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SUMMARY REPORT — PROJECT ROWBOAT

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Bruce Myers

October 5, 1964

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ABSTRACT

Rowboat was a high-explosive row-charge cratering experiment in desert alluvium. Its purpose was to study the effects of depth of burial and charge separation on crater dimensions. The experiment utilized 278-lb charges placed in a row and buried at equal depths and with equal separations. A total of eight linear craters were produced; four configurations were tested, with one repeat of each array to test reproducibility.

The first two shots used optimum depth of burst and charge separation as predicted from single-crater theory. The shots produced similar craters which were the largest formed in Rowboat. The half-widths and depths of these craters were the only ones to scale with single-crater data. Shots 3 and 4 used optimum depth of burst, but the largest feasible charge separation. These shots produced smaller but similar craters with the expected saddles between shot points. Shots 5 and 6 tested the extreme end of the single-crater depth-of-burst curve with optimum charge separation. This depth of burst proved to be too large to produce even a recognizable crater. Shot 6 reduced the number of charges to three to test the effects of reduced row number. No significant change in crater cross-section dimensions resulted from the reduced row number. Shots 7 and 8 tested the intermediate depth of burst and charge separation. These shots produced craters that scaled somewhat below the single-crater data, indicating a sharper decline of linear cross-section dimensions with increased depth of burst than for the single craters. Shots 7 and 8 had single "normalizing" charges far removed from the ends of the linear array. The depths of the single craters formed by these shots compared well with the prevailing single-crater data. The radius of single crater 7 agreed with prevailing data, but that of shot 8 was higher than even the scatter of the data at this depth of burst.

Support studies included surface motion photography, surface throwout measurements, and seismic measurements. The throwout measurements verified that very little throwout occurs at the ends of linear craters. They also showed the absence of uniform range dependence of the amount of throwout material deposited at the sides of the Rowboat craters. Studies of surface-motion photographs showed the peak velocities of ground zero surface and their related negative accelerations to be sharp functions of depth of burst. Large vents in several of the surface domes did not affect the surface velocities or the final craters formed.

1. INTRODUCTION

A major part of the Plowshare Program is devoted to development of nuclear cratering theory. Of particular interest is the application of nuclear cratering to the production of canals and waterways. To this end there has been considerable study of scaling parameters applicable to linear nuclear cratering. Earlier linear cratering experiments with chemical explosives at shallow depths of burst had shown that uniform canals can be formed by simultaneous detonations of linear charge arrays.^{1,2} Rowboat was an experimental program to test these parameters in Area 10 desert alluvium at the Nevada Test Site. The two parameters of interest were the scaled depth of burst and the charge separation. The experiment consisted of eight detonations of linear arrays. Each array consisted of four spherical charges weighing 278 lb each, which were detonated simultaneously.

One important consideration in nuclear cratering projects is the degree of containment of the radioactivity. Single-charge nuclear detonations have indeed shown that radioactivity containment for large scaled depths of burst is sufficient to render nuclear cratering safe. The primary concern of Rowboat was to investigate the linear crater dimensions for these large depths of burst.

An important and unique parameter in linear cratering is the scaled charge separation. Charges placed too far apart produce a cusping that results in "saddles" between detonation points. If the charges are placed closer than necessary, the explosive energy is not efficiently utilized for crater production. In Rowboat minimum and maximum charge separations were tested. When one considers that operational costs and radioactivity production are inversely proportional to the charge separation, the importance of this parameter becomes obvious.

A third consideration is the reproducibility of results in a given medium. Firing a second shot for a given array was made contingent on the results of the first shot; each array that produced measurable results was repeated.

Technical studies included crater surveys, throwout measurements, surface-motion photography, and close-in seismic measurements. The "end effect" (absence of throwout at the ends of linear-charge detonations) noted in earlier row craters was of special interest in the throwout measurements. High-speed and normal-speed movies were made of mound formation and dust cloud motion. Close-in seismic measurements within the end quadrants were made to measure the variations in the surface motion as a function of the angle between the axis of the array and the line of measurement.

While many other linear cratering studies had been performed before Rowboat, they were at shallow depths of burst and in different media from alluvium. The results of these studies, along with the well-known single-crater theory for alluvium, were used in planning the experiment.

Background

Depth of Burst

Crater size and degree of radioactivity containment are the two most important considerations in selecting depths of burial for nuclear linear cratering shots. Nuclear cratering experiments have shown the percent of radioactive containment to be a strong function of the ratio of depth of burst to apparent crater depth. (See Fig. 1.1).³ Plowshare is interested in obtaining greater than 90% radioactivity containment in any cratering detonation. A minimum depth ratio of 2 corresponds to a containment of about 95% and defines the minimum depth of burst used in the Rowboat series.

Figures 1.2 and 1.3 are curves representing the scaled depths and radii as functions of the scaled depth of burst for single craters in Area 10 desert alluvium. These plots were used with the radioactivity containment requirement (95%) to select a minimum depth of burst for Rowboat. From Fig. 1.2 we see that a scaled depth of burst of $167 \text{ ft/kt}^{1/3.4}$ produces a crater depth of $84 \text{ ft/kt}^{1/3.4}$, which gives a depth ratio of 2.

Figures 1.2 and 1.3 show this depth of burst to be in the range near optimum crater size production. The first four arrays were used to test this depth of burst with minimum and maximum charge separations. For the next

Fig. 1.1. Activity partition.

Fig. 1.2. Apparent crater depth vs depth of burst for Nevada desert alluvium.

Fig. 1.3. Apparent crater radii vs depth of burst for Nevada desert alluvium.

two arrays the depth of burst was increased by 50% to $247 \text{ ft/kt}^{1/3.4}$. Thus, the maximum depth of burst tested in Rowboat was used in conjunction with the minimum depth of burst tested in Rowboat. When these produced a crater too small to measure reasonably, an intermediate depth of burst of $208 \text{ ft/kt}^{1/3.4}$ was chosen for Shots 7 and 8.

Spacing

The spacing between charges is as important as the depth of burst for the production of uniform linear craters. Results from earlier work^{1,2} indicated a charge separation equal to or less than the maximum single-charge radius expected for a given scaled depth of burst would produce a linear crater with uniform width and depth. This criterion is not expected to apply to depths of burst so shallow that the overburden provides inadequate containment to allow charge interaction. Nor does it apply to charges buried too deeply to have the energy required to break and throw out sufficient overburden to form a canal.

Here again the single-crater theory was used to find a linear cratering parameter. Figure 1.3 shows crater radii as a function of depth of burst for single-charge craters in desert alluvium. Although this curve shows a maximum scaled radius of $190 \text{ ft/kt}^{1/3.4}$, this value was rounded off to $200 \text{ ft/kt}^{1/3.4}$ for the minimum charge separation used in Rowboat. This spacing was used for a pair of shots at the minimum depth of burst and a pair at the maximum depth of burst shots: 1 and 2 and 5 and 6, respectively. The maximum scaled charge separation was chosen to be 50% greater than the minimum value of $200 \text{ ft/kt}^{1/3.4}$. This scaled charge separation of $300 \text{ ft/kt}^{1/3.4}$ was tested in shots 3 and 4 at the minimum depth of burst. This separation proved to be too large to produce a crater even at the minimum depth of burst and was reduced to $250 \text{ ft/kt}^{1/3.4}$ with a depth of burst of $247 \text{ ft/kt}^{1/3.4}$ for shots 7 and 8. Single normalizing shots were detonated some distance from the ends of shots 7 and 8. Table 1.1 lists the parameters used for the eight arrays tested in Rowboat.

Table 1.1. Shot array.

Shot	Date	DOB (ft)	Charge separation (ft)	Scaled DOB (ft/kt ^{1/3.4})	Scaled charge separation (ft/kt ^{1/3.4})
1	6-2-61	11.9	14.3	167	200
2	6-5-61	11.9	14.3	167	200
3	6-13-61	11.9	21.4	167	300
4	6-15-61	11.9	21.4	167	300
5	6-20-61	17.8	14.3	249	200
6	6-22-61	17.8	14.3	249	200
7 ^a	6-26-61	14.9	17.9	208	250
8 ^a	6-28-61	14.9	17.9	208	250

^a Shots 7 and 8 included a single normalizing charge detonated 80 ft from the end of each array.

2. PROCEDURE

Site

Location and Geology

The Rowboat series was detonated at the Nevada Test Site in Area 10 desert alluvium. Figure 2.1 shows the exact location. The site is near the northern end of a broad basin rimmed by a system of mountain ranges that rise to elevations of 2000-4000 ft above the valley floor. Local topography exhibits a 0-5% grade, draining west to southwest. A mile to the east the Banded Mountains, containing both sedimentary and volcanic rocks, rise steeply. A fault striking north-south crosses the valley about 1 mile west of the area and is evidenced by a well-defined scarp. A geologic sketch of this part of the valley is presented in Fig. 2.2. The valley fill at the site is in excess of 1000 ft of alluvial deposits that exhibit a wide variety of texture and sorting. Locally, dry, well-consolidated sand, containing some silt and gravel forms a white-to-tan surface layer, 1 to 3 ft thick. When sufficiently disturbed, it becomes floury and readily windborne. Local vegetation includes sagebrush, various grasses, and occasional Yucca cactus.

Soil tests exhibit almost no plastic range and a substantial portion passes No. 100 sieve. In-place densities run between 1.5-1.6 g/cc. Below

GEOLOGIC SKETCH OF ROWBOAT AREA

Fig. 2.2. Geologic sketch of Rowboat area.

the surface layer "caliche" exists as a slight to well-cemented gravelly bed, white to gray, multilayered, well jointed, and up to several feet thick. Occasional humus striae occur separating lenses as thin as 1/2 in. This "caliche" overlies several feet of fine silty sand, tan to red brown, containing some gravel, and exhibiting the first substantial moisture content encountered, (5 to 8%). These three layers are readily found and identified at nearly all vertical exposures near this site. In addition, occasional lenses and pockets of well- to poorly-sorted, fine to coarse gravels occur at random and locally may completely displace any of the generally pervading layers.

Shallow seismic refraction surveys reveal surface layer velocities generally less than 1000 ft/sec. There is consistent evidence of velocities of 2000 to 2500 ft/sec associated with the "caliche." Below 5- to 10-ft depths velocities are consistent at 2800 to 3000 ft/sec to the extent of the surveys.

Site Preparation

The Rowboat site was located on both sides of a pre-existing entry road. An area 1200 by 900 ft was cleared and leveled by bulldozing. Roadways were also cleared for the mobile photo station. A control trailer was established 1500 ft due north of the site. This trailer contained the timing and firing equipment, the seismic recording apparatus, and a radio communication system. A gas-driven generator supplied the power for the control trailer. The detonation and seismic cables were laid between the control trailer and the site.

Charge Emplacement

The emplacement holes were drilled with a 24-in. rotary earth auger. While the drilling results were reasonably good, slough-in occurred in gravel layers in the alluvium. These resulted in bulges up to 40 in. and variations in drilling time by factors of 10. Approximately 1 ft of overdrill was provided to control slough-in and expedite accurate emplacement. The charges were lowered in place in a Nylon high explosive harness with 3/4-in. rope. An air tugger mounted with an A-frame on a four-wheel-drive truck was used to lower the charges. Charge depth was measured by a gage line fixed on the high explosive harness to surface survey points. Charge separation was measured to surface survey points. These measurements were accurate to within 1/10 ft.

After alignment, one wheelbarrow of fine sand was washed and settled around the positioned charge with three gallons of water. Two more wheelbarrows of sand were added to completely cover the charge. The support ropes were then cut and the next charge emplaced. When all charges were emplaced, the holes were stemmed with moist drillings and tamped in 2-ft increments with hand tampers.

Shot Procedure

A total of thirty-three 278-lb charges in eight arrays were detonated in Rowboat. Each of the eight arrays was surveyed separately. The original plan called for one repetition of each of three different arrays containing four charges in a row, with two final shots whose design would be contingent on the results of the first six shots. This was changed for the sixth shot, which had a reduced number of charges, and for the seventh and eighth shots, which had single-charge detonations widely spaced from the row.

Shots 1 and 2 used four 278-lb charges, each with depths of burst of 11.9 ft and charge separations of 14.3 ft. Shots 3 and 4 used four 278-lb charges at depths of burst of 11.9 ft and charge separations of 21.4 ft. Shot 5, which had depth of burst of 17.8 ft, and charge separations of 14.3 ft, produced a very little crater. It was decided that a repetition of this array would yield no increased information. The remaining 13 charges were used as follows: Shot 6 was reduced to three 278-lb charges at depths of burst of 17.8 ft and charge separations of 14.3 ft. This permitted studies of the effect of reduced charge numbers on row-charge phenomena. The two final shots tested intermediate depths of burst and charge separation and included single-charge normalization data points for comparison with past single-charge data in desert alluvium. Shots 7 and 8 each used four 278-lb charges in a linear array plus a single charge along the row line, but far enough away to avoid throwout interaction. All charges for shots 7 and 8 had depths of burst of 14.9 ft. The row arrays had charge separations of 21.4 ft with the single charge 80 ft from the end of each row array. All of the five charges in each shot were detonated simultaneously (see Table 1.1).

Technical Programs

Crater Survey

Surveys of the pre- and post-shot terrain were used to define the channel size and lip heights. Cross sections of all craters are presented in Figs. 3.1 through 3.8. The figures include cross sections in the planes parallel to the charge lines and perpendicular to surface of the earth. They also include cross sections perpendicular to both the charge line and the earth's surface for points through and between each charge. The throwout measurements were used to obtain the smaller lip heights. These were added to the survey to obtain the entire lip heights shown in Tables A-1 through A-8.

Throwout Measurements

Two methods were used to measure lip heights and mass distribution for the Rowboat series. The first six shots used canvas strips for side and end throwout studies. Canvas strips 6 × 100 ft were placed down around the arrays to define the pre-shot terrain. (See Figs. 2.3 and 3.16.) The canvas strips were replaced by lines of 1-ft-square boards in shots 7 and 8. Lines of the 1-ft-square, 1/4-in. plywood boards were also placed in two end quadrants to study further the throwout patterns at the row ends on all of the shots. Figure 2.4 shows a typical array.

The height of the material on the canvas was measured by laying a steel tape along the center of the canvas to a fiducial stake. Measurements at 3-ft intervals along the radii were made where the lip height ranged from 9 in. to 3-1/4 in. This was accomplished by pushing a ruler vertically down to the canvas strips. For the array of plywood squares, each board was marked and backed by a vertical stake driven in along the line of desired radius. The throwout on the boards was emptied into plastic bags for weighing and volume measurement.

Surface Photography

High-speed movies of the detonations were made by EG & G.⁴ These included high-speed photography of the surface motion, venting, debris throwout, and base-surge development. Detailed measurements of the surface motion have been taken from these films and included in the results. Ground and aerial photographs of individual shots and of the entire array are shown in Figs. 3.16 through 3.19.

Fig. 2.3. General layout of canvas strips used to define the preshot terrain for the first six shots. Lines of collector boards replaced the strips for shots 7 and 8.

Fig. 2.4. Radii along which the collectors were placed to measure the angular dependency of the end effect.

The photography was accomplished by a mobile photo station. Its view angle and range varied for each shot as shown in Fig. 2.5. The ground zero area was marked by approximately a dozen 3-ft X 4-ft X 1/2-in. plywood targets. The exact number of targets and their placement are shown in Figs. 2.6 through 2.13. Two targets with a zero-time flash were placed in the foreground to act as stationary fiducial markers.

Figures 2.6 through 2.13 show the target locations and their identification numbers. The northernmost shot point was numbered 1 and the remainder sequentially toward the south. The code works as follows:

"1 4 N 5" is the target from shot 1 which is located 5 ft north of shot point 4.

<u>Shot No.</u>	<u>Shot Point No.</u>	<u>Direction</u>	<u>Distance</u>
1	4	N	5

"22.5 SE5" is the target from shot 2 located 5 ft east of the point midway between shots points 2 and 3. Examination of the diagrams will clarify the coding.

Camera emplacement varied for different shots. Three to four 35-mm Mitchells and a 35-mm full frame Fastax were generally used. On all shots two Mitchells recorded surface motion and throwout with long-focal-length lenses. One Mitchell recorded dust cloud formation and another recorded surface motion and throwout with infrared film. This was an attempt to "see" through the dust cloud to study the mass distribution of the throwout. A Fastax operating at a thousand frames per second was used to photograph the surface displacement. The surface displacements and the related velocities were taken from these films. Table 2.1 is a complete listing of the films taken in Rowboat.

Ground Shock

Near-in ground shock measurements were obtained with acceleration gages for each of the detonations. The gage locations are presented in Fig. 2.14. Each gage consisted of a pair of Statham A5A strain-gage accelerometers oriented radially and vertically on a single support and assembled as shown in Fig. 2.15. This assembly was cast into a block consisting of a mixture of alluvium and cement designed to produce an acoustic impedance match with the in-situ material. A gage assembly is shown in Fig. 2.16.

Table 2.1. Rowboat films.

Event	Expend date	Camera	Nom film SPD PPS	RERF-NO	Film
1	6-2-61	M	100	79900	ECN
		M	24	79901	ECN
		FF35	1000	79902	BX
		M	100	79903	IR
2	6-5-61	M	100	79904	ECN
		M	100	79905	IR
		M	24	79906	ECN
		FF35	1000	79907	PX
		M	100	79909	ECN
3	6-13-61	M	100	79910	IR
		FF35	1000	79911	PX
		M	100	79912	ECN
		M	24	79913	ECN
		M	100	79914	FX
4	6-15-61	FF35	1000	79915	PX
		M	100	79916	ECN
		M	24	79917	ECN
		M	100	79918	FX
		M	100	79919	IR
5	6-20-61	FF35	1000	79920	PX
		M	100	79921	ECN
		M	24	79922	ECN
		M	100	79923	BX
		M	100	79924	IR
6	6-22-61	M	100	79925	BX
		M	100	79926	ECN
		M	24	79927	ECN
		M	100	79928	IR
		FF35	1000	79908	DX
7	6-26-61	M	24	79929	ECN
		M	100	79930	ECN
		M	100	79931	BX
		FF35	1000	79933	FX
8	6-28-61	M	24	79934	ECN
		M	100	79935	ECN
		M	100	79936	BX
		FF35	1000	79932	DX

M	= 35-mm Mitchell camera	FX	= Panatomic X film
FF35	= 35-mm full frame Fastax camera	DX	= Double X Pan film
ECN	= Eastman color negative film	IR	= Infrared film
BX	= Background X film	PX	= Plus X film

Fig. 2.5. Rowboat shot areas and photo station locations.

Fig. 2.6. Target array, shot 1.

④

Fig. 2.7. Target array, shot 2.

Fig. 2.8. Target array, shot 3.

Fig. 2.9. Target array, shot 4.

Fig. 2.10. Target array, shot 5.

Fig. 2.11. Target array, shot 6.

Fig. 2.12. Target array, shot 7.

Fig. 2.13. Target array, shot 8.

Fig. 2.14. Typical accelerometer locations, shots 1 through 6.

Fig. 2.15. A typical pair of Statham ASA strain-gage accelerometers oriented radially and vertically on a single support.

Fig. 2.16. A pair of gages cast into a mixture of alluvium and cement to produce an impedance match with the in-situ material.

All gages were buried 2.5 ft below the undisturbed surface level in a 6-in.-diameter drilled hole which was refilled and tamped. Recordings were obtained with a Minneapolis-Honeywell Visicorder Oscillograph Model 1012, using Heiland M-200 galvanometers. The recorder was started and stopped manually at shot time and operated at a paper speed of about 20 in./sec.

3. RESULTS

Crater Dimensions

Table 3.1 lists the Rowboat crater cross sections shown in Figs. 3.1 through 3.8. These measurements include the widths, depths, and lip heights of the cross sections taken through and between each charge point. The dimensions of each crater were averaged, scaled to the $1/3.4$ law, and plotted in Figs. 3.9 and 3.10 with the single-crater data for the same medium.

Single Crater Dimension

While the linear craters are not expected to have the same scaled dimensions as single craters, it is of interest to compare them. The closest correlation of the linear-crater data to the single-crater data occurs for optimum crater-producing parameters. As Figs. 3.9 and 3.10 show, both the average scaled half-widths and depths of shots 1 and 2 agree fairly well with the single-crater data. The half-widths for shots 3 and 4 also scale, but the large charge separation has reduced the average depths to about half the single-crater data. Table 3.2 shows that the mean deviation of the half-widths of these four shots is consistently small, while those of the depths have large variation. The comparison implies that for optimum depth of burial, average channel widths formed by row charges are equal to crater widths formed by single charges.

The channel depths, on the other hand, depend quite strongly on the charge separation. This is to be expected, since saddles were produced between shot points. The average depths of shots 1 and 2 scale quite well to the single-crater depth curve. The average depths of shots 3, 4, 7, and 8, all with larger charge separations, fell significantly below the single-crater curve. The effect of optimum charge separation with large depth of burst was tested in shots 5 and 6. These shots produced craters whose cross-section

Table 3.1. Crater dimensions for Rowboat (all dimensions in feet).

Station	DOB = 11.9 Spacing = 14.3 ft				DOB = 11.9 ft Spacing = 21.4 ft				DOB = 17.8 ft Spacing = 14.3 ft				DOB = 14.9 ft Spacing = 17.9 ft			
	Shot 1		Shot 2		Shot 3		Shot 4		Shot 5		Shot 6		Shot 7		Shot 8	
	W ^a	D ^b	W	D	W	D	W	D	W	D	W	D	W	D	W	D
1	27.5	4.0	26.0	6.1	26.4	2.8	27.0	3.7	6.2	0.8	-	-	16.3	1.9	13.7	1.2
1.5	30.3	5.1	28.4	7.6	23.3	2.4	21.8	3.8	4.9	1.1	19.0	0.7	8.3	1.5	14.7	1.5
2	30.0	5.6	29.8	6.8	23.5	2.6	25.7	3.9	17.1	1.5	0	0	15.3	0.9	17.5	1.6
2.5	31.3	6.4	28.7	6.0	21.8	3.4	24.2	3.8	14.8	2.1	12.7	1.0	21.0	0.9	19.8	2.1
3	31.0	6.7	30.4	6.1	26.0	4.4	25.8	3.5	15.8	2.5	16.4	1.6	12.0	0.6	18.6	2.3
3.5	30.0	7.4	28.7	6.8	23.5	3.3	25.7	3.6	15.9	1.0	13.0	1.2	2.6	0	19.7	2.9
4	29.9	5.4	27.5	6.9	26.8	2.9	26.2	3.7	16.8	1.1	9.7	1.1	21.6	1.4	22.3	3.7
Single charges													22.1	2.9	28.7	2.5
Ave.	30.1	5.8	28.8	6.6	24.5	3.0	25.2	3.7	13.1	1.4	13.5	0.9	14.0	1.0	18.0	2.2
	± 0.8	± 0.9	± 1.0	± 0.5	± 1.5	± 0.5	± 1.3	± 0.1	± 4.4	± 0.5	± 4.4	± 0.3	± 5.4	± 0.4	± 2.4	± 0.7
Scaled	217	81	200	92	172	42	176	52	92	19.6	94	13	98	14	126	31
Scaled single charges													156	41	200	35

^a Crater width

^b Crater depth

Fig. 3.1a. Crater cross sections, shot 1.

Fig. 3.1b. Crater cross sections, shot 1.

Fig. 3.2a. Crater cross sections, shot 2.

Fig. 3.2b. Crater cross sections, shot 2.

----- Preshot
———— Postshot

Scale (ft)
Horizontal 0 10 20 30
Vertical 0 2 4 6

Fig. 3.3a. Crater cross sections, shot 3.

Profile midway between charges 2 and 3

Profile at charge No. 3

Profile midway between charges 3 and 4

Profile at charge No. 4

----- Preshot
————— Postshot

Scale (ft)
Horizontal 0 10 20 30
Vertical 0 2 4 6

Fig. 3.3b. Crater cross sections, shot 3.

Longitudinal profile

Profile at charge No. 1

Profile midway between charges 1 and 2

Profile at charge No. 2

----- Preshot
———— Postshot

Scale (ft)
Horizontal 0 10 20 30
Vertical 0 2 4 6

Fig. 3.4a. Crater cross sections, shot 4.

Fig. 3.4b. Crater cross sections, shot 4.

----- Preshot
——— Postshot

Scale (ft)
Horizontal 0 10 20 30
Vertical 0 2 4 6

Fig. 3.5a. Crater cross sections, shot 5.

Profile midway between charges 2 and 3

Profile at charge No. 3

Profile midway between charges 3 and 4

Profile at charge No. 4

Fig. 3.5b. Crater cross sections, shot 5.

Fig. 3.6a. Crater cross sections, shot 6.

Profile at charge No. 3

Profile midway between charges 3 and 4

Profile at charge No. 4

----- Preshot

———— Postshot

Scale (ft)
Horizontal 0 10 20 30
Vertical 0 2 4 6

Fig. 3.6b. Crater cross sections, shot 6.

Fig. 3.7a. Crater cross sections, shot 7.

Fig. 3.7b. Crater cross sections, shot 7.

Longitudinal profile

Profile at charge No. 1

Profile midway between charges 1 and 2

Profile at charge No. 2

Profile midway between charges 2 and 3

Fig. 3.8a. Crater cross sections, shot 8.

Profile at charge No. 3

Profile midway between charges 3 and 4

Profile at charge No. 4

Profile at single charge

Longitudinal profile

Fig. 3.8b. Crater cross sections, shot 8.

Fig. 3.9. Apparent crater depth vs depth of burst for Nevada desert alluvium, high explosives and nuclear explosives, $W^{1/3.4}$ scaling.

Fig. 3.10. Apparent crater radii vs depth of burst for Nevada desert alluvium, high explosives and nuclear explosives, $W^{1/3.4}$ scaling.

measurements fell in the lower extreme of the single-crater data. The scatter in the cross-section depths was approximately equal to the depth measurement.

Table 3.2. Mean deviations of crater cross-section dimensions(%).

Shot	1	2	3	4	5	6	7	8
Radius	2.7	3.0	4.0	4.0	32.0	16.0	32.0	13.0
Depth	16.0	8.0	17.0	3.0	36.0	28.0	33.0	32.0
Lip Ht.	14.0	26.0	13.0	24.0	13.0	32.0	23.0	24.0

Crater Reproducibility

Table 3.3 is a listing of the percent differences of the crater dimensions of like charge arrays. As can be seen, the reproducibility is also strongly dependent on the depth of burial. Craters 1 and 2 have parameters which differ from each other by no more than 8% and craters 3 and 4 by 3%. Craters 5 through 8 have larger percentage differences in radii and depth.

The above shows that the 278-lb charges can produce reproducible uniform craters in alluvium if the depth of burial is restricted to near optimum. At intermediate and large depths of burial, the craters formed were neither uniform nor reproducible. All overburdens were broken into small particles and accelerated uniformly. This was verified by on-site inspection and examination of the surface-motion films. The shots at optimum depth of burial experienced uniform mound growth and subsequent crater formation even though major gas vents occurred at early times (see Figs. 3.11 and 3.12). The deeper shot experienced equally uniform mound growth, with no early vents, but produced uneven craters.

Table 3.3. Percent difference of average dimensions of similar arrays.

Shot	Repeat shot	% Difference ave. radii	% Difference ave. depths
1	2	8	5
3	4	2	3
5	6 ^a	40	3
7	8	60	21

^a Shot 6 had one less charge than shot 5.

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Fig. 3.11. Shots 1 (top) and 2 (bottom) after 0.2 sec of mound growth. The large vent in the mound of shot 2 is clearly shown. A slight tendency to cusp between shot points is also shown.

Fig. 3.12. Mounds 3 (top) and 4 (bottom) after 0.3 sec. Mound 3 has two large vents. The cusping shows the effect of the large charge separation with optimum depth of burst.

Lip Height (Survey)

Tables A-1 through A-6 list the height of the throwout as a function of radius. The lip heights were taken from the pre- and post-shot surveys and in the lower ranges by direct measurement of the height of the deposited material on canvas strips. (Figure 3.19 clearly shows the throwout on the canvas strips.)

These measurements verify that very little throwout occurs at the ends of linear channeling arrays. The average maximum height of the end lip was $30\% \pm 15\%$ of the maximum average of the side lips. The end lip heights as a function of radius decrease much faster. Also included in the throwout measurements are the percent deviations of the lip heights of the cross sections taken through each channel (see Table 3.2).

Throwout Measurement

Lip Heights (Canvas Strip Measurement)

The lip heights of the throwout were measured along the six radii defined in Fig. 2.3. The survey data was used with the direct lip height measurements to obtain the lip profile. This data is contained in the Tables A-1 through A-8 in Appendix A. The asterisk in each column marks the end of the survey data and the beginning of the canvas-strip measurements.

Mass Distribution

The mass distribution was measured for end quadrants of each shot. This data is contained in Tables B-1 through B-8 in Appendix B. The radii are defined in Fig. 2.4. The mass distribution was not uniform in the end quadrants. In some cases randomly oriented spikes of material were thrown into the end quadrants. Some of these irregularities can be seen in Fig. 3.19. In shots 7 and 8 the canvas strips were replaced by collection trays to obtain the mass distribution off the sides of the crater. Tables B-7 and B-8, which contain these data, clearly show the low mass throwout off the end of the craters.

Throwout Density

The density of the throwout material was measured for 24 samples. The average density was 1.52 g/cm^3 with a mean deviation of 0.08 g/cm^3 . The highest density measured was 1.78 g/cm^3 and the lowest was 1.16 g/cm^3 .

Photography

Mound Stills

Figures 3.11 through 3.14 show the mounds at intermediate times for all eight events. The first four events, all with optimum depth of burst, experienced unusual venting. Early vent occurred for each of the two geometries used in these four shots. These photos, along with surface motion data and final crater dimensions, show that for optimum depth of burst early vents (through intermediate stages of mound growth) do not have a strong effect on final throwout distribution. This implies that the gas acceleration phase had its major effect before venting occurred.

From these photos we see that shot 2 vented before half of the coherent mound growth had occurred, while shot 1, with the same depth of burst and charge separation, did not vent. Later photos show that the vented mounds and unvented mounds expanded evenly. Furthermore, the size of the crater at the vented end was essentially equal to that of the unvented end (see Figs. 3.1 through 3.8). A comparison of the displacement data for shots 1 and 2 shows that the effect of the vent on the time rate of displacement at the mound was not measurable. Finally, Table 3.2 shows the mean deviations of crater 2 to be smaller than those of crater 1.

Shot 3 experienced two early vents, while its duplicate, shot 4, did not have a significant vent even at late times. In this case the mean deviation of the depth for shot 3 was much larger than that of shot 4. This occurred even though all mounds expanded uniformly and their growth rates were comparable. The effect of these vents does not appear to systematically change the crater dimensions. The mean deviations of the lip height do not appear to correlate with early vents. Shot 2 had a high mean deviation for the lip height of 26%, while shot 3 had one of the lowest, at 13% (see Table 3.2).

Shots 5 through 8, all with large depths of burst, were well-contained. Shots 5 and 6, both with the maximum depth of burst tested in Rowboat, did not experience vents. While their containment was complete, the gas boost was not sufficient to form measurable craters. Shots 7 and 8 both vented slightly at late stages of mound growth, but there was no measurable effect on throwout from these vents.

Fig. 3.13. Shots 5 (top) and 6 (bottom) after 0.4 sec of mound growth. The large depths of burial have completely contained the expanding gases. The composite mounds are uniform and show no cusping. The targets have remained perpendicular to the expanding surface, indicating the absence of rotation of the immediate surface material.

Fig. 3.14. Mounds 7 (top) and 8 (bottom) after 0.4 sec show a slight tendency to cusp and vent. As in Figs. 3.11 and 3.12, the targets are skewed and are beginning to rotate.

Pre- and post-shot stills of the site are included with description subtitles in Figs. 3.15 thru 3.19.

Surface Motion

Displacements

Displacement measurements were taken from the high-speed photographs of the surface motion. The target arrays shown in Figs. 2.6 through 2.13 were photographed with a 33-mm full-frame Fastax camera operating at 1000 pictures per second.

The individual frames were measured for surface motion by comparing the target displacement with a stationary foreground fiducial target. These measurements were made on a photo analyzer. The resulting data were then plotted against time. A smooth curve was drawn through the data points for each target.

Figures 3.20 through 3.27 contain the complete smoothed curves for all vertical target displacements. (See Fig. 2.26 for target identification code.) These measurements were taken until the targets disappeared in the dust clouds. The displacement data are contained in Tables C-1 through C-8 in Appendix C. Enlarged plots (not shown) of the first couple of feet of mound displacement were made for targets directly over shot points. These early time plots were made in an attempt to see the initial gas acceleration time and the ensuing acceleration history. While the latter part of the gas acceleration phase was evident in these plots, its beginning was not resolved. In all cases the beginning of the gas acceleration appears to begin before 0.03 sec had elapsed.

Velocities

The smoothed displacement curves were differentiated by measuring average displacement over small time intervals. Resulting data were plotted against time to obtain velocity curves and thus the acceleration histories. Representative velocity curves are shown in Figs. 3.28 through 3.35. There were four time periods of interest in these velocity curves. The first phase was the duration of the spall, free fall, and initial gas acceleration phase. The resolution of the films and the accuracy of the reading process was clearly insufficient to resolve this phase from the data. In all cases it started

Fig. 3.15. Sequence showing mound growth for shot 5. **The mound** contains no saddles, expands evenly along its crest and experienced no major vents.

Fig. 3.16. Typical preshot layout. The canvas strips were used to define the preshot terrain. The targets were used to define surface displacement and the lines of collection trays measured the throwout in their respective quadrants.

Fig. 3.17. Late throwout and beginning of the base surge.

Fig. 3.18. Crater 2. Note the uniform sides and the small lip at the end of the crater.

Fig. 3.19. Rowboat site with craters.

Fig. 3.20. Rowboat shot 1 displacements of all targets with time.

Fig. 3.21. Rowboat shot 2 displacements of all targets with time.

Fig. 3.22. Rowboat shot 3 displacements of all targets with time.

Fig. 3.23. Rowboat shot 4 displacements of all targets with time.

Fig. 3.24. Rowboat shot 5 displacements of all targets with time.

Fig. 3.25. Rowboat shot 6 displacements of all targets with time.

Fig. 3.26. Rowboat shot 7 displacements of all targets with time.

Fig. 3.27. Rowboat shot 8 displacements of all targets with time.

Fig. 3.28. Rowboat shot 1. Velocity curve for target 13E2.

Fig. 3.29. Rowboat shot 1. Velocity curve for target 13NE7.

Fig. 3.30. Rowboat shot 4. Velocity data for target 41E2.

Fig. 3.31. Rowboat shot 5. Two separate readings of the velocity history of target 52E2.

Fig. 3.32. Rowboat shot 6. Velocity data for target 63E2.

Fig. 3.33. Rowboat shot 7. Velocity data for target 72E4.

Fig. 3.34. Rowboat shot 7. Velocity data for target 72N6.

Fig. 3.35. Rowboat shot 8. Velocity data for target 82E4.

sometime before the first 0.010 sec and ended before 0.035 sec and involved less than a foot of total vertical displacement. In no case was the displacement measurement better than ± 6 in. The second phase was that in which the gas acceleration force was greater than the combined gravitational and air resistance forces. This last part of the phase is clearly represented by the increasing values of the velocity data. It is during this time that the expanding gas performs the work on the overburden. The third phase is that in which the peak velocity of the expanding mound is reached, i. e., the period during which the acceleration is very small. At this point the forces are in equilibrium. The width of this period approximates the length of time the forces stay in equilibrium. The fourth phase is marked by the decrease in velocity.

Table 3.4 lists the peak velocities of the ground-zero targets and their approximate negative acceleration. The accelerations were obtained by drawing a straight line through the velocity data. In cases where the acceleration was not approximated by one straight line, a second line was drawn to approximate the final acceleration. Examples of large changes in the negative acceleration are shown in Figs. 3.28 and 3.29. In most cases the velocity data either did fit a straight line or were insufficient to define more than one line. The large negative acceleration experienced by some targets was due to the rotation of the target fiducial mark around its center of mass. This was pronounced for targets whose vertical displacement was small.

These data show that both the peak velocity and the negative acceleration are strong functions of depth of burial. For targets over shot points in shots 1, 3, and 4 the peak velocities were very nearly equal, the average value being 61 ± 2 ft/sec. The negative acceleration for these targets was -82 ± 17 ft/sec². While the scatter is large, the average acceleration was clearly much larger than a simple "g" fall. (The data from shot 2 were ignored because the films containing these data were very poor.) For the large depths of burial these values were greatly reduced. The maximum depth of burial of shots 5 and 6 resulted in an average peak velocity of 31 ± 1 ft/sec and an average acceleration of -30 ± 1 ft/sec². The intermediate depth of burial of shots 7 and 8 produced an average peak velocity of 35 ± 3 ft/sec and an average acceleration of 44 ± 9 ft/sec².

Table 3.4. Peak velocities and negative accelerations of the vertical target motion.

<u>Targets over shot points</u>			<u>Targets next to and between shot points</u>			<u>Targets neither next to or between shot points</u>		
Target number	Peak velocity (ft/sec)	Neg. accel. (ft/sec ²)	Target number	Peak velocity (ft/sec)	Neg. accel. (ft/sec ²)	Target number	Peak velocity (ft/sec)	Neg. accel. (ft/sec ²)
13E2	55	92→29	14N5	54	44	14S10	24	31
14E2	64	52→35	13S5	60	43	13NE14	25	-
21E2	-	-	31S5	50	-	31N10	21	-
22E2	-	-	32N5	57	-	32.5E5	31	46
31E2	60	84	41S5	52	50	32.5E10	15	33
32E2	60	94	42N5	54	60	41N10	28	45
41E2	63	60	42.5N5	50	-	51N10	20	30
42E2	62	100	52N5	30	29	52.5E14	25	28
51E2	30	27	63N5	31	30	52.5E21	14	30
52E2	31	31	71S6	38	40	62N10	18	50
62E2	32	31	72N6	35	40	63E8	20	38
63E2	28	30	81S6	45	-	61N10	8	36
71E4	32	34	82N6	42	43	63E13	14	40
72E4	32	38	<u>Targets not next to but between shot points</u>			71N12	15	34
81E4	36	62				72.5E6	30	54
82E4	38	42	32N10	60	-	72.5E12	15	-
<u>Targets next to shot points and off the end of the array</u>			32.5N	48	-	72.5E18	9	26
			42.5N	46	-	81N12	13	34
14S5	43	60	52.5N	30	29	82.5E6	38	-
31N5	42	-	52.5SE7	31	32	82.5E12	18	-
41N5	47	40	72.5N	35	38			
51N5	27	26	82.5N	44	-			
62N5	26	30						
71N6	28	-						
81N6	29	-						

Targets not over shot points experienced varying peak velocities and accelerations. Their motions were dependent on their placement relative to shot points and the separation of the shot points. Targets with similar placement are listed together in Table 3.4.

Seismic Results and Interpretation

No previous studies of the seismic effects of a series of detonations widely distributed in space, but fired simultaneously, have been reported. Evaluation of the effects of this distribution is the primary purpose of this section. The principal effects studied are: influence of depth of burial on seismic signals; attenuation of peak acceleration with range; and azimuthal effects, all at short ranges. For comparing single and multiple charge detonations, data from Project Mole, a test series involving single 256-lb charges, were used.

Peak values of radial and vertical accelerations recorded on Rowboat are shown in Table 3.5. The distribution of peak radial acceleration with azimuth is presented for each shot in Fig. 3.36. The peak radial and vertical accelerations recorded at each of the several gage locations are shown in Fig. 3.37 for shots 1-6. Three gage locations for shots 7 and 8 are included because only they were at locations comparable to those used on earlier events. Oscillograph images for all records are reproduced in Appendix F.

The interpretation of the Rowboat results is limited by at least four factors:

- a. Single-shot data are not available except from the Mole series 200 and 400 shots, which were fired at ranges out to 4000 ft from the Rowboat site, and it is known that the characteristics of the alluvium can change greatly in a short distance; therefore, Mole data may not be appropriate for use at the Rowboat sites.
- b. Geologic variations among the Rowboat sites are not known. Were sufficient data available, better agreement might be obtained between identical shots.
- c. The manner in which signals from several simultaneously detonated shots combine (coalesce) has not been thoroughly studied.
- d. It cannot be stated unequivocally that air blast had no effect on the recorded Rowboat ground-acceleration initial peaks; however, the results of Mole where air blast time of arrival was recorded and the Rowboat accelerograms indicate that air blast should not affect the first peaks.

Table 3.5. Peak radial and vertical accelerations (ft/sec²) for Rowboat.

Shot	Gage	Range (ft)		Bearing from centerline of array	Initial peak acceleration		Peak accel- eration if other than initial
		From center of array	From end charge ^a		Vert.	Rad.	
1	1	45		80	1.6	5.7	
	2	66.5		90	0.8	2.8	
	3	66.5		67.5	1.0	3.1	
	4	66.5		45	0.4	1.6	0.8
	5	66.5		22.5	0.6	1.7	0.9
	6	66.5	45	0	0.8	2.7	
2	1	45		80	2.2	4.5	
	2	66.5		90	1.2	2.9	
	3	66.5		67.5	1.2	3.9	
	4	66.5		45	0.9	2.0	1.1
	5	66.5		22.5	1.0	1.7	
	6	66.5	45	0	0.8	2.1	
3	1	45		80	1.4	8.8	
	2	77.1		90	1.4	1.3	
	3	77.1		67.5	1.5	3.5	
	4	77.1		45	0.7	2.4	1.1
	5	77.1		22.5	1.0	2.9	
	6	77.1	45	0	0.4	3.4	0.7
4	1	45		80	1.6	7.0	
	2	77.1		90	1.2	3.8	1.6
	3	77.1		67.5	0.8	2.2	1.1
	4	77.1		45	1.1	2.2	
	5	77.1		22.5	1.6	3.0	
	6	77.1	45	0	0.8	4.1	1.0
5	1	45		80	2.3	4.0	
	2	66.5		90	0.8	3.7	
	3	66.5		67.5	1.0	2.5	
	4	66.5		45	1.4	2.5	
	5	66.5		22.5	1.9	2.6	
	6	66.5	45	0	0.4	2.7	0.9
6 (3 charges)	1	45		80	1.3	4.2	
	2	66.5		90	0.9	2.6	
	3	66.5		67.5	1.3	2.7	
	4	66.5		45	0.5	2.0	0.9
	5	66.5		22.5	1.5	2.0	
	6	66.5	45	0	0.8	2.7	

Table 3.5. (Continued)

Shot	Gage	Range (ft)		Bearing from centerline of array	Initial peak acceleration		Peak accel- eration if other than initial
		From center of array	From end charge ^a		Vert.	Rad.	
7	1	45		90	1.4	3.7	
	2	65		90	0.9	2.1	
	3	90		90	1.3	1.2	
	4	62	35.1	0	0.5	3.1	
	5	72	45.1	0	1.5	2.1	
	6	92	65.1	0	0.8	1.3	
8	1	45		90	1.4	4.8	
	2	65		90	0.7	2.6	
	3	90		90	0.5	1.5	0.9
	4	62	35.1	0	1.5	3.0	
	5	72	45.1	0	1.0	2.6	
	6	92	65.1	0	0.7	2.0	

^a For gages along extension of array centerline.

Effect of Depth of Burst

For a constant charge size fired at varying depths in a single medium, the highest values of peak acceleration recorded at a given relative gage location might be expected from the deepest detonation because the energy should be more efficiently coupled into the medium.

Horizontally the explosive and instrument arrays were identical for shots 1, 2, 5, and 6, except that shot 6 consisted of 3, not 4, charges. The depth of burst for shots 1 and 2 was 11.9 ft, for shots 5 and 6, 17.8 ft. Comparison of data for any gage location in Fig. 3.37 for these four shots does not support the argument that the more deeply buried shots should produce greater signals. No systematic pattern emerges from such a comparison.

In a further attempt to evaluate the effect of depth of burial on acceleration, the value of peak radial and vertical acceleration at the gage located 45 ft from the end charge on each shot was tabulated and plotted as a function of depth of burst in Fig. 3.38. On all shots the peak vertical acceleration was within the range 0.4-1 g. Except for shots 3 and 4, the peak radial acceleration was 2.1 to 2.7 g. The significant departure of the values for horizontal acceleration caused by shots 3 and 4 cannot be explained.

It appears that peak acceleration is not greatly affected by changes in scaled charge depths between $167 \text{ ft/kt}^{1/3.4}$ and $249 \text{ ft/kt}^{1/3.4}$.

Fig. 3.36. Azimuthal distribution of peak radial acceleration. Numbers denote gage locations.

Fig 3.37. Peak acceleration at each gage location for events 1 through 6 and gages 1, 2, and 5 for events 7 and 8.

Fig. 3.38. Peak acceleration as a function of depth of burial.

Fig. 3.39. Peak acceleration vs range for Rowboat shots 7 and 8.

Attenuation with Range

Figure 3.39, a plot of data from shots 7 and 8, suggests that in a direction perpendicular to the charge array peak radial acceleration attenuates with $R^{-1.7}$. However, this does not apply to the other shots based on the data from gages 1 and 2. For shots 7 and 8, the only shots on which there was more than one gage along the array extension, the attenuation was uniform in this direction for either shot; however, it varied markedly between the two shots, being with $R^{-2.1}$ for 7 and $R^{-1.0}$ for 8.

Rowboat results are insufficient to determine general attenuation exponents.

Magnitude of Peak Acceleration

In Fig. 3.36 it can be seen that the maximum horizontal acceleration was generally recorded at gages located perpendicular to or along the extension of the charge array. On three events, however, gage 3 recorded accelerations higher than those at gage 2.

In all cases except one (the anomolous reading at gage 2, shot 3) the maximum horizontal acceleration occurred in the first half cycle. This was not true for the vertical acceleration. Some records show maximum values associated with the downward motion immediately following the initial upward acceleration, while others show late arriving peaks greater than the initial accelerations. The fact that there are no pronounced late peaks in the horizontal records suggests that these motions were air blast induced.

Selected data from Table 3.5 are plotted in Figs. 3.40-3.43. Also shown are results from experiments involving the detonation of single 256-lb charges in Nevada Test Site alluvium. Figures 3.37-3.43 show that the first peak vertical acceleration was invariably less than the radial at any gage, and that the scatter about a line based on scaled Mole data is of the same order for both radial and vertical motion.

Table 3.6 shows that the peak horizontal motion at a given distance perpendicular to the array is about 1.5 to 2.5 times greater than the horizontal motion at the same range from the end of the charge array, and 0.7 to 1.5 times as great when range is measured from the center of the array. (See Figs. 3.40, 3.41, and 3.42.)

Fig. 3.40. Peak radial acceleration along charge array extension as a function of range from center of shot array.

Fig. 3.41. Peak radial acceleration as a function of range from end of shot array.

Table 3.6. Ratio of peak acceleration at gages perpendicular to and parallel the charge array.

Shot	Gages	Range (ft)		Acceleration ratio perpendicular extension
		From center of array	From end of array	
1	2/ 6	66.5		$\frac{2.8}{2.7} = 1.0$
	1/ 6		45	$\frac{5.7}{2.7} = 2.1$
2	2/ 6	66.5		$\frac{2.9}{2.1} = 1.4$
	1/ 6		45	$\frac{4.5}{2.1} = 2.1$
3	1/ 6		45	$\frac{8.8}{3.4} = 2.6$
4	2/ 6	77.1		$\frac{3.8}{4.1} = 0.9$
	1/ 6		45	$\frac{7.0}{4.1} = 1.7$
5	2/ 6	77.1		$\frac{3.7}{2.7} = 1.4$
	1/ 6		45	$\frac{4.0}{3.1} = 1.5$
6	2/ 6	66.5		$\frac{2.6}{2.7} = 1.0$
	1/ 6		45	$\frac{4.2}{2.7} = 1.6$
7	1/ 5		45	$\frac{3.7}{2.1} = 1.8$
	2/ 6		65	$\frac{2.1}{1.3} = 1.6$
8	2/ 4	65		$\frac{2.1}{3.1} = 0.7$

Figure 3.40 might be explained in a gross way by considering the Rowboat sources as a single charge located at the center of the array with a scaled yield of 4 (or 5 for shots 7 and 8, 3 for shot 6) times 256 lb. If we assume that at the same scaled range acceleration varies with $W^{-2/3}$, the scaled Mole curves fit the Rowboat points within a factor of 2. Such scatter often occurs in the results of a strong-motion studies on nuclear shots. Therefore, it might be concluded that the replacement of the series of charges with one equivalent charge (scaled by $W^{2/3}$ or perhaps some other power of W) is valid.

Also shown on the figure (3.40) as a dashed line are the Mole accelerations quadrupled. The scaled (solid) curve represents the effect of the summation of the charge weights, while the dashed curve represents the motion which is the summation of the motions due to the individual charges.

A second inference, which might be drawn from Fig. 3.41, is that along the extension of the charge array, the motion resulting from the nearest charge overrides all others, so that the effect at some distance from the end of the shot array of the multiple detonation is the same as would result from detonation of the end (nearest) charge only. Figure 3.41 shows that the scatter about the curve representing a single 256-lb charge is less than a factor of 2, with the peak radial acceleration at a distance of 45 ft ranging from 2.1 to 4.1 g.

While future experiments may support one of the above arguments, neither can be established by the Rowboat results.

The most satisfying explanation seems to be that presented below.

Synthetic Accelerograms

The significant factors which should be considered in an evaluation of the surface motion resulting from detonations such as Rowboat include: size of individual charges; range between the point of interest and each charge; peak motion due to detonation of an individual charge, as a function of range; travel time as a function of range; phase relationship among arriving waves; effects of geology; and energy coupling.

Of these, the only factors on Mole which definitely apply to Rowboat are the first two. The others may or may not be applicable, and can only be assumed. The charges for both Mole and Rowboat were 256-lb high explosive. While the Rowboat tests were within 4000 ft of the Mole 200- to 400-series

sites, the alluvium could vary widely in this distance, and there are no data for comparing significant parameters such as seismic velocity at the various locations. The greatest depth of burial employed for the Mole events was 6.35 ft, used on shots 202, 212, and 404. Rowboat depth of burial varied between 11.9 and 17.8 ft. One other variable which introduces uncertainty is gage depth of burial, which on Mole was 5 ft; and on Rowboat 2.5 ft. The lack of contradictory information dictates the assumption that Mole variables apply directly to the Rowboat situations.

In order to incorporate as many of the above factors as possible in an interpretation of the Rowboat seismic results, a "synthetic accelerogram" procedure is employed. A synthetic accelerogram for a multiple-charge shot is defined as the time history for acceleration at a particular location obtained from the superposition of the signals from the individual charges appropriately attenuated and spaced in time for the distance involved. Only the first motion can be reasonably considered.

The attenuation, average pulse shape, and time-of-arrival data were approximately the same for Mole shots 202, 212, and 404. Using the data from shot 212, synthetic radial accelerogram for gage 6 Rowboat 1 and 2 were prepared (Fig. 3.44). Using data from other Mole shots does not significantly affect the results. The good agreement between the recorded and synthetic accelerogram suggested the validity of the approach. This procedure was used to plot the first motion at gage 1 which was at a perpendicular distance of 45 ft from the center of the charge array. Because the travel times from all the individual charges to gage 1 were approximately the same, the synthetic accelerogram was a spike shown in Fig. 3.45. In order to lower the peak and increase pulse duration, a travel time based on an assumed seismic velocity of 2500 fps, rather than 3650 fps, was used to plot Fig. 3.46. No significant improvement resulted, and this velocity was then used to determine its effect on the accelerogram drawn first, this result also being shown in Fig. 3.46. It can be seen from this figure that the agreement between the synthetic and recorded first peak for Rowboat 1 is better than between Rowboat 1 and Rowboat 2. Additional plots were evaluated, but it was concluded that the parameters used in this figure were suitable for use in further plotting in view of the uncertainty in other parameters. Plots were prepared for other gages as shown in Figs. 3.47 and 3.48.

Fig. 3.44. Synthetic accelerogram (Σ -Mole) and Rowboat 1 and 2, gage 6 traces assuming seismic velocity of 3650 fps.

Fig. 3.45. Synthetic accelerogram and Rowboat 1 and 2, gage 1 traces assuming seismic velocity of 3650 fps.

Fig. 3.46. Synthetic accelerogram and Rowboat 1 and 2, gages 1 and 6 traces assuming seismic velocity of 2500 fps.

Fig. 3.47. Synthetic accelerograms, Rowboat 3 and 4, gages 1 and 6 traces.

Fig. 3.48. Synthetic accelerograms, Rowboat 5 and 6, gages 1 and 6 traces.

The fact that the synthetic accelerograms for gages perpendicular to the array show higher peak values and shorter durations than were actually recorded (except for Rowboat 3 and 4) might be explained qualitatively by considering the components of the acceleration due to each charge. The radial component of motion from each charge is actually at some angle to the line along which radial accelerometers were oriented, so that the accelerometers recorded the radial component multiplied by the cosine of the angle, which is slightly less than the true radial acceleration. Slight differences in travel time might explain the longer pulse durations. Consideration of transverse acceleration probably provides a more realistic explanation of the differences in both peak values and duration. The travel time for transverse waves is greater than the travel time for radial waves. It has been observed on underground nuclear experiments that the peak transverse motion can be equal to or greater than the radial motion, so that the radial motions recorded on Rowboat could have been greatly distorted by the transverse component from the charges at the ends of the array. The possible effect of transverse motion is illustrated in Fig. 3.49.

The distance between charges might explain the apparently high values of acceleration at gages 1 and 6 on shots 3 and 4. The spacing on these shots was 21.9 ft, greater than on any other shot. This configuration might permit a reinforcement of the individual signals, leading to values greater than those predicted by the synthetic accelerograms. For the more closely spaced charges the phase relationships could lead to a net cancellation, reducing the actual motion below that obtained by superposition. The lack of detailed refraction information precludes an involved evaluation of this effect, and makes necessary the assumption that each individual Rowboat charge can be considered equivalent to a Mole charge.

4. CONCLUSIONS

Crater Size

The optimum scaled depth of burst and charge separations tested in shots 1 and 2 did produce reasonably uniform craters whose cross-section dimensions scaled with single-crater data. The effect of the large charge separation with optimum depth of burst as tested in shots 3 and 4 was to produce shallow craters with the expected saddles between shot points. The

Fig. 3.49. Effect of late-arriving transverse wave on "radial" synthetic accelerogram.

extreme depth of burst tested with the optimum charge separation in shots 5 and 6 clearly showed it to be too large to produce any measurable crater. The intermediate cratering parameters used in shots 7 and 8 produced craters whose dimensions scaled somewhat below the single-crater data. These results, together with those of shots 1 and 2, imply that for near-optimum charge separation the linear cratering dimensions will have a sharper decline with increasing depths of burst than the single crater data.

The uniformity of the craters was within that observed for single-crater scatter at respective depths of burst. The large variation of the smaller craters formed by shots 5 through 8 is also explained by the rapid increase of overburden with increasing depths of burst. The widths and depths of the craters were quite uniform for optimum depth of burst, but appeared to have large percent variations for large depths of burst. It should be pointed out here that for the large craters the width measurement is actually a measurement of the true crater, while for the shallow craters it is a measure of how the throwout has refilled the true crater. The depth measurement is always a measurement of how the throwout has refilled the true crater. The absolute variation in depth was found to be quite uniform for all craters.

The reproducibility of the craters proved to be quite good for the shots with optimum depth of burst but for the shots with large depths of burst variations of ditch dimensions within each ditch were so large as to make reproducibility meaningless. This proved that at least for near-optimum depth of burst the 280-lb charge can be used for a more diversified set of linear cratering experiments in this medium.

Surface Velocities

The peak ground zero surface velocities were found to decrease sharply with increasing depth of burst. The negative accelerations also appear to follow this rule. Early major vents in the expanding earth mounds were not found to consistently affect either the surface velocity curves of the venting mound or the final crater formed under the mound. This, along with the fact that the peak surface velocities occurred before the earliest vent, shows that the overburden had received most of the impulse before venting occurred.

Throwout Studies

The absence of throwout from the ends of the linear crater was verified for Rowboat. In no case was there more than a few percent of the throwout mass deposited in the end of the quadrants. While no angular dependence of throwout into the end quadrants was found, a tendency of spikes of material to be thrown out into the quadrants was noted. The throwout off the sides did not exhibit uniform range dependence or even symmetry for a given shot.

Seismic

The Rowboat seismic program does not resolve the uncertainty of degree of containment on seismic energy coupled into the shot medium.

While results of two of the shots suggest that peak first acceleration attenuates as $R^{-1.7}$ perpendicular to the array, this is apparently contradicted by other data. There seems to be no general conclusion about attenuation which can be drawn from Rowboat results.

Even when the effect of air blast is included, the maximum horizontal motion at any gage location was greater than the vertical motion at the location.

It appears that the peak acceleration at any short distance from the center of the shot array is about the same in the direction perpendicular to the array as it is along an extension of the array. For distances along the extension measured from the end charge the peak horizontal acceleration is 0.4 to 0.7 g, the acceleration at the same range in a direction perpendicular to the array.

It appears that for cratering detonations at or near optimum depth of burial and spacing, "synthetic accelerograms" might be used to predict the peak first motion at short ranges. At longer ranges, where the effect of intervening geology has greater influence than other variables, this technique would not be applicable. A more reasonable approach would be to use formulas developed by USC & GS treating the entire shot array as a single charge. An upper limit should be obtained by calculating the motion due to each charge and summing. Use of the total yield in the array in the formula should permit an estimate of a lower bound, thus bracketing the peak motion at any intermediate range.

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APPENDIX A. LIP HEIGHT VS RADIUS FOR SHOTS 1-6.

Table A-1. Variation of lip height with radius for shot 1 (all dimensions in feet).

Strip 1		Strip 2		Strip 3		Strip 4		Strip 5		Strip 6	
Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht
24	3.94	30	2.62	16	3.10	33	1.84	23	4.26	17	1.30
27	3.84	40	1.25	18	2.30	43	1.20	30	3.92	21	0.56
31	3.28	47 ^a	0.44	21	1.47	50	1.00	33	3.38	23 ^a	0.43
35	2.72	50	0.49	24	0.71	56 ^a	0.65	38	1.64	26	0.24
38	2.30	53	0.33	29 ^a	0.44	59	0.46	46	1.32	29	0.11
44	1.96	56	0.21	32	0.25	62	0.33	55	0.75	32	0.11
50	1.18	59	0.15	35	0.28	65	0.27	60	0.65	35	0.44
56 ^a	0.52	62	0.04	38	0.21	68	0.15			38	0.44
59	0.30	65	0.04	41	0.07	71	0.12			41	0.03
62	0.21	68	0.03	44	0.04	74	0.12				
65	0.19			47	0.03	77	0.03				
68	0.27										
71	0.11										
74	0.04										
77	0.03										

^a Radius at which direct measurement begins and survey stops.

Table A-2. Variation of lip height with radius for shot 2 (all dimensions in feet).

Strip 1		Strip 2		Strip 3		Strip 4		Strip 5		Strip 6	
Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht
18	2.70	13	1.30	19	0.92	14	1.48	37	2.50	20	0.82
24	2.70	20	0.49	23	0.52	18	0.95	42	1.70	22	0.65
28	1.97	26	0.56	26 ^a	0.13	21	0.65	48	1.10	23 ^a	0.52
40	1.70	35	0.69	29	0.13	28	-	56	0.59	26	0.30
48	1.70	40	0.69	32	0.10	33	0.98	62 ^a	0.39	29	0.13
53	1.60	45	0.98	35	0.03	38	0.82	65	0.19	32	0.16
77 ^a	0.49	50	0.76			43	0.46	68	0.10	35	0.10
80	0.46	71 ^a	0.49			47	0.59	71	0.10	38	0.03
83	0.46	74	0.36			50	1.30	74	0.03		
86	0.36	77	0.09			54	1.30	77	0.03		
89	0.26	80	0.13			59	0.40				
92	0.19	83	0.16			62 ^a	0.49				
95	0.30	86	0.03			65	0.42				
98	0.10					68	0.20				
101	0.10					71	0.16				
						74	0.20				
						77	0.16				
						80	0.03				
						83	0.03				

^a Radius at which direct measurement begins and survey stops.

Table A-3. Variation of lip height with radius for shot 3 (all dimensions in feet).

Strip 1		Strip 2		Strip 3		Strip 4		Strip 5		Strip 6	
Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht
16	2.95	16	1.64	14	0.78	16	2.5	16	3.44	23	0.49
21	2.62	21	1.64	18	0.65	20	2.2	18	3.28	27	0.16
25	1.97	30	0.43	21	0.52	23	1.5	22	1.48		
33	0.65	33 ^a	0.30	23 ^a	0.46	30	0.28	29 ^a	0.46		
36 ^a	0.33	36	0.26	26	0.21	34 ^a	0.24	32	0.10		
39	0.10	39	0.10	29	0.10	37	0.24	35	0.07		
42	0.13	42	0.07	32	0.03	40	0.24	38	0.03		
45	0.07	45	0.03			43	-				
						46	0.24				
						49	0.28				
						52	0.15				
						55	0.03				
						58	0.10				
						61	0.03				

^a Radius at which direct measurement begins and survey stops.

Table A-4. Variation of lip height with radius for shot 4 (all dimensions in feet).

Strip 1		Strip 2		Strip 3		Strip 4		Strip 5		Strip 6	
Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht
21	3.28	18	2.28	16	0.98	16	2.26	20	4.50	21	1.97
28	1.51	20	1.97	21	0.26	22	2.20	24	4.10	27	0.49
32	0.49	23	1.97	28	0.49	27	2.20	26	2.79	35 ^a	0.36
41 ^a	0.52	29	1.31	31 ^a	0.46	33	0.75	34	1.31	38	0.10
44	0.39	32	0.65	34	0.23	39 ^a	0.30	41 ^a	0.52	41	0.03
47	0.39	41 ^a	0.49	37	0.10	42	0.26	44	0.26		
50	0.39	44	0.49	40	0.10	45	0.26	47	0.13		
53	0.10	47	0.30	43	0.03	48	—	50	0.10		
56	0.03	50	0.10			51	0.20	53	0.03		
		53	0.03			54	0.30				
		56	0.07			57	0.16				
		59	0.03			60	0.03				

^a Radius at which direct measurement begins and survey stops.

Table A-5. Variation of lip height with radius for shot 5 (all dimensions in feet).

Strip 1		Strip 2		Strip 3		Strip 4		Strip 5		Strip 6	
Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht
16	2.95	21	22	20	0.46	22	1.47	17	2.30	22	0.95
20	2.89	26	0.98	23 ^a	0.26	25	0.65	20	1.53	29 ^a	0.16
26	2.62	30	0.33	26	0.03	28 ^a	0.19	26	1.07	32	0.03
28	1.48	32 ^a	0.26	29	0.03	31	0.13	31	1.07		
31	0.82	35	0.16			34	0.13	37 ^a	0.40		
35	0.49	38	0.07			37	0.03	40	0.26		
38 ^a	0.16	41	0.03			40	0.03	43	0.03		
41	0.16	44	0.03								
44	0.03										
47	0.03										

^a Radius at which direct measurement begins and survey stops.

Table A-6. Variation of lip height with radius for shot 6 (all dimensions in feet).

Strip 1		Strip 2		Strip 3		Strip 4		Strip 5		Strip 6	
Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht	Radius	Lip ht
21	1.47	23	2.10	22	1.09	17	2.30	11	1.31	18	0.33
28	0.59	27	0.59	24	0.98	20	1.80	13	1.31	29 ^a	0.13
30 ^a	0.33	29 ^a	0.10	32 ^a	0.40	23	1.54	16	1.64	32	0.10
33	0.07	32	0.03	35	0.13	27 ^a	0.71	18	1.54	35	0.07
36	0.03			38	0.10	30	0.43	23	1.64	38	0.03
39	0.03			42	0.03	33	0.30	29 ^a	0.30	41	0.03
42	0.03					36	0.10	32	0.16	44	0.03
						39	0.10	35	0.03	47	0.03
						42	0.10				
						45	0.10				
						48	0.03				

^a Radius at which direct measurement begins and survey stops.

APPENDIX B: MASS DISTRIBUTION

Table B-1. Variation of mass throwout with radius for shot 1.

Line radius (ft)	A	B	C	D	A'
	$\leftarrow \text{---} (\text{kg}/\text{m}^2) \text{---} \rightarrow$				
60	3.3	0.7	2.8	86	1.3
70	1.0		0.9	—	0.8
80	1.0		1.8	36	0.2
90	0.5		0.7	23	0.7
100	0.8		0.5		1.8
115	0.8		0.1		0.3
					0.2

Table B-2. Variation of mass throwout with radius for shot 2.

Line radius (ft)	A	B	C	D	A'	B'	C'
	$\leftarrow \text{---} (\text{kg}/\text{m}^2) \text{---} \rightarrow$						
30	13.8	—	41.0	58.7	120.3	36.7	2.6
35	6.2	11.0	23.9	58.1	—	—	—
40	7.2	2.9	10.1	14.7	22.2	34.0	1.5
45	3.4	1.4	7.5	22.9	—	—	—
50	4.2	2.0	35.5	19.1	4.0	4.6	4.6
55	2.6	2.6	38.2	15.0	—	—	—
60	2.0	1.3	5.9	7.6	2.5	1.7	1.2
65	2.1	—	5.5	5.1	—	—	—
70		1.4	5.5	3.8	1.3	3.3	2.6
80		—	2.0	1.1	1.4	1.1	1.0
90					1.8	1.3	1.4
100					1.0	0.9	—

Table B-3. Variation of mass throwout with radius for shot 3.

Line radius (ft)	A	B	C	D	A'	B'	C'	D'
	(kg/m^2)							
20	11.2	39.4	115.7	-	No date ↓	99.6	78.9	64.2
25	-	29.4	59.3	69.4		-	16.8	-
30	15.4	10.3	43.1	36.6		11.1	-	-
35	-	4.6	10.4	23.2		-	-	-
40	9.9	3.9	-	-		27.7	-	-
45	-	3.3	-	-		-	-	-

Table B-4. Variation of mass throwout with radius for shot 4.

Line radius (ft)	A	B	C	D	A'	B'	C'	D'
	(kg/m^2)							
25	-	70.4	-	-	12.7	7.6	15.7	28.0
30	-	19.9	-	-	-	-	-	-
35	98.1	8.2	23.4	81.4	8.5	12.7	10.9	6.5
40	25.1	5.3	15.7	32.0	-	-	-	-
45	11.5	8.2	6.5	13.2	4.6	-	4.8	-
50	4.4	-	5.1	4.9	-	-	-	-
55	-	-	-	-	2.5	-	9.7	-
60	-	-	-	-	-	-	-	-

Table B-5. Variation of mass throwout with radius for shot 5.

Line radius (ft)	A	B	C	D	D'	E
	(kg/m^2)					
20	3.9	9.2	4.8	17.0	-	19.6
25	-	-	3.0	-	-	-
30	-	-	-	-	4.4	-

Table B-6. Variation of mass throwout with radius for shot 6.

Line radius (ft)	A	B	C	D	A'	B'	C'	D'
	(kg/m^2)							
20	49.5	-	-	-	84.5	-	-	-
25	5.1	56.1	122.0	84.8	-	-	-	-
30	2.1	1.1	2.1	21.6	10.7	1.6	0.65	32.5
35	T	T	-	1.0	-	-	-	-
40	-	-	1.5	0.6	3.2	T	0.4	0.3
45	-	-	T	T	-	-	-	-
50	-	-	-	-	0.6	-	T	T

Table B-7. Variation of mass throwout with radius. Includes shots off sides and ends. Shot 7.

Line radius (ft)	1	2	A	B	C	D	3	4	5	6	Single shot West South	
	(kg/m ²)											
21					30.3	92.3	67.9					
24			67.3	31.9	16.3	30.6	30.3				57.8	
27			67.8	18.3	10.9	16.2	4.9				21.2	68.3
30			9.2	2.4	11.2	4.0	3.7			5.6	9.2	17.3
33	85.6		3.2	2.1	14.2	5.0	4.5		52.6	2.4	7.0	10.9
36	33.7	74.2	1.4	1.9	17.8	3.9	4.5	46.0	89.3	0.8	4.6	2.1
39	22.6	61.3	0.6	2.3	10.2	3.2		14.2	3.0	1.4	-	2.3
42	9.2	27.5	0.5	1.1	11.2	2.1		2.3	3.4	0.9	7.9	0.7
45	6.8	12.4		0.5	8.2	-		-	-		-	
48	2.9	5.8			2.9	2.1		1.2	2.5		7.3	
51	2.5	3.6			0.7	1.9		1.7	1.6			
54	3.8								2.3			

Table B-8. Variation of mass throwout with radius. Includes mass distribution off sides and ends. Shot 8.

Line radius (ft)	1	2	A	B	C	D	3	4	5
	(kg/m ²)								
21						46.5			
24					43.0	16.8			
27				44.0	22.1	5.6	9.2		
30			54.5	35.7	6.5	3.6	5.7	22.0	
33			-	19.8	2.3	4.9	2.8	9.2	
36			12.4	9.6	1.7	4.2	0.8	1.0	52.0
39		56.1	1.4	0.6	-	3.0		4.4	14.2
42	16.9	36.9	1.4		0.8	0.9			4.4
45	3.1	24.4	1.0			1.6			-
48	2.1	21.2	1.8			0.7			5.8
51	4.3								1.0
54	1.5								-
57	1.6								2.2
60	0.9								
63	1.3								

APPENDIX C. DISPLACEMENT DATA

Table C-1. Target displacement, shot 1.

Target time (sec)	14S15	14S10	14S5	14E2	14N5	13S5	13E2	13NE7	13NE14	13NE21	13NE28
	Displacement (ft)										
0.0049	0	0	0	0	0	0	0	0	0	0	0
0.0146	0.041	0.164	0.287	0.287	0.287	0.492	0.287	0.287	0.082	0.041	0.041
0.0244	0.041	0.204	0.615	0.615	0.615	0.615	0.617	0.615	0.328	0.082	0.082
0.0344	0.246	0.369	0.738	0.984	0.984	0.984	0.984	0.984	0.410	0.205	0.205
0.0432	0.205	0.574	1.025	1.312	1.312	1.312	1.312	1.107	0.533	0.164	0.164
0.0531	0.164	0.697	1.435	1.763	1.763	1.804	1.886	1.435	0.615	0.410	0.410
0.0628	0.246	0.943	1.763	2.050	2.132	2.132	2.255	1.886	0.820	0.451	0.287
0.0722	0.369	1.066	2.132	2.501	2.624	2.706	2.706	2.173	0.861	0.451	0.328
0.0819	0.328	1.312	2.460	3.075	3.116	3.157	3.362	2.583	0.984	0.533	0.328
0.0916	0.656	1.599	2.911	3.608	3.772	3.772	4.018	3.116	1.353	0.738	0.697
0.1006	0.533	1.845	3.198	4.141	4.182	4.305	4.428	3.362	1.476	0.861	0.533
0.1099	0.533	1.968	3.567	4.510	4.633	4.797	4.920	3.690	1.476	0.820	0.328
0.1201	0.779	2.296	3.936	5.002	5.166	5.535	5.576	4.223	1.988	0.984	0.615
0.1289	0.738	2.501	4.305	5.453	5.576	5.863	6.109	4.510	2.091	0.861	0.574
0.1381	0.861	2.788	4.838	6.068	6.191	6.560	6.765	4.920	2.296	1.107	0.738
0.1471	0.943	2.911	5.084	6.478	6.847	7.093	7.503	5.330	2.419	1.271	0.820
0.1575	1.025	3.239	5.576	7.052	7.216	7.708	7.831	5.781	2.665	1.435	0.861
0.1654	1.025	3.362	5.822	7.626	7.667	8.077	8.528	6.068	2.788	1.230	0.820
0.1754	0.861	3.362	6.191	7.913	8.200	8.446	8.938	6.355	2.911	1.271	0.697
0.1841	1.025	3.649	6.478	8.487	8.651	9.102	9.553	6.724	3.034	1.394	0.779
0.1942	1.148	4.018	6.929	9.102	9.102	9.758	10.332	7.093	3.280	1.517	0.902
0.2015	1.271	4.223	7.421	9.553	9.758	10.332	10.988	7.585	3.444	1.568	1.025
0.2120	1.189	4.346	7.626	9.922	10.086	10.783	11.316	7.749	3.362	1.476	0.738
0.2212	1.312	4.633	7.954	10.537	10.742	11.316	12.054	8.282	3.731	1.517	0.943
0.2293	1.066	4.510	8.036	10.619	10.824	11.644	12.341	8.323	3.485	1.230	0.738
0.2589	0.984	5.289	9.184	12.095	12.464	13.243	14.268	9.348	3.854	1.394	0.861
0.2799	1.148	5.781	10.045	12.710	13.858	14.350	15.457	10.086	3.895	1.353	0.738
0.3027	0.779	5.986	10.619	13.448	14.514	15.293	16.646	10.701	3.977	1.189	0.492
0.3245	0.984	6.396	11.521	15.252	15.867	16.564	18.122	11.439	4.100	1.353	0.738
0.3494	0.943	6.929	12.218	15.088	16.851	17.712	19.270	11.972	4.182	1.271	0.574
0.3701	0.861	7.175	12.710	15.498	17.958	18.532	20.541	12.628	4.264	1.312	0.574
0.3908	0.615	7.503	13.079	16.400	19.147	19.639	21.566	13.079	4.100	0.984	0.369
0.4159	0.738	7.872	13.653	17.548	20.295	20.910	22.960	13.817	4.059	1.230	0.533
0.4373	0.328	7.995	13.817	18.532	20.992	21.156	23.534	13.735	3.567	0.656	0.205
0.4582	0.738	8.528	14.637	19.434	22.099	22.673	25.092	14.678	4.100	1.066	0.492
0.5028	0.246	8.856	15.580	20.418	23.903	24.026	26.978	15.293	4.018	0.656	0.287
0.5496	0.820	9.389	16.113	20.992	25.666	25.666	29.397	16.195	3.936	1.476	0.369
0.6812	0.615	10.414	17.876	23.821	30.627	30.627	35.178	21.812		2.870	0.123
0.7691	0.205	10.947	18.327	25.256	33.046	33.866	38.991	19.311		1.968	0.164
0.8590	0.615	11.357	20.131	29.971	35.916	36.736	42.476	19.967		1.025	0.205
1.0347	2.542	11.726	18.327	28.905	40.467	41.369	49.036	21.402			
1.1649	1.435	12.300	20.910	32.554	43.132	44.034	52.849	21.566			

Table C-2. Target displacement, shot 2.

Target time (sec)	21N10	21N5	21E2	21S5	22N5	22E2	22S5	22E10	22E15	22E20
	Displacement (ft)									
0.0044	0	0	0	0	0	0	0	0	0	0
0.0220	0.033	0.676	0.364	0.624	0.624	0.624	0.624	0.624	0.624	0.624
0.0443	0.099	0.624	0.624	0.624	0.884	0.884	0.884	0.884	0.208	0.208
0.0658	0.198	1.092	2.080	2.080	2.132	2.236	2.756	2.860	0.936	0.364
0.0877	0.165	1.404	2.704	3.848	3.848	3.848	3.848	3.848	1.404	0.208
0.1093	0.033	1.976	4.108	4.784	4.784	5.044	5.044	5.044		1.300
0.1306	0.165	2.444	5.044	6.084	6.292	6.292	6.292	6.604	1.664	1.040
0.1519	0.165	2.912	5.772	7.332	7.332	7.748	7.280	7.592	0.728	0.468
0.1727	0.198	3.172	7.176	9.412	9.412	9.412	8.400	8.944	3.640	1.196
0.1951	0.462	3.536	8.528	10.712	10.712	10.712	10.452	10.452	3.432	0.468
0.2151	0.363	2.912	10.868	10.868	10.868	10.868	10.868	10.816	3.484	0.260
0.2567	0.165	4.888	16.276	16.276	16.276	14.664	14.508	14.664	5.512	0.936
0.2992	0.132	4.680	18.876	18.876	18.876	18.876	16.484	16.484	6.032	1.092
0.3443	0.165	4.940	21.736	21.580	21.580	21.580	18.460	18.460	5.720	0.624
0.3818	0.264	5.668	25.168	25.116	25.116	25.116	21.216	21.216	6.968	1.664
0.4672	0.165	6.032	30.212	30.004	30.316	30.316	24.596	24.596	7.280	0.676
0.5936	0.165	6.864	38.272	38.064	38.064	38.064	29.328	29.328	8.164	0.780

Table C-3. Target displacement, shot 3.

Target time (sec)	32.5E15	32.5E10	32.5E5	32.5E0	32.5N5	32E2	32N5	32N10	31S5	31E2	31N5	31N10
	Displacement (ft)											
0.0011	0	0	0	0	0	0	0	0	0	0	0	0
0.0032	0.046	0.138	0.138	0	0	0.184	0.276	0.276	0.092	0.092	0.322	0
0.0076	0	0	0	0.138	0.138	0.230	0.322	0.322	0.138	0.138	0.460	0.276
0.0097	0.046	0.092	0.092	0.230	0.322	0.598	0.276	0.276	0.092	0.092	0.506	0.322
0.0119	0.230	0.230	0.230	0.322	0.276	0.552	0.230	0.230	0.046	0.046	0.460	0.046
0.0140	0.046	0.138	0.138	0.276	0.276	0.368	0.368	0.368	0.184	0.184	0.460	0.276
0.0162	0.138	0.138	0.230	0.368	0.368	0.506	0.414	0.414	0.368	0.368	0.644	0.414
0.0184	0.122	0.138	0.368	0.506	0.506	0.598	0.460	0.460	0.276	0.276	0.460	0.138
0.0205	0.322	0.322	0.322	0.460	0.460	0.690	0.690	0.690	0.506	0.322	0.736	0.460
0.0227	0.230	0.230	0.460	0.736	0.966	0.920	0.828	0.552	0.598	0.598	0.644	0.460
0.0248	0.184	0.230	0.322	0.644	0.828	0.920	0.690	0.690	0.552	0.552	0.690	0.506
0.0270	0.138	0.138	0.138	0.506	0.506	0.874	0.598	0.460	0.690	0.690	0.690	0.322
0.0302	0.092	0.184	0.414	0.690	0.782	1.058	0.736	0.506	0.736	0.736	0.874	0.092
0.0334	0.414	0.552	0.644	0.966	1.426	1.472	1.196	0.874	1.104	1.012	1.196	0.552
0.0366	0.322	0.322	0.552	0.920	1.150	1.380	0.966	0.782	0.920	0.920	1.196	0.598
0.0399	0.506	0.690	0.736	1.196	1.334	1.610	1.380	1.288	1.288	1.288	1.426	0.874
0.0431	0.552	0.598	0.828	1.150	1.242	1.840	1.288	1.196	1.472	1.472	1.426	0.782
0.0463	0.552	0.552	0.920	1.380	1.472	2.024	1.518	1.242	1.472	1.472	1.610	0.782
0.0495	0.368	0.598	1.058	1.334	1.518	1.886	1.564	1.334	1.518	1.518	1.702	0.736
0.0538	0.322	0.644	0.874	1.472	1.702	2.070	1.794	1.242	1.794	1.748	1.794	0.828
0.0591	0.552	0.966	1.150	1.610	1.656	2.208	2.162	1.472	2.070	2.024	2.070	0.966
0.0645	0.552	0.920	1.242	1.748	2.024	2.622	2.208	1.656	2.300	2.300	2.162	0.966
0.0698	0.506	0.828	1.380	2.024	2.346	2.760	2.346	1.748	2.346	2.346	2.438	1.058
0.0751	0.598	1.012	1.656	2.254	2.760	3.266	2.944	2.024	2.760	2.760	2.622	1.104
0.0804	0.414	1.104	1.656	2.162	2.668	3.266	2.990	2.208	2.806	3.036	2.806	1.012
0.0858	0.598	1.334	1.978	2.346	3.128	3.772	3.404	2.576	3.220	3.220	2.990	1.196
0.0910	0.782	1.242	1.932	2.576	3.036	4.048	3.496	2.622	3.358	3.588	3.312	1.656
0.0963	0.644	1.196	1.978	2.668	3.312	4.140	3.772	2.714	3.634	3.634	3.358	1.472
0.1017	0.598	1.242	2.070	2.622	3.496	4.324	3.910	2.852	3.726	3.772	3.496	1.426
0.1069	0.828	1.288	2.438	3.174	4.048	4.876	4.462	3.312	4.186	4.186	4.002	1.840
0.1122	0.460	1.380	2.346	3.266	4.048	4.922	4.646	3.266	4.370	4.370	4.048	1.794
0.1175	0.782	1.472	2.622	4.278	5.198	5.152	1.196	1.932	2.852	3.772	4.922	5.474
0.1228	1.012	1.656	3.174	4.002	4.968	5.750	5.382	4.232	5.198	5.244	4.738	2.208
0.1280	0.966	1.932	3.266	4.232	5.152	6.164	5.658	4.370	5.566	5.566	4.876	2.254
0.1333	0.966	1.978	3.358	4.278	4.830	6.302	5.704	4.278	5.520	5.658	5.014	2.254
0.1385	1.058	1.932	3.496	4.416	5.106	6.440	5.980	4.232	5.888	6.118	5.106	2.392
0.1438	1.058	1.932	3.588	4.554	5.658	6.946	6.302	4.876	6.072	6.440	5.198	2.438
0.1490	0.920	1.794	3.818	4.968	6.026	7.084	6.670	5.244	6.302	6.532	5.704	2.898
0.1543	0.920	2.208	3.910	4.876	6.348	7.222	6.900	5.520	6.486	7.038	5.888	2.806
0.1595	1.288	2.346	4.416	5.704	7.544	8.050	7.498	6.026	7.176	7.682	6.486	3.312
0.1647	0.828	2.254	4.416	5.474	7.222	7.958	7.498	5.612	6.946	7.728	6.348	3.220
0.1699	1.104	2.530	4.830	5.980	7.682	8.556	8.096	6.256	7.498	8.096	6.900	3.404
0.1751	1.104	2.392	4.508	6.072	7.452	8.694	7.912	6.302	7.452	8.280	6.808	3.082
0.1803	1.058	2.484	4.738	6.946	7.222	8.740	8.142	5.980	8.050	8.602	6.992	3.266
0.1855	1.012	2.484	4.738	6.486	7.866	8.970	8.464	6.762	7.912	8.648	7.360	3.266
0.1907	0.966	2.714	5.060	8.142	8.648	9.430	8.832	6.762	8.326	9.292	7.636	3.588
0.1959	1.104	2.760	5.244	7.636	8.556	9.798	9.062	7.084	8.464	9.476	7.682	3.496
0.2010	1.196	2.714	5.106	7.314	8.694	10.166	9.338	7.406	9.016	9.844	7.958	3.542
0.2062	0.920	2.852	5.474	7.498	9.384	10.350	9.739	7.774	9.016	10.120	8.096	3.772
0.2114	1.242	2.806	5.612	7.498	8.418	10.626	10.028	7.866	9.246	10.580	8.234	3.680
0.2217	1.242	3.128	6.026	8.188	9.246	11.408	10.396	8.648	9.844	11.132	8.740	4.048
0.2320	1.150	3.266	6.072	9.154	10.534	11.776	11.178	9.154	10.166	11.454	9.200	3.956
0.2424	1.058	3.220	6.348	9.016	11.316	12.558	11.546	9.706	10.856	12.098	9.522	4.002
0.2526	1.242	3.634	6.762	10.304	12.144	13.202	12.466	10.350	11.408	13.018	10.304	4.508
0.2629	1.242	3.772	6.992	9.844	11.868	13.754	13.340	11.086	12.052	13.616	10.580	4.830
0.2835	1.104	3.634	7.406	10.948	13.754	14.904	13.156	12.236	13.846	14.812	11.454	4.922
0.3040	1.288	4.002	7.958	12.328	15.088	16.100	14.490	13.432	15.318	16.008	12.190	5.152
0.3241	1.012	4.232	8.418	12.282	15.686	17.204	15.364	14.444	16.330	16.928	12.972	5.060
0.3448	1.058	4.278	8.832	13.616	16.836	18.170	16.238	15.134	17.526	18.492	13.064	5.336
0.3654	1.012	4.462	9.292	14.260	17.572	19.504	15.824	15.364	17.710	19.550	12.834	5.428
0.4160	0.920	4.922	10.212	15.134	19.090	21.988	21.206	19.366	21.344	22.862	15.594	5.842
0.4663	0.736	5.106	11.040	15.732	21.068	24.380	23.368	21.896	24.334	25.622	17.986	6.026
0.5288	0.828	4.922	11.776	18.446	22.862	26.496	26.266	24.610	21.758	28.336	18.860	6.210
0.5467	0.690	4.830	12.466	17.940	23.138	28.382	27.232	25.346	27.738	31.004	22.034	6.256
0.6210	0.782	4.784	12.788	19.688	24.150	29.900	28.704	27.094	30.682	33.580	22.724	6.210

Table C-4. Target displacement, shot 4.

Target time (sec)	41N10	41N5	41E2	41S5	42N10	42N5	42E2	42.5N5	42.5N0	42.5E5	42.5E10
	Displacement (ft)										
0.0010	0	0	0	0	0	0	0	0	0	0	0
0.0041	0.216	0.216	0.270	0.162	0.108	0.081	0.324	0.189	0.081	0.162	0.189
0.0073	0.216	0.297	0.486	0.270	0.243	0.189	0.432	0.459	0.216	0.270	0.243
0.0104	0.162	0.189	0.459	0.162	0.054	0.081	0.378	0.216	0.081	0.054	0.054
0.0135	0.108	0.432	0.378	0.405	0.270	0.594	0.648	0.486	0.270	0.324	0.162
0.0197	0.675	0.783	0.999	0.648	0.594	0.783	0.837	0.702	0.486	0.486	0.432
0.0228	0.432	0.594	0.432	0.594	0.486	0.540	0.756	0.567	0.297	0.297	0.270
0.0259	0.216	0.378	0.567	0.432	0.378	0.432	0.702	0.540	0.270	0.270	0.027
0.0290	0.567	0.729	1.188	0.918	0.675	0.864	1.053	0.891	0.62	0.594	0.216
0.0321	0.702	0.891	1.296	1.026	0.783	0.999	1.188	1.026	0.756	0.756	0.432
0.0352	0.594	1.053	1.215	0.972	0.729	1.026	1.188	1.026	0.756	0.756	0.351
0.0383	0.810	1.215	1.458	1.215	0.972	1.215	1.539	1.377	0.918	0.810	0.648
0.0414	0.648	1.269	1.350	1.134	0.891	1.242	1.512	1.350	0.864	0.810	0.594
0.0445	0.864	1.431	1.512	1.404	0.864	1.485	1.782	1.512	1.215	1.107	0.783
0.0476	0.864	1.512	1.701	1.458	1.188	1.323	1.647	1.485	1.026	0.972	0.648
0.0507	0.972	1.485	1.728	1.593	1.323	1.539	1.890	1.728	1.188	1.107	0.675
0.0537	1.053	1.809	1.971	1.728	1.431	1.836	2.133	1.917	1.404	1.242	0.756
0.0568	1.053	1.674	2.187	1.863	1.485	1.863	2.025	1.863	1.458	1.323	0.972
0.0599	1.053	1.944	2.268	1.971	1.566	2.106	2.214	2.052	1.431	1.188	0.648
0.0630	1.350	2.295	2.484	2.268	1.890	2.295	2.457	2.295	1.674	1.458	0.945
0.0671	1.215	2.187	2.430	2.187	1.809	2.214	2.619	2.187	1.593	1.485	0.67
0.0712	1.458	2.430	2.862	2.457	1.998	2.592	2.592	2.457	1.836	1.701	1.188
0.0763	1.674	2.673	3.024	2.997	2.403	2.970	3.267	2.835	2.214	1.863	1.080
0.0814	1.782	2.808	3.429	3.240	2.484	3.267	3.537	3.051	2.376	2.214	1.188
0.0875	1.701	3.024	3.645	3.186	2.592	3.348	3.537	3.02	2.565	2.133	1.080
0.0926	1.836	3.213	3.888	3.456	2.781	3.537	3.780	3.483	2.646	2.187	1.215
0.0977	2.106	3.564	4.293	3.726	2.997	3.969	4.212	3.672	2.970	2.538	1.458
0.1028	2.214	3.780	4.509	4.050	3.240	4.131	4.509	4.050	3.078	2.700	1.404
0.1079	2.457	4.023	4.779	4.212	3.564	4.536	4.725	4.239	3.348	2.862	1.620
0.1130	2.538	4.212	4.941	4.482	3.672	4.698	5.022	4.266	3.348	2.916	1.674
0.1181	2.646	4.482	5.184	4.671	3.834	4.914	5.238	4.671	3.780	3.213	1.782
0.1231	2.943	4.590	5.643	5.211	4.104	5.292	5.589	4.887	3.915	3.375	1.836
0.1282	2.970	4.860	5.913	5.130	4.239	5.427	5.940	5.130	3.969	3.537	1.971
0.1322	2.970	5.157	5.994	5.373	4.455	5.670	6.048	5.346	4.185	3.591	1.971
0.1383	3.456	5.535	6.696	5.778	4.914	6.183	6.696	5.778	4.671	3.969	2.214
0.1434	3.402	5.562	6.696	6.021	4.968	6.210	6.723	5.805	4.644	4.050	2.079
0.1484	3.591	5.940	7.020	6.210	5.211	6.642	7.182	6.210	4.752	4.266	2.322
0.1534	3.699	6.102	7.371	6.561	5.562	6.993	7.425	6.399	5.049	4.428	2.457
0.1585	3.699	6.291	7.587	6.696	5.535	7.074	7.695	6.453	5.184	4.590	2.592
0.1635	3.888	6.642	7.11	6.966	5.805	7.398	7.884	6.804	5.292	4.860	2.646
0.1686	4.212	6.858	8.289	7.344	5.859	7.614	8.424	7.047	5.697	4.860	2.673
0.1735	4.185	7.047	8.532	7.533	6.291	7.884	8.640	7.371	5.832	5.211	2.727
0.1786	4.131	7.182	8.694	7.587	6.318	8.154	8.748	7.425	5.832	5.211	2.592
0.1836	4.617	7.614	9.180	8.019	6.669	8.532	9.342	7.803	6.021	5.562	2.862
0.1886	4.536	7.776	9.450	8.289	6.993	8.748	9.450	8.073	6.399	5.670	3.078
0.1936	4.725	7.965	9.693	8.451	7.155	8.937	9.936	8.208	6.534	5.832	2.889
0.1986	4.941	8.154	9.963	8.667	7.425	9.234	10.233	8.424	6.831	5.832	2.970
0.2036	5.103	8.451	10.422	9.180	7.776	9.693	10.503	8.937	7.101	6.264	3.105
0.2135	5.292	8.937	10.800	9.504	7.803	10.044	11.043	9.234	7.425	6.561	3.321
0.2235	5.454	9.423	11.475	10.125	8.424	10.611	11.691	9.936	8.235	6.831	3.321
0.2335	5.643	9.639	12.015	10.395	8.721	11.043	12.150	10.152	8.748	7.074	3.483
0.2434	5.859	10.260	12.717	10.908	9.261	11.556	12.717	10.719	10.503	7.425	3.402
0.2631	9.153	13.851	16.497	14.607	12.771	15.471	18.902	14.634			6.615
0.2833	6.804	12.069	14.877	10.854	13.743	13.743	15.120	12.555	12.285	8.532	3.969
0.3027	7.074	12.690	15.957	13.446	11.475	14.715	16.308	13.392	13.122	9.072	3.915
0.3225	7.506	13.500	17.199	14.418	12.177	15.579	17.631			9.477	3.969
0.3419	8.046	14.445	18.360	15.255	12.906	16.821	18.522	15.255	15.012	10.206	4.023
0.3624	8.478	15.390	19.575	16.065	13.851	17.793	19.872	16.686	16.416	10.719	4.482
0.3813	8.721	15.822	20.331	16.821	14.229	18.225	20.655	16.983	16.740	11.070	4.077
0.4006	8.856	16.713	21.276	17.415	15.147	19.224	21.438			11.556	4.239
0.4216	9.180	17.172	22.329	18.036	15.552	20.061	22.005			11.961	4.239
0.4598	9.963	18.657	24.354	19.305		21.492	21.330	21.168	19.926	12.906	4.266
0.4988	10.260	19.764	26.001	20.844		22.923	17.95			13.392	4.104
0.5581	11.016	21.897	28.809	23.031		25.596	23.085			14.202	4.131
0.6183	11.394	23.841	30.969				26.622			14.742	3.807

Table C-5. Target displacement, shot 5.

Target time (sec)	Displacement (ft)										
	51N10	51N5	51E2	52N5	52E2	52.5N0	52.5SE7	52.5SE14	52.5SE21	52.5SE28	52E2
0.0011	0	0	0	0	0	0	0	0	0	0	0
0.0032	0.093	0.093	0	0.062	0.093	0	0.093	0	0	0.031	0.031
0.0054	0.186	0.155	0.186	0.093	0.031	0.093	0.155	0.186	0.186	0.062	0.062
0.0076	0	0.031	0.093	0.062	0.093	0.062	0.031	0.031	0.031	0.093	0
0.0097	0.217	0.124	0.062	0.124	0.031	0	0.093	0.062	0.062	0.093	0.093
0.0119	0.062	0.031	0.093	0.062	0.093	0.093	0	0.031	0.031	0	0.093
0.0140	0.093	0	0.124	0.031	0.062	0.031	0.093	0.093	0	0	0.093
0.0162	0.093	0	0.031	0.093	0.124	0.062	0.031	0.062	0.062	0.093	0.093
0.0184	0.124	0.186	0.341	0.310	0.310	0.310	0.217	0.248	0.155	0.186	0.186
0.0216	0.124	0.186	0.279	0.310	0.372	0.403	0.155	0.186	0.155	0.062	0.124
0.0270	0.062	0.124	0.186	0.217	0.279	0.248	0.186	0.124	0.124	0.062	0.062
0.0324	0.062	0.372	0.496	0.558	0.620	0.558	0.465	0.403	0.310	0.217	0.279
0.0377	0.093	0.310	0.434	0.434	0.496	0.496	0.403	0.279	0.186	0.124	0.217
0.0431	0.217	0.403	0.558	0.682	0.744	0.620	0.527	0.403	0.310	0.434	0.434
0.0484	0.248	0.558	0.651	0.713	0.775	0.620	0.651	0.465	0.341	0.155	0.496
0.0538	0.341	0.527	0.775	0.775	0.930	0.837	0.744	0.620	0.403	0.279	0.620
0.0591	0.403	0.682	0.961	1.085	1.085	0.992	0.961	0.651	0.403	0.217	0.806
0.0645	0.341	0.682	0.992	1.023	1.085	1.116	0.992	0.744	0.465	0.310	0.868
0.0698	0.434	0.744	1.054	1.116	1.178	1.054	0.961	0.713	0.310	0.186	0.899
0.0751	0.434	0.868	1.178	1.333	1.364	1.333	1.147	0.868	0.589	0.341	0.992
0.0804	0.589	1.147	1.488	1.550	1.581	1.488	1.395	0.992	0.682	0.372	1.271
0.0858	0.682	1.240	1.488	1.612	1.674	1.581	1.457	1.085	0.682	0.341	1.333
0.0910	0.837	1.488	1.736	1.860	1.922	1.798	1.705	1.333	0.837	0.403	1.612
0.0963	0.837	1.426	1.643	1.767	1.829	1.674	1.643	1.240	0.744	0.279	1.612
0.1017	0.899	1.457	1.891	1.984	2.046	1.953	1.798	1.395	0.806	0.310	1.829
0.1069	1.054	1.736	1.984	2.108	2.170	2.077	1.984	1.457	0.806	0.341	1.891
0.1175	1.209	1.984	2.325	2.449	2.542	2.387	2.294	1.798	0.992	0.434	2.201
0.1280	1.457	2.294	2.666	2.759	2.852	2.728	2.635	1.984	1.085	0.558	2.635
0.1386	1.643	2.573	2.852	3.100	3.162	3.007	2.914	2.232	1.333	0.651	2.821
0.1490	1.860	2.790	3.100	3.379	3.441	3.286	3.193	2.511	1.488	0.682	3.131
0.1596	2.108	3.255	3.534	3.782	3.906	3.751	3.658	2.821	1.767	0.837	3.503
0.1701	2.263	3.348	3.782	3.937	3.999	3.844	3.751	2.914	1.550	0.620	3.658
0.1805	2.418	3.751	4.216	4.340	4.495	4.340	4.247	3.224	1.891	0.837	4.092
0.1908	2.635	4.030	4.464	4.681	4.836	4.681	4.526	3.503	2.108	0.775	4.495
0.2016	2.883	4.309	4.867	5.084	5.146	4.991	4.836	3.875	2.232	0.930	4.743
0.2118	3.100	4.650	5.084	5.332	5.394	5.239	5.084	3.875	2.232	0.775	4.898
0.2220	3.131	4.743	5.208	5.363	5.487	5.332	5.270	4.123	2.263	0.682	5.177
0.2325	3.441	5.177	5.580	5.952	6.014	5.797	5.704	4.464	2.573	0.899	5.642
0.2431	3.503	5.301	5.797	6.138	6.200	6.045	5.952	4.712	2.542	0.868	5.890
0.2531	3.627	5.642	6.107	6.510	6.541	6.386	6.138	4.867	2.635	0.775	6.076
0.2632	3.968	5.921	6.479	6.758	6.820	6.665	6.572	5.115	2.790	0.868	6.386
0.2744	3.968	6.169	6.696	7.068	7.130	6.975	6.727	5.425	2.852	0.899	6.603
0.2842	4.216	6.386	7.006	7.440	7.471	7.316	7.161	5.642	3.069	0.837	6.975
0.2941	4.495	6.758	7.657	7.812	7.874	7.719	7.595	6.045	3.348	1.023	7.378
0.3047	4.619	6.975	7.595	7.936	8.091	7.936	7.626	6.076	3.286	1.023	7.533
0.3150	4.743	7.316	7.905	8.246	8.308	8.153	7.874	6.138	3.348	0.837	7.781
0.3356	5.022	7.719	8.587	8.990	8.990	8.835	8.525	6.758	3.565	1.054	8.339
0.3554	4.929	7.688	8.618	9.176	9.238	9.083	8.587	6.882	3.441	0.651	8.587
0.3770	5.611	8.711	9.548	10.168	10.199	10.044	9.517	7.595	4.030	1.147	9.455
0.3969	5.673	8.990	10.075	10.633	10.695	10.540	9.920	7.874	3.999	0.930	9.703
0.4172	6.045	9.517	10.602	11.222	11.222	11.067	10.385	8.184	4.154	1.023	10.292
0.4688	6.417	10.323	11.594	12.152	12.214	12.183	11.470	9.083			11.346
0.5198	7.037	11.532	12.958	13.640	13.578	13.578	12.710	10.044		1.333	12.648
0.5697	7.533	12.276	14.043	14.787	14.570	14.694	13.640	10.540		1.612	13.578
0.6217	7.905	12.927	14.849	15.624	15.500	16.275	14.539	11.160	4.495	1.395	14.291
0.6731	8.060	13.733	15.779	16.523	16.399	17.236	15.376	11.594	4.898	1.364	15.252
0.7226	8.4012	14.353	16.802	17.608	17.205	18.259	16.182	12.338	4.960	1.364	15.903
0.7717	8.3398	14.725	17.484	18.166	17.794	18.972	16.585	12.462	4.867	1.457	16.492
0.8481	8.6496	15.469	18.290	18.972	18.383	19.933	17.329	13.020	4.588	1.302	17.174
0.8299	8.7424	15.965	19.096	19.530	18.972	20.708	18.042	13.516	4.588	1.178	17.887
0.9283	8.7114	16.368	19.592	20.181	19.065	21.328	18.197	13.299	4.185	1.488	18.011
0.9761	8.7424	16.647	20.088	20.708	19.437	22.010	18.569	13.423	4.061	1.178	18.352
1.0755	8.5566	17.298	21.142	21.793	19.561	23.095	19.003	13.392	4.123	1.147	18.910

Table C-6. Target displacement, shot 6.

Target time (sec)	61N15	61N10	61N5	62N8	62E3 Displacement (ft)	63N5	63E3	63E8	63E13	63E18
0.0012	0	0	0	0	0	0	0	0	0	0
0.0048	0.031	0.031	0.031	0.093	0.093	0.093	0.124	0.031	0.031	0.217
0.0096	0.248	0.248	0.031	0.031	0.031	0	0	0.155	0.062	0.062
0.0143	0.062	0.062	0.062	0	0.062	0.062	0	0.124	0.186	0.062
0.0191	0.341	0.310	0.310	0.217	0.279	0.279	0.217	0.031	0.279	0.465
0.0239	0.031	0	0.031	0.248	0.186	0.093	0.093	0.093	0.093	0
0.0287	0.186	0.186	0.186	0.186	0.341	0.248	0.093	0.093	0.093	0
0.0313	0.155	0.155	0.155	0.341	0.589	0.527	0.310	0.062	0	0.031
0.0337	0.124	0.124	0.124	0.434	0.434	0.434	0.341	0.093	0.124	0.093
0.0379	0.310	0.279	0.279	0.341	0.651	0.527	0.372	0.031	0.124	0.031
0.0427	0.372	0.496	0.496	0.713	0.837	0.930	0.744	0.651	0.527	0.434
0.0474	0.434	0.496	0.465	0.806	0.868	0.806	1.159	0.589	0.558	0.527
0.0522	0.372	0.372	0.620	0.434	0.930	0.930	0.930	0.682	0.558	0.465
0.0569	0.465	0.403	0.651	1.054	1.054	1.116	1.085	0.713	0.496	0.403
0.0616	0.434	0.527	0.651	0.868	1.054	1.054	1.085	0.713	0.496	0.403
0.0663	0.297	0.589	0.558	0.930	1.147	1.209	1.147	0.620	0.434	0.403
0.0710	0.682	0.868	0.961	1.395	1.612	1.426	1.395	0.899	0.713	0.651
0.0757	0.558	0.868	0.930	1.426	1.612	1.519	1.302	0.899	0.465	0.403
0.0804	0.620	0.899	1.085	1.612	1.643	1.705	1.705	0.868	0.620	0.434
0.0851	0.651	0.775	0.961	1.302	1.674	1.643	1.426	1.023	1.116	0.651
0.0898	0.651	0.992	1.147	1.860	1.860	1.860	1.643	1.240	1.054	0.775
0.0945	0.620	1.054	1.271	1.581	1.736	1.705	1.674	1.209	0.806	0.558
0.0992	0.558	0.775	1.023	1.674	1.953	1.736	1.674	1.023	0.930	0.589
0.1038	0.806	1.085	1.426	1.984	2.108	2.108	1.674	1.023	0.930	0.589
0.1085	0.899	1.240	1.674	2.232	2.542	2.170	2.170	1.333	0.992	0.806
0.1131	0.806	1.178	1.488	2.077	2.015	2.108	1.922	1.364	0.837	0.713
0.1248	0.744	1.240	1.674	2.418	2.542	2.511	2.201	1.426	0.775	0.527
0.1363	0.899	1.364	1.953	2.604	2.914	2.821	2.635	1.891	1.364	0.868
0.1480	0.992	1.550	2.232	3.131	3.255	3.100	2.790	1.953	1.240	0.682
0.1595	0.868	1.736	2.449	3.286	3.503	3.286	3.007	2.232	1.333	0.682
0.1710	1.147	2.046	2.821	3.813	4.030	3.937	3.410	2.387	1.736	0.837
0.1823	1.271	2.201	3.038	4.216	4.216	4.154	3.782	2.914	1.767	0.837
0.1942	1.178	2.325	3.472	4.402	4.960	4.557	3.782	2.914	1.767	0.837
0.2054	1.302	2.573	3.720	4.712	4.991	4.991	4.371	3.162	2.139	0.899
0.2167	1.643	2.945	3.999	5.518	5.487	5.208	4.774	3.565	2.294	1.147
0.2283	1.643	3.441	4.464	5.611	6.014	5.797	5.115	3.937	2.511	1.147
0.2513	1.643	3.503	4.774	6.355	6.293	6.107	5.642	4.030	2.759	1.085
0.2738	1.612	3.658	5.239	7.006	7.037	6.820	6.231	4.557	3.131	0.992
0.2962	1.953	4.278	6.076	7.843	7.905	7.688	6.231	4.557	3.131	0.992
0.3202	1.891	4.619	6.448	8.401	8.463	8.277	7.502	5.642	3.503	1.116
0.3420	2.015	4.805	7.068	9.176	9.238	8.866	8.122	5.983	3.906	1.271
0.3641	1.984	5.022	7.533	9.920	9.765	9.455	8.432	6.324	3.999	1.271
0.3875	2.077	5.487	8.122	10.478	10.447	10.106	9.393	6.944	4.216	1.240
0.4101	1.984	5.456	8.525	11.129	11.036	10.726	9.734	7.192	4.433	1.271
0.4311	1.891	5.735	8.866	11.749	11.563	11.129	10.137	7.316	4.402	1.302
0.4543	1.767	5.828	9.393	12.369	12.121	11.811	10.664	7.564	4.402	1.302
0.4890	1.798	5.828	10.044	13.113	12.741	12.741	11.687	8.122	4.650	1.178
0.5222	1.488	5.952	10.571	13.795	13.671	12.989	12.028	8.618	4.650	1.147
0.5542	1.488	6.014	11.191	14.818	14.384	14.043	12.710	8.556	4.867	0.775
0.6232	1.240	5.921	12.183	16.461	15.903	15.252	13.795	9.734	4.650	0.930
0.6573	0.775	5.952	12.431	16.678	16.275	15.624	14.043	9.362	4.464	0.744
0.6869	0.961	5.921	13.206	17.608	17.205	16.461	14.818	10.013	4.774	0.837
0.7230	0.868	5.673	13.330	18.073	17.391	16.833	15.190	10.230	4.495	0.744
0.7566	0.744	5.208	13.888			17.484	15.407	10.075	3.813	0.620
0.7885	0.806	4.991	13.981		18.631		15.872	10.323	3.968	0.620
0.8204	0.651	4.681	14.384		18.972		16.182	10.168	3.441	0.744
0.8897	0.651	3.689	14.663	20.491	19.747	18.848	16.678	9.982	3.007	0.620
0.9208	0	2.790	14.043	20.460	19.995	19.282	16.616	10.013	2.108	0.186
0.9511	0.093	2.666	15.066			19.654	17.298	10.013	2.077	0.558
0.9861	0.124	1.953	15.097			19.778	17.143	9.858	1.302	0.403

Table C-7. Target displacement, shot 7.

Target time (sec)	71N18	71N12	71N6	71E4	71S6	72N6	Target time (sec)	71N18	71N12	71N6	71E4	71S6	72N6
	Displacement (ft)							Displacement (ft)					
0.0011	0	0	0	0	0	0	0.1672	0.759	1.914	3.828	4.752	4.719	4.554
0.0032	0.033	0.033	0.099	0.066	0.033	0	0.1723	0.858	2.211	3.993	4.785	5.049	4.818
0.0053	0.099	0.132	0.099	0.231	0.099	0.165	0.1773	0.825	2.376	3.960	4.884	5.115	4.818
0.0075	0.198	0.099	0.066	0.033	0.033	0.132	0.1826	0.693	2.211	4.323	5.115	5.346	5.049
0.0096	0.165	0.132	0.165	0.297	0.198	0.099	0.1877	0.792	2.178	4.455	5.313	5.544	5.280
0.0117	0.033	0.033	0.165	0.297	0.297	0.132	0.1928	0.792	2.343	4.455	5.379	5.610	5.412
0.0139	0.165	0.066	0.198	0.330	0.264	0.363	0.1979	0.627	2.244	4.488	5.478	5.808	5.445
0.0160	0.165	0.165	0.462	0.462	0.429	0.363	0.2030	1.122	2.673	4.884	5.841	6.303	5.907
0.0181	0.198	0.198	0.363	0.462	0.528	0.495	0.2081	0.759	2.376	4.653	5.808	6.138	5.775
0.0202	0.462	0.495	0.627	0.759	0.693	0.792	0.2182	0.990	2.805	5.049	6.402	6.765	6.369
0.0223	0.363	0.297	0.495	0.594	0.561	0.528	0.2284	1.056	2.970	5.412	6.600	7.194	6.600
0.0244	0.165	0.033	0.297	0.429	0.495	0.330	0.2386	0.957	3.036	5.412	6.930	7.425	6.864
0.0266	0.132	0.165	0.363	0.528	0.594	0.462	0.2485	1.287	3.267	5.775	7.260	7.953	7.524
0.0287	0.165	0.363	0.495	0.693	0.660	0.528	0.2587	1.122	3.168	5.973	7.557	8.184	7.755
0.0308	0.264	0.396	0.132	0.165	0.132	0.099	0.2689	1.221	3.498	6.270	7.887	8.547	8.085
0.0329	0.165	0.132	0.495	0.561	0.627	0.627	0.2789	0.891	3.366	6.171	7.920	8.712	8.085
0.0350	0.165	0.297	0.561	0.693	0.726	0.693	0.2888	0.891	3.531	6.501	8.415	9.174	8.580
0.0371	0.330	0.363	0.660	0.792	0.858	0.891	0.2981	1.056	3.432	6.501	8.547	9.537	8.943
0.0392	0.297	0.297	0.792	0.759	0.825	0.792	0.3091	1.056	3.795	7.029	8.943	9.999	9.174
0.0414	0.231	0.396	0.693	0.924	0.957	0.957	0.3189	0.990	3.828	6.864	9.141	10.395	9.405
0.0435	0.198	0.264	0.660	0.990	0.924	0.891	0.3289	1.122	3.960	7.194	9.669	10.725	9.966
0.0456	0.264	0.429	0.891	1.089	1.122	1.056	0.3391	1.023	4.026	7.392	9.801	10.989	10.098
0.0477	0.198	0.396	0.759	0.891	0.990	0.924	0.3489	0.858	3.894	6.996	9.933	11.187	10.263
0.0498	0.231	0.396	0.660	1.155	1.122	1.122	0.3586	1.353	4.356	7.821	10.461	11.847	10.857
0.0519	0.231	0.462	0.825	1.089	0.990	1.056	0.3691	1.254	4.422	7.656	10.692	12.177	10.956
0.0540	0.363	0.561	0.891	1.221	1.287	1.287	0.3789	0.891	4.323	7.854	10.857	12.177	11.187
0.0635	0.297	0.528	1.056	1.518	1.551	1.353	0.3882	1.056	4.488	8.151	11.187	12.705	11.517
0.0687	0.396	0.627	1.353	1.617	1.650	1.518	0.3985	1.056	4.488	8.085	11.550	12.903	11.715
0.0739	0.396	0.759	1.518	1.749	1.782	1.617	0.4087	1.089	4.488	8.382	11.814	13.233	12.177
0.0792	0.495	0.990	1.617	1.947	1.947	1.782	0.4281	0.957	4.521	8.514	11.946	13.860	12.672
0.0844	0.528	0.825	1.650	2.145	2.013	1.881	0.4477	1.056	4.884	9.108	12.903	14.619	13.398
0.0896	0.495	0.792	1.749	2.211	2.211	2.046	0.4684	1.353	5.082	9.570	13.431	15.510	13.926
0.0948	0.396	0.924	1.650	2.145	2.244	2.046	0.4874	1.188	5.049	9.603	13.893	16.038	14.487
0.1001	0.528	0.990	2.046	2.640	2.607	2.310	0.5065	0.990	4.983	9.207	14.091	16.401	14.652
0.1052	0.627	1.287	2.277	2.805	2.805	2.475	0.5346	0.825	4.785	9.207	14.388	16.764	15.081
0.1104	0.495	0.957	2.310	2.772	2.739	2.706	0.5766	1.122	4.983	10.131	15.708	18.315	16.467
0.1156	0.627	1.320	2.442	2.970	3.102	2.805	0.6048	1.056	5.148	10.494	16.302	19.305	17.292
0.1208	0.660	1.320	2.607	3.168	3.168	3.036	0.6349	0.858	4.785	10.098	16.302	19.635	17.523
0.1260	0.924	1.716	3.036	3.630	3.762	3.531	0.6649	0.792	4.785	4.950	16.665	20.528	18.051
0.1312	0.660	1.386	2.805	3.432	3.597	3.531	0.6935	0.924	4.719	4.851	4.950	21.318	18.744
0.1363	0.363	1.254	2.904	3.531	3.630	3.531	0.7212	0.528	4.455	4.092	4.059	21.582	18.975
0.1415	0.627	1.518	3.135	3.795	3.894	3.762	0.7629	0.693	4.422	4.191	4.323	22.473	19.932
0.1466	0.627	1.650	3.300	3.927	3.993	3.894	0.8014	0.231	3.861	4.191	4.323	23.100	20.592
0.1518	0.858	1.980	3.663	4.323	4.356	4.257	0.8477	0.429	3.597	3.729	3.861	23.991	21.450
0.1569	0.726	1.881	3.597	4.389	4.554	4.356	0.8976	0.099	3.201	3.465	3.597	25.080	21.846
0.1621	0.825	1.815	3.630	4.620	4.620	4.356	0.9477	0.033	2.211	2.376	2.508	25.476	25.608
							1.3938	0.033	2.310	2.442	2.574	26.169	26.268

Table C-8. Target displacement, shot 8.

Target time (sec)	81N18	81N12	81N6	81E4	81S6	82N6	82E4	82.5N0	82.5E6	82.5E12	82.5E18
	Displacement (ft)										
0.0200	0.037	0.148	0.296	0.185	0.333	0.370	0.370	0.444	0.296	0.259	0.111
0.0250	0.037	0.111	0.259	0.148	0.259	0.333	0.296	0.444	0.444	0.222	0.037
0.0300	0.074	0.185	0.370	0.259	0.407	0.444	0.444	0.629	0.444	0.296	0.074
0.0350	0.074	0.148	0.666	0.444	0.629	0.629	0.592	0.814	0.555	0.444	0
0.0400	0	0.185	0.629	0.592	0.629	0.629	0.629	0.814	0.629	0.111	0.074
0.0450	0.148	0.555	0.962	0.851	1.147	1.258	1.221	1.258	1.110	0.777	0.407
0.0500	0.185	0.333	0.814	0.814	0.925	1.036	1.110	1.147	0.851	0.518	0.259
0.0550	0.296	0.518	1.073	1.036	1.036	1.110	1.147	1.258	1.147	0.592	0.259
0.0600	0.074	0.555	1.073	1.036	1.147	1.258	1.406	1.554	1.221	0.703	0.333
0.0650	0.296	0.703	1.369	1.332	1.517	1.517	1.554	1.702	1.369	0.740	0.370
0.0700	0.185	0.629	1.184	1.295	1.554	1.702	1.554	1.776	1.480	0.777	0.296
0.0750	0.222	0.592	1.332	1.480	1.591	1.739	1.813	1.924	1.554	0.703	0.296
0.0800	0.333	0.777	1.665	1.850	1.924	2.146	2.183	2.294	1.998	0.999	0.555
0.0850	0.296	0.666	1.554	1.739	1.961	2.072	2.109	2.294	1.776	0.851	0.296
0.0900	0.296	0.703	1.850	1.924	2.331	2.294	2.368	2.516	2.072	0.962	0.296
0.0950	0.185	0.814	1.813	2.109	2.331	2.516	2.442	2.701	2.368	1.295	0.407
0.1000	0.444	0.925	2.257	2.405	2.664	2.664	2.812	2.849	2.627	1.406	0.555
0.1050	0.259	0.999	2.257	2.405	2.775	2.775	2.886	2.997	2.664	1.295	0.518
0.1100	0.333	1.110	2.368	2.590	2.886	2.997	3.108	3.404	2.701	1.443	0.555
0.1150	0.333	1.036	2.701	2.886	3.071	3.404	3.293	3.589	3.182	1.665	0.777
0.1200	0.333	1.147	2.812	3.108	3.404	3.478	3.404	3.737	3.071	1.517	0.666
0.1250	0.555	1.221	2.960	3.219	3.515	3.589	3.700	3.922	3.293	1.702	0.666
0.1300	0.333	1.073	2.775	3.219	3.552	3.626	3.774	3.774	3.293	1.702	0.555
0.1350	0.518	1.332	3.219	3.663	3.959	3.996	4.070	4.107	3.811	1.961	0.851
0.1400	0.407	1.258	3.330	3.737	3.959	4.070	4.107	4.218	3.885	1.961	0.629
0.1450	0.407	1.443	3.441	3.922	4.292	4.292	4.292	4.218	3.959	2.183	0.629
0.1500	0.370	1.480	3.404	4.144	4.292	4.477	4.662	4.477	4.144	2.072	0.629
0.1550	0.444	1.480	3.700	4.292	4.292	4.699	4.699	4.736	4.255	2.294	0.777
0.1600	0.592	1.702	4.033	4.588	4.958	5.069	4.958	5.328	4.736	2.516	0.962
0.1650	0.444	1.628	3.885	4.514	5.032	5.143	5.032	5.217	4.736	2.516	0.777
0.1700	0.296	1.554	3.848	4.477	4.847	5.143	5.069	5.180	4.662	2.220	0.481
0.1750	0.655	1.665	4.255	4.884	0	5.402	5.328	5.513	5.143	2.590	0.703
0.1800	0.703	1.924	4.366	5.106	0	5.957	5.587	5.809	5.550	2.849	0.888
0.1850	0.814	1.998	4.625	5.513	5.772	6.179	6.068	5.994	5.735	2.775	0.777
0.1900	0.592	1.924	4.551	5.439	5.698	6.106	5.994	6.290	5.846	2.997	0.925
0.1950	0.592	2.035	4.884	5.698	6.216	6.438	6.438	6.512	5.957	3.034	1.036
0.2000	0.481	1.998	4.921	5.735	6.290	6.401	6.327	6.734	5.957	3.034	0.851
0.2100	0.444	1.998	5.069	5.883	0	6.660	6.549	6.919	6.031	2.997	0.814
0.2200	0.407	2.035	5.328	6.549	7.178	7.437	7.030	7.326	6.845	3.293	0.777
0.2300	0.555	2.331	5.735	6.919	7.178	7.585	7.474	7.770	7.141	3.404	0.999
0.2400	0.481	2.146	5.476	6.919	7.807	8.140	7.585	7.881	7.215	3.256	0.925
0.2500	0.851	2.368	6.179	7.585	8.325	8.510	8.066	8.732	7.659	3.441	0.925
0.2600	0.518	2.479	6.327	7.918	9.065	9.028	8.510	8.991	8.103	3.774	0.925
0.2700	0.518	2.553	6.327	8.288	9.287	9.472	8.769	9.287	8.325	3.700	0.888
0.2800	0.703	2.553	6.771	8.399	9.731	9.953	9.250	9.731	8.658	3.996	1.110
0.2900	0.407	2.442	6.623	8.510	9.916	10.249	9.51	10.25	8.750		
0.3000	0.629	2.590	7.067	8.917	10.397	10.545	9.75	10.40	9.30		
0.3150	0.333	2.368	7.215	9.250	10.915	11.137	10.25	10.75	9.60		
0.3300	0.444	2.516	7.622	9.768	11.285	11.729	10.75	11.50	10.15		
0.3450	0.370	2.553	7.770	10.064	11.914	12.543	11.137	12.136	10.360	3.996	0.851
0.3600	0.333	2.405	7.918	10.471	12.210	12.876	11.433	13.135	10.656	4.366	0.814
0.3750	0.370	2.553	8.288	10.693	12.543	13.431	11.766		11.026	4.181	0.925
0.3900	0.481	2.294	8.436	11.100		13.986	12.210		11.396	3.959	0.666
0.4050	0.481	2.405	8.362	11.655		14.615	12.691		11.803	4.144	0.629
0.4200	0.259	2.109	8.769	11.729		15.059	13.172		12.136	3.959	0.740
0.4400	0.296	1.665	8.214	11.470		15.096	13.024		12.136	3.404	0.222
0.4600	0.259	2.220	9.065	12.654		16.465	14.060		12.950	3.811	0.703
0.4800	0.148	1.924	9.139	12.802		16.946	14.578		13.246	3.811	0.703
0.5000	0.370	1.332	9.472	13.246		17.575	15.096		13.764	3.626	0.740
0.5400	0.296	0.999	9.472	13.801		18.833	15.614		14.319	3.404	0.703
0.5800	0.074	0.184	9.435	13.986		19.610	16.428		14.726	2.812	0.518
0.6200		1.111	8.917	13.616		20.535	17.094		14.578	2.035	0.370
0.6600			8.658	13.394		21.571	17.686		15.022		0.444
0.7000			8.917	13.838		22.348	18.500		15.355		0.370
0.7400			8.880	14.578		23.199	18.981		16.465		

APPENDIX D. WIND VELOCITIES

Wind velocity was approximated for both magnitude and direction. A manometer was used to measure wind speed at the control point. These speeds and the estimated directions can only be expected to apply for speeds of 4 knots or more.

Shot	Speed (knots)	Direction
1	5	southwest
2	5	southwest
3	12	south
4	2	west
5	6	southwest
6	12	north
7	7	southwest
8	8	southwest

APPENDIX E. OSCILLOGRAPH IMAGES - SEISMIC PROGRAM

Scales

Accelerations

Gage	Sensitivity (g/in.)	
	Vertical	Horizontal
1	3.68	3.66
2	4.10	3.37
3	3.55	3.62
4	3.49	4.35
5	3.24	3.43
6	3.97	3.35

Time

17 in. = 1 sec

Fig. E.1. Seismic traces, Rowboat 1.

Fig. E.2. Seismic traces, Rowboat 2.

Fig. E.3. Seismic traces, Rowboat 3.

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Fig. E.4. Seismic traces, Rowboat 4.

Fig. E. 5. Seismic traces, Rowboat 5.

Fig. E.6. Seismic traces, Rowboat 6.

Fig. E.7. Seismic traces, Rowboat 7.

Fig. E.8. Seismic traces, Rowboat 8.

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