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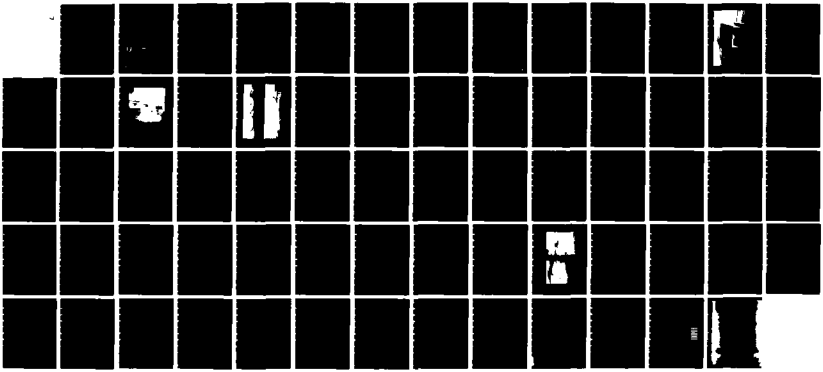

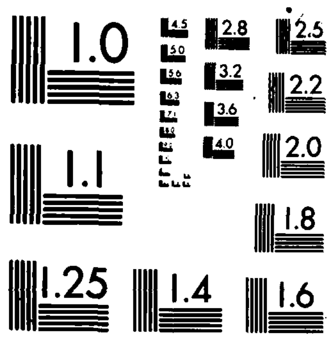

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TECHNICAL REPORT ARBRL-TR-02557

BLAST LOADING ON ABOVE GROUND BARRICADED MUNITION STORAGE MAGAZINES

Charles N. Kingery
Gerald Bulmash
Peter Muller

May 1984

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of a study designed to determine the blast loading on above ground munition storage magazines. The magazines are located at a separation distance of K2 ($2W^{1/3}$), where W is the maximum allowable weight in pounds mass, and have barricades between each structure. Responding and non-responding 1/23.5 scaled structural models were designed for the tests. Blast loading with and without the donor magazine over the charge was documented.

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I. INTRODUCTION

A. Background

This study was sponsored and funded by the Department of Defense Explosives Safety Board (DDESB). Most of the munition stored by the three services are in standard arch-type earth-covered magazines. The safe separation distances for these storage magazines are well established and documented.[1,2] In some areas of Europe and the United Kingdom munition are stored in box-type structures with barricades between them but no earth cover over the structure. This is the scenario of the brick magazines located in Machrihanish, Scotland.[3] Specific magazines located at this site are the subject of this investigation.

B. Objective

The primary objective of this project is to determine through scale model experiments the blast loading on the walls and roof of an acceptor magazine in the event of an accidental explosion in a donor magazine. The assumption is that the net explosive weight (NEW) detonates in mass and contributes to the blast loading. That is, the effect of munitions casing on blast attenuation is not accounted for; but the effect of the magazine structure on blast attenuation is documented in this series of experiments.

A secondary objective added after the experimental program was in progress was to study the effect of barricade construction. Is a loose low density sand barricade better or worse than a highly compacted soil barricade? The results will be discussed in the Results section of this report.

II. TEST PROCEDURE

Discussed in the test procedures are five areas of interest. They are: the design of the scale models, the test charges, instrumentation, layout, and matrix.

A. Design of Structure Models

Two scaled models were designed for this test program. One was a steel non-responding acceptor model instrumented with piezo-electric pressure transducers. The second model design was a scaled concrete structure used both as a donor structure and a responding acceptor model.

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[1] *Frederick H. Weals, "ESKIMO 1 Magazine Separation Test," NWC TP 5430, April 1973.*

[2] *Charles Kingery, George Coulter, and George Watson, "Blast Parameters from Explosions in Model Earth Covered Magazines," BRL MR 2680, September 1976 (AD A031414).*

[3] *F.B. Porzel, J.M. Ward, "Explosive Safety Analysis of the Machrihanish Magazine," NSWC TR79-359, December 1979.*

1. Steel Non-Responding Model. The acceptor model (see Figure 1) is a 1/23.5 scale version of a munitions magazine located at the Machrihanish Facility in Scotland. Typically, one of these magazines may contain a variety of munitions. Assuming that a bare Pentolite charge equivalent to a full magazine load is 13,000 kilograms, the scaling to a 1 kilogram test charge would result in a 1/23.5 scale.

The scaled dimensions are 30.5 cm x 33.3 cm x 41.1 cm. The model was constructed from 2.54 cm thick steel plate. All surfaces were welded together except for the front wall which was bolted to the model to facilitate emplacing gauges, wires, and connectors. For stability the model extends 15 cm below the surface. Therefore the exposed dimensions are 15.5 cm x 33.3 cm x 41.1 cm.

There are 18 pressure transducer positions on the model: two each on the end walls, six on the front side-wall (closest to the charge), five on the roof, and three on the back side-wall (farthest from the charge).

2. Concrete Donor/Acceptor Model. The concrete donor (or acceptor) model is also a 1/23.5 scale version of a Machrihanish munitions magazine. This model is composed of five separate concrete slabs and a cardboard door. Refer to Figure 2, a photograph showing the floor, walls, and roof; the door closure is not present.

The slabs were poured in small wooden forms. Copper wire was criss-crossed in the soft concrete in the forms to provide reinforcement so that the slabs would not break while being handled. "Sakrete Sand Mix" was used; gravel mix would not work because the stones are larger in diameter than the slab thickness. The roof has a minimum thickness of 0.64 cm and the floor has a maximum thickness of 1.27 cm.

To create a complete donor model, the concrete slabs and cardboard door were placed together. The parts stood on their own; no binding was needed to hold the model together.

A responding concrete acceptor was placed on the test pad for Shots 4 and 5. The design is similar to the concrete donor. Neither pressure transducers nor other instrumentation devices was mounted on the responding acceptor. It was, however, photographed at 2000 frames per second with a high speed movie camera.

B. Test Charges

A convenient test charge weight for scale model work is one kilogram. The BRL Hot Melt Laboratory cast one kilogram bare hemispherical Pentolite charges (Pentolite has approximately 1.17 times the explosive power of TNT) which were used for the donor charges. The charges were detonated from the center of the flat side which was placed on the concrete floor.

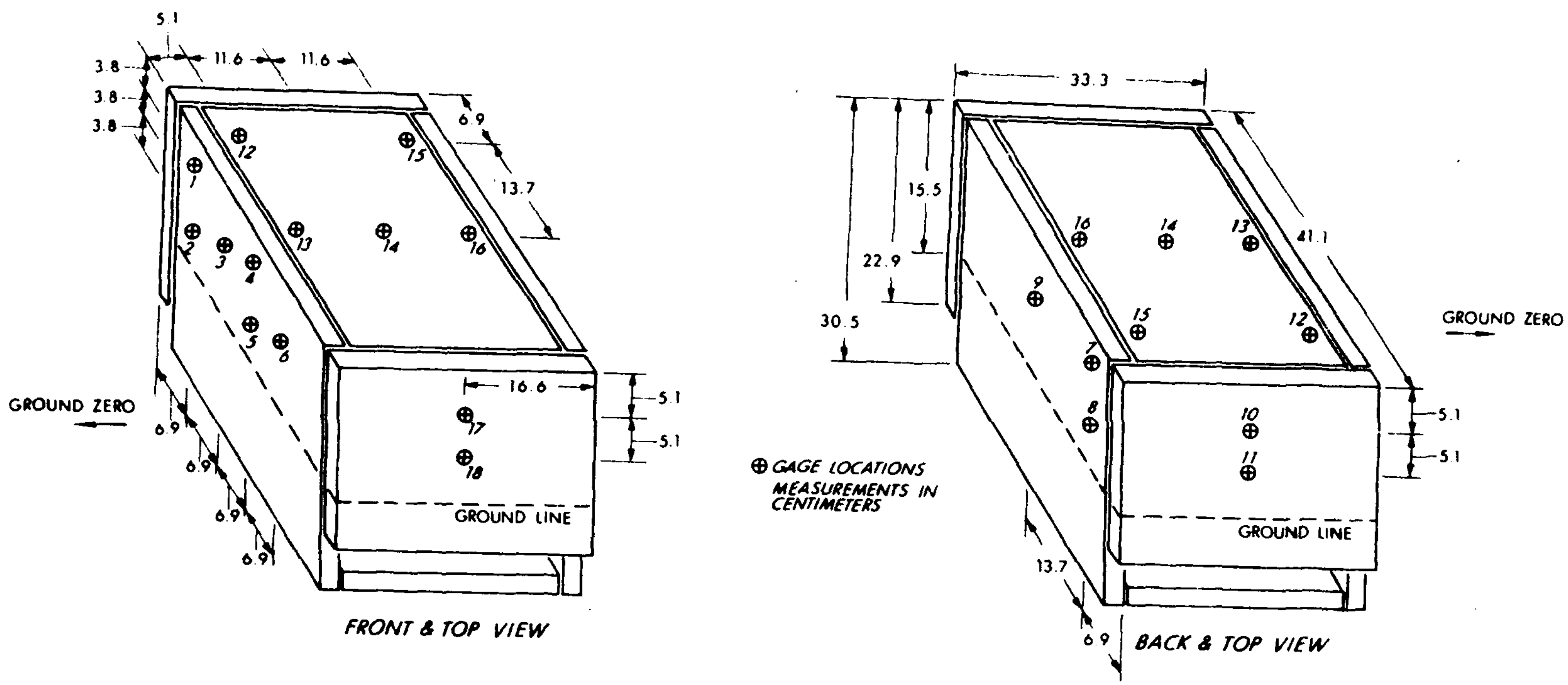


Figure 1. Non-Responding Acceptor Model

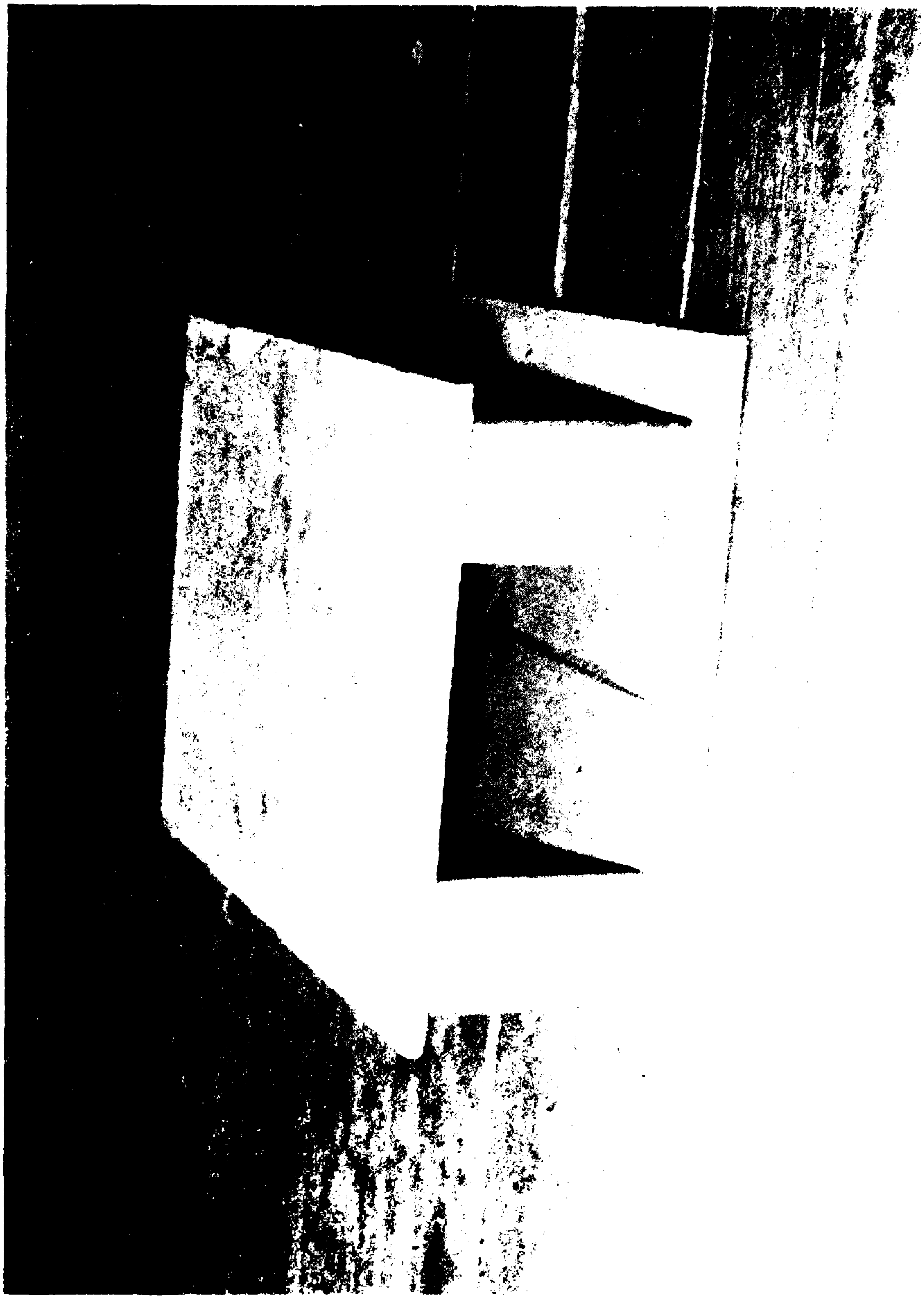


Figure 2. Photograph of Concrete Donor Model

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 3.

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 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 **(TEKTRONIX 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 also be stored for future analysis.

D. Test Layout

1. Donor Charge in Structure. Figure 4 shows a diagram of the test layout, and Figure 5 is a photograph of the layout for Shot 4. The entire test site, i.e., the donor, acceptor(s), and berms, are 1/23.5 scale. Note that all models and berms were not used on every test and that the berm material was sometimes sand and sometimes soil. Refer to Table 1 in the Test Matrix Section for the exact test configuration of each shot.

The steel acceptor model, which remained in place during the project, was stabilized in several ways. The lower 15.2 cm of the walls were buried in the sand. Four steel straps were placed across and around the floor of the model, and these straps were secured with eight spikes, each 61.0 cm long, driven into the test pad. Furthermore, a sand bag was placed inside the model. These measures assured that the model remained non-responding.

Berms were constructed around the models as shown in Figure 4. The center of the floor of the concrete donor was placed at ground zero. The floor has a small center hole to allow for the detonator and charge placement. The walls, roof, and door were placed on the floor to complete the donor construction. On two shots a responding concrete acceptor model without instrumentation was also included in the test layout; refer to Table 1 in the Test Matrix Section.

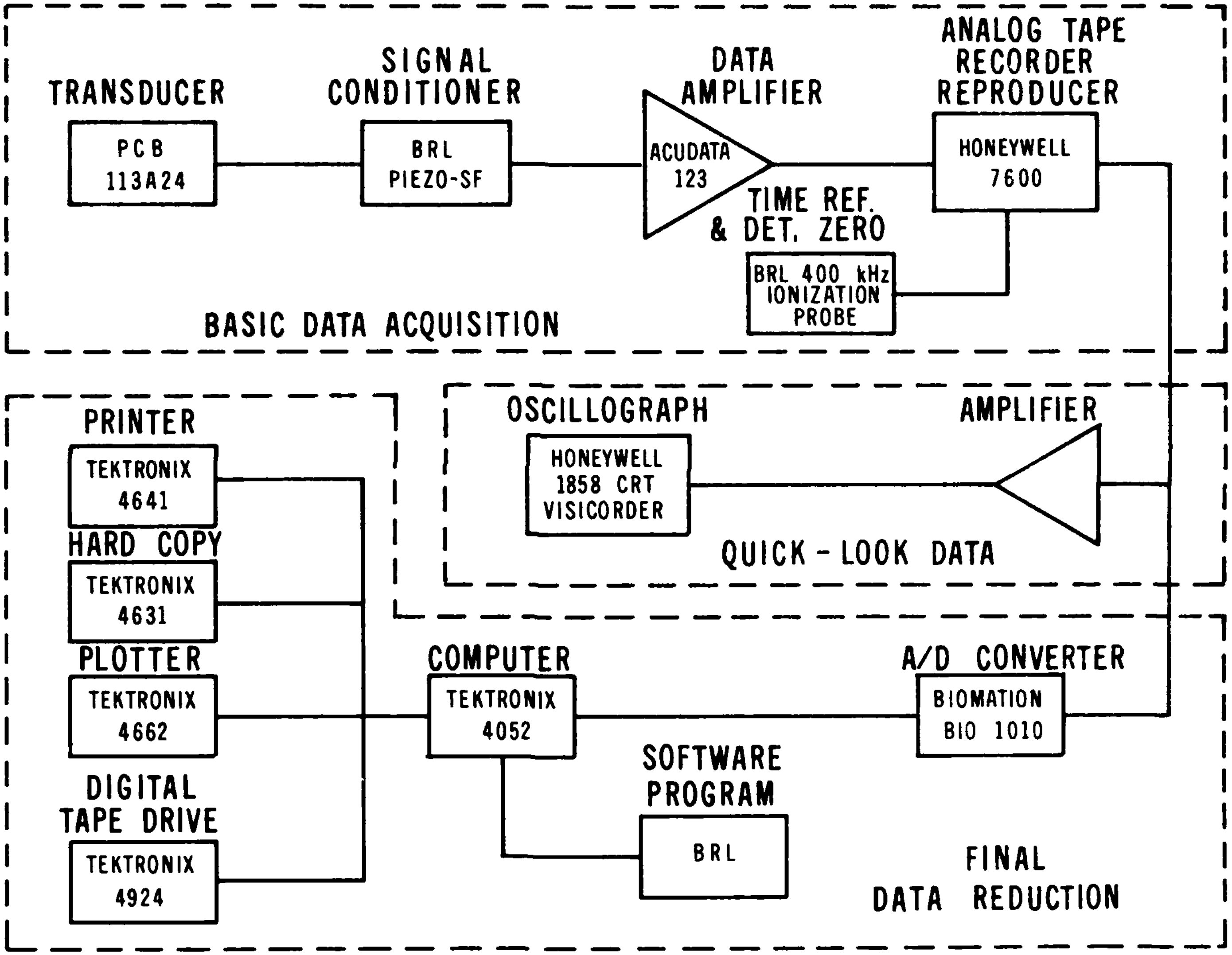


Figure 3. Data Acquisition/Reduction System

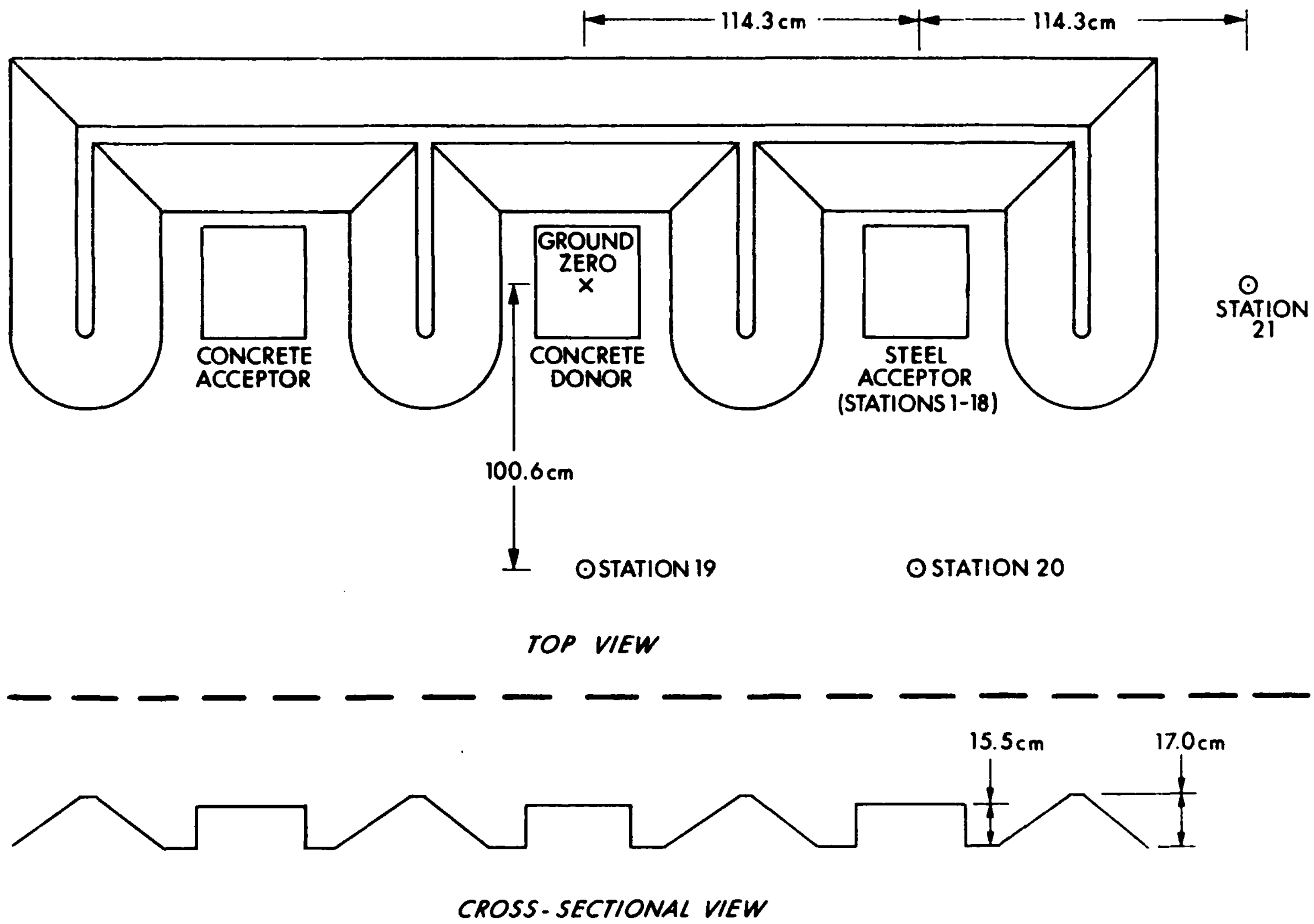


Figure 4. Test Layout

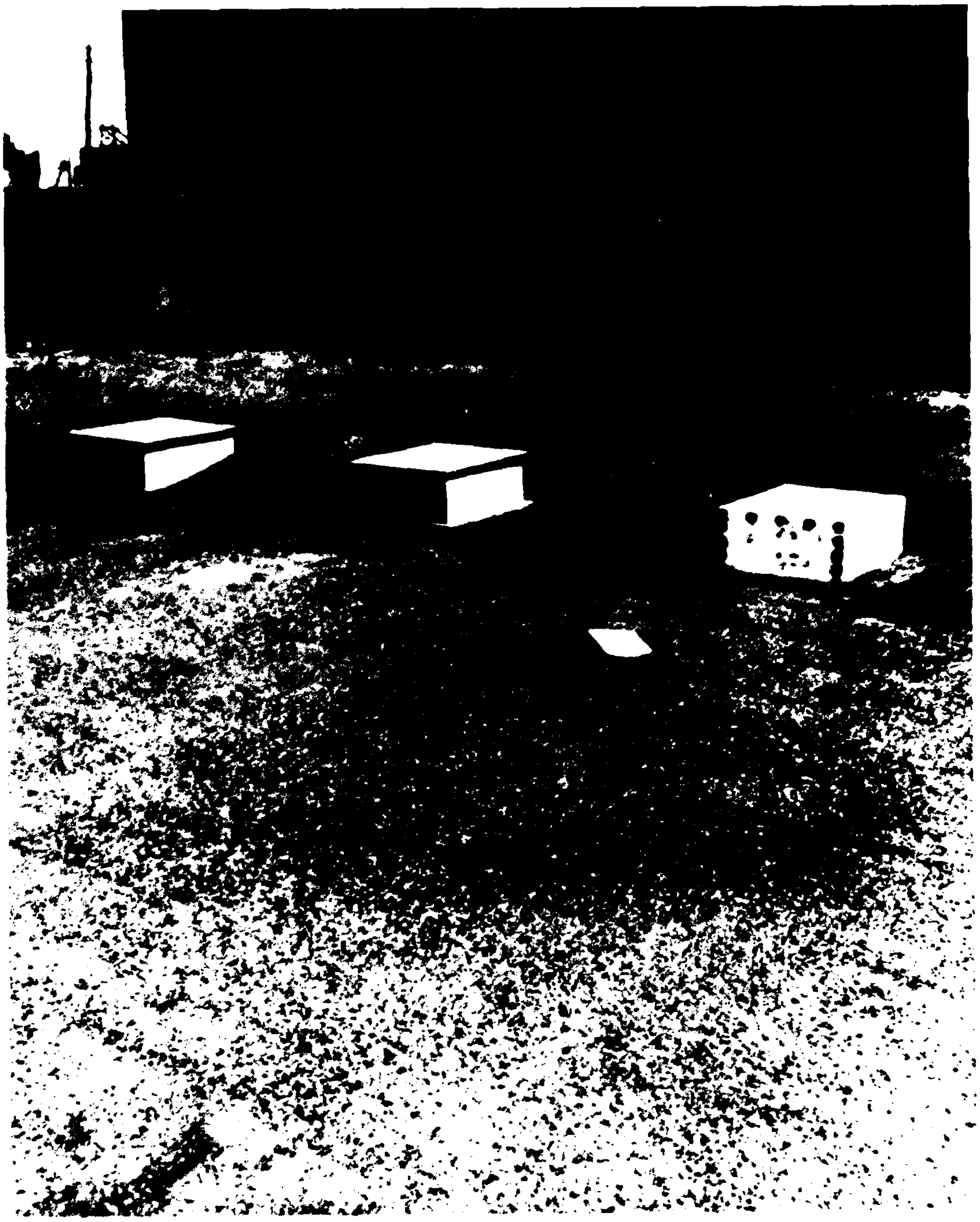


Figure 5. Photograph of Test Layout

With all three models in place the test pad configuration is symmetric about an axis drawn through the long side of the donor model and passing through ground zero. Refer to Figure 4. Because of this symmetry, the blast loading on the concrete responding acceptor and non-responding steel acceptor should be the same.

High speed cameras were used to photograph the blast event. One camera focused on the entire test layout; the other camera focused on one acceptor model.

Eighteen pressure transducers were mounted in the steel acceptor. Also, three pressure transducers were mounted in lead bricks to measure the pressure at three locations on the test pad. One (Station 19) was located 100.6 cm in front of ground zero; another (Station 20) was placed at the same distance in front of the steel acceptor, or 152.3 cm from ground zero. The third gage location (Station 21) was located 228.6 cm from ground zero. Refer to Figure 4.

2. Donor Charge Unconfined. On Shots 2 and 5 the concrete donor model was not used. The bare Pentolite charge was placed on the donor's concrete floor; but the walls, roof, and door were not used to confine the charge. The purpose of these tests was to determine the suppressive effect of the donor structure on the blast propagation. A pre- and post-shot view of the model and barricades are shown in Figure 6.

E. Test Matrix

Five test shots were fired during the period 5 August 1983 - 16 August 1983 at Range 8 on Spesutie Island. For a concise summary of the firing program, refer to Table 1.

On Shots 1, 2, and 3 the berms were composed of coarse sand. Shot 1 used a concrete donor and steel acceptor model. Shot 2 did not use a concrete donor; only the donor floor was in place. Shot 3 was a repeat of Shot 1.

For Shots 4 and 5 the berms were changed to soil which was packed down firmly. Additionally, for these last two shots, a concrete acceptor was placed on the test pad. Shot 4 used a concrete donor; Shot 5 was similar to Shot 4 except the donor was not used. Only the donor floor was present on Shot 5.

III. RESULTS

The results will be presented in the form of tables, pressure versus time records, and discussions of the blast loads impinging on the walls and roof of the acceptor structure for different donor charge confinements and barricades.

Figure 6. Pre- and Post-Shot View of Models and Barricades

TABLE 1. FIRING PROGRAM CHRONOLOGY

Shot No.	Date Fired	Concrete Donor	Steel Acceptor	Concrete Acceptor	Berm Material
1	5 Aug 83	Yes	Yes	No	Coarse Sand
2	10 Aug 83	Floor Only	Yes	No	Coarse Sand
3	11 Aug 83	Yes	Yes	No	Coarse Sand
4	15 Aug 83	Yes	Yes	Yes	Hardpacked Soil
5	16 Aug 83	Floor Only	Yes	Yes	Hardpacked Soil

A. Blast Loading on the Front Side-Wall of the Acceptor Structure

The blast loading on the front side of the acceptor structure (side facing the donor) will now be discussed. The result will be presented and compared for donor charge confined with loose sand barricades (Shot 3), donor charge confined with compacted soil barricades (Shot 4), and donor charge unconfined with compacted soil barricades (Shot 5). Blast parameter values are listed in Table 2. The authors' conception of the incident and reflected shock loading on two walls and the roof is presented in Figure 7.

The overpressures versus time recorded at Stations 1 and 4 for the three conditions (Shots 3, 4, and 5) are presented in Figure 8.* (The peak reflected pressures at Stations 1 and 4 show increases in order of Shot number.) The sand barricade gave pressures lower than the soil barricade (-15 percent), and the soil barricade with charge confined recorded pressures approximately 55 percent lower than the unconfined donor charge. The small reflection occurring on all records at three milliseconds is the reflection from the ground surface moving back up the wall.

The next two stations presented for comparison in Figure 9 are Stations 3 and 6. These stations are located the same distance down from the top, 0.076 m, and the same distance from the ends, 0.138 m. The overpressure versus time records are presented in Figure 9 for Stations 3 and 6 from Shots 3, 4, and 5. The general shape of the overpressure versus time records is similar for the two locations. There is a difference in the pressures recorded from shot to shot. Shot 3 results are again lower (-15 percent) than Shot 4, and Shot 4 results are approximately 50 percent lower than Shot 5. Note that the second reflection occurs sooner (2.5 msec) and is of greater magnitude than recorded at Stations 1 and 4.

The last two stations on the structure wall facing the donor are Stations 2 and 5. They are located 0.114 metres down from the top. Station 2 is 0.069 meters from the end, and Station 5 is along the center line. The overpressures versus time recorded at these two stations are presented in Figure 10 for Shots 3, 4, and 5. The stations are near the ground surface, and the reflected shock occurs sooner. The reflected shock is almost equal in magnitude to the incident shock with the exception of Station 5 on Shot 3 where the incident shock is smaller than the reflected shock. The authors have no explanation for this anomaly.

B. Blast Loading on the Roof of the Acceptor Structure

There were five stations on the roof of the acceptor structure. The numerical values of the blast parameters are listed in Table 3. The first two stations to be discussed are located near the front edge. The angle of the shock front striking the roof is quite different from the angle of the shock front striking the front side-wall. The front side is in a regular reflection region while the roof is in a Mach reflection region. This is deduced from the difference in the magnitude of the peak overpressure. Station 1 recorded 1112 kPa on Shot 3 while Station 12 recorded a value of

Although all figures are titled pressure versus time they also include the overpressure impulse versus time.

TABLE 2. BLAST LOADING ON FRONT SIDE-WALL

Shot	Station	Peak Pressure kPa	Impulse kPa-ms	Arrival Time ms	Duration ms
3	1	1112	183	0.785	0.84
	2	1026	229	0.857	0.79
	3	821	195	0.850	0.70
	4	943	184	0.807	0.67
	5	1139	240	0.885	0.64
	6	891	188	0.840	0.63
4	1	1305	199	0.870	0.82
	2	1049	247	0.895	0.69
	3	1093	239	0.890	0.71
	4	1089	220	0.847	0.67
	5	1045	282	0.917	0.64
	6	993	237	0.872	0.62
5	1	2489	230	0.495	0.53
	2	2015	205	0.527	0.49
	3	2015	240	0.512	0.58
	4	2612	226	0.463	0.56
	5	1745	307	0.535	0.50
	6	2073	227	0.490	0.49

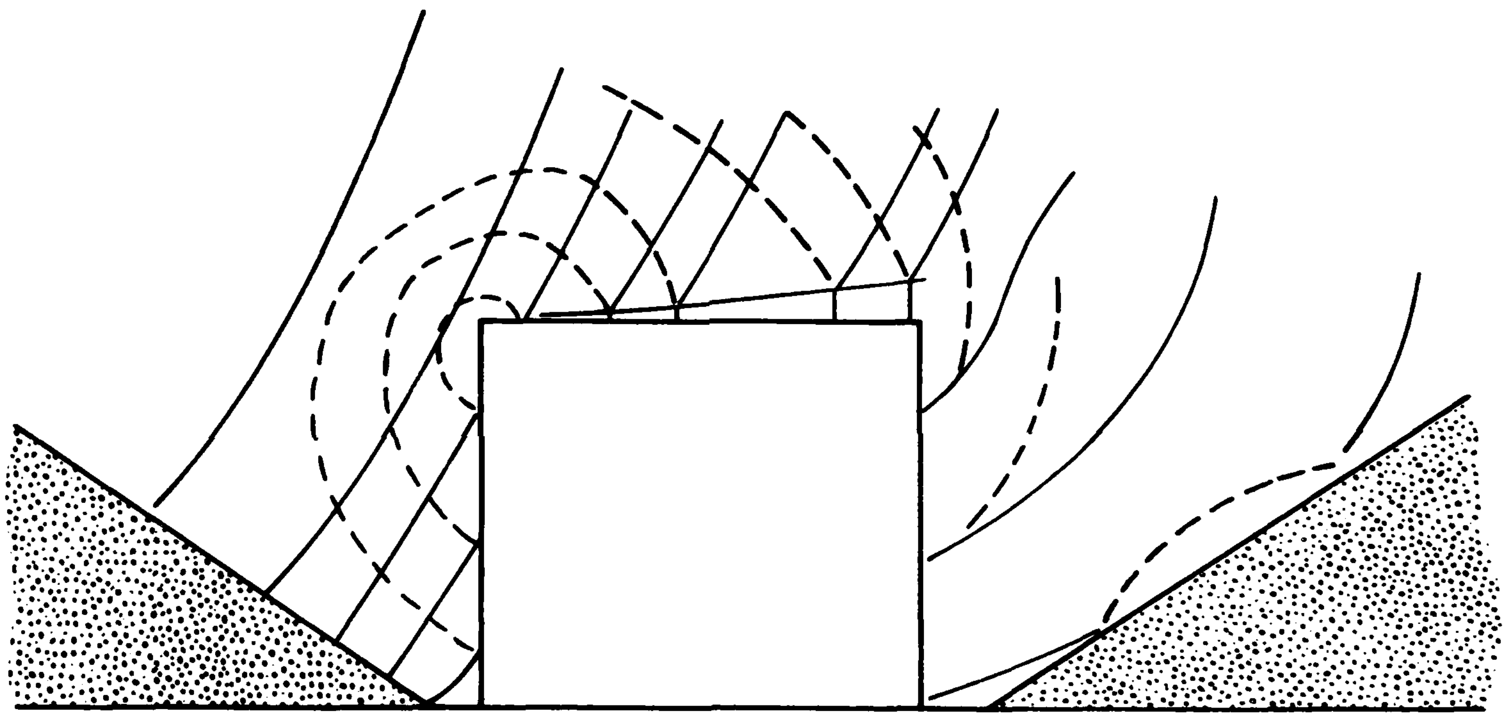


Figure . Incident and Reflected Shock Loading on Acceptor

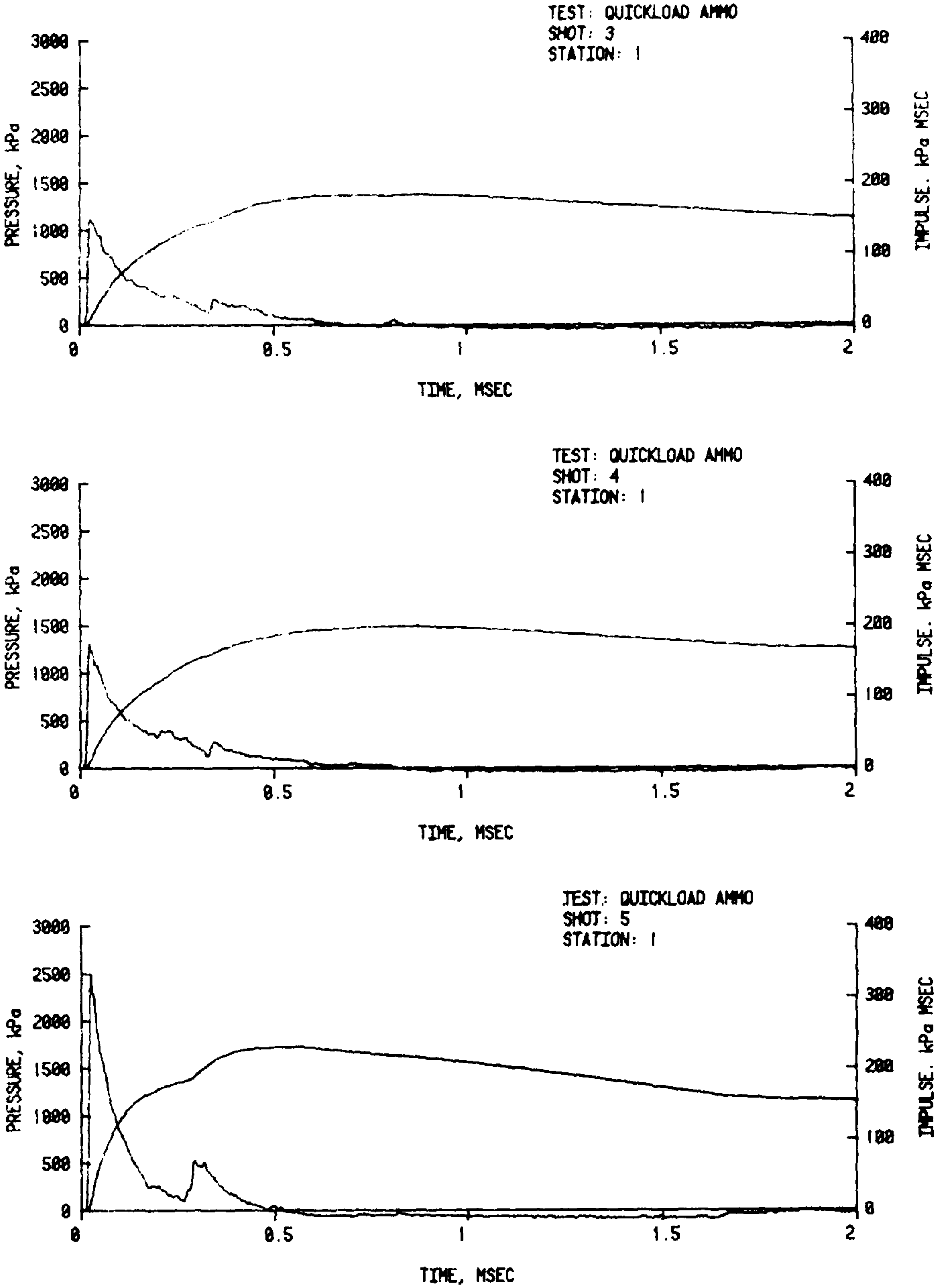
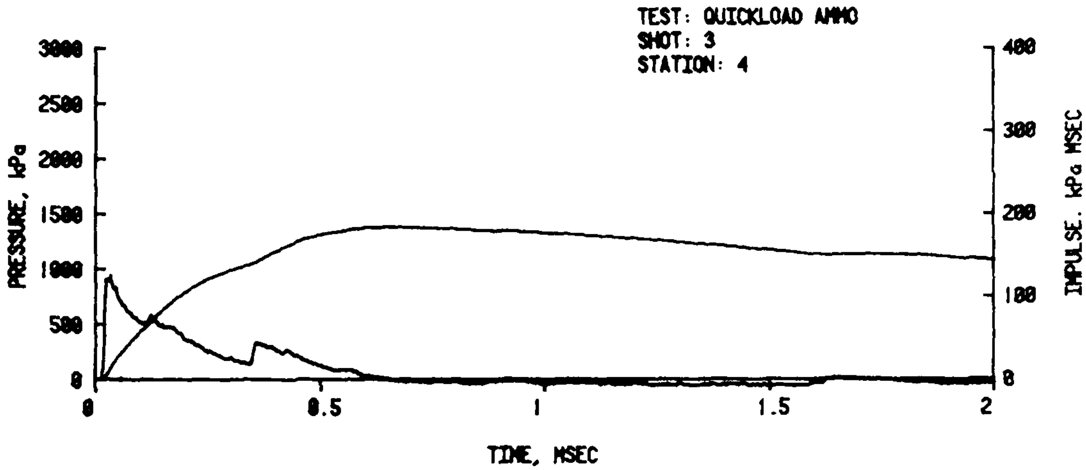
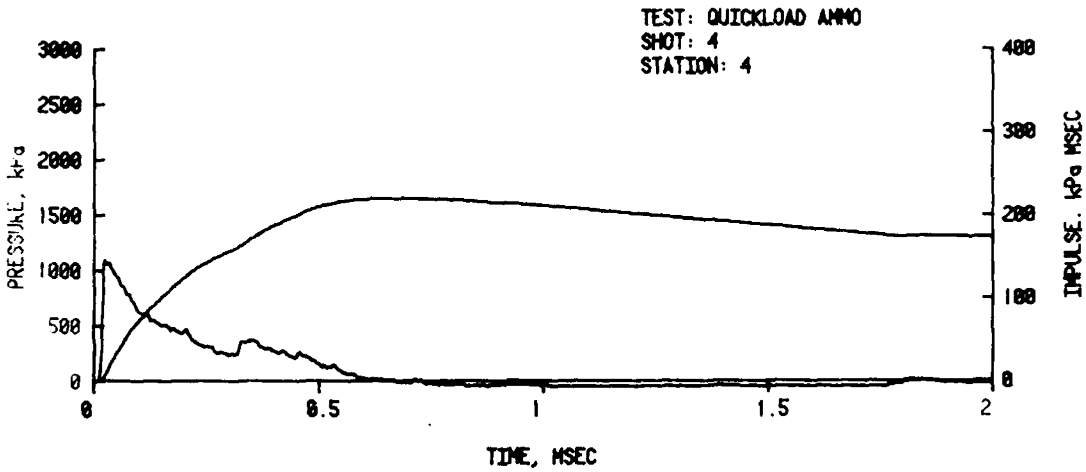


Figure 8. Pressure versus Time, Stations 1 and 4 for Shots 3, 4, and 5





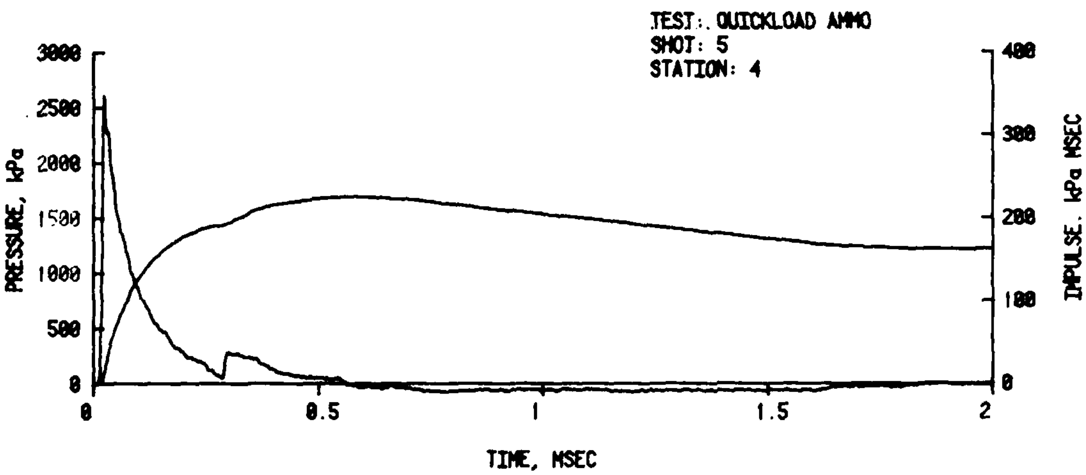
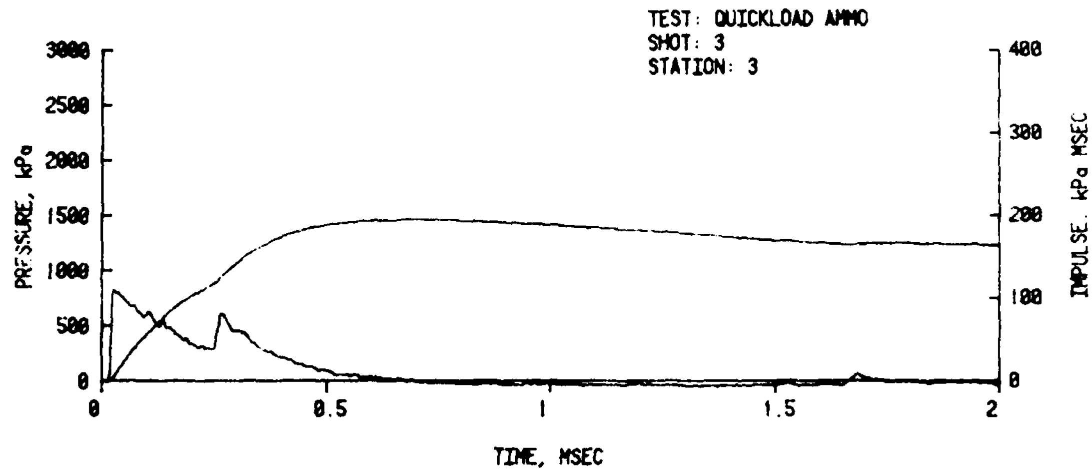
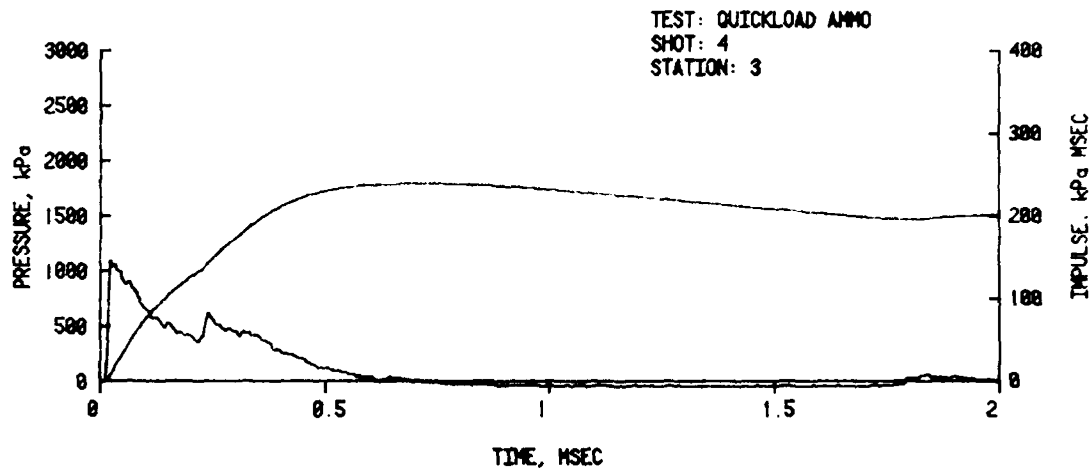


Figure 8. Pressure versus Time, Stations 1 and 4 for Shots 3, 4, and 5 (Continued)





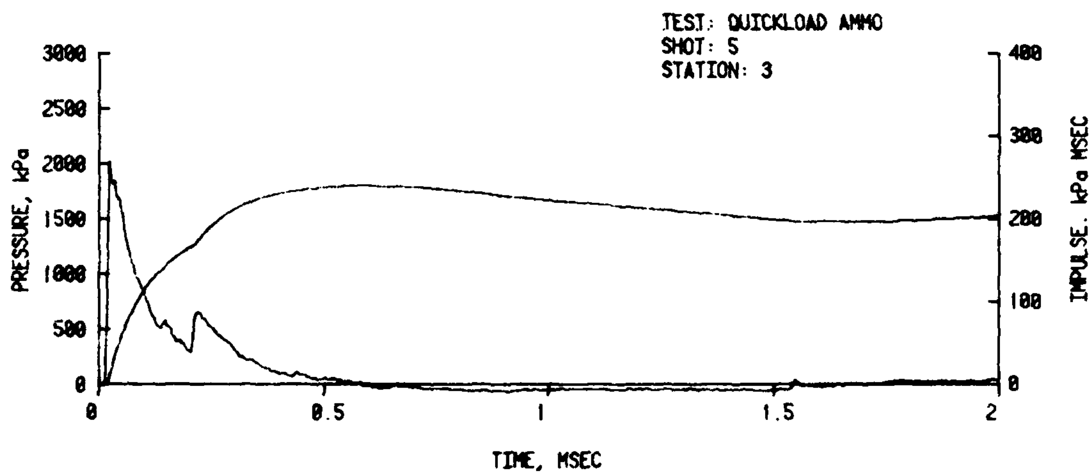


Figure 9. Pressure versus Time, Stations 3 and 6 for Shots 3, 4, and 5

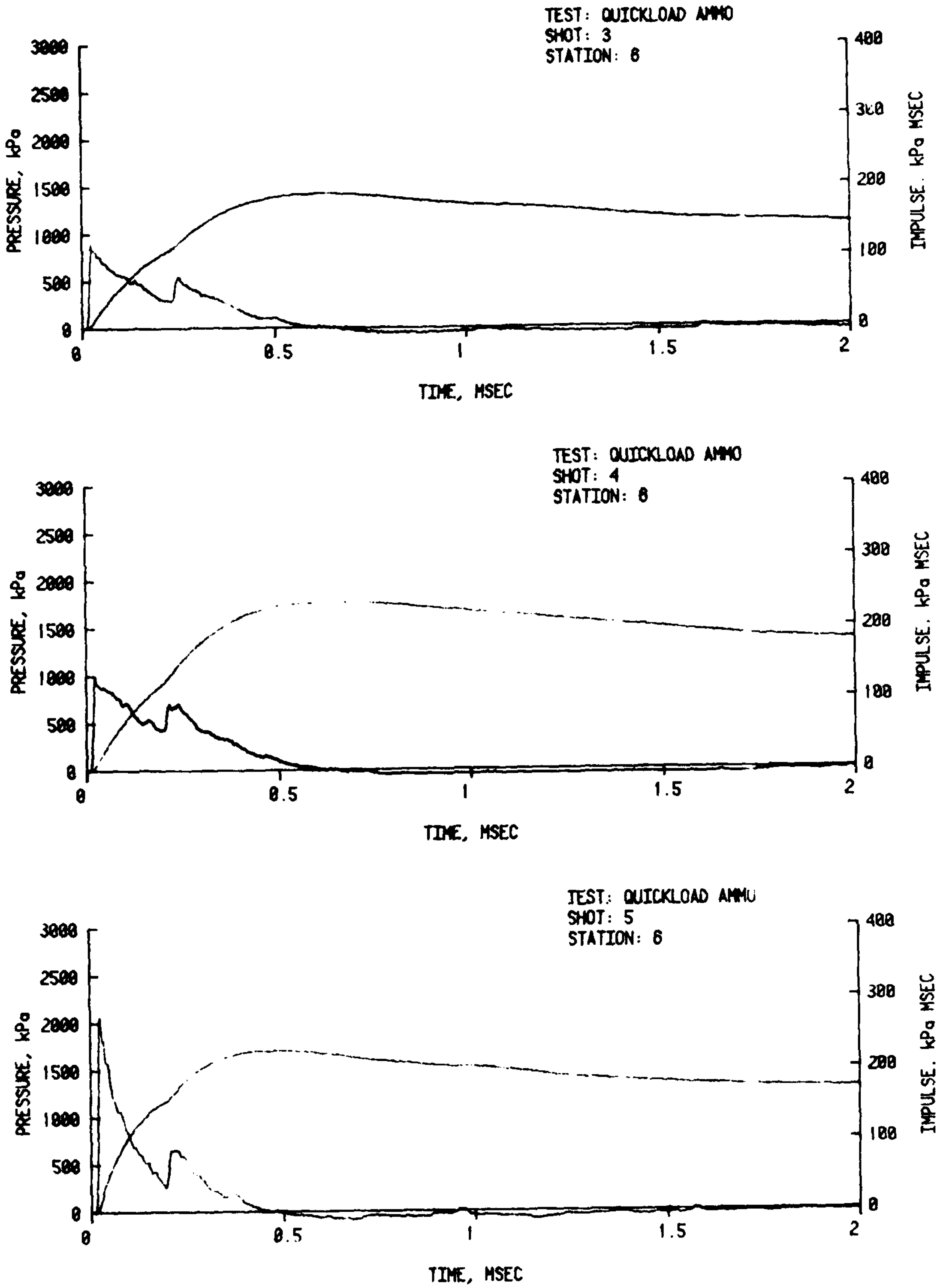


Figure 9. Pressure versus Time, Stations 3 and 6 for Shots 3, 4, and 5 (Continued)

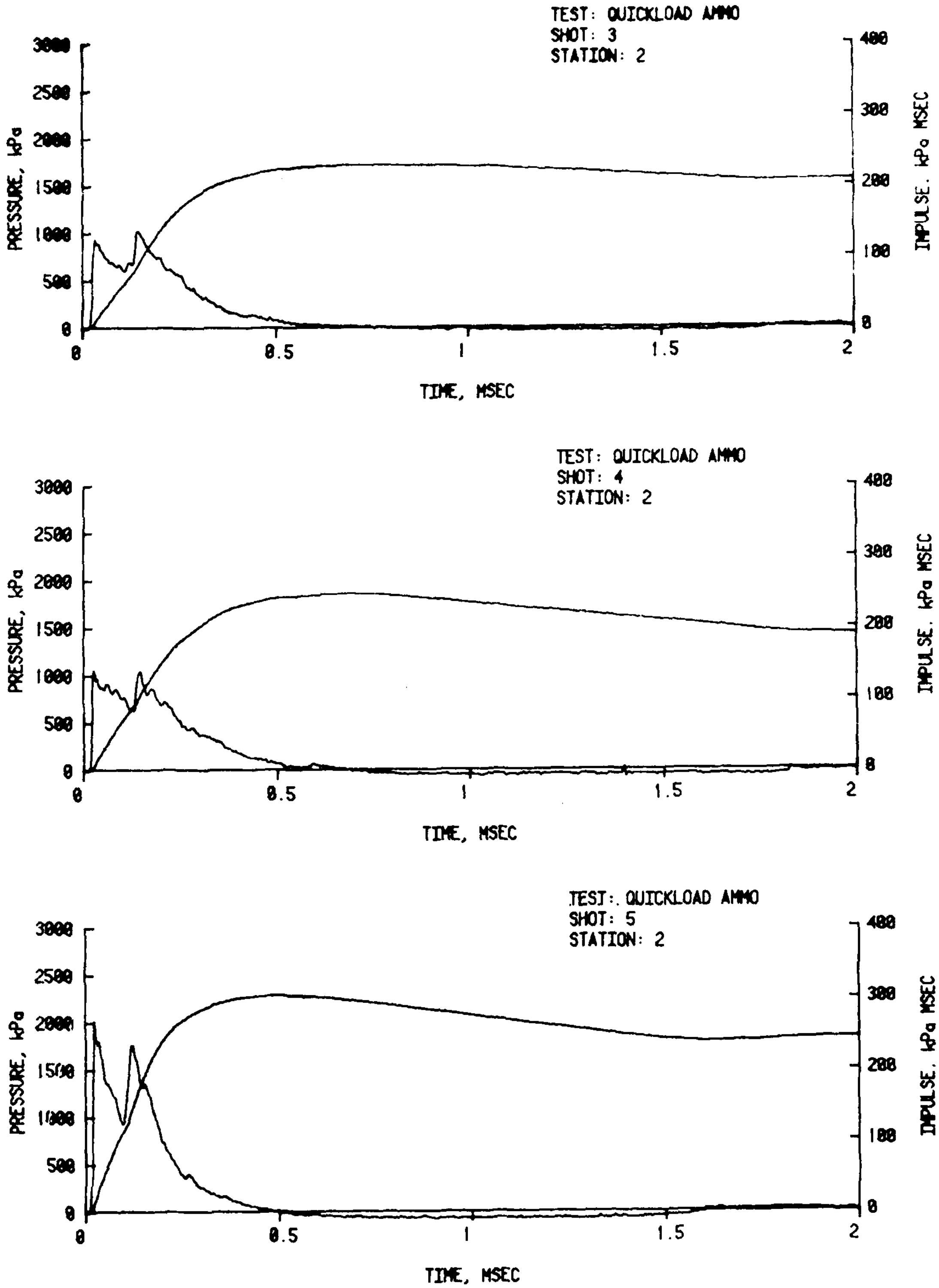


Figure 10. Pressure versus Time, Stations 2 and 5 for Shots 3, 4, and 5

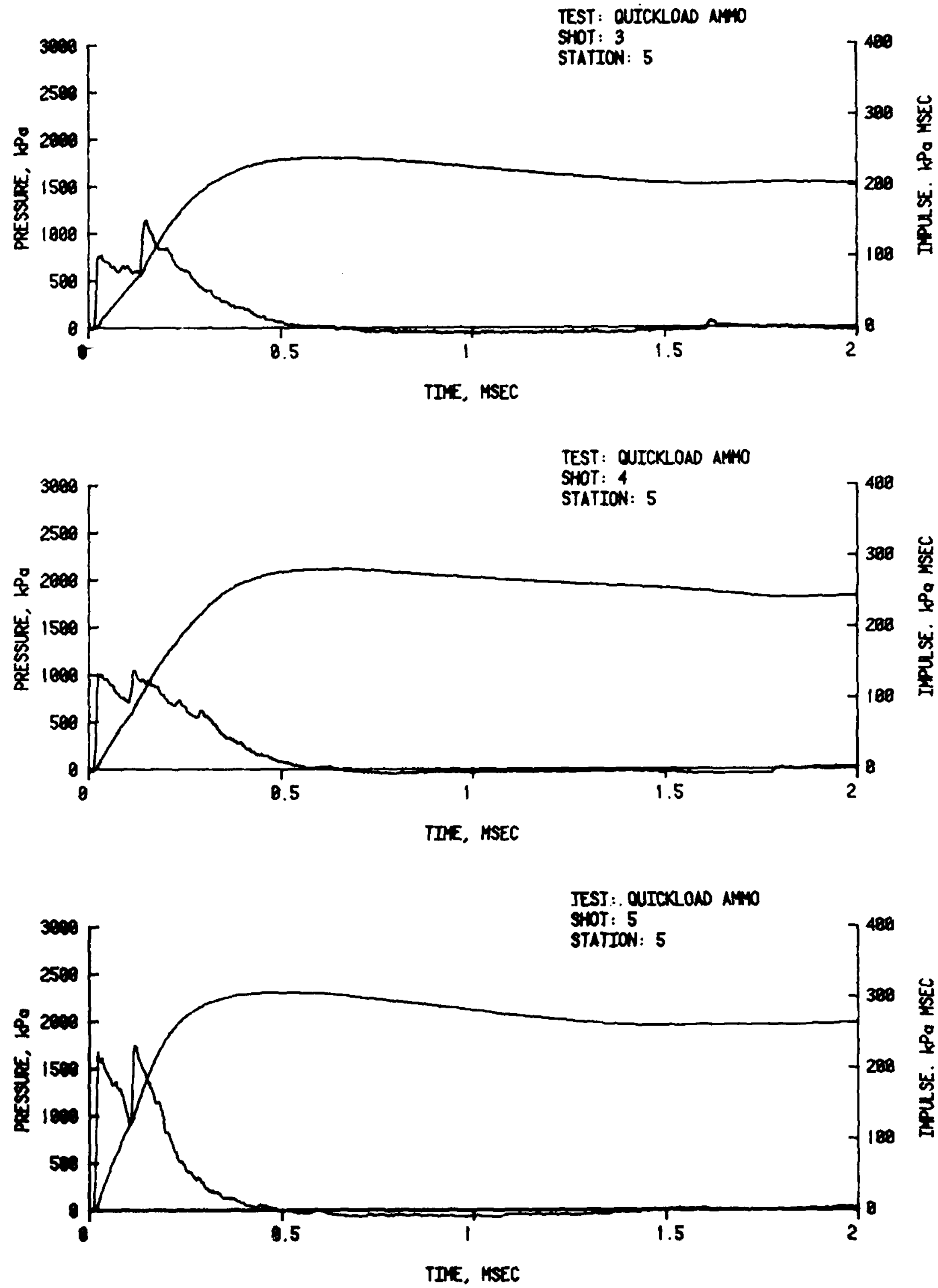


Figure 10. Pressure versus Time, Stations 2 and 5 for Shots 3, 4, and 5 (Continued)

TABLE 3. BLAST LOADING ON ROOF

Shot	Station	Peak Pressure kPa	Impulse kPa-ms	Arrival Time ms	Duration ms
3	12	419	109	0.845	1.12
	13	409	120	0.845	1.14
	14	348	121	1.007	1.50
	15	308	99	1.172	1.58
	16	288	111	1.182	1.60
4	12	423	106	0.890	0.97
	13	448	150*	0.867	1.70
	14	400	-	1.047	-
	15	277	91	1.225	0.91
	16	285	90	1.217	0.90
5	12	896	152	0.497	1.25
	13	977	124	0.482	0.85
	14	764	109	0.598	0.55
	15	609	110	0.740	0.70
	16	543	116	0.732	0.80

*Questionable value

419 kPa. Based on reflection factor curves for various angles of incidence,[4] it appears that the incident peak overpressure is 305 kpa; and the angle of incidence of the shock front striking the front wall is 27 degrees; and the angle of the shock front striking the roof is 63 degrees. At station 12 shown in Figure 11 there is no significant difference in Shots 3 and 4 in peak overpressure or overpressure impulse. Station 13 records a peak overpressure approximately 9 percent lower on Shot 3 than Shot 4. The peak overpressures recorded at Stations 12 and 13 on Shot 4 are 54 percent lower than recorded on Shot 5 (the unconfined donor charge).

Station 14 is in the center of the roof. The peak overpressure shown in Figure 12 is 13 percent lower on Shot 3 than Shot 4, and Shot 4 is 48 percent lower that Shot 5. The records from Station 14 also record a lower peak overpressure than Station 13 because of the pressure decay associated with distance from the donor.

Stations 15 and 16 are located on the rear edge of the roof - away from the donor. In Figure 13 the peak overpressures versus time recorded at Stations 15 and 16 on Shots 3 and 4 show no significant differences. The peak overpressure falls within ± 6 percent of a mean value and the impulses fall within +13 percent -9 percent. The peak overpressures recorded at Stations 15 and 16 are 51 percent lower on Shot 4 than on Shot 5. This follows the same trend established at the other stations on the roof and front face.

C. Blast Loading on the Back Side-Wall of the Acceptor Structure

Stations 7, 8, and 9 are located on the back side (away from the donor) of the structure model. A detailed analysis will not be made for each station and shot, but some general observations will be made. Station 7 is located at the top corner and as shown in Figure 14 receives the first shock expanding over the top with a decay associated with the vortex moving down the structure wall. The pressure increase starting at 0.75 msec is believed to be a reflection from the barricade back against the rear wall. Shot 5 produces peak overpressures somewhat larger than Shots 3 or 4 but not the magnitude noted on the top and front. Numerical values are listed in Table 4.

Station 8 is located in the center of the back wall. The overpressures versus time for Shots 3, 4, and 5 are presented in Figure 14. The first pressure is from over the top of the structure while the second pressure rise is from reflections off the ground surface and the barricade.

The second pressure rise is greater in Shot 4 than recorded on Shot 3. The record from Shot 5 is the same general shape as recorded on Shot 4, but the magnitude is much greater. The Shot 4 record is 40 percent lower in overpressure than Shot 5.

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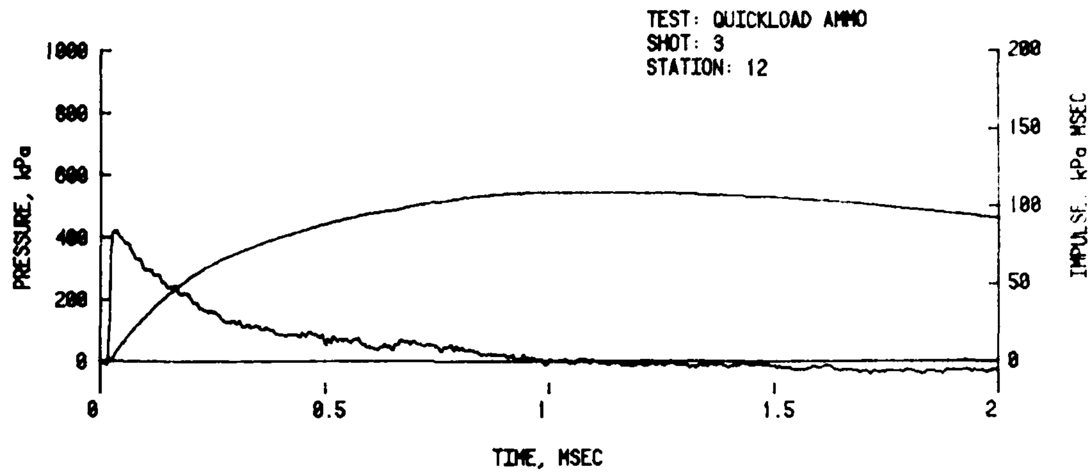
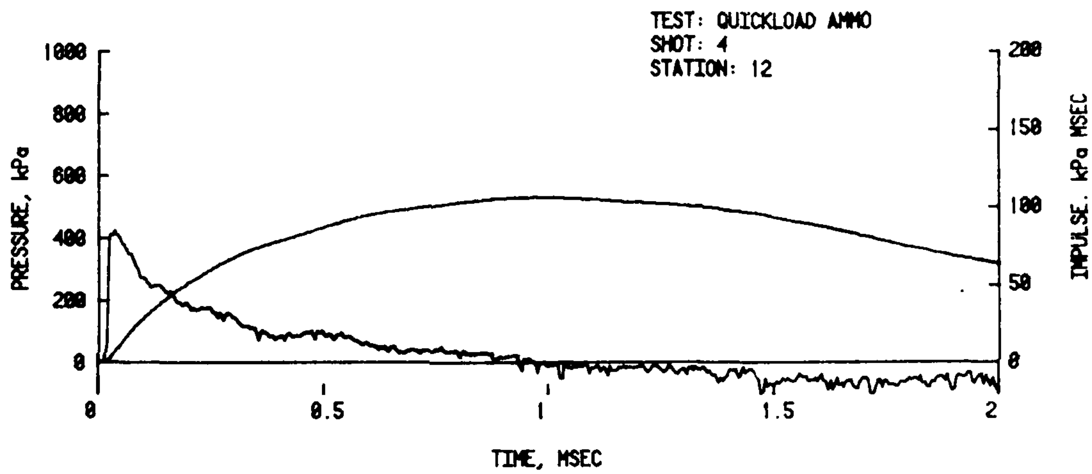
[4] *Charles N. Kingery and George A. Coulter "Reflected Overpressure Impulse on a Finite Structure," Tech Report ARBRL-TR-02537, December 1983 (AD A137259).*





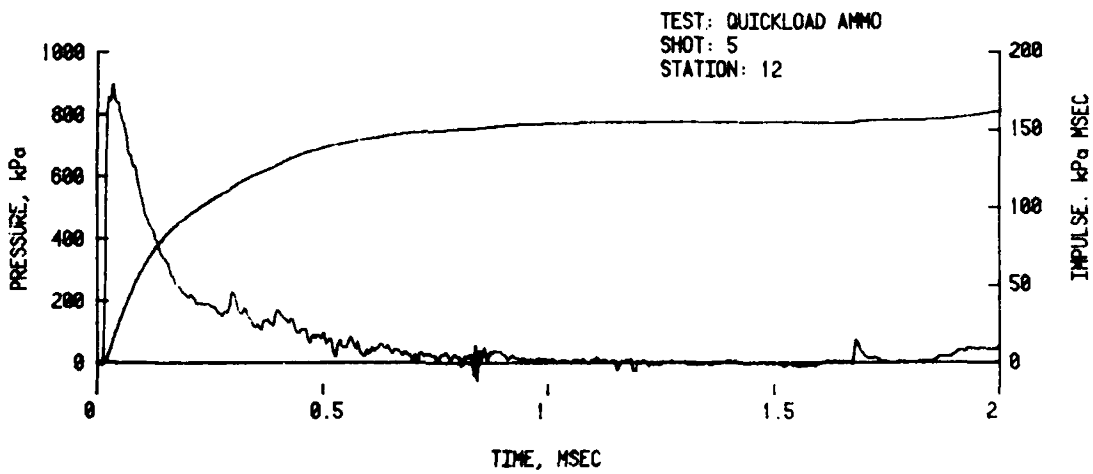


Figure 11. Pressure versus Time, Stations 12 and 13 for Shots 3, 4, and 5

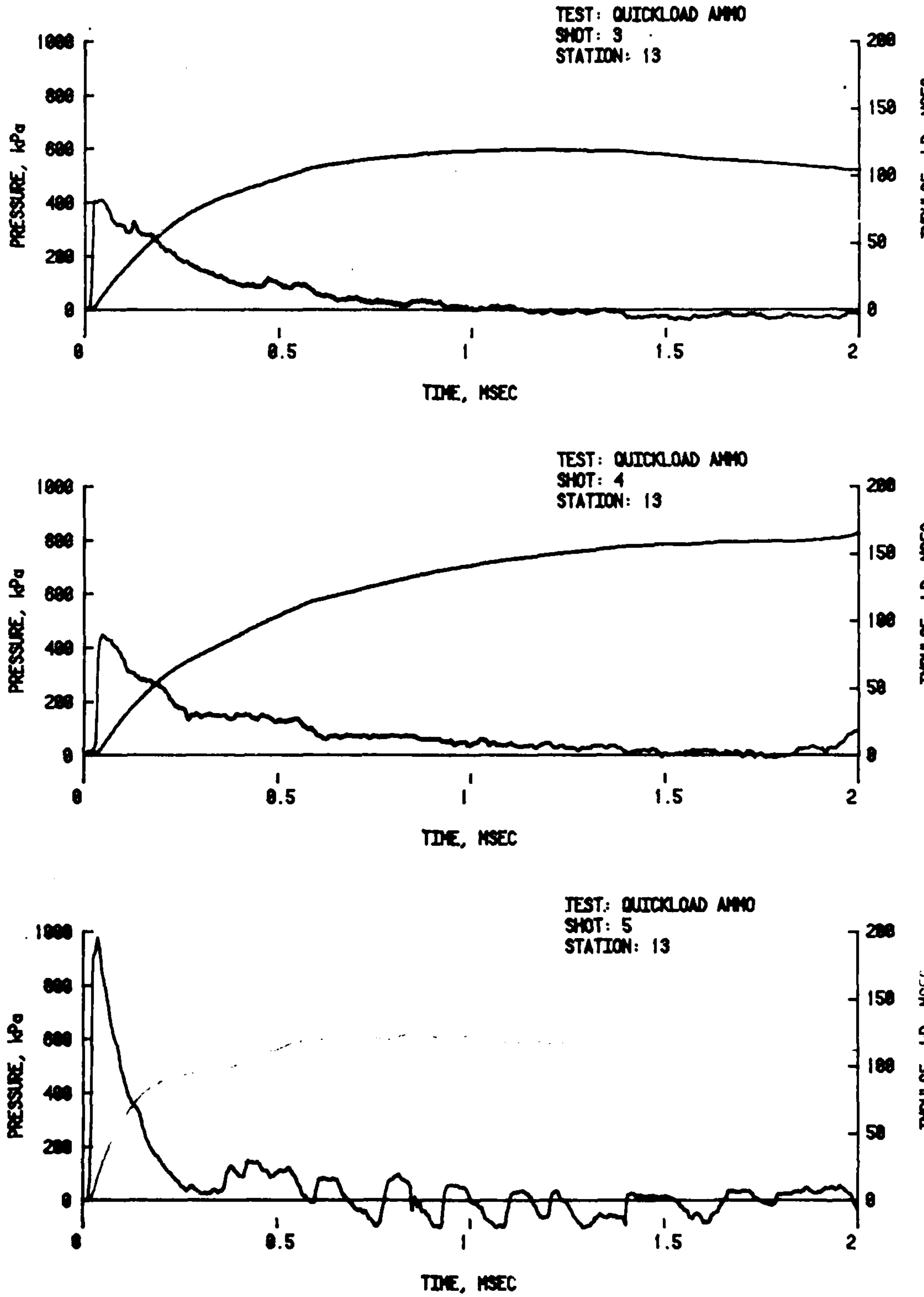


Figure 11. Pressure versus Time, Stations 12 and 13 for Shots 3, 4, and 5 (Continued)

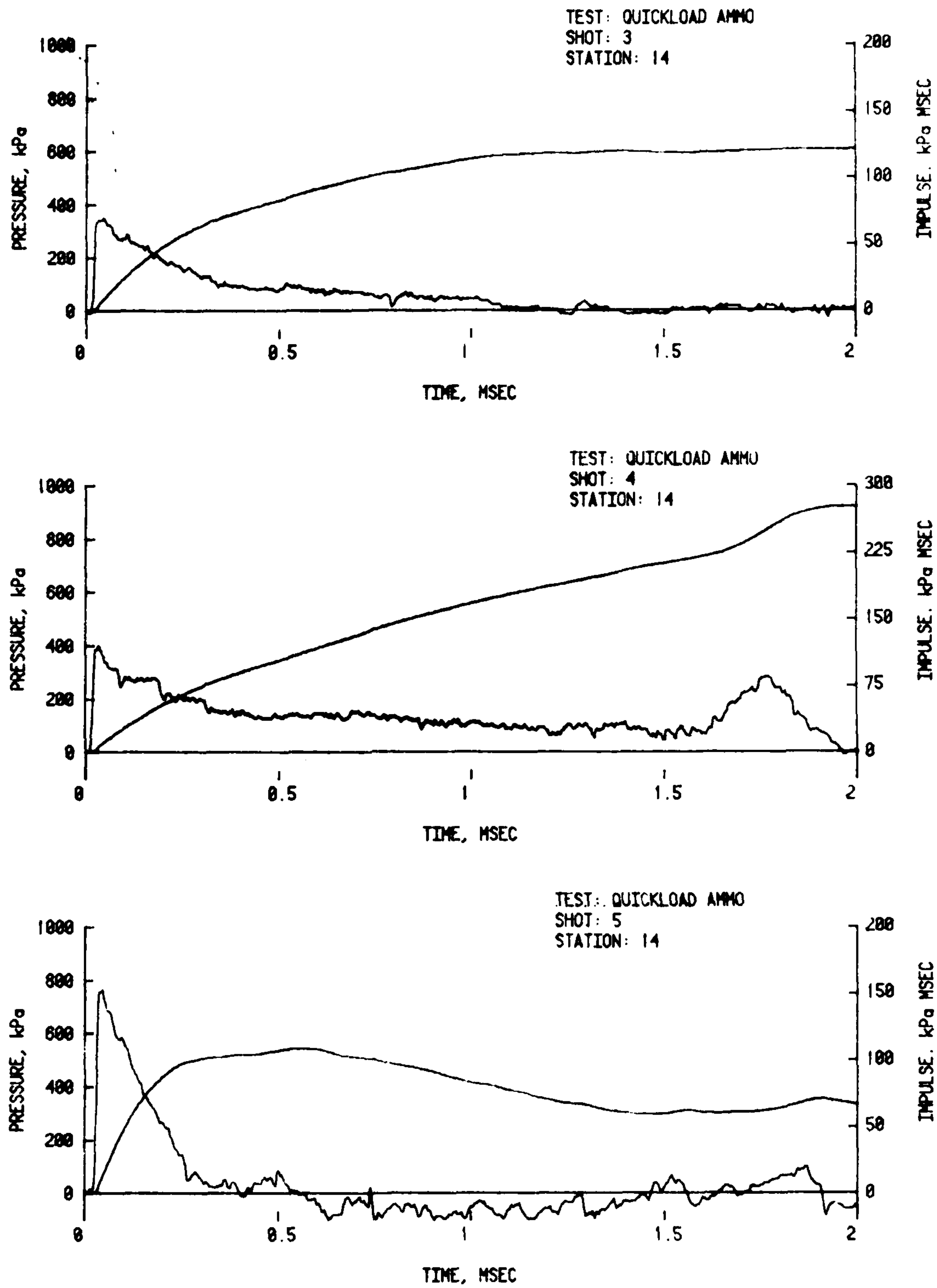


Figure 12. Pressure versus Time, Station 14 for Shots 3, 4, and 5

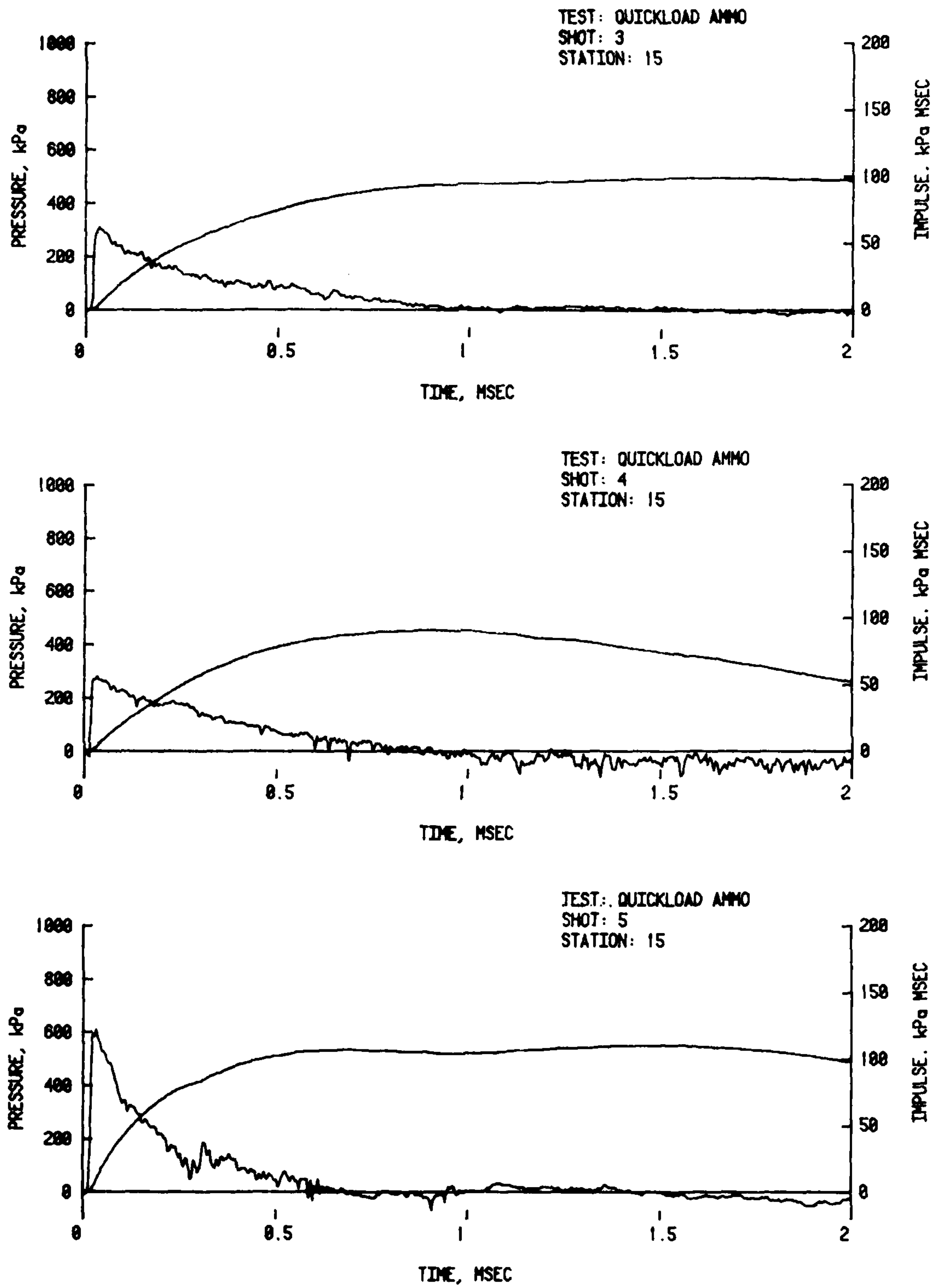
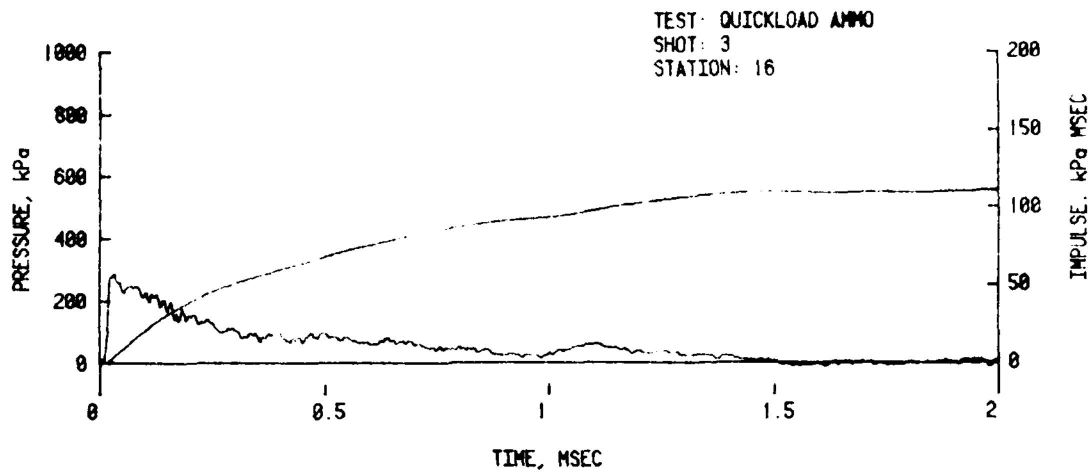
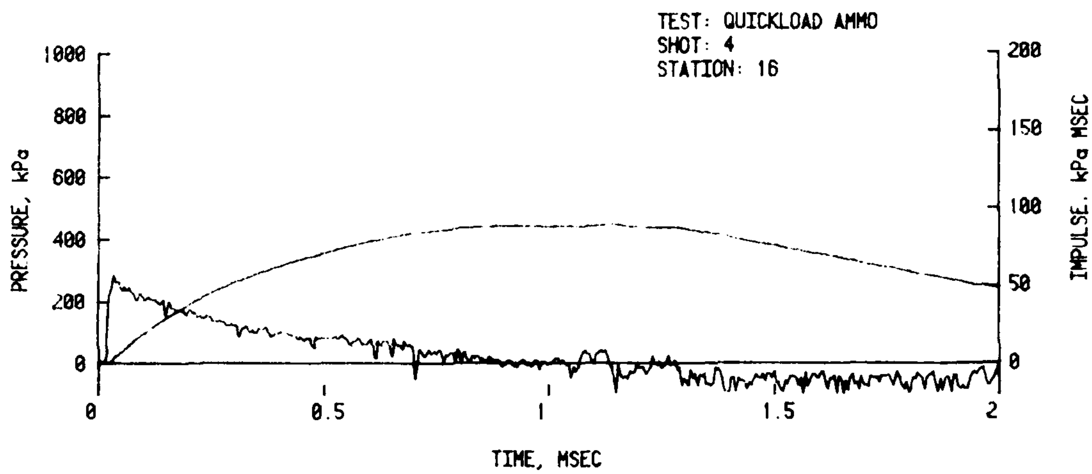


Figure 13. Pressure versus Time, Stations 15 and 16 for Shots 3, 4, and 5





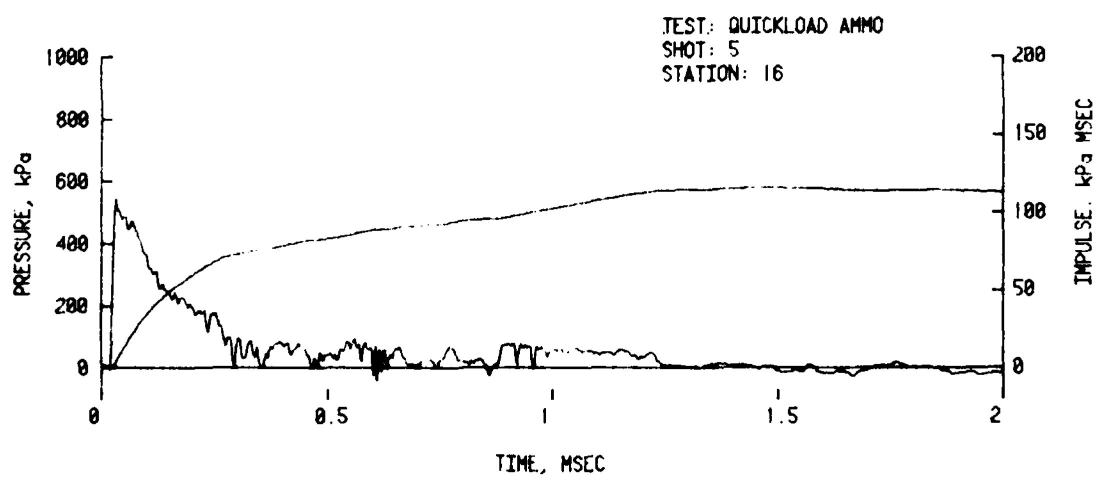
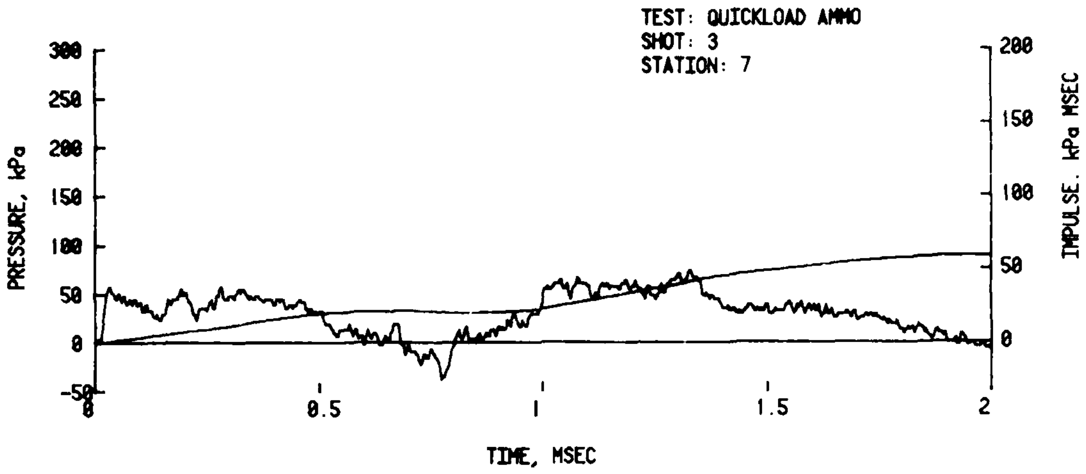
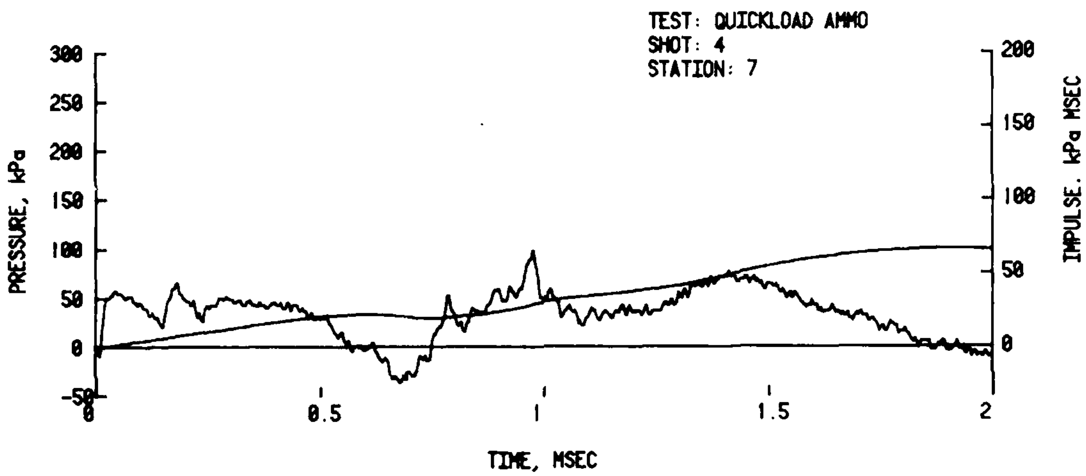


Figure 13. Pressure versus Time, Stations 15 and 16 for Shots 3, 4, and 5 (Continued)





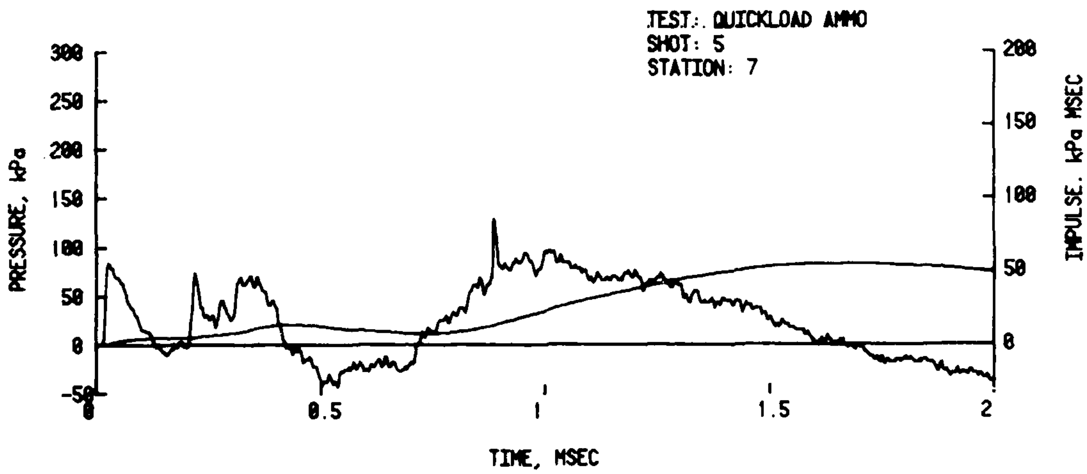


Figure 14. Pressure versus Time, Stations 7, 8, and 9 for Shots 3, 4, and 5

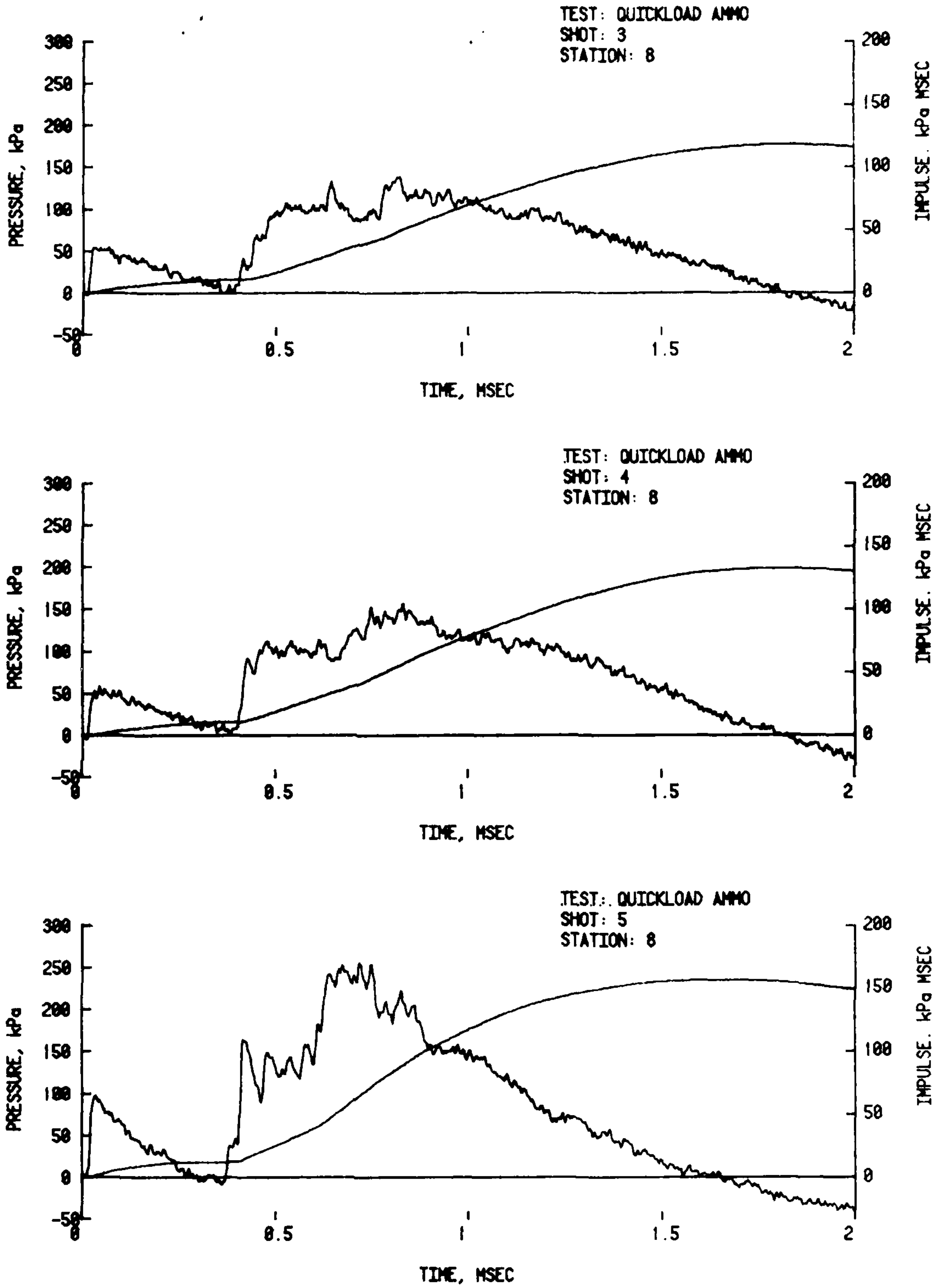


Figure '4. Pressure versus Time, Stations 7, 8, and 9 for Shots 3, 4, and 5 (Continued)

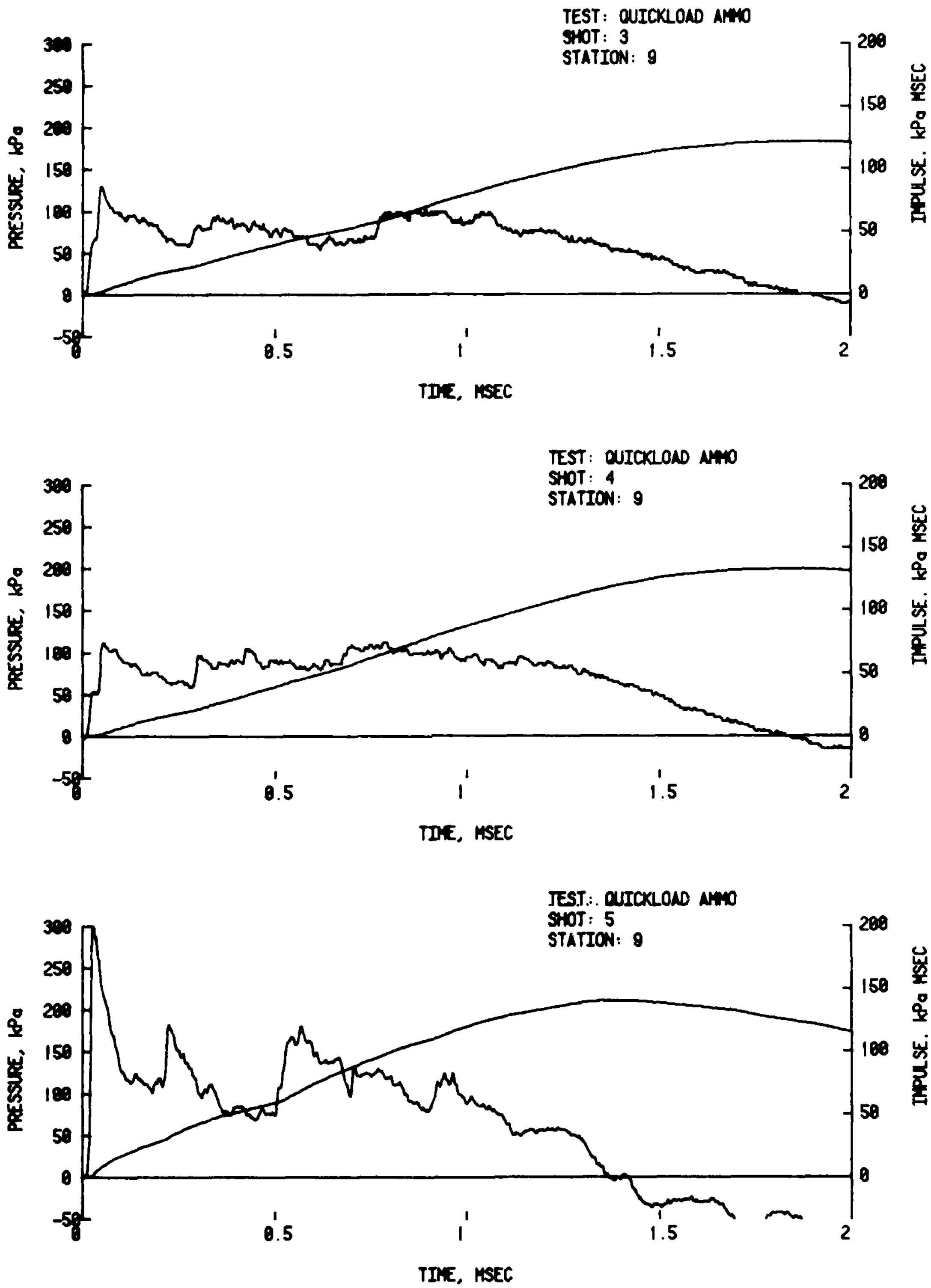


Figure 14. Pressure versus Time, Stations 7, 8, and 9 for Shots 3, 4, and 5 (Continued)

TABLE 4. BLAST LOADING ON BACK SIDE-WALL

Shot	Station	Peak Pressure kPa	Impulse kPa-ms	Arrival Time ms	Duration ms
3	7	60/73*	59	1.370	1.95
	8	52/139*	117	1.447	1.82
	9	130	122	1.525	1.90
4	7	60/98*	66	1.427	1.90
	8	55/156*	132	1.487	1.80
	9	112	133	1.577	1.84
5	7	80/129*	55	0.907	1.67
	8	96/256	157	0.962	1.66
	9	301	140	1.072	1.37

*Reflected Shock

Station 9 is located near the bottom of the wall and is subjected to reflected pressures immediately after the incident shock. Pressures versus time for Shots 3, 4, and 5 are presented in Figure 14. Shots 3 and 4 are similar while Shot 5 records the large reflected pressure produced from a re-entrant corner effect.

D. Blast Loading on the Ends of the Acceptor Structure

There were two station locations (10 and 11) on the back end of the structure and two (17 and 18) on the front (door) end. The predicted wave shape for Stations 10 and 17 would be an incident shock followed by a reflected wave from the ground surface passing back up the wall. At Stations 11 and 18 the reflected wave from the ground surface should arrive sooner and be of greater magnitude than recorded at stations 10 and 17. Because of the location of the barricade near the back end of the structure, the reflected wave from the ground surface would be predicted larger at Stations 10 and 11 than at Stations 17 and 18. Numerical values of the blast parameters are listed in Table 5.

Upon examining the pressures versus time recorded at Stations 10 and 11 for Shots 3, 4, and 5 (Figure 15), the same trend is seen here as noted earlier. That is, the soil barricade shot records pressure higher than the sand barricades and the unconfined charge produces higher pressures than the confined charge.

The same trend is noted at Stations 17 and 18 and shown in Figure 16. The sand barricades produce lower pressures, and the reflection from the surface occurs sooner and is greater at Station 18 than at Station 17.

E. Free-Field Pressure versus Time Recordings

Stations 19, 20, and 21 were mounted flush with the ground surface and located as shown in Figure 3. These gage locations were placed to monitor the blast wave propagating to the front and side of the donor and the overpressure versus time in front of the acceptor. The pressures versus time recorded at Station 19 on Shots 3, 4, and 5 are presented in Figure 17. On Shots 3 and 4 the donor charge was covered with a scaled concrete structure model with a frangible door. The blast was focused forward. Numerical values for the three stations are listed in Table 6. The difference in peak overpressure at Station 19 between Shots 3 and 4 is 31 percent, but the difference in impulse is only 10 percent. The difference in peak overpressure is quite large, but this cannot all be attributed to the sand versus clay barricades. The unconfined donor charge (Shot 5) produces 34 percent less peak overpressure and 25 percent less impulse than the covered donor on Shot 4.

The effect of the focusing to the front is quickly lost at Station 20 where the peak overpressure is 52 percent less and the impulse is 23 percent less on Shot 4, the covered donor charge, than on Shot 5, the uncovered donor charge. These records are shown in Figure 18.

TABLE 5. BLAST LOADING ON END WALLS

Shot	Station	Peak Pressure kPa	Impulse kPa-ms	Arrival Time ms	Duration ms
3	10	248/274	109	1.067	1.23
	11	327	112	1.102	1.22
	17	214/214	103	1.082	1.33
	18	200/272	109	1.120	1.23
4	10	200/358	99	1.120	1.08
	11	401	102	1.165	1.02
	17	250/300	107	1.082	1.26
	18	250/392	117	1.120	1.23
5	10	375/806	134	0.685	0.77
	11	375/1016	160	0.735	0.71
	17	390/350	122	0.670	1.00
	18	375/527	130	0.717	0.95

/Indicates two peaks

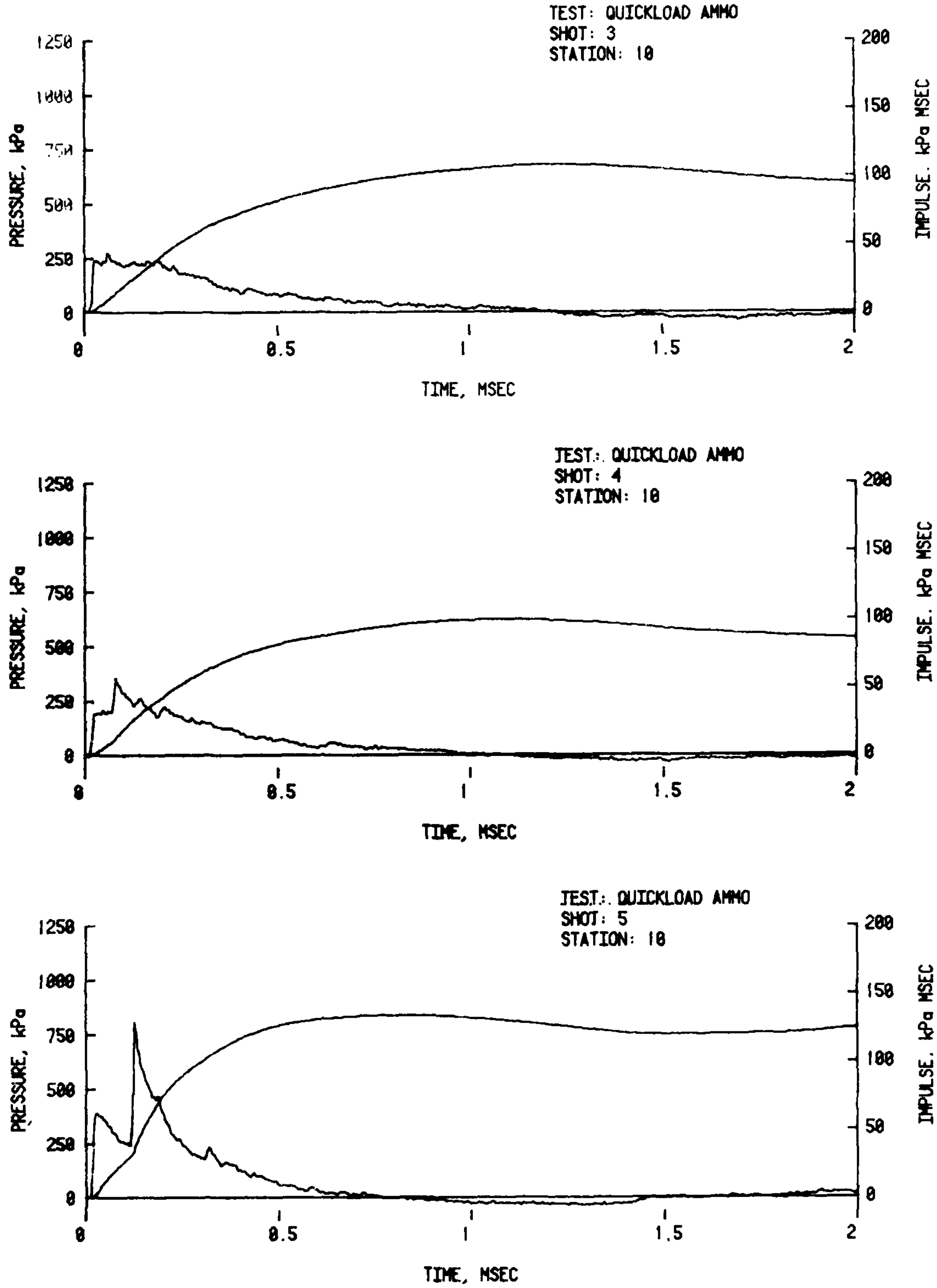


Figure 15. Pressure versus Time, Stations 10 and 11 for Shots 3, 4, and 5

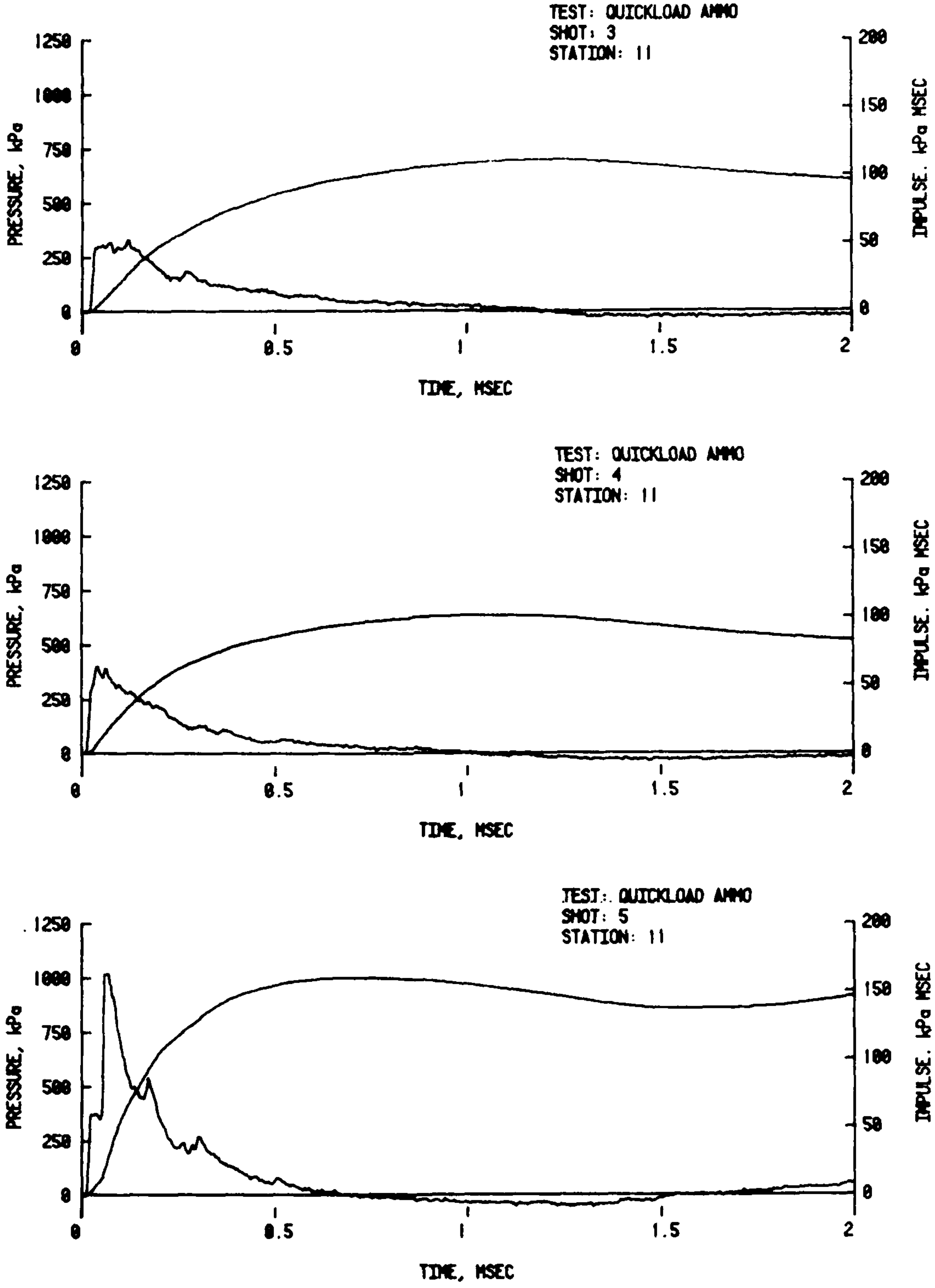
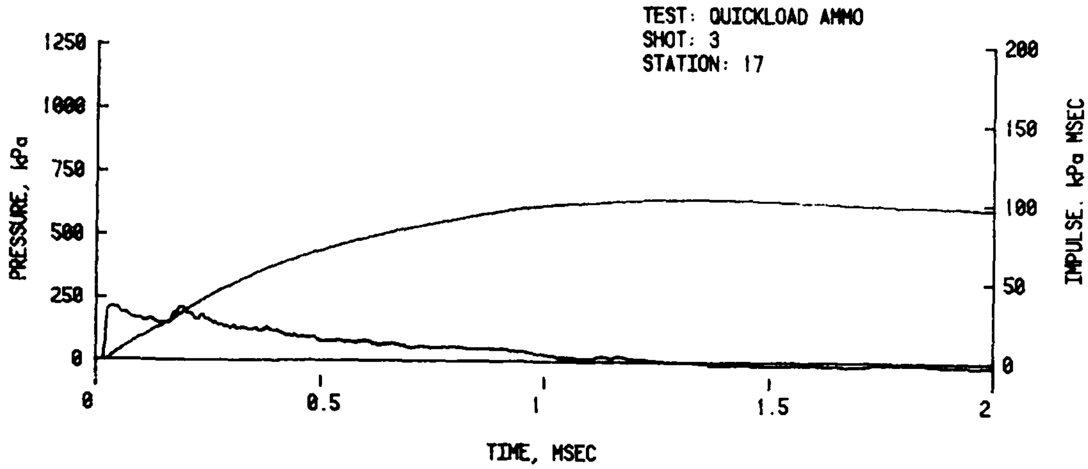
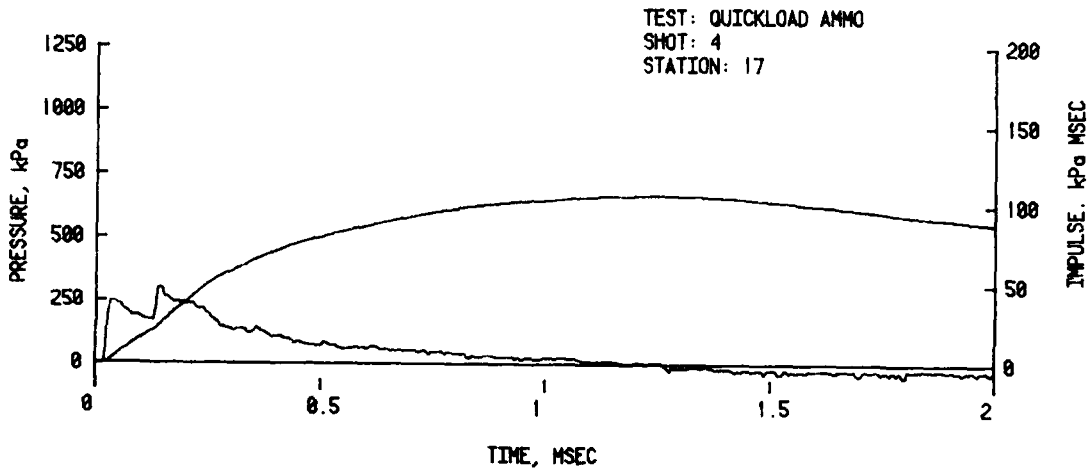


Figure 15. Pressure versus Time, Stations 10 and 11 for Shots 3, 4, and 5 (Continued)





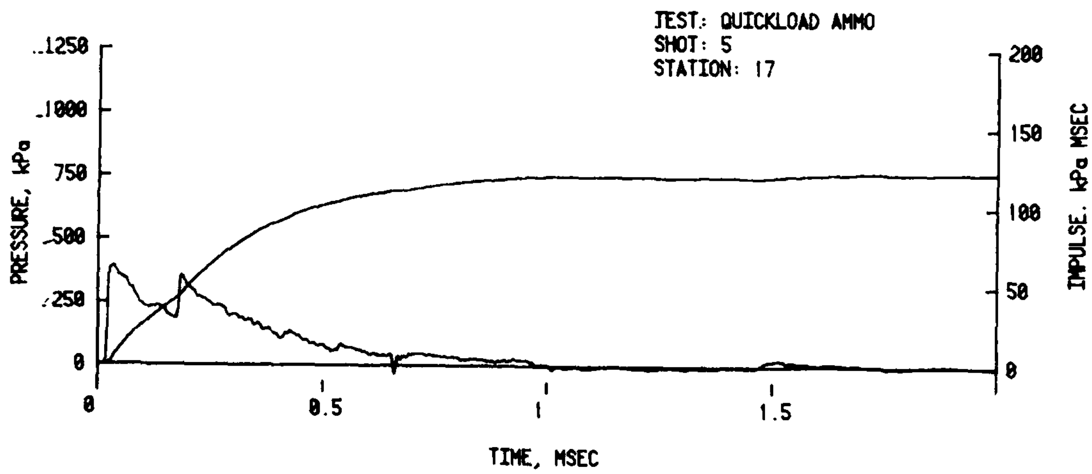


Figure 16. Pressure versus Time, Stations 17 and 18 for Shots 3, 4, and 5

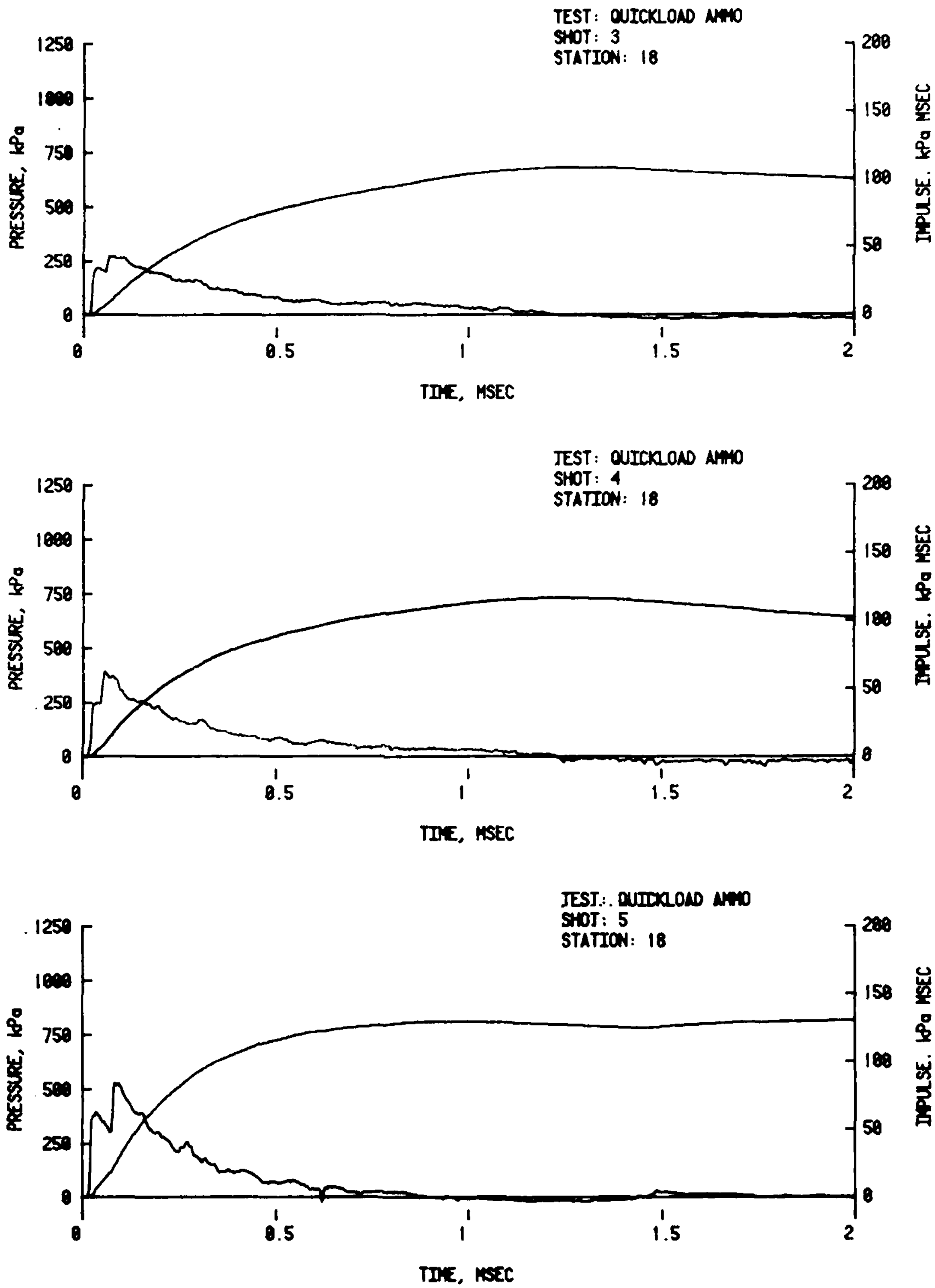


Figure 16. Pressure versus Time, Stations 17 and 18 for Shots 3, 4, and 5 (Continued)

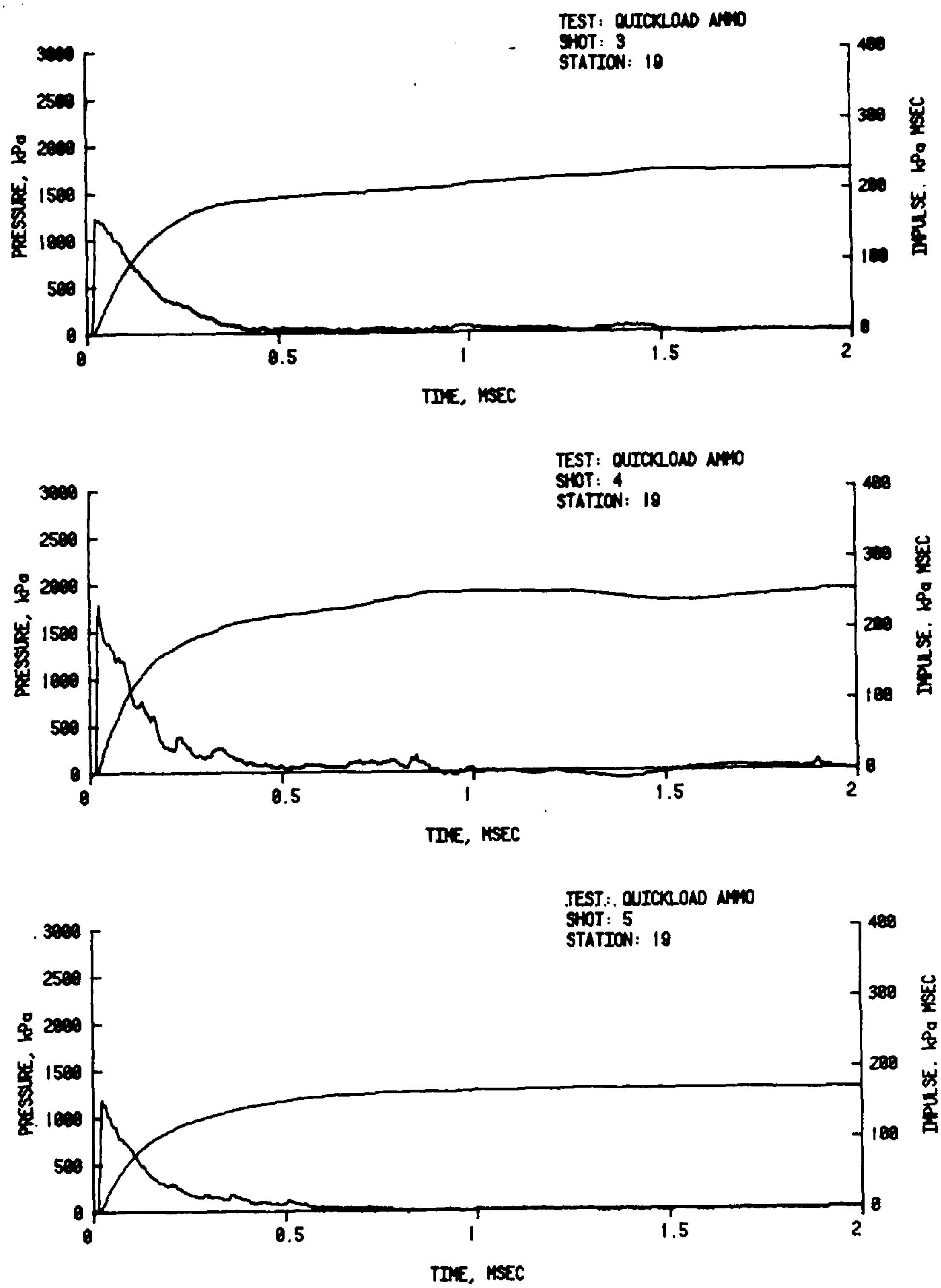


Figure 17. Pressure versus Time, Station 19 for Shots 3, 4, and 5

TABLE 6. FREE FIELD BLAST PARAMETERS

Shot	Station	Distance m	Peak Pressure kPa	Impulse kPa-ms	Arrival Time ms	Duration ms
3	19	1.006	1236	229	0.477	1.55
	20	1.523	245	-	1.347	-
	21	2.286	138	73	3.297	2.00
4	19	1.006	1796	256	0.380	1.11
	20	1.523	209	105	1.285	1.59
	21	2.286	150	-	3.330	-
5	19	1.006	1188	172	0.455	1.31
	20	1.523	434	136	1.035	2.00
	21	2.286	170	101	2.547	2.50

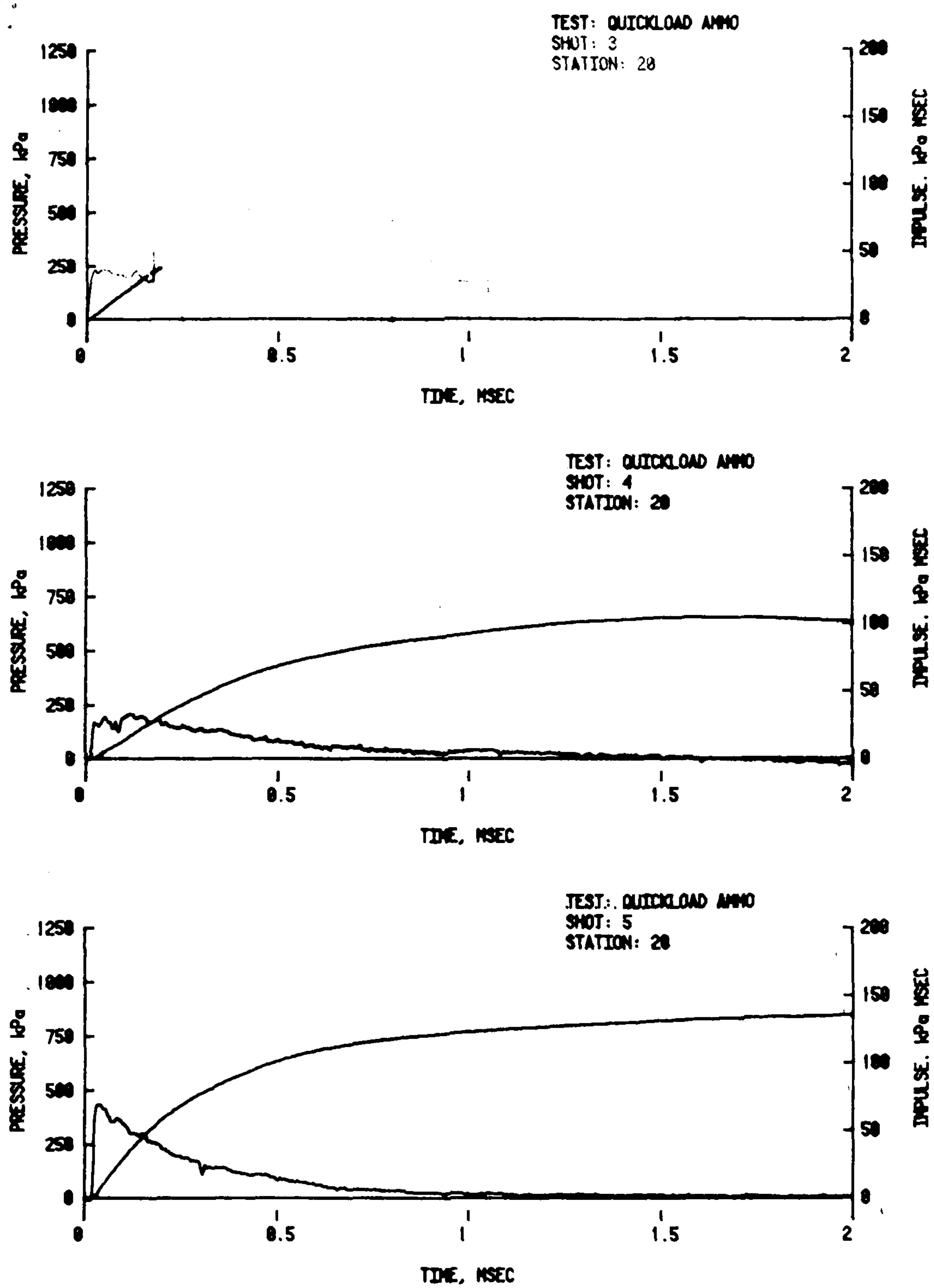


Figure 18. Pressure versus Time, Station 20 for Shots 3, 4, and 5

In Figure 19 the pressure versus time records from Station 21 are presented for Shots 3, 4, and 5. The peak overpressure recorded on Shot 3 is 8 percent lower than Shot 4, and Shot 4 is 11 percent lower than Shot 5. This implies that to the side of the donor the peak overpressure from an unconfined charge will be higher than a covered one, and the soil barricades will produce higher overpressures than the sand barricades. This conclusion would probably also be true for the blast propagating to the rear of the donor structure.

F. Exposure of Responding Acceptor Model

Direct visual evidence of the responding concrete model's dynamic behavior was not obtained although it was photographed at two thousand frames per second. The fireball enveloped the responding model in the first frame after detonation. Subsequently, a debris cloud obscured the model for the duration of the event.

Figure 20 shows the site after the event. Notice that the concrete slabs have moved and are partially buried. For both Shots 4 and 5, the responding acceptor slabs were cracked but not broken apart. Each slab remained substantially in one piece although small chunks were broken off. Figure 21 shows the condition of the slabs after the blast.

The authors had anticipated the disintegration of the concrete slabs. The slabs remained substantially intact. In scaling the test site by 1/23.5, the magazine mass was scaled correctly. The full scale roof, for example, has a volume of 17.26 cubic metres and a mass of 38,662 kilograms. Dividing the mass by 23.5^3 results in 2.98 kg scaled mass. The average mass of the model roof was 2.82 kg which is only 5.4% less than the actual scaled mass.

The authors did not specifically scale the material strength. Sand mix was a good common sense material to employ in creating a miniature model of a concrete and brick structure, but it must be remembered that the real munitions structure is more complex than a simple concrete slab structure. Copper wire was used to reinforce the model. This was not intended to scale the steel reinforcing bars in the actual structure. The wire was used to hold together very thin concrete sections. Therefore, it is possible that the responding acceptor was stronger than expected.

As previously stated the responding acceptor was not fixed in place or bound together. The positive phase blast loading duration on the closest surface of the non-responding acceptor was between 0.62 and 0.82 msec on Shot 4 and between 0.49 and 0.58 msec on Shot 5. The responding acceptor should have experienced the same loading. It was thought that because of this short duration most damage to the concrete slabs would occur before it began to move. Perhaps the response of this structure would have been different if the slabs were bound together and fixed in place on the pad.

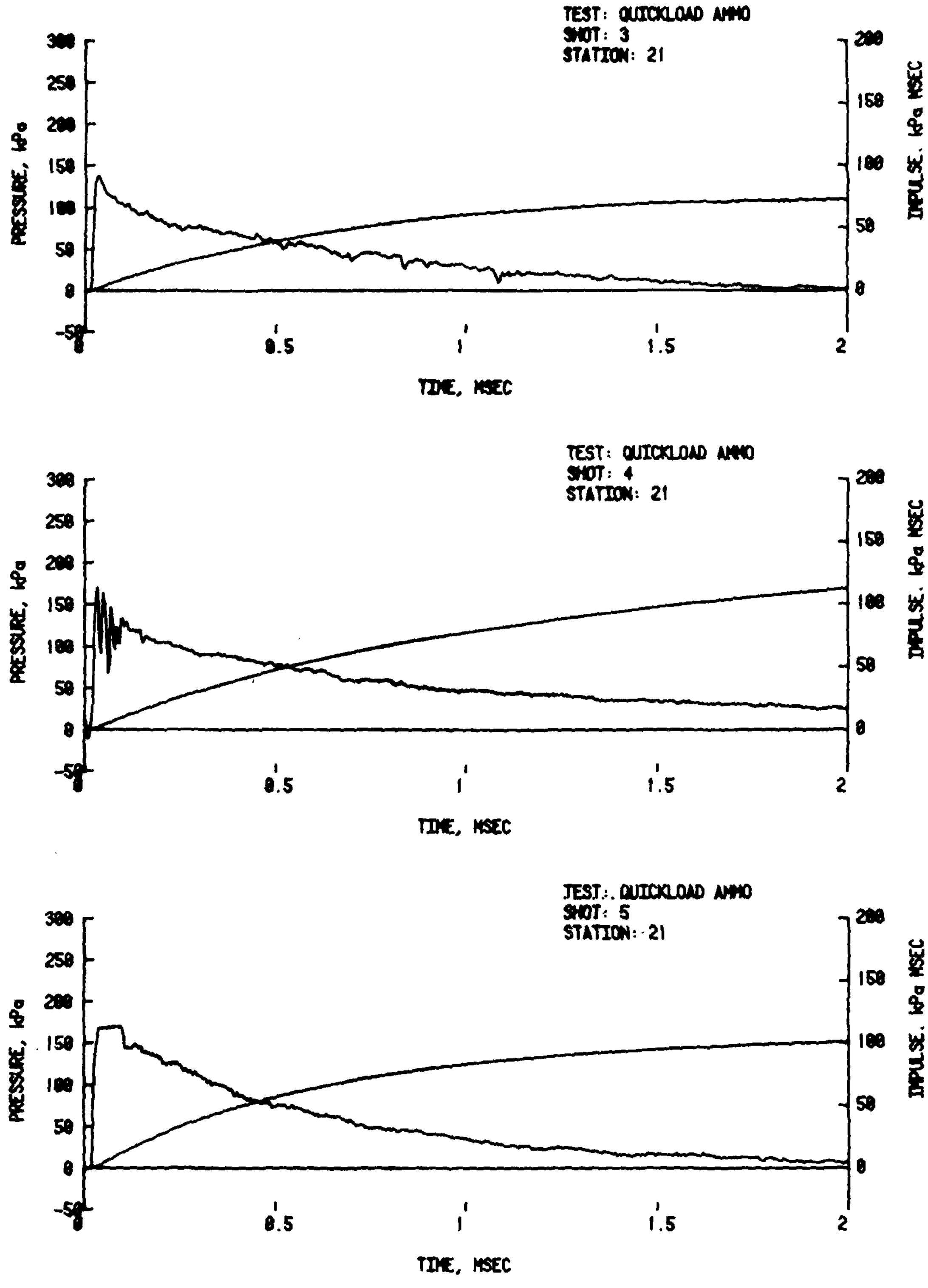


Figure 19. Pressure versus Time, Station 21 for Shots 3, 4, and 5

Figure 20. Post-Shot View of Test Site

Figure 21. Post-Shot View of Concrete Slabs

This report is concerned with the blast loading on a non-responding steel acceptor model. The responding concrete acceptor was included in this study as a prelude to a future experiment that will measure the velocity of fragments from a responding acceptor.

G. Effects of the Structure in Blast Suppression

The donor structure confined the bare pentolite charge, reducing the blast effects. To determine the confinement effects, Reference 3 was used to calculate the bare TNT equivalent weight of a confined bare Pentolite charge.

$$W_{TNT} = f_e \times f_c \times W_{NEW} \qquad (1)$$

where

W_{TNT} = equivalent TNT weight

f_e = equivalent weight factor relative to TNT based on peak overpressure

f_c = case correction factor

W_{NEW} = net explosive weight

The pressure equivalent weight factor for Pentolite was obtained from Reference 5. For Pentolite $f_e = 1.17$. The case correction factor adjusts for the mass of the confining structure.

$$fc = 0.20 + \frac{0.80}{1 + \frac{W_{CT}}{W_{NEW}}} \qquad (2)$$

where W_{CT} = total case weight,

is the mass of the donor magazine walls, roof, and door. For Shots 3 and 4 an average value of f_c is 0.32. Therefore, from Equation 1, $W_{TNT} = 1.17 \times 0.32 \times 1.0 = 0.374$ kg.

The blast effects of the 1 kg Pentolite charge for Shots 3 and 4 should be equivalent to a 0.374 kg bare TNT charge. To check the calculation from Equation 1 the reflected pressures recorded on the center line of the roof of the structure on Shots 4 and 5 were plotted in Figure 22. Two curves of peak reflected pressure versus distance were established using the relationship

$$\frac{R_1}{(W_1)^{1/3}} = \frac{R_2}{(W_2)^{1/3}} \quad \text{for equal pressure} \qquad (3)$$

[5] *"Structure to Resist the Effects of Accidental Explosion," Dept. of the Army Technical Manual, TM 5-1300, June 1969.*

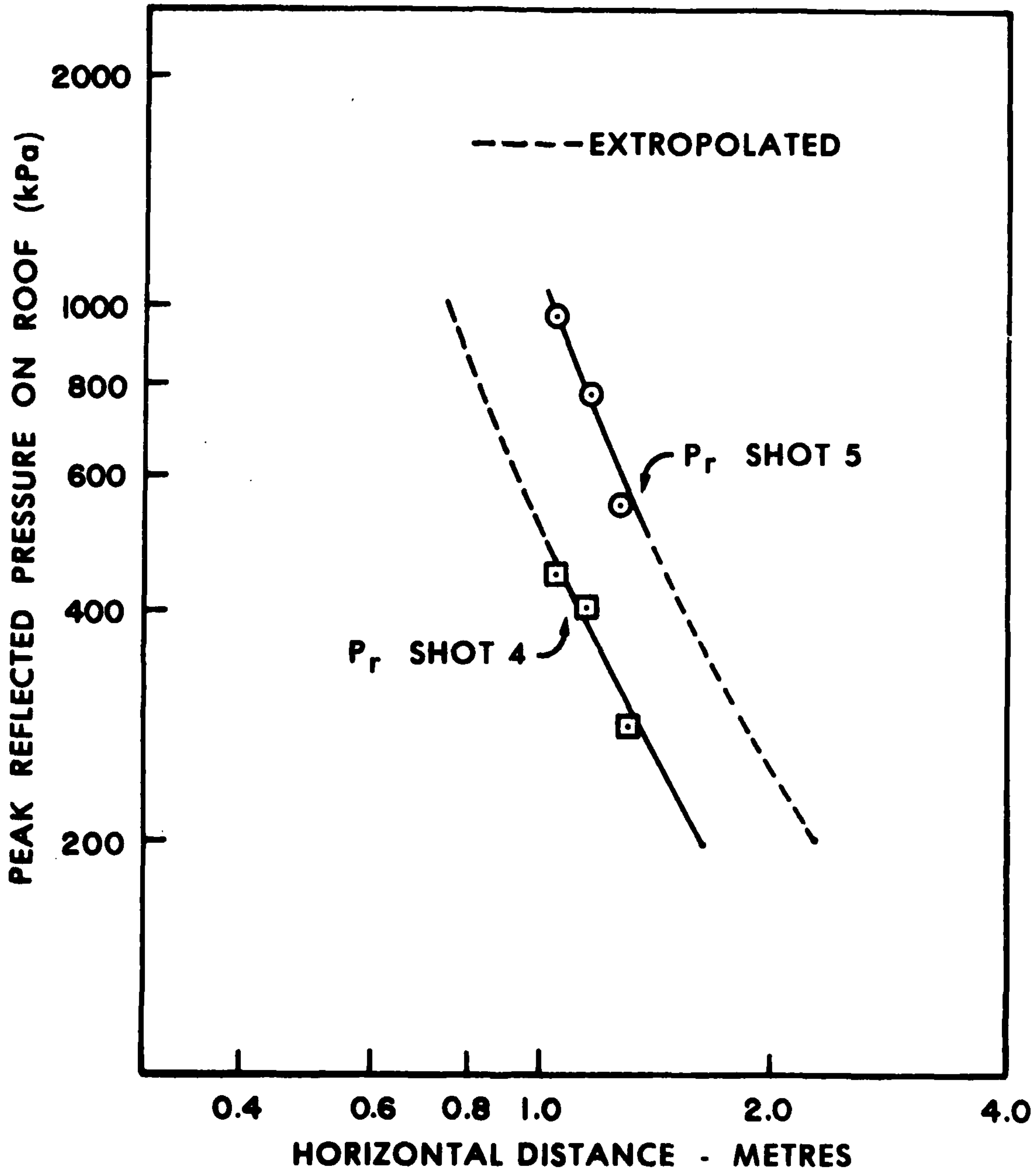


Figure 22. Reflected Pressure on Roof versus Distance for Shots 4 and 5.

where R_2 = distance for selected peak pressure for W_2

W_2 = 1 kg explosive

R_1 = distance for same peak pressure

W_1 = explosive mass uncovered that will be equivalent to 1 kg covered

Calculations from Equation 3 establish W_1 equivalent to 0.384 kg of Pentolite. This means that a 0.384 kg Pentolite hemisphere uncovered should produce the same pressure on the structure as a 1 kg covered. The value of 0.384 kg determined from Equation 3 compares amazingly well with the value of 0.374 kg calculated from Equation 1 and 2. Referring to Table 3 it can be seen that this relationship does not hold for impulse measurements. While the peak overpressure is suppressed approximately 50 percent, the impulse is suppressed approximately 10 percent.

IV DISCUSSION

The intention of this report is to present through the use of scaled structural models certain trends that can be expected in the event of an accidental explosion in a full size storage magazine. The blast loading recorded on the acceptor model can be used to calculate the break-up of the full size structure, and estimates of the velocities imparted to the debris can be made. From the debris velocity a determination can be made on the probability of causing stored munitions to explode.

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4. Charles N. Kingery and George A. Coulter "Reflected Overpressure Impulse on a Finite Structure," Tech Report ARBRL-TR-02537, December 1983 (AD A137259).

5. "Structure to Resist the Effects of Accidental Explosion," Dept. of the Army Technical Manual, TM 5-1300, June 1969.

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