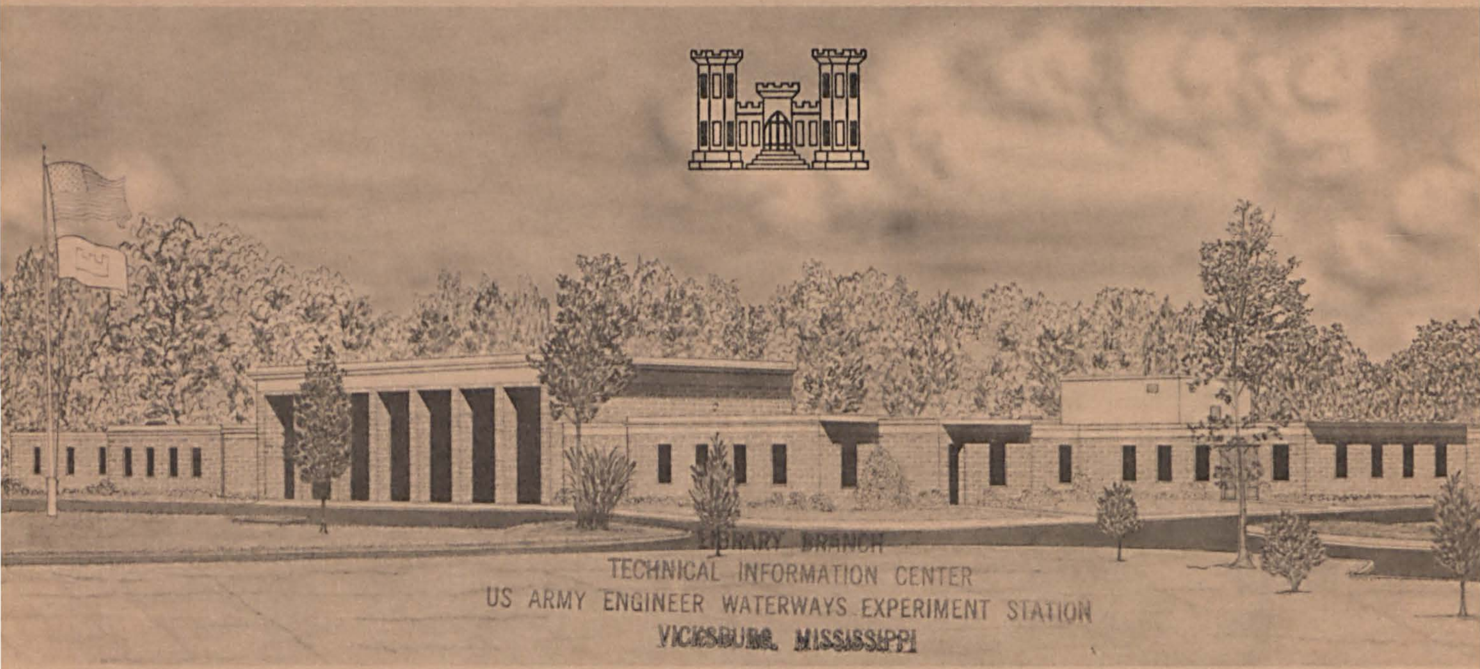
MISCELLANEOUS PAPER N-72-10

GROUND MOTIONS FROM HIGH-EXPLOSIVE EXPERIMENTS

by

L. F. Ingram



December 1972

Conducted by U. S. Army Engineer Waterways Experiment Station
Weapons Effects Laboratory
Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

FOREWORD

This paper was prepared for presentation at the Colloquium to Review the State-of-the-Art in Predicting Ground Motions in Rock Media held at Defense Nuclear Agency 1-3 November 1972. Costs attendant to this presentation were borne by Defense Nuclear Agency funds allocated to the Waterways Experiment Station (WES) for operations MIDDLE GUST and MIXED COMPANY.

The data processing assistance provided by D. W. Murrell, Charles Joachim, Truman Brogan, J. L. Drake, and H. D. Carleton is acknowledged. The cooperation of CPT Steve Melzer and Mr. Jimmie Bratton of the Air Force Weapons Laboratory in connection with the MIDDLE GUST data is appreciated.

The presentation was prepared in the Weapons Effects Laboratory under the general direction of W. J. Flathau, Chief. The Waterways Experiment Station Director was COL Ernest D. Peixotto; Mr. F. R. Brown was Technical Director.

ABSTRACT

A review of ground shock data from recent large, near-surface high-explosive tests is made. Emphasis is on close-in motions in rock.

Wave forms are shown for selected shots and locations. Comparisons are made among wave forms for similar test conditions in different geologic materials including soil, shale, granite, and sandstone.

Variations in peak motion amplitudes at various depths and ranges are discussed for the different geologic materials.

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TABLES

FIGURES

INTRODUCTION

Purpose

The purpose of this presentation is to acquaint the colloquium participants with recent high explosive tests which provide a source of ground shock information for near-surface bursts on rock and to describe the ground motions in regions of interest.

Background

Over the past few years the Defense Nuclear Agency has conducted several high explosive tests involving multiton, TNT, spherical charges detonated near the surface of the earth. The objective of these tests have largely been (1) to improve ground shock predictions for nuclear explosions by both empiricism and analytical methods, (2) to obtain a better understanding of the blast, shock and cratering phenomenology in geologic settings of military significance, and (3) to determine the response of various structures and targets to the explosion environment.

Approach

Pertinent test information is presented in tabular form; applicable references are cited.

Particle velocity and transient displacement wave forms are presented for different ranges, depths, and geologies. Comments are made on effects of test parameters on wave forms and amplitudes.

Scope

The scope of this presentation is limited to the following:

a. Tests conducted since 1964 with TNT spheres.

b. Charge weights of 20 tons or more.

c. Heights of burst ranging from zero (1/2 in, 1/2 out) to two charge radii (above the surface).

It should be noted that some excellent ground motion (and cratering) information was obtained from the AFWL 1000-lb MIDDLE GUST series.

DATA PRESENTATION

Review of Tests

Table 1 lists some pertinent information for the spherical TNT shots considered within the scope of this presentation. Available references are indicated as well as information on apparent crater volumes; the volumes for MIDDLE GUST and MIXED COMPANY should be considered preliminary as results of stereophotography are not available.

Description of Test Sites

Flat Top I was executed in a fairly competent limestone outcrop on the south end of Banded Mountain in Area 9 of NTS. Compression wave velocities were 13,000 ft/sec horizontally and 19,000 ft/sec vertically.[1]

Distant Plain 6 was conducted at DRES Watching Hill Range. A thorough, comprehensive description of this site and its dynamic properties may be found in Reference 5, from which the following seismic velocities were extracted:

Depth Interval ft	Seismic Velocity ft/sec
0-21	1,150
21-42	4,850
42-130	5,500
130-215	6,000
215	7,500

The Mine Shaft site near Cedar City, Utah consisted of a granite rock called "tonalite." Its properties were relatively uniform with depth; it was a relatively weak granite with in situ seismic velocities ranging from 8,000 to 12,000 fps. Laboratory tests on cores gave somewhat higher values

The MIDDLE GUST wet site was near Crowley, Colorado. Some of the properties are shown in Table 2.

Table 1

Large Spherical TNT Tests on Rock With Ground Motion Measurements

(Numbers in parenthesis are references shown at end of text.)

Shot or Event	Date of Test	Yield (tons)	HoB (Charge Radii)	Test Site	Site Material	Apparent Crater Volume (ft^3)	Spread of Depth Instrumented (ft)	Spread of Distances Instrumented (ft)	Data Return
Flat Top I (1)	22 Jun 64	20	0	NTS	Limestone	10,000	1.5-100	0-150	Poor
Distant Plain 6[1] (2)	Jul 67	100	1.0	DRES	Alluvium	35,800	1.5-10	49-680	Good
Mine Under (3)	22 Oct 68	100	2.0	Cedar City	Granite	Nil	1.5-18	39-400	Fair
Mine Ore (3)	12 Nov 68	100	0.9	Cedar City	Granite	5,940	1.5-18	28-434	Good
Mineral Rock (4)	8 Oct 69	100	0.9	Cedar City	Granite	8,100	2.0-36	40-500	Exc
Middle Gust I	16 Sep 71	20	0	Crowley	Soil/Wet Shale	70,000	1.5-60	0.280	Fair
Middle Gust II	14 Dec 71	100	2.0	Crowley	Soil/Wet Shale	50,700	1.5-60	0-500	Fair
Middle Gust III	13 Mar 72	100	1.0	Crowley	Soil/Wet Shale	95,000	1.5-80	0-500	Exc
Middle Gust IV	22 Jun 72	100	1.0	Ordway	Soil/Dry Shale	47,000	1.5-80	0-400	Exc
Middle Gust V	10 Aug 72	20	0	Ordway	Soil/Dry Shale	21,300	1.5-80	0-400	Exc
Mixed Company I	1 Jun 72	20	0	Glade Park	Soil/Sandstone	10,100	2.0-20	25-175	Good
Mixed Company II	13 Jul 72	20	1.0	Glade Park	Soil/Sandstone	2,250	1.5-5	54-294	Exc
Mixed Company III	13 Nov 72	500	1.0	Glade Park	Soil/Sandstone	69,000	1.5-88	0-1431[2]	Exc

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[1] Although not fired on rock, DP-6 is included for comparison with several other 100-ton tangent sphere events.

[2] The limit of "strong motion" instrumentation is 1,431 ft; seismometers extend to approximately one mile beyond this line.

Table 2

MIDDLE GUST Wet Site Material Property Profile

Layer No.	Depth	Wet Unit Weight pcf	Initial Constrained Modulus ksi	Water Content %	Saturation %	Compressional Velocity ft/sec	Material Description
1	0- 4	130.5	10	16.5	85.3	1000 to 1700	Tan, silty, sandy clay
2	4- 9	135.2	12	17.6	96.9	2600 to 5300	Sandy clay/clayey sand
3	9-15	129.3	30	21.3	94.8	6300	Tan to gray soft weathered clay shale
4	15-23	143.5	75	11.3	95.3	8200 to 90,000	Dark gray fractured clay shale
5	23-45	148.5	300	8.0	94.3	8200 to 10,000	Gray to black clay shale
6	45-125	149.7	525	7.7	94.8	8200 to 10,000	Gray to black clay shale

The MIDDLE GUST dry site is near Ordway, Colorado; properties are shown in Table 3.

The MIXED COMPANY site, near Grand Junction, Colorado, is 7 miles from the Glade Park community. A clayey silt of variable depth (from 0-6 ft) overlies massive sandstone. The seismic velocity in the overburden is 2,000 to 3,000 fps, the velocity in the rock ranges from 6,000 to 8,000 fps. A detailed property investigation is being performed by the WES Soil Dynamics Branch.

Display and Discussion of Wave Forms

Mineral Rock motions

Figures 1 through 10 show particle velocity and displacement time histories measured from the Mineral Rock Event of the Mine Shaft Series. The charge was 100 tons of TNT essentially tangent to the granite surface (buried 0.1 R).

The vertical motion waveforms are characteristic of vertical motions observed in relatively uniform earth materials. Initial downward motions are produced by the airblast wave; these are followed by relatively large upward motions caused by rebound and cratering action. Net upward motions occurred at these ranges. A comparison of the vertical motions at the 80- and 110-ft ranges reveals that the upward motions caused by cratering action predominate at 80 ft and that the upward and downward peaks (both velocity and displacement) became more nearly equal further out.

It is interesting to note that the basic wave shapes are the same at the three depths shown (2, 18 and 36 ft).

Figures 2 and 4 show corresponding horizontal motions at the 80- and 110-ft ranges, respectively. It is apparent that the horizontal motions have nearly identical shapes and that there is very little attenuation of horizontal motion magnitudes with depth at these ranges.

Figure 5 shows horizontal velocity wave forms for Mineral Rock at seven different ranges from 40-110 ft. This array spans the 1500-600 psi overpressure region. The small perturbation at the beginning of each trace is caused by arrival of the airblast-induced shock. An interesting

Table 3

MIDDLE GUST Dry Site Material Property Profile

Layer No.	Depth	Wet Unit Weight pcf	Initial Constrained Modulus ksi	Water Content %	Saturation %	Compressional Velocity ft/sec	Material Description
1	0-2	118	15	14	55.8	Not yet available	Light clay shale
2	2-4.5	126	25	13	63.8		Weathered gray to brown clay shale
3	4.5-7.5	134	35	13	77.5		Weathered, fractured gray clay shale
4	7.5-11.5	138	50	13	85.2		Weathered, fractured gray clay shale
5	11.5-20	138	70	14.5	91.0		Weathered, fractured gray clay shale
6	20-23	133	90	14.5	81.0		Weathered, fractured gray clay shale
7	28-45	147	150	10	95.6		Unweathered, competent gray clay shale
8	45-70	148.5	225	9.3	95.9		Gray clay shale
9	70-100	149	450	9.0	95.6		Dark gray clay shale
10	100-160	150.5	750	9.0	95.1		Dark gray clay shale

feature of these records is the simple wave shape. It may be noted that the rock response becomes more nearly elastic at greater ranges; this is demonstrated by the increasingly negative portion of the wave forms at larger ranges.

Figure 6 displays the horizontal displacements derived by integration of the velocity records of Figure 5. The decrease in amplitude with increasing range is evident as well as the tendency toward elasticity also observed on the velocity records.

Figure 7 shows Mineral Rock horizontal velocities at the 18-ft depth for the ranges 40-110 ft; Figure 8 provides corresponding displacements. Similar data for the 36-ft depth is provided on Figures 9 and 10.

Middle Gust III motions

Figures 11 through 14 show vertical and horizontal velocity and displacement wave forms for the 80-ft range (approximately 900 psi) from Middle Gust III. Excellent measurements of both components were made at seven depths ranging from 1.5 to 80 ft, thus, this data set is one of the best and most complete motion documentations of record for large explosions in a layered geology.

Middle Gust III was a 100-ton tangent sphere detonated at the AFWL wet site near Crowley, Colorado. The geology consisted roughly of wet soil and weathered shale over more competent shale at a depth of about 20 ft. Table 2 shows properties of some of the layers.

Large upward and outward motions occurred near the surface (to a depth of about 11 ft) as a result of the cratering action. Rather dramatic changes toward shorter pulses (higher frequencies) are seen with increasing depth; this is especially evident on the horizontal velocity records, Figure 13. It is also interesting to note the change in direction of initial vertical motion, i.e., above 20 ft the initial motions are upward while below 20 ft they are down.

The most interesting feature of this data, however, is the graphic evidence on Figure 14 of a significant horizontal shear which occurred at a depth between 12 and 20 ft. Within this zone the soil properties change markedly.

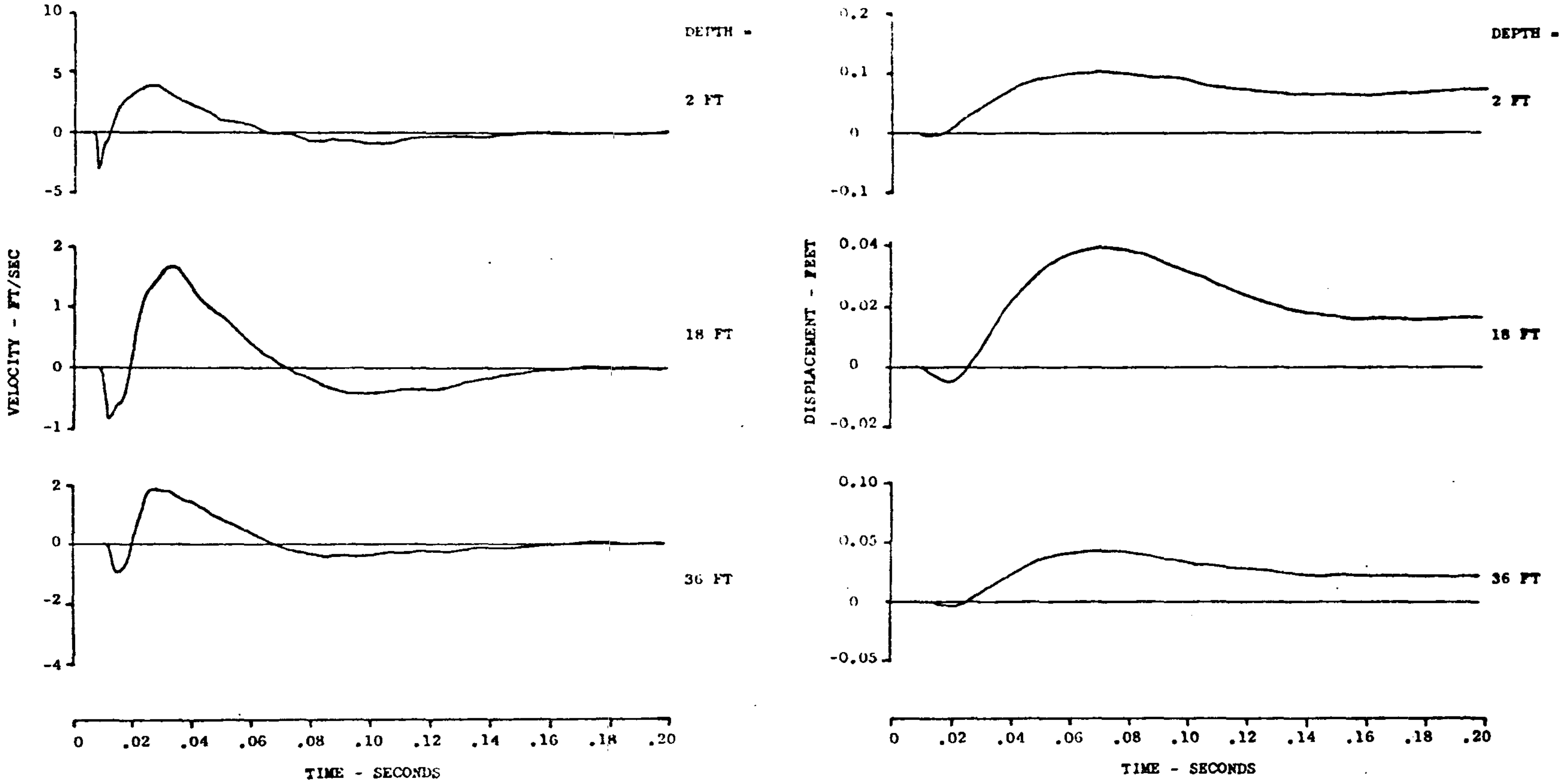
Mixed Comapny II motion

Figures 15 through 18 show vertical and horizontal velocity and displacement time histories (measured at the 1.5-ft depth) for this 20-ton tangent sphere on a soil over sandstone geology scaled to the planned 500-ton event of this series. Although the wave forms are similar to those observed at the Mine Shaft and Middle Gust sites, it was observed that the near-surface transient vertical motions were predominantly down compared to the prevailing upward motions at the other sites. (The preliminary data shown on Figures 15 through 18 is subject to additional editing and adjustment.)

Figures 19 and 20 show scaled Mixed Comapny II peak downward and outward velocities, respectively, compared to the data trends of Distant Plain 6 and Mine Shaft. Although no 5-ft depth wave forms are shown in this presentation, the peaks observed are also plotted.

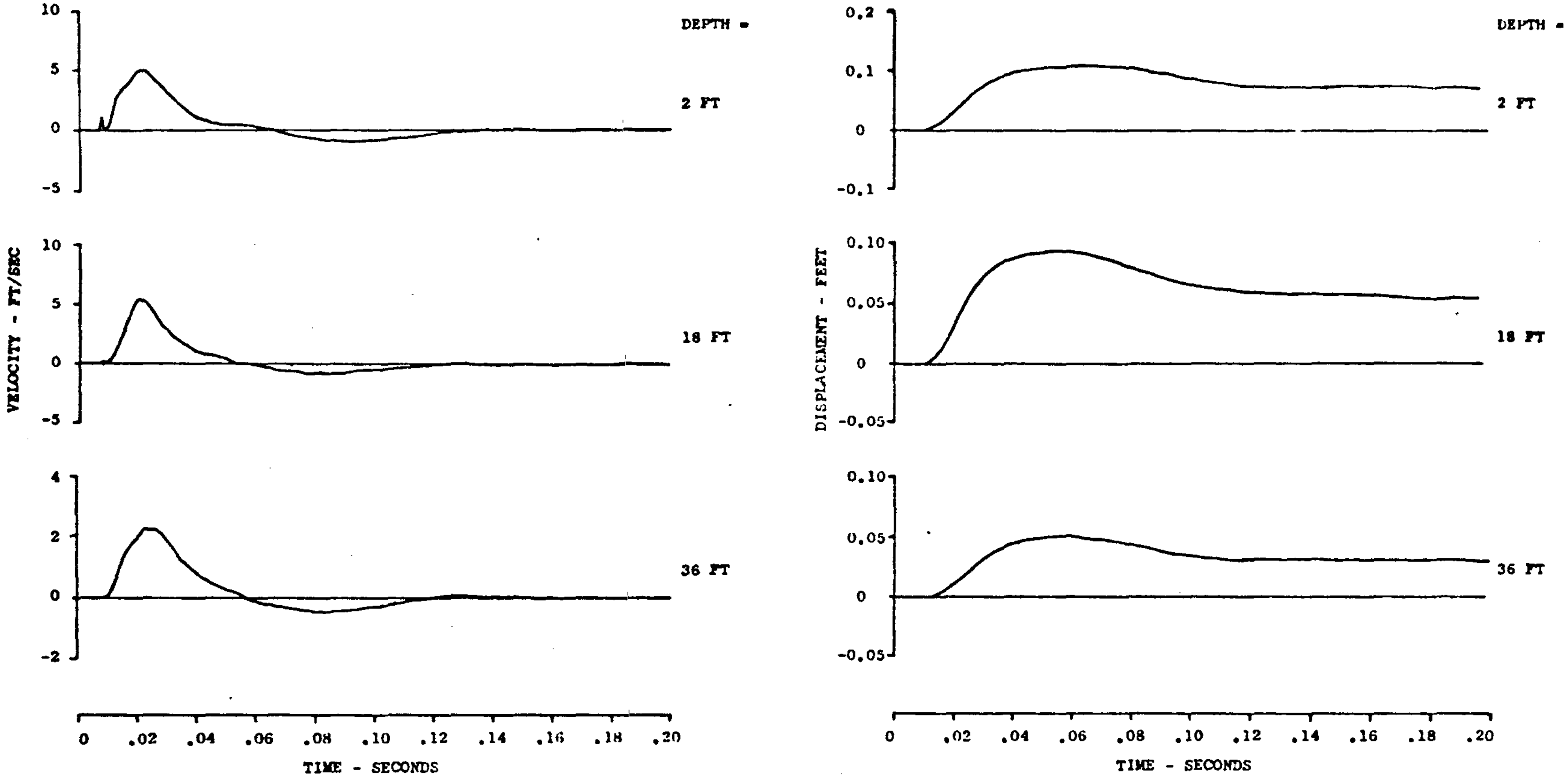
From Figure 19 we may see that the 1.5-ft downward velocities are comparable to those observed at DRES; the Mixed Company 5-ft velocities exceed those measured near the granite surface.

A significant observation of the horizontal motions at the Mixed Company site is evident in Figure 20 where the scaled peak values at 5-ft depth exceed both the Mine Shaft and Canadian data. Although horizontal particle velocities observed on Mixed Comapny II at 5-ft depth were considerably higher than those at 1.5-ft depth, a cursory look showed no gross differences in displacements at these depths.



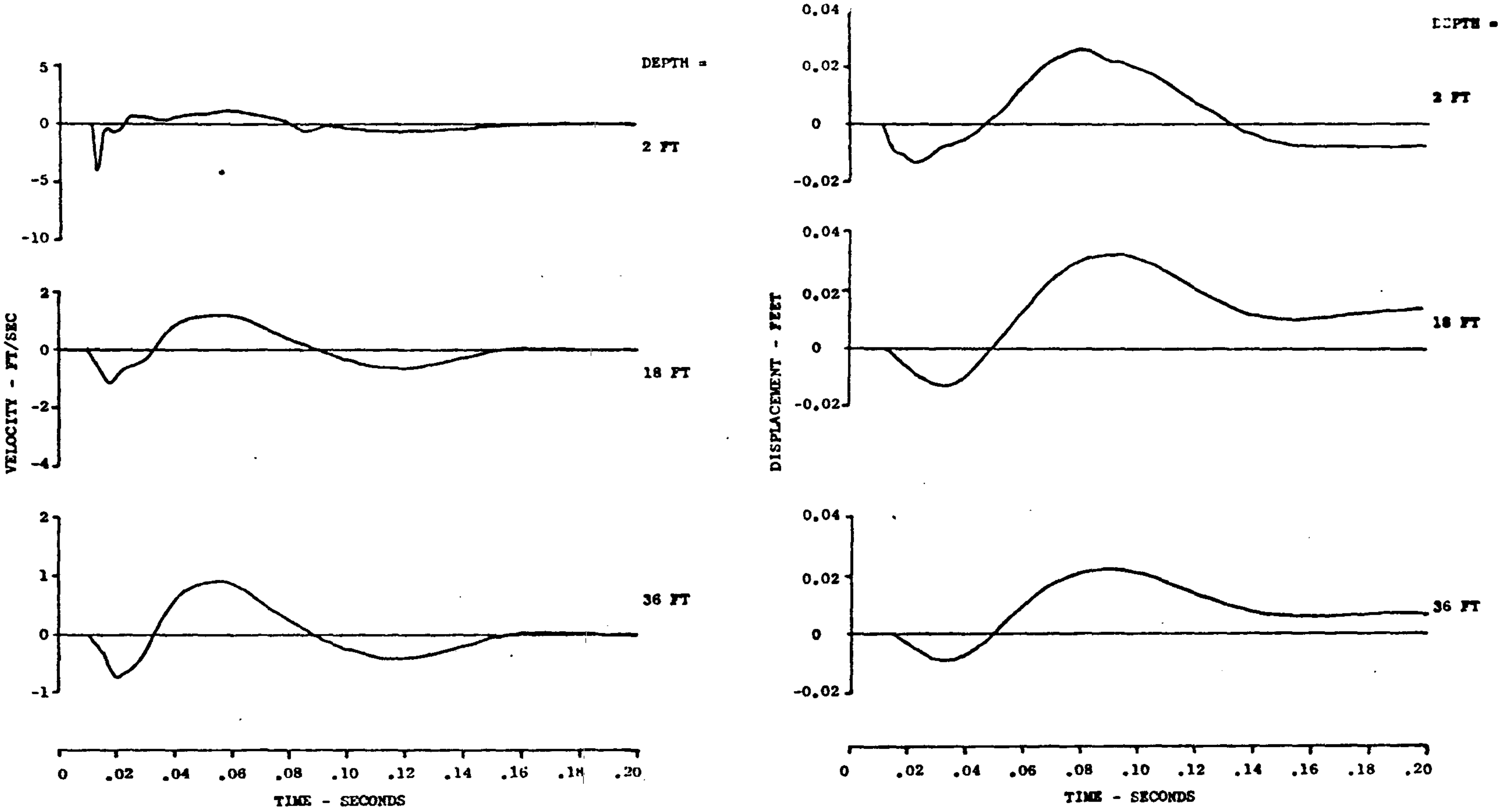
MINERAL ROCK VERTICAL MOTIONS AT 80-FT RANGE, EAST LINE

Figure 1



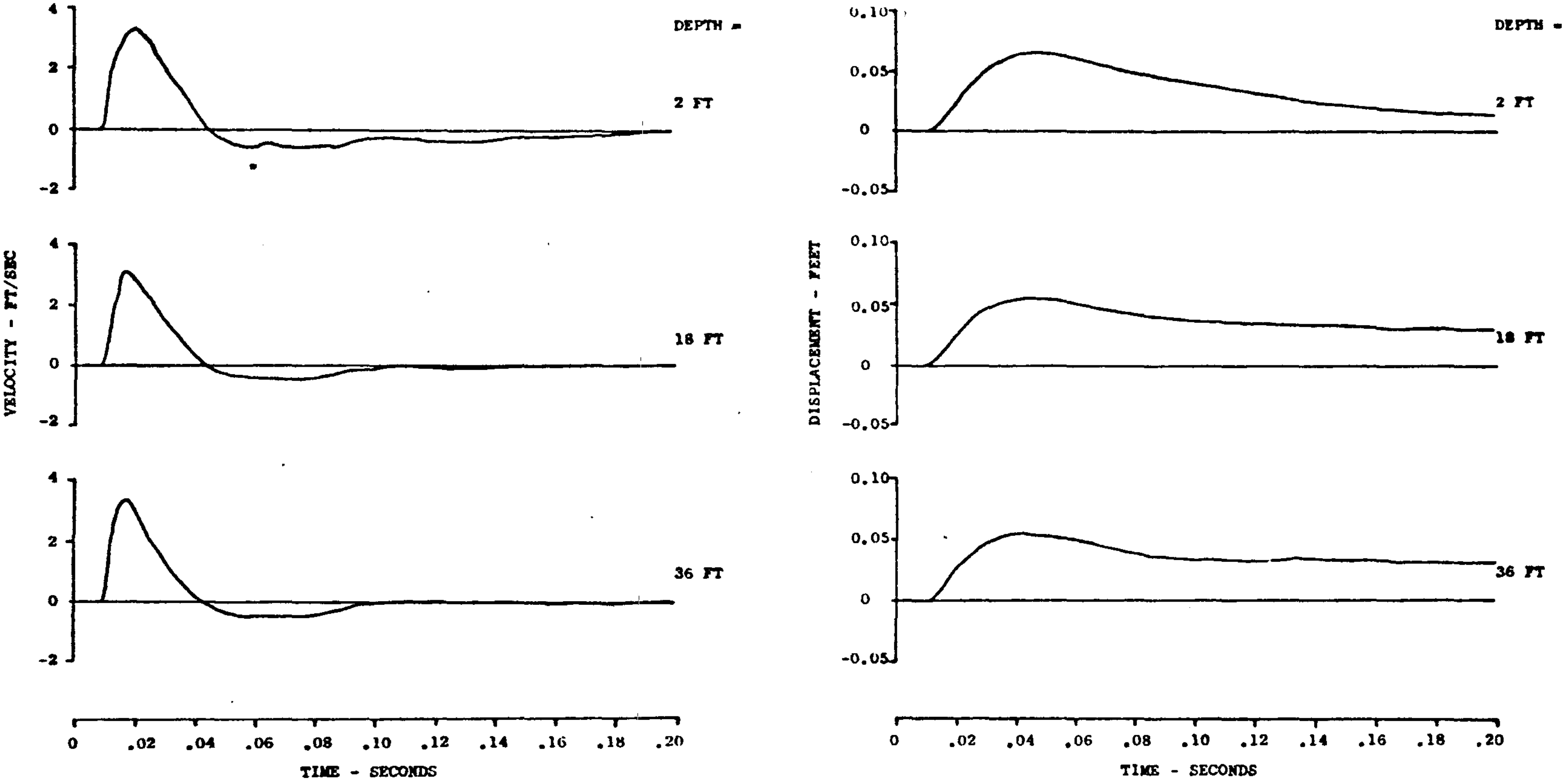
MINERAL ROCK HORIZONTAL MOTIONS AT 80-FT RANGE, EAST LINE

Figure 2



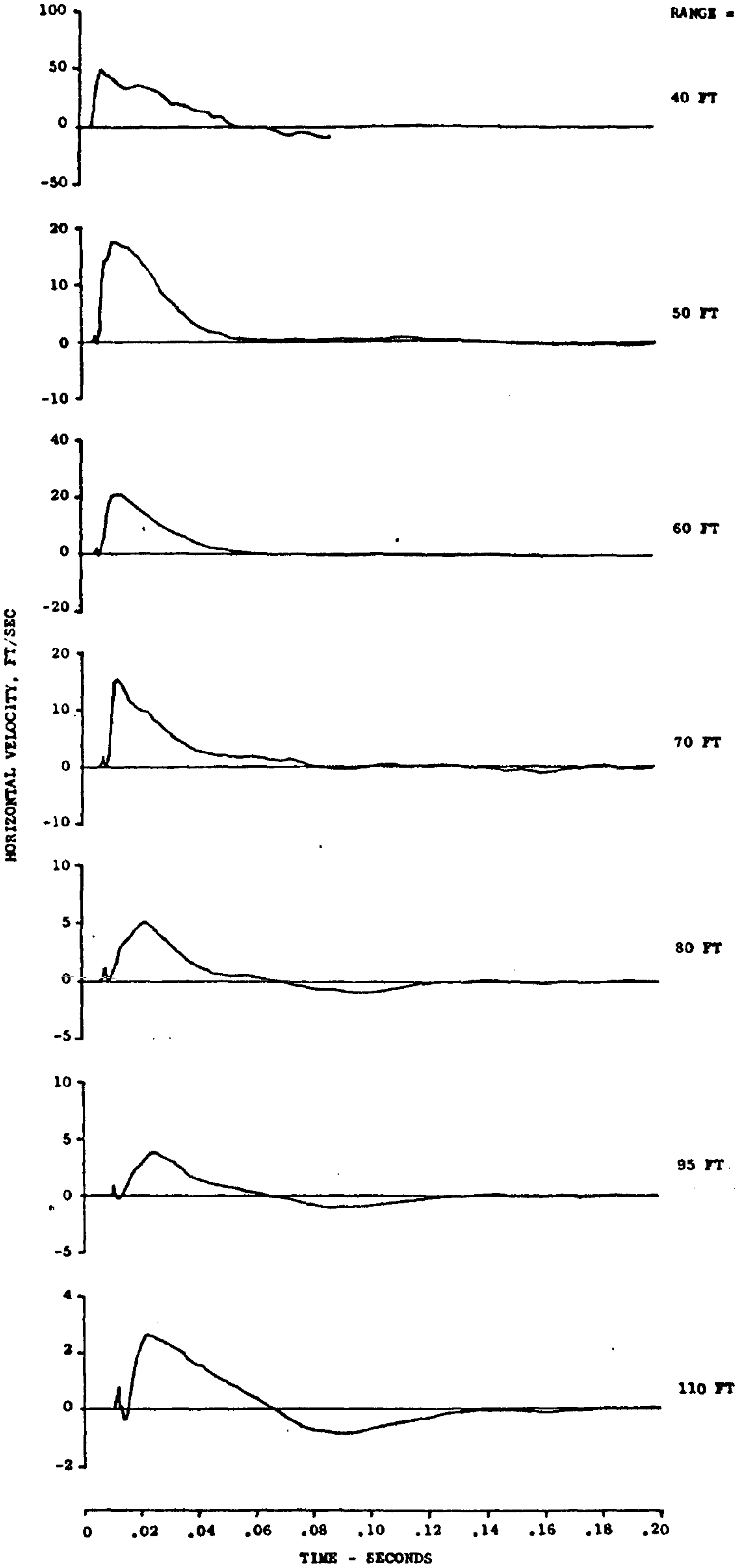
MINERAL ROCK VERTICAL MOTIONS AT 110-FT RANGE, NORTH LINE

Figure 3

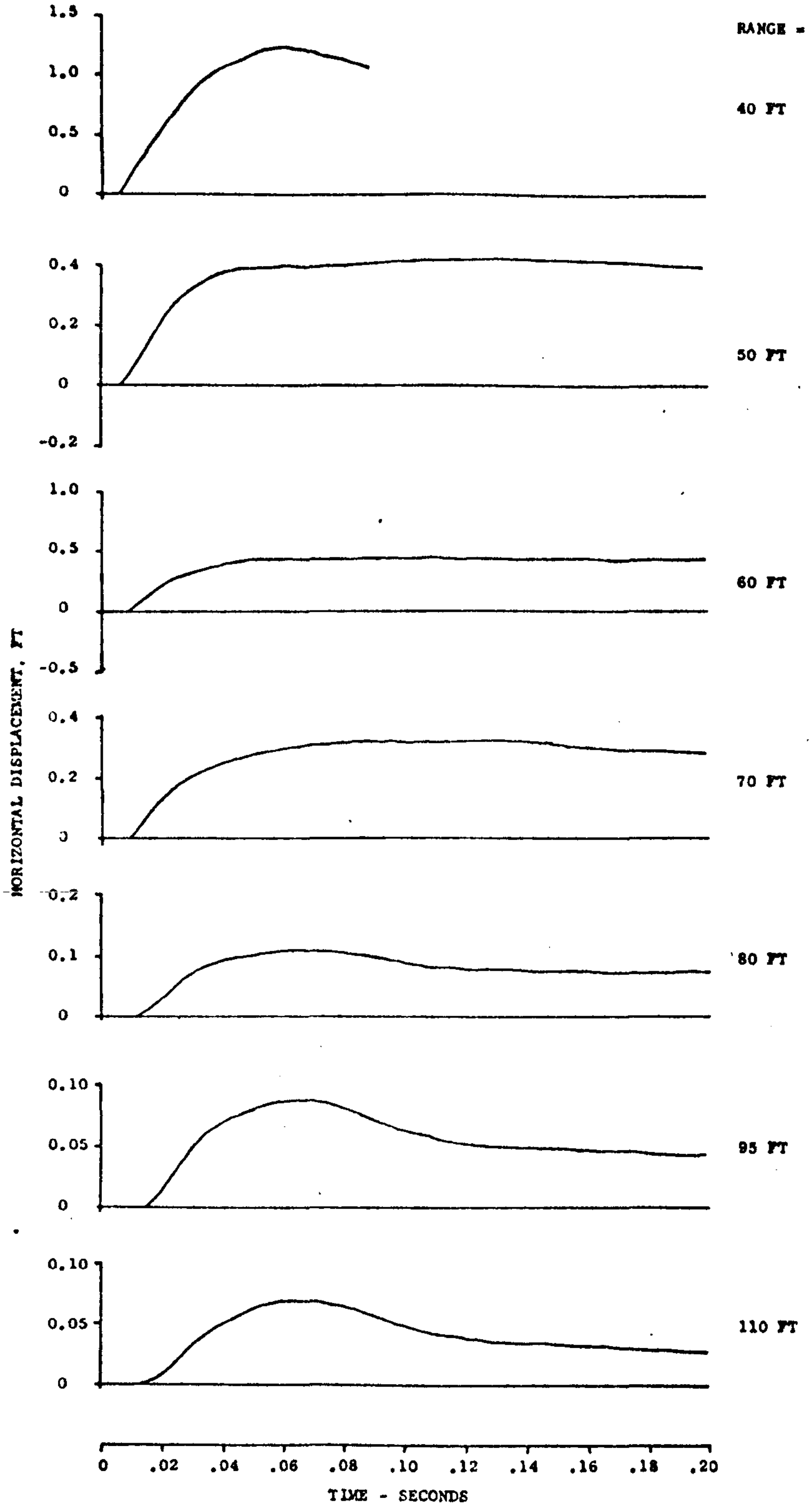


MINERAL ROCK HORIZONTAL MOTIONS AT 110-FT RANGE, NORTH LINE

Figure 4

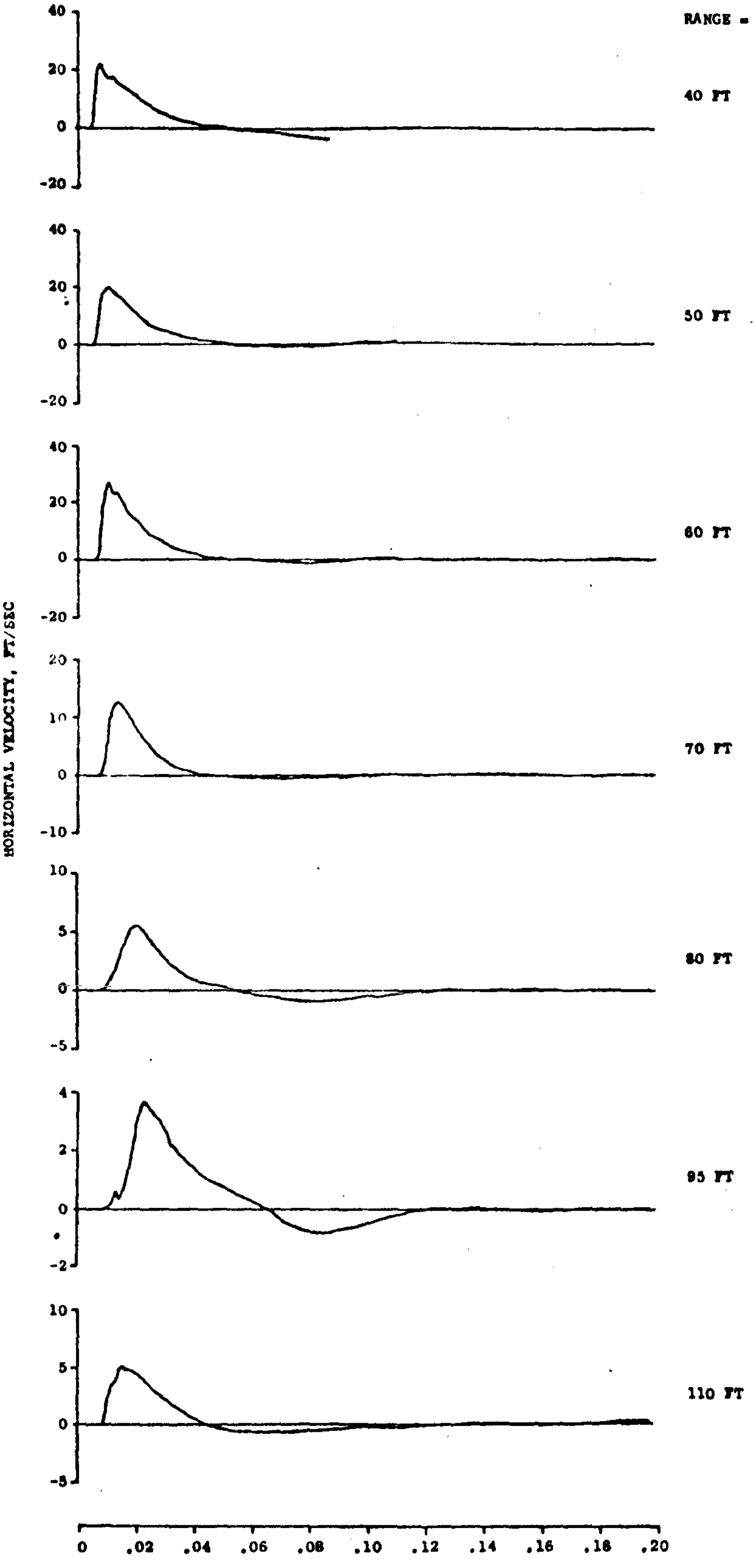


MINERAL ROCK HORIZONTAL VELOCITIES AT 2-FT DEPTH
Figure 5



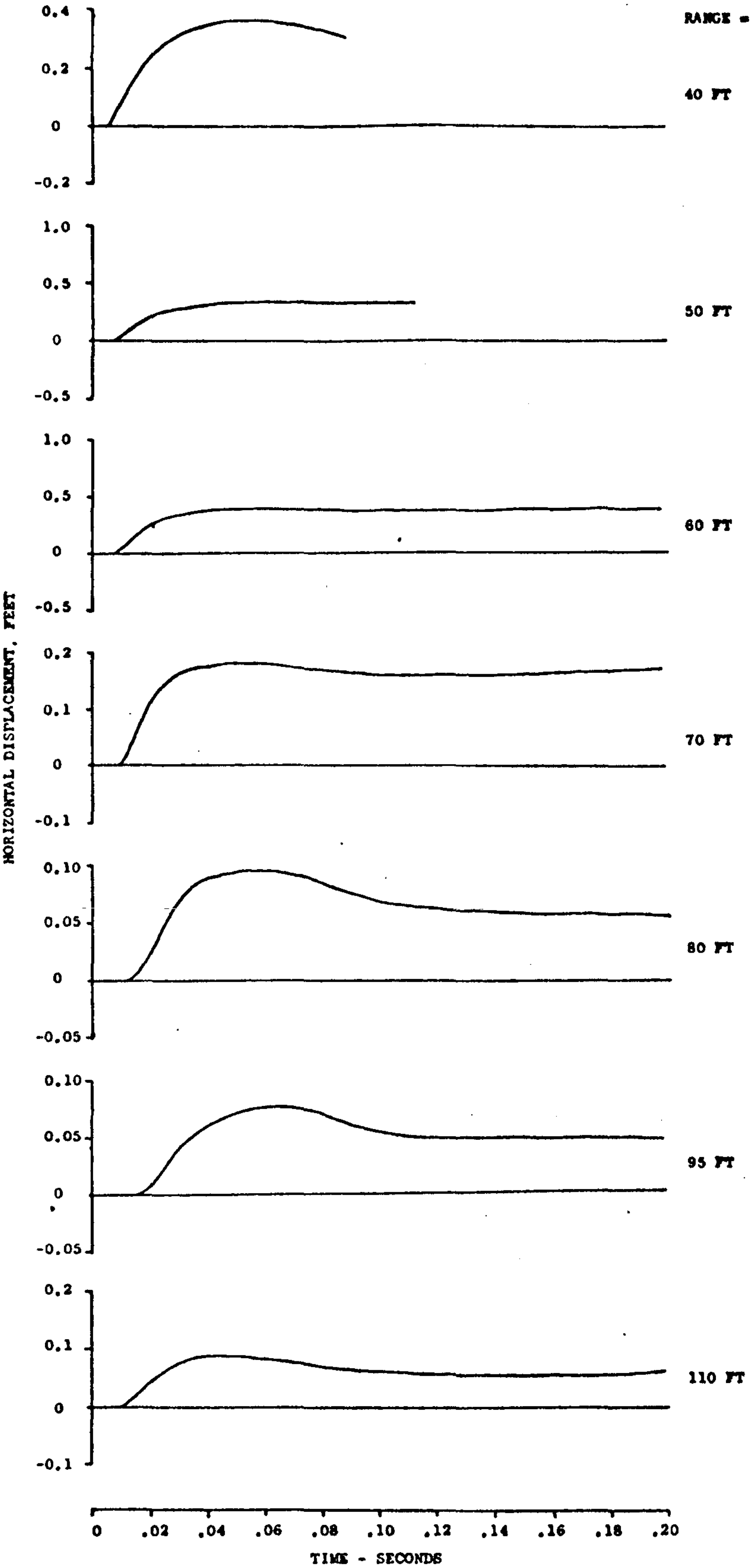
MINERAL ROCK HORIZONTAL DISPLACEMENTS AT 2-FT DEPTH

Figure 6

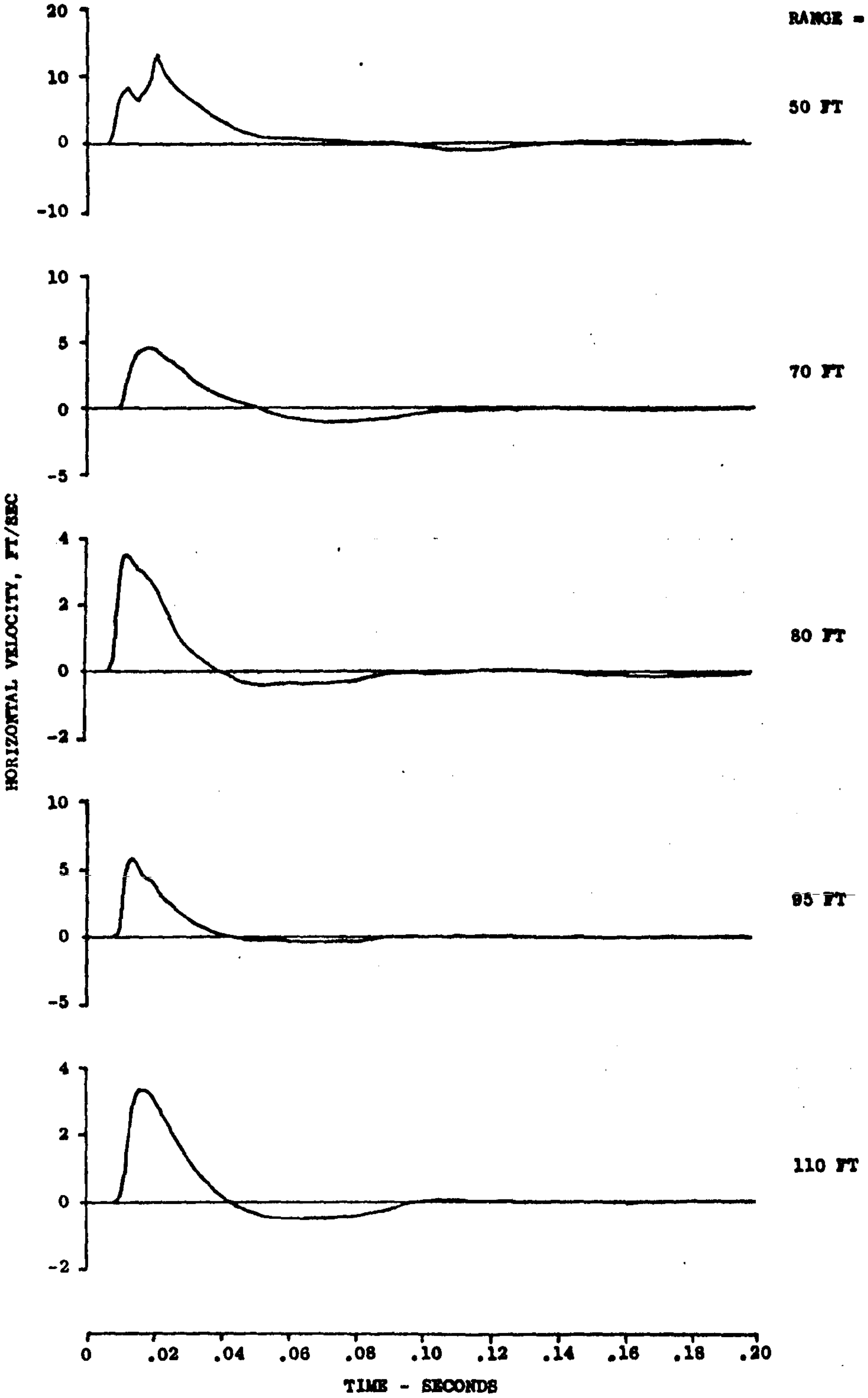


MINERAL ROCK HORIZONTAL VELOCITIES AT 18-FT DEPTH

Figure 7

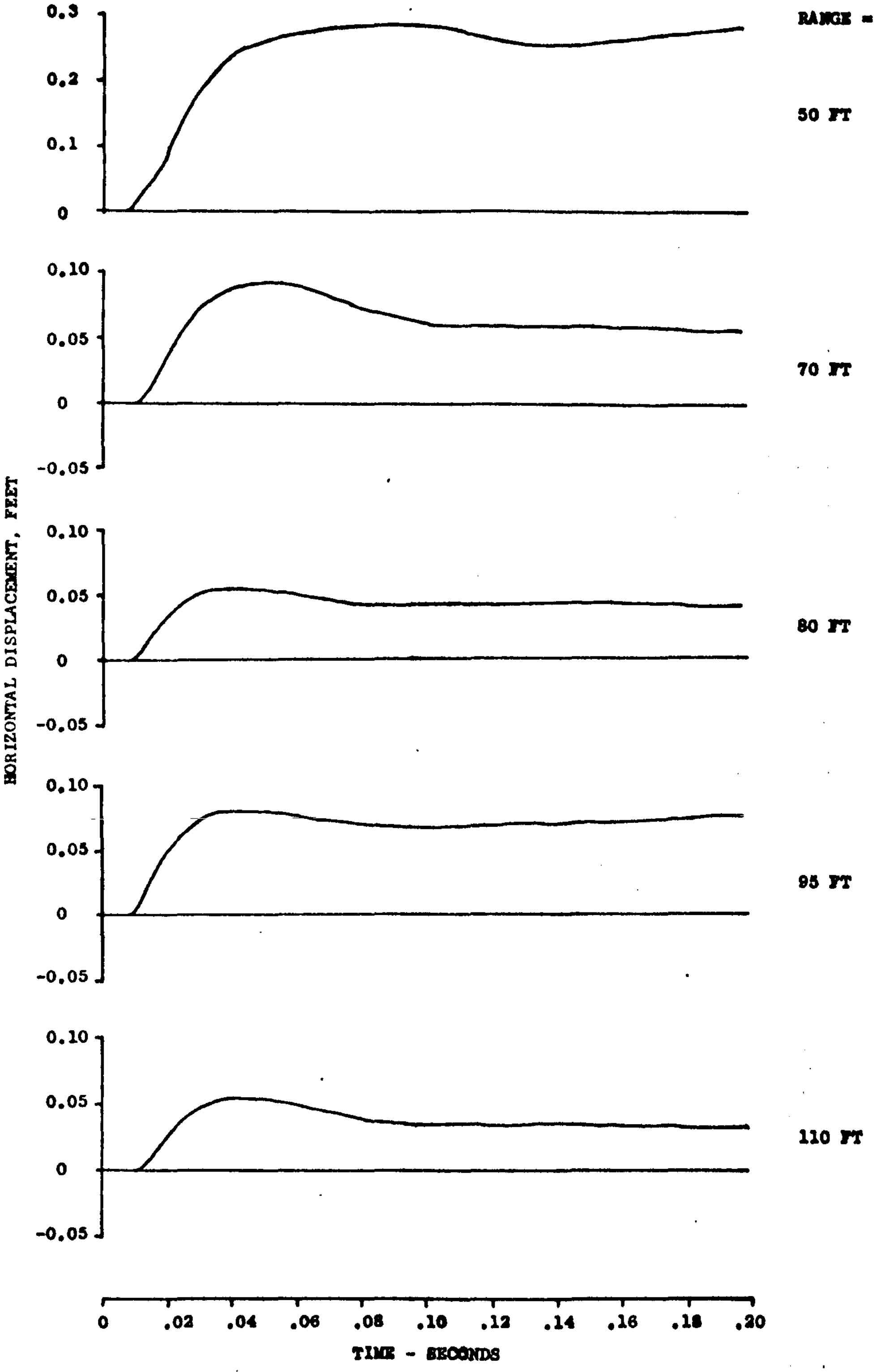


MINERAL ROCK HORIZONTAL DISPLACEMENTS AT 18-FT DEPTH
Figure 8



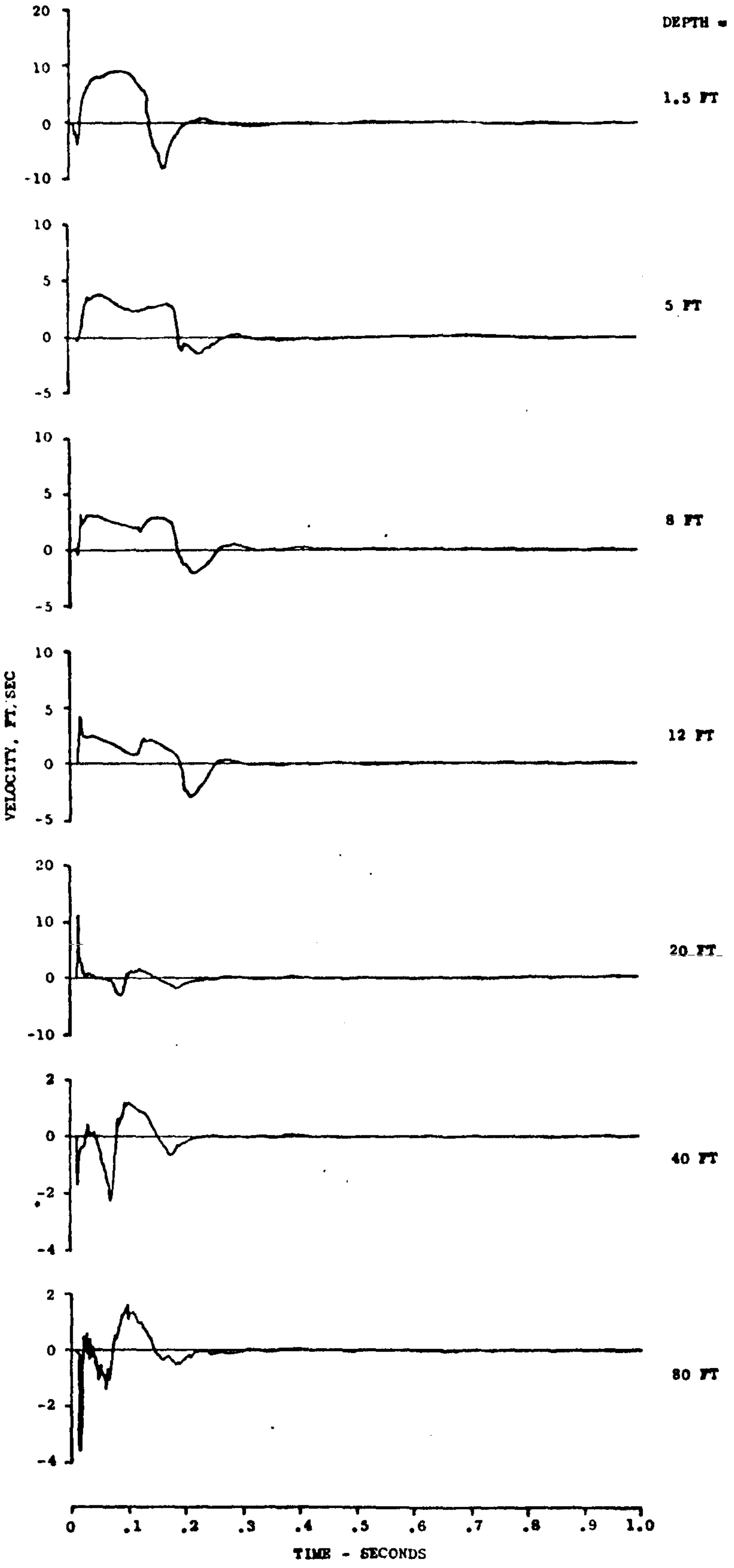
MINERAL ROCK HORIZONTAL VELOCITIES AT 36-FT DEPTH

Figure 9

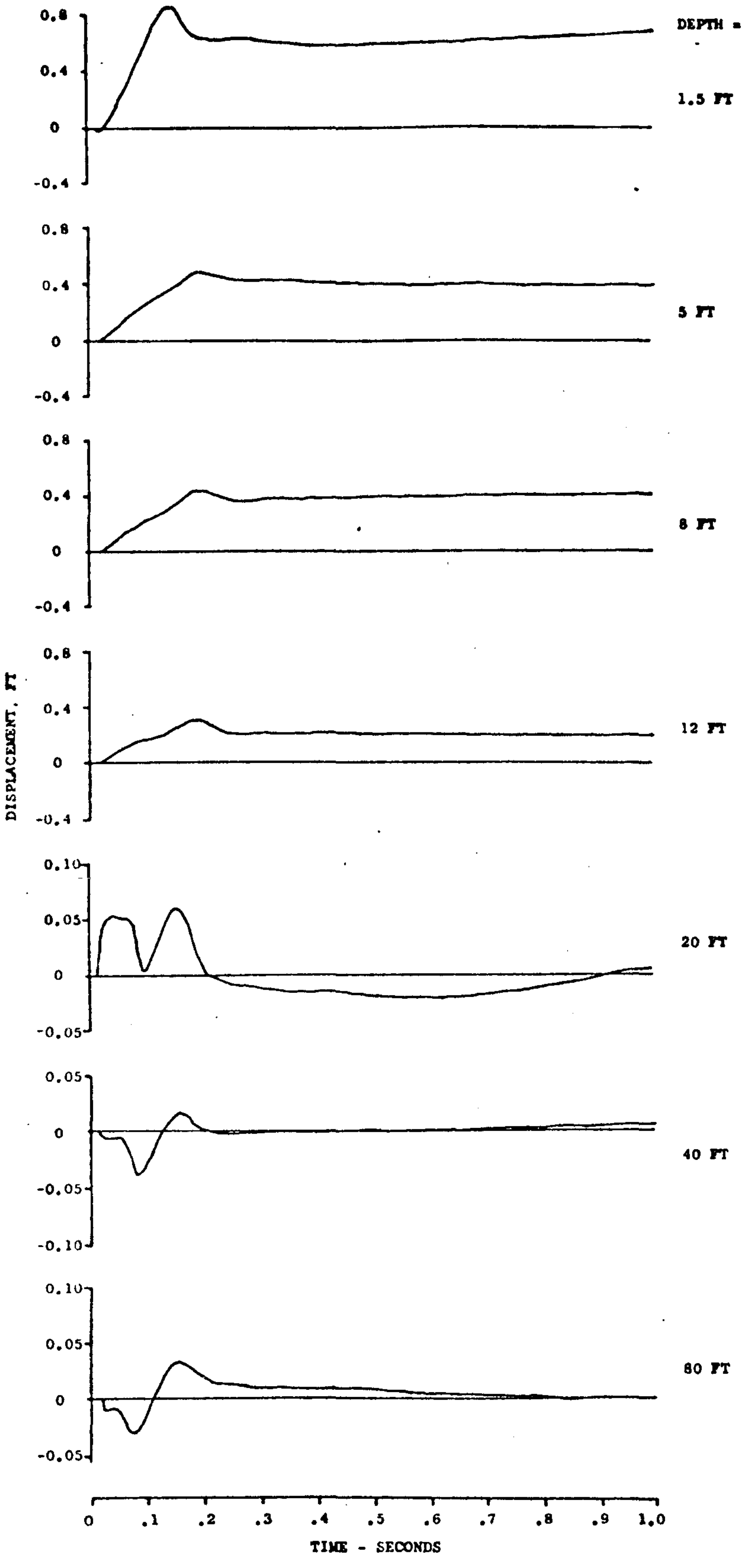


MINERAL ROCK HORIZONTAL DISPLACEMENTS AT 36-FT DEPTH

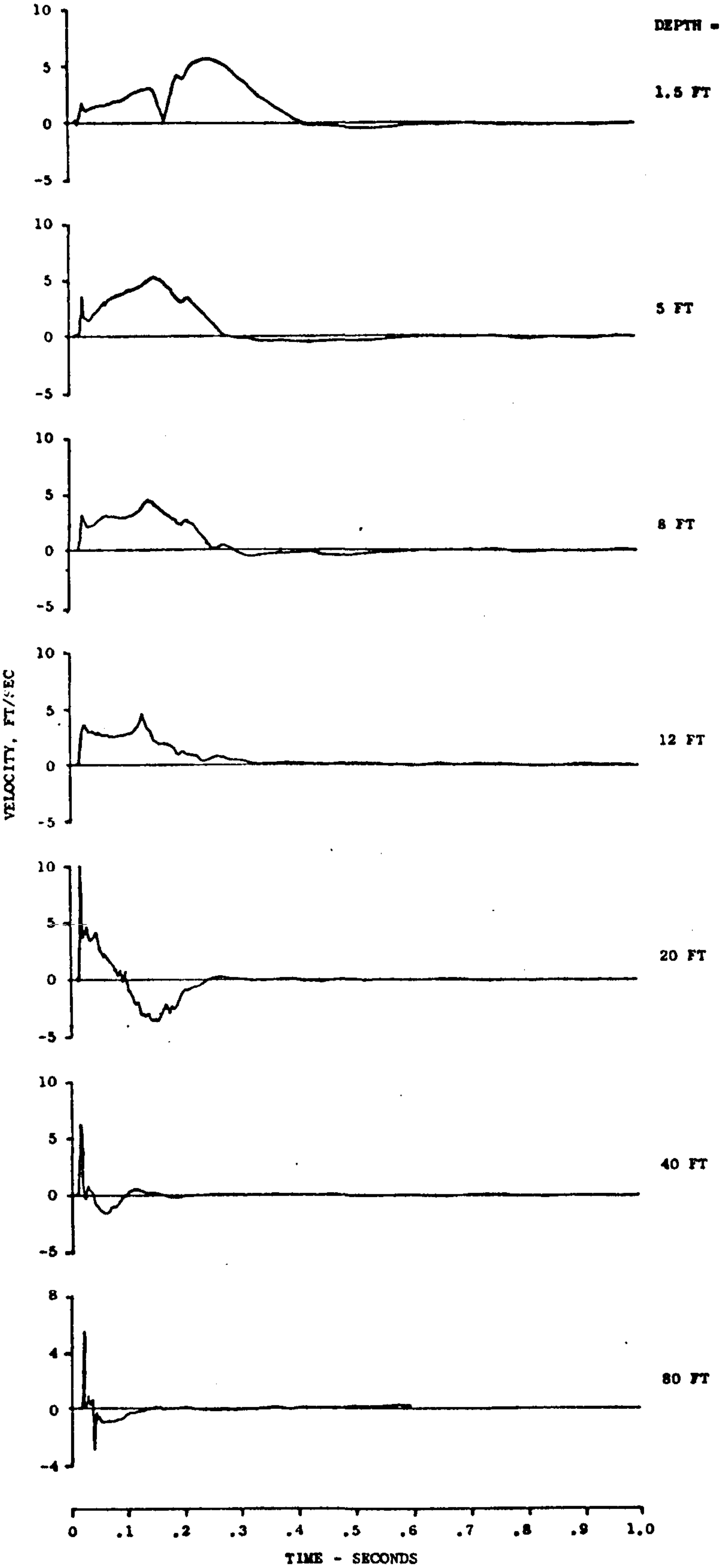
Figure 10



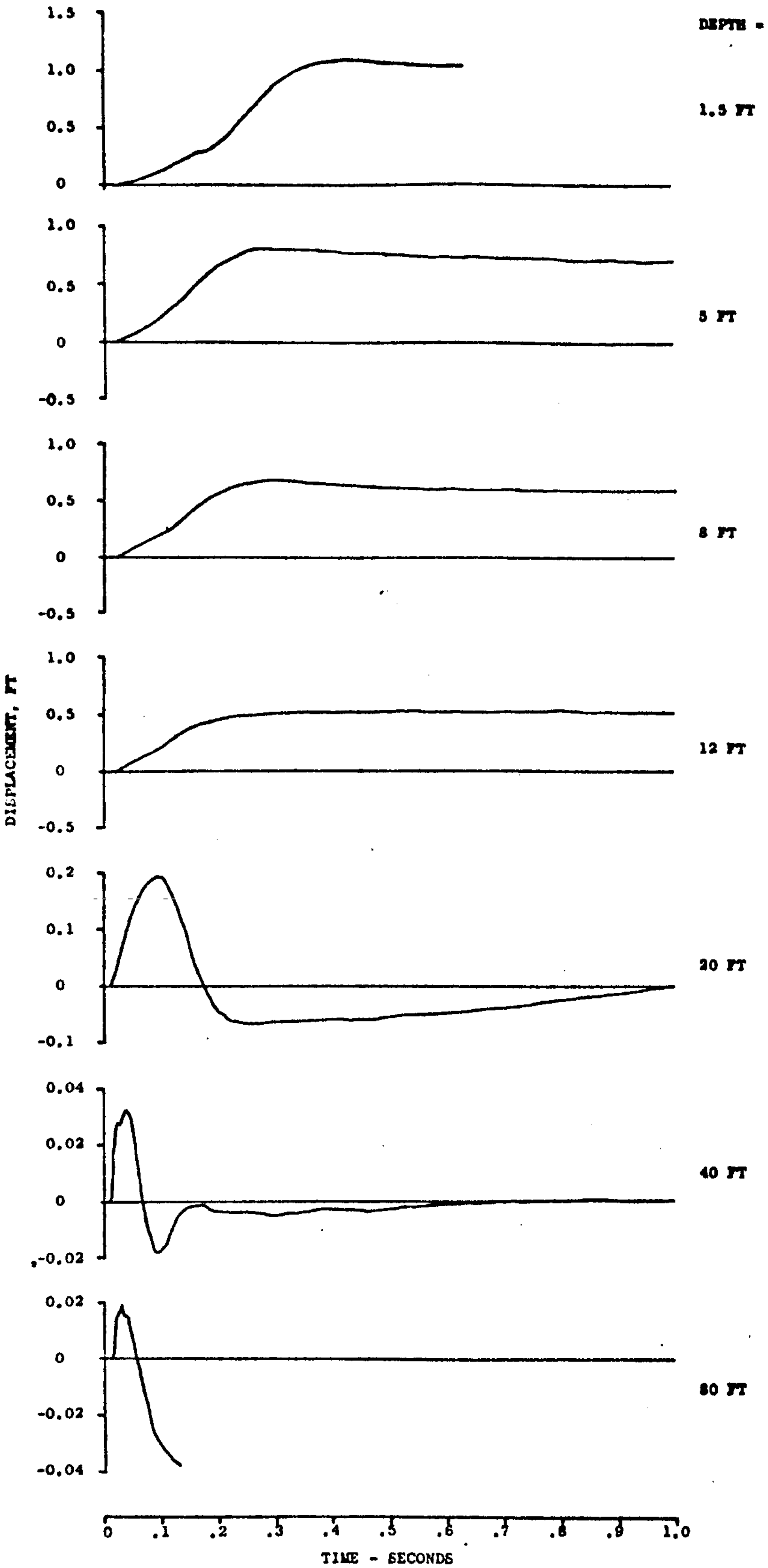
MIDDLE GUST III VERTICAL VELOCITY AT 80-FT RANGE
Figure 11



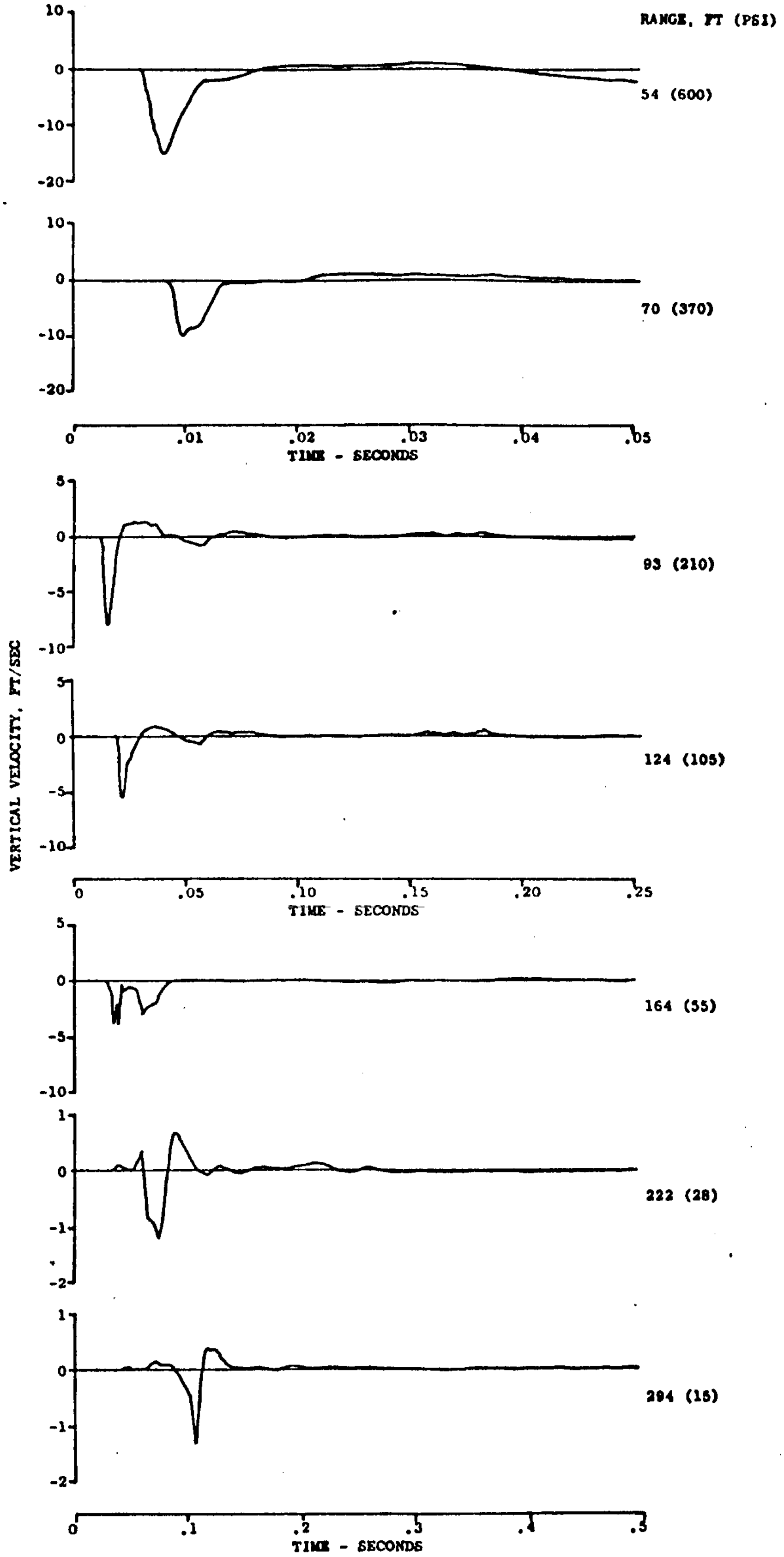
MIDDLE GUST III VERTICAL DISPLACEMENT AT 80-FT RANGE
Figure 12



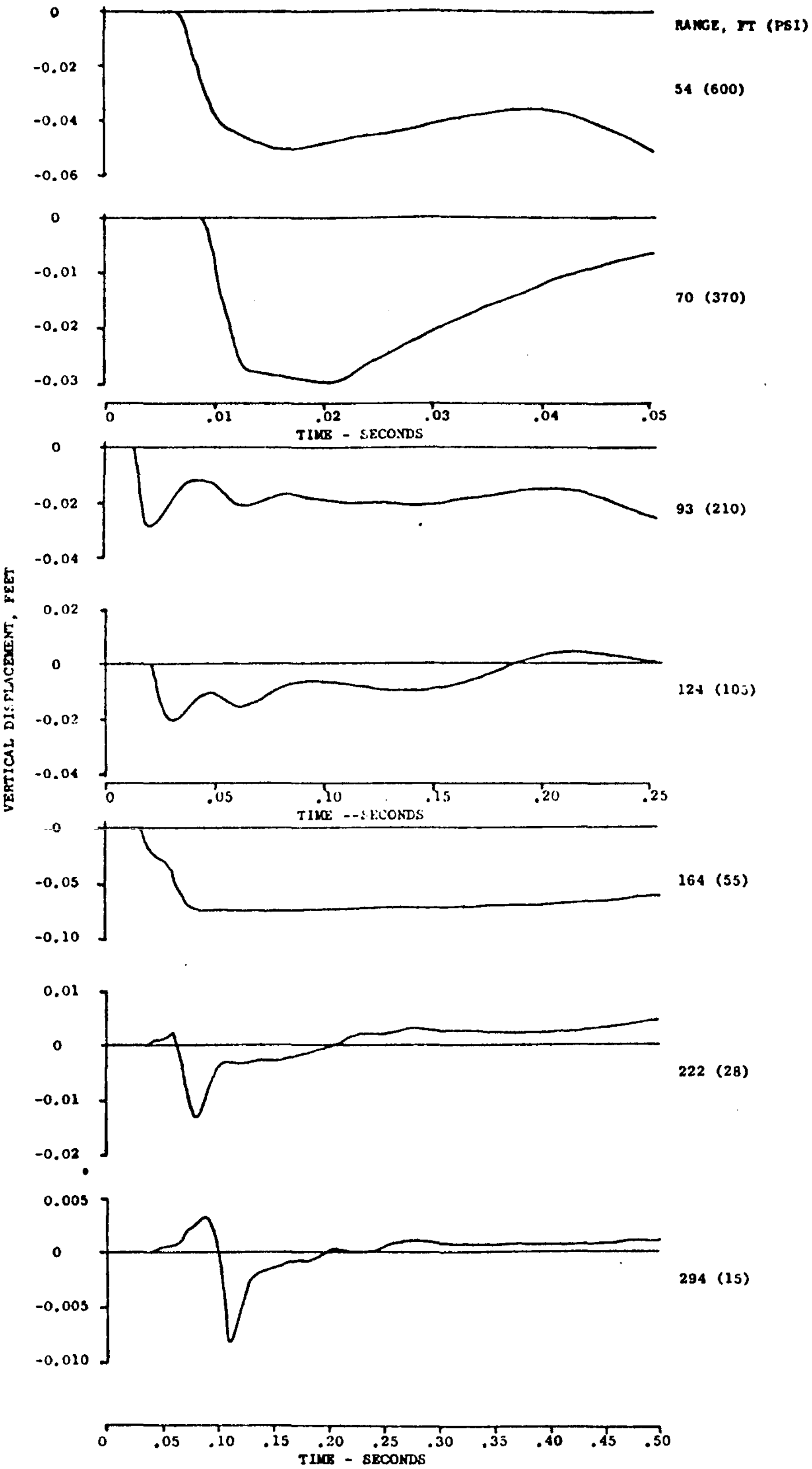
MIDDLE GUST III HORIZONTAL VELOCITY AT 80-FT RANGE
Figure 13



MIDDLE GUST III HORIZONTAL DISPLACEMENT AT 80-FT RANGE
Figure 14

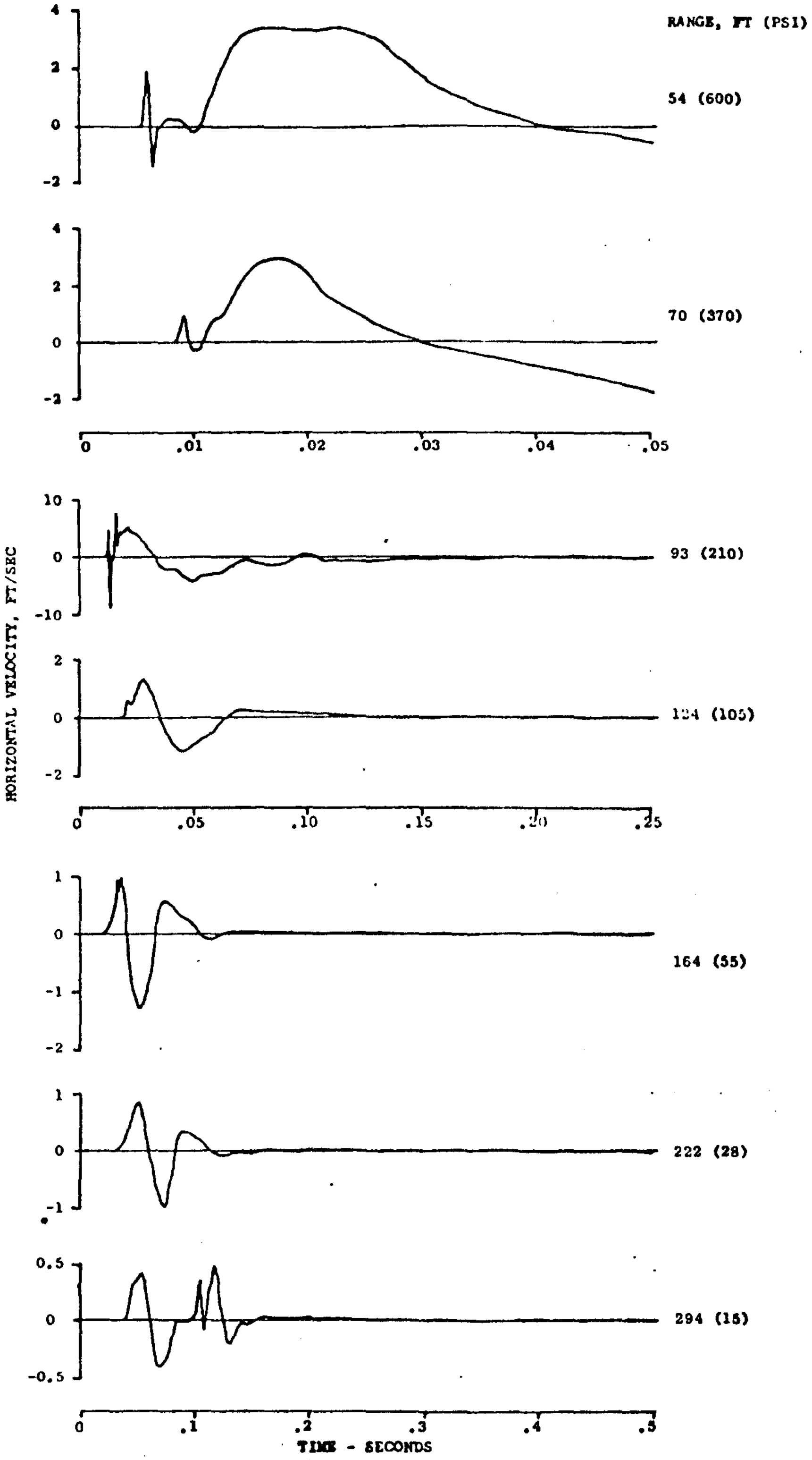


MIXED COMPANY II VERTICAL VELOCITIES AT 1.5-FT DEPTH
Figure 15

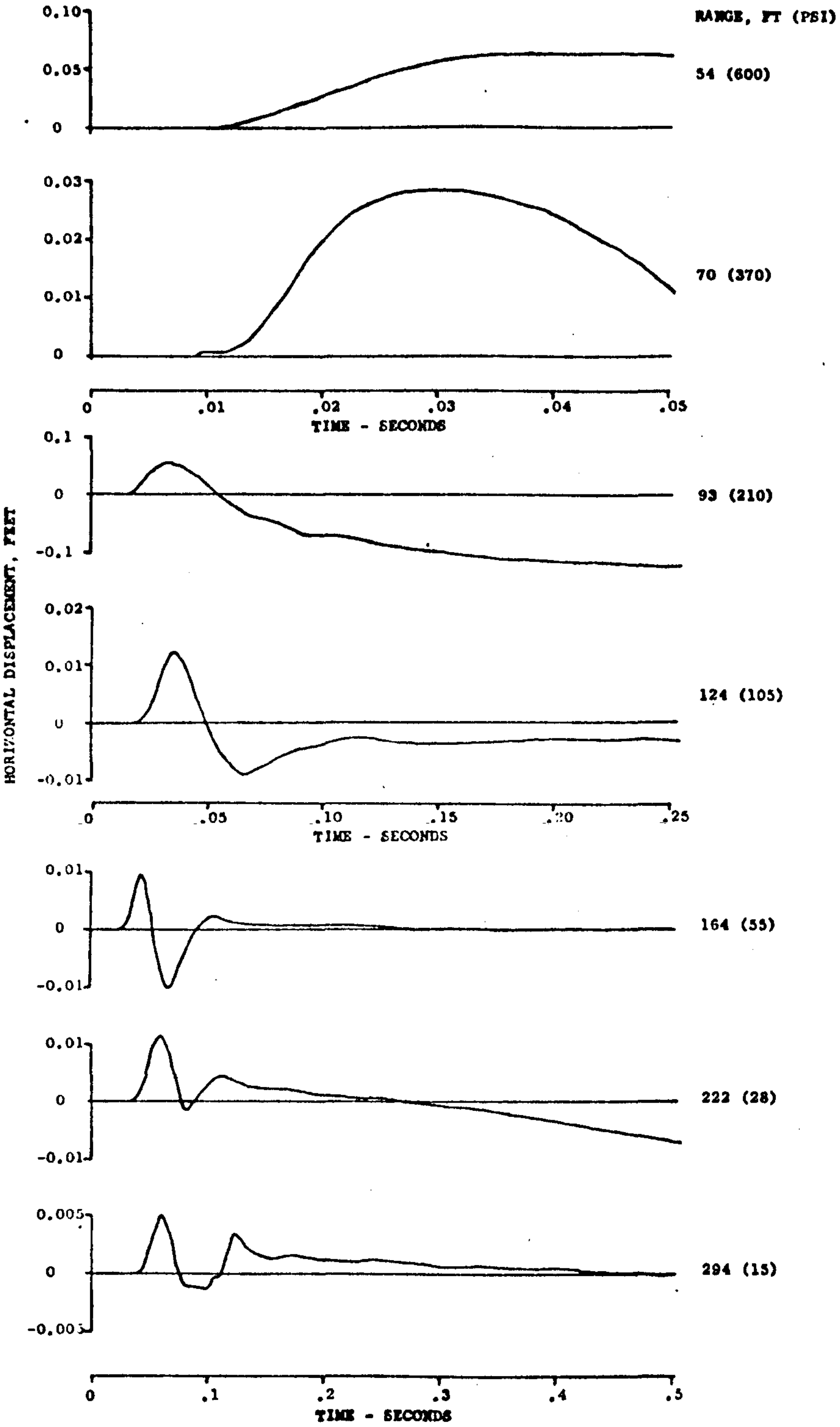


MIXED COMPANY II VERTICAL DISPLACEMENTS AT 1.5-FT DEPTH

Figure 16

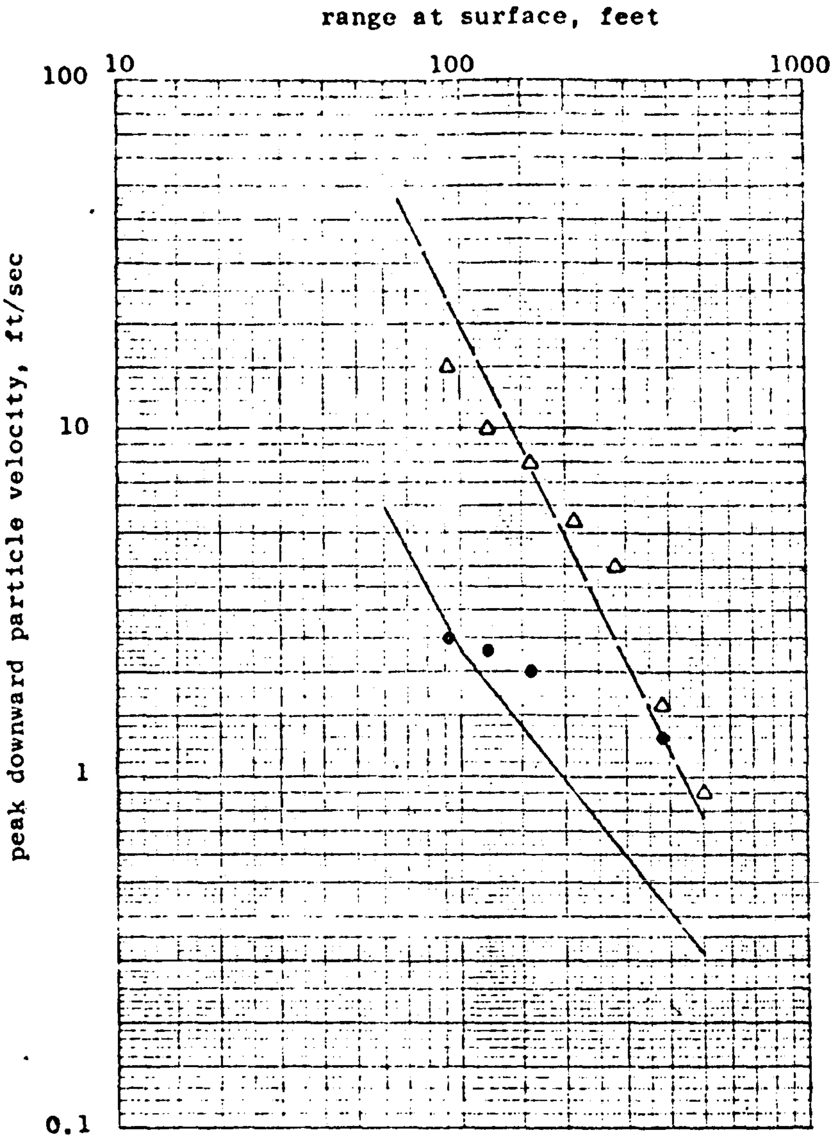


MIXED COMPANY II HORIZONTAL VELOCITIES AT 1.5-FT DEPTH
Figure 17



MIXED COMPANY II HORIZONTAL DISPLACEMENTS AT 1.5-FT DEPTH

Figure 18



KEY TO DATA SOURCES:

——·————— Distant Plain 6 data trend for 1½-ft depth in alluvium

————·—— Mine Shaft data trend for 1⅔- and 2-ft depths in granite

△ Mixed Company II gages at 1½-ft depth in alluvium (scaled to 100 tons)

● Mixed Company II gages at 5-ft depth in sandstone (scaled to 100 tons)

Figure 19. A comparison of peak downward particle velocities from 100-ton detonations on soil and rock.

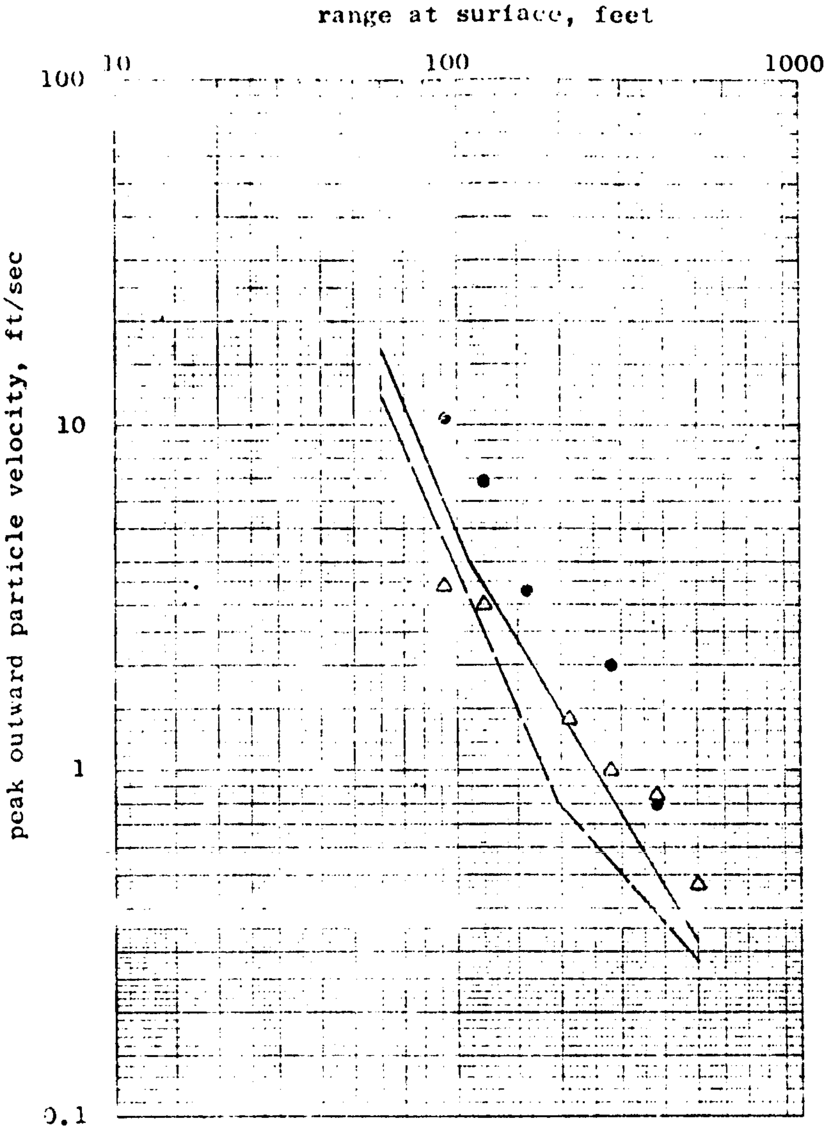


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Figure 20. A comparison of peak outward particle velocities from 100-ton detonations on soil and rock.

CONCLUSIONS

Within the past few years a large quantity of high quality experimental ground motion data has been obtained at sites with widely varying geologies and material properties. Sites are representative of tactically significant regions. This information may be used as a basis for checking computer generated predictions as well as providing bases for improved empirical predictions.

A thorough analysis of this high explosive data will enhance our understanding of ground shock phenomenology and improve our ability to predict ground shock generated by nuclear explosions.

It is recommended that data analysts be very careful in correlating peak motions. This is especially so in layered geologies where wave shapes may change rapidly with reflections, refractions, interferences, etc.

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13. ABSTRACT

A review of ground shock data from recent large, near-surface high-explosive tests is made. Emphasis is on close-in motions in rock. Wave forms are shown for selected shots and locations. Comparisons are made among wave forms for similar test conditions in different geologic materials including soil, shale, granite, and sandstone. Variations in peak motion amplitudes at various depths and ranges are discussed for the different geologic materials.

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