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PROPAGATION OF EXPLOSIVE SHOCK THROUGH RUBBLE SCREENS.(U)
JUL 80 J W BROWN, D W MURRELL, J H STOUT
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PROPAGATION OF EXPLOSIVE SHOCK THROUGH RUBBLE SCREENS

by

Jerry W. Brown, Donald W. Murrell, John H. Stout

Structures Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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Final Report

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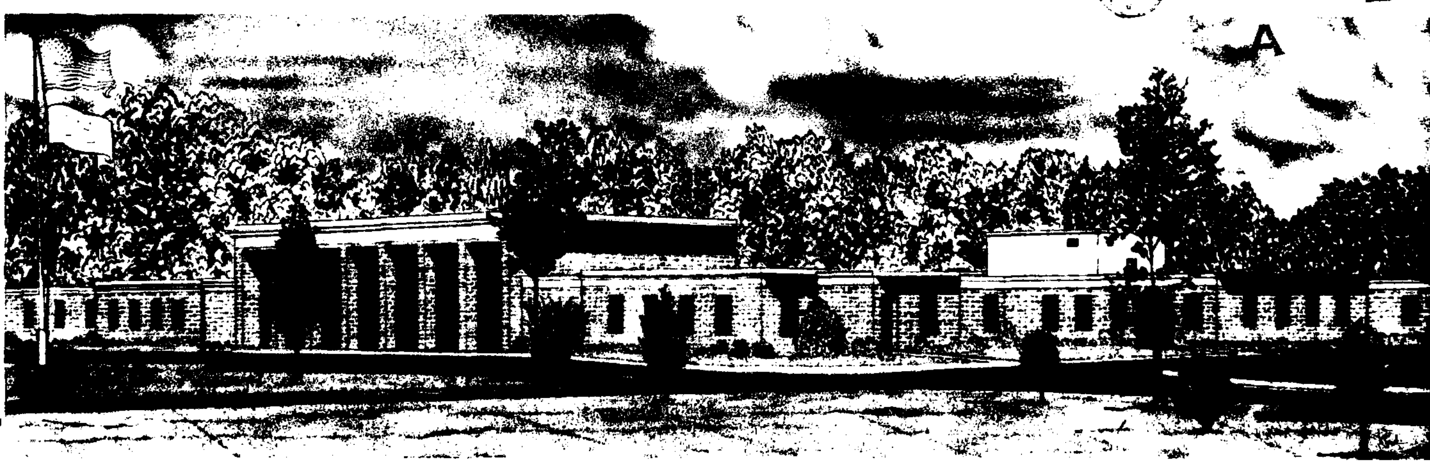

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This report describes tests conducted on shock transmitted through rubble screens from explosions on the top of the screens. The results are compared with shock transmitted through slabs and through free soil. There appears to be little difference in shock transmission in the three cases.

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PREFACE

This report is one of several planned on a work unit entitled "Shielding Methods for Conventional Weapons." The work was sponsored by the Office, Chief of Engineers, U. S. Army, under Project 4A762719AT40, "Mobility and Weapons Effects Technology," and was conducted by the Structures Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES).

The report was prepared by Messrs. Jerry W. Brown, Donald W. Murrell, and John H. Stout under the supervision of Mr. Bryant Mather, Chief of the Structures Laboratory.

Director of WES during this study and the preparation of this report was COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

A

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LIST OF FIGURES

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
feet per second	0.3048	metres per second
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (force) per square inch	6.894757	kilopascals

PROPAGATION OF EXPLOSIVE SHOCK THROUGH RUBBLE SCREENS

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Previous studies of hardened, buried structures indicate that placing a shield such as a rubble screen or concrete slab over these structures might be a cost effective method of increasing their hardness. Such shields can possibly destroy, stop or deflect incoming weapons, thus eliminating the explosion of the weapon or providing increased standoff distance between the explosion and the structure. Also, the presence of the shield might mitigate the shock transmitted to the structure.

1.2 OBJECTIVE

The objectives of this study were to measure the shock transmitted below a rock rubble screen from an explosion on the top surface of the screen and to compare this with the shock expected from like explosions on concrete slabs and on the free-field ground surface.

CHAPTER 2

TEST DESCRIPTION

2.1 TEST SITE

The experiments described in this report were conducted at the Queen 15 area in the north central portion of the White Sands Missile Range, NM. Geologically, the test area was located on an alluvial fan at the northwestern extremity of the Tularosa Basin. The soil profile at the site was characterized by roughly three feet of silt overlying some twenty feet of gray to reddish brown clay. Lenses of sand, sandy clay, and caliche were common. The ground water table was at a depth of 4.7 feet.[1]

No comprehensive soils property investigation was undertaken. Detailed information is available, however, for a test area roughly 500 feet to the north, and has been published by Jackson, et al.[2,3]

2.2 TEST PROCEDURES

2.2.1 General. Eight individual tests were conducted for this program, each consisting of the detonation of a single charge of nitromethane. The first four, of progressively larger yields, were detonated over a rubble screen. In all cases, measurements of acceleration and soil stress were made directly beneath the charge and off-axis. Table 2.1 lists, by event number, the charge weights and test media.

2.2.2 Test Bed Construction. For ease of gage placement, and for lateral containment of the rubble, these tests were conducted over a pit

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1 A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on page 4.

2 Jackson, A. E., Jr., Ballard, R. F., Jr., and Curro, J. R., Jr.; "Material Property Investigation for Pre-Dice Throw I and II: Results from the Subsurface Exploration Programs"; June 1976; U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

3 Jackson, A. E., Jr., and Peterson, R. W.; "Material Property Investigation for Pre-Dice Throw I and II: Results from the Laboratory Testing Programs"; November 1976; U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

10 x 20 x 4 feet deep. After the pit was excavated, instrumentation holes were hand-augered to the required depths and gages were installed. The holes were backfilled with sand. The pit was then backfilled with tamped soil to a depth of 1.5 feet, placing additional motion and stress gages as the backfill progressed. The remaining pit depth was filled with rubble for the first four tests. For the control tests the rubble was removed and replaced with recompacted soil. Figures 2.1 and 2.2 show details in a plan view and cross-section, respectively. Shot point number one was the location of the eight pound and 27 pound charges (tests 1, 2, 5, and 6), and shot point two was the location of the larger tests (tests 3, 4, 7, and 8). Accelerometers were installed in instrument holes one and three, and stress gages in holes two and four. All instrument holes were offset one foot from the shot point axes.

2.2.3 Rubble Properties. The rubble used on tests 1-4 was purchased from a local contractor and consisted of quarry scrap from a source near Las Cruces, NM. Samples were returned to WES for petrographic examination and physical property tests.

Petrographic examination showed the rock to be a rhyolite porphyry. Principal mineral composition proved to be plagioclase feldspar and quartz, with lesser amounts of other minerals present.

Average values of physical properties determined on three cored samples are as follows:

effective unit weight	158 lb/ft^3
dry unit weight	156 lb/ft^3
shear velocity	10,300 ft/sec
compressional velocity	15,900 ft/sec
unc. compressive strength	27,000 psi
Tensile split strength	1,380 psi
modulus of elasticity	5.6×10^6 psi
Poisson's ratio	0.23

Individual rubble pieces were quite angular, and considerable care was exercised during placement to avoid close fitting (as in a puzzle). Although each piece was not weighed, roughly 80% of the rubble was within the target boundaries of 30 to 60 pounds. Upper and lower weight bounds were approximately 80 pounds and 15 pounds, respectively.

2.2.4 Charge Configuration. Each charge used in this program was a liquid explosive (nitromethane) boosted with 0.5 pounds of C-4 located at the charge center. Charge containers were capped cylinders of PVC schedule 40 pipe. For the four charge weights (see Table 2.1), pipe diameters were 4 in., 6 in., 8 in., and 10 in., respectively. Length to diameter ratios were 3.9:1 for all cylinders.

2.2.5 Instrumentation. Measurements of acceleration and soil stress were made at seven depths beneath each shot point for each test, with gages beneath the inactive shot point providing off-axis data. Thus, a total of 28 data channels were recorded for each test. Table 2.2 lists, by an arbitrarily assigned measurement number, the types and locations of each gage installed.

TABLE 2.1 TEST DETAILS

Event No.	Charge wt.,lb	Test Media
1	8	rubble/backfill/in situ soil
2	27	rubble/backfill/in situ soil
3	64	rubble/backfill/in situ soil
4	125	rubble/backfill/in situ soil
5	8	backfill/in situ soil
6	27	backfill/in situ soil
7	64	backfill/in situ soil
8	90*	backfill/in situ soil

* Actual charge weight; scheduled to be 125 lb as in Event 4.

TABLE 2.2 INSTRUMENTATION LAYOUT

Meas. No.	Gage Type and Orientation*	Instrumentation Hole No.	Depth (ft)
101	AV	1	2.5
102	AV	1	2.5
103	AV	1	3.0
104	AV	1	3.5
105	AV	1	4.5
106	AV	1	6.0
107	AV	1	8.0
201	SV	2	2.0
202	SV	2	2.5
203	SV	2	3.0
204	SV	2	3.5
205	SV	2	4.5
206	SV	2	6.0
207	SV	2	8.0
108	AV	3	2.5
109	AV	3	3.5
110	AV	3	4.5
111	AV	3	6.0
112	AV	3	8.0
113	AV	3	9.0
114	AV	3	11.0
208	SV	4	2.5
209	SV	4	3.5
210	SV	4	4.5
211	SV	4	6.0
212	SV	4	8.0
213	SV	4	10.0
214	SV	4	11.0

* AV = vertical acceleration, SV = vertical stress

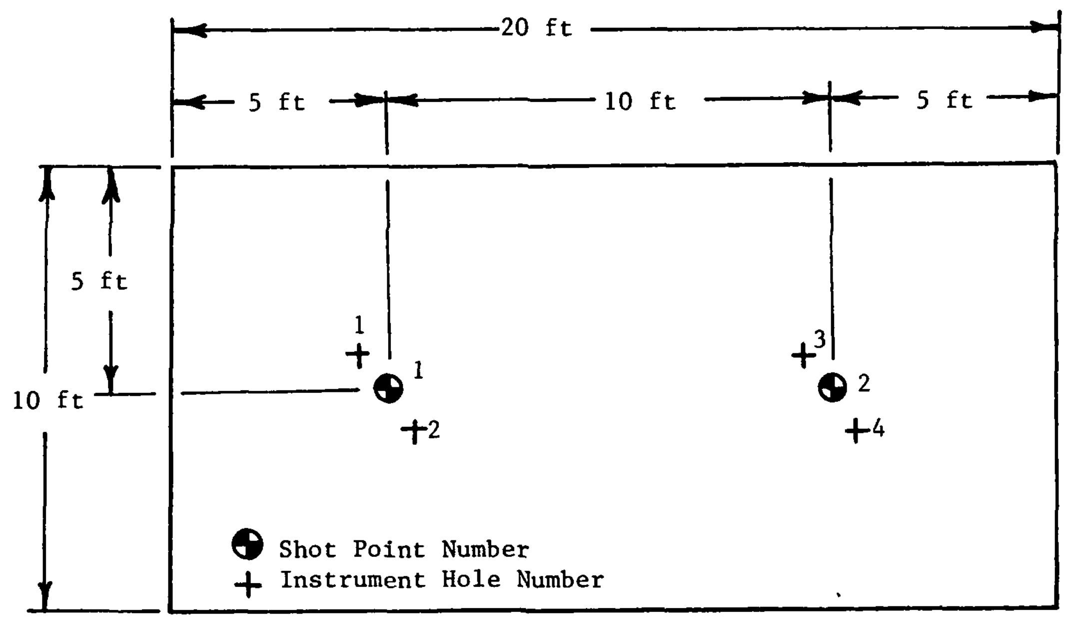

Figure 2.1. Plan view of test pit.

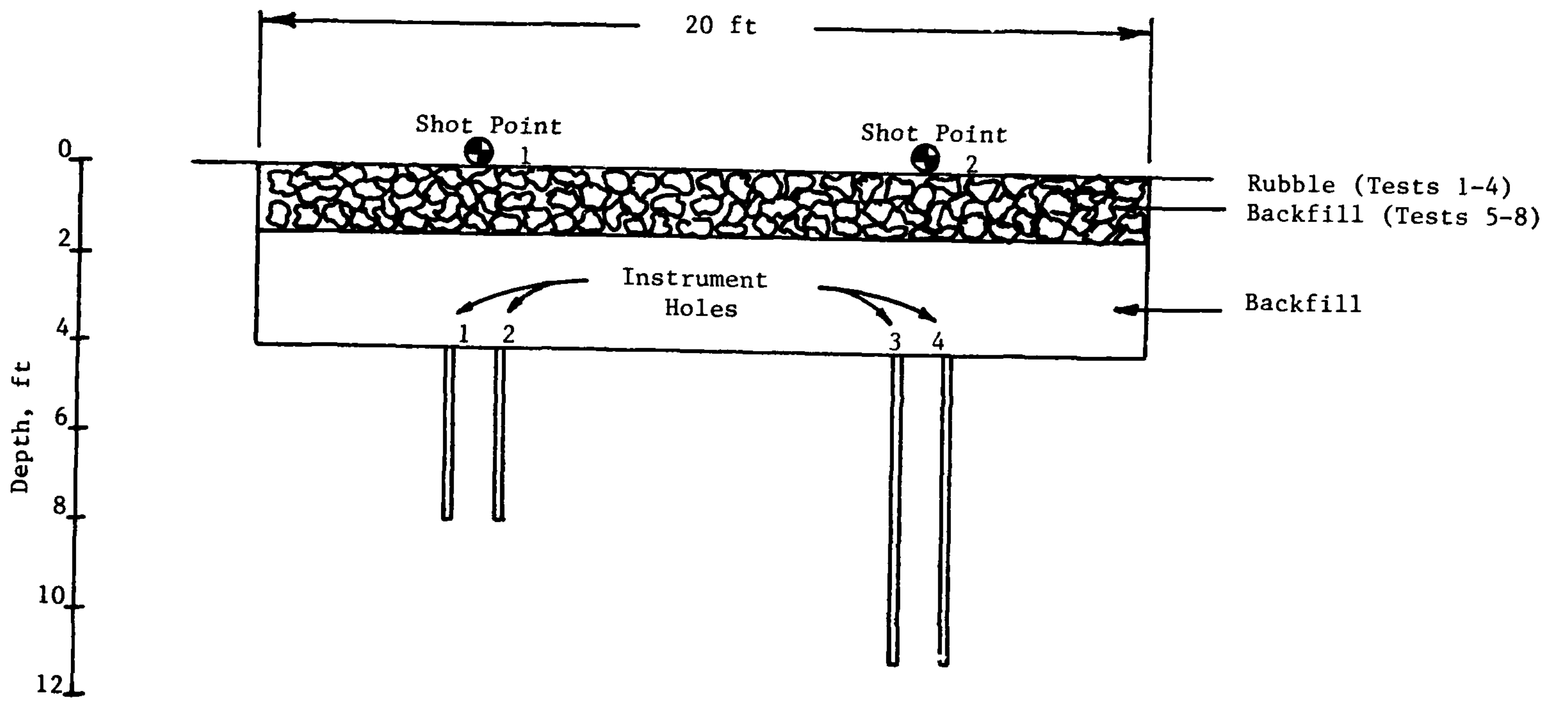

Figure 2.2. Cross section of test pit.

CHAPTER 3

RESULTS AND ANALYSIS

3.1 SYSTEM PERFORMANCE

The eight detonations comprising this test series were all conducted on schedule. The explosive initiation system performed as programmed and high order detonations were obtained on each test.

All ground shock gages were operable during the test series and data were recorded from all gages on each test. In a few cases data from off-axis gages were of marginal quality due to high gage ranges relative to measured signals. Over 95% of the gages, however, yielded high quality data.

3.2 CONTROL TEST MOTION AND STRESS DATA

3.2.1 Acceleration Data. Figure 3.1 shows the sequence of acceleration time-histories beneath the shot point for the 27 pound event. Records from all seven depths show similar waveforms, characterized by a single, sharp, downward spike followed by an upward rebound of lesser magnitude and longer duration. The peak downward motion attenuates rapidly with increasing depth, while its duration increases slightly, from 1.2 msec at the shallowest point to 4 msec at the deepest. Both the attenuated magnitude and increased duration are typical of shock transmission through soils. The subsequent upward rebound also attenuates with increasing depth, but less rapidly than the initial motion, such that it becomes relatively more noticeable at greater depths.

Data from the other three control tests were identical in appearance, and the scope of their discussion will be limited to magnitudes. Actual time histories of all measured and derived parameters (i.e. particle velocity and displacement) are available to qualified requestors from the WES.

Peak initial downward accelerations for all control tests plotted versus scaled depth ($D \div W^{1/3}$, where w = charge weight in pounds) in Figure 3.2. It should be pointed out that, while scaling theory dictates plotting scaled acceleration ($g \times w^{1/3}$) on the ordinate, such practice often leads to increased data scatter and unscaled accelerations are commonly plotted. This is certainly the case in Figure 3.2, where data from the two large yield events are noted to fall uniformly on or above the fitted least squares curve and data from the smaller yields fall on or below it. Thus, scaling of the peak accelerations would effectively decorrelate the data to an even greater degree.

Accelerations in Figure 3.2 vary from 8000 g to 4 g, attenuating sharply with increasing depth for all events. The least squares fit to all the data points has the equation $A = 650\ (D/w^{1/3})^{-3.09}$. Scatter bounds of ±60% include all but one of the data points for the three smallest events, with data from the 90 pound test falling above the upper bound. A yield dependency is clearly indicated in Figure 3.2, and is inverse to that suggested by scaling theory in that accelerations at the same scaled depth increase as the yield increases.

3.2.2 Stress Data. Peak stresses for all control tests are plotted versus scaled depth in Figure 3.3. It is readily apparent that stresses are less well behaved than were accelerations. Cube root scaling does not serve to collapse the data, and data from individual events attenuate with depth in manners which preclude use of least squares fitted curves. A significant point to be noted on Figure 3.3 is the occurrence of stress "jumps" at scaled depths of 1, 1.5, and 2.25 for the 90 pound, 27 pound, and 8 pound events, respectively. These scaled depths all correspond to an actual depth of 4.5 feet, which was the surface of the ground water table, and stress wave reflection at this point is the source of the jump in peak stresses. Such a jump was not observed for the 64 pound event, but this lack may have been caused by relatively minor anomalies in the shock front itself.

3.3 RUBBLE SHIELD MOTION AND STRESS DATA

3.3.1 Acceleration Data. Acceleration time-histories beneath the 27 pound shot point are shown in Figure 3.4. The waveforms are noted to be virtually identical in all respects to those obtained on the control test, with no anomalous behavior at any depth. Again, data from the other three rubble shield events were indistinguishable, on the basis of wave shape, from those shown in Figure 3.4, and are not shown here.

Peak accelerations for all rubble shield tests are plotted versus scaled depth in Figure 3.5. Accelerations decay sharply with increasing depth, varying from 4000 g to 13 g over the range of depths instrumented. A least squares fit to all the data points has the equation $A = 451\ (D/w^{1/3})^{-2.97}$. Scatter bounds of ±50% include all the data points from the three smallest events, with data from the 125 pound event falling on or above the fitted curve. For the rubble shield tests, data from the 64 pound event do not fall uniformly above or below the fitted curve and, in fact, are well mixed with data points from the 8 pound and 27 pound tests. This fact lends added weight to the soil compaction hypothesis since the 64 pound event on the rubble shield series was the first test fired over instrument holes 3 and 4 and, hence, the only "large" (i.e. 64 pound or larger) test detonated over virgin soil.

3.3.2 Stress Data. Peak stresses for the four rubble shield tests are plotted versus sealed depth in Figure 3.6. These data correlate noticeably better than did stresses from the control tests. Considerably less scatter is present, particularly among data from the three smallest events, and for purposes of empirically describing stress amplitudes a curve may be fitted to the data. Such a fit results in the expression $S = 170\ (D/w^{1/3})^{-2}$. A stress jump at the ground water table is evident only for the 8 pound test, but a jump is noted at the 8 foot depth for both the 64 pound and 125 pound events (scaled depths of 2.0 and 1.60, respectively).

3.4 DATA COMPARISON - CONTROL AND RUBBLE SHIELD EXPERIMENTS

3.4.1 Acceleration Comparison. Comparing the equations for peak acceleration versus scaled depth for the rubble shield and control tests provides a rough measure of the effect of the rubble screen on acceleration. Evaluating both equations at scaled depths of 0.8 and 2.0, and taking the ratio of $A_{(rubble)}/A_{(control)}$, it is found that these ratios are 0.67 and 0.76 respectively. This suggests that the rubble screen reduced accelerations below the shot point by some 30%. However, it is emphasized that these figures were derived from a treatment of the data in two groups, without differentiating on the basis of yield. Further, a yield sensitivity was observed, tentatively attributed to soil compaction by successive large events, which had a profound effect on the apparent efficacy of the rubble screen in reducing accelerations. A somewhat different picture evolves when a point-by-point comparison of corresponding data for rubble screen and control tests is made. The ratios of $A_{(rubble)}/A_{(control)}$ for the 8 pound events vary from 0.90 to 1.43, and average 1.16. For the 27 pound events, the ratios vary from 0.92 to 1.56, and average 1.14. The ratios for the 64 pound events, however, vary from 0.29 to 0.75; and average 0.42. Since it has already been shown (3.3.1) that data from the 64 pound rubble screen event agreed well with those from the 8 pound and 27 pound tests, accelerations from the 64 pound control test must cause the anomalously low ratio by being higher than would ordinarily occur. The event in question was the third test of 64 pounds or larger fired over instrument holes 3 and 4, and soil compaction undoubtedly was a significant factor. Similar conclusions would follow for the largest yield tests, but the different yields (90 pounds versus 125 pounds) rule out a point-by-point comparison.

3.4.2 Stress Comparison. Stress data for the control tests did not lend themselves to correlation by means of a fitted curve, so comparison of stresses must be limited to a point-by-point analysis. The average ratio $S_{(rubble)}/S_{(control)}$ for the 8 pound events was 1.20, with bounds of 0.75 and 1.51, and for the 27 pound tests was 1.31, with bounds of 1.05 and 1.54. Again, the comparative ratio is much lower for the 64 pound tests, with an average of 0.73 and bounds of 0.49 and 1.03. The causative factor here, as with acceleration peaks, is soil compaction on the large yield tests.

3.4.3 Data Comparison Summary. For the 8 pound and 27 pound tests, the rubble screen increased accelerations by 15% and stresses by 25%, whereas these parameters showed apparent decreases for the rubble screen effect on the 64 pound events. More accurately, due to soil compaction, accelerations and stresses were increased on the control tests. Consequently, more confidence is placed in the small charge data, and a rubble screen of the composition and thickness used on this test actually enhances shock transmission slightly, at least relative to the same thickness of recompacted soil.

3.5 COMPARISON WITH PREVIOUS EXPERIMENTS USING MONOLITHIC BURSTER SLAB SHIELDING

3.5.1 General. During 1973-1974 a large amount of stress data was acquired on a series of burster slab experiments at WES.[4] Pertinent tests in this series used both bare charges and model general purpose bombs with charge weights of 2 pounds to 300 pounds detonated over concrete slabs. Scaled thicknesses ($T/w^{1/3}$) of the slabs were maintained at 0.4 for all of these tests. In contrast, scaled thicknesses of the rubble shield described herein varied from 0.30 for the 125 pound test to 0.75 for the 8 pound test. Stress measurements were made on the vertical axis beneath each shot point for the burster slab tests in a manner virtually identical to that used on the rubble shield experiments. Soils beneath the burster slab tests were silty clays to clayey sand, and were moist to wet. Ground water tables lay well beneath the lowest gages. Details of the five burster slab experiments selected for comparison are listed in Table 3.1.

3.5.2 Stress Data from Burster Slab Tests. Peak stress data for the five burster slab experiments are plotted versus scaled depth in Figure 3.7. Depth scaling serves well to collapse the data from a wide range of yields (2 lbs to 300 lbs), and data scatter is small enough to

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[4] Drake, J. L.; Unpublished data from Project 85 Burster Slab Experiments; 1973-1974; U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

allow a curve to be fitted. The resultant curves has the equation $S = 250\ (D/w^{1/3})^{-3.1}$.

3.5.3 Comparison of Burster Slab and Rubble Shield Test Data. Peak stresses, undifferentiated except as to shielding type (slab versus rubble), are plotted versus scaled depth in Figure 3.8. It is immediately apparent from the slopes of the fitted curves that data from the burster slab tests are attenuating more rapidly with increasing depth. The lesser attenuation rate observed for the rubble shield tests is, without question, influenced by the stress jumps at locations at or near the ground water table and may thus be treated as somewhat atypical. Nevertheless, data points from the two shielding methods are generally well mixed, and tend to correlate in comparison about as well as they correlate separately. Consequently, it would be difficult to conclude from Figure 3.8 that stresses from either method predominate. Rather it appears that, neglecting points perturbed by stress reflections, stresses are equally affected (or unaffected) by the presence of either of these types of shielding.

TABLE 3.1 BURSTER SLAB TEST DETAILS

Test No.	Charge Configuration	Charge wt. (lbs)	Slab Thickness (ft)	Soil Type
1	Bare sphere	300	2.67	clayey sand
2	model GP bomb	300	2.67	clayey sand
3	Bare sphere	16	1.0	silty clay
4	Bare sphere	27	1.25	silty clay
5	Bare sphere	2	0.50	silty clay

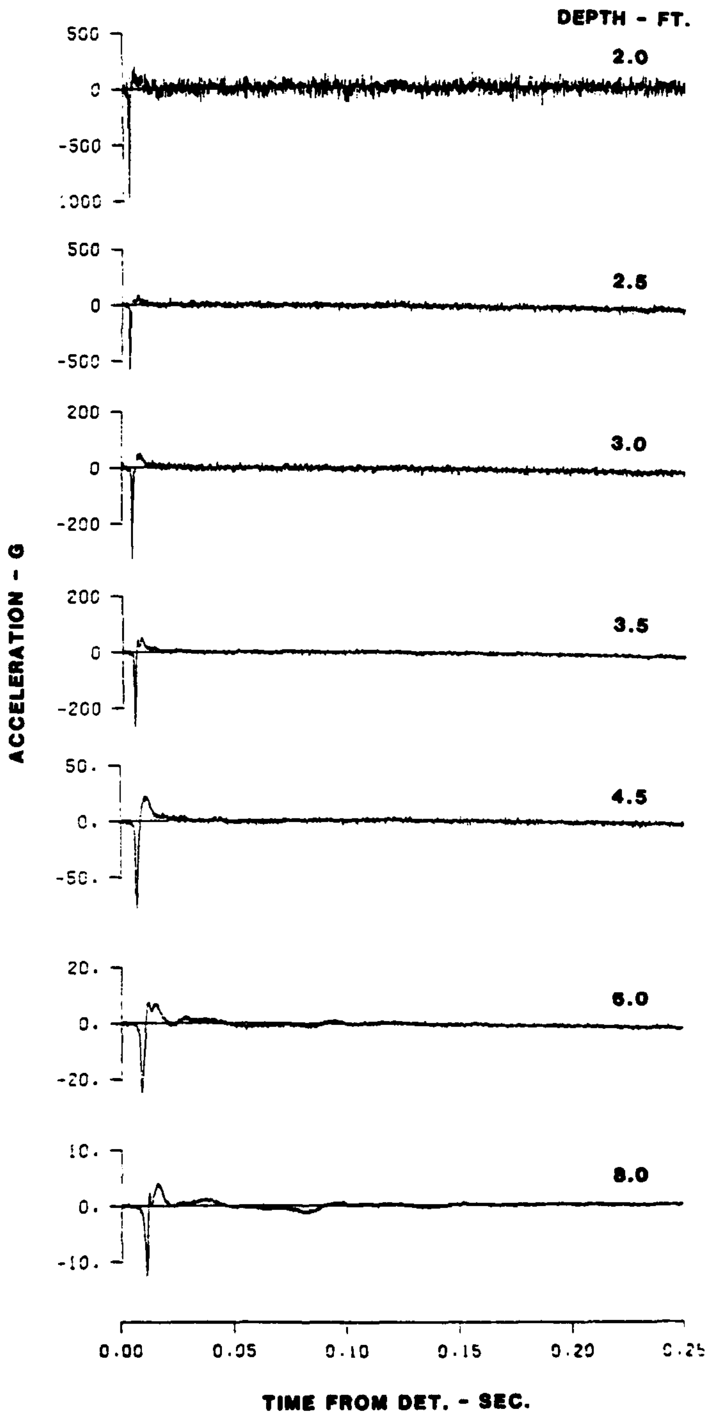

Figure 3.1. Acceleration time-histories, 27-pound control test.

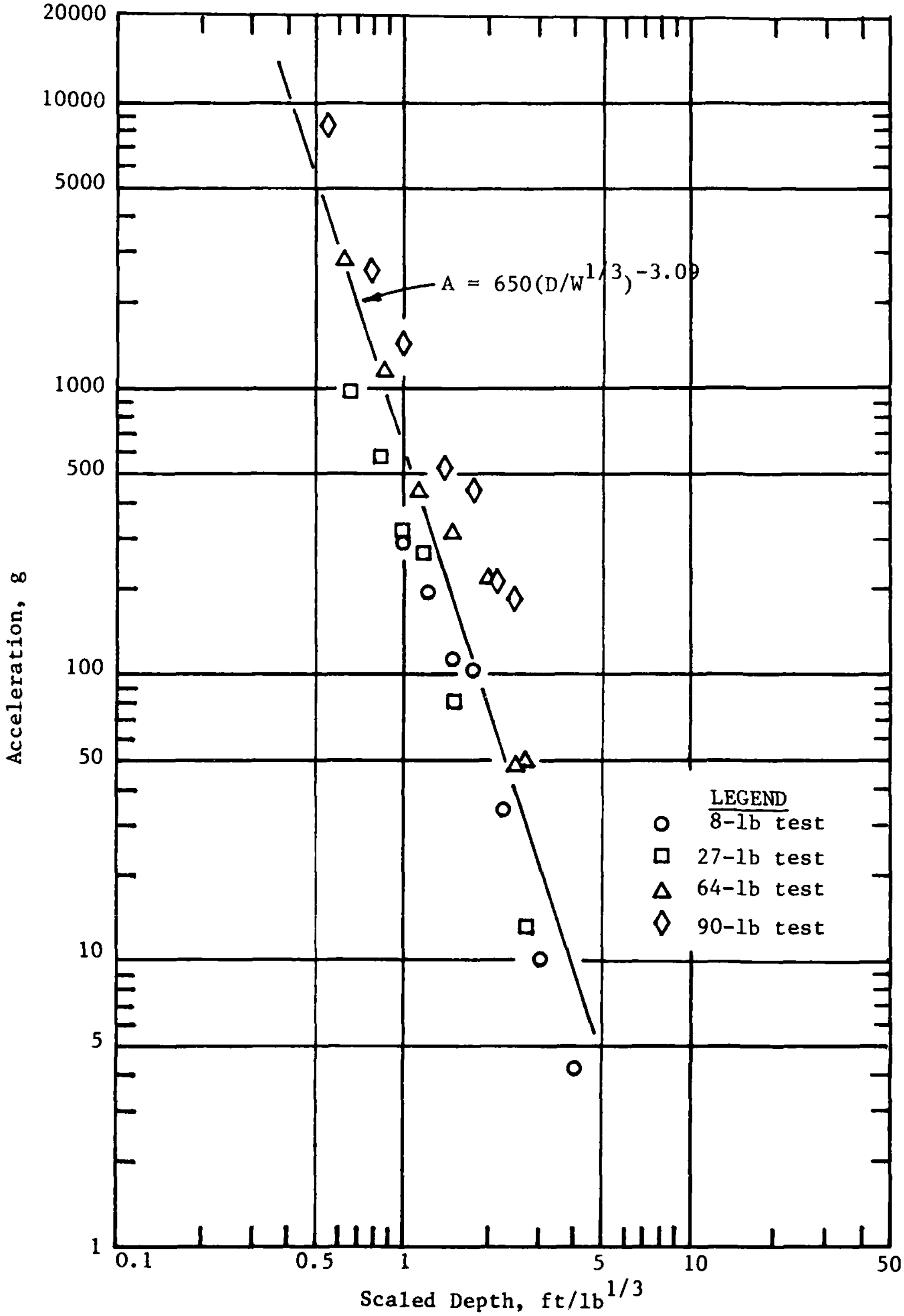

Figure 3.2. Peak acceleration versus scaled depth, control tests.

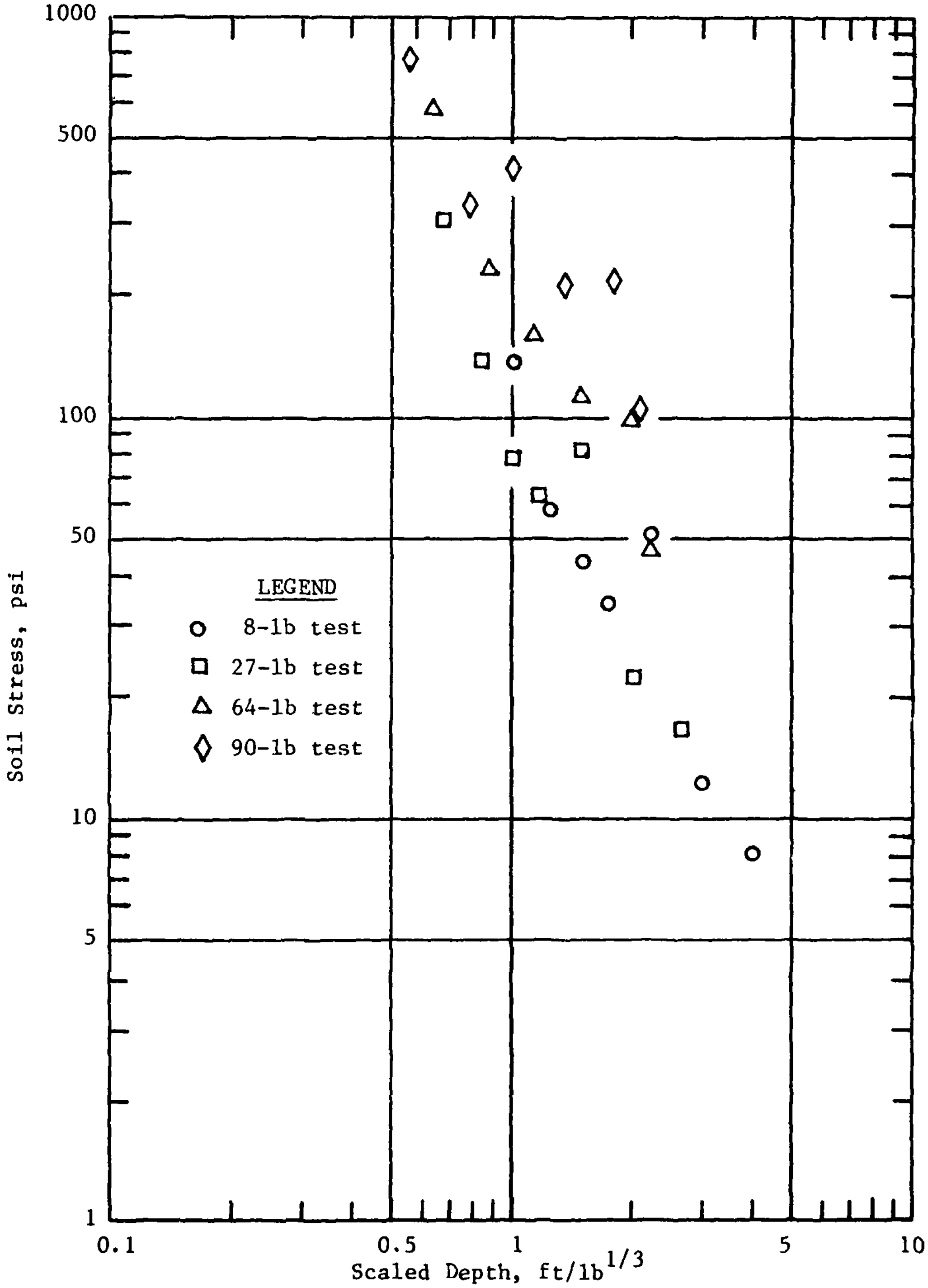

Figure 3.3. Peak stress versus scaled depth, control tests.

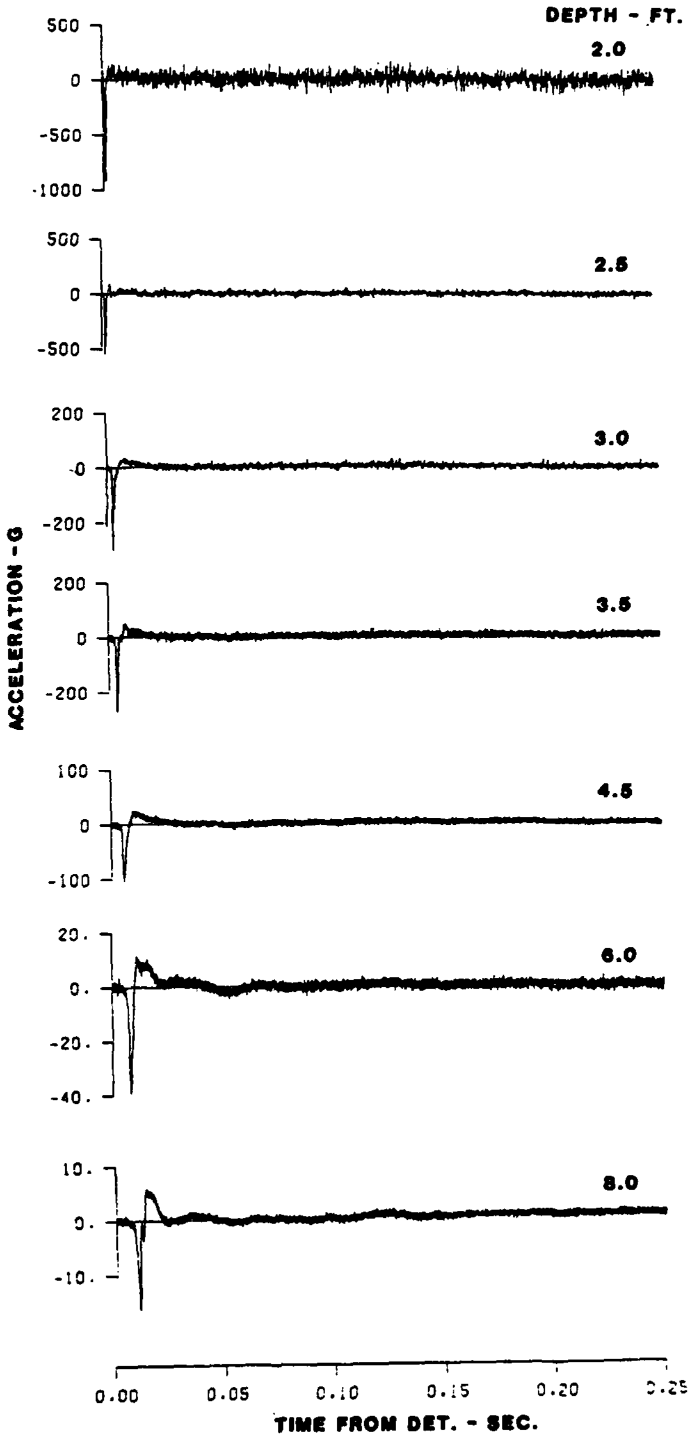

Figure 3.4. Acceleration time-histories, 27-pound rubble shield test.

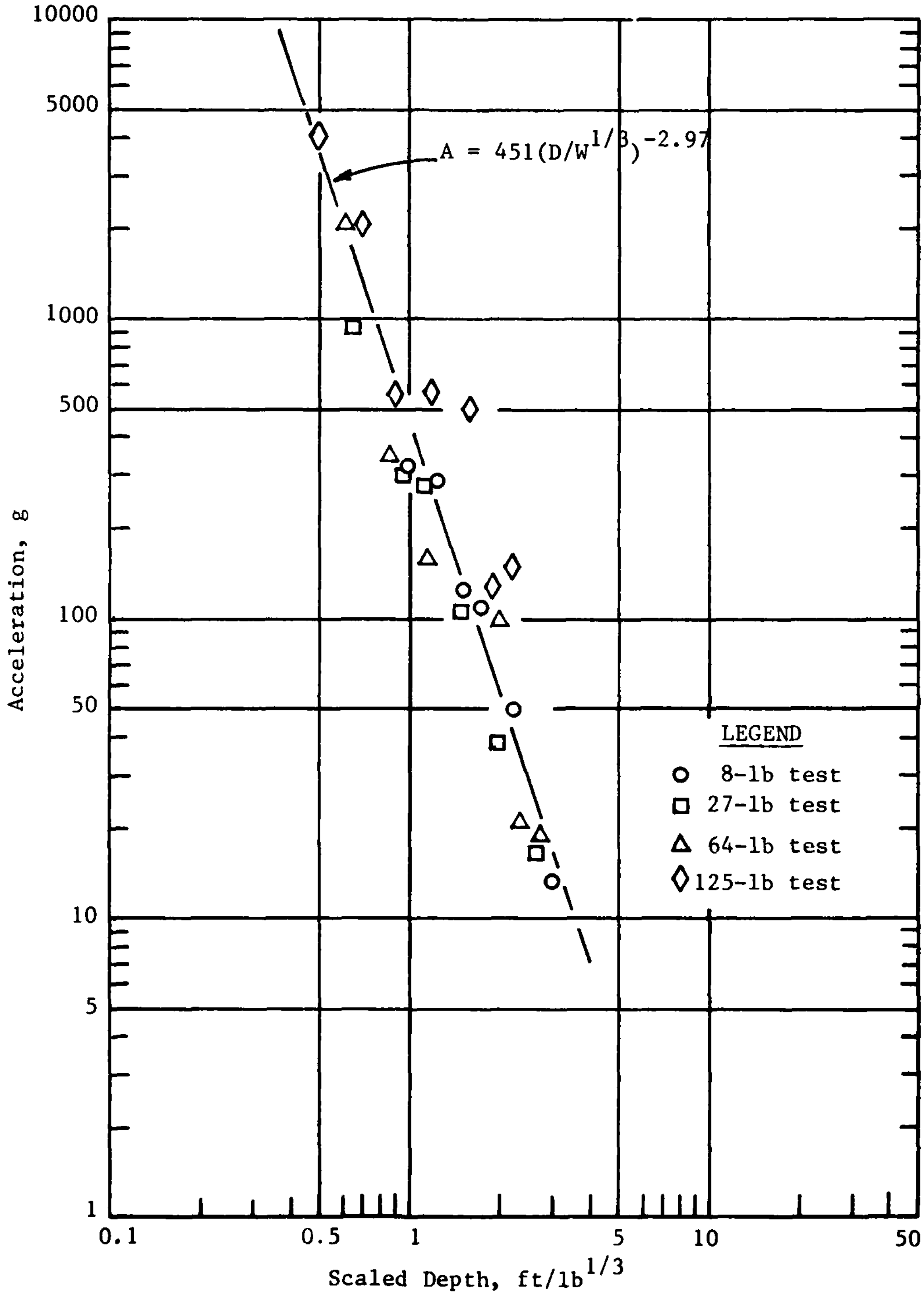

Figure 3.5. Peak acceleration versus scaled depth, rubble shield tests.

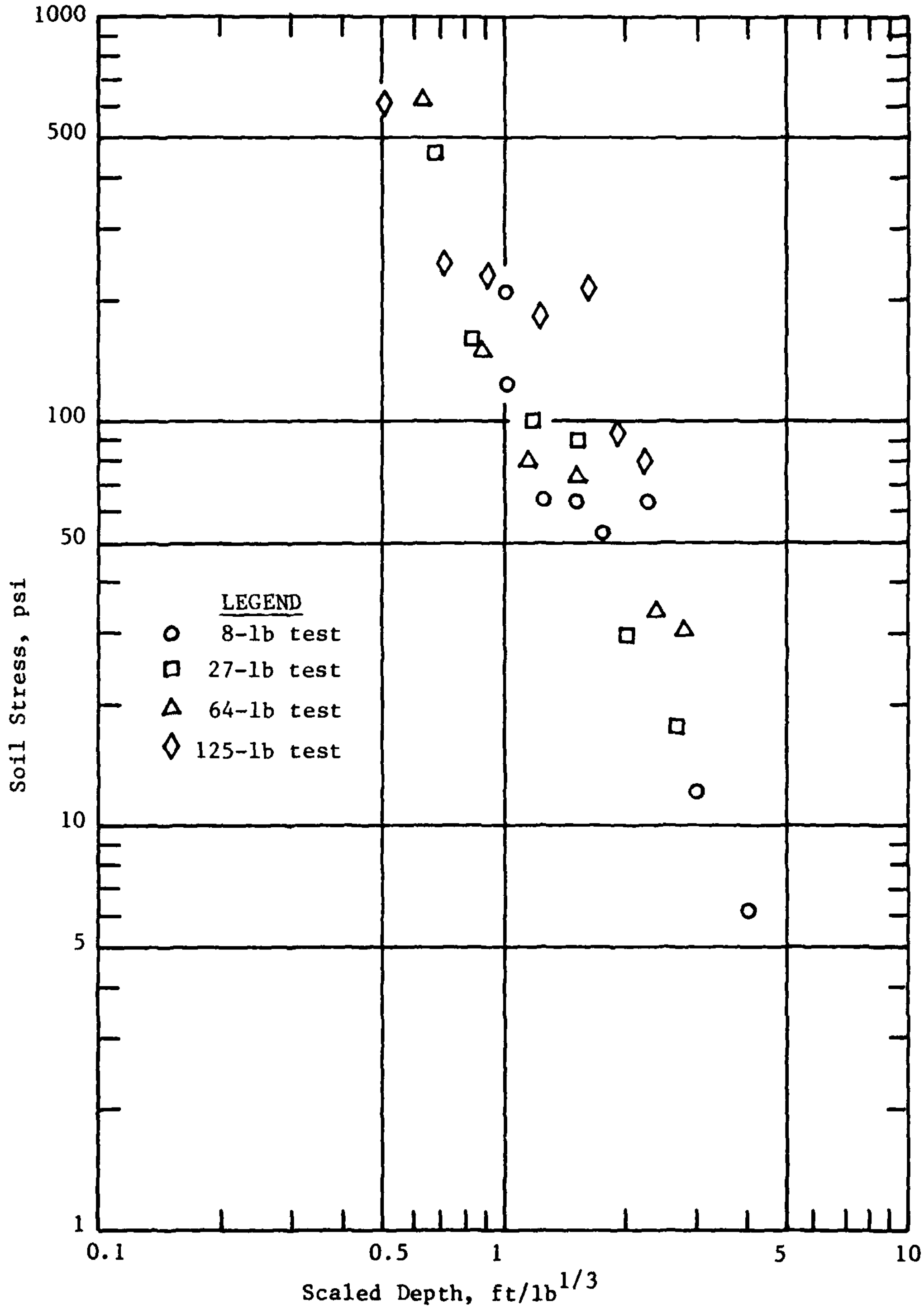

Figure 3.6. Peak stress versus scaled depth, rubble shield tests.

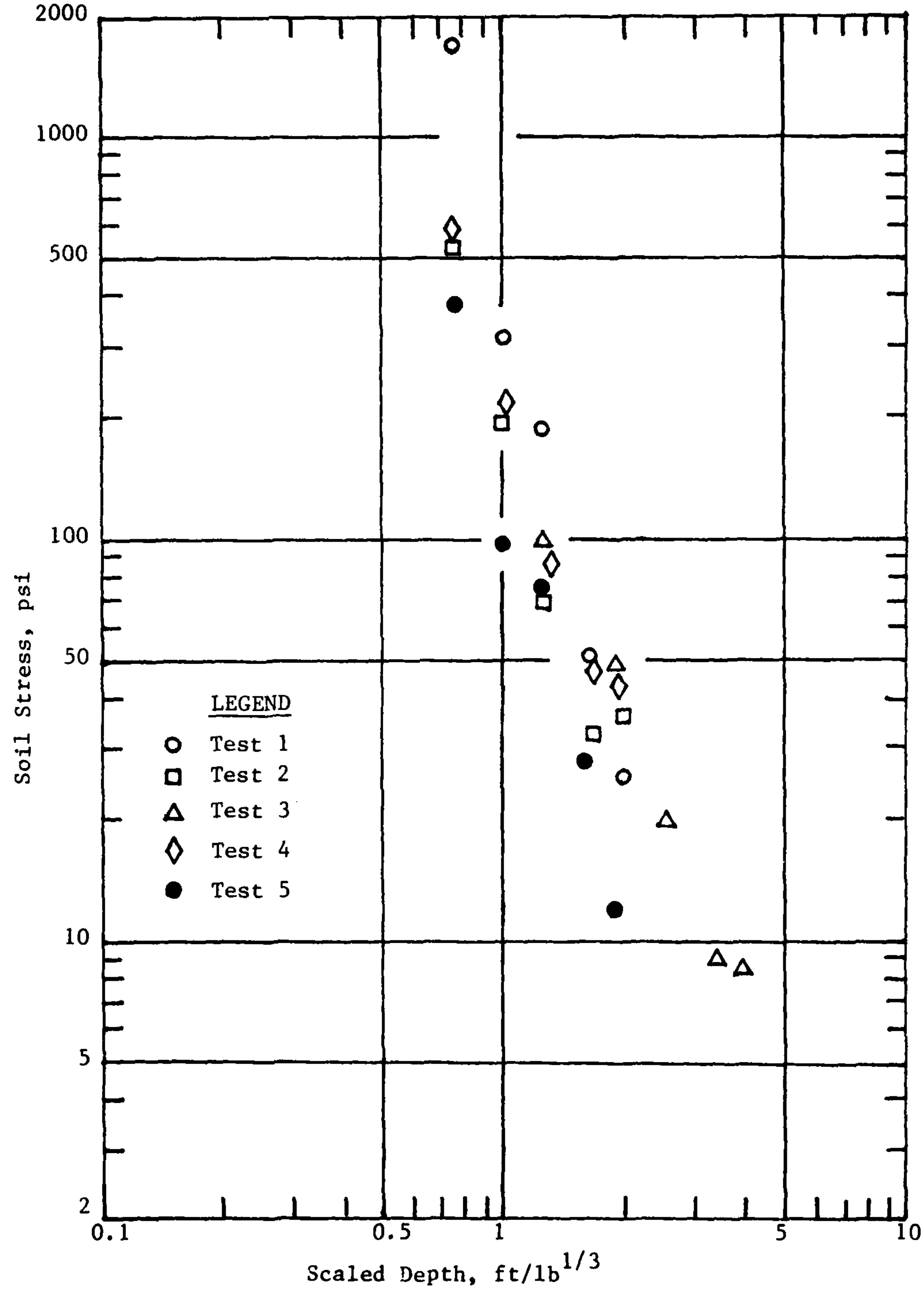

Figure 3.7. Peak stress versus scaled depth for burster slab tests.

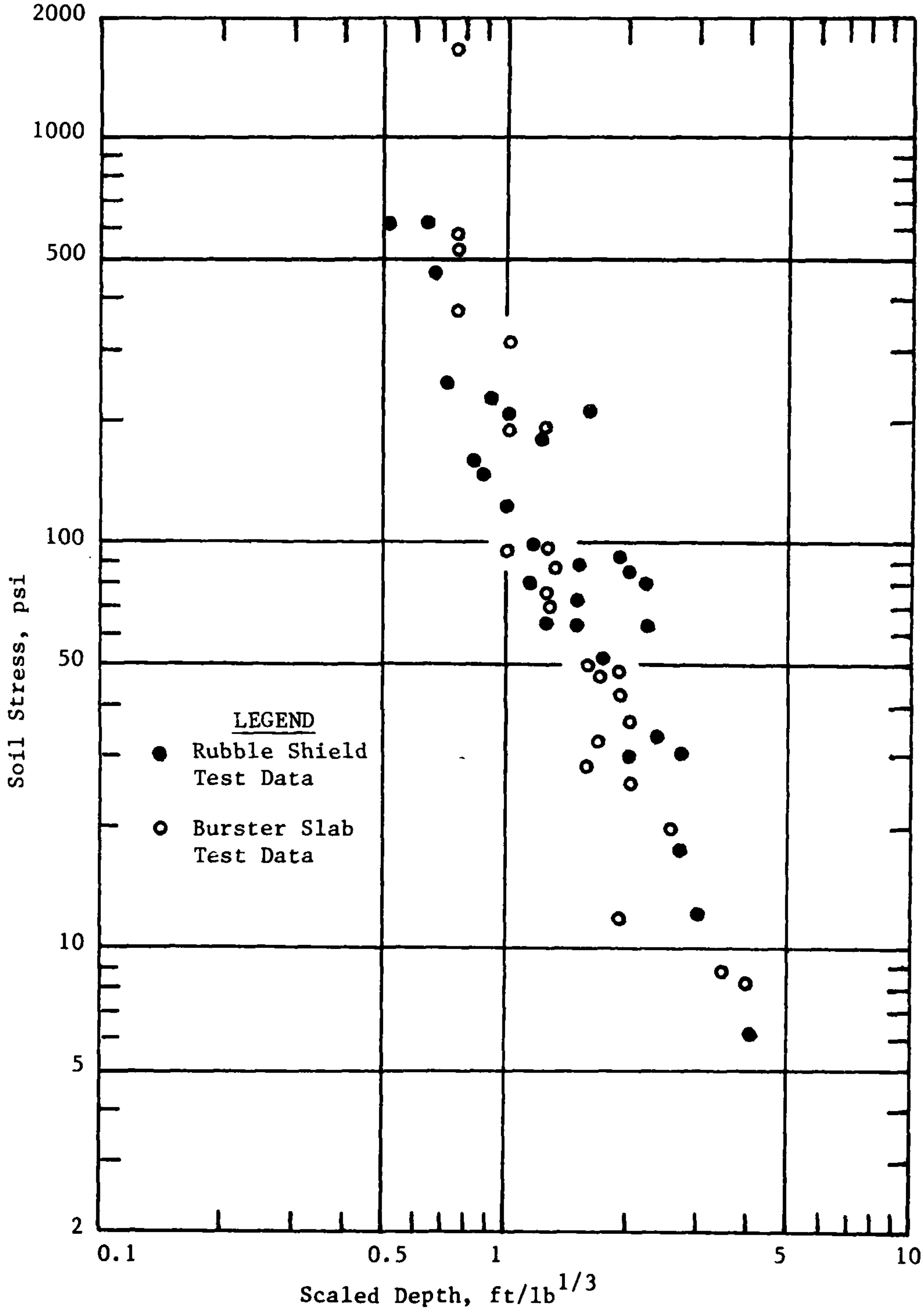

Figure 3.8. Comparison of peak stresses from rubble shield and burster slab tests.

CHAPTER 4

CONCLUSIONS

These tests indicate that, within the normal band of scatter expected from experimental data, there is no difference in shock transmitted to an underground structure from an explosion on the ground surface, whether that structure is unprotected by a shield or protected by a concrete slab or rock rubble screen, as long as the explosion remains at equal standoff distance. For design of underground structures, all three cases may be considered to produce equal stresses and motions.

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