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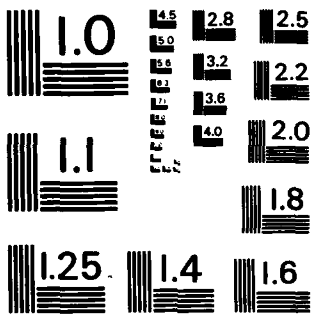

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US Army Corps of Engineers

RESULTS OF FORT CARSON, COLORADO TERRAIN DUST OBSCURATION TESTS USING EXPLOSIVES

SOIL, CRATER, AND DUST CLOUD PROPERTIES

by

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The US Army Engineer Waterways Experiment Station (WES) conducted explosive dust obscuration measurements at Fort Carson, Colo., in April and August 1983 to demonstrate the validity of WES volumetric models for predicting dust loading. Based on measurements of dust cloud mass concentrations, soil craters, and soil/terrain properties for a series of uncased C-4 high-explosive detonations at the terrain surface, it was found that crater volumes generally correlate well with charge weight, but that the same factor could not be shown

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to contribute to airborne dust loading (using available measurement techniques). The latter depends on soil texture and moisture, but significant dependence on other basic soil properties is not yet indicated. The Dust Obscuration Test series produced an extensive sampling of explosive dust clouds together with the comprehensive crater and soil measurements. It also provided measurements of shock-induced dust, which can be a significant obscurant generated as, for example, in the case of muzzle blasts.

Five diagrams are included showing the probable path of each cloud in the horizontal, with an hypothesized σ of the cloud width as a function of path traveled (which is itself a function of lapsed time).

sigma

Preface

The work reported herein was conducted by the US Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL), for the Office, Chief of Engineers, US Army, under Project 4A263734DT08, Work Unit 001. Dr. C. A. Meyer, DAEN-ZCM, was the Technical Monitor. This research was conducted under the AirLand Battlefield Environment Thrust. The purpose was to identify factors in the environment influencing the amount of dust lofted from explosive bursts of various sizes. These studies were conducted in April and August 1983 at Fort Carson, Colo., with the cooperation of Fort Carson personnel.

In the April 1983 exercise, US Army Atmospheric Sciences Laboratory personnel performed the tasks of test layout and meteorological and dust data collection; WES personnel provided crater and soil characterization and photographic coverage. In the August 1983 exercise, a WES contractor, PEDCo Environmental, Inc., devised and executed the dust sampling program.

Mr. James B. Mason of the Environmental Analysis Group (EAG), Environmental Systems Division (ESD), EL, directed the April exercise; Mr. Randall R. Williams, EAG, directed the August exercise. The report was prepared by Ms. Katherine S. Long, Mr. Mason, and Mr. Bartley P. Durst, EAG, under the direct supervision of Mr. Harold W. West, Chief, EAG, and under the general supervision of Mr. Bob O. Benn, Chief, ESD, and Dr. John Harrison, Chief, EL.

The Commander and Director of WES during the study and preparation of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

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Contents

RESULTS OF FORT CARSON, COLORADO, TERRAIN DUST OBSCURATION TESTS USING EXPLOSIVES

Soil, Crater, and Dust Cloud Properties

Introduction

1. The US Army Engineer Waterways Experiment Station (WES) in Vicksburg, Miss., is conducting research related to the determination of the terrain dust concentration and composition for realistic battlefield conditions. This research is sponsored by the Office, Chief of Engineers, under the auspices of the Battlefield Terrain Working Group of the AirLand Battlefield Environment (ALBE) Thrust (Deepak 1983). The importance of terrain dust has increased as a result of the development of high technology weapons, sensors, and surveillance systems. The potential effects of terrain dust upon battlefield operations and equipment are significant, and dust properties and characteristics vary greatly with geographic location, climate, season, and even time of day. The prediction of dust concentrations and composition in a region being used for a military activity is an integral part of combat survivability. WES's primary thrust has been to determine the terrain and environmental factors affecting dust generation and transmission. This research will provide data to analysts involved in combat effectiveness studies and to military engineer teams involved in predicting the performance of weapon systems in combat.

2. An experimental research program is being conducted at WES to determine data and relationships for use in an analytical procedure for prediction of terrain dust generated by explosions such as impacting munitions, moving vehicles, weapon firings, and helicopter landings and takeoffs. The principal goal of the explosive tests has been to measure and characterize soil and resulting crater conditions to develop a database to correlate soil properties with airborne dust loading. The initial series of tests in the Corps of Engineers' dust research program focused on determining the correlations with dust loading by considering the sand, silt, and clay content of soils before explosive detonation. This test series was designated the Battlefield Environments from Tailored Soils (BETS) (Mason and Long 1981, Kennedy 1982, Mason and Long 1983). The objective of BETS was to account for the material removed from

craters produced by uncased simulated munition rounds to infer the dust cloud mass and distribution.

3. The second series of experimental explosive tests, conducted at Fort Carson, Colo., in April and August 1983, was designated the terrain Dust Obscuration Tests (DOT). These tests were conducted jointly by the US Army Atmospheric Sciences Laboratory (ASL), White Sands Missile Range, N. Mex., and the WES. The objective of these tests was to evaluate and refine the relations between in situ soil parameters and resulting craters and dust mass loading developed in the BETS experiments.

Objectives

4. The purposes of this paper are to briefly describe the important terrain and environmental parameters affecting dust generation and lofting, to describe some of the preliminary results of the explosive DOTs, and to compare these results with the results of previous experiments.

Parameters Influencing Dust

5. The identification and classification of important terrain and environmental parameters are prerequisites to the prediction of dust generation potential of battle areas. Therefore, a brief description of the important parameters influencing dust generation and loading is given below.

6. "Dust" has been defined as any airborne material of terrain origin of a size less than 100 μm in diameter. It may consist of mineral particles, organic debris, and carbon products of burned vegetation, and even water droplets originating from in situ soil moisture or vegetation. A "dust cloud" is defined as a suspension of terrain-based particles or aerosol droplets that remain airborne within the environment for a sufficient length of time to affect the operation and use of military systems, electro-optical (E-O) sensors, and equipment.

Soil

7. The principal soil parameter affecting dust concentration and composition is the grain size (or texture) of the in situ soil. Typically, soil texture is characterized using the classification procedures of the Unified Soil Classification System (USCS), which are based on the percent of soil

with different grain sizes. However, the mineralogy also influences particle shape, chemical composition, and mass, which in turn influence the nature and amount of dust in a dust cloud.

8. Water is also important and acts as a soil particle binding agent. The percent water present in a soil is controlled by the voids fraction and the sizes of voids between particles. Thus, an accurate measurement or prediction of soil moisture in the surface and near-surface layers is required to determine dust potential of a terrain region.

9. Soil density is an important factor in the binding together of particles and the potential for separation of dust from the soil. Cemented or indurated soils (such as desert pavements) have a high surface density and can encrust with a hard surface layer. Such layers often prevent naturally occurring wind-eroded dust; however, these surface layers are often weak, so that once disturbed (by vehicles, for example), the soil becomes a significant dust contributor.

Vegetation

10. Another terrain factor, vegetation ground cover, limits the amount of dust generated by different sources. Above-ground vegetative growth and roots impede dust emissions and dust lofting. Methods for quantifying the relations between vegetation and its dust-suppression capabilities were also addressed in the test program, but the range of vegetation conditions was inadequate to develop a good correlation.

Meteorological conditions

11. Climate and meteorology act as intervening variables that must be described since they impact soil formation and soil conditions. Rainfall affects the in situ moisture content of soils. Wind speed and direction affect dust cloud lofting movements and particle dispersions. More important primary variations attributed to climate and meteorological events, such as droughts, can, as expected, affect the dust potential from season to season. However, short-term phenomena such as diurnal meteorological variations also occur, with dust potential tending to be lowest in early morning. In fact, certain arid or semiarid regions are known to portray, at certain periods of the day, electrostatic forces that tend to buoy up particles of varying zeta potential. That is, dust of various particle shapes and charges has been noted to levitate to various levels without the presence of wind or other forcing factors.

Description of Test Sites, Instrumentation, and Explosive Tests

Location of test sites

12. The two test sites used for the Fort Carson DOTs were located 2 km north of the southernmost gate of the Military Reservation (Site 1) and southeast of Camp Red Devil (Site 2), as shown in Figure 1. The Fort Carson reservation can be considered analogous to many semiarid regions of the world in

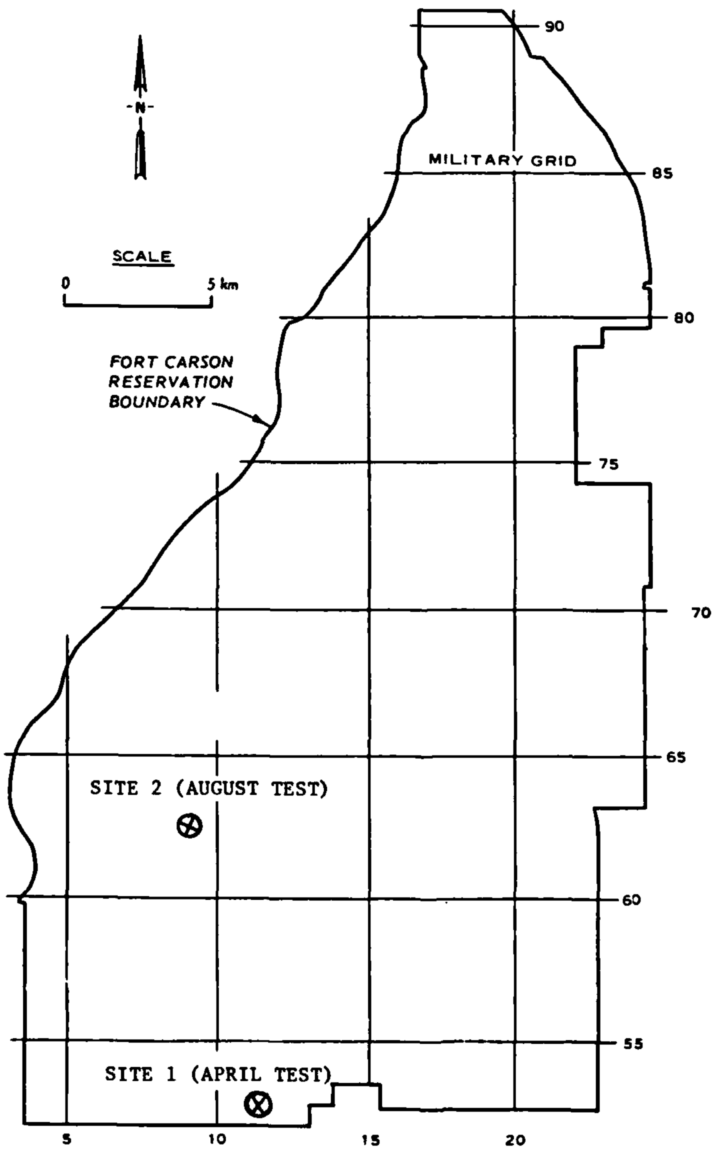


Figure 1. Location of test sites, Fort Carson, Colo.

terms of surface soil types and vegetation ground cover types. Figure 2 shows the portions of the reservation that are covered by the predominant short- and mixed-grass prairie species that occur at the two test sites.

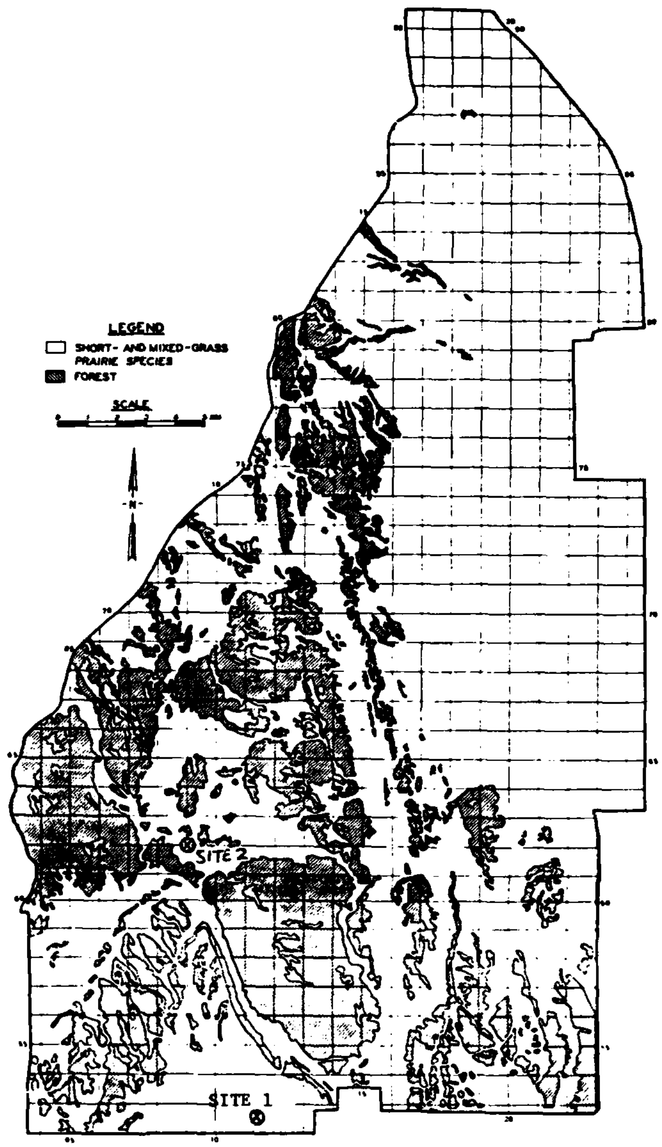


Figure 2. Vegetation cover at Fort Carson, Colo.

Environmental conditions

13. Soil. The surface soil at Site 1 (April 1983 tests) was a light brown sandy clay material classified according to the USCS as a sandy clay (CL). The in situ moisture content of the surface soil ranged between 6.7 and 26.7 percent, with the maximum moisture occurring just after the site received some light rainfall. Soil strength or cone index (CI) was 50 at the surface and increased to approximately 200 at a 15-cm depth and 750+ at a 30-cm depth.

14. The surface soil at Site 2 (August 1983 tests) was a reddish-brown, sandy clay-sandy silt material classified as ML according to the USCS. The moisture content ranged from 7.2 to 14.9 at the surface, and the soil strength varied from 100 CI in the surface layer to 750+ CI at the depth of 15-30 cm. Figure 3 shows the surface soil grain sizes at the two test sites.

15. The soil data collected in support of the eight high-explosive DOT tests are summarized in Table 1.

16. Vegetation. The predominant vegetation types occurring at the sites

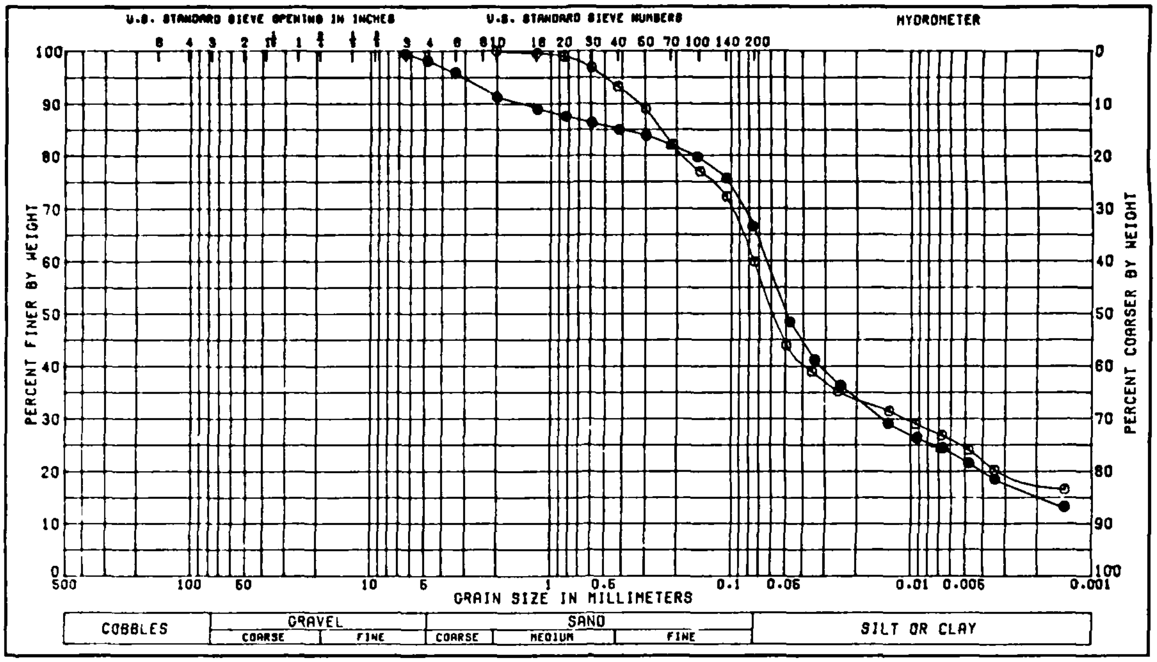


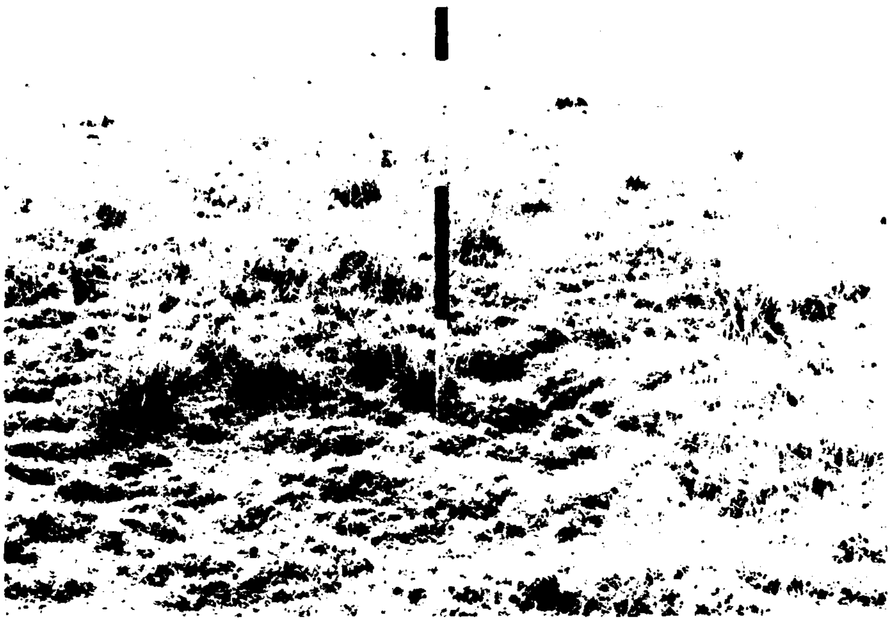
Figure 3. Soil grain size curves for Sites 1 and 2,
DOTs, Fort Carson, Colo.

were short grasses and plants of blue grama, Russian thistle, lamb's-quarters, and prickly pear. Height of the plants ranged from 10-20 cm, and the ground area of coverage was 50-70 percent, as illustrated in Figure 4.

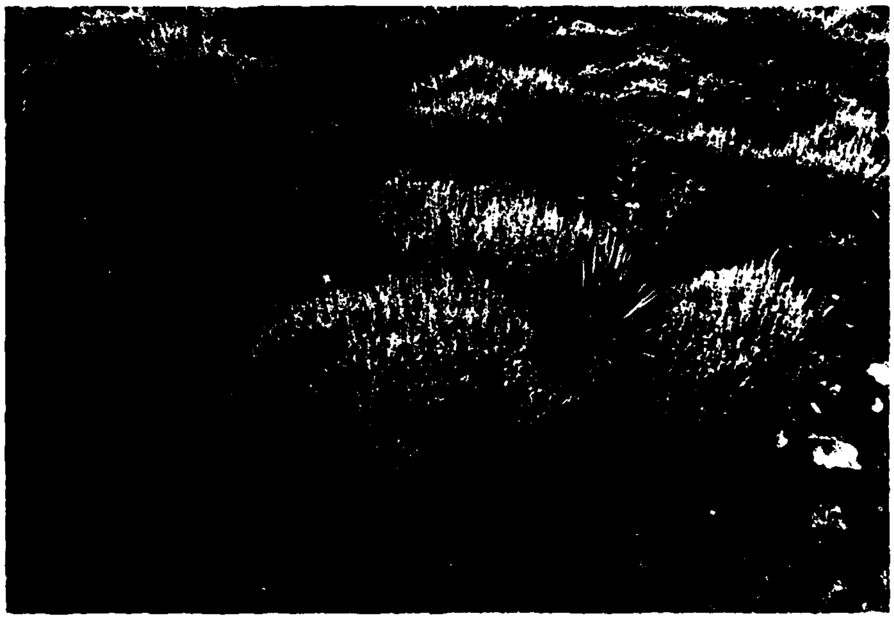
17. Historical rainfall. Site 1 near the southern boundary normally receives approximately 9-11 in. (23-28 cm) average annual rainfall; Site 2, near Camp Red Devil, receives an average of 12-13 in. (30-33 cm) of rainfall annually. Some rainfall did occur during both the April and August tests, which is reflected in the in situ moisture data presented above.

Instrumentation

18. The instrumentation for the April explosive tests was provided by the ASL and consisted of a multiwavelength transmissometer, eight Hi-Vol dust samplers (height 1.5 m, spaced 6 to 10 m apart), five nephelometers, a Knollenberg counter, a spectrophone, four Gelman vertical samplers (heights 2, 6, 11, 15 m) and 2- and 16-m meteorological towers containing sensors for measurements of wind speed, wind direction, air temperature, dew point, humidity, and solar radiation. Additional meteorological sensors were included on the 16-m tower at heights of 4 and 8 m. Meteorological sensor measurements were digitally recorded at 2-sec intervals. Figure 5a shows the layout and general

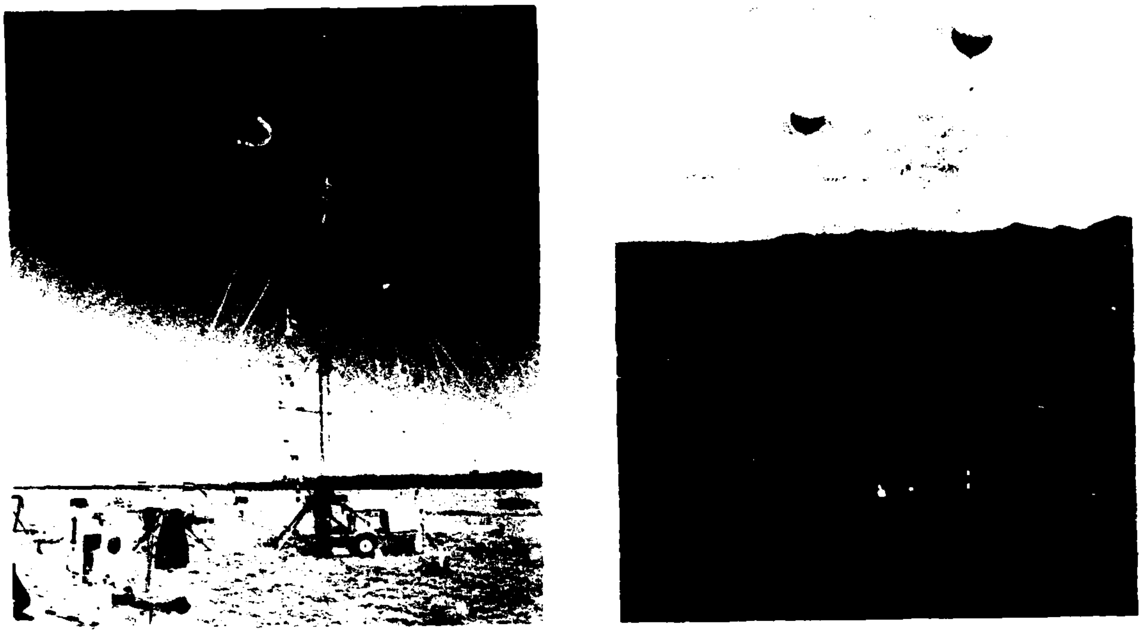


a. Site 1 (April tests)



b. Site 2 (August tests)

Figure 4. Ground cover of vegetation at Fort Carson test sites



a. Site 1 (April tests) b. Site 2 (August tests)

Figure 5. Instrumentation used for Fort Carson DOTs

ground-level view of the instrumentation. Further description of the instrumentation and calibration procedures is provided in Hoock (1983).

19. For the August tests, the instrumentation (Figure 5b) consisted of five Hi-Vol dust samplers (spaced 20 m apart and 2.5 m above ground), two tethered balloons each with four 47-mm polyvinyl chloride (PVC) vertical samplers located at heights of 1.5, 7.6, 15.2, and 22.9 m above the ground, and several meteorological sensors (wind speed, wind direction, air temperature, barometric pressure, relative humidity, and solar intensity) located at a height of 2 m. The instrumentation for Site 2 was provided by PEDCo Environmental, Inc., under contract to WES. The instrumentation and calibration procedures are described in PEDCo Environmental, Inc. (1984).

High-explosive tests

20. The high-explosive agent used for the tests was C-4 spherical charges in three different sizes: 7.5, 15, and 25 lb (3.4, 6.8, and 11.3 kg). Eight tests were conducted with 15- and 25-lb C-4 explosives. Figure 6 shows a typical dust cloud that resulted from a 15-lb charge detonated at Site 1 (April). The location for the point of burst (POB) was an important consideration for the tests. The POB for the April tests was determined by using the

onsite measured wind direction and speed data and the center (location of sampler 3) of the Hi-Vol sampler array. The actual POB was determined by using the direction from which the wind was blowing and selecting a distance from the Hi-Vol array that would allow representative measurement of the horizontal and vertical composition of the dust cloud. The POB distance ranged from 19-75 m for all of the April tests, but for the five tests described herein, the distances ranged between 35 and 72 m. The actual POB was different for each test. The POB distance range for the August tests (Site 2) was somewhat less (40-45 m).

Post-test terrain measurements

21. Measurements were made to describe the geometry of the resulting soil crater and the density and strength of the soil material within and adjacent to the crater. The geometry of the crater was determined by measuring, at 10-cm intervals, two surface terrain profiles, one east/west and the other north/south across the crater. Profile measurements were made to describe both the apparent top of loose soil material within the crater) and the true crater.

22. Soil density and CI measurements were obtained within and

a. Time, 0.1 sec

b. Time, 0.5 sec

c. Time, 1.0 sec

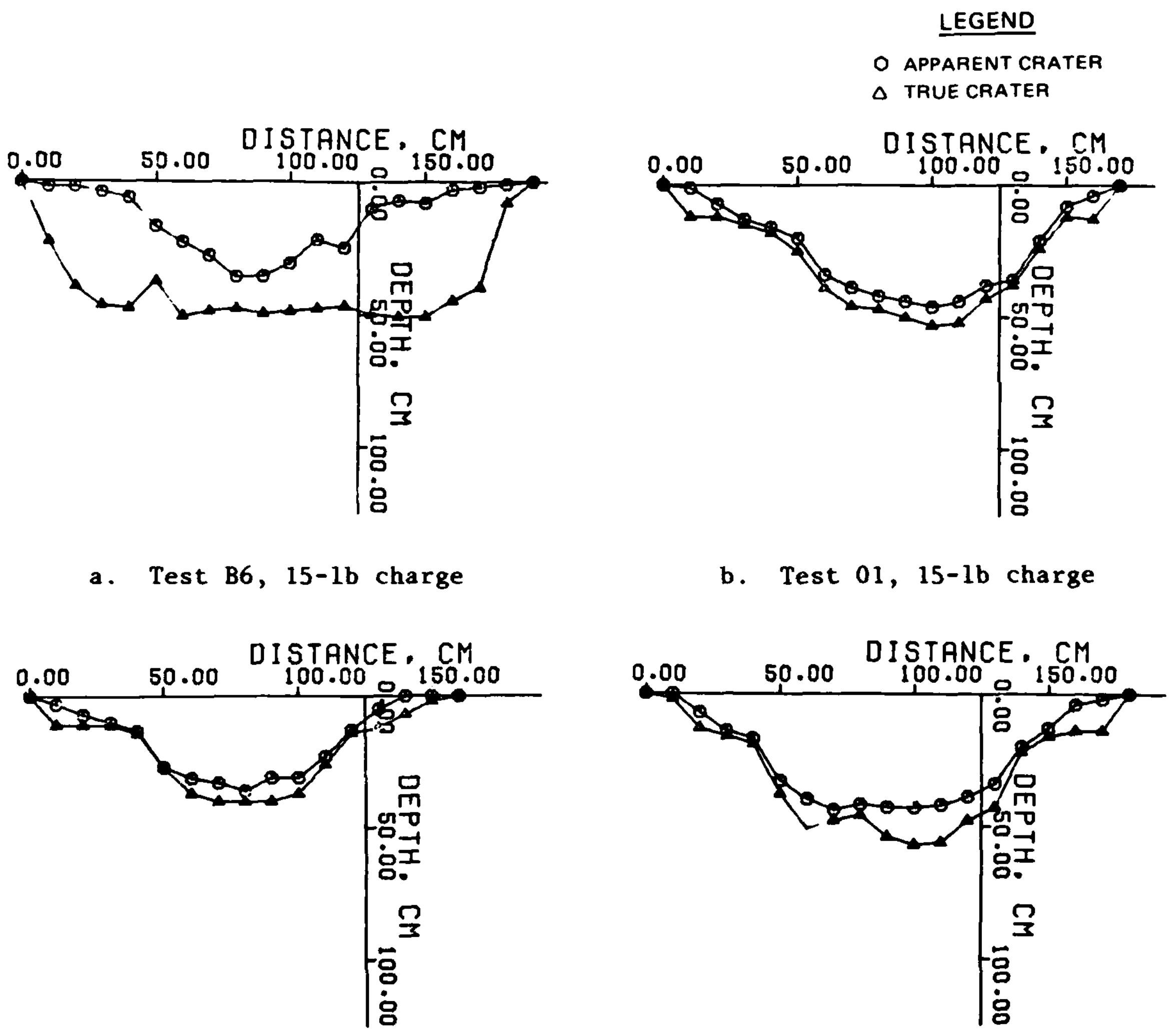
Figure 6. Dust cloud generated at Site 1 (April 1983) using a 15-lb C-4 charge

adjacent to the crater to determine the effects of the explosive shock wave on the in situ soil materials.

Data Analysis

Resulting soil craters and calculated volumes

23. Four of the eight soil craters resulting from the C-4 explosions are shown graphically in Figure 7. The soil crater data were then used to



a. Test B6, 15-lb charge

b. Test 01, 15-lb charge

c. Test 02, 15-lb charge

d. Test 03, 15-lb charge

Figure 7. North/south terrain surface profiles of apparent and true soil craters

calculate the volume of material that was removed and/or displaced during the high-explosive shock-wave event. The soil true and apparent crater volumes calculated using the Modified Simpson Rule Equation are given in Table 2.

Ground-based nephelometer sampler data

24. The nephelometer data for the ground-based samplers (presented as measured voltages) are presented in Figure 8. These plots are time histories of particulate accumulations that occurred during the passage of the dust clouds. Each curve represents the maximum particulate accumulation that was measured by any of the four ground-based nephelometers within the sampling array. Three of the plots (Figures 8b, 8c, and 8d) show dust particle accumulation due both to the blast or shock wave and the slower moving cloud. These data show maximum particulate accumulation ranging from 2.9 to 4.1 V for the five explosive-generated dust clouds. The maximum particulate accumulation occurred during a time from 4 sec to approximately 22 sec after detonation.

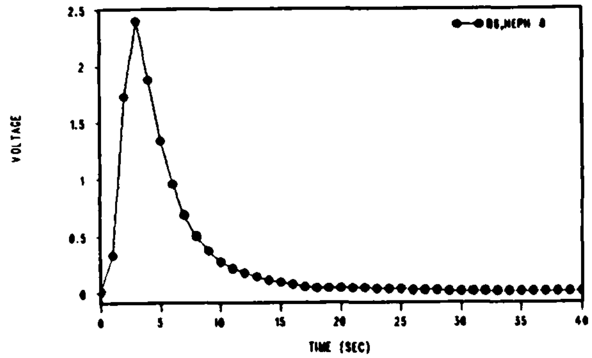
Comparison of soil craters
and TNT explosive sizes

25. The calculated apparent soil crater volumes resulting from the C-4 explosions placed on the ground surface at Fort Carson were compared with the volumes resulting from similar explosive tests conducted at Fort Polk, La., and White Sands Missile Range, N. Mex., as shown in Figure 9. These data in general show increasing apparent crater volumes with increasing explosive charge sizes (or masses) for charges between 2 and 14 kg of TNT.

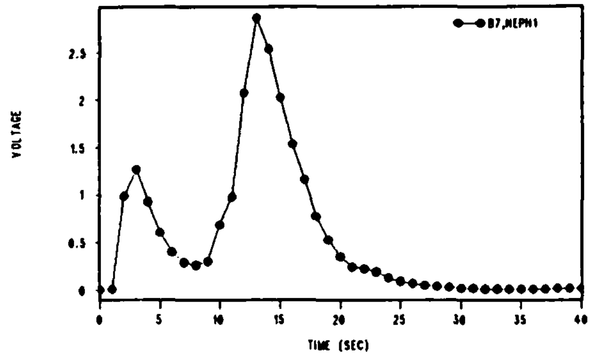
26. Relations between apparent crater volume and dust cloud size and concentrations have been established for some soil and environmental conditions and, therefore, relations between charge size, terrain parameters, and wind conditions are needed to allow analytical predictions of dust cloud potential for different geographical regions.

Tower-based nephelometer data

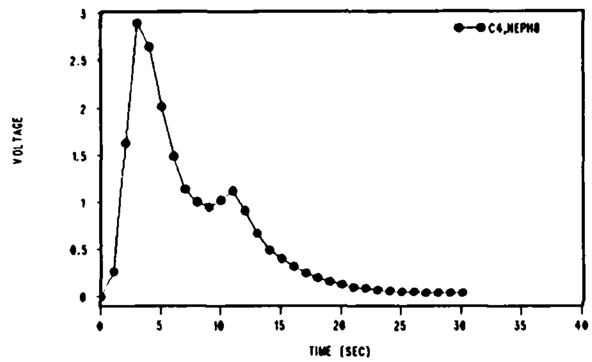
27. The nephelometer data obtained with the single sampler located at a tower height of 11.1 m are shown in Figure 10. These sampler data also show particulate accumulations due both to the shock wave (first peak) and the passing dust cloud (second peak). The maximum threshold voltage was insufficient to record the maximum particulate accumulations; however, these data are considered useful in terms of loading times and other cloud geometry characteristics. Figure 10e shows a third peak, probably representing a complexity in the cloud geometry.



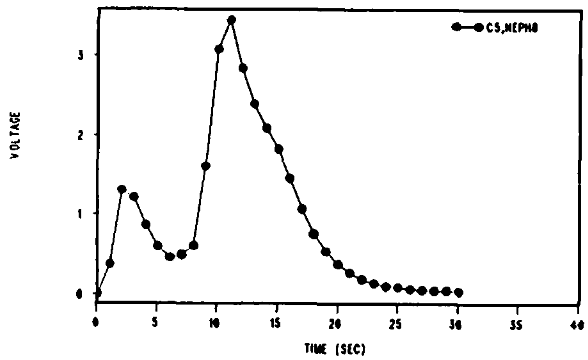
a. Test B6, Neph. 8



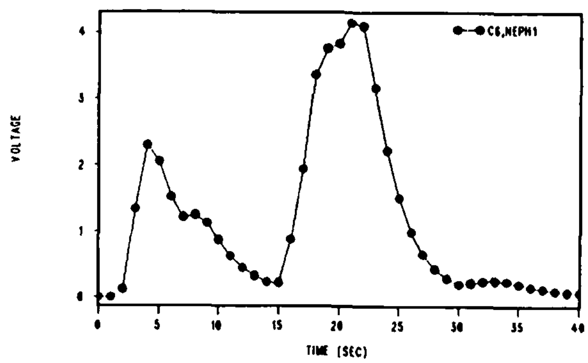
b. Test B7, Neph. 1



c. Test C4, Neph. 8



d. Test C5, Neph. 8



e. Test C6, Neph. 1

Figure 8. Time history of particulate masses collected by ground-based (1.5-m height) nephelometers, April tests

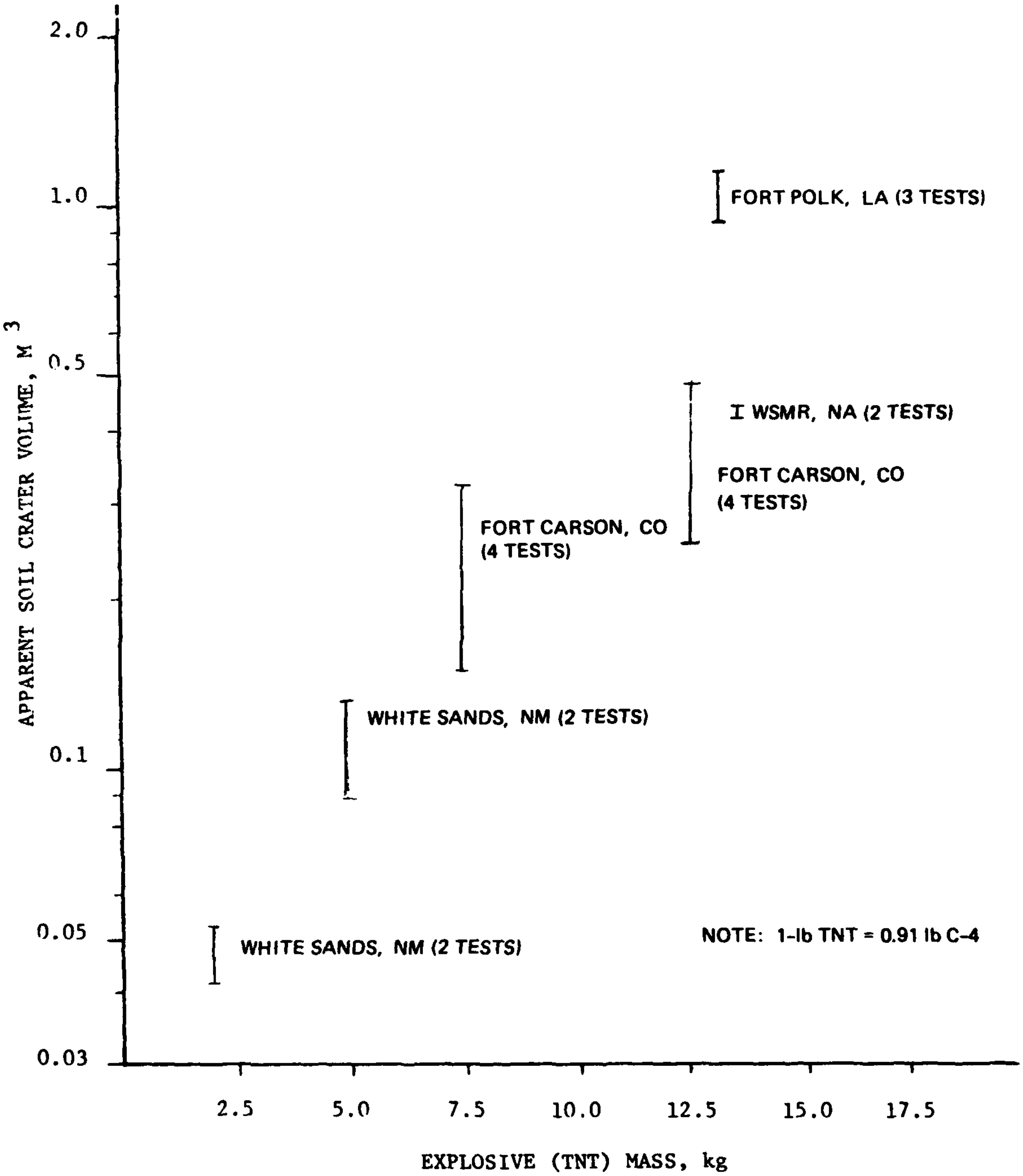
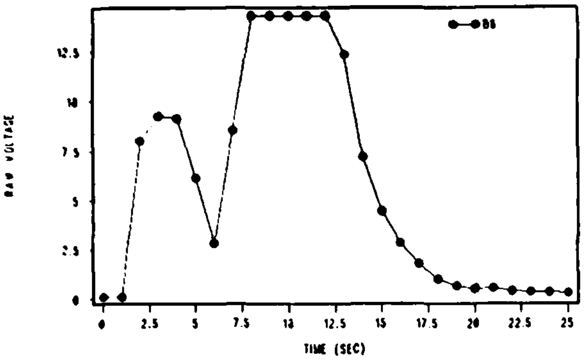
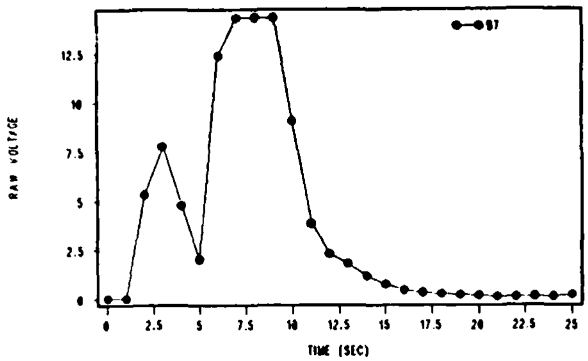


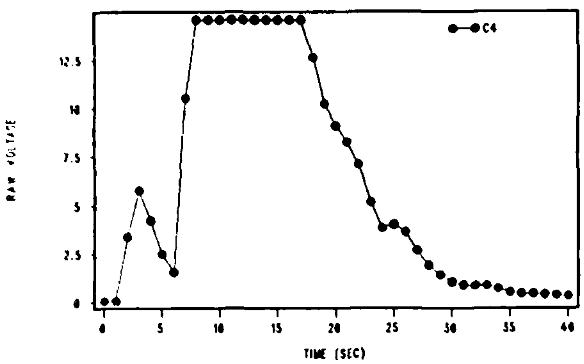
Figure 9. Comparison of apparent soil crater volumes resulting from high explosives at various test sites



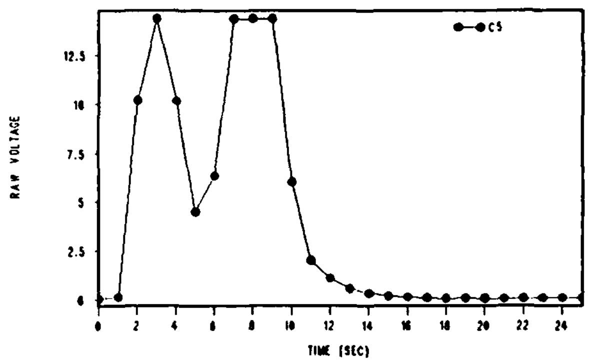
a. Test B6, neph. on tower



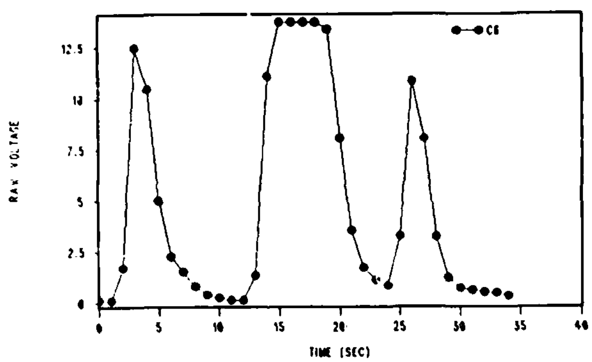
b. Test B7, neph. on tower



c. Test C4, neph. on tower



d. Test C5, neph. on tower



e. Test C6, neph. on tower

Figure 10. Time history of particulate masses collected by tower nephelometers (11.1 m above ground), April tests

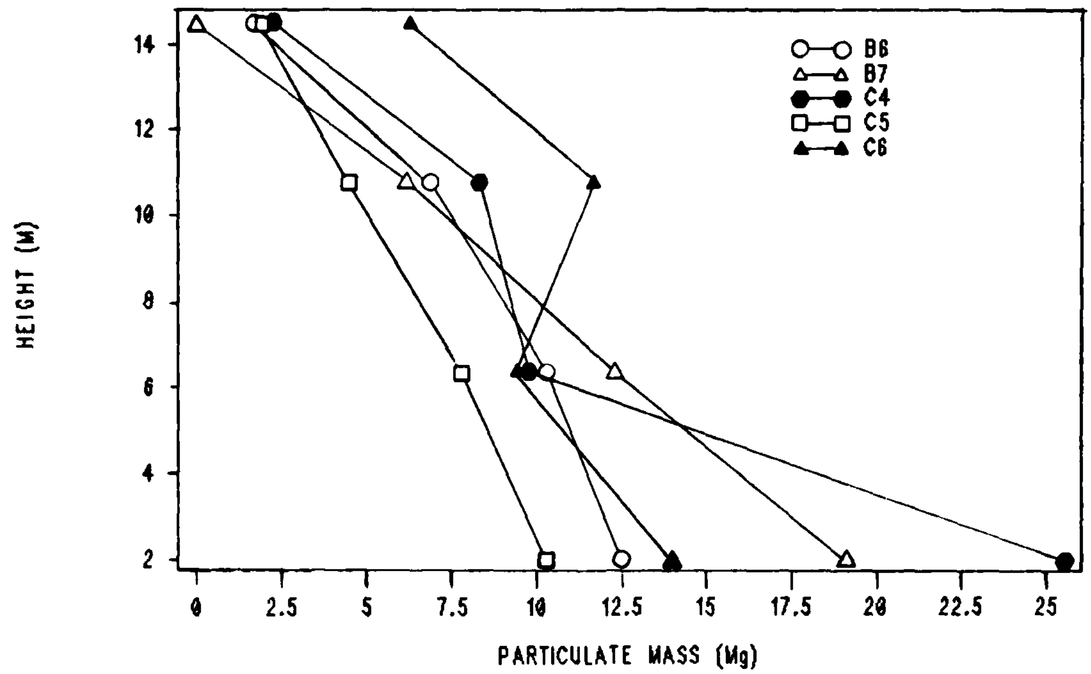


Figure 11. Particulate mass collected by Gelman sampler

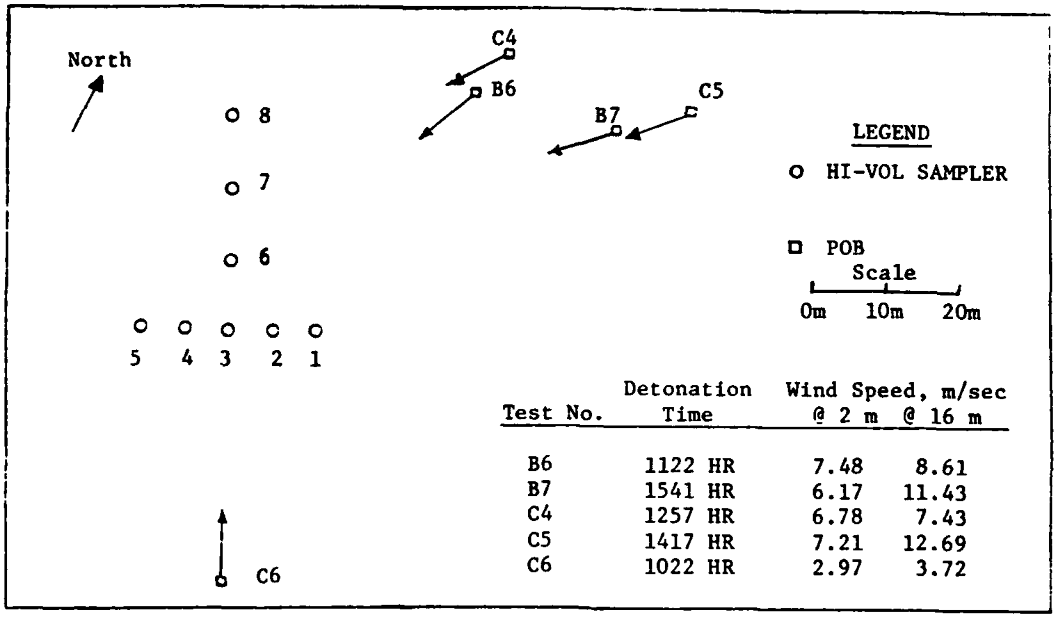
Tower-based Gelman data

28. The vertical component of the generated dust cloud was measured by Gelman samplers positioned at different heights on the tower (April tests) and PVC samplers at different heights on the two tethered balloons (August tests). The heights of the four Gelman samplers for the April tests were 2, 6.4, 10.8, and 14.5 m; for the August tests, heights were 1.5, 7.6, 15.2, and 22.9 m. The particulate mass data, as measured by the Gelman samplers for the five tests in April, are illustrated in Figure 11. Similar data were obtained for the August tests.

29. The Gelman samplers provide measurements of the cloud mass along the vertical dimension or profile. These data indicate the height of the dust cloud as it passed over the sampler array. For one test (Test C6, Figure 11), it is apparent that the dust cloud reached a height that was significantly greater than the height of the highest sampler.

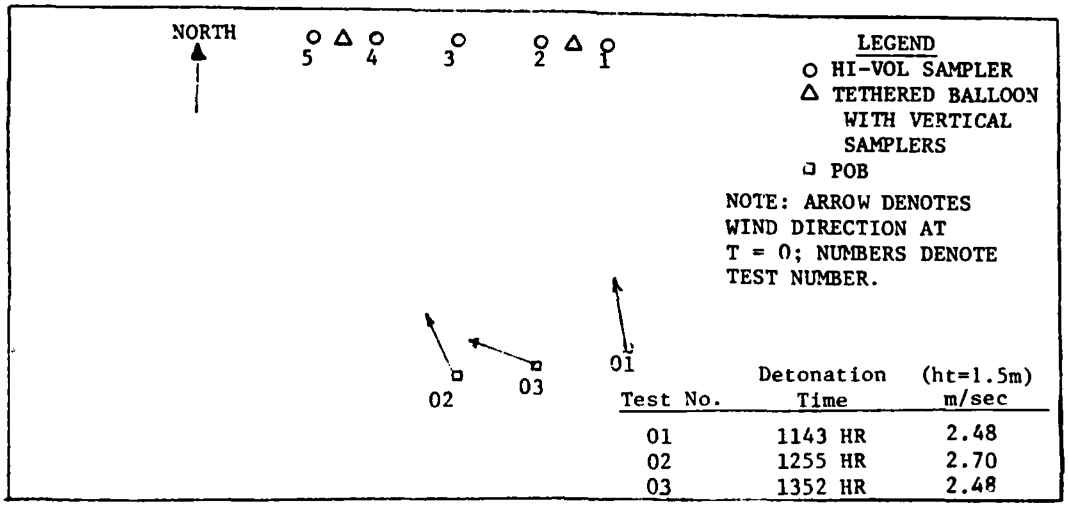
POBs and wind conditions

30. As stated earlier, the C-4 POB was determined by using the measured wind data just prior to detonation. Figure 12 depicts the POBs, wind data (speeds and directions) at the time of the C-4 detonation, and the locations



Test No.	Detonation Time	Wind Speed, m/sec @ 2 m	Wind Speed, m/sec @ 16 m
B6	1122 HR	7.48	8.61
B7	1541 HR	6.17	11.43
C4	1257 HR	6.78	7.43
C5	1417 HR	7.21	12.69
C6	1022 HR	2.97	3.72

a. Site 1, initial test conditions

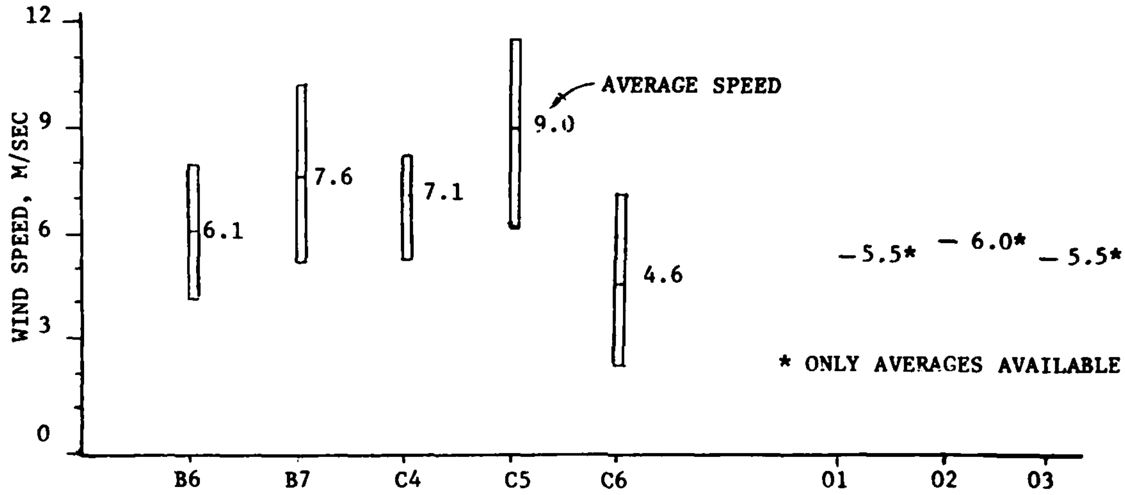


Test No.	Detonation Time	(ht=1.5m) m/sec
01	1143 HR	2.48
02	1255 HR	2.70
03	1352 HR	2.48

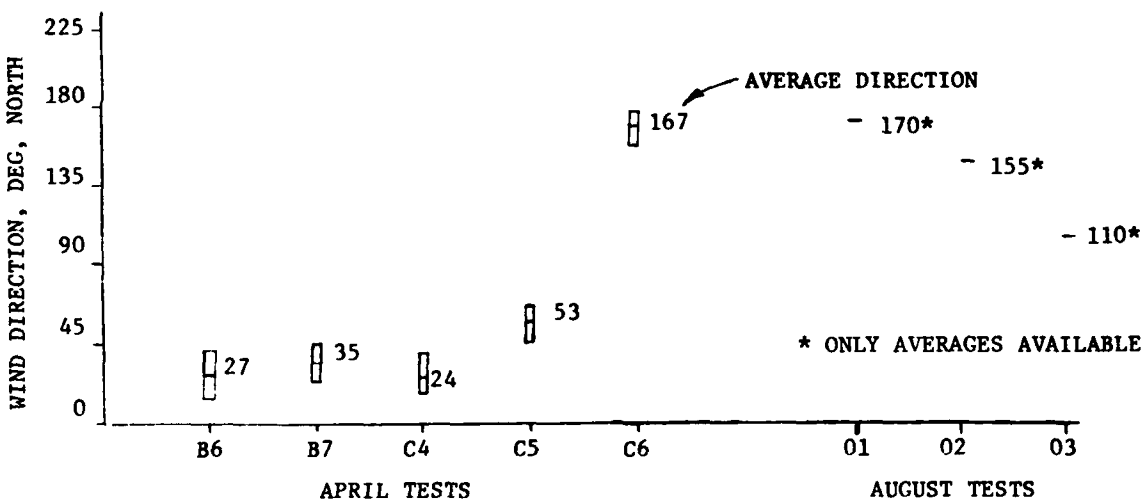
b. Site 2, initial test conditions

Figure 12. Locations of explosive POBs and Hi-Vol samplers and initial wind conditions

of the Hi-Vol dust samplers used for the April and August tests. Since the dust cloud event lasts several seconds and is affected significantly by the wind conditions, it was necessary to analyze the wind data to depict the variation in the speeds and direction during the time of the dust cloud development. Figure 13 depicts the minimum, maximum, and average values for the wind



a. Wind speed



b. Wind direction

Figure 13. Minimum, maximum, and average wind speeds and directions occurring during Fort Carson DOTs

speed and direction during each of the tests. It is noteworthy that these data show significant wind variations at both sites during the tests.

31. The eight high-explosive tests described in this paper are the ones in which a large portion of the generated dust cloud passed over the Hi-Vol sampler array. Other high-explosive dust tests conducted at Fort Carson are

described in Hoock (1983), PEDCo Environmental, Inc. (1984), and Mason and Long (1983).

Determination of dust cloud path and size

32. In support of the DOT, it was not possible to measure the actual three-dimensional path and size of the generated dust cloud, although color and black-and-white 35mm, 16mm, and video coverage were acquired during each test. Figure 6 shows a series of 35mm scenes of a developing dust cloud as a function of time from detonation. Since the three-dimensional geometry of the dust cloud is considered important to the interpretation of the test results, computer software was developed to provide an "estimation" of the path and the diameter of the horizontal component of the cloud. This procedure consists of two parts and is described below.

33. XY path of dust cloud. The path was predicted using the wind speed and wind direction data for each 2 sec of time during the dynamic dust event, starting with the initial POB. Calculations were made of the horizontal distance of travel between each 2-sec time interval, and the cloud was assumed to move at a uniform speed during those 2 sec in the direction that the wind was blowing at the beginning of the interval. Figure 14 shows the predicted XY paths for the five tests conducted in April at Site 1 in relation to the XY locations of the Hi-Vol dust samplers. Each point along the path represents the XY coordinate that was calculated for each respective 2-sec time interval.

34. Size of dust cloud. The size, i.e., horizontal diameter of the dust cloud, was also predicted using a procedure that consisted of calculating one standard deviation cloud radius value for each predicted XY point along the generated path that was dependent upon an experimentally derived Pasquill (Hanna, Briggs, and Hosker 1982) stability categories likely to occur during the daytime with wind speed classes of <2 m/sec, 2-4 m/sec, 4-6 m/sec, and >6 m/sec. The one standard deviation values for each 2-sec time period were computed by the following equation:

$$\sigma = ax^b$$

where

σ = one standard deviation radius of horizontal diameter of dust cloud at a straight-line distance X from POB

a and b = parameters determined by the four wind categories listed above

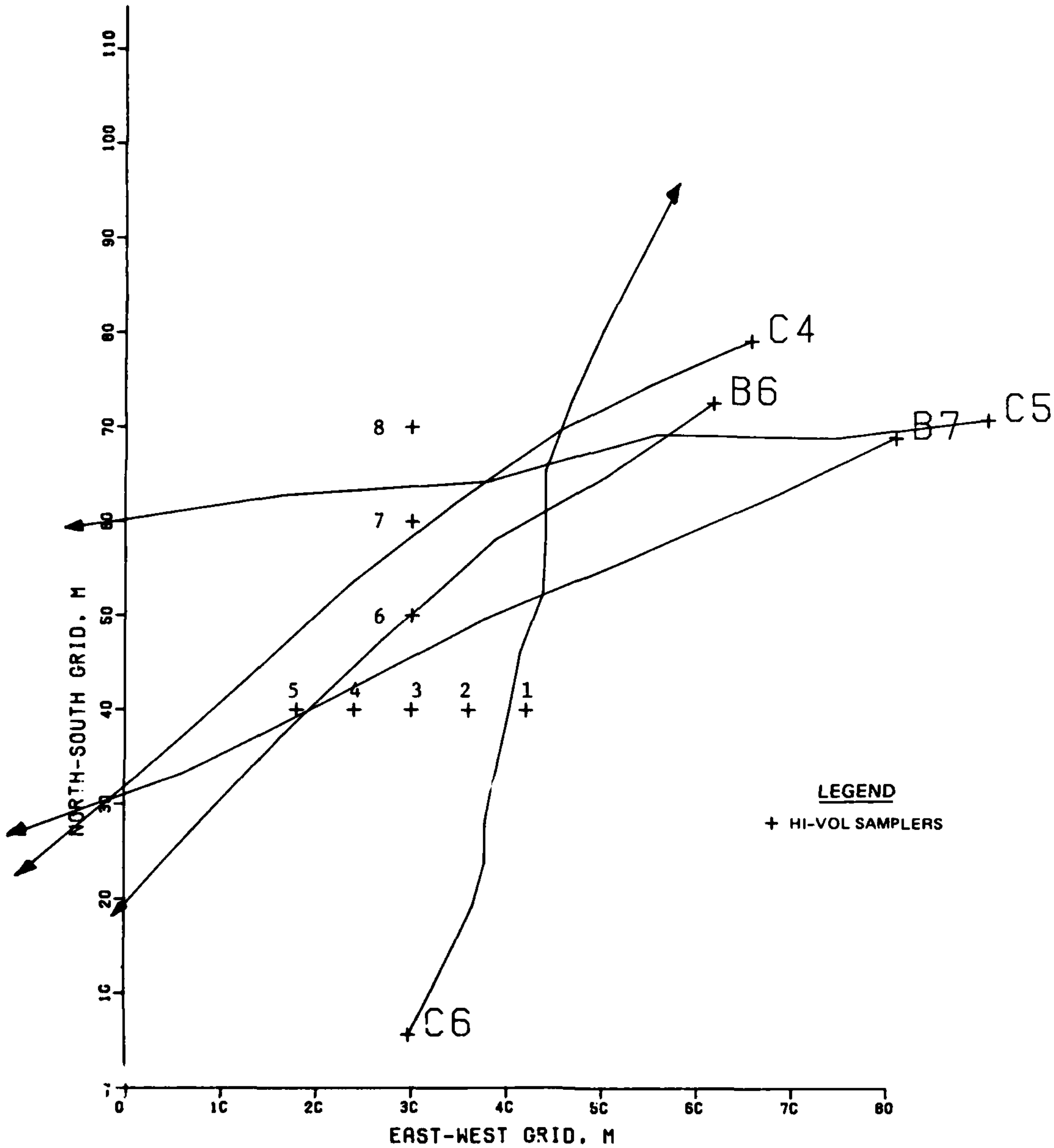
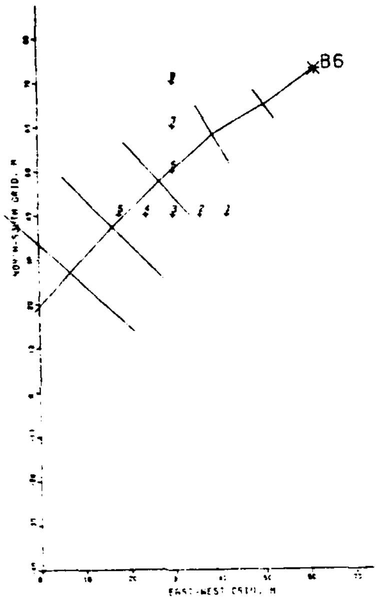


Figure 14. Predicted XY paths of dust cloud for five tests in April

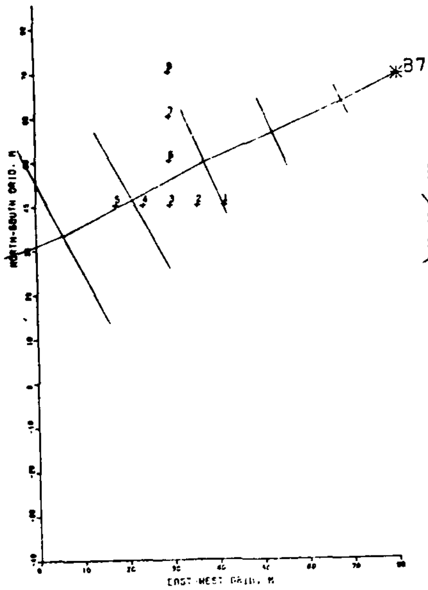
x = horizontal distance from the POB along the path to the point where σ is to be calculated

Using the above procedure, the predicted horizontal diameters of the five dust clouds were calculated and plotted in relation to the location of a Hi-Vol sampler array (and the Gelman vertical samplers), as shown in Figure 15.

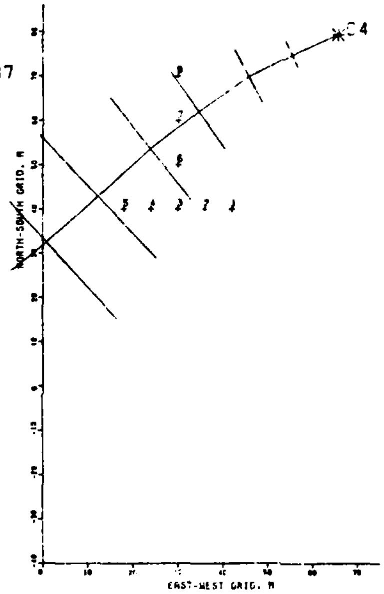
35. Dust cloud mass loading. The relative sample masses for each of the eight tests are illustrated in Figures 16 and 17. In this representation, the



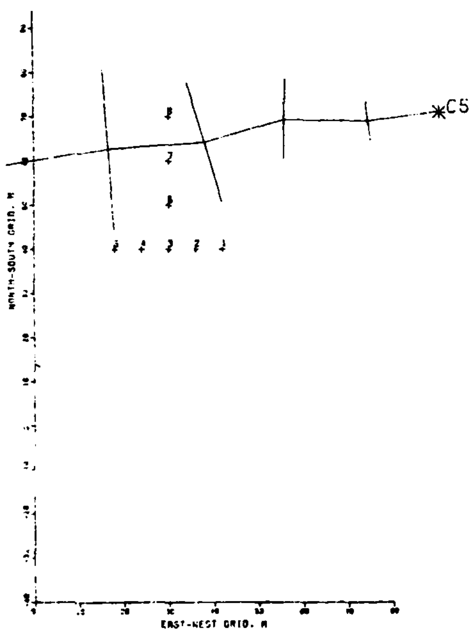
a. Test B6



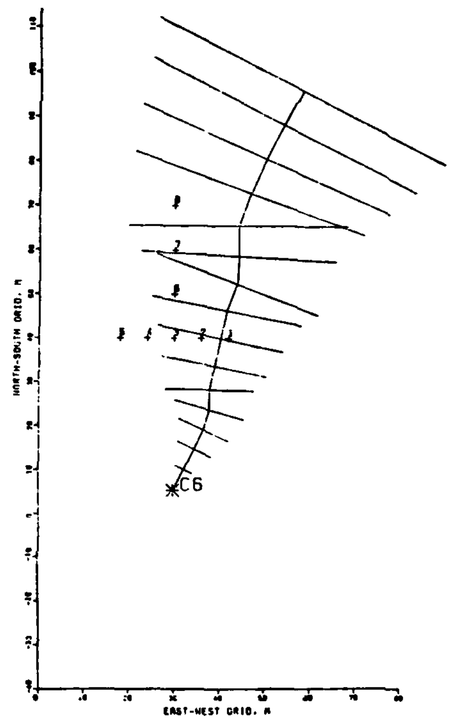
b. Test B7



c. Test C4

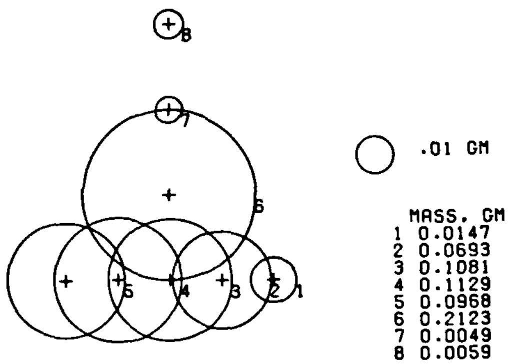


d. Test C5

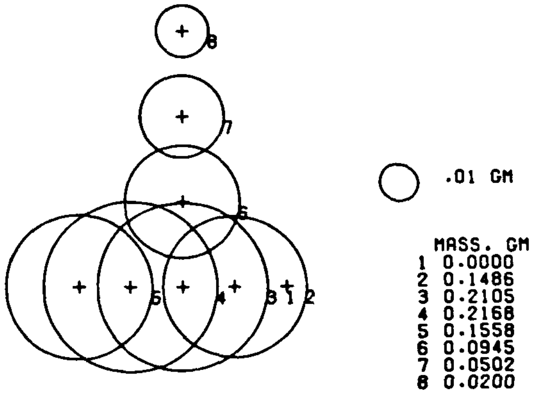


e. Test C6

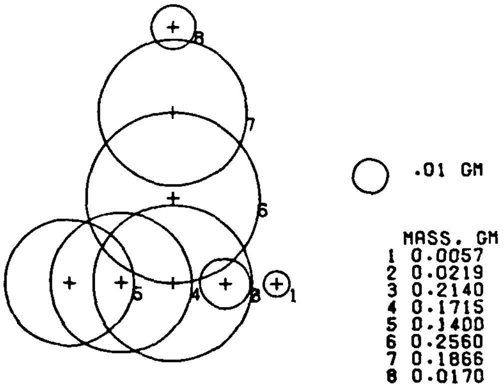
Figure 15. Plot of predicted XY cloud path and diameters



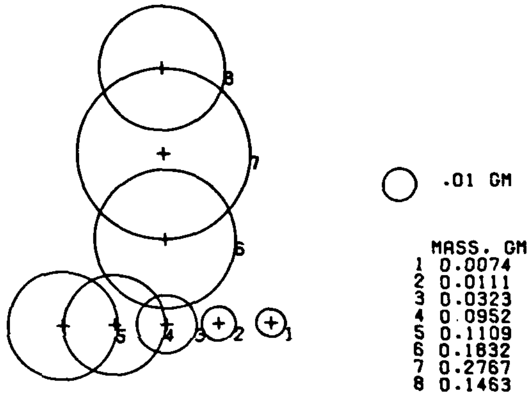
a. Test B6, 15-lb charge



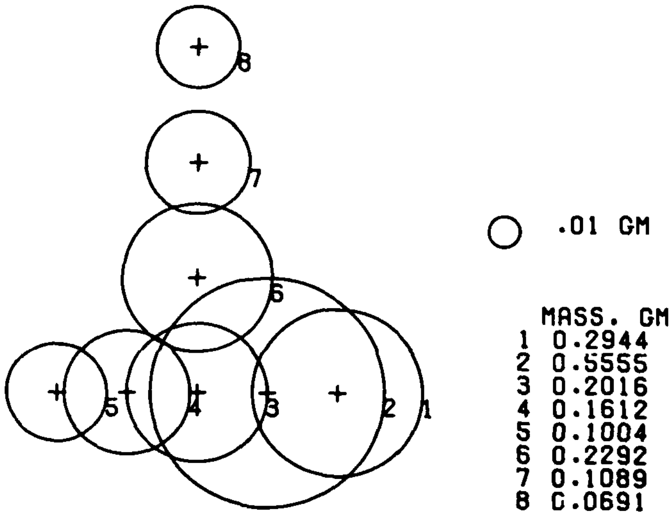
b. Test B7, 15-lb charge



c. Test C4, 25-lb charge

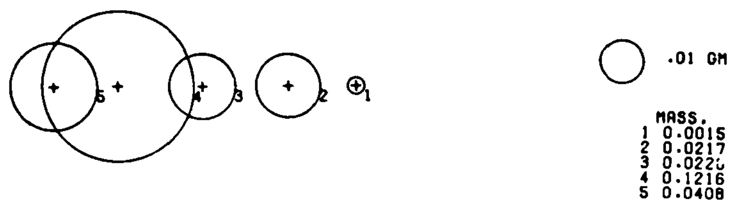


d. Test C5, 25-lb charge

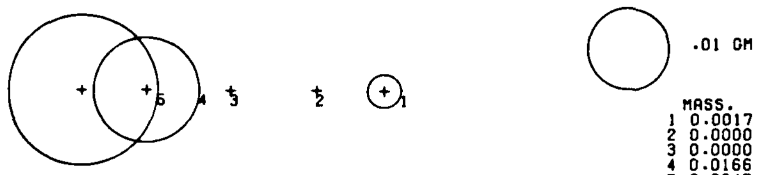


e. Test C6, 25-lb charge

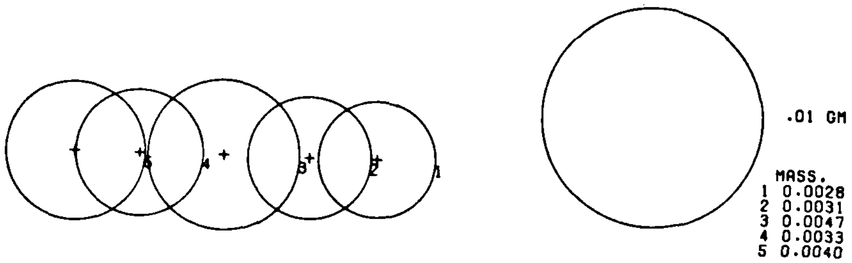
Figure 16. Particulate masses measured by Hi-Vol samplers, April tests



a. Test 01, 15-lb charge



b. Test 02, 15-lb charge



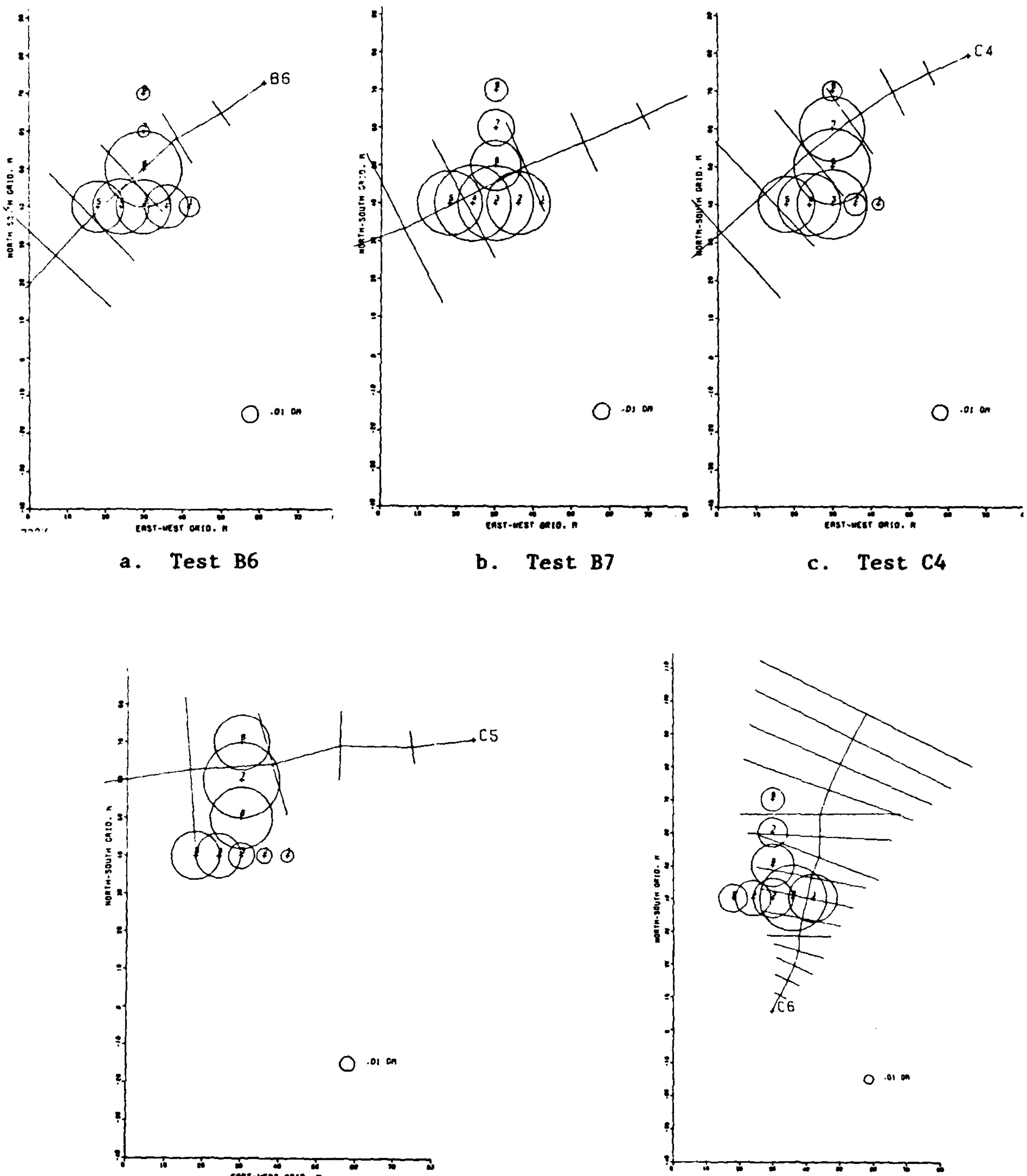
c. Test 03, 25-lb charge

Figure 17. Particulate masses measured by ground-based Hi-Vol samplers, August tests

areas of the circles are proportional to the masses collected. The unit area corresponding to 0.01 g is shown in each case for reference. When combined with the tracks and Gaussian plume widths of the clouds as computed from 2-sec interval surface wind data (Figure 18), the integrity of this sampling method can be seen. The agreement between cloud track and sample sizes is remarkable.

36. Not only is the cloud width evident in the sample results, but also in the decay with time. Those samplers nearer the POB (in time) generally obtained the larger samples. The time interval along the track may be determined by counting 2 sec for each crossbar. Thus, test C-4 arrived at the array in 7 sec while C-6 required 14 sec.

37. <u>Cloud mass computation</u>. Total cloud mass is computed by assuming that the cloud disperses as a Gaussian plume in the horizontal plane.



a. Test B6 b. Test B7 c. Test C4

d. Test C5 e. Test C6

Figure 18. Plot of predicted XY cloud path and diameters and particulate mass measurements made with Hi-Vol samplers

Dispersion in the vertical is complicated by the buoyant rise of the cloud and gravitational settling of the particles. To describe it, the samples collected on the tower (Figure 5) are considered. A two-dimensional Gaussian envelope is fitted to the surface array data to describe a horizontal slice through the cloud. Assuming cloud density to be symmetrical about the vertical axis, a single integration of the Gaussian envelope suffices to yield a total mass for the slice. Using the tower data to establish the vertical distribution and integrating over it yields total cloud mass.

38. Total cloud masses are presented in the bar graph of Figure 19 as computed by the ASL for the April data and by PEDCo Environmental, Inc., for the August data. In general, a trend is evident toward larger masses for larger yields, as would be expected, but the variance exhibited in this small sample makes further analysis difficult. The low value for C-6 is considered anomalous and does not seem to be consistent with sampled results. That test was conducted at much lower wind speeds than the others, and a further examination of its data is in progress. Test C-5 cannot be explained in this way, nor is an anomaly evident in the tower data (to indicate that it went above the samplers). Some other explanation may be indicated--possibly in the soil data. It must be remembered, however, that because of the variability of the winds and of cloud dynamics, no single example should be scrutinized too closely. The data presented in Figure 19 comprise a very small statistical sampling.

39. If it is assumed that the cloud mass computations from the two sites are equally valid, then Figure 19 suggests slightly greater dust loading at Site 2. Since the soils were similar in size distribution and moisture content, other differences are considered. The principal differences between the sites were:

Site 1	Site 2
South-facing slope	North-facing slope
Red-colored soil	Light tan- to gray-colored soil
Predominant grasslike vegetation	Predominant forbs

40. The vegetation seems to provide the most significant difference. A comparison of root structures was not made, but the amount of matter above the surface was denser at Site 2, which could contribute to increased debris loads. Surface coverage was about 70 percent at both sites, but the short grass at

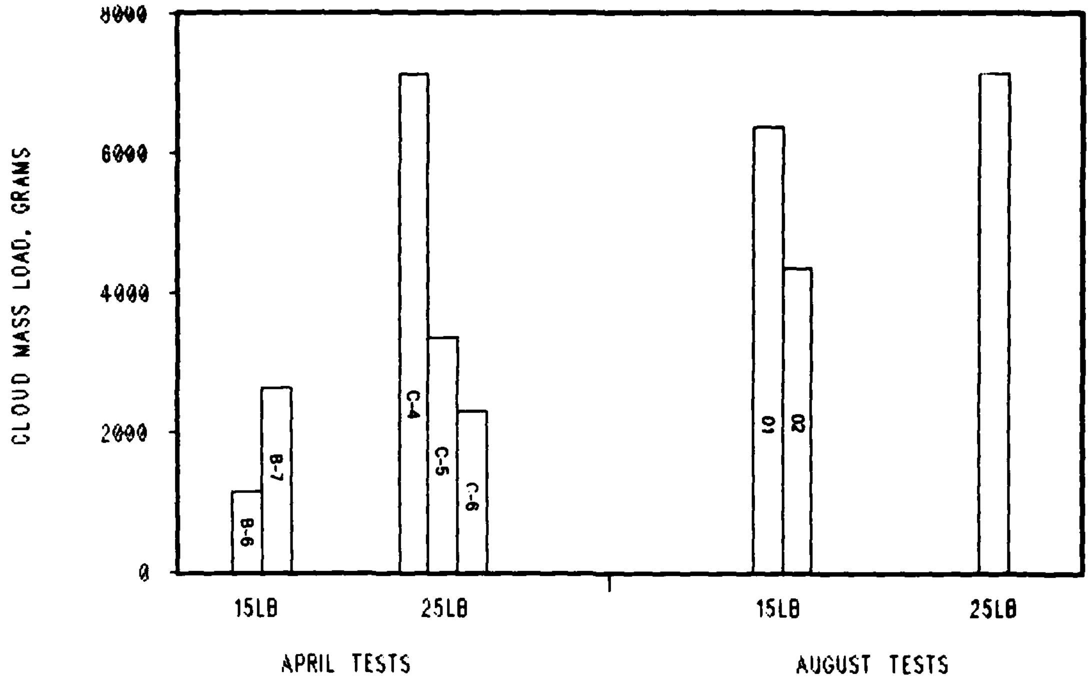


Figure 19. Calculated cloud masses

Site 1 tended to occur in clumps with intermingled root structure that could serve to impede upward movement of dust. There is currently a need for more evidence and more analysis of existing data regarding vegetation effects.

Conclusions

41. The principal objective of the explosive DOT exercise, which was to demonstrate the effectiveness of using crater volumes to predict dust cloud mass, was accomplished. The volume of apparent crater was found not to correlate with cloud mass for the conditions and charge yields tested. When volume corrections were applied to account for compaction, a slight improvement was noted. The best volumetric correlations with dust mass were those of the true crater and of the flowage, but both were only marginally significant.

42. The most significant correlations were obtained between true volume and soil density and between true volume and charge yield. Since dust cloud mass is expected to correlate with yield, the mass-volume correlations observed here are considered secondary.

43. Moisture content was not sufficiently varied at the two sites to

provide meaningful correlations with dust masses, and even soil properties proved to be more similar than originally expected on the basis of field inspection. Grain sizes and percentage of fines proved not to vary significantly between the sites. Mineral content and cone index were the most significant variants; however, an analysis of these data is not yet complete.

44. Perhaps the most significant result of the test was to demonstrate the difficulty of obtaining accurate measurements of dust cloud mass for explosive events. The procedure used was based on extensive and redundant sampling, and innovative field procedures were used to allow for wind variability. In spite of these procedures, only about 20 percent of the tests yielded measurements with adequate confidence figures. The comparisons of cloud tracks as derived from 2-sec wind data and the cumulative mass samples obtained by the sample array were in surprisingly good agreement. Relative sample sizes within the array coincide well with computed cloud positions for single events. Comparison among events was less satisfactory. Likewise, indications of cloud dispersion based on wind computations appear to have been consistent with sampled masses. However, computations of overall cloud masses did not reflect this consistency, and it is not clear at this time whether the difficulty lies in the sampling method or the cloud mass computation. It is clear that accurate and repeatable measurements of such transient dust events require serious, dedicated, and generally expensive effort. Finally, the effects of vegetation, which have generally been excluded, may warrant more careful consideration. Future tests should provide more detailed characterization and measurement of vegetation and moisture content, under a wider range of conditions.

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Table 1

Soil Data for High-Explosive DOT Tests

Date of Test	Test No.	Soil Characteristics: Wet Density g/cc	Soil Characteristics: Average Moisture Content, %	Average Cone Index at Depth, cm: Surface	7.5	15	30
Apr 83	B6	1.38	13.1	25	175	150	325
Apr 83	B7	1.28	11.8	50	400	500	225
Apr 83	C4	1.36	13.5	153	250	375	425
Apr 83	C5	1.23	12.7	25	175	187	150
Apr 83	C6	1.34	--	67	242	275	317
Aug 83	01	1.71	11.6	42	375	375	633
Aug 83	02	1.94	17.5	67	292	450	750
Aug 83	03	1.93	13.2	42	400	633	750

Table 2

Soil Crater Characteristics

DOT Site No.	Test No.	Maximum Depth, cm	Maximum Diameter cm	True Volume m^3	Apparent Volume m^3	Charge Weight, lb*
April						
1	B6	50	210	1.26	0.23	15
1	B7	65	150	0.84	0.23	15
1	C4	59	173	0.80	0.31	25
1	C5	72	200	1.30	0.56	25
1	C6	--	--	1.28	0.48	25
August						
2	01	53	170	0.43	0.32	15
2	02	40	190	0.25	0.19	15
2	03	51	190	0.52	0.39	25

* To convert pounds (mass) to kilograms, multiply by 0.4535924.

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