MISCELLANEOUS PAPER N-68-6

SHOCK ISOLATION BY DISCONTINUITIES

by

J. T. Brogan

D. W. Murrell

November 1968

Sponsored by

Office, Chief of Engineers
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U. S. Army Engineer Waterways Experiment Station
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FOREWORD

This paper presents results of an In-House Laboratory Independent Research Project entitled, "Shock Isolation by Discontinuities." The study was conducted at the Big Black Test Site of the U. S. Army Engineer Waterways Experiment Station (WES). Spherical charges of TNT weighing 0.814 lb were used as the explosive, and trenches and augered holes were used as the discontinuities. The field tests were conducted during the winters of 1963-1964 and 1964-1965.

The work was performed under the general supervision of Mr. G. L. Arbuthnot, Jr., Chief of the Nuclear Weapons Effects Division, WES, and Mr. L. F. Ingram, Chief of the Physical Sciences Branch, WES, and under the direct supervision of Mr. J. D. Day, Chief of the Blast and Shock Section. Mr. J. T. Brogan was the project engineer; Mr. C. M. Wright accomplished the field work, including explosive charge preparation; and Messrs. K. Daymond and F. P. Leake provided instrumentation support. This paper was prepared by Messrs. J. T. Brogan and D. W. Murrell.

COL Alex G. Sutton, Jr., CE, was Director of WES during the early portion of this study. COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE, were Directors during the preparation of this report. Mr. J. B. Tiffany was Technical Director.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
pounds	0.45359237	kilograms
feet per second per second	0.3048	meters per second per second

SUMMARY

The objective of the study reported herein was to determine the effectiveness of several simple discontinuities in attenuating explosively produced ground shock. In a series of field tests, open trenches and augered holes were used to attenuate ground motion produced by small buried HE detonations. Measurements of particle acceleration obtained during the test program indicated a reduction factor of about 6 due to an intervening trench of 3.5λ depth. Augered holes as discontinuities produced little or no effects until a hole spacing of 3 in. was reached. A reduction factor of about 2 was noted for this spacing.

SHOCK ISOLATION BY DISCONTINUITIES

OBJECTIVE OF INVESTIGATION

1. The objective of the study reported herein was to determine the effectiveness of several simple discontinuities in attenuating explosively produced ground shock.

BACKGROUND

2. A discontinuity in the acoustic impedance ρc caused by a fault or interface in a soil or rock mass is known to significantly modify the seismic energy transmitted across the interface. The equation relating the transmitted stress σ_t to incident stress σ_i is

$$\sigma_t = \frac{2\rho_t c_t}{\rho_t c_t + \rho_i c_i} \sigma_i \qquad (1)$$

where i refers to the medium on the incident side of the discontinuity and t refers to the medium on the far side. It can be seen that if $\rho_i c_i >> \rho_t c_t$, the proportion of energy transmitted across the interface will be quite small. This would be the case if a free surface were involved, with air being the $\rho_t c_t$ medium. It is then possible to effect a reduction in the transmitted seismic energy, or ground motion, by inserting artificial discontinuity, such as a void, in the soil medium. With these principles in mind, this study was undertaken to assess the effectiveness of open trenches as discontinuities on reducing earth particle acceleration produced by a small TNT detonation. The need for a second phase of this program became apparent during the series of trench tests, since excavation of deep trenches was considered to be impractical. This second series was conducted using augered holes at various spacings to approximate the trench.

EXPERIMENTAL PLAN

3. The test series for the first phase of this study was designed to provide measurements of particle acceleration at scaled distances of 2.5 to 10λ (λ = charge weight$^{1/3}$) along two radial lines from the shot point. On all shots except 7 and 8, which were control shots, an intervening trench was excavated perpendicular to one radial line at a distance of 3.25 ft* or about 3.5λ from the charge. The trench was approximately 7 in. wide by 3 ft deep by 12 ft long. Fig. 1 shows the gage layout for shot 1, which was of typical geometry for the trench series. Fig. 2 shows the layout for shot 202, a representative shot in the hole series.

4. In the second phase of testing, 6-in.-diam augered holes were used in place of the trench. Shot 201 of this series was a control shot with no discontinuities. Shots 205, 210, and 211 had holes bored 3 in. apart, shots 202, 203, 208, and 209 had a hole spacing of 6 in., and shots 206 and 207 had hole spacings of 9 in. Table 1 presents a summary of instrumentation installed for each shot.

5. The explosives for all shots of both series were spherical TNT charges weighing 0.814 lb ($W^{1/3}$ = 0.93). They were detonated by an electric blasting cap placed at the charge center. All charges were buried at a scaled depth λ of 1 (0.93 ft).

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* A table of factors for converting British units of measurement to metric units is presented on page vii.

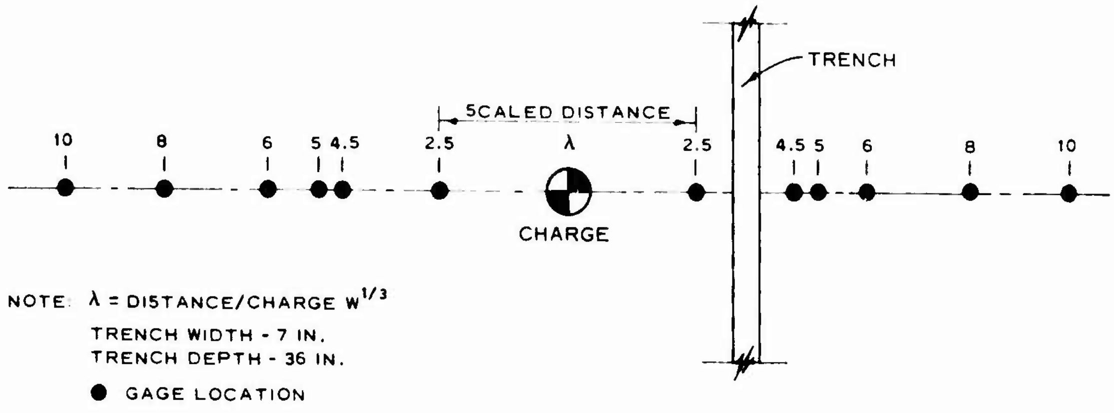


Fig. 1. Typical gage array, trench series

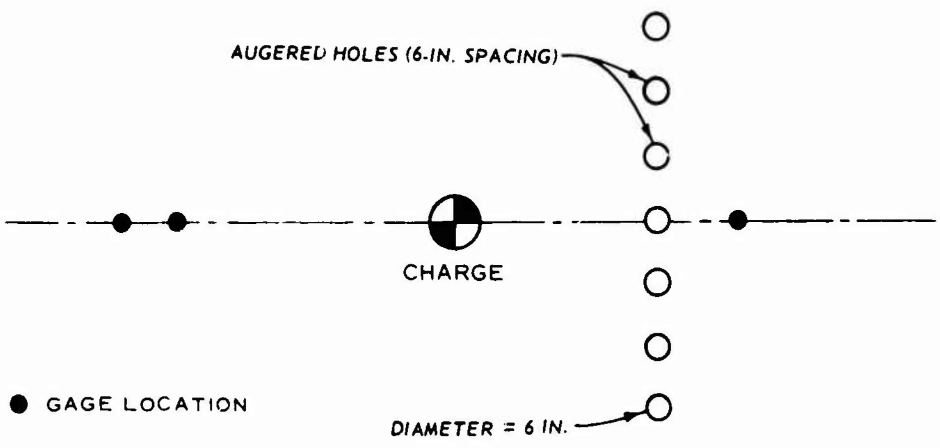


Fig. 2. Typical gage array, hole series

TEST SITE

6. The field tests were conducted at the Big Black Test Site. Severe conditions of high water and mud periodically caused delays in the test schedule, but these conditions did not materially affect the tests themselves.

7. The instrumentation shelter at the test site, located about 140 ft from the testing area, housed the amplifiers and recording equipment.

INSTRUMENTATION

8. Strain-gage accelerometers were used to measure radial particle acceleration during the trench series. Two triaxial gages were installed for shots 5-9 to obtain vertical and tangential motions. All shots of the hole series were instrumented with three triaxial gages. Before field tests were begun, a spin table was used to calibrate the accelerometers. All calibrations were made with proper lengths of cables attached to the

accelerometers. Precision resistors of known values were shunted across one arm of the accelerometer bridge circuit, producing an unbalanced signal step. A comparison of these unbalanced signal steps with signal steps produced by known accelerations made by the spin table established a reference calibration value for each accelerometer.

9. To ensure that the accelerometers would give equal response to the same dynamic impulse, gages that were to measure ground motion at comparable distances in the field were tested simultaneously on a drop table. The dynamic impulse tests on the drop table were performed before and after mounting the gages for the field.

10. Each accelerometer was mounted inside a small wooden box. The void inside the box was filled with silicone rubber, ensuring watertightness as well as a good bonding of the gage to the box. A very good density match was obtained between the gage assembly and the in situ soil. Gages were placed at a scaled depth of 1, and placement holes were backfilled with native soil. Signal conditioning equipment used was the CEC System D. Galvanometer oscillographs were used for data recording. An automatic programmer produced capacitor charging, recorder start, calibration, and charge detonation signals.

RESULTS AND DISCUSSION OF RESULTS

11. Measurements of particle acceleration were obtained during the test program. Shots 3, 4, 9, and 10 of the trench study series were beset with signal conditioning and calibration problems and yielded little useful data. All shots of the hole study series except shot 204 provided usable data. Tables 2 and 3 present a summary of measurements for the trench series and hole series, respectively. Photograph 1 shows typical postshot conditions for each series.

TRENCH DISCONTINUITY SERIES

12. As previously mentioned (paragraph 3), shots 7 and 8 of this series were control shots with no trenches and were designed to define the pattern of motions produced in the free field. In addition, shots 1, 2, and 6 had one or more gages placed in the free field with no intervening trench. Radial (outward) acceleration data from these control shots are plotted versus scaled distance ($\lambda = d/W^{1/3}$) in plate 1a. From this plot it can be seen that the control data from the five shots are quite consistent and none of the shots produced data that were uniformly high or low with respect to the general least squares fit. The equation of the least square curve is $A = 1.38 \times 10^4 \lambda^{-3.88}$ where A is in g's ($1g = 32.2$ ft/sec^2).

13. Plate 1b, a companion plot to plate 1a, shows radial acceleration data obtained from gages located on the far side of the attenuating trench from the charge for shots 1, 2, 5, and 6. The equation of a fitted curve using all the data points shown in plate 1b is as follows: A (in g's) $= 0.69 \times 10^4 \lambda^{-4.38}$.

14. A comparison can now be made between radial accelerations measured with no intervening trench (A) and with a trench (A_t). Ratios of A_t/A computed from the preceding equations vary from 0.29 at $\lambda = 3$ to 0.16 at $\lambda = 10$, indicating a greater trench influence at larger distances. This is contrary to what might be expected and can be attributed to the more rapid decay of the trench data (λ exponent of -4.38 compared to -3.88). Close examination of plate 1b reveals that two data points from shot 1, at $\lambda = 4.5$ and 5 , fall considerably above the fitted curve and heavily influence the curve slope in the least squares analysis, while the remainder of the points tend to define a curve with the equation $A = 2.2 \times 10^3 \lambda^{-3.75}$, which is shown in plate 1b. This decay exponent is essentially the same as the no-trench exponent, and, if used, produces an A_t/A ratio of very nearly 0.16 or a reduction factor of 6 for all distances instrumented.

15. Although measurements of vertical and tangential accelerations for shots 5-8 showed more scatter than did the radial acceleration measurements, an important trend was noted. In general, the trench appeared to have a lesser effect on accelerations in these directions than it did for the radial motions. Ratios of vertical to radial and tangential to radial accelerations are presented in table 4. Using these ratios and the 6 to 1 reduction for the trench condition noted for radial motions, a ratio of accelerations with an intervening trench to those without a trench was calculated to be about 0.4. It can thus be inferred that the trench did attenuate vertically and tangentially by a factor of roughly 2-1/2, although this relation is experimentally much less precise than that found for radial measurements.

HOLE DISCONTINUITY SERIES

16. Data from the shot series using augered holes as discontinuities are much less dramatic than those from the trench study; nevertheless, certain results are noted for this series.

17. The first shot of this series, shot 201, was designed as a control shot with no discontinuities. Data from subsequent shots were to be compared with these control data. Such a comparison proved to be unrealistic, though, since relatively small scatter in the data produced inconsistent or misleading results. Therefore, test data from the far side of a discontinuity were compared directly with data from a control gage emplaced on every shot with no intervening discontinuity.

18. Shots 205, 210, and 211, which had hole spacings of 3 in. (67 percent void), demonstrated an important trend of attenuation. This trend was especially apparent and consistent in the radial direction, where ratios of radial accelerations with discontinuities to those without discontinuities were 0.43 for shot 205, 0.46 for shot 210, and 0.5 for shot 211. These ratios, while definitely showing attenuation, also show that even this relatively close spacing of holes (67 percent void) is a rather poor approximation to the trench (100 percent void) condition. The A_v and A_t measurements did show a trend toward attenuation for all shots with the 3-in. spacing, although there was too much scatter in the data to allow a percentage reduction to be calculated.

19. Results of shots 202, 203, 208, and 209, which had augered hole discontinuities 6 in. apart (50 percent void), and shots 206 and 207, which had spacings of 9 in. (40 percent void), indicated no noticeable effect on accelerations beyond the discontinuity within the data scatter. This was true for all three axes of motion.

CONCLUSIONS

20. The effectiveness of a trench in attenuating the radial ground motion produced by a small HE detonation has been demonstrated by this test series. Measurements of radial acceleration in the region 2.5 to 10λ from the charge indicate a reduction by a factor of about 6 due to an intervening trench of 3.5λ depth. Vertical and tangential measurements were attenuated to a lesser degree over the same region.

21. Augered holes as discontinuities produced little or no effects until a hole spacing of 3 in. was reached. A reduction factor of about 2 was noted for radial motions for this spacing, which was still much less effective than the trench in attenuating motion.

Table 1

Summary of Instrumentation

Trench Series					Hole Series				
Shot No.	No. of Acceleration Measurements			Remarks	Shot No.	No. of Acceleration Measurements			Remarks
	Radial	Vertical	Tangential			Radial	Vertical	Tangential	
1	12	0	0	Charge W = 0.814 lb buried at 1λ depth for all shots	201	3	3	3	No holes
2	12	0	0		202	3	3	3	6-in. spacing
3	12	0	0		203	3	3	3	6-in. spacing
4	12	0	0		204	3	3	3	3-in. spacing
5	6	2	2		205	3	3	3	3-in. spacing
6	6	2	2		206	3	3	3	9-in. spacing
7	4	2	2	No trench	207	3	3	3	9-in. spacing
8	4	2	2	No trench	208	3	3	3	6-in. spacing
9	6	2	2		209	3	3	3	6-in. spacing
10	6	2	2		210	3	3	3	3-in. spacing
					211	3	3	3	3-in. spacing

Table 2

Summary of Measurements, Trench Series

Shot No.	Scaled Distance λ $ft/W^{1/3}$	Peak Acceleration, g — Without Trench: Radial	Without Trench: Vertical	Without Trench: Tangential	With Trench: Radial	With Trench: Vertical	With Trench: Tangential
1	2.5	500					
	2.5	686					
	4.5	43			26.4		
	5.0	25.7			14.0		
	6.0	15.2			2.75		
	8.0	1.64			0.49		
	10.0	2.26			0.40		
2	3.0	294					
	3.0	234					
	4.0	56.7					
	4.0	46.8					
	5.0	21.8					
	5.0	40.0					
	7.0	9.43			1.07		
	8.0	5.02			1.21		
	10.0	2.11			0.54		
5	5.0				6.1	2.9	
	6.0				1.39		
	7.0				1.76		
	7.0				0.96		
6	3.25	123					
	5.0				3.22	2.25	2.88
	6.0				1.37		
	7.0				1.01	0.49	1.16
	7.0				0.93		
7	3.25	50.4					
	5.0	36.4	5.4	2.9			
	6.0	14.2					
	7.0	7.9	1.99	3.5			
8	3.25	77.7					
	5.0	43	6.7	3.9			
	6.0	13.9					
	7.0	7.1	1.49	3.4			

Table 3

Summary of Measurements, Hole Series

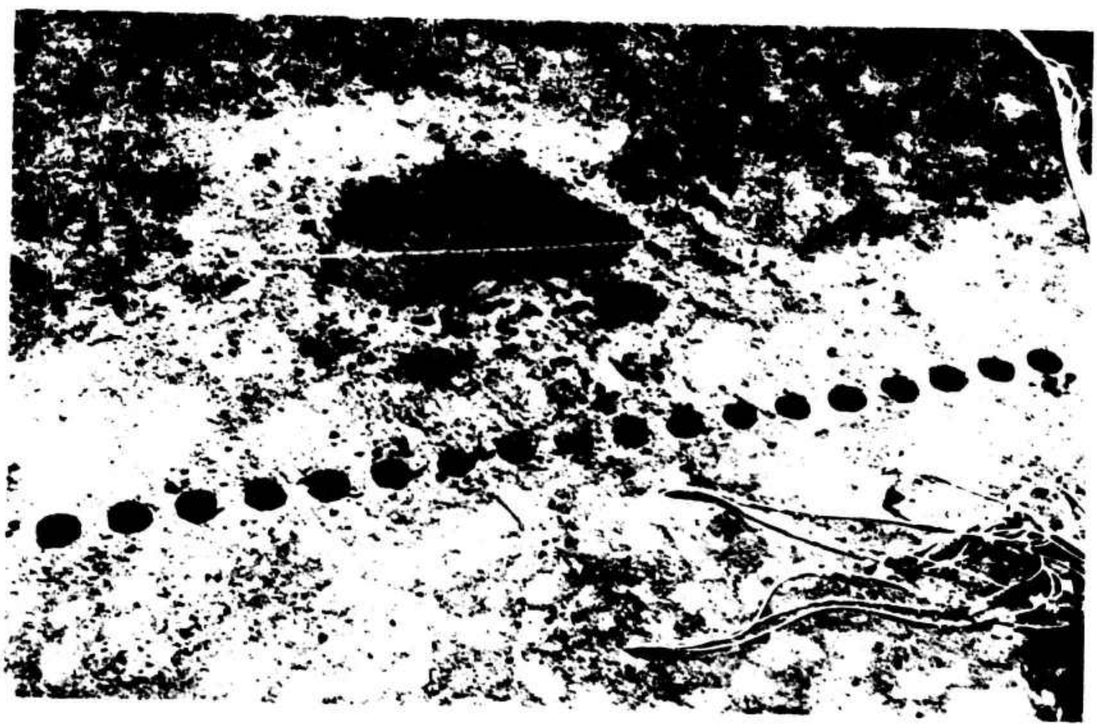
Shot	Hole Spacing in.	Scaled Distance λ $ft/W^{1/3}$	Peak Acceleration, g: With Holes Radial	With Holes Vertical	With Holes Tangential	Without Holes Radial	Without Holes Vertical	Without Holes Tangential
201	No holes	5				19.5	9.7	9.42
		5				17.9	--	5.91
		6				10.7	5.25	2.17
202	6	5				1.53	3.04	0.65
		5	16.8	--	0.68			
		6	7.1	2.48	0.58			
203	6	5				22.2	5.8	--
		5	22.5	1.24	3.14			
		6	10.8	1.46	0.87			
205	3	5				22.5	6.72	1.81
		5	9.70	2.58	0.77			
		6	5.88	1.18	0.39			
206	9	5				14.3	3.86	1.06
		5	18.9	3.52	1.99			
		6	8.26	2.52	0.28			
207	9	5				21.9	4.44	1.03
		5	14.6	2.58	1.31			
		6	6.94	2.02	0.44			
208	6	5				28.8	4.87	1.47
		5	20.6	4.18	1.27			
		6	9.47	1.21	1.15			
209	6	5				11.6	6.52	2.17
		5	18.5	--	0.96			
		6	8.77	1.52	0.59			
210	3	5				30.8	6.5	0.75
		5	14.3	2.83	0.72			
		6	7.1	1.14	0.58			
211	3	5				24.7	15.5	1.39
		5	12.3	1.27	0.43			
		6	5.35	2.17	0.71			

Table 4

Vertical to Radial and Tangential to Radial Acceleration Ratios

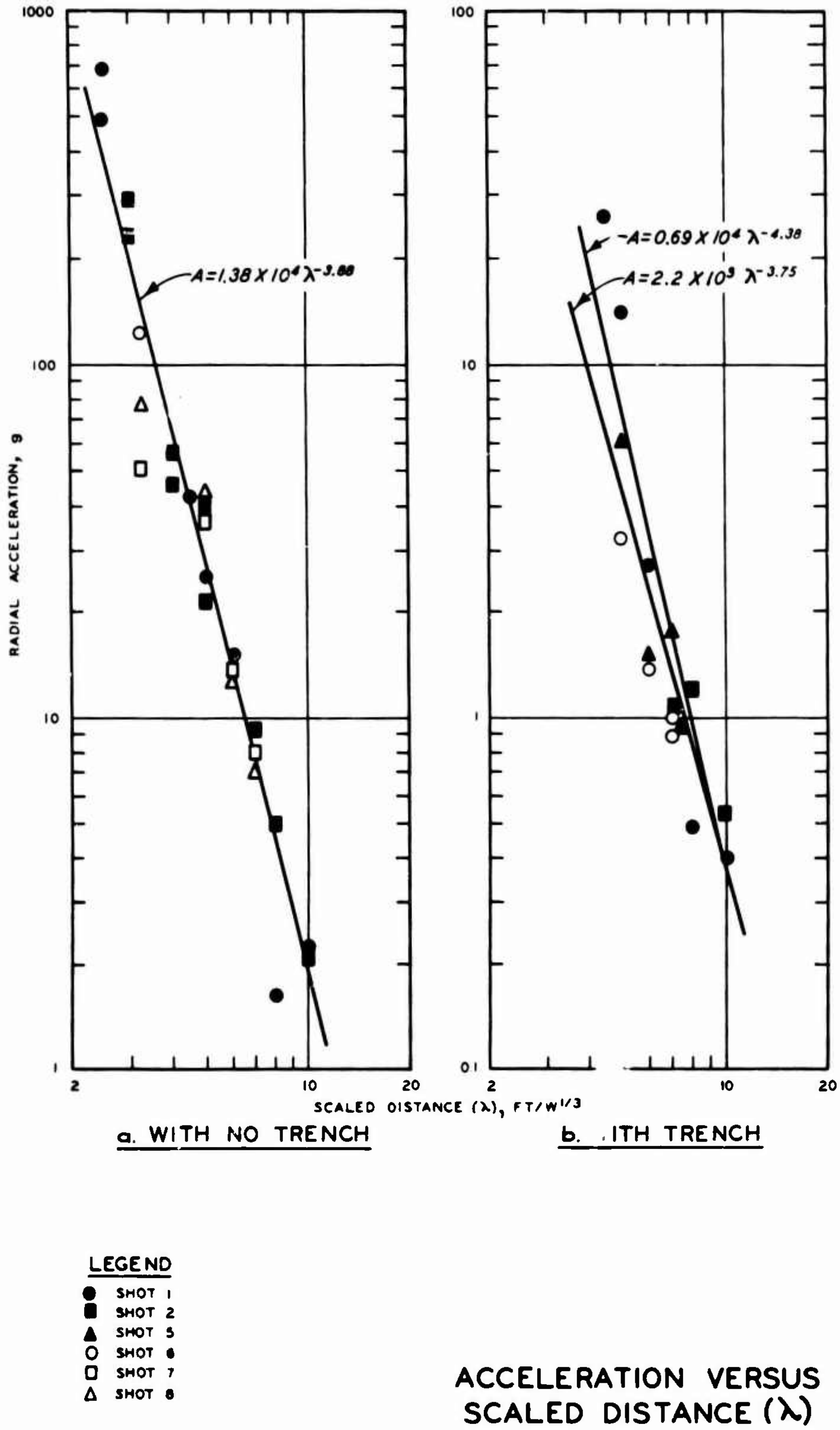
Shot No.	Scaled Distance λ ft/$W^{1/3}$	Ratio Without Trench Vertical/Radial	Ratio Without Trench Tangential/Radial	Ratio With Trench Vertical/Radial	Ratio With Trench Tangential/Radial
5	5			0.48	--
	7			--	--
6	5			0.70	0.89
	7			0.49	1.15
7	5	0.15	0.08		
	7	0.25	0.44		
8	5	0.16	0.09		
	7	0.21	0.48		

a. Trench series



b. Hole series

Photograph 1. Typical postshot conditions for trench and hole series



ACCELERATION VERSUS SCALED DISTANCE (λ)

WITH NO TRENCH AND WITH TRENCH

Unclassified

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13. ABSTRACT

The objective of the study reported herein was to determine the effectiveness of several simple discontinuities in attenuating explosively produced ground shock. In a series of field tests, open trenches and augered holes were used to attenuate ground motion produced by small buried HE detonations. Measurements of particle acceleration obtained during the test program indicated a reduction factor of about 6 due to an intervening trench of 3.5λ depth. Augered holes as discontinuities produced little or no effects until a hole spacing of 3 in. was reached. A reduction factor of about 2 was noted for this spacing.

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Ground shock						
Explosion effects						
Discontinuities						

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