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HASTINGS IGLOO HAZARDS TESTS FOR
SMALL EXPLOSIVE CHARGES

Harry Reeves
Walton T. Robinson

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) Full-scale field tests have been conducted to characterize the hazards to an exposed site when limited quantities of bulk explosives, positioned inside igloo magazines, are statically detonated. Specific test objectives were to (1) determine the explosive quantity which, when detonated inside a standard-size, earth-covered magazine, produces no significant external effect and (2) evaluate the dispersal of structure debris and measure external airblast for the range of explosive quantities from that marginally contained up to 68 Kg (150 lb). | | |

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Test results in the form of overall structural response, airblast measurements and hazardous fragment distributions are provided for selected explosive charge weights from 5.4 Kg (12 lb) to 68 Kg (150 lb).

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TABLE OF CONTENTS

| | <u>Page</u> |
|--|-------------|
| LIST OF ILLUSTRATIONS | 5 |
| LIST OF TABLES | 7 |
| I. INTRODUCTION | 9 |
| II. DESCRIPTION OF TESTS | 10 |
| III. RESULTS AND OBSERVATIONS | 10 |
| IV. DISCUSSION | 32 |
| V. CONCLUSIONS AND RECOMMENDATIONS | 40 |
| APPENDIX A | 41 |
| APPENDIX B | 57 |
| DISTRIBUTION LIST | 67 |

LIST OF ILLUSTRATIONS

| <u>Figure</u> | | <u>Page</u> |
|---------------|---|-------------|
| 1 | Oblique View of Igloo Magazine with Blast Shield. | 11 |
| 2 | Side View of Igloo Magazine Headwall, Blast Shield and Access Road. | 12 |
| 3 | Schematic Drawing of Igloo Magazine and Blast Shield. | 13 |
| 4 | Test Layout Showing Location of Igloo, Blast Shield, Roads and Instrumentation | 14 |
| 5 | Rear View of Blast Shield Showing Cleared Path for Pressure Transducers | 15 |
| 6 | Instrumentation System. | 16 |
| 7 | Test Results-Test No., 1, 18 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall | 20 |
| 8 | Test Results-Test No., 2, 11 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall | 21 |
| 9 | Test Results-Test No., 3, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall | 22 |
| 10 | Test Results-Test No., 4, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall | 23 |
| 11 | Test Results-Test No., 5, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall | 24 |
| 12 | Test Results-Test No., 6, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall | 25 |
| 13 | Test Results-Test No., 7, 7.3 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall | 26 |
| 14 | Test Results-Test No., 8, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Rearwall | 27 |
| 15 | Test Results-Test No., 8, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Rearwall | 28 |
| 16 | Hazardous Fragment Densities (600 ft ²) Versus Distance in Front of an Igloo Magazine-27Kg TNT Charge Positioned in the Center of the Igloo Statically Detonated. | 34 |
| 17 | Hazardous Fragment (600 ft ²) Versus Distance in Front of an Igloo Magazine-36Kg TNT Charge Positioned in the Center of the Igloo Statically Detonated. | 35 |
| 18 | Hazardous Fragment Densities (600 ft ²) Versus Distance in Front of an Igloo Magazine-45Kg TNT Charge Positioned in the Center of the Igloo Statically Detonated. | 36 |

LIST OF ILLUSTRATIONS

| <u>Figure</u> | <u>Page</u> | |
|---------------|---|----|
| 19 | Hazardous Fragment Densities (600 ft ²) Versus Distance in Front of an Igloo Magazine-68Kg TNT Charge Positioned in the Center of Igloo Statically Detonated. | 37 |
| A-1 | Pressure Time Histories, Test No. 2, 12.9Kg TNT Charge Positioned 4 Metres from Headwall. | 43 |
| A-2 | Pressure Time History, Test No. 4, 5.4Kg TNT Charge Positioned 4 Metres from Headwall. | 44 |
| A-3 | Pressure Time Histories, Test No. 5, 5.4Kg TNT Charge Positioned 4 Metres from Headwall. | 45 |
| A-4 | Pressure Time Histories, Test No. 5, 5.4Kg TNT Charge Positioned 4 Metres from Headwall. | 46 |
| A-5 | Pressure Time Histories, Test No. 6, 5.4Kg TNT Charge Positioned 20.4 Metres from Headwall | 47 |
| A-6 | Pressure Time Histories, Test No. 5, 5.4Kg TNT Charge Positioned 20.4 Metres from Headwall | 48 |
| A-7 | Pressure Time Histories, Test No. 7, 7.3Kg TNT Charge Positioned 4 Metres from Headwall. | 49 |
| A-8 | Pressure Time Histories, Test No. 7, 7.3Kg TNT Charge Positioned 4 Metres from Headwall. | 50 |
| A-9 | Pressure Time Histories, Test No. 8, 5.4Kg TNT Charge Positioned 20.4 Metres from Headwall | 51 |
| A-10 | Pressure Time Histories, Test No. 8, 5.4Kg TNT Charge Positioned 20.4 Metres from Headwall | 52 |
| A-11 | Pressure Time Histories, Test No. 9, 45.4Kg TNT Charge Positioned 12 Metres from Headwall | 53 |
| A-12 | Pressure Time Histories, Test No. 9, 45.4Kg TNT Charge Positioned 12 Metres from Headwall | 54 |
| A-13 | Pressure Time Histories, Test No. 10, 68Kg TNT Charge Positioned 12 Metres from Headwall | 55 |
| A-14 | Pressure Time Histories, Test No. 10, 68Kg TNT Charge Positioned 12 Metres from Headwall | 56 |

LIST OF TABLES

| <u>Table</u> | | <u>Page</u> |
|--------------|---|-------------|
| 1 | Test Results - Explosive Charges Positioned Inside Earth-Covered Igloo Magazines. | 17 |
| 2 | Peak Overpressure, Impulse and Time of Arrival from TNT Charges Statically Detonated Inside Igloo Magazines. | 30 |
| 3 | Test Results - Hazardous Fragment Densities per 600 ft ² for Discrete Angular and Distance Increments. | 33 |
| 4 | Estimates of Initial Door Velocities and Times of Arrival of the Reflected Shock Waves. | 38 |
| B-1 | Individual Fragment Recovery Data. | 60 |

I. INTRODUCTION

In 1979 the Ballistic Research Laboratories (BRL) conducted a series of full-scale field tests* designed to characterize the hazards to an exposed site when either 68 Kg (150 lb) or 206 Kg (450 lb) TNT charges, positioned inside earth-covered reinforced concrete igloos, were statically detonated. Test results took the form of airblast profiles and concrete fragment distributions in terms of densities, weights, and their locations relative to igloo orientation. These tests were conducted at the NAVAJO Depot Activity near Flagstaff, Arizona, where excess igloos, constructed in 1942 according to U.S. Army specifications, were made available for destructive tests.

While the Flagstaff tests were conducted to support a hazards analysis at a particular site, they have also been used to support changes in the "Manual on NATO Safety Principles for the Storage of Ammunition and Explosives" that requires a minimum distance of 400 metres between inhabited buildings and igloos containing Hazard Division 1.1 ammunition or explosives. No minimum net explosive quantity is associated with this 400-metre restriction.

The conclusions reached in the Flagstaff tests were:

1. The 400-metre minimum distance requirement between inhabited buildings and igloos containing Hazard Division 1.1 ammunition or explosives is excessive for small explosive weights. This is true for both fragment and peak overpressure hazards.

2. The use of a barricade in front of the headwall and a re-design of the vent stack at the rear of the igloo would have reduced the density of hazardous fragments to an insignificant level.

3. The peak overpressure and fragment hazards to the sides and rear of earth-covered igloos are significantly less than those to the front for relatively small explosive weights. These directional effects should be considered when establishing minimum distance requirements.

The Flagstaff tests have been supplemented with additional full-scale tests designed to (1) determine the explosive quantity which, when detonated inside a standard-size, earth-covered igloo, produces no significant external effect and (2) evaluate the concrete fragment and external airblast hazards for a range of explosive quantities from that marginally contained, up to 68 Kg (150 lb).

All tests were sponsored by the Department of Defense Explosives Safety Board.

A description of these tests, test results and analysis are presented in the following sections.

*P. Howe, H. Reeves, and O. Lyman, "An Approach to Munitions Storage Applicable to the McNair Compound of the Berlin Brigade," ARBRL-SP-00013, Ballistic Research Laboratory, September 1979 (AD C019277L).

II. DESCRIPTION OF TESTS

All tests were conducted at the Nebraska State National Guard Weekend Training Site near Hastings, Nebraska, where a total of twelve excess igloo magazines were made available for destructive tests in support of this effort. This site is part of an abandoned Navy Ammunition Depot that was constructed during WW II. All of the igloos exhibited structural failures in the form of hairline cracks in the sidewalls, arch crest, backwall, and headwall. The igloos were constructed according to US Navy specifications and were designed to be earth-covered to a depth of at least 0.6 m (2 ft). Erosion of the earth-cover was observed in many cases due to a lack of maintainance. All of the magazines were weed-covered up to a height of 0.9 m (3 ft). The magazine headwalls faced an earth-backed concrete blast shield. The distance between the vertical headwalls and the blast shields varied between 3.7 m (12 ft) at the base to 3.7 m (15 ft) at the top. See Figures 1 through 3.

Pre-test site preparation included cutting the grass in front of the magazines out to a distance of 150 m (500 ft). The width of this cleared recovery area varied due to the presence of an elevated access road on the right side of the igloos. See Figure 4. The grass was cut out to the road on the right side. The cleared area on the left side of the igloos was essentially infinite. These recovery areas were searched after each test, and concrete fragments weighing at least 0.18 Kg (0.4 lb) were catalogued in terms of numbers per discrete weight groups and their location relative to the front of the igloo. A postage scale was used to establish fragment weights up to 0.9 Kg (2 lb). The weights of heavier fragments were estimated.

Two high-speed (500 fps) 16 mm cameras were positioned to the side of the headwalls to monitor initial headwall fragment velocities. Air blast parameters were monitored by pressure transducers, flush mounted, via teflon collars, to lead blocks positioned to the sides and fronts of the igloos. A cleared path from the headwall to the pressure transducers was prepared using a front-end loader to remove vegetation and level the ground. See Figure 5. The data-gathering instrumentation system is shown in Figure 6.

Standard 3.36 Kg (8 lb) blocks of TNT, with a small C4 booster charge, were positioned inside the igloos and statically detonated using long lengths of mild detonating fuze activated with electrically sensitive detonators. The position of the TNT charge was deliberately varied, in those tests involving 5.44 Kg (12 lb) charges, to determine the influence of charge location on incipient headwall failure.

III. RESULTS AND OBSERVATIONS

The tests results are presented in three catagories: structural response, external airblast, and hazardous fragment distributions; and each are discussed in the following sections.

A. Structural Response

The test results in terms of structural response are presented in Table 1 and Figures 7 through 15.

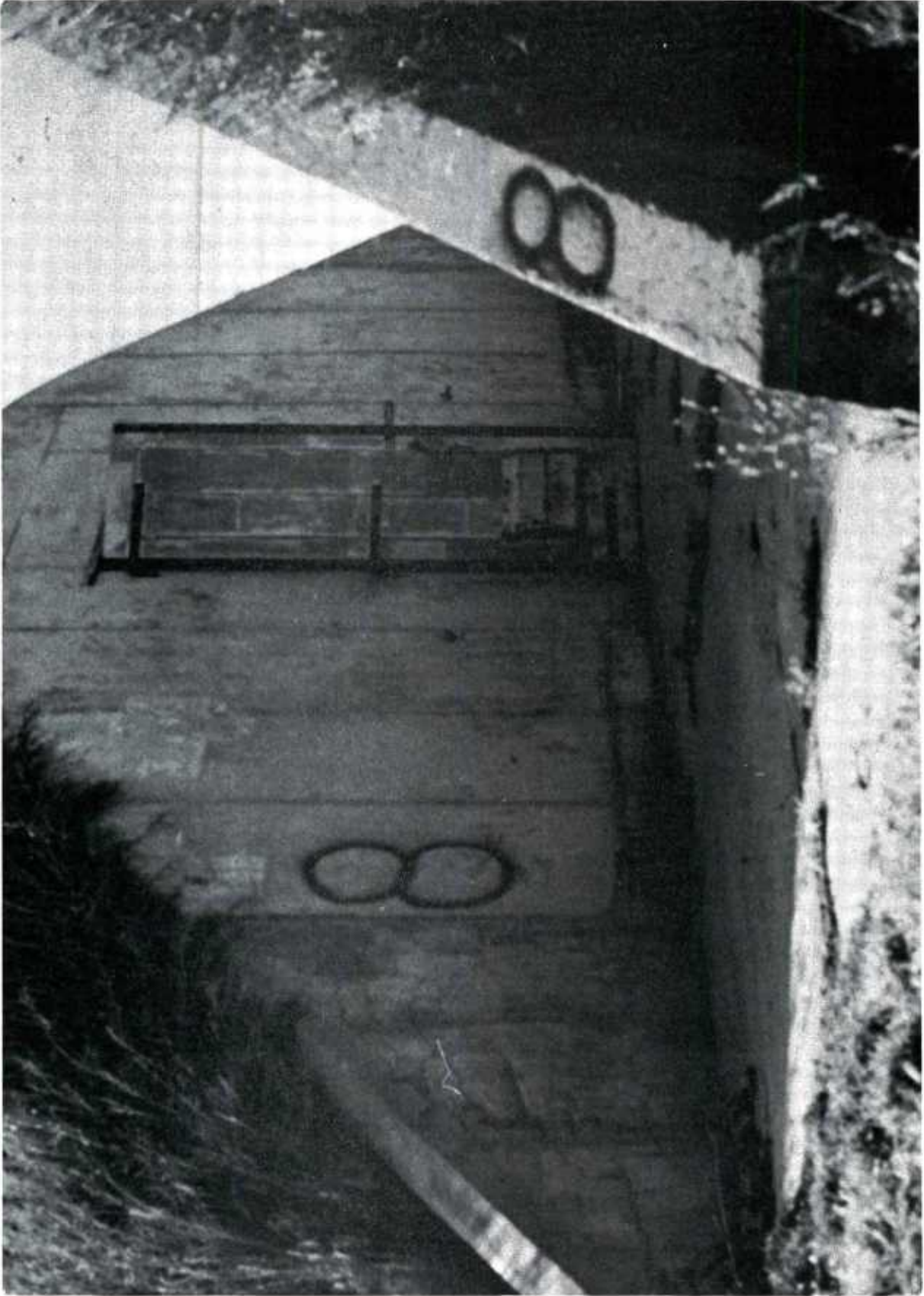


Figure 1. Oblique View of Igloo Magazine with Blast Shield

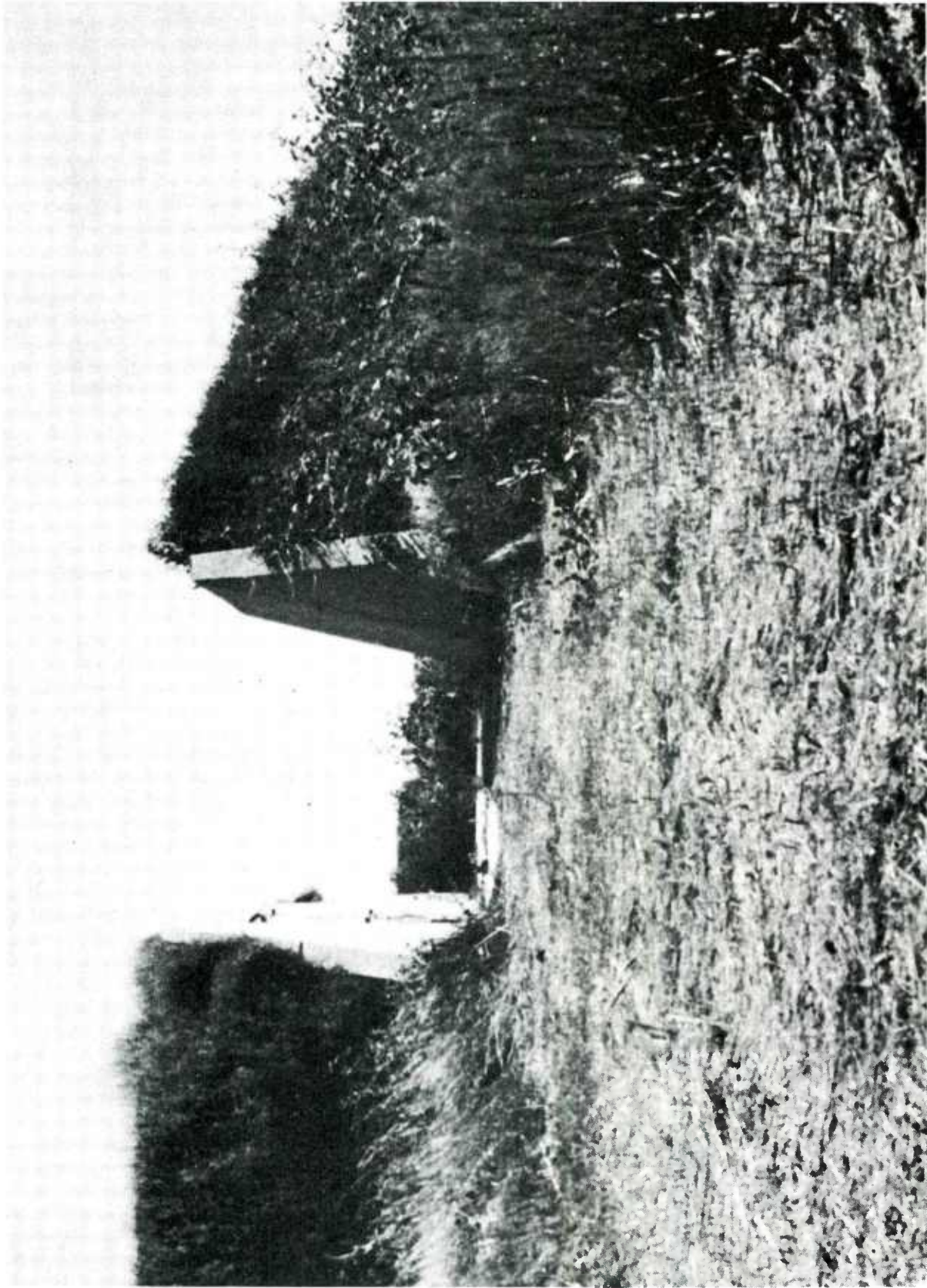


Figure 2. Side View of Igloo Magazine Headwall,
Blast Shield and Access Road

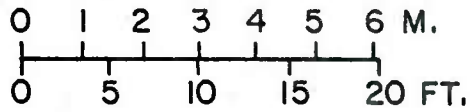
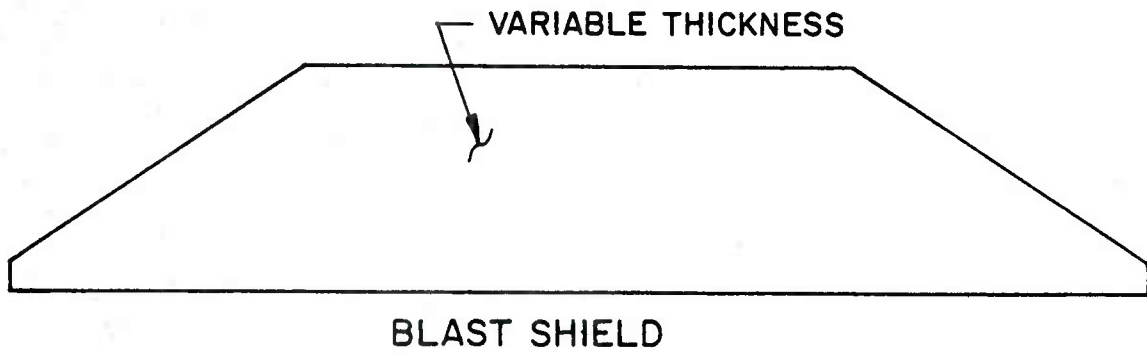
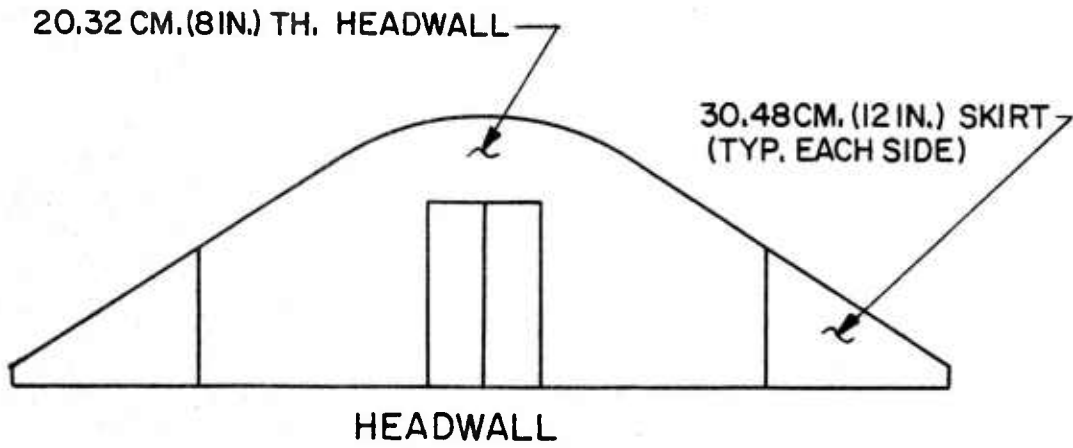


Figure 3. Schematic Drawing of Igloo Magazine and Blast Shield

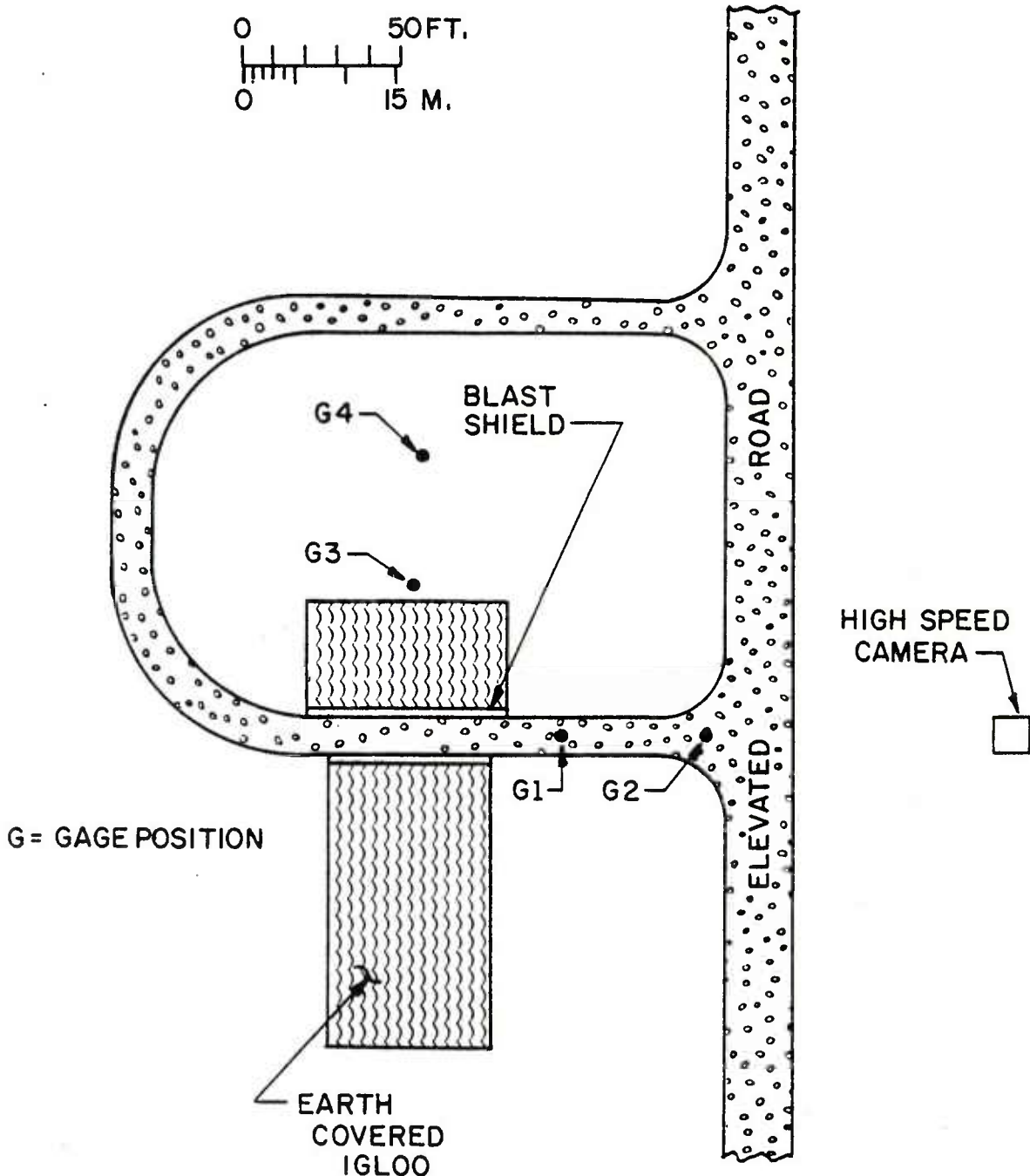


FIGURE 4 . TEST LAYOUT SHOWING LOCATION OF IGLOO, BLAST SHIELD, ROADS AND INSTRUMENTATION

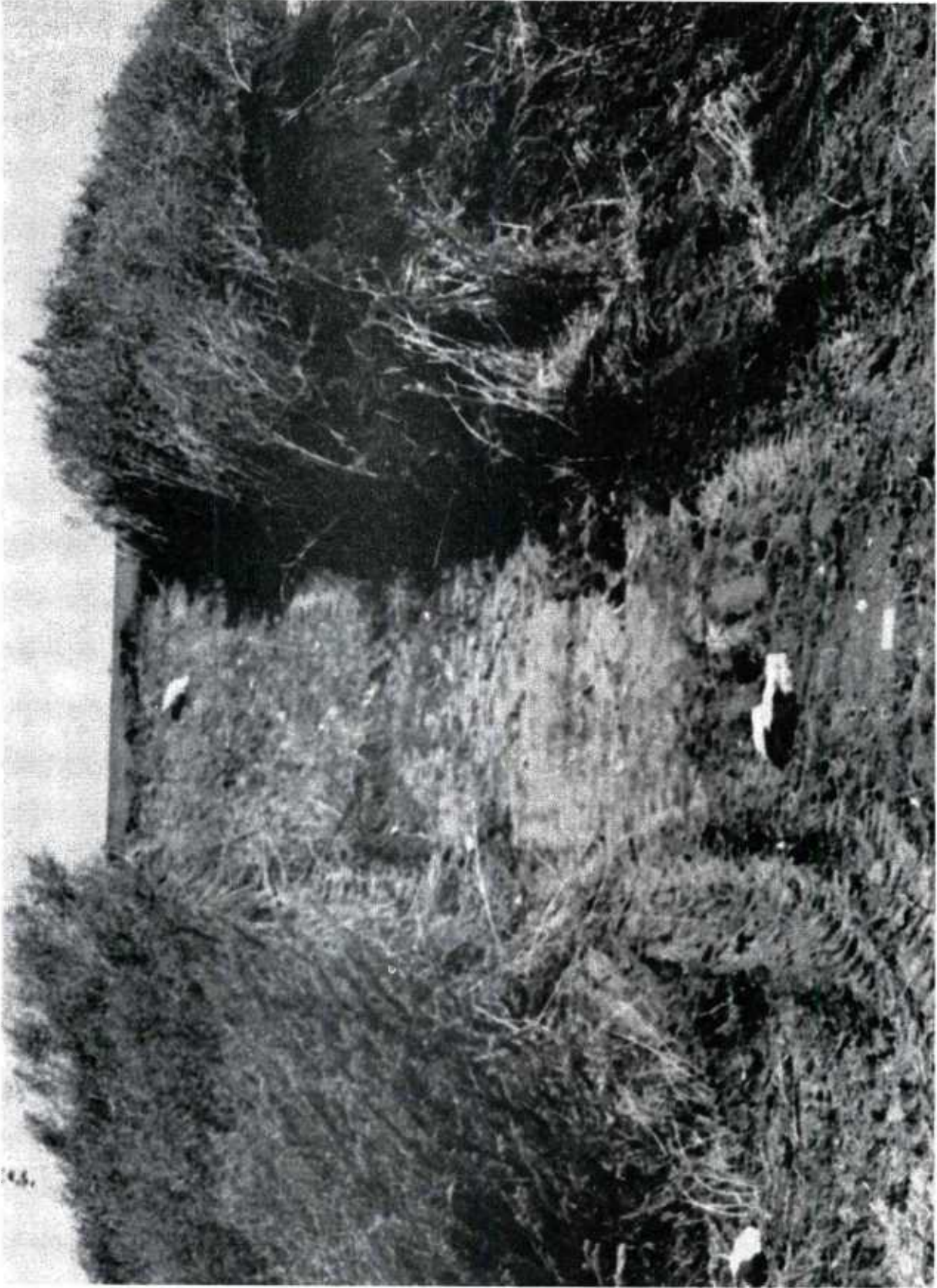


Figure 5. Rear View of Blast Shield Showing Cleared Path for Pressure Transducers

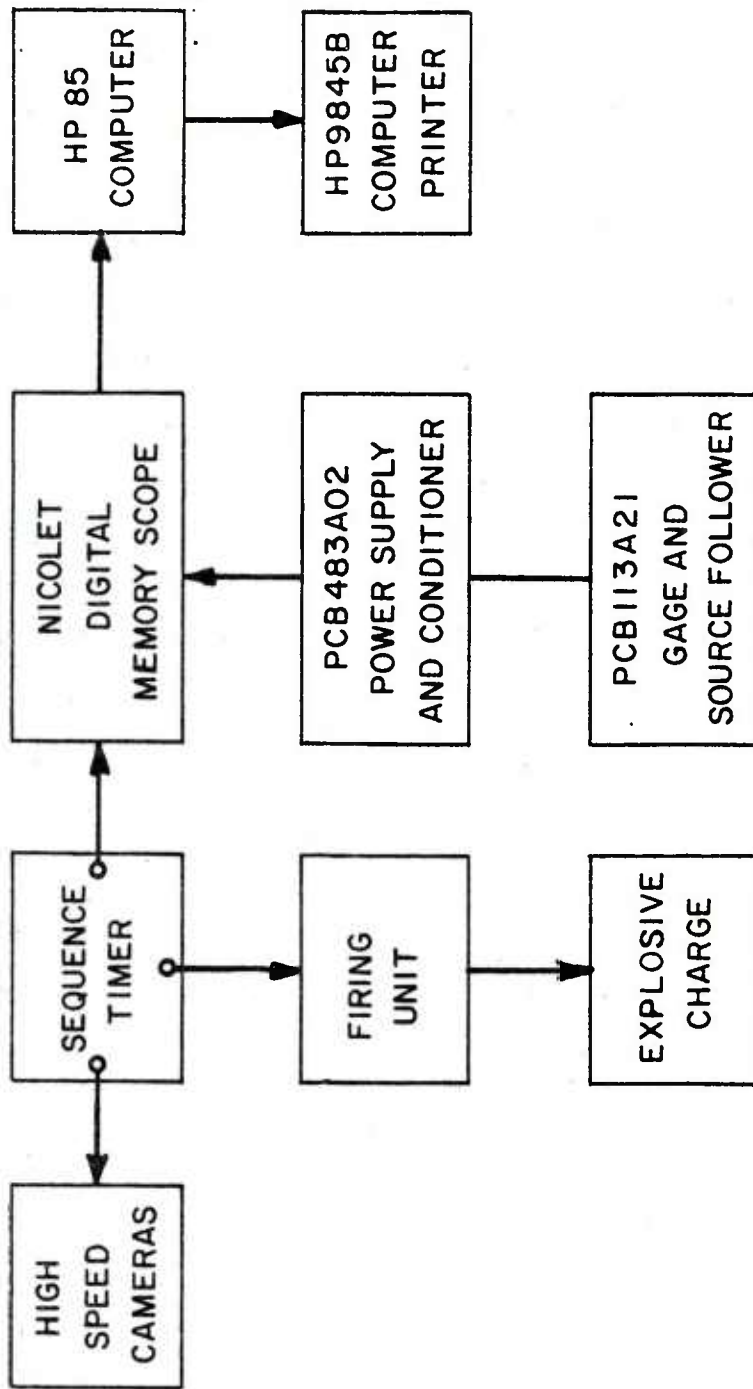


FIGURE 6. INSTRUMENTATION SYSTEM

Table 1. Test Results - Explosive Charges Positioned Inside Earth-Covered Igloo Magazines

| Test No. | Charge Wgt. | Charge Position | Remarks |
|----------|-------------------|------------------------------|---|
| 1 | 18 Kg (40 lb) | 4 m (13 ft) from headwall | Headwall failed. Approximately 50% of the arch crest and 35% of the sidewalls in the front and rear of the igloo destroyed. All debris from arch crest and sidewall recovered on the floor of the igloo. Large center section of the igloo remained standing. Some debris from headwall scattered along entrance roadway after bouncing off blast shield. One large piece (5.4 Kg) of concrete from headwall cleared blast shield and recovered 40 metres in front of the headwall. Parts of terra cotta vent stack scattered up to 10 metres from the rear of the magazine. The wood core and metal sheathed doors were destroyed and recovered between headwall and blast shield. See Figure 7. |
| 2 | 11 Kg (24 lb) | 4 m (13 ft) from headwall | Headwall failed. Arch crest cracked and displaced. Forward section of left sidewall failed. See Figure 8. A total of nine concrete fragments weighed in excess of 4 Kg. The remainder of the fragments weighed between 0.5 Kg and 2.0 Kg. A large piece of the door (9Kg) recovered 30 metres to the right and 7 metres behind the headwall. |
| 3 | 5.4 Kg (12 lb) | 4 m (13 ft) from headwall | There was a large crack in the face of the headwall. The headwall was still in one piece and standing in place. See Figure 9. The right side door recovered 15 metres from the center of the headwall on the right side. The left side door recovered 30 metres from the center of the headwall on the left side. |

Table 1. Test Results - Explosive Charges Positioned Inside Earth-Covered Igloo Magazines (Continued)

| Test No. | Charge Wgt. | Charge Position | Remarks |
|----------|----------------|----------------------------|--|
| 4 | 5.4 Kg (12 lb) | 4 m (13 ft) from headwall | The headwall separated from the sidewall and exhibited several large cracks. The headwall was still standing and held together by rebar. See Figure 10. The right door recovered 24 metres from the center of the headwall. The left door recovered 49 metres from the center of the headwall on the left side. |
| 5 | 5.4 Kg (12 lb) | 4 m (13 ft) from headwall | The headwall failed and separated into several large pieces, however, the headwall held in place by rebar. See Figure 11. The left door, almost intact, recovered 40 metres from the center of the headwall on the left side. The right door recovered in one piece 56 metres on the right side. |
| 6 | 5.4 Kg (12 lb) | 4 m (13 ft) from rear wall | The headwall failed completely, separated from the sidewall, and fractured into several large pieces. The left door recovered 31 metres to the side and 15 metres to the rear of the headwall. The right door recovered 27 metres to the side and 1.8 metres to the rear of the headwall. See Figure 12. |
| 7 | 7.3 Kg (16 lb) | 4 m (13 ft) from headwall | A 6 metre (20 ft) long section of the right rear sidewall remained standing. The remainder of sidewall and headwall was destroyed. A large piece of the left door recovered 37 metres to the left side of the igloo. A large section of the right door recovered 12 metres to the right side. Four large pieces of concrete, all approximately 9 Kg, recovered on the rear side of the blast shield earth fill. See Figure 13. |

Table 1. Test Results - Explosive Charges Positioned Inside Earth-Covered Igloo Magazines (Continued)

| Test No. | Charge Wgt. | Charge Position | Remarks |
|----------|---------------------|-------------------------------|--|
| 8 | 5.4 Kg (12 lb) | 4 m (13 ft) from rear wall | Headwall failed and fractured into several large pieces. A large crack in arch crest entire length of the igloo. Several large cracks in the sidewall on each side. Further examination was not possible as igloo was in imminent danger of collapsing. Large pieces of right door recovered 30 metres to the side and 18 metres and 24 metres to the rear of the headwall. Large pieces of left door recovered 24 metres and 40 metres to the side and 24 metres to the rear of the headwall. One other piece of left door recovered 61 metres from the headwall on the left side. See Figures 14 and 15. |
| 9 | 45.4 Kg (100 lb) | Center of the igloo | The igloo was completely destroyed. Concrete fragments recovered out to a distance of 149 metres. |
| 10 | 68 Kg (150 lb) | Center of the igloo | The igloo was completely destroyed. Concrete fragments recovered out to a distance of 244 metres. |
| 11 | 36 Kg (80 lb) | Center of the Igloo | The igloo was completely destroyed. Concrete fragments recovered out to a distance of 143 metres. |
| 12 | 27 Kg (60 lb) | Center of the igloo | The igloo was completely destroyed. Concrete fragments recovered out to a distance of 110 metres. |



Figure 7. Test Results - Test No. 1, 18 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Headwall

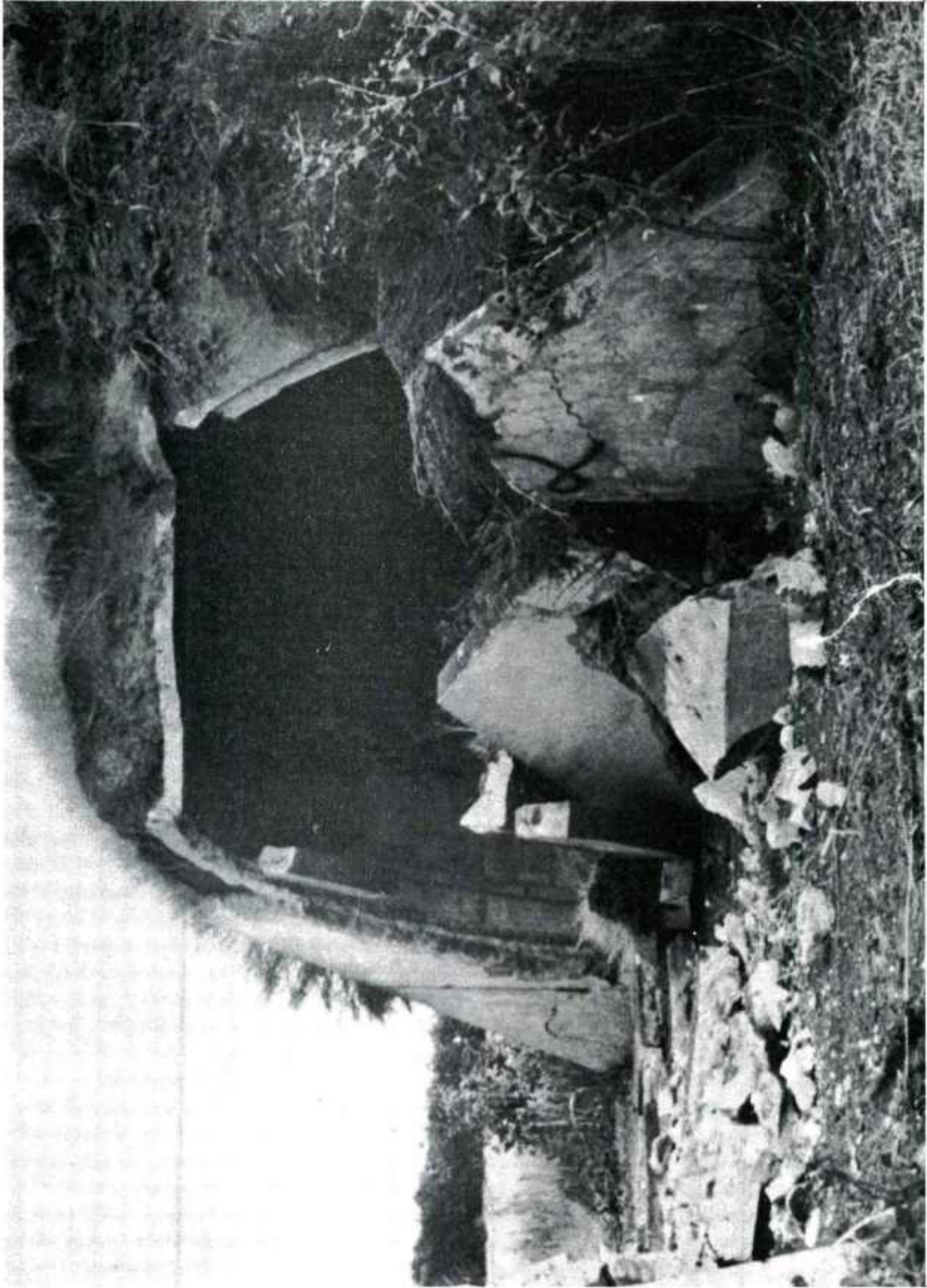


Figure 8. Test Results - Test No. 2, 11 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Headwall



Figure 9. Test Results - Test No. 3, 5.4 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Headwall

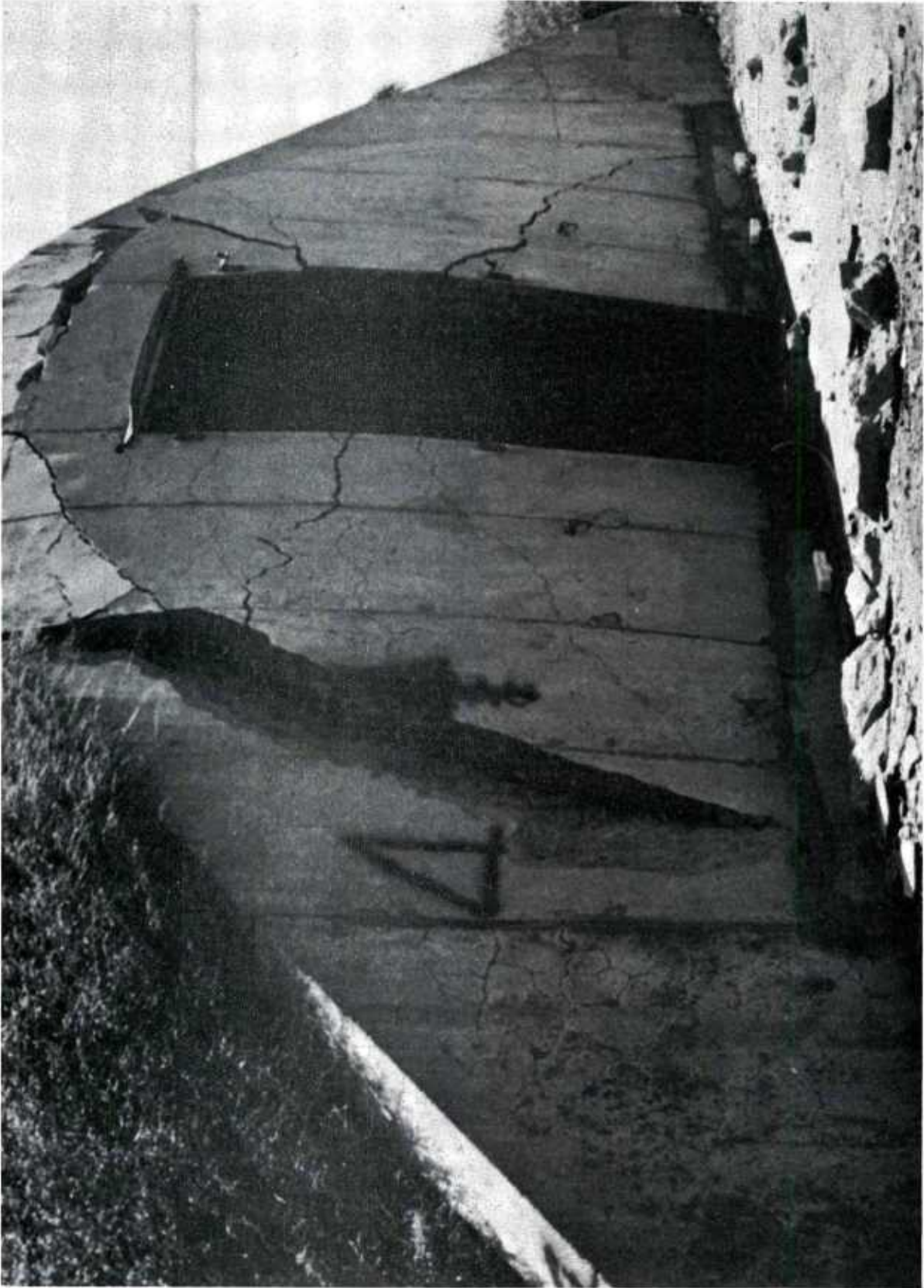


Figure 10. Test Results - Test No. 4, 5.4 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Headwall



Figure 11. Test Results - Test No. 5, 5.4 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Headwall

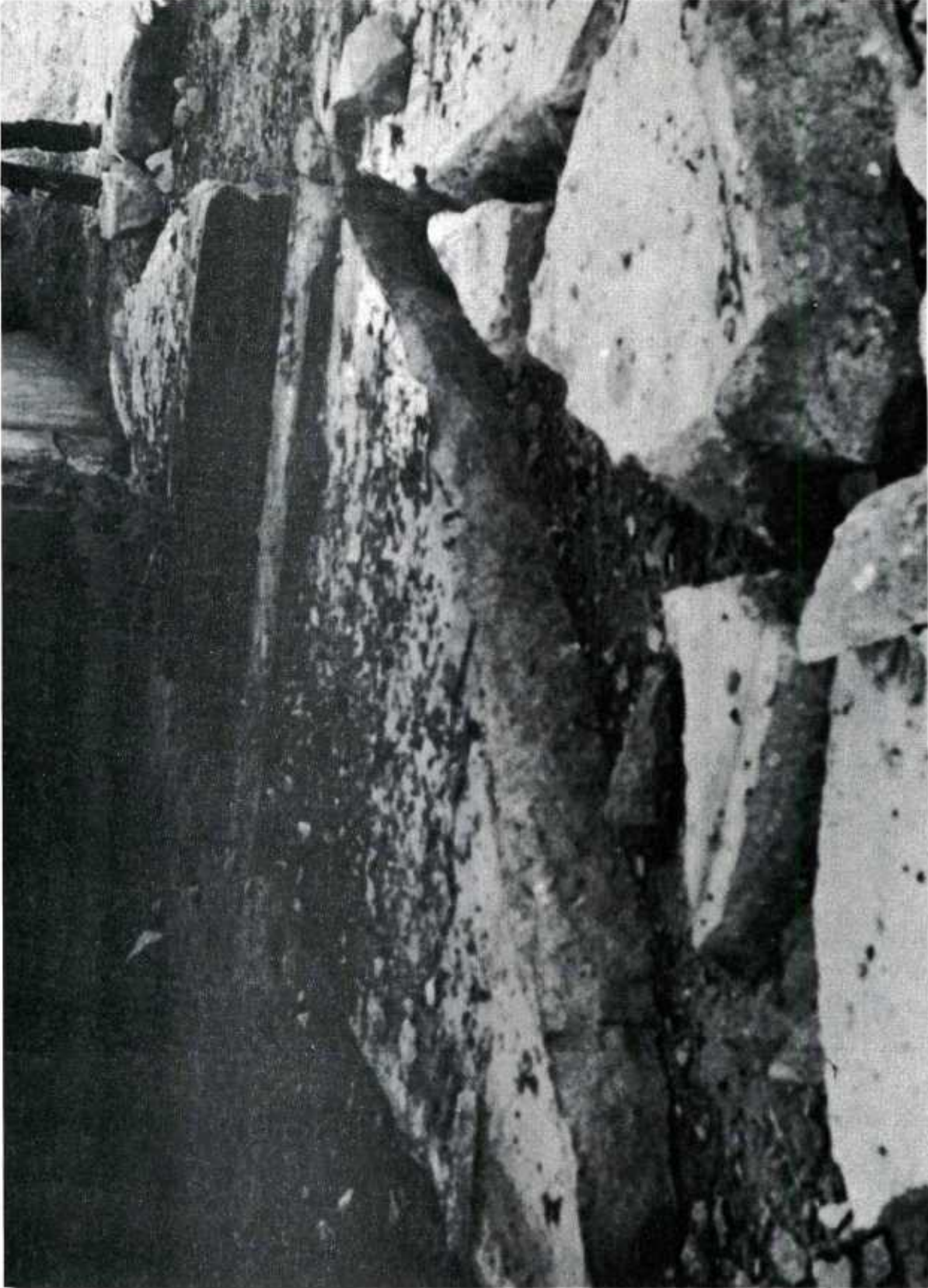


Figure 12. Test Results - Test No. 6, 5.4 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Headwall

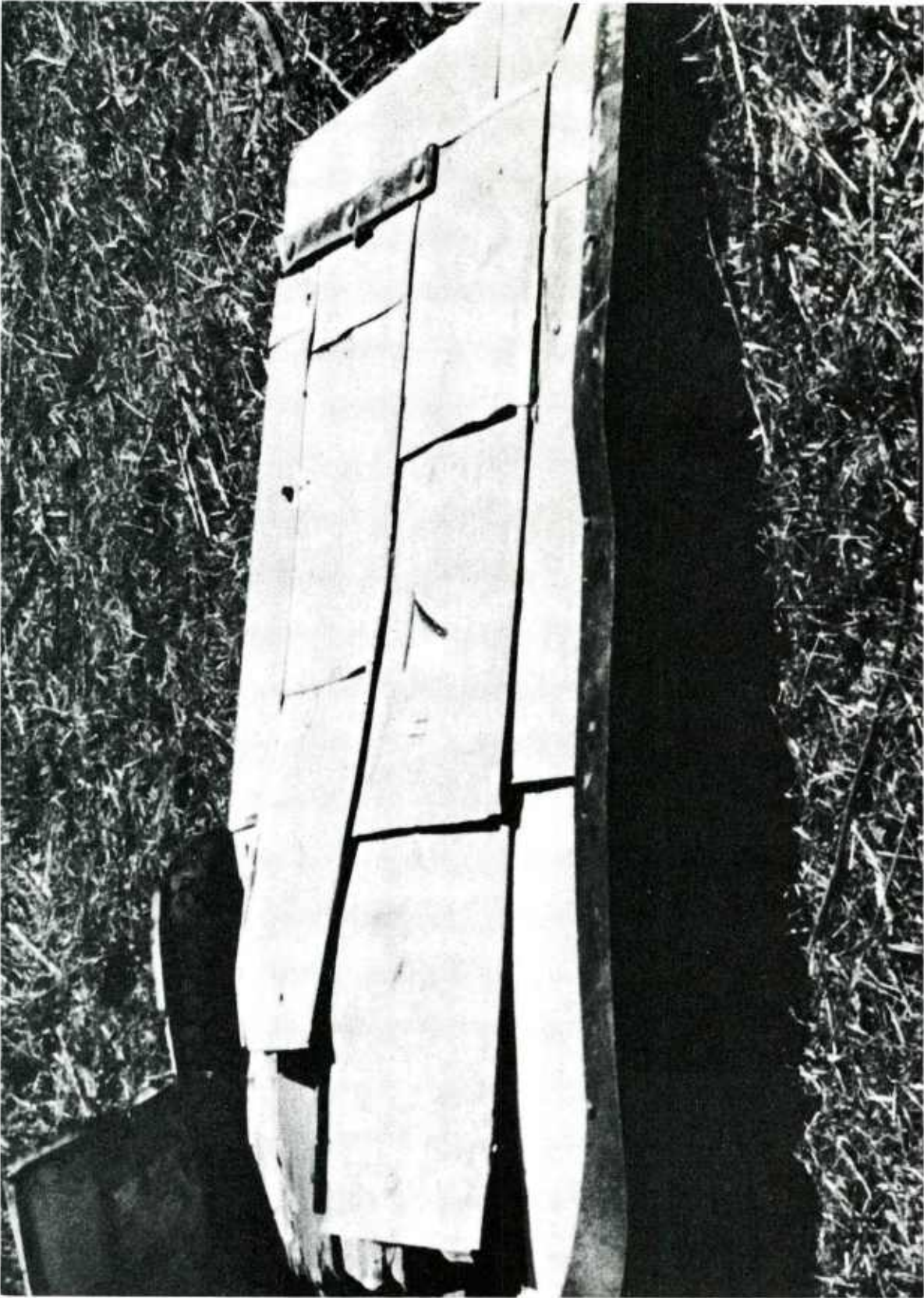


Figure 13. Test Results - Test No. 7, 7.3 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Headwall



Figure 14. Test Results - Test No. 8, 5.4 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Rearwall

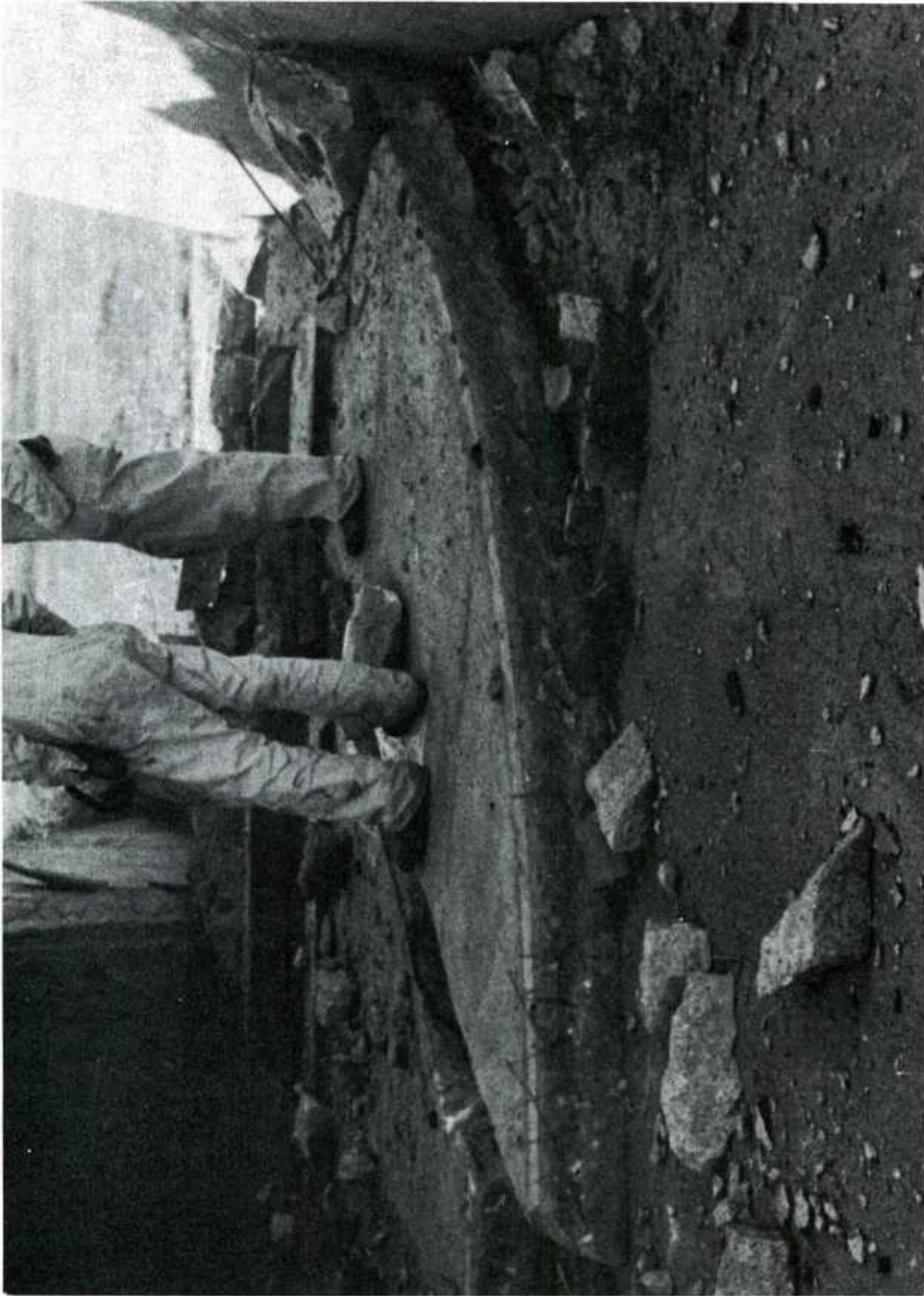


Figure 15. Test Results - Test No. 8, 5.4 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Rearwall

While the results of Tests 3, 4, and 5 (5.4 Kg charge positioned 4 metres from the headwall) are observably different, the differences in terms of structural response are not significant and could be explained in terms of variations in the structural integrity of these 40-year old magazines.

The complete headwall failures observed in Tests 6 and 8, where the 5.4 Kg charge was positioned 4 metres from the rearwall, were different in terms of structural response from the results of Tests 3, 4, and 5. However, these differences had little or no effect in defining hazardous distances. When the headwalls failed in Tests 6 and 8, they fractured into large pieces that were recovered in front of the blast shield. (See Figures 12 and 15.) The real hazards in the 5.4 Kg test series were the doors that were thrown clear of the area between the headwall and the blast shield after bouncing off the blast shield.

The inconsistency observed between the results of Tests 1, 2, and 7, where a 7.3 Kg charge produced more severe structural damage than either an 11 Kg or 18 Kg charge, can only be explained in terms of unobservable differences in the condition of the magazines before testing.

As expected, charge weights in excess of 27 Kg completely destroyed the magazines.

B. External Airblast Measurements

Peak overpressure, impulse, and time-of-arrival measurements are presented in tabular form in Table 2. The individual pressure-time history records are presented in Appendix A. Instrumentation was not available for Tests 1, 9, and 10. Data for Test 3 was lost due to equipment malfunction.

There were no hazardous overpressures measured in any of these tests. While some of the pressure-time history records were difficult to read due to low pressure levels and non-classical shapes, they are mutually supporting.

It is of interest to note that the pressure-time histories recorded for explosive charge weights up to 10.9 Kg were apparently reflected shock pressure-time histories; i.e., the incident shock removed the doors allowing the shock wave that was reflected off the rear wall to escape unimpeded. The presence of the reflected shock wave was verified photographically and explains the apparent anomaly in the time-of-arrival measurements recorded in those tests where the 5.4 Kg charge was positioned near the rear wall. No reflected shock wave was observed in the 45.4 Kg and 68 Kg charge weight tests where the entire igloo was destroyed rapidly, allowing pressure to vent upward. The pressure-time histories recorded for these tests were from the incident wave.

C. Hazardous Fragment Distributions

The results of the fragment collection effort for those tests with charge weights between 27 and 68 Kg, positioned in the center of the magazines, are presented in Table 3 in terms of hazardous fragment densities per 600 ft.²

Table 2. Peak Overpressure, Impulse and Time of Arrival from TNT Charges Statically Detonated Inside Igloo Magazines

| Weight Kg | TNT Charge Position ^a | | Gage Position ^b | | Pressure | | Impulse | | TOA msec |
|--------------|-------------------------------------|----|-------------------------------|-------|----------|------|----------|----------|-------------|
| | m | ft | m | ft | psi | kPA | psi-msec | kPA-msec | |
| 10.9 | 24 | 4 | 13 | 24.3F | 80 | 0.5 | 3.4 | Lost | 161 |
| | | | | 27.4F | 90 | 0.4 | 2.8 | Lost | 168 |
| | | | | 18.3S | 60 | 0.76 | 5.2 | 3.75 | 25.9 |
| | | | | 27.4S | 90 | 0.55 | 3.8 | 2.59 | 17.9 |
| 45.4 | 100 | 12 | 40 | 18.3F | 60 | 1.0 | 6.9 | 9.85 | 67.9 |
| | | | | 27.4F | 90 | 0.7 | 4.8 | 7.78 | 53.7 |
| | | | | 15.2S | 50 | 1.2 | 8.3 | 8.55 | 59.0 |
| | | | | 27.4F | 90 | 0.74 | 5.1 | 4.11 | 28.3 |
| 68.0 | 150 | 12 | 40 | 18.3F | 60 | 1.41 | 9.7 | 13.46 | 92.8 |
| | | | | 27.4F | 90 | 1.23 | 8.5 | 9.94 | 68.6 |
| | | | | 15.2S | 50 | 1.53 | 10.6 | 8.83 | 60.9 |
| | | | | 27.4F | 90 | 1.07 | 7.4 | 7.21 | 49.7 |

a. Distance measured from the headwall to where the TNT charge was positioned inside the igloo.

b. Distance measured from the center of the headwall to where the gage was positioned. F= in front of the headwall. S= to the side of the headwall.

Table 2. Peak Overpressure, Impulse and Time of Arrival from TNT Charges Statically Detonated Inside Igloo Magazines (Continued)

| TNT Charge Weight | Position ^a | | Gage Position ^b | | Pressure | | Impulse | | TOA |
|-------------------|-----------------------|----|----------------------------|----|----------|-----|----------|----------|------|
| | m | ft | m | ft | psi | kPA | psi-msec | kPA-msec | |
| 5.4 12 | 4 | 13 | 18.3F | 60 | 0.4 | 2.8 | 4.69 | 32.2 | Lost |
| 5.4 12 | 4 | 13 | 18.3F | 60 | 0.62 | 4.3 | 4.83 | 33.3 | 147 |
| | | | 27.4F | 90 | 0.46 | 3.2 | 3.27 | 22.6 | 172 |
| | | | 15.2S | 50 | 0.67 | 4.6 | 5.52 | 38.1 | 132 |
| | | | 27.4S | 90 | 0.34 | 2.3 | 3.06 | 21.0 | 168 |
| 5.4 12 | 20.4 | 67 | 18.3F | 60 | 0.16 | 1.1 | 0.53 | 3.7 | 110 |
| | | | 27.4F | 90 | 0.25 | 1.7 | 1.73 | | 135 |
| | | | 15.2S | 50 | 0.39 | 2.7 | 1.91 | 13.2 | 97 |
| | | | 27.4S | 90 | 0.23 | 1.6 | 1.10 | 7.6 | 134 |
| 5.4z 12z | 20.4 | 67 | 18.3F | 60 | 0.36 | 2.5 | 2.87 | 19.6 | 114 |
| | | | 27.4F | 90 | 0.33 | 2.3 | 1.05 | 7.2 | 139 |
| | | | 15.2F | 50 | 0.69 | 4.8 | 2.37 | 16.3 | 100 |
| | | | 27.4S | 90 | 0.27 | 1.9 | 1.05 | 7.2 | 135 |
| 7.3 16 | 4 | 13 | 18.3F | 60 | 0.49 | 3.4 | 4.03 | 27.8 | 138 |
| | | | 27.4F | 90 | 0.34 | 2.3 | 2.50 | 17.2 | 163 |
| | | | 15.2S | 50 | 0.51 | 3.5 | 3.24 | 22.3 | 138 |
| | | | 27.4S | 90 | 0.35 | 2.4 | 2.36 | 16.3 | 166 |

a. Distance measured from the headwall to where the TNT charge was positioned inside the igloo.

b. Distance measured from the center of the headwall to where the gage was positioned. F= in front of the headwall. S= to the side of the headwall.

for the discrete angular and distance increments.* These distributions were generated by averaging all the fragment data for a given test when fragment data from both the right and left side recovery areas was available. When fragment data from only one side was available, symmetry was assumed. These distributions do not reflect the uneven distribution observed in some of these tests where the number of fragments recovered on the left side of the recovery area was greater than that recovered on the right. These skewed distributions are assumed to be an anomaly.

Exponential density functions for these tests were generated using the density distributions in Table 3 to compare predicted and observed densities, per 600 ft.², independent of angle; i.e., the highest density value for a given distance increment was used in the calculation. See Figures 16 through 19. Fragment density distributions at distances less than 53 metres were not used due to the masking effect of the blast shield.

The raw field recovery data is provided in Appendix B for each fragment in terms of its position and weight group. Only those fragments weighing at least 0.18 Kg (0.4 lb) were considered hazardous. While all of the fragments, weighing in excess of 0.18 Kg, for a given test were combined in arriving at hazardous density distributions, their segregation into weight groups, in Appendix B, has been preserved for future reference.

Attempts to measure initial headwall fragment velocities photographically were unsuccessful. The field of view between the headwalls and blast shields was obscured by combustion products and other debris before the headwalls failed and before the doors hit the blast shields. However, estimates of initial door velocities and the times of arrival of the reflected shock waves, between the headwalls and blast shields, were taken from the high speed films and are provided in Table 4. The door velocity estimates are crude. The exact time that the doors hit the blast shield can only be estimated, and it is not known if the doors were accelerating when they impacted the blast shield.

There is good agreement between the time-of-arrival measurements of the reflected shock wave obtained photographically and those obtained from the pressure transducers.

IV. DISCUSSION

The maximum explosive quantity which, when detonated inside the standard-size, earth-covered magazines used in this series of tests, produces no significant external effect was not determined due to door separation. These large wood core doors were attached to the headwalls by three hinges that failed rapidly under all test conditions. The doors were observed impacting the blast shields and were recovered in areas off the side of the magazines. It is

*The origin of the coordinate system used in generating these distributions was the front of the igloo.

Table 3. Test Results - Hazardous Fragment Densities per 600 ft² for Discrete Angular and Distance Increments

| Distance M | 27 Kg (60 lb) Test | | 36 Kg (80 lb) Test | | 45 Kg (100 lb) Test | | 68 Kg (150) Test | |
|---------------|--------------------|-------|--------------------|-------|---------------------|-------|------------------|-------|
| | 0-5° | 5-10° | 0-5° | 5-10° | 0-5° | 5-10° | 0-5° | 5-10° |
| 31 | 6.3 | 4.7 | 9.0 | 0 | 0 | 0 | 3.1 | 2.4 |
| 38 | 24.3 | 21.9 | 26.8 | 0 | 0.6 | 0 | 0 | 3.0 |
| 46 | 19.9 | 10.0 | 7.1 | 10.0 | 10.5 | 23.8 | 21.9 | 12.5 |
| 53 | 40.4 | 25.0 | 23.2 | 28.6 | 16.8 | 16.8 | 10.2 | 5.9 |
| 61 | 19.4 | 12.7 | 6.3 | 20.4 | 13.2 | 3.0 | 19.1 | 12.5 |
| 69 | 18.0 | 9.7 | 4.7 | 15.5 | 10.7 | 0 | 3.9 | 3.8 |
| 76 | 20.7 | 13.3 | 3.1 | 18.4 | 10.9 | 20.8 | 1.2 | 1.2 |
| 84 | 10.4 | 6.3 | 1.8 | 4.1 | 3.1 | 2.0 | 7.2 | 6.2 |
| 91 | 2.0 | 1.5 | 0.3 | 11.4 | 6.6 | 3.8 | 5.8 | 4.8 |
| 99 | 1.8 | 2.2 | 1.1 | 0.9 | 1.3 | 3.6 | 4.5 | 2.9 |
| 107 | 1.6 | 0.8 | 0.6 | 2.4 | 1.6 | 0 | 4.8 | 4.6 |
| 114 | 1.5 | 0.8 | 0.2 | 3.0 | 1.5 | 0 | 9.9 | 5.5 |
| 122 | 0 | 0 | 0.8 | 5.6 | 3.2 | 0 | 4.2 | 3.0 |
| 130 | 1.4 | 0.7 | 0.1 | 0.7 | 0.7 | 0 | 4.7 | 2.7 |
| 137 | | | | 1.3 | 0.8 | 0.3 | 3.2 | 1.8 |
| 145 | | | | 1.2 | 0.6 | 0.2 | 2.4 | 2.0 |
| 152 | | | | 2.8 | 1.7 | 0.7 | 2.3 | 1.7 |
| 160 | | | | 1.1 | 0.5 | 0.1 | 3.2 | 2.0 |
| 168 | | | | | | | 5.0 | 2.6 |
| 175 | | | | | | | 0 | 0.1 |
| 183 | | | | | | | 1.0 | 0.7 |
| 191 | | | | | | | 2.2 | 1.3 |
| 198 | | | | | | | 2.2 | 1.4 |
| 206 | | | | | | | 0.4 | 0.3 |
| 213 | | | | | | | 0.4 | 0.2 |
| 221 | | | | | | | 0 | 0 |

NOTE: Explosive charges were positioned in the center of the magazines. Angular deviations are half angles.

60 LB. CHARGE

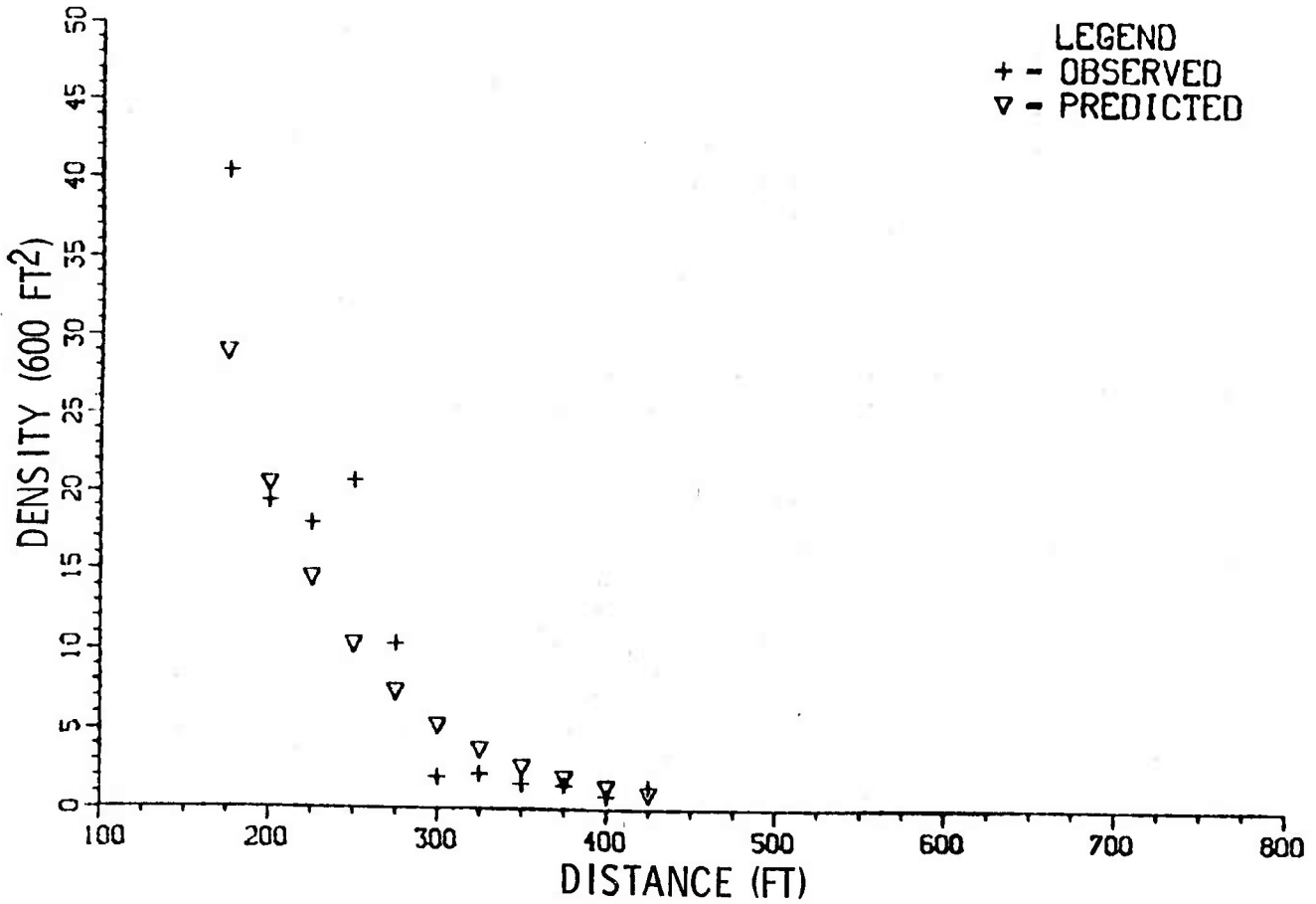


Figure 16. Hazardous Fragment Densities (600 ft²) Versus Distance in Front of an Igloo Magazine-27Kg TNT Charge Positioned in the Center of Igloo Statically Detonated

80 LB. CHARGE

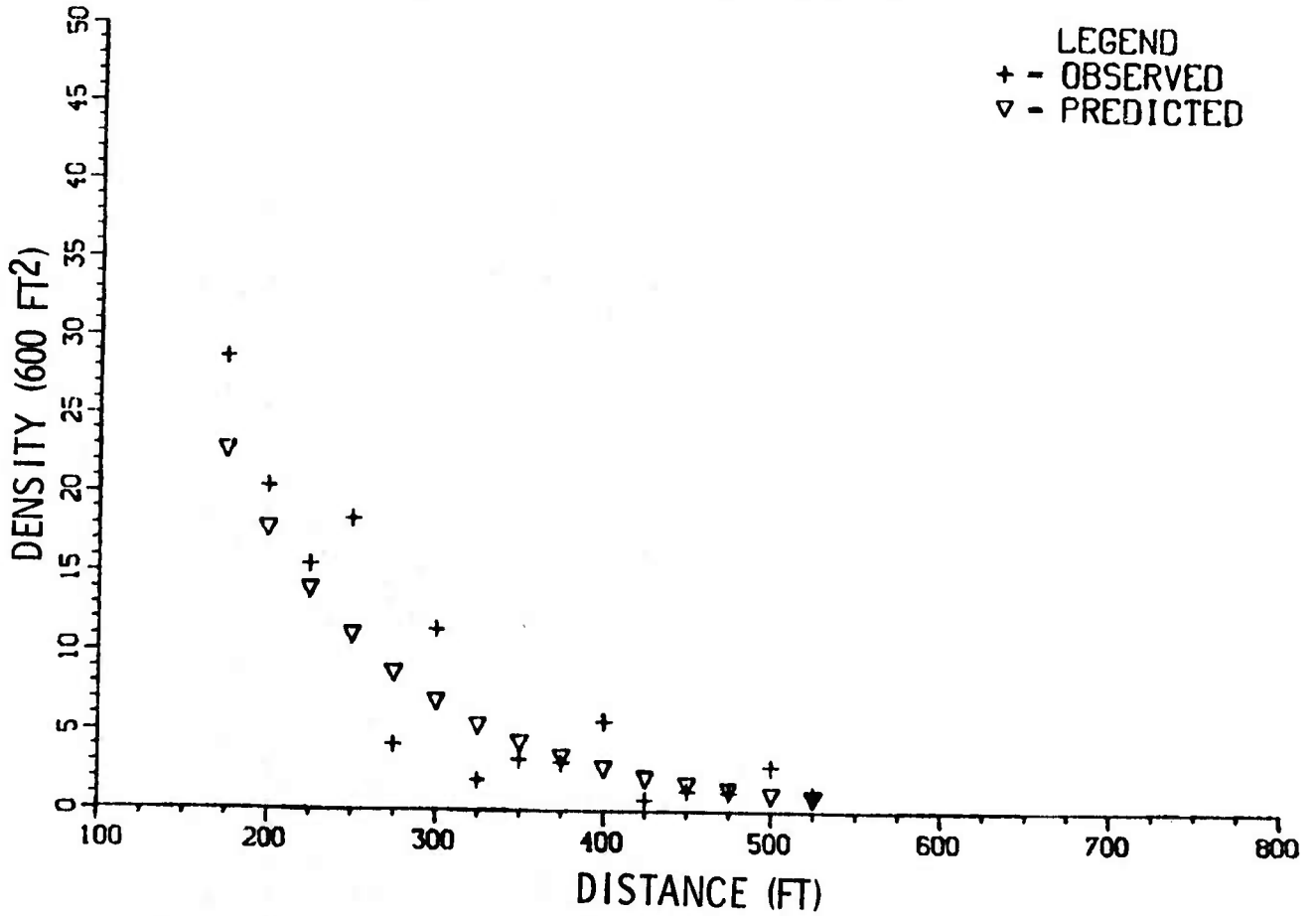


Figure 17. Hazardous Fragment (600 ft²) Versus Distance in Front of an Igloo Magazine-36Kg TNT Charge Positioned in the Center of the Igloo Statically Detonated

100 LB. CHARGE

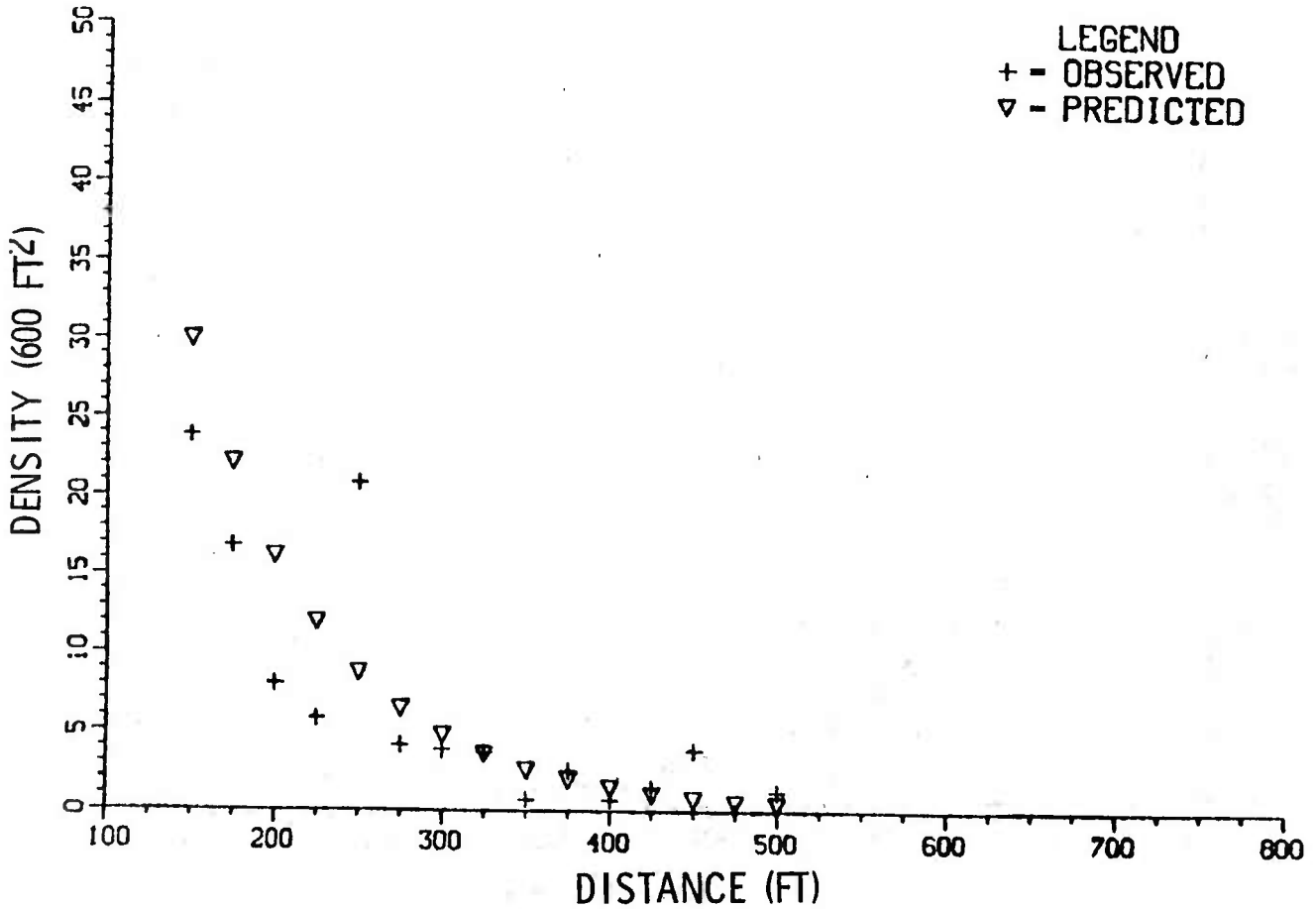


Figure 18. Hazardous Fragment Densities (600 ft²) Versus Distance in Front of an Igloo Magazine-45 Kg TNT Charge Positioned in the Center of Igloo Statically Detonated

150 LB. CHARGE

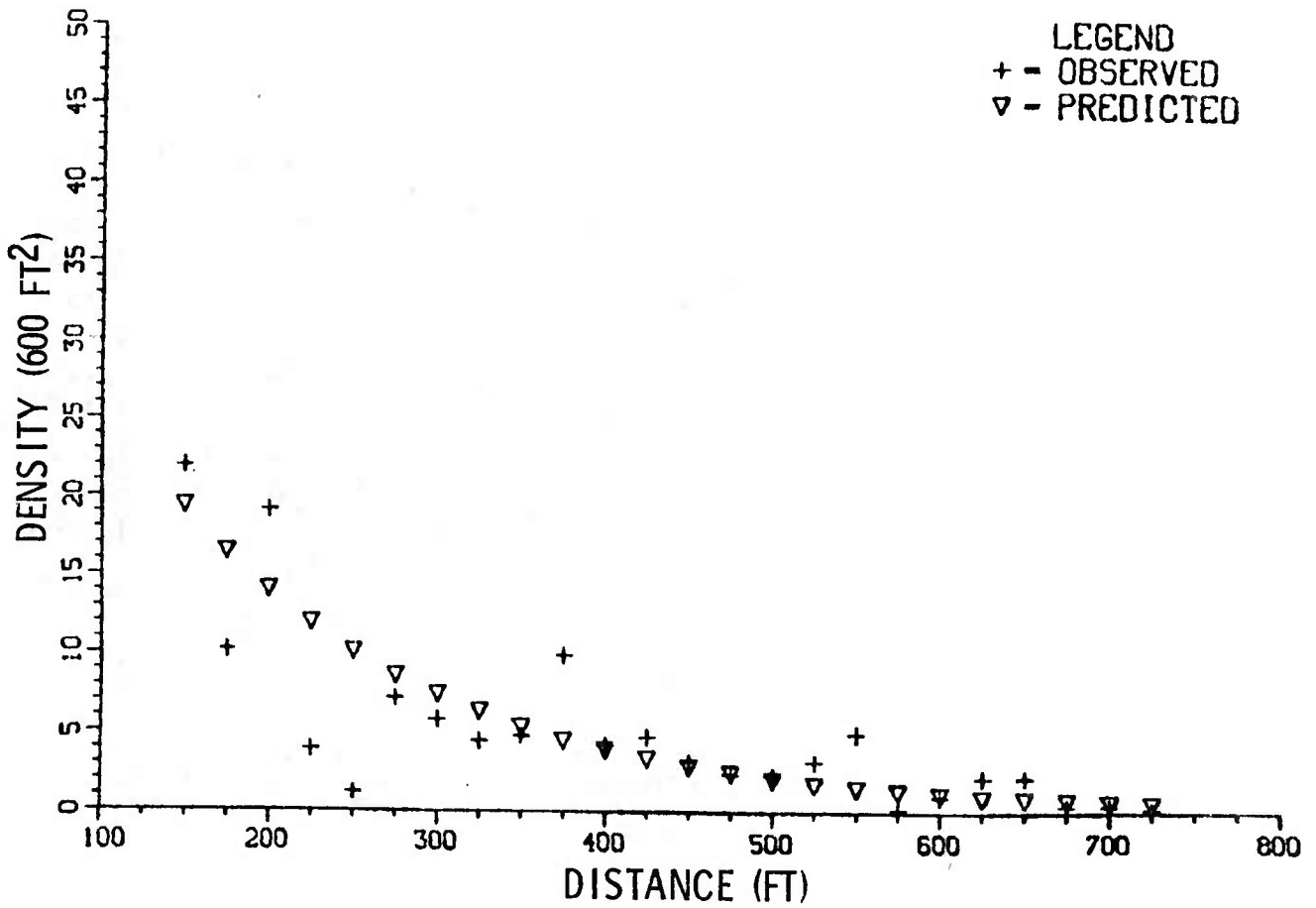


Figure 19. Hazardous Fragment Densities (600 ft²) Versus Distance in Front of an Igloo Magazine-68 Kg TNT Charge Positioned in the Center of Igloo Statically Detonated

Table 4. Estimates of Initial Door Velocities and Times of Arrival of the Reflected Shock Waves

| Charge | Initial Door Velocity (mps) | Times of Arrival (m sec) |
|--|-----------------------------|--------------------------|
| 5.4 Kg - 4 metres from the headwall | 28 | 145 |
| 5.4 Kg - 20.4 metres from the headwall | 41 | 81 |
| 7.3 Kg - 4 metres from the headwall | 29 | 132 |
| 10.9 Kg - 4 metres from the headwall | 50 | 131 |
| 45.4 Kg - 12 metres from the headwall | 91 | Not observed |

assumed that the doors could have traveled up to 150 metres in front of the magazines, at explosive charge weights of only 5.4 Kg, if the blast shields were not in place. The hazards associated with door separation, at low explosive charge weights, could be eliminated by employing fully vented doors, e.g., stretch chain link fencing fabric over metal door frames.

Variations in the structural response of the magazines, at HE charge weights up to 18 Kg, were not significant in terms of establishing hazardous fragment* distances, i.e., the maximum distance at which the hazardous fragment density is at least one per 600 ft². The sidewalls and arch crest of the magazine either remained standing or fell to the floor, at these low charge weights. The sidewalls were blown out and recovered in large pieces off the sides of the magazines. The headwalls tended to break up into smaller pieces as the charge weight increased with more and more of them being projected over the blast shield and to the sides of the magazines. An apparent reversal in this trend can be found in Table 3, where the hazardous fragment densities for the 36 Kg test were greater than those for the 45 Kg test. However, an examination of the individual fragment recovery data for these two tests show that more fragments were recovered outside the 45 degree recovery zone in the 45 Kg test than in the 36 Kg test.

The maximum distance at which the hazardous fragment density exceeded one per 600 ft², in these tests, was greater than that observed in the Navajo tests at identical explosive charge weights (68 Kg). These differences are assumed to be real and the result of a different door and headwall design. The presence of the blast shield did not affect maximum hazardous fragment distances. Those fragments that travelled the farthest came from the top of the headwall and were projected over the top of the blast shield. However, the blast shield did stop many fragments; and had it not been in place the density close in would have been much greater. Fragment hazards to the front of the magazines could have been eliminated in this series of tests if the blast shields had been higher. Unfortunately, employing higher blast shields to control fragment hazards in front of the magazines, at small HE charge weights, would increase hazardous fragment densities to the sides of the magazines.

If the headwalls and doors were replaced with chain link fencing fabric, full venting would occur; and fragments would not be produced by these currently used structures. In this case, thousands of pounds of explosives would be required to produce overpressures to the front or fragment hazards to the sides and rear of the magazine, which are unacceptable. Primary fragments from any ordnance items stored in the magazines could be controlled via sandbag barrier walls.

The non-hazardous overpressures measured off the side of the headwall in this series of tests, with an HE charge weight of 68 Kg, were slightly higher than those observed in the Navajo tests (8.5kPa at 27.4 metres versus 3.4kPa at 24.4 metres) at the same charge weight. The increase can be attributed to the presence of the blast shield in the Hastings test, the relatively heavy

*Any fragment weighing at least 0.18 Kg (0.4 lb) is assumed to be hazardous.

steel doors on the Navajo magazines, and variations in the design of the headwalls.

V. CONCLUSIONS AND RECOMMENDATIONS

The maximum distance requirement between inhabited buildings and standard-size, earth-covered igloo magazines containing small explosive charge weights will be determined by door displacement and not by concrete fragments from the headwall. Blast shields will reduce this distance and change the direction of the hazard from the front to the sides, at small charge weights.

Blast shields are effective in controlling concrete fragment hazards from the headwalls at explosive charge weights up to 18 Kg. At higher explosive charge weights, significant numbers of fragments will be projected over the blast shield.

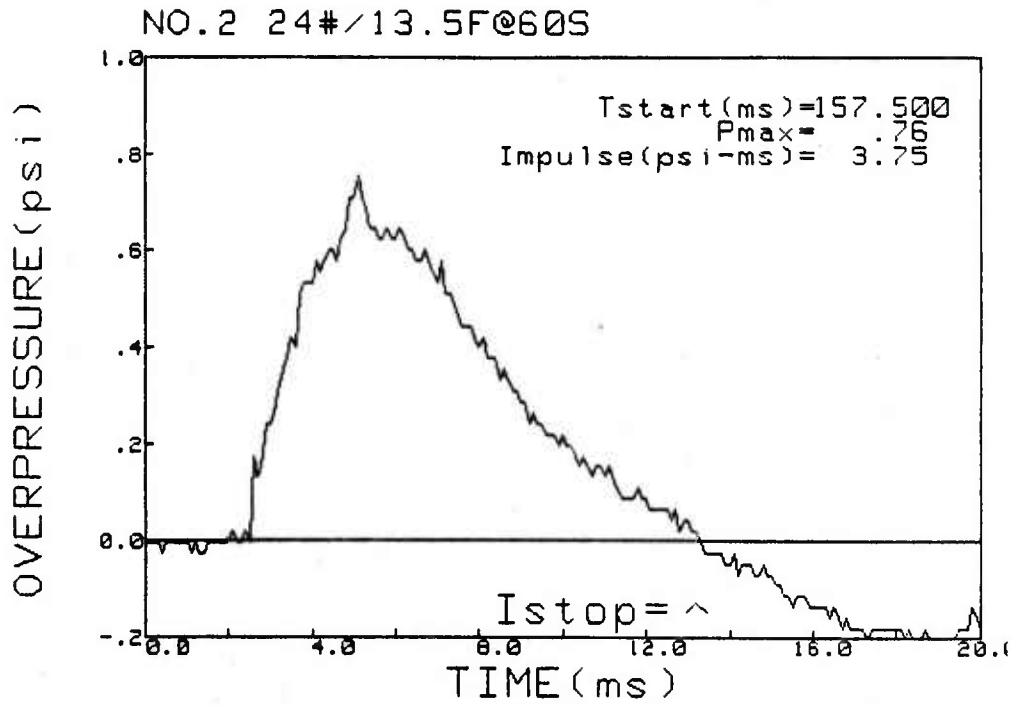
Igloo magazines will suffer severe structural damage when explosive charges as small as 5.4 Kg TNT detonate inside a magazine. Explosive charge weights of 7.3 Kg can completely destroy a magazine.

There are no significant overpressure hazards, outside of a magazine, associated with the detonation of up to 68 Kg TNT inside a magazine.

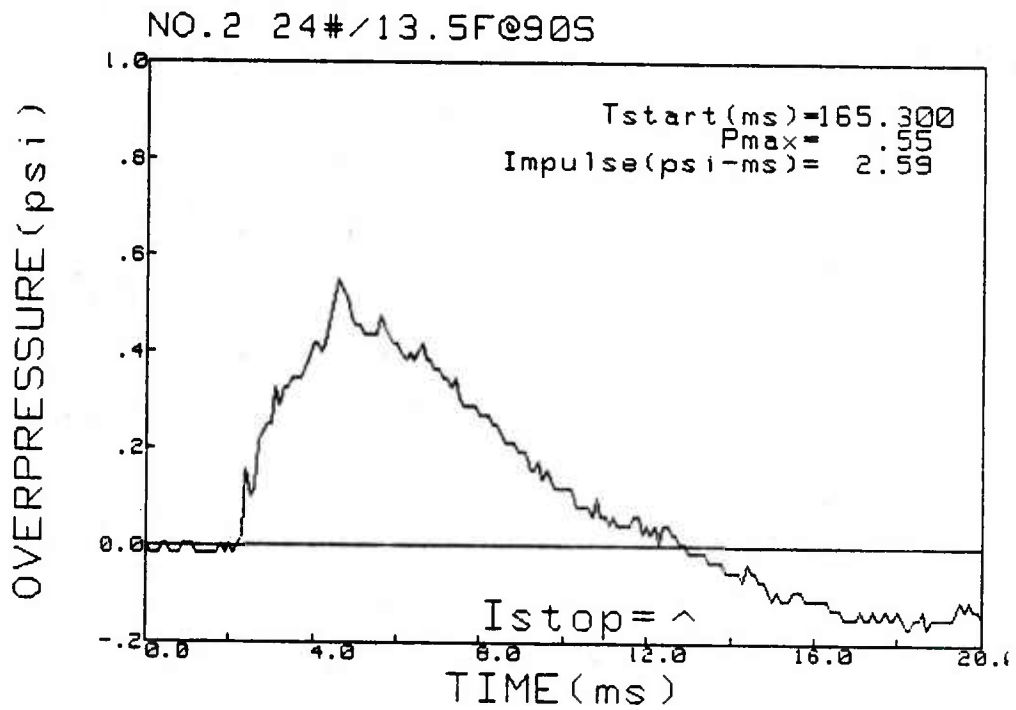
Tests should be conducted to determine overpressure and fragment hazards when explosive charges are detonated inside igloo magazines with fully vented non-fragment producing headwalls and doors.

APPENDIX A

External Pressure Time Histories From
Explosive Charges Positioned Inside
Earth Covered Igloo Magazines

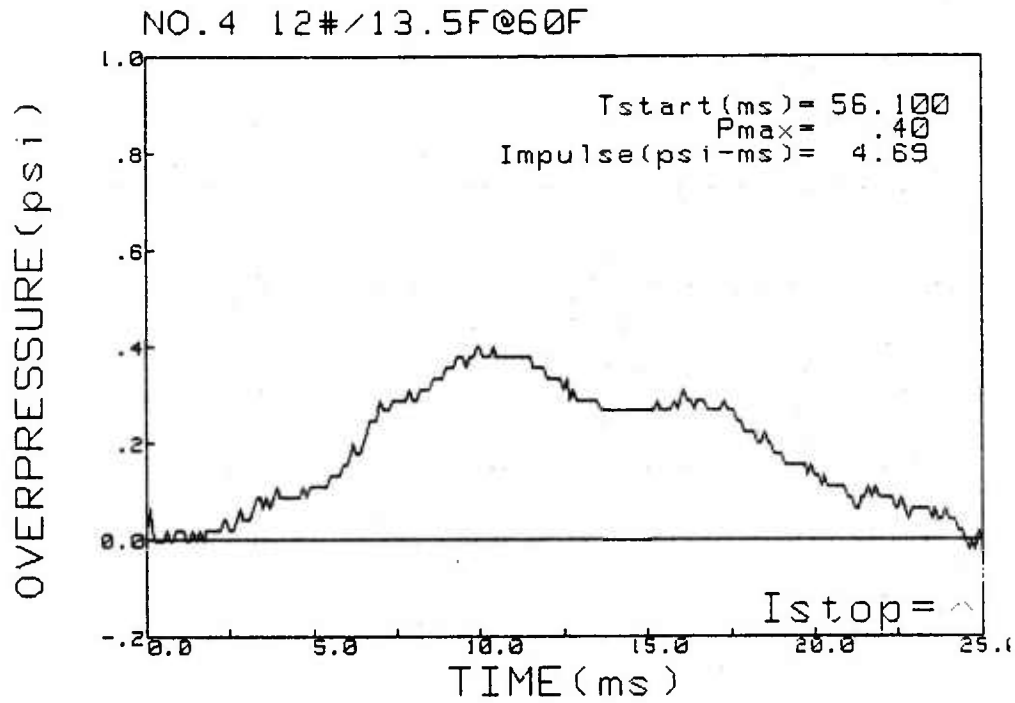


Gage positioned 18.3 m off the side of the headwall



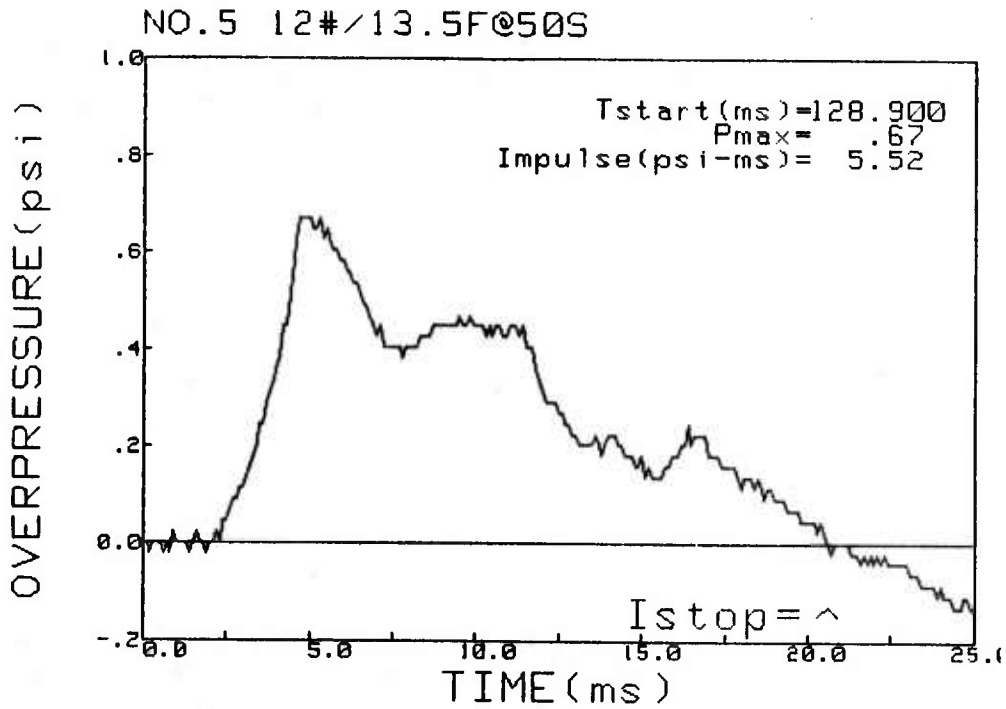
Gage positioned 27.4 m off the side of the headwall

Figure A-1. Pressure Time Histories, Test No. 2, 12.9 Kg TNT Charge Positioned 4 Metres from Headwall

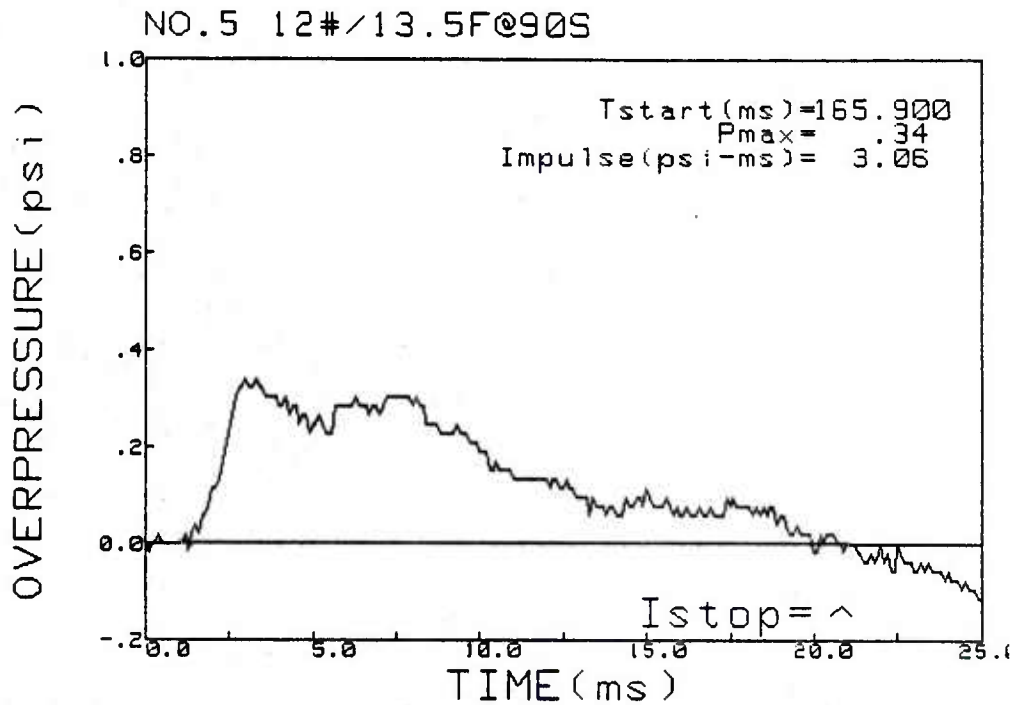


Gage positioned 18.3 m in front of the headwall

Figure A-2. Pressure Time History, Test No. 4, 5.4 Kg TNT Charge Positioned 4 Metres from Headwall



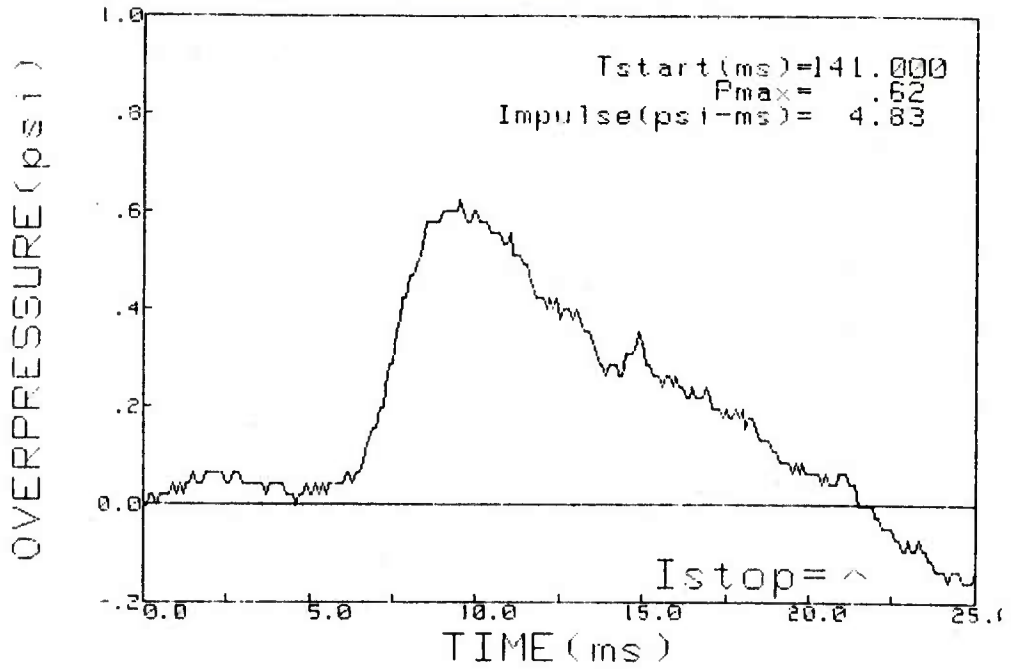
Gage positioned 15.2 m off the side of the headwall



Gage positioned 27.4 m off the side of the headwall

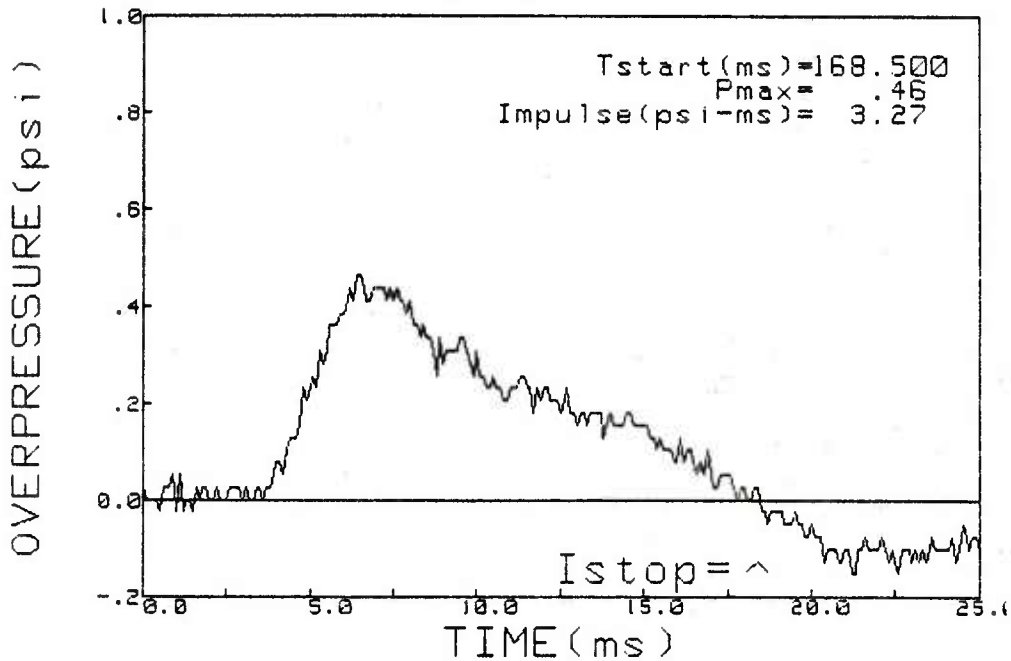
Figure A-3. Pressure Time Histories, Test No. 5, 5.4 Kg TNT Charge Positioned 4 Metres from Headwall

NO.5 12#/13.5F@60F



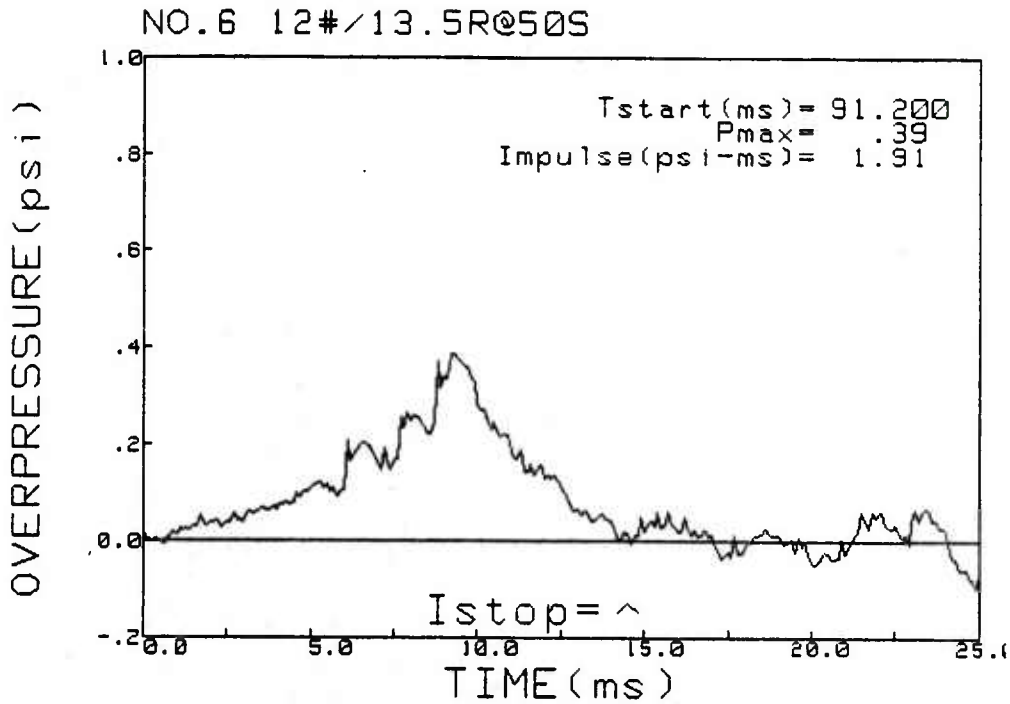
Gage positioned 18.3 m in front of the headwall

NO.5 12#/13.5F@90F

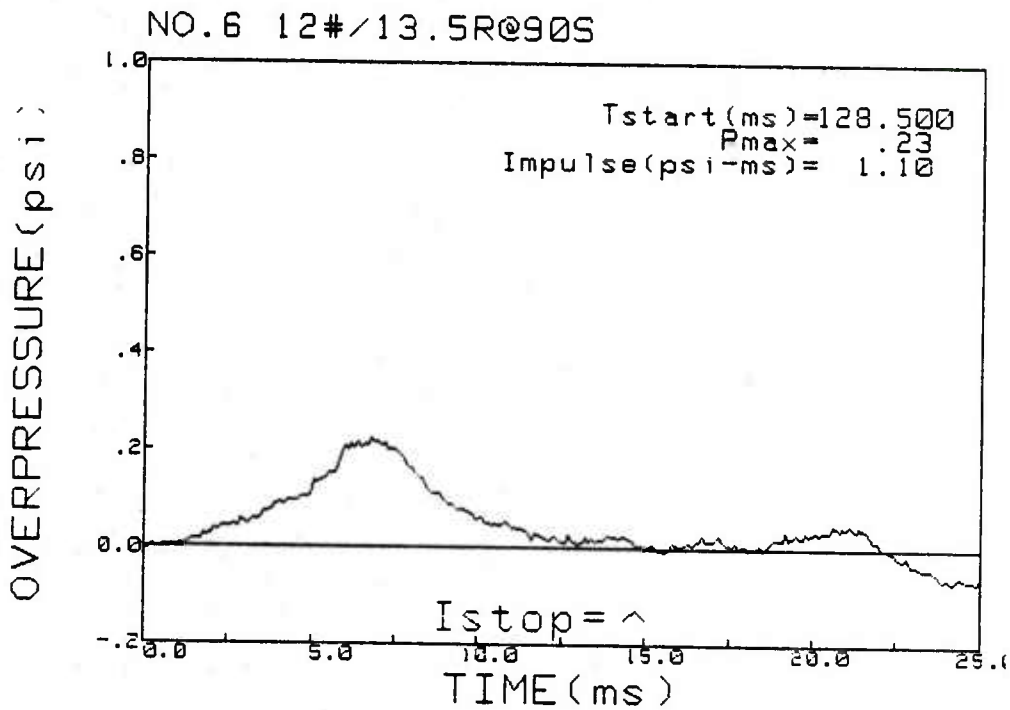


Gage positioned 27.4 m in front of the headwall

Figure A-4. Pressure Time Histories, Test No. 5, 5.4 Kg TNT Charge Positioned 4 Metres from Headwall

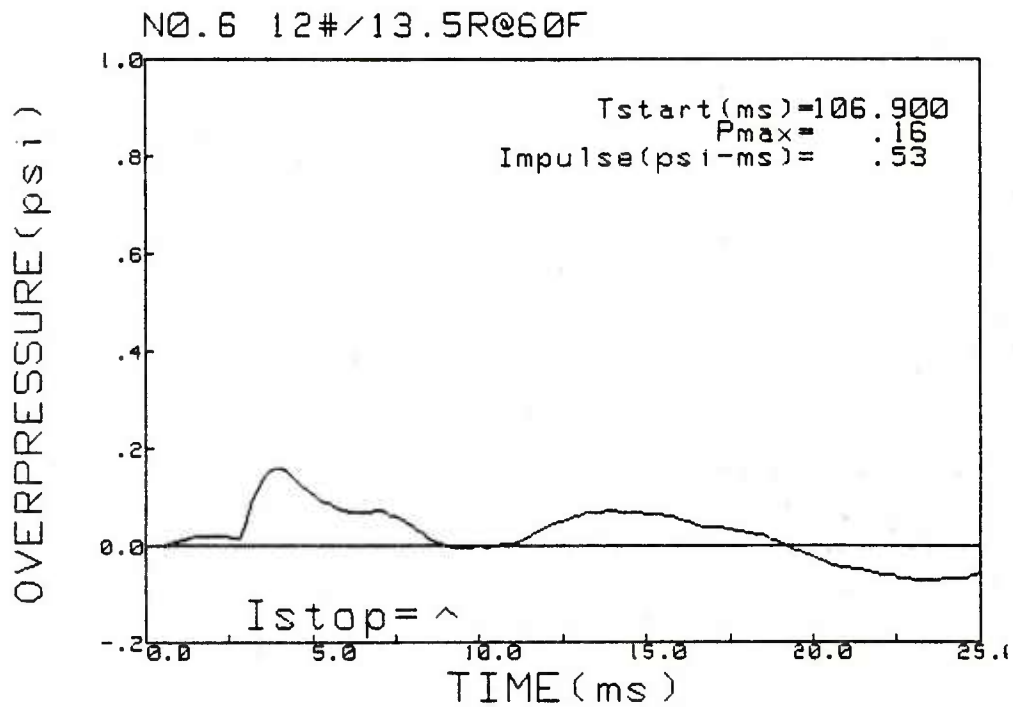


Gage positioned 15.2 m off the side of the headwall

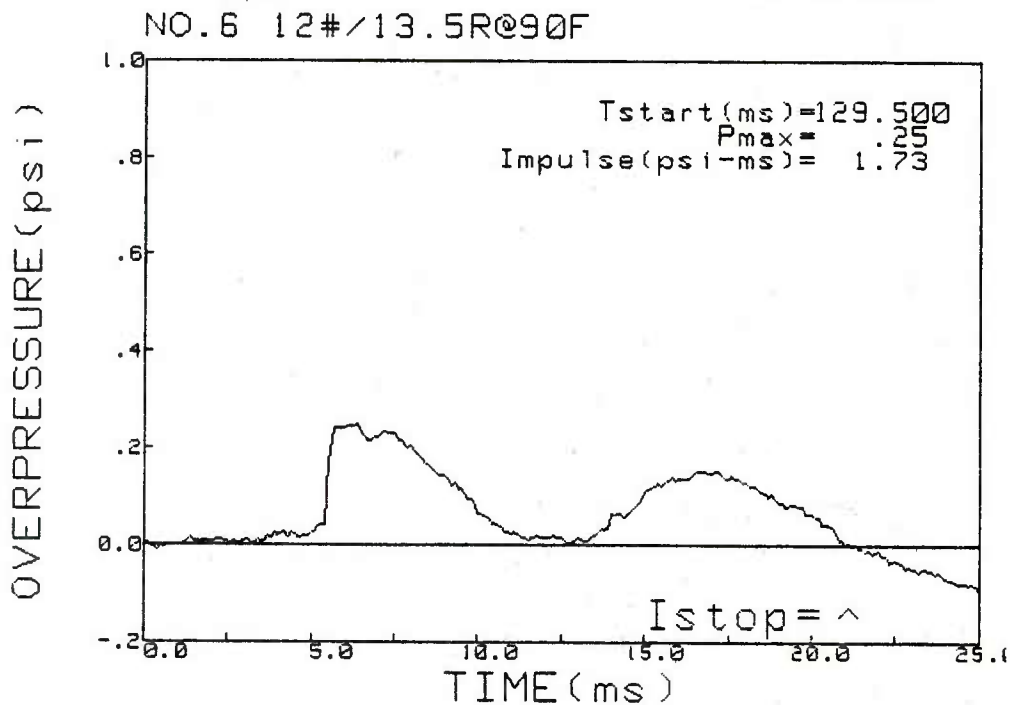


Gage positioned 27.4 m off the side of the headwall

Figure A-5. Pressure Time Histories, Test No. 6, 5.4 Kg TNT Charge Positioned 20.4 Metres from Headwall

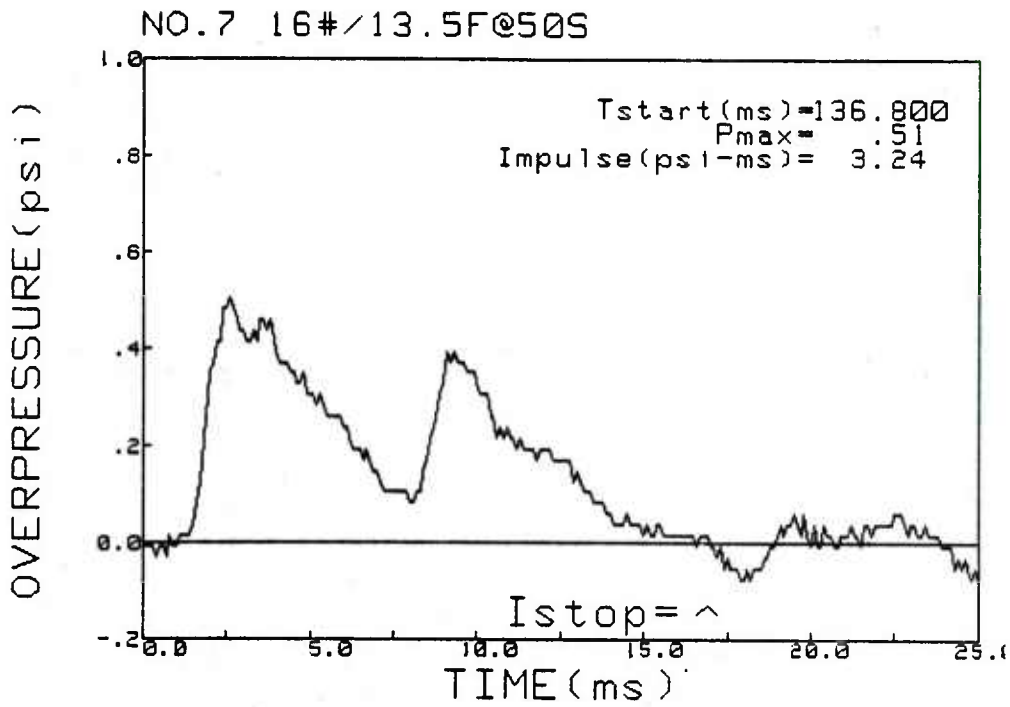


Gage positioned 18.3 m in front of the headwall

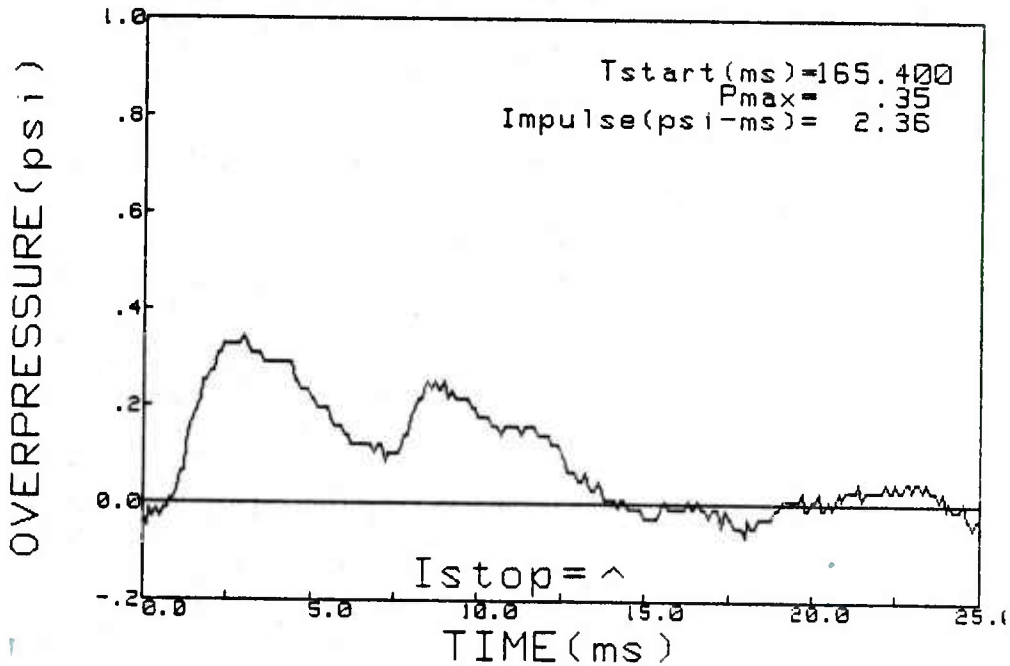


Gage positioned 27.4 m in front of the headwall

Figure A-6. Pressure Time Histories, Test No. 5, 5.4 Kg
TNT Charge Positioned 20.4 Metres from Headwall

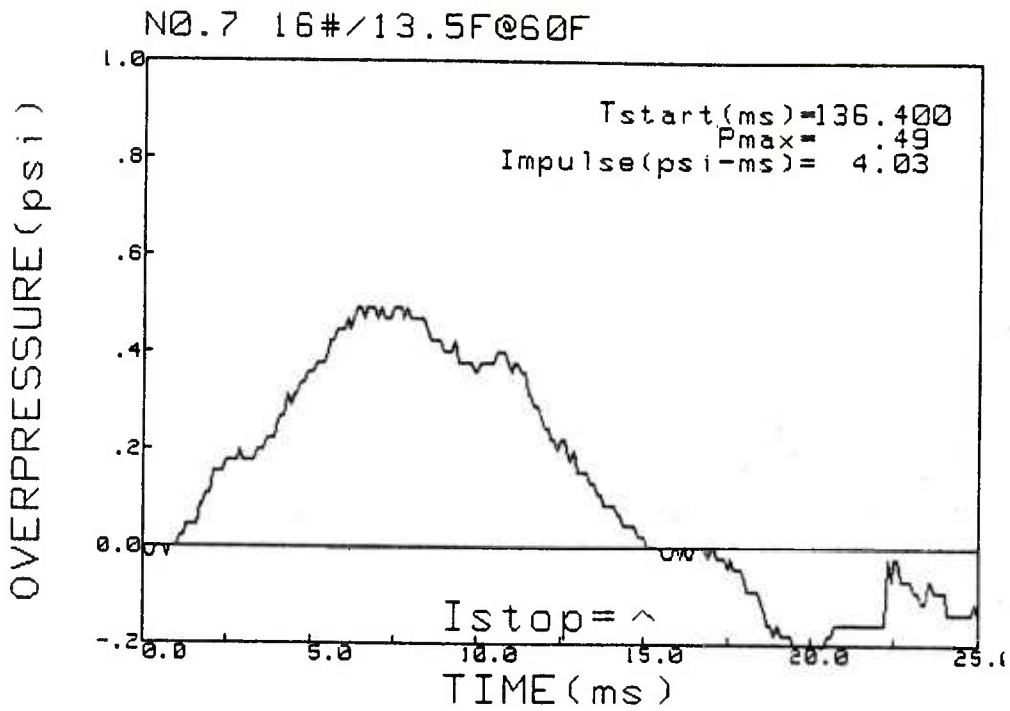


Gage positioned 15.2 m off the side of the headwall
NO.7 16#/13.5F@90S

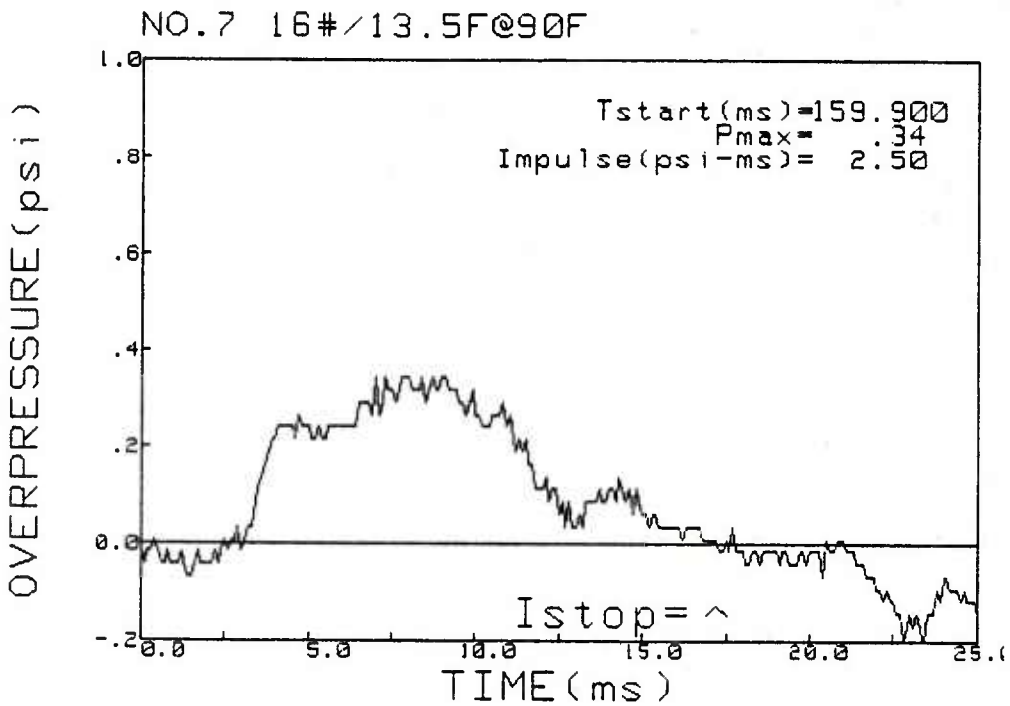


Gage positioned 27.4 m off the side of the headwall

Figure A-7. Pressure Time Histories, Test No. 7, 7.3 Kg TNT Charge Positioned 4 Metres from Headwall

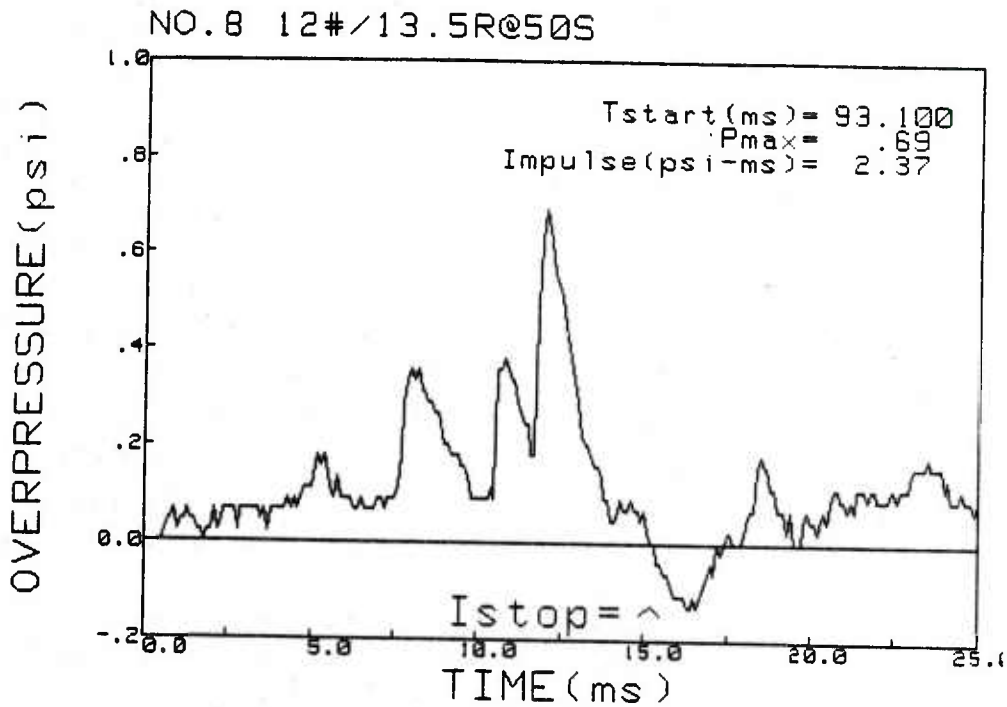


Gage positioned 18.3 m in front of the headwall

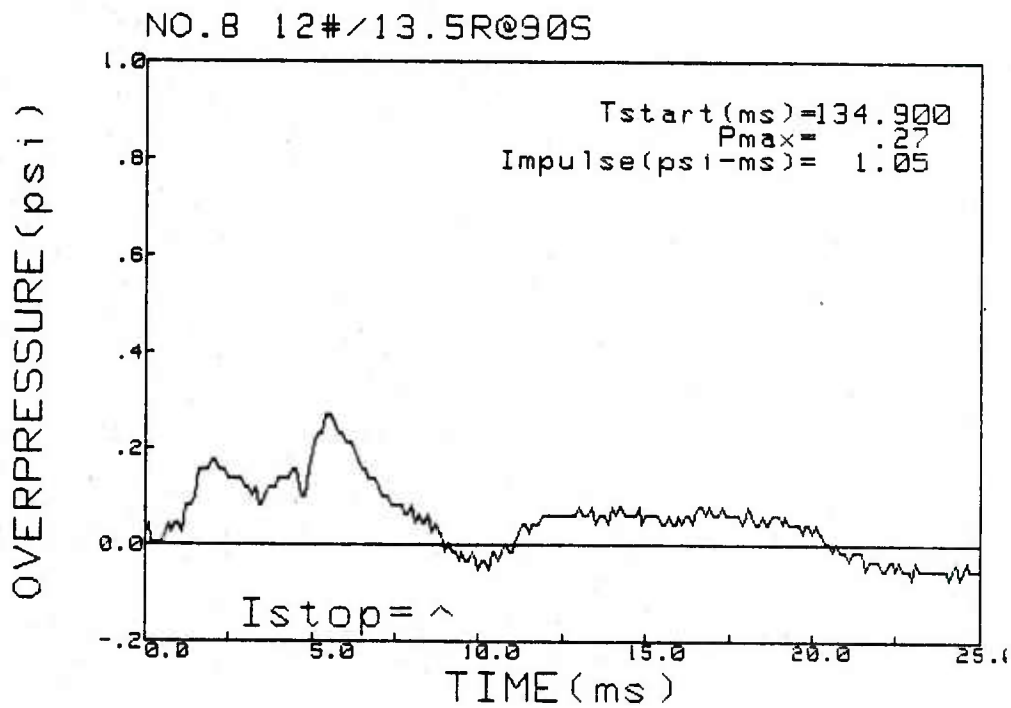


Gage positioned 27.4 m in front of the headwall

Figure A-8. Pressure Time Histories, Test No. 7, 7.3 Kg TNT Charge Positioned 4 Metres from Headwall

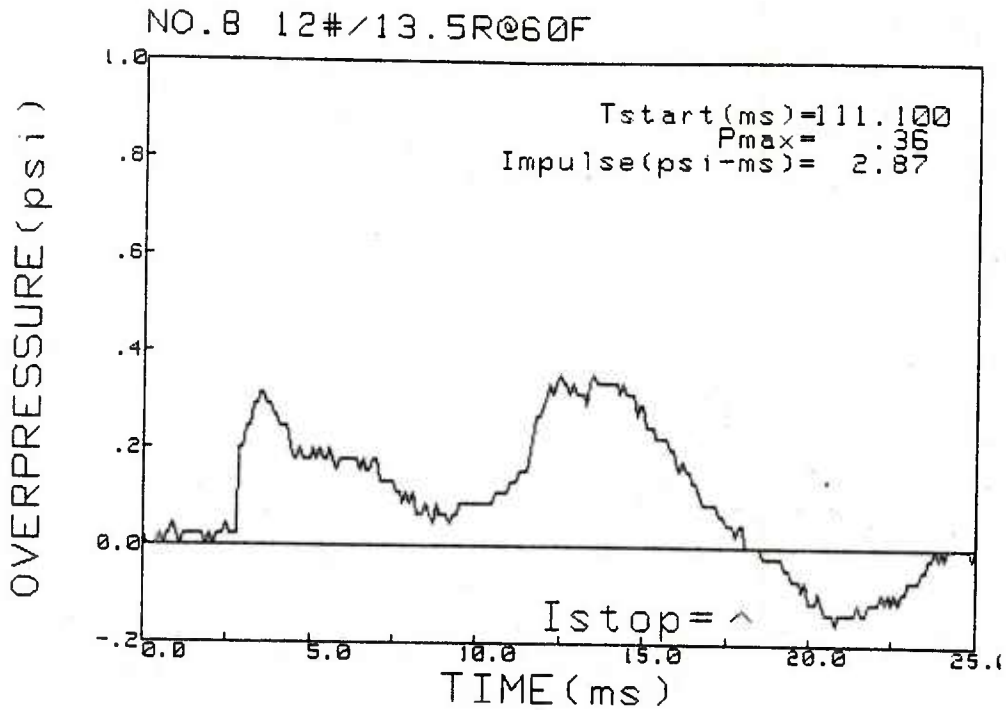


Gage positioned 15.2 m off the side of the headwall

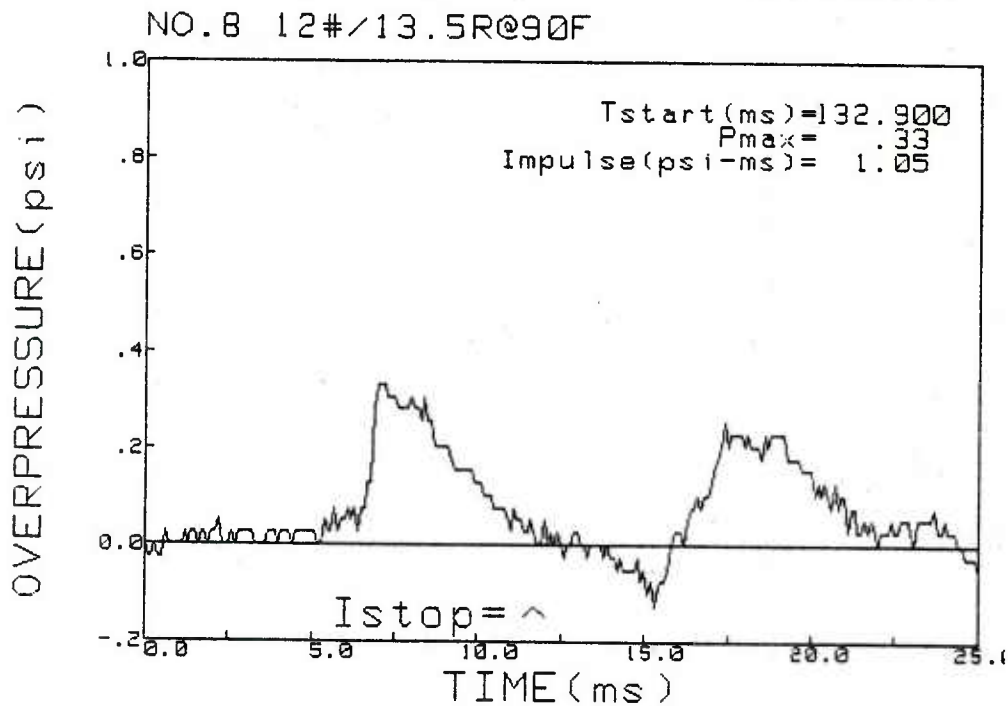


Gage positioned 27.4 m off the side of the headwall

Figure A-9. Pressure Time Histories, Test No. 8, 5.4 Kg TNT Charge Positioned 20.4 Metres from Headwall

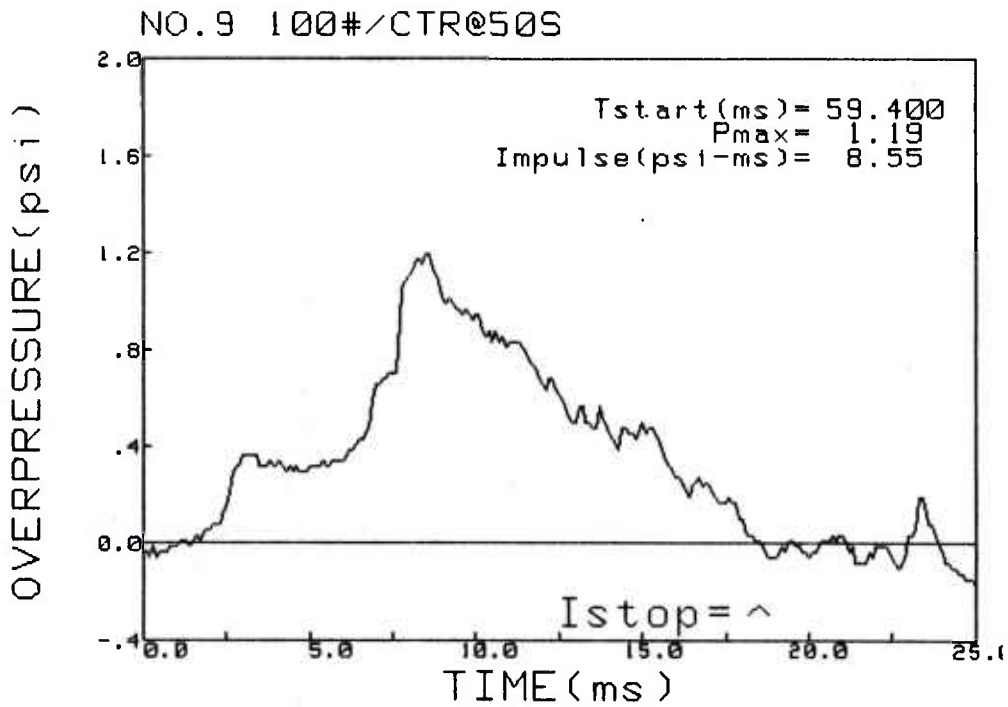


Gage positioned 18.3 m in front of the headwall

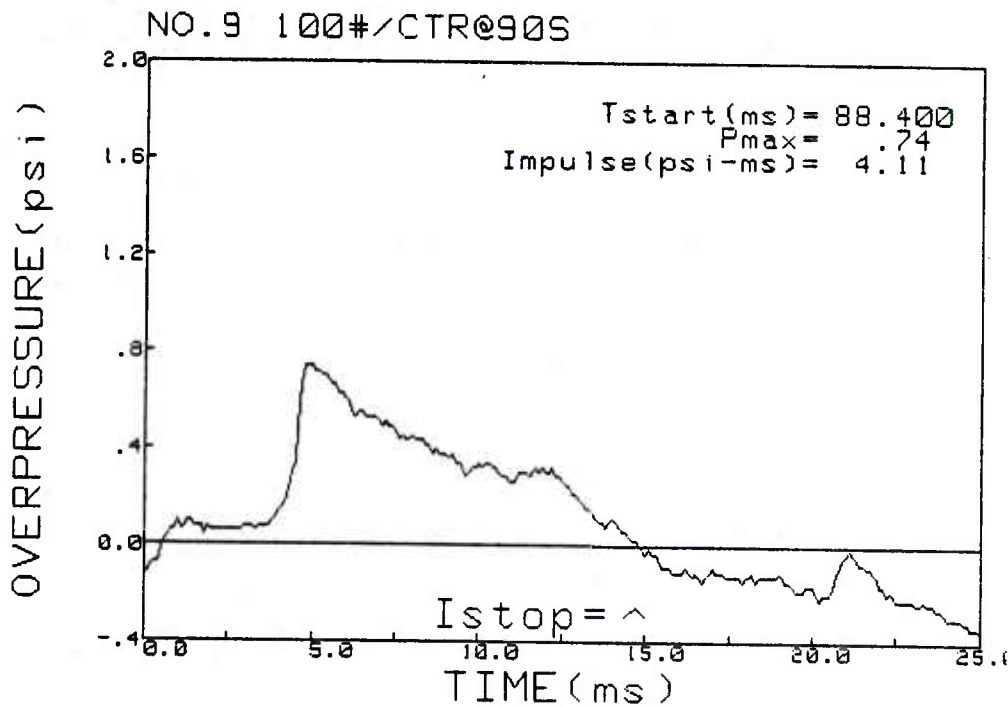


Gage positioned 27.4 m in front of the headwall

Figure A-10. Pressure Time Histories, Test No. 8, 5.4 Kg
TNT Charge Positioned 20.4 Metres from Headwall



Gage positioned 15.2 m off the side of the headwall



Gage positioned 27.4 m off the side of the headwall

Figure A-11. Pressure Time Histories, Test No. 9, 45.4 Kg TNT Charge Positioned 12 Metres from Headwall

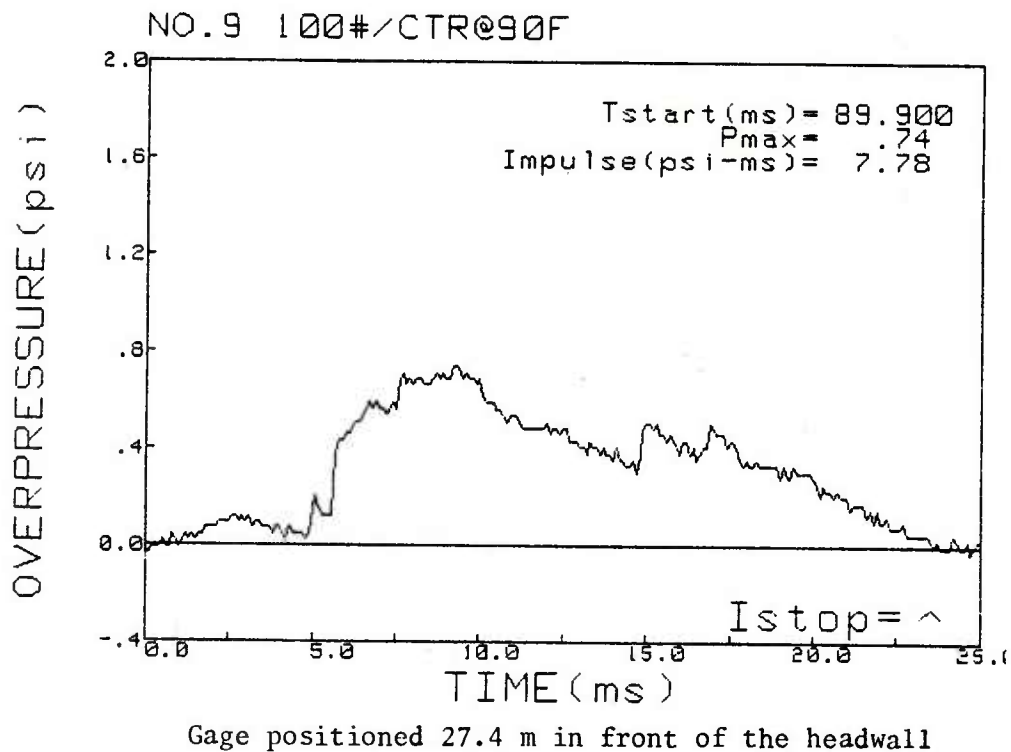
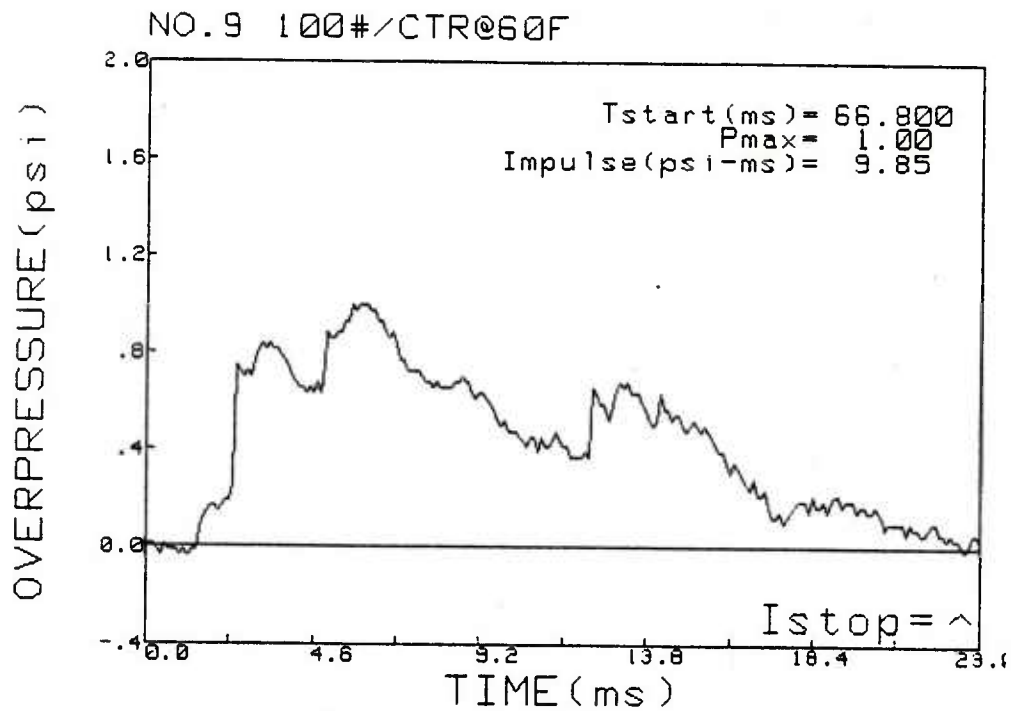
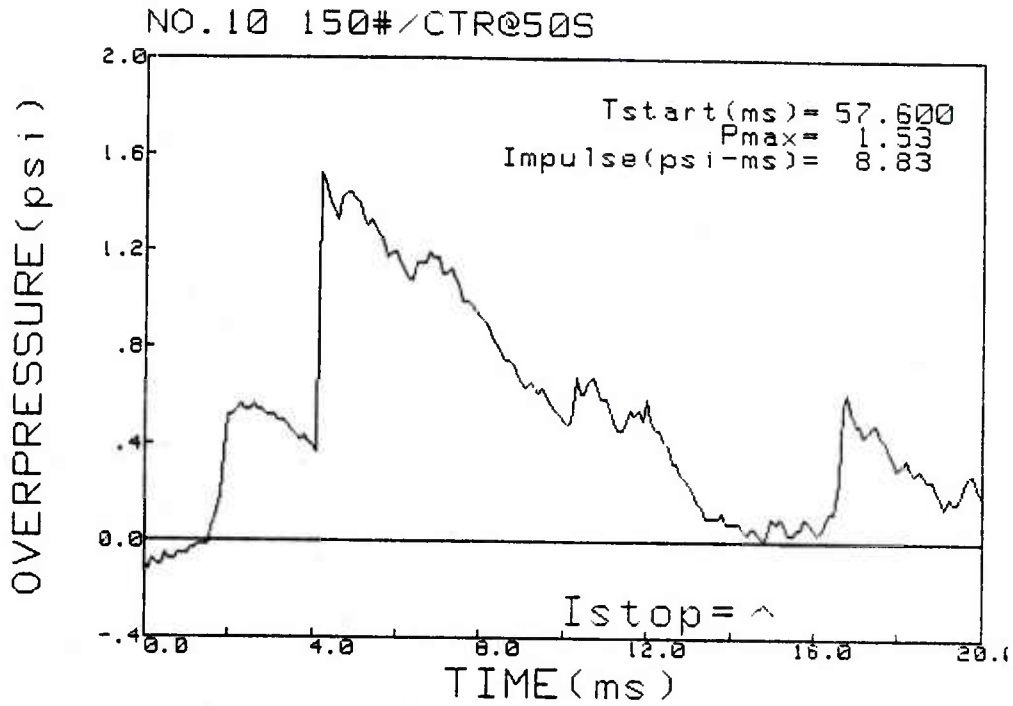
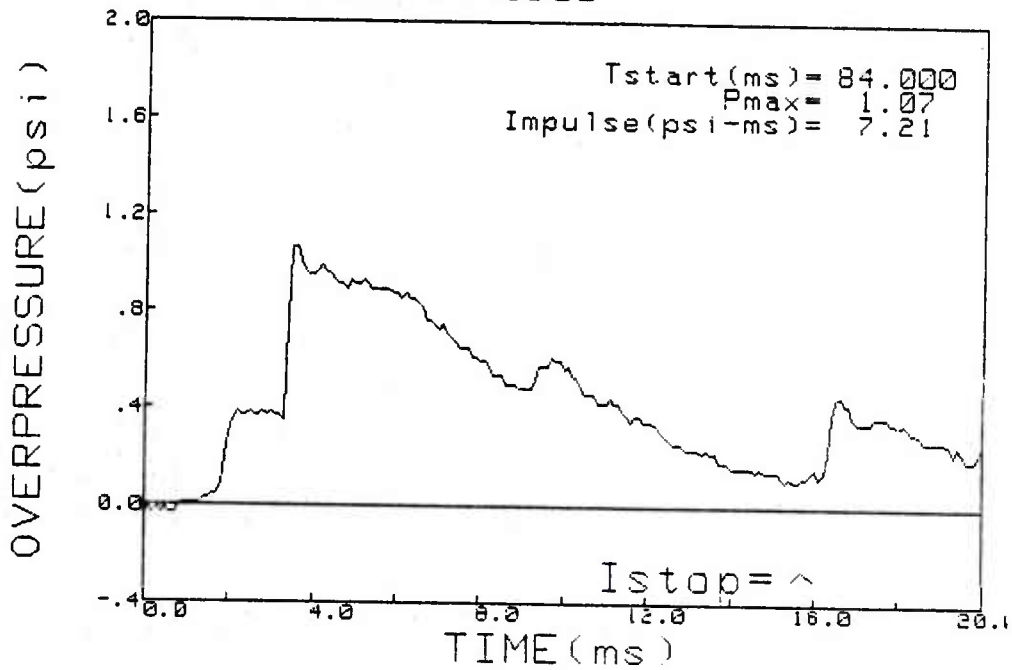


Figure A-12. Pressure Time Histories, Test No. 9, 45.4 Kg TNT Charge Positioned 12 Metres from Headwall

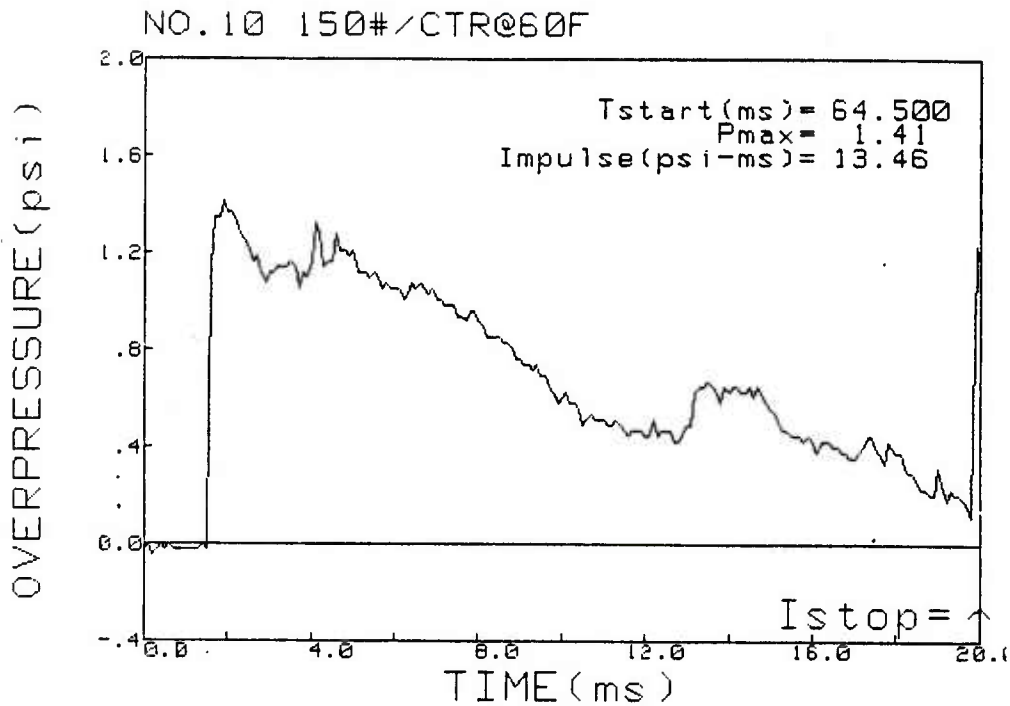


Gage positioned 15.2 m off the side of the headwall
NO. 10 150#/CTR@90S

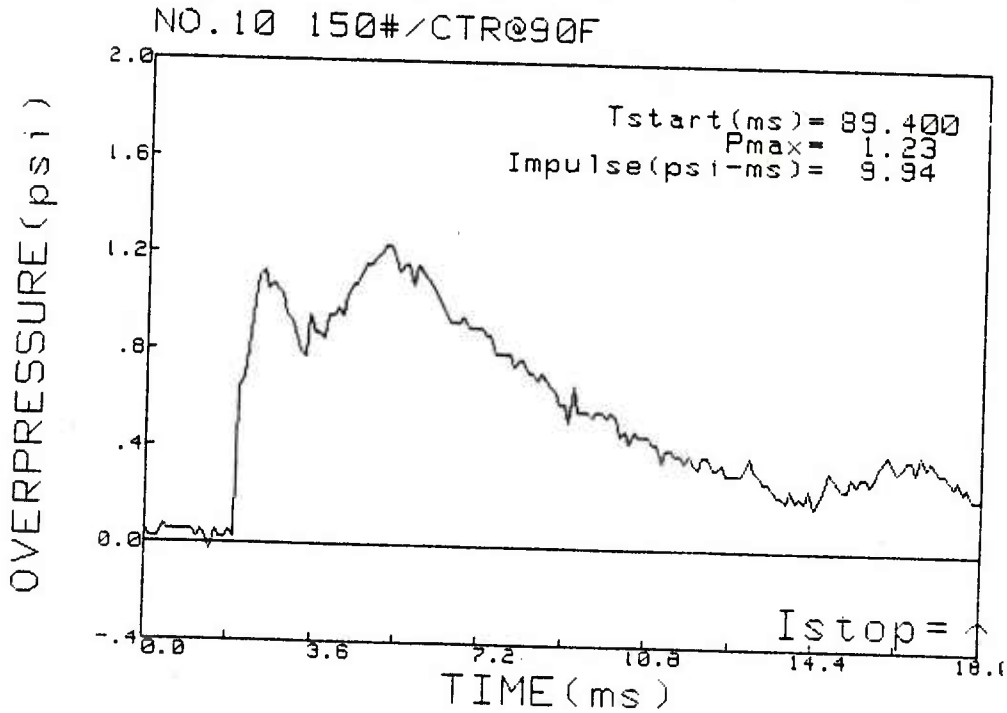


Gage positioned 27.4 m off the side of the headwall

Figure A-13. Pressure Time Histories, Test No. 10, 68 Kg TNT Charge Positioned 12 Metres from Headwall



Gage positioned 18.3 m in front of the headwall



Gage positioned 27.4 m in front of the headwall

Figure A-14. Pressure Time Histories, Test No. 10, 68 Kg TNT Charge Positioned 12 Metres from Headwall

APPENDIX B

Individual Fragment Recovery Data

APPENDIX B

Individual Fragment Recovery Data

Coded Data Format Instructions

First entry in the three letter code is the HE charge weight:

A = 27 Kg, B = 36 Kg, C = 45 Kg, D = 68 Kg

Second entry is the weight group in pounds:

E = 0.4-1.0, F = 1-5, G = 5-10, H = 10-50, I = 50+

Third entry denotes recovery area:

L = Left side recovery area, R = Right side recovery area

First column entry is the distance (ft.) to the front or behind the head-wall, if preceded by a - sign, where the fragment came to rest.

Second column entry is the deviation (ft.) to either the right side or the left side, from the centerline, where the fragment came to rest.

| A E L | AEL | AFL | AFL | AHL |
|--------|---------|---------|---------|---------|
| | 0 180 | 125 25 | 230 90 | 135 5 |
| | 120 130 | 125 25 | 175 75 | 320 20 |
| 0 55 | | 125 25 | 170 90 | 175 65 |
| 30 65 | A F L | 125 25 | 160 55 | 135 25 |
| 30 65 | | 125 25 | 140 60 | 155 5 |
| 30 65 | -10 70 | 130 5 | 120 90 | 170 45 |
| 30 65 | 0 60 | 135 35 | 10 150 | 170 15 |
| 10 50 | 10 75 | 135 15 | 20 125 | 105 65 |
| 40 70 | 10 60 | 140 5 | 20 140 | 100 55 |
| 65 20 | 20 75 | 135 30 | 30 180 | 130 15 |
| 65 20 | 15 100 | 130 25 | 30 130 | 185 35 |
| 65 20 | 25 65 | 130 25 | 55 140 | 205 25 |
| 70 20 | 20 75 | 145 40 | 60 125 | 255 40 |
| 70 20 | 20 75 | 140 10 | 75 160 | 0 180 |
| 70 20 | 10 50 | 140 25 | 75 190 | 10 250 |
| 80 5 | 40 65 | 150 20 | 90 140 | -80 275 |
| 80 5 | 50 70 | 150 15 | 140 140 | |
| 80 5 | 50 60 | 155 20 | 150 150 | A I L |
| 80 25 | 50 95 | 160 30 | 150 150 | |
| 95 5 | 50 80 | 170 5 | 160 150 | -10 70 |
| 110 20 | 60 0 | 170 15 | 280 195 | -5 90 |
| 110 25 | 70 70 | 180 20 | | 60 95 |
| 115 10 | 70 65 | 180 25 | A G L | |
| 130 5 | 65 5 | 180 25 | | A E R |
| 130 5 | 65 15 | 190 25 | 20 65 | |
| 125 30 | 65 20 | 190 20 | 60 15 | 15 100 |
| 135 5 | 70 20 | 190 25 | 60 20 | 15 50 |
| 135 30 | 70 20 | 190 35 | 70 35 | 15 70 |
| 140 5 | 70 15 | 195 35 | 85 15 | 200 10 |
| 140 10 | 70 20 | 200 25 | 70 15 | 30 65 |
| 145 15 | 70 25 | 205 5 | 70 15 | 55 50 |
| 195 10 | 80 20 | 205 10 | 95 5 | 65 20 |
| 200 5 | 75 25 | 210 10 | 80 20 | 220 15 |
| 200 5 | 75 25 | 230 5 | | 70 10 |
| 205 5 | 75 20 | 250 25 | A H L | 90 5 |
| 215 35 | 90 10 | 260 15 | | 110 15 |
| 220 10 | 100 30 | 260 25 | 60 65 | 235 25 |
| 250 40 | 95 0 | 275 50 | 65 60 | 185 5 |
| 260 5 | 105 0 | 275 45 | 65 20 | 195 10 |
| 275 5 | 110 5 | 310 5 | 95 35 | 205 20 |
| 270 60 | 115 10 | 350 15 | 250 100 | 250 25 |
| 200 60 | 125 30 | 340 90 | 230 90 | |
| 200 60 | 120 25 | 340 100 | 95 25 | A F R |
| 140 75 | 125 10 | 300 75 | 135 10 | |
| 100 60 | 130 5 | 275 55 | 135 5 | 0 60 |

Table B-1 Individual Fragment Recovery Data

| AFL | | AGR | | BFL | | BFL | | BGL | |
|-------|-----|-------|-----|-----|----|-------|-----|-------|-----|
| 0 | 90 | 150 | 5 | 70 | 35 | 330 | 25 | 250 | 0 |
| 20 | 55 | 300 | 5 | 70 | 30 | 340 | 20 | 295 | 5 |
| 40 | 70 | | | 80 | 20 | 365 | 40 | 300 | 0 |
| 20 | 60 | A H R | | 90 | 20 | 450 | 90 | 430 | 100 |
| 25 | 70 | | | 95 | 15 | 450 | 90 | 300 | 80 |
| 35 | 50 | 230 | 0 | 100 | 5 | 350 | 90 | 35 | 60 |
| 50 | 70 | 340 | 90 | 115 | 20 | 340 | 55 | 35 | 60 |
| 40 | 100 | | | 120 | 20 | 290 | 100 | 15 | 60 |
| 240 | 40 | B E L | | 130 | 5 | 280 | 100 | 350 | 125 |
| 45 | 50 | | | 135 | 35 | 225 | 55 | 20 | 240 |
| 55 | 50 | 60 | 40 | 140 | 5 | 230 | 50 | | |
| 65 | 75 | 70 | 35 | 140 | 5 | 240 | 100 | B H L | |
| 65 | 75 | 70 | 40 | 145 | 20 | 190 | 65 | | |
| 60 | 10 | 100 | 5 | 150 | 0 | 140 | 90 | 140 | 20 |
| 60 | 20 | 120 | 5 | 150 | 0 | 80 | 75 | 190 | 25 |
| 65 | 10 | 120 | 20 | 145 | 30 | 50 | 50 | 340 | 25 |
| 70 | 30 | 135 | 5 | 150 | 20 | 50 | 60 | 345 | 20 |
| 70 | 5 | 135 | 5 | 150 | 25 | 50 | 70 | 285 | 100 |
| 250 | 100 | 175 | 25 | 150 | 15 | 40 | 80 | 70 | 160 |
| 70 | 10 | 175 | 25 | 155 | 25 | 35 | 60 | 10 | 250 |
| 75 | 5 | 190 | 40 | 160 | 0 | 45 | 55 | | |
| 80 | 5 | 375 | 25 | 170 | 30 | 45 | 70 | B E R | |
| 100 | 20 | 425 | 25 | 175 | 25 | 40 | 70 | | |
| 105 | 5 | 310 | 100 | 175 | 30 | 45 | 55 | 10 | 70 |
| 105 | 10 | 300 | 100 | 175 | 25 | 80 | 160 | 20 | 65 |
| 125 | 15 | 295 | 55 | 180 | 25 | 210 | 165 | 65 | 75 |
| 120 | 55 | 285 | 60 | 180 | 5 | 205 | 145 | 50 | 95 |
| 135 | 5 | 285 | 60 | 180 | 20 | 300 | 125 | 100 | 30 |
| 250 | 20 | 280 | 100 | 180 | 20 | 290 | 110 | 100 | 30 |
| 130 | 10 | 50 | 90 | 190 | 20 | 300 | 170 | 130 | 0 |
| 135 | 0 | 40 | 70 | 190 | 0 | 300 | 110 | 130 | 0 |
| 150 | 5 | 250 | 145 | 190 | 40 | 340 | 125 | 130 | 5 |
| 160 | 0 | 250 | 175 | 190 | 5 | 400 | 150 | 160 | 40 |
| 170 | 50 | 250 | 150 | 205 | 20 | 400 | 150 | 160 | 5 |
| 170 | 60 | 325 | 125 | 205 | 10 | 275 | 260 | 170 | 10 |
| 190 | 15 | 400 | 150 | 205 | 10 | | | 180 | 0 |
| 190 | 5 | 270 | 260 | 210 | 15 | B G L | | 175 | 20 |
| 240 | 40 | 200 | 200 | 215 | 20 | | | 210 | 15 |
| 255 | 25 | 70 | 240 | 250 | 25 | 135 | 5 | 220 | 25 |
| 360 | 85 | | | 255 | 30 | 140 | 5 | 220 | 25 |
| | | B F L | | 255 | 25 | 140 | 5 | 235 | 5 |
| A G R | | | | 260 | 5 | 145 | 15 | 245 | 5 |
| | | 65 | 35 | 280 | 30 | 175 | 0 | 245 | 5 |
| 50 | 70 | 70 | 60 | 280 | 10 | 200 | 0 | 260 | 70 |
| 125 | 25 | 65 | 40 | 290 | 20 | 240 | 25 | 290 | 60 |

Table B-1 Individual Fragment Recovery Data (continued)

| BER | | BFR | | BFR | | CEL | | GFL | |
|-----|-------|-----|-----|-----|-------|-----|-------|-----|-----|
| 295 | 75 | 140 | 100 | 375 | 80 | 90 | 10 | 30 | 100 |
| 300 | 75 | 140 | 50 | 390 | 25 | 90 | 15 | 25 | 90 |
| 330 | 15 | 140 | 30 | 390 | 15 | 95 | 5 | 25 | 90 |
| 330 | 100 | 145 | 5 | 390 | 85 | 95 | 110 | 25 | 90 |
| 360 | 75 | 150 | 10 | 415 | 20 | 60 | 110 | 35 | 40 |
| 440 | 75 | 160 | 30 | 450 | 40 | 20 | 100 | 45 | 60 |
| 440 | 20 | 160 | 30 | 440 | 20 | 15 | 100 | 45 | 60 |
| 440 | 20 | 170 | 10 | 445 | 20 | 145 | 15 | 60 | 75 |
| | | 170 | 10 | 470 | 30 | 165 | 205 | 70 | 40 |
| | | 170 | 10 | | | 300 | 195 | 75 | 45 |
| | B F R | 180 | 40 | | B G R | 200 | 230 | 80 | 85 |
| | 5 | 180 | 5 | | | 300 | 195 | 95 | 80 |
| | 10 | 190 | 5 | 10 | 95 | 300 | 75 | 90 | 15 |
| | 30 | 200 | 30 | 110 | 5 | 295 | 65 | 85 | 20 |
| | 55 | 200 | 20 | 110 | 10 | 385 | 60 | 85 | 20 |
| | 55 | 210 | 15 | 140 | 30 | 380 | 55 | 95 | 5 |
| | 60 | 220 | 25 | 180 | 10 | 230 | 25 | 85 | 110 |
| | 60 | 210 | 15 | 195 | 5 | 220 | 30 | 70 | 130 |
| | 55 | 210 | 0 | 250 | 20 | 210 | 20 | 65 | 115 |
| | 65 | 225 | 15 | 280 | 60 | 215 | 50 | 105 | 100 |
| | 100 | 230 | 35 | 360 | 20 | 210 | 25 | 20 | 100 |
| | 100 | 230 | 20 | 360 | 70 | 210 | 40 | 15 | 100 |
| | 100 | 240 | 5 | 390 | 70 | 210 | 30 | 15 | 100 |
| | 100 | 240 | 5 | 445 | 60 | 210 | 25 | 0 | 115 |
| | 100 | 245 | 10 | 470 | 40 | 210 | 35 | 10 | 140 |
| | 100 | 250 | 30 | | | 190 | 15 | 50 | 280 |
| | 110 | 250 | 20 | | B H R | 190 | 0 | 90 | 235 |
| | 110 | 250 | 5 | | | 180 | 30 | 100 | 375 |
| | 110 | 260 | 30 | 190 | 0 | 180 | 30 | 150 | 210 |
| | 110 | 260 | 5 | 195 | 25 | 150 | 50 | 140 | 315 |
| | 120 | 270 | 45 | 200 | 10 | 130 | 30 | 250 | 250 |
| | 120 | 270 | 50 | 210 | 25 | 130 | 25 | 260 | 260 |
| | 120 | 275 | 45 | 240 | 50 | 130 | 25 | 300 | 230 |
| | 120 | 290 | 30 | 270 | 70 | 125 | 30 | 240 | 205 |
| | 120 | 300 | 30 | 335 | 95 | 110 | 30 | 280 | 170 |
| | 125 | 295 | 70 | | | | | 300 | 190 |
| | 125 | 300 | 70 | | C E L | | C F L | 325 | 190 |
| | 130 | 300 | 75 | | | | | 350 | 150 |
| | 130 | 300 | 90 | 45 | 60 | 10 | 95 | 320 | 140 |
| | 135 | 330 | 30 | 45 | 60 | 15 | 95 | 340 | 125 |
| | 135 | 330 | 15 | 80 | 90 | 10 | 95 | 325 | 75 |
| | 130 | 330 | 5 | 80 | 80 | 20 | 95 | 270 | 75 |
| | 140 | 340 | 30 | 90 | 15 | 25 | 90 | 360 | 60 |
| | 140 | 360 | 20 | 90 | 15 | 25 | 85 | 310 | 60 |
| | 140 | 360 | 20 | 90 | 10 | 25 | 80 | 320 | 50 |

Table B-1 Individual Fragment Recovery Data (continued)

| CFL | | CFL | | CHL | | C F R | | CGR | |
|-----|----|-------|-----|-------|-----|-------|-----|-------|----|
| 320 | 40 | 140 | 30 | 90 | 20 | | | 105 | 0 |
| 360 | 40 | 130 | 10 | 90 | 20 | 15 | 95 | 165 | 5 |
| 320 | 40 | 130 | 50 | 95 | 120 | 20 | 90 | 200 | 10 |
| 300 | 30 | 130 | 35 | 200 | 10 | 20 | 55 | 375 | 90 |
| 390 | 0 | 130 | 0 | 65 | 125 | 30 | 60 | -100 | 5 |
| 270 | 45 | 125 | 5 | 15 | 105 | 30 | 60 | | |
| 250 | 20 | 120 | 40 | 300 | 195 | 30 | 70 | | |
| 250 | 20 | 120 | 25 | 115 | 25 | 35 | 80 | C H R | |
| 275 | 40 | 120 | 40 | 300 | 180 | 30 | 95 | 30 | 55 |
| 240 | 25 | 125 | 40 | 280 | 20 | 35 | 80 | 30 | 70 |
| 230 | 5 | 125 | 40 | 270 | 20 | 35 | 75 | 30 | 80 |
| 240 | 40 | 115 | 10 | 100 | 30 | 50 | 65 | 85 | 20 |
| 240 | 40 | 105 | 35 | | | 60 | 50 | 180 | 30 |
| 230 | 30 | 105 | 5 | C I L | | 65 | 5 | 380 | 40 |
| 230 | 45 | | | | | 75 | 0 | -90 | 0 |
| 225 | 40 | C G L | | 90 | 100 | 80 | 5 | -100 | 5 |
| 210 | 10 | | | 95 | 110 | 80 | 15 | | |
| 225 | 40 | 25 | 80 | 0 | 160 | 80 | 20 | C I R | |
| 210 | 35 | 25 | 80 | 295 | 60 | 100 | 20 | | |
| 205 | 20 | 75 | 95 | 140 | 40 | 105 | 0 | 80 | 10 |
| 200 | 40 | 60 | 100 | | | 115 | 10 | 240 | 10 |
| 200 | 20 | 90 | 235 | C E R | | 160 | 30 | -125 | 10 |
| 200 | 10 | 230 | 230 | | | 170 | 0 | -95 | 10 |
| 200 | 5 | 400 | 30 | 20 | 90 | 180 | 0 | | |
| 190 | 10 | 370 | 30 | 60 | 70 | 190 | 5 | D E L | |
| 190 | 30 | 440 | 40 | 65 | 5 | 200 | 30 | | |
| 175 | 35 | 400 | 35 | 70 | 10 | 240 | 20 | 220 | 25 |
| 175 | 30 | 205 | 25 | 80 | 0 | 270 | 5 | 220 | 25 |
| 175 | 35 | 190 | 10 | 85 | 75 | 280 | 5 | 220 | 40 |
| 175 | 30 | 180 | 45 | 90 | 90 | 280 | 5 | 220 | 40 |
| 170 | 30 | 150 | 30 | 105 | 0 | 300 | 20 | 220 | 40 |
| 165 | 30 | 135 | 25 | 125 | 20 | 300 | 15 | 220 | 40 |
| 165 | 30 | 120 | 10 | 125 | 50 | 375 | 60 | 230 | 15 |
| 150 | 20 | 120 | 25 | 125 | 75 | 385 | 5 | 240 | 10 |
| 150 | 20 | 120 | 25 | 140 | 30 | 400 | 15 | 240 | 15 |
| 150 | 20 | 120 | 25 | 150 | 0 | 450 | 30 | 230 | 35 |
| 155 | 25 | 110 | 10 | 150 | 10 | 450 | 70 | 230 | 35 |
| 160 | 40 | | | 150 | 20 | 490 | 90 | 245 | 15 |
| 150 | 40 | C H L | | 165 | 5 | | | 245 | 20 |
| 145 | 25 | | | 200 | 10 | C G R | | 250 | 20 |
| 145 | 30 | 20 | 80 | 200 | 40 | | | 250 | 25 |
| 145 | 30 | 25 | 80 | 200 | 50 | 5 | 55 | 240 | 60 |
| 150 | 45 | 25 | 95 | 450 | 75 | 35 | 100 | 240 | 60 |
| 140 | 35 | 215 | 25 | | | 80 | 40 | 260 | 20 |
| 145 | 40 | 105 | 30 | | | 85 | 110 | 250 | 60 |

Table B-1 Individual Fragment Recovery Data (continued)

| DEL | | DEL | | DFL | | DFL | | DFL | |
|-----|-----|-------|-----|-----|-----|-----|-----|-----|-----|
| 270 | 20 | 65 | 120 | -5 | 100 | 140 | 360 | 145 | 10 |
| 270 | 20 | 75 | 115 | -5 | 90 | 140 | 350 | 150 | 5 |
| 300 | 5 | 105 | 30 | -5 | 75 | 150 | 290 | 150 | 5 |
| 320 | 15 | 5 | 160 | 85 | 15 | 160 | 190 | 140 | 5 |
| 320 | 25 | 30 | 135 | 85 | 15 | 180 | 180 | 150 | 0 |
| 320 | 25 | 105 | 30 | 90 | 20 | 150 | 30 | 160 | 0 |
| 320 | 25 | 65 | 145 | 75 | 20 | 160 | 135 | 165 | 0 |
| 350 | 10 | 95 | 160 | 85 | 25 | 110 | 140 | 200 | 75 |
| 360 | 20 | 120 | 30 | 85 | 30 | 150 | 95 | 220 | 20 |
| 350 | 30 | 5 | 210 | 90 | 30 | 200 | 100 | 220 | 50 |
| 375 | 10 | 0 | 250 | 75 | 30 | 140 | 60 | 230 | 20 |
| 380 | 10 | 140 | 35 | 75 | 30 | 110 | 70 | 230 | 35 |
| 385 | 5 | 60 | 445 | 100 | 25 | 190 | 150 | 240 | 35 |
| 390 | 5 | 140 | 480 | 100 | 25 | 150 | 50 | 240 | 35 |
| 415 | 35 | 130 | 450 | 90 | 35 | 150 | 45 | 250 | 35 |
| 425 | 60 | 150 | 375 | 90 | 40 | 175 | 50 | 250 | 35 |
| 440 | 30 | 115 | 50 | 70 | 20 | 175 | 150 | 250 | 35 |
| 460 | 50 | 150 | 100 | 60 | 95 | 175 | 50 | 250 | 35 |
| 480 | 30 | 105 | 105 | 60 | 90 | 180 | 35 | 250 | 50 |
| 475 | 50 | 115 | 50 | 70 | 90 | 150 | 30 | 265 | 20 |
| 425 | 300 | 105 | 105 | 15 | 110 | 165 | 35 | 250 | 50 |
| 495 | 20 | 105 | 105 | 10 | 120 | 115 | 30 | 275 | 45 |
| 500 | 5 | 110 | 45 | 50 | 100 | 120 | 30 | 275 | 25 |
| 510 | 40 | 105 | 95 | 50 | 125 | 135 | 25 | 630 | 90 |
| 565 | 40 | 140 | 60 | 65 | 115 | 105 | 10 | 185 | 250 |
| 565 | 40 | 160 | 65 | 65 | 120 | 160 | 25 | 150 | 325 |
| 560 | 80 | 120 | 60 | 5 | 160 | 160 | 25 | 290 | 40 |
| 530 | 230 | 130 | 50 | 5 | 150 | 610 | 15 | 300 | 25 |
| -5 | 100 | 150 | 30 | 50 | 145 | 450 | 300 | 305 | 35 |
| 90 | 0 | 105 | 10 | 15 | 190 | 325 | 150 | 320 | 35 |
| 95 | 5 | 105 | 10 | 40 | 170 | 160 | 25 | 320 | 35 |
| 90 | 30 | 200 | 30 | 605 | 20 | 160 | 25 | 320 | 35 |
| 90 | 35 | 200 | 50 | 800 | 20 | 160 | 25 | 325 | 25 |
| 100 | 60 | 215 | 30 | 520 | 240 | 110 | 10 | 325 | 25 |
| 60 | 90 | | | 40 | 165 | 105 | 10 | 340 | 50 |
| 20 | 120 | D F L | | 50 | 140 | 105 | 10 | 355 | 45 |
| 130 | 10 | | | 55 | 170 | 120 | 10 | 360 | 50 |
| 40 | 125 | 675 | 75 | 90 | 200 | 105 | 10 | 360 | 75 |
| 40 | 125 | 660 | 140 | 85 | 170 | 105 | 10 | 380 | 85 |
| 40 | 125 | -150 | 0 | 100 | 150 | 135 | 10 | 385 | 10 |
| 40 | 110 | -125 | 15 | 25 | 360 | 140 | 10 | 390 | 35 |
| 40 | 110 | -120 | 30 | 0 | 390 | 140 | 10 | 410 | 35 |
| 130 | 10 | -85 | 55 | 130 | 425 | 140 | 10 | 410 | 85 |
| 60 | 105 | -10 | 120 | 175 | 400 | 160 | 10 | 420 | 15 |
| 65 | 110 | -10 | 105 | 180 | 390 | 160 | 10 | 430 | 25 |

Table B-1 Individual Fragment Recovery Data (continued)

| DFL | | DGL | | DIL | | DFR | | DGR | |
|-----|----|-----|-------|-----|-------|-----|-------|-------|-----|
| 435 | 35 | 355 | 85 | 50 | 95 | 50 | 50 | | |
| 435 | 50 | 355 | 60 | 40 | 110 | 50 | 0 | 140 | 5 |
| 450 | 50 | 370 | 45 | 45 | 105 | 50 | 0 | 300 | 20 |
| 450 | 30 | 375 | 55 | 0 | 150 | 50 | 40 | 425 | 55 |
| 445 | 30 | 450 | 10 | 0 | 150 | 60 | 20 | 430 | 55 |
| 450 | 75 | 490 | 20 | 0 | 150 | 60 | 15 | 430 | 55 |
| 475 | 50 | 550 | 125 | 0 | 160 | 75 | 45 | 250 | 250 |
| 475 | 35 | 560 | 35 | 0 | 160 | 85 | 40 | | |
| 460 | 55 | 575 | 90 | 15 | 440 | 85 | 85 | | |
| 465 | 45 | 610 | 50 | 185 | 100 | 120 | 0 | D I R | |
| 485 | 10 | 610 | 75 | 330 | 30 | 140 | 80 | 50 | 0 |
| 500 | 50 | 630 | 60 | 395 | 5 | 140 | 0 | 325 | 5 |
| 510 | 30 | 630 | 230 | | | 280 | 40 | 425 | 0 |
| 510 | 40 | | | | | 295 | 5 | 595 | 50 |
| 540 | 50 | | D H L | | D E R | 300 | 5 | 600 | 50 |
| 575 | 20 | | | 55 | 50 | 305 | 40 | | |
| 590 | 65 | -5 | 80 | 60 | 40 | 330 | 15 | | |
| 580 | 20 | 40 | 90 | 70 | 15 | 325 | 100 | | |
| 590 | 80 | 40 | 95 | 75 | 15 | 400 | 50 | | |
| 650 | 45 | 55 | 90 | 75 | 20 | 380 | 15 | | |
| | | 30 | 120 | 80 | 25 | 380 | 15 | | |
| | | 0 | 160 | 95 | 20 | 400 | 15 | | |
| | | 10 | 165 | 120 | 10 | 450 | 120 | | |
| | | 0 | 200 | 150 | 40 | 510 | 10 | | |
| | | 15 | 445 | 175 | 10 | 510 | 15 | | |
| | | 125 | 35 | 185 | 5 | 480 | 30 | | |
| | | 275 | 50 | 165 | 20 | 480 | 40 | | |
| | | 355 | 20 | 165 | 20 | 490 | 30 | | |
| | | 390 | 50 | 165 | 20 | 550 | 90 | | |
| | | 490 | 75 | 195 | 40 | 575 | 50 | | |
| | | 490 | 30 | 195 | 0 | 630 | 70 | | |
| | | 550 | 270 | 225 | 0 | 630 | 50 | | |
| | | 450 | 350 | 270 | 20 | 110 | 120 | | |
| | | | | 320 | 15 | | | | |
| | | | | 320 | 15 | | D G R | | |
| | | | | 340 | 40 | | | | |
| | | | | 330 | 20 | 80 | 40 | | |
| | | -90 | 40 | 330 | 20 | 260 | 15 | | |
| | | -90 | 40 | 340 | 10 | 290 | 10 | | |
| | | -85 | 50 | 430 | 50 | 510 | 0 | | |
| | | -70 | 60 | 525 | 65 | 300 | 250 | | |
| | | -40 | 110 | | | 140 | 120 | | |
| | | 80 | 75 | | | | | | |
| | | 85 | 75 | | D F R | | | | |
| | | 25 | 95 | | | | | | |
| | | 40 | 95 | 60 | 80 | | D H R | | |
| | | | | | | 50 | 80 | | |

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