MEASURED AND PREDICTED PERFORMANCE

The vehicle performance parameters measured and predicted in the DICE THROW crater and ejecta areas are given in Table 3.4. Plots comparing measured and predicted DBP/W and MR/W are shown in Figure 3.6 and those comparing measuring and predicted speeds are shown in Figure 3.7.

Table 3.4 shows that the performance of the vehicles in terms of go-no go was predicted correctly in every case. Table 3.4 and Figure 3.6 show that the predicted values of DBP/W in most cases were slightly higher than the measured values. All predicted values for DBP/W and MR/W were well within the acceptable limits of prediction accuracy as the model now stands. Table 3.4 and Figure 3.7 show that the variation in measured and predicted values of speed was somewhat larger than for the other parameters. The relative deviations of the predicted values for each terrain unit tested are shown in Table 3.6.

The mean absolute deviation shown in Table 3.6 varied from a minimum of 0.2 km/hr (0.1 mph) to a maximum of 6.1 km/hr (3.8 mph) from the predicted to the measured values indicating that the average absolute deviations were relatively small from the standpoint of vehicle speed. The overall average relative deviation for all vehicles tested was 6.8 percent. Based on average relative deviation, the M60A1 presented the best prediction accuracy (1.5 percent), and the M715 presented the worst prediction accuracy (14.5 percent). The average relative deviations indicated good correlation between model-predicted speeds and field-measured speeds for all the test vehicles. The relative deviations of the predicted values from the measured values increased from the original surface to GZ in every case. This is as would be expected, since AMM-74X is set up to evaluate natural terrain such as the original surface. The average deviations in the cratered areas were well within the acceptable limits of prediction accuracy as the model now stands.

TABLE 3.1

SURFACE COMPOSITION MEASURED CONE INDEX DATA

Terrain Unit		Average Cone Index at Depths Indicated[a]											
No.	Description	mm-0 in.-0	25.4 (1)	50.8 (2)	76.2 (3)	102 (4)	127 (5)	152 (6)	229 (9)	350 (12)	381 (15)	457 (18)	610 (24)
1	Original Surface	27	101	289	370	420	489	554	573	624	750+	--[b]	--
2	Outer Lip	7	20	32	57	83	96	105	168	205	218	267	330
3	Crater Lip	11	20	30	37	45	48	47	47	53	51	48	62
4	Crater Wall	5	10	20	30	31	44	46	47	59	83	84	128
5	Crater Floor	48	136	202	248	216	178	134	156	236	282	290	446

[a] The average cone index values shown are an average of all cone index readings taken in each terrain unit.

[b] -- denotes beyond range of instrument, i.e., CI > 750.

TABLE 3.2

CONE INDEX, MOISTURE CONTENT, AND DRY DENSITY SURFACE COMPOSITION DATA

Terrain Unit		Average Depth of Ejecta	Cone Index		Moisture Content Percent Dry Weight			Dry Density				Surface Geometry	
								0 to 152 mm (0 to 6 in.)		152 to 305 mm (6 to 12 in.)			
No.	Description	mm (in.)	0 to 152 mm (0 to 6 in.)	152 to 305 mm (6 to 12 in.)	0 to 25.4 mm (0 to 1 in.)	0 to 152 mm (0 to 6 in.)	152 to 305 mm (6 to 12 in.)	kg/m^3	(lb/ft^3)	kg/m^3	(lb/ft^3)	Average Slope %	rms in.
1	Original Surface	NA[a]	321	584	1.0	3.2	2.6	1.35	84.2	1.36	84.8	1.6	0.85
2	Outer Lip	102 (4)	57	159	1.3	3.0	4.4	1.39	86.9	1.41	88.2	3.0	1.61
3	Inner Lip	610 (>24)	34	49	0.5	1.7	4.8	1.41	87.9	1.41	87.8	13.7	2.84
4	Crater Wall	610 (24)	27	51	11.4	20.6	20.2	1.15	71.8	1.21	75.4	53.0	NA
5	Crater Floor	NA	166	175	12.4	17.2	24.9	1.33	82.8	1.28	80.0	4.5	NA

[a] NA means not applicable.

TABLE 3.3

SURFACE GEOMETRY DATA

Terrain Unit 2		Terrain Unit 3		Terrain Unit 4	
Station m (ft)	Elevation m (ft)	Station m (ft)	Relative Elevation m (ft)	Distance from GZ m (ft)	Relative Elevation m (ft)
0.00 (0.0)	0.16 (0.50)	0.00 (0.00)	0.26 (0.85)	3.05 (10.0)	3.99 (13.1)
0.15 (0.5)	0.19 (0.58)	0.10 (0.33)	0.27 (0.90)	4.27 (14.0)	4.33 (14.2)
0.30 (1.0)	0.23 (0.75)	0.15 (0.50)	0.24 (0.78)	5.79 (19.0)	4.76 (15.6)
0.46 (1.5)	0.27 (0.88)	0.24 (0.80)	0.21 (0.70)	6.70 (22.0)	4.91 (16.1)
0.61 (2.0)	0.27 (0.90)	0.37 (1.20)	0.20 (0.65)	7.31 (24.0)	5.21 (17.1)
0.76 (2.5)	0.27 (0.90)	0.41 (1.33)	0.23 (0.75)	8.53 (28.0)	5.55 (18.2)
0.91 (3.0)	0.27 (0.88)	0.51 (1.67)	0.18 (0.60)	9.14 (30.0)	5.55 (18.2)
1.07 (3.5)	0.28 (0.91)	0.61 (2.00)	0.21 (0.70)	10.36 (34.0)	6.19 (20.3)
1.22 (4.0)	0.28 (0.92)	0.71 (2.33)	0.23 (0.75)	12.19 (40.0)	7.35 (24.1)
1.37 (4.5)	0.28 (0.91)	0.81 (2.67)	0.26 (0.85)	14.63 (48.0)	7.56 (24.8)
1.52 (5.0)	0.27 (0.90)	0.91 (3.00)	0.24 (0.80)	15.85 (52.0)	7.74 (25.4)
1.68 (5.5)	0.27 (0.90)	1.07 (3.51)	0.24 (0.90)	16.46 (54.0)	7.96 (26.1)
1.83 (6.0)	0.28 (0.91)	1.27 (4.15)	0.27 (0.90)	17.38 (57.0)	8.48 (27.8)
1.98 (6.5)	0.34 (1.10)	1.41 (4.63)	0.30 (1.00)	18.60 (61.0)	9.06 (29.7)
2.13 (7.0)	0.37 (1.20)	1.56 (5.13)	0.29 (0.95)	19.82 (65.0)	10.09 (33.1)
2.29 (7.5)	0.35 (1.15)	1.72 (5.63)	0.27 (0.90)	21.04 (69.0)	10.76 (35.3)
2.44 (8.0)	0.34 (1.12)	1.87 (6.13)	0.34 (1.13)	21.95 (72.0)	11.04 (36.2)
2.59 (8.5)	0.33 (1.08)	1.95 (6.38)	0.30 (1.00)	22.56 (74.0)	11.52 (37.8)
2.74 (9.0)	0.32 (1.07)	2.01 (6.60)	0.32 (1.05)	23.17 (76.0)	12.23 (40.1)
2.90 (9.5)	0.32 (1.05)	2.06 (6.76)	0.33 (1.08)	24.09 (79.0)	12.90 (42.3)
3.05 (10.0)	0.38 (1.26)	2.11 (6.93)	0.29 (0.95)	25.00 (82.0)	13.45 (44.1)
3.20 (10.5)	0.43 (1.41)	2.27 (7.44)	0.42 (1.38)	26.22 (86.0)	14.12 (46.3)
3.35 (11.0)	0.43 (1.42)	2.52 (8.27)	0.37 (1.20)	27.13 (89.0)	14.42 (47.3)
3.51 (11.5)	0.41 (1.35)	2.67 (8.77)	0.40 (1.30)	28.05 (92.0)	14.48 (47.5)
3.66 (12.0)	0.40 (1.32)	2.86 (9.38)	0.40 (1.30)		
3.81 (12.5)	0.40 (1.33)	3.15 (10.33)	0.44 (1.45)		
3.96 (13.0)	0.40 (1.33)	3.25 (10.67)	0.37 (1.20)		
4.12 (13.5)	0.40 (1.31)	3.35 (11.00)	0.38 (1.25)		
4.27 (14.0)	0.40 (1.30)	3.45 (11.33)	0.27 (0.90)		
4.42 (14.5)	0.40 (1.30)	3.76 (12.33)	0.24 (0.80)		
4.57 (15.0)	0.39 (1.28)	3.87 (12.70)	0.24 (0.80)		
4.73 (15.5)	0.38 (1.25)	3.99 (13.10)	0.28 (0.91)		
4.88 (16.0)	0.38 (1.25)	4.15 (13.60)	0.27 (0.90)		
5.00 (16.4)	0.37 (1.21)	4.30 (14.10)	0.30 (1.00)		
		4.45 (14.60)	0.37 (1.20)		
		4.63 (15.20)	0.29 (0.95)		
		4.82 (15.80)	0.30 (1.00)		
		4.88 (16.00)	0.26 (1.30)		
		5.00 (16.40)	0.30 (1.00)		

NOTE: Terrain Units 1 and 5 were essentially smooth; therefore, profile data not shown.

TABLE 3.4

MEASURED AND PREDICTED VEHICLE PERFORMANCE IN THE DICE THROW CRATER

Terrain Unit		Performance Parameter							
		Go-No Go		Optimum Drawbar Pull/Weight		Motion Resistance/Weight		Speed	
No.	Description	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured km/hr (mph)	Predicted km/hr (mph)
				M60A1 Tank					
1	Original Surface	Go	Go	NM[a]	NP[b]	NM	NP	22.2 (13.8)	22.4 (13,9)
2	Outer Lip	Go	Go	NM	NP	NM	NP	19.0 (11.8)	19.3 (12.0)
3	Inner Lip	Go	Go	NM	NP	NM	NP	NM	NP
4	Crater Wall	NM	Go	NM	NP	NM	NP	NM	NP
5	Crater Floor	NM	Go	NM	NP	NM	NP	NM	NP
				M551 Sheridan Tank					
1	Original Surface	Go	Go	NM	NP	NM	NP	23.8 (14.8)	24.2 (15.0)
2	Outer Lip	Go	Go	NM	NP	NM	NP	19.3 (12.0)	18.5 (11.5)
3	Inner Lip	Go	Go	NM	NP	NM	NP	NM	NP
4	Crater Wall	No Go	No Go	NM	NP	NM	NP	NA[c]	NP
5	Crater Floor	Go	Go	NM	NP	NM	NP	NM	NP
				M577A1 Command Post Carrier					
1	Original Surface	Go	Go	0.59	0.62	0.08	0.06	29.5 (18.3)	30.1 (18.7)
2	Outer Lip	Go	Go	0.54	0.58	0.14	0.13	18.5 (11.5)	16.6 (10.3)
3	Inner Lip	Go	Go	NM	NP	NM	NP	NM	NP
4	Crater Wall	Go	Go	NM	NP	NM	NP	NM	NP
5	Crater Floor	Go	Go	NM	NP	NM	NP	NM	NP
				M109 Self-Propelled Howitzer					
1	Original Surface	Go	Go	NM	NP	NM	NP	24.8 (15.4)	25.8 (16.0)
2	Outer Lip	Go	Go	NM	NP	NM	NP	22.2 (13.8)	19.0 (11.8)
3	Inner Lip	Go	Go	NM	NP	NM	NP	NM	NP
4	Crater Wall	Go	Go	NM	NP	NM	NP	NM	NP
5	Crater Floor	Go	Go	NM	NP	NM	NP	NM	N NP

(Continued)

[a] NM means not measured.

[b] NP means not predicted.

[c] NA means not applicable.

(Sheet 1 of 2)

TABLE 3.4 (CONCLUDED)

Terrain Unit		Go-No Go		Optimum Drawbar Pull/Weight		Motion Resistance/Weight		Speed	
No.	Description	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured km/hr (mph)	Predicted km/hr (mph)
				M35A2C 2-12/-Ton Cargo Truck					
1	Original Surface	Go	Go	0.43	0.46	0.08	0.05	25.7 (16.0)	26.6 (16.5)
2	Outer Lip	Go	Go	0.37	0.38	0.14	0.12	21.7 (13.5)	19.8 (12.3)
3	Inner Lip	Go	Go	NM	NP	NM	NP	NM	NP
4	Crater Wall	No Go	No Go	NM	NP	NM	NP	NA	NP
5	Crater Floor	Go	Go	NM	NP	NM	NP	NM	NP
				M715 1-1/4-Ton Cargo Truck					
1	Original Surface	Go	Go	0.52	0.54	0.10	0.07	36.5 (22.7)	39.3 (24.4)
2	Outer Lip	Go	Go	0.45	0.49	0.16	0.13	29.6 (18.4)	23.5 (14.6)
3	Inner Lip	Go	Go	NM	NP	NM	NP	NM	NM
4	Crater Wall	No Go	No Go	NM	NP	NM	NP	NA	NP
5	Crater Floor	Go	Go	NM	NP	NM	NP	NM	NP

(Sheet 2 of 2)

TABLE 3.5

DEGRADATION OF VEHICLE PERFORMANE

Terrain Unit No.	Terrain Unit Description	Speed km/hr	Speed (mph)	Speed Degradation pct	Optimum Drawbar Pull/Weight	Drawbar-Pull Degradation pct
				M60A1 Tank		
1	Original Surface	22.2	(13.8)	0	NM[a]	NM
2	Outer Lip	19.0	(11.8)	14	NM	NM
3	Inner Lip	NM	NM	NM[b]	NM	NM
4	Crater Wall	NM	NM	100	NM	NM
5	Crater Floor	NM	NM	NM	NM	NM
				M551 Sheridan Tank		
1	Original Surface	23.8	(14.8)	0	NM	NM
2	Outer Lip	19.3	(12.0)	19	NM	NM
3	Inner Lip	NM	NM	NM	NM	NM
4	Crater Wall	NM	NM	100	NM	NM
5	Crater Floor	NM	NM	NM	NM	NM
				M577A1 Command Post Carrier		
1	Original Surface	29.5	(18.3)	0	0.59	0
2	Outer Lip	18.5	(11.5)	38	0.54	8
3	Inner Lip	NM	NM	NM	NM	NM
4	Crater Wall	NM	NM	100	NM	100
5	Crater Floor	NM	NM	NM	NM	NM
				M109 Self-Propelled Howitzer		
1	Original Surface	24.8	(15.4)	0	NM	NM
2	Outer Lip	22.2	(13.8)	10	NM	NM
3	Inner Lip	NM	NM	NM	NM	NM
4	Crater Wall	NM	NM	100	NM	100
5	Crater Floor	NM	NM	NM	NM	NM

(Continued)

[a] Not measured - either due to no-go condition or lack of test area.

[b] None of the vehicles were able to make a safe entry into the crater due to steep slopes.

(Sheet 1 of 2)

TABLE 3.5 (CONCLUDED)

Terrain Unit No.	Terrain Unit Description	Speed km/hr	Speed (mph)	Speed Degradation pct	Optimum Drawbar Pull/Weight	Drawbar-Pull Degradation pct
			M35A2C 2-1/2-Ton Cargo Truck			
1	Original Surface	25.7	(16.0)	0	0.43	0
2	Outer Lip	21.7	(13.5)	16	0.37	14
3	Inner Lip	NM	NM	NM	NM	NM
4	Crater Wall	NM	NM	100	NM	100
5	Crater Floor	NM	NM	NM	NM	NM
			M715 1-1/4-Ton Cargo Truck			
1	Original Surface	36.5	(22.7)	0	0.52	0
2	Outer Lip	29.6	(18.4)	19	0.45	13
3	Inner Lip	NM	NM	NM	NM	NM
4	Crater Wall	NM	NM	100	NM	100
5	Crater Floor	NM	NM	NM	NM	NM

(Sheet 2 of 2)

TABLE 3.6

NUMERICAL EVALUATION PARAMETERS

Terrain Unit[a] No.	Description	Mean Absolute Deviation km/hr (mph)		Relative Deviation pct
		M60A1 Tank		
1	Original Surface	0.2 (0.1)		1
2	Outer Lip	0.3 (0.2)		2
			Average	1.5
		M551 Sheridan Tank		
1	Original Surface	0.4 (0.2)		2
2	Outer Lip	0.8 (0.5)		5
			Average	3
		M577A1 Command Post Carrier		
1	Original Surface	0.6 (0.4)		2
2	Outer Lip	1.9 (1.2)		10
			Average	6
		M109 Self-Propelled Howitzer		
1	Original Surface	1.0 (0.6)		4
2	Outer Lip	3.2 (2.0)		14
			Average	9
		M35A2C 2-1/2-Ton Cargo Truck		
1	Original Surface	0.9 (0.5)		4
2	Outer Lip	1.9 (1.3)		9
			Average	6.5
		M715 1-1/4-Ton Cargo Truck		
1	Original Surface	2.8 (1.7)		8
2	Outer Lip	6.1 (3.8)		21
			Average	14.5

[a] Only the terrain units where speed tests were conducted are shown.

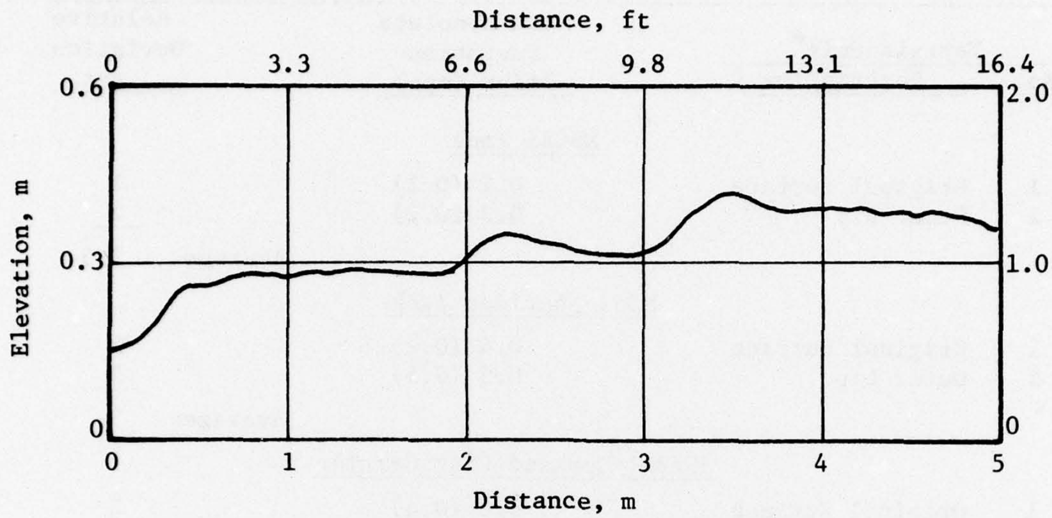


Figure 3.1. Microprofile of a typical section of Terrain Unit 2 (outer lip) roughly parallel to crater wall.

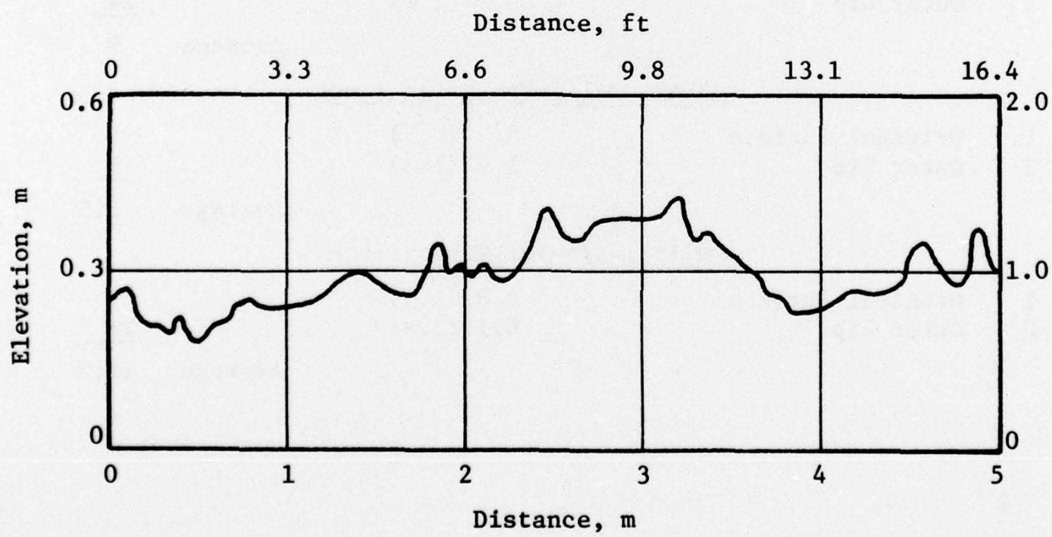


Figure 3.2. Microprofile of typical section of Terrain Unit 3 (inner lip) roughly parallel to crater wall.

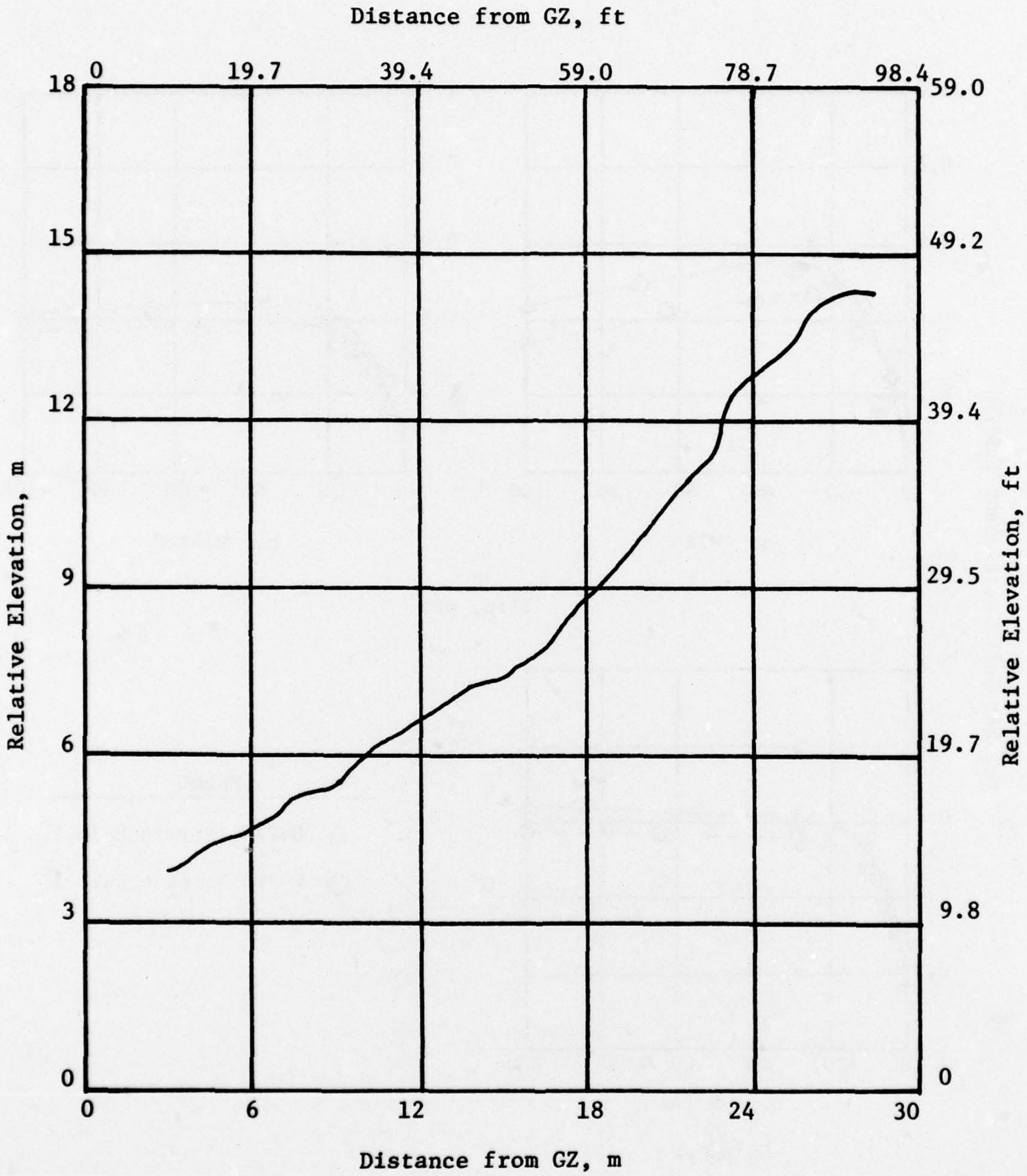


Figure 3.3. Elevation profile of Terrain Unit 4, crater wall of maximum slope.

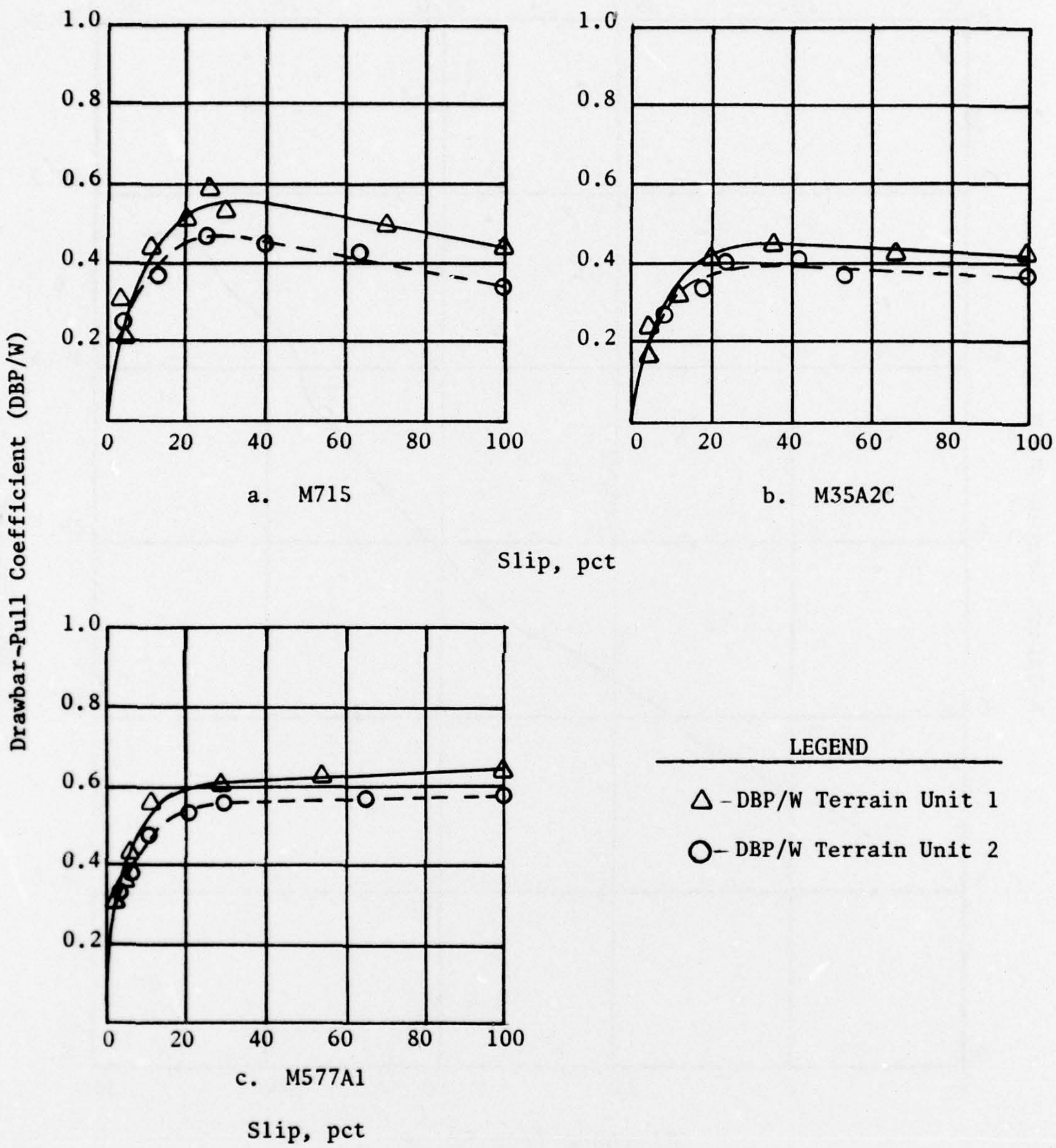


Figure 3.4. Drawbar-pull coefficient (DBP/W) versus slip.

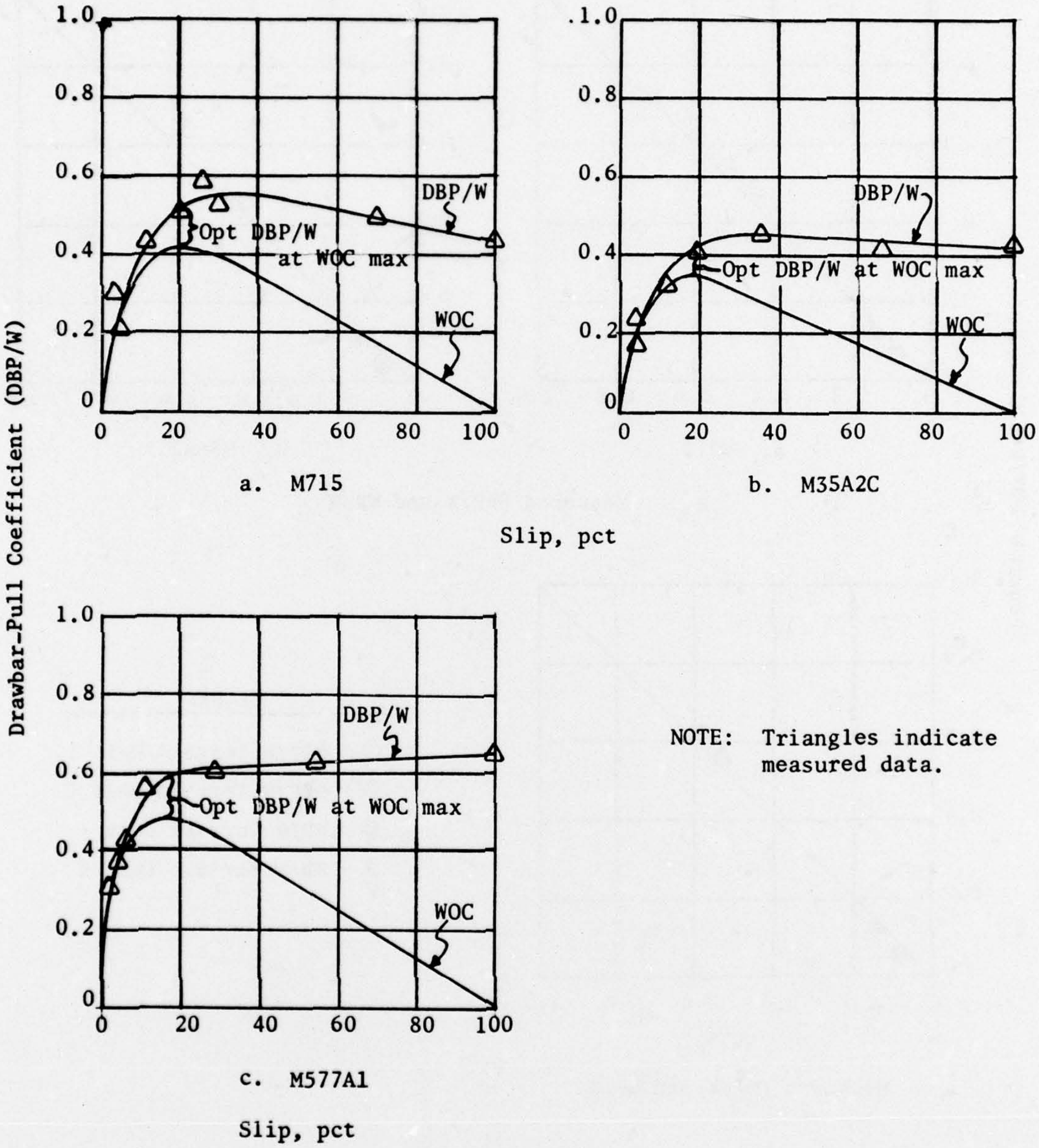


Figure 3.5. Determination of optimum DBP coefficient (DBP/W) for three of the test vehicles in Terrain Unit 1.

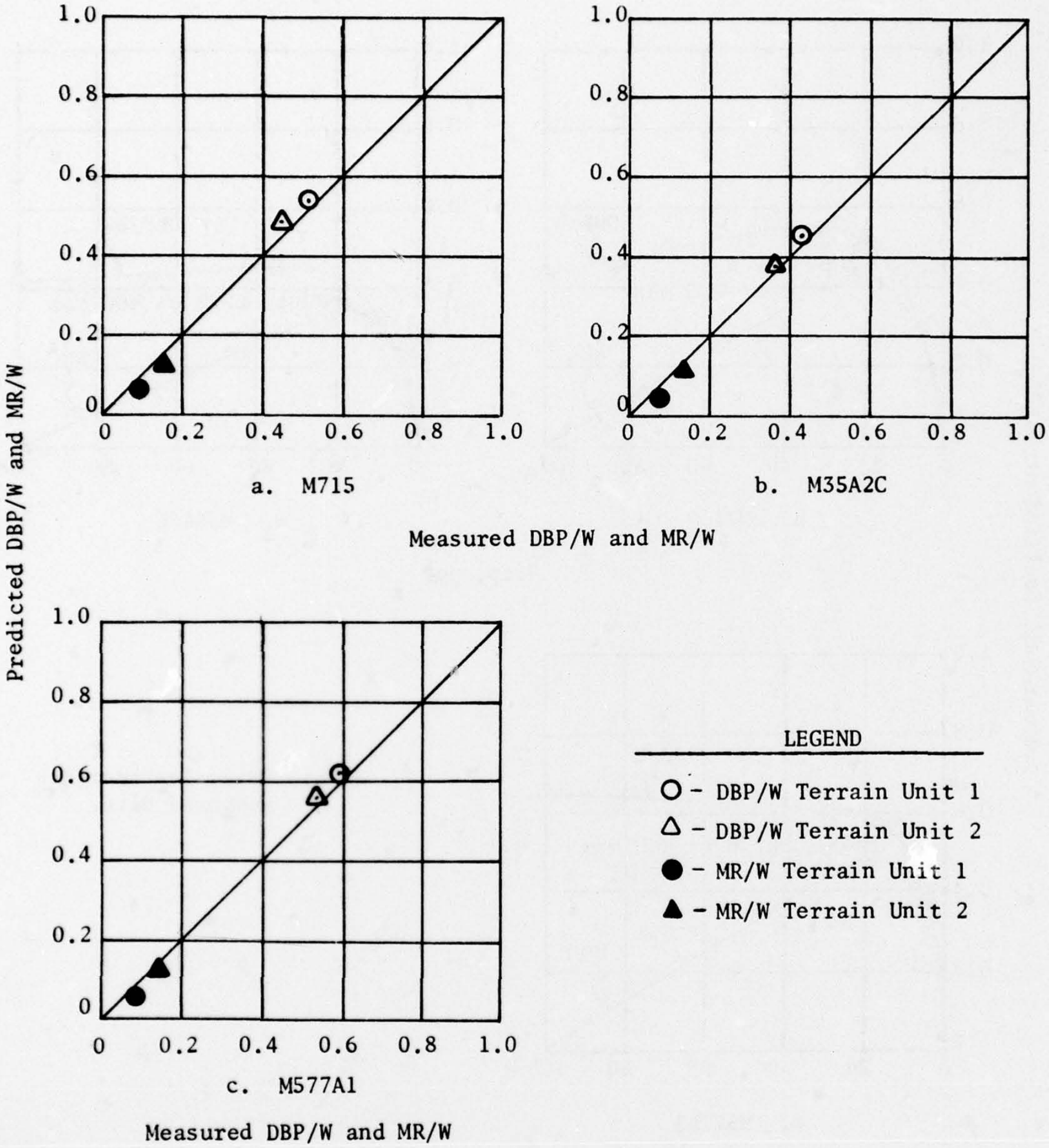


Figure 3.6. Comparison of measured and predicted DBP/W and MR/W for three of the test vehicles.

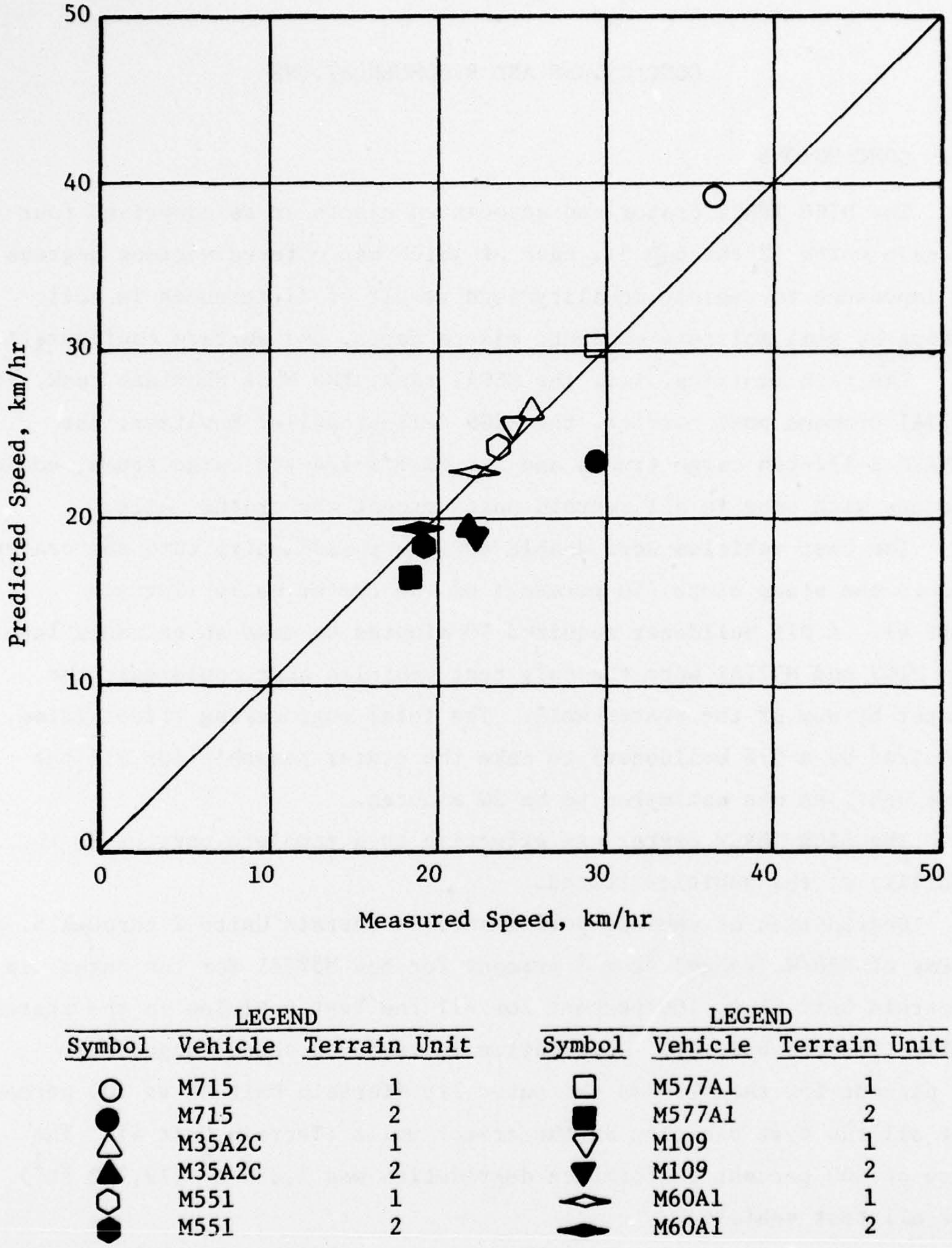


Figure 3.7. Comparison of measured and predicted speeds.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The DICE THROW crater and associated ejecta areas comprised four terrain units (2 through 5), each of which was offered various degrees of impedance to vehicle mobility as a result of differences in soil strength, soil moisture content, ejecta depth, and surface configuration.

The test vehicles, i.e. the M60A1 tank, the M551 Sheridan tank, the M577A1 command post carrier, the M109 self-propelled howitzer, the M35A2C 2-1/2-ton cargo truck, and the M715 1-1/4-ton cargo truck, could operate with ease in all terrain units except the crater walls.

The test vehicles were unable to make a safe entry into the crater due to the steep slope (50 percent) of the crater walls (Terrain Unit 4). A D7F bulldozer required 10 minutes to make an entrance lane. The M109 and M577A1 were the only test vehicles that could exit the crater by way of the crater wall. The total engineering effort (time required by a D7F bulldozer) to make the crater passable for all the test vehicles was estimated to be 20 minutes.

The DICE THROW crater was effective as a complete barrier to the mobility of the vehicles tested.

Degradation of vehicle performance in Terrain Units 2 through 5, in terms of DBP/W, ranged from 8 percent for the M577A1 for the outer lip (Terrain Unit 2) to 100 percent for all the test vehicles on the crater walls (Terrain Unit 4). Degradation in terms of speed ranged from 10 percent for the M109 on the outer lip (Terrain Unit 2) to 100 percent for all the test vehicles on the crater walls (Terrain Unit 4). The area of 100 percent performance degradation was 1,839 m^2 (19,782 ft^2) for all test vehicles.

The degraded area per gigajoule (0.24 ton) of explosive was 0.73 m^2 (7.85 ft^2), which indicates that large-scale surface explosives in this type of material (silty sand), although effective, are not an efficient means of creating barriers to military vehicles.

The effective no-go width for the crater was 48 metres (160 feet), which indicates that a similar charge in the same soil conditions would be effective in combat conditions for creating obstacles in this width range.

Comparison of measured values and values predicted by AMM-74X (Army Mobility Model) for four vehicle performance parameters revealed that the overall accuracy of the predictions for go-no go, DBP, MR, and speed were acceptable in every case.

4.2 RECOMMENDATIONS

It is recommended that investigations be continued in a range of consolidated and unconsolidated layered materials to increase the catalog of cratered terrain information for ground mobility purposes. These investigations should also include vehicle tests to collect data for refining techniques for predicting vehicle performance in crater ejecta. These techniques should include a simple and rapid solution to be incorporated into field manuals for predicting performance in cratered terrain that will evaluate all terrain factors of significance to mobility.

The potential of small row charges or multiple detonations as a barrier to mobility should also be investigated.

The scope of future projects should be extended to include a barrier-counter barrier analysis, i.e. for both offensive and defensive military operations.

It is further recommended that in all future test programs the amount of construction effort required to remove ejecta and to bypass, bridge, or fill craters to make them passable for ground vehicles be determined.

It is also recommended that in all future projects involving suface or subsurface explosives, the craters be characterized for mobility purposes so that vehicle performance can be predicted.

Finally, sufficient data need to be gathered such that an analysis can be made to compare obstacle effectiveness against mobility caused by cratering various geologic media (e.g., hard and soft rock and wet and dry soils of significantly different mineralogy).

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