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EFFECT OF LOW LOADING DENSITY ON BLAST PROPAGATION FROM EARTH COVERED MAGAZINES

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report contains the results from a series of high explosive tests designed to determine the airblast parameters propagating to the front, side, and rear of an earth covered munition storage magazine with a low loading density. The tests were conducted with 1/30th-scale donor models and hemi-cylindrical pentolite charges of 0.227, 0.363, 1.088, 1.814, and 5.040 kg masses. These charge masses simulate full size munition storage magazines filled with 6130, 9800, 29370, 48980 and 136080 kg of explosive. The 48980		

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) kg full size load was used as the baseline for comparing blast attenuation or enhancement from a full size load of 6130 kg. There was attenuation of both peak overpressure and impulse to the side and rear of the structure at the lower loading density. The impulse propagating to the front of the structure was enhanced while the peak overpressure showed no significant effect of the low loading density.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

I. INTRODUCTION

A. Background

This study is an extension of earlier work sponsored by the Department of Defense Explosives Safety Board (DDESB) to determine the airblast parameters propagating to the front, side, and rear of a munition storage magazine in event of an accidental explosion. In Reference 1 the model (1/50th-scale) study was based on 226800 kg, 136100 kg, and 45400 kg of explosive stored in a standard (18.3 metre length), steel single arch magazine.

Comparisons of the results from the model tests with full scale test results were excellent and added to the validity of using scaled models to simulate blast effects from full scale accidental explosions.

There are requirements for storing, in standard magazines, net explosive quantities, smaller than those tested in Reference 1. The earth cover suppresses the blast to the side and rear of the magazine in the near field but there is no suppression effect at the explosive work shop distance* and beyond for a Q of 45400 kilograms. It is surmised that there will be some suppressive effect at the greater distances, ($> 7.14\ Q^{1/3}$m) for smaller quantities stored in this magazine. If true it would permit siting of operating buildings and other controlled facilities closer to the above ground storage magazines.

B. Objectives

The objective of this series of tests is to obtain from scale-model experiments data on the suppression of blast propagation from stored quantities of munition in the range from 45400 kg (100090 lbm) down to approximately 4540 kg (10009 lbm).

This should provide a basis for establishing the quantity-distances to certain exposures from igloos containing small quantities of explosives. The distances of interest range from the safe separation distance $0.5Q^{1/3}$ m ($1.25\ w^{1/3}$ ft) out to $16Q^{1/3}$ m ($40\ w^{1/3}$ ft) where Q is in kilograms and distance is metres, and w is in pounds mass and distance is in feet.

A second objective was added to the program after the first series of tests were completed. Because the overlap of data from the 1/50th-scale model results simulating 45400 kg full scale and the 1/30th-scale model simulating 45400 kg full scale were not within an acceptable error band it was proposed to fire a 5.04 kg charge in the 1/30th-scale donor model to check the full scale magazine loaded with 136080 kg (300,000 lbm) as reported in Reference 1.

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[1] C. Kingery, G. Coulter, and T. Watson, "Blast Parameters from Explosions in Model Earth Covered Magazines," BRL-MR-2680, Sept 1976.

* The explosive work shop distance is defined as $d_e = 7.14\ m/kg^{1/3}$, scaled to the cube root of the mass Q(kg) of explosive: $D_e = d_e \times Q^{1/3}$.

II. TEST PROCEDURE

The test procedures followed to meet the objective were to (1) design the scale model, (2) design the explosive source, and (3) establish the instrumentation and blast lines.

A. Design of Magazine Model

The standard munitions storage magazine being modeled for this series of tests is shown in Figure 1. The overall width including the earth cover is 27.43 metres (90 feet) and the length is 28.96 metres (95 feet). The total volume of earth cover is 1665 m^3 (58,812 ft^3). The volume of the interior of the magazine is 496 m^3 (17,500 ft^3).

The model scale in Reference 1 was 1/50th and was sufficient for the simulation of large quantities of explosives. In order to simulate smaller quantities of explosives and work with similar size scaled charges a decision was made to use 1/30th-scale donor models. All linear dimensions were scaled down by a factor of 30. The scaled down model, with dimensions, is presented in Figure 2. The total volume of modeling sand is 0.0617 m^3 (2.178 ft^3) and the interior volume of the model is 0.018 m^3 (0.648 ft^3). A photograph of the interior portion of the model without the sand cover is shown in Figure 3. The model arch is aluminum rather than steel as used in the full-size magazines. Scaled steel doors were attached to the masonite headwall to more nearly simulate the suppression of blast associated with the closed doors.

The donor magazine model with the steel doors and modeling sand cover is shown in Figure 4.

B. Test Charges

The test charges used as the explosive source were cast Pentolite (50 PETN/50 TNT). The mass of the charges are usually based on the quantity to be stored in the full size magazine. For this series of tests the three molds for the hemi-cylinderical charges used in the tests reported in Reference 1 were still available and therefore a 1/30th-scale was selected to meet the range of explosive quantities of interest. Two additional molds were designed and manufactured, one to cover the low end of the desired range, and one for the additional high range shot.

The range of scaled charge weights tested were 0.227 kg, 0.363 kg, 1.066 kg, 1.814 kg and 4.99 kg (0.5, 0.8, 2.4, 4.0 and 11.0 lbm). When these masses are scaled up by 30^3 (27,000) then the full scale simulation is 6130 kg, 9800 kg, 28780 kg, 48980 kg, and 134730 kg (13,510, 21,605, 64,750, 107,980, and 297,000 lbm). These charges cover a range from 134730 kg down to 6130 kg which is very close to the original request for a range of 136080 kg down to 4536 kg.

The test charge was always placed with the flat side down and with the center of flat side at the geometric center of the magazine floor. The point of initiation was on the end toward the doors or along the zero degree blast line. The ratio of the mass of the model charge to the interior volume of the model was the same as the mass of the explosive in the storage magazine to the interior volume of the storage magazine.

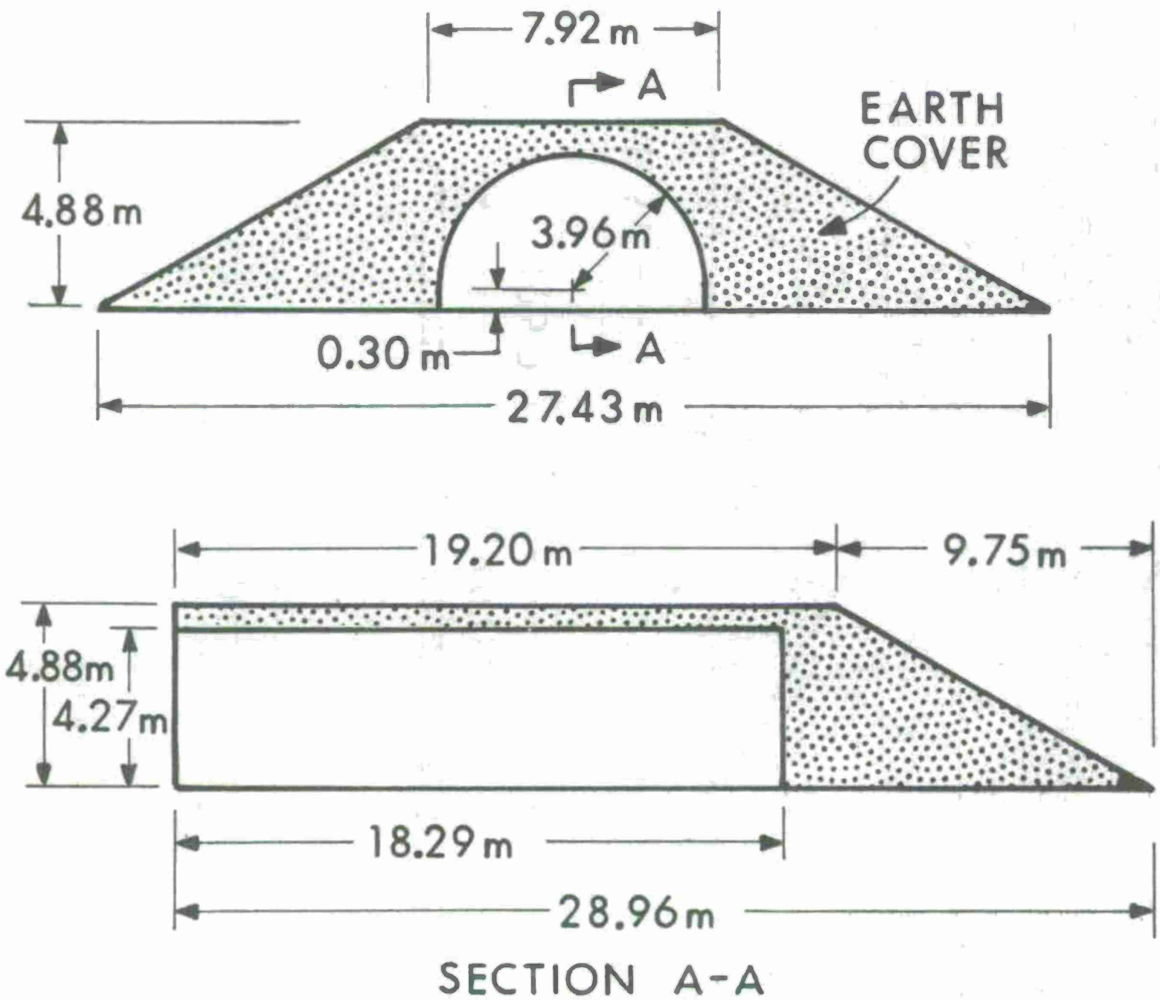

Figure 1. Standard munition storage magazine.

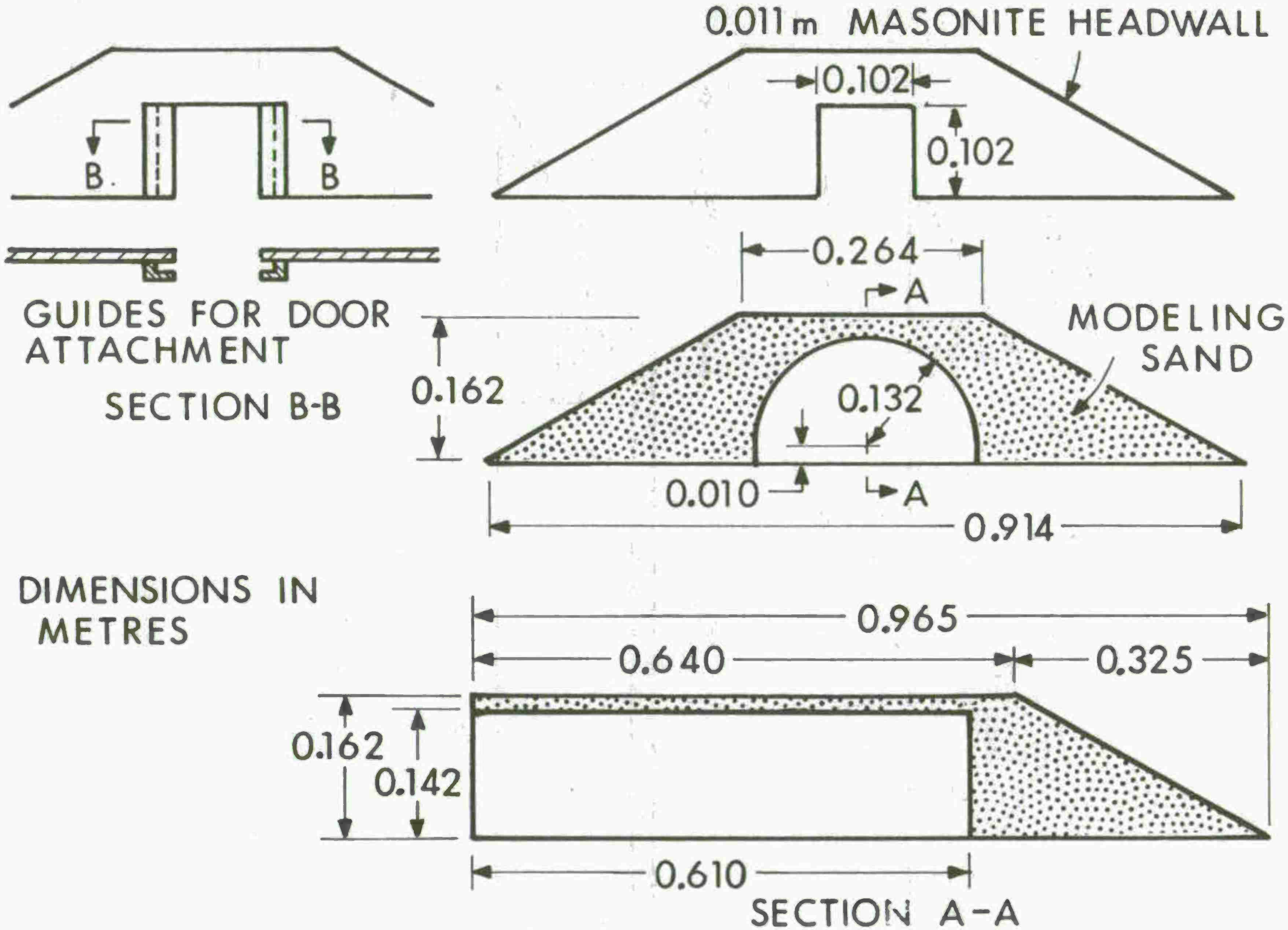

Figure 2. 1/30th-scale munition storage magazine model.

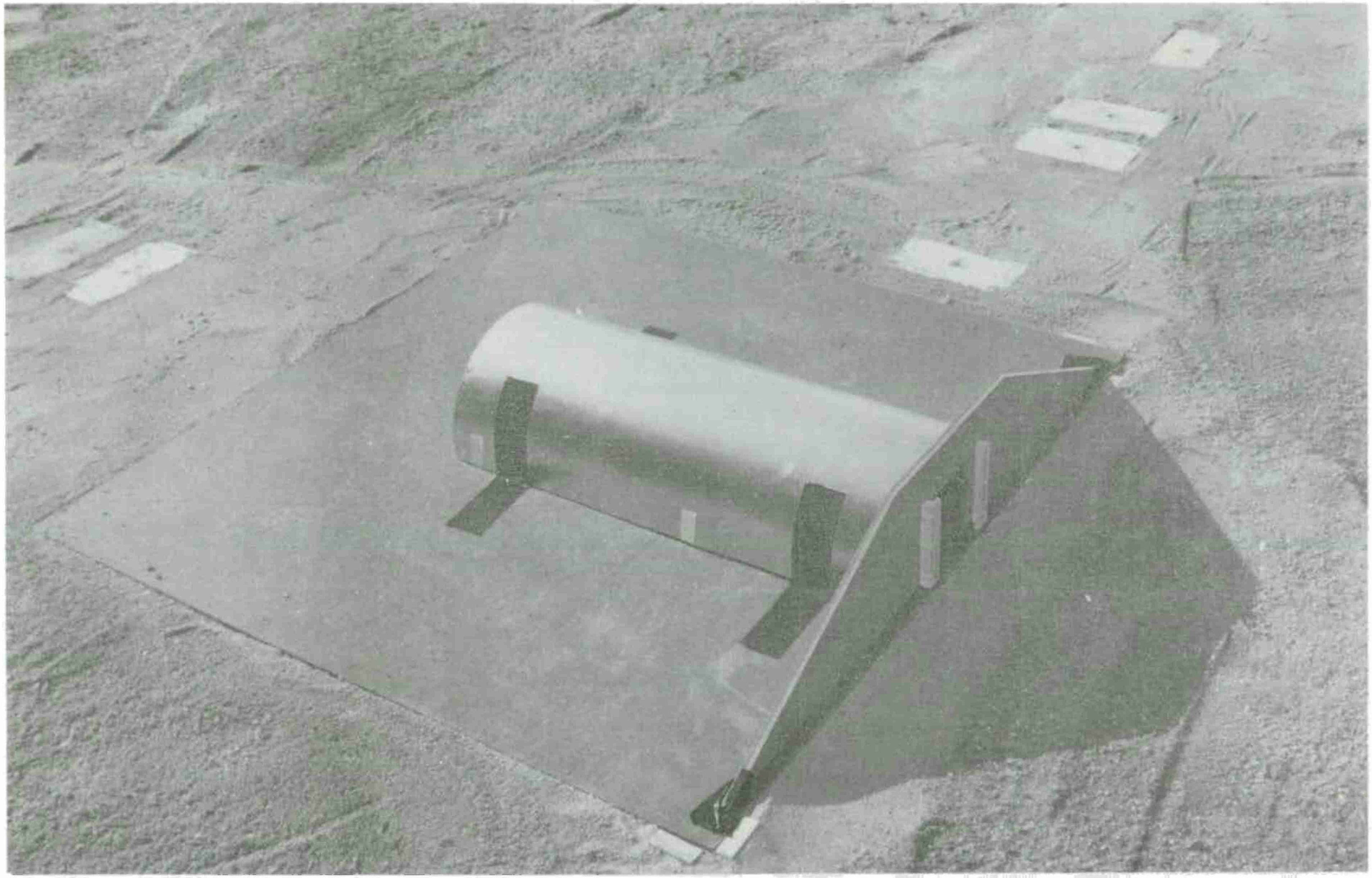

Figure 3. Photograph of internal portion of the magazine model.

Figure 4. Photograph of magazine model with sand cover.

C. Test Instrumentation

The instrumentation for this test series consisted of pressure transducers, magnetic tape recorder/playback, and a data reduction system. A block diagram is shown in Figure 5.

1. Pressure Transducers. Piezo-electric pressure transducers were used for this series of tests. The PCB Electronics Inc., models 113A22, 113A24, and 113A28, with quartz sensing elements and built-in source followers were used extensively.

2. Tape Recorder System. The tape recorder consisted of three basic units, the power supply and voltage calibrator, the amplifiers, and the FM recorder. The FM tape recorder was a Honeywell 7600 having a frequency response of 80 kHz. Once the signal was recorded on the magnetic tape it was played back and recorded on a Honeywell Visicorder. This oscillograph has 5 kHz frequency response and the overpressure versus time recorded at the individual stations can be read directly from the playback records for preliminary data analysis.

3. Data Reduction System. For the final data output, the tape signals were processed through an analog-to-digital converter, to a digital recorder-reproducer, and then to a computer. The computer (TEKTRONX 4051) was programmed to apply the calibration values and present the data in the proper units for analysis. From the computer, the data is put on a digital tape from which the final form can be plotted or tabulated. The digital tape can be also stored for future analysis.

D. Test Layout

The objective of this program was to document the blast propagation from a scaled munition magazine model assuming an accidental explosion of a specific amount of explosive. This required three lines instrumented with pressure transducers. One to the front of the magazine, designated the 0-degree blast line. One to the side of the magazine, designated the 90-degree blast line, and one to the rear of the magazine designated the 180-degree blast line. The field test layout is shown in Figure 6.

1. Donor Charges in Magazine. When the tests are conducted with the donor charge in the magazine model there are specific distances that should be documented along the blast line. The first of those is the "safe separation" distance. This is defined as the required separation of munition storage magazines. It is a function of the quantity of explosive to be stored and relative locations of the magazines. The safe separation distance to the front and rear of the donor magazine, the 0-degree and 180-degree blast line, is defined as

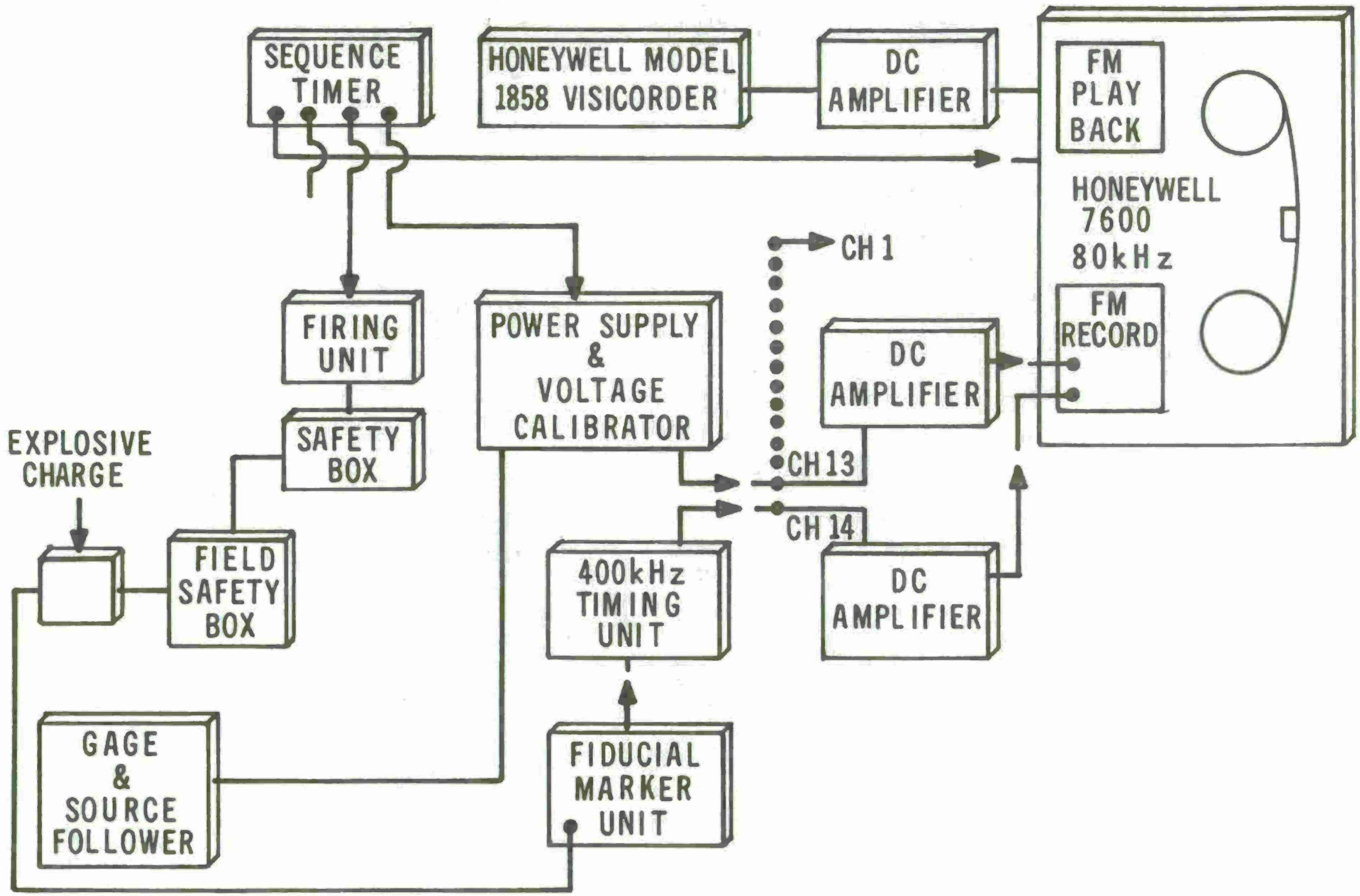

Figure 5. Instrumentation block diagram.

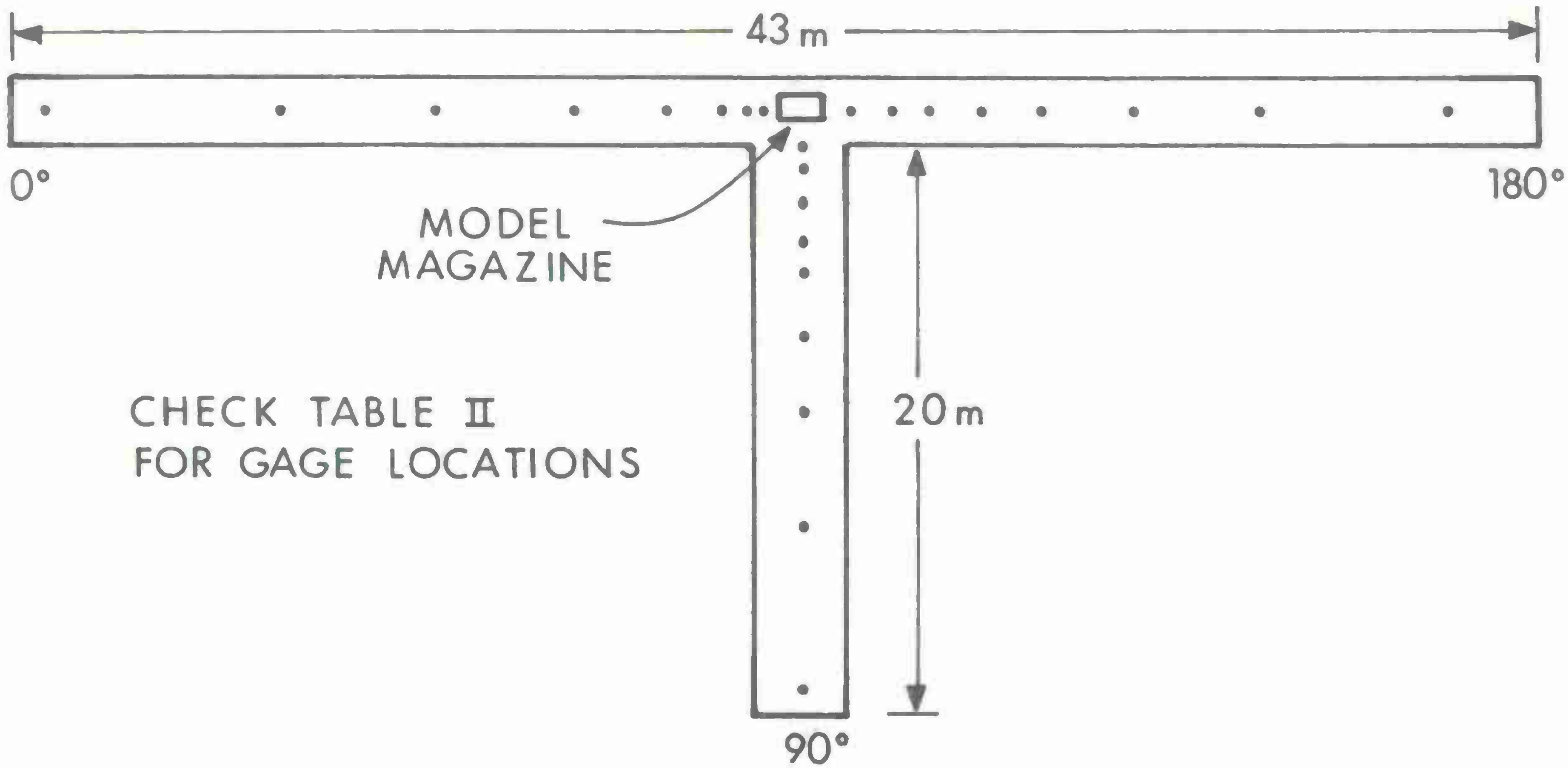

Figure 6. Test field layout.

$$D_{SF\ 0-180} = 0.8 \times Q^{1/3}\ \text{m}. \quad (1)$$

To the side of the magazine (the 90-degree blast line) the separation distance is defined as

$$D_{SF\ 90} = 0.5 \times Q^{1/3}\ \text{m}. \quad (2)$$

The safe separation distance is measured from the interior walls of the magazine. The pressure transducer station distances are measured from the geometric center of the floor of the magazine. An adjusted distance of 0.305 m was added to the 0-degree and 180-degree line safe separation distance for the first station and 0.132 m was added to the 90-degree line safe separation distance for the location of the first station. That is

$$D_{SF\ 0/180} + 0.305 = 0.8Q^{1/3} + 0.305 \quad (3)$$

$$D_{SF\ 90} + 0.137 = 0.5Q^{1/3} + 0.137 \quad (4)$$

Table 1 shows the location of the first station on each blast line for the five charge weights.

TABLE 1. LOCATION OF FIRST STATIONS

Q	$Q^{1/3}$	$.8Q^{1/3}$ m	0 and 180 $.8Q^{1/3} + .305$ m	$.5Q^{1/3}$ m	90 $.5Q^{1/3} + .132$ m
.227	.610	.488	.793	0.305	0.437
.363	.713	.570	.875	0.357	0.487
1.089	1.029	.823	1.128	0.514	0.646
1.814	1.220	.976	1.281	0.610	0.742
4.990	1.709	1.367	1.672	0.855	0.987

The station locations for the five charge weights and the three blast lines are listed in Table 2. The distances range from 0.57 m to 21.3 m with many station distances repeated for the different charge masses in order to keep movement of gage stations to a minimum and thereby keep the turn around time per test as short as possible. Station 90-1 was placed no closer than 0.57 m because the sand cover, the masonite base, and the gage mount would not allow the measurement to be made closer.

2. Donor Charge Unconfined. To meet the objectives of the test and determine the suppressive effect of the earth cover one must establish a base for comparison. Therefore the blast parameters along the 0, 90, and 180-degree blast lines were determined for four charge masses without the magazine in place, ie, charge unconfined. The 5.0 kg charge was not tested unconfined.

E. Test Matrix

The series was designed to conduct the minimum number of tests to meet the objective. Tests were conducted both with the charges covered, ie, in the

TABLE 2. GAGE STATION LOCATIONS

Charge Mass (kg)	4.99	1.814	1.066	0.363	0.227
Station	Distance m	Distance m	Distance m	Distance m	Distance m
0-1	1.68	1.27	1.12	0.87	0.79
0-2	2.29	1.68	1.27	1.27	1.27
0-3	3.20	2.29	1.68	1.68	1.68
0-4	4.27	3.20	2.29	2.29	2.29
0-5	6.00	4.27	3.20	3.20	3.20
0-6	8.40	9.14	6.10	6.10	4.27
0-7	14.00	12.80	10.67	10.67	6.10
0-8	21.00	21.34	18.29	18.29	10.67
90-1	0.99	0.74	0.64	0.61*	0.57*
90-2	1.50	1.12	1.12	1.12	1.14
90-3	2.00	1.27	1.27	1.27	1.68
90-4	3.20	1.68	1.68	1.68	2.30
90-5	4.50	2.29	2.29	2.29	3.35
90-6	6.00	3.20	5.03	5.03	5.03
90-7	8.00	6.71	6.10	6.80	6.80
90-8	12.50	12.80	12.80	12.80	9.14
90-9	21.00	21.34	18.29	18.29	12.80
180-1	1.68	1.27	1.12	0.87	0.79
180-2	2.29	1.68	1.27	1.27	1.27
180-3	3.20	2.29	1.68	1.67	1.68
180-4	4.27	3.20	2.29	2.29	2.29
180-5	6.00	4.27	3.20	3.20	3.20
180-6	8.40	6.10	6.10	6.10	4.27
180-7	14.00	12.80	10.67	10.67	6.10
180-8	21.00	21.34	18.29	18.29	10.67

*Station was as close as the sand covered slope would allow.

magazine, and uncovered to establish any suppressive effect at the lower stored quantities of munitions. The number of tests and conditions planned are listed in Table 3.

TABLE 3. PLANNED TEST MATRIX

Charge Mass kg	Charge In-Magazine Tests	Charge Unconfined Tests
.227	2	1
.363	2	1
1.089	2	1
1.814	2	1
5.040	2	0

If large variations were found in the results from the two "in-magazine tests" then a third test would be conducted. Likewise if the uncovered shots do not follow the trend established in Reference 1, then a repeat test would be conducted.

III. RESULTS

The results will be presented in the form of tables and graphs. Each blast line will be treated separately for the various charge masses in order to show any suppressive effect the earth cover might have at the lower loading densities. See Appendixes for pressure time records for each blast line.

The program was modified during the field test phase because the overlap expected at the 45360 kg charge mass between the 1/50th-scale (Reference 1) and the 1/30th-scale results did not occur at the safe separation distance. A test series to include the simulation of a full-scale 136,080 kg in a standard magazine was added to further check the 1/50 and 1/30 scaled model results.

There is also some concern in the comparison of the suppressive effect of the earth cover when using a hemicylindrical charge as the donor because of the second shock pulse that develops at the greater distances when detonated in an uncovered environment. Test Number 7 was added in which a hemispherical charge of 1.128 kg was tested in the 1/30th-scaled magazine model of a standard munition storage magazine. The results of this test will be compared with the in-magazine hemicylindrical charge tests. They may also be compared with the standard hemispherical surface burst data.[2] The tests as conducted are listed in Table 4.

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[2] C.N. Kingery, "Air Blast Parameters versus Distance for Hemispherical TNT Surface Burst," BRL R 1344, September 1960.

TABLE 4. TEST MATRIX AS CONDUCTED

Test No.	Charge Mass, kg	Charge Environment
1	1.814	in magazine
2	1.814	in magazine
3	1.814	free-field
4	1.070	in magazine
5	1.066	in magazine
6	1.066	in magazine
7[a]	1.128	in magazine
8	1.066	free-field
9	0.363	in magazine
10	0.363	in magazine
11	0.363	free-field
12	0.227	in magazine
13	0.227	in magazine
14	0.227	in magazine
15	0.227	free-field
16	4.99	in magazine
17	4.99	in magazine

[a] hemisphere

A. Blast Parameters Along the 0-Degree Blast Line.

The 0-degree blast line extends to the front of the magazine. The results from Reference 1 indicate an enhancement of the blast parameters because of the focusing effect of the three earth barriers and the weakness of the headwall and door. As listed in Table 4 either two or three tests were conducted for the covered conditions therefore an average value is listed in the data tables. Only one test was conducted for the unconfined charges. The 5.0 kg charge was not fired unconfined. The blast parameters for all blast lines and charge masses are listed in Table 5 through 14.

1. Peak Overpressure versus Scaled Distance, 0-Degree Blast Line. The average peak overpressures versus scaled distances recorded at Stations 0-1 through 0-8 for the unconfined tests are listed in Tables 6, 8, 10, and 12. The values are plotted in Figure 7. Where double peaks were recorded along the blast line only the maximum values are plotted. There is excellent agreement between the various charge masses when scaled to 1 kg mass. The results follow the same trend as established in Reference 1.

The peak overpressure versus scaled distance along the 0-degree blast line for the five charge masses, tested in magazine, are plotted in Figure 8. The results indicate a smooth pressure decay with distance over the full range of measurements. It was unexpected that the 5.0 kg tests would produce pressure values lower than average at scaled distances greater than 3 $m/kg^{1/3}$.

TABLE 5. AIR BLAST PARAMETERS FROM 1.814 kg IN MAGAZINE

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$
0-1	1.27	4.17	1504	218	292	42.3	0.528	0.95	1.04	239
0-2	1.68	5.50	1001	145	257	37.3	0.861	1.31	1.38	211
0-3	2.29	7.50	572	83	212	30.8	1.536	2.51	1.88	174
0-4	3.20	10.50	225	33	137	19.8	2.870	2.60	2.62	112
0-5	4.27	14.00	113	16.1	99.6	14.4	5.185	2.75	3.50	81.7
0-6	9.14	30.00	22.4	3.25	34.9	5.06	18.00	4.15	7.49	28.6
0-7	12.80	42.00	12.4	1.79	25.6	3.71	28.51	4.50	10.50	21.0
0-8	21.34	70.00	5.49	0.80	14.4	2.09	53.21	5.60	17.50	11.8
90-1	0.74	2.42	273/390	39.6/56.6	135	19.6	1.075	1.24	0.61	111
90-2	1.12	3.68	304	44.0	126	18.2	1.630	1.44	0.92	103
90-3	1.27	4.17	333	48.3	123	17.8	1.885	1.39	1.04	101
90-4	1.68	5.50	228	33.1	115	16.8	2.560	1.87	1.38	94.3
90-5	2.29	7.50	157	22.8	113	16.4	3.765	2.56	1.88	92.7
90-6	3.20	10.50	94.9	13.8	90.1	13.1	5.935	2.77	2.62	73.9
90-7	6.71	22.01	36.3	5.26	52.7	7.65	14.93	4.37	5.50	43.2
90-8	12.80	42.00	12.0	1.75	29.8	4.33	32.11	5.33	10.50	24.4
90-9	21.34	70.00	5.99	0.87	18.8	2.77	56.84	6.55	17.50	15.4
180-1	1.27	4.17	288	41.8	95.5	13.8	1.700	1.93	1.04	78.3
180-2	1.68	5.51	209	30.3	88.0	12.8	2.420	1.66	1.38	72.2
180-3	2.29	7.51	113	16.5	76.9	11.2	3.745	2.52	1.88	63.1
180-4	3.20	10.50	66.9	9.70	57.8	8.38	5.875	2.99	2.62	47.4
180-5	4.27	14.00	44.0	6.38	49.1	7.12	8.663	3.65	3.50	40.3
180-6	6.10	20.01	27.5	4.00	39.9	5.78	13.56	4.55	5.00	32.7
180-7	12.80	42.00	8.24	1.20	20.5	2.98	32.67	5.41	10.50	16.8
180-8	21.34	70.00	4.50	0.65	12.5	1.81	57.62	6.04	17.50	10.2

TABLE 6. AIR BLAST PARAMETERS FROM 1.814 kg UNCONFINED

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$
0-1	1.27	4.17	911	132	269	39.0	0.462	1.27	1.04	220
0-2	1.68	5.50	543	787	182	26.4	0.907	1.82	1.38	149
0-3	2.29	7.50	304	44.1	124	18.0	1.790	1.93	1.88	102
0-4	3.20	10.50	106	15.4	104	15.1	3.510	3.50	2.62	85.3
0-5	4.27	14.00	61.0/48.8	8.8/7.1	94.3	12.6	6.060	3.75	3.50	77.3
0-6	9.14	30.00	33.8	4.90	53.9	7.81	19.32	4.90	7.49	44.2
0-7	12.80	42.00	16.1	2.34	36.6	5.30	29.44	5.10	10.50	30.0
0-8	21.34	70.00	8.09	1.17	22.4	3.25	53.92	6.10	17.50	18.4
90-1	0.74	2.42	4153	602	215	31.2	0.125	0.28	0.61	176
90-2	1.12	3.68	2462	357	251	36.4	0.290	0.49	0.92	206
90-3	1.27	4.17	—	—	—	—	—	—	1.04	—
90-4	1.68	5.50	1508	219	303	44.0	0.665	1.12	1.38	248
90-5	2.29	7.50	550	79.8	155	22.5	1.350	1.24	1.88	127
90-6	3.20	10.50	216	31.4	110	16.0	2.990	3.98	2.62	90.2
90-7	6.71	22.01	40.5	5.87	60.4	8.77	11.52	4.91	5.50	49.6
90-8	12.80	42.00	11.6	1.69	34.2	4.96	28.78	6.42	10.50	28.0
90-9	21.34	70.00	5.48	0.80	21.2	3.07	53.84	7.25	17.50	17.4
180-1	1.27	4.17	—	—	—	—	—	—	1.04	—
180-2	1.68	5.51	—	—	—	—	—	—	1.38	—
180-3	2.29	7.51	—	—	—	—	—	—	1.88	—
180-4	3.20	10.50	332	48.1	109	15.8	1.690	1.61	2.62	89.2
180-5	4.27	14.00	68.9	10.0	66.7	9.67	3.855	3.68	3.50	54.7
180-6	6.10	20.01	24.6/39.6	3.57/5.74	76.4	11.1	8.637	7.68	5.00	62.7
180-7	12.80	42.00	4.43/18.8	.643/2.73	37.4	5.43	28.01	7.12	10.50	30.7
180-8	21.34	70.00	2.25/8.28	.327/1.20	22.0	3.20	53.27	7.13	17.50	18.1

TABLE 7. AIR BLAST PARAMETERS FROM 1.066 kg IN MAGAZINE

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$
0-1	1.12	3.68	1400	203	203	29.5	0.491	0.75	1.10	198
0-2	1.27	4.17	1430	207	257	37.3	0.596	1.10	1.24	251
0-3	1.68	5.50	827	120	241	35.0	0.980	2.20	1.64	236
0-4	2.29	7.50	356	51.6	146	21.2	1.772	2.34	2.24	143
0-5	3.20	10.50	166	24.1	96	13.4	3.462	2.77	3.13	94
0-6	6.10	20.00	33.1	4.80	40.4	5.87	10.76	3.00	5.97	39.5
0-7	10.67	35.00	12.7	1.85	25.6	3.71	23.82	3.97	10.44	25.0
0-8	18.29	60.00	5.28	0.77	12.1	1.75	45.76	4.41	17.90	11.9
90-1	0.64	2.10	282/317	40.9/46.0	109	15.8	1.060	1.22	0.63	107
90-2	1.12	3.68	194/226	28.1/32.8	100	14.5	1.782	1.49	1.10	97.9
90-3	1.27	4.17	200	29.0	97.4	14.1	2.067	1.68	1.24	95.4
90-4	1.68	5.50	163	23.6	91.8	13.3	2.850	1.98	1.64	89.9
90-5	2.29	7.50	116	16.8	84.0	12.1	4.178	2.24	2.24	82.2
90-6	5.03	16.50	44.0	6.39	52.8	7.65	11.21	3.26	4.92	51.6
90-7	6.10	20.00	29.5	4.28	39.0	5.66	14.06	3.77	5.97	38.2
90-8	12.80	42.00	8.72	1.27	19.4	2.82	33.28	4.70	12.53	19.0
90-9	18.29	60.00	5.15	0.75	14.0	2.02	49.38	5.65	17.90	13.7
180-1	1.12	3.68	249	36.1	77.2	11.2	1.554	1.14	1.10	75.6
180-2	1.27	4.17	223	32.3	75.0	10.9	1.801	1.32	1.24	73.4
180-3	1.68	5.50	156	22.6	68.7	10.0	2.632	1.78	1.64	67.3
180-4	2.29	7.50	90.2	13.1	55.2	8.00	3.977	2.29	2.24	54.0
180-5	3.20	10.50	48.4	7.02	41.3	6.00	6.275	2.83	3.13	40.5
180-6	6.10	20.00	18.4	2.66	26.3	3.82	14.21	4.56	5.97	25.8
180-7	10.67	35.00	7.36	1.07	16.1	2.34	27.42	4.85	10.44	15.8
180-8	18.29	60.00	3.71	0.54	8.96	1.30	49.90	5.34	17.90	8.78

TABLE 8. AIR BLAST PARAMETERS FROM 1.066 kg UNCONFINED

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	m/kg$^{1/3}$	kPa-ms/kg$^{1/3}$
0-1	1.12	3.68	708	03	185	27.0	0.422	1.21	1.10	182
0-2	1.27	4.17	625	91.0	184	26.7	0.575	1.70	1.24	180
0-3	1.68	5.50	290	39.5	108	15.7	1.170	1.50	1.64	106
0-4	2.29	7.50	166	24.1	82.0	11.9	2.240	1.98	2.24	80.2
0-5	3.20	10.50	67.5/73.2	9.79/10.5	84.6	12.3	4.290	3.00	3.13	82.8
0-6	6.10	20.00	23.6/37.9	3.42/5.50	57.2	8.29	12.04	4.00	5.97	56.0
0-7	10.67	35.00	18.2	2.63	35.8	5.19	24.70	4.50	10.44	35.0
0-8	18.29	60.00	7.42	1.08	18.1	2.62	46.78	5.20	17.90	17.7
90-1	0.64	2.10	2634	382	176	25.5	0.085	0.30	0.63	172
90-2	1.12	3.68	2345	340	259	37.6	0.315	1.10	1.10	254
90-3	1.27	4.17	1352	196	183	26.5	0.420	0.58	1.24	179
90-4	1.68	5.50	849	123	180	26.1	0.775	0.88	1.64	176
90-5	2.29	7.50	318	46.1	121	17.6	1.665	2.07	2.24	118
90-6	5.03	16.50	56.1	8.14	64.1	9.29	8.165	4.00	4.92	62.7
90-7	6.10	20.00	33.3	4.83	47.1	6.83	11.04	4.56	5.97	46.1
90-8	12.80	42.00	8.80	1.28	23.5	3.41	30.39	5.55	12.53	23.0
90-9	18.29	60.00	5.21	0.76	17.0	2.46	46.66	6.23	17.90	16.6
180-1	1.12	3.68	4375	634	505	73.2	0.265	1.85	1.10	494
180-2	1.27	4.17	—	—	—	—	—	—	1.24	—
180-3	1.68	5.50	2193	318	205	29.7	0.535	0.65	1.64	200
180-4	2.29	7.50	557	80.8	148	21.4	1.060	1.37	2.24	144
180-5	3.20	10.50	94.8	13.7	72.9	10.6	2.815	4.49	3.13	71.3
180-6	6.10	20.00	17.3/47.9	2.51/6.95	55.7	8.08	10.64	5.43	5.97	54.6
180-7	10.67	35.00	4.70/19.4	0.68/2.81	33.2	4.81	24.10	5.35	10.44	32.4
180-8	18.29	60.00	1.40/8.94	0.20/1.30	18.0	2.62	46.97	5.30	17.90	17.7

TABLE 9. AIR BLAST PARAMETERS FROM 0.363 kg IN MAGAZINE

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$
0-1	0.87	2.86	1215	176	173	25.1	0.541	0.54	1.22	243
0-2	1.27	4.17	572	83.0	148	21.4	0.969	1.44	1.78	207
0-3	1.68	5.50	201	29.2	102	14.8	1.620	1.56	2.35	143
0-4	2.29	7.50	176	25.5	74.7	10.8	2.900	2.03	3.20	105
0-5	3.20	10.50	55.7	8.08	46.7	6.77	4.940	2.98	4.49	65.5
0-6	6.10	20.00	19.6	2.85	22.5	3.27	12.88	3.40	8.55	31.6
0-7	10.67	35.00	6.28	0.91	11.4	1.65	26.30	3.96	14.96	16.0
0-8	18.29	60.00	3.10	0.45	6.00	0.87	48.95	4.46	25.64	8.41
90-1	0.61	2.00	85/.105	12.3/15.2	67.5	9.79	1.215	1.55	0.86	94.6
90-2	1.12	3.68	64.5/83.9	9.35/12.2	57.4	8.33	2.098	1.85	1.57	80.5
90-3	1.27	4.17	59.0/89.4	8.6/13.1	57.1	8.28	2.413	1.85	1.78	80.0
90-4	1.68	5.50	46.5/70.6	6.74/10.2	52.5	7.62	3.343	2.10	2.35	73.6
90-5	2.29	7.50	36.2/52.8	5.25/7.66	46.9	6.80	4.985	2.30	3.20	65.8
90-6	5.03	16.50	22.0	3.19	22.8	3.31	12.61	2.58	7.05	32.0
90-7	6.80	22.30	11.8	1.71	16.2	2.35	17.57	2.95	9.53	22.7
90-8	12.80	42.00	4.68	0.68	8.58	1.24	35.26	3.44	17.95	12.0
90-9	18.29	60.00	2.90	0.42	5.78	0.84	51.54	3.92	25.64	8.11
180-1	0.87	2.86	120	17.4	42.1	6.11	1.455	1.50	1.22	59.0
180-2	1.27	4.17	82.4	11.9	36.6	5.31	2.330	1.80	1.78	51.3
180-3	1.67	5.50	51.2	7.43	30.8	4.47	3.328	2.32	2.35	43.2
180-4	2.29	7.50	32.3	4.68	26.7	3.87	5.108	2.67	3.20	37.4
180-5	3.20	10.50	21.4	3.10	21.7	3.15	7.650	2.70	4.49	30.4
180-6	6.10	20.00	9.92	1.44	12.3	1.79	15.92	3.10	8.55	17.3
180-7	10.67	35.00	4.64	0.67	7.60	1.10	29.23	3.25	14.96	10.6
180-8	18.29	60.00	2.17	0.31	4.22	0.61	51.69	3.40	25.64	5.92

TABLE 10. AIR BLAST PARAMETERS FROM 0.363 kg UNCONFINED

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$
0-1	0.87	2.86	568	82.4	104	15.1	0.490	0.95	1.22	146
0-2	1.27	4.17	—	—	—	—	—	—	1.78	—
0-3	1.68	5.50	173	25.1	71.4	10.4	1.825	1.77	2.35	100
0-4	2.29	7.50	80.5	11.7	62.4	9.04	3.165	2.10	3.20	87.4
0-5	3.20	10.50	40.8	5.91	46.7	6.78	5.530	2.40	4.49	65.5
0-6	6.10	20.00	25.2	3.66	27.7	4.02	13.44	3.19	8.55	38.8
0-7	10.67	35.00	8.96	1.29	16.1	2.34	26.57	3.66	14.96	22.6
0-8	18.29	60.00	4.17	0.61	8.70	1.26	49.04	4.13	25.64	12.2
90-1	0.61	2.00	2145	311	158	22.9	0.143	0.30	0.86	222
90-2	1.12	3.68	772	112	109	15.8	0.528	0.80	1.57	153
90-3	1.27	4.17	457	66.3	91.4	13.3	0.710	0.84	1.78	128
90-4	1.68	5.50	295	42.8	85.2	12.4	1.368	1.30	2.35	119
90-5	2.29	7.50	135	19.6	63.4	9.20	2.600	2.25	3.20	88.9
90-6	5.03	16.50	26.2	3.80	33.9	4.91	9.838	3.20	7.05	47.5
90-7	6.80	22.30	12.3	1.78	22.4	3.24	14.91	3.50	9.53	31.3
90-8	12.80	42.00	4.64	0.67	10.5	1.53	32.70	4.20	17.95	14.8
90-9	18.29	60.00	3.24	0.47	8.21	1.19	49.14	4.93	25.64	11.5
180-1	0.87	2.86	1713	248	174	25.2	0.168	0.60	1.22	244
180-2	1.27	4.17	836	121	128	18.6	0.465	1.58	1.78	179
180-3	1.67	5.50	239	34.7	65.6	9.51	1.022	1.70	2.35	92.0
180-4	2.29	7.50	89.4	13.0	55.2	8.01	2.230	3.50	3.20	77.4
180-5	3.20	10.50	33.2/34.8	4.82/5.05	52.5	7.61	4.560	3.90	4.49	73.6
180-6	6.10	20.00	10.5/27.7	1.52/4.02	30.6	4.44	12.74	4.05	8.55	42.9
180-7	10.67	35.00	4.00/14.0	0.58/2.03	17.9	2.60	26.08	4.10	14.9	25.1
180-8	18.29	60.00	4.46	0.65	9.49	1.38	48.40	4.10	25.64	13.3

TABLE 11. AIR BLAST PARAMETERS FROM 0.227 kg IN MAGAZINE

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$
0-1	0.79	2.60	974	141	146	21.1	0.388	0.60	1.30	239
0-2	1.27	4.17	310	44.9	134	19.4	1.038	2.02	2.08	219
0-3	1.68	5.50	193/185	28.0/26.8	92.0	13.3	1.808	1.86	2.75	151
0-4	2.29	7.50	116/135	16.8/19.6	60.4	8.77	3.132	2.75	3.75	99.1
0-5	3.20	10.50	61.8	8.96	32.2	4.66	5.158	3.06	5.25	52.7
0-6	4.27	14.00	30.0	4.20	23.3	3.38	8.228	3.04	7.00	38.2
0-7	6.10	20.00	9.67/13.4	1.40/1.94	15.5	2.25	13.23	3.50	9.99	25.4
0-8	10.67	35.00	1.81/4.54	0.26/0.66	8.9	1.29	25.61	4.13	17.49	14.6
90-1	0.57	1.87	72.0/77.0	10.4/11.2	55.4	8.04	1.230	1.50	0.93	90.8
90-2	1.14	3.73	48.0/64.7	7.0/9.4	49.3	7.15	2.270	1.80	1.87	80.2
90-3	1.68	5.50	32.7/53.0	4.74/7.69	42.4	6.15	3.640	2.00	2.75	69.5
90-4	2.30	7.54	25.00/40.6	3.74/5.89	34.0	4.93	5.200	2.24	3.76	55.8
90-5	3.35	11.00	15.3/25.1	2.22/3.64	24.6	3.57	8.170	2.40	5.50	40.3
90-6	5.03	16.50	15.5	2.25	17.2	2.50	12.78	2.51	8.24	28.3
90-7	6.80	22.30	8.80	1.28	12.2	1.77	17.85	2.90	11.14	20.1
90-8	9.14	30.00	6.03	0.88	8.80	1.28	24.70	3.01	14.99	14.4
90-9	12.80	42.00	3.81	0.55	6.29	0.91	35.49	3.20	21.00	10.3
180-1	0.79	2.60	108	15.7	38.4	5.57	1.375	1.60	1.30	63.0
180-2	1.27	4.17	72.0	10.4	32.2	4.67	1.715	1.71	2.08	52.8
180-3	1.68	5.50	39.7	5.76	24.4	3.54	3.542	1.80	2.75	40.0
180-4	2.29	7.50	26.7	3.87	20.5	2.97	5.443	2.23	3.75	33.6
180-5	3.20	10.50	19.5	2.83	16.5	2.39	7.810	2.75	5.25	27.1
180-6	4.27	14.00	11.4	1.65	11.7	1.70	11.12	2.90	7.00	19.2
180-7	6.10	20.00	7.39	1.07	8.85	1.28	18.00	3.00	9.99	14.5
180-8	10.67	35.00	3.41	0.50	5.07	0.74	29.57	3.40	17.49	8.32

TABLE 12. AIR BLAST PARAMETERS FROM 0.227 kg UNCONFINED

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$
0-1	0.79	2.60	760	110	102	14.8	0.322	0.80	1.30	167
0-2	1.27	4.17	186	27.0	57.3	8.31	1.045	0.94	2.08	93.9
0-3	1.68	5.50	101	14.7	51.4	7.45	1.902	1.76	2.75	84.3
0-4	2.29	7.50	53.3	7.73	45.8	6.65	3.330	1.98	3.75	75.1
0-5	3.20	10.50	35.1	5.09	33.9	4.92	5.715	2.23	5.25	55.6
0-6	4.27	14.00	32.8	4.76	29.8	4.32	8.500	2.60	7.00	48.8
0-7	6.10	20.00	18.7	2.71	20.6	2.99	13.46	3.09	9.99	33.8
0-8	10.67	35.00	7.04	1.02	11.8	1.71	26.26	3.38	17.49	19.3
90-1	0.57	1.87	1690	245	120	17.4	0.133	0.22	0.93	197
90-2	1.14	3.73	543	78.8	92.9	13.5	0.610	0.75	1.87	152
90-3	1.68	5.50	195	28.3	56.5	8.19	1.490	2.00	2.75	92.6
90-4	2.30	7.54	90.0	13.1	49.6	7.20	2.795	2.30	3.76	81.3
90-5	3.35	11.00	41.9	6.08	34.0	4.93	5.455	2.56	5.50	55.7
90-6	5.03	16.50	22.4	3.25	23.6	3.42	9.875	2.63	8.24	38.7
90-7	6.80	22.30	10.8	1.57	15.8	2.29	14.76	3.50	11.14	25.9
90-8	9.14	30.00	7.01	1.02	11.7	1.70	21.39	3.51	14.99	19.2
90-9	12.80	42.00	4.40	0.64	8.13	1.18	31.81	3.52	21.00	13.3
180-1	0.79	2.60	1858	269	130	18.9	0.362	1.00	1.30	213
180-2	1.27	4.17	474	68.8	91.0	13.2	0.490	1.50	2.08	149
180-3	1.68	5.50	142	20.6	55.8	8.09	1.097	2.30	2.75	91.5
180-4	2.29	7.50	49.0/20.0	7.11/2.90	44.3	6.43	2.450	3.80	3.75	72.6
180-5	3.20	10.50	20.00/38.4	2.90/5.57	36.8	5.34	4.870	3.60	5.25	60.3
180-6	4.27	14.00	10.53/34.4	1.52/5.00	28.7	4.16	7.845	3.80	7.00	47.1
180-7	6.10	20.00	6.44/23.4	0.93/3.39	22.9	3.32	13.04	3.95	9.99	37.5
180-8	10.67	35.00	2.08/9.05	0.30/1.31	12.3	1.78	26.20	3.50	17.49	20.2

TABLE 13. AIR BLAST PARAMETERS FROM 1.128 kg (HEMISPHERE) IN MAGAZINE

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$
0-1	1.12	3.68	1288	187	195	28.3	0.415	0.40	1.08	187
0-2	1.27	4.17	1333	193	257	37.3	0.515	0.67	1.22	247
0-3	1.68	5.50	718	104	267	38.7	0.912	1.53	1.61	256
0-4	2.29	7.50	370	53.7	181	26.2	1.620	1.80	2.20	174
0-5	3.20	10.50	169	24.5	132	19.1	3.345	2.40	3.07	127
0-6	6.10	20.00	47.5	6.89	64.5	9.36	10.42	3.50	5.86	62.0
0-7	10.67	35.00	14.3	2.07	27.4	3.97	23.15	4.00	10.25	26.3
0-8	18.29	60.00	5.73	0.83	15.1	2.19	45.48	5.00	17.57	14.5
90-1	0.64	2.10	130/539	18.8/78.2	129	18.7	1.010	1.35	0.62	124
90-2	1.12	3.68	141/272	20.4/39.4	118	17.1	1.685	1.57	1.08	113
90-3	1.27	4.17	118/264	17.1/38.3	112	16.2	1.950	1.74	1.22	108
90-4	1.68	5.50	91.0/193	13.2/28.0	105	15.2	2.755	1.64	1.61	101
90-5	2.29	7.50	138	20.0	97.3	14.1	4.105	2.45	2.20	93.5
90-6	5.03	16.50	46.3	6.72	57.3	8.31	11.07	3.34	4.83	55.0
90-7	6.10	20.00	33.7	4.89	43.9	6.37	13.94	3.85	5.86	42.2
90-8	12.80	42.00	9.15	1.33	20.9	3.03	33.35	4.80	12.30	20.1
90-9	18.29	60.00	5.44	0.79	15.0	2.18	49.64	5.73	17.57	14.4
180-1	1.12	3.68	308	44.7	84.0	12.2	1.378	0.75	1.08	80.7
180-2	1.27	4.17	273	39.6	80.0	11.6	1.607	1.25	1.22	76.9
180-3	1.68	5.50	181	26.2	93.1	13.5	2.487	2.30	1.61	89.4
180-4	2.29	7.50	105	15.2	75.8	11.0	3.980	2.32	2.20	72.8
180-5	3.20	10.50	58.2	8.44	50.5	7.32	5.970	3.00	3.07	48.5
180-6	6.10	20.00	24.3	3.52	29.6	4.29	13.78	4.72	5.86	28.4
180-7	10.67	35.00	8.24	1.20	17.2	2.49	26.90	5.05	10.25	16.5
180-8	18.29	60.00	3.83	0.56	9.71	1.41	49.32	5.48	17.57	9.33

TABLE 14. AIR BLAST PARAMETERS FROM 4.99 kg IN MAGAZINE

Station	Distance from Ground Zero		Peak Overpressure		Overpressure Impulse		Arrival Time	Positive Duration	Scaled Distance	Scaled Impulse
	metres	feet	kPa	psi	kPa-ms	psi-ms	ms	ms	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$
0-1	1.68	5.51	1837	266	328	47.6	.709	1.02	.983	192
0-2	2.29	7.51	1113	161	460	66.8	1.168	2.76	1.34	270
0-3	3.20	10.50	61.4	89.0	258	37.4	2.156	2.58	1.87	151
0-4	4.27	14.01	228	33.1	167	24.2	3.571	2.96	2.50	97.5
0-5	6.00	19.69	74.5	10.8	112	16.2	7.033	4.89	3.51	65.5
0-6	8.40	27.56	43.7	6.34	76.3	11.1	12.916	6.23	4.92	44.7
0-7	14.00	45.93	14.7	2.13	37.7	5.47	28.061	7.34	8.19	22.1
0-8	21.00	68.90	7.50	1.09	27.4	3.97	47.48	11.07	12.29	16.0
90-1	0.99	3.25	49.8	72.2	198	28.7	1.198	1.67	.579	116
90-2	1.50	4.92	338	49.0	186	27.0	1.87	1.93	.878	109
90-3	2.00	6.56	276	40.0	179	26.0	2.67	2.44	1.17	105
90-4	3.20	10.50	166	24.1	165	24.0	4.84	3.53	1.87	96.8
90-5	4.50	14.76	91.3	13.2	121	17.6	7.58	4.23	2.63	70.9
90-6	6.00	19.69	65.7	9.53	99.3	14.4	11.05	4.57	3.51	58.1
90-7	8.00	26.25	47.8	6.93	95.9	13.9	15.96	5.92	4.68	56.1
90-8	12.50	41.01	24.7	3.58	64.8	9.39	27.61	7.25	7.32	37.9
90-9	21.00	68.90	11.1	1.61	38.5	5.56	50.86	8.46	12.29	22.5
180-1	1.68	5.51	266	38.6	115	16.7	1.90	1.99	.983	67.2
180-2	2.29	7.51	196	28.4	116	16.8	2.94	2.72	1.34	67.9
180-3	3.20	10.50	102	14.8	101	14.7	4.75	3.35	1.87	59.2
180-4	4.27	14.01	70.4	10.2	88.3	12.8	7.09	3.96	2.50	51.7
180-5	6.00	19.69	45.0	6.53	78.0	11.3	11.29	6.78	3.51	45.7
180-6	8.40	27.56	29.2	4.24	62.0	9.00	17.43	6.87	4.92	36.3
180-7	14.0	45.93	17.5	2.54	40.5	5.88	32.46	7.91	8.19	23.7
180-8	21.0	68.90	8.63	1.25	27.8	4.04	51.76	8.75	12.29	16.3

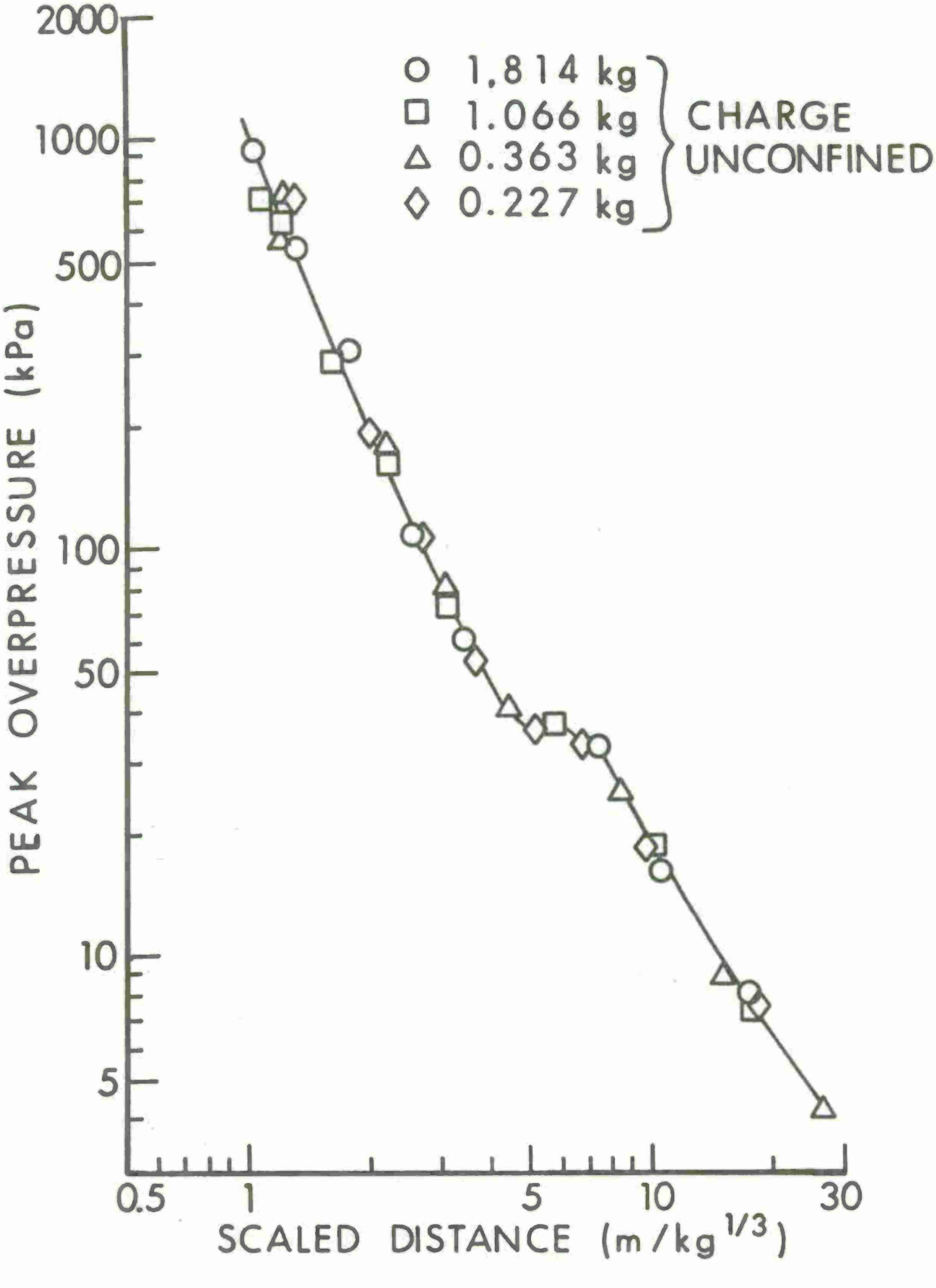

Figure 7. Peak overpressure versus scaled distance along the 0-degree blast line, charge unconfined.

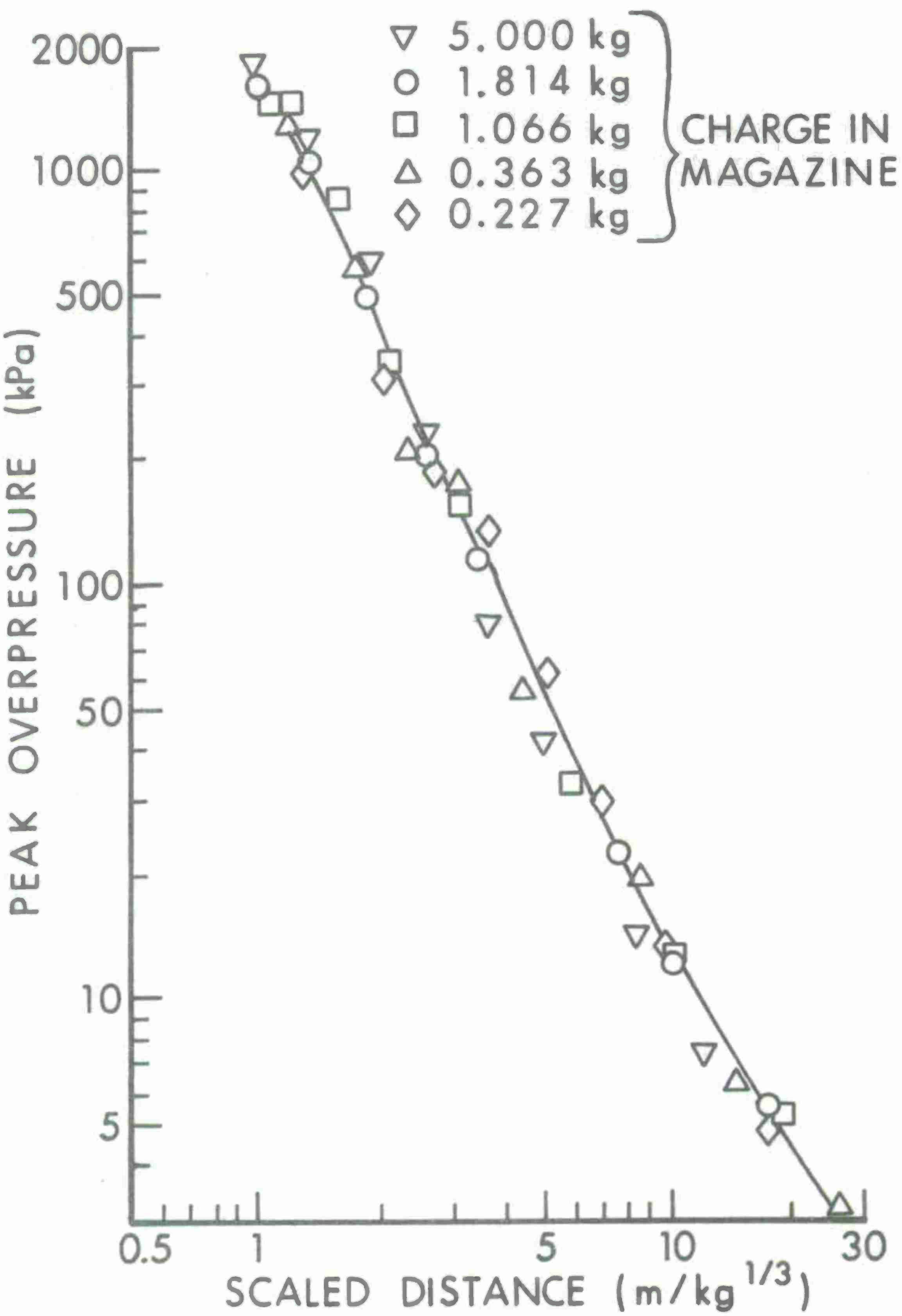

Figure 8. Peak overpressure versus scaled distance along the 0-degree blast line, charges in magazine.

As noted in Reference 1 the peak overpressures measured from the in-magazine charges are higher than recorded for the uncovered charges but only out to a scaled distance of 6.5 m/kg$^{1/3}$. In this region there is a cross-over and the uncovered charges produce higher values at the greater distances. This cross-over of peak overpressure is caused by a second peak wave[3] which develops from a "bridge wave" as described in Reference 3. There is no suppressive effect noted along the 0-degree blast line for the in-magazine lower loading density. The in-magazine peak overpressure values are approximately 25 percent lower than the uncovered values at scaled distances greater than 8 m/kg$^{1/3}$.

2. Scaled Overpressure Impulse versus Scaled Distance, 0-Degree Blast Line. The scaled overpressure impulse versus scaled distance recorded at Stations 0-1 through 0-8 for the four unconfined charge masses are plotted in Figure 9. There is excellent correlation and with all values scaled to 1 kg there is no apparent mass effect. The scaled values for the five charge masses tested in-magazine are plotted in Figure 10. A phenomenon similar to that noted on the peak overpressure curves are noted on the scaled impulse curves. That is, the overpressure impulse recorded for the in-magazine tests are higher than those recorded on the unconfined tests out to a distance of approximately 5 m/kg$^{1/3}$ where there is a cross-over. Beyond this range the free-field values of impulse are larger than the in-magazine values. At distances greater than 7 m/kg$^{1/3}$ the in-magazine values of scaled impulse are approximately 25 percent lower than the unconfined values. The scaled impulse recorded from the larger charges tested in-magazine show greater attenuation at distances greater than 1.5 m/kg$^{1/3}$ than do the smaller charges. This is the reverse of what might be expected from lower density loading. It is surmised that for the larger charge masses the earth barriers have less effect on the focusing along the 0-degree blast line. As can be seen in Figure 10 the scaled values from the 0.227 kg charge are in general higher than the scaled values from the 5.0 kg charges.

B. Blast Parameters along the 90-Degree Blast Line

The 90-degree blast line extends to the side of the magazine. The gage station locations run from 90-1 to 90-9. The distances are listed in Table 2. The results are listed in Tables 5 through 14 for the five charge masses in-magazine and the four charge masses unconfined. The values of peak overpressure from the tables are plotted versus scaled distance in Figures 11 and 12. The values of scaled overpressure impulse versus scaled distance are plotted in Figures 13 and 14.

1. Peak Overpressure versus Scaled Distance, 90-Degree Blast Line. The values of peak overpressure versus scaled distance along the 90-degree blast line for the unconfined tests are plotted in Figure 11 and show excellent correlation of data when scaled to 1 kg. There is some scatter of data points at scaled distances less than 1 m/kg$^{1/3}$. The results follow the same trend as established in Reference 1.

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[3] R.E. Reisler, L. Giglio-Tos, and G.D. Teel, "Air Blast Parameters from Pentolite Cylinders Detonated on the Ground," BRL MR 2472, April 1975.

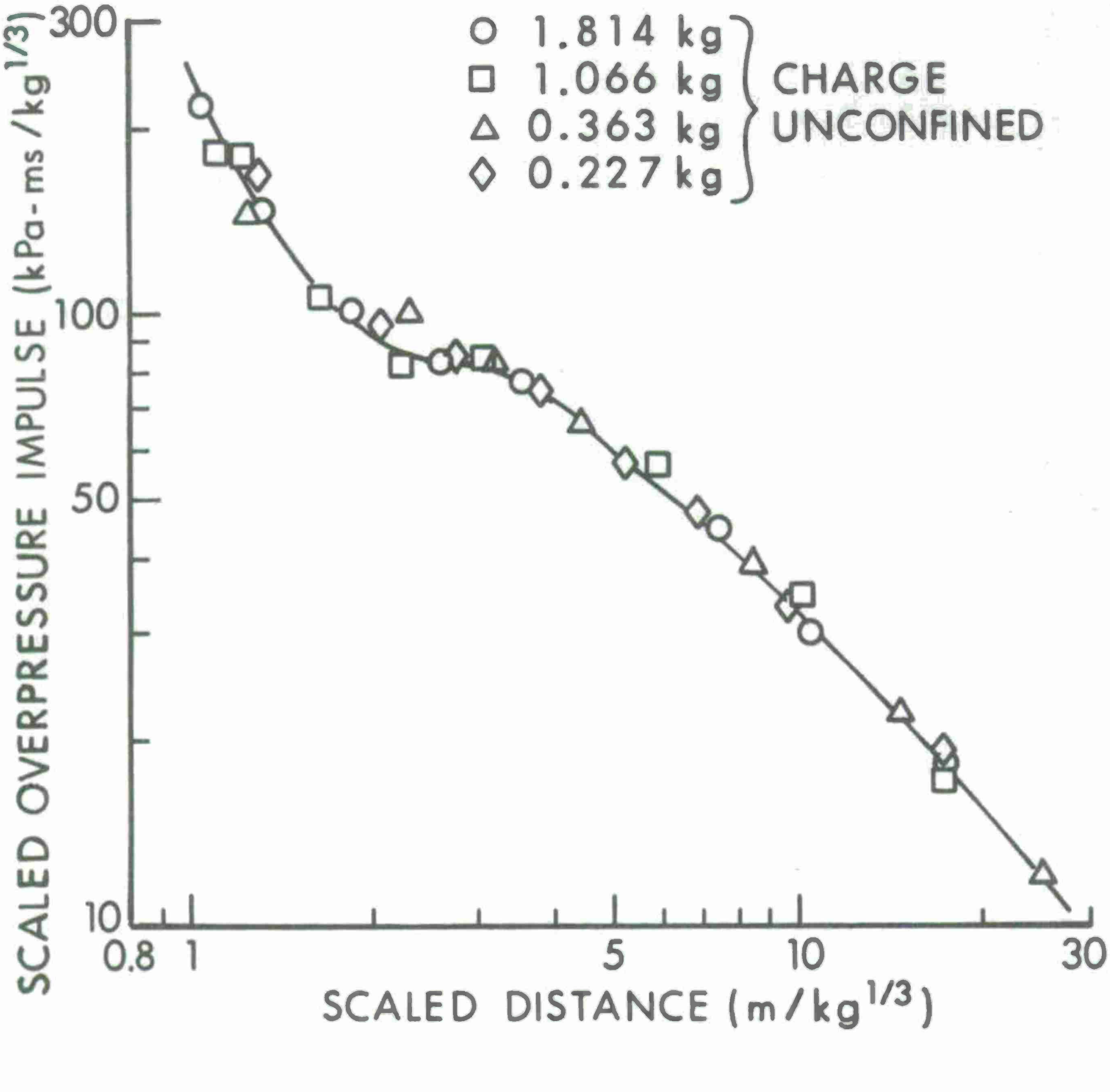


Figure 9. Scaled overpressure impulse versus scaled distance along the 0-degree blast line, charges unconfined.

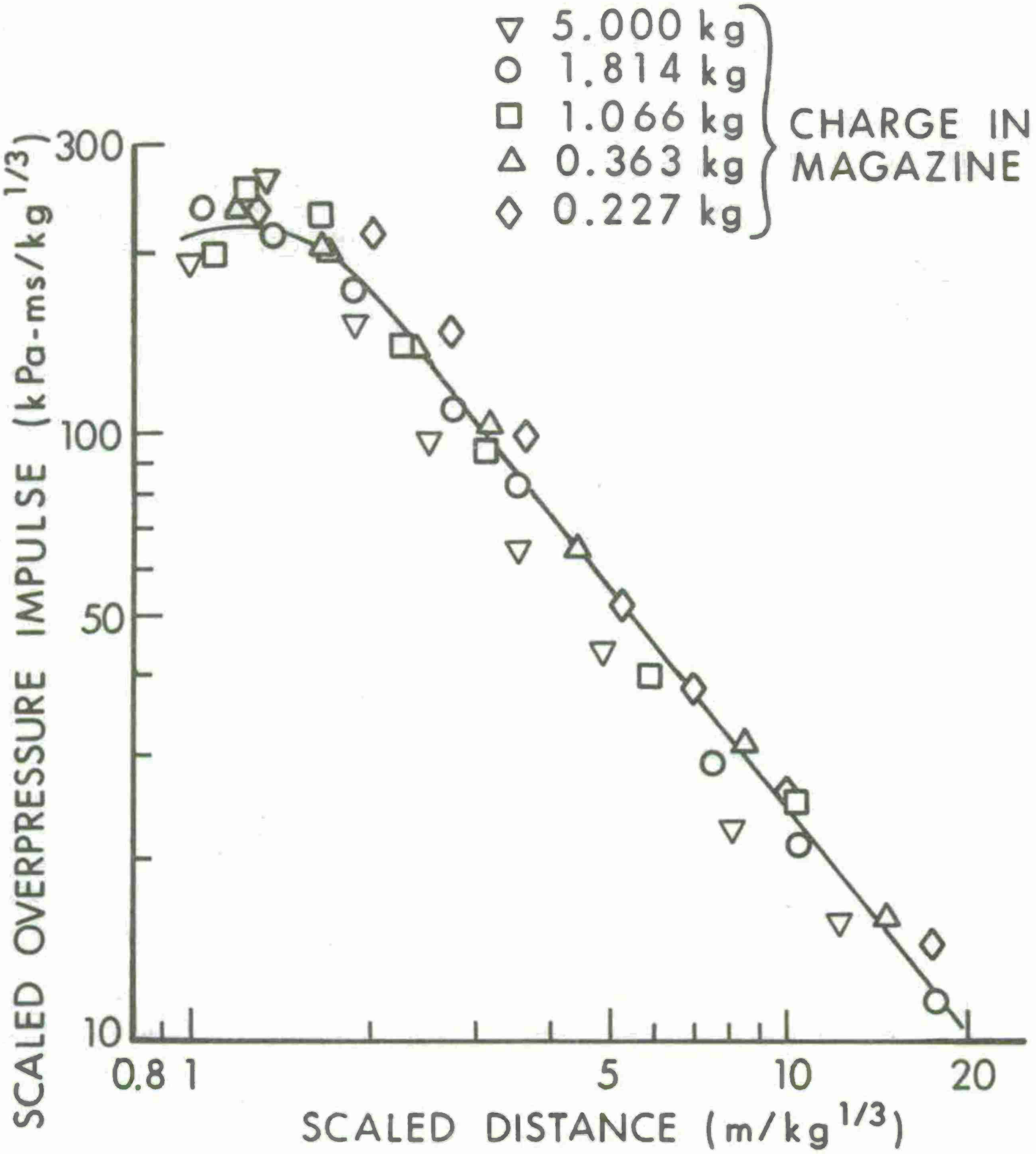


Figure 10. Scaled overpressure impulse versus scaled distance along the 0-degree blast line.

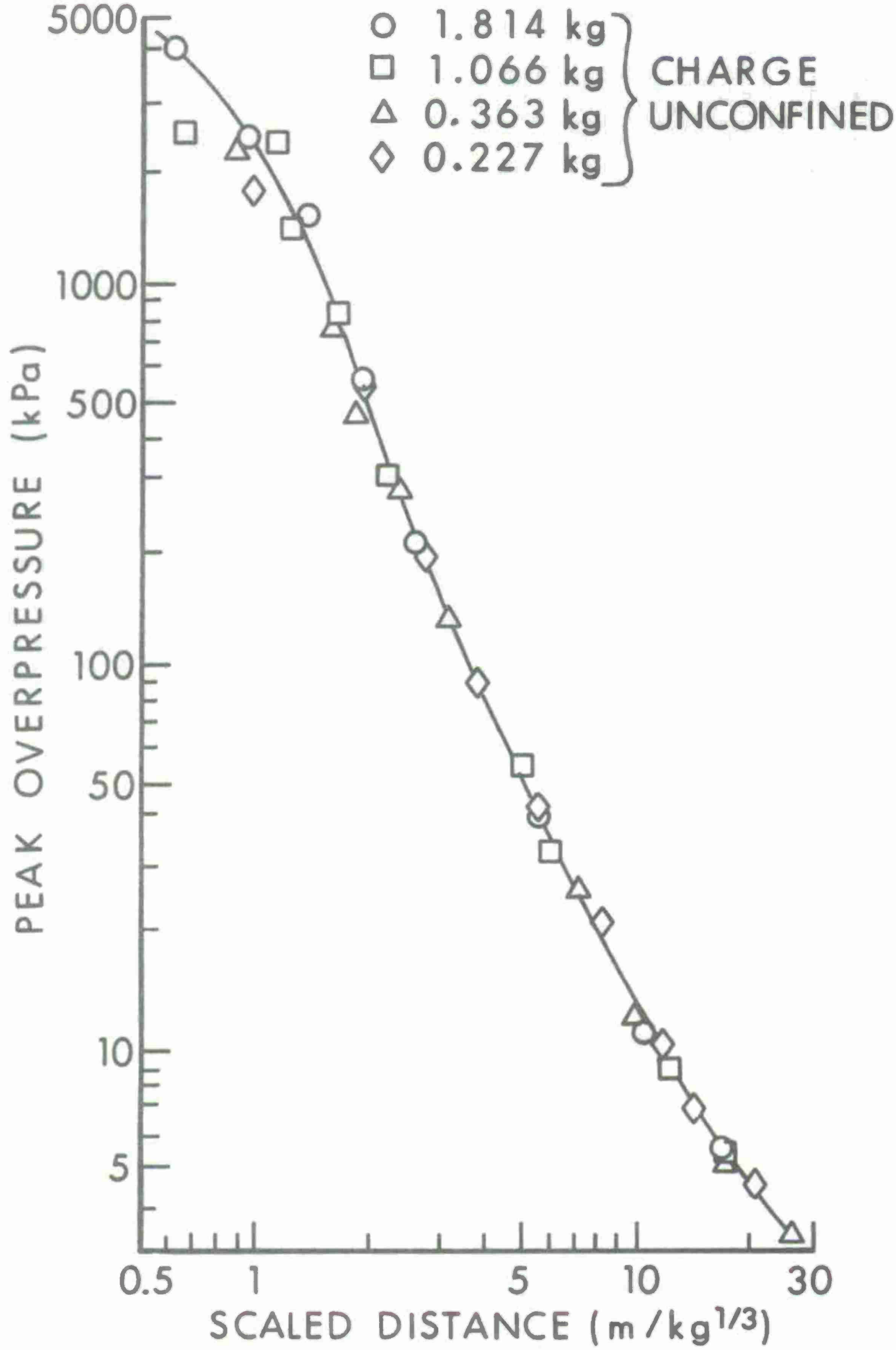


Figure 11. Peak overpressure versus scaled distance along the 90-degree blast line, charges unconfined.

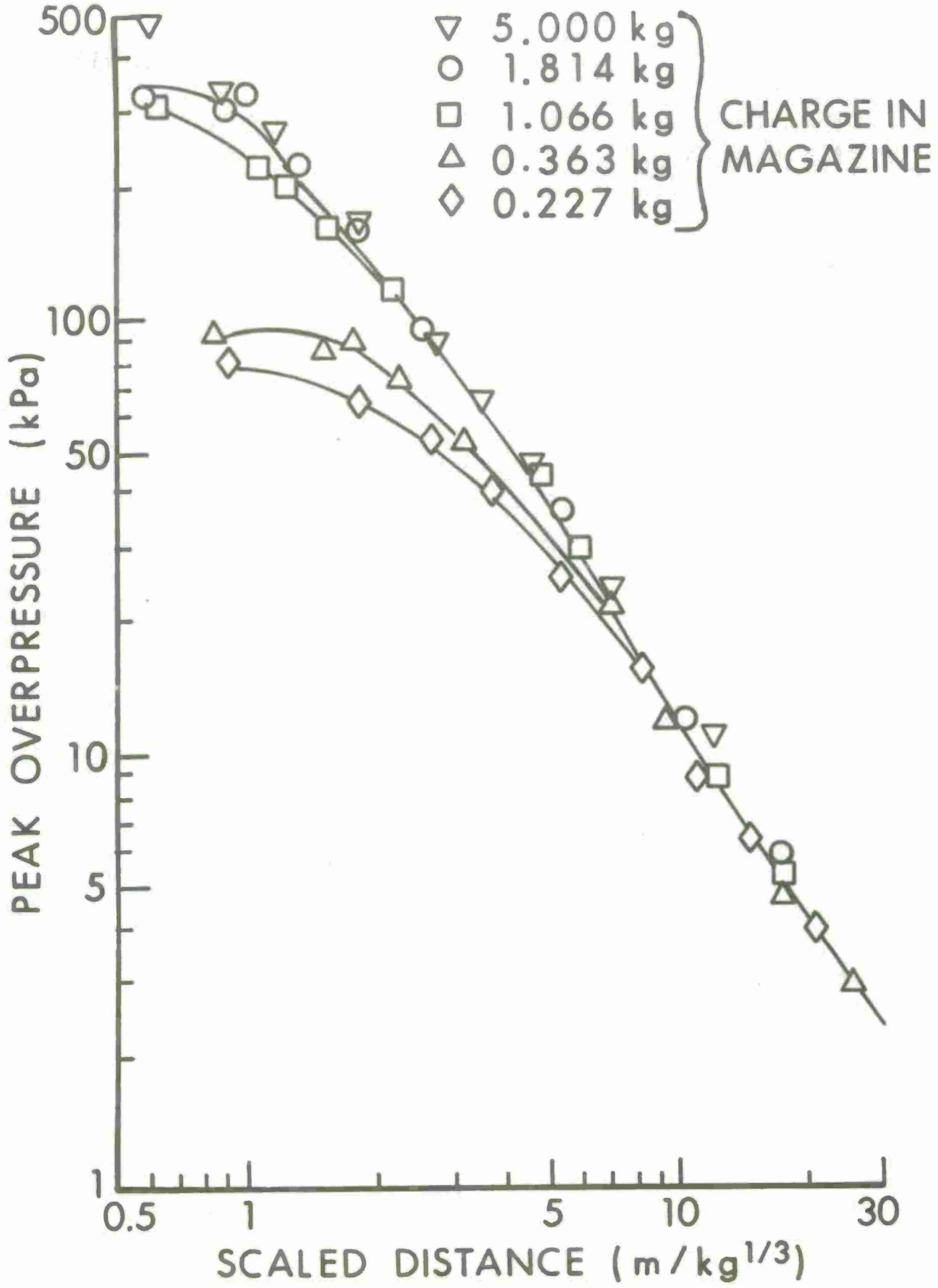


Figure 12. Peak overpressure versus scaled distance along the 90-degree blast line, charges in magazine.

The values of peak overpressure versus scaled distance along the 90-degree blast line for the five charge masses tested in the magazine are plotted in Figure 12. There is a very large loading density effect on the peak overpressure from a scaled distance of 0.6 $m/kg^{1/3}$ out to 6.0 $m/kg^{1/3}$. Beyond 6.0 $m/kg^{1/3}$ the suppression effect of the various loading densities becomes less evident. A discussion of the effect of low loading on the peak overpressure versus distance will be given later in this report.

2. Scaled Overpressure Impulse versus Scaled Distance, 90-Degree Blast Line. The values of scaled impulse versus scaled distance recorded along the 90-degree blast line for the four charge masses, unconfined, are plotted in Figure 13. The values establish a good trend and follow that reported in Reference 1. The charge masses range over a factor of 8, but using cube root scaling the scaled values show very little scatter.

The values of scaled impulse along the 90-degree blast line for the in-magazine tests are plotted in Figure 14. Although the peak overpressure values plotted in Figure 12 show a greater suppression at the lower loading densities (0.363 and 0.227 kg charges) this is not evident in the scaled overpressure impulse versus scaled distance presented in Figure 14. The peak overpressures were lower but because there were double peaks this apparently added to the impulse making only small differences in the scaled impulse. The second peak is an interior reflection from the magazine's arch.

When comparing the values of scaled impulse recorded from the in-magazine and uncovered charges there is suppression evident over the complete range of distances. From a scaled distance of 2 $m/kg^{1/3}$ out to 20 $m/kg^{1/3}$ the average attenuation of the in-magazine values is 25 percent of the unconfined values. The scaled impulse values do not merge into one curve at the greater distances as the peak overpressure values did along the 90-degree blast line.

In Figure 14 it can be seen that the suppression of the positive impulse along the 90-degree blast line is a function of loading density. The magnitude of this effect will be discussed later in this report.

C. Blast Parameters along the 180-Degree Blast Line

The 180-degree blast line extends to the rear of the magazine. This is away from the door and the point of initiation of the charge. The gage locations for stations 180-1 through 180-8 are listed in Table 2 while the peak overpressure and impulse values are listed in Tables 5 through 14.

1. Peak Overpressure versus Scaled Distance, 180-Degree Blast Line. The values of peak overpressure versus scaled distance along the 180-degree blast line for the unconfined tests are plotted in Figure 15. Here the effect of the configuration of the charge and point of detonation can clearly be seen. The station from 1.0 to 3.0 $m/kg^{1/3}$ record higher peak overpressure along the 180-degree blast line than along the 0-degree blast line. This is because detonation point is at 0-degree blast line end of the charge. A major curve inflection is noted at a scaled distance of 4.5 $m/kg^{1/3}$ where a second shock develops and becomes increasingly greater in

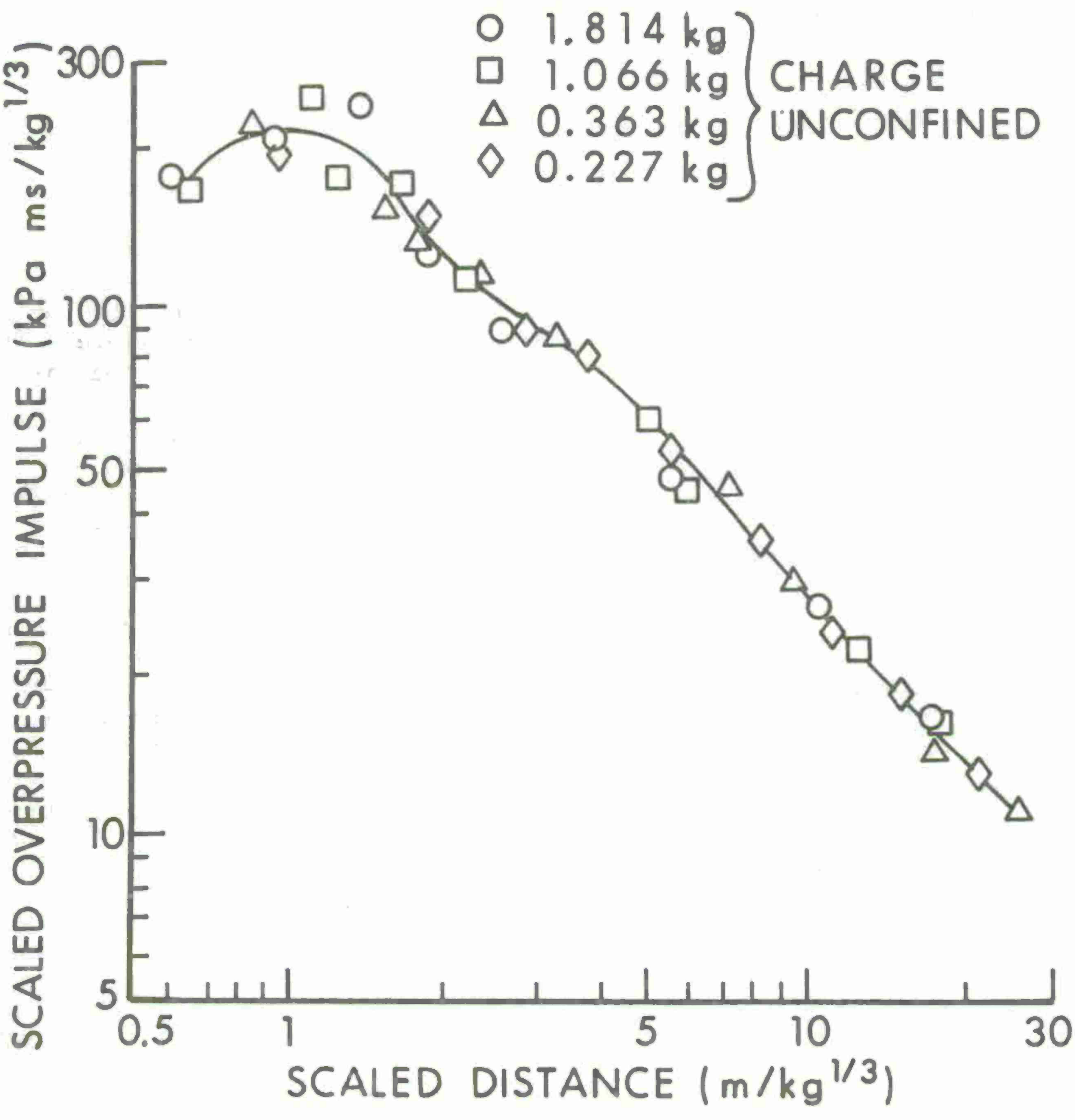


Figure 13. Scaled overpressure impulse versus scaled distance along the 90-degree blast line, charges unconfined.

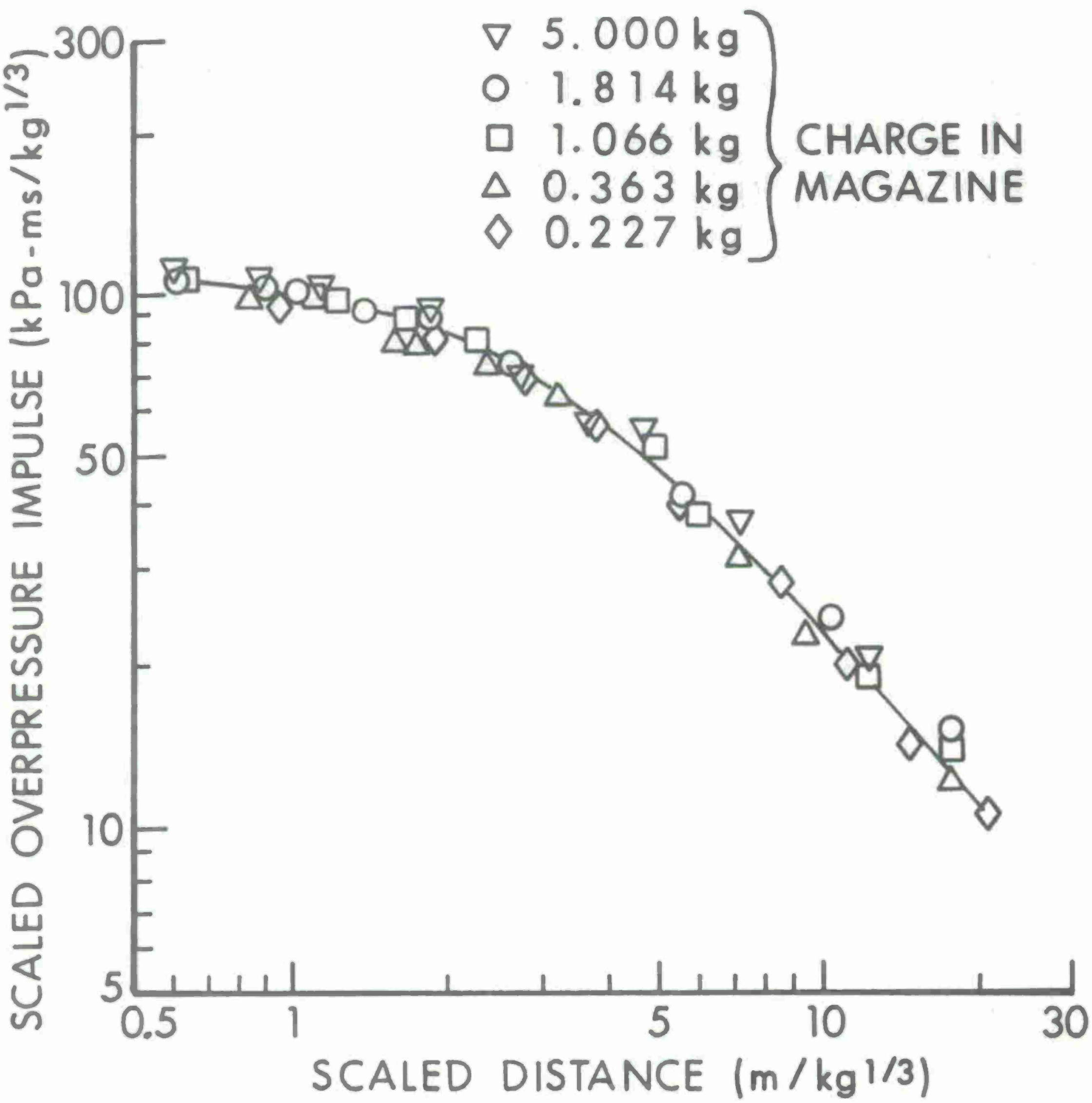


Figure 14. Scaled overpressure impulse versus scaled distance along the 90-degree blast line, charges in magazine.

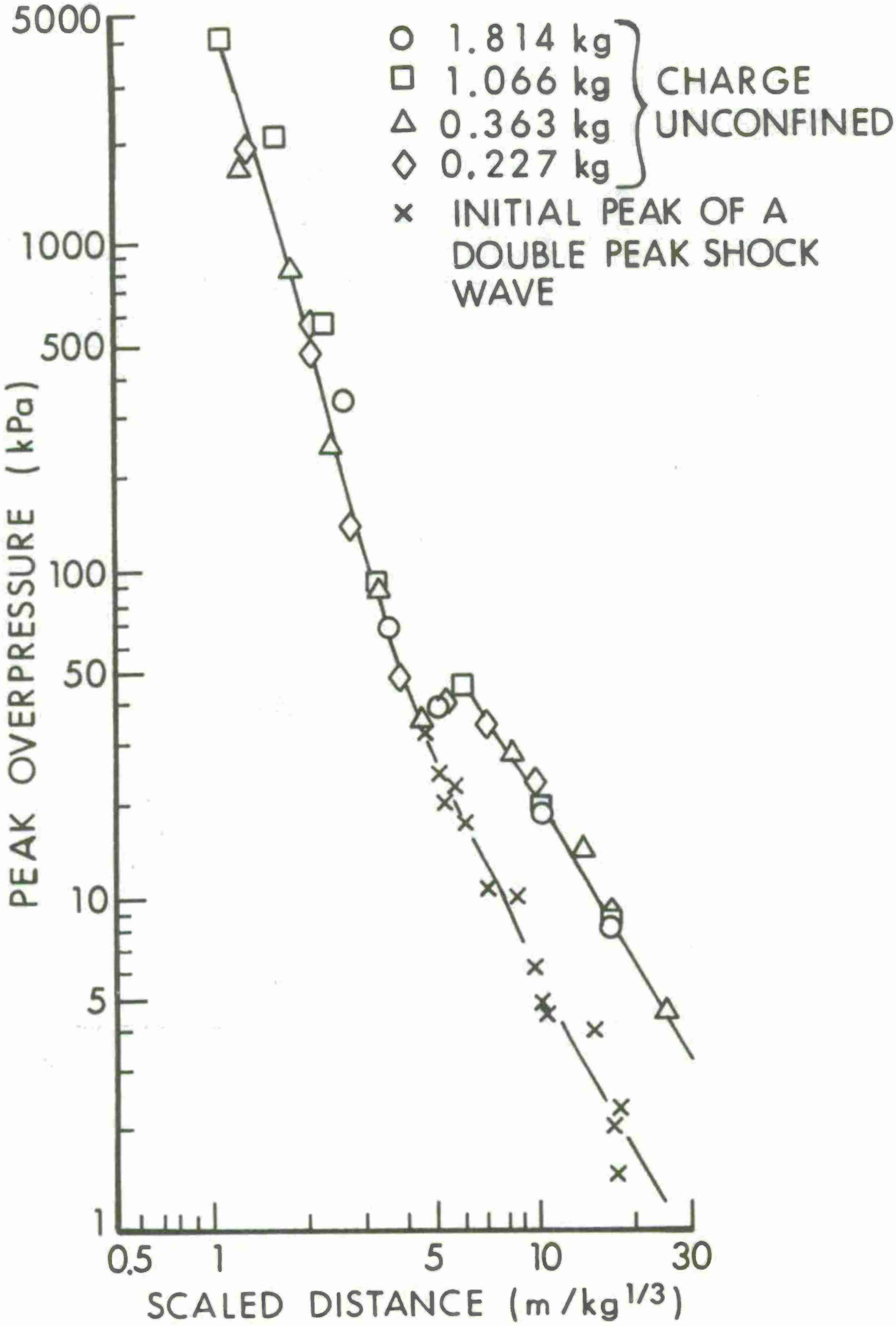


Figure 15. Peak overpressure versus scaled distance along the 180-degree blast line, charges unconfined.

magnitude than the initial shock as the distance increases. A second shock does not develop when the charge is tested in the storage magazine.

The values of peak overpressure recorded from the in-magazine tests are plotted versus scaled distance in Figure 16. Here we see a trend similar to that noted on the 90-degree blast line. The two small charge masses show some blast attenuation over the total range because of a loading density effect. The magnitude of the loading density effect will be discussed later.

When comparing the in-magazine tests (Figure 16) with the unconfined test (Figure 15) it is quite evident that there is blast attenuation over the complete range of measurements.

2. Scaled Impulse versus Scaled Distance, 180-Degree Blast Line. The scaled impulse values recorded for the unconfined charges are listed in Tables 6, 8, 10, and 12 and plotted in Figure 17. The change in the slope of the curve at scaled distance of $3 m/kg^{1/3}$ is caused by the increase in impulse which in turn is caused by the second shock noted in Figure 15. The scaled impulse values for all four charge masses follow the same trend.

The values of a scaled overpressure impulse along the 180-degree blast line for the in-magazine tests are listed in Table 5, 7, 9, 11, and 14. These values are plotted in Figure 18. There appears to be some suppressive effect on scaled impulse along the 180-degree which is a function of loading density. The 1.814 kg values are ~ 10 percent less than the 5.04 kg values while the 1.066 kg values are ~ 10 percent less than the 1.814 kg values. The 0.363 and 0.227 kg values are ~ 10 percent less than the 1.066 kg values of scaled impulse. These suppressions of impulse are not great but they do appear consistent and valid.

The attenuation of scaled impulse because of confinement is 50 percent or greater along the 180-degree blast line. The attenuation of scaled impulse because of loading density is quite evident in Figure 18 and will be discussed in the following section.

D. Blast Attenuation as a Function of Loading Density

The preceding sections have pointed out the enhancement or attenuation of the blast waves as a function of a confined charge (in-magazine) relative to an unconfined charge. The following discussion will include the attenuation of the blast wave as a function of explosive loading density within the storage magazine model. The 1.814 kg charge which simulates a 48980 kg (107760 lbm) will be used as the baseline for comparison. The 0.227 kg charge will be used to determine the attenuation at selected distances. The four distances of primary interest are (1) the safe separation distance (0.8 $Q^{1/3}$ m for 0 and 180-degree blast line and 0.5 $Q^{1/3}$ m for the 90-degree blast line), (2) the unbarricaded intraline distance 7.2 $Q^{1/3}$ m, (3) the public traffic routes 9.6 $Q^{1/3}$ m, and (4) inhabited building distance 16 $Q^{1/3}$ m. The attenuation or enhancement of peak overpressure will be treated in two ways. First the difference in peak overpressure at the selected distances and second the difference in

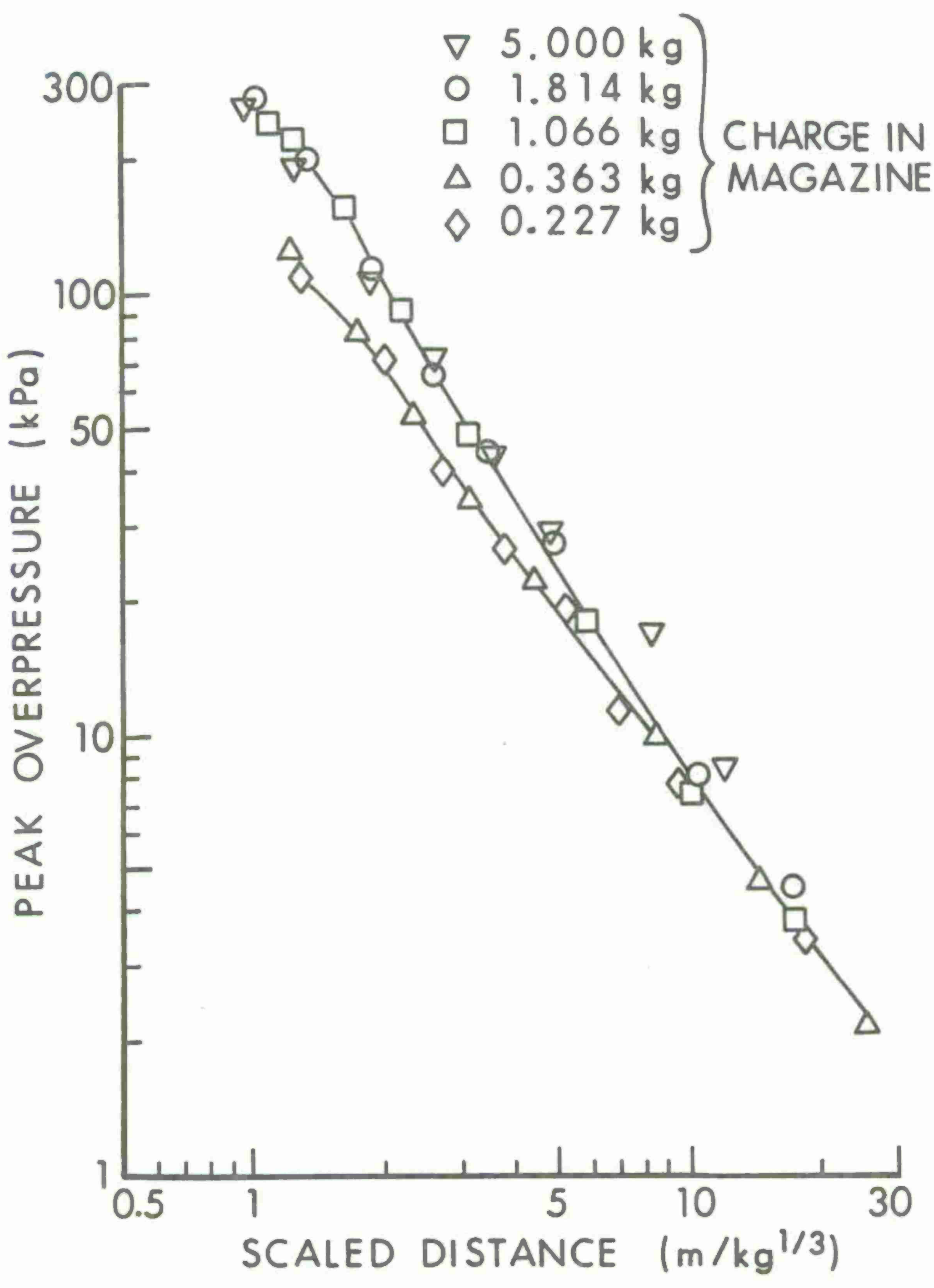


Figure 16. Peak overpressure versus scaled distance along the 180-degree blast line, charges in magazine.

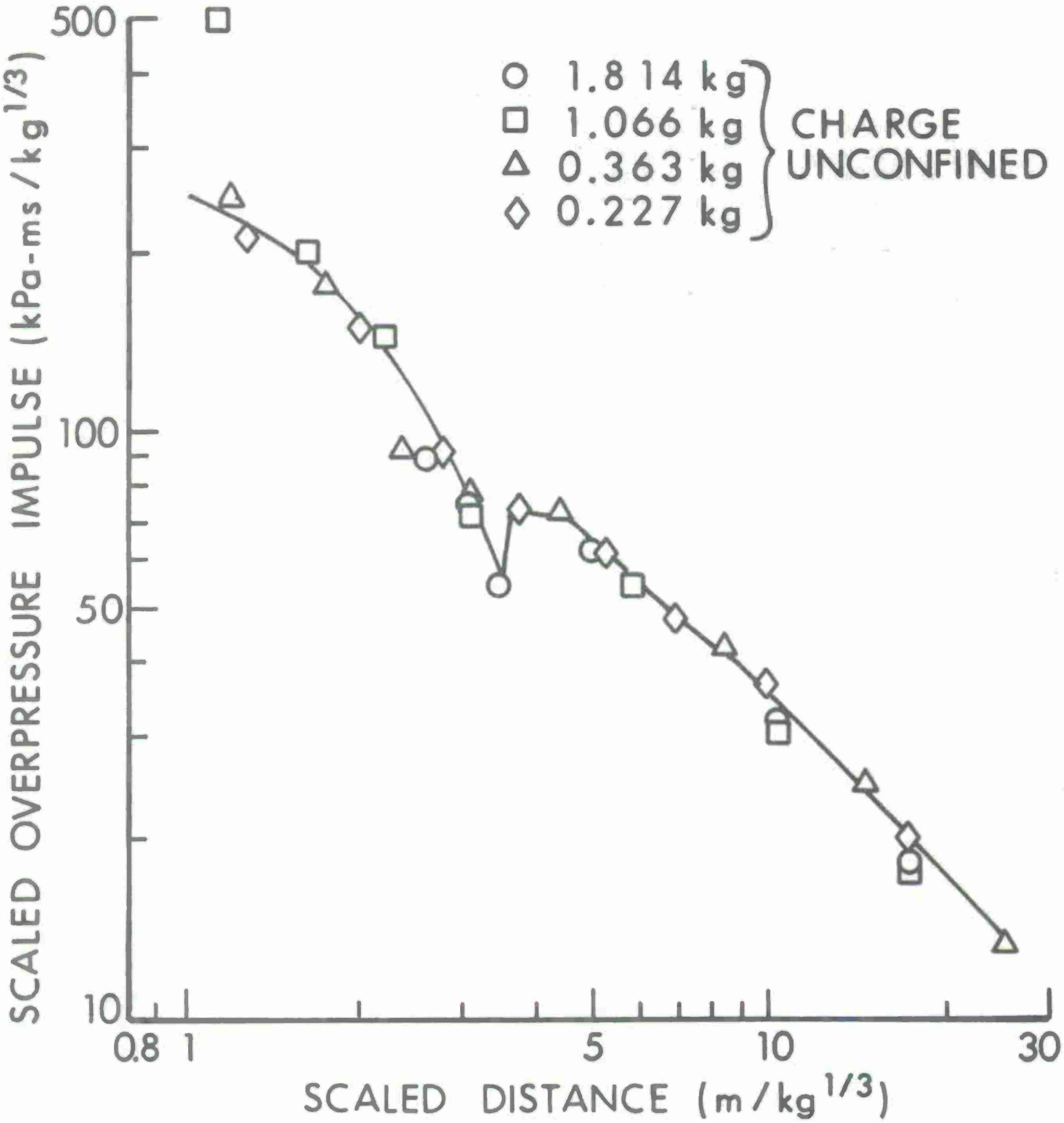


Figure 17. Scaled impulse versus scaled distance along the 180-degree blast line, charges unconfined.

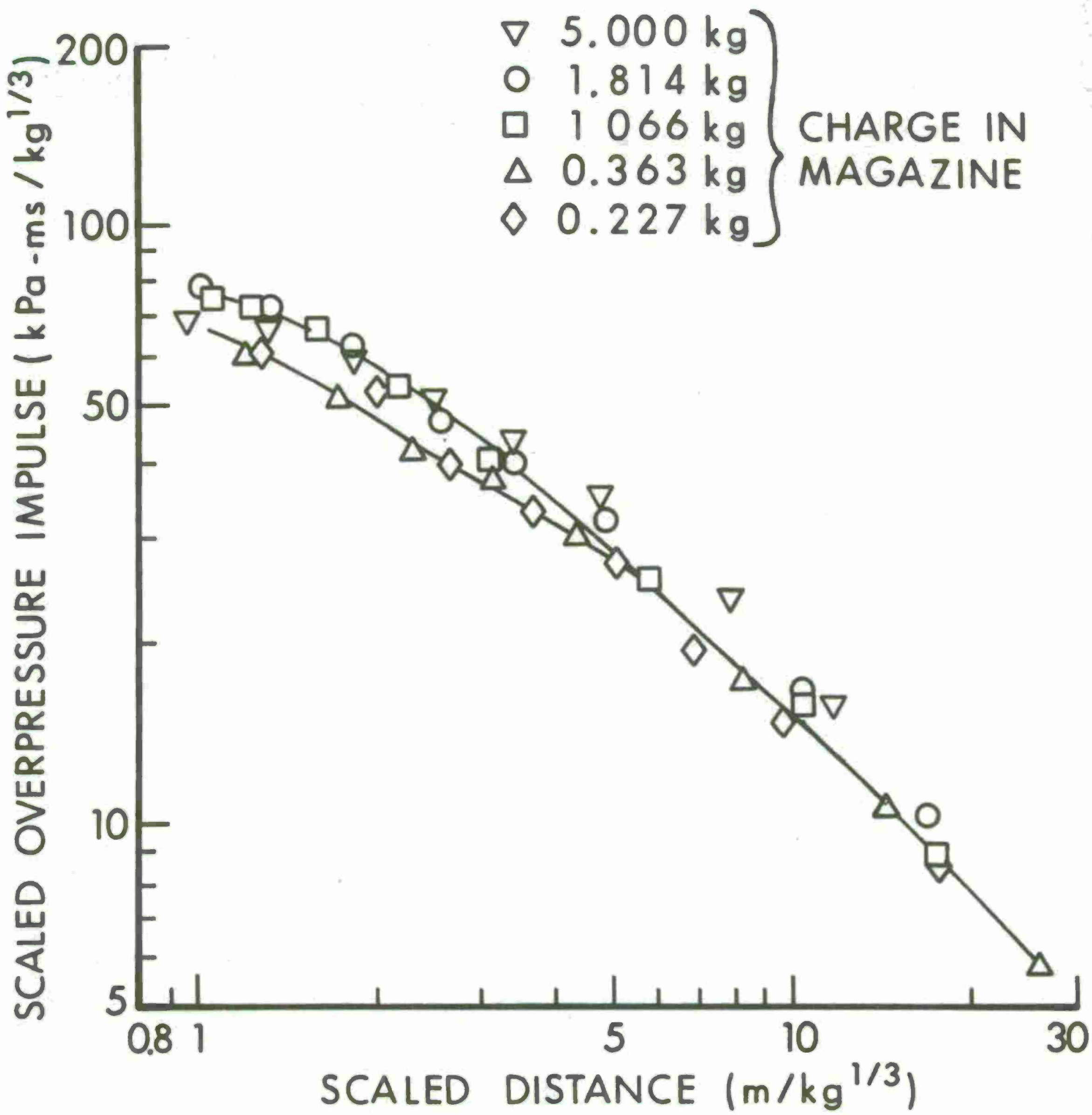


Figure 18. Scaled impulse versus scaled distance along the 180-degree blast line, charges in magazine.

scaled distance for the peak overpressure associated with the baseline curve. From the second method the equivalent mass factor will be determined.

The effect of loading density on the overpressure impulse will also be determined. This method will also be based on the equivalent mass factor. A ratio of the scale impulse/scaled distance for the baseline plot (1.814 kg scaled to 1 kg) will be computed and the scaled impulse versus scaled distance curve for 0.227 kg will be searched to determine an equal ratio. From this ratio the scaled distance will be determined and used to calculate the equivalent mass factor.

1. Loading Density Effects on Peak Overpressure. The effects of loading density on peak overpressure is presented in Table 15 for four selected distances along three blast lines. The percentage difference listed in column six is the difference in the low loading density (0.227 kg) relative to the medium loading density (1.814 kg).

There is little or no loading density effect on peak overpressure along the 0-degree blast line. An average of the percentage differences noted in column six would fall within a relative difference band of ± 6 percent.

Along the 90-degree blast line the major attenuation is at the safe-separation distance where it is 79.4 percent. The other three selected distances indicate an average of 14.6 percent attenuation of peak overpressure.

The attenuation of peak overpressure along the 180-degree blast line is also greatest at the safe separation distance (44 percent) while the average attenuation at the other three distances is 19 percent.

2. Effect of Pressure, Attenuation on Equivalent Yield. The attenuation of peak overpressure along the blast lines can also be expressed in equivalent yield or an equivalent mass factor (EMF). That is, the explosive yield of the attenuated pressure-distance curve relative to the baseline curve. The equivalent mass factors (EMF) are listed in column six of Table 16 for the three blast lines.

The EMF determined along the 0-degree blast line follows the same trend as the peak overpressure differences. Some are less than 1.0 and some greater than 1.0. The average is 0.98 indicating there is no significant effect of loading density on the EMF along the 0-degree line.

The EMF values based on pressure attenuation along the 90-degree blastline are listed in column six of Table 16. A value could not be calculated for the first distance but the last three distances give an average EMF of 0.69 $\pm$ 7 percent.

The EMF determined for the 180-degree line for the last three selected distances is to .62, +5, -8 percent. This follows the same trend established in Table 15 where the 180-degree line recorded greater peak overpressure attenuation than the 90-degree line.

TABLE 15. LOADING DENSITY EFFECTS ON PEAK OVERPRESSURE

BLAST LINE	SCALED DISTANCE	PEAK OVERPRESSURE 1.814 kg	PEAK OVERPRESSURE 0.227 kg	DIFFERENCE Δ	DIFFERENCE %
DEGREE	$m/kg^{1/3}$	kPa	kPa	kPa	
0	1.1	1400.0	1250.0	-150.0	-10.7
	7.2	24.5	28.0	+3.5	+14.0
	9.6	14.3	14.9	+0.6	+4.0
	16.0	6.2	5.4	-0.8	-15.0
90	0.63	378.0	78.0	-300.0	-79.4
	7.2	21.5	18.0	-3.5	-16.5
	9.6	13.6	11.9	-1.7	-11.8
	16.0	6.5	5.5	-1.0	-15.4
180	1.1	270.0	119.0	-151.0	-44.0
	7.2	13.8	11.1	-2.7	-20.0
	9.6	9.3	7.8	-1.5	-16.0
	16.0	4.9	3.8	-1.1	-22.0

TABLE 16. LOADING DENSITY EFFECTS ON EQUIVALENT YIELDS

BLAST LINE	PEAK OVERPRESSURE	SCALED DISTANCE 1.814 kg R_1	0.227 kg R_2	EMF $(R_2/R_1)^3$
DEGREES	kPa	m/kg$^{1/3}$	m/kg$^{1/3}$	
0	1400.0	1.10	1.02	0.80
	24.5	7.20	7.70	1.22
	14.3	9.60	9.80	1.06
	6.2	16.00	15.00	0.82
90	-	-	-	-
	21.5	7.20	6.25	0.65
	13.6	9.60	8.70	0.74
	6.5	16.00	14.10	0.68
180	-	-	-	-
	13.8	7.20	6.2	0.64
	9.3	9.60	8.3	0.65
	4.8	16.00	13.3	0.57

3. Loading Density Effects on Impulse. The effect of loading density on the overpressure impulse along the three blast lines is listed in Table 17. The percentage difference between the baseline curve and the low loading density curve is listed in column six for the four selected distances along each blast line.

Although the 0-degree blast line recorded very little difference in the peak overpressure because of loading density the impulse is enhanced. This enhancement is +7 percent at the first distance and an average of +21 percent for the last three stations.

Along the 90-degree blast line there is an attenuation of impulse as well as peak overpressure. The percentage difference appears to increase with distance, going from -7.8 percent at the first station to -20.5 percent at the last station.

The impulse recorded along the 180-degree blast line is also attenuated. The percentage attenuation of impulse at the last three stations is almost the same as recorded for peak overpressure at the last three stations shown in Table 15, ie, -18.8 vs -19.3 percent.

4. Effect of Impulse Variations on Equivalent Yield. The equivalent mass factors will be determined based on the variation of impulse along the blast lines as a function of loading density. The method described under Section D will be used to determine EMF. Values are listed in Table 18.

The values of the EMF determined along the 0-degree blast line based on impulse again show an enhancement. The average EMF is 1.31 showing that the low loading density will give higher scaled impulse values along the 0-degree blast line. The focusing effect of the three earth barricades is more effective for low density loads than the higher density loads. This is borne out in Figure 10 where the high loading density (5.0 kg) recorded much lower scaled impulse values than the low loading density (0.227 kg).

The average EMF along the 90-degree blast line was 0.81 ± 7 percent while the average EMF along the 180-degree blast line was 0.74 ± 1.3 percent.

E. Hemicylindrical versus Hemispherical Charges in Magazine

There was some difficulty in determining the effect of earth cover on the suppression of blast when comparing the confined (in-magazine) and unconfined hemicylindrical charge because of the double peaked shock waves recorded along both the 0-degree and 180-degree blast lines when unconfined. These double peaks did not materialize when the charges were confined.

1. Comparison of Peak Overpressure versus Scaled Distance. One test was conducted with a 1.128 kg hemispherical charge placed in a 1/30th-scale munition storage magazine model. The results from this test are listed in Table 13. The values listed in Table 13 were scaled to a 1 kg equivalent and are compared with a 1.066 kg hemicylindrical charge tested in the magazine model. The hemicylindrical charge values are listed in Table 7.

TABLE 17. LOADING DENSITY EFFECTS ON IMPULSE

BLAST LINE	SCALED DISTANCE	IMPULSE 1.814 kg	IMPULSE 0.227 kg	DIFFERENCE Δ	DIFFERENCE %
DEGREE	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$	
0	1.1	235.0	250.0	+15.0	+7.0
	7.2	30.0	37.0	+7.0	+23.0
	9.6	22.5	27.0	+4.5	+20.0
	16.0	12.8	15.5	+2.7	+21.0
90	.63	103.0	95.0	-8.0	-7.8
	7.2	34.5	32.0	-2.5	-7.2
	9.6	27.0	23.5	-3.5	-13.0
	16.0	17.0	13.5	-3.5	-20.5
180	1.1	78.0	68.0	-10.0	-12.5
	7.2	23.5	19.0	-4.5	-19.2
	9.6	18.0	14.8	-3.2	-17.7
	16.0	11.2	9.0	-2.2	-19.6

TABLE 18. EQUIVALENT YIELD FROM IMPULSE VARIATIONS

BLAST LINE	1.814 kg SCALED DISTANCE	SCALED IMPULSE	I_1/R_1	0.227 kg SCALED DISTANCE	SCALED IMPULSE	EMF
DEGREE	R_1	I_1		R_2	I_2	$(R_2/R_1)^3$
	$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$		$m/kg^{1/3}$	$kPa\text{-}ms/kg^{1/3}$	
0	1.1	235.0	213.6	1.15	246.0	1.14
	7.2	30.0	4.2	8.0	33.0	1.37
	9.6	22.5	2.3	10.5	24.6	1.31
	16.0	12.8	0.8	18.0	14.0	1.42
90	0.63	103.0	163.0	0.59	96.0	0.81
	7.20	34.5	4.8	6.90	33.0	0.88
	9.60	27.0	2.8	9.00	25.5	0.82
	16.00	17.0	1.1	14.50	15.4	0.74
180	1.1	78.0	70.9	1.0	71.0	0.75
	7.2	23.5	3.3	6.5	21.2	0.74
	9.6	18.0	1.9	8.6	16.2	0.73
	16.0	11.2	0.7	14.5	10.1	0.74

The comparison of peak overpressure along the three blast lines are presented in Figures 19, 20, and 21. The peak overpressure versus scaled distance along the 0-degree blast line for the two charge configurations is shown in Figure 19.

The peak overpressures versus scaled distances along the 90-degree blast line for the two charge configurations are plotted in Figure 20. Here the peak overpressures recorded from the hemicylindrical charge are lower than the hemispherical charge out to a scaled distance of 4 $m/kg^{1/3}$. From 4 $m/kg^{1/3}$ out to the inhabited building distance (16 $m/kg^{1/3}$) there is no significant difference in the plotted data.

The peak overpressures versus scaled distance recorded along the 180-degree blast line are plotted in Figure 21. Here again the values from the hemicylindrical charge are lower than the values from the hemispherical charge out to a scaled distance of 2.2 $m/kg^{1/3}$. From 2.2 $m/kg^{1/3}$ out to 17.5 $m/kg^{1/3}$ there is no significant difference in the two sets of data.

2. Comparison of Scaled Impulse versus Scaled Distance. The values of scaled impulse versus scaled distances plotted in Figures 22, 23, and 24 were taken from Tables 7 and 13. In Figure 22, the 0-degree blast line, the values from the two charge configurations compare quite well at scaled distances from 1 $m/kg^{1/3}$ out to 2 $m/kg^{1/3}$ and from 10 $m/kg^{1/3}$ out to 20 $m/kg^{1/3}$. From 2$m/kg^{1/3}$ to 10 $m/kg^{1/3}$ the scaled values of impulse from the hemicylindrical charge are lower.

Along the 90-degree blast line the values from the hemicylindrical charge as shown in Figure 23 are lower out to 4 $m/kg^{1/3}$ but beyond that there is no significant difference.

In Figure 24 the scaled impulse versus scaled distance values from the 180-degree blast line are plotted for the two charge configurations. The trend is similar to the 0-degree blast line where the beginning and end of the curves compare well. There is no significant difference in values beyond 6 $m/kg^{1/3}$.

For future tests where the suppression of blast parameters from earth cover is an objective it may be advisable to use hemispherical charges in the magazine model rather than hemicylindrical charges.

F. 1/30th-Scale versus 1/50th-Scale Testing

When simulating the effects of an accidental explosion in a munition storage magazine with an explosive source of 45360 kg (100,000 lbm) using munition storage magazine models a 0.363 kg charge was used in the 1/50th-scale tests and a 1.814 kg charge was used in the 1/30th-scale tests.

For the simulation of 136000 kg (300,000 lbm) a 1.080 kg charge was used for the 1/50th-scale tests while a 5.04 kg charge was used for the 1/30th-scale tests.

All data were scaled to a 1 kg equivalent for analysis and correlation of results.

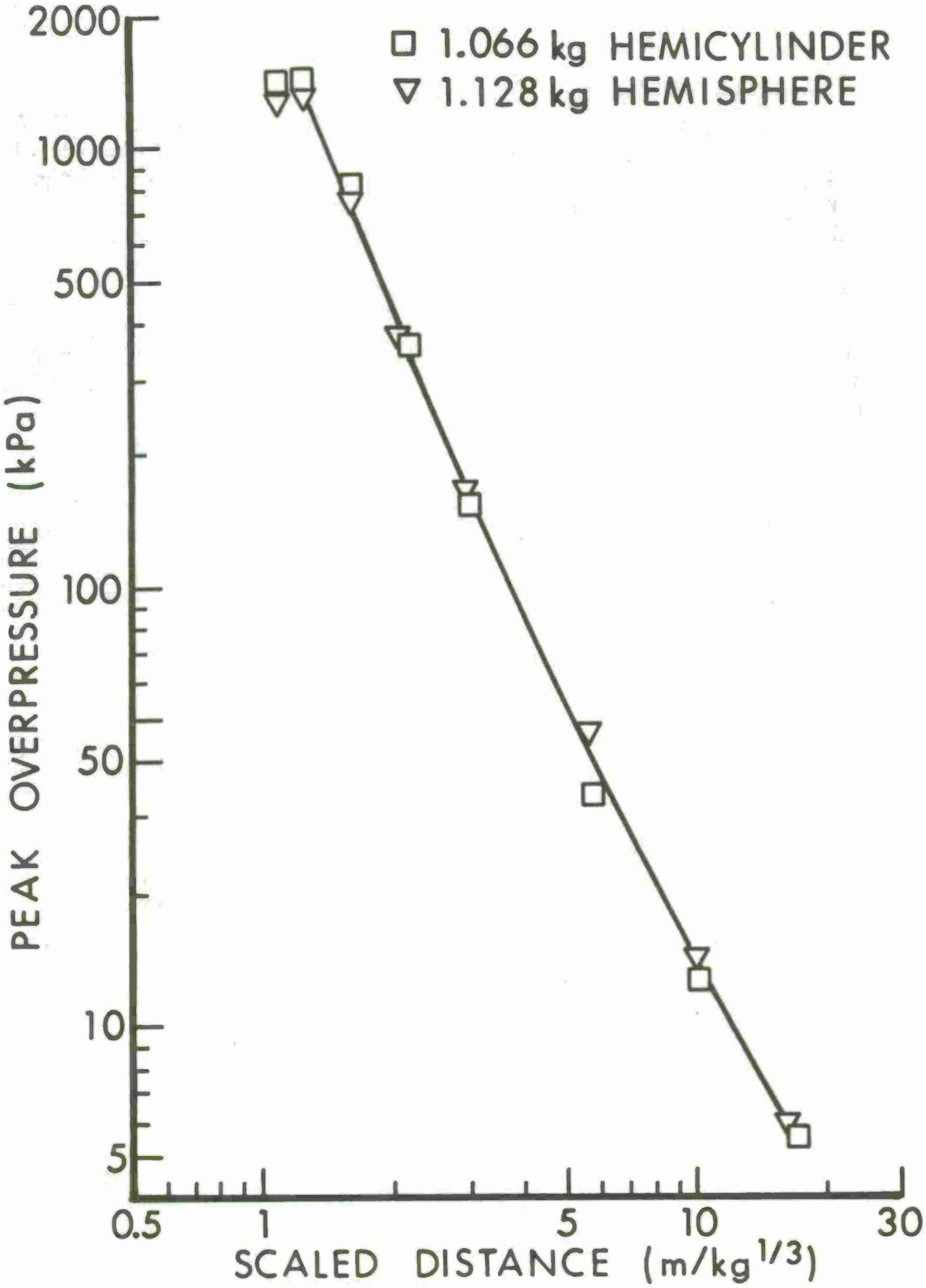


Figure 19. Peak overpressure versus scaled distance along the 0-degree blast line, hemicylinder and hemisphere in magazine.

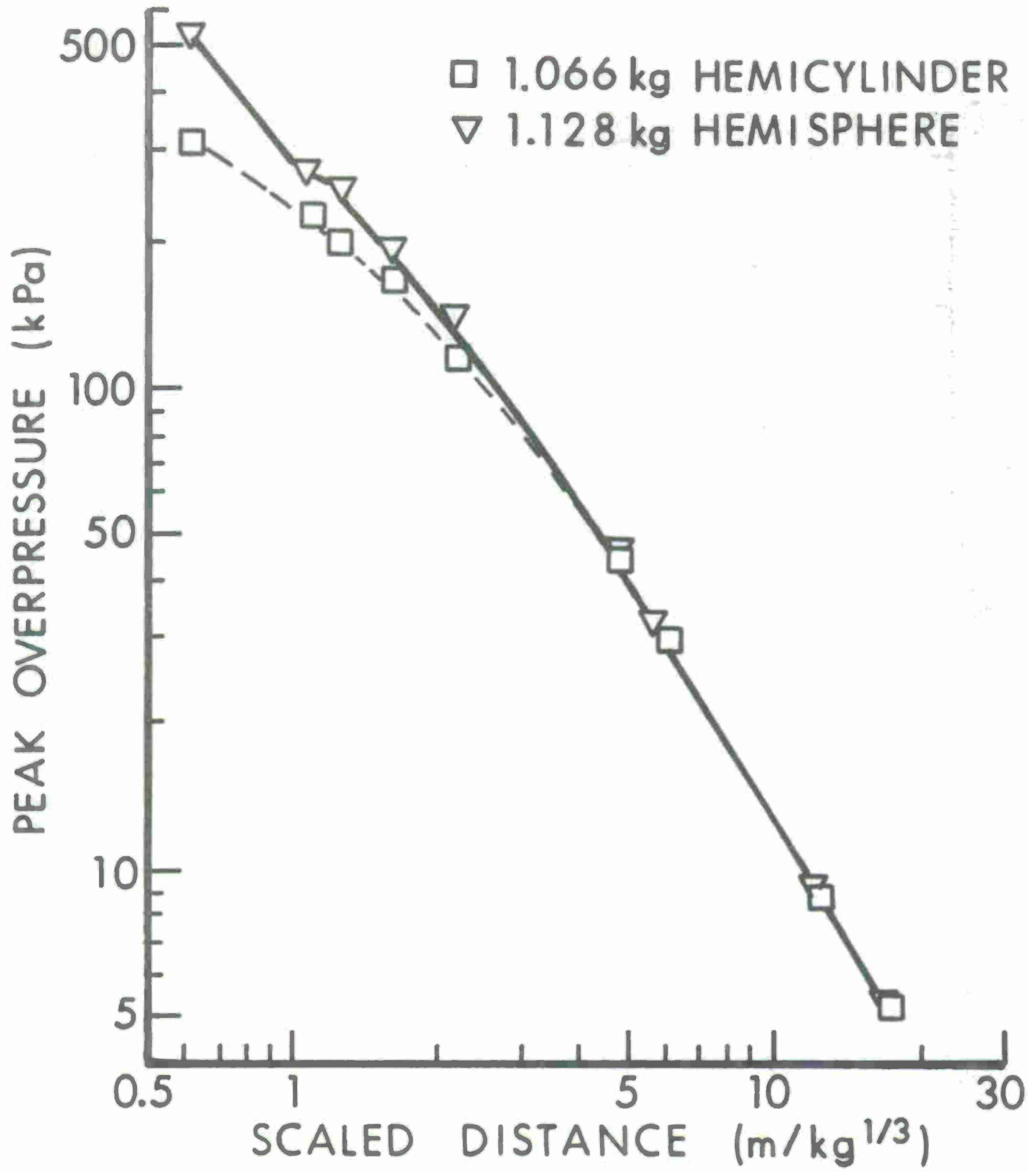


Figure 20. Peak overpressure versus scaled distance along the 90-degree blast line, hemicylinder and hemisphere in magazine.

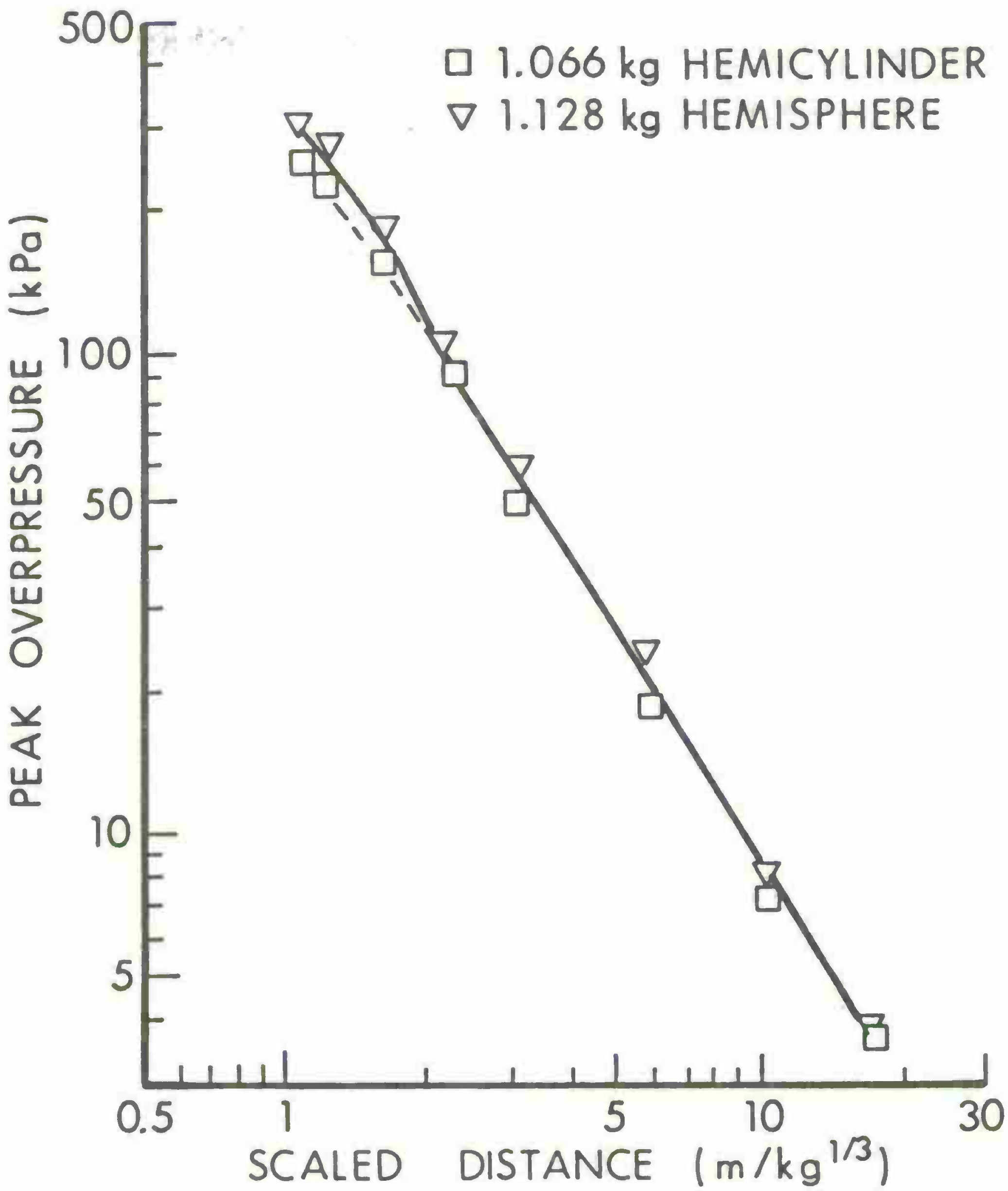


Figure 21. Peak overpressure versus scaled distance along the 180-degree blast line, hemicylinder and hemisphere in magazine.

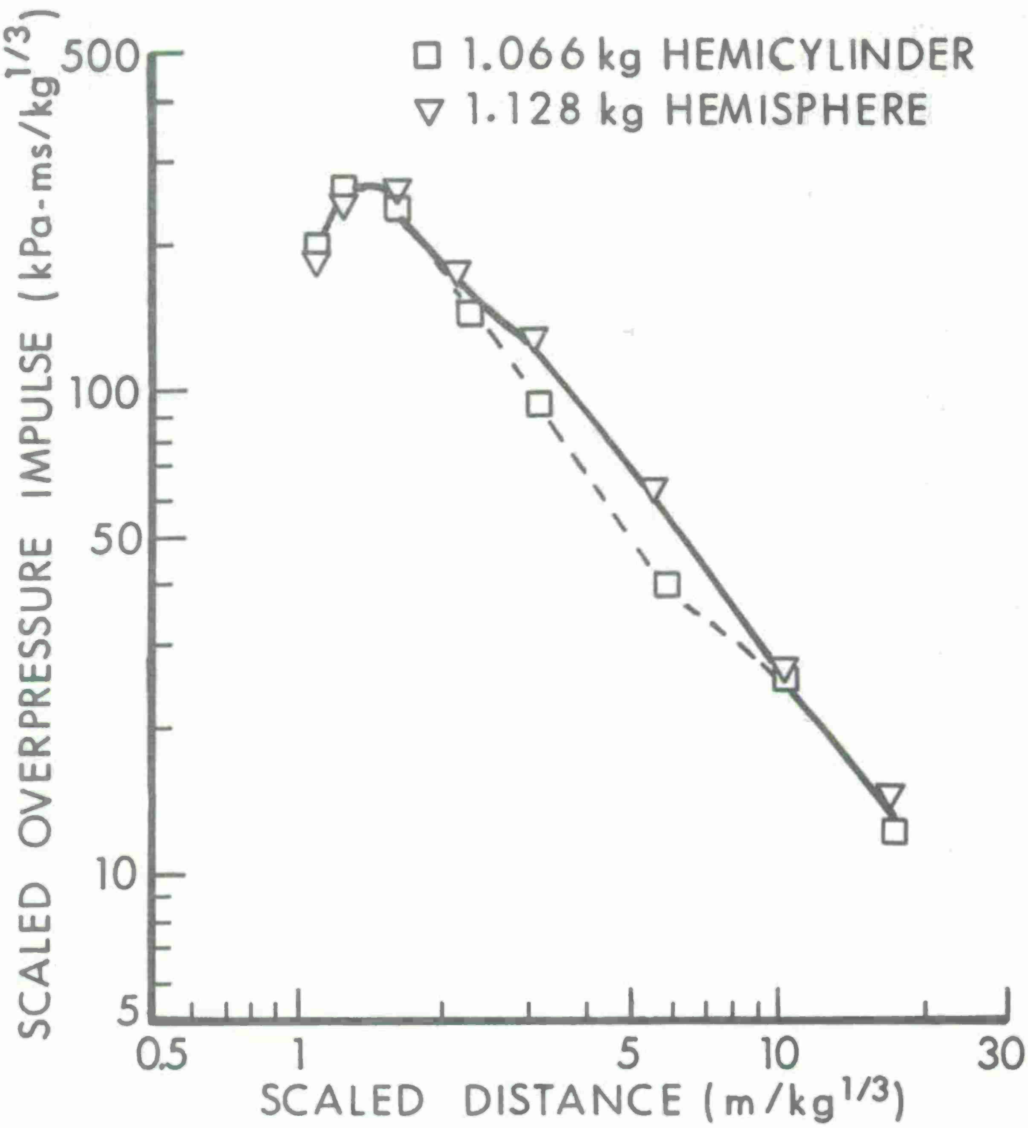


Figure 22. Scaled impulse versus scaled distance along the 0-degree blast line, hemicylinder and hemisphere in magazine.

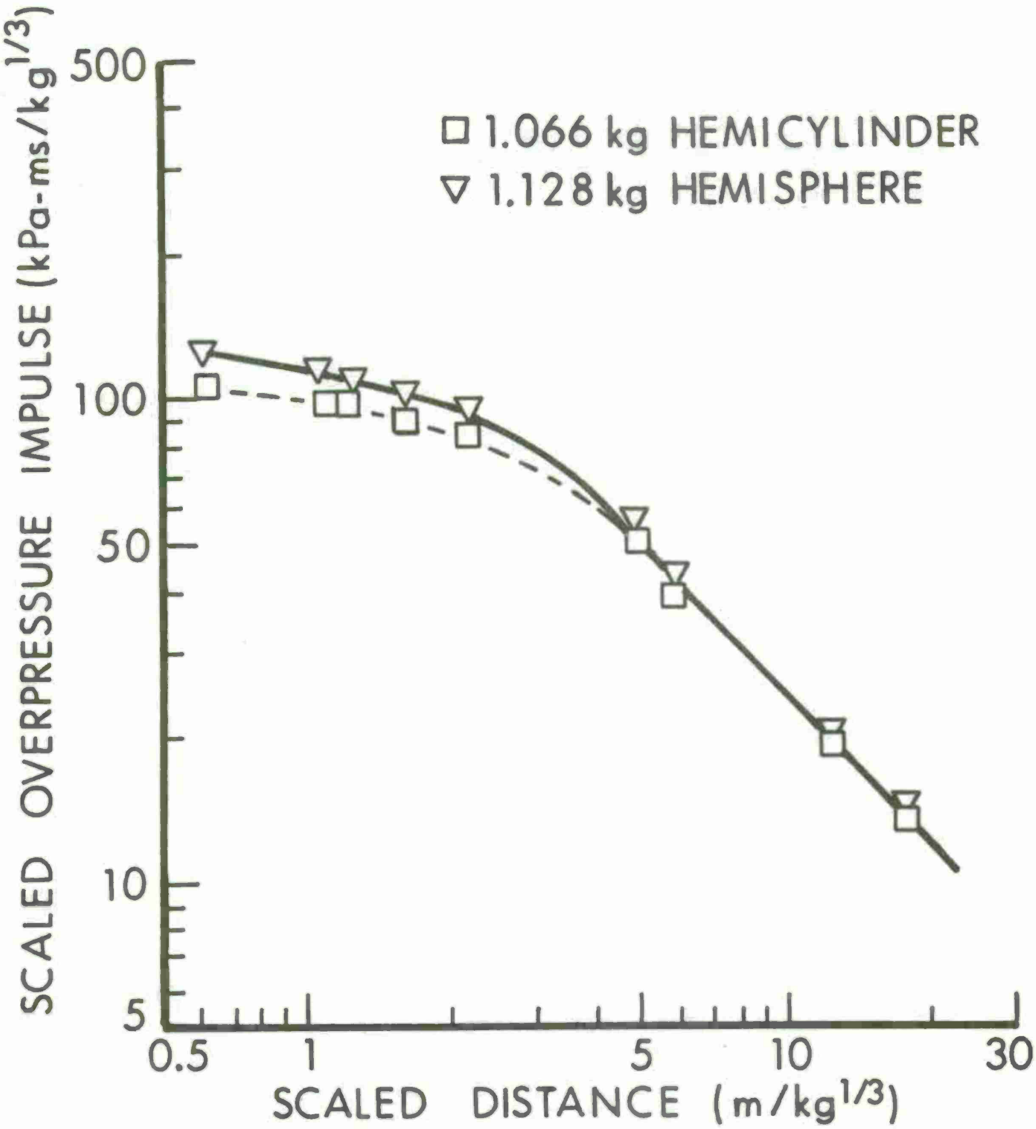


Figure 23. Scaled impulse versus scaled distance along the 90-degree blast line, hemicylinder and hemisphere in magazine.

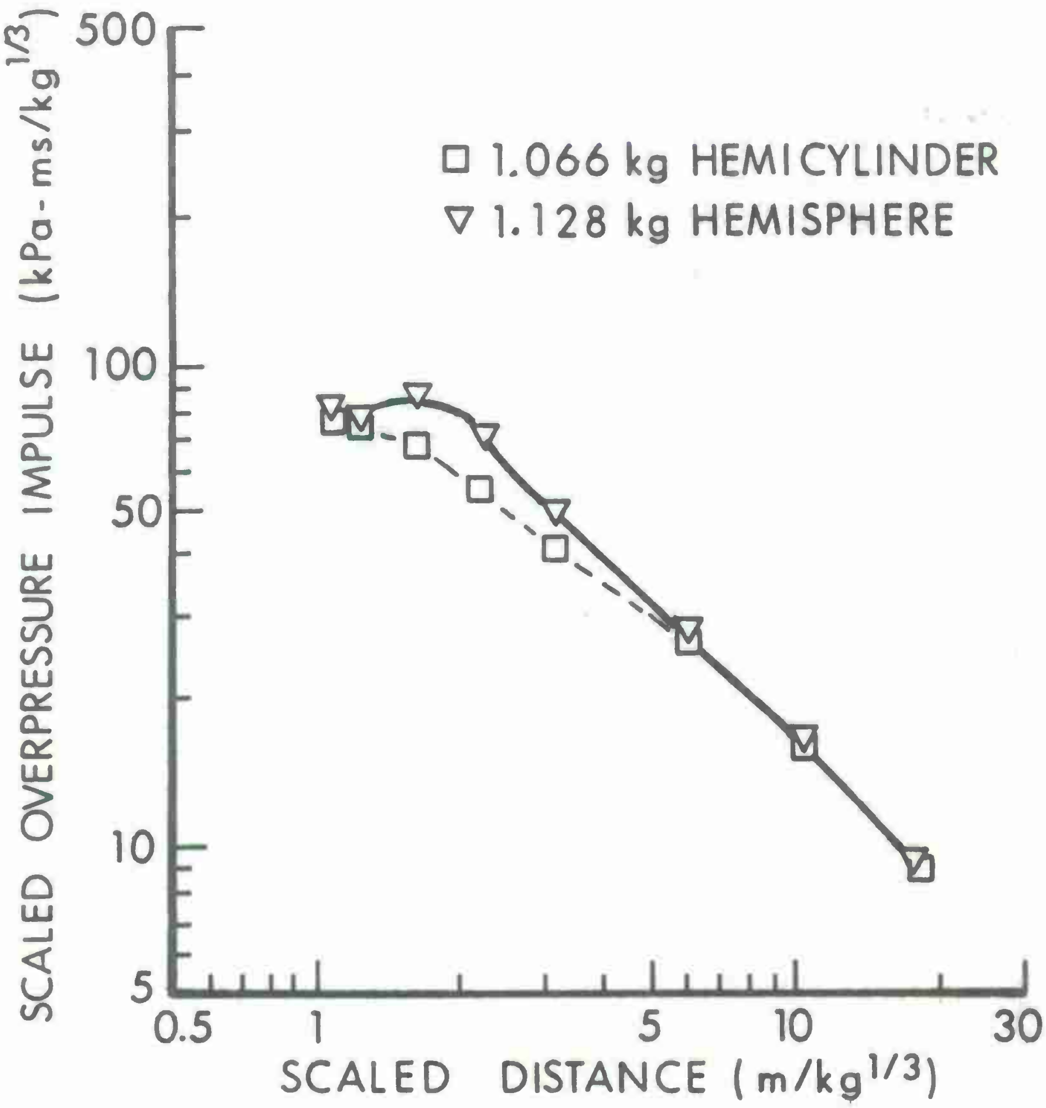


Figure 24. Scaled impulse versus scaled distance along the 180-degree blast line, hemicylinder and hemisphere in magazine.

The results published in Reference 1 (1/50th-scale) were compared with the present test results (1/30th-scale). The values of peak overpressure along the 0-degree blast line, recorded on the 1/50th-scale tests are approximately 25 percent lower than the 1/30th-scale test results at a scaled distance of 1 $m/kg^{1/3}$ but the results merge together at 2.5 $m/kg^{1/3}$ for both the 45360 kg and the 136000 kg full-size simulations. There is no significant difference in the impulse values along the 0-degree blast line when comparing the results from the 1/50th-scale and 1/30th-scale tests.

The peak overpressures along the 90-degree blast line were lower on the 1/50th-scale tests than the 1/30th-scale tests out to 2.5 $m/kg^{1/3}$ on the 45360 kg simulation. The comparison of peak overpressure is quite good between the two scaled tests on the 136000 kg simulation. The impulses recorded along the 90-degree blast line for the 1/50th-scale tests were 11 percent lower than those recorded on the 1/30th-scale tests for the 45360 kg simulation. The correlation of impulse recorded, on the 1/50th and 1/30th-scale tests along the 90-degree blast line for the 136000 kg simulation was good. Only one data point fell outside an acceptable scatter.

The largest difference noted in peak overpressure is along the 180-degree blast line when simulation 45360 kg full scale, the 1/50th-scale tests results were 50 percent lower than the 1/30th-scale values at 1 $m/kg^{1/3}$. The data from the two scale tests merge and beyond the scaled distance of 2.5 $m/kg^{1/3}$ the values are the same. The peak overpressures along the 180-degree blast line for the 136000 kg simulation were an average of 13 percent lower on the 1/50th-scale results compared to the 1/30th-scale tests.

The impulses along the 180-degree blast line for the 45360 kg simulation from the 1/50th-scale tests were an average of 20 percent lower than the 1/30th-scale test results. Comparison of impulse for the 136000 kg simulation gave an average difference of less than $\pm$ 1 percent for the two scaled test results along 180-degree blast line.

A detailed analysis to determine the cause of the differences recorded between the 1/50th-scale test results and the 1/30th-scale test results has not been made. The larger differences are generally at scaled distances less than 2.5 $m/kg^{1/3}$.

IV. CONCLUSIONS

The conclusions reached after analysis and discussion of results are listed below.

1. There is a loading density effect on the blast propagation along the three blast lines.

2. Along the 0-degree blast line the lowest loading density tests (12.6 kg/m^3) gave the highest peak overpressures from a scaled distance of 3 $m/kg^{1/3}$ to 10 $m/kg^{1/3}$.

3. Along the 0-degree blast line the lowest loading density tests ($12.6\ kg/m^3$) gave the highest scaled impulse values beyond a scaled distance of $1.5\ m/kg^{1/3}$.

4. Along the 90-degree blast line the lowest loading density tests ($12.6\ kg/m^3$) gave lower peak overpressures and lower scaled impulses over the entire blast line.

5. Along the 180-degree blast line the two lower loading density tests ($12.6\ kg/m^3$ and $20.2\ kg/m^3$) gave lower peak overpressure and lower scaled impulses over the entire blast line.

6. Quantity-distance criterion can be reduced for low loading densities along the 90-degree and 180-degree blast lines but should be increased along the 0-degree blast line.

7. The 1/30th-scale test results are recommended for 6130 kg (13,500 lbm) through 136000 kg (300,00 lbm) full size simulations. The 1/50th-scale tests are satisfactory for 226800 kg (500,000 lbm) full size simulations.

APPENDIX A

OVERPRESSURE VERSUS TIME RECORDS FROM IN-MAGAZINE TESTS

NOTE: Records from the top of the page, down are:

1.814 kg, Shots 1 and 2
1.066 kg, Shots 5 and 6
0.363 kg, Shots 9 and 10
and 0.227 kg, Shots 12, 13, and 14

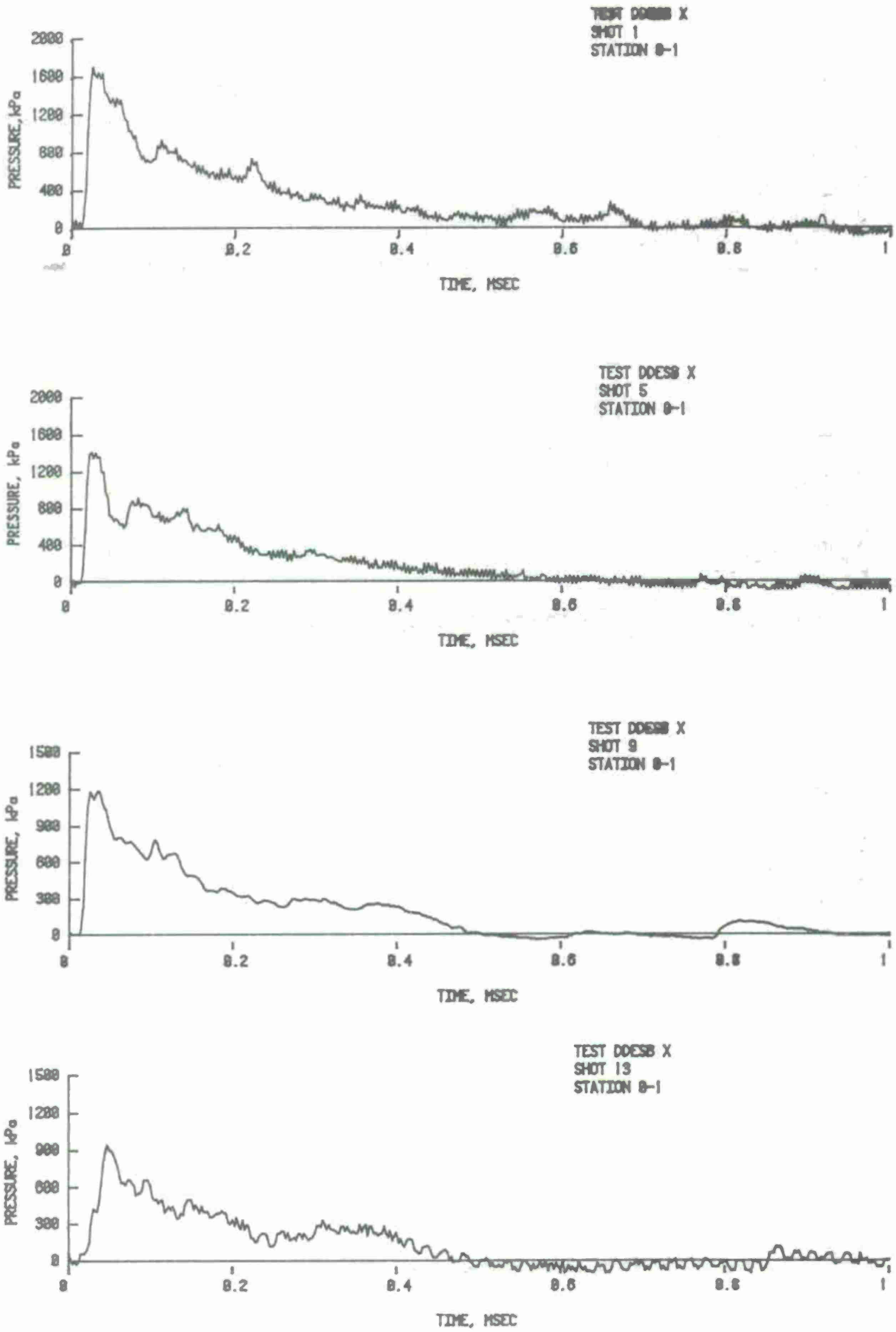


Figure A-1. Pressure versus time records, Station 0-1.

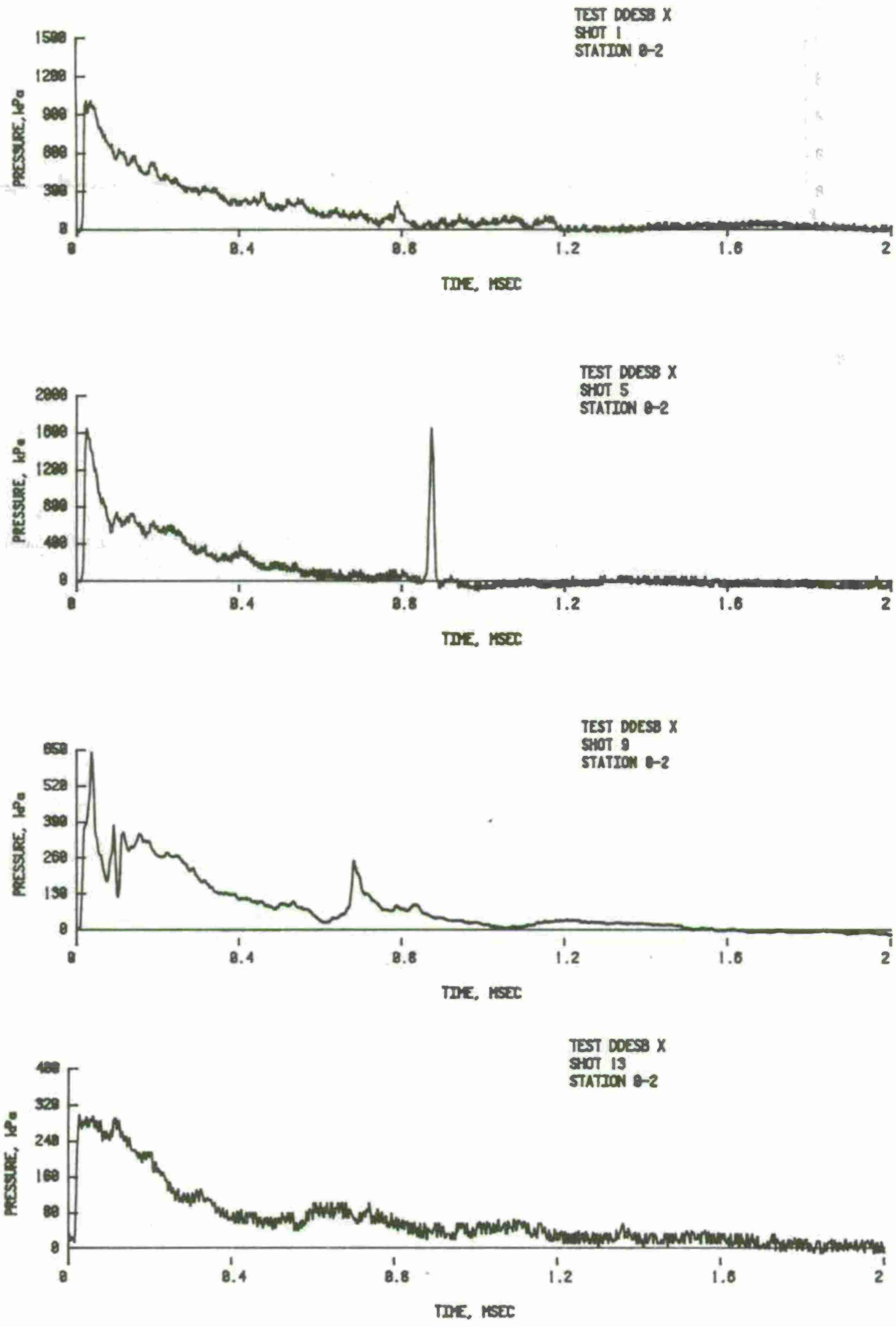


Figure A-2. Pressure versus time records, Station 0-2.

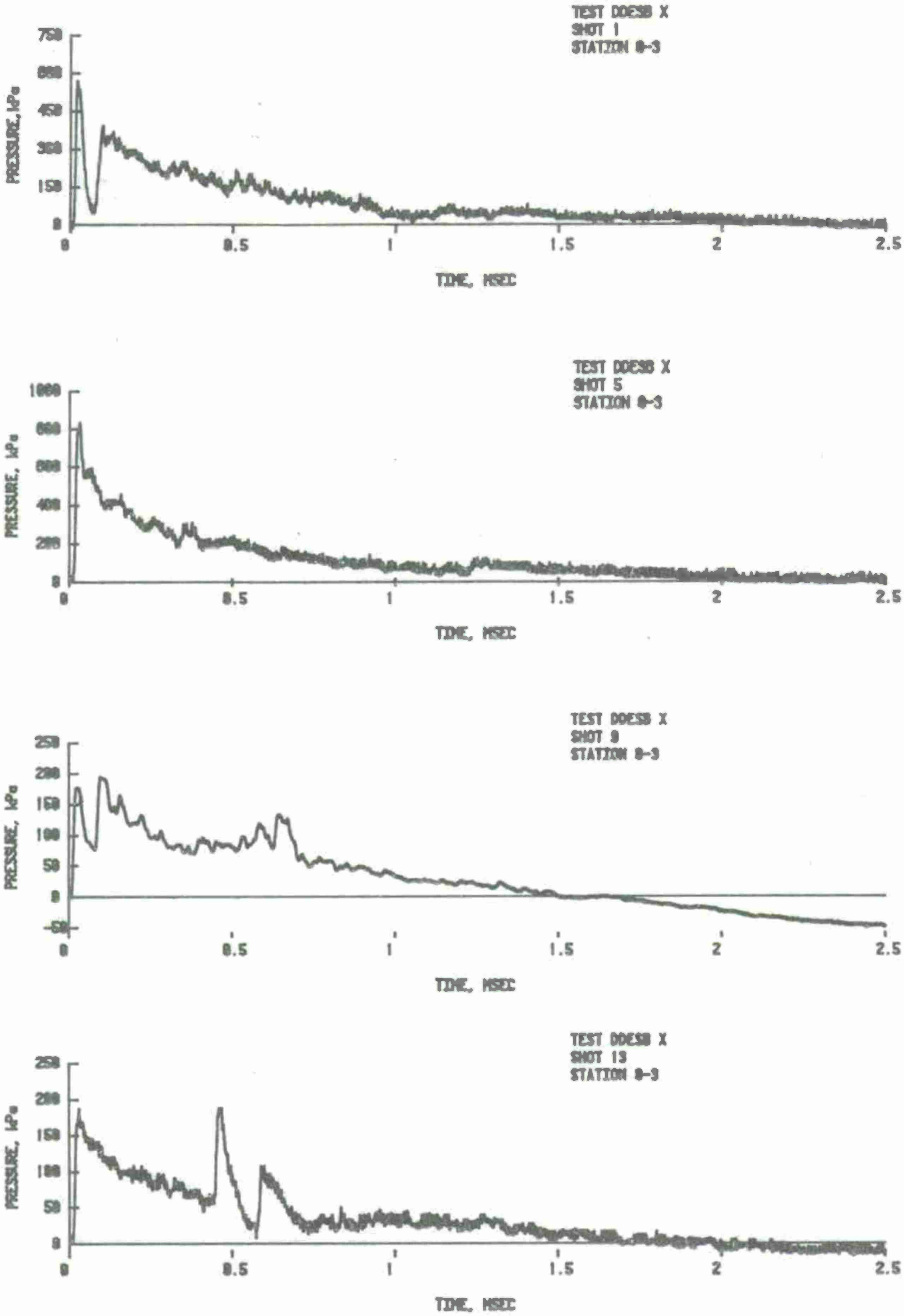


Figure A-3. Pressure versus time records, Station 0-3.

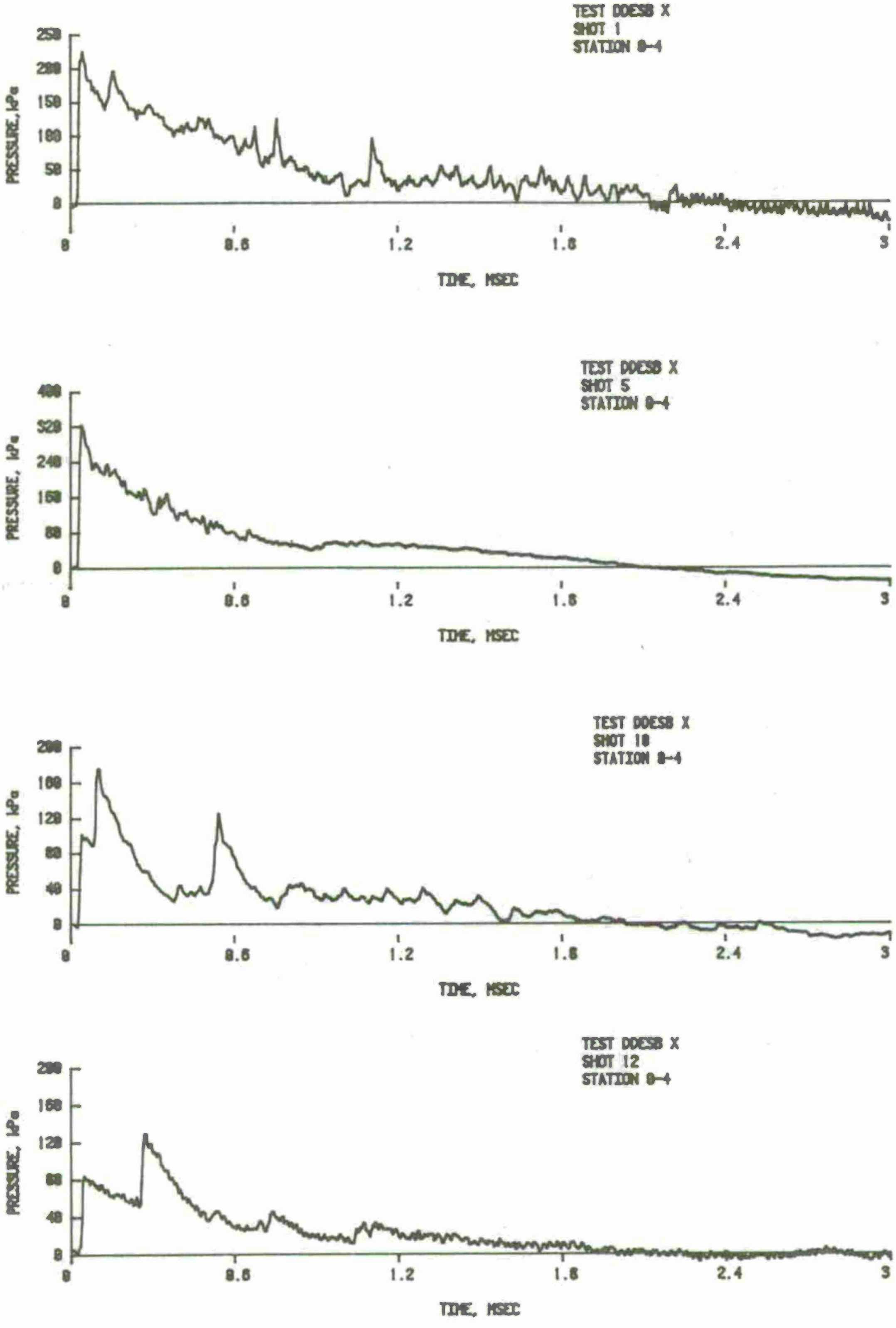


Figure A-4. Pressure versus time records, Station 0-4.

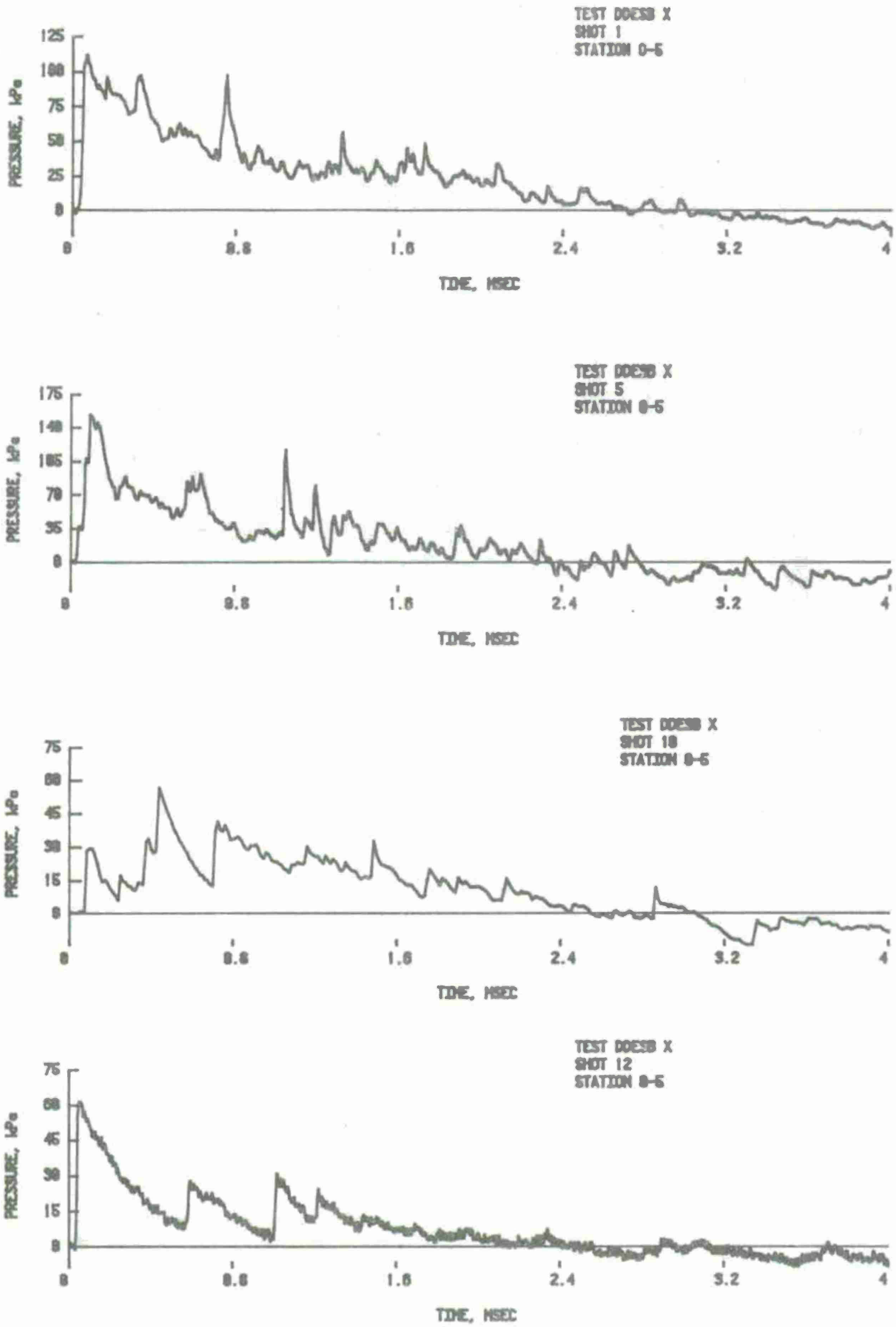


Figure A-5. Pressure versus time records, Station 0-5.

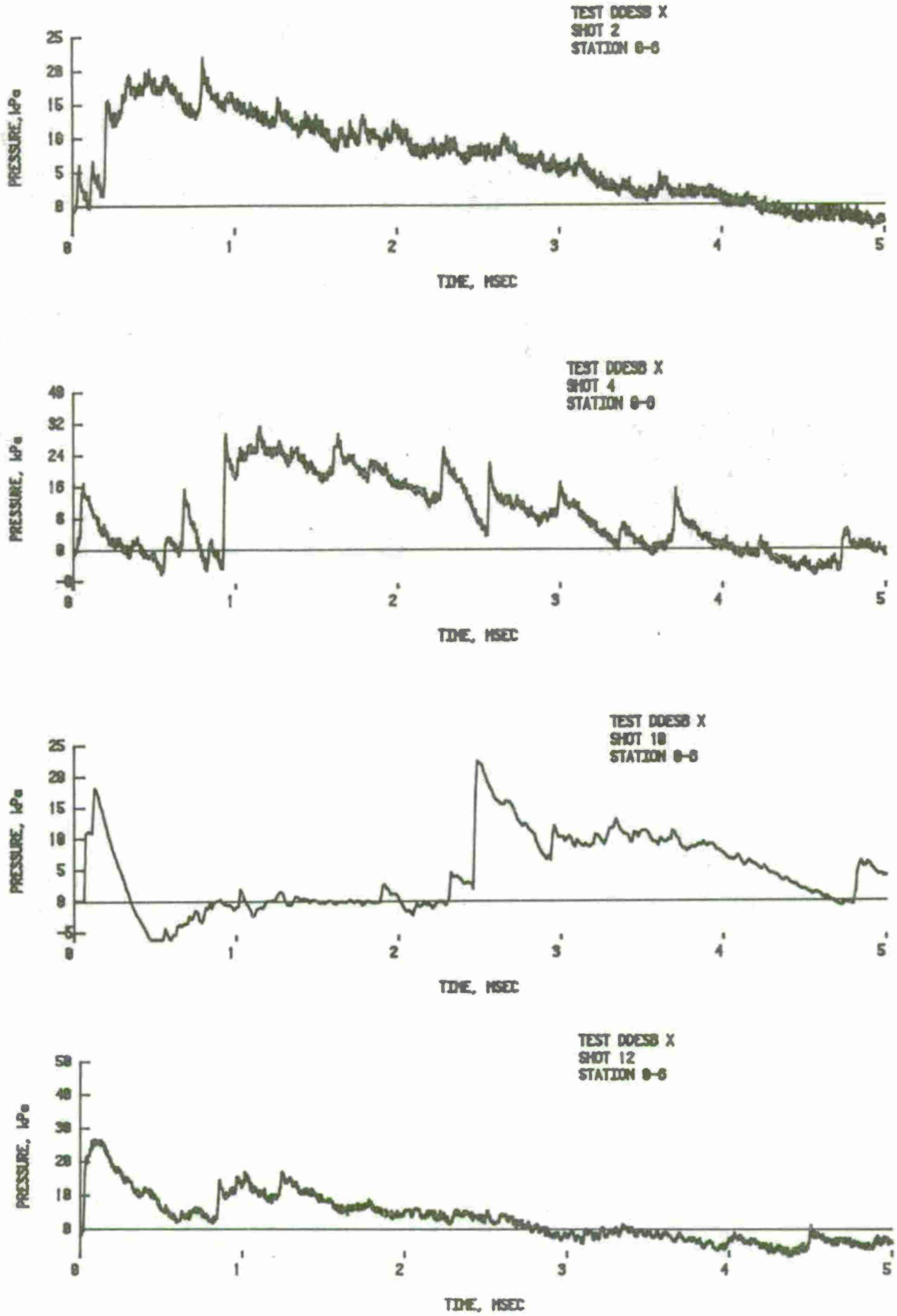


Figure A-6. Pressure versus time records, Station 0-6.

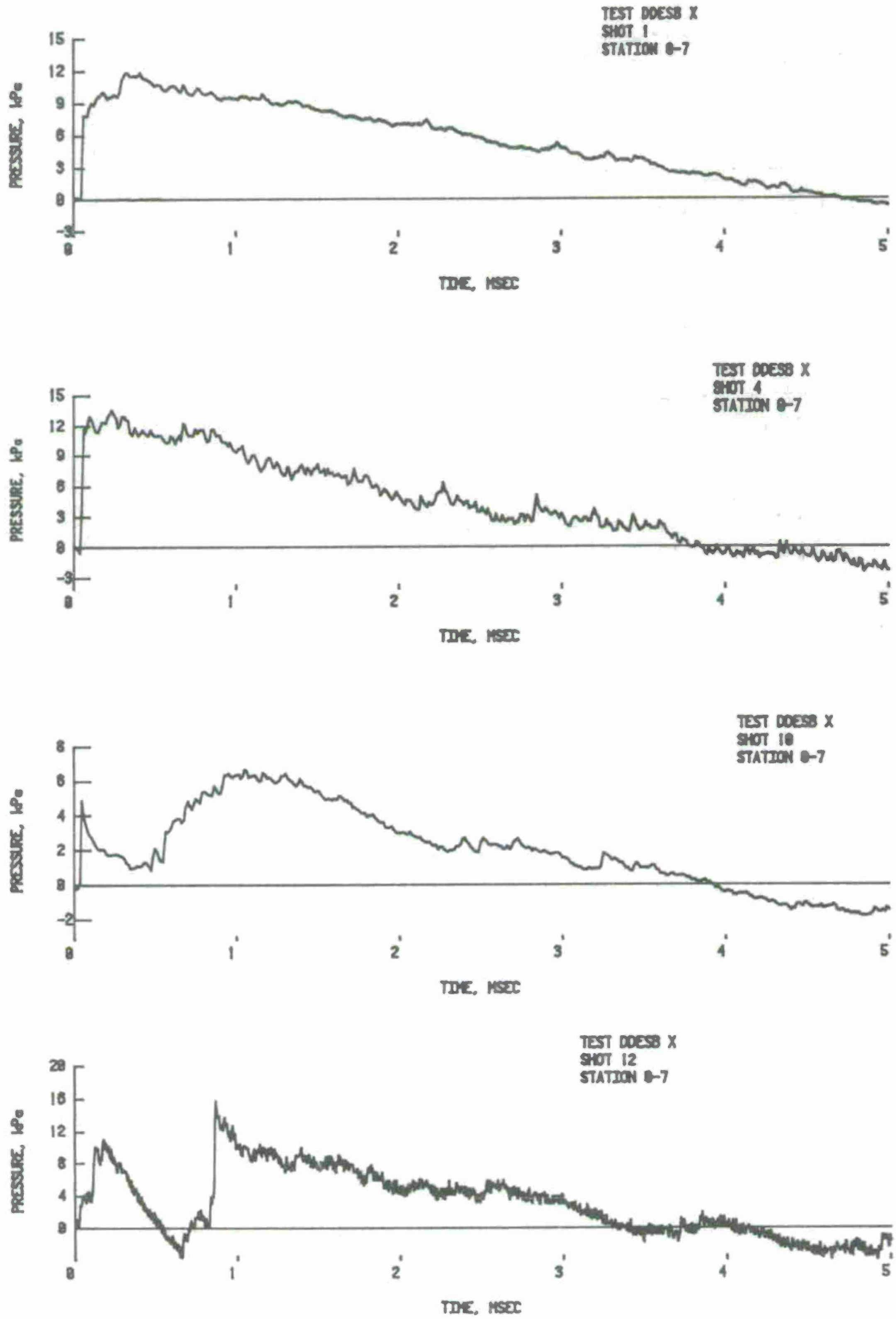


Figure A-7. Pressure versus time records, Station 0-7.

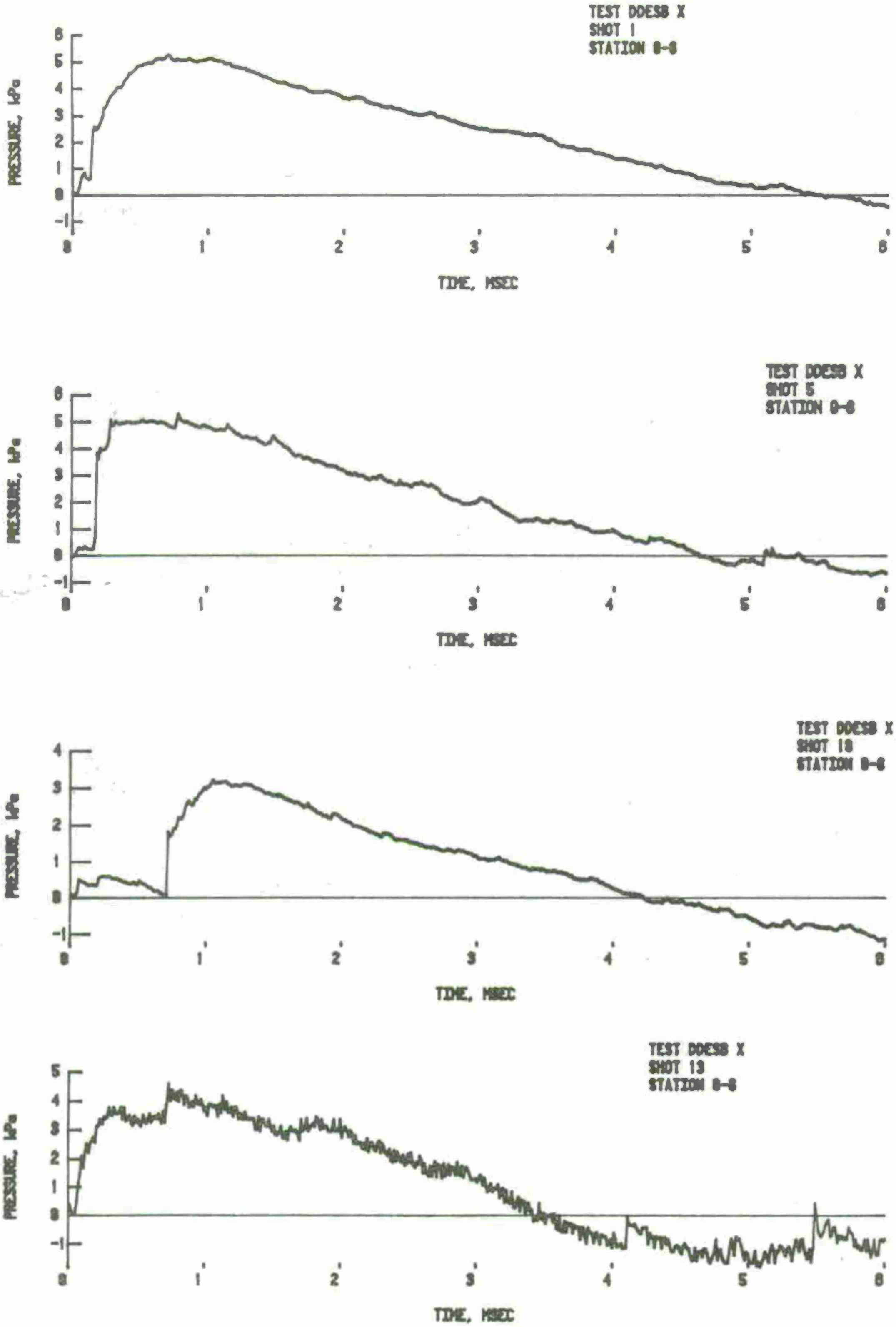


Figure A-8. Pressure versus time records, Station 0-8.

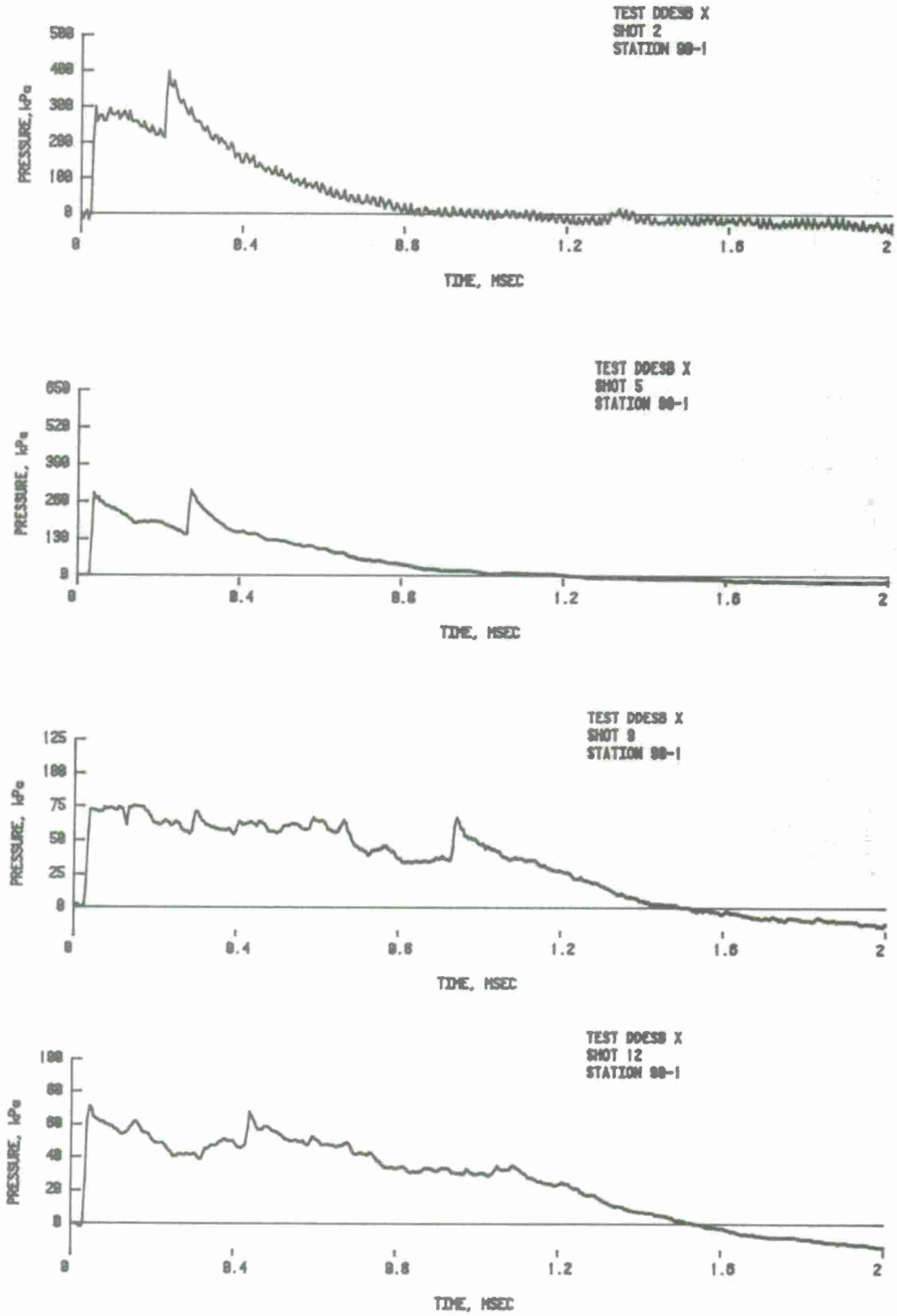


Figure A-9. Pressure versus time records, Station 90-1.

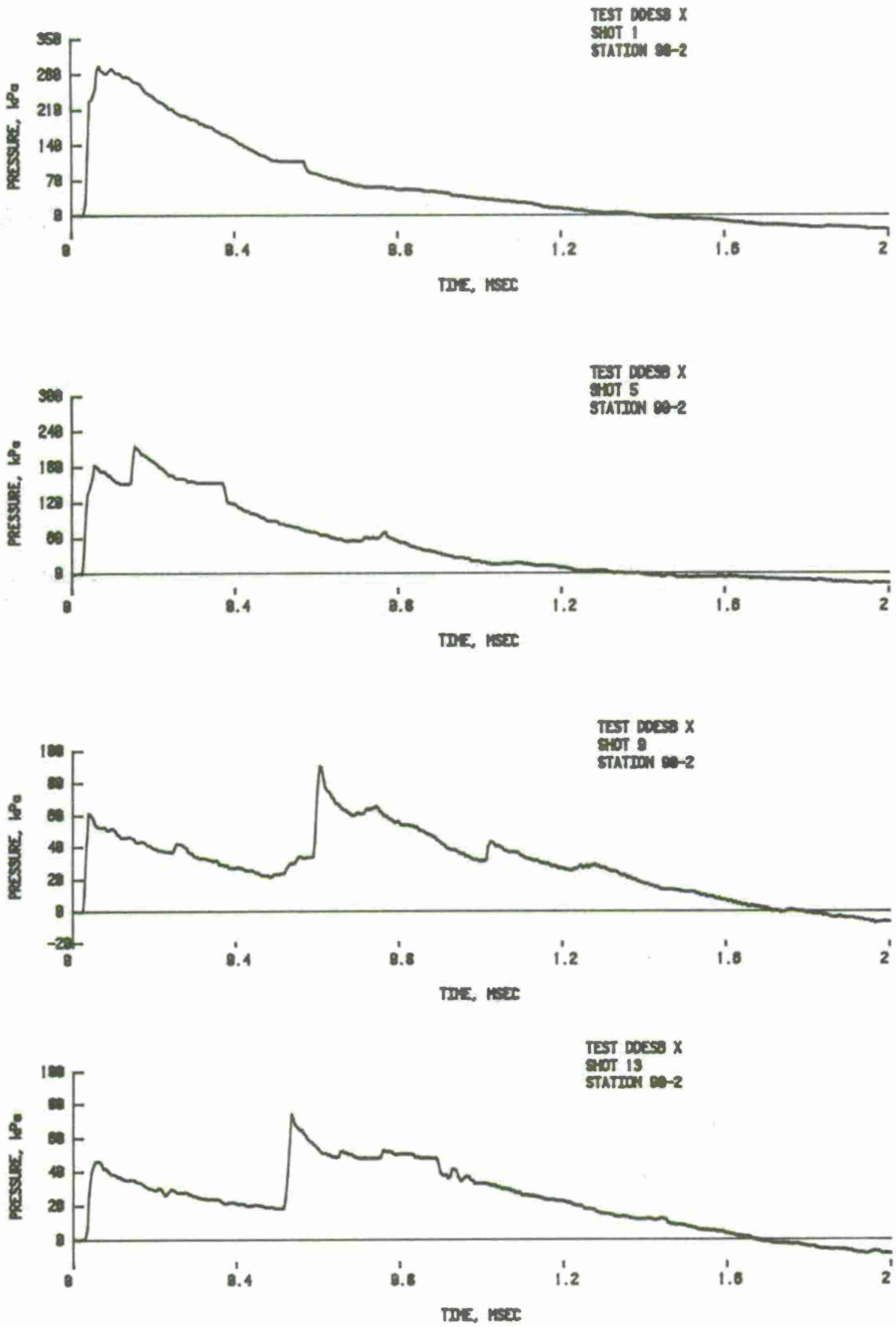


Figure A-10. Pressure versus time records, Station 90-2.

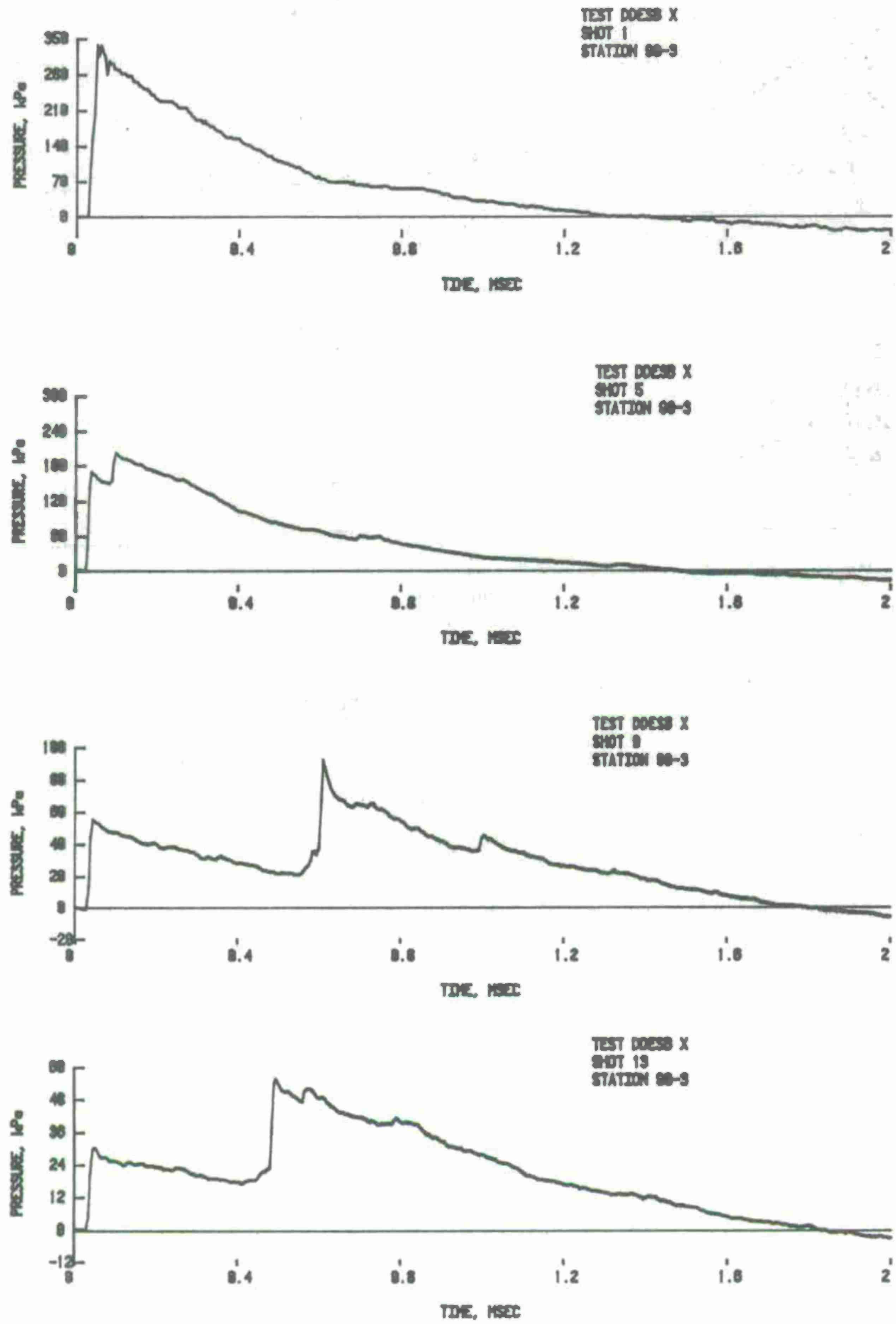


Figure A-11. Pressure versus time records, Station 90-3.

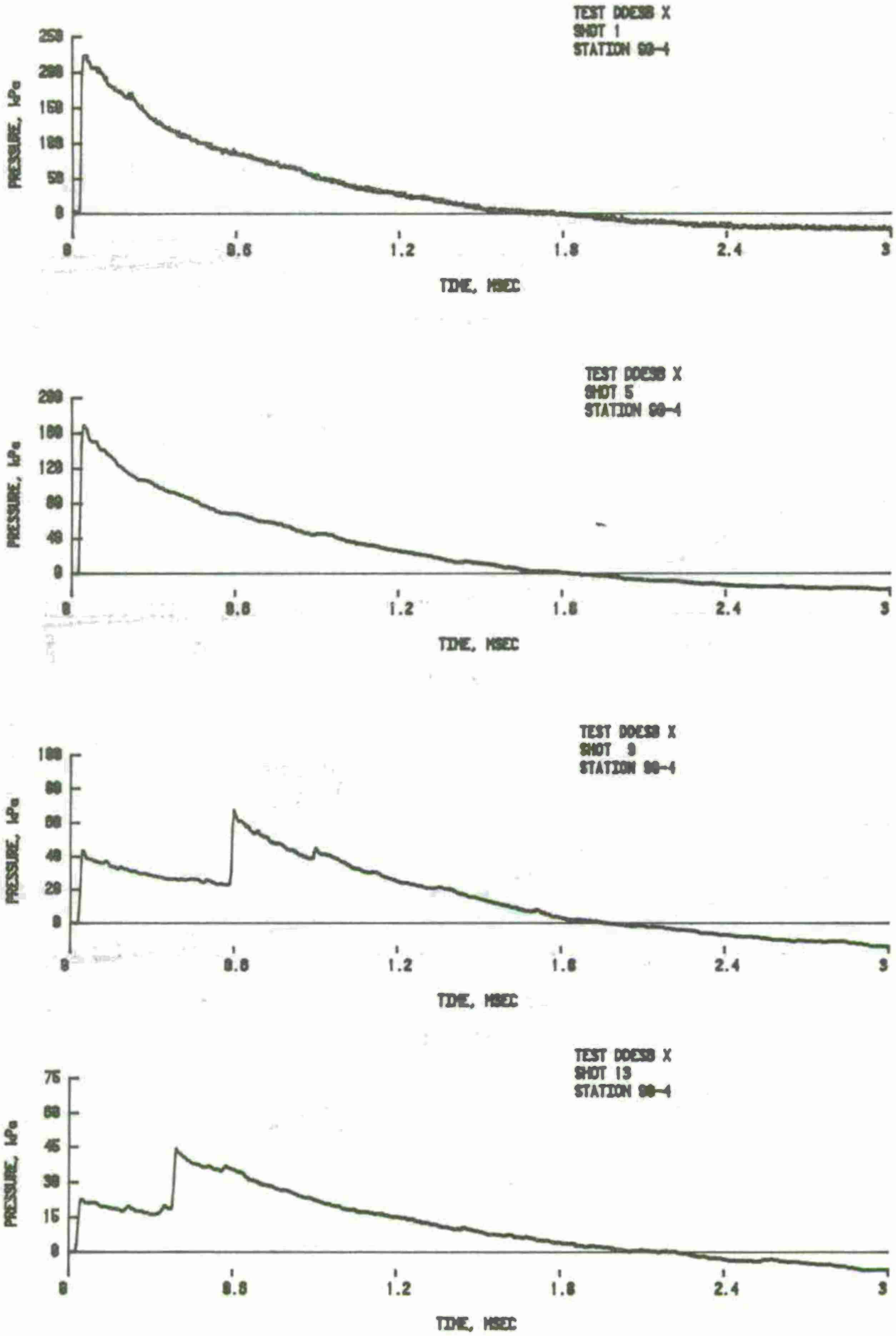


Figure A-12. Pressure versus time records, Station 90-4.

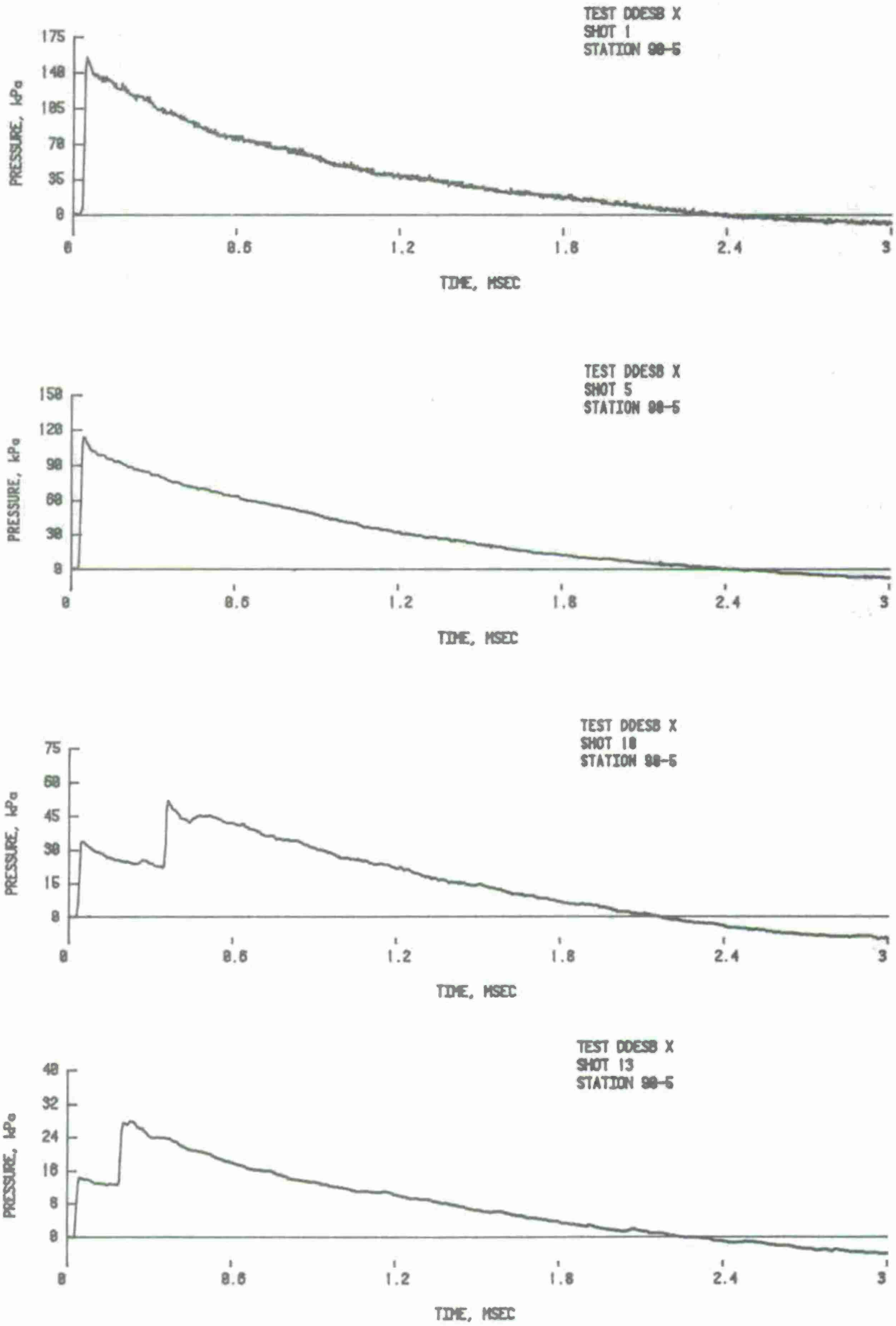


Figure A-13. Pressure versus time records, Station 90-5.

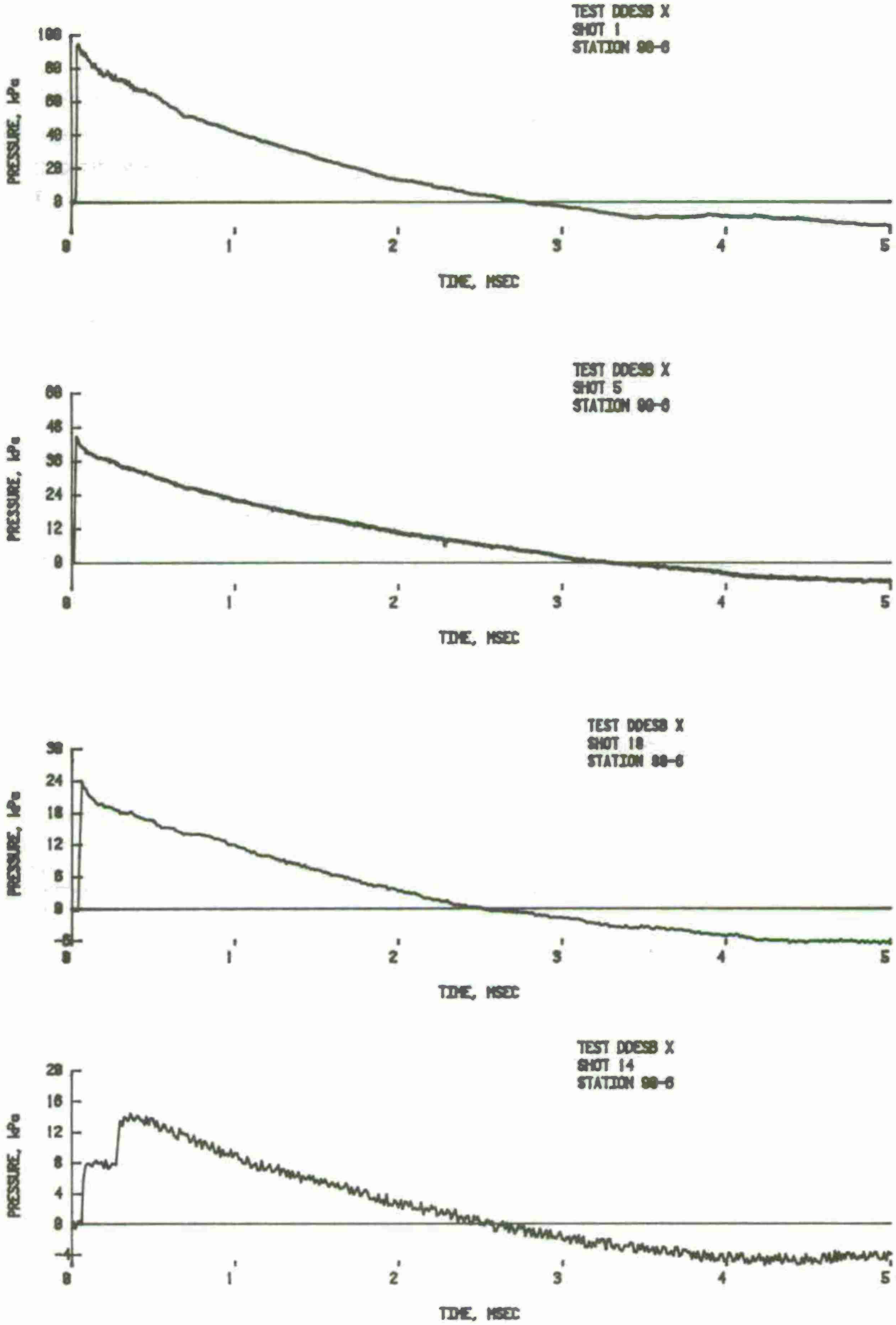


Figure A-14. Pressure versus time records, Station 90-6.

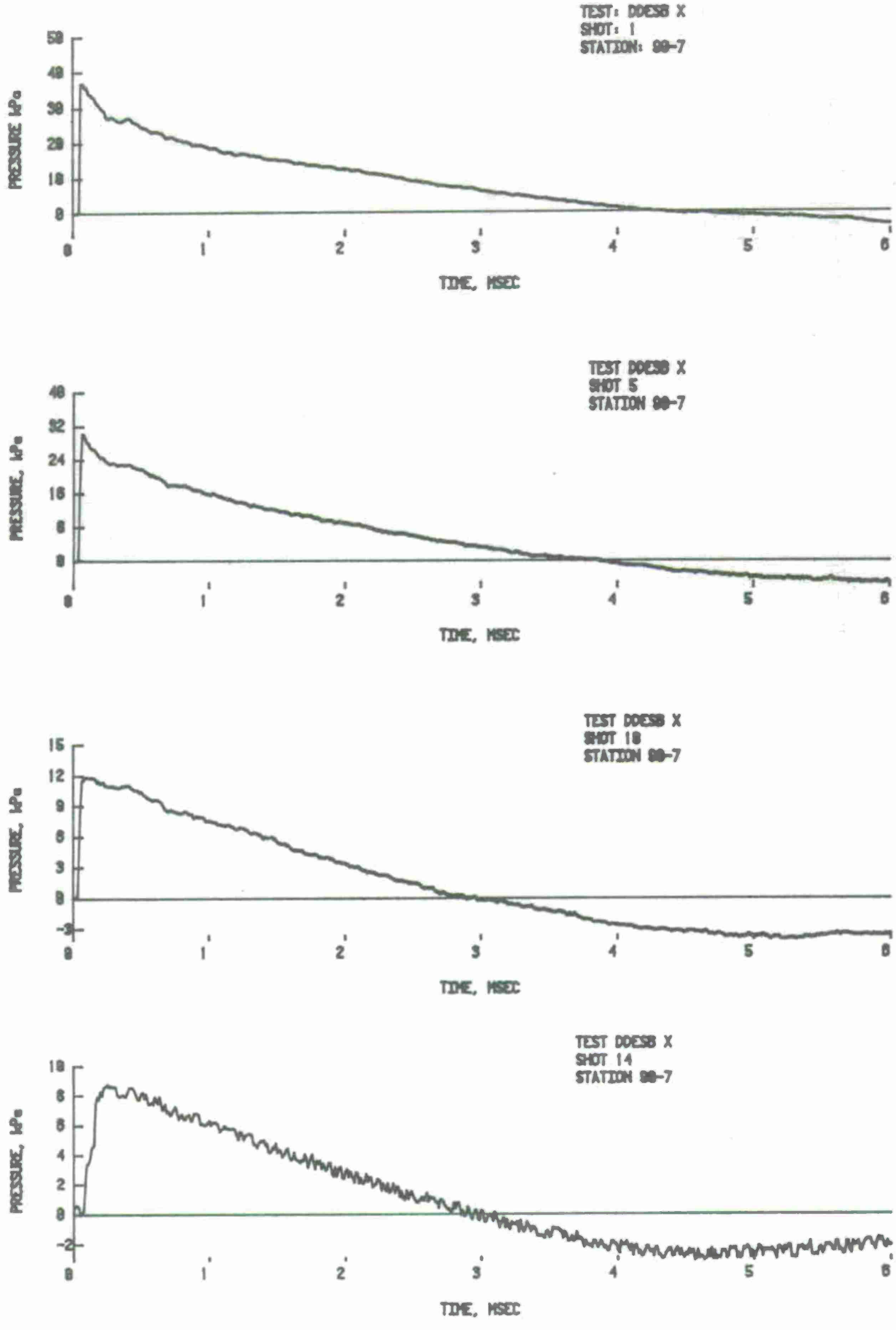


Figure A-15. Pressure versus time records, Station 90-7.

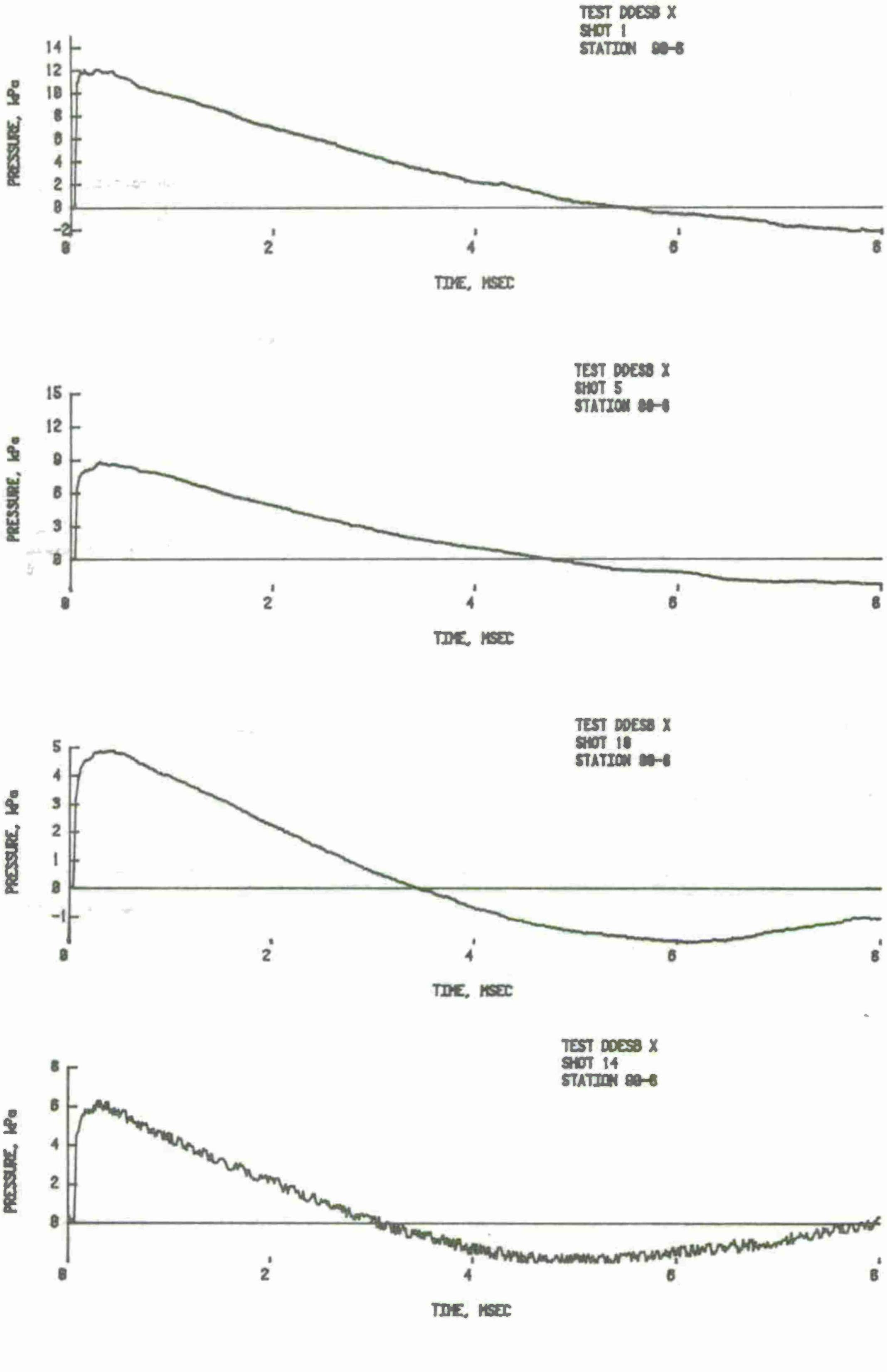


Figure A-16. Pressure versus time records, Station 90-8.

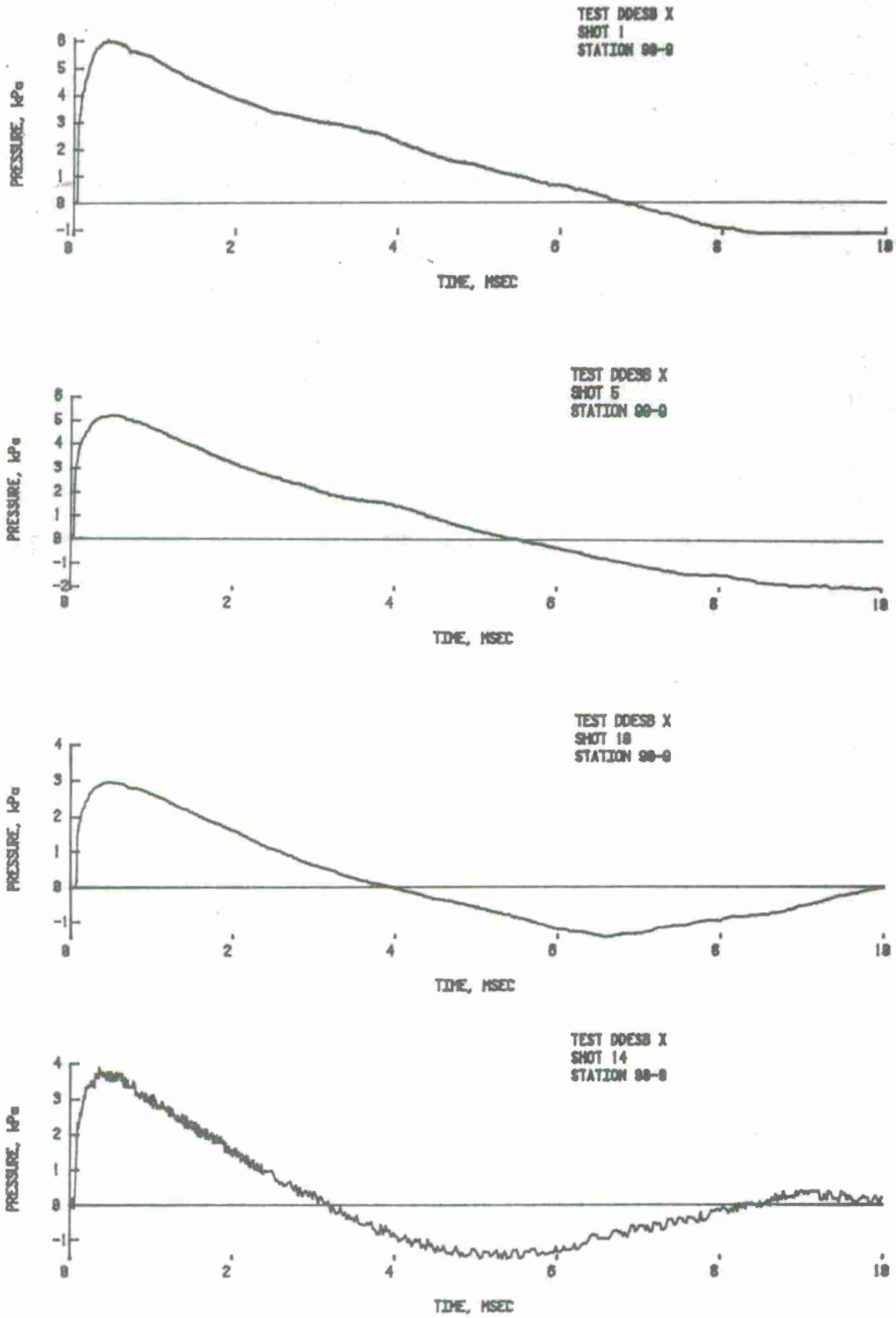


Figure A-17. Pressure versus time records, Station 90-9.

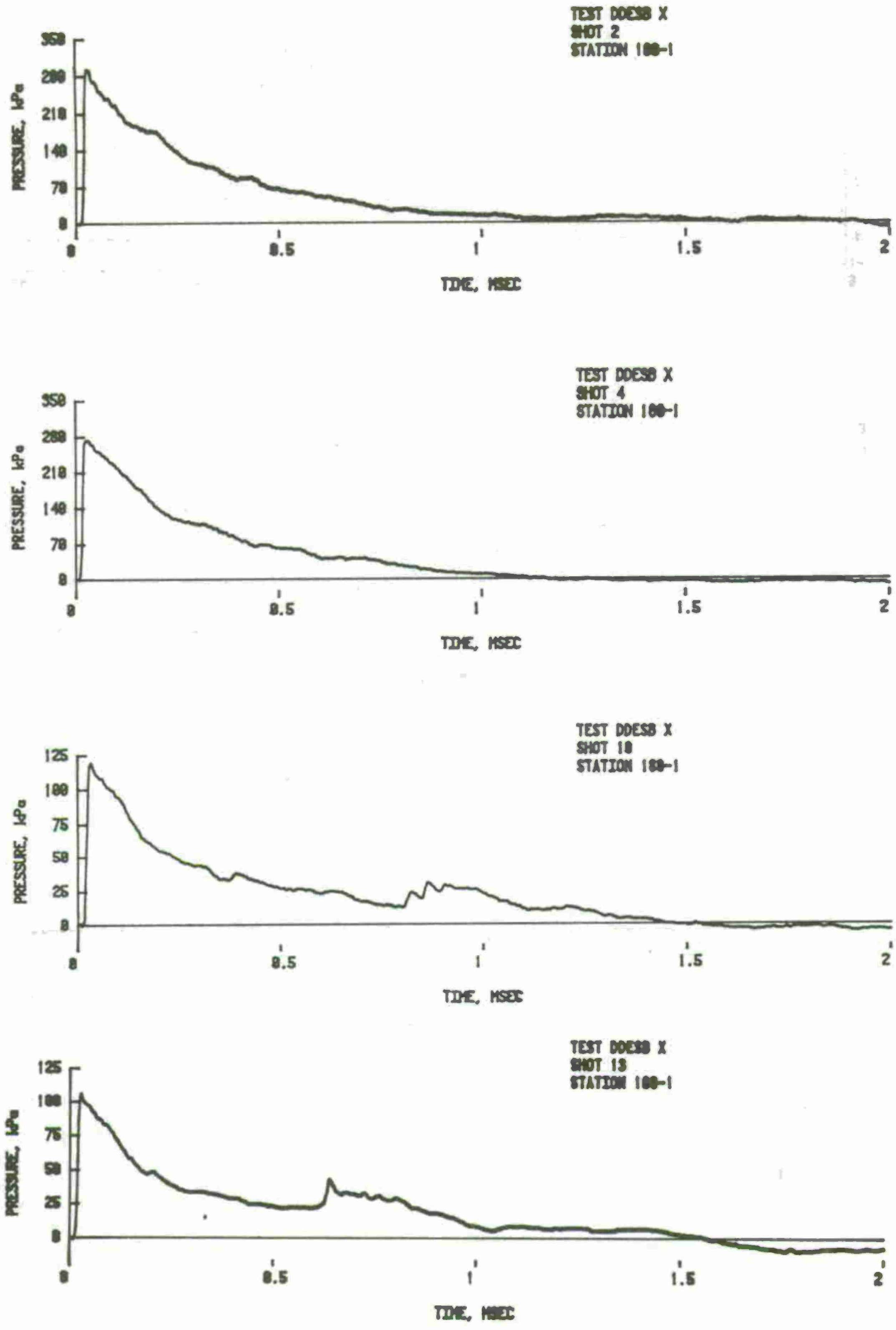


Figure A-18. Pressure versus time records, Station 180-1.

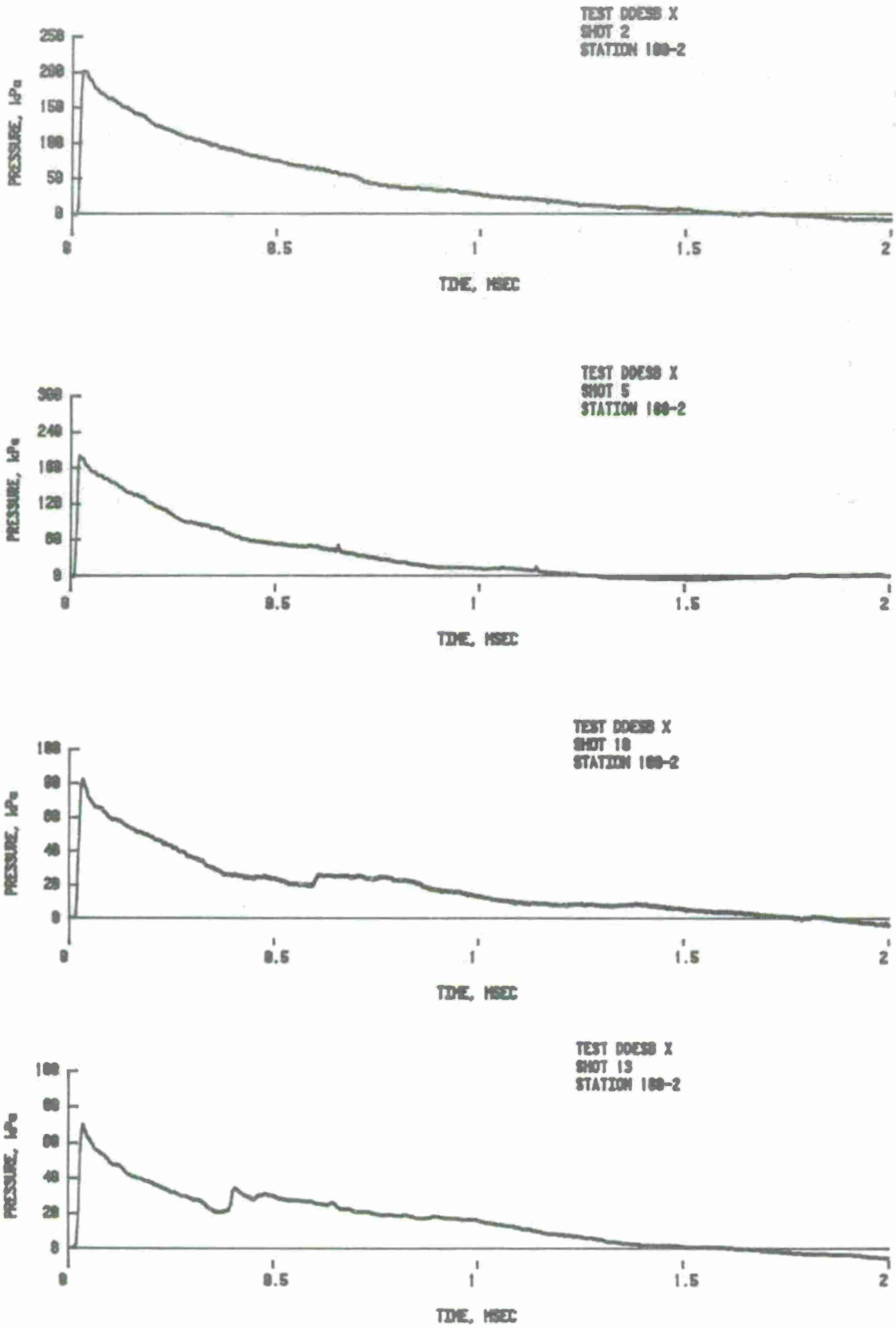


Figure A-19. Pressure versus time records, Station 180-2.

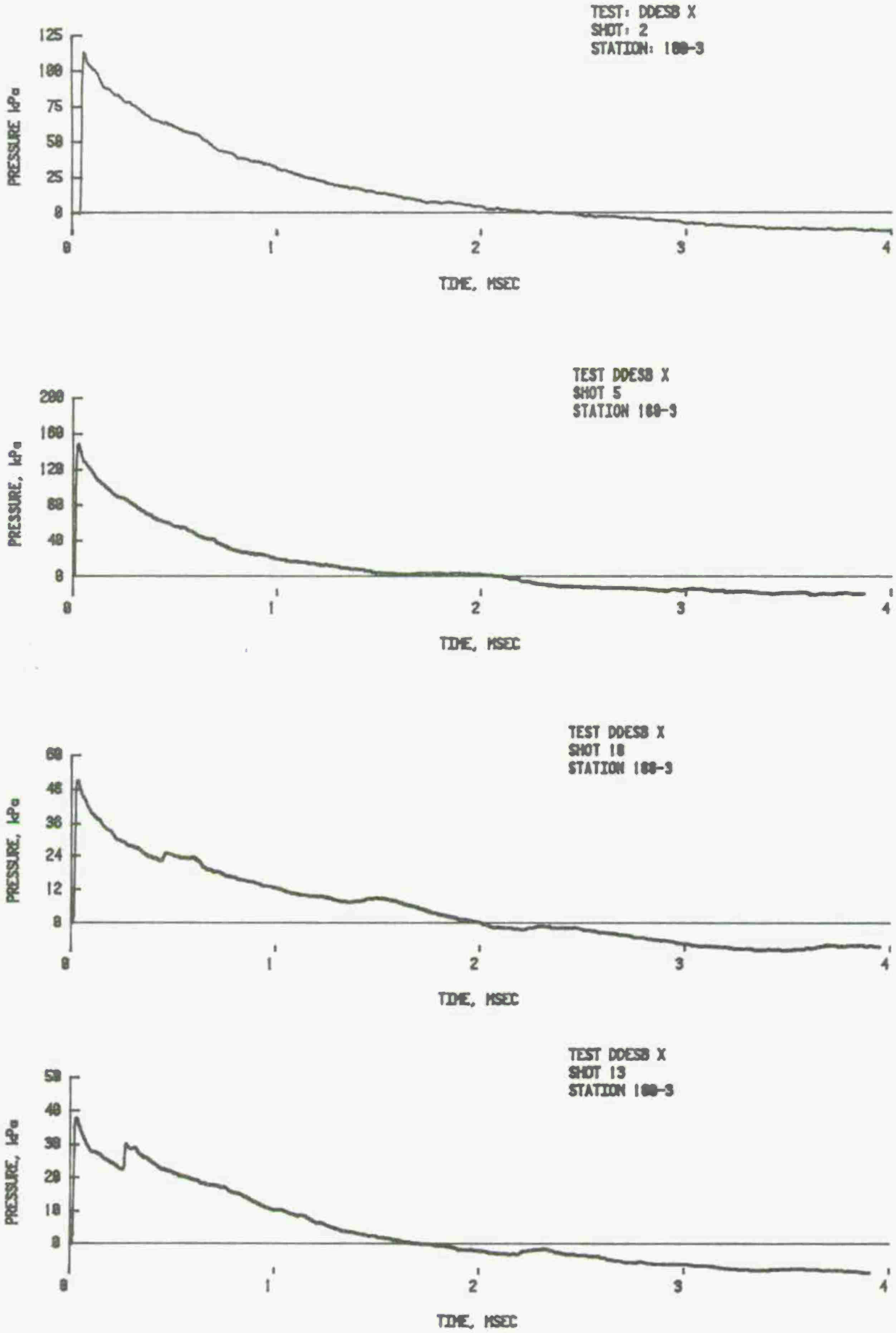


Figure A-20. Pressure versus time records, Station 180-3.

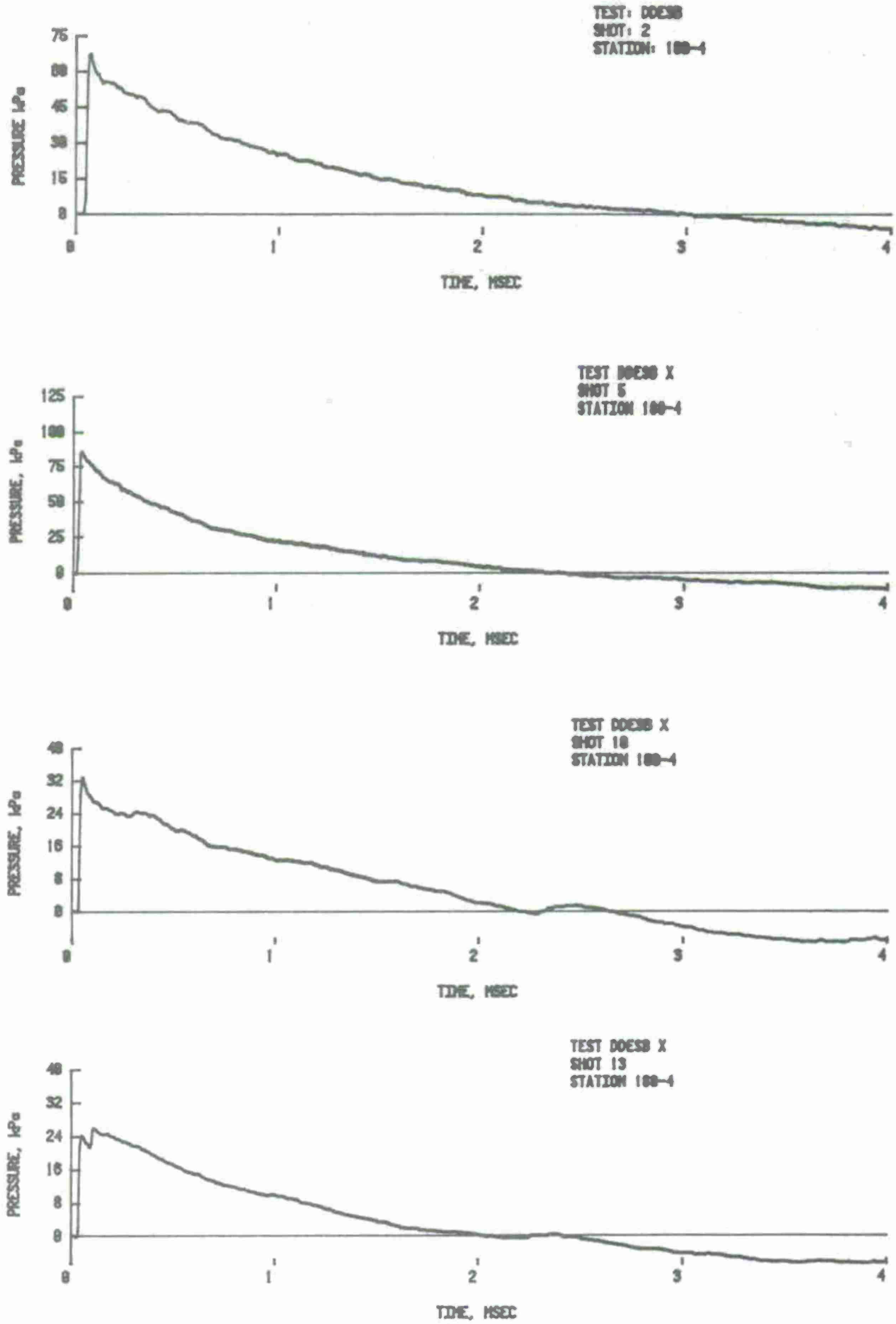


Figure A-21. Pressure versus time records, Station 180-4.

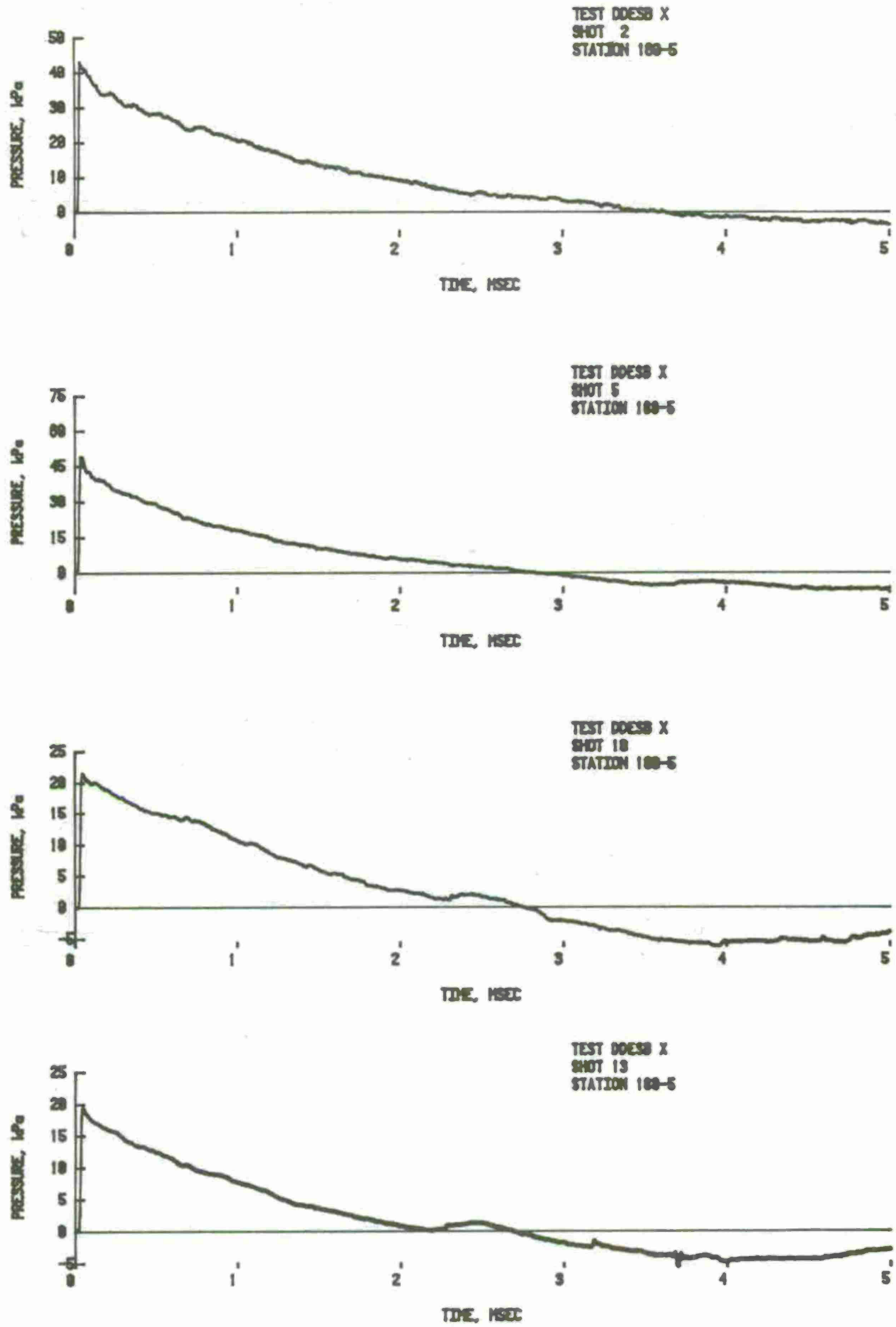


Figure A-22. Pressure versus time records, Station 180-5.

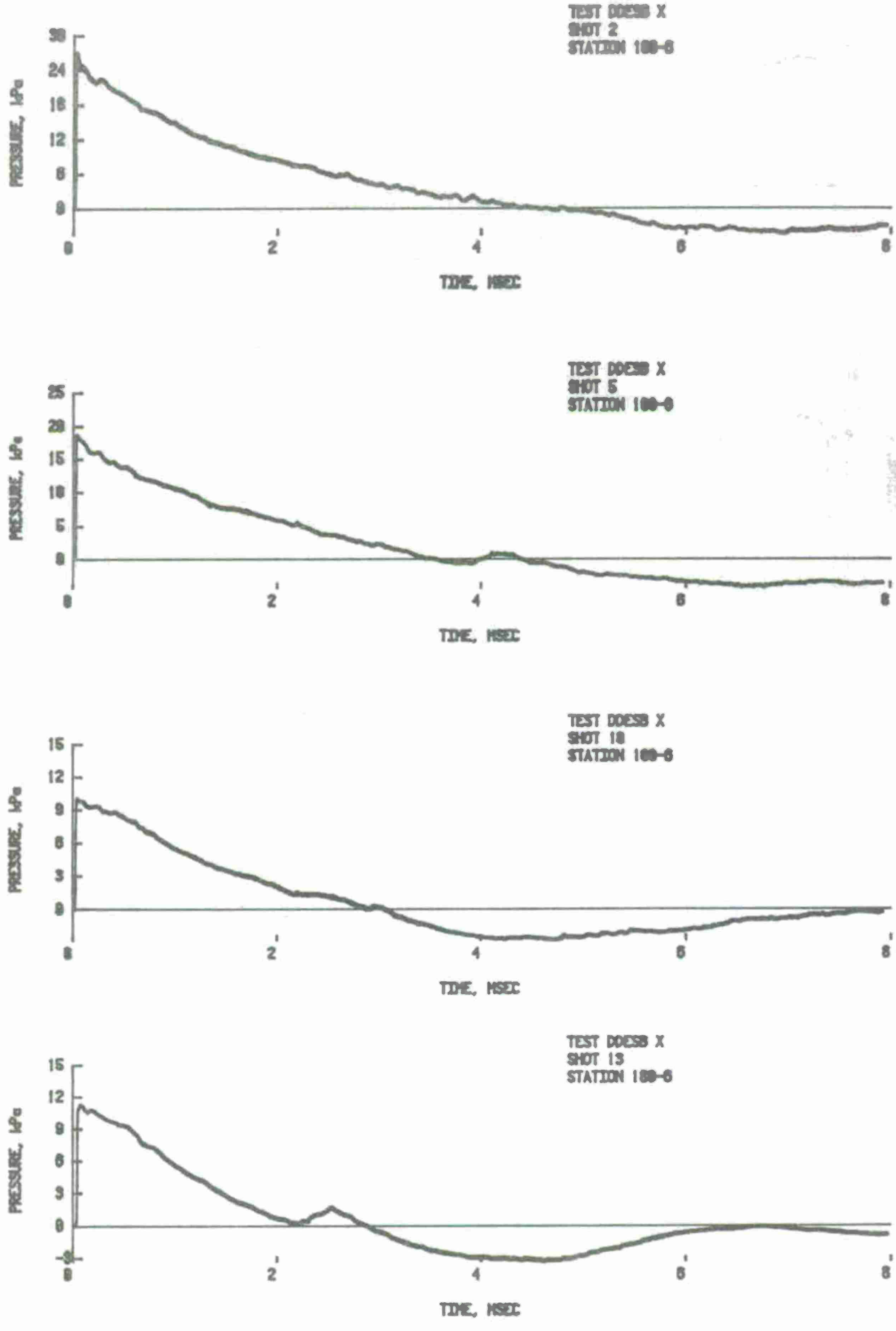


Figure A-23. Pressure versus time records, Station 180-6.

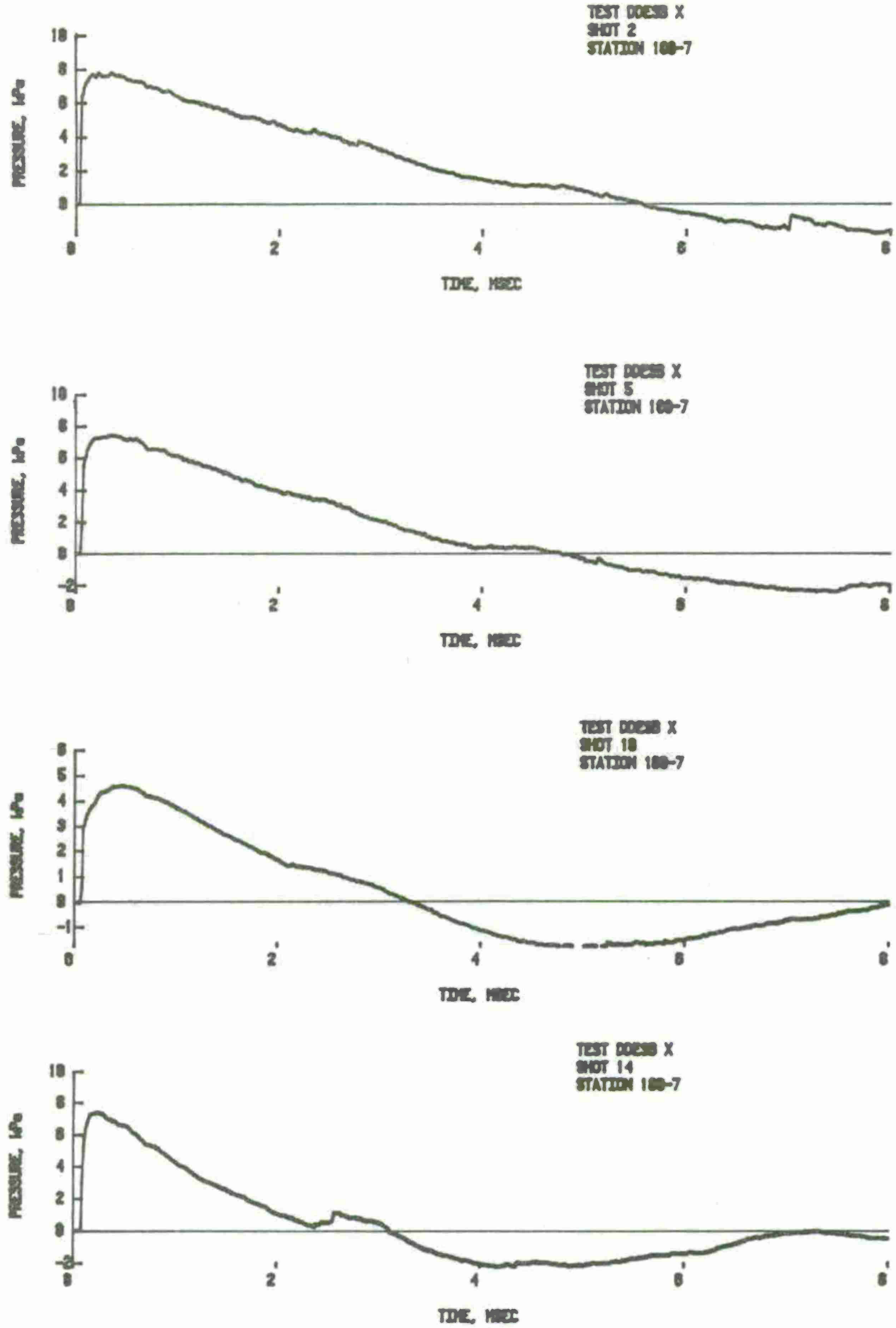


Figure A-24. Pressure versus time records, Station 180-7.

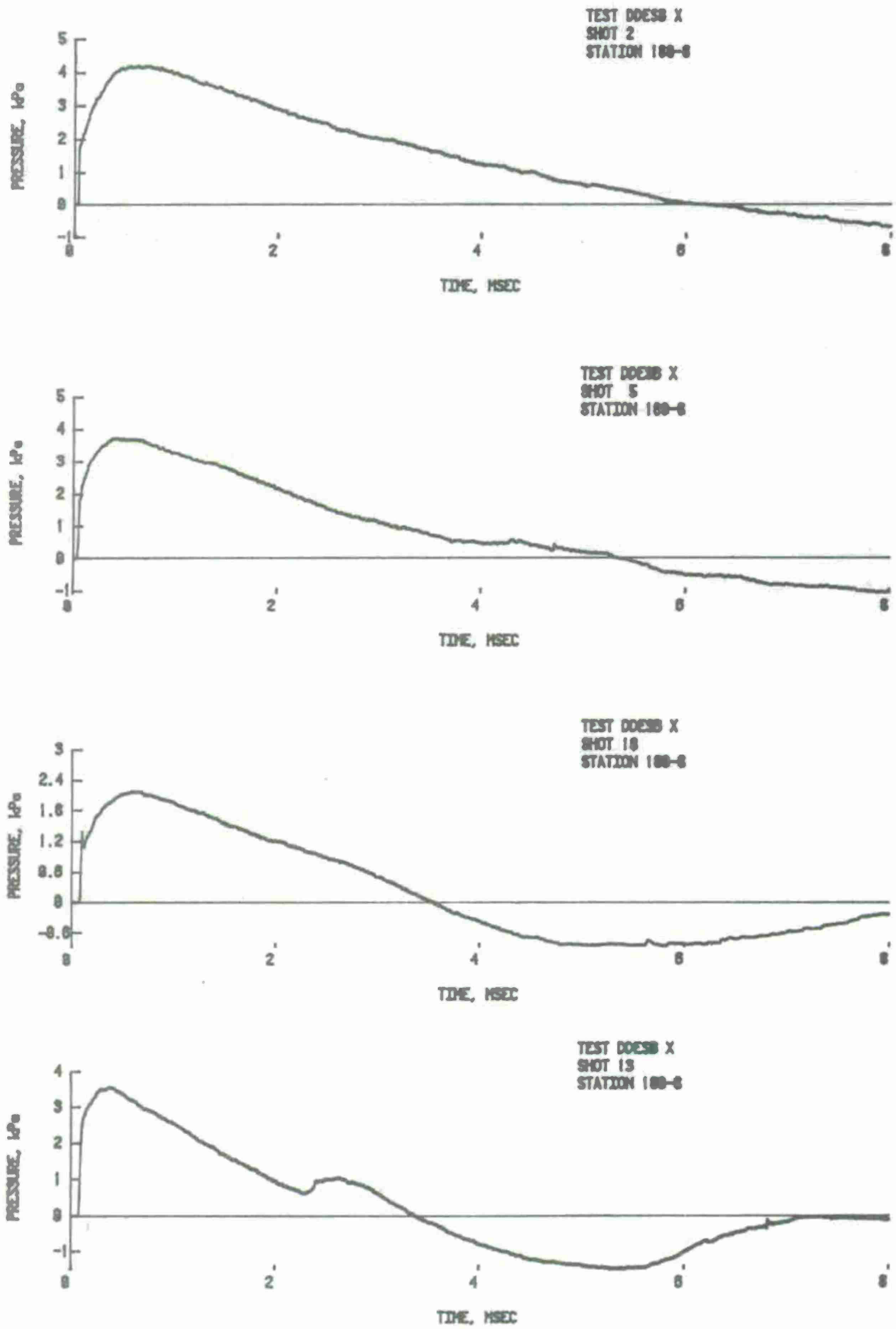


Figure A-25. Pressure versus time records, Station 180-8.

APPENDIX B

OVERPRESSURE VERSUS TIME RECORDS FROM IN-MAGAZINE TESTS (4.99 kg)

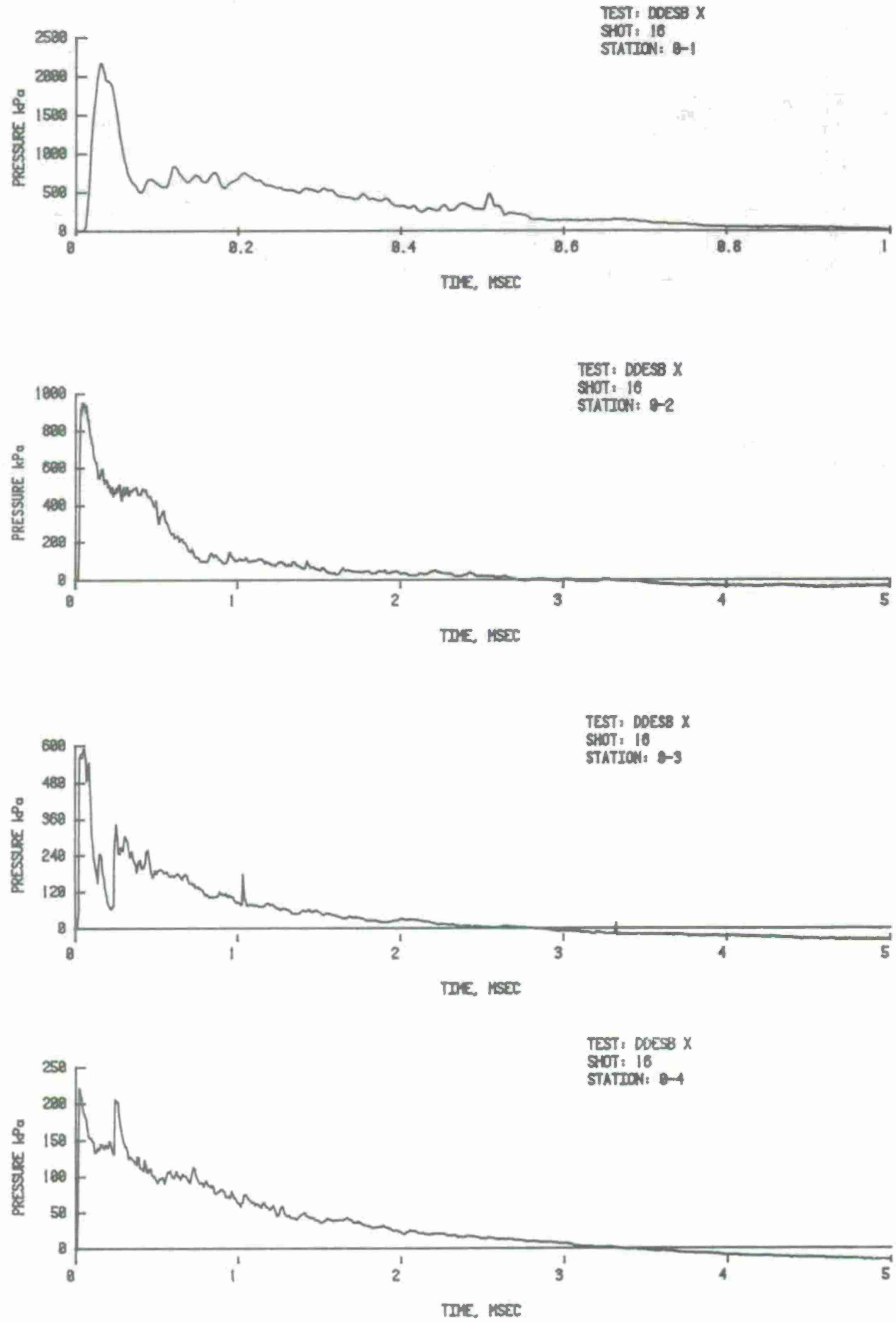


Figure B-1. Pressure versus time records, Stations 0-1 through 0-4.

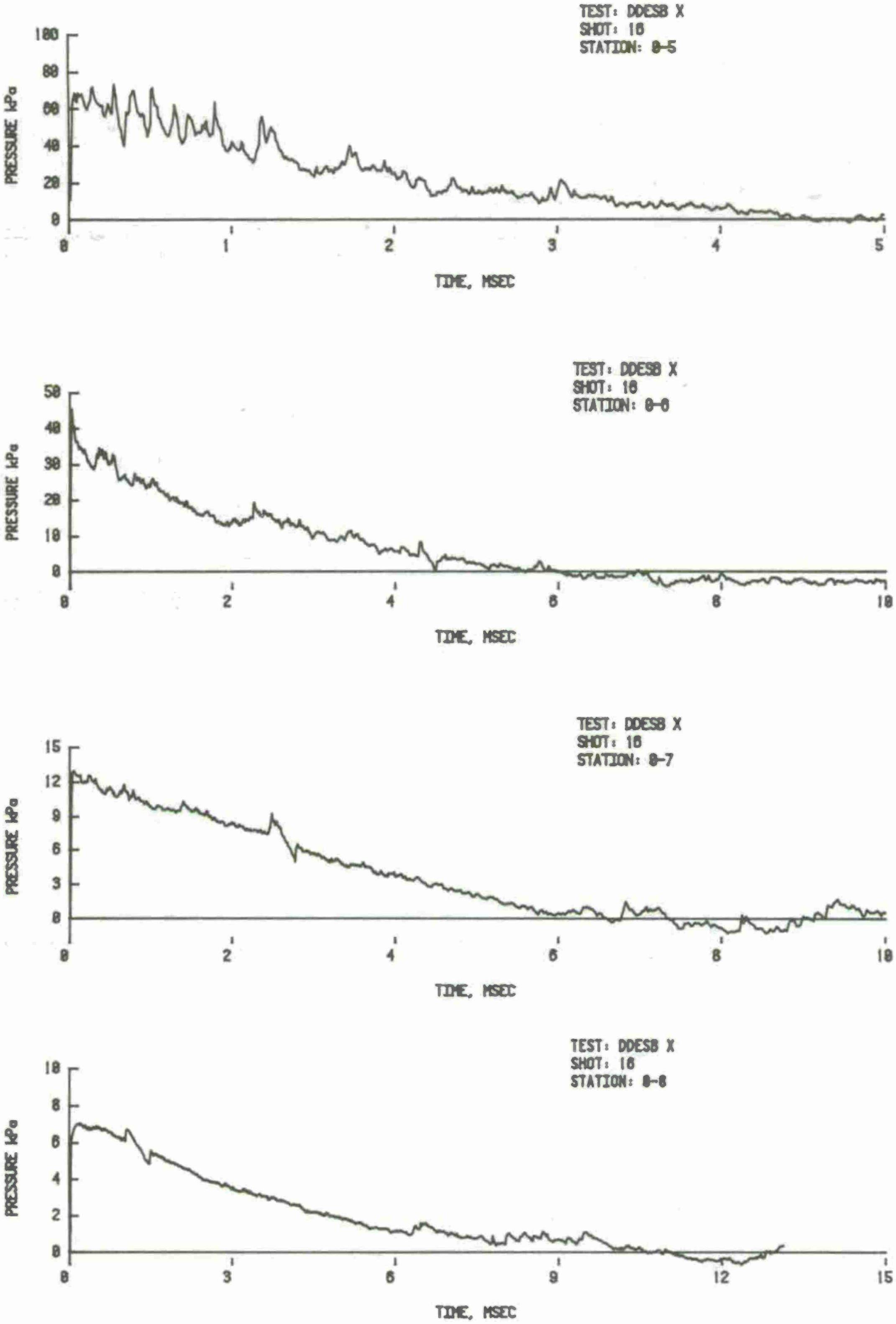
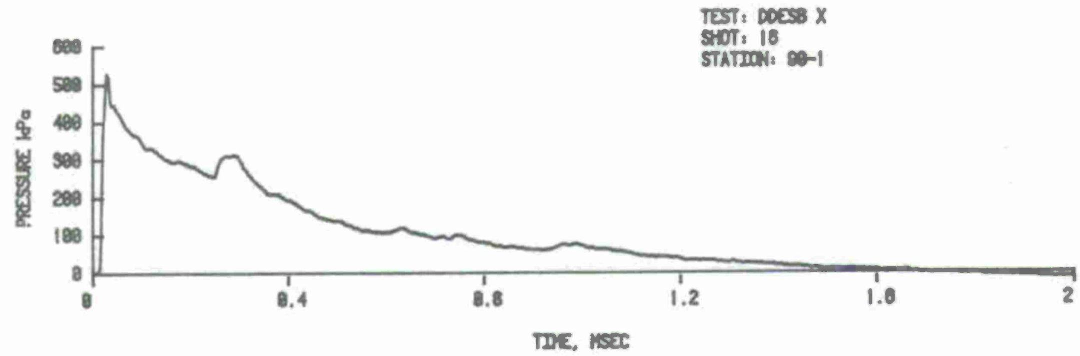
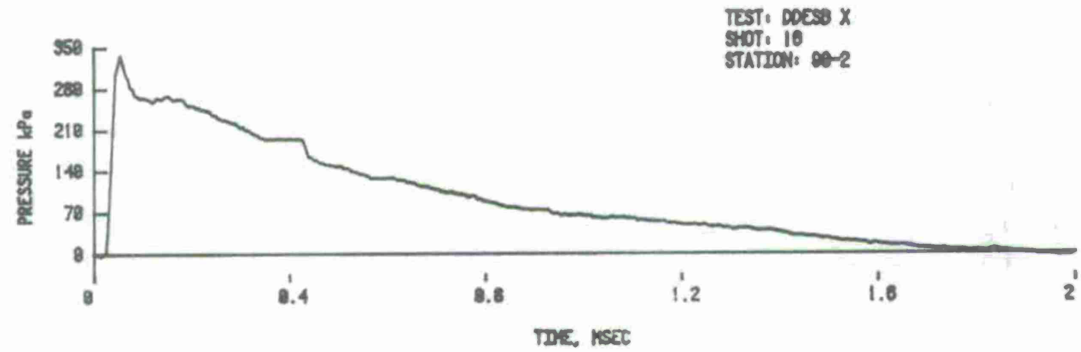
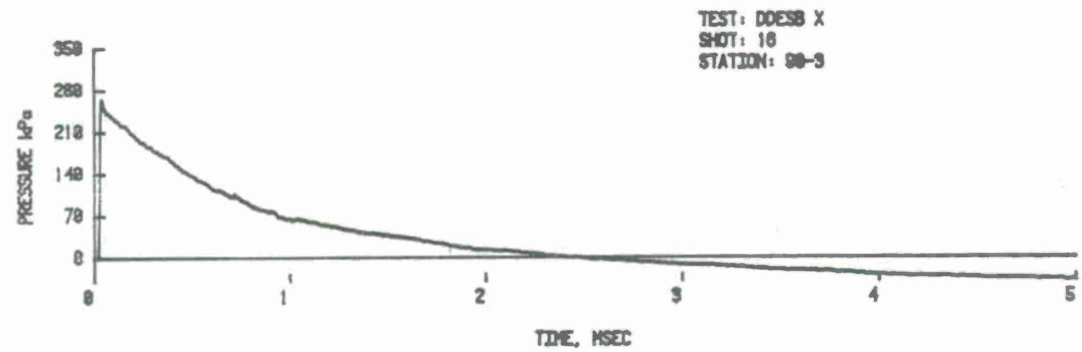


Figure B-2. Pressure versus time records, Stations 0-5 through 0-8.







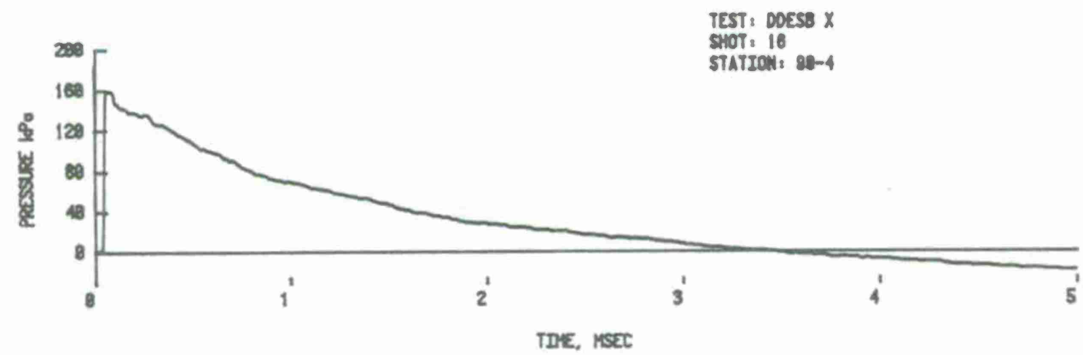
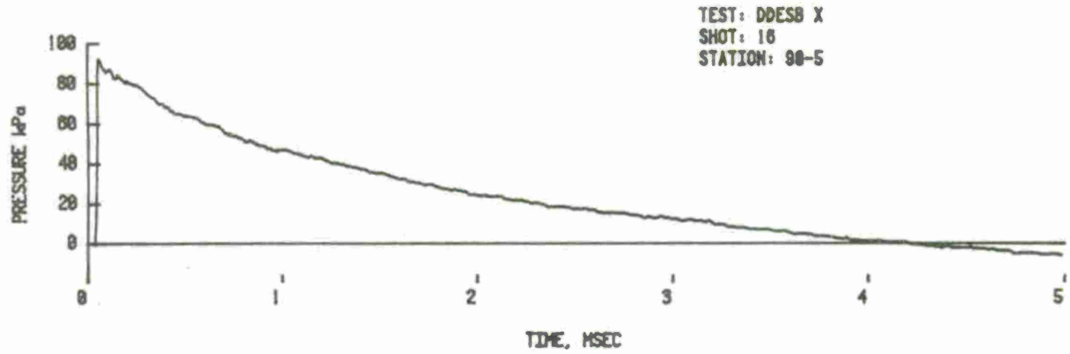
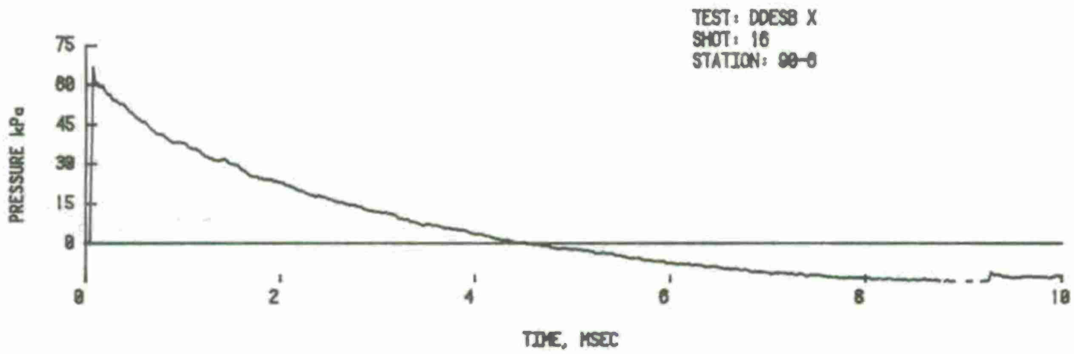
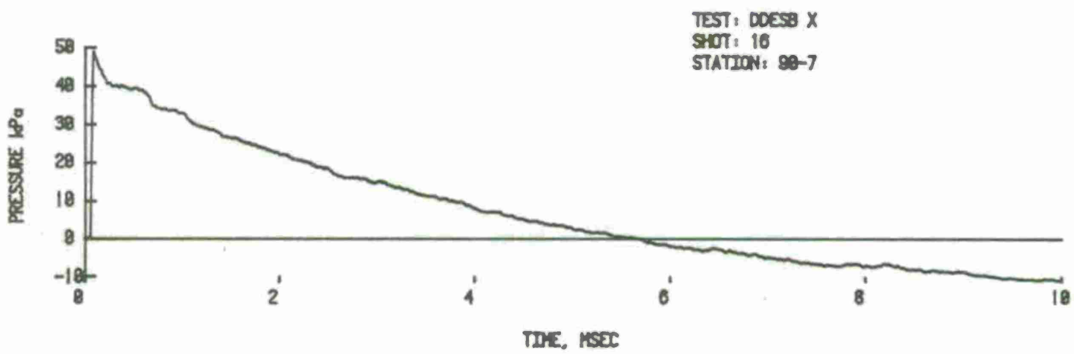


Figure B-3. Pressure versus time records, Stations 90-1 through 90-4.







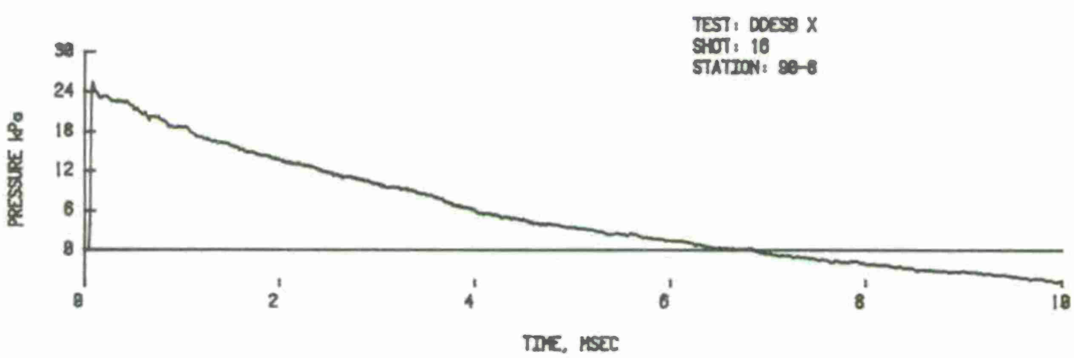


Figure B-4. Pressure versus time records, Stations 90-5 through 90-8.

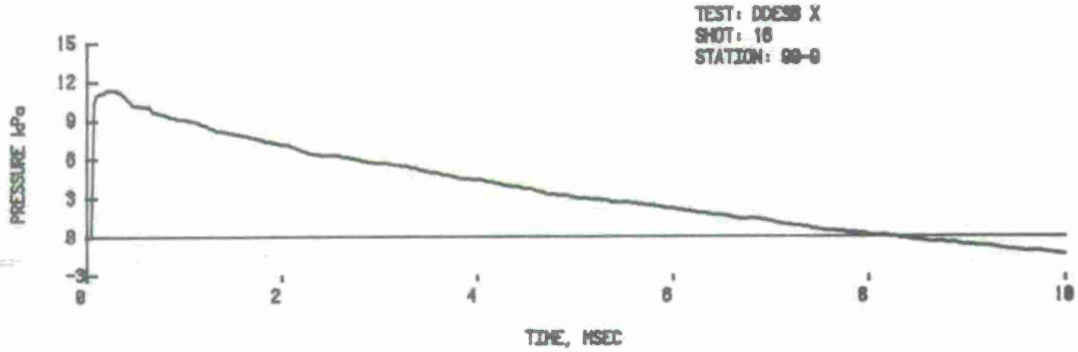


Figure B-5. Pressure versus time record, Station 90-9.

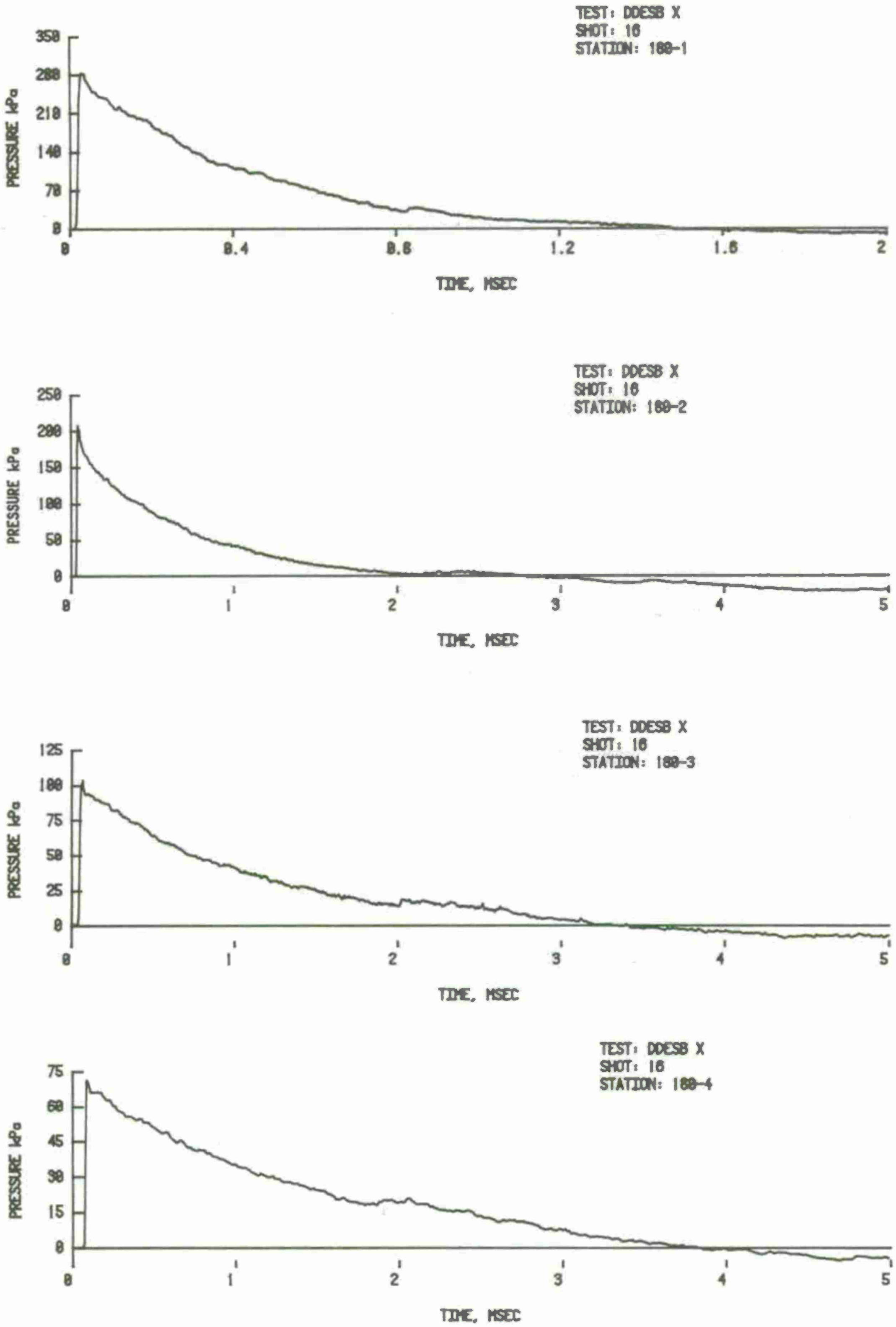


Figure B-6. Pressure versus time records, Stations 180-1 through 180-4.

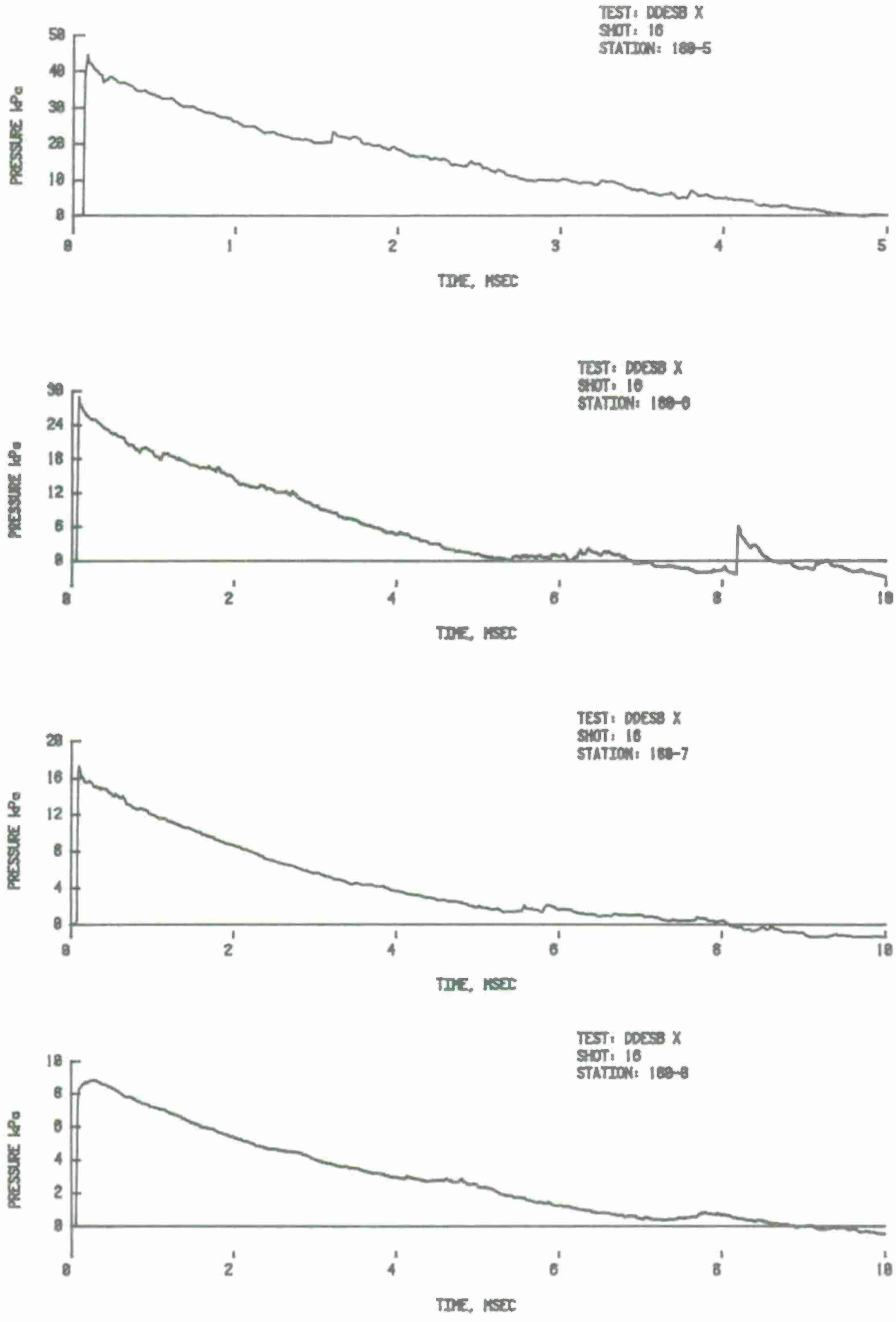


Figure B-7. Pressure versus time records, Stations 180-5 through 180-8.

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