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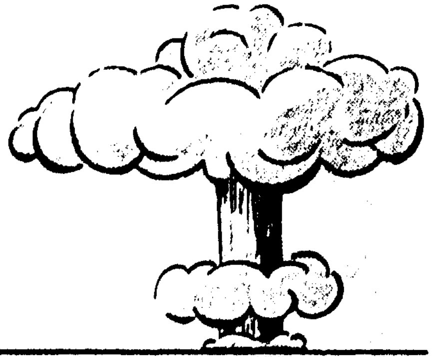
JANGLE

NEVADA PROVING GROUNDS
OCTOBER-NOVEMBER 1951

Project 1(9)a

GROUND ACCELERATION, GROUND AND AIR PRESSURES FOR UNDERGROUND TEST



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OPERATION JANGLE

PROJECT 1(9)a

GROUND ACCELERATION, GROUND AND AIR PRESSURES FOR UNDERGROUND TEST

By

E. B. Doll and V. Salmon

April 1952

Classification canceled (or changed to Unclass) by authority of TID [illegible] June 1976 by [illegible]
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PROJECT 1(9)a

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PROJECT 1(9)a

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PROJECT 1(9)a

ABSTRACT

The earth accelerations, earth pressures, and air-blast pressures measured in Project 1(9)a of the underground nuclear explosion are reported. These measurements were taken on a blast line which was 90° removed from the major blast line and gages of the variable-reluctance type were used. Reproductions of representative oscillograph gage records are presented.

Comparisons are made between the Project 1(9)a results and the predictions made in the report on Project 1(9)-1. These predictions were made on the basis of direct scaling of the Operation JANGLE scaled HE tests up to an assumed 1.0 KT equivalent TNT charge. For air pressure, the nuclear charge is found to be equivalent to about a 0.85 KT charge of TNT. However, it is not possible to assign a unique charge equivalence with respect to earth acceleration or earth pressure. In almost every case the earth phenomena results indicate an energy equivalence somewhat less than 1.0 KT of TNT.

The earth phenomena are found to be a combination of air-induced and direct-earth effects. Attempts are made to separate these air-blast induced effects from the direct earth phenomena. Some rough integrations of the horizontal earth accelerations, yielding particle velocities, are presented and discussed. A brief discussion of damage criteria in relation to surface structures is included.

The results of the underground nuclear explosion are compared with the HE-1 and HE-2 tests of Operation JANGLE and with the Dugway dry clay tests of 1951.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The program covered by Project 1(9)a of the underground nuclear test at the Nevada Test Site during November 1951 had as its principal objectives the following:

1. To use techniques and instrumentation as similar as possible to those used on the scaled HE tests (Project 1(9)-1), and on similar tests at the Dugway Proving Ground, so as to obtain correlation between these tests and underground nuclear explosions.

2. To obtain information so that general phenomena resulting from nuclear explosions can be compared with those resulting from TNT explosions.

3. To obtain specific information bearing on certain of the useful military effects of a shallow underground 1 KT nuclear explosion, and to obtain data to assist in the extrapolation of these effects to those of a 20 KT weapon.

4. To supply back-up measurements for the Naval Ordnance Laboratory (earth acceleration, Project 1.1), Ballistic Research Laboratories (earth pressure, Project 1.2a-2), and Sandia Corporation (air-blast pressure, Project 1.4).

5. To make measurements of underground explosion phenomena on a gage line 90 degrees removed from the main blast line in order to estimate the asymmetry of the phenomena.

6. To make measurements for indicating approximately the effect of gage burial depth upon measurements of underground phenomena.

7. To obtain additional information in the general field of underground explosion phenomena with respect to such items as attenuation characteristics, wave form, and scale and model laws.

1.2 HISTORICAL

For the detailed historical background leading up to Project 1(9)a of the nuclear test the reader is referred to Section 2.1 of the Stanford Research Institute report on scaled HE tests (Project 1(9)-1).[1]* As stated in this reference, it must be emphasized that as larger test charges are investigated the departure of the earth from a homogeneous isotropic medium plays an increasingly important role in influencing the resulting phenomena.

1.3 THEORETICAL

Reference is made to Section 1.3 of the scaled HE tests report (Project 1(9)-1),[1] in which a discussion of the model law as normally applied to explosion phenomena is presented. As in that report, the symbol λ is here used in describing the reduced or scaled dimensions of an experiment, where λ is defined by the relation,

$$\lambda = R/W^{1/3} \tag{1.1}$$

In this equation, following the established convention, R is the horizontal radius in feet as measured from ground zero and W is the weight of the charge in pounds of TNT of equivalent energy release. In this report, λ refers specifically to scaled horizontal distances measured from ground zero. The term λ_c describes the charge depth and the term λ_g describes the gage depth.

In relation to scale or model law conditions, the underground test presented two main disturbing problems on the basis of past experience. Primarily, the equivalent charge weight was considerably greater than those that had been used at Dugway[2,3,4] and in the JANGLE scaled HE tests.[1,5,6,7] Secondly, the charge was assumed to give rise to an energy release of 1 KT of TNT explosive and therefore the charge burial depth, λ_c, was determined with this assumption in mind.

The first of these considerations, the magnitude of the nuclear charge, would be expected to give rise to deviations from the model law because the properties of the medium do not in practice follow this law. For example, while in a theoretical sense the properties

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* Superscript numbers refer to references listed in the Bibliography at the end of this report.

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of the medium may change if they satisfy the condition that they be identical at scaled distances, nevertheless in practical applications to underground explosion phenomena this kind of permitted variation is unrealistic, and homogeneity and isotropy of the medium are required. As was stated previously, inhomogeneities in the medium become more important as the size of the charge is increased. The reasoning here is tied up with Equation 1.1, from which it is noted that for a constant reduced distance, λ , the reference distance in feet must increase as the cube root of the weight of the charge increases. When this reference distance approaches the dimensions of variations from homogeneity in the medium, these variations can significantly alter the model law behavior of the explosion phenomena.

The second of the factors described above, the assumption that the energy release of the underground nuclear charge is equivalent to 1 KT of TNT detonated at the same scaled depth, must also be considered. It is at once obvious that the explosive source characteristics of a nuclear charge are not equivalent to those of a TNT charge; for instance, the equivalent yield for thermal and radiation effects will obviously be different from the equivalent yield for such mechanical effects as pressure and acceleration. Moreover, the hydrodynamics and thermodynamics of the expanding gas bubble are different for the two types of explosions. For relatively shallow charge depths it is believed that the effect of these differences would be even more pronounced, since the energy partition in the venting processes can be critically affected by the thermodynamics of the gas bubbles. These facts were known when the predictions were made concerning phenomena to be produced by the underground nuclear explosion.[6,7] However, there were not sufficient data available prior to the underground test to ascertain the details of how a nominal 1 KT nuclear explosion might differ from the explosion of 1 KT of TNT. For this reason, predictions made using the model law assumed a charge of 1 KT of TNT.

The experiment described in this report was intended to investigate ground motions, ground pressures, and air pressures produced by a buried (shallow) nuclear explosive. All of these physical quantities are functions of at least two independent variables, the horizontal distance from ground zero (R) and the time (t). When scaling or model laws are applied to a phenomenon, it would be misleading and incomplete to omit either of these independent variables from consideration. If a particular quantity considered in its entirety (throughout the region of interest for variations of both R and t) does not meet model law requirements from one test to another, then at best the scale laws produce only an estimate of an upper or a lower limit.

If model law conditions are met, the scale factor, S, between two explosion tests can be defined by

[redacted]

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$$S = (W_2/W_1)^{1/3} \qquad (1.2)$$

where W_1 and W_2 are the charge weights in pounds of TNT of equivalent energy release. In the HE tests[1,5] the scaled experiments (HE-1 and HE-2) were compared using many different criteria such as peak air-blast pressure, positive duration of air pressure, and first positive peak earth acceleration. Using these criteria, it was shown that the cube root of the calculated energy release ratio for the air and earth effects due to the two explosions was close to the scale factor, S, for the tests.

In a similar manner, the equivalent energy release associated with each of the various phenomena measured in the underground test may be computed by comparisons to the HE tests results.[1,5] The principal question then remaining is that of energy partition, which is probably different for HE and nuclear explosions. For example, the calculation of the air-blast equivalent TNT tonnage can be made with the understanding that this need not apply to other phenomena.

These considerations will be discussed in more detail and examples will be presented in Chapter 5 (Discussion) of this report.

CHAPTER 2

TEST DESCRIPTION

2.1 SITE

The test site for the Project 1(9)a underground nuclear explosion was located at Yucca Flat, a portion of the Nevada Test Site, Mercury, Nevada. The reader is referred to the Project 1(9)-1 report[1] for a description of the test site.

2.2 EXPLOSIVE CHARGE

The nuclear charge was buried at a depth of 17 feet. On a scaled basis this depth would correspond to λ_c equal to 0.135 for a charge of 1.0 KT of TNT equivalent energy release. This λ_c value is approximately equal to that used in the HE-1 and HE-2 scaled tests conducted under Project 1(9)-1.[1]

For this report it will be assumed for the most part that the charge had a nominal energy release of 1.0 KT of TNT. Unless otherwise stated, values of λ are based on this figure, with $W^{1/3} = 126$ (i.e. $\lambda = 1$ corresponds to $R = 126$ feet).

2.3 GAGE LINE

The gage line used for Project 1(9)a measurements was 90 degrees removed from the major blast line. The major blast line was parallel to the line used for the HE-2 test of Project 1(9)-1. Figure 2.1 illustrates the gage station layout used in the underground test.

The principal earth acceleration measurements were made at a gage depth of five feet. Two components of acceleration were measured, the horizontal radial component and the vertical component. Earth accelerations were obtained at ranges varying in λ from 2.08 to 24.4 (262 to 3080 feet), with the principal concentration of instruments in the region λ less than 10 (1260 feet). In addition, two-component earth accelerations were measured at gage depths of 17, 34, and 68 feet at nominal values of λ of 3.0 and 8.15. For correlation with data taken by the Naval Ordnance Laboratory, some horizontal earth acceleration measurements were made at gage depths of 10 feet. These gages were placed in λ range from 2.70 to 15.

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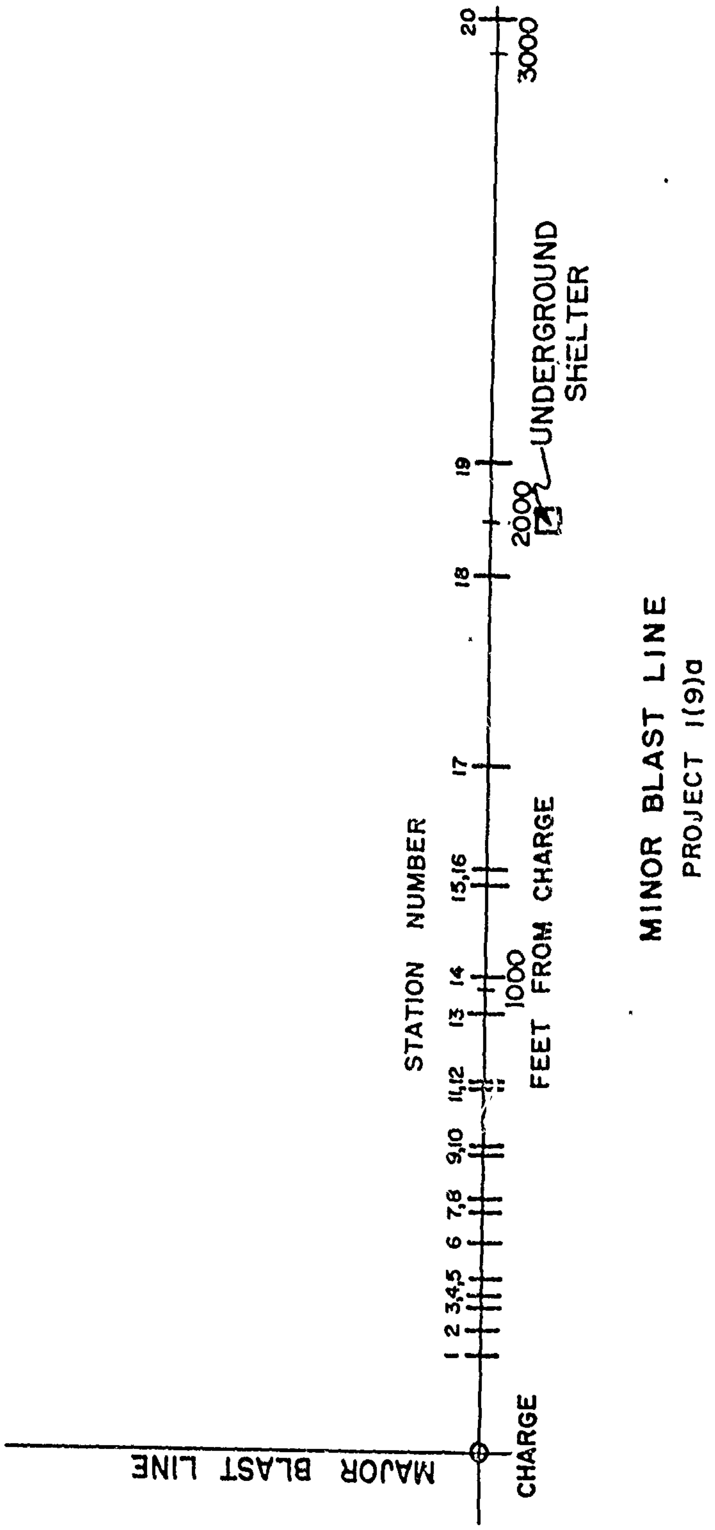

Fig. 2.1 Blast Line Layout for the Underground Test

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Earth pressure measurements were made at a gage depth of 10 feet for λ ranging from 1.72 to 24.4, with the principal concentration in the region of λ less than 10. In addition, earth pressure gages at depths of 17 and 34 feet were included at $\lambda = 1.72$ and at depths of 17 feet, 34 feet, and 68 feet for λ values of 3.0 and 8.15.

Air-blast pressures were obtained at a height of 40 inches above the ground surface at distances ranging from $\lambda = 2.5$ to 24.4. Previous measurements at Dugway indicated no significant difference in pressure as a function of height above the ground up to a scaled gage height of $\lambda_g = -0.3$ (34 feet for 1 KT).

The five-foot deep accelerometers were placed on a radial line and the remaining gages were located as close as possible to this same line.

CHAPTER 3

INSTRUMENTATION

With a few minor exceptions, the instrumentation on Project 1(9)a (underground nuclear test) was the same as that used on Project 1(9)-1 (scaled HE tests). For a complete description of the apparatus and general experimental procedures the reader is referred to Chapter 4 of the report on Project 1(9)-1.[1]

3.1 RECORDING STATION

A buried recording shelter located 2000 feet from ground zero housed the recorders and the associated control equipment. This shelter was a concrete structure 8 feet by 11 feet and 7 feet high, having walls 2 feet thick and covered with 2 feet of earth. Access to the shelter interior was through a small hatch in the top. Adequate protection from radiation was obtained without further aids. No trace of background fogging on the photosensitive oscillograph paper was detected.

The shelter was designed for unattended remote operation of the recording equipment. The remote operation was controlled by the central automatic sequence-timer system provided for all participants in the test program. Unlike the scaled HE test operation,[1] there were no monitoring circuits to the distant control point. The timer operated as follows: AC power to the carrier oscillators on at zero time minus 30 minutes, recorder warm-up battery circuits on at minus 5 minutes, and recorder paper transport on at minus 15 seconds. It was further arranged that the minus 15 seconds signal initiated a time delay relay designed to shut off all equipment at plus 2 minutes.

3.2 POWER

The AC power was supplied from the central distribution system established at the test site. In addition a gasoline-driven generator was connected to a dummy load and was kept on a stand-by basis near the recording shelter. An automatic transfer circuit was provided to transfer this generator to the recording equipment in the event of central power failure. The generator was started three hours prior to zero time; however, its use was not required.

The power for the recorders was supplied from batteries installed in the underground shelter.

3.3 CABLE

Most of the cables used in the scaled HE tests did not exceed 1000 feet in length. However, since some gage cables up to 2000 feet in length were used in the underground nuclear test, it became necessary to modify the circuits associated with these long cables. This involved changing the input networks to achieve proper phase relations at the ring demodulator element of the recording circuit.

3.4 FIELD CALIBRATION

The methods of field calibration were essentially those used in the scaled HE tests. Some refinements were introduced in the form of more precise instruments and techniques. A dead-weight tester was used to calibrate the earth pressure gages and the air pressure gages after they were connected to their respective cables and associated operating circuits.

3.5 EARTH COUPLING

The earth acceleration canisters (each containing two accelerometers), which were buried in 5- and 10-foot holes, were cemented in with Calseal, a quick-setting gypsum cement. The holes were then filled with tamped earth. The 17-, 34-, and 68-foot canisters were cemented similarly, but only about five feet of earth was placed on top of them.

In the case of the earth pressure gage coupling, each of the 10-foot gage holes was filled to the top with a thin solution of Aquagel. This filling process was duplicated for the deeper gage holes. Precautions were taken to see that all holes were filled to the top at the time of the test.

CHAPTER 4

RESULTS

4.1 INSTRUMENT PERFORMANCE

Table 4.1 presents the over-all gage plan for the Project 1(9)a underground nuclear explosion test. A total of 72 gage channels were used. Of these gage channels, 60 included the dual recording feature[1] for increased dynamic range and 12 used single galvanometers, giving a total of 132 gage traces.

All instrumentation performed satisfactorily, with one exception. The paper feed mechanism jammed on one recorder, and records were obtained on only 57 of the 72 gage channels connected. It was fortuitous that the lost recorder included the channels of least importance. The defective recorder ultimately functioned in time to obtain most of the record from the outermost air-pressure gage. These late traces indicated that all gage channels functioned properly. In Table 4.1, parentheses designate the gages from which the incomplete records were obtained.

4.2 TRANSIENT RECORDS

This report includes all the data obtained at the test site in connection with Project 1(9)a, with the exception of the 10-foot earth acceleration measurements taken for correlation with those of the Naval Ordnance Laboratory. Copies of these latter data have been forwarded directly to NOL.

Figure 4.1 shows a portion of an oscillograph camera record obtained in this test, reduced in size from the original height of 12 inches. The polarity is such that positive record deflections correspond to positive pressures, radially outward horizontal accelerations, and upward vertical accelerations. In order to reduce the data further and form conclusions about relative wave forms and amplitudes, it is necessary to trace each individual gage record onto a separate sheet of paper. No smoothing or editing of these records is done when they are traced. Figures 4.2 to 4.12 inclusive show some representative gage records obtained on this underground nuclear test.

TABLE 4.1

General Gage Plan*

Sta. No.	Horizontal Radius		Accelerometers					Earth Pressure				Air-Blast AB
	(ft)	λ	H,V 5 ft	H 10 ft	H,V 17 ft	H,V 34 ft	H,V 68 ft	P 10 ft	P 17 ft	P 34 ft	P 68 ft	
1	217	1.72						2	2	2		
2	262	2.08	2,2					2				
3	314	2.49	2,2					(2)				1
4	340	2.70		1								
5	378	3.0	(2,2)		(2,2)	(2,2)	(2,2)	2	2	2	2	
6	456	3.62	2,2					2				
7	520	4.13		1								
8	542	4.30	2,2					2				1
9	642	5.1		1								
10	655	5.2	2,2					2				
11	788	6.25	2,2					2				
12	794	6.3		1								
13	945	7.5	2,2					2				1
14	1025	8.15	2,2		2,2	2,2	2,2	(2)	(2)	(2)	(2)	
15	1213	9.63		(1)								
16	1230	9.75	2,2					2				
17	1480	11.7	2,2					2				1
18	1890	15.0		1								
19	2130	16.9	2,2					2				1
20	3080	24.4	2,2					2				(1)

*The letters H and V in the headings refer to horizontal and vertical accelerometers respectively. The gage burial depths are also given in the headings. The fifth column presents the gages used for correlation with measurements by the Naval Ordnance Laboratory. The numbers refer to the number of galvanometers connected to each gage channel. The number 1 designates a so-called single channel and the 2 refers to a duo-channel.

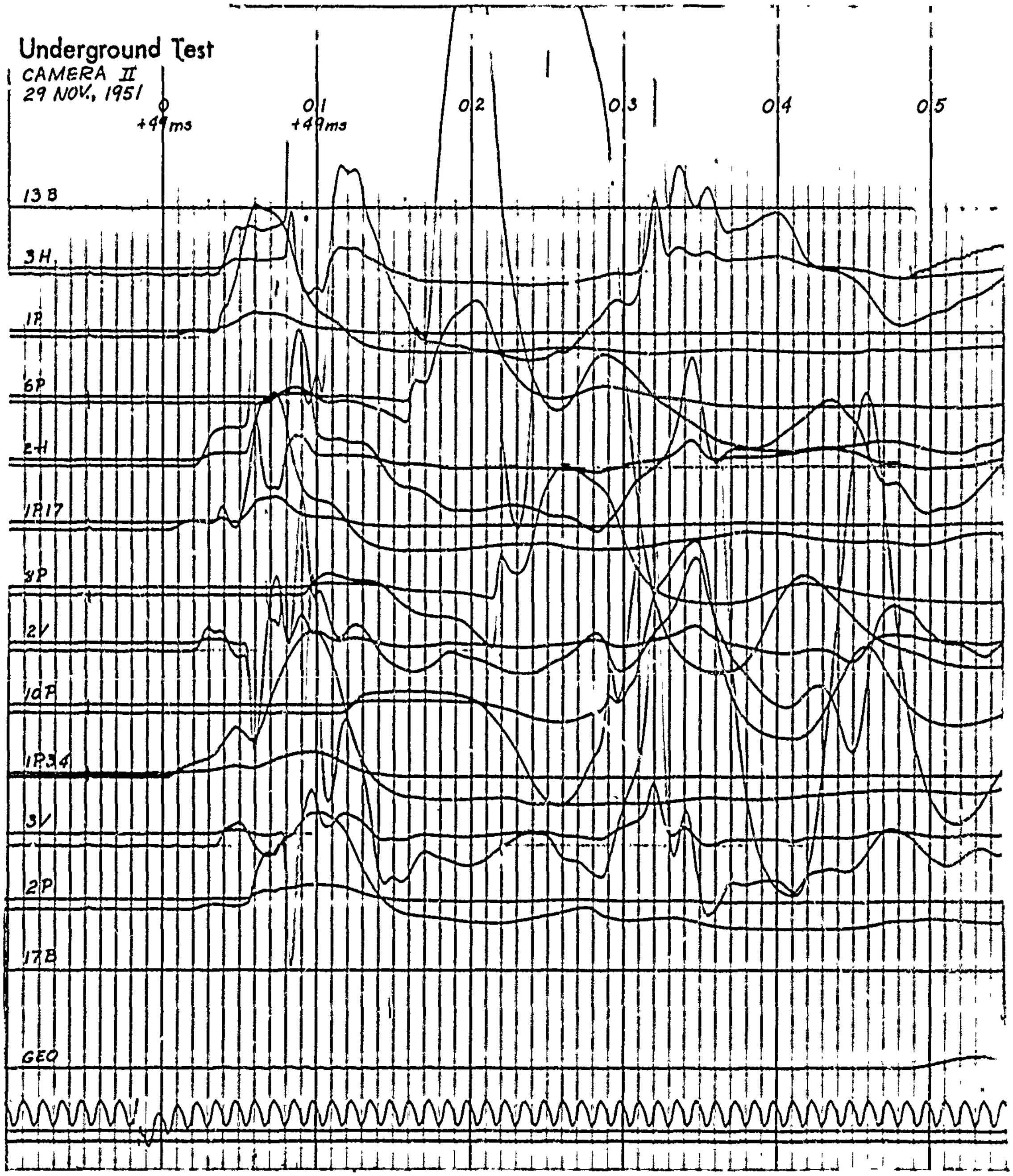

Fig. 4.1 Reduction of Typical Oscillograph Record. Height of original record 12 inches

The air-blast pressures as a function of time are presented in Figure 4.2 (note that the two bottom curves have interrupted time axes). The air-blast pressures were not reduced to sea-level equivalent pressures, since the scaled HE tests and the underground nuclear test were performed at the same site. Figures 4.3 and 4.4 show horizontal earth accelerations as they appeared on the oscillograph records, while the vertical earth accelerations are displayed in Figures 4.5 and 4.6.

It was possible, using a graphical method, to obtain a rough preliminary determination of the first integral of the horizontal earth acceleration records. This integration yields the horizontal particle velocity, a few representative curves of which are shown in Figure 4.7.

Figures 4.8 and 4.9 display the results of the deep acceleration measurements made with gages placed at four different depths. The earth pressure records from the gages closest to the charge are shown in Figure 4.10. And finally, the deep earth pressure transient records are presented in Figures 4.11 and 4.12.

4.3 TABLES

As an introduction to the data in tabular form, Figure 4.13 presents a series of idealized transient records which are labeled to correspond to the table headings of Tables 4.2, 4.3, 4.4, and 4.5. Each curve in Figure 4.13 is marked for proper table reference.

The gage code numbers describe the type of gage used and its relative position on the blast line. The first number refers to the gage station number and locates the gage on the blast line (see Figure 2.1 and Table 4.1). The letter following the station number indicates the type of gage. The letters H and V designate the horizontal and vertical earth accelerometers respectively. The letter P refers to earth pressure and B to air-blast pressure. The numbers after the letter designate the depth of burial (in feet) of the gage. The absence of numbers after H or V indicates a five-foot burial depth, whereas the P gages were 10 feet deep unless otherwise indicated.

The λ values given in the tables were computed on the basis of the underground nuclear charge as a nominal equivalent of 1.0 KT of TNT, $W^{1/3}$ = 126 feet. The data contained in these tables are presented in graphical form in Chapter 5 of this report.

4.4 FUTURE WORK

A more complete analysis of the data from this explosion test can be made when the earth acceleration records are integrated to yield earth velocity and, finally, earth displacement. A rough integration of only the horizontal acceleration was done; however, more precise methods are needed before firm conclusions can be drawn. These more accurate integrations will be made at a later date, in time to be included in the final contract report of Project 1(9)a.[8] Although the permanent displacement survey results on Project 1(9)a are not yet available, it is hoped that these results can be used for checking the displacements found from double integration of the acceleration records.

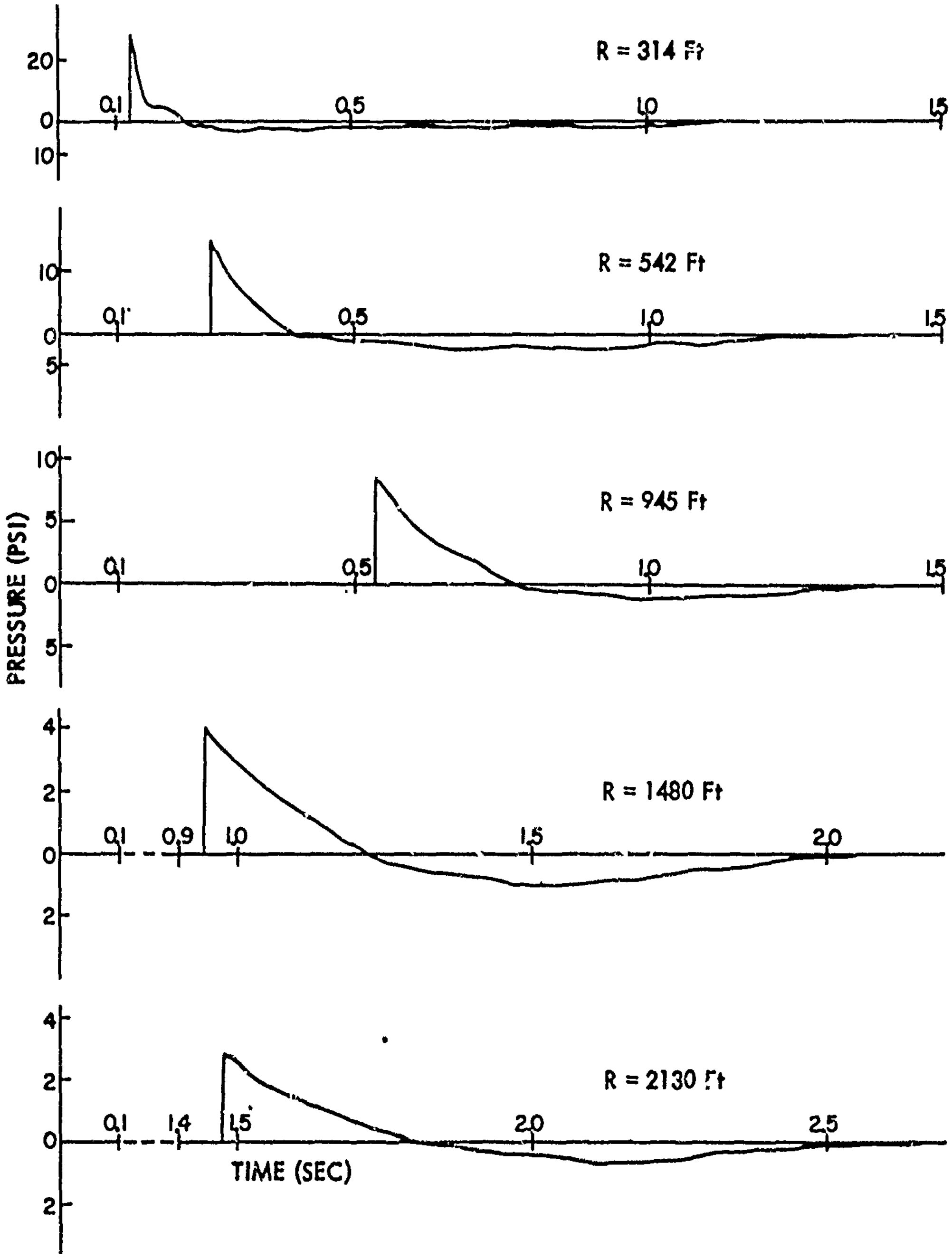

Fig. 4.2 Air Blast Pressure vs. Time for the Underground Test. Note interrupted time scales on bottom two curves

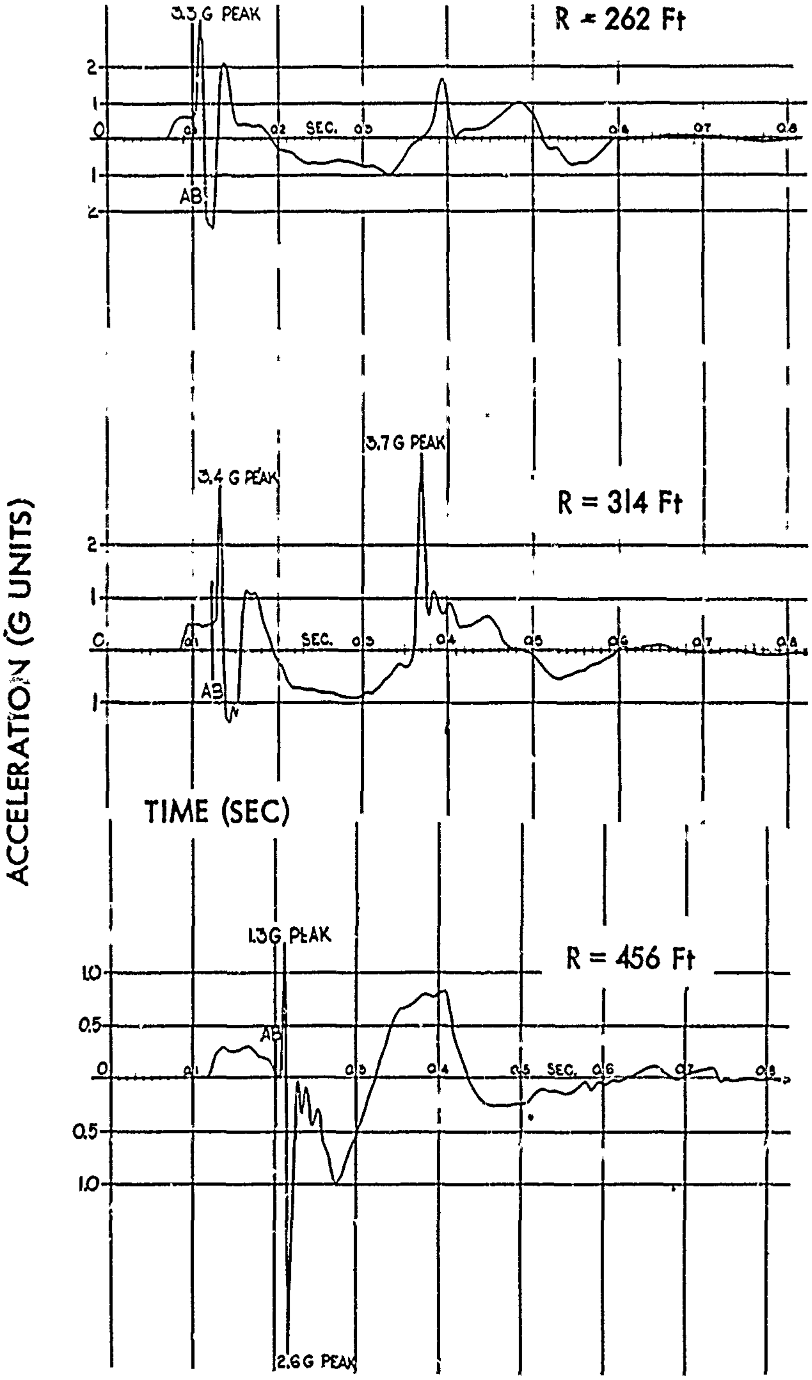

Fig. 4.3 Horizontal Earth Acceleration vs. Time for the Underground Test. Gage depth, 5 feet

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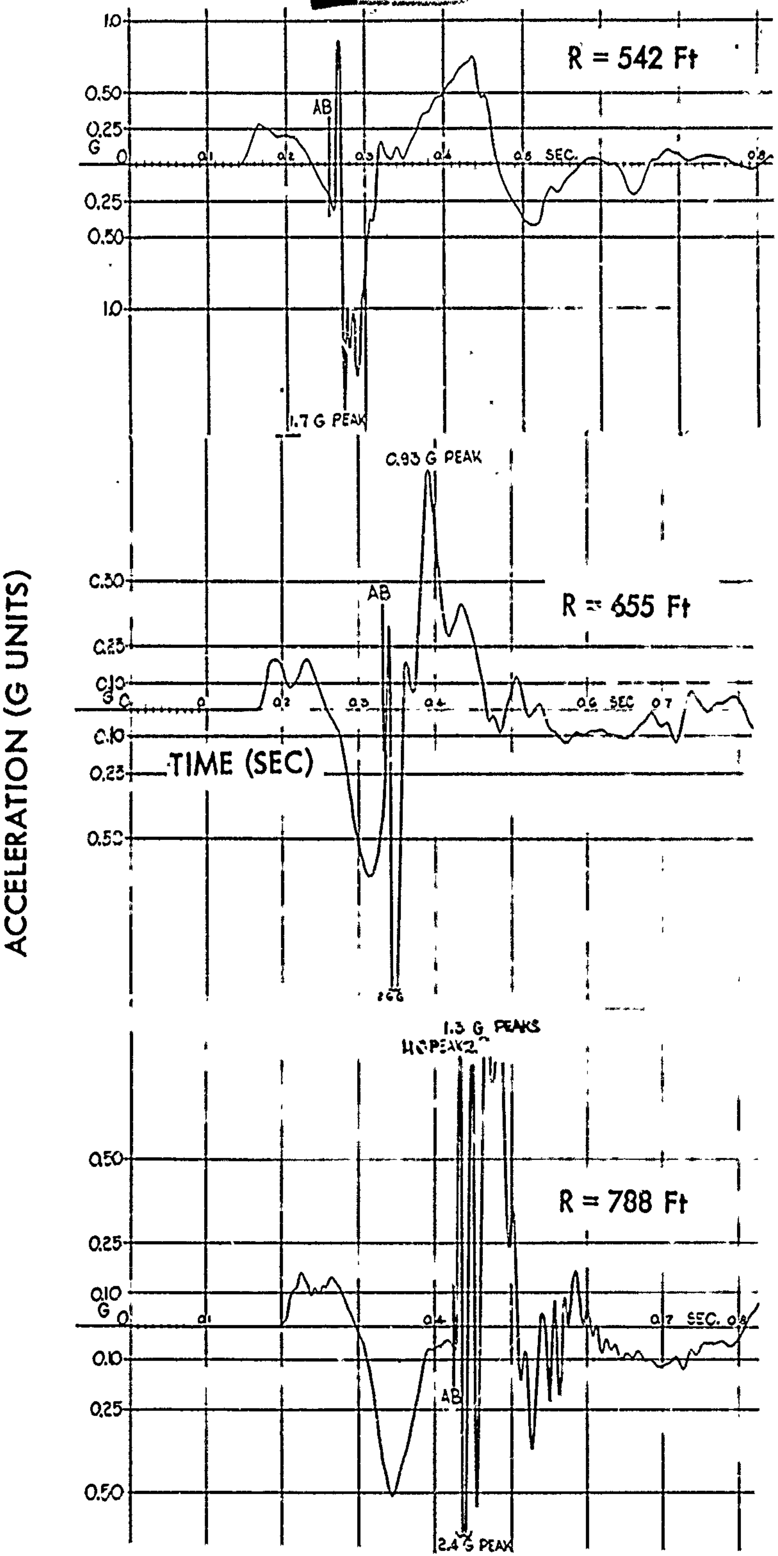

Fig. 4.4 Horizontal Earth Acceleration vs. Time for the Underground Test. Gage depth, 5 feet

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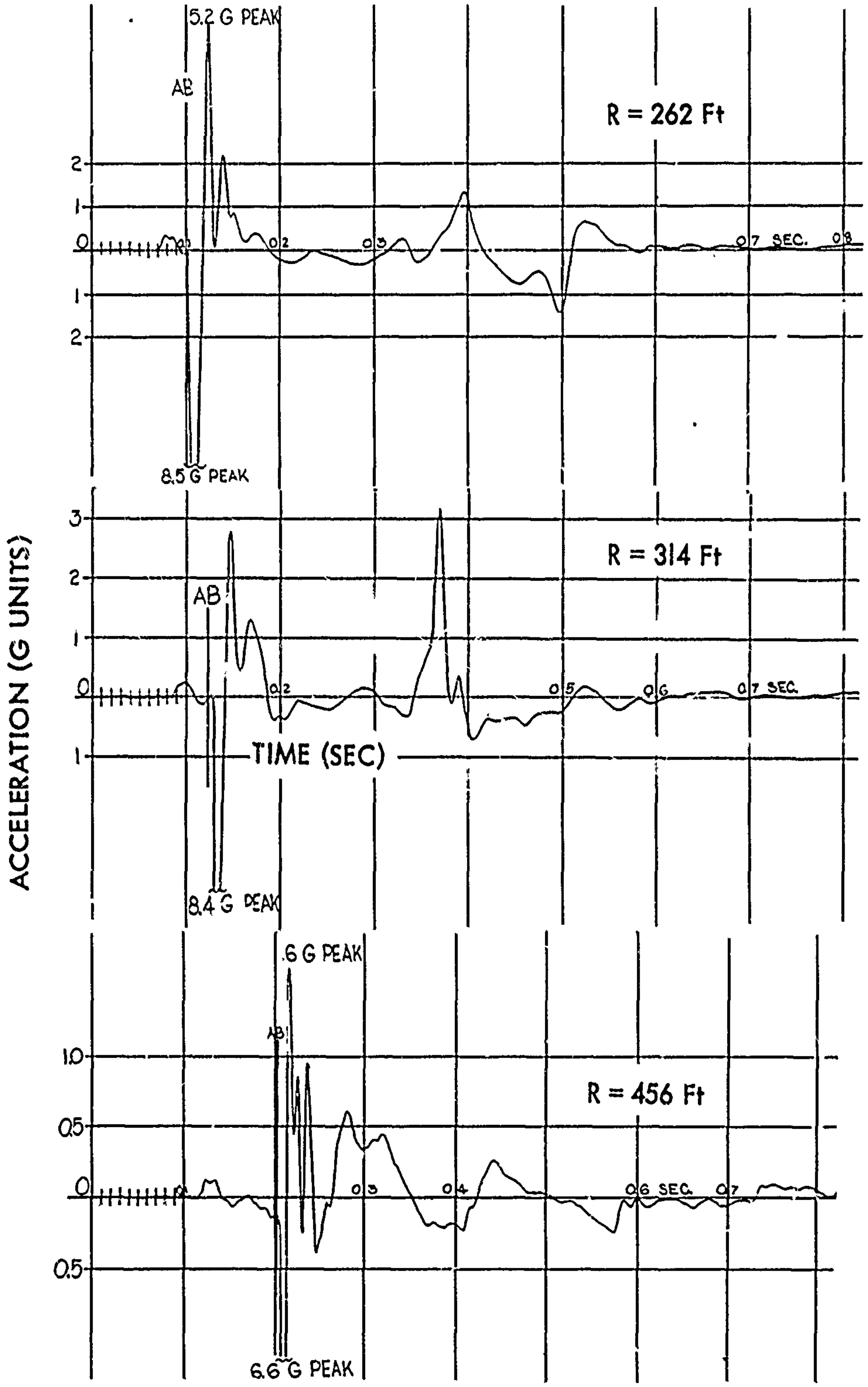

Fig. 4.5 Vertical Earth Acceleration vs. Time for the Underground Test. Gage depth, 5 feet

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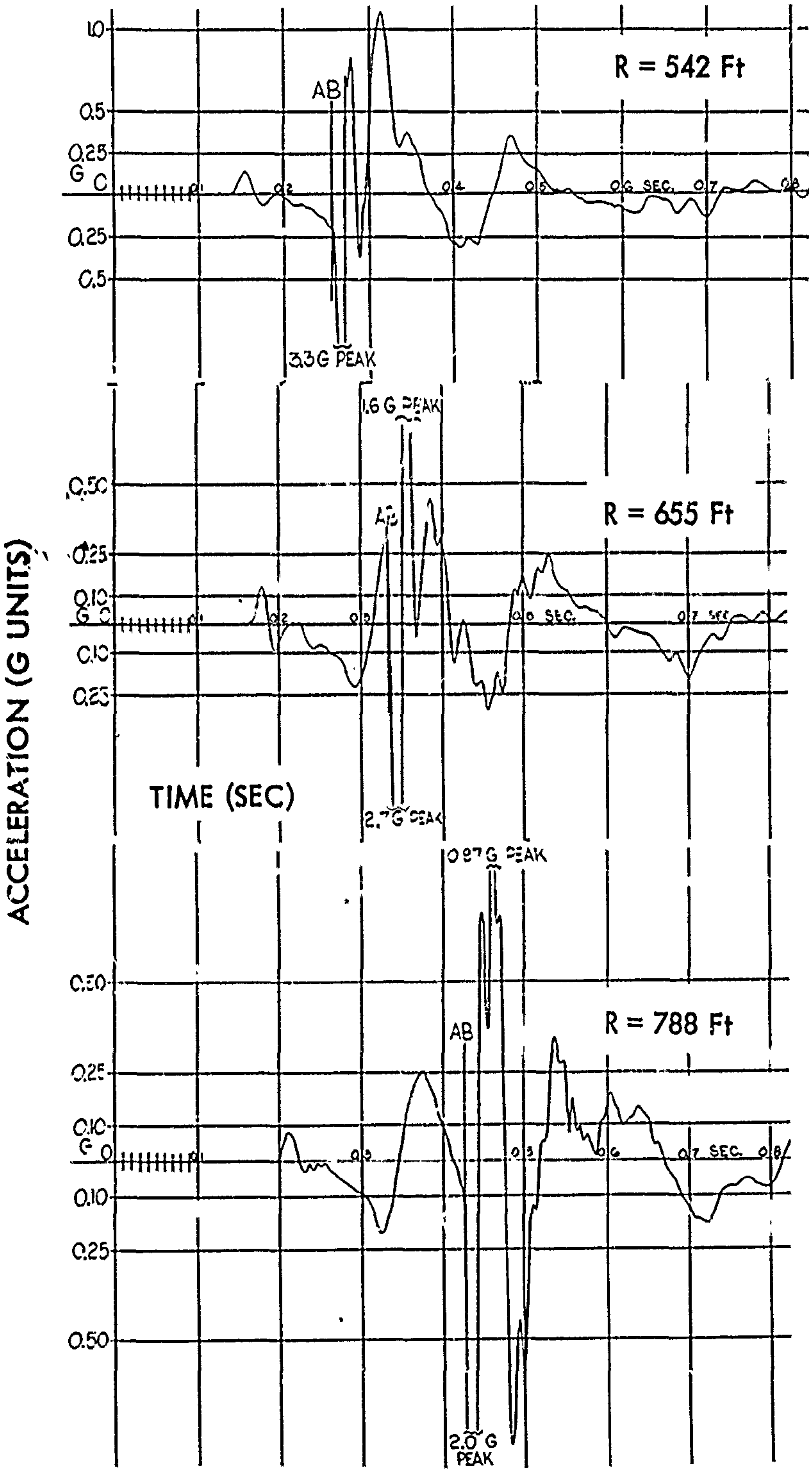

Fig. 4.6 Vertical Earth Acceleration vs. Time for the Underground Test. Gage depth, 5 feet

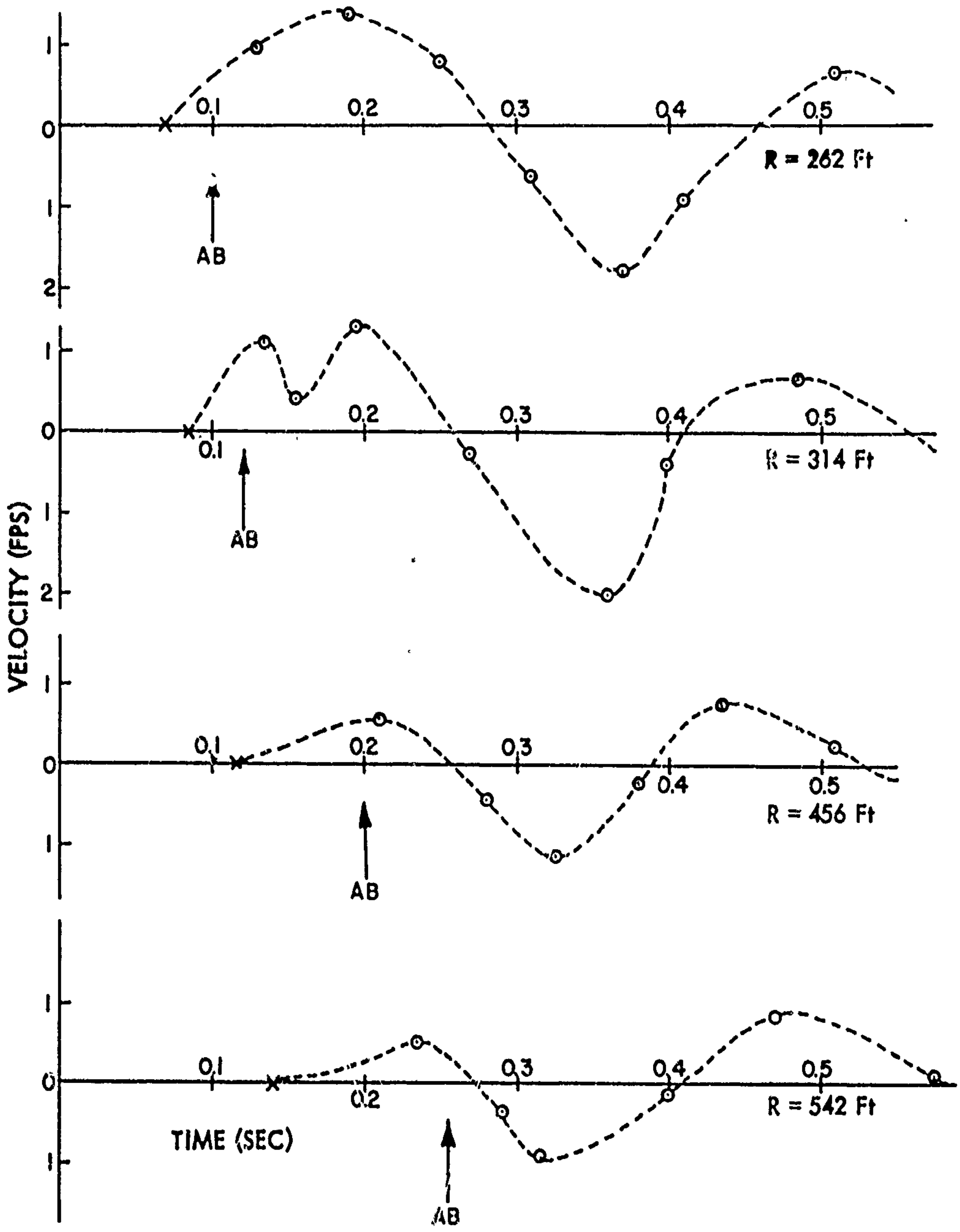

Fig. 4.7 Horizontal Earth Velocity vs. Time for the Underground Test. These curves are the results of rough integrations of the horizontal acceleration records.

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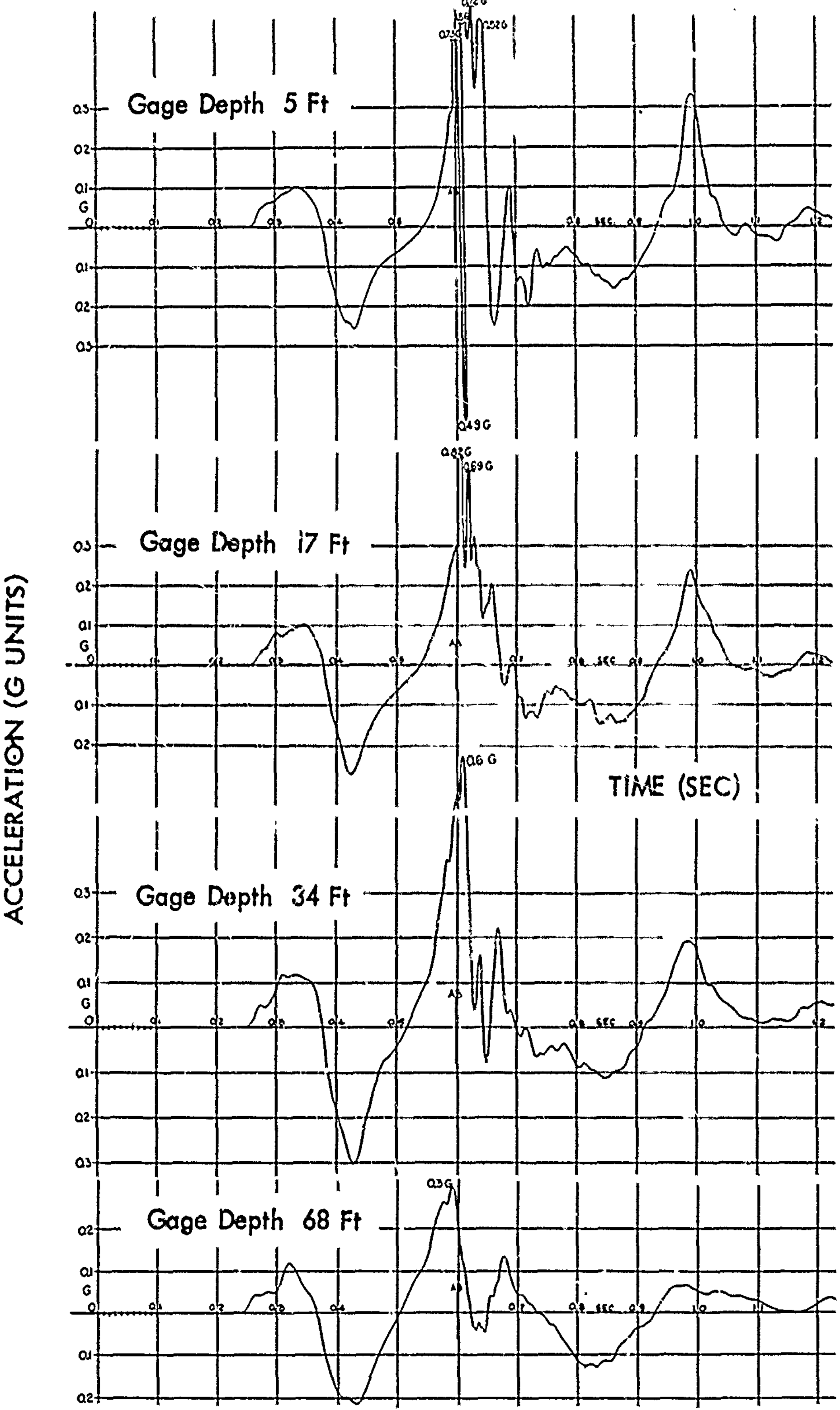

Fig. 4.8 Horizontal Earth Acceleration vs. Time, Measured at Various Depths for the Underground Test, R = 1025 ft

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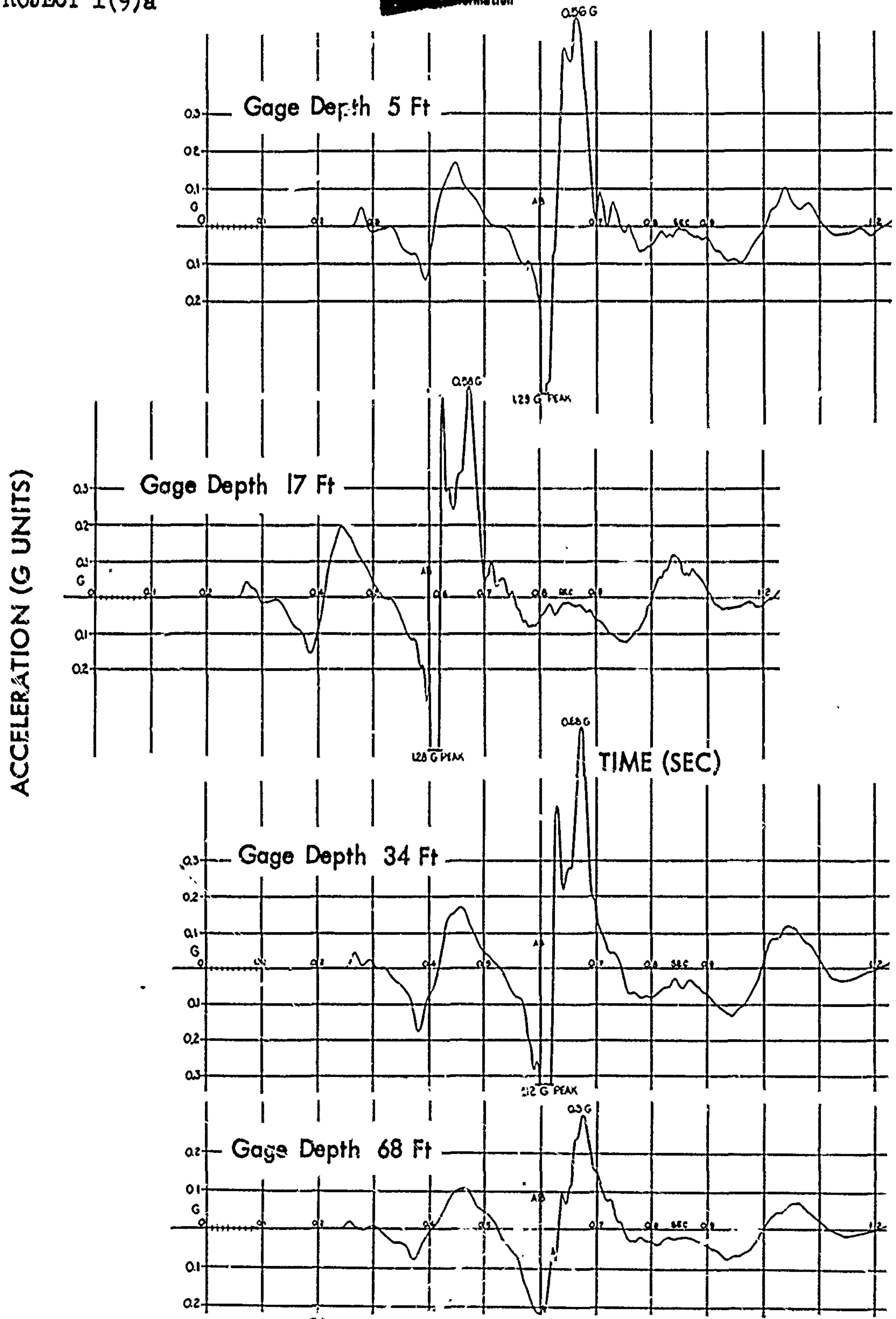

Fig. 4.9 Vertical Earth Acceleration vs. Time, Measured at Various Depths for the Underground Test, R = 1025 ft

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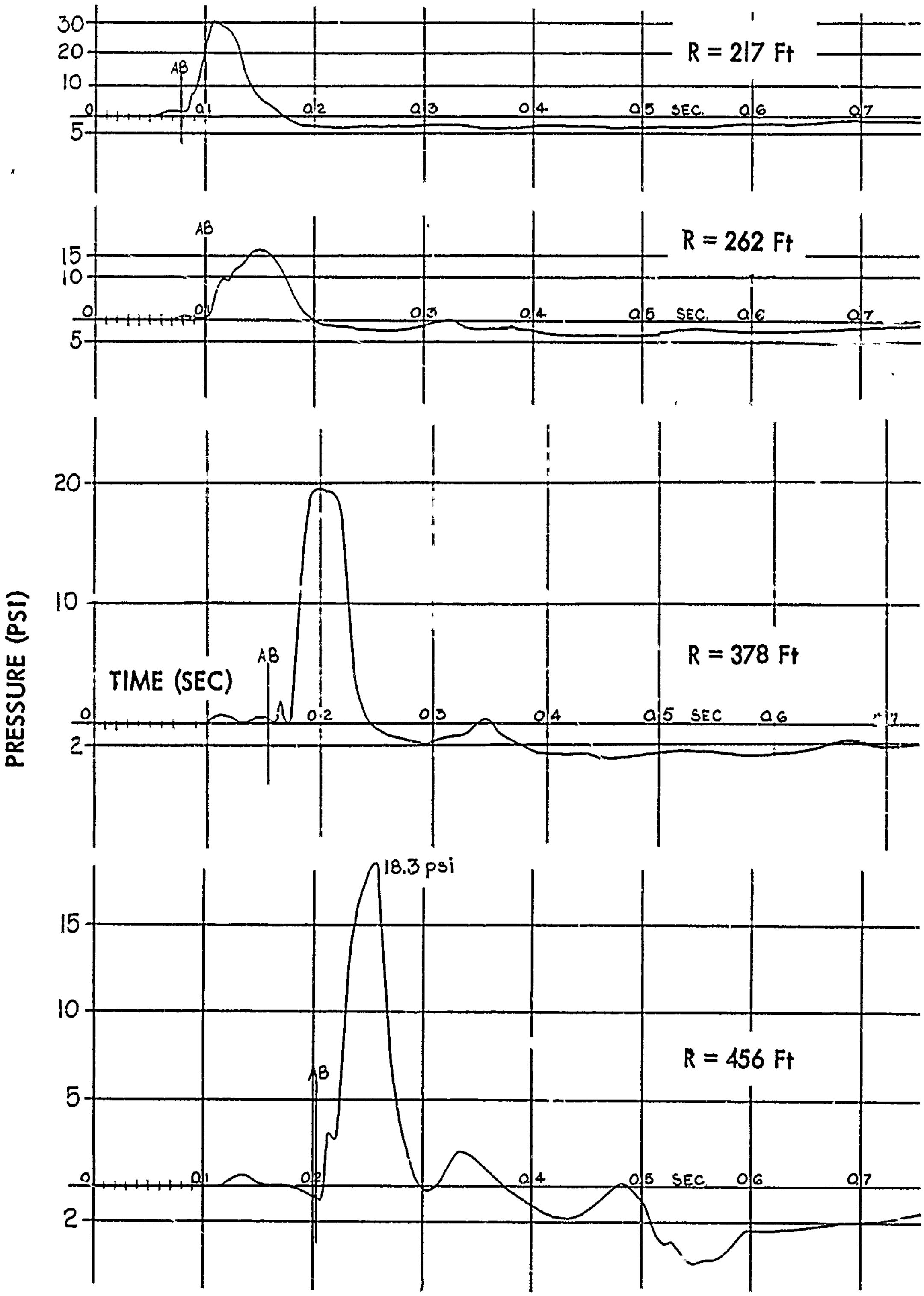

Fig. 4.10 Earth Pressure vs. Time for the Underground Test. Gage depth, 10 feet

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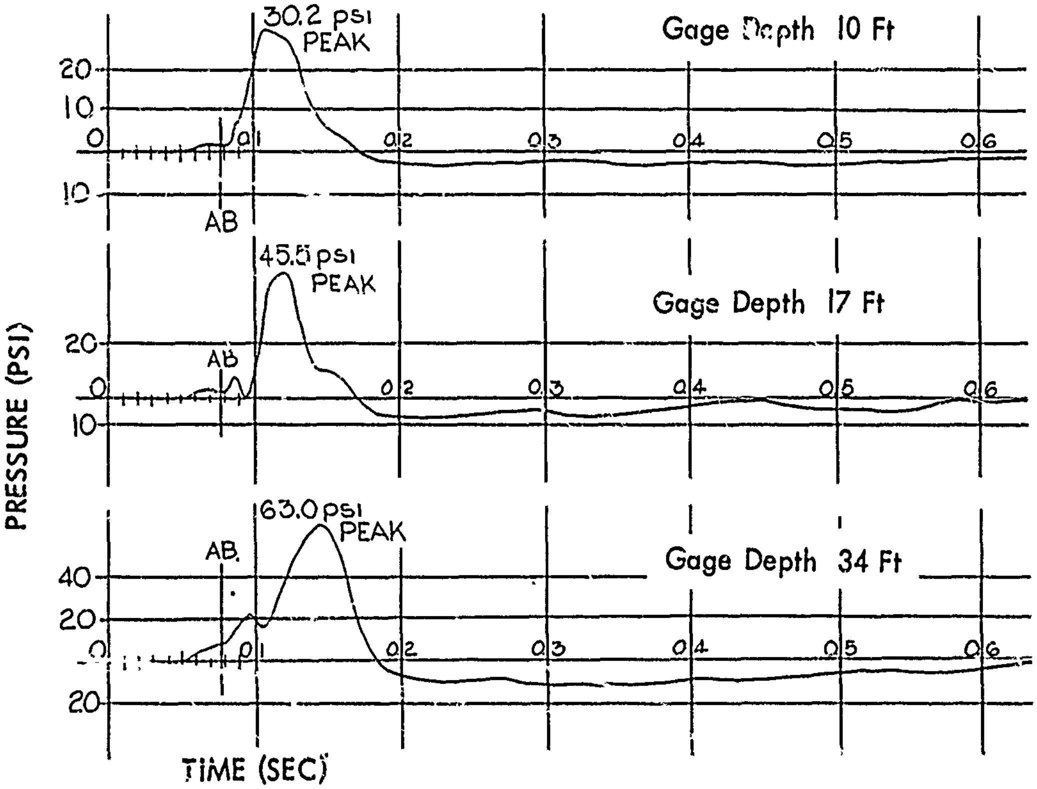

Fig. 4.11 Earth Pressure vs. Time Measured at Various Depths for the Underground Test, R = 217 ft

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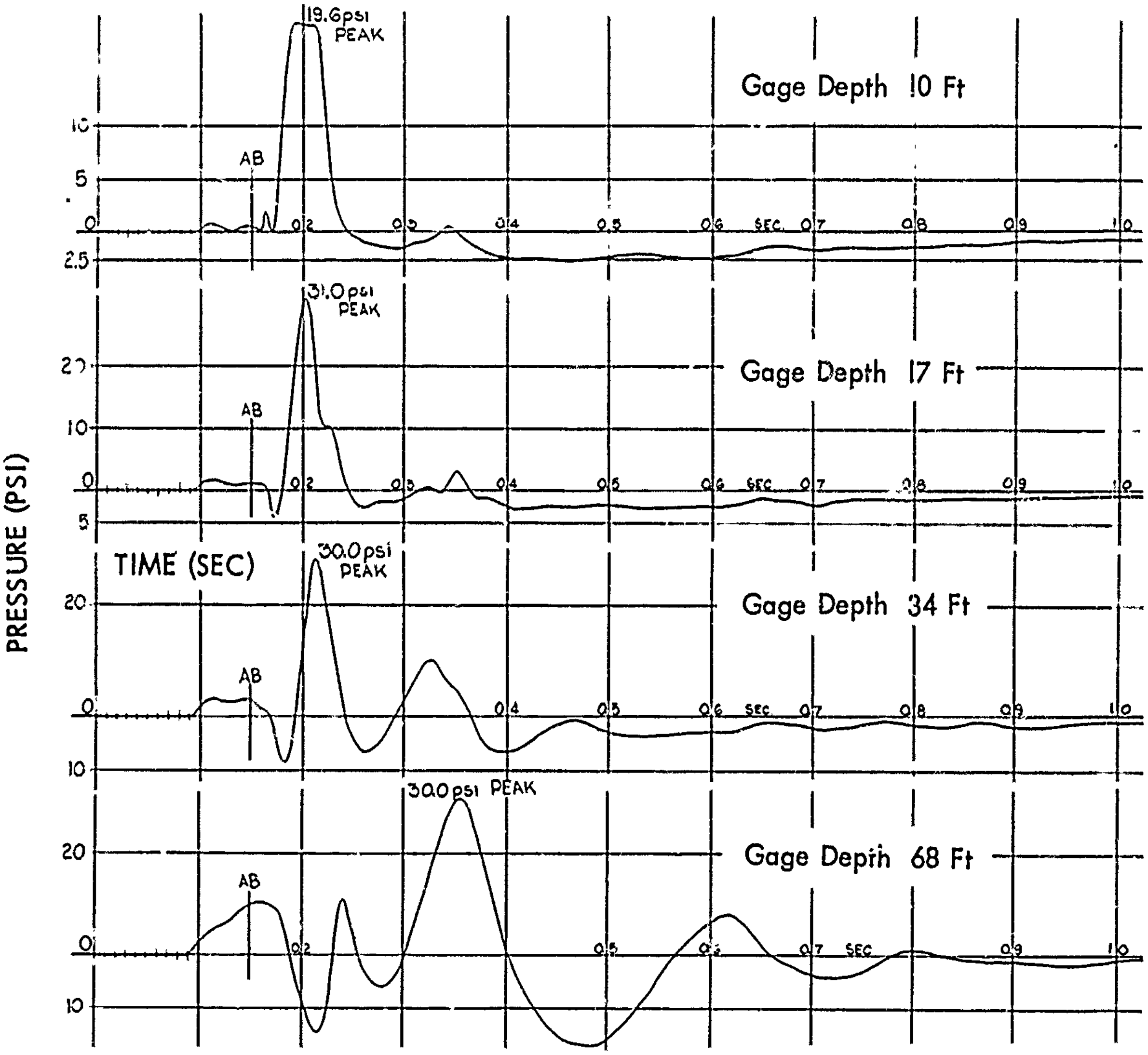

Fig. 4.12 Earth Pressure vs. Time Measured at Various Depths for the Underground Test, R = 378 ft

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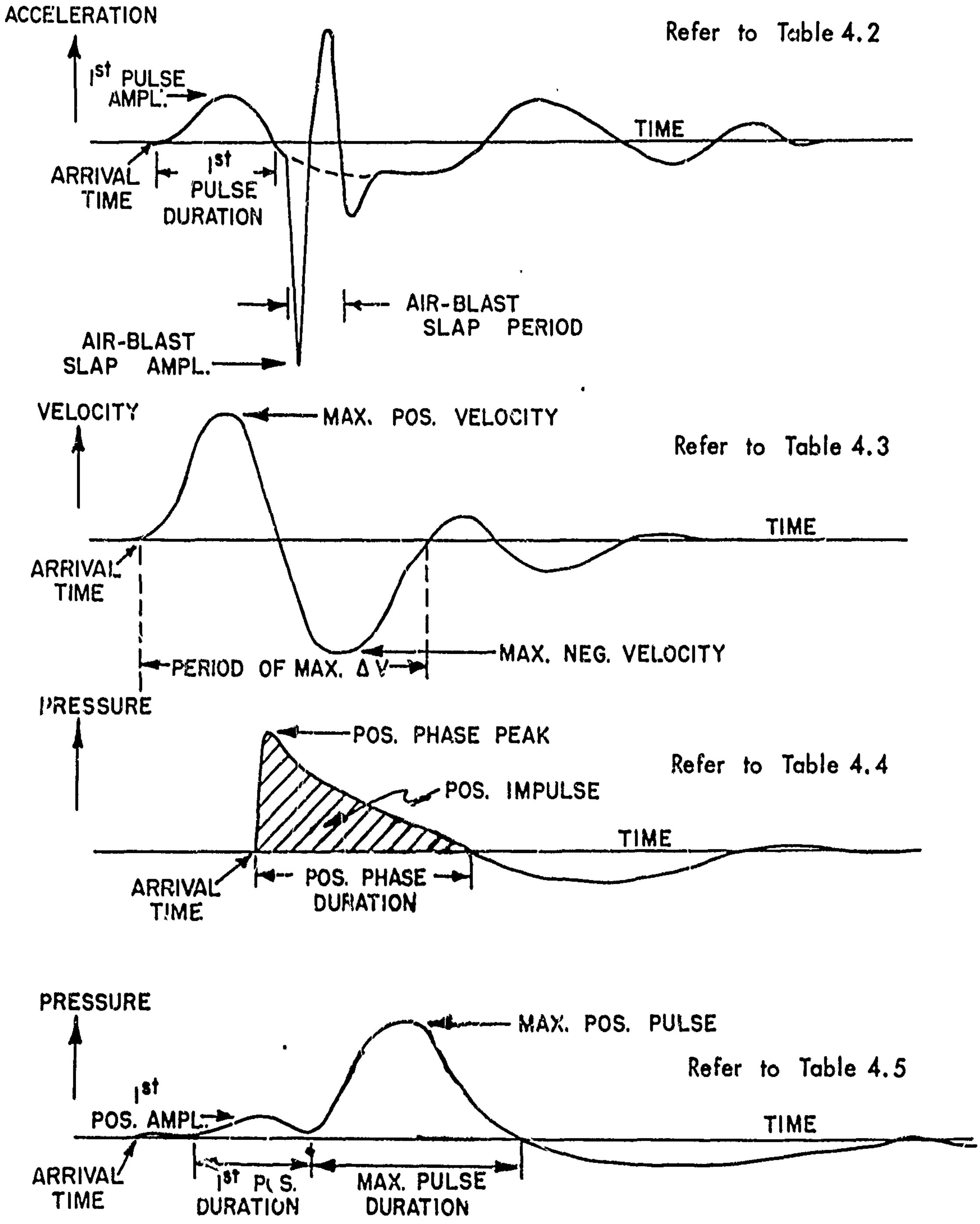

Fig. 4.13 Quantities Measured from Transient Records for the Underground Test

TABLE 4.2

Earth Acceleration

Gage Code No.	Gage Rating (G)	Horizontal Radius (ft)	Horizontal Radius λ	Arrival Time (sec)	First Pulse Ampl. (G)	First Pulse Durat'n (sec)	Air-Blast Slap Ampl. (G)	Air-Blast Slap Period (sec)
				Horizontal				
2H	5	262	2.08	0.068	0.59	0.120		
3H	5	314	2.49	0.084	0.49	0.110		
6H	5	456	3.62	0.114	0.28	0.092		
8H	5	542	4.3	0.138	0.28	0.093		
10H	5	655	5.2	0.165	0.19	0.092		
11H	5	788	6.25	0.195	0.16	0.100		
13H	5	945	7.5	0.243	0.12	0.105		
14H	1	1025	8.15	0.261	0.10	0.120		
16H	1	1230	9.75	0.318	0.030	0.138		
17H	1	1480	11.7	0.386	0.026	0.128		
19H	0.5	2130	16.9	0.560	0.011	0.100		
20H	0.5	3080	24.4	–	0.012	0.100		
				Vertical				
2V	5	262	2.08	0.068	0.33	0.025	8.5	0.026
3V	5	314	2.49	0.084	0.24	0.025	8.4	0.022
6V	5	456	3.62	0.115	0.125	0.025	6.6	0.020
8V	5	542	4.3	0.138	0.13	0.027	3.3	0.027
10V	5	655	5.2	0.164	0.134	0.025	2.7	0.031
11V	5	788	6.25	0.196	0.080	0.025	2.0	0.029
13V	5	945	7.5	0.241	0.067	0.026	2.1	0.034
14V	1	1025	8.15	0.262	0.050	0.035	1.3	0.040
16V	1	1230	9.75	0.313	0.034	0.048	0.86	0.033
17V	1	1480	11.7	0.382	0.032	0.051	0.92	0.036
19V	0.5	2130	16.9	0.556	0.014	0.092	0.26	0.040
20V	0.5	3080	24.4	–	0.013	0.085	–	–

[redacted]

TABLE 4.3

Horizontal Earth Velocity

Gage Code No.	Horizontal Radius		Peak Vel. (fps)		Aver. Ampl. (fps)	Period (sec)
	(ft)	λ	Max. Pos.	Max. Neg.		
2H	262	2.08	1.8	2.1	1.95	0.360
3H	314	2.49	1.3	2.0	1.65	0.345
6H	456	3.62	0.75	1.2	0.98	0.315
8H	542	4.3	0.85	0.94	0.90	0.305
10H	655	5.2	0.15	1.15	0.65	0.300
11H	788	6.25	0.45	0.60	0.53	0.390
13H	945	7.5	0.45	0.45	0.45	0.455
14H	1025	8.15	0.90	0.30	0.60	0.505
16H	1230	9.75	0.30	0.35	0.33	0.490
17H	1480	11.7	0.30	0.55	0.43	0.495
19H	2130	16.9	0.13	0.15	0.14	0.640

TABLE 4.4

Air-Blast Pressure

Gage Code No.	Gage Rating (psi)	Horizontal Radius		Arrival Time (sec)	Positive Phase		Positive Impulse (psi-sec)
		(ft)	λ		Peak (psi)	Durat'n (sec)	
3B	100	314	2.49	0.122	29.2	0.097	0.700
8B	10	542	4.3	0.255	14.3	0.174	0.725
13B	10	945	7.5	0.534	7.06	0.220	0.660
17B	10	1480	11.7	0.946	4.16	0.295	0.490
19B	10	2130	16.9	1.476	2.67	0.330	0.373

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TABLE 4.5

Earth Pressure

Gage Code No.	Gage Rating (psi)	Horizontal Radius		Arrival Time (sec)	First Pos. Pulse		Max. Pos. Pulse	
		(ft)	λ		Ampl. (psi)	Dur. (sec)	Ampl. (psi)	Dur. (sec)
1P	100	217	1.72	0.055	1.77	0.036	30.2	0.088
2P	100	262	2.08	0.068	0.99	0.035	16.5	0.095
5P	100	378	3.0	0.096	0.64	0.033	19.6	0.072
6P	10	456	3.62	0.116	0.67	0.045	18.3	0.087
8P	10	542	4.3	0.138	0.58	0.059	16.1	0.095
10P	10	655	5.2	0.165	0.43	0.092	17.7	0.076
11P	10	788	6.25	0.197	0.43	0.063	15.0	0.091
13P	10	945	7.5	0.238	0.27	0.037	9.8	0.090
16P	10	1230	9.75	0.312	0.17	0.050	9.05	0.080
17P	10	1480	11.7	0.383	0.13	0.052	8.7	0.070
19P	1	2130	16.9	0.555	0.070	0.050	----*	----*
20P	1	3080	24.4	0.815	0.020	0.085	----*	----*

*Galvanometer trace is off the oscillograph record; data are questionable.

CHAPTER 5

DISCUSSION

5.1 GENERAL

The discussion of the results of Project 1(9)a will cover seven main topics: air pressure; earth acceleration; damage; time of arrival; earth pressure; comparison with the scaled HE tests; and comparison with the Dugway dry clay tests in 1951.

The Project 1(9)-1 report[1] on the HE tests includes several predictions for the underground nuclear test. The HE-1 and HE-2 test results were examined and definite predictions were made for the experimental quantities which scaled properly for these TNT explosions. It will be one purpose of this discussion to compare these predictions with the underground test results.

The foregoing predictions were made assuming the underground nuclear charge to be equivalent to 1.0 KT of TNT energy release. Wherever possible, the equivalent TNT energy release of the underground nuclear charge will be computed for the particular phenomenon concerned, using HE-2 data[1] as the reference for TNT, assuming the normal explosive model laws.

5.2 AIR PRESSURE

The transient records of the air pressure measurements on Project 1(9)a are presented in Figure 4.2 of the previous chapter. Reference to this figure shows that the wave forms were very similar to those obtained in the HE-1 and HE-2 tests of Project 1(9)-1.[1] The shock fronts, or the initial abrupt pressure rises, are seen to be devoid of extraneous disturbances. In particular, there is no "front porch" effect such as was observed in the HE-3 test, which is what would be predicted from the fact that the nuclear charge burial depth was shallow. The reader is referred to the report on Project 1(9)-1[1] for a more detailed discussion of this "front porch" effect. The records in Figure 4.2 further illustrate that the duration of the positive phase increases with increasing distance from the charge.

The most important aspects of the air pressure records are the peak pressure, the positive phase duration, and the positive impulse. These quantities are shown plotted against the horizontal distance from ground zero for the underground nuclear test in Figures 5.1, 5.2, and 5.3 respectively. In addition to the empirical curves, the figures also show the predictions for each of these quantities that were made in the Project 1(9)-1 report.[1] These predictions were scaled from the HE-2 test, assuming the underground nuclear test to be a scaled experiment and the charge energy release to be equivalent to 1.0 KT of TNT.

When comparison is made between the results of the underground nuclear test and the predictions for peak air pressure (Figure 5.1) it is observed that the curves are slightly different in form. The predicted pressure curve droops at small scaled distances, following HE-2. However, it was noted that for HE-1 the droop started at a larger value of λ. If this is a real effect of charge size, the net effect is to improve the curve fit at small λ.

At large ranges, the slopes of both curves of Figure 5.1 become constant, indicating a relation of the form

$$p \quad \frac{A}{R^n}, \qquad (5.1)$$

where A is a constant and -n is the slope of the log log plot. The exponent n is 1.4 and 1.25 for the predicted and observed curves, respectively. Thus the attenuation laws for peak pressure are about the same for the underground nuclear and HE-2 tests.

Figure 5.2 shows the experimental and predicted values of the duration of the positive phase as a function of the horizontal range. The curves have essentially the same form, with the predicted values lying above the experimental points shown. Similar behavior is exhibited in the positive impulse curves of Figure 5.3.

The scaling for air pressure between HE-1 and HE-2 was excellent, and the wave forms and attenuation laws observed on the nuclear test are similar to those from HE-2. Consequently there is justification for the calculation of equivalent yields for the various aspects of air-blast phenomena. Methods for doing this have been outlined in Section 5.2 of the report on Project 1(9)-1[1] and Section 5.3 of this report. With air pressure phenomena it is possible to get five scale factors (cube root of the yield ratio) by adjusting the curves for best fit. With a log log plot, as for peak pressure (Figure 5.1), only one adjustment is needed when the slopes are the same. Data for positive phase duration and positive impulse may be presented to advantage on a semi-log plot, in which two factors are used to match the curves. The five scale factors resulting for air blast, then, are as below

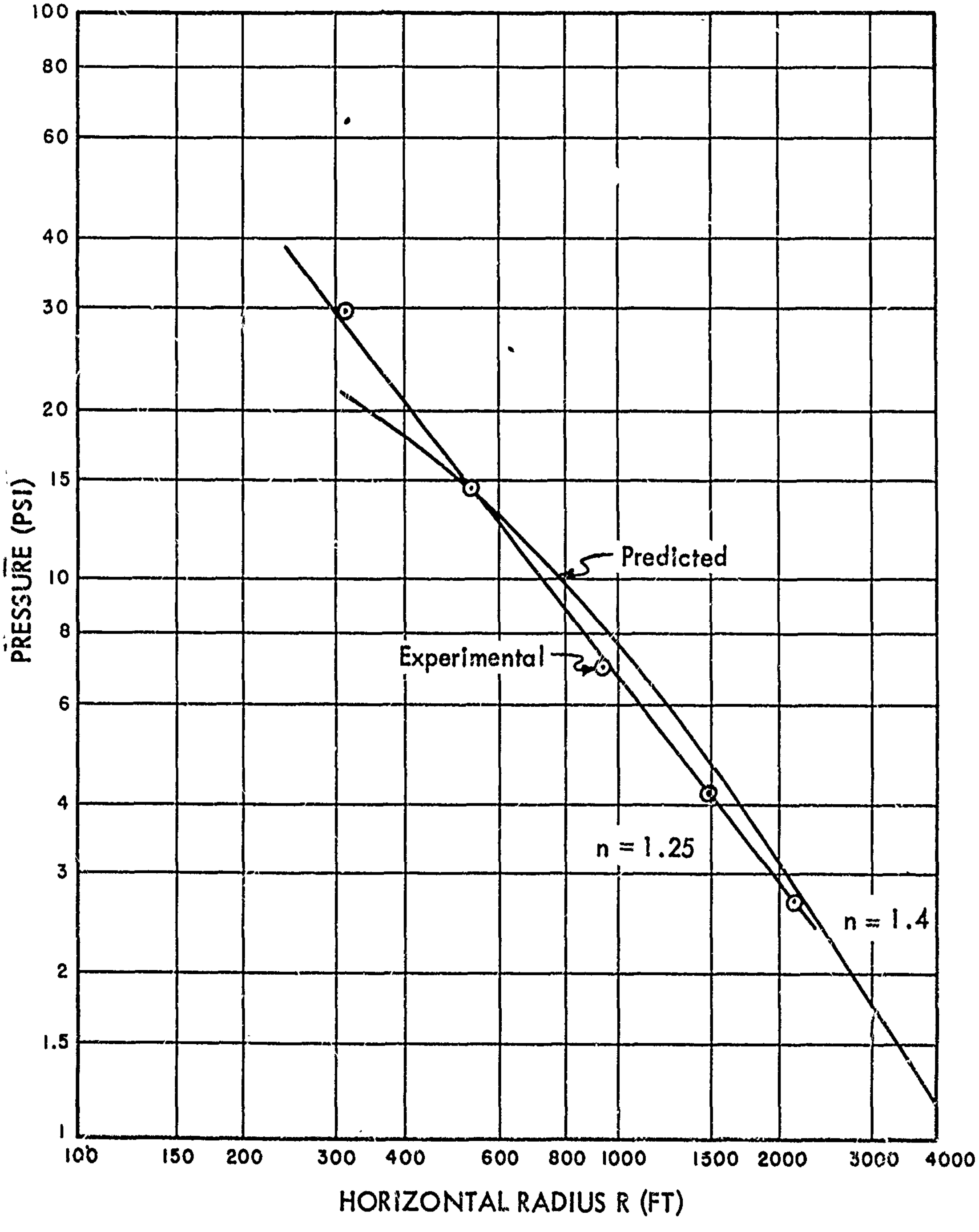

Fig. 5.1 Air-Blast Peak Pressure vs. Horizontal Radius for the Underground Test, with Curve Predicted for 1 KT of TNT

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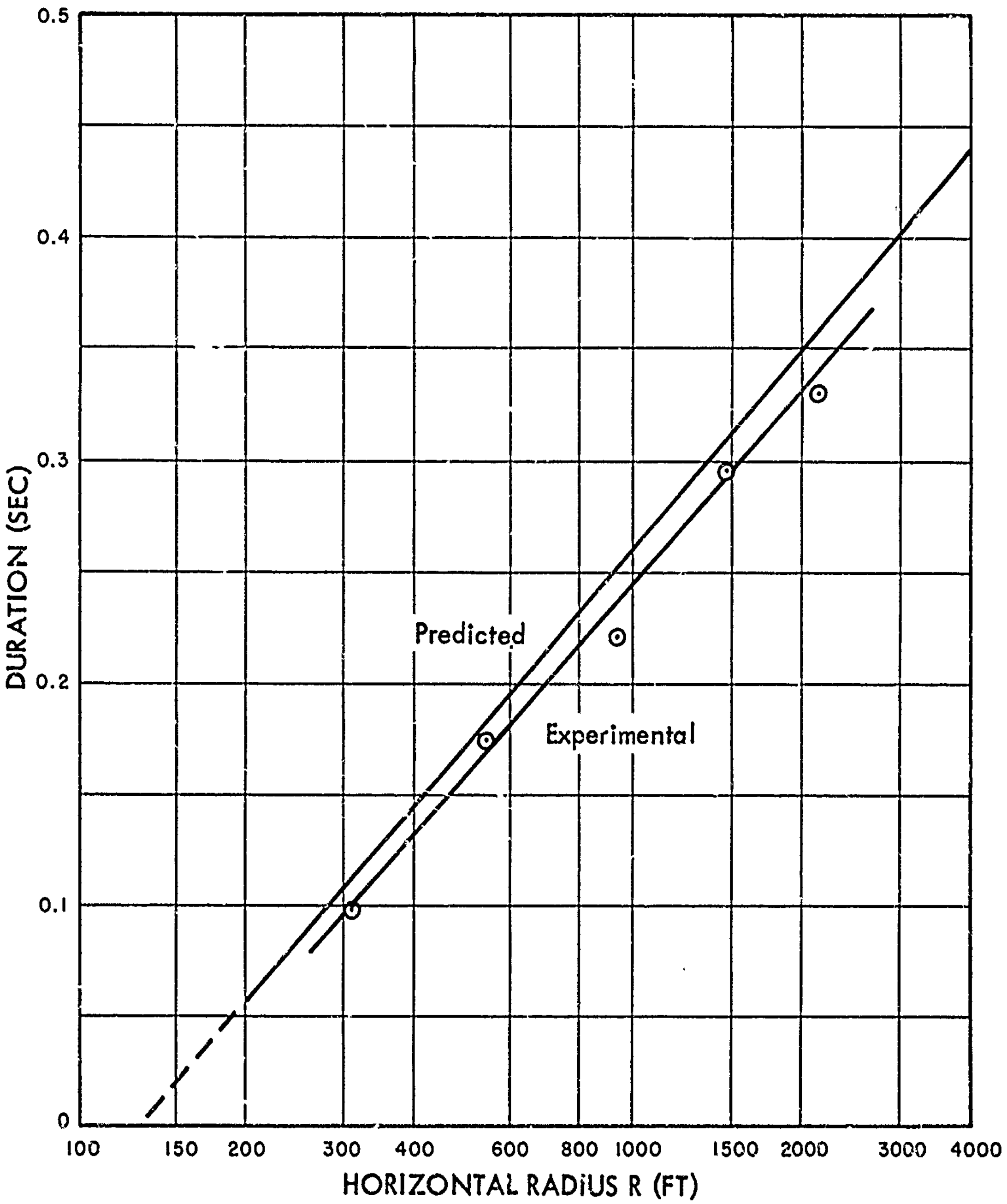

Fig. 5.2 Air Blast Positive Pulse Duration vs. Horizontal Radius for the Underground Test with Curve Predicted for 1 KT of TNT.

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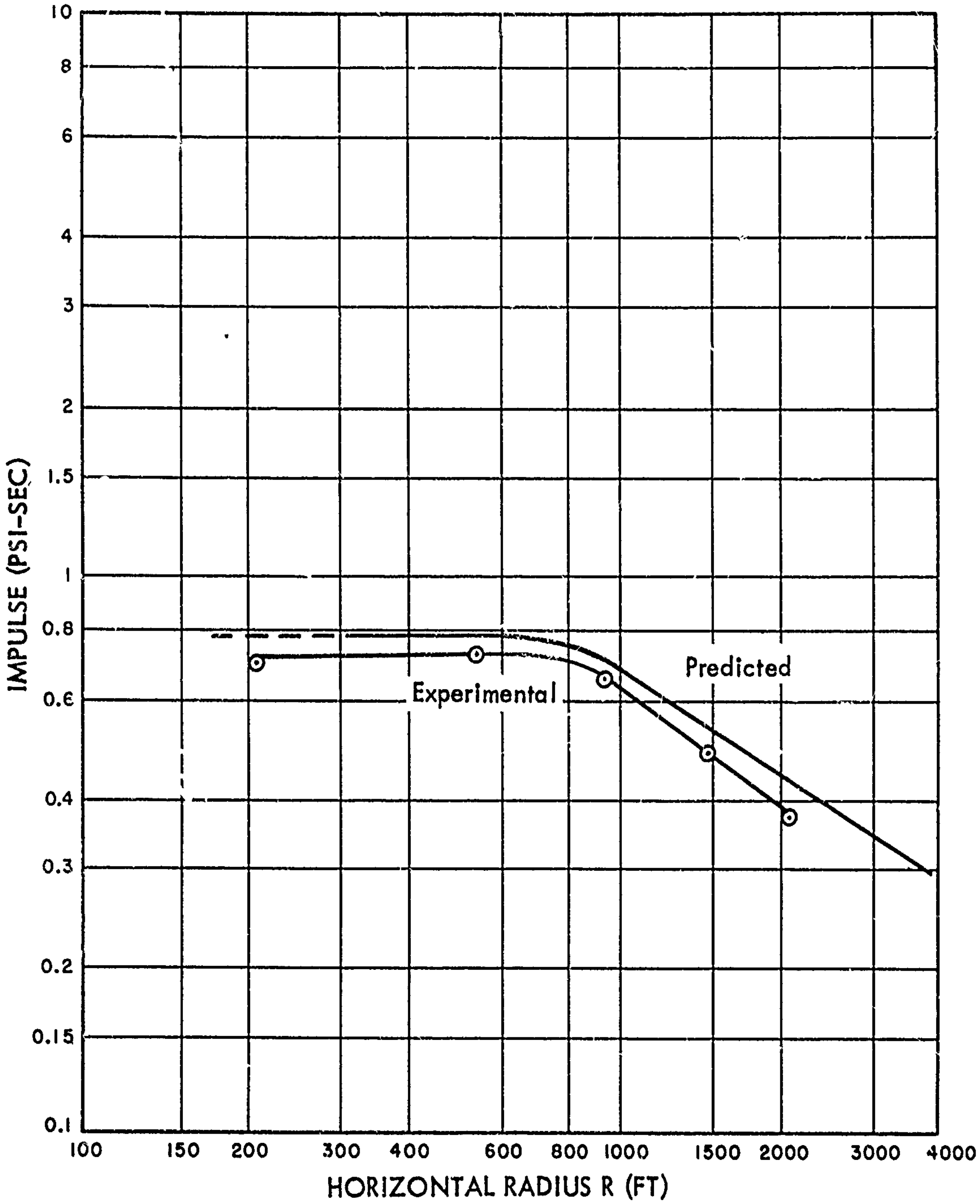

Fig. 5.3 Air Blast Positive Impulse vs. Horizontal Radius for the Underground Test, Curve Predicted for 1 KT of TNT

Quantity	Method	Scale Factor $\left(\frac{W_N}{W_{HE-2}}\right)^{1/3}$
Peak pressure	Curve fitting	3.5
Positive phase duration	Slope	3.4
	Intercept	3.6
Positive impulse	Slope	3.2
	Intercept	3.8

The arithmetic mean of the above values is 3.5, with a mean deviation of 0.16, or about four per cent. This air-blast scale factor corresponds to an equivalent yield of 0.85 KT of TNT, as judged by the ability of the underground charge to produce air blast. Of course, it must be pointed out that this yield is based upon the results of the air pressure measurements alone and it would be unwise, without further investigation to state that the underground nuclear charge of Project 1(9)a performed in all respects as a 0.85 KT charge of TNT would have performed under similar circumstances. The small deviation is an indication of the reliability of this yield calculation for air pressure. Since the radiochemical yield was announced to be 1.2 KT, the equivalent TNT efficiency was 70 per cent with respect to production of air pressure.

Figures 5.4, 5.5, and 5.6 show how well this scale factor of 3.5 holds between HE-2 and the underground nuclear test. The air pressure positive peaks, positive phase durations, and positive impulses are plotted in that order for both tests. In Figure 5.4 the curve represents the results of the nuclear test where the λ values have been computed on the basis of a charge equivalent of 0.85 KT of TNT. The points represent the HE-2 results. Except for low λ values, the fit is very good. The positive phase duration is treated in Figure 5.5. Since the time variable between two tests scales directly as the scale factor, it was necessary to multiply the HE-2 results by 3.5 to show the graphical correspondence. Here again, the underground test curve is drawn assuming a charge of 0.85 KT of TNT and the points are from HE-2 data. The curve appears to represent the plotted points very well. The positive impulse, shown in Figure 5.6, is treated in the same way. The curve, in this case, fits the plotted points for all λ values.

The preceding analysis gives a clear insight into the factors that must be considered when applying the model or scaling laws. A physical quantity, in this case air pressure, cannot be said to scale from one test to another unless its variation with respect to both radius (R) and time (t) are considered in detail. If, for any reason, the

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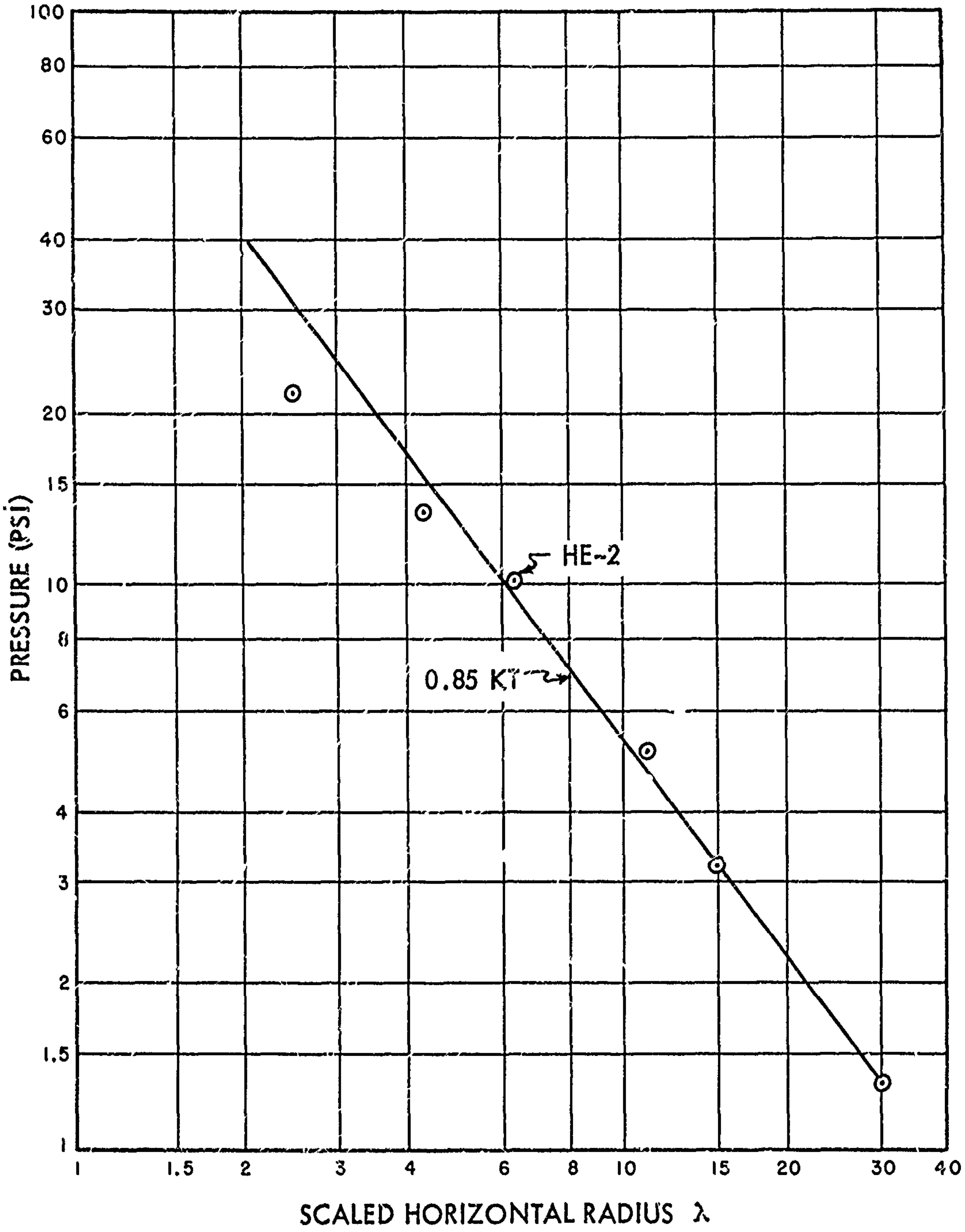

Fig. 5.4 Air Blast Peak Pressure vs. Scaled Horizontal Radius for 0.85 KT of TNT and HE-2 Test. Plotted points refer to HE-2

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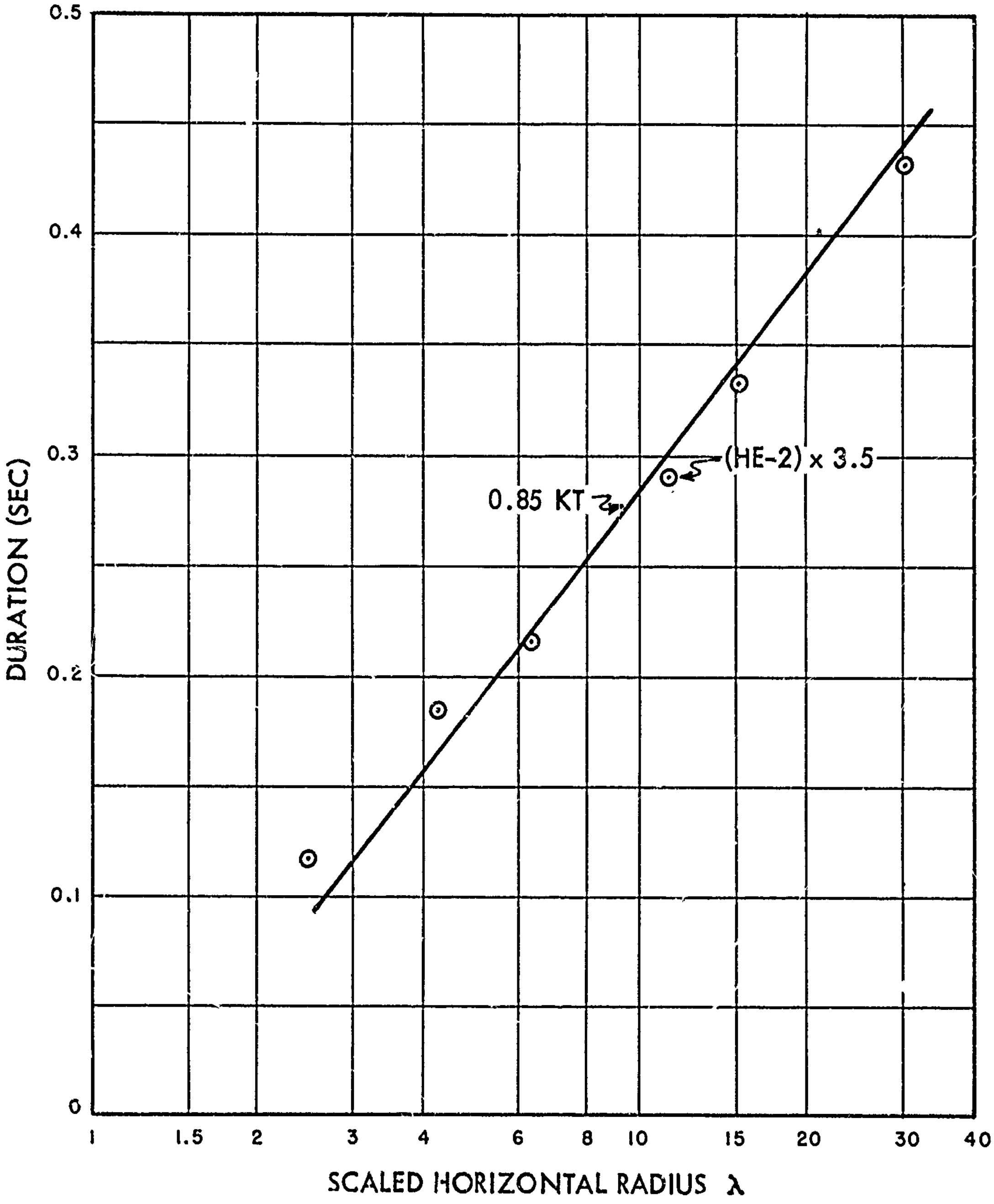

Fig. 5.5 Air Blast Positive Pulse Duration vs. Scaled Horizontal Radius for 0.85 KT of TNT and HE-2 Test. Plotted points refer to HE-2

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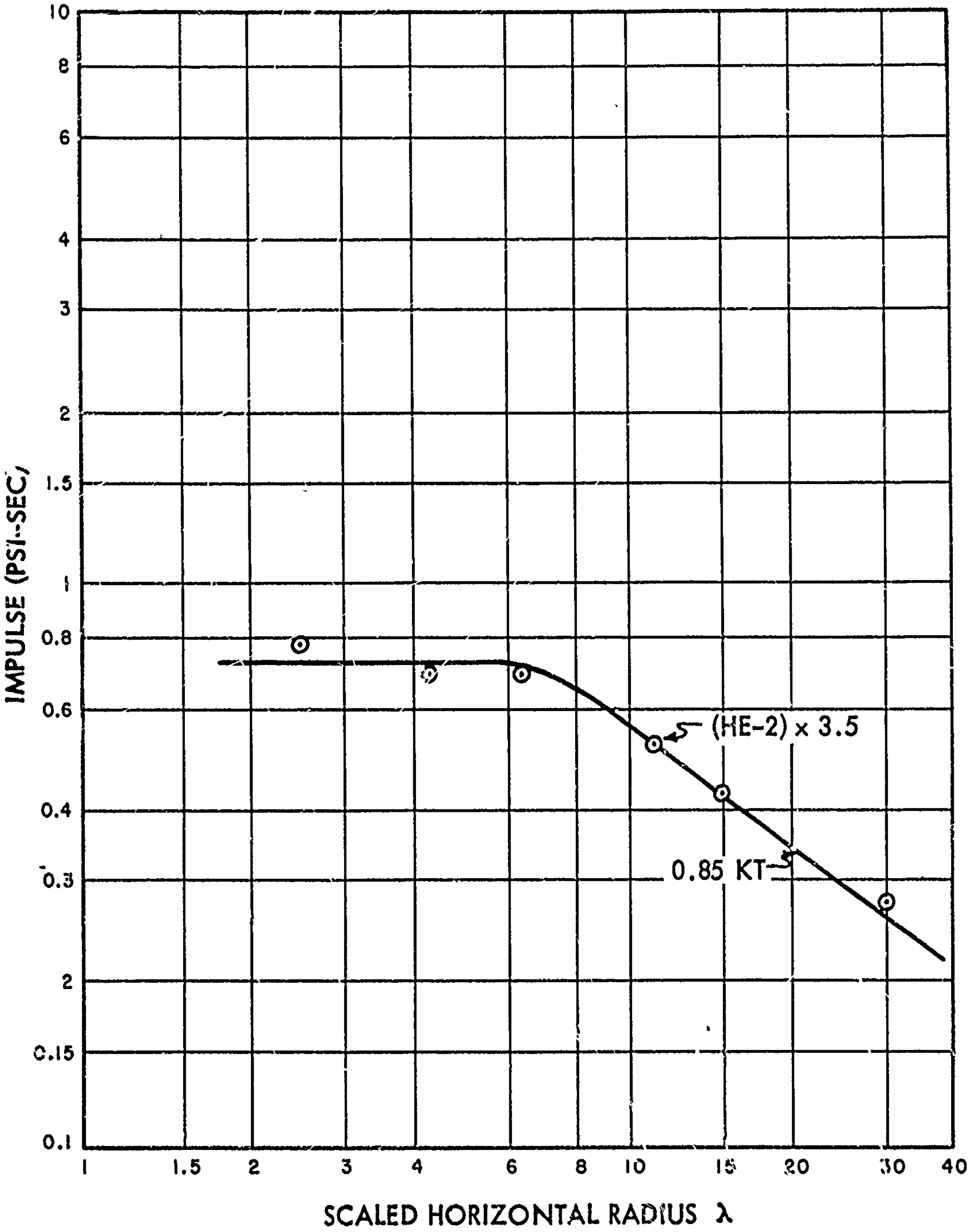

Fig. 5.6 **Air Blast Positive Impulse vs. Scaled Horizontal Radius for 0.85 KT of TNT and HE-2 Test. Plotted points refer to HE-2**

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computed scale factors had been widely different, there would have been no basis upon which to compute an air-pressure equivalent yield of the nuclear test charge. To compute a different equivalent yield for peak pressure, for positive phase duration, and for positive impulse would have little practical meaning. This very problem presents itself when the phenomenon of earth motion is considered and it will be discussed later in this report.

Figure 5.7 presents air pressure records for the HE-1, HE-2, and underground nuclear tests at a constant λ value. The time scales have been scaled down appropriately, where the nuclear charge is assumed as 1.0 KT of TNT equivalent. The bottom graph shows a composite of all three records. According to the model laws, the pressures (at the same λ) should be equal. The composite graph shows that the three tests scaled quite well both in pressure and in time. One reason that the arrival times are different is that the velocity of the shock front in air is a function of the magnitude of the peak pressure. Since the nuclear charge gave rise to higher pressures near ground zero than did the other charges, the velocity of the shock front would be higher at first and the front would arrive earlier at the same scaled radial distance.

The time of arrival graph of the air-blast pressure (Figure 5.8) illustrates that the velocity is a function of pressure. The slope of the curve in the figure starts out low and increases up to a constant value. The low slope corresponds to a high velocity near ground zero where the pressures are high. The final velocity of 1220 feet per second would be expected for a shock overpressure of 3.4 psi for the atmospheric pressure (12.8 psi) and sound velocity (1100 feet per second) prevailing at the time of the test. This agrees very well with the mean pressure of about 3.5 psi over the outer range of the blast line.

For direct comparison to other nuclear tests the underground nuclear peak air pressure measurements have been normalized to standard conditions of 1.0 KT (radiochemical yield) at sea level. Using the announced yield of 1.2 KT and the ambient barometric pressure of 864 millibars, the distance correction factor becomes

$$\left[\frac{(864)(1.0)}{(1013)(1.2)}\right]^{1/3} = 0.89 \tag{5.2}$$

and the pressure correction factor is

$$\left(\frac{1013}{864}\right) = 1.17 \tag{5.3}$$

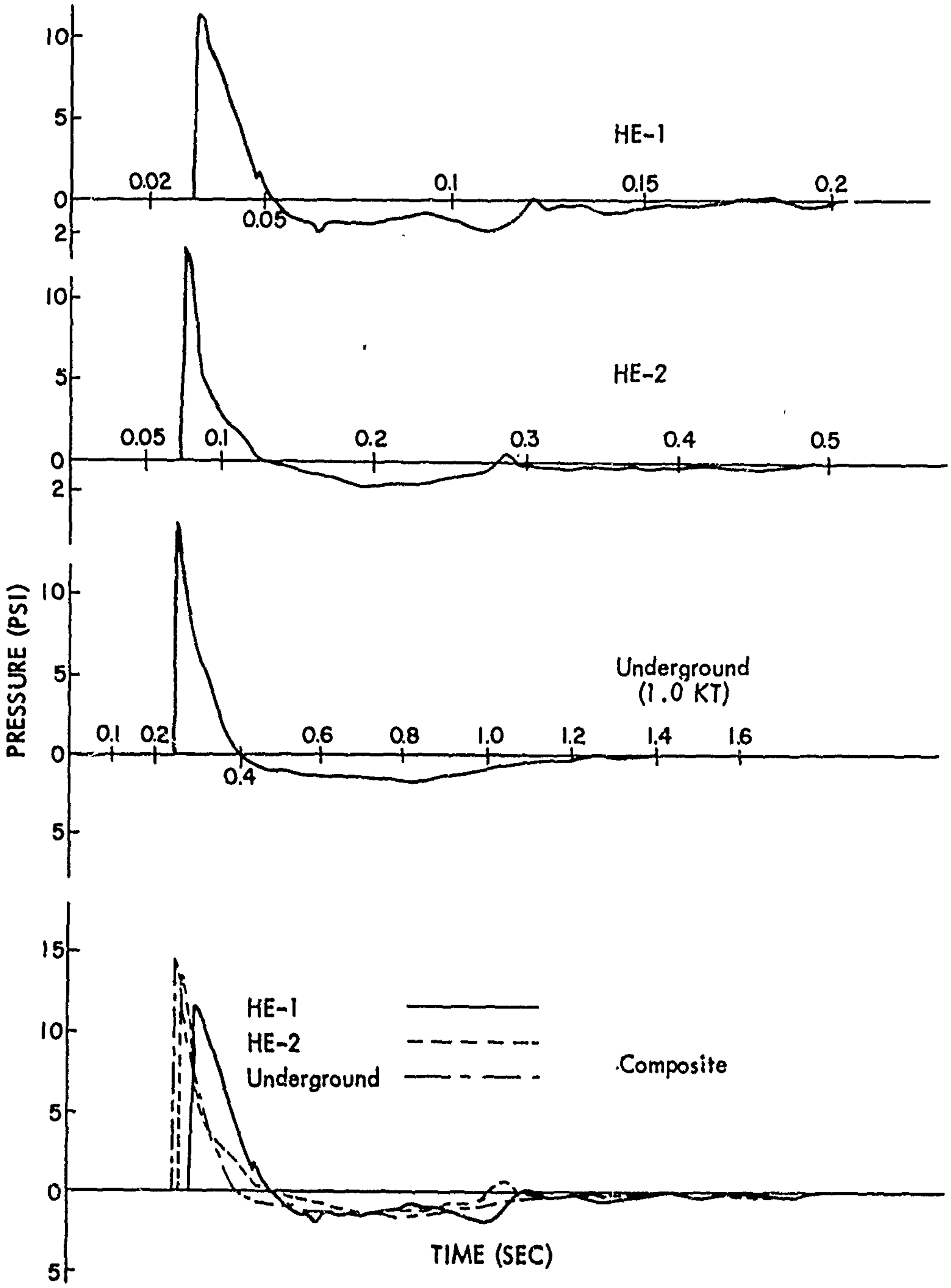

Fig. 5.7 Air Blast Pressure vs. Time at λ = 4.3 for HE-1, HE-2, and Underground Tests. Note that the time axes have been altered to correspond to scaling laws. The bottom graph is a composite of the three tests

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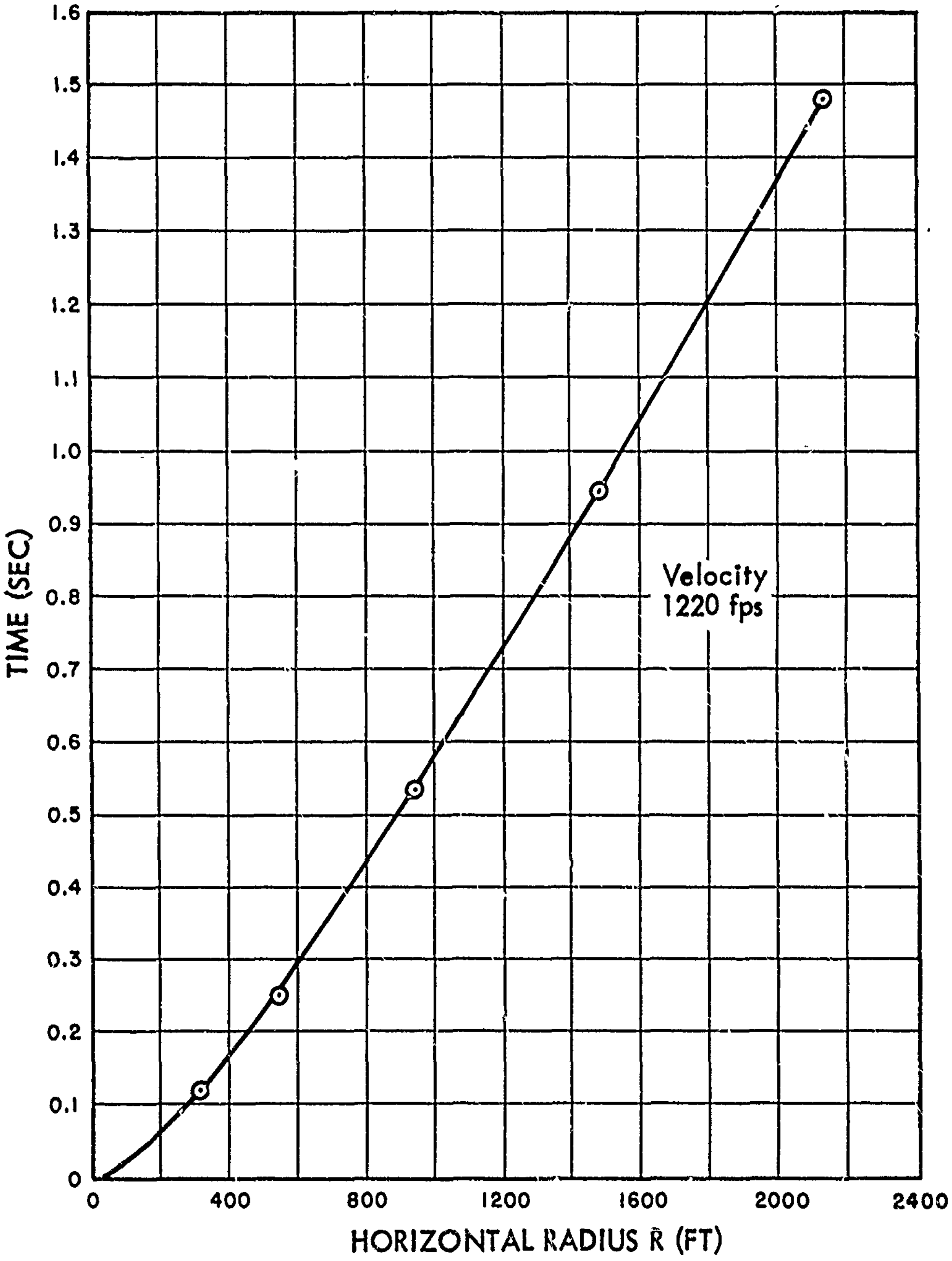

Fig. 5.8 Air Blast Pressure, Time of First Arrival vs. Horizontal Radius for Underground Test

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PROJECT 1(9)a

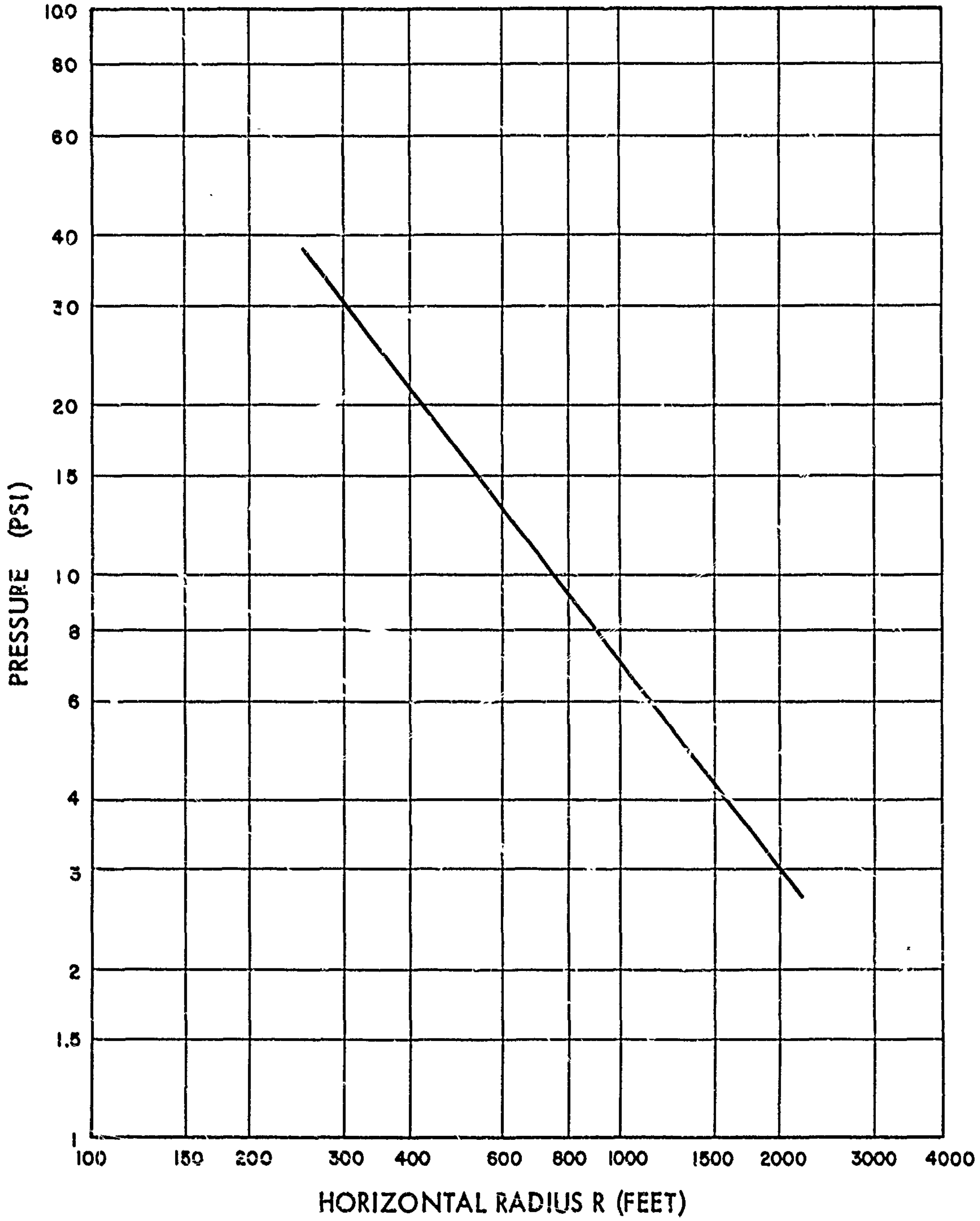

Fig. 5.9 Air-Blast Peak Pressure vs. Horizontal Radius for a 1 KT Nuclear Explosion. Detonated at a depth of 17 feet in JANGLE soil at sea level

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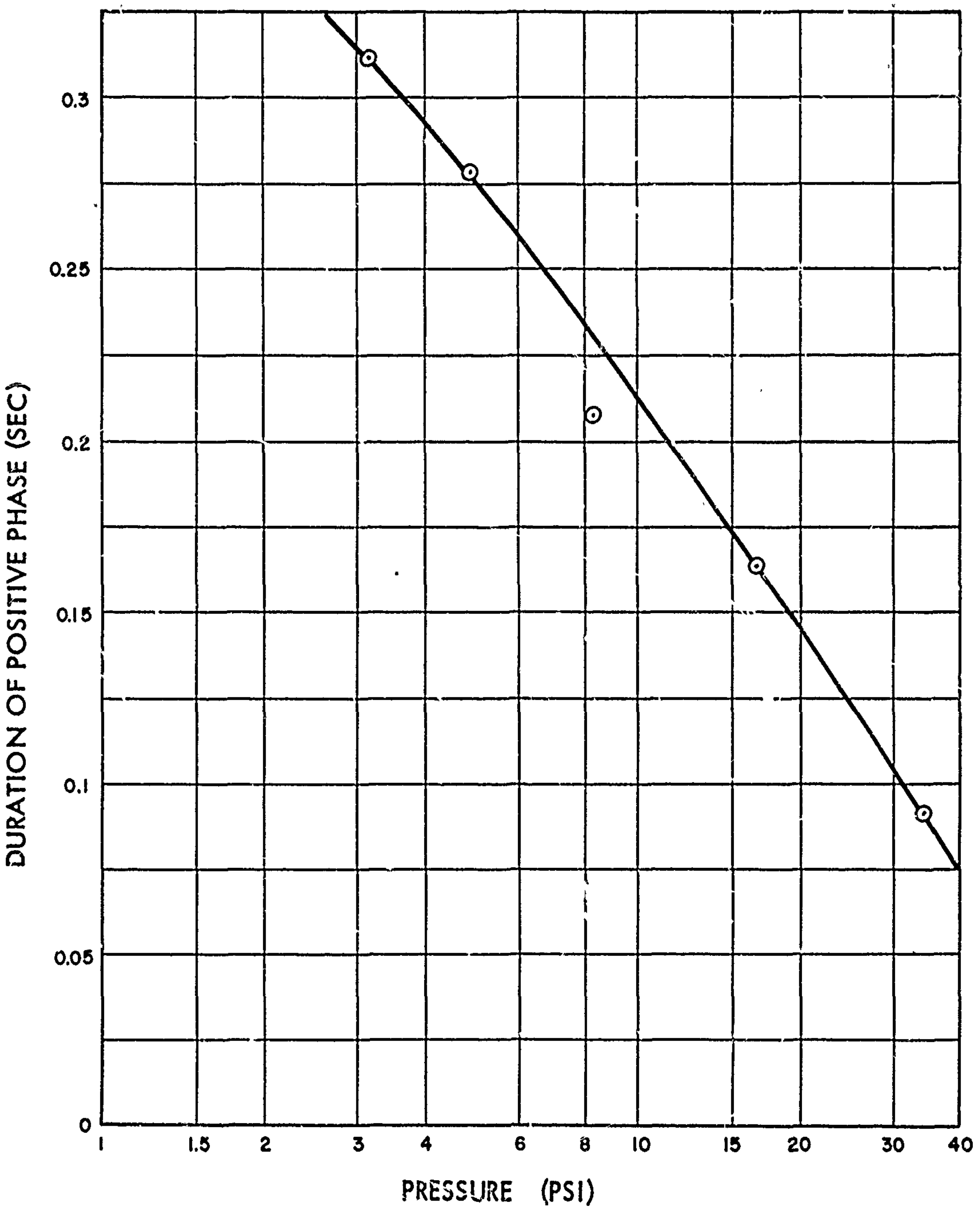

Fig. 5.10 Duration of Air-Blast Positive Phase vs. Peak Pressure for a 1 KT Nuclear Explosion at a Depth of 17 Feet in JANGLE Soil at Sea Level

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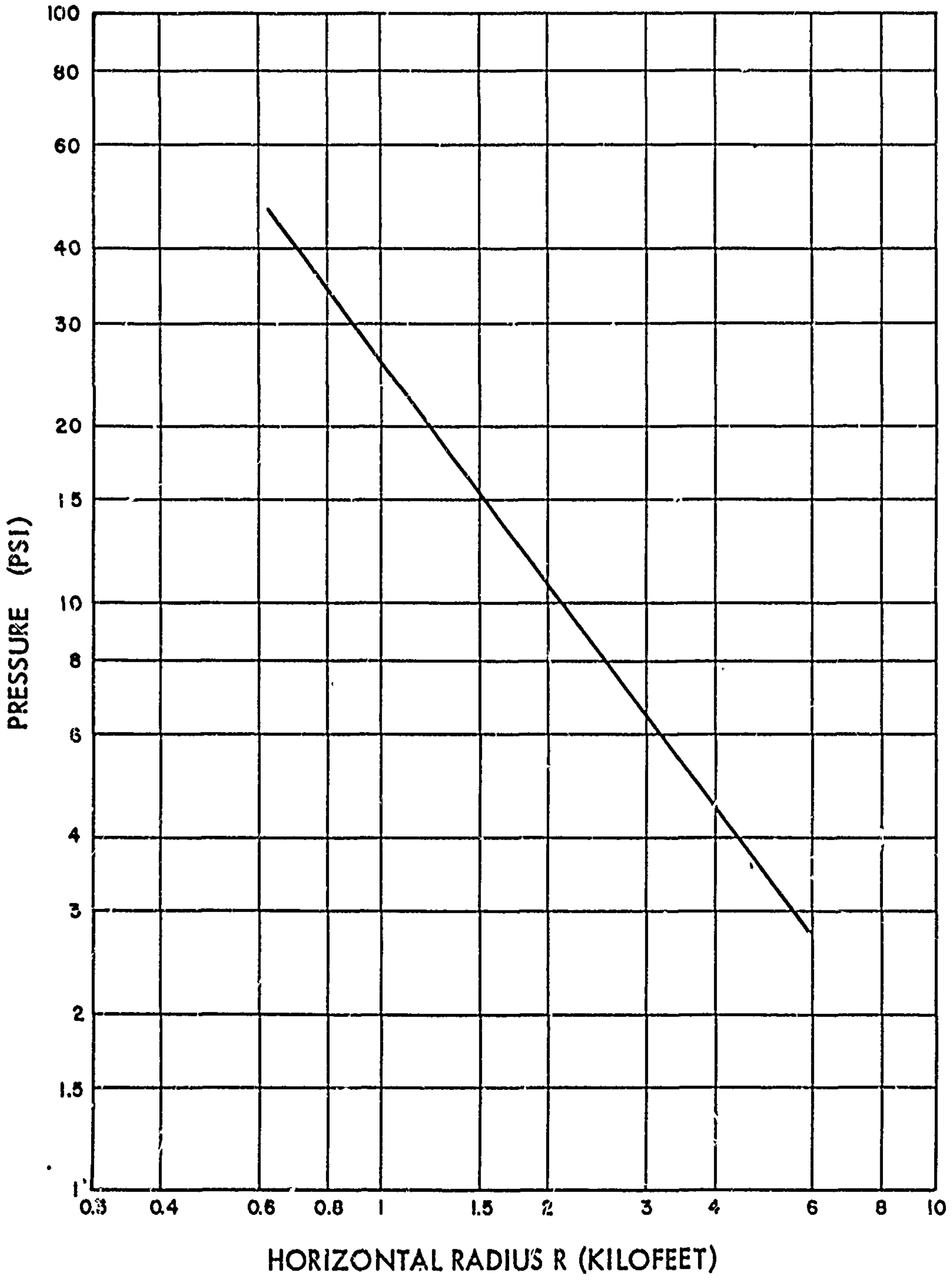

Fig. 5.11 Air-Blast Peak Pressure vs. Horizontal Radius for a 23 KT Nuclear Explosion at a Depth of 17 Feet in JANGLE Soil at Sea Level

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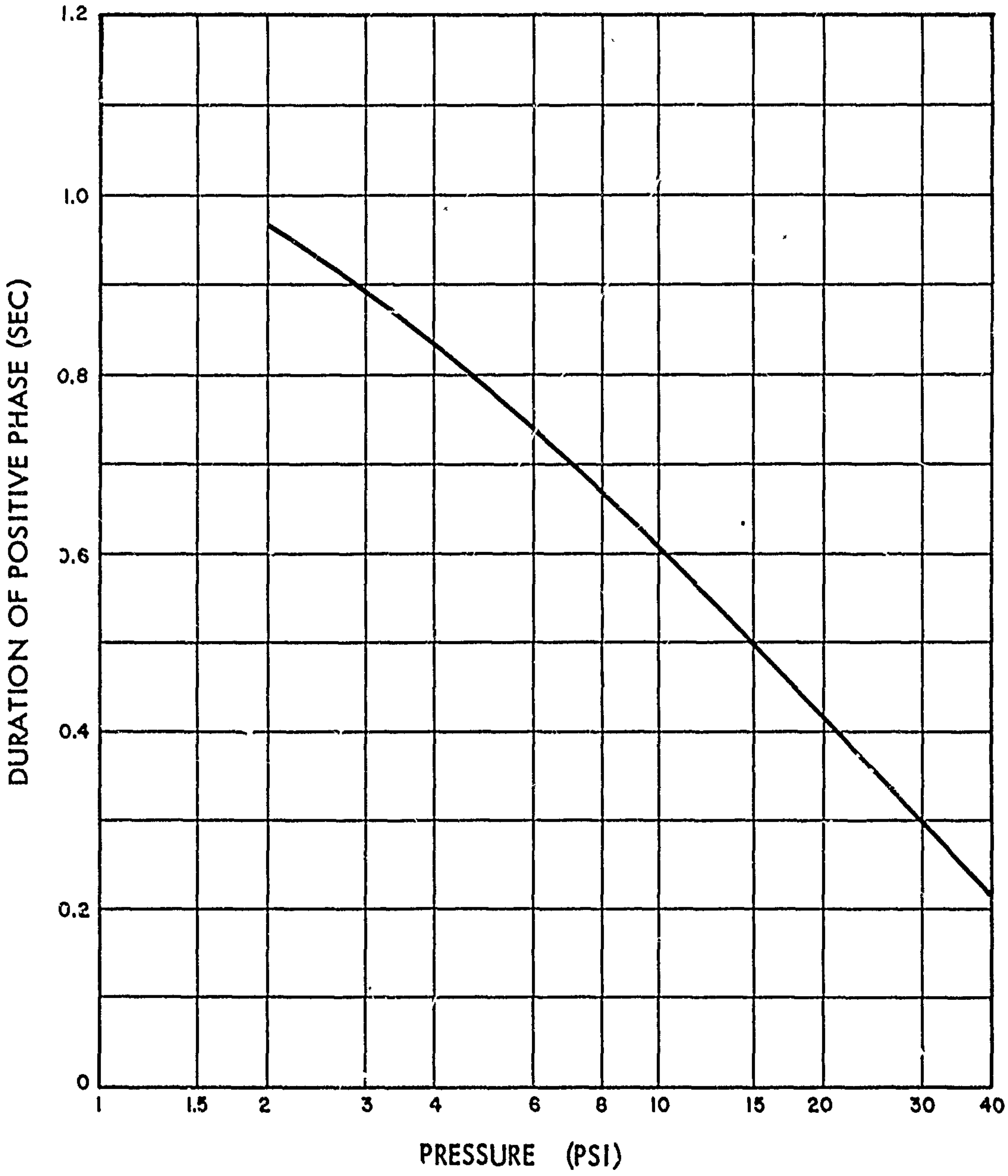

Fig. 5.12 Duration of Air-Blast Positive Phase vs. Peak Pressure for a 23 KT Nuclear Explosion at a Depth of 17 Feet in JANGLE Soil at Sea Level

The resultant normalized peak pressure data are shown in Figure 5.9, while Figure 5.10 presents the positive phase duration as a function of normalized peak pressure.

The excellent model law behavior for air pressure makes it possible to predict the results for a scaled 23 KT experiment at the same test site with good reliability. The predicted peak air pressure vs. distance curve for a 23 KT weapon at a depth of 46 feet is shown in Figure 5.11, while Figure 5.12 shows the predicted positive phase duration as a function of peak pressure.

From comparisons between the scaled HE tests and the tests at the Dugway dry clay site, there is some indication that the air pressure produced by an underground explosion is a function of the soil characteristics. It is believed that this effect is relatively small for the shallow burial depth, $\lambda_c = 0.135$, used for the underground nuclear test. However, very limited experimental data are available for the air pressure effects produced by buried charges, and the effect of soil type cannot be estimated or neglected with certainty.

5.3 EARTH ACCELERATION

The transient records of the earth acceleration measurements on Project 1(9)a are presented in the previous chapter. Figures 4.3 and 4.4 present the horizontal earth acceleration at a depth of 5 feet as a function of time as measured at various distances from the charge. Reference to these figures shows some large high-frequency pulses superimposed upon the low-frequency variations of acceleration. Since these short pulses are initiated very soon after the arrival of the air-blast shock at all gage stations (this arrival is denoted by the AB designation), it is concluded that the air-blast pressure is the cause. These results indicate that there is some energy being fed into the earth medium from the air. The amount of this "feed-back" energy does not appear to be insignificant. The first low-frequency acceleration pulse is probably most representative of the direct earth transmitted effects.

Concerning the horizontal earth acceleration data, Figure 5.13 presents the first pulse amplitude and duration as a function of horizontal radius. The amplitude values indicate a slope of about 1.25 out to 1000 feet. This is the same attenuation as shown in Figure 5.1 for the air-blast peak pressure. At larger radii, the amplitude drops off abruptly. These results are compared with the predicted values in Figure 5.14. It is at once obvious that one cannot proceed with an analysis similar to that developed in the case of the air-blast pressure. The two curves in Figure 5.14 take different

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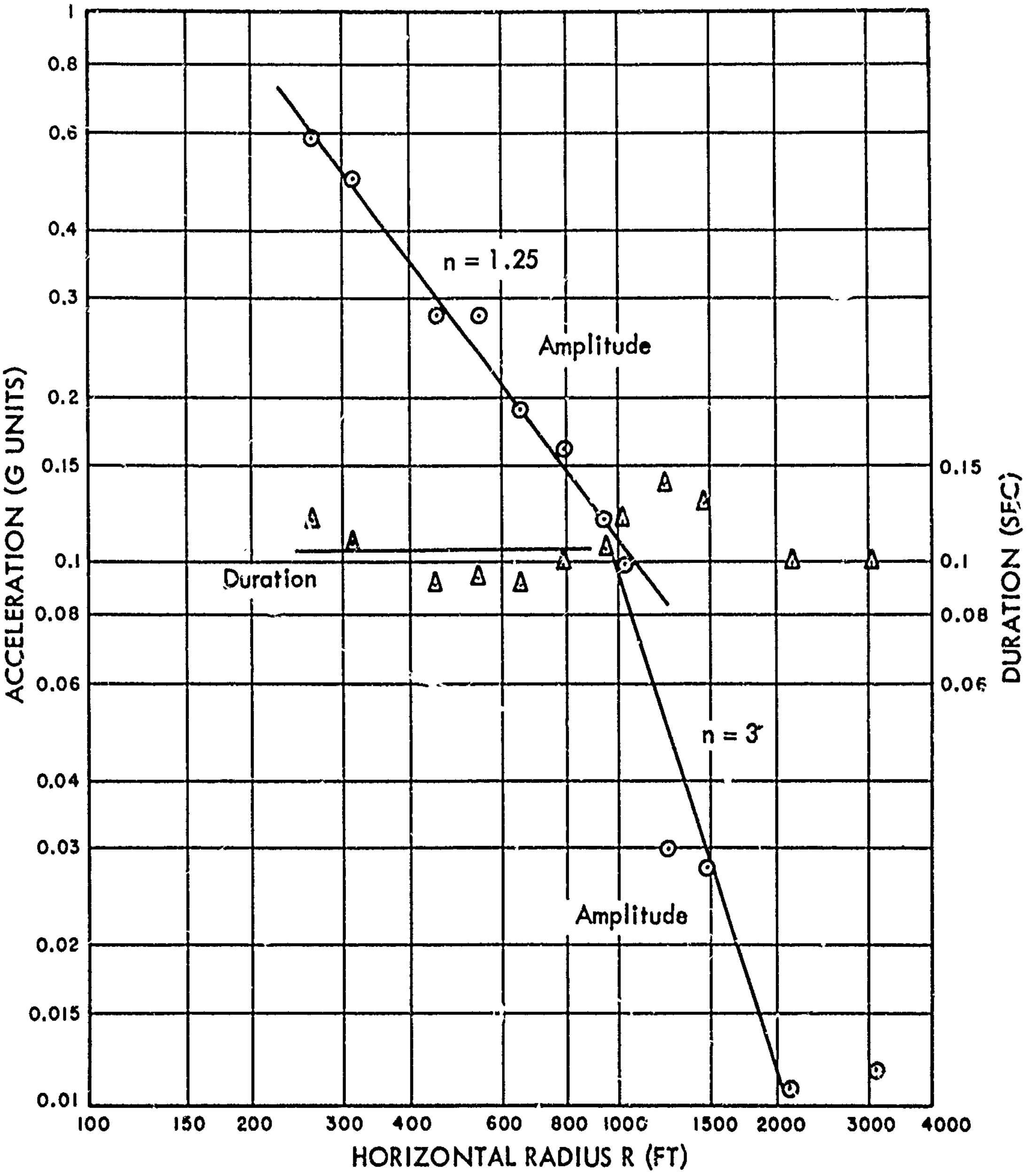

Fig. 5.13 Horizontal Earth Acceleration, First Pulse Amplitude and Duration vs. Horizontal Radius for the Underground Test. Gage depth, 5 feet

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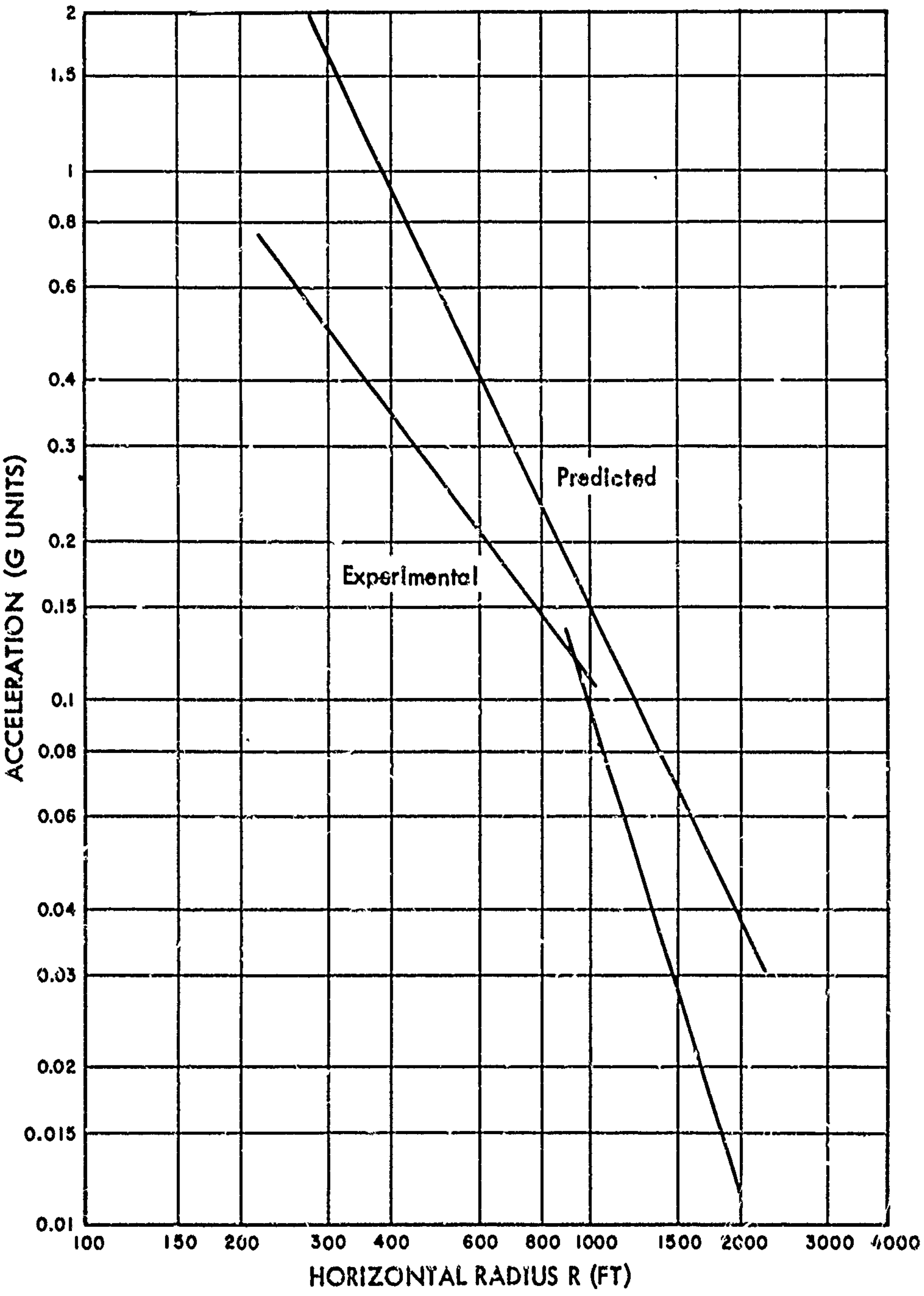

Fig. 5.14 Horizontal Earth Acceleration, First Pulse Amplitude vs. Horizontal Radius for the Underground Test Curve Predicted for 1 KT of TNT. Gage depth 5 feet

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forms and it is not possible to regard them in toto. The predicted curve being above the empirical one indicates that the energy equivalent for horizontal acceleration is everywhere less than 1.0 KT of TNT.

When two curves are not of the same form, as is the case in Figure 5.14, the energy equivalent is a function of the magnitude of the measured quantity (in this case, acceleration), or of the distance chosen for comparison. This problem can be presented in a more general way by referring to Figure 5.15. Here the curves for two hypothetical tests, 1 and 2, have decidedly different forms and it would be impossible to calculate one scale factor between them which would hold for all values of the ordinate (independent variable). Let us assume that the energy release in equivalent pounds of TNT is known for Test 1 and is to be computed for Test 2. According to the scaling laws, pressure and velocity are the same at the same scaled horizontal distances for all tests. Therefore, if the curves in Figure 5.15 were plots of pressure or velocity vs. horizontal radius (using the same coordinate axes for both curves), then the scale factor at point P,v is given by the ratio between R_1 and R_2. However, it is evident from the figure that this ratio will be different for different values of the ordinate (labeled "Physical Quantity" in the figure). If the ratio or scale factor were a constant for all values of the ordinate, then the two curves would necessarily have the same form and a unique energy equivalence could be computed for Test 2.

Another possible approach would be to plot the curves on their own respective coordinate axes and then slide the axes relative to one another, maintaining ordinates parallel, until the curves intersect at the desired ordinate value, here labeled P,v. Again, if the curves take different forms, this will yield a scale factor (R_1/R_2) which is a function of the ordinate value chosen.

For an acceleration vs. distance graph, both the ordinate and abscissa are scaled quantities. Therefore, the Test 2 curve is moved along a 45-degree line (on log log paper) as indicated in Figure 5.15. This yields an acceleration scale factor which is valid for the one point that is labeled A on the ordinate. This procedure corresponds to sliding the separate graphs (for Test 1 and Test 2) over one another so that the point labeled "Acceleration" moves along the 45-degree line indicated in Figure 5.15. In a like manner, the time variable associated with an explosion test may be used to compute the scale factor as is shown in the figure. It must be pointed out that this graphical method is particularly useful when the results of two tests plot as a scatter of points through which a smooth curve cannot be drawn. In this case, the same general procedure of sliding the graphs over one another can be employed, matching the results where

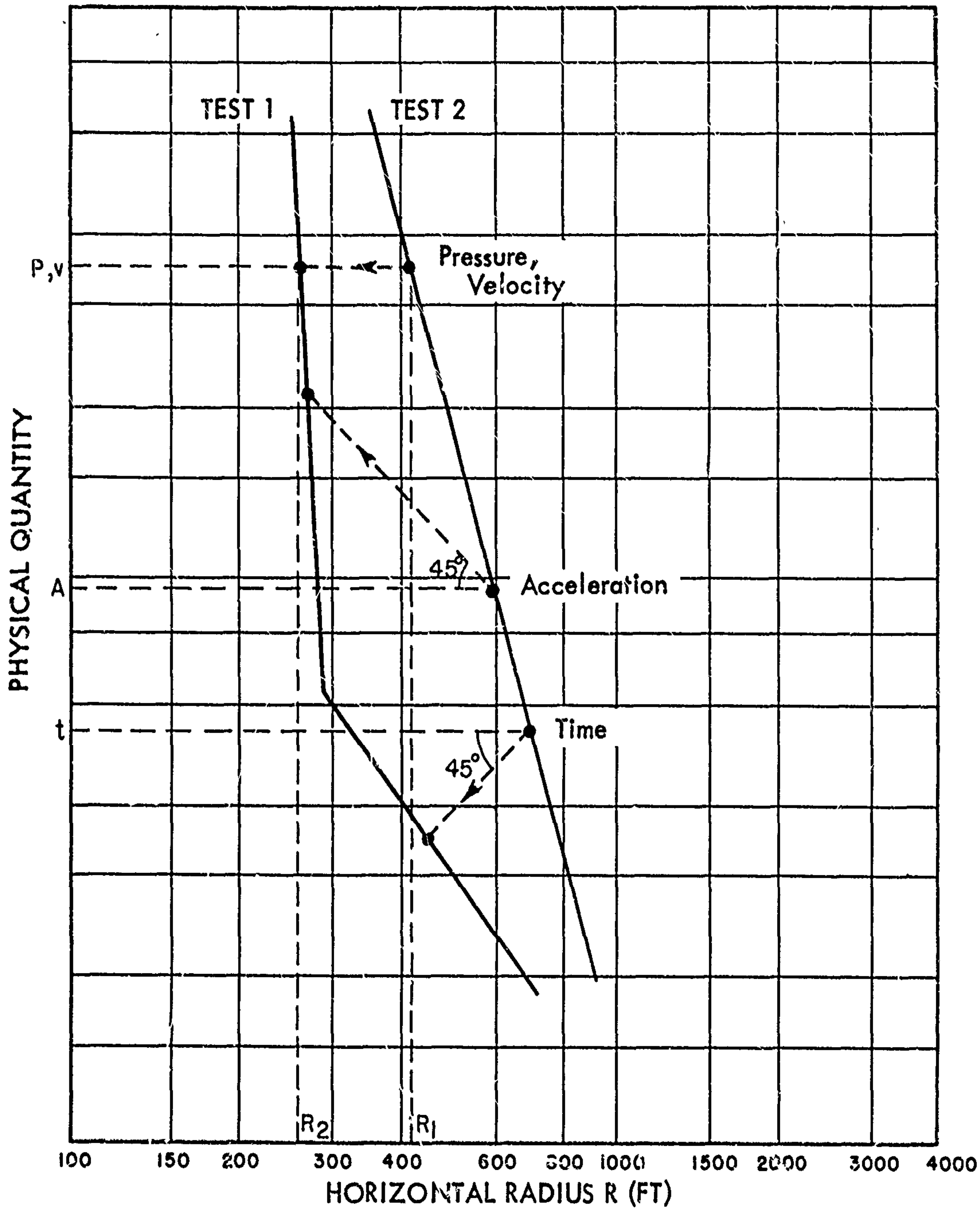

Fig. 5.15 A Graphical Method for Computing the Scale Factor between Two Explosion Tests when the Phenomenon Curves are not of the Same Form

the points appear to intermesh the best.

Using this graphical method on the curves in Figure 5.14, we can compute the energy equivalent for the underground nuclear test (first peak, horizontal acceleration) at any desired acceleration level. At the 0.60 G level (250 - 500 foot range), the equivalent is 0.02 KT of TNT, and at 0.20 G (600 - 900 foot range) the equivalent is 0.12 KT of TNT. At the 0.1 G level (1000 - 1250 foot range), where the nuclear test results seem to approach the predicted values most closely, the equivalent underground nuclear charge is about 0.33 KT of TNT.

The vertical component of the earth acceleration should be examined in a similar manner. Figures 4.5 and 4.6 show that the vertical transient acceleration records are in many ways similar to the horizontal records. The verticals show stronger air-blast induced effects and weaker first pulse amplitudes than the horizontals. The first pulse amplitudes and durations are plotted in Figure 5.16. This figure shows that the amplitude attenuation follows an inverse square law with a break in the attenuation curve from about 450 feet to 700 feet. This break is not inconsistent with the vertical acceleration results of the HE-1 and HE-2 tests of Project 1(9)-1.[1] On both these HE tests a similar break in the curve was observed at about 450 feet. As is pointed out in the Project 1(9)-1 report,[1] this result indicates that the effect is characteristic of the medium, rather than of the charge size. It is also postulated that the jog in the curve is due to an abrupt variation of seismic velocity with depth in the ground. The presence of a high velocity substratum would explain the effect adequately. The dotted curve in Figure 5.16 represents the air-blast pressure attenuation and is included for comparison.

Figure 5.17 presents the comparison between the nuclear test results (from Figure 5.16) and the predicted results. For values of R less than about 400 feet the experimental and predicted curves are quite close. In this region, the graphical method indicates that the equivalent underground nuclear energy release was about 0.75 KT of TNT.

Predictions were not made for the durations of the first pulse of acceleration because this quantity did not follow the model laws for the HE-1 and HE-2 tests.[1] The HE tests results could only give an idea of the limits to be expected on the nuclear test. As shown in the previous figures, the first pulse durations for the horizontal acceleration are about four times larger than those for the vertical acceleration. The significance of this result will be dealt with later in this section in connection with damage criteria.

It is quite possible that the "feed-back" effect referred to

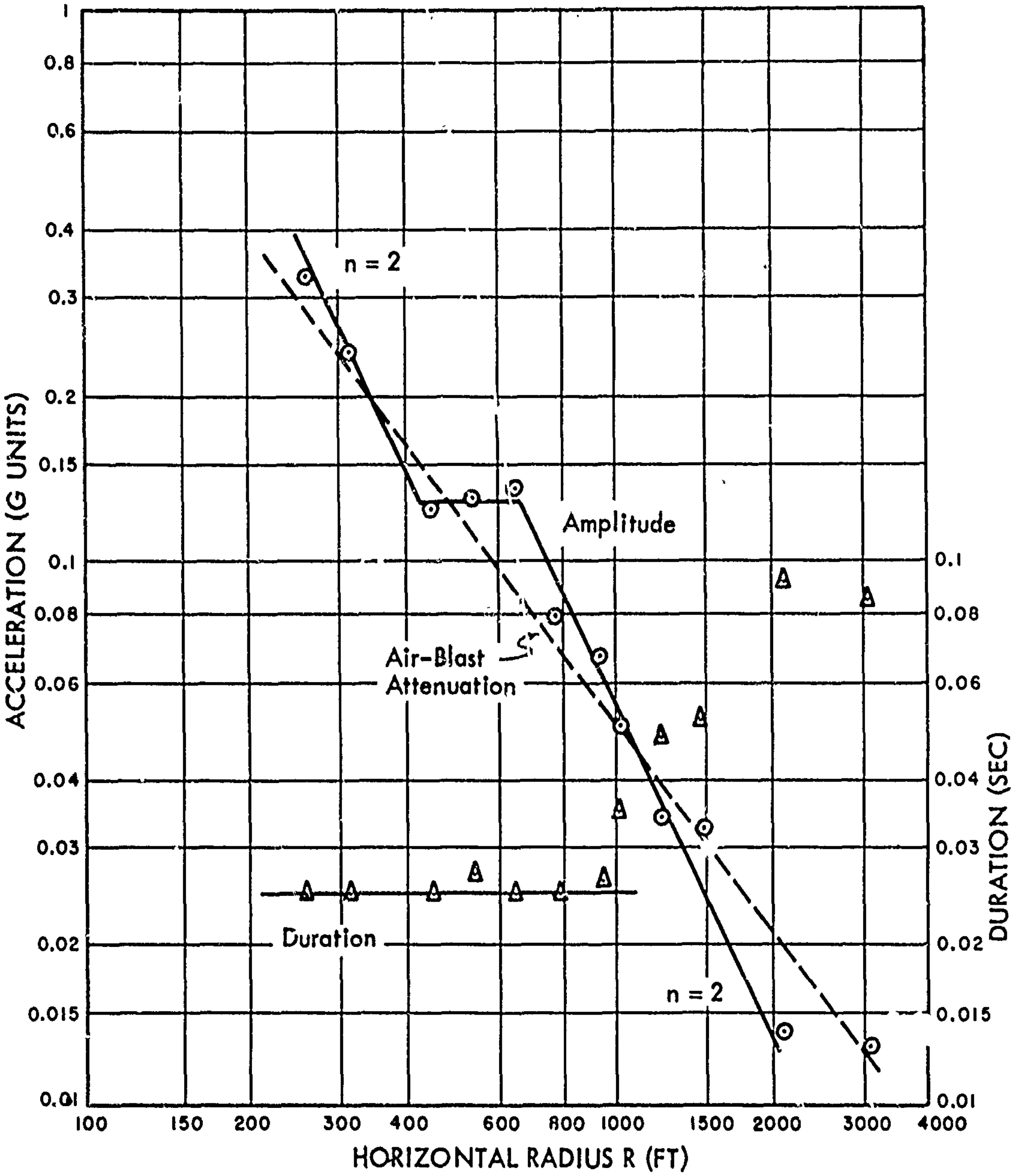

Fig. 5.16 Vertical Earth Acceleration, First Pulse Amplitude and Duration vs. Horizontal Radius for the Underground Test, Gage depth, 5 feet

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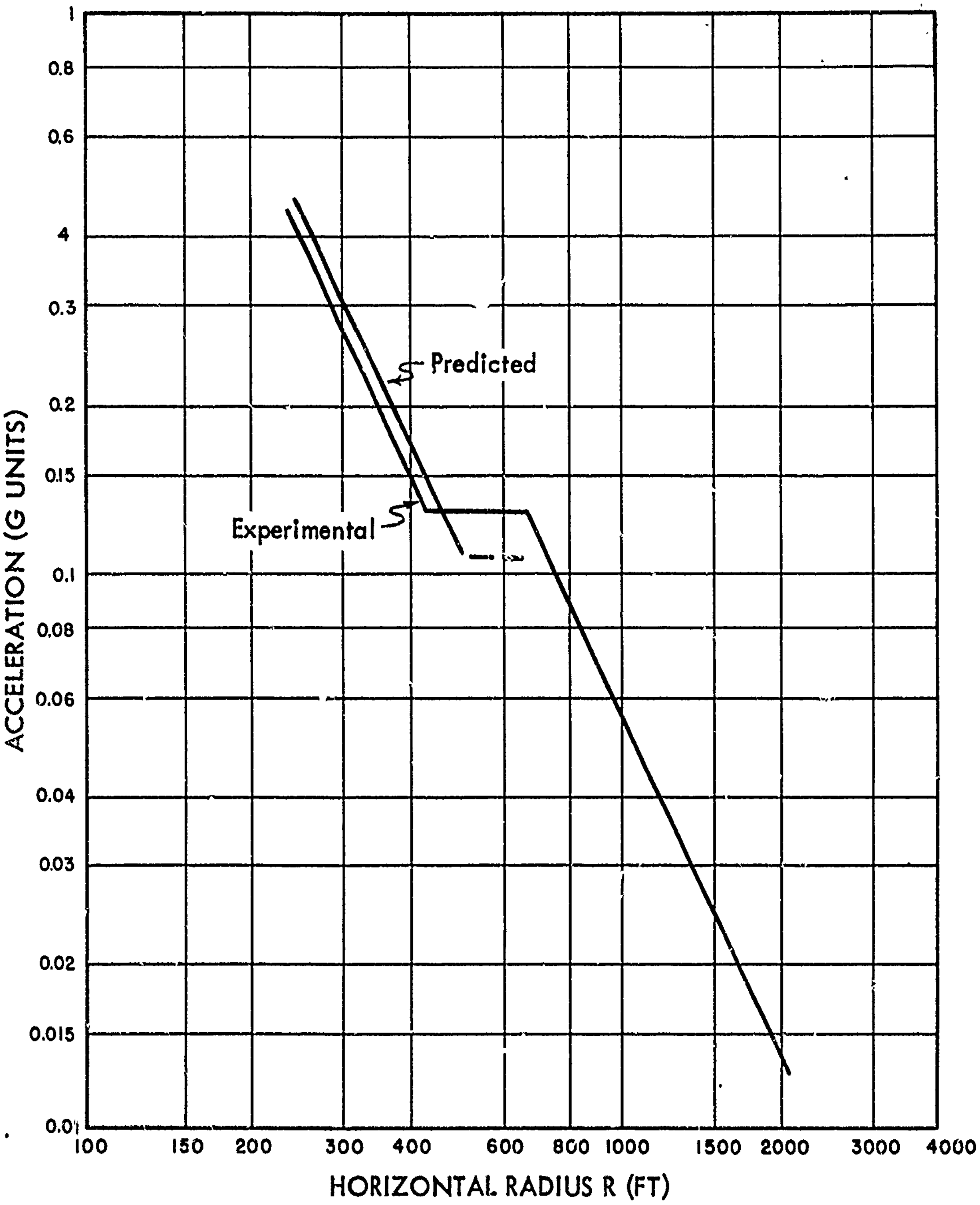

Fig. 5.17 Vertical Earth Acceleration, First Pulse Amplitude vs. Horizontal Radius for the Underground Test, with Curve Predicted for 1 KT of TNT. Gage depth 5 feet

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previously could be responsible for deviations from model law behavior in the case of earth phenomena. Under extreme conditions two different types of scaling, air and earth, may be encountered. In fact, if energy fed back from the air predominates, we should expect scaling appropriate to air to determine the earth phenomena.

These "feed-back" phenomena, if they truly exist, make data analysis quite complex. The air-blast pressure and the direct earth acceleration scale differently, and the two quantities obey different attenuation laws. In addition, one must consider that the air disturbance travels more slowly in air than it does when transmitted through the earth.

It would be worthwhile to attempt to separate the air-blast induced effects from the direct earth effects. Since the air-blast effect was more consistent and predominant on the vertical component of the earth acceleration, this separation was performed on the vertical records. The separation process involves a smoothing of the acceleration record in the region of the air disturbance (see dotted portion on the top curve of Figure 4.13). The smoothed curve is taken as the "true" earth acceleration and the high frequency acceleration superimposed upon it is called the air-blast "slap" acceleration. The wave form corresponding to one of these slaps is shown in Figure 5.18. The wave is characterized by a strong negative onset (corresponding to a downward acceleration) and a highly damped, high-frequency oscillation.

If all other factors are maintained to scale, it is evident that the induced "slap" acceleration becomes more dominant (with respect to amplitude) as the charge size is increased. This arises since, for scaled tests at the same λ range, air pressure is constant, while acceleration is inversely proportional to $W^{1/3}$.

Figure 5.19 shows the plot of the negative peak air-blast slap acceleration against horizontal radius. The curve drawn through the points represents the air-blast pressure attenuation shown in Figure 5.1 where $n = 1.25$. If the slap acceleration for the underground nuclear test is compared with that predicted from scaling the HE-1 and HE-2 tests, then one obtains the plot shown in Figure 5.20. The curve is the predicted slap amplitude on the basis of 1.0 KT equivalent energy release and the plotted points refer to the experimental results Close to the charge, out to a radius of about 500 feet, the nuclear test gave air-blast slap accelerations exceeding the predictions, undoubtedly because the blast pressures were greater in this region than for HE-2. However, at larger horizontal distances the empirical values fall off more rapidly with distance than do the predictions. This is illustrated by the fact that at the 7.0 G level the underground nuclear charge energy equivalent for the slap is about 4.0 KT of TNT,

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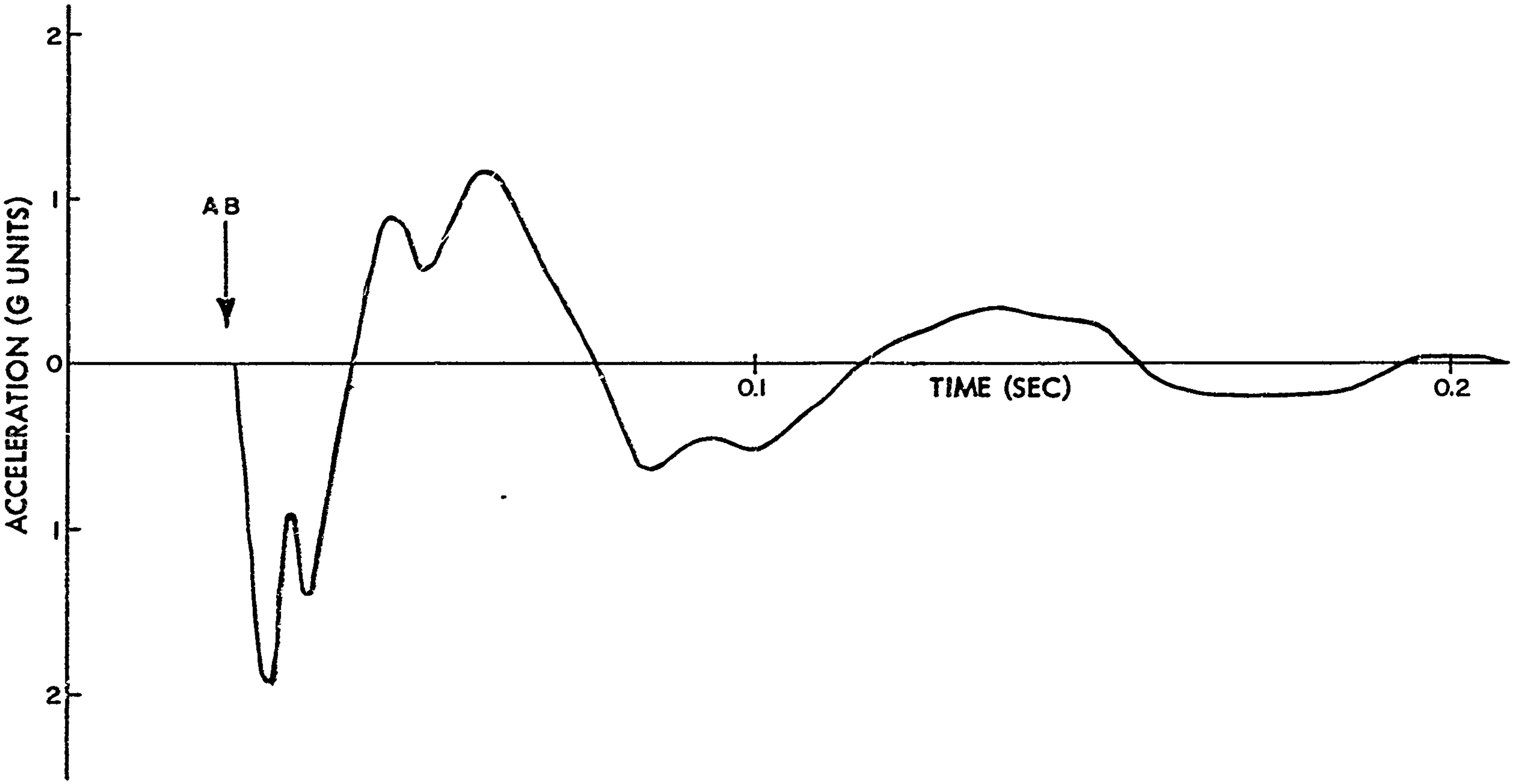

Fig. 5.18 Wave Form of Air Blast Slap in Vertical Acceleration for the Underground Test, R = 788 ft. Gage depth, 5 ft.

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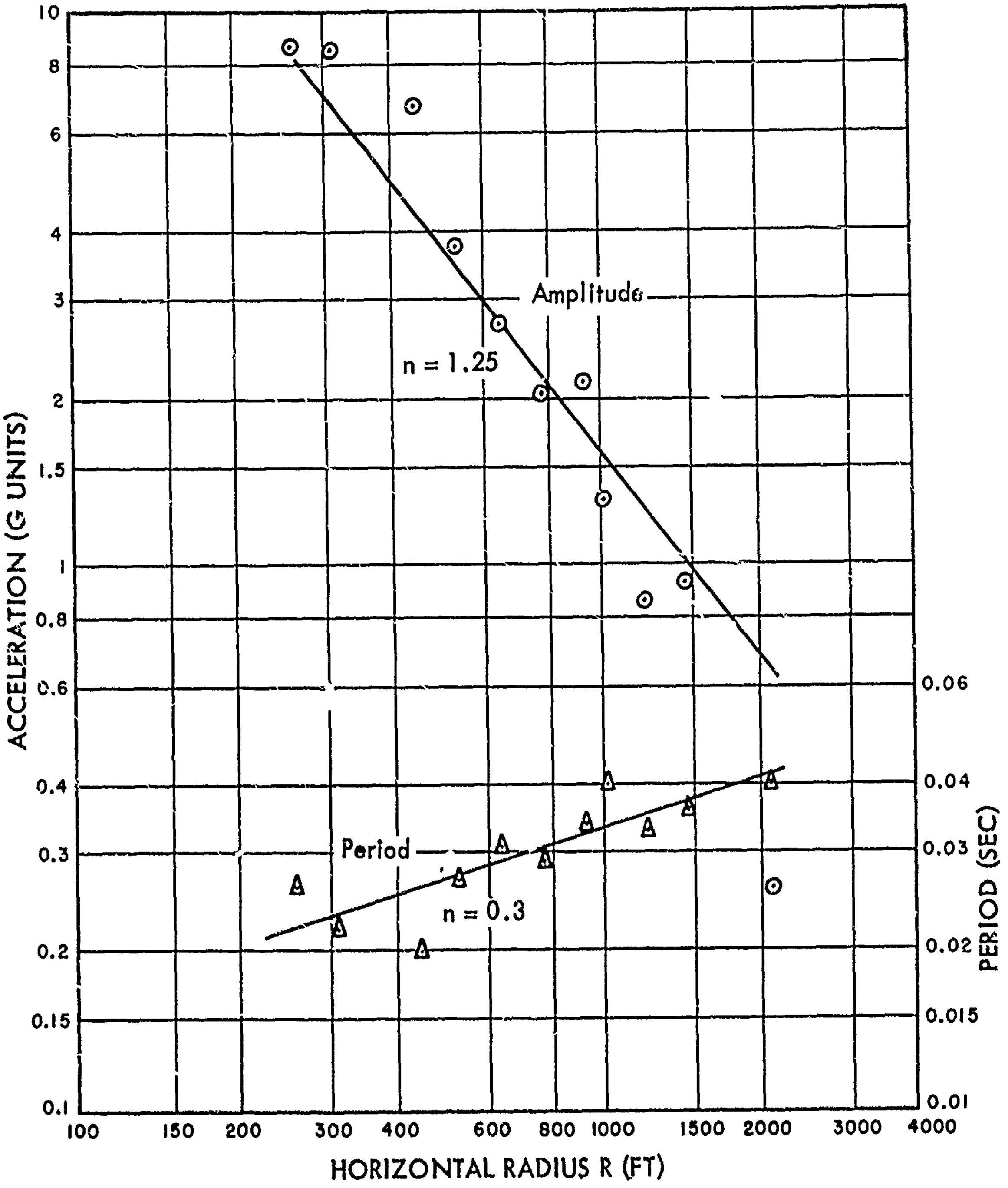

Fig. 5.19 Negative Peak in Vertical Earth Acceleration Due to Air Blast Slap. Amplitude and estimated period vs. horizontal radius for the underground test. Gage depth, 5 feet

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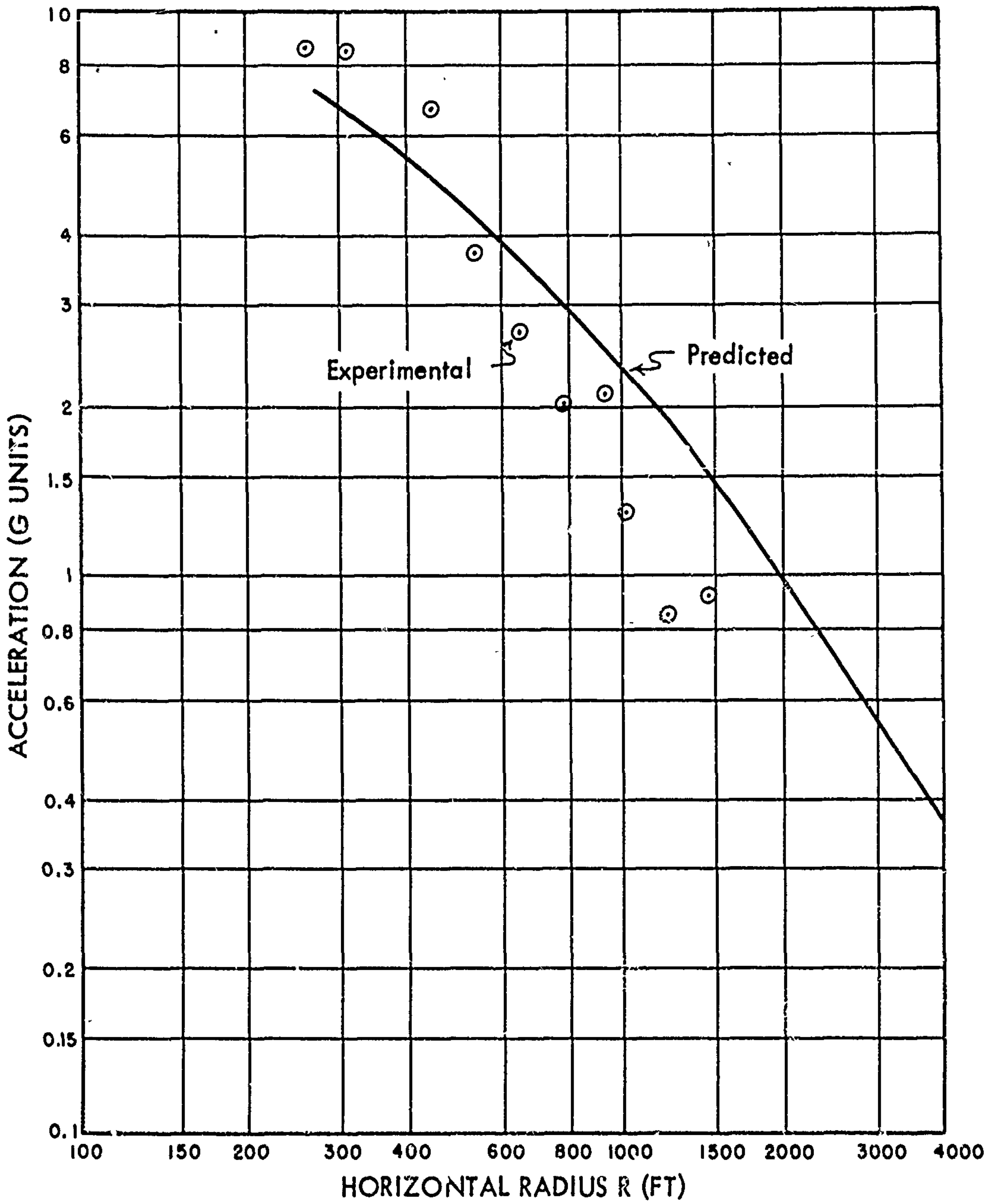

Fig. 5.20 Negative Peak in Vertical Earth Acceleration Due to Air Blast Slap. Amplitude vs. horizontal radius for the underground test, with curve predicted for 1 KT of TNT. The plotted points refer to underground test results. Gage depth, 5 feet

[redacted]

[redacted]

while at 1.0 G the equivalent is approximately 0.2 KT of TNT.

The acceleration measurements taken at depths greater than five feet were presented in Chapter 4 in the form of reductions of the traced records. The horizontal and vertical deep accelerations are shown in Figures 4.8 and 4.9. The records show that the general wave form and amplitudes are not altered appreciably as the gage is buried deeper. However, it is observed that the effect of the air blast is much reduced beyond the 34-foot depth. This reduction of the air-blast slap effect at the 68-foot gage is evident in both the horizontal and the vertical components of earth acceleration.

5.4 COMPARISONS WITH SCALED HE TESTS

By way of summarizing the comparisons between the underground nuclear test and the scaled HE tests, the earth acceleration records at two radial distances are presented showing the transient records from the HE-1, HE-2, and nuclear tests. The curves have been normalized in the sense that the time and acceleration coordinates have been scaled according to the model laws. This means that if the three tests obeyed the model requirements in every respect the three records at a single scaled radius should appear exactly alike. For uniformity, the nuclear charge has been assumed to be an equivalent of 1.0 KT of TNT. Therefore the scale factors are HE-1 : HE-2 : nuclear as 1 : 2.5 : 9.2. These normalized records are shown in Figures 5.21 and 5.22 (horizontal components) and Figures 5.23 and 5.24 (vertical components).

Looking at the horizontal components, it is noted that the air-blast slap acceleration is insignificant on the HE-1 record, while it reaches huge proportions on the underground test record. The $\lambda = 2.08$ records for HE-1 and HE-2 show very similar wave forms (excluding the air-blast slap on HE-2). However, the nuclear test record shows a time "squeeze" of this wave form, bringing out how poorly the time quantity followed the $W^{1/3}$ model law in the nuclear test. At $\lambda = 5.2$ much the same analysis applies. In addition, the first pulse amplitudes show a marked deviation from scaling and HE-1 exhibits a large second positive pulse that is not measured on the other tests.

The vertical accelerations presented in Figures 5.23 and 5.24 show that the air-blast effects grow far out of proportion to the charge scaling factors when the nuclear test results are considered. Here again we find that the time quantity scales poorly from HE-2 to the nuclear test and it becomes increasingly more difficult to separate the "true" earth effects from the air-blast induced effects.

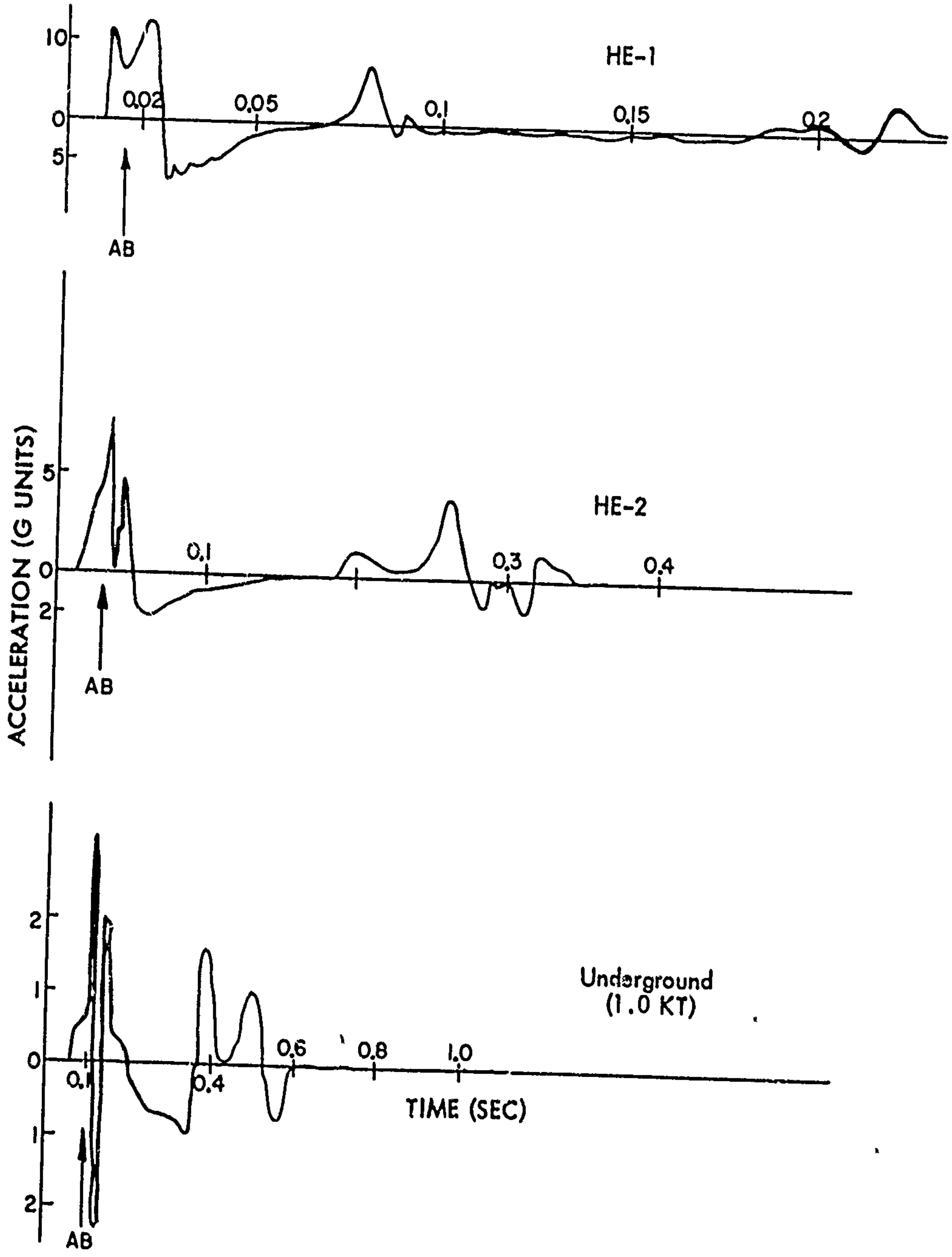

Fig. 5.21 Horizontal Earth Acceleration vs. Time at $\lambda = 2.08$ for HE-1, HE-2, and Underground Tests. Note that the coordinates have been normalized assuming model law conditions, Gage depth, 5 feet

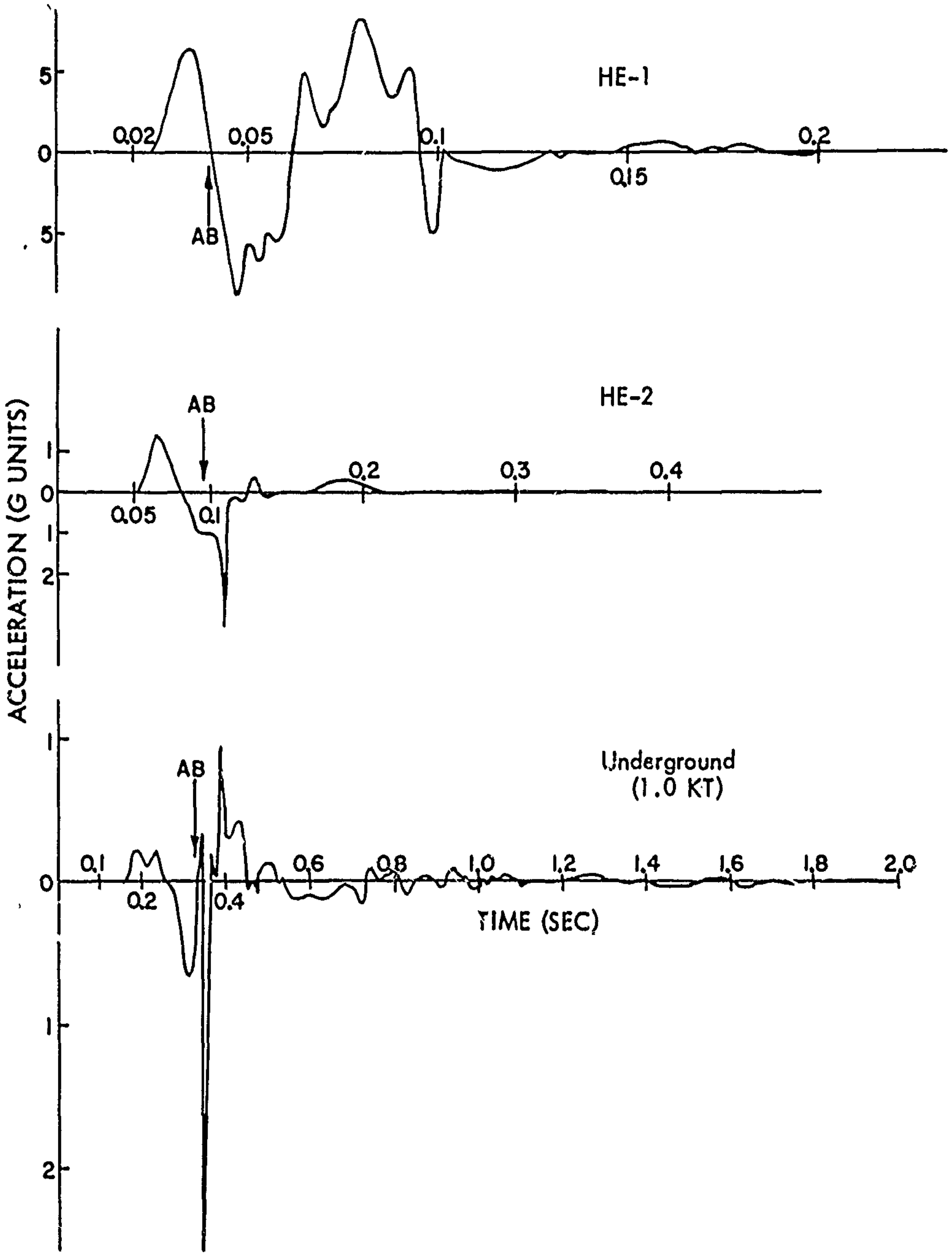

Fig. 5.22 Horizontal Earth Acceleration vs. Time at $\lambda = 5.2$ for HE-1, HE-2, and Underground Tests. Note that the coordinates have been normalized assuming model law conditions. Gage depth, 5 feet

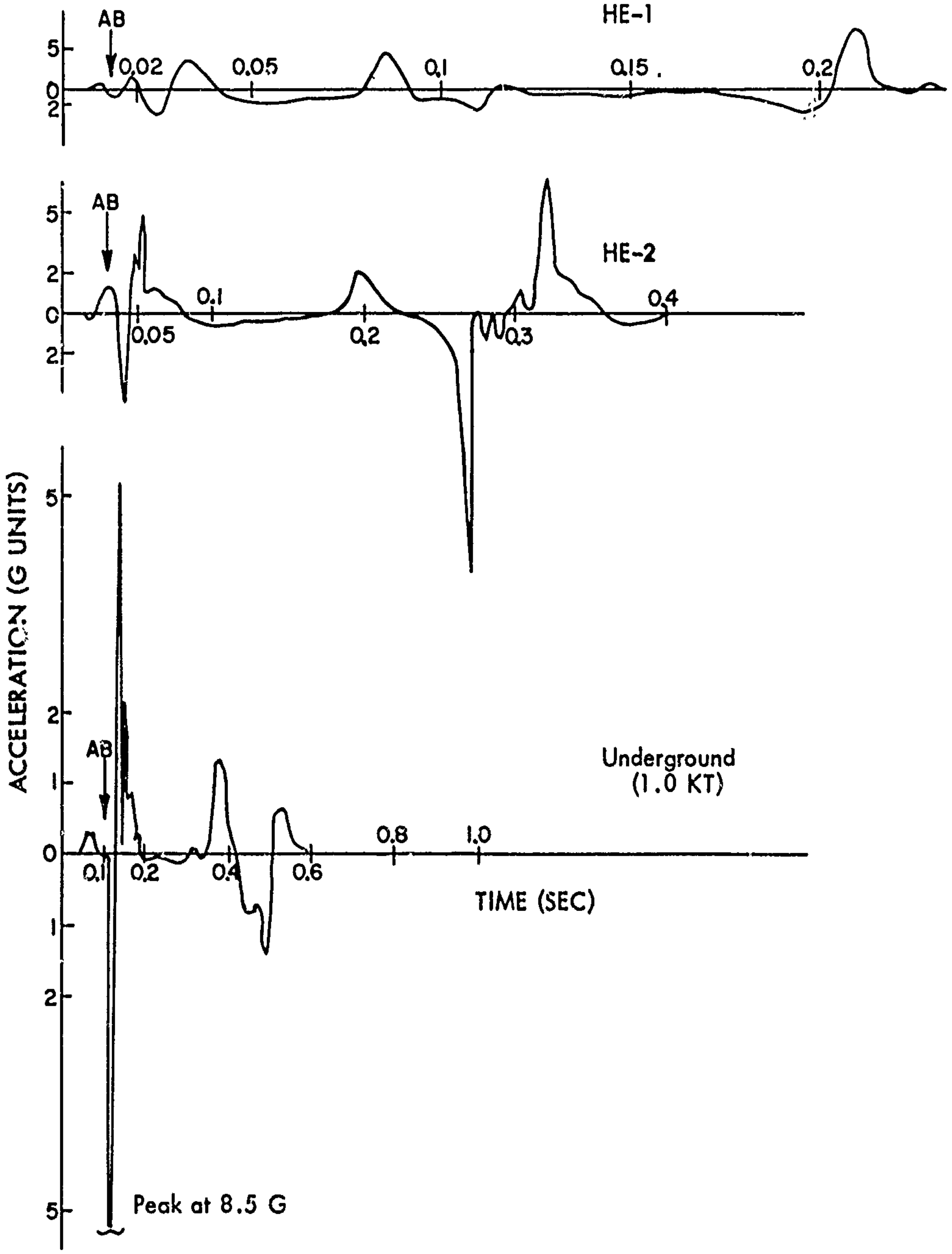

Fig. 5.23 Vertical Earth Acceleration vs. Time at λ = 12.08 for HE-1, HE-2, and Underground Tests. Note that the coordinates have been normalized assuming model law conditions. Gage depth, 5 feet

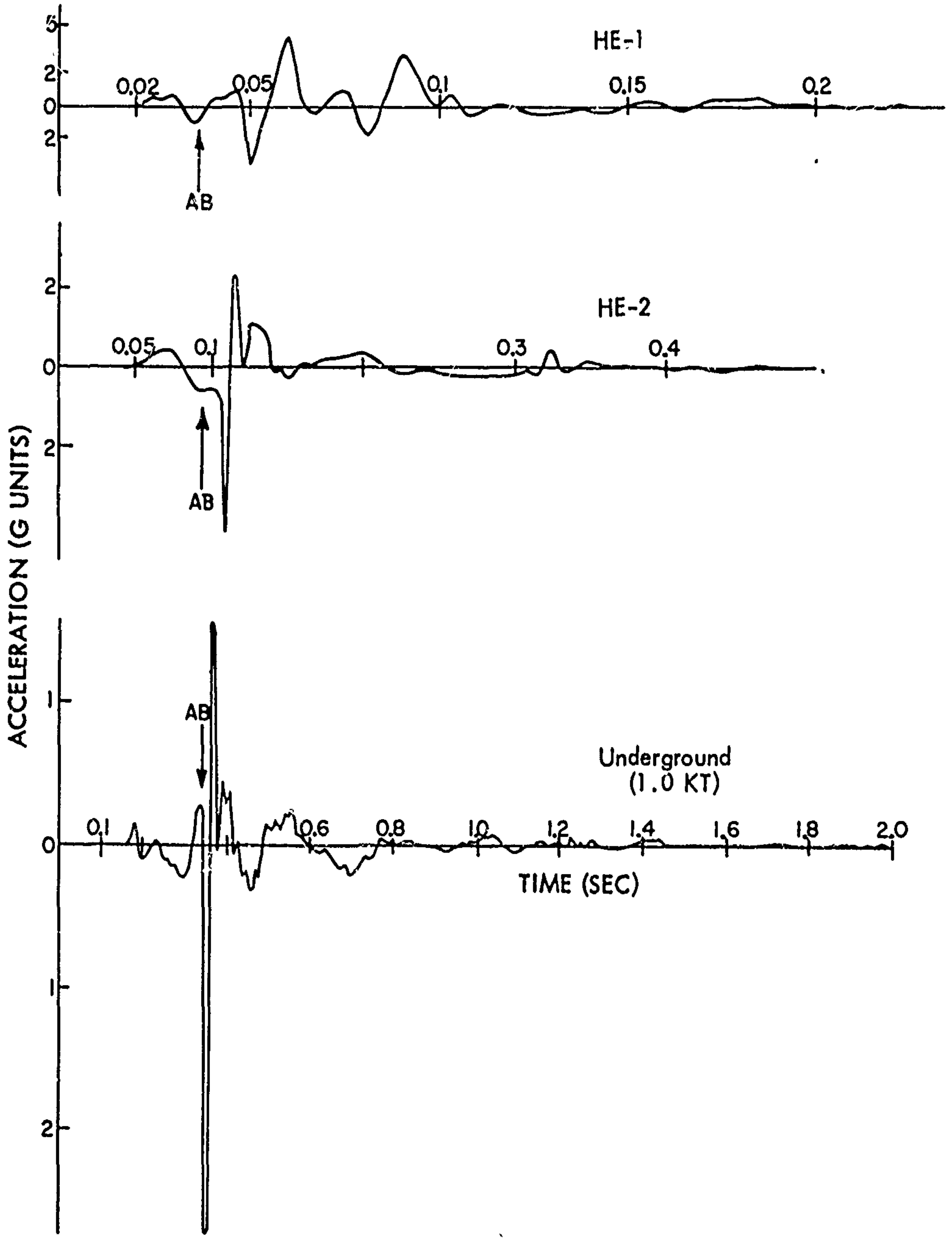

Fig. 5.24 Vertical Earth Acceleration vs. Time at $\lambda = 5.2$ for HE-1, HE-2, and Underground Tests. Note that the coordinates have been normalized assuming model law conditions. Gage depth, 5 feet

Figure 5.25 presents the time of first arrival of the horizontal earth acceleration plotted against horizontal radius for the Project 1(9)a underground nuclear explosion test. From this curve it is possible to compute the average seismic velocity for the test medium, where it is recognized that the seismic velocity varies with depth. The velocity turns out to be 3730 ft/sec. This result must be compared with the 3500 ft/sec and 3400 ft/sec obtained for HE-1 and HE-2 respectively. A discontinuity in the curve on Figure 5.25 near ground zero is not unlike the result obtained in the JANGLE HE tests. It is thought that this break indicates some anomaly in the subsurface geology.

5.5 DAMAGE

The damage to a surface structure whose foundation is well coupled to the earth is more or less proportional to the deformation of the structure. The choice of the earth motion phenomena most closely correlated to such damage depends essentially upon the ratio of the characteristic period of the earth motion to that of a typical structure being attacked. For small charges this ratio is much less than unity, and a simple analysis indicates that earth displacement is the principal factor influencing structure deformation. As this ratio approaches unity, earth particle velocity becomes the principal factor determining structure deformation. Furthermore, as the ratio increases to values much larger than unity, the earth acceleration more nearly governs damage.

Results of damage obtained from the surface structure tests at the Dugway Proving Ground[4] seemed to indicate that satisfactory damage criteria were (1) the maximum peak-to-peak particle velocity and (2) the period associated with this maximum velocity oscillation. In addition, it was found that the horizontal component of the earth motion was the most significant in damage analysis, since structures are least strong in the horizontal direction. The Dugway explosion tests gave rise to longer periods in earth than was the case in the nuclear test. This fact, in the light of the analysis above, would make the earth displacement data of the underground nuclear test more significant from a damage standpoint than it was at Dugway. However, on the nuclear test the largest acceleration was almost always caused by the air-blast slap passing over the gage. This slap acceleration has such a short period that the structure deformation would be governed by the resulting earth displacement. Since the earth displacement is roughly proportional to the product of peak acceleration and the period squared, it is evident that this direct air-blast effect contributes little to structure damage, because of the short period of the air-blast slap.

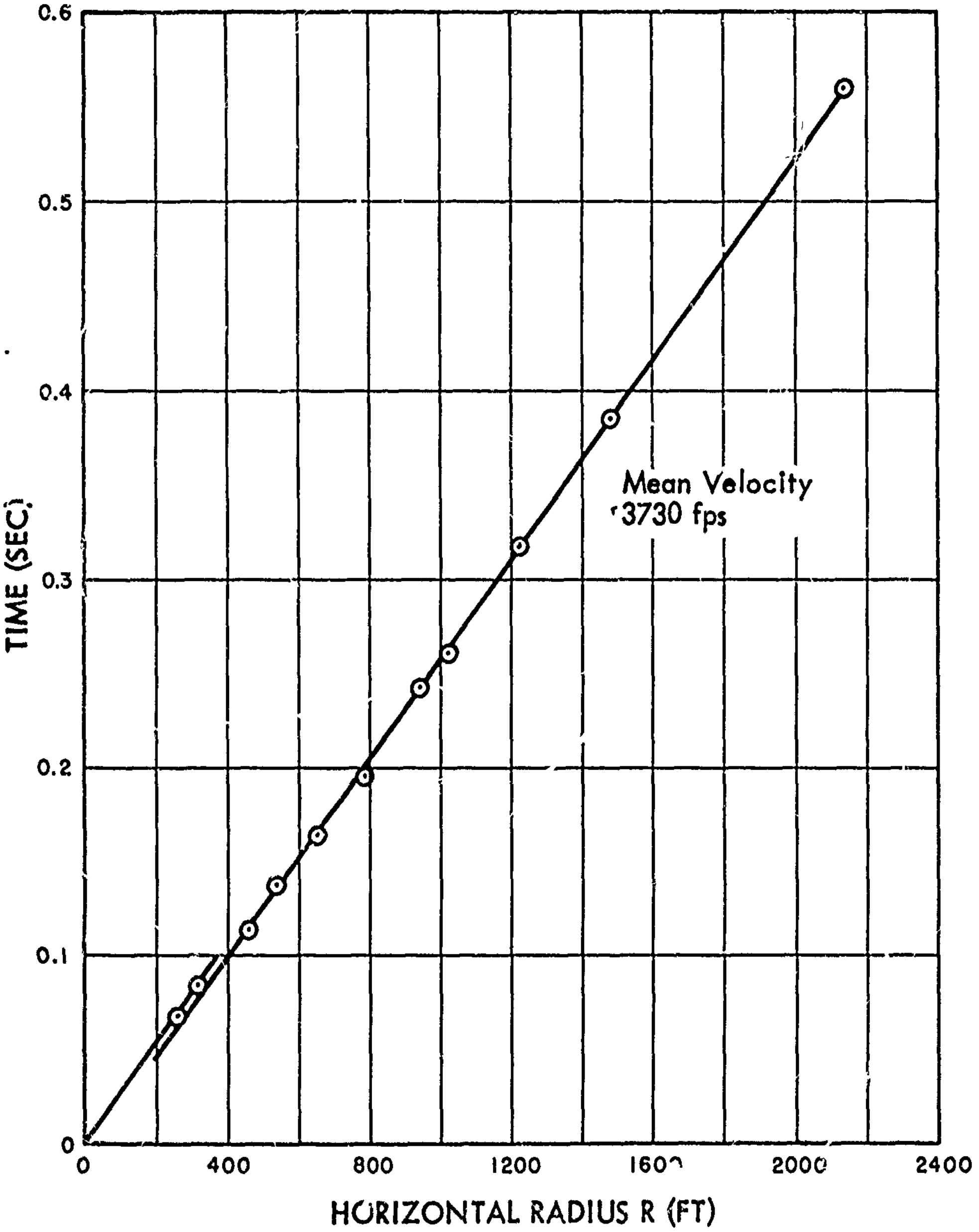

Fig. 5.25 Horizontal Earth Acceleration, Time of First Arrival vs. Horizontal Radius for the Underground Test

Since the horizontal particle velocity is of interest from a damage standpoint, it was decided that the horizontal acceleration records from the nuclear test should be integrated, if only roughly. Some of these integration curves are presented in Figure 4.7, where the label AB designates the arrival time of the air-blast pressure at the gage station. Figure 4.13 illustrates the data that were taken from these integration curves. In Figure 5.26 are shown plots of the average amplitude of the maximum velocity wave and the period associated with this wave. With the exception of two points, the amplitude data follow the same decay with horizontal radius as that for air pressure. The period which characterizes the maximum velcoity wave is reasonably constant at 0.33 second for measurements out to about 800 feet. For larger distances the period increases abruptly.

Because the horizontal velocity data from the HE-1 and HE-2 tests[1] did not follow the model law, it was not possible to make predictions for this quantity for the nuclear test. However, it proves interesting to consider the characteristic periods of the velocity phenomenon in more detail. Figure 5.27 shows this period (mean) plotted on semi-log paper where the abscissa is the scale of the explosive charge. The HE-2 test is used as a reference with its scale equal to unity and the underground nuclear charge is assumed to be equivalent to 1.0 KT. The mean deviations of the velocity period are indicated for each plotted point on this graph. When the straight line drawn through the points is extrapolated to the scale factor 10 (corresponding to a 20 KT operational weapon), the period corresponds to a value between 0.4 and 0.5 second. This period is in the range of the natural period of many surface structures; therefore this analysis appears to lead to a significant result. That is, in the type of medium encountered at the Nevada Test Site, the horizontal particle velocity is the measured quantity which best determines structural damage.

When the results obtained at the Nevada site are compared with those from the Dugway dry clay tests, some significant differences are observed. Figure 5.28 shows representative horizontal acceleration records from the Dugway Round 315 test, the HE-2 test at Nevada, and the underground nuclear test, also at Nevada. The Round 315 and the HE-2 test charges both used 40,000 pounds of TNT; however, the Dugway charge was buried deeper than the HE-2 charge, while the HE-2 charge was at about the same scaled depth, λ_c, as the underground nuclear test. The Project 1(9)-1 report shows that the effect of this change in λ_c (0.5 to 0.150) upon the periods of the low-frequency earth acceleration is small. This means that differences in durations of acceleration between Dugway Round 315 and HE-2 are due mainly to the different soil characteristics at the two sites.

Reference to Figure 5.28 shows that the first pulse duration at

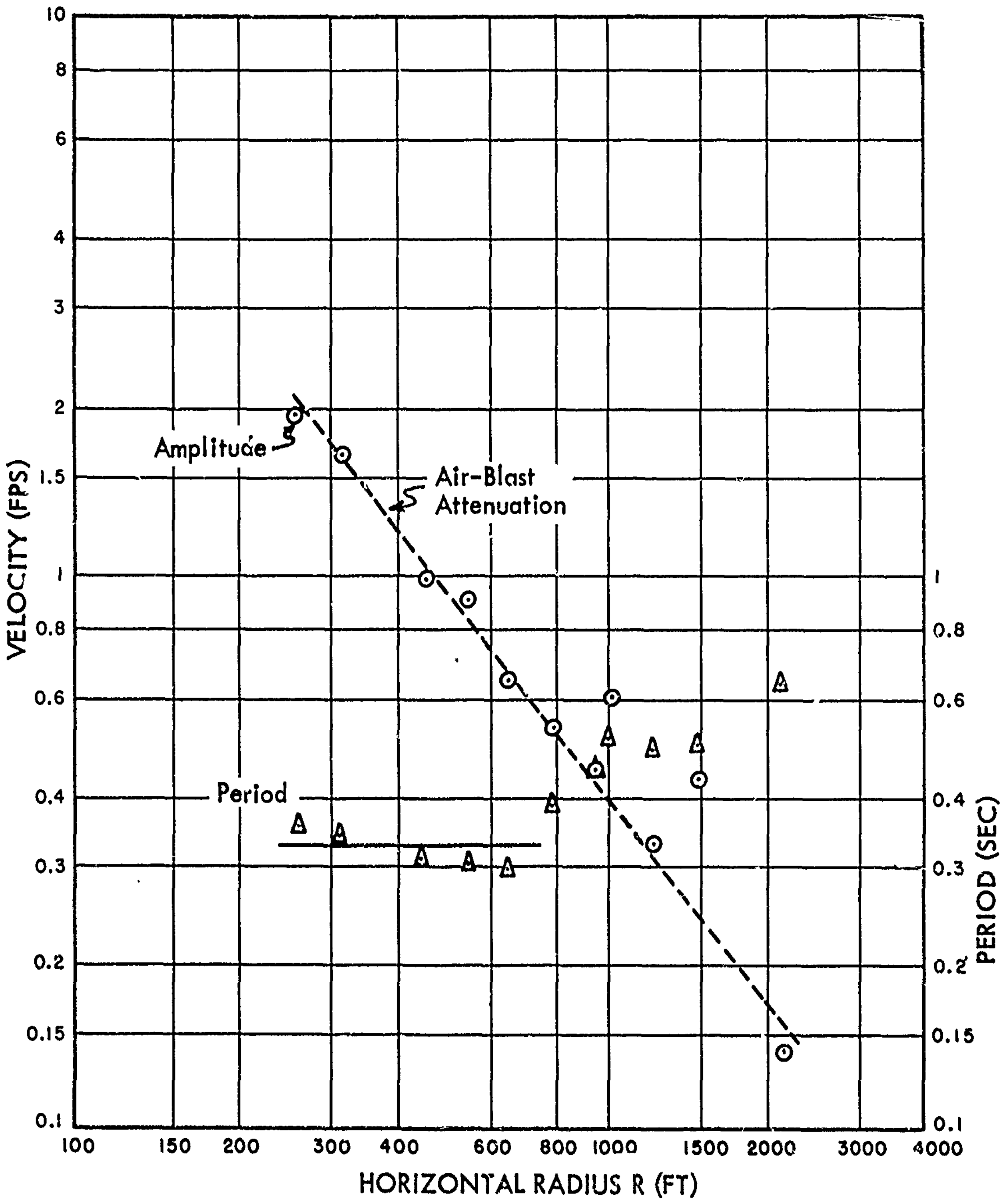

Fig. 5.26 Horizontal Earth Velocity, Maximum Peak-to-Peak Amplitude (Average) and Period vs. Horizontal Radius for the Underground Test. Dotted line indicates air blast attenuation. Gage depth, 5 feet

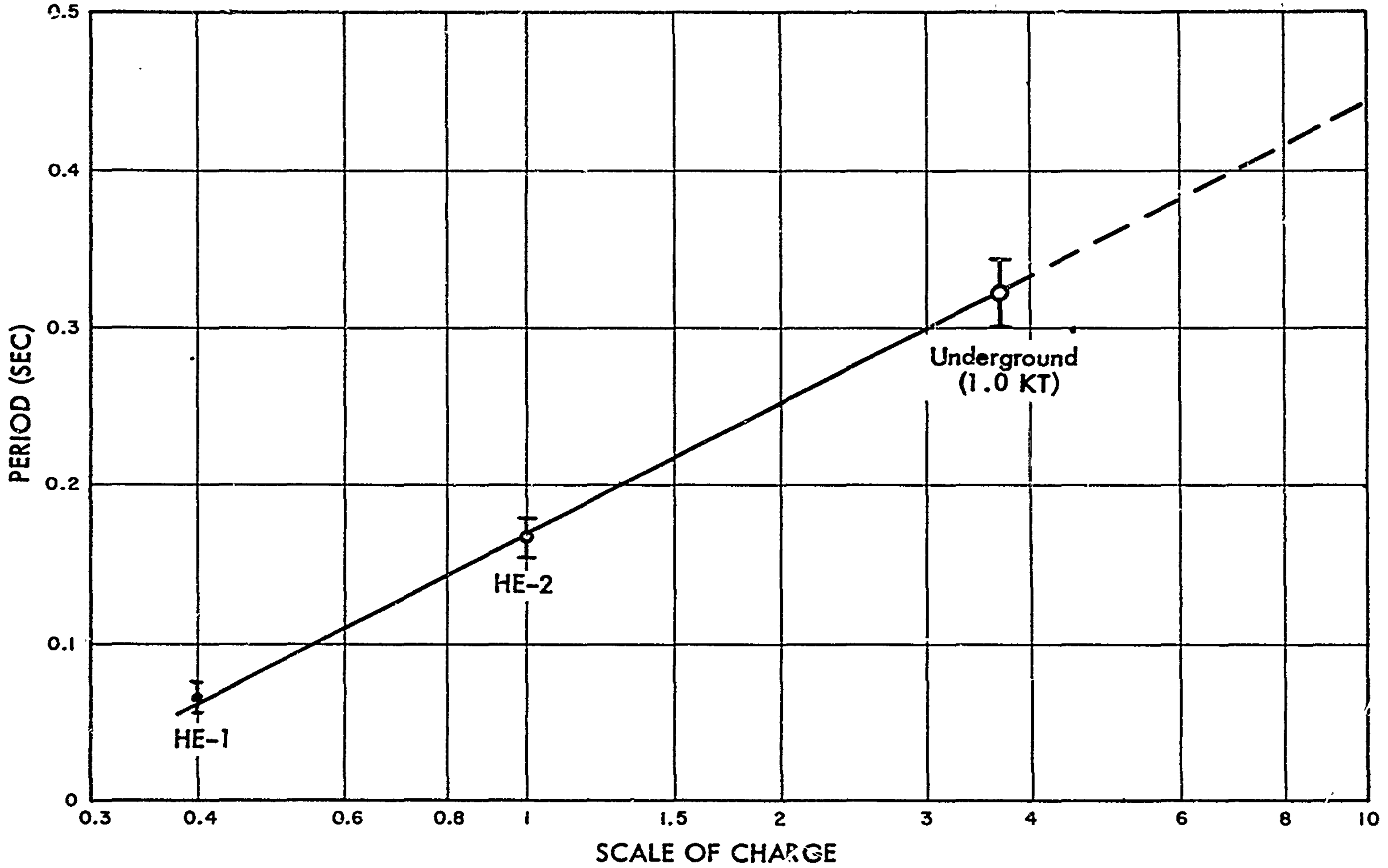

Fig. 5.27 Horizontal Earth Velocity, Period of Maximum Velocity Wave vs. Scale of Charge for HE-1, HE-2, and the Underground Tests (Scale of HE-2 taken as unity). Gage depth, 5 feet

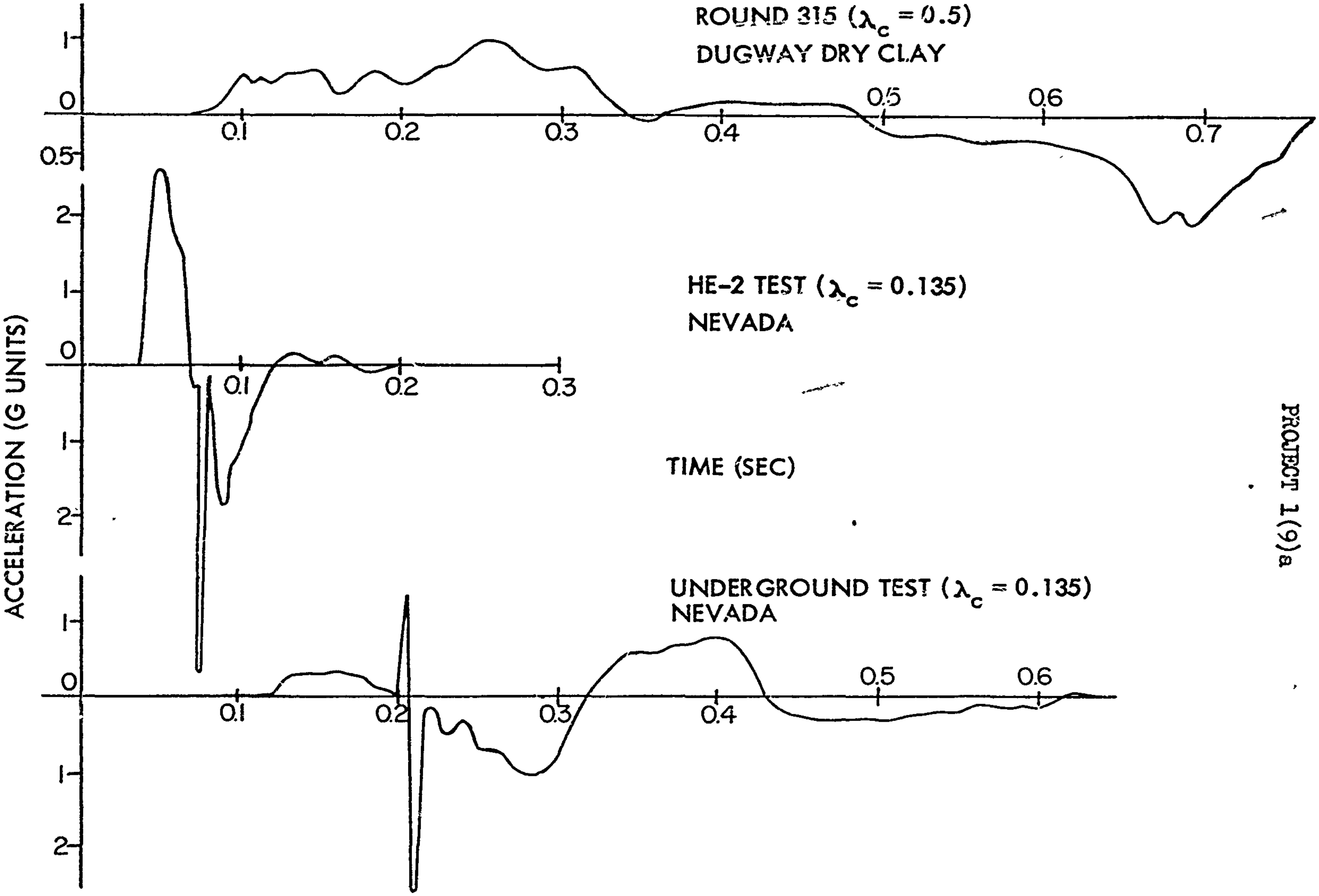

Fig. 5.28 Horizontal Earth Acceleration, Comparison between Dugway and Nevada Tests, $\lambda = 3.5$. Gage depth, 5 feet

Dugway is almost ten times longer than that at Nevada (HE-2). As would be expected on the basis of charge size, the durations corresponding to the nuclear test are longer than those observed on the HE-2 test, even though the $W^{1/3}$ time scaling law was not satisfied. However, the nuclear test durations are still shorter than those measured in the Dugway dry clay. When these acceleration records are integrated to obtain particle velocity and displacement, these differences in durations become very significant.

The Project 1(9)-1 report[1] includes detailed comparisons between Dugway and the scaled HE tests. The general conclusions are that the first pulse velocities are approximately the same at the two sites, which means that the displacements depend directly on the durations of the velocity pulse. It was found[1] that the permanent displacements (for identical tests) were ten to fifty times larger in Dugway dry clay than in Nevada desert soil (HE tests).

Although the permanent displacement data for the underground nuclear test are not yet available, the acceleration record comparisons in Figure 5.28 indicate that the displacements for the nuclear shot were less than those measured at Dugway for a considerably smaller charge (1.0 scale was 0.16 KT of TNT on Round 318). This would indicate that at equal distances from ground zero the damage to surface structures due to earth motion would have been less for the Nevada underground nuclear test than it was for the much smaller Dugway Round 318. Of course, to make statements concerning final damage, factors such as throwout and air-blast pressure would have to be considered.

The reader is reminded that the soil type may have a very marked effect on the ground motions produced by an underground explosion.[3,10, 11,12] The soil type can change the time scale of the phenomena by large amounts, yielding damage differences which would not be apparent from a casual study of peak accelerations produced. It appears safe to conclude that the 1.0 KT underground explosion would have had far greater damage effects on structures if it had been fired at the Dugway dry clay site. It is not safe to judge the effects of underground nuclear explosions by the results of the single test reported here, since there is insufficient information to estimate the effect of terrain on the characteristics of the various output phenomena which cause the principal damage to structures.

These are conclusions drawn from a rough and incomplete analysis of the earth motion data taken for Project 1(9)a. More precise integrations of the earth acceleration records are planned for the future in order to obtain accurate velocity and displacement data at all gage stations. With these data, it should be possible to make a more detailed analysis of damage to surface structures.

5.6 EARTH PRESSURE

The transient records from the 10-foot earth pressure gages are presented in Figure 4.10 in Chapter 4. All of these records exhibit the same general characteristics, a small first positive pulse followed by a relatively large second positive pulse. In every case, the large pulse seems to occur shortly after the arrival of the air-blast pressure at the gage location (designated by AB on the records). This would indicate that the large pulse is caused by the air-blast pressure. However, this pulse does not appear to decay appreciably with increasing horizontal radii out to 800 feet.

A plot of the first (small) pulse amplitude and duration is shown in Figure 5.29. The curve drawn through the points has the same decay as the air-blast pressure, that is, the slope is 1.25. However, it is not believed that this first earth pressure pulse is caused by the air blast. The points corresponding to pulse duration are scattered so much that no sensible curve could be drawn. No predictions were made for the earth pressure in the Project 1(9)-1 report, because the phenomenon was quite erratic and did not obey the model laws for the HE tests.

Transient records from the deeper earth pressure gages are shown in Figures 4.11 and 4.12, where the first figure gives results obtained at the closest station to ground zero. For this close station, the effect of depth upon the general wave form was slight. As the depth of measurement was increased, the amplitudes also increased. It is noted that the maximum positive pressure recorded at the 34-foot deep gage was about twice the same pressure measured at the 10-foot gage. The records at the 378-foot station show slightly different depth effects. The wave form shows a tendency to change for the 34-foot depth and then a marked difference is observed in the form of the pressure wave at 64 feet. At the 64-foot depth, there appears to be a build-up of pressure after the more shallow pressures have almost disappeared. Unlike the observations at the closer-in station, these pressure measurements show no marked build-up of amplitude with increasing depth.

As has been stated in previous reports,[1,5] the significance and operational techniques concerning earth pressure measurements are rather vague. For this reason, no attempt is made in this report to use the earth pressure data for predicting damage to underground structures.

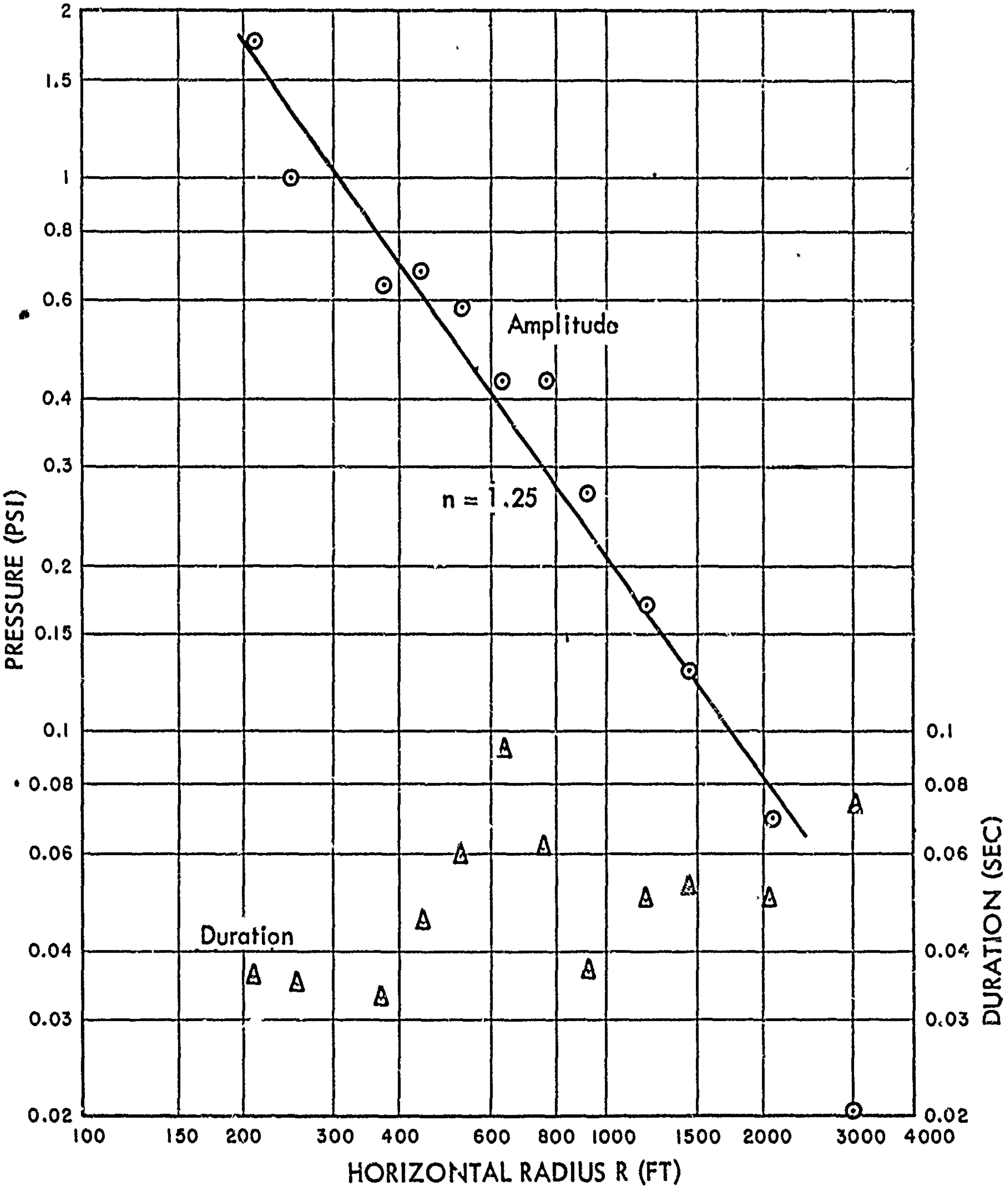

Fig. 5.29 Earth Pressure, First Pulse Amplitude and Duration vs. Horizontal Radius for the Underground Test. Gage depth 10 feet.

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CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6. AIR PRESSURE

Considered as a function of both distance and time, the air pressure phenomenon followed the conventional model laws[9] quite closely on the scaled HE-1 and HE-2 tests. The air pressure vs. time measurements for the underground nuclear test could be scaled in a consistent manner to those of HE-2. As a consequence, it is possible to draw the following conclusions concerning air blast with reasonable certainty.

1. The air pressure from the underground nuclear test was equivalent to that from 0.85 KT of TNT at the same burial depth at the JANGLE test site. Thus the equivalent TNT yield (for air pressure) was 70 per cent of the radiochemical yield (1.2 KT).

2. Scaling to a 23 KT weapon at a depth of 46 feet appears justified. At sea level a peak overpressure of 10 psi should occur at a distance of about 2100 feet, with a positive phase duration of about 0.6 second. At sea level the peak pressure vs. distance should follow the relation:

$$P = \frac{150,000}{R^{1.25}} \qquad (6.1)$$

where the units are psi and feet

3. It is expected that air blast will be affected by the type of soil, but the influence of soil type should decrease as the scaled depth of burial decreases.

Two recommendations are made.

1. In future underground tests, both HE and nuclear, the air blast phenomenon should be measured. This is particularly true for shallow scaled depths of burial, where air blast can be a major cause of damage to surface targets.

2. More information is needed on the effects of soil type and depth of burial. Because of excellent scaling with HE, relatively small charges may be used in scaled experiments.

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6.2 EARTH ACCELERATION

Earth acceleration as a complete phenomenon exhibited many departures from the conventional model laws. This could be attributed to several possible causes: (a) departure from conventional model laws due to gravity effects, requiring a different but analytically consistent set of model laws; (b) the inability to conduct truly scaled experiments in a uniform test medium or in a test medium where the variations are scaled; (c) the effects of air-pressure induced phenomena, involving different scaling factors; (d) other unknown causes. As a consequence, relatively few scaling conclusions are presented in this report.

1. The earth acceleration measurements show a combination of direct and air-pressure induced effects. The air pressure produces a local effect by its action on the ground surface directly above the gage location. There is an additional distributed air-coupled effect due to the earth transmission of the effects of the air pressure acting on the ground surface at distances remote from the gage location. The direct effects are defined as those similar to what would be produced if the charge were buried so deeply that no significant air blast would be produced. The first of these three effects can be readily separated from the acceleration gage records for large charges. No suitable technique has been developed for differentiating between the latter two effects.

2. The local air-pressure induced acceleration (slap) appears as a damped wave train of relatively high frequency as compared to the other frequency components of the earth acceleration. This frequency should become a function only of the soil type and the gage depth for explosive yields large enough so that the positive phase duration for air pressure is long compared to the natural period of vertically compressed earth.

3. For large charges the slap acceleration will produce the maximum peak amplitudes, and these peaks will become more dominant in the earth acceleration records as the charge size is increased, except for very great gage depths. The slap is more evident and consistent in the vertical component of earth acceleration. For large charges the peak vertical slap amplitude is determined by the peak air pressure above the gage location. The ratio was 0.25 for the underground nuclear test and 0.3 for HE-1 and HE-2, in G units per psi for a gage depth of five feet.

4. The slap acceleration is attenuated with depth. The vertical component at a depth of five feet is about ten times greater than at a depth of 68 feet.

5. No technique has been developed for separating the direct earth effects from the distributed air-pressure induced effects, since they seem to have somewhat similar wave forms. A simple examination of the conventional model laws demonstrates that the relative importance of the two could be a function of the charge size for scaled experiments, with the air-pressure effects becoming more significant for large charges. This may explain, in part, the apparent departure of the earth acceleration phenomena from the accepted model laws.

Since there are pronounced differences between the nuclear test earth acceleration wave forms and those recorded for the scaled HE experiments, it is difficult to obtain consistent tabular data for direct scale comparisons. It would be improper to attempt scale comparisons between the HE tests and the underground nuclear test by the comparison of non-corresponding parts of the acceleration records. As a consequence, particular attention has been paid to the first acceleration pulse, which may give the most representative indication of the direct earth effects. Because of possible importance with respect to military effects, some attention has been paid to the maximum earth acceleration defined as the maximum peak-to-peak difference between successive pulses, along with the duration of the corresponding complete cycle, after the slap acceleration has been separated.

The following conclusions concern the earth acceleration after the local air-pressure induced effect (slap) has been separated.

6. In general the amplitude of the first peak of earth acceleration showed no consistent scale relationship to the scaled HE-1 and HE-2 tests. Whereas for the HE tests the first pulse was generally the maximum pulse, for the underground nuclear test following acceleration pulses were frequently considerably greater than the first pulse.

7. The maximum peak-to-peak horizontal earth acceleration for distances greater than 500 feet followed the approximate relation:

$$ {}_{pp}A_H = \frac{63,000}{R^{1.7}} \qquad (6.2) $$

for R in feet and A_H in G units (peak-to-peak). Two stations closer to the charge (310 and 260 feet) gave values approximately the same as for 500 feet. Direct application of the conventional model laws[9] yields a similar expression of

$$_{pp}A_H = \frac{130,000}{R^{1.7}} \qquad (6.3)$$

for a 23 KT weapon at a scaled depth of 46 feet at the JANGLE site, since the scaling between HE-1 and HE-2 for this parameter was fairly good.

8. The mean period of the cycle of maximum horizontal acceleration was about 0.3 second. Direct upward scaling ($W^{1/3}$) to a 23 KT weapon would give a mean period of 0.86 second. However, a $W^{1/4}$ time scale relationship would give a mean period of 0.63 second, which may be the more dependable estimate. The limited experimental data indicate an empirical $W^{1/4}$ time scaling factor, although a consistent use of this factor would require different model laws for the other aspects of the phenomena, for which no theoretical or experimental foundation has yet been established.

9. The maximum peak-to-peak vertical acceleration followed the approximate relation:

$$_{pp}A_V = \frac{1800}{R^{1.25}} \qquad (6.4)$$

It was considerably less than the horizontal component except at large distances, where the military effects would be unimportant. It is to be noted that this attenuation law is the same as that for peak air pressure, indicating that air-blast induced effects may be of principal importance even after the local slap is separated. No estimate is made for a 23 KT weapon, since the scaling for this parameter between HE-1 and HE-2 was not good.

10. At the one radius of measurement (1025 feet) the earth acceleration (less slap) was reasonably constant in both amplitude and wave form to a depth of 68 feet. At very small distances from the charge a depth effect could be expected, due to simple geometry considerations. On the HE-2 test little variation in depth was experienced where the 68-foot deep gage string subtended an angle of eight degrees at the charge center, corresponding to a radius of about 400 feet for the underground nuclear test.

11. The amplitude of the first pulse of vertical earth acceleration exhibited a step or shelf in the distance attenuation curve at a distance of about 450 feet. This result was observed in the scaled HE test series and is consistent with calculations based on the presence of a subsurface layer of higher seismic velocity at the JANGLE site.

12. Inconsistent scale factors were obtained for various aspects of the earth acceleration phenomenon when comparisons were made to the results of the HE-2 test. Consequently, no reliable estimate can be made of the equivalent TNT yield for earth acceleration for the underground nuclear test. There is some evidence that the equivalent TNT yield was considerably less than 1 KT. The equivalent TNT yield for earth acceleration would not necessarily be the same as that for air pressure, since the energy partition between the air and earth effects for an underground nuclear explosion could be different from that for TNT.

13. Upon comparing the scaled HE tests and the underground nuclear test with the Dugway dry clay tests,[2,3,4] it is evident that the soil type had a profound effect on earth acceleration. The JANGLE acceleration periods (durations) were far less than those obtained at Dugway for identical tests. The pronounced variation of the time scale of earth acceleration with soil type indicates that earth motion damage criteria could be affected much more by soil type than a study of peak acceleration amplitudes would indicate. For the JANGLE site the permanent and transient earth displacements were much less than those for identical tests in Dugway dry clay. No quantitative explanation of this effect of soil type has been attempted for this report. It is likely that a simple propagation type soil constant is inadequate to explain the significant differences between soil types with respect to earth shock phenomena. Perhaps such factors as cohesiveness, plastic flow, and dynamic stress-strain relations are of major importance in determining the earth effects of underground explosions.

The work of Project 1(9)a was not completed at the time this report was prepared. Further analysis is planned prior to the preparation of the final contract report.[8] This analysis will include a more complete study of the earth acceleration phenomena, with particular attention given to the complete records obtained and to their first and second integrals, yielding transient earth particle velocity and displacement information. At the time this report was prepared the surveyed permanent displacement data were not available to assist in these integrations.

It is apparent that more information is needed concerning model law behavior for large shallow underground explosions, with consideration given to possible model law variations, both empirical and analytical. Extensive additional studies are required on the influence of soil types and test medium variations on the underground effects of shallow underground explosions. The additional analysis planned includes correlation of the results of the JANGLE experiments with those from other extensive underground explosion test programs,[9,10,11,12] where

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possible. The material contained in References 10, 11, and 12 was not available at the time this report was prepared. Insufficient information has been made available to include any symmetry effect studies in this report.

Until the further studies outlined above have been completed, only the following recommendations are made with regard to earth acceleration on future large shallow underground explosion tests.

1. Extensive measurements should be made at depths corresponding to those for underground targets of military interest. Such depths would probably markedly reduce the local air-pressure induced effects (slap) and present the distributed air-coupled effects in their proper proportion for military usefulness.

2. More attention should be given to "close-in" measurements where earth motion is of real importance in producing damage to underground and surface targets. In particular, measurements should extend to the edge of the true crater, and a sufficient number of instrument points should be included in the region of military interest so that the interpretation is not influenced by the results at larger distances having no apparent damaging usefulness.

6.3 EARTH PRESSURE

There exists a real undertainty in the relation between the true earth pressure and the quantity measured as earth pressure by the experimental techniques used for this project. No systematic pattern was obtained when comparisons were attempted with the measurements obtained on the scaled HE test series. The few conclusions presented apply to the records obtained for the quantity measured as earth pressure, with no interpretation as to the significance of this quantity with respect to military usefulness.

1. The earth pressure measurements include a mixture of direct effects and air-pressure induced effects, as described for earth acceleration. The largest recorded earth pressures appear to be the result of the action of the air pressure on the ground immediately above the gage locations or on the liquid columns in which the hydrostatic pressure gages were immersed. Although these principal peaks do not bear a consistent amplitude relationship to the corresponding peak air pressures, the time of their occurrence correlates with the air blast phenomena.

2. Certain portions of the earth pressure records appear unrelated to the local air-induced effects in that they have the same

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propagation velocity as the direct earth acceleration, this velocity being nearly equal to the known seismic velocity. These direct earth-pressure effects were very small and were probably insignificant and unimportant with respect to military damage. If significant direct earth-pressure effects existed, they were masked by the action of the air-blast phenomena.

3. The effect of depth on the quantity measured as earth pressure was a function of the horizontal distance from the charge. At a small radius (217 feet) the peak earth pressures increased markedly with depth (to 34 feet), although the general wave forms changed only slightly. However, at a larger radius (378 feet) a change in wave form occurred between the 34- and 68-foot depths, with no marked increase in pressure below 17 feet. Although no deep acceleration measurements were obtained at these two radii, a comparison with the HE-2 results indicates completely different behavior of the earth acceleration. No explanation is advanced for this discrepancy, although it is expected to lie, in part at least, in the uncertainties of the instrumental techniques used for earth pressure measurement.

Additional studies are planned prior to the preparation of the final contract report.[8] It is evident that attention must be given to the extensive measurements obtained at the Dugway explosion tests in soils.[10,11,12] Only after such extended study can specific recommendations be made. However, it does appear that particular emphasis should be placed upon the development of techniques for the measurement of the phenomena known as earth pressure, which will permit direct correlation with the damage inflicted on representative underground targets. Attention whould be given to the directional properties of pressure in a medium capable of supporting shear stresses. Such work is strongly recommended in advance of any future large scale underground explosion tests, to permit a better understanding of the test results that might be obtained. It is likely that analytical support will aid in the interpretation of existing experimental data and in the development and design of future experimental techniques.

For future large underground explosion tests the recommendations for deep measurements and extensive close-in measurements made for earth acceleration are also made for earth pressure.

6.4 DAMAGE CRITERIA - SURFACE STRUCTURES

1. For large shallow underground explosions at the JANGLE test site, it is believed that air blast will be the major factor in determining damage to conventional surface structures. For greater

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burial depths and/or for nuclear explosions in different soil types, it is possible that both earth motion and throwout could be major contributors to the damage of structures of this type. Of course, if air blast damage alone is desired, the underground detonation is far from optimum.

2. Depending upon the size of the explosion, the soil type, and the target type, either earth acceleration, particle velocity, or displacement can be the principal criterion for judging the damaging effect of earth motion on surface targets. For a 23 KT weapon at a depth of 46 feet at the JANGLE site, it is estimated that the earth particle velocity will be the most dependable criterion of damage to conventional surface structures, since its estimated period of 0.5 second is within the region of the natural periods of two- to four-story structures.

3. For large nuclear charges in more cohesive soils, such as at the Dugway dry clay site, earth acceleration would probably be the best single earth motion parameter for judging surface structure damage, exclusive of air blast.

4. Since the time characteristics of the driving forces can be of dominant importance in determining the marginal damage limits for certain types of structures, it is of extreme importance to have a better understanding of the wave forms of the earth motion phenomena produced by underground explosions. Methods for predicting the peak values alone of acceleration, velocity, and displacement for different charge sizes in different soil types are insufficient, and a means is necessary for estimating the time scale of the complete earth motion phenomena.

5. It is conceivable that a more complex subsurface stratigraphy could produce significant earth motion damage to surface structures at larger distances than would be predicted for an essentially uniform test medium. Subsurface reflection and refraction of energy back toward the surface could give reinforcement under certain conditions to produce this effect.

6. Because of the potential importance of transient earth particle velocity and transient earth displacement in establishing damage criteria, it is recommended that efforts be directed toward the direct measurements of these quantities on future tests, if such direct measurements can give more reliable information than would be available from the single and double integration of accelerometer records.

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6.5 DAMAGE CRITERIA - UNDERGROUND TARGETS

In this report the underground nuclear test results have not been evaluated with respect to damage criteria for underground or buried targets. The factors governing damage to underground targets are not clearly understood by the authors, and the results of previous extensive underground explosion tests[9,10,11,12] must be evaluated before major conclusions or recommendations can be made. Pending such an evaluation, the following tentative conclusions and recommendations are presented.

1. It is likely that the strong local air-induced phenomena are of negligible importance in damaging buried targets, due to their short periods and their apparent attenuation with depth.

2. Earth motion can be a contributing factor to the damage of underground targets. The target characteristics, plus the time scale of the earth motion, will determine the relative importance of acceleration, velocity, and displacement as damage criteria. For a 23 KT weapon the principal earth motion wave lengths should be long compared to the dimensions of many representative buried targets, and damage could be estimated by considering the response of the target and its contents when the target moves as a whole with the surrounding earth. However, the interval of differential movements when the earth-motion wave is passing over the target is far more complex and could be of major importance.

3. If a buried target can be considered as a rigid body, compared to the surrounding earth, it is possible that the flow of earth material around the target could be of major significance in determining damage. In addition to the normal pressure forces developed, friction forces due to the slippage of earth along target surfaces could be important.

4. It is likely that earth pressure is of major significance in determining damage to buried targets. Crushing and fracturing of external walls of such targets could be the result of pressure forces transmitted by the earth.

5. As noted above, under Earth Pressure, more information is required in order to permit the measurement of "free earth" phenomena which can be directly translated into damaging effects on buried targets. Particular attention should be given to this problem in advance of any future large underground explosion tests, after the results of previous tests[9,10,11,12] have been evaluated in connection with the JANGLE underground nuclear test.

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6. It is likely that the region of major importance for damage to underground targets is confined to the region of important rupture and permanent displacement in the earth medium surrounding the underground explosion. As a consequence, the region of important damage should be located relatively close to the crater boundaries.

APPENDIX A

PERSONNEL

Project 1(9)a of Operation JANGLE was performed by Stanford Research Institute under Contract No. N7onr-32104 with the office of Naval Research, Washington. Mr. J. W. Smith and Mr. J. Kane served as Project Officers for ONR.

All Stanford Research activities on Project 1(9)a were under the direction of Dr. E. B. Doll. Dr. Doll supervised the initial planning for the test program and directed the field activities, with Mr. L. M. Swift serving as field party chief. Additional members of the field party were L. H. Inman, V. E. Krakow, C. C. Hughes, S. C. Ashton, and W. M. Stewart. This report was prepared by Dr. Doll and Dr. V. Salmon, with typing and drafting assistance from Miss Blanche Shoemake and Mrs. Jane Simons, respectively.

LCDR D. C. Campbell USN of Program One coordinated the activities of this project with the remainder of Operation JANGLE.

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