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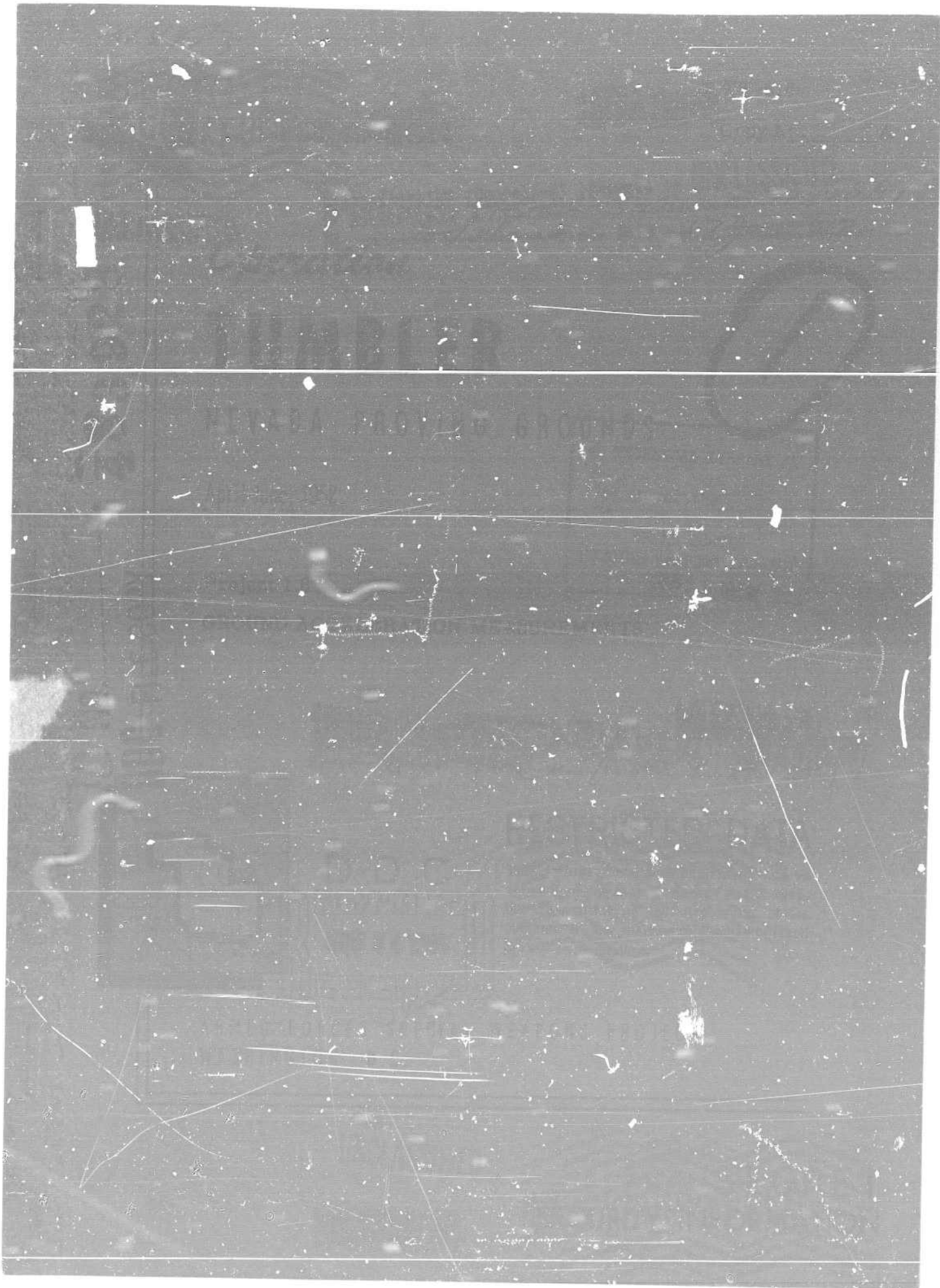
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Report on OPERATION TUMBLER,
Nevada Proving Grounds,
April-June, 1952, Project 1.6.

18 AEC

19 WT-516

6 GROUND ACCELERATION MEASUREMENTS.

9 REPORT TO THE TEST DIRECTOR,

by

10 John S. Fischer
Ralph E. Reisler.

11 January 1953,

12 51p.

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ABSTRACT

↳ Maximum vertical, radial, and transverse ground accelerations induced by air blast as measured at various distances on Operation TUMBLER are reported. Self-recording accelerometers, manufactured by Engineering Research Associates, Inc. (ERA) of St. Paul, Minnesota were used as a secondary measuring instrument to back up the electronically operated system of Stanford Research Institute (SRI).

↳ The gages were mounted at a 5 ft. depth on a cube of concrete grouted into the undisturbed soil. Results indicate that a considerable part of the energy entering the ground was absorbed within the first 5 feet. In Shots 1, 2, and 3, the beginning of the Mach region was clearly defined by the difference in vertical acceleration readings between two adjacent stations. No indication of the formation of the Mach region was evident on Shot 4 as the Mach was formed before reaching the first station. Agreement between results obtained with the ERA self-recording gages and the SRI electronic accelerometers is within the 30 percent limit of error reported.

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PREFACE

The primary purpose of the work described in this report was to determine the ground acceleration resulting from several air burst nuclear explosions. Personnel of the Explosion Kinetics Branch of the Ballistic Research Laboratories (BRL) participated in this project.

The original group consisted of the following members:

Thomas J. Andrews, Lt Col, USAF
Robert A. Eberhard
John S. Fischer, Pfc, USA
Ralph E. Reisler

John M. Shallenberger, Pfc, USA assisted with the field work following the departure of Lt. Col. Andrews and Pfc. Fischer for new assignments.

Acknowledgment is made to Sandia Corporation, Albuquerque, New Mexico and the Ballistic Measurement Laboratory, Aberdeen Proving Ground, Md. for their loans of needed seismic elements; to Paul H. Lorrain for his assistance with the project; to J. J. Meszaros, E. J. Bryant, W. T. Matthews, and W. J. Taylor for preliminary preparation of the test site.

All work was done under the general supervision of Dr. Edward E. Minor and Wesley E. Curtis, Project Officer and Deputy for Projects 1.5 and 1.6.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

Project 1.6 was organized for the purpose of obtaining secondary ground acceleration measurements on a series of air burst nuclear explosions conducted at the Nevada Proving Grounds of the Atomic Energy Commission during the spring of 1952. Considerable interest had been shown in the amount of air blast energy absorbed by the ground during such an explosion. It was hoped that the ground acceleration measurements obtained might provide data from which a correlating factor could be obtained.

1.2 PREVIOUS HISTORY

The system for obtaining ground accelerations with ERA accelerometers was used extensively on Operation JANGLE¹. Prior to this a large number of gages were used on Operation GREENHOUSE for measuring accelerations of structures and a small number for ground shock². Much of the fundamental work in ground shock occurring as a result of explosions has been done by C. W. Lampson and others using small charges³. Further work on ground shock measurements was carried out by Stanford Research Institute at Dugway, Utah using charge weights up to 320,000 lbs. at shallow depths⁴. A more complete history of ground shock measurements may be found in the references cited together with a thorough study of the basic theory of ground shock measuring instruments.

¹ Thomas J. Andrews, Lt Col, USAF, Edward J. Bryant, Paul H. Lorrain, and Nicholas M. Masich, Lt. Col., USAF, "Transient Ground Mechanical Effects from HE and Nuclear Explosions" Operation JANGLE Project 1.2a-2.

² David R. Powers, Lt, USA and John J. O'Connor, "Ground Shock Measurements" Operation GREENHOUSE Annex 1.6 Part V Section 1.

³ C. W. Lampson, "Final Report on Effects of Underground Explosions" NDRC Report No. A-479 (OSRD-6645).

⁴ E. B. Doll, Interim Report, "Underground Explosions at Dugway" Corps of Engineers, U. S. Army Contract DA-04-167 Eng - 379 Stanford Research Institute.

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CHAPTER 2

EXPERIMENTAL PROCEDURE

2.1 FIELD LAYOUT

Each station consisted of two ERA accelerometers mounted perpendicular to each other on a steel plate (18" x 12") (Fig. 2.1). This steel plate was then bolted to another similar steel plate in the bottom of a 5 ft. deep cased hole 3 ft. in diameter (Fig. 2.2). The latter plate was previously anchor-bolted in the top of an 18 in. concrete cube grouted into the undisturbed earth.

One accelerometer was parallel to the blast line and the other perpendicular to it. Thus, the two elements perpendicular to each other in each of the two accelerometers gave three components of acceleration: viz., two vertical, one horizontal in a radial direction from ground zero, and one horizontal in a transverse direction perpendicular to the radial direction.

After the accelerometers were secured (Fig. 2.3) the cased hole was filled with sandbags to within 1 ft. of the top (Fig. 2.4). The box containing the starting battery and relay (Fig. 2.5) was placed on the sandbags and the necessary lines spliced to the accelerometers and to the firing line (Fig. 2.6). The casing was then filled with packed sand until the battery box was sufficiently covered to protect it from excessive radiation and blast damage.

For Shot 1 in the Frenchman Flat area no hole casing was used. A trench approximately 20 ft. long and 6 ft. wide was excavated at each station as shown in Fig. 2.7. After mounting the accelerometer on the cube of concrete as stated above, the trench was filled in with loose sand. Long bolts extended from the mounting plate to the ground surface for easy removal of the accelerometers after the shot (Fig. 2.8).

2.1.1 Blast Range Layout

Operation TUMBLER Shot 1 was fired over Frenchman Flat at an altitude of 793 ft. This area was chosen as a smooth, thermal reflecting, dust and smoke free terrain. ERA accelerometers were mounted at six stations along the blast line between ground zero and 3000 ft.

For TUMBLER Shots 2, 3, and 4 a thermal absorbing, dust and smoke producing area was chosen (Area T-7). Five stations were located

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between ground zero and 4500 ft. for Shot 2, and seven stations between zero and 9000 ft. for Shots 3 and 4. Statistics for the shots are given in Table 2.1.

TABLE 2.1

Shot Data

Shot No.	Area	Bomb Yield W_{RC}	Height of Burst
1	F	1.05 KT	793 ft.
2	T-7	1.15 KT	1109 ft.
3	T-7	30.0 KT	3447 ft.
4	T-7	19.6 KT	1040 ft.

2.2 DESCRIPTION OF ERA ACCELEROMETER

The ERA accelerometer (Fig. 2.13) is a magnetic, self-recording gage for measuring two orthogonal components of acceleration. The entire recording mechanism is encased in a two-piece aluminum cover. A starting line is the only external connection.

A drive spool driven by a spring motor moves the 3/4 in. wide by 5 ft. long three-channel magnetic tape from a drag spool containing a viscous oil to maintain a constant velocity past two seismic elements and a timing element.

The seismic element consists of a mass-spring system with a small permanent magnet mounted on the mass and displaced three thousandths of an inch from the tape. Thus, a portion of the pre-recorded 1280 cps carrier signal is erased in the element's rest position. Movement of the element is perpendicular to the tape and increases or decreases the amplitude of the signal depending on the direction of the acceleration. The acceleration is recorded on the first two channels while channel three records a timing signal from a torsion timing pendulum held in a displaced position and released when the accelerometer is fired. The pendulum, containing a tiny permanent magnet, then oscillates at its natural frequency (40 to 50 cps) erasing a portion of the pre-recorded carrier signal.

Firing the accelerometer is accomplished by blowing a music wire fuse with two amperes of current from two 6-volt dry cell batteries connected in parallel. The fuse holds down a two-piece trigger spring

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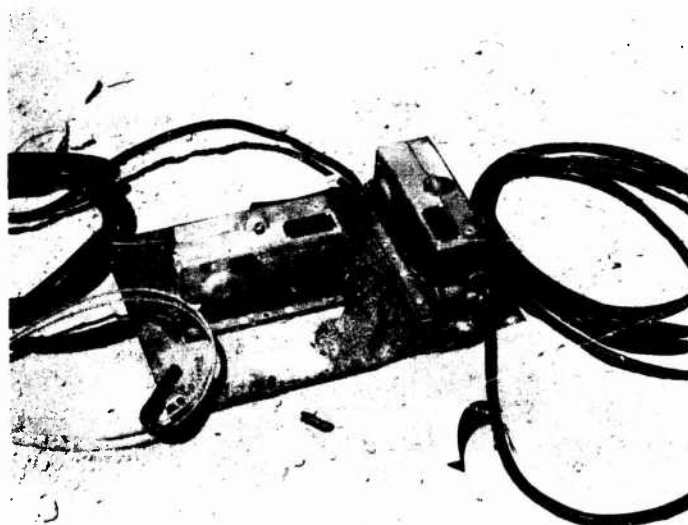


Fig. 2.1 ERA Accelerometers on Mounting Plate



Fig. 2.2 Base Mounting Plate on Concrete Block in
5 ft Cased Hole

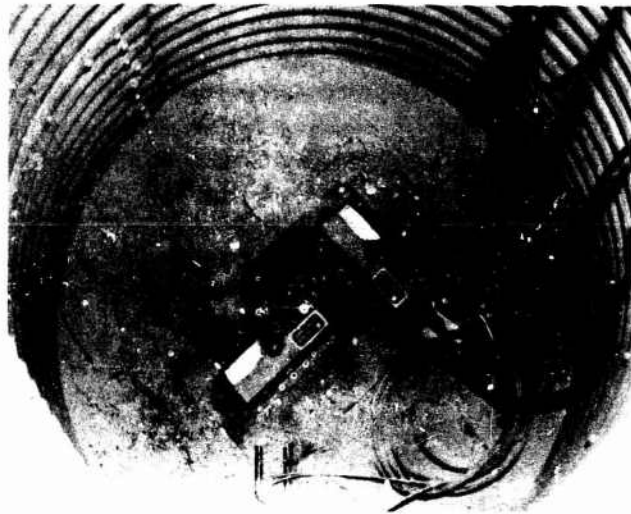


Fig. 2.3 Mounted ERA Accelerometers



Fig. 2.4 Accelerometer Hole Filled with Sandbags

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Fig. 2.5 Box with Relay and Batteries for Initiating Accelerometers



Fig. 2.6 Battery Box in Place

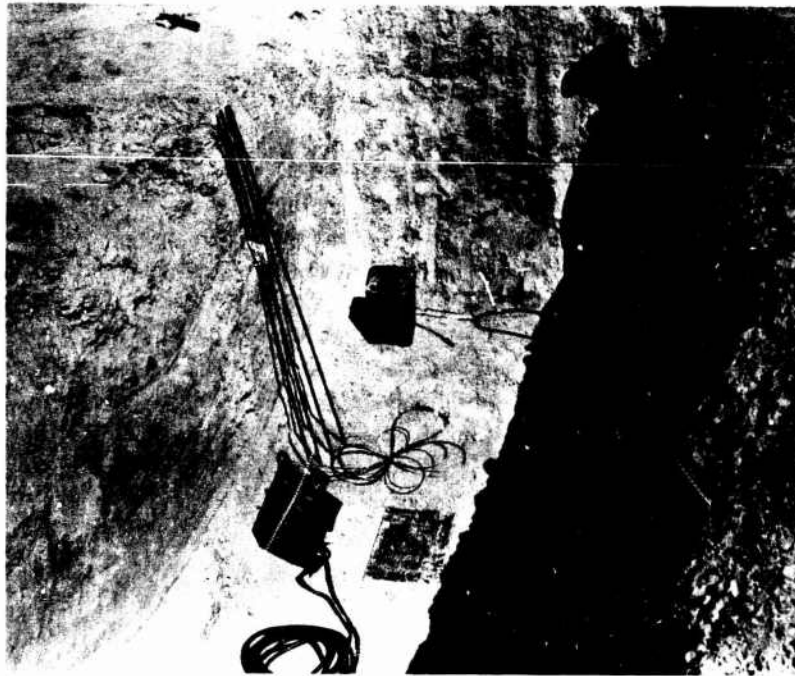


Fig. 2.7 Base Mounting Plate for Shot 1

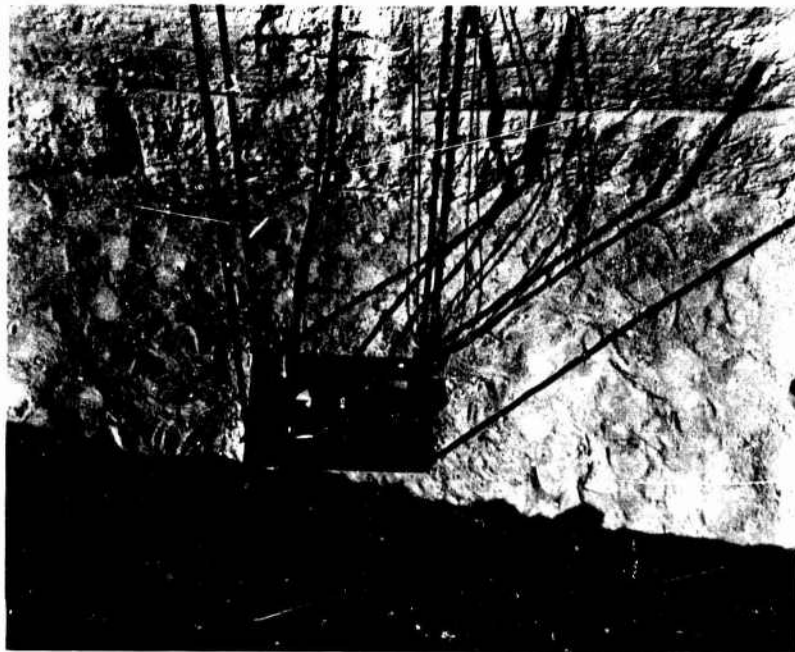


Fig. 2.8 Accelerometer Mounting for Shot 1

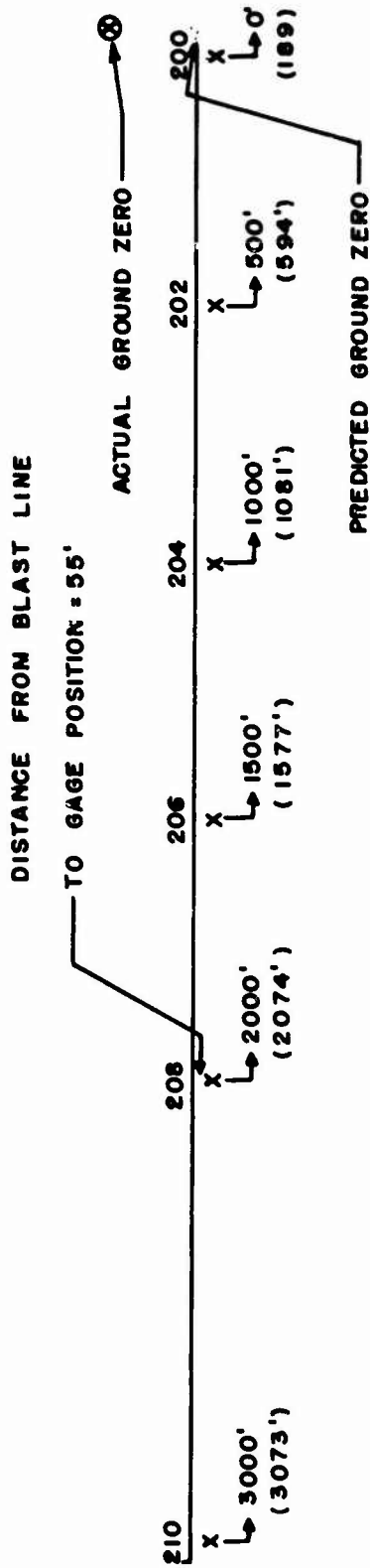


Fig. 2.9 Blast Line Layout, Shot 1

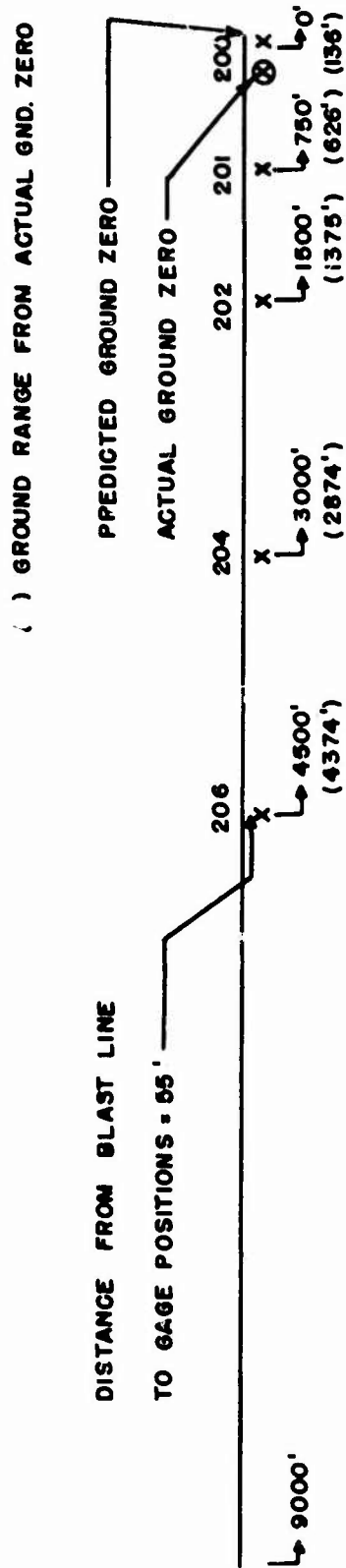


Fig. 2.10 Blast Line Layout, Shot 2

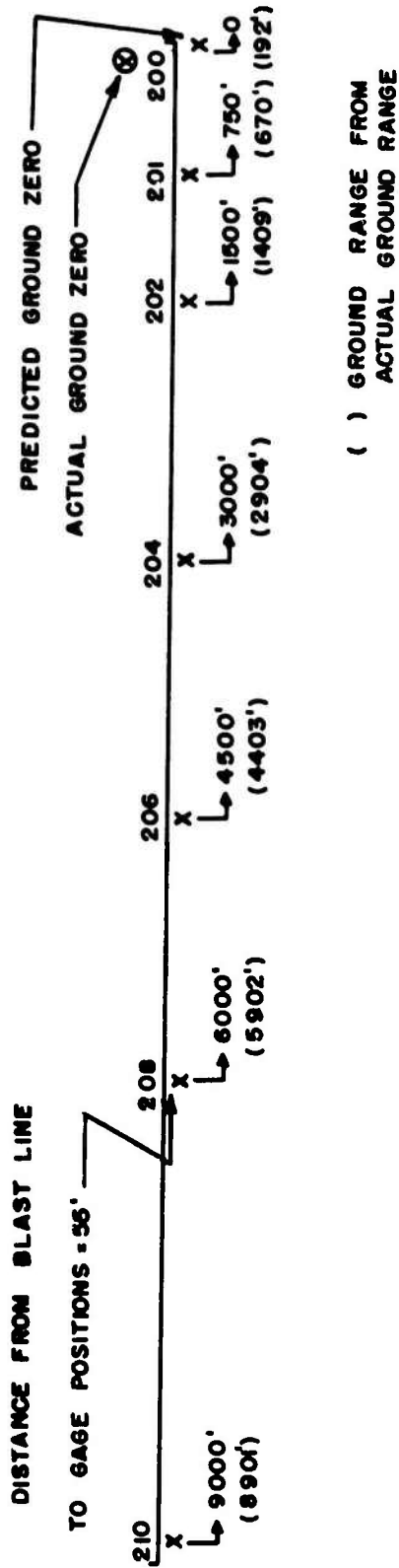


Fig. 2.11 Blast Line Layout, Shot 3

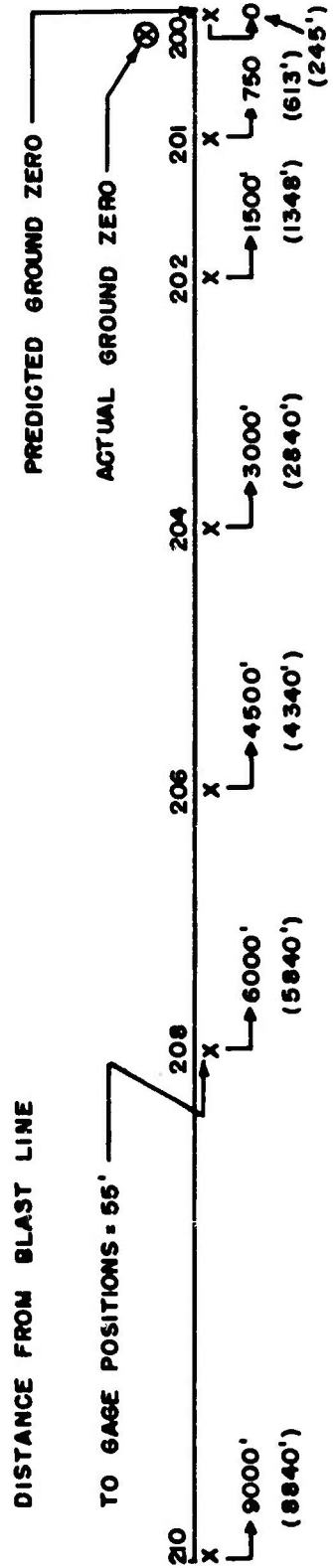


Fig. 2.12 Blast Line Layout, Shot 4

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which in turn depresses two spring-loaded locking pins (Fig. 2.14). One locking pin prevents rotation of the drag spool and the other holds the torsion timing pendulum displaced. Running time for the 30 in. of useable recording tape varies from 7 to 9 seconds depending upon the viscosity of the oil in the drag spool cup. Maximum velocity is reached in one-tenth of a second.

The circuit from the dry cell batteries to the fuse in the accelerometer is closed by means of a 24-volt relay which is mounted in a box together with the batteries and buried near the accelerometer. The relay is operated at minus 1 second by cable from the control station where the Edgerton, Germeshausen, and Grier (EG&G) timing relay energizes the line with a 24-volt wet cell battery.

2.3 EQUIPMENT FOR READING RECORDS

2.3.1 Playback Equipment

Playback equipment consisting of a mechanical playback unit, an electronic display unit, and a power supply (Fig. 2.15) was used to record the carrier signal on the magnetic tape and to playback the recorded transient. The tape was wrapped around the 30 in. circumference drum in the playback unit and rotated past the magnetic recording head which was positioned against the tape. Vertical adjustment of the head to three positions provided for recording or playing back the three channels on the tape.

The signal was displayed on a cathode-ray tube screen in the electronic playback unit. All necessary triggering and expanding circuits to allow analysis of the entire record of acceleration were contained in the playback unit. In addition, the signal was applied to a second cathode-ray oscilloscope and photographed with a Fairchild oscillographic camera.

2.3.2 Reading Records

The percentage of the carrier signal amplitude erasure or non-erasure depended upon the direction and amplitude of the shock applied to the gage. This was readily obtained by measurement of the photographed record (Fig. 2.16). Calibration curves provided by the manufacturer for each element gave per cent amplitude erasure versus distance through which the element moved. The product of this distance and the gage constant gave the acceleration recorded by the gage. Reading of the oscillographic film record was greatly facilitated by the use of a Kodagraph viewer.

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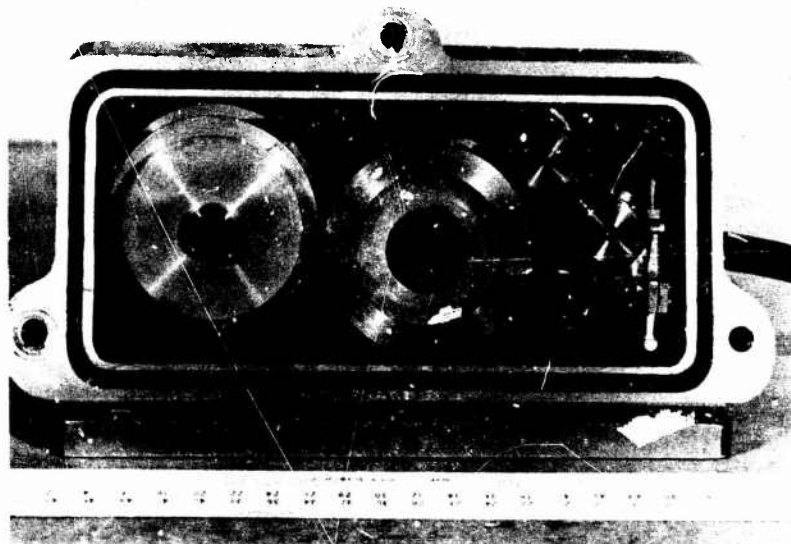


Fig. 2.13 Loaded Accelerometer with Cover Plate Removed

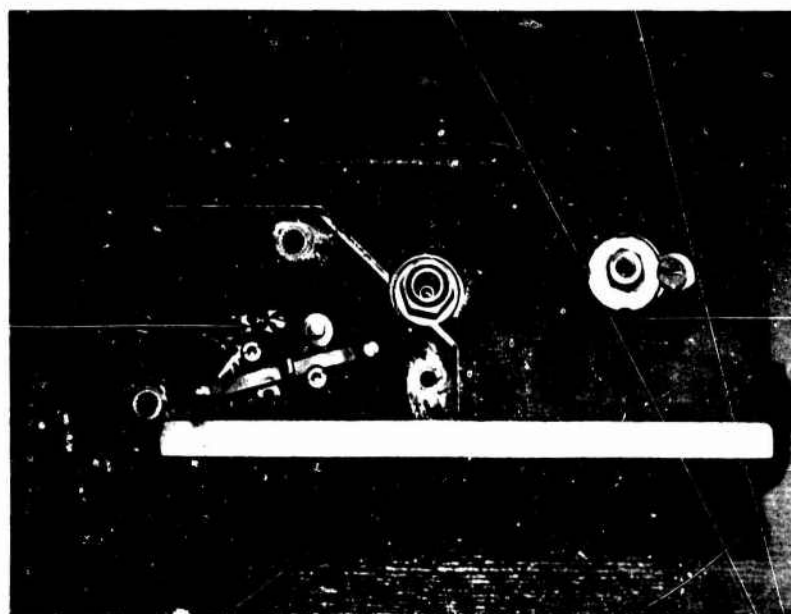


Fig. 2.14 Accelerometer Starting Mechanism

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Fig. 2.15 ERA Playback Equipment

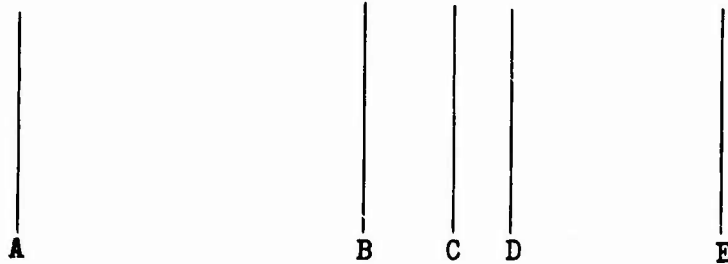


Fig. 2.16

Typical Acceleration Record from ERA Accelerometer

- A-B: Unerased carrier
- B-C: Normally erased carrier
- C-D: Acceleration record
- D-E: Normally erased carrier

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CHAPTER 3

TEST RESULTS

3.1 SHOT 1

Results were obtained from five of the six stations used on Shot 1. The numerical results are given in Table 3.1 and plotted in Figs. 3.1 through 3.4 inclusive. No records were obtained at Station 202 due to non-operation of one gage and inaccurate choice of range of the secondary gage. No records of horizontal acceleration, radial or transverse, were obtained at the two close-in stations 200 and 202, due to the accelerations encountered being below the minimum reading range of the gages.

The difference in results obtained at Stations 204 and 206 would indicate that the formation of the Mach stem occurred between 1100 and 1600 ft.

The scaled distance versus vertical acceleration is plotted in Fig. 3.2. Considerable scatter of points made it inadvisable to fit any curves to the presentation of the data in the graphs.

3.2 SHOT 2

Results were obtained from the five stations used on Shot 2. The numerical results are given in Table 3.2 and plotted in Figs. 3.5 through 3.8 inclusive. No record of horizontal transverse acceleration was obtained at Station 204 since the magnetic tape release mechanism did not function properly. No records of horizontal radial acceleration were obtained at Stations 200 and 201. The accelerations encountered were below the minimum reading of the gages.

Again the probable Mach stem origin is indicated by the difference in reading in the vertical downward acceleration between 626 and 1375 ft. (Fig. 3.5).

The scaled distance versus vertical acceleration is plotted in Fig. 3.6. No attempt was made to fit curves to the points due to the considerable scatter.

3.3 SHOT 3

Results were obtained from all stations used on Shot 3. The numerical results are given in Table 3.3 and plotted in Figs. 3.9

TABLE 3.1
Results Shot 1

Station	Ground Range (ft)	Reduced Distance ($\frac{ft}{w^{1/3}}$)	Gage Range (g's)		Vertical (g's)		Radial (g's)		Transverse (g's)		
			Horizontal	Vertical	Upward	Downward	Outward	Inward	Counter-clockwise	Clockwise	
200	189	1.47	10	10	5	5.56	No Record	-	-	No Record	
202	594	4.64	10	3	No Record	No Record	No Record	-	-	Gage Failure	
204	1081	8.44	6	3	Gage Failure	Gage Failure	-	-	-	-	
206	1577	12.31	5	5	1.75	2.7	0.7	1.4	-	0.51	0.26
208	2074	16.20	5	2	0.45	1.78	-	-	-	0.51	0.26
210	3073	23.98	2.5	2.5	2.32	2.56	0.84	1.36	-	-	-
			1	1	1.18	1.14	-	-	-	.10	0.44
			2.5	2.5	1.45	0.93	1.37	1.03	-	-	-
			1	.75	0.52	0.96	-	-	-	0.25	0.25
			2	2	0.20	1.11	0.44	1.1	-	-	-
			.75	.75	0.92	0.92	-	-	-	0.42	0.21

The value of $w^{1/3}$ was assumed to be 128.1 for this shot based on a TNT equivalent of 1.05 KT.

Note: Vertical high range results plotted.

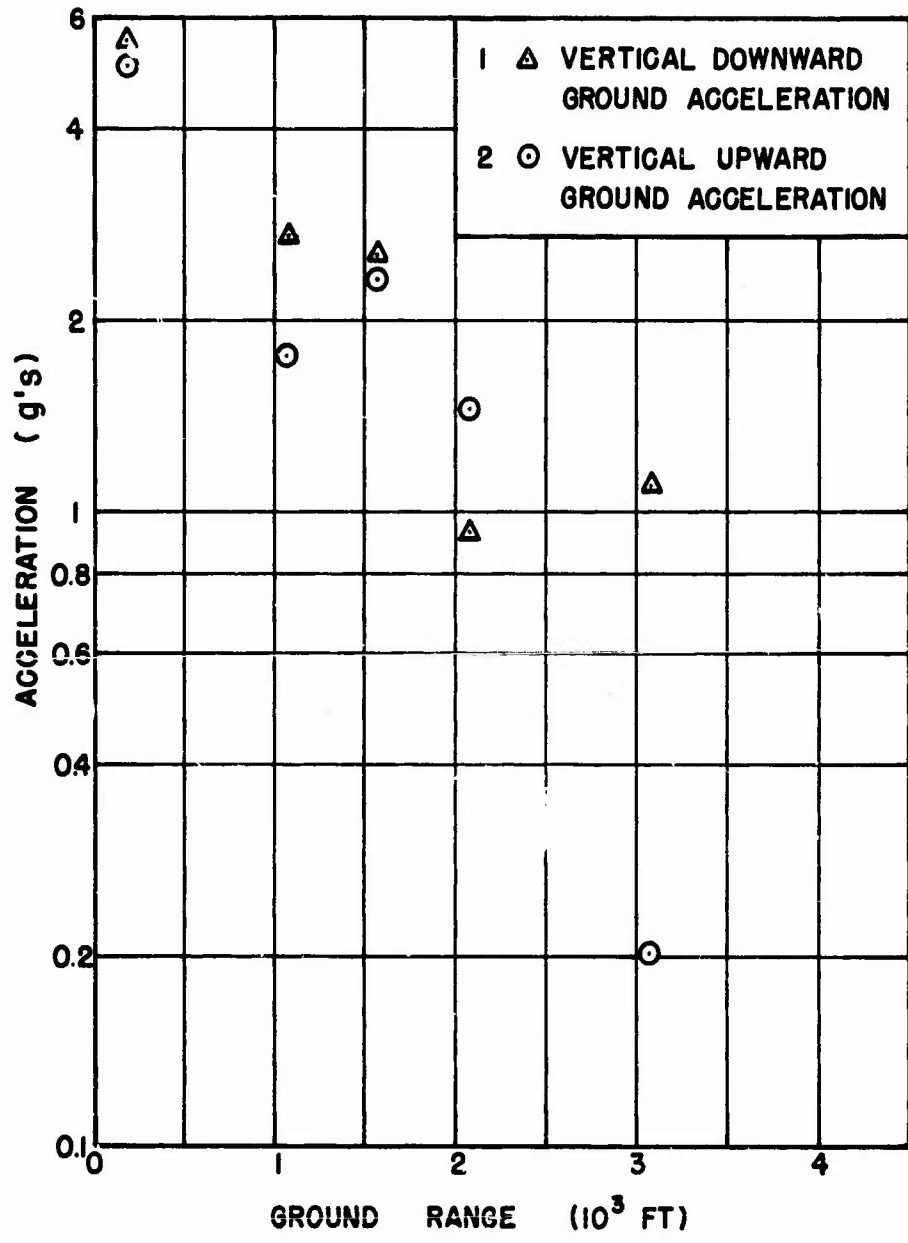


Fig. 3.1 Maximum Vertical Ground Acceleration vs Ground Range

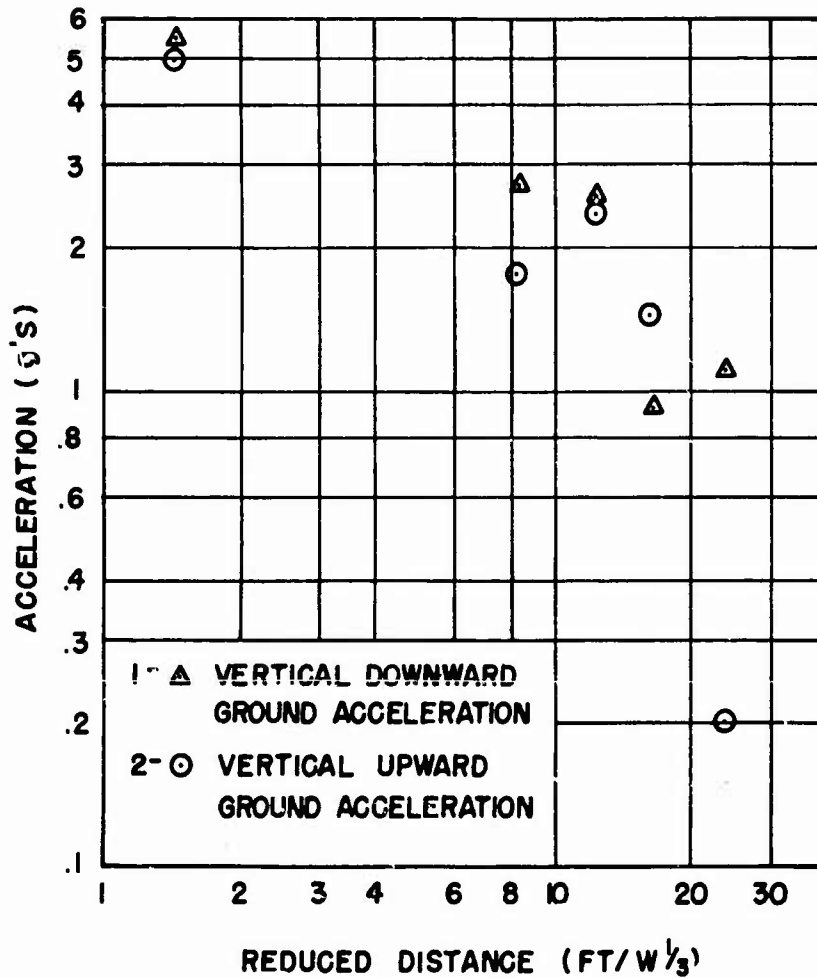


Fig. 3.2 Maximum Vertical Ground Acceleration vs Reduced Distance, Shot 1

through 3.12 inclusive. No record of horizontal transverse acceleration was obtained at Station 210, presumably because the acceleration encountered was below the minimum reading of the gage. Similarly, no record of horizontal radial acceleration was obtained at Station 201 because the gage range chosen was too high. At Station 204, the gage release mechanism did not function properly.

Again, as evident in Shots 1 and 2, the Mach reflection region is shown by the change in vertical downward accelerations between 1500 and 3000 ft.

The scaled distance versus vertical acceleration is plotted in Fig. 3.10. Again no curves have been fitted to the points because of the extreme scatter.

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3.4 SHOT 4

Results were obtained from six of the seven stations used on Shot 4. The numerical results are given in Table 3.4 and plotted in Figs 3.13 through 3.16 inclusive. No record of vertical acceleration was obtained at Station 202. No record of horizontal radial acceleration was obtained at Stations 200 and 201. The gage at Station 200 did not fire. No record of horizontal transverse acceleration was obtained at Stations 202.

As the Mach stem origin was rather close to ground zero, no indication of the beginning of the Mach stem was given by the acceleration data. No curves were fitted to the points in the data presentation.

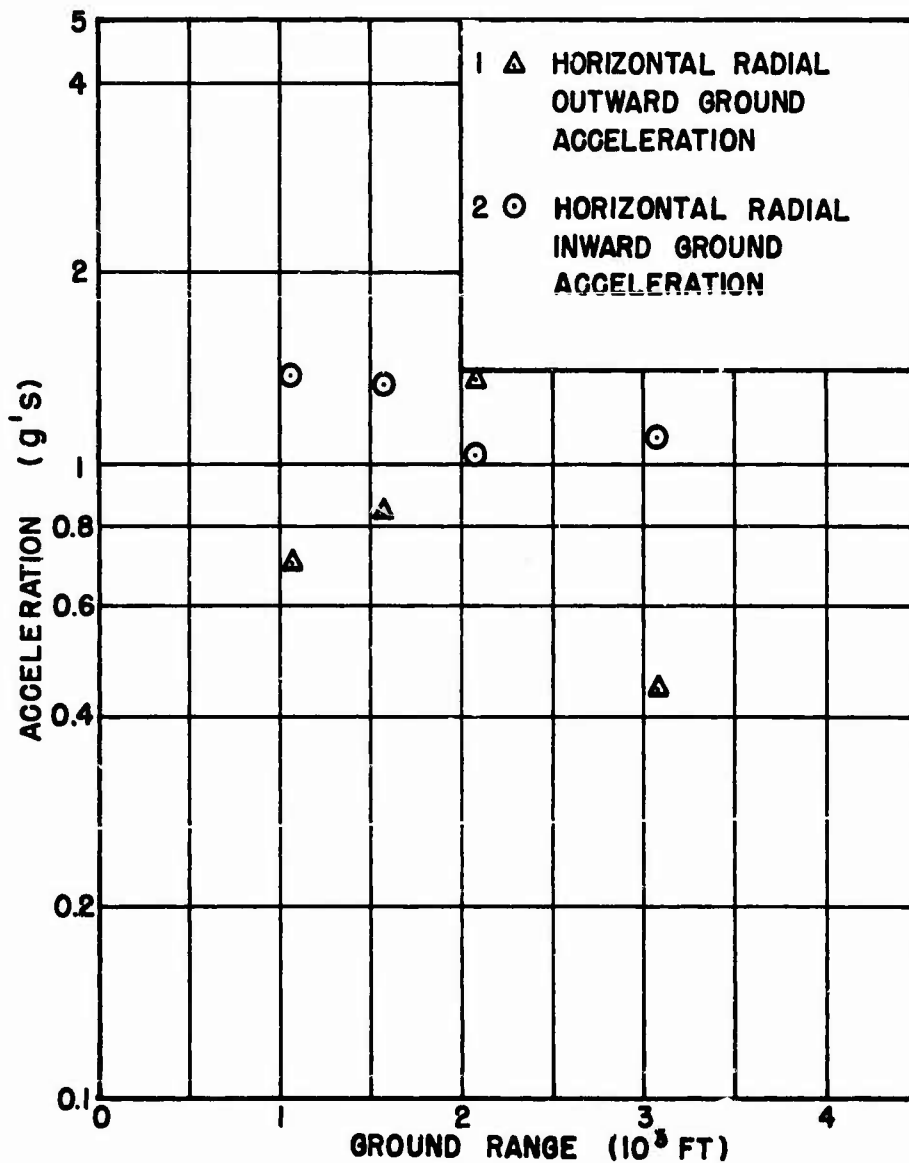


Fig. 3.3 Maximum Horizontal Radial Ground Acceleration vs Ground Range, Shot 1

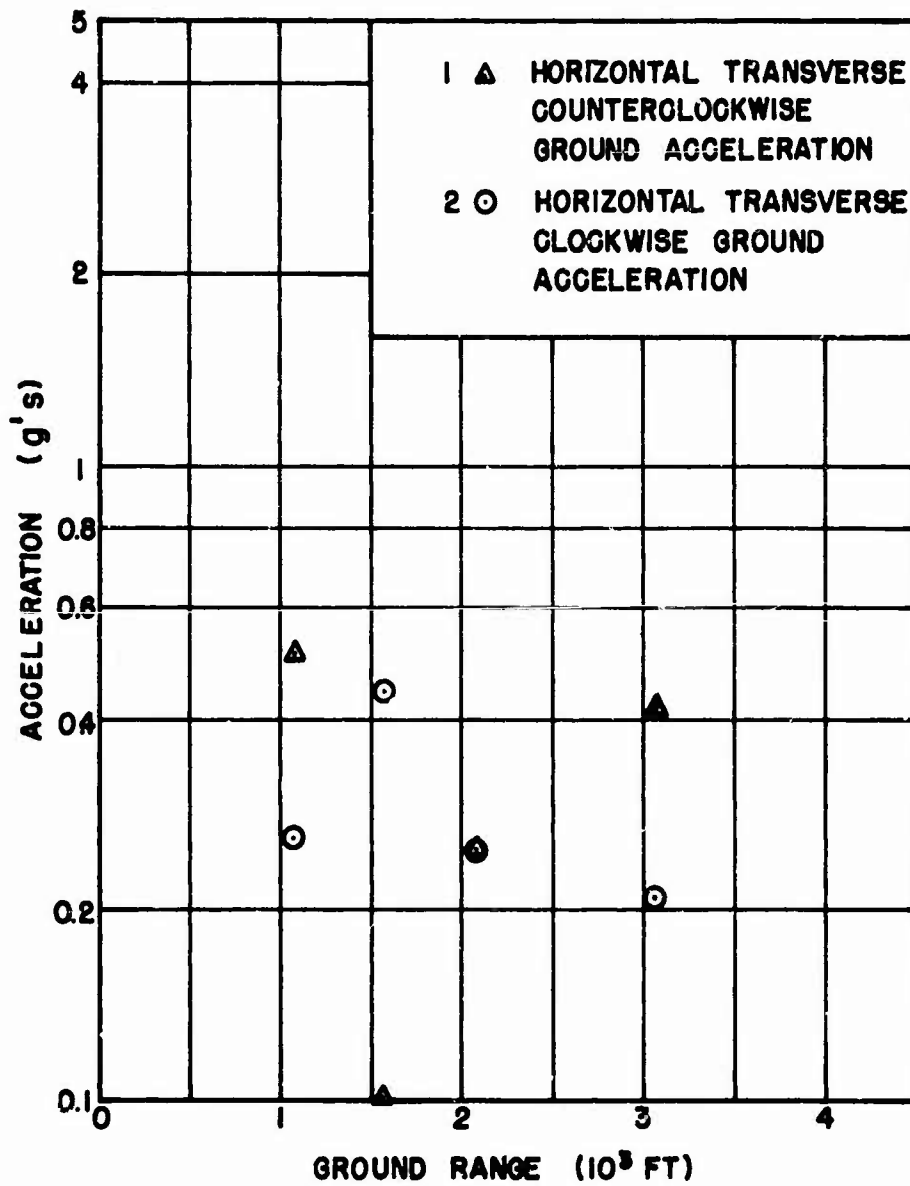


Fig. 3.4 Maximum Horizontal Transverse Ground Acceleration vs Ground Range, Shot 1

TABLE 3.2
Results Shot 2

Station	Ground Range (ft)	Reduced Distance $(\frac{ft}{w^{1/3}})$	Gage Range (g's)		Vertical (g's)		Radial (g's)		Transverse (g's)	
			Horizontal	Vertical	Upward	Downward	Outward	Inward	Counter-Clockwise	Clockwise
200	136	1.03	2.5 2.5	30 10	No Record 1.67	2.22	No Record -	No Record -	- 0.57	- 0.46
201	626	4.74	2 1.5	10 6	No Record 1.24	1.24	No Record -	No Record -	- 0.70	- 0.59
202	1375	10.41	1 1	6 10	No Record 1.21	1.81	0.43 -	0.14 -	- 0.34	- 0.20
204	2874	21.77	.75 .75	2.5 30	1.0 Gage Failure	1.2	0.35 -	0.31 -	- Gage Failure	- -
206	4374	33.14	.75 .75	1.0 .75	0.31 Off Scale	0.49	0.21 -	0.13 -	- 0.18	- 0.20

The value of $w^{1/3}$ was assumed to be 132.0 for this shot, based on a TNT equivalent of 1.15 KT.

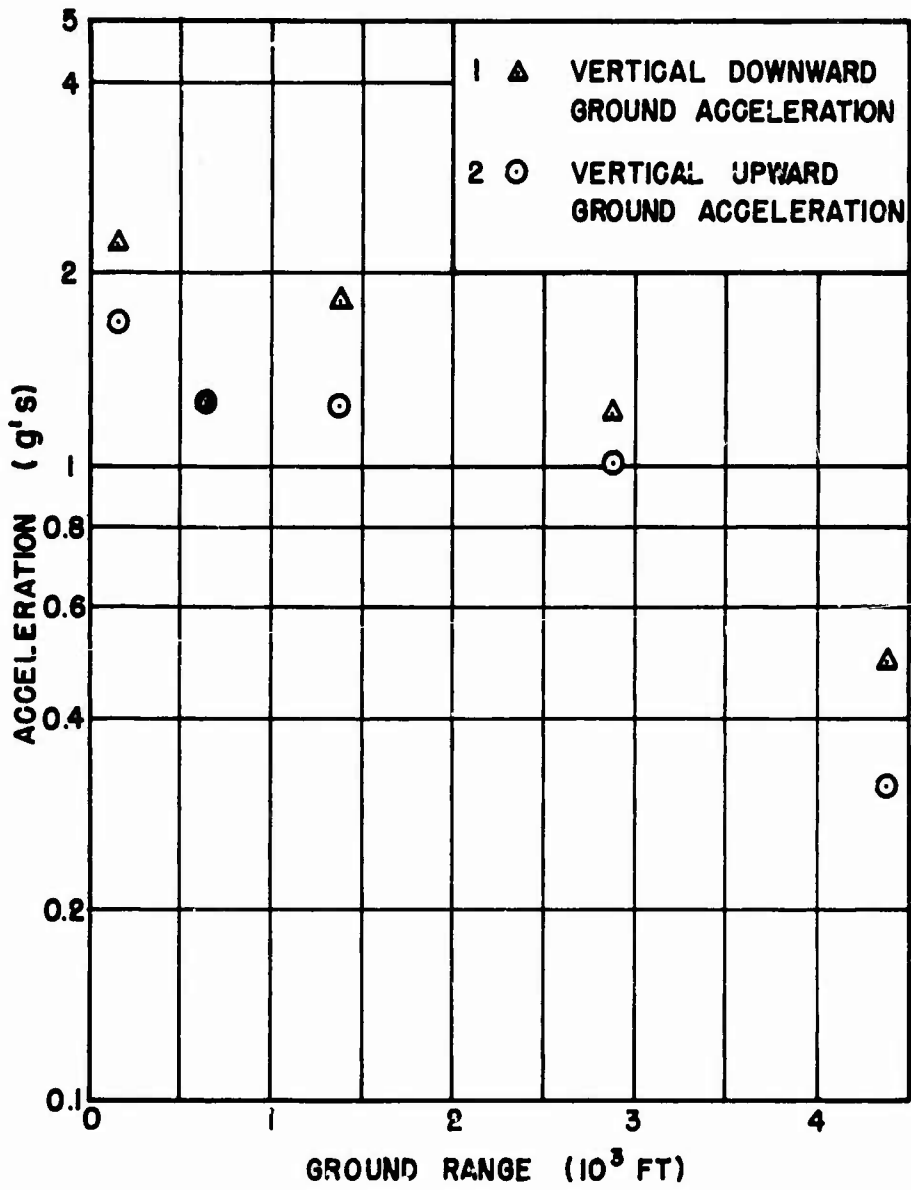


Fig. 3.5 Maximum Vertical Ground Acceleration vs Ground Range, Shot 2

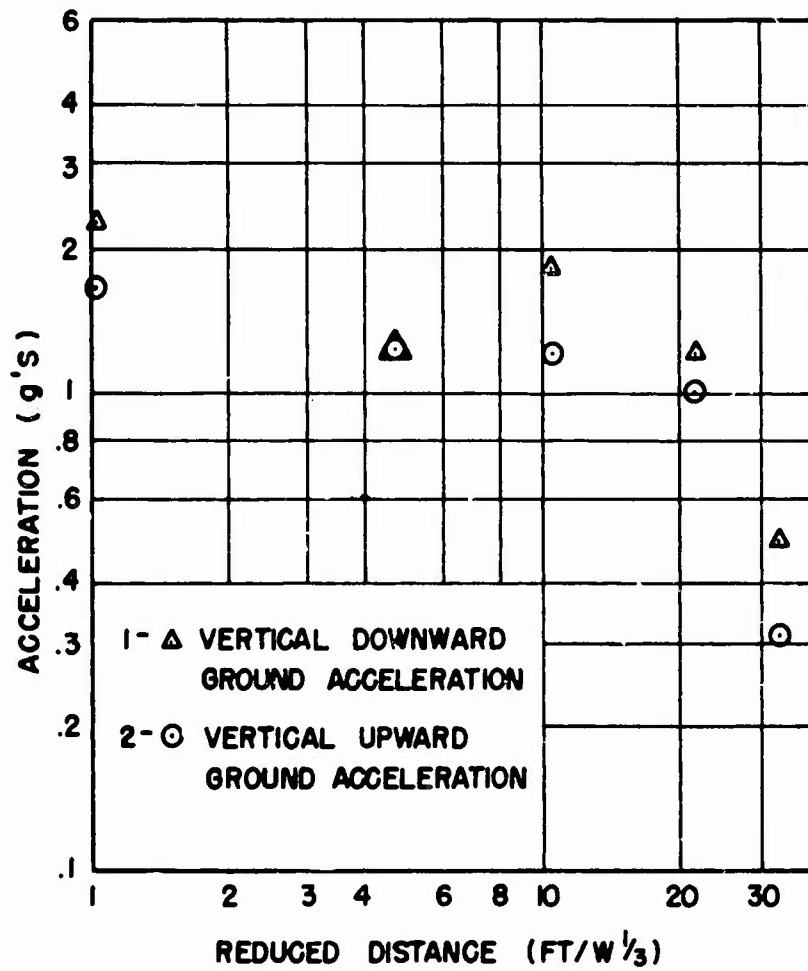


Fig. 3.6 Maximum Vertical Ground Acceleration vs Reduced Distance, Shot 2

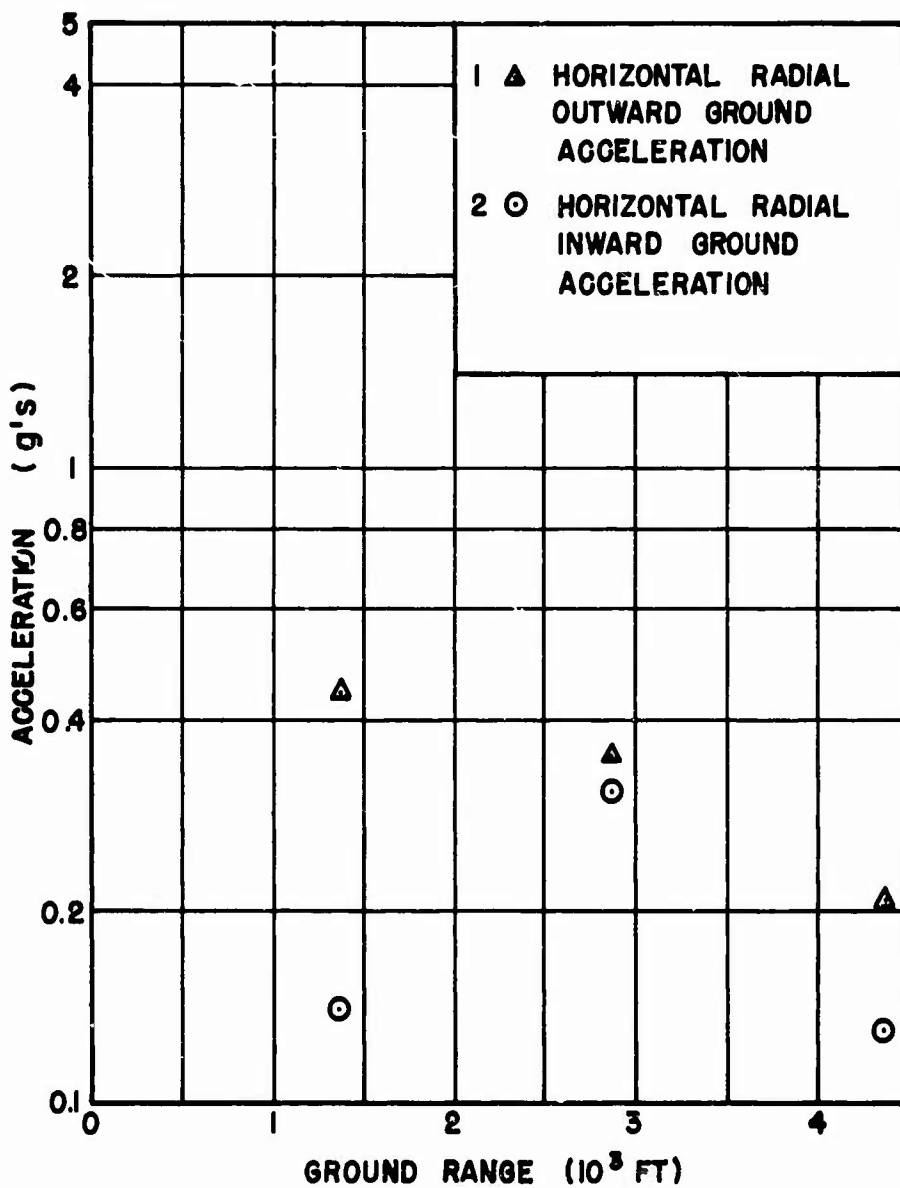


Fig. 3.7 Maximum Horizontal Radial Ground Acceleration vs Ground Range, Shot 2

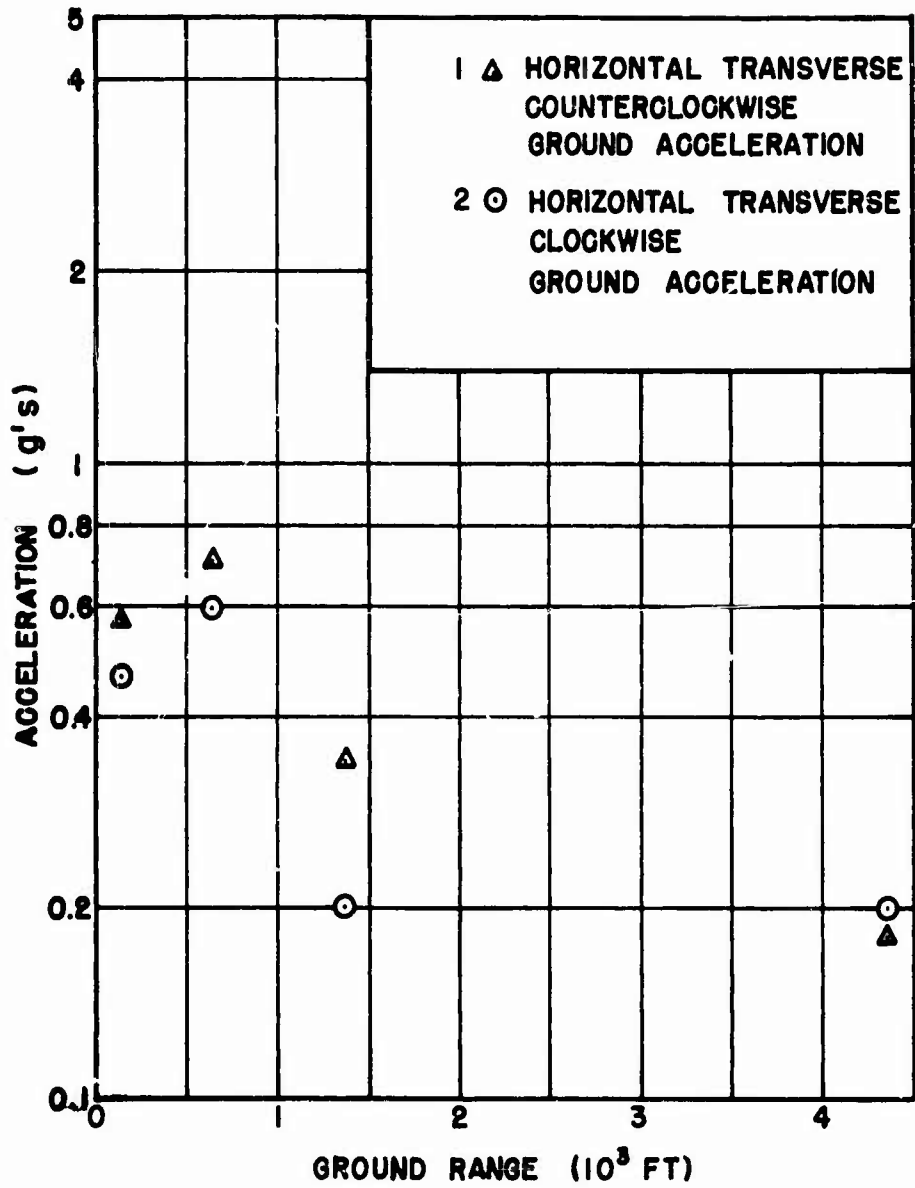


Fig. 3.8 Maximum Horizontal Transverse Ground Acceleration vs Ground Range, Shot 2

TABLE 3.3
Results Shot 3

Station	Ground Range (ft)	Reduced Distance ($\frac{ft}{w^{1/3}}$)	Gage Range (g's)		Vertical (g's)		Radial (g's)		Transverse (g's)	
			Horizontal	Vertical	Upward	Downward	Outward	Inward	Counter-Clockwise	Clockwise
200	192	4.90	2.5	30	No Record	No Record	0.29	1.31	-	-
			2.5	10	1.67	3.62	-	-	0.17	0.42
201	670	1.71	2	10	No Record	No Record	No Record	No Record	-	-
			1.5	6	1.50	1.78	-	-	0.67	0.75
202	1109	3.59	1	6	1.43	1.27	0.18	0.31	-	-
			1	10	1.92	2.41	-	-	0.80	0.28
204	2904	7.42	1	5	Gage Failure	Gage Failure	Gage Failure	Gage Failure	-	-
			0.75	2.5	0.83	1.43	-	-	0.48	0.25
206	4403	11.24	0.75	2.5	0.60	1.50	0.45	0.25	-	-
			0.75	3	0.61	1.25	-	-	0.23	0.18
208	5902	15.07	0.75	1	0.34	0.56	0.40	0.70	-	-
			0.75	0.75	0.70	0.61	-	-	0.54	0.29
210	8901	22.74	0.5	1	0.24	0.58	0.35	0.60	-	-
			0.5	0.5	Off Scale		-	-	-	No Record

The value of $w^{1/3}$ was assumed to be 391.5 for this shot, based on a TNT equivalent of 30.0 KT.

The vertical values first listed were plotted.

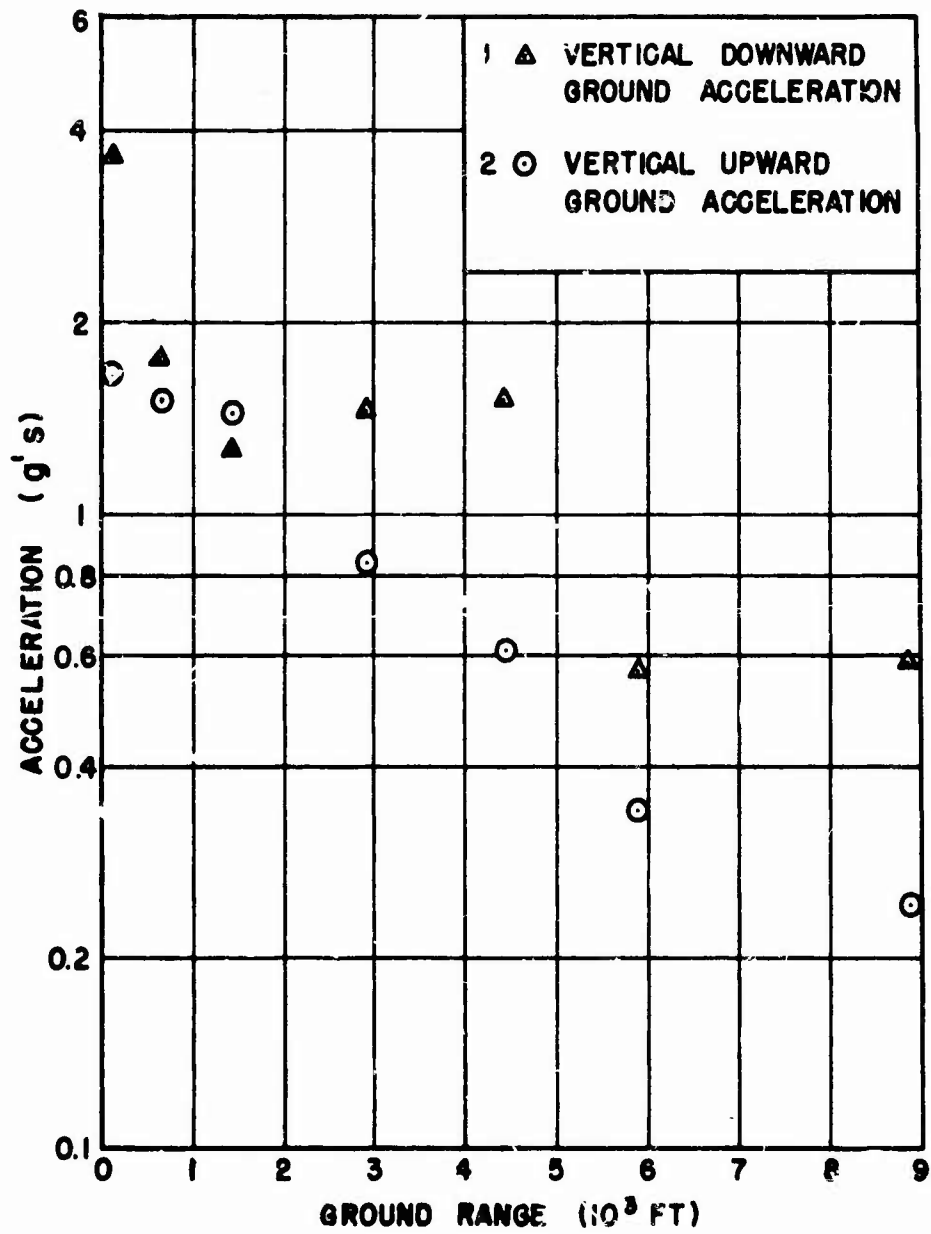


Fig. 3.9 Maximum Vertical Ground Acceleration vs Ground Range, Shot 3

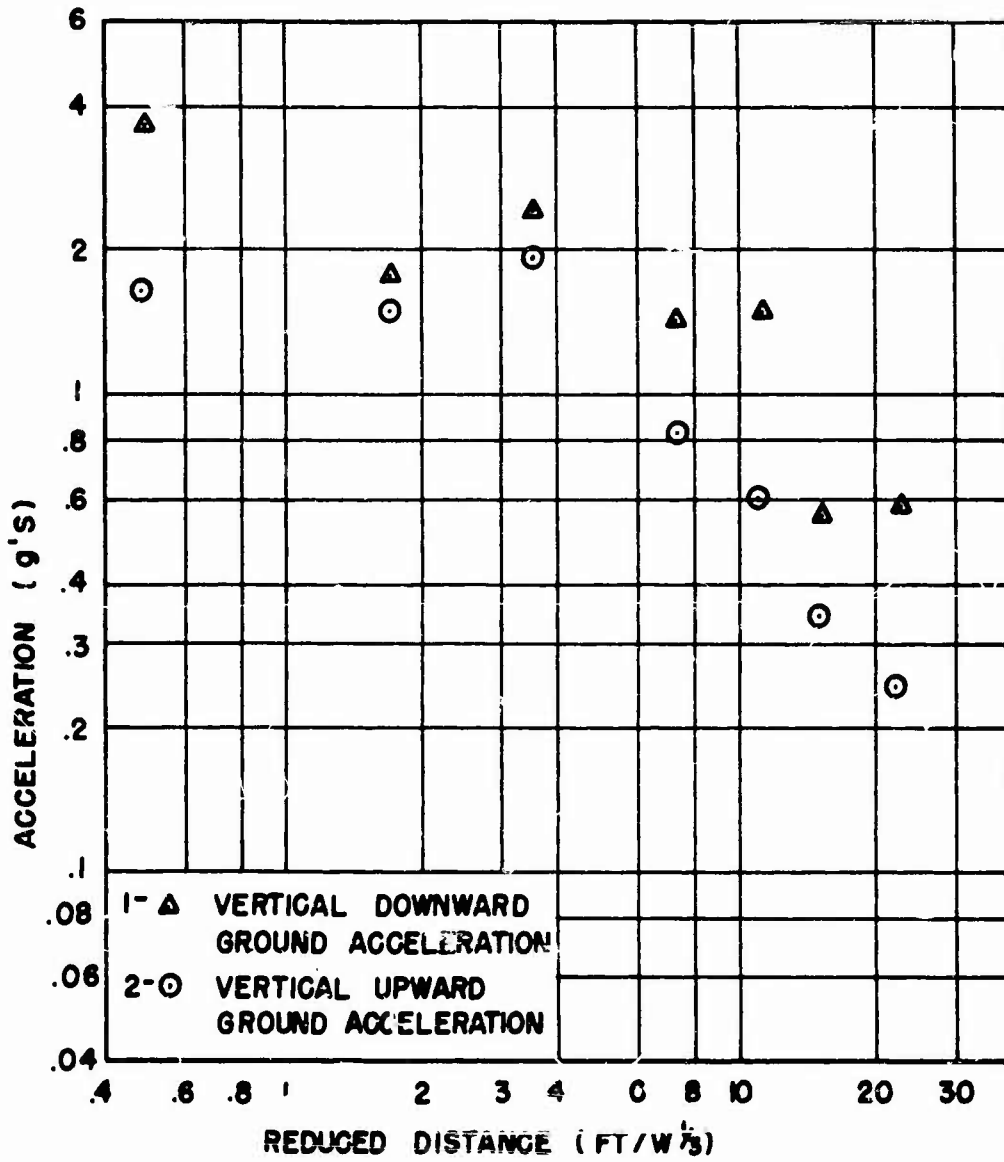


Fig. 3.10 Maximum Vertical Ground Acceleration vs Reduced Distance, Shot 3

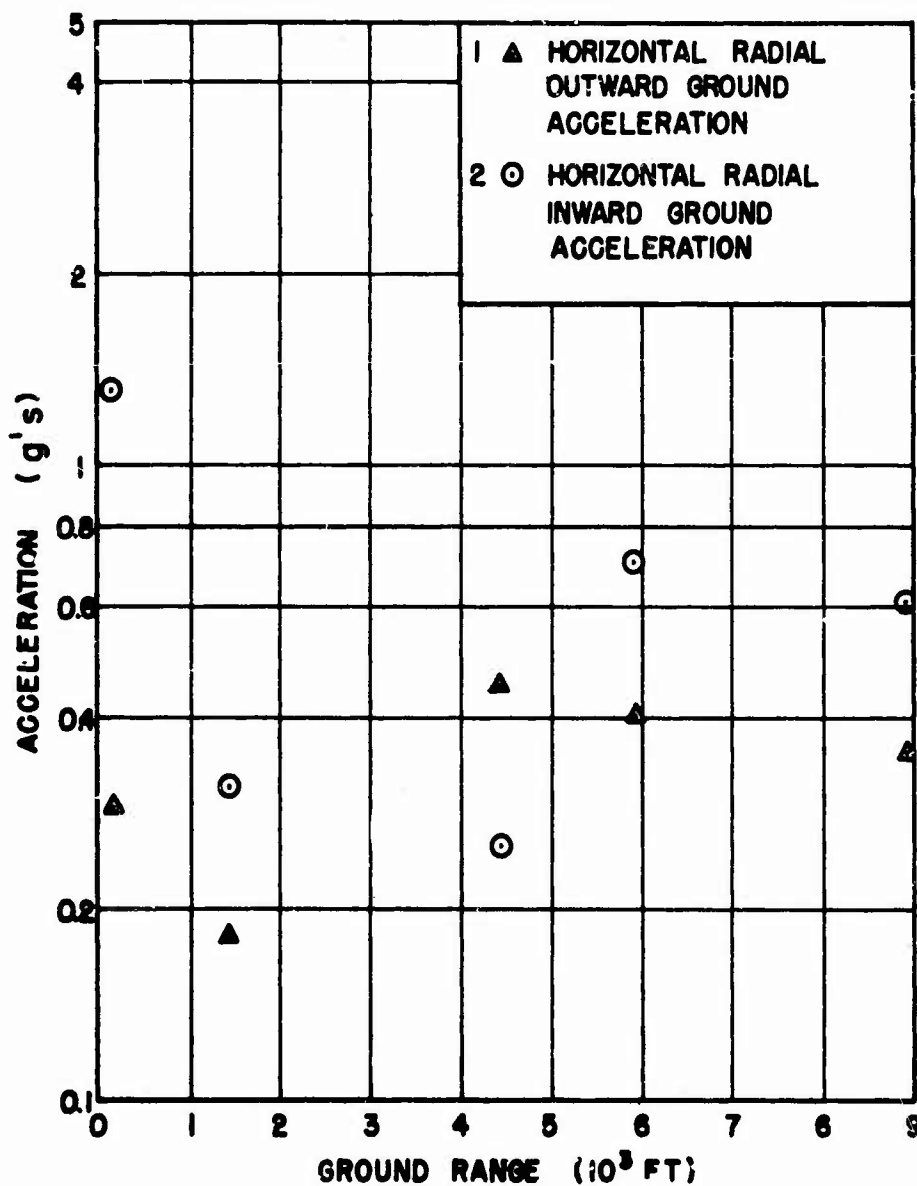


Fig. 3.11 Maximum Horizontal Radial Ground Acceleration vs Ground Range, Shot 3

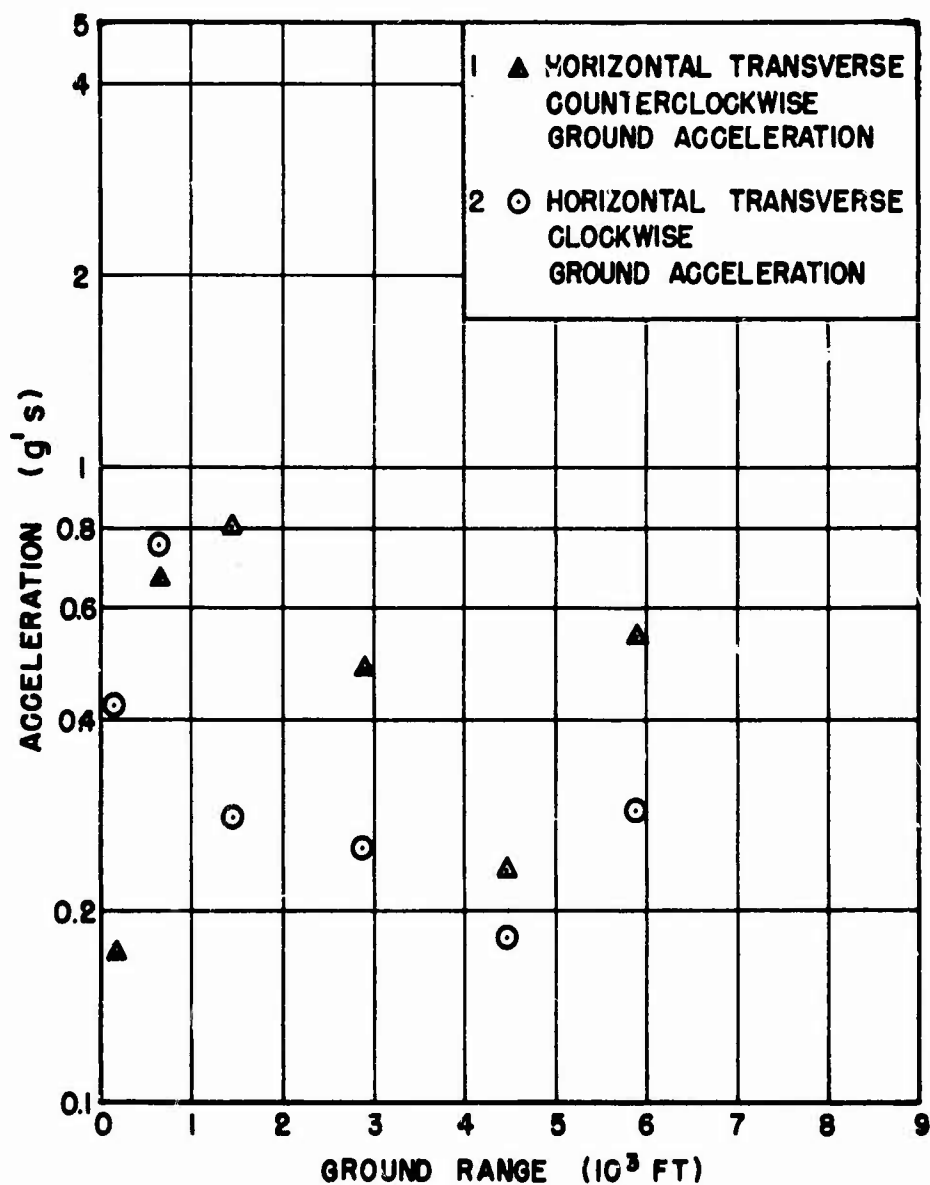


Fig. 3.12 Maximum Horizontal Transverse Ground Acceleration vs Ground Range, Shot 3

TABLE 3.4
Results Shot 4

Station	Ground Range (ft)	Reduced Distance $(\frac{ft}{w^{1/3}})$	Gage Range (g's)		Vertical (g's)		Radial (g's)		Transverse (g's)		
			Horizontal	Vertical	Upward	Downward	Outward	Inward	Counterclockwise	Clockwise	
200	245	.721	2.5	30	Gage Failure	Gage Failure	Gage Failure	-	-	-	-
			2.5	10	Off Scale	7.49		-	-	2.22	0.97
201	613	1.80	2	10	No Record	No Record	No Record	No Record	No Record	-	-
			1.5	6	6.14	6.6		-	-	Off Scale	1.27
202	1348	3.96	1	6	No Record	No Record	No Record	0.34	0.19	-	-
			1	10	No Record	No Record	No Record	-	-	No Record	-
204	2840	8.36	1	5	1.41	3.39	1.8	0.55	-	-	-
			0.75	2.5	1.75	2.5	-	-	-	0.53	0.31
206	4340	12.77	0.75	2.5	0.89	2.1	0.46	0.83	-	-	-
			0.75	3	0.79	1.92	-	-	-	0.60	0.28
208	5840	17.19	0.75	1	0.47	0.98	0.11	0.74	-	-	-
			0.75	0.75	Off Scale		-	-	-	0.27	0.61
210	8840	26.02	0.5	1	0.17	0.59	0.19	0.34	-	-	-
			0.5	0.5	0.12	0.50	-	-	-	0.09	0.5

The value of $w^{1/3}$ was assumed to be 339.7 for this shot, based on a TNT equivalent of 19.6 KT.

The vertical values first listed were plotted.

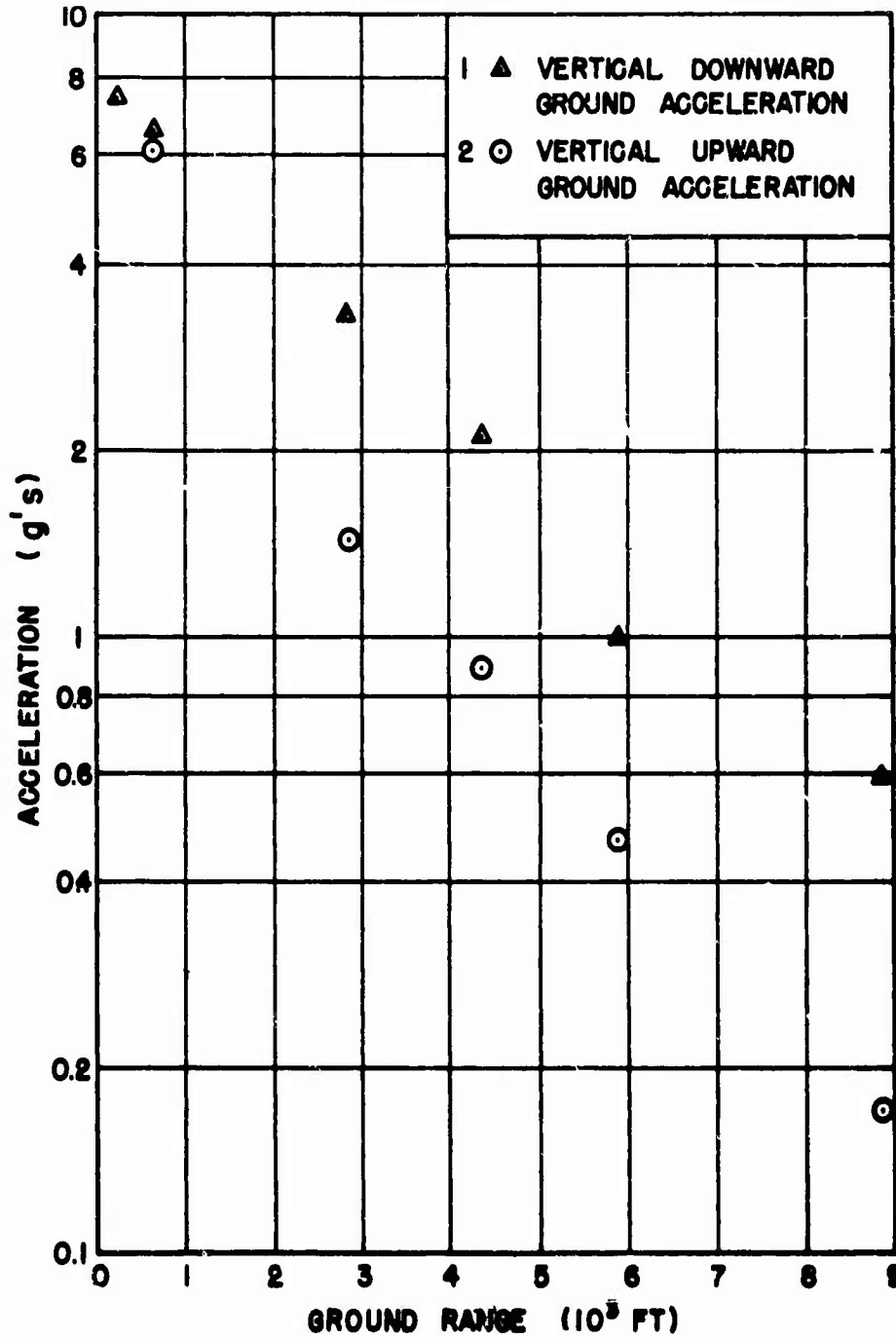


Fig. 3.13 Maximum Vertical Ground Acceleration vs Ground Range, Shot 4

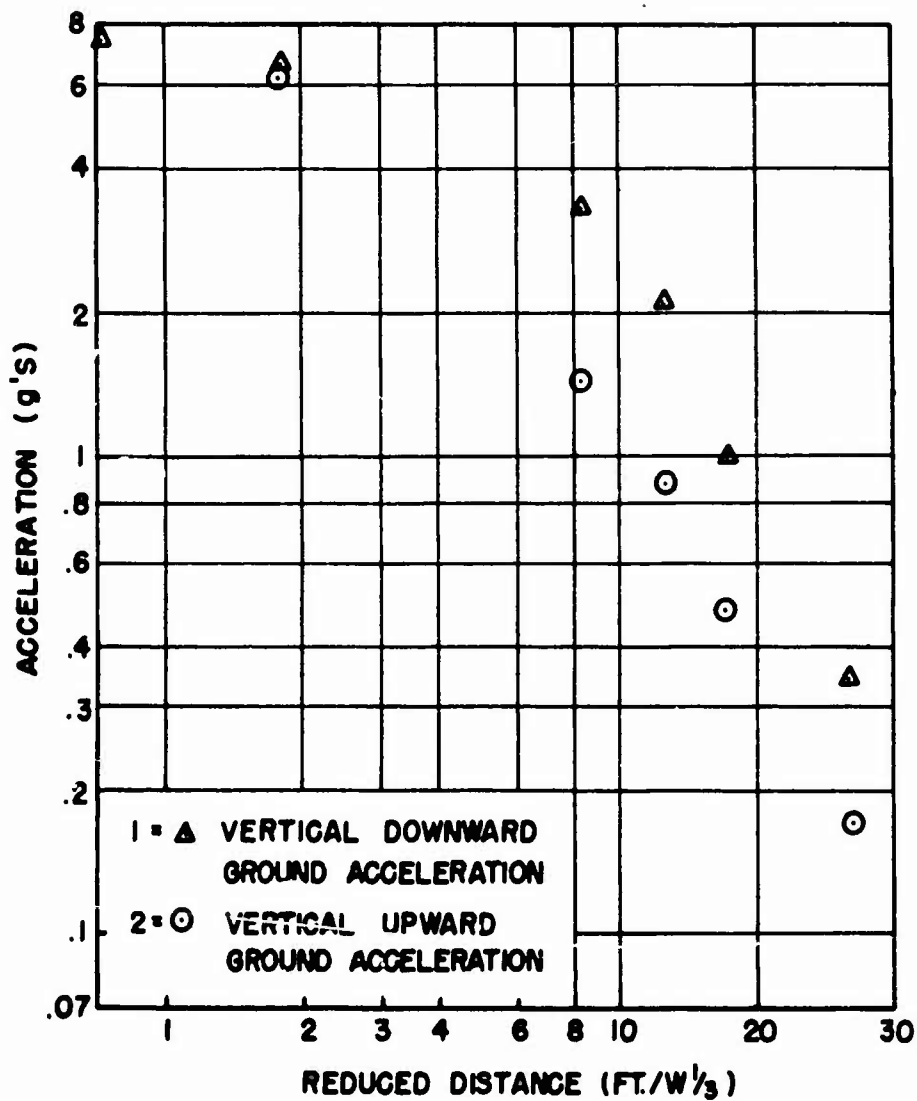


Fig. 3.14 Maximum Vertical Ground Acceleration vs Reduced Distance, Shot 4

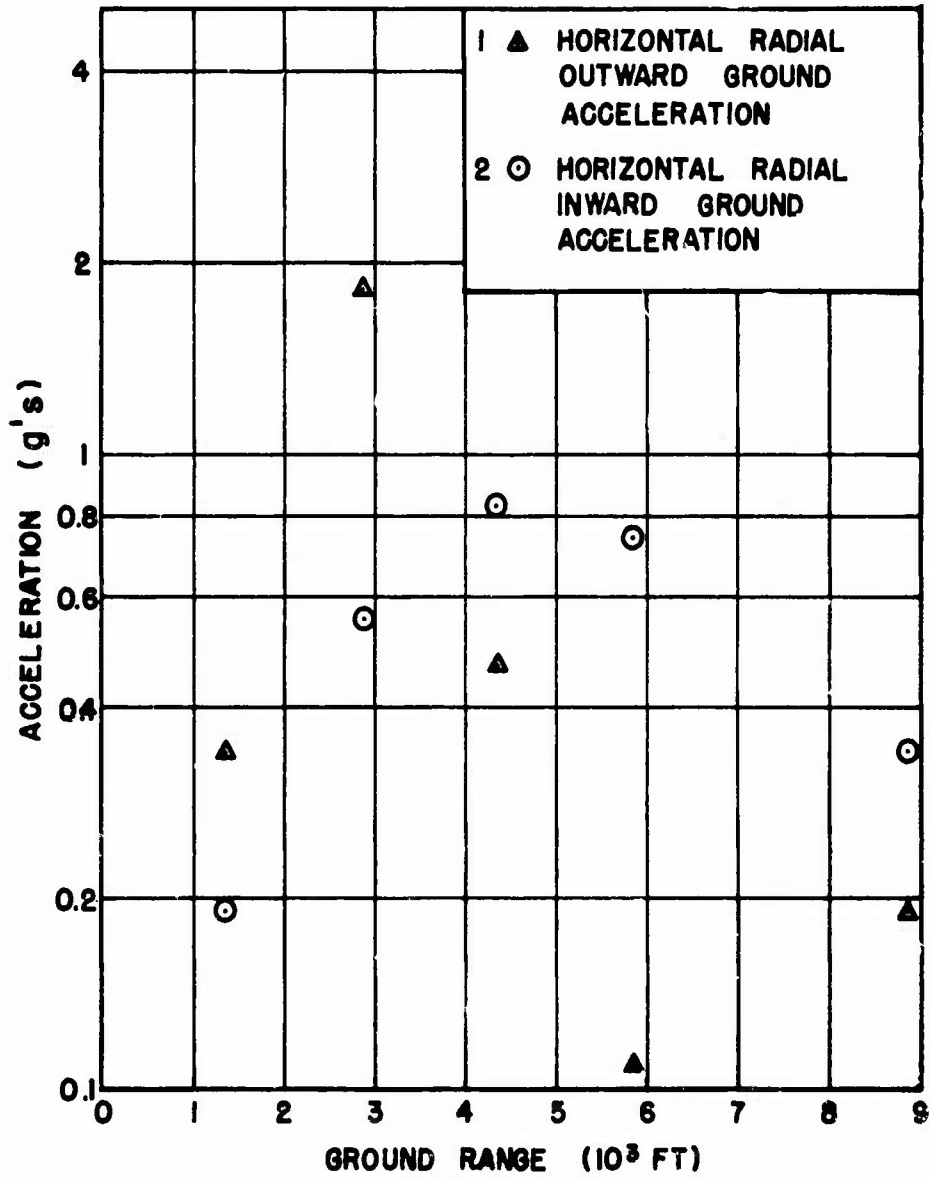


Fig. 3.15 Maximum Horizontal Radial Ground Acceleration vs Ground Range, Shot 4

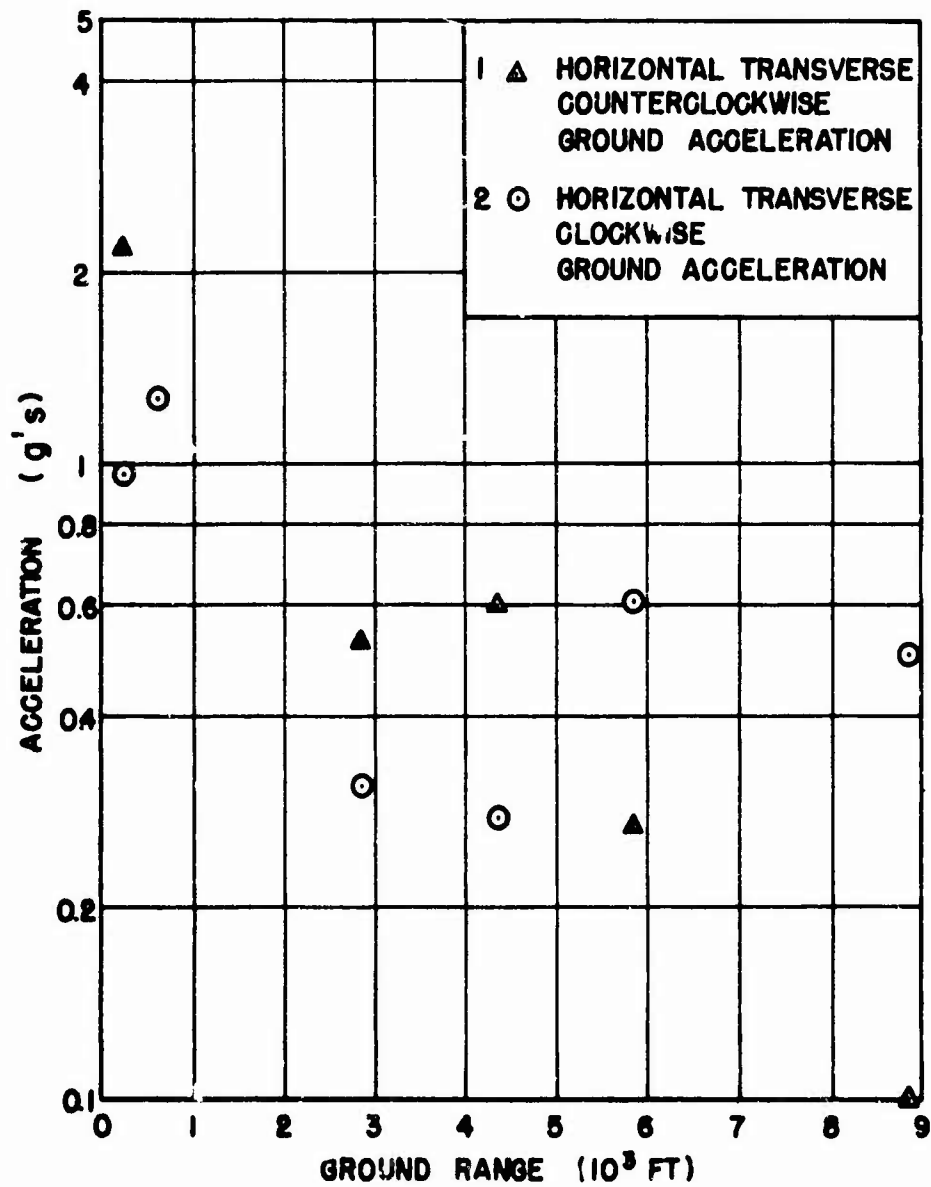


Fig. 3.16 Maximum Horizontal Transverse Ground Acceleration vs Ground Range, Shot 4

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CHAPTER 4

DISCUSSION and CONCLUSIONS

4.1 INSTRUMENTS

As secondary measuring instruments, the ERA accelerometers were fairly satisfactory. Their expense to the project was practically nil as the gages and related equipment were available from Operation JANGLE. However, there is a question whether the high initial cost (approximately \$900 per gage), lack of reliability of the instruments, and extensive labor involved in calibration, adjustment, and installation warrant their extensive use in further tests.

To increase the accuracy of the data, the gages between the ranges of 0.75 and 6 g were re-calibrated in the earth's gravitational field. This was done at the test site and was adequate for the purpose but not as complete a calibration as desired, since only 1 and 2 g could be used as calibration points.

On returning to Aberdeen Proving Ground, a more complete calibration was carried out with the high range gages using a half-sine wave pulse generator borrowed from the Sandia Corporation. Satisfactory calibrating points between 3 and 10 g were obtained indicating an accuracy of 90-95 per cent for the manufacturer's calibration curves. The condition of the element damping was readily observed by the records obtained in this calibration.

4.2 CONCLUSIONS

Maximum vertical and horizontal transverse and radial accelerations at a depth of 5 ft. have been obtained for four air burst nuclear detonations. Comparison of the direct vertical acceleration results with those of the ground level air blast pressures as obtained by the Stanford Research Institute to determine a ratio of acceleration to air pressure gives the following average results: Shot 1, 0.28; Shot 2, 0.24; Shot 3, 0.19; and Shot 4, 0.38. An average of these figures for the four shots result in a correlating factor of .27.

With due consideration for the height of burst, the accelerations resulting from Shot 1 were not appreciably smaller than for the other shots. Sandbags in preference to loose fill were used on the later shots to facilitate the recovery of the gages and to more nearly simulate the undisturbed medium.

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No correlation between vertical and horizontal (radial) or vertical and horizontal (transverse) acceleration was obtained.

The manufacturer claims an accuracy of 10 per cent for the gages but the experience of the authors indicates that 25-30 per cent is more nearly correct. The results are indicative of an order of magnitude only.

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CHAPTER 5

RECOMMENDATIONS

The ERA gages were chosen as back-up gages for these tests because they were the only self-recording accelerometers commercially available which would operate under conditions of radiation and electrical interference obviating the use of electronic instruments. The basic ideas incorporated in the design of the ERA instrument satisfied the conditions that had to be met, however, several engineering details in the gage might have been improved; viz:

1. A change in the drive mechanism to allow a more accurate adjustment of tape speed and provide a more constant speed.
2. A better method of adjusting the spacing between elements and tape, possibly by a vernier screw system.
3. A timing device which would provide accurate and dependable marks on the acceleration record.
4. A longer useable run on the magnetic tapes.
5. Better design of sensitive elements providing accurate damping and increased ruggedness and dependability.
6. A more dependable starting mechanism.
7. An hermetically sealed case.