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SUMMARY REPORT OF EARTH-COVERED, STEEL-ARCH MAGAZINE TESTS

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by

A. R. Sound
Test Department

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ABSTRACT. Between January 1962 and December 1963, a series of tests of earth-covered, steel-arch igloo magazines was conducted to determine the minimum spacing distance between adjacent igloos needed to prevent the propagation of an explosion from one magazine to another. It was shown that the distance in feet between the side walls can be determined by multiplying the cube root of the stored explosive weight in pounds by the factor 1.25, and the distance between facing rear walls can be determined by using the factor 1.50.

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AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

J. I. HARDY, CAPT., USN — Commander

WM. B. McLEAN, PH.D. — Technical Director

FOREWORD

This report documents a series of full-scale igloo magazine tests conducted at NOTS from January 1962 to December 1963. It relates the tests to each other and includes data that had not been assessed at the time the individual preliminary reports were issued. The tests were part of the Armed Services Explosives Safety Board (ASESB) Dividing Wall program and were documented for the ASESB and participating services. The portion of the Dividing Wall program conducted at NOTS is supported by funds from the three Military Departments and from the Defense Atomic Support Agency (DASA) under the currently identified Task Assignment RUME-4E-000/216-1/F008-11-05 and Local Project No. 556.

Full-scale and model experiments conducted previously at other locations had demonstrated that the historical criteria for the storage of high explosives could be substantially improved when standard, reinforced-concrete igloo magazines were used. The series of tests reported here was conducted to determine the feasibility of reducing the land area required for high-explosive storage by reducing the magazine spacing; to establish the minimum safe distance permissible between earth-covered, steel-arch magazines; and to compare the protection afforded by the more economical steel-arch magazines with that afforded by reinforced-concrete arch magazines.

As a result of these tests, the minimum safe spacing between the side walls of adjacent earth-covered, steel-arch magazines was redefined; a decreased spacing between the rear walls of magazines situated back-to-back was shown to be safe; and spacings for other siting relationships were confirmed. Certain additional effects were noted, primarily as a result of fragment-distribution analysis and detailed examination of pressure gage data.

This report has been reviewed for technical accuracy by the Chairman and the Secretariat of the ASESB Dividing Wall Work Group.

Released by
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Under authority of
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The individual tests summarized in this report were conducted by R. H. Harris and R. E. Boyer. The preliminary reports, from which a large part of the material was collected, were written by R. E. Boyer, P. H. Miller, and F. H. Weals, who also contributed suggestions toward the structure and content of this report.

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INTRODUCTION

A series of six igloo magazine tests was conducted at the U. S. Naval Ordnance Test Station (NOTS), China Lake, California, between January 1962 and December 1963 to determine the minimum permissible spacing between earth-covered, steel-arch magazines, while reasonably assuring the prevention of propagation of an explosion between magazines. A seventh test, employing magazines of similar construction, was conducted by the Defense Atomic Support Agency (DASA) at a Nevada test site and provided supplementary data. The tests at NOTS were a follow-on series related to experiments conducted at Woods Hole, Massachusetts (Ref. 1), and Arco, Idaho (Refs. 2, 3, & 4), under the auspices of the Underwater Explosive Research Laboratory and the Armed Services Explosives Safety Board (ASESB).

The earlier tests and this series were conducted to determine whether the rules for spacing magazines provided adequate safety, or whether they were unnecessarily conservative, resulting in inefficient use of the available land. The revised specifications for siting magazines resulting from the earlier tests specified that the separation in feet between adjacent magazines shall be based on the cube root of the weight in pounds of the high explosive to be stored, multiplied by a factor dependent upon the barricades between magazines, or

$$\text{Distance in feet} = (\text{Factor})(\text{weight in pounds})^{1/3}$$

The factor varied, in general, between 2.35 and 11.0, depending on whether a barricade at each magazine separated them, whether only one magazine was barricaded, or whether no barricades existed.

The igloo tests at Arco, Idaho, indicated that separate earth-covered, standard concrete arch magazines could be located with the distance between side walls determined by the equation

$$D = (2.35)(W)^{1/3}$$

and still maintain a low probability of explosion propagation between magazines.

As a result of the series of tests at NOTS it was determined that the distance between side walls of adjacent earth-covered, steel-arch magazines could be determined by the equation

$$D = (1.25)(W)^{1/3}$$

It was also shown that when magazines of this type are located back-to-back, the space between the rear walls can be determined by

$$D = (1.5)(W)^{1/3}$$

when the magazines are covered by a common earth fill. The tests also demonstrated that a spacing of

$$D = (4.5)(W)^{1/3}$$

from the rear wall of an earth-covered storage magazine to the unbarricaded concrete headwall of another magazine is safe. No requirement was presented for testing this configuration at a lesser separation.

The tests are documented in sections in this report. The figures used to illustrate test setup, donor and acceptor charge positions, pressure gage location, and test results appear at the end of each section.

SECTION ONE

TEST NO. 1 (E-6819)

To determine whether the space factor $(2.35)(W)^{1/3}$ was the minimum safe distance between magazines, or whether closer spacing could be permitted (requiring less landscape per unit of stored explosive), test number E-6819 was conducted at the Victor Range site at NOTS at 1106 PST, 17 January 1962, using distances of $0.5\ W^{1/3}$ and $1.0\ W^{1/3}$ between the side walls of steel-arch magazines (both earth-covered), and $4.5\ W^{1/3}$ from the unbarricaded front of an identical earth-covered acceptor magazine to the rear wall of an earth-covered donor magazine.

TEST STRUCTURES

To fulfill the primary requirements of this test, four 12-ft by 25-ft by 7-ft high steel-arch, earth-covered storage igloos (ADC type) were constructed of 8-gage (U. S. standard) corrugated plate steel in accordance with Air Force Drawing AP 33-15-63, omitting certain interior facilities which were not pertinent to the test. The donor igloo had an acceptor igloo located on each side, one at a clear separation distance through earth fill of 6.5 feet, and the other at 13 feet. The distances were determined from the equations

$$\text{Distance} = (0.5)(W\ \text{lb})^{1/3} = 6.5\ \text{ft, and}$$

$$\text{Distance} = (1.0)(W\ \text{lb})^{1/3} = 13.0\ \text{ft}$$

The fourth igloo, used as another acceptor magazine, was located to the rear of the donor magazine with its unbarricaded doors facing the donor magazine. The distance of separation was determined from the equation

$$\text{Distance} = (4.5)(W\ \text{lb})^{1/3} = 59\ \text{ft}$$

Doors were installed on the donor and rear acceptor igloos, and were omitted from the flanking acceptor igloos. The earth fill was compacted during the covering operation, and covered each magazine to a depth of two feet at the highest point of the arches, with the sides graded to a slope of 1 in 1½.

To obtain information pertaining to the degree of protection afforded by personnel shelters at locations somewhat removed from an explosion, three additional structures were built and covered by earth fill. The first was a 36-inch diameter corrugated steel pipe of 20-ft length located in front of the donor magazine with its axis perpendicular to the face of the magazine. The earth fill covering this pipe also closed the end nearest the magazine. This near end was about 45 ft from the magazine such that

$$D = 45 \text{ ft} = (3.5)(W \text{ lb})^{1/3}$$

placing the open far end at 65 ft such that

$$D = 65 \text{ ft} = (5.0)(W \text{ lb})^{1/3}$$

The other two structures were a 4-ft by 4-ft magazette and a 16-ft long, 8-gage steel arch of 6-ft radius located 290 ft in front of the donor magazine with the fronts facing away from the igloo such that

$$D = 290 \text{ ft} = (22.0)(W \text{ lb})^{1/3}$$

Earth fill protected the top, sides, and rears of both structures. The 6-ft arch was left open, while the magazette was fitted with a door. Figure 1 shows the completed igloos and shelters.

The front and rear walls of the igloos were built of nominal 2,500 psi high early strength, reinforced concrete using standard construction techniques. The front wall common to the donor and flanking acceptor magazines was constructed with shear joints between adjacent magazines.

DONOR CHARGES

The donor charges for this test consisted of eight 500-lb GP bombs AN-M-64A1, each of which contained 273 lb of Composition B. While Composition B is about 113% as energetic as TNT in blast yield, the reduction in explosive effect due to the bomb cases permitted the donor charge to be considered as 2,200 lb of TNT, so that $(W \text{ lb})^{1/3} = 13$. The eight bombs were arranged in two rows three feet from the sides of the donor magazine, spaced 6 ft 4 inches from each other. Figure 2 shows the bombs in place. All the donors were detonated simultaneously using a high-voltage power supply.

ACCEPTOR CHARGES

Twelve standard dividing wall spherical acceptor charges, each containing 100 lb of cyclotol and a full complement of detonators, were located in the acceptor magazines as shown by Fig. 3, to indicate whether explosions would be induced by the detonation of the donors. Five of these charges were arranged in a row on wood stands in each flanking acceptor igloo, three feet from the magazine wall adjacent to the donor igloo. The charges were spaced five feet apart with sandbag barricades between them to reduce the possibility of cross-propagation of an explosion within a magazine. Two of the acceptor charges were located in the rear igloo on wood stands 12 ft from the door with a sandbag barricade between them. One was in the magazine center, and the other was three feet from a side wall. Views of all the acceptor charges are presented in Fig. 4.

INSTRUMENTATION

PHOTOGRAPHIC DATA

Six 16mm cameras, set to operate at 8,000 frames per second, were located about 400 ft from the donor igloo, positioned to obtain front, front quarter, and side views of the three adjacent magazines. Two 16mm cameras, set to operate at 1,000 frames per second, were located 750 ft and 2,100 ft from the magazine array, positioned to provide coverage of the entire group. One 16mm camera, operated at 128 frames per second, was located at long range to obtain broad view coverage of the test area. All the cameras used color film.

BLAST PRESSURE DATA

An array of 22 Ballistic Research Laboratory (BRL) self-recording blast pressure gages were installed as shown in Fig. 5 to measure the overpressure wave resulting from the detonation. The gages were buried in the ground with their pressure ports flush with the surface to record the side-on overpressure.

The gages along the southwest, northwest, southeast, north, and east lines were to measure any effects of the earth-covered igloo on the overpressure wave, providing comparisons between the front, sides, and rear of the igloo.

The gages at the A-1 IN, B-1 IN, and B-3 IN locations were to measure the pressure and impulse to be expected within the simulated personnel shelters as compared with the data from the gages in the open at the same distance from the donor magazine. The gages at the SW-1, SW-3A, and SW-3B locations were to provide information on the effect of small barricades on the overpressure wave, correlating with the gages inside and outside the shelters.

TEST RESULTS

The simultaneous detonation of the eight donor charges did not propagate to any acceptor charges, although the flanking acceptor igloos were extensively damaged (Figs. 6 and 7). The acceptor igloo located 6.5 ft from the donor igloo ($0.5 \times W^{1/3}$) was well within the resulting crater, and was displaced and almost totally collapsed (Fig. 8). Three of the acceptor charges in this magazine were sheared apart at the flanges, while the other two were extensively dented.

The acceptor igloo located 13 ft from the donor ($1.0 \times W^{1/3}$) was crushed by the explosion (Fig. 9), but was less broken up. Damage to the acceptor charges ranged from moderate denting to shearing at the flanges.

The rear acceptor igloo located 59 ft from the donor ($4.5 \times W^{1/3}$) was virtually undamaged by the explosion (Fig. 10) although debris accumulated at the front. The acceptor charges inside were undamaged.

The 36-inch, 20-ft culvert; the 6-ft arch structure; and the magazette were not damaged by the blast.

Heavier structural debris (i.e., 200 lb or more) thrown outward by the explosive blast, was largely confined to a radius of 500 feet. Some smaller fragments (60 lb and less) were thrown directly forward to distances up to 2,800 feet. At positions 30 degrees or more off the forward projected axis of the donor magazine there was no evidence of fragments beyond 2,000 feet.*

*The values of 2,800 ft and 2,000 ft were derived from an inspection of the fragment area following the similar Test No. 2, E-6923. It is considered likely that fragment patterns were similar for the two tests; however, there is no direct evidence that they were the same.

Although the camera coverage was not planned to provide information on the height attained by the earth thrown up by the explosion, later analysis permitted this to be estimated at 600 feet. A technical motion picture (No. 144, Earth-Covered, Steel-Arch Magazine Propagation Tests--1963), including this test and the subsequent Test No. 2, E-6923, has been produced and given limited distribution.

The data derived from the BRL gages is presented in Table 1, while the identification data for the individual gages is listed in Appendix A.

The overpressure data as a function of the scale distance is presented in Fig. 11. The scale distance was determined (Ref. 5) from the equation:

$$\text{Scale distance} = \frac{(\rho/\rho_0)^{1/3}\ (\text{actual distance})}{W^{1/3}}$$

where ρ = local atmospheric density

and ρ_0 = sea level atmospheric density at 1,013 millibars and 59°F.

The overpressures used were the peak pressures registered by the gages rather than extrapolated pressures (in the case of a sharply rising pressure front), or average peak pressures (in the case of a slowly rising and falling pressure wave). It is acknowledged that inertia in the gage components affects the record; however, it is apparent that the igloo also had a definite effect on the overpressure wave emanating from the detonation. It is uncertain whether particular anomalies in the records result from gage effects or from the effect of igloo construction. The data, as presented in Fig. 11, have been converted to standard sea level conditions according to the equation

$$\frac{\text{Local overpressure}}{\text{Local ambient pressure}} = \frac{\text{Sea level overpressure}}{\text{Sea level ambient pressure}}$$

in order to show a comparison with the overpressure to be expected from the detonation (on the surface at sea level) of the same quantity of TNT. This overpressure curve was derived from the data in the BRL Memorandum Report No. 1518 of April 1964 by C. N. Kingery and B. F. Pannill

TABLE 1. BRL Gage Data for Test No. 1, F

Ambient Conditions: 941.9 mbar, 48°F

Station	Direction from donor	Distance (ft)	Peak over-pressure (psi)	Converted scale distance	Overpressure converted to sea level (psi)	Impulse (psi-msec)	Impul conver to sea (psi-m
N-1	Rear Quarter	65	3.07	4.85	3.30	37.4	38
[1]N-2	Rear Quarter	590	0.33	44.0	0.35	----	--
N-3	Rear Quarter	1180	0.15	88.0	0.16	4.6	4
[2]E-1	Rear Quarter	65	3.39	4.85	3.65	133.3	139
E-2	Rear Quarter	590	0.35	44.0	0.38	9.1	9
E-3	Rear Quarter	1180	0.19	88.0	0.20	4.2	4
NE-1	Rear	59	3.49	4.36	3.76	32.9	34
NW-1	Side	65	4.14	4.85	4.45	49.0	50
NW-2	Side	130	2.07	9.7	2.23	24.7	25
SE-1	Side	65	4.34	4.85	4.66	60.4	62
[3]SE-2	Side	130	----	----	----	----	--
[4]A-2 OUT	Front	50	34.87	3.68	37.55	44.1	45
A-1 IN		50	19.41	3.68	20.90	351.7	365
SW-1		65	16.93	4.85	18.21	159.1	165
SW-2	Front	130	13.01	9.7	14.01	155.8	161
[5]B-2 OUT	Front	280	3.64	20.8	3.92	24.4	25
B-1 IN		280	2.43	20.8	2.62	70.3	73
[6]B-3 IN		285	0.88	21.2	0.95	----	--
SW-3A		290	1.26	21.6	1.36	52.7	54
SW-3B		290	1.38	21.6	1.49	49.0	50
SW-4	Front	590	0.99	44.0	1.07	23.1	24
SW-5	Front	1180	0.44	88.0	0.47	9.9	10

[1]Duration and impulse incorrect due to low battery voltage in gage.

[2]Duration and impulse data incorrect.

[3]No record from gage.

[4]Duration and impulse incorrect due to bent motor shaft.

[5]Data corrected for 10 rpm motor.

[6]Gage failed to run; overpressure data unreliable.

A

, Gage Data for Test No. 1, E-6819

Conditions: 941.9 mbar, 48°F.

erpressure nverted to ea level (psi)	Impulse (psi-msec)	Impulse converted to sea level (psi-msec)	Scale impulse	Pulse duration (msec)	Pulse duration converted to sea level (msec)	Scale pulse duration
3.30	37.4	38.9	2.99	40.1	39.0	3.00
0.35	----	----	----	----	----	----
0.16	4.6	4.8	0.369	65.1	63.4	4.87
3.65	133.3	139.8	10.76	132.3	128.8	9.91
0.38	9.1	9.4	0.723	61.7	60.1	4.62
0.20	4.2	4.4	0.338	64.5	62.7	4.82
3.76	32.9	34.2	2.63	25.2	24.5	1.88
4.45	49.0	50.9	3.92	33.1	32.2	2.48
2.23	24.7	25.7	1.97	33.6	32.7	2.51
4.66	60.4	62.8	4.83	43.6	42.4	3.26
----	----	----	----	----	----	----
37.55	44.1	45.8	3.52	3.27	3.2	0.244
20.90	351.7	365.5	28.1	40.9	39.8	3.06
18.21	159.1	165.4	12.72	16.1	15.7	1.21
14.01	155.8	161.9	12.46	46.5	45.3	3.48
3.92	24.4	25.4	1.95	26.6	25.8	1.984
2.62	70.3	73.1	5.62	47.5	46.2	3.48
0.95	----	----	----	----	----	----
1.36	52.7	54.8	4.21	58.5	56.9	4.38
1.49	49.0	50.9	3.92	53.9	52.4	4.03
1.07	23.1	24.0	1.85	64.9	63.2	4.86
0.47	9.9	10.3	0.792	62.0	60.3	4.64

e in gage.

B

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The data, as presented in Fig. 11, indicate that the short-range and mid-range overpressures off the igloo front (as shown by the SW line of gages) were somewhat enhanced over the pressures to be expected from a detonation of the same explosive in the open, while the corresponding overpressures off the sides and rear of the igloo were substantially reduced (as shown by the N, E, NW, and SE lines of gages). It is of interest to note that the test data tend to approach the surface burst curve as the distance from the detonation increases.

The overpressure recorded at the A-2 OUT position was less than is indicated by the trend of the other pressure data in the open along the SW leg. This may have been due to the inability of the gage to follow the sharply rising pressure front this close to the detonation, or may have been caused partially by a faulty gage. While it was subsequently determined that the motor shaft in this gage was bent, causing the gage to run slow and register incorrect pulse duration time and impulse, this should not have caused an error in the peak pressure recording. The other gages along the SW leg (SW-2, B-2 OUT, SW-4, SW-5) show a pressure wave (Fig. 12) that generally follows the typical pattern.

The overpressure experienced inside the 36-inch, 20-ft pipe (position A-1 IN) was reduced from the value recorded outside. A reproduction of the trace from this gage is shown in Fig. 13. It is unknown at this time whether the step at the front of the curve is real or was caused by a faulty gage. The overpressure developed within the six-foot arch shelter (location B-1 IN) appears to have developed into a pulsating or ramming effect as can be seen from the curves shown in Fig. 13. This pulsation was present to a lesser degree within the 20-ft pipe. Unfortunately, the gage within the magazette failed to run, so the spike representing the overpressure is somewhat unreliable. The additional random trace may have been created during installation or removal of the gage.

Reproductions of the records from the gages located in front of the shelters are presented in Fig. 14. These records indicate that a simple barricade tends to flatten an overpressure wave near the side away from the detonation, while the data presented in Fig. 11 for these positions (SW-1, SW-3A, SW-3B) show that the peak overpressure has been reduced below the value occurring in the open at the same distance.

Reproductions of the records obtained from the gages located along the N and E lines (extending at right angles from the rear of the donor igloo) are presented in Fig. 15. It can be seen that they show the classical shape for a shock wave passage. This figure also includes the record obtained from the gage located immediately in front of the rear acceptor igloo. This record shows four definite steps in the overpressure curve, that may be due to reflections between the rear acceptor magazine and the group of donor and acceptor magazines in front.

The overpressures measured by these gages form consistent curves when plotted as a function of scaled distance, as in Fig. 11. The general effect of the igloo was to reduce the overpressures experienced to its rear.

The overpressure traces of Fig. 16, recorded by the gages located off the sides of the igloo (along the NW and SE lines) again show a typical pattern. Reference to Fig. 11 shows that their peak overpressures match the data recorded by the gages behind the donor igloo.

A phenomenon that has become evident is the series of apparent low-amplitude pressure pulses which preceded the main shock wave off the front of the donor igloo. These were recorded by almost every gage along the SW line (Figs. 12, 13, and 14), but were not recorded by any gages to the sides or rear (Figs. 15 and 16). Since only the gages in front recorded these pulses, it seems improbable that they can be attributed to a ground shock wave. The motion picture records of the explosion show a flash of light around the doors of the donor igloo about 19 milliseconds before the rise of the earth over the magazine, so it is speculated that a small shock wave or series of shocks accompanied the light flash, and were focused out the front by the igloo construction. Further detailed analysis of these small overpressure excursions is beyond the scope of this report.

The scaled impulse and scaled positive phase duration data are shown as a function of scaled distance in Figs. 17 and 18. To obtain scaled impulse, the measured impulse was first converted to values which would be expected under standard sea level conditions according to the equation

$$I_o = I_z \, (T_z/T_o)^{1/2} \, (P_o/P_z)^{2/3}$$

where I_o = Impulse at sea level

I_z = Local measured impulse

T_z = Local ambient temperature

T_o = Sea level standard temperature (59°F.)

P_o = Sea level standard pressure (1013 millibars)

P_z = Local ambient pressure

The converted impulse values were then scaled to the cube root of the explosive weight in pounds, or

$$\text{Scaled impulse} = \frac{I_o}{W^{1/3}}$$

The scaled positive phase duration was determined by first converting the measured duration to that which would be expected at sea level through the equation

$$t_o = t_z \, (P_z/P_o)^{1/3} \, (T_z/T_o)^{1/6}$$

where

t_o = duration at sea level

t_z = local measured duration

P_z, P_o, T_z, T_o = as used above.

The converted duration values were then scaled through the equation

$$\text{Scale duration} = \frac{t_o}{W^{1/3}}$$

The data presented in Fig. 17 generally agree with the overpressure data of Fig. 11, when compared to the scaled impulse to be expected from the detonation in the open at sea level of a hemispherical charge of TNT on the surface. (This comparison curve was derived from the curve transmitted in the Ballistic Research Laboratories letter CNKingery/sri/31258 of 11 Sept 1964 to NOTS.)

The scaled pulse duration data as a function of scale distance presented in Fig. 18 is compared to a TNT surface-burst curve which was derived from data included in the Ballistic Research Laboratories Report No. 1410 of October 1964.

CONCLUSIONS

Although no acceptor charges were initiated during this test, the subsequent condition of the charges in the flanking acceptor igloos indicated that this would not necessarily repeat, so a spacing factor of $0.5 \times W^{1/3}$ and $1.0 \times W^{1/3}$ between buried igloo magazines is too low for safe storage.

The excellent condition of the rear acceptor magazine after the test indicates that a space factor of $4.5 \times W^{1/3}$ from the rear of a buried donor magazine to the unbarricaded front of an acceptor magazine is acceptably safe.

Figures 1 through 18 illustrate the characteristics and results of Test No. 1, conducted under E-6819.

FIG 1. Igloo Magazine and Shelter Complex.

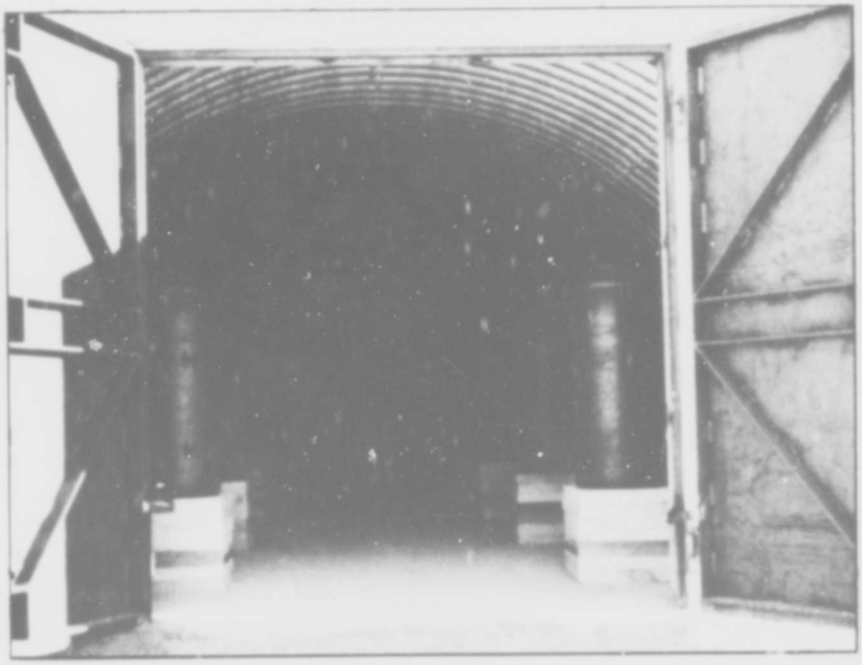


FIG. 2. Donor Charges.

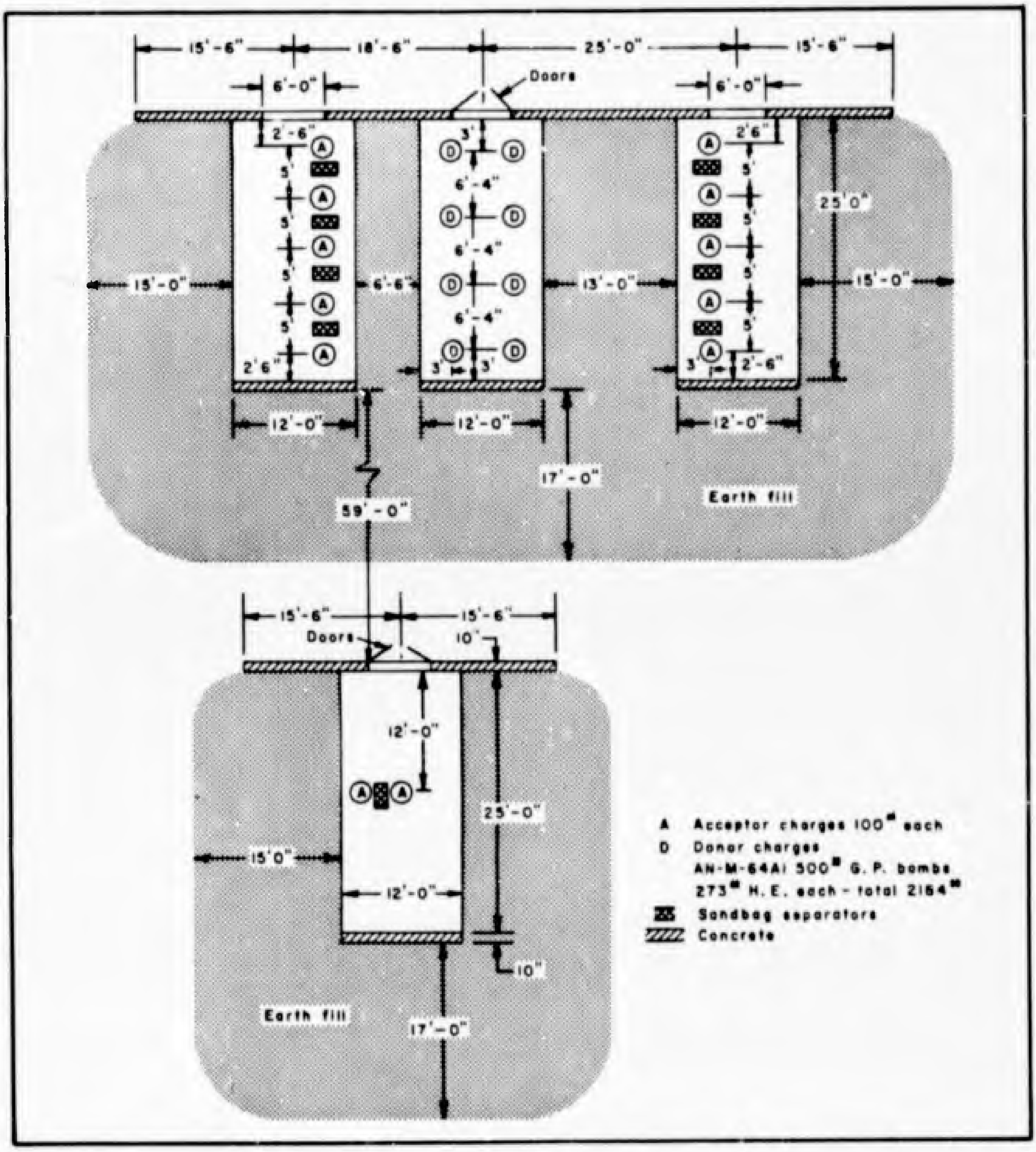


FIG. 3. Igloo Plan.

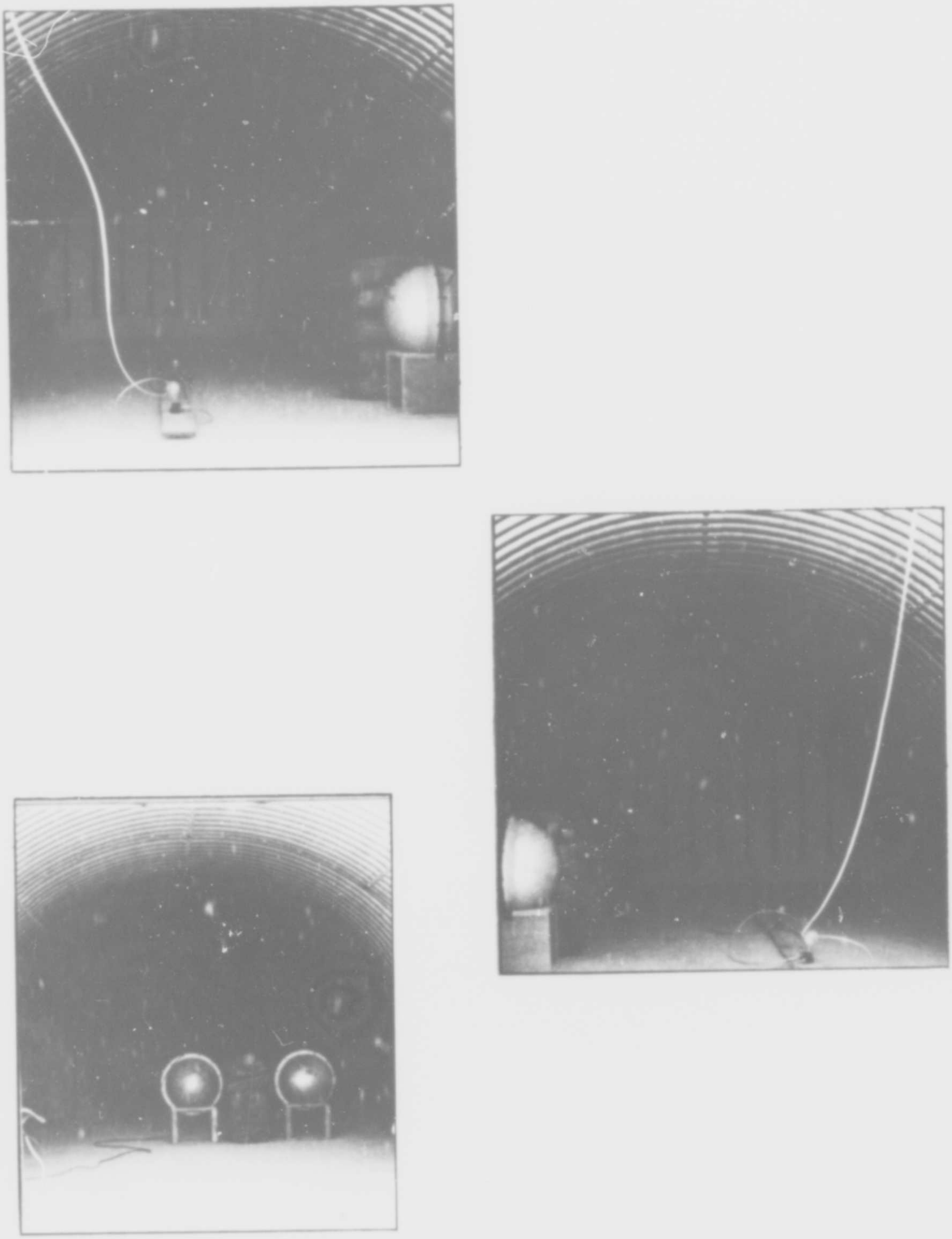


FIG. 4. Acceptor Charges.

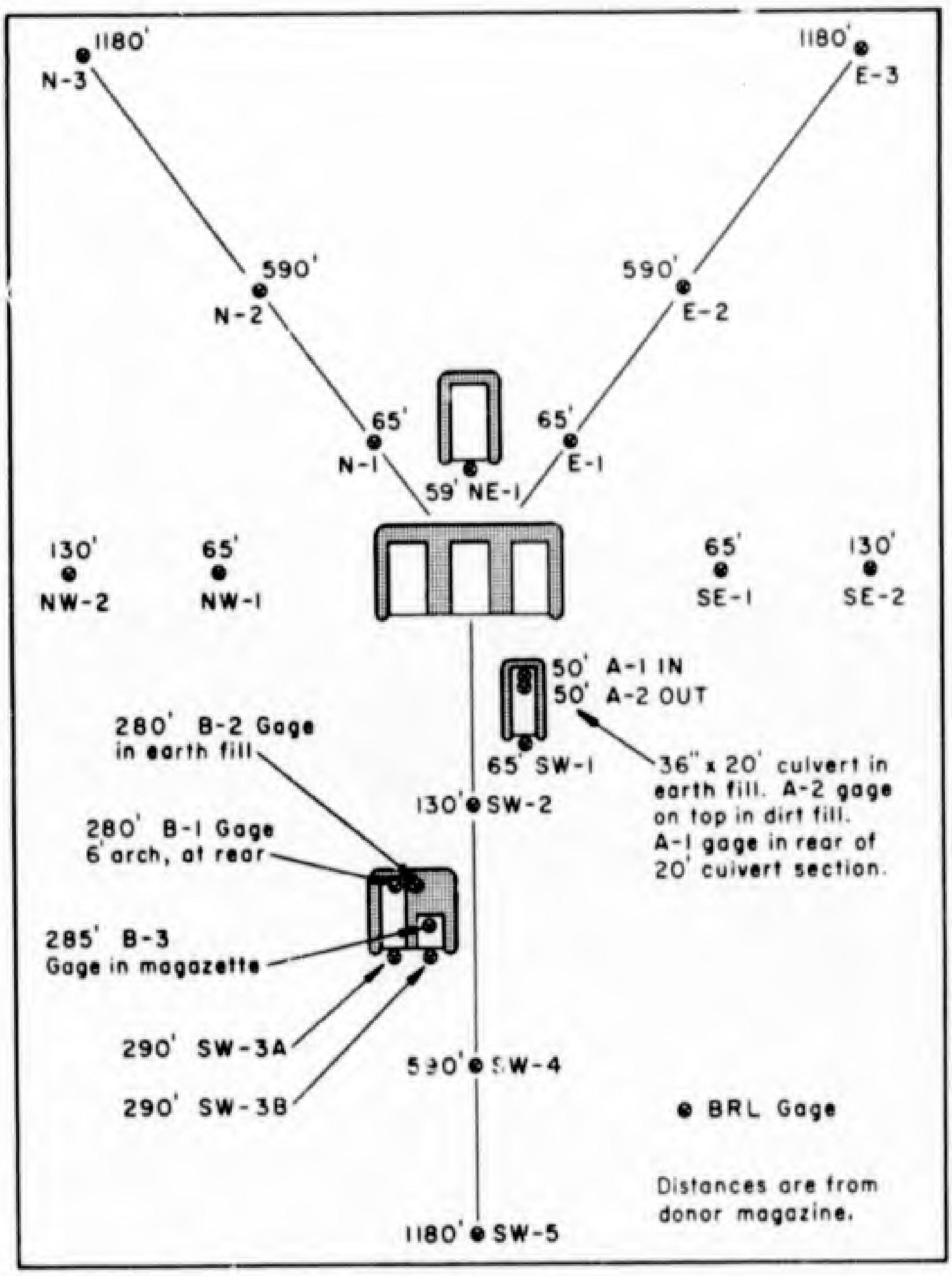
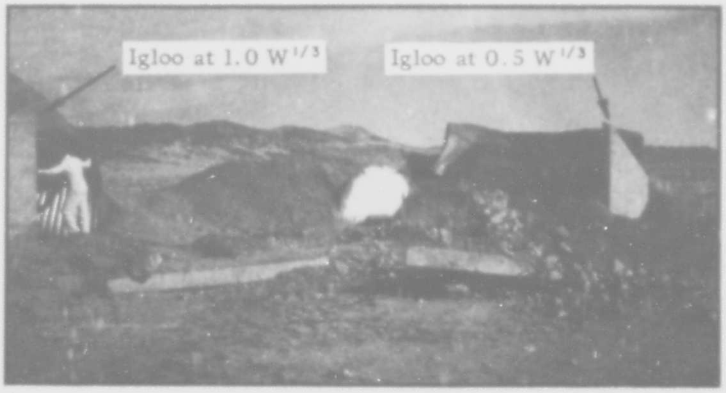


FIG. 5. E-6819 Blast Pressure Gage Locations.

FIG. 6. Igloo Complex After Test.



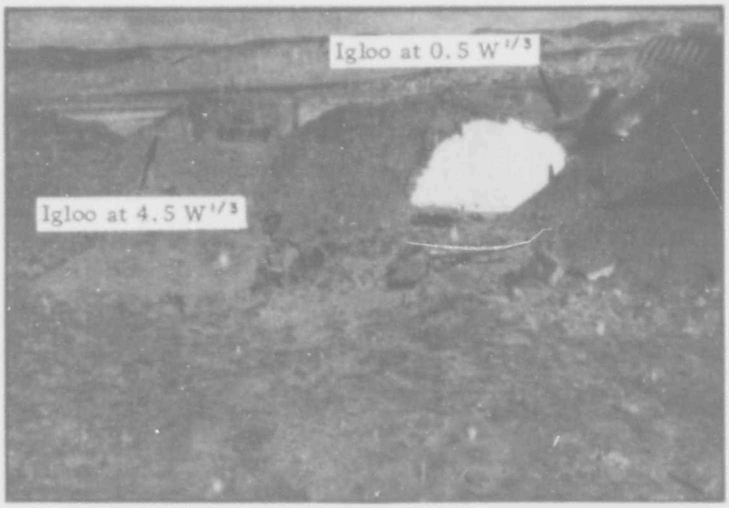


FIG. 7. Magazine After Firing Test.

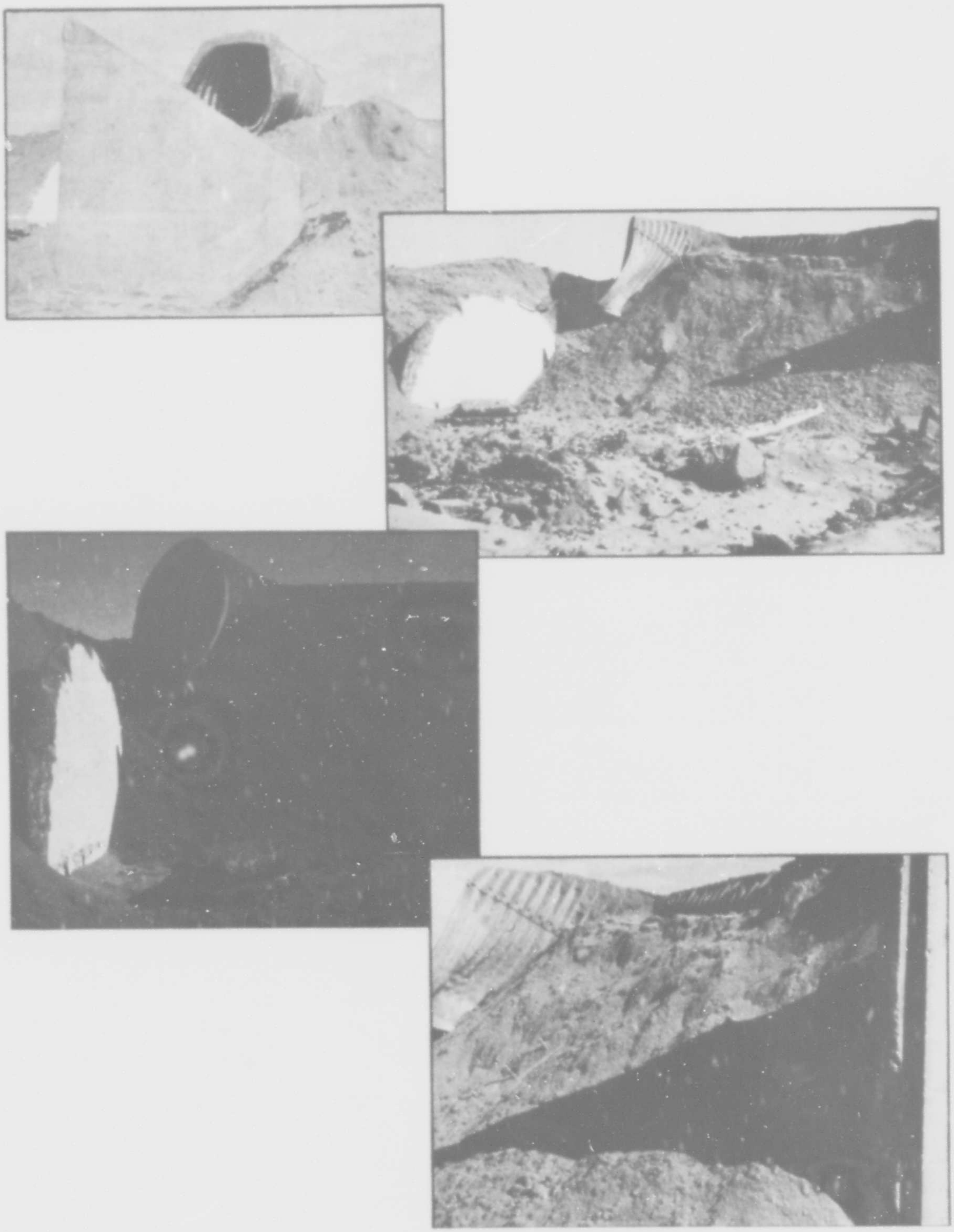


FIG. 8. Magazine at 6.5-Ft Separation.

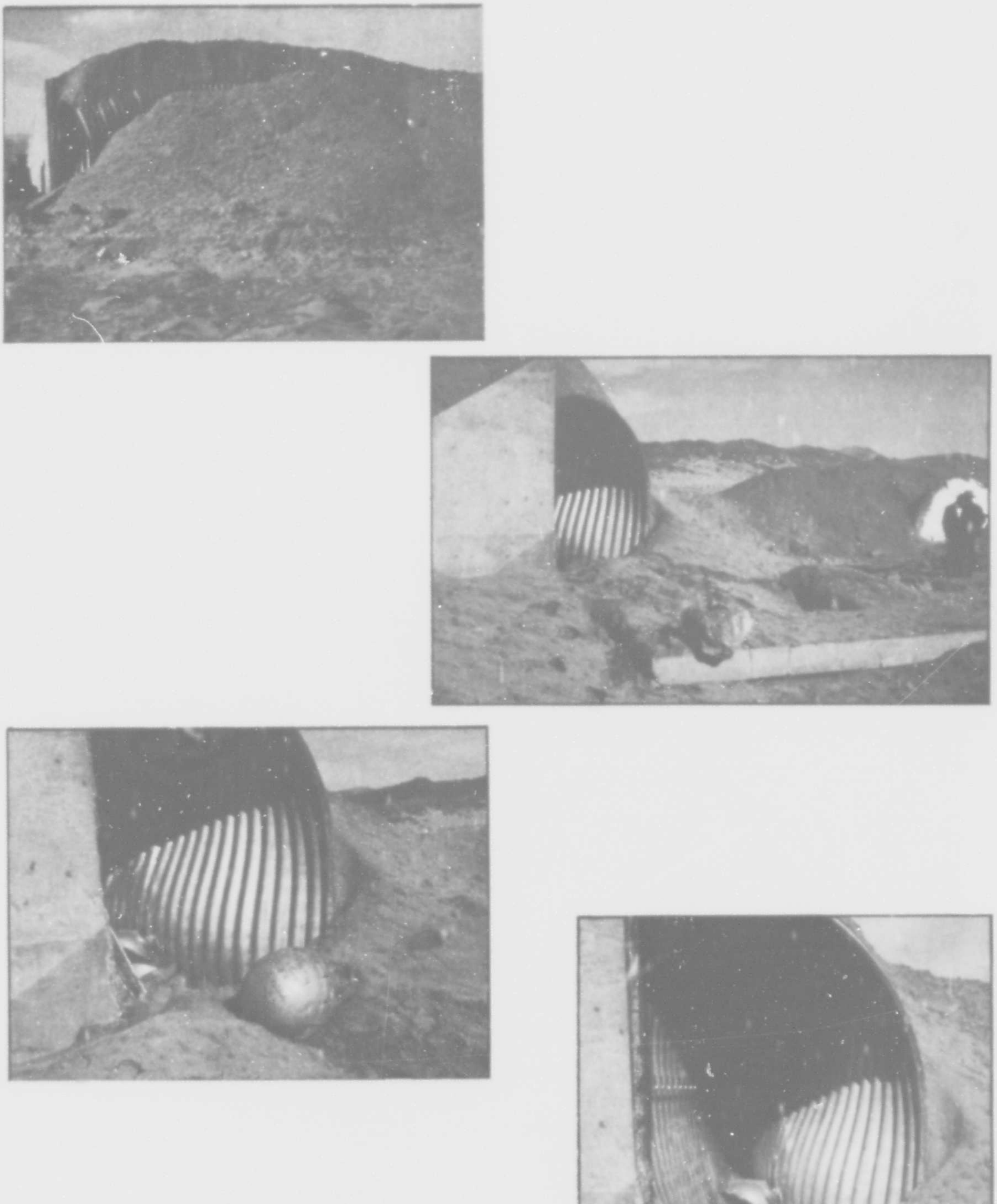


FIG. 9. Entrance to the Magazine at 13-Ft Separation.

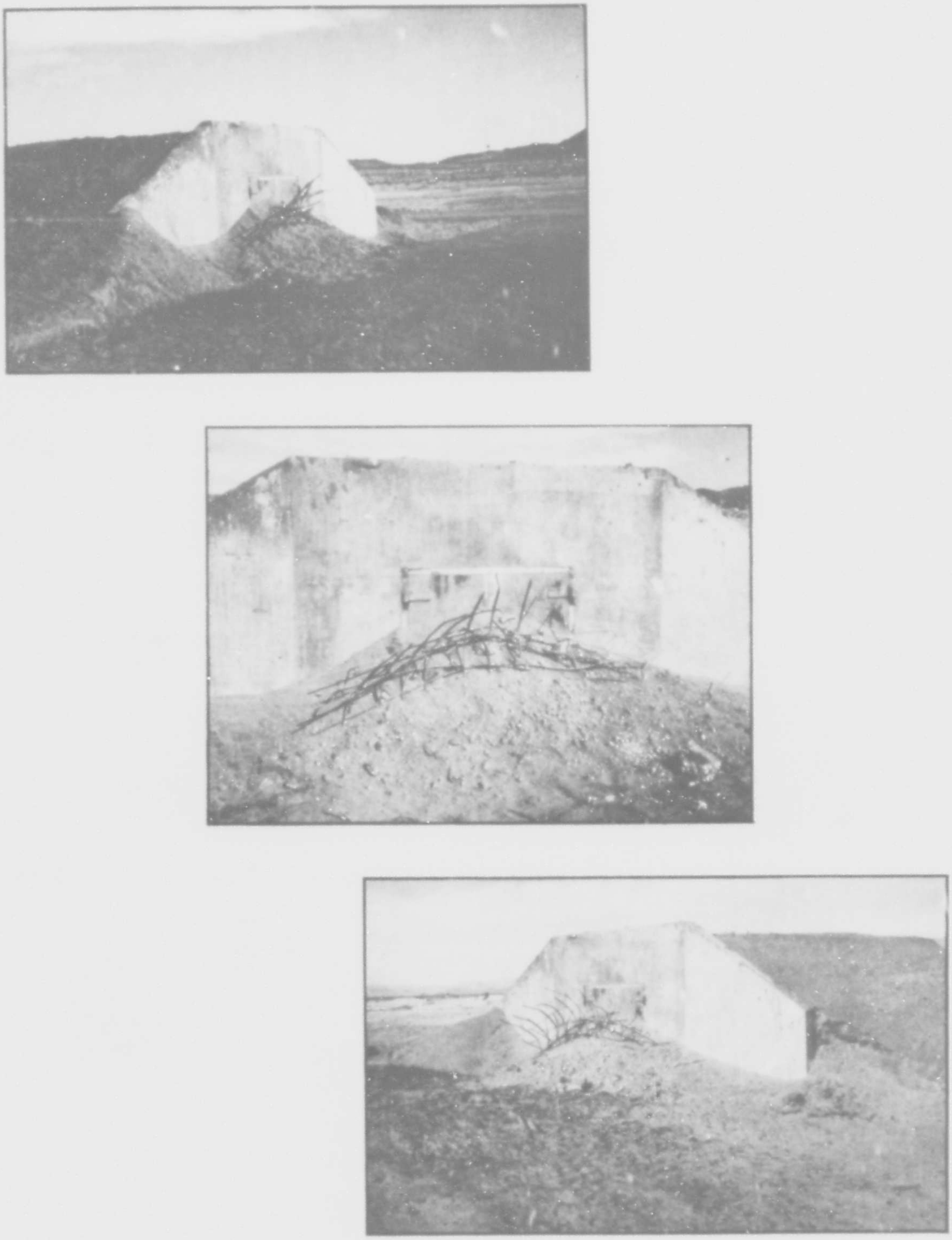


FIG. 10. Undamaged Rear Magazine.

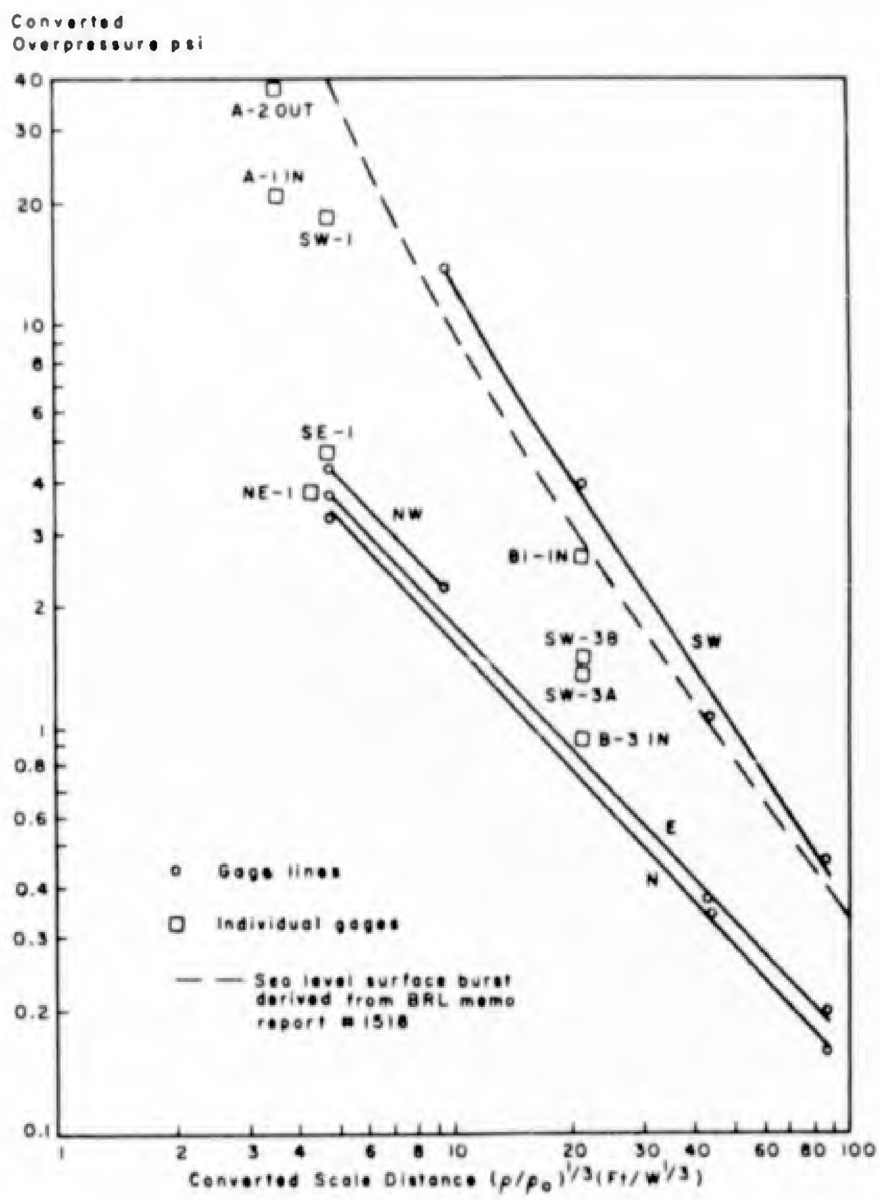


FIG. 11. Overpressure Versus Scale Distance.

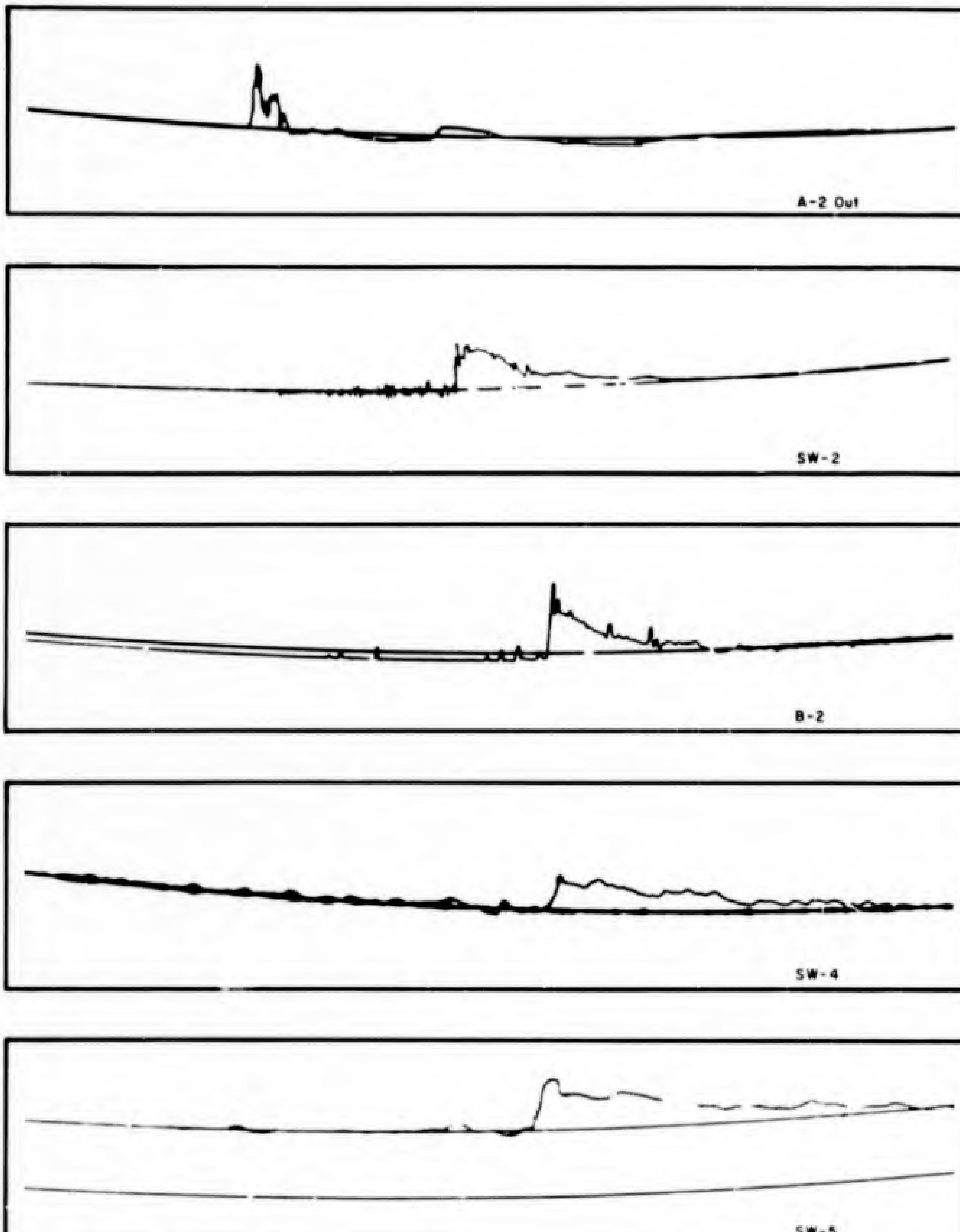


FIG. 12. Records From BRL Gages Along SW Line (Donor Front).

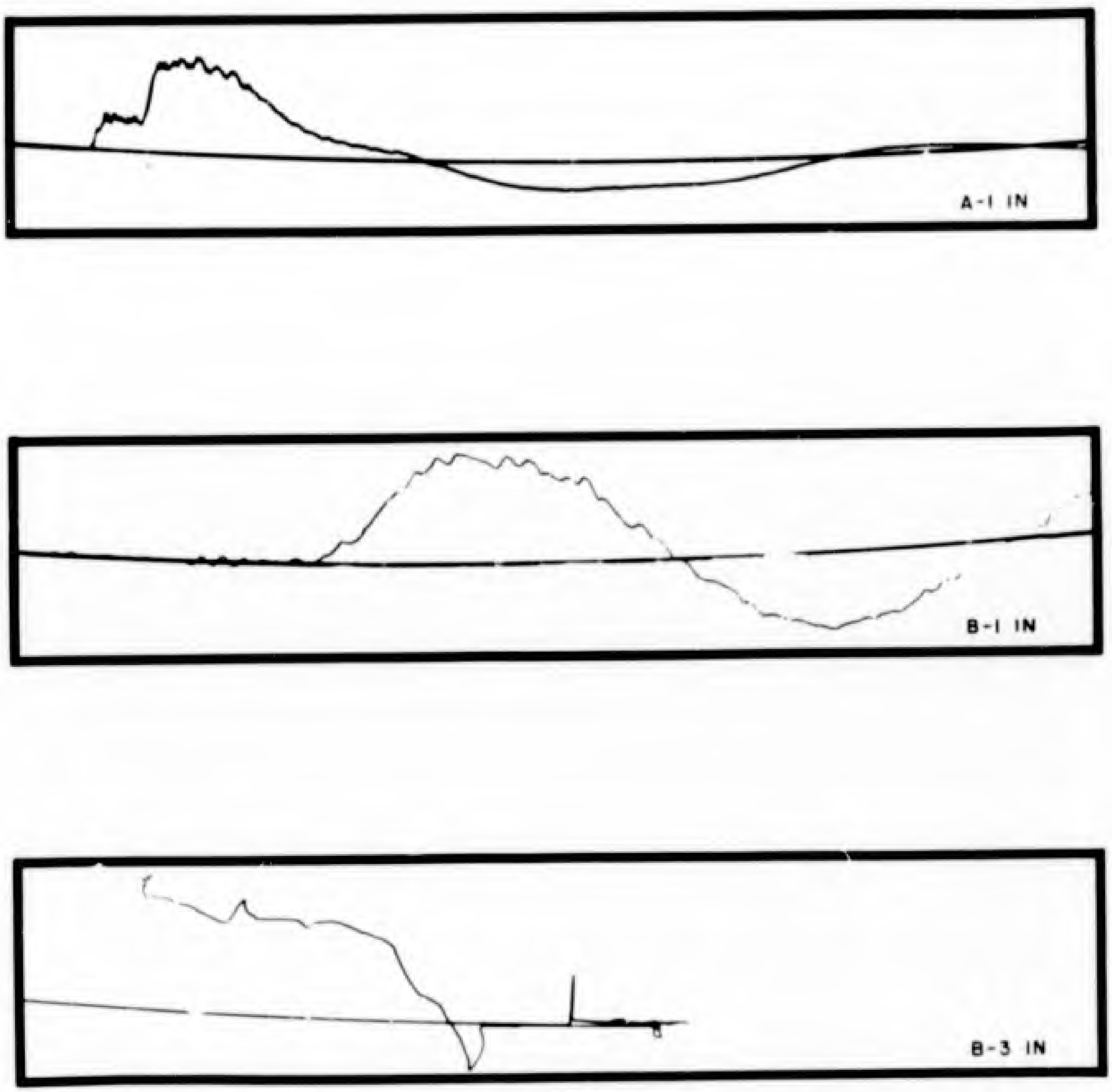


FIG. 13. Records From BRL Gages Within Shelters.

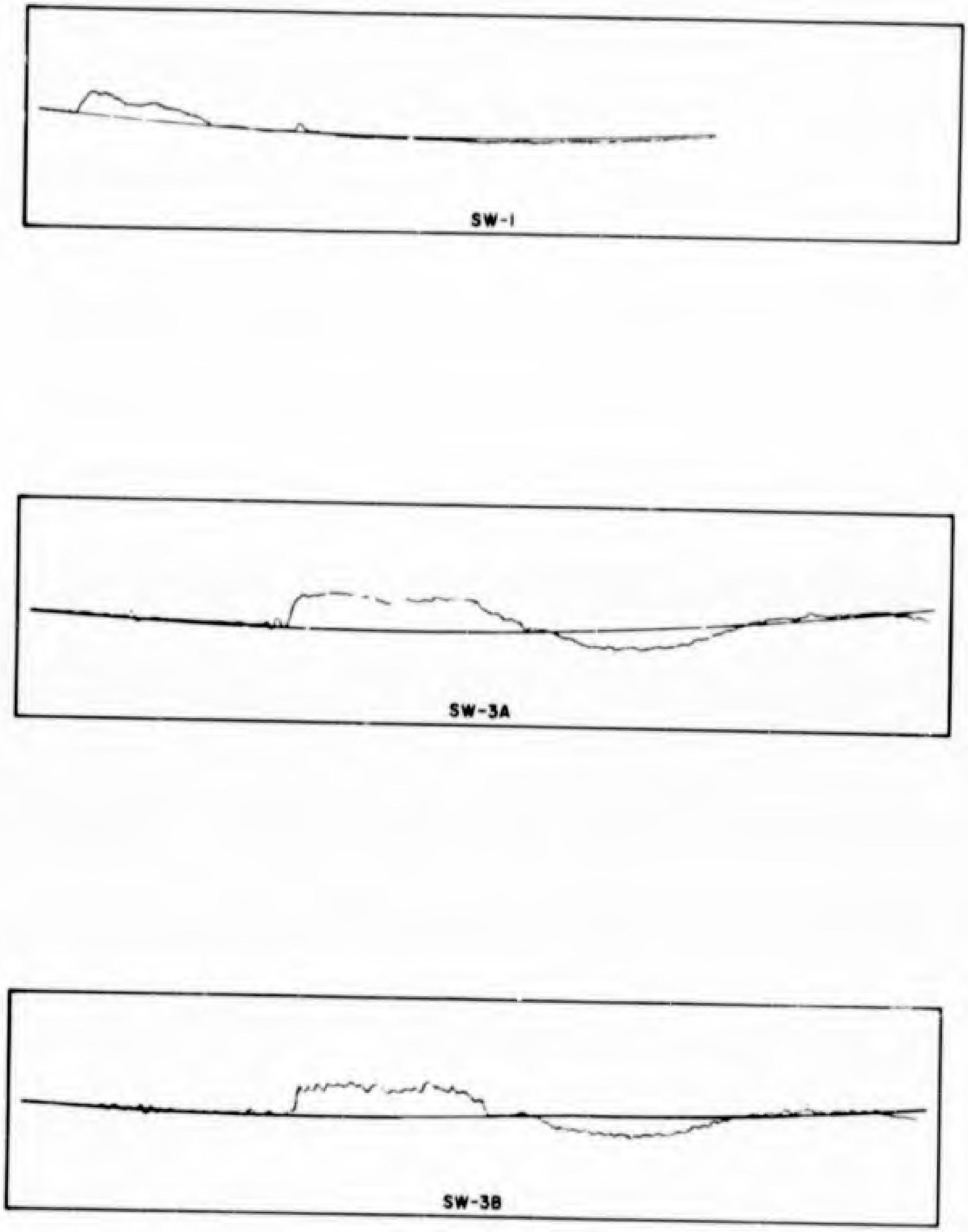


FIG. 14. Records From BRL Gages in Front of Shelters.

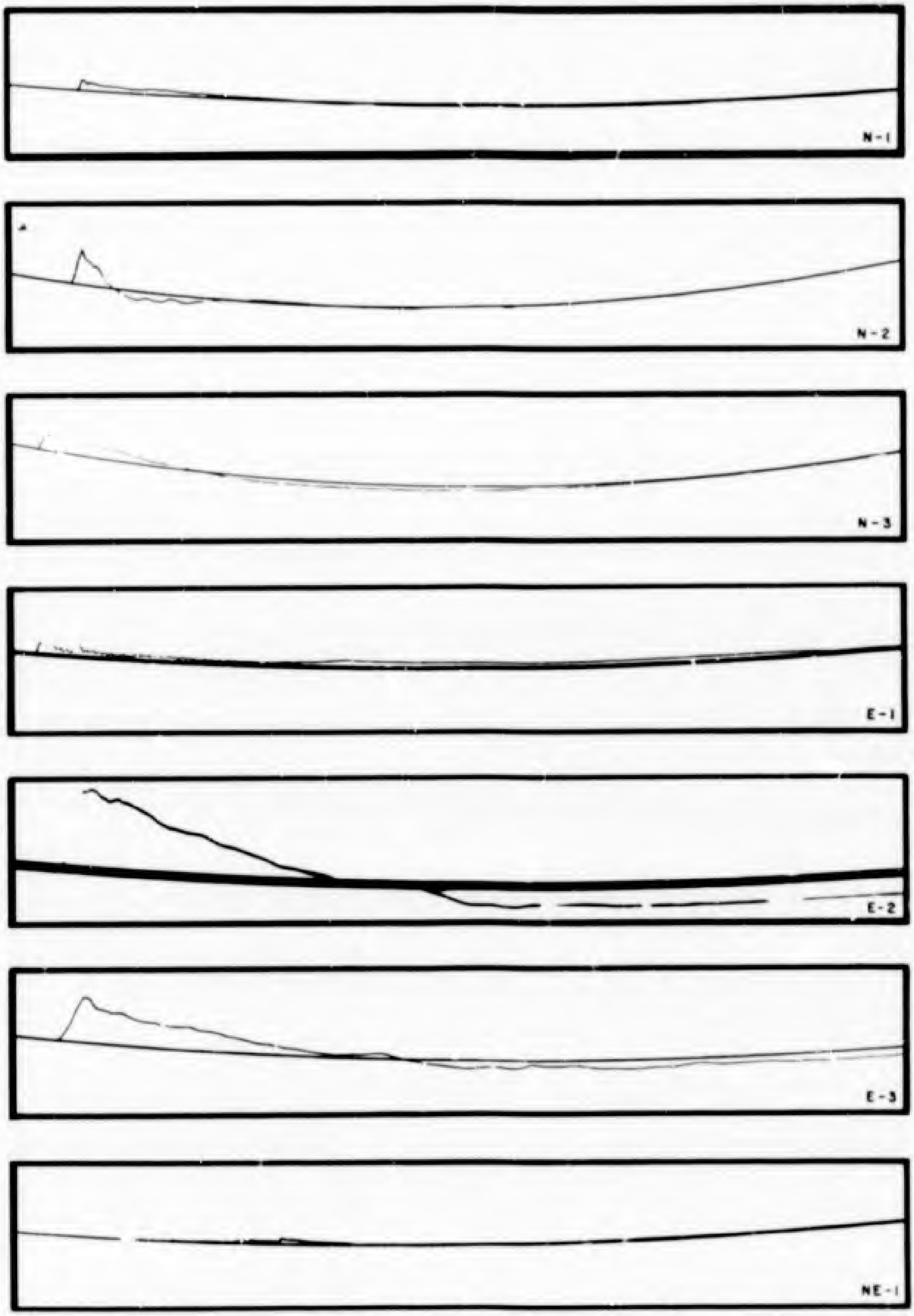


FIG. 15. Records From BRL Gages Along North and East Lines (Donor Rear Quarter) and at Rear Acceptor Igloo.

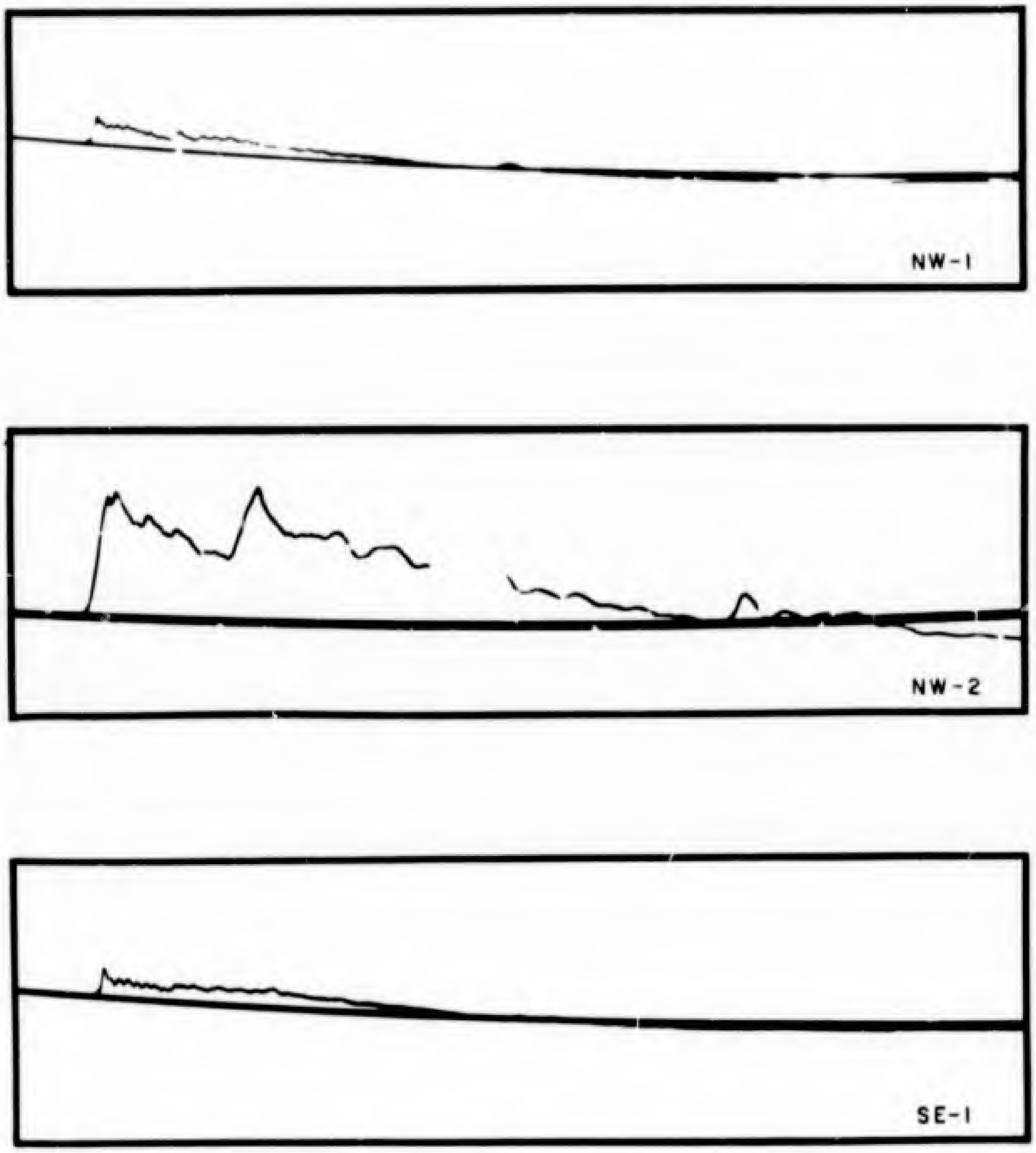


FIG. 16. Records From BRL Gages Along Northwest and Southeast Lines (Donor Sides).

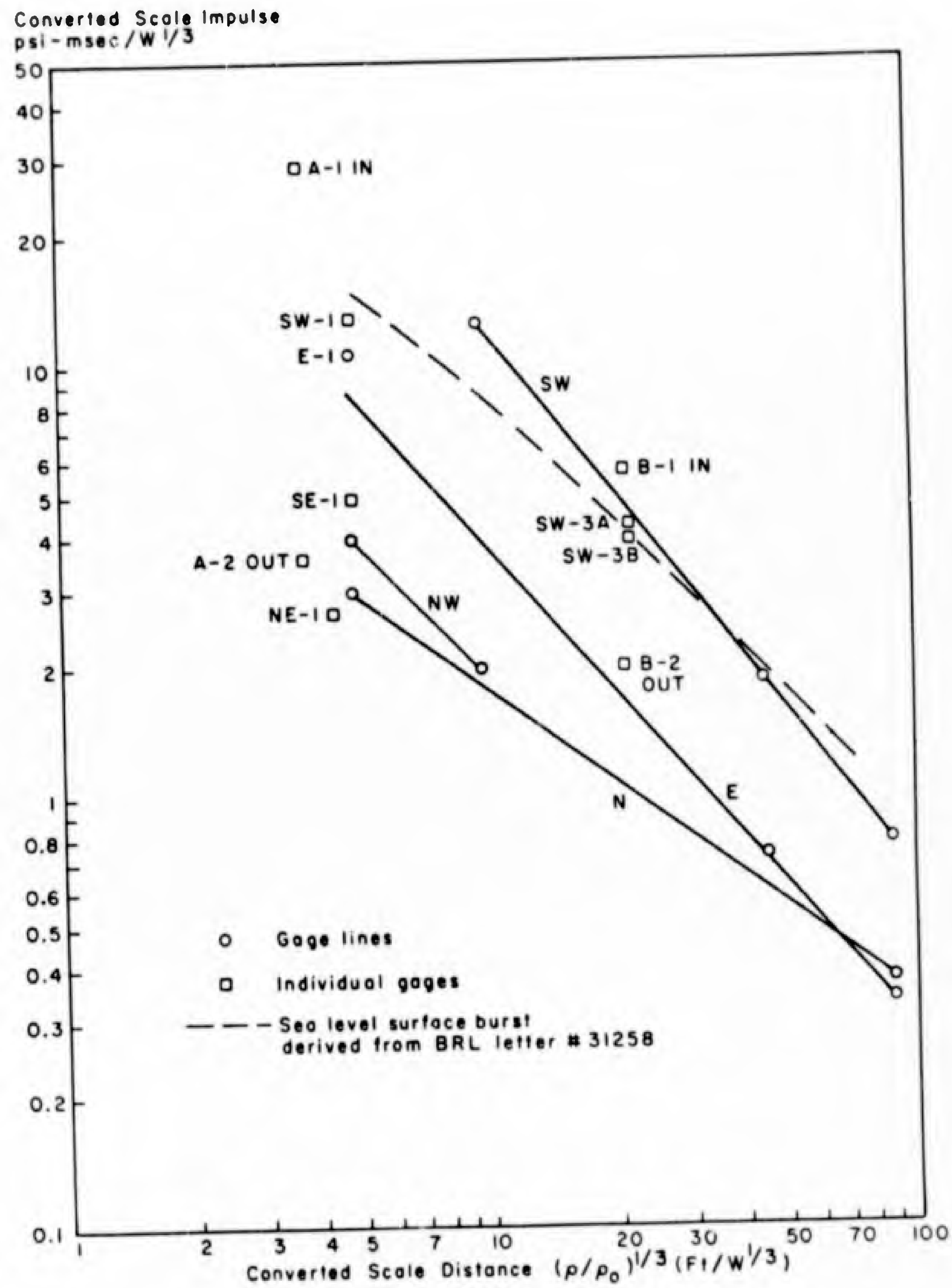


FIG. 17. Scale Impulse Versus Scale Distance.

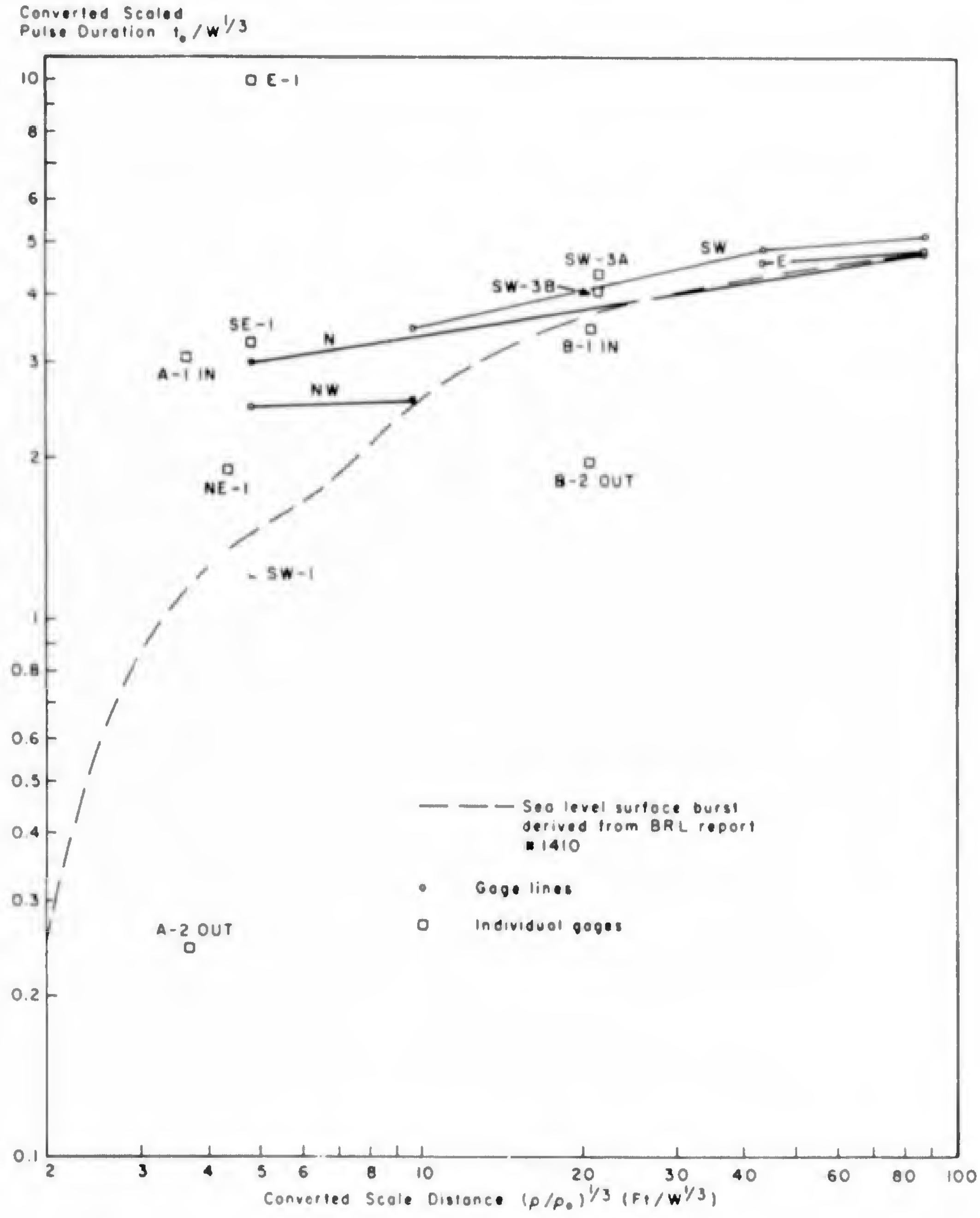


FIG. 18. Scale Pulse Duration Versus Scale Distance.

SECTION TWO

TEST NO. 2 (E-6923)

Since the previous test showed that a factor of 1.0 x $W^{1/3}$ was insufficient spacing through earth fill between adjacent magazines for safe storage of explosives, Test No. E-6923 was conducted using distances determined by 1.5 x $W^{1/3}$ and 2.0 x $W^{1/3}$. This test was conducted at 1106 hours PST on 6 April 1962 at the Victor Range of NOTS.

TEST STRUCTURES

The igloos for this test consisted of the undamaged rear magazine remaining from test E-6819, with an additional igloo built on each side, using the same specifications and construction techniques as those used in the former test. The compressive strength test of the nominal 2,500 psi high early strength concrete gave results ranging between 2,700 and 3,900 psi.

The clear separation distances between the center and flanking magazines were set at 19.5 ft and 26 ft, to satisfy the equations

$$19.5 \text{ ft} = (1.5)(W \text{ lb})^{1/3} \text{ and}$$

$$26 \text{ ft} = (2.0)(W \text{ lb})^{1/3}$$

Doors were included on the donor magazine, but were omitted from the acceptor magazines. As before, shear joints were built into the front wall common to the donor and flanking acceptor igloos. The completed group of igloos is shown in Fig. 19. The undamaged simulated personnel shelters remaining from the previous test were again instrumented for comparison of the data.

DONOR CHARGES

The donor charges for this test consisted of nine 350-lb Mk 54-1 depth bombs, each containing 248 lb of HBX-1, for a total of 2,232 lb of high explosive. While HBX-1 is about 121% as energetic as TNT, the reduction in explosive effect due to the bomb cases permitted the total donor charge to be considered as 2,200 lb of TNT, so that $(W \text{ lb})^{1/3} =$ 13. Eight of the depth bombs were arranged in two rows three feet from the sides of the igloo, as shown in Fig. 20, with the ninth bomb in the center. Figure 21 shows the donor charges in place (in their shipping containers) at the completion of test preparations. All nine bombs were detonated simultaneously.

ACCEPTOR CHARGES

Ten standard dividing wall acceptor charges, each containing 100 lb of cyclotol and a full complement of detonators, were arranged in the acceptor magazines as shown in Fig. 20 to indicate whether explosions would be induced by the detonation of the donor charges. The acceptor charges were spaced five feet apart in a row three feet from the magazine wall adjacent to the donor igloo, with sandbag barricades between the charges to reduce the probability of cross-propagation within a magazine. The acceptor charges in place for the test are shown in Fig. 22.

INSTRUMENTATION

PHOTOGRAPHIC COVERAGE

Seven 16mm cameras set to operate at 8,000 frames per second were located about 400 ft from the donor igloo, positioned to obtain front, rear, and side views of the three magazines. Two 16mm cameras set to operate at 1,000 frames per second were located 750 ft and 2,100 ft from the magazines, positioned to provide 3/4 rear views of them. Four 16mm and 35mm cameras, operated at 120 to 500 frames per second, were located at long range to provide overall coverage of the test area. All cameras used color film.

BLAST PRESSURE DATA

An array of 17 BRL self-recording blast-pressure gages was installed to the front and rear of the donor igloo, as shown in Fig. 23, to measure the overpressure wave developed by the detonation. The gages were buried in the ground with the pressure ports flush with the surface, to record the side-on overpressure.

The gages along the south and north lines were to measure the effects of the igloo construction on the overpressure wave, providing comparisons between the front and rear of the igloo, and with the results of the first test of the series, E-6819. Gages were again installed inside, outside, and in front of the small shelters to obtain additional data on the effect of the shelters on the overpressure wave.

TEST RESULTS

The simultaneous detonation of the nine donor charges did not propagate to any acceptor charges, although the donor igloo was destroyed (Fig. 24), and the acceptor igloos were damaged (Fig. 25). Each of the donor charges punched a crater in the donor magazine floor (Fig. 26). The earth crater was about 14 ft wide at the base and 48 ft wide at the top; however, the latter measurement applies at a height of one to two feet above the top of the original earth fill where the earth was heaped up. The crater was entirely above the original floor level. The remaining mound of earth at the rear was approximately four feet above floor level. The rear concrete closure wall was broken up and thrown approximately 120 ft to the rear of its original position. The minimum thickness of earth cover remaining between the crater and the closer igloo was four to five feet. The corresponding distance at the farther igloo approximated 10 feet.

The acceptor igloo spaced 19.5 ft (1.5 x $W^{1/3}$) from the donor igloo was not destroyed, although the head wall was blown outward and fell forward, and the side of the metal arch nearest the donor igloo was forced inward about 13 inches. A large transverse crack and several smaller cracks occurred in the floor, and multiple cracks developed in the rear concrete wall.

Three of the five acceptor charges in this igloo were dislodged from their stands, but virtually no damage was sustained by any of them (Fig. 27a).

The acceptor igloo located 26 ft (2.0 x $W^{1/3}$) from the donor magazine suffered less damage than the nearer acceptor igloo. The concrete head wall was separated from the steel arch and forced slightly outward. The side of the metal arch adjacent to the donor charges was forced inward approximately six inches from the original position. The concrete floor cracked, but not as extensively as in the other acceptor magazine. The rear concrete closure wall was also cracked.

Three of the five acceptor charges were upset from their stands, but again they sustained virtually no damage (Fig. 27b).

The deflection of the metal arches of the two acceptor igloos was measured at six sections as shown by Fig. 28. The results of the measurements of the igloo at 19.5 ft are shown in Figs. 29, 30, and 31. Figs. 32, 33, and 34 show the results of the measurements of the magazine at 26 feet.

Based on the photographic data, the estimated maximum height of the earth-cover travel above the magazine was 1,000 ft, although the bulk of the projected mass probably did not exceed 400 feet. The resulting spread of earth on the ground extended about 500 ft to each side of the igloos, about 100 ft to the front, and about 300 ft to the rear. The general pattern is indicated in Fig. 24.

The spread of heavier structural debris (200 lb or more) was largely confined to a radius of 500 ft; however, some sizeable fragments were thrown directly forward 2,900 feet. These included reinforced concrete fragments weighing up to 60 lb and a steel door fragment weighing 155 pounds. These large fragments were confined to a limited sector within 30° of each side of the forward axis of the donor magazine. There was no evidence of fragments beyond 1,800 ft outside this 60° sector.

The data derived from the ERL pressure gages is presented in Table 2, and the gage identification is listed in Appendix B.

TABLE 2. BRL Gage Data for Test No. 2,

Ambient Conditions: 948.7 mbar, 77

Station	Direction from donor	Distance (ft)	Peak over-pressure (psi)	Converted scale distance	Overpressure converted to sea level (psi)	Impulse (psi-msec)	Impu conve to sea (psi-m
[1]S-1	Front	65	----	----	----	----	--
S-2	Front	130	10.08	9.67	10.78	122.80	130
S-3A OUT	Front	131	9.63	9.75	10.29	105.97	112
S-3A IN		131	7.47	9.75	7.98	159.03	168
S-4		149	8.28	11.08	8.85	115.37	122
S-5	Front	290	4.14	21.55	4.42	50.07	53
S-B2 OUT	Front	366	2.38	27.25	2.54	37.26	39
S-B1 IN		366	1.74	27.25	1.86	51.94	55
S-B3 OUT		376	1.93	27.95	2.06	40.27	42
S-B4 IN		371	1.40	27.60	1.50	39.23	41
[2]S-6	Front	590	1.09	43.90	1.17	10.87	--
S-7	Front	1180	0.35	87.80	0.37	10.73	11
N-1	Rear	59	5.32	4.39	5.68	49.08	52
N-2	Rear	130	2.56	9.67	2.74	28.19	29
N-3	Rear	290	1.09	21.55	1.17	18.85	19
N-4	Rear	590	0.40	43.90	0.427	9.02	9
N-5	Rear	1180	0.25	87.80	0.267	4.96	5

[1]No record obtained.

[2]Gage slow due to bent motor shaft.

A

age Data for Test No. 2, E-6923

ditions: 948.7 mbar, 77°F.

ressure rted to level si)	Impulse (psi-msec)	Impulse converted to sea level (psi-msec)	Scale impulse	Pulse duration (msec)	Pulse duration converted to sea level (msec)	Scale pulse duration
---	----	----	----	----	----	----
.78	122.80	130.0	10.0	43.33	42.6	3.28
.29	105.97	112.2	8.63	41.73	41.1	3.16
.98	159.03	168.5	12.96	44.27	43.5	3.35
.85	115.37	122.2	9.40	45.47	44.7	3.44
.42	50.07	53.0	4.08	54.80	53.9	4.14
.54	37.26	39.45	3.03	57.73	56.8	4.36
.86	51.94	55.0	4.23	48.54	47.7	3.67
.06	40.27	42.6	3.28	62.53	61.5	4.73
.50	39.23	41.6	3.20	60.67	59.6	4.58
.17	10.87	----	----	30.60	----	----
.37	10.73	11.38	0.88	70.40	69.2	5.32
.68	49.08	52.0	4.00	28.84	27.4	2.11
.74	28.19	29.85	2.29	36.87	36.2	2.78
.17	18.85	19.97	1.54	52.97	52.1	4.01
.427	9.02	9.56	0.735	54.25	53.4	4.11
.267	4.96	5.25	0.404	60.03	59.0	4.54

B

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The overpressure data converted to sea level values and plotted as a function of scale distance is presented in Fig. 35. It is evident (as in Test No. 1, Fig. 11) that the overpressure wave off the front of the igloo was somewhat higher than the overpressure to be expected from a sea level open-air surface burst of the same quantity of explosive, and again the trend of the curve at greater distances from the detonation was toward the surface burst curve. The overpressure wave to the rear of the igloo, as recorded by the north line of gages, was again less than the surface burst overpressure, and the data trended toward the surface burst curve as the distance increased, similar to the results of Test No. 1.

The overpressures which developed within and in front of the small shelters (Stations S-3A IN, S-4, B-1 IN, B-3, and B-4 IN) were again less than the free-air pressures, although the difference was generally less than occurred in Test No. 1.

The overpressure wave within the 20-ft pipe developed a pulse effect (similar to the results of Test No. 1, Fig. 13) as shown by the record at Station S-3A IN (Fig. 36). The same "pulsing" occurred within the six-foot arch, Station B-1 IN. This compares to the record from Station B-1 IN of Fig. 13. The gage within the magazette (Station B-4 IN, Fig. 36) did not exhibit the pulsing. The gages in front of the shelters (Stations S-4 and B-3, Fig. 36) did not record a flattening of the pressure peak as was recorded during Test No. 1 at the corresponding stations (SW-1, SW-3A, SW-3B, Fig. 14).

The small pressure shocks preceding the main pressure impulse off the front of the igloo were more evident on this test (Figs. 36 and 37) than they were on Test No. 1. As before, none of these developed behind the magazine (Fig. 38). Figure 37 also shows that the increase with distance of these preliminary shocks relative to the main pressure impulse was more evident on this test than it was previously (Fig. 12).

CONCLUSIONS

The condition of the acceptor charges and igloos after this test indicates that a spacing factor of $1.5 \times W^{1/3}$ between earth-covered, steel-arch igloos provides adequate protection against explosion propagation when the donor explosive weight approximates that used in the test.

Further analysis (and probably testing) would be necessary to determine the efficacy of the personnel shelters.

Figures 19 through 38 illustrate the characteristics and results of Test No. 2, conducted under E-6923.

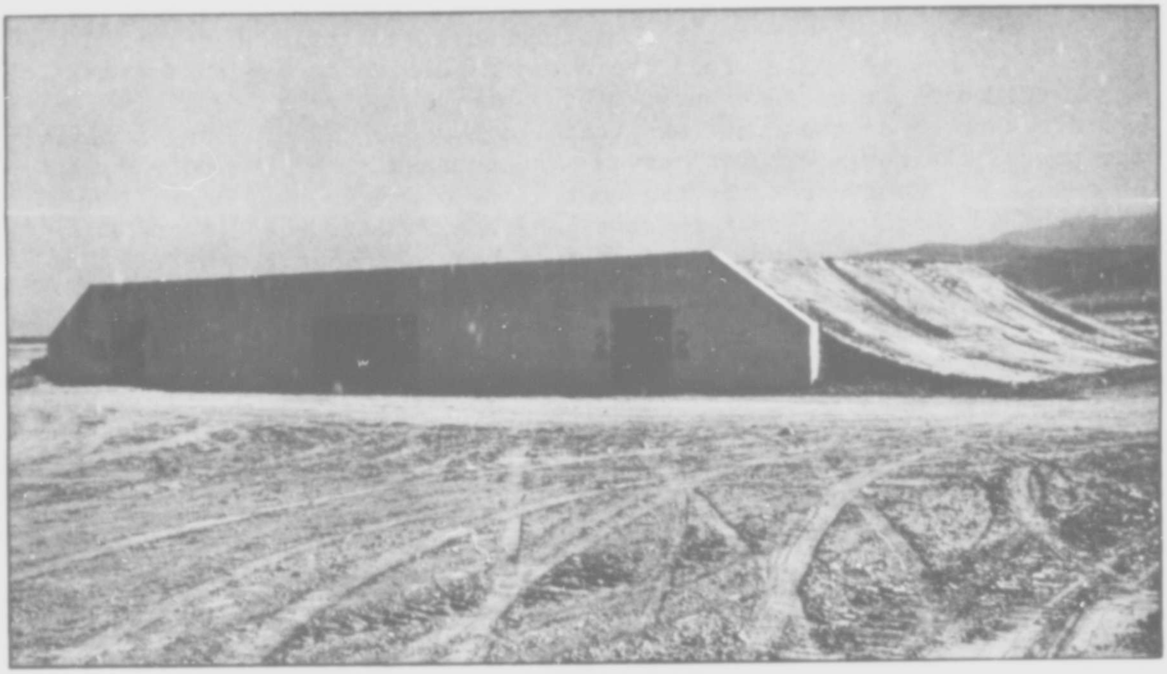


FIG. 19. Donor and Flanking Acceptor Igloos.

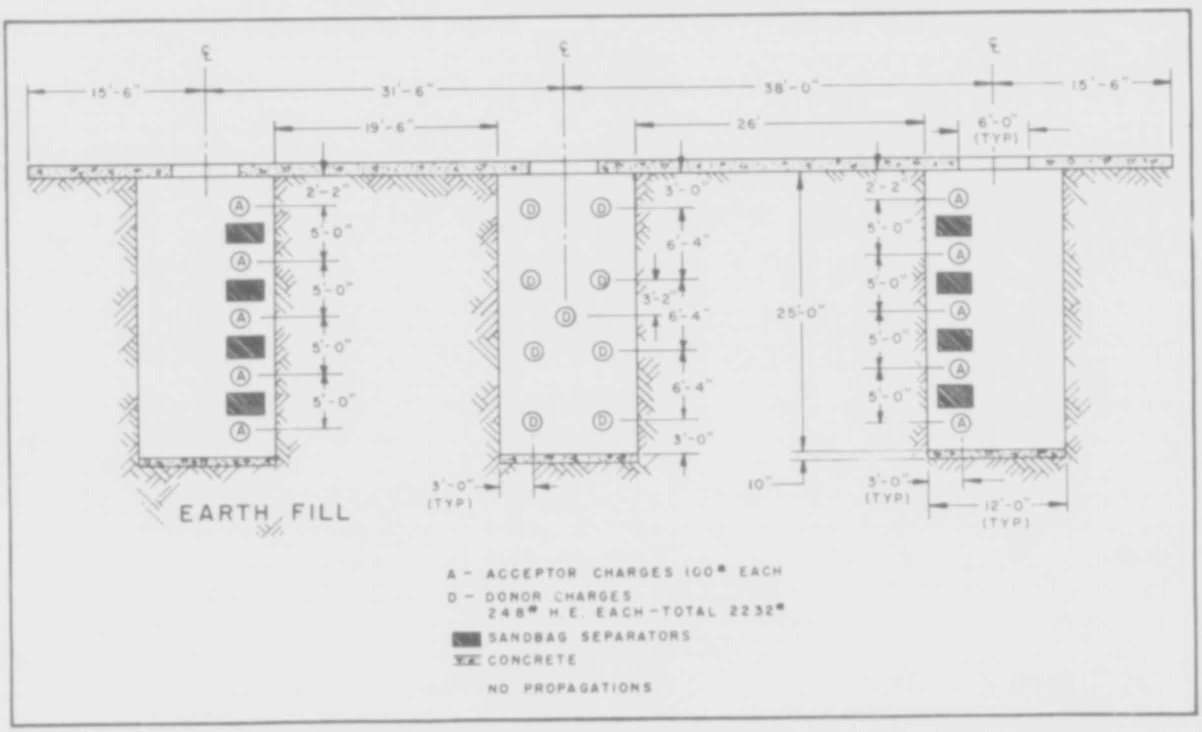


FIG. 20. Donor and Acceptor Igloos and Charges.

FIG. 21. Donor Charges in Place for Test.

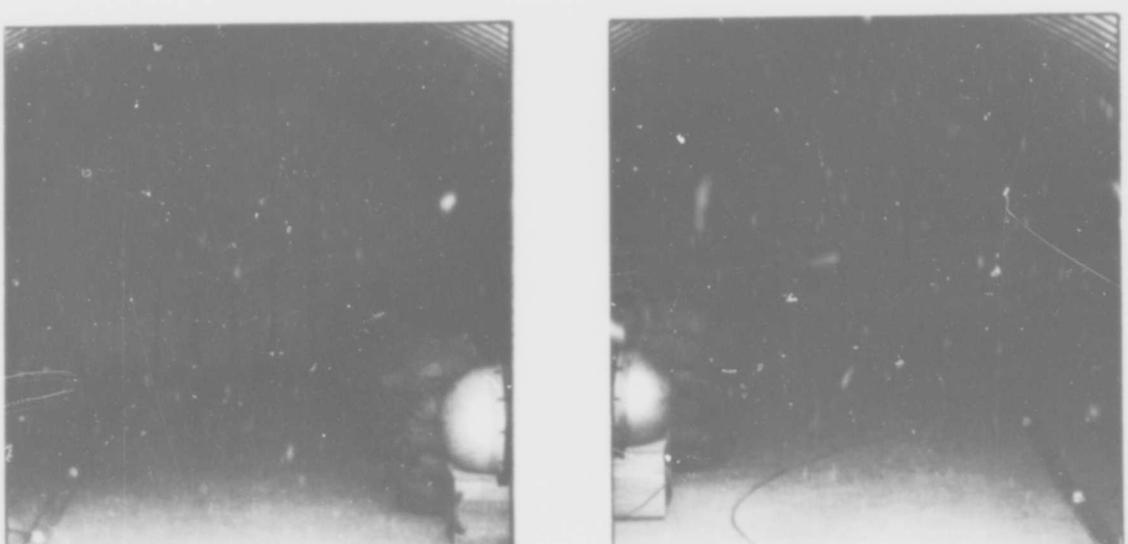


FIG. 22. Acceptor Charges in Place for Test.

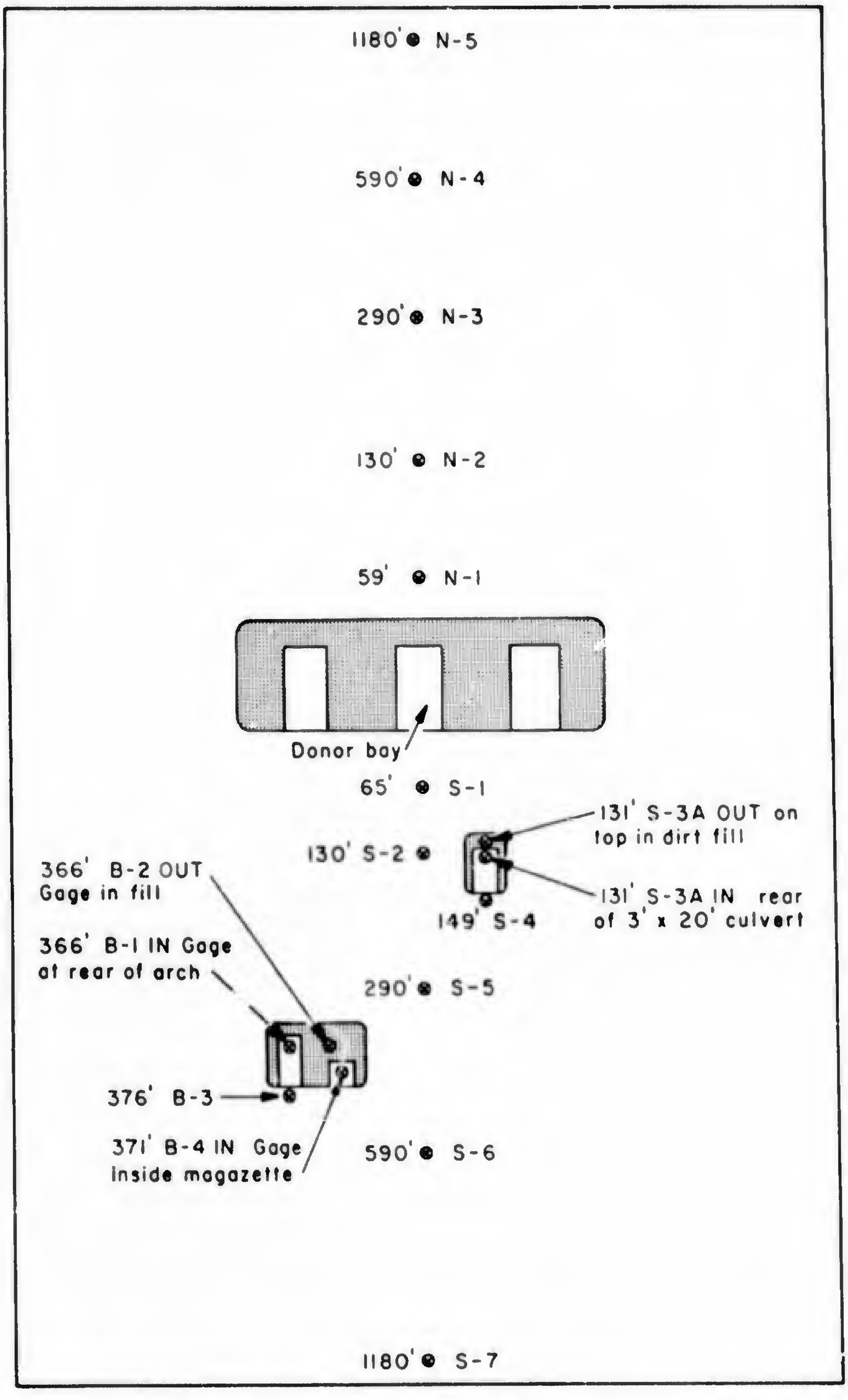


FIG. 23. BRL Pressure Gage Array.

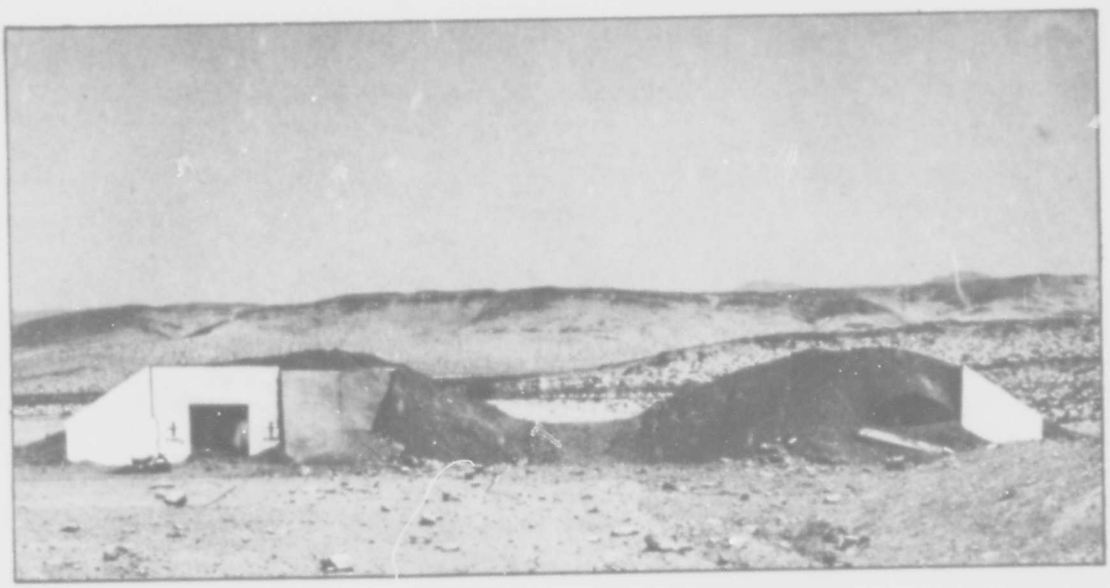


FIG. 24. Three-Igloo Complex After Test.

FIG. 25. Acceptor Igloos After Test.

FIG. 26. Donor Igloo Floor.

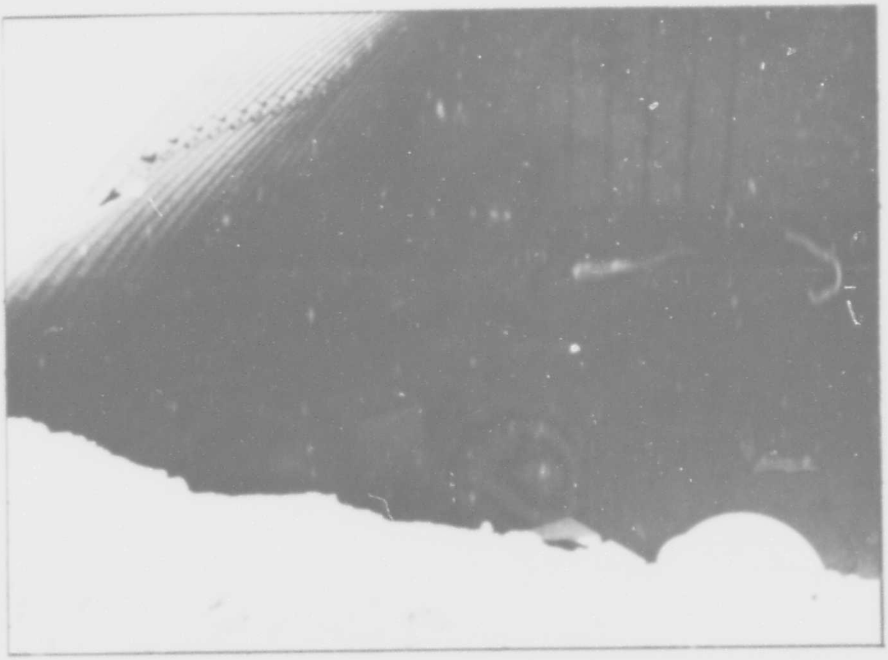


FIG. 27a. Acceptor Charges in Magazine at 19.5 Feet After Test.

FIG. 27b. Acceptor Charges in Magazine at 26 Feet After Test.

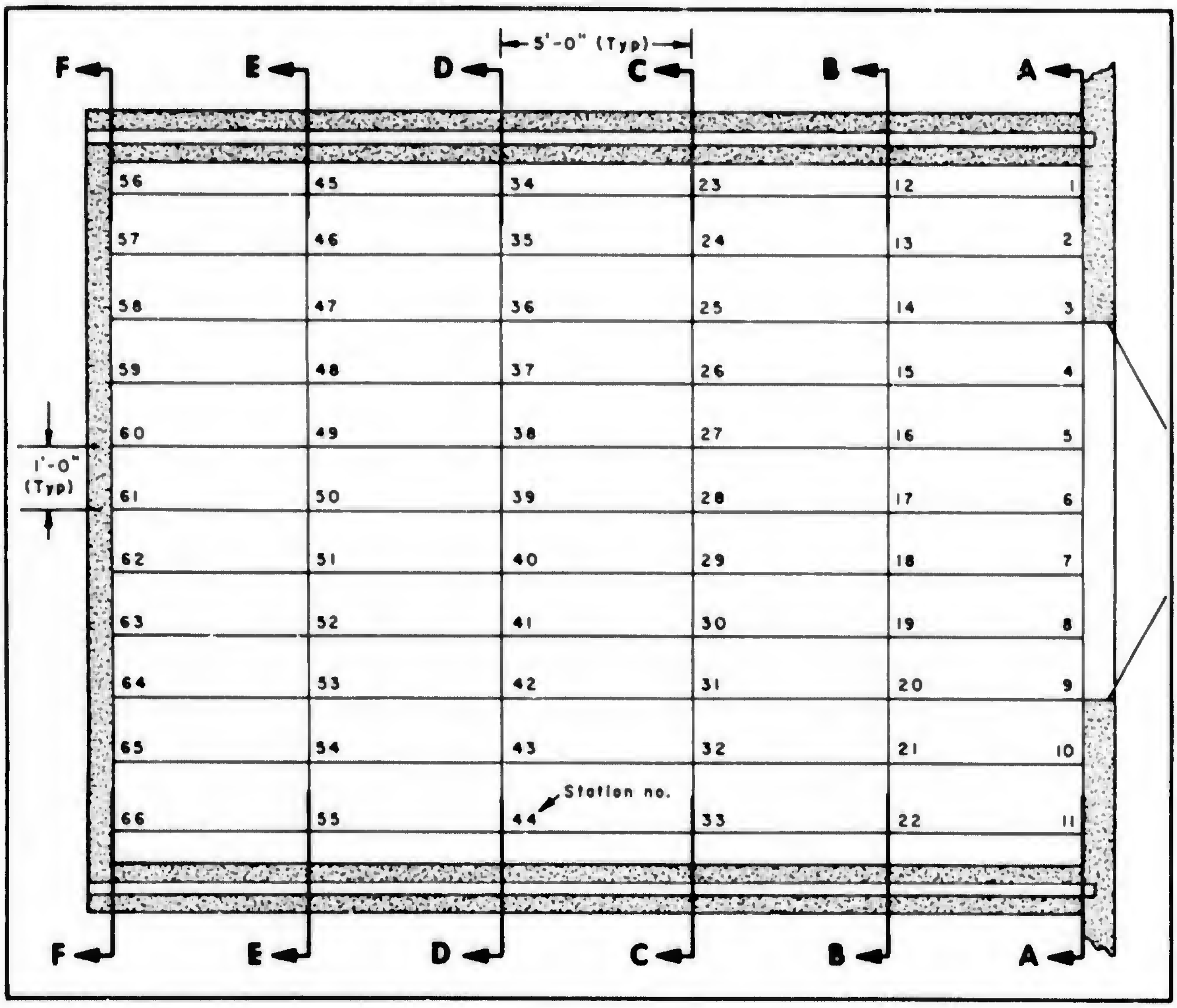


FIG. 28. Typical Plan View.

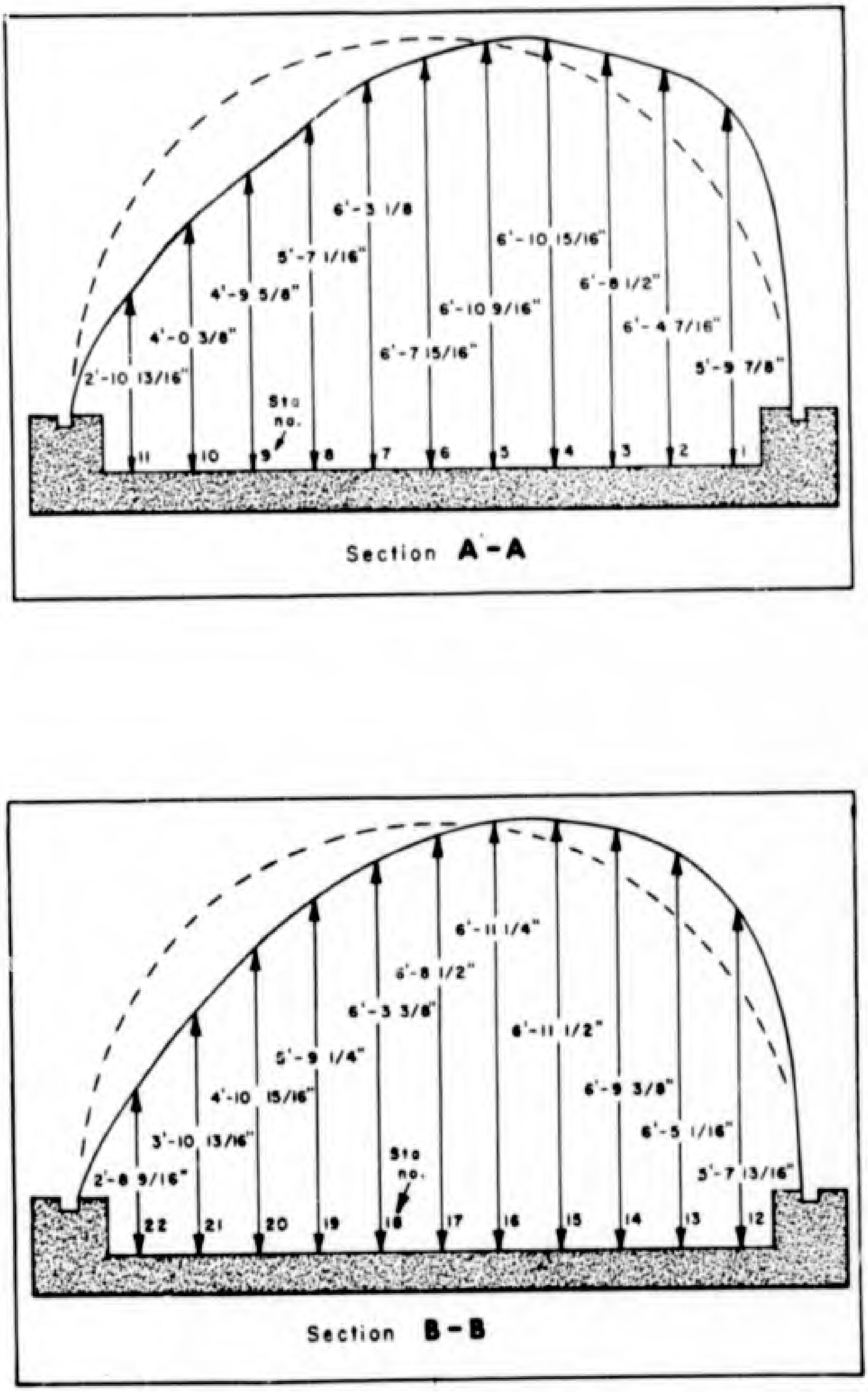
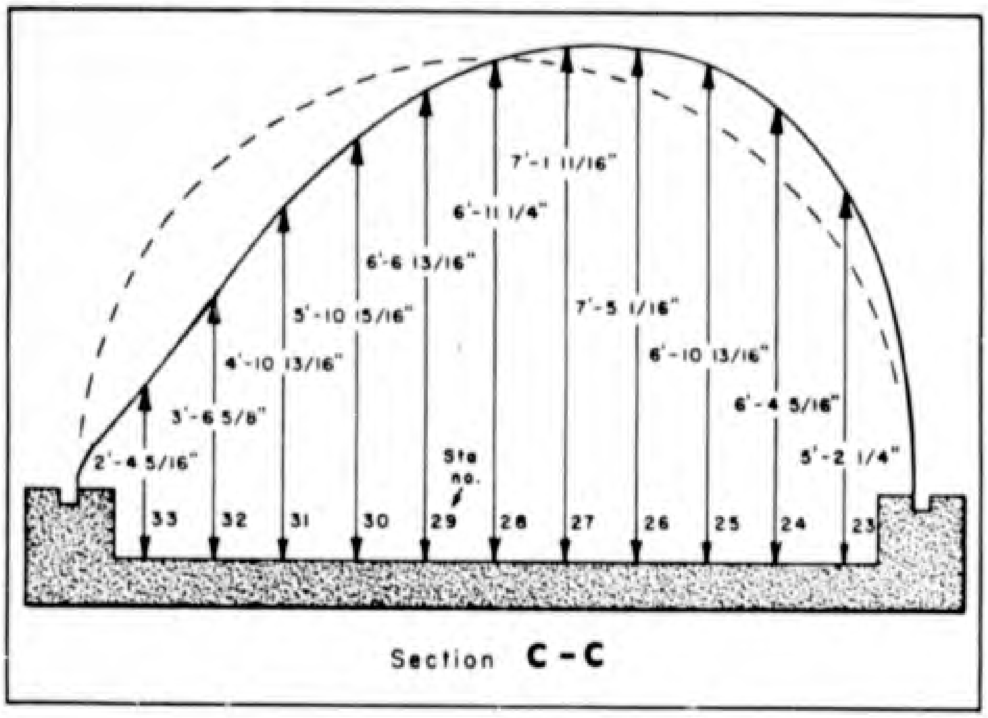


FIG. 29. Acceptor Magazine at 19½-Foot Separation Distance (Secs. A-A & B-B).



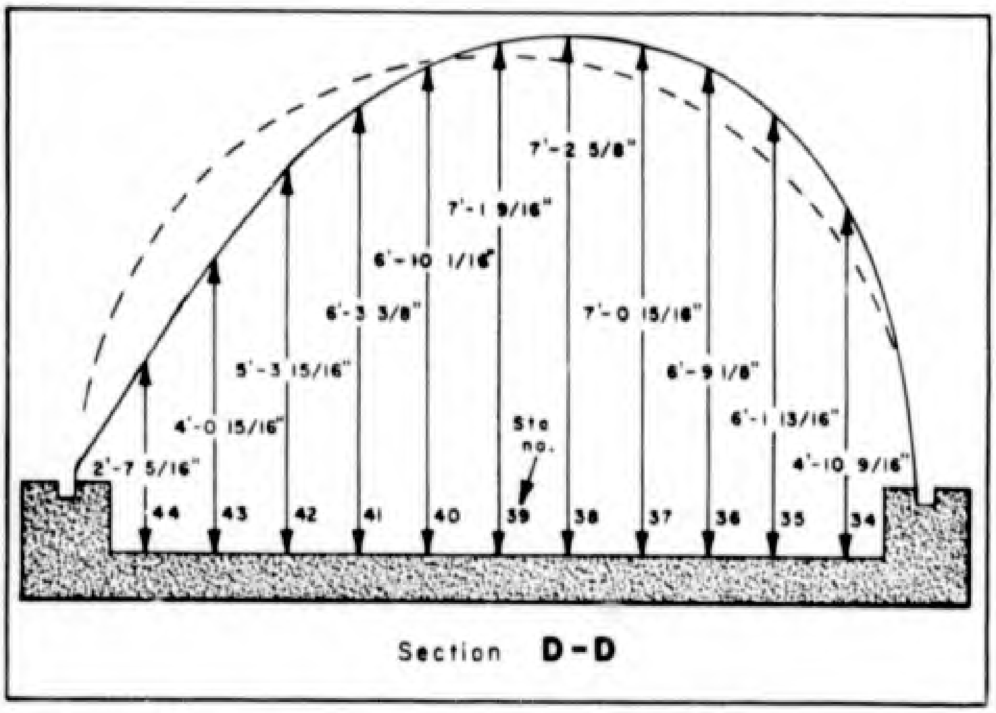


FIG. 30. Acceptor Magazine at 19½-Foot Separation Distance (Secs. C-C & D-D).

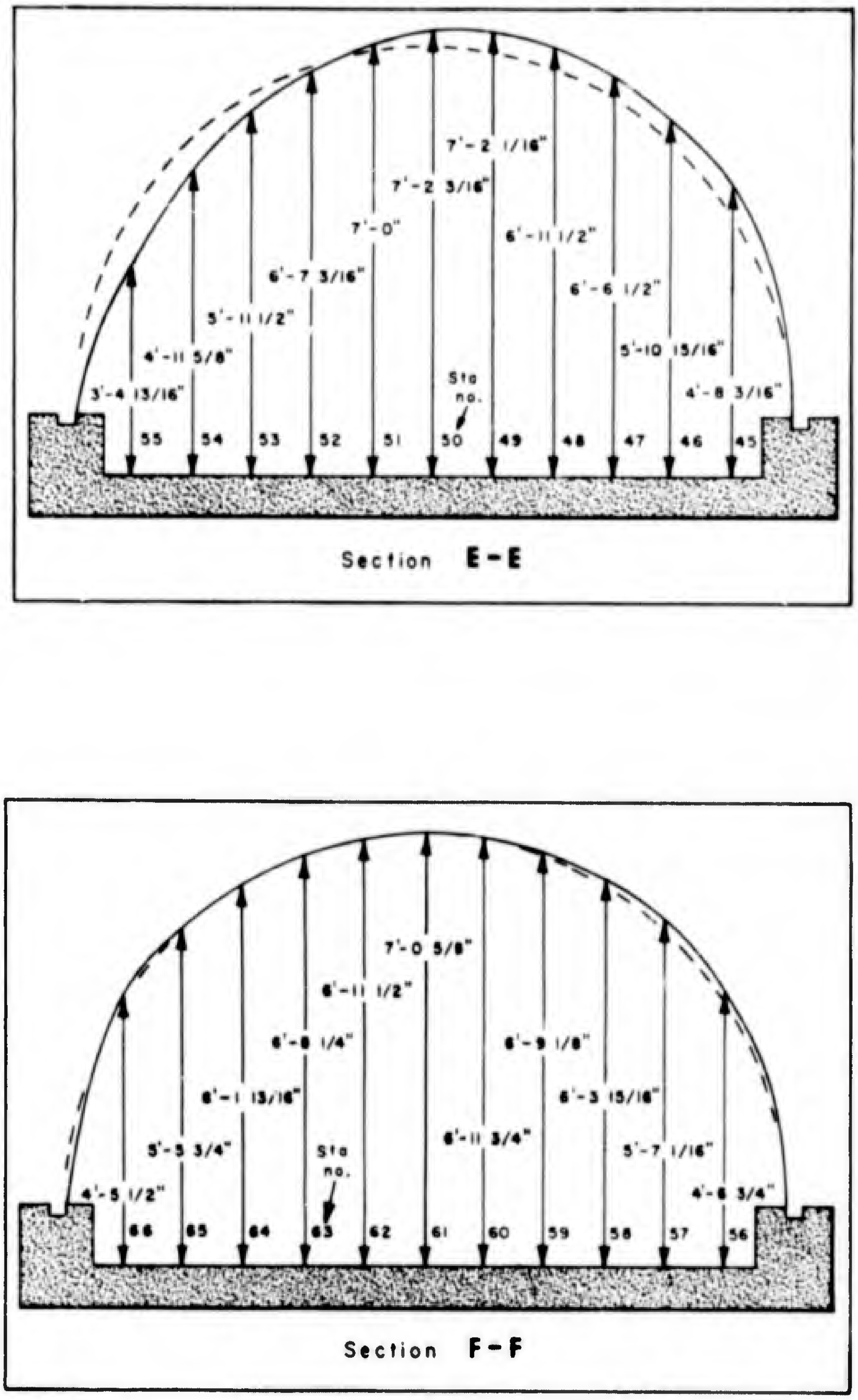


FIG. 31. Acceptor Magazine at 19½-Foot Separation Distance (Secs. E-E & F-F).

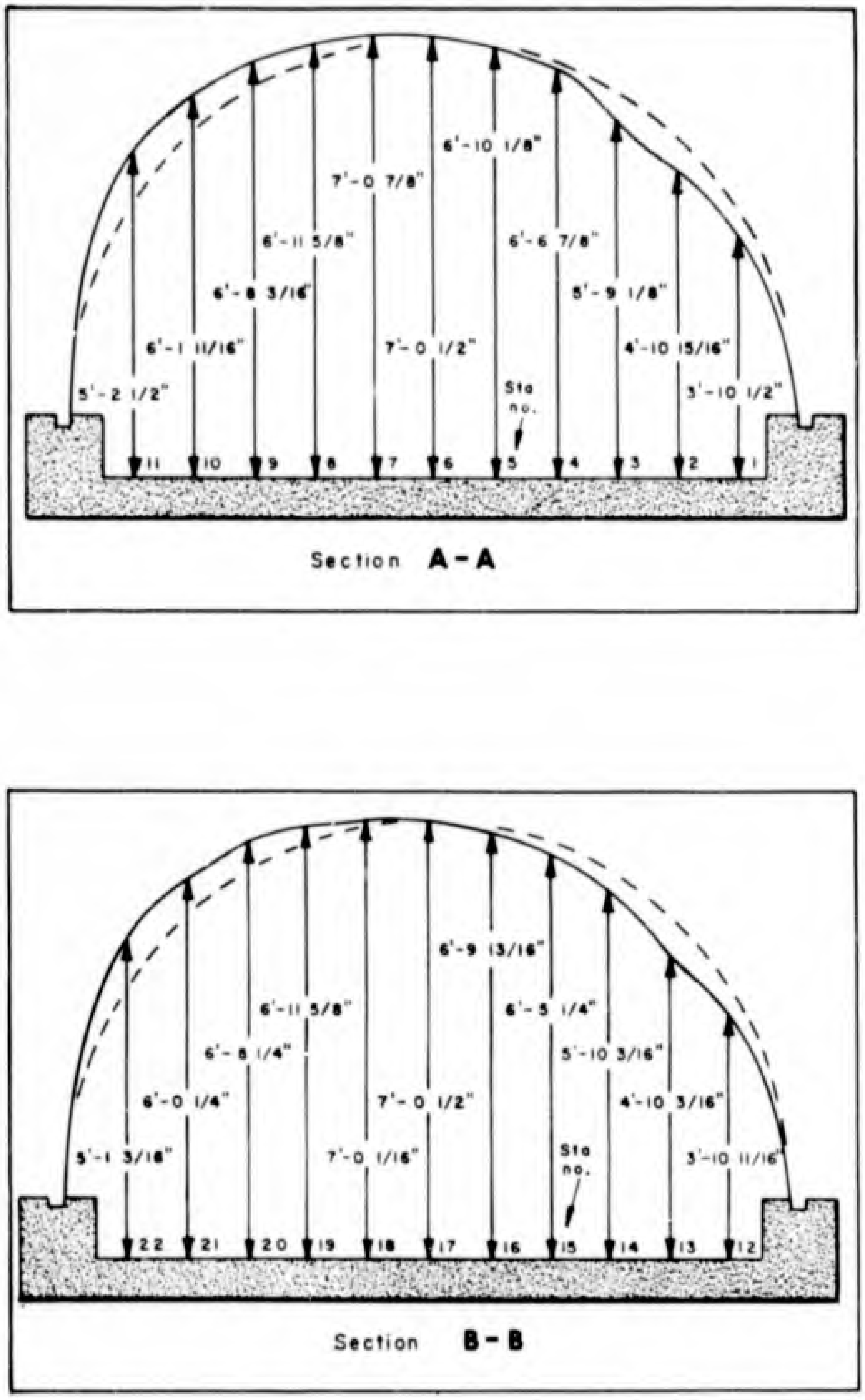


FIG. 32. Acceptor Magazine at 26-Foot Separation Distance (Secs. A-A & B-B).

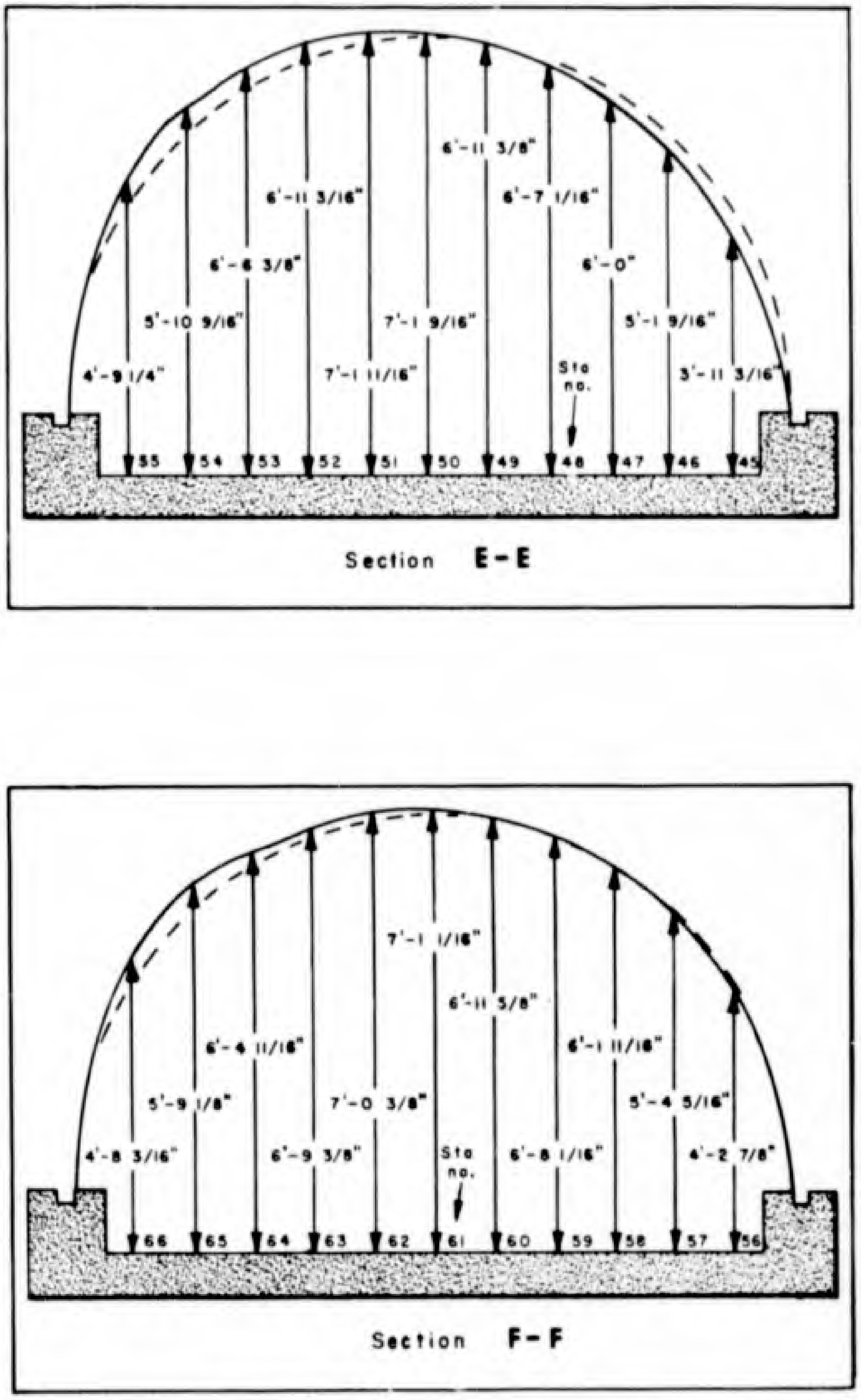


FIG. 33. Acceptor Magazine at 26-Foot Separation Distance (Secs. C-C & D-D).

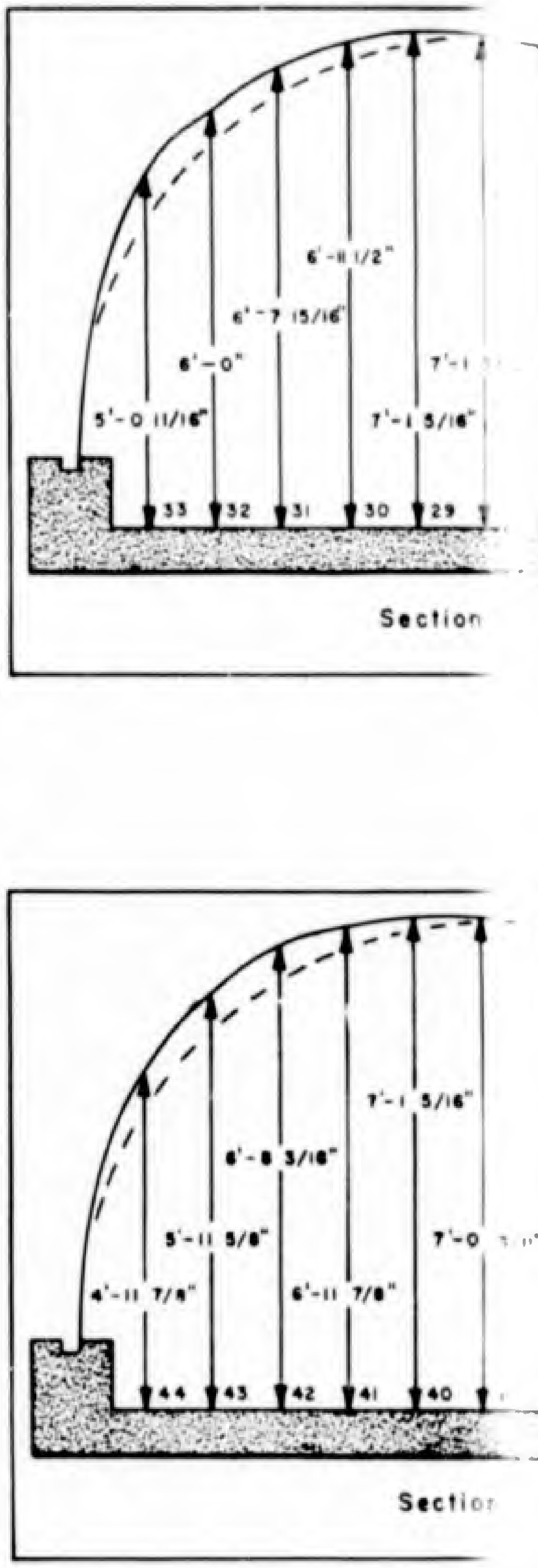
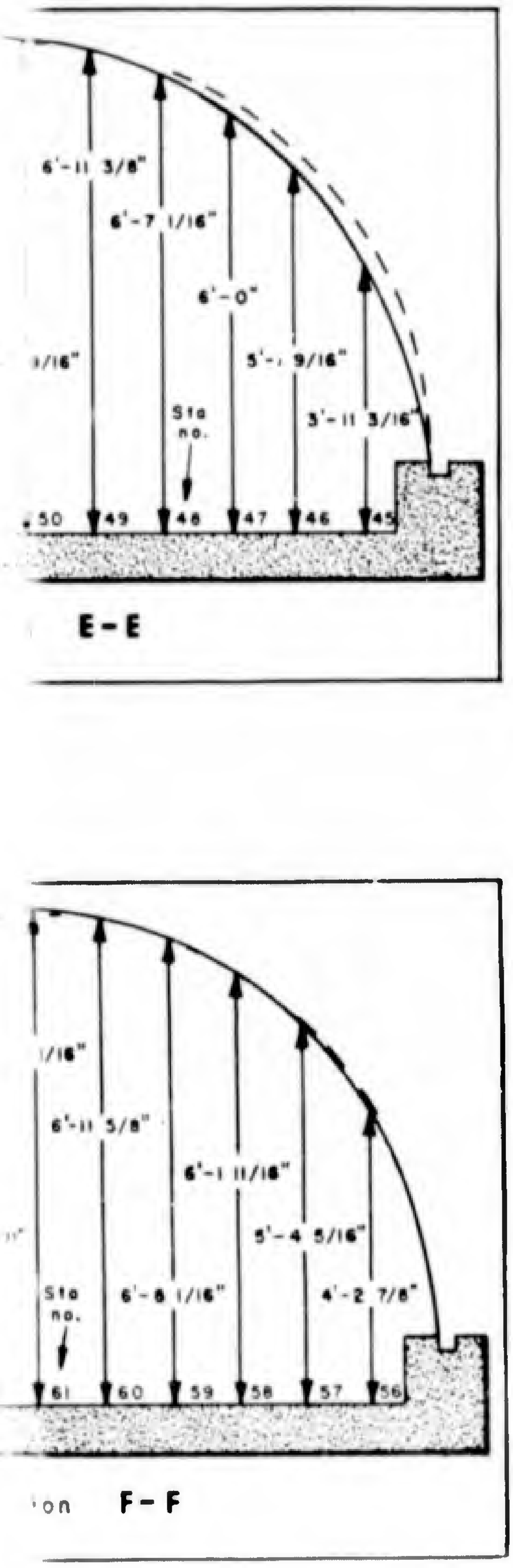
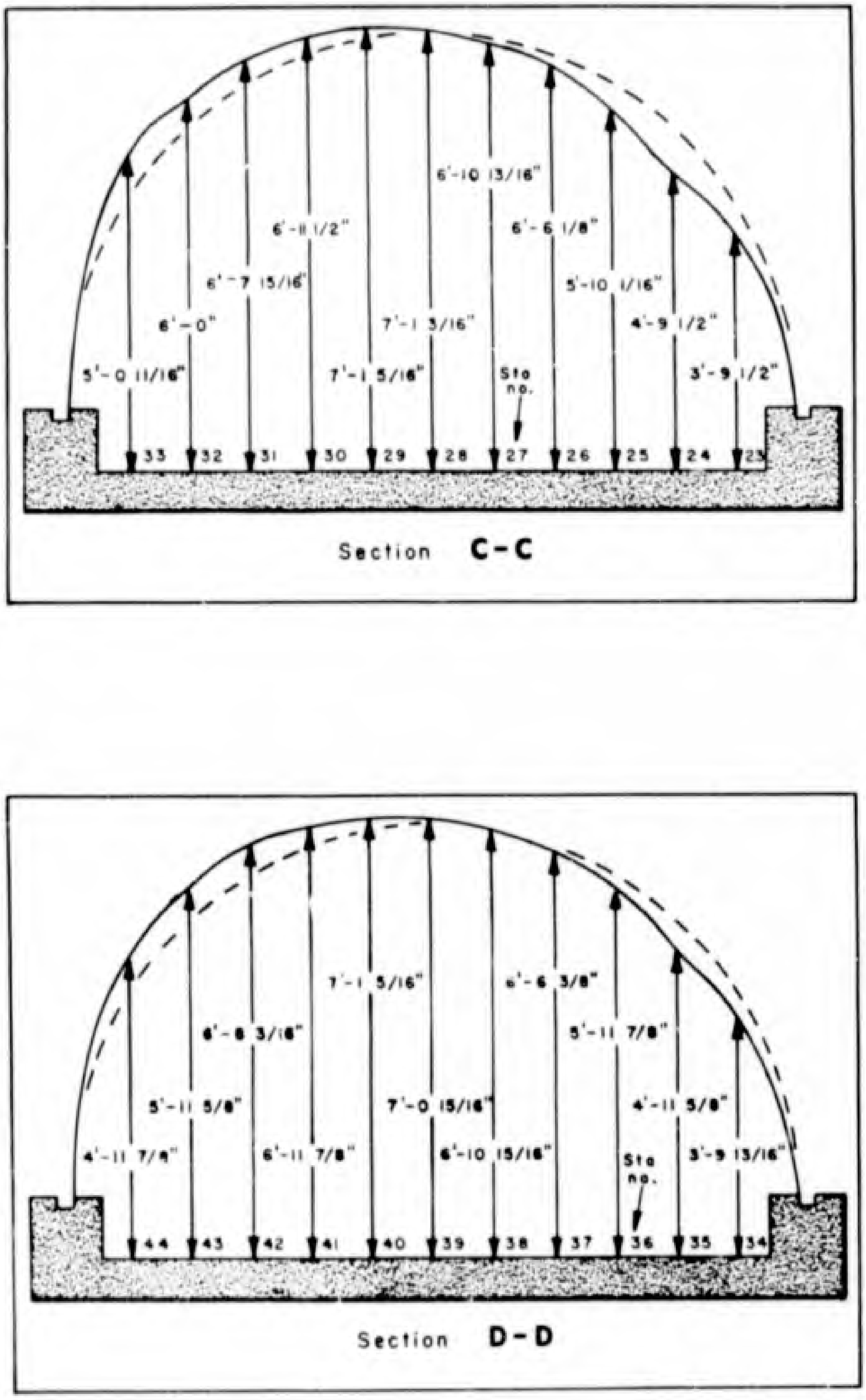


FIG. 34. Acceptor
Separation Distance

A





: Magazine at 26-Foot
(Secs. C-C & D-D).

FIG. 34. Acceptor Magazine at 26-Foot Separation Distance (Secs. E-E & F-F).

B

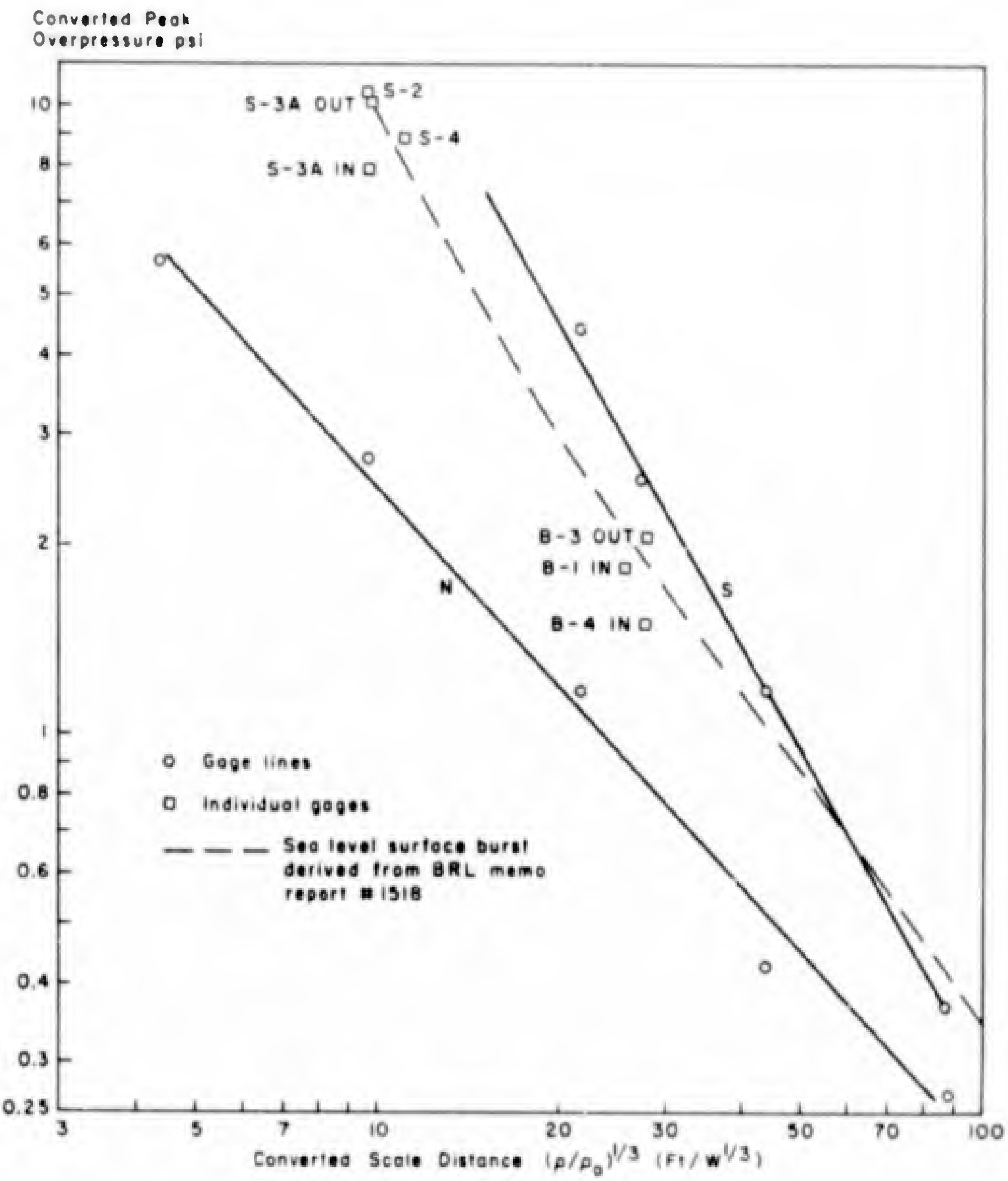


FIG. 35. Overpressure Versus Scale Distance.

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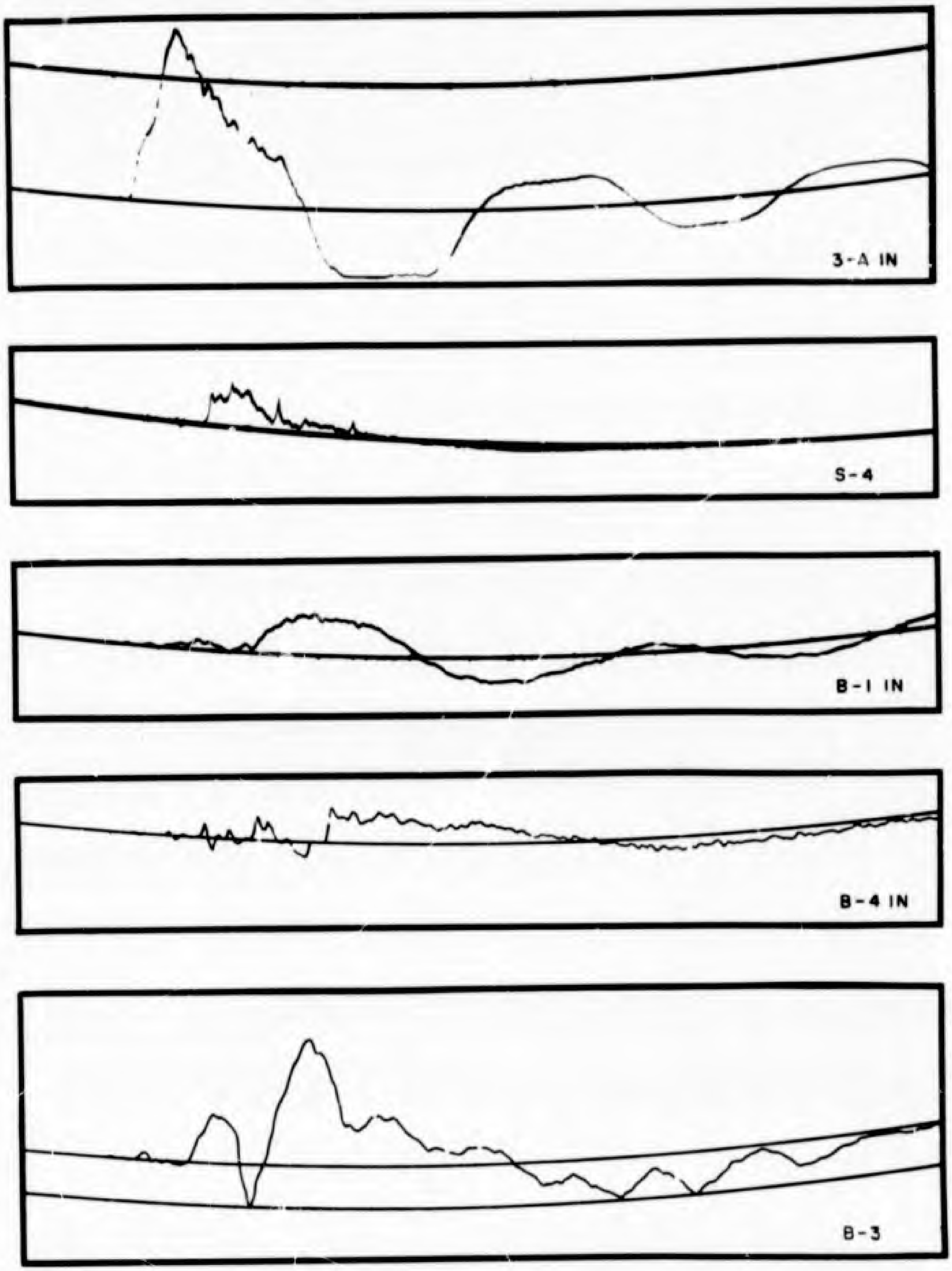


FIG. 36. BRL Gage Records for Stations Inside and in Front of Shelters.

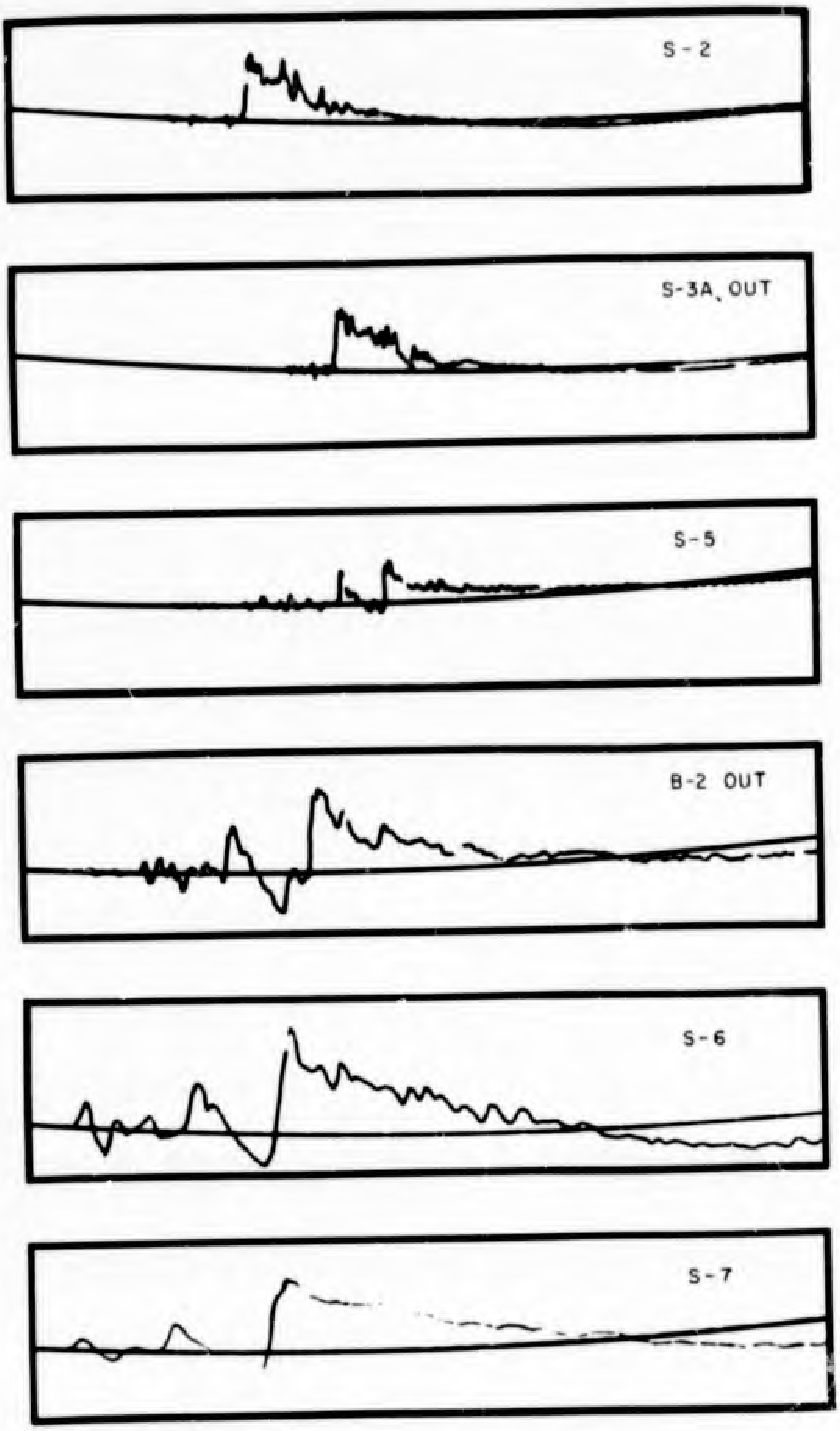


FIG. 37. BRL Gage Records for South Stations (Donor Front).

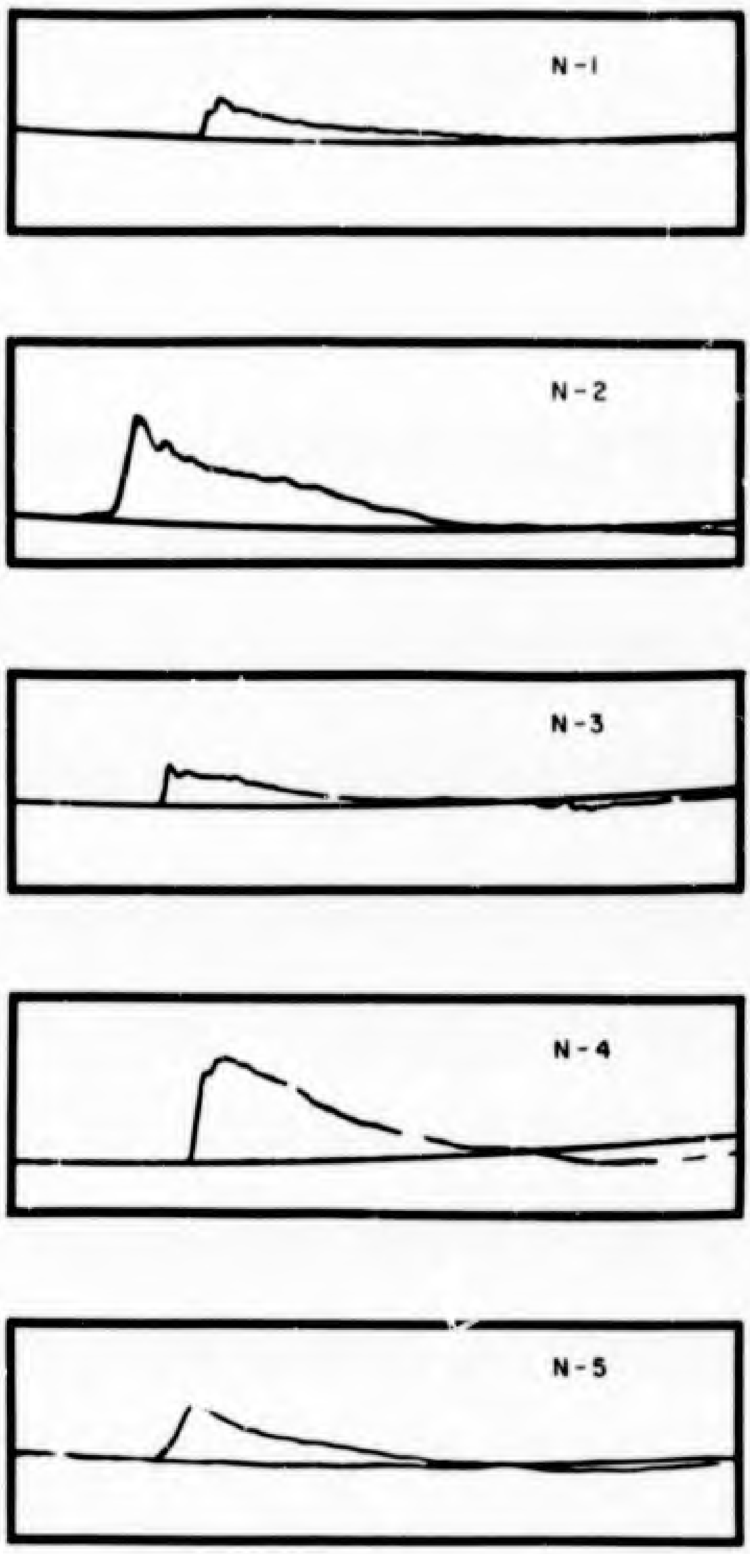


FIG. 38. BRL Gage Records for North Stations (Donor Rear).

SECTION THREE

TESTS 3 AND 4 (E-7093)

The third and fourth tests in this series were conducted (as E-7093 Round 1 and Round 2) to measure the dust cloud formation and the soil dispersion from the cover over an igloo and from the resulting crater when the explosives in the magazine are detonated. A secondary test purpose was to determine the probability and characteristics of explosion cross-propagation within an igloo.

The damaged igloos remaining from Test No. 2 of this series were used for these tests, after suitable rebuilding. Test No. 3 was conducted at 1130 PDT, 28 August 1962, and Test No. 4 was conducted at 1130 PDT, 29 August 1962, at the Victor Range of NOTS.

TEST STRUCTURES

The damaged magazines remaining from the previous test were prepared by replacing the missing portions of the concrete face with wood shoring, and replacing the earth cover to a two-foot depth over the top of the arches. To measure the soil dispersion resulting from the blasts, the earth over the west igloo (used for Test No. 3) was "salted" with 800 lb of zinc sulphate in solution, and the earth over the east igloo was salted with 800 lb of copper sulphate in solution. The chemicals were distributed through the soil during the covering operation.

A ten-foot high earth barricade was built 25 ft in front of and across the face of the igloo for Test No. 3. The 55-ft length of the barricade top subtended an angle of about 70° to the front of the igloo. The magazines and barricade are shown in Fig. 39. No special effort was made to compact the earth for the magazine cover or the barricade.

DONOR AND ACCEPTOR CHARGES

The donor charges for each of these tests consisted of four GP Bombs AN-M-64A1 containing 273 lb of Composition B each, and two standard dividing wall spheres, containing 100 lb of cyclotol each, for a total of 1,292 lb of high explosive. The bombs were primed in the nose, while the primer charges for the spherical donors were attached to the case on the side toward the igloo doorway. A 3-1/8 lb lead shell containing 15 lb of manganese dioxide was placed in each of the spherical donors.

Two standard dividing wall spheres with full complements of detonators were also located in each igloo in an attempt to assess the possibility of eliminating cross propagation within a magazine through the use of sand barricades. The arrangement of the barricades (which extended one foot higher than the acceptor charges), the donor charges, and the acceptor charges is shown in Fig. 40. For Test No. 3, the barricades were formed of sandbags, while the sand was in corrugated paper cartons for Test No. 4. Interior views of the igloos after completion of the test preparations are shown in Figs. 41 and 42.

INSTRUMENTATION

CAMERAS

Photographic coverage for this test was organized to provide data on the size, formation, and action of the dust cloud resulting from the explosion, in addition to recording the reaction of the igloos and barricade. Four 16mm cameras operated at 8,000 frames per second provided side views of the igloos and barricade from 400 ft on each test. (A fifth 16mm camera operated at 8,000 frames per second providing a front view of the igloo door from 400 ft was added for Test No. 4.) A 16mm camera operated at 1,500 frames per second was located 750 ft from the igloos to provide a rear quarter view of the formation of the dust cloud over the igloos. Three 35mm cameras operated at 30 frames per second were located at long range on tracking mounts to follow the dust cloud, providing views from three angles. One of these mounts also incorporated a 35mm camera operated at 1,000 frames per second to record the blast out the igloo doors.

BLAST GAGES

To measure the side-on overpressure wave resulting from the detonations, two BRL gages were installed in the ground with their pressure ports flush with the surface at the locations indicated in Fig. 43. This figure also indicates the location of the modified copper indenter gages below the igloo floor to provide qualitative indication of the detonation of the acceptor charges. The gages shown at the rear of the igloo were directly beneath the acceptor charges, with the gages at the front providing comparison information.

SOIL AND AIR SAMPLES

To determine the direction and extent of soil dispersion from the igloo cover, procedures were established to collect air samples at eleven points at various distances about the test area and to collect soil fallout samples at 40 points on a circular grid pattern surrounding the igloos to a 5,000-ft radius, both by collecting dust fallout in cups of distilled, de-ionized water and by collecting samples of the earth.

TEST RESULTS

The explosions destroyed both of the previously damaged igloos, leaving craters with sides sloping about 35° from vertical. The floor slab of the west igloo was shattered by Test No. 3 (Fig. 44) and the rear wall was forced up and to the rear. Comparison of the copper indenter gages under the acceptor charges with those at the front of the igloo showed the acceptors did explode, corroborating the conclusion reached when no acceptor parts could be found immediately after the test. The earth barricade in front of the magazine was virtually undamaged by the test, although it retained parts of the timber shoring and the steel arch.

The floor of the east igloo was shattered by Test No. 4, and the rear wall was thrown upward and rearward (Fig. 45). Since the modified copper indenter gages were not recovered from the west igloo in time for use on Test No. 4, the only indication of the action of the acceptor charges was the recovery after the test of a small quantity of high explosive and pieces of case material, varying between five and ten square inches in area. This indicated that less than full contribution to the explosion was made by the acceptor charges.

The limited local photographic data assessment indicated that the bulk of the earth thrown up by both of the explosions did not exceed a height of 400 ft, although one or two small fingers of the earth plume reached about 800 feet. The height of the dust remaining in the atmosphere after the tests was estimated at 1,000 feet. The smoke and particles from the fireball cloud were estimated to reach a 2,300-ft height. The estimated horizontal travel of the visible fireball smoke cloud was 1-1/2 miles along the direction of travel, while the visible dust cloud was estimated to travel 2-1/2 miles along the same direction. The meteorological data for both tests are included in Appendix C.

Copies of all the film and camera calibration data were transmitted to the Logistics Directorate, Defense Atomic Support Agency, Washington, D. C., for complete analysis.

The atmosphere was sampled at the eleven locations during each test, and the 40 water and earth samples were collected immediately after each test. In addition, it was necessary to collect natural soil samples at various locations on the range to determine the composition of the normal desert terrain. The results of the analyses were ambiguous, since it was difficult to distinguish between the copper and zinc sulphates, lead, and manganese dioxide contributed by the test additives and those same materials naturally occurring in the soil. As a result, the determination of the fallout pattern from the tests could only be considered approximate and inconclusive. The data and analyses results were also sent to the Logistics Directorate of the Defense Atomic Support Agency.

A limited survey to determine the fragment dispersion pattern showed that essentially all of the large items of structural debris, such as concrete and steel-arch segments weighing over 200 lb, were spread within a 500-ft radius; however, medium-size fragments of five pounds were thrown up to 2,900 ft on the forward extension of the magazine centerline, or the 6:00 o'clock line. Fragments to 25 lb were thrown to 2,650 ft on the same line. No fragments were found beyond 1,900 ft on the 5:00 o'clock and 7:00 o'clock lines. Since the igloo for Test No. 3, with the ten-foot earth barricade in front, had about two-thirds of the concrete head wall in place, while the igloo for Test No. 4 had about one-third of the concrete head wall in position (Fig. 39), it was not possible to adequately assess the retention effects of the barricade on the fragment dispersion by comparing the tests. The table in Appendix D lists the results of the limited fragment survey conducted after Test No. 4, and Fig. 46 shows the fragments collected in a 100-ft by 150-ft area located 2,600 ft in front of the igloos.

The BRL gage results from Test No. 3 are presented in Table 3, and the gage identification numbers are in Appendix E. These gages were not operated on Test No. 4. A comparison of the overpressure data with that to be expected from a surface detonation of the same weight of high explosive is shown in Fig. 47. For this comparison, the total weight of explosive was computed as 1,400 lb since the two acceptor charges did explode. It would appear that less overpressure was developed than would be experienced in the open; however, the limited amount of data decreases the reliability of the indication. The impulse and pulse duration data derived from the gage at Station No. 1 is considered incorrect due to a faulty gage that was apparently running slow.

CONCLUSIONS

This test was of limited value in determining the soil dispersion to be expected when an explosion occurs in a buried igloo magazine, but the experience gained was of useful application to Test No. 5, conducted at NOTS, and to Project Roller Coaster, a series of tests subsequently conducted at another location.

Since the acceptor charges exploded in Test No. 3, but may not have exploded in Test No. 4, the effectiveness of the sand barricades within the magazines appeared to be marginal. The effectiveness of multiple barricades within earth-covered magazines has subsequently been investigated much more extensively by Picatinny Arsenal in a series of tests at Hastings, Nebraska.

TABLE 3. BRL Gage Data, Test No. 3, E-7093
Ambient Conditions: 933.8 mbar, 99°F.

Station	Direction from donor	Distance (ft)	Peak overpressure (psi)	Converted scale distance	Overpressure converted to sea level (psi)
1	Front	462	0.83	38.3	0.90
2	Front	922	0.35	76.4	0.38

Cont'd

Station	Impulse (psi-msec)	Impulse converted to sea level (psi-msec)	Scale impulse	Pulse duration (msec)	Duration converted to sea level (msec)	Scale duration
1	2.95	3.23	0.282	8.80	8.45	0.739
2	7.34	8.05	0.702	47.47	45.5	3.97

Figures 39 through 47 illustrate the characteristics and results of Test Nos. 3 and 4, conducted under E-7093.

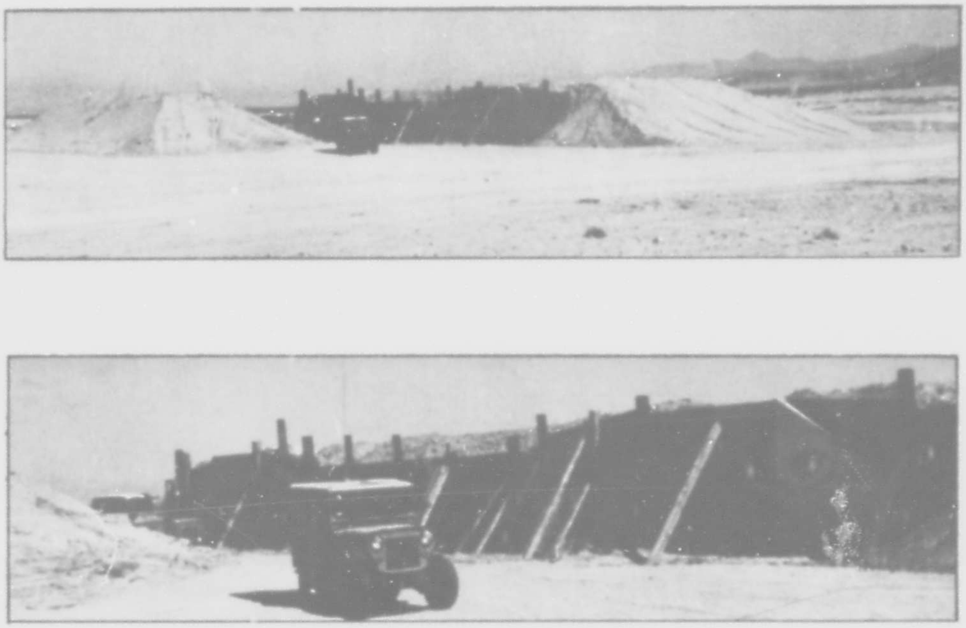


FIG. 39. Igloo Magazines and Barricade (Tests 3 and 4).

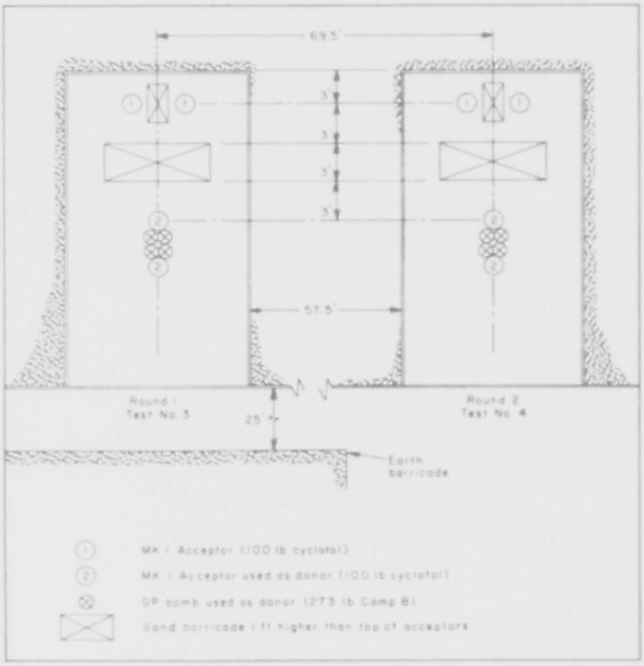


FIG. 40. Donor Charges, Acceptor Charges, and Barricades (Tests 3 and 4).

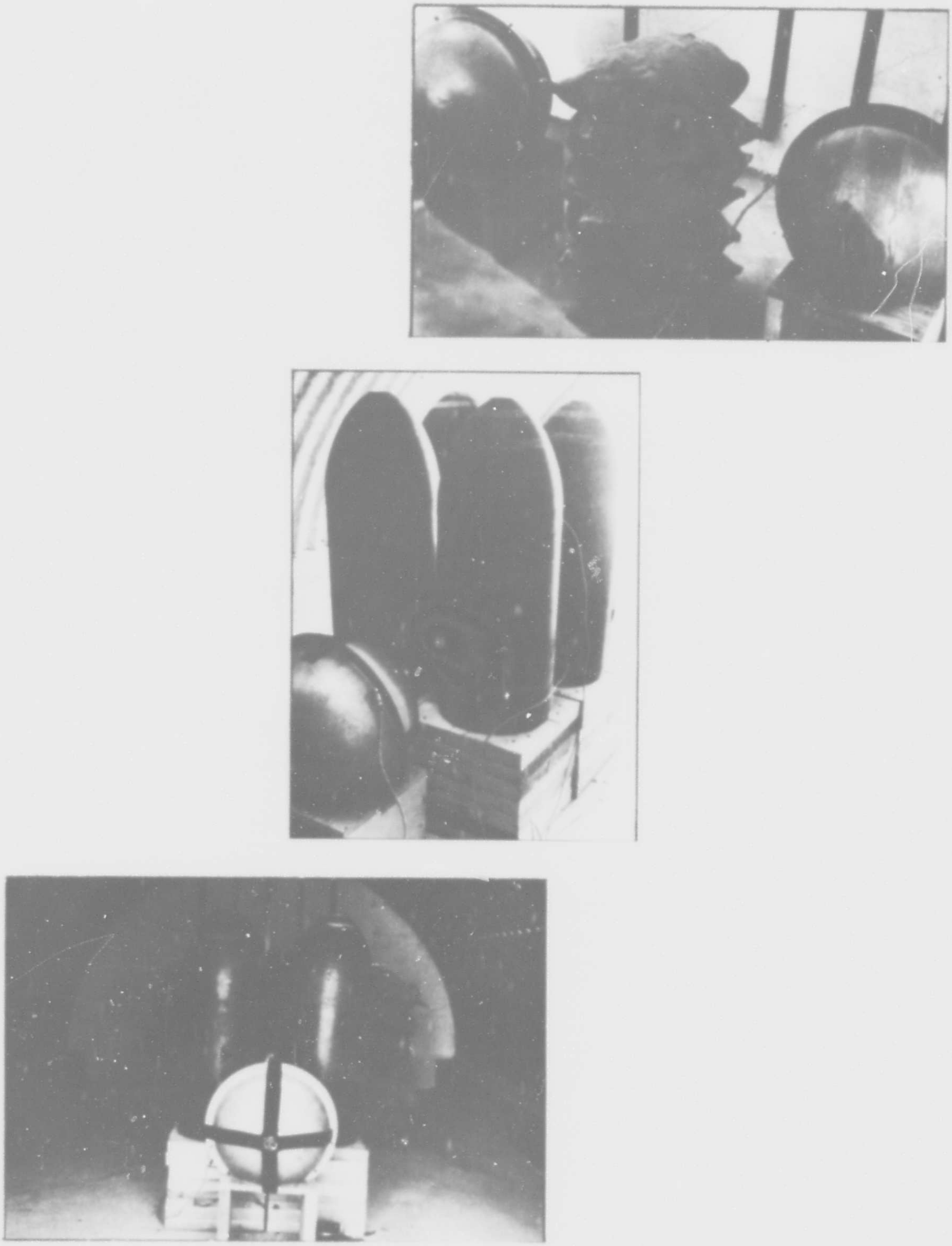


FIG. 41. Igloo Magazine Interior (Test 3).

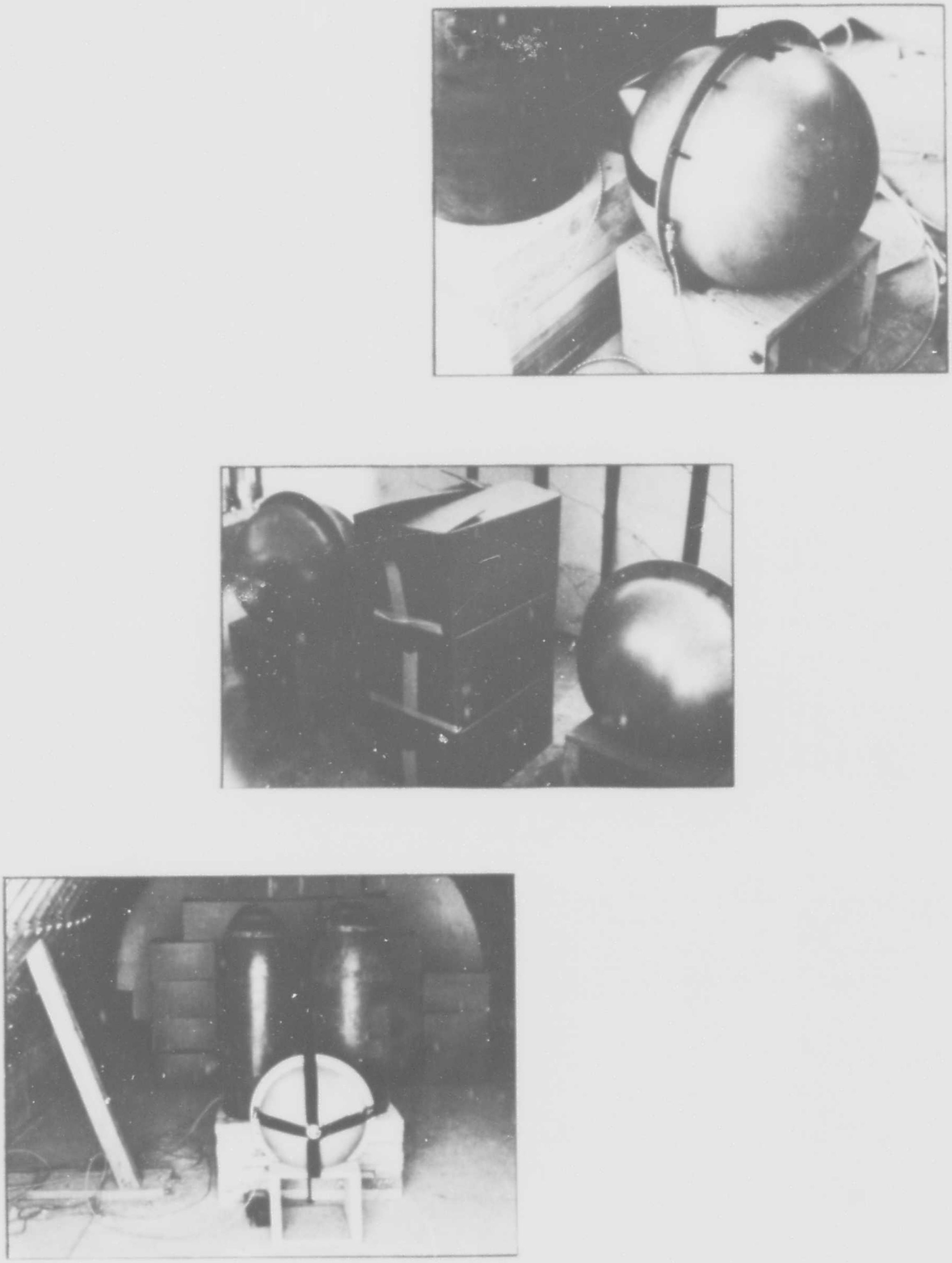


FIG. 42. Igloo Magazine Interior (Test 4).

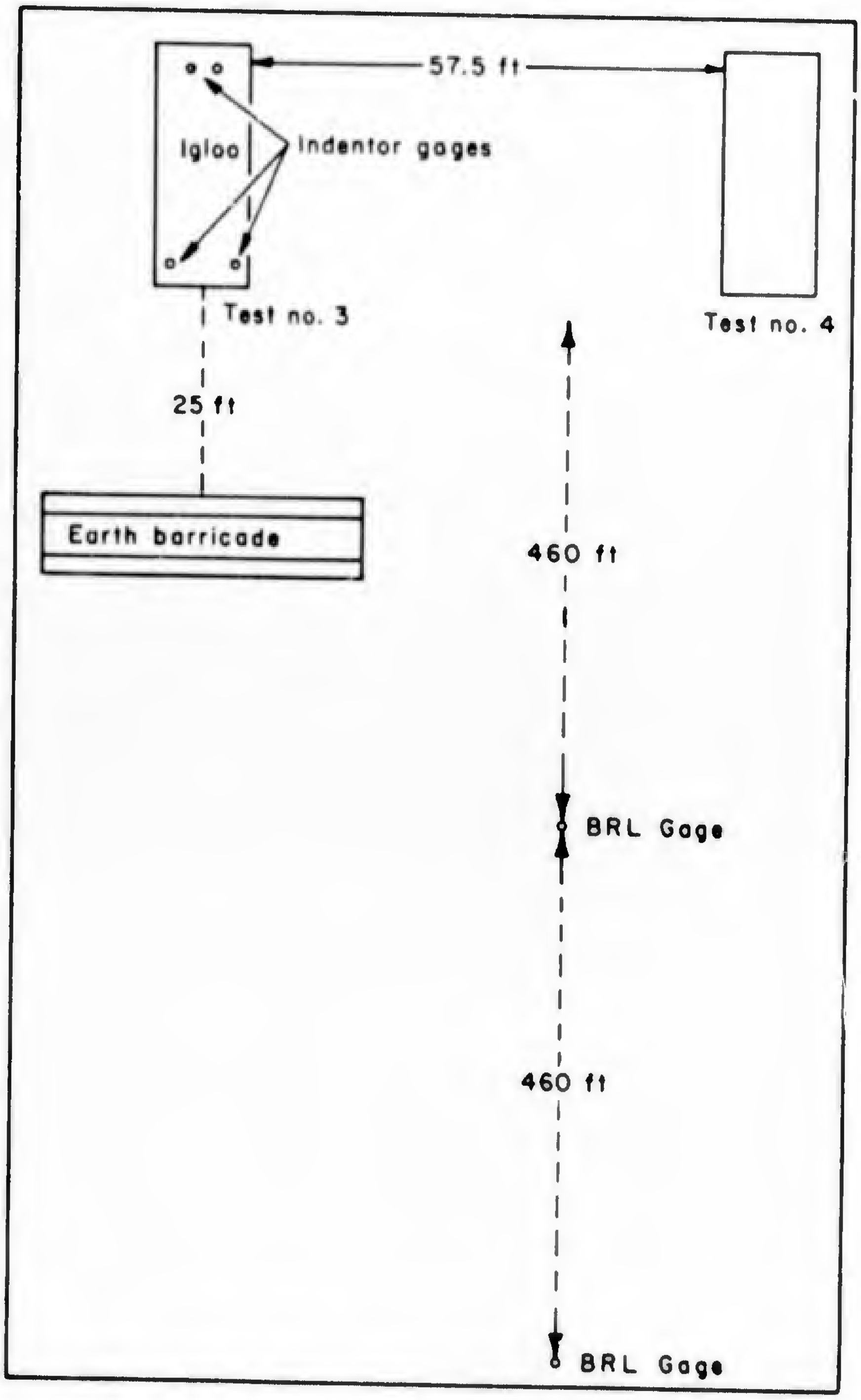


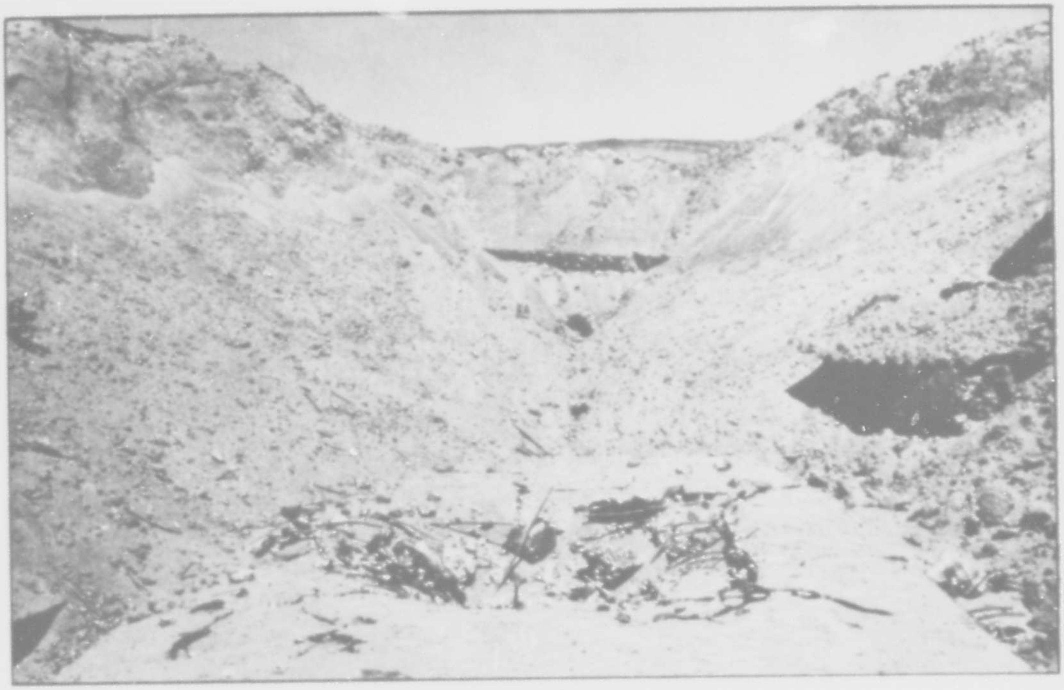
FIG. 43. BRL Pressure Gage and Copper Indenter Gage Locations (Tests 3 and 4).

a. Front View.

b. Rear View.

c. Barricade Slope Facing Igloo.

FIG. 44. West Igloo After Test No. 3.



a. Front View.

b. Rear View.

FIG. 45. East Igloo After Test No. 4.

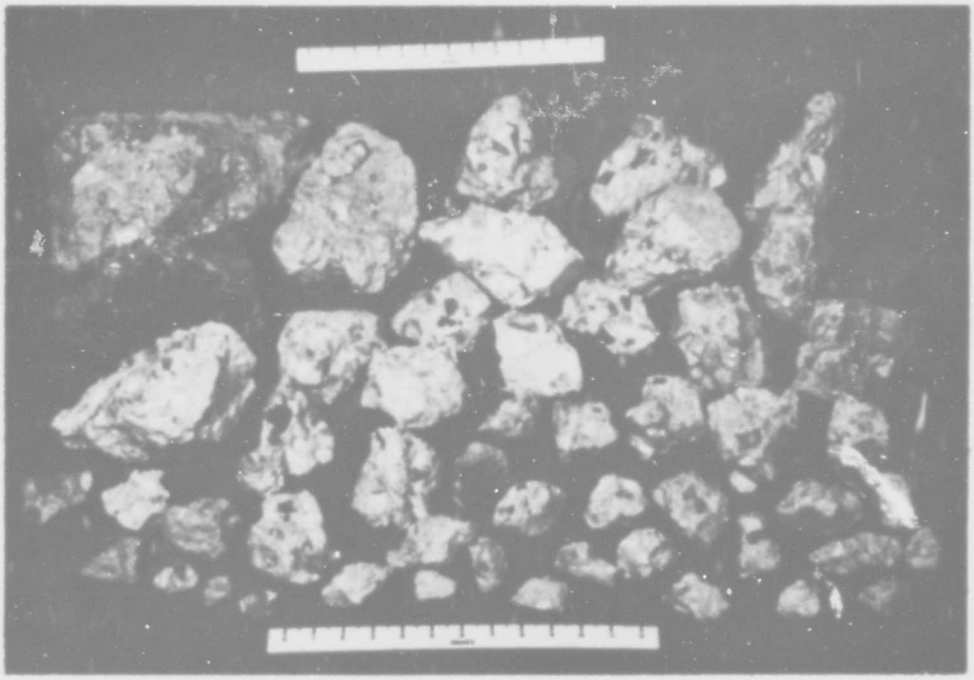


FIG. 46. Fragments From Area 2600 Feet in Front of Igloos After Test No. 4.

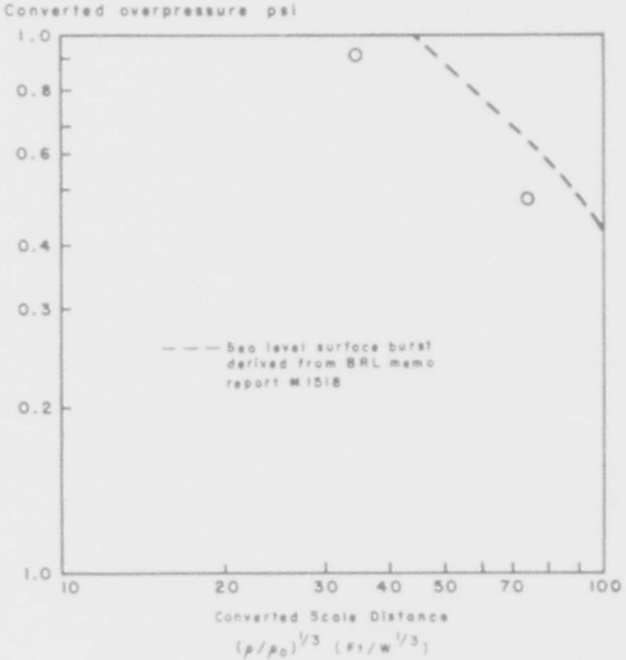


FIG. 47. Overpressure Versus Scale Distance (Test 3).

SECTION FOUR

TEST NO. 5 (E-7520)

Since Test No. 2 indicated that a clear side-to-side spacing factor of 1.5 x $W^{1/3}$ for earth-covered igloos provided reasonable assurance against explosion propagation (when the stored weight of explosive was of a 2,000-lb magnitude), and Test No. 1 indicated that 1.0 x $W^{1/3}$ might not prevent explosion propagation, Test No. 5 was conducted using side-to-side spacing factors of 1.5 x $W^{1/3}$ and 1.25 x $W^{1/3}$ to confirm the results of the second test and determine whether the spacing factor could be reduced below 1.5. This test also included an igloo situated to determine whether a spacing factor of 1.5 x $W^{1/3}$ between the rear walls of earth-covered igloos was safe. (The results of Test No. 1 showed that a space factor of 4.5 x $W^{1/3}$ from the rear of a covered igloo to the front of an unprotected magazine was safe.)

Secondary test purposes were to further develop techniques for measuring the soil and dust dispersion when an explosion destroys an igloo (referred to as Operation Sideshow by DASA), and to measure the pressures and accelerations to which the igloo structures are subjected.

Test No. 5 was conducted under E-7520 at 1421 hours PST on 4 April 1963 at the NOTS Victor Range.

TEST STRUCTURES

Four steel-arch igloos were constructed and situated as shown by the plan of Fig. 48 (in accordance with OCE Drawings AP 33-15-63 as approved by the ASESB), with clear side-to-side spacing of 16.5 ft (1.5 x $W^{1/3}$) between igloos A and B, and 14 ft (1.25 x $W^{1/3}$) between igloos A and C, with igloo A containing the donor charge. The rear walls of igloos A and D were separated by 16.5 ft (1.5 x $W^{1/3}$). The entire group of magazines was covered to a depth of two feet over the highest point of the arches by a common earth fill, which was compacted during the fill operation. The longitudinal axis of the donor igloo was located at 90° to the anticipated wind direction. Figure 49 shows the completed magazine complex.

During construction of the igloos, a test of a dampproofing system was conducted at the request of representatives of the Office of the Chief of Engineers, Department of the Army, and of the Waterways Experiment Station, Vicksburg, Mississippi. To accomplish the test, acceptor igloo B was dampproofed in accordance with extracts from Specification No. 33-16-63-22. This consisted of building the igloo with a gasket material (an extra-heavy plastic joint sealant tape made by ARMCO Drain and Metal Company) in the joints of the steel arches, then coating the completed assembly with Koppers No. 50, a corrosion preventive bituminous mastic of brush consistency. While covering the igloos with dirt fill, the dampproofing was tested by pooling water to a one-foot depth along one side of the igloo from the inside of the concrete head wall to halfway across the rear wall. The water covered some of the seams in the steel arch. The pool was refilled after several hours to replace the water which had soaked into the earth, then remained overnight for a period of about 15 hours. The following morning a careful examination of the magazine interior showed no seepage. The only water lost was through the shear joint between the concrete wingwall and the concrete door pilaster, a junction which had not been sealed, since it does not lead into the igloo. Figure 50 illustrates the dampproofing test.

DONOR CHARGE

The donor charge consisted of three complete missiles containing explosive warheads and live rocket motors, so that the total weight of propellant and explosive charge was considered as 1,275 pounds. In addition, the center missile contained three pounds of material in the warhead for tracer analysis of the soil dispersion after the test.

The donor weapons were arranged in a row on wood stands, 24 inches off the floor, with the nose cones three inches from the rear wall, and the outer missiles 26 inches from the magazine side walls. Detonation was accomplished by simultaneous firing of two adjacent detonators in each warhead from a high-voltage power supply.

ACCEPTOR CHARGE

Each of the three acceptor igloos contained one missile identical to the missiles used as donors, and two additional missiles consisting of live rocket motors and nose cones containing warheads with full complements of detonators. The acceptor charges were positioned like the donor charges.

INSTRUMENTATION

PHOTOGRAPHIC DATA

Photographic coverage of the explosion and subsequent igloo reaction was obtained by nine 16mm cameras operated at speeds between 2,000 and 8,000 frames per second using color film. Three M-45 tracking mounts, incorporating a 35mm camera operated at 30 frames per second with black and white film and a 35mm camera operated at 1,000 frames per second with color film, were used to record the action of the fireball and smoke and dust clouds. Film records were obtained until the smoke and dust were no longer visible. Airborne photographic coverage was obtained with medium and high-speed cameras operated in a helicopter hovering 5,000 ft above the ground.

Three Askania cinetheodolites tracked a balloon released just before the test to obtain upper air wind data.

METEOROLOGICAL DATA

To predict the dust travel and to aid in correlating dispersion results, extensive measurements of the wind and atmosphere characteristics were made at intervals before, during, and following the test, using manually tracked pibal balloons and the electronic rawinsonde system. These measurements were obtained from two separate locations. These data were supplemented by the cinetheodolites tracking the balloon released five seconds before initiation of the donor charges.

BLAST PRESSURE DATA

The overpressure wave resulting from the explosion was recorded by BRL gages (Fig. 51c) located at 40, 50, 100, 200, 500, and 920 ft on a line extending forward from the donor igloo. The blast pressure was also measured by four Wiancko electronic pressure-time gages (Fig. 51b) located on the door outside each acceptor igloo and on top of the earth fill above acceptor igloo B. (The locations of these and the following gages are indicated in Fig. 48.)

EARTH PRESSURE DATA

Earth pressures were measured by four Wiancko earth pressure-time gages (Fig. 51d) in two sets (one horizontal and one vertical gage per set) located three feet below the surface of the earth fill at one side of acceptor igloos B and D. The horizontal component of the peak earth pressure was measured by three gages; one in the earth about one foot below the top of the curb at the side of igloo C, and two others in a similar position at the side of igloo B about six feet in from each end of the igloo.

ACCELERATION DATA

To measure the accelerations experienced by the magazines, eight Wiancko accelerometers were used in four sets (Fig. 51a) with one accelerometer in each set installed to measure the horizontal acceleration component and one to measure the vertical component. These sets were installed near the center of the floor of acceptor igloos B and C, and at the side of acceptor igloos B and D three feet below the surface of the earth fill. A ninth accelerometer was installed behind igloo C, three feet below the surface of the earth fill, to measure horizontal accelerations.

DOOR MOTION

To measure the movement of the acceptor igloo doors at the time of detonation, two scratch gages were designed, fabricated, and mounted on the doors of igloos B and C.

SOIL DATA

Measurements of the characteristics of the earth fill were conducted at the request of the Office of the Chief of Engineers, Department of the Army, to relate the test results to what might be expected when other soil types were used for igloo cover. The detailed data requested and the test results are included in Appendix F.

EARTH DISPERSION

The deposition and character of the soil from the crater and earth cover were measured by several methods. Dissemination of the throwout material was determined by locating 126 stakes in the ground over the magazines and out to 100 ft, setting them deep enough to prevent vertical displacement during the explosion. The level of the earth was measured on the stakes before and after the test.

The throwout material was also measured by locating pie-pan and plastic-lined metal washtub collectors, as shown in Figs. 52 and 53, about the igloo complex at 50-ft intervals on concentric circles of 50, 75, and 100 ft radii; and at 50-ft intervals on 45° arcs of 150, 200, 250, 300, 350, 400, 500, 600, 700, and 800 ft radii on the predicted downwind side of the igloos. The washtub and pie-pan collectors were supplied and installed by Eberline Instrument Corporation, Santa Fe, New Mexico.

To measure the fallout dispersion of the tracer material from the one donor warhead, about 150 two-foot square platforms were installed three feet above ground level on 90° arcs of 500, 750, 1000, 3000, and 5000 ft radii on the downwind side of the igloos. These platforms (Fig. 54) supported sticky plates and other collection media provided by Isotopes, Incorporated, Westwood, New Jersey.

The dispersion of the tracer material within the crater was measured by core samples extracted by the Eberline Instrument Corporation.

TEST RESULTS

Detonation of the donor charge destroyed donor igloo A (Fig. 55), while the explosion did not propagate to any acceptors. Visual and photographic observations of firebrands showed that a portion of the rocket motor propellant burned rather than exploding.

The rear wall of the donor igloo was broken from the floor, raised about one foot, and tilted back about 42°, but did not appear to be extensively cracked. The main floor slab was moved back about one inch, while the south curb was separated and moved about five feet forward and the north curb was separated and moved about 1-1/2 ft forward.

The acceptor missiles in igloo C (located 14 ft from the donor igloo, nominally 1.25 x $W^{1/3}$) were undamaged, although their stands were slightly displaced. The entire igloo was shifted sideways, being displaced 1.8 inches at the front and 3.2 inches at the rear. Both doors were bowed inward, 2.2 inches and 4.0 inches, but could be opened manually. Both door liners were loosened, one falling off. The remaining wingwall, which was cracked, was separated about 1/2 inch from the door pilaster, which was also cracked. Both curbs, the floor, and the rear wall were extensively cracked. The steel arch was bowed inward on both sides as shown by Figs. 56, 57, and 58.

The acceptor missiles in igloo B were undisturbed, although the entire igloo (spaced 16.5 ft from the donor igloo, nominally 1.5 x $W^{1/3}$) was shifted laterally, 1.4 inches at the front and about 3.4 inches at the rear. Both doors were bowed inward, 2.3 inches and 4.15 inches, to such an extent that they could not be opened by hand. The remaining wingwall was separated 3/4 inch from the door pilaster, and both the wingwall and pilaster were cracked in several places. Both curbs, the floor, and the rear wall were extensively cracked. The steel arch was bowed inward (as shown by Figs. 59, 60, and 61), but to a lesser extent than in igloo C. The displacement of the floors of igloos A, B, and C were determined by measurements from undisturbed points exterior to the magazine complex.

The doors on igloo D were undamaged and opened easily. The explosion had forced the entire igloo forward about three inches relative to the wingwalls (Fig. 62a), cracking the wingwalls, and tilted the rear wall inward six to seven inches at the top. The door pilaster was tilted outward about 3/4 inch at the top. When the rear wall moved forward, it was extensively cracked (Fig. 62b), and it struck the noses of all three acceptor missiles, tipping them on their stands causing one missile to strike and puncture a door liner, fracturing the missile wing.

A survey of the fragment dispersion showed that it was largely confined to an 80° arc out to 500 ft, to a 40° arc between 500 and 1,000 ft, and to a 20° arc beyond 1,000 feet. No concrete fragments were found beyond 1,100 ft, while part of a metal door was found beyond 3,000 feet. Part of the fragments are listed in Table 4, their location is indicated in Fig. 63, and illustrations of selected pieces are included in Fig. 64.

Complete motion-picture and still test coverage was obtained. Copies of the film and the camera constants were transmitted to DASA for complete analysis.

The atmospheric data obtained prior to, during, and following the test are included in Appendix G. The trajectory of the balloon obtained from the cinetheodolite data is included in Appendix H.

The earth deposition as determined by measurements on the stakes is shown in Fig. 65, where contour lines have been sketched at one-inch increments of deposit. Values above five inches were obtained immediately around the crater, but were omitted from Fig. 65 for clarity, and are indicated in Fig. 66.

TABLE 4. Fragment Distribution, Test No. 5 (E-7520)

Fragment ID No.	Description (see Fig. 64)
1	Large piece corrugated steel arch, #1.
2	Four large pieces corrugated steel arch (in immediate vicinity of crater and near acceptor igloo C), #2.
3	Concrete fragment with reinforcing rods (11"x14"x17"), #3.
4	Bottom right side of donor door frame and pilaster, #4.
5	Motor entrance nozzle, #5.
6	Top piece of south door of donor (45" x 42"), #6.
7	Bottom piece of south door of donor (51" x 56"), #7.
8	Piece of north door of donor (44" x 38"), #8.
9	Piece of corrugated steel arch (45" x 38").
10	Small (about 5 lb) concrete fragment (6" x 7" x 8").
11	Large concrete fragment with reinforcing rods (40" x 29" x 17").
12	Large concrete fragment with reinforcing rods (39" x 26" x 16").
13	Motor exit nozzle.
14	Piece of motor (about 8 lb).
15	Piece of motor (about 10 lb).
16	Piece of motor (about 5 lb).
17	Limitation of debris.
18	Large piece of concrete with reinforcing rods. Part of donor door frame and pilaster (Est. 6'x20"x18").
19	Piece of door frame.
20	Motor entrance and exit nozzles (attached).
21	Motor exit nozzle.
22	Large piece metal door frame.
23	Concrete fragment (about 50 lb).
24	Piece of donor door (24" x 24").
25	Plow-shaped piece of donor metal door frame.
26	Piece of metal donor door frame.
27	Part of donor door hinge-strap.
28	Small part of internal door framing.

The dimensions obtained from crater measurements are listed in Table 5.

TABLE 5. Width of Crater, Test No. 5 (E-7520)

Width (ft)	Across the top of crater
42.4	At front (head wall) opening
45.5	3 ft back from front opening
41.0	6 ft " " " "
40.0	9 ft " " " "
39.0	12 ft " " " "
38.0	15 ft " " " "
36.0	18 ft " " " "
34.0	21 ft " " " "
31.0	24 ft " " " "
26.0	27 ft " " " "

The washtub and pie-pan collectors were gathered up and analyzed by Eberline Instrument Corporation, who reported their data to DASA.

The sticky plates and other collection media from the platforms were collected by Isotopes, Inc., who also reported their results to DASA.

The Eberline Instrument Corporation obtained core samples from the lip and floor of the crater to perfect the techniques to be used on a subsequent test at another location. Twenty-five two-inch cores of three-foot length were desired from the lip and walls of the crater, and ten cores of one-inch length were desired from the concrete donor floor. Results of the operation and analysis of the cores were reported to DASA.

The data derived from the BRL gages is presented in Table 6, and the gage identification is listed in Appendix I. The measured side-on overpressures converted to sea level values are presented as a function of scale distance in Fig. 67, with the scale distance based upon an explosive weight of 1,275 pounds. It is of interest to note that in contrast to the results of Tests 1 and 2, the overpressures recorded in this test by the three gages nearest the igloo were lower than that to be expected from the detonation of the same weight of high explosive in the open air on the surface, while the overpressures measured by the three farther gages were of the same relative magnitude as in the earlier tests.

The relatively higher overpressures recorded by the three farther gages may be partially explainable through reference to Fig. 68. The records from the three gages nearest the igloo seem to show a second pressure pulse, or a plateau of pressure, which appears to overtake the initial pulse as the distance from the explosion increases. This second

TABLE 6. BRL Gage Data for Test No. 5, I

Ambient Conditions: 945.4 mbar, 69°I

Station	Direction from donor	Distance (ft)	Peak over-pressure (psi)	Converted scale distance	Overpressure converted to sea level (psi)	Pulse duration (msec)	Pulse d conve to sea (mse
1W	Front	40	45.48	3.53	48.8	24.0	23.
2W	Front	50	24.46	4.41	26.2	26.4	25.
3W	Front	100	8.80	8.82	9.44	35.2	34.
4W	Front	200	4.03	17.64	4.32	40.67	39.
5W	Front	500	1.19	44.1	1.28	49.33	48.
6W	Front	920	0.47	81.1	0.50	51.6	50.

E Gage Data for Test No. 5, E-7520

F nditions: 945.4 mbar, 69°F.

ressure erted a level si)	Pulse duration (msec)	Pulse duration converted to sea level (msec)	Scale duration	Impulse (psi-msec)	Impulse converted to sea level (psi-msec)	Scale impulse
.5 .8	24.0	23.5	2.14	225.01	237.0	21.5
.8 .2	26.4	25.8	2.35	238.37	251.0	22.8
.4 .44	35.2	34.4	3.13	148.21	156.2	14.2
.8 .32	40.67	39.8	3.62	70.79	74.6	6.78
.3 .28	49.33	48.3	4.39	26.54	27.9	2.54
.5 .50	51.6	50.5	4.59	10.88	11.46	1.04

B

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pulse appears to have blended with the initial pulse between gage stations 3W and 4W, which may have resulted in a relatively higher peak pressure at the three farther gages.

The source of the second pulse could have been the explosion of the rocket motor propellant a discrete interval later than the detonation of the warheads. It is also possible that the propellant exploded in a manner distinctly different from a high-explosive detonation, perhaps developing an overpressure curve with characteristics different from the typical high-explosive overpressure wave.

It would appear that additional igloo experiments comparing detonations of propellants to explosives would be of value. Admittedly, the paucity of data from this single test can provide only an indication of what may have occurred.

The results obtained from the Wiancko electronic blast pressure-time gages secured to the igloo doors and on the earth fill over igloo B are listed in Table 7. Each of the gages was oriented normal to the door.

TABLE 7. Wiancko Electronic Blast Pressure-Time Gage Data, Test No. 5

Location	Gage range (psi)	Overpressure (psi)
Igloo C door	250	34
Igloo B door	250	36
Above Igloo B	250	25
Igloo D door	100	4

The measurements obtained from the Wiancko earth pressure-time gages located beside igloos B and D three feet below the earth surface are listed in Table 8.

The copper indenter peak earth pressure gages provided data, but it was determined subsequent to the test that the data were difficult to interpret because of doubt concerning the suitability of the gages for the measurement desired.

TABLE 8. Wiancko Earth Pressure-Time Gage Data, Test No. 5

Location	Orientation	Gage range (psi)	Measured pressure (psi)
Igloo B	Horizontal	50	2
Igloo B	Vertical	50	2
Igloo D	Horizontal	25	1.75
Igloo D	Vertical	25	1.75

The results from the Wiancko accelerometers located on the igloo floors and in the earth fill are listed in Table 9.

TABLE 9. Wiancko Accelerometer Data, Test No. 5

Location	Direction	Gage range (g)	Acceleration recorded (g)
Igloo C floor	Horizontal	1000	10
Igloo C floor	Vertical	100	3
Behind Igloo C	Horizontal	1000	Below gage threshold
Igloo B floor	Horizontal	1000	10
Igloo B floor	Vertical	100	7
Beside Igloo B	Vertical	100	12
Beside Igloo D	Horizontal	100	10
Beside Igloo D	Vertical	100	10

The ranges of the gages used to measure the accelerations, blast pressures, and earth pressures were selected on the best information available at the time regarding the values to be expected. Since the quantities encountered were so small in comparison, the accuracy of their information was downgraded.

Although the scratch gages mounted on the doors of igloos B and C were designed to measure twice the amount of door movement expected, the actual movement was so large that no data were obtained. It is believed that the detonation caused the scratch elements to jump off the recording plates, then return to the plates and remain at rest.

CONCLUSIONS

Results of this test showed that, for test parameters used, a side-to-side space factor of $1.25 \times W^{1/3}$ between earth-covered, steel-arch magazines, and of $1.5 \times W^{1/3}$ between the rear walls of the same magazines, is effective in preventing the propagation of explosions from one igloo to another.

The test also provided experience in the application of procedures for determining the dispersion and fallout of soil, dust, and weapon residue resulting from an explosion in a buried magazine.

Figures 48 through 68 illustrate the characteristics and results of Test No. 5, conducted under E-7520.

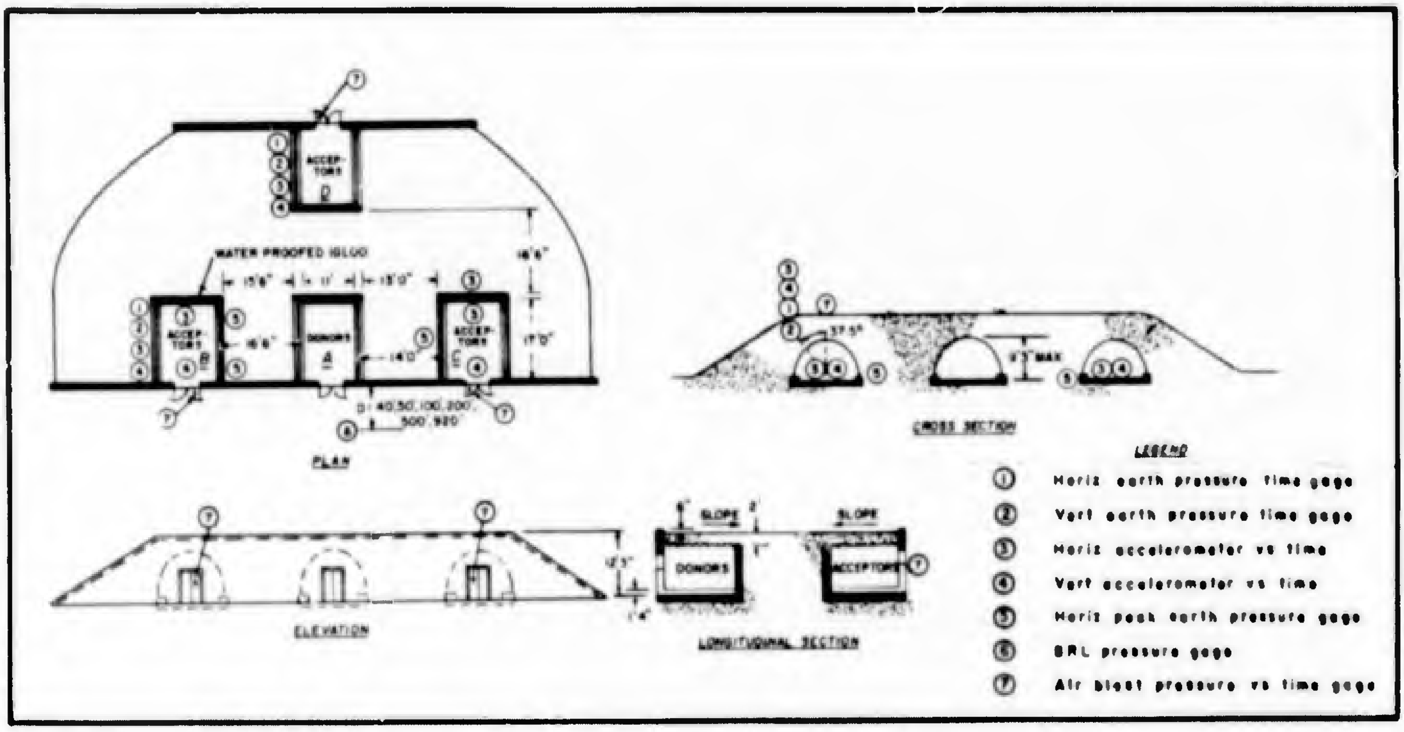


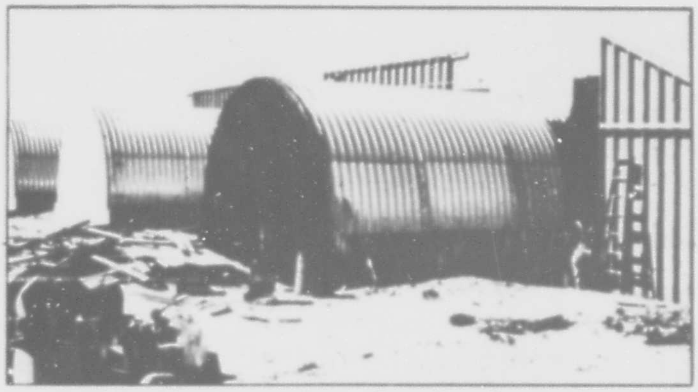
FIG. 48. ADC Igloo Complex.

a. Igloo Complex During Construction.

b. Front of Complex.

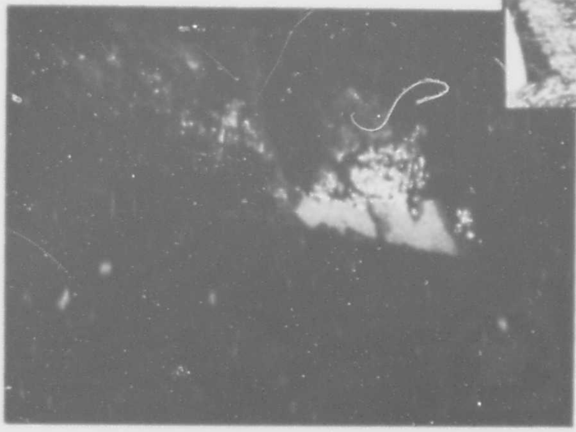
c. Rear of Complex.

FIG. 49. Test Igloos.



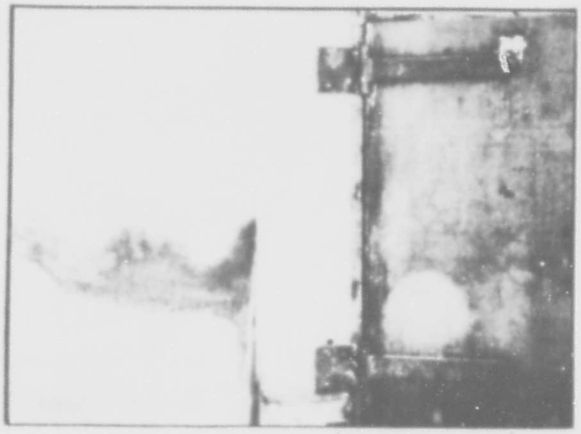
a. Application of Water-Proofing Compound.

b. Water-Proofed Igloo and Headwall.



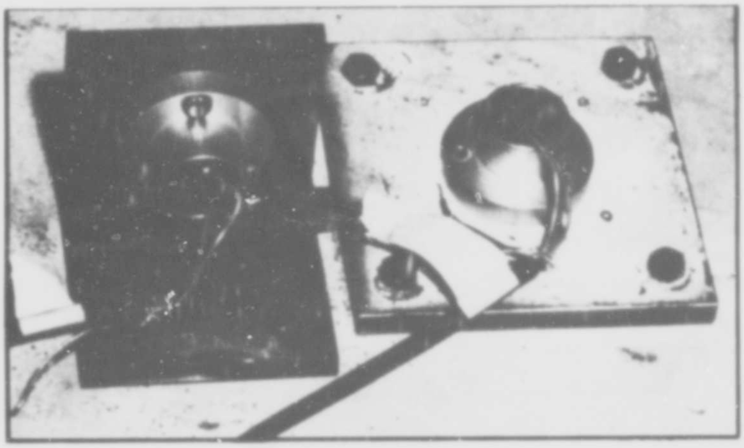
c. Where Water Had Been Pooled.

e. Results of Water-Proofing Test

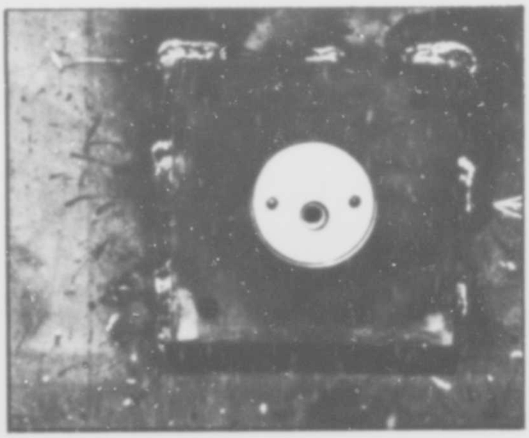


d. Location of Leaks (External Only).

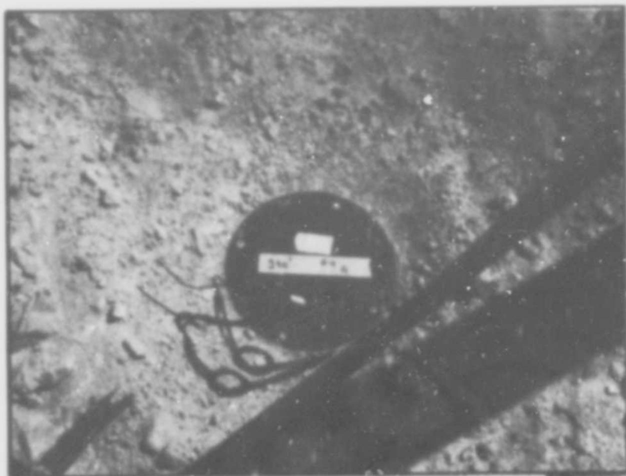
FIG. 50. Water Seepage Test.



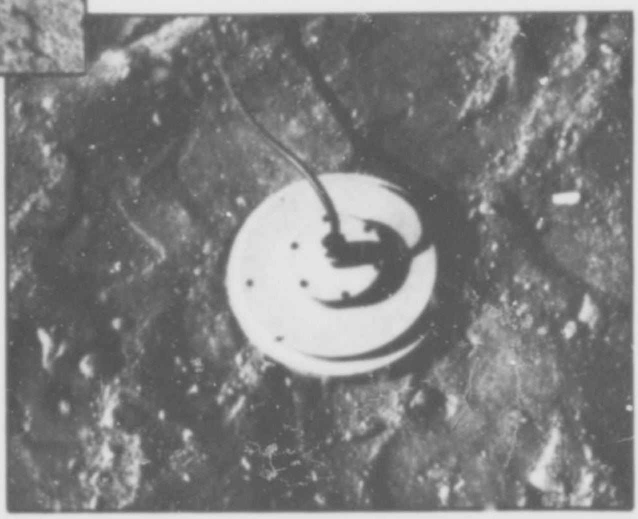
a. Floor-Mounted Horizontal and Vertical Accelerometers.



b. Door-Mounted Pressure-Time Gage.



c. BRL Pressure Gage.



d. Earth Pressure-Time Gage.

FIG. 51. Pressure and Acceleration Gages.

FIG. 52. Plastic-Lined Washtub Type Throw-Out Collectors.

FIG. 53. Pie-Pan Type Throw-Out Collectors.

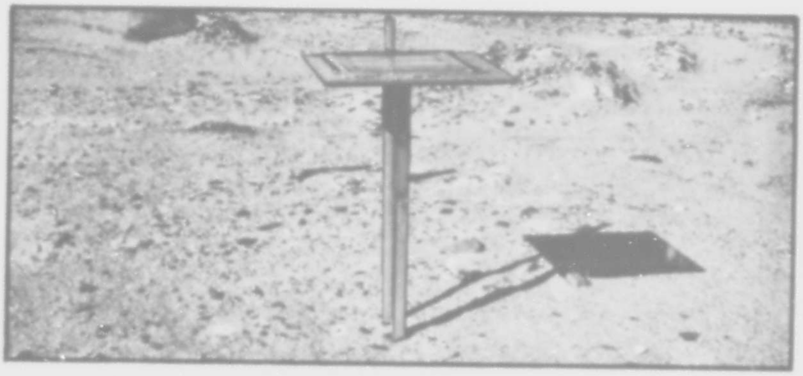


FIG. 54. Support Platform for Fallout Collection Media.

FIG. 55. Igloo Complex After Test.

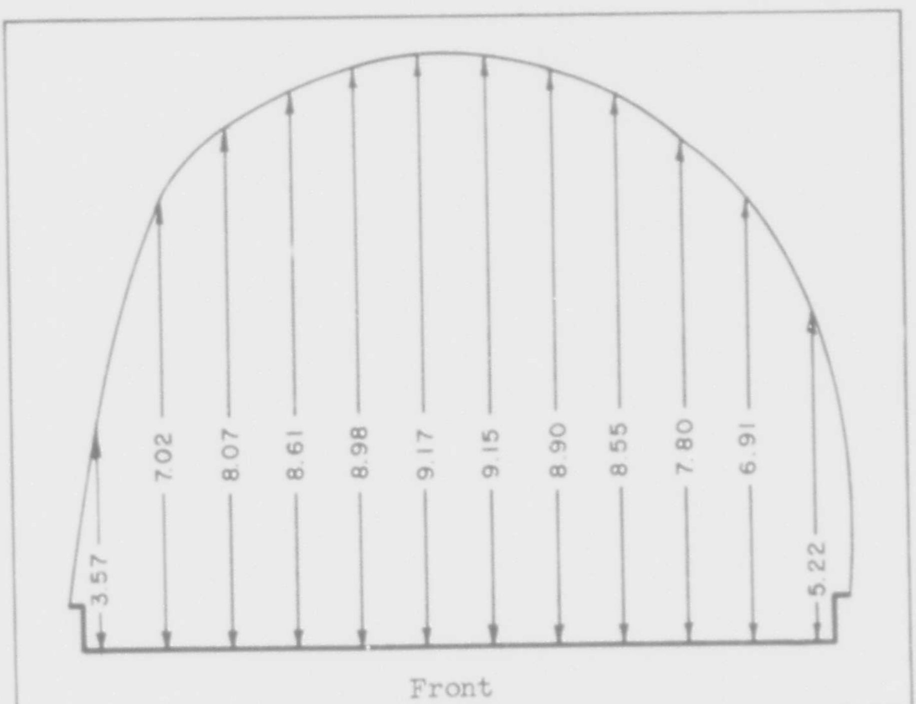


FIG. 56. Igloo C Arch Distortion
(Photo and Front View).

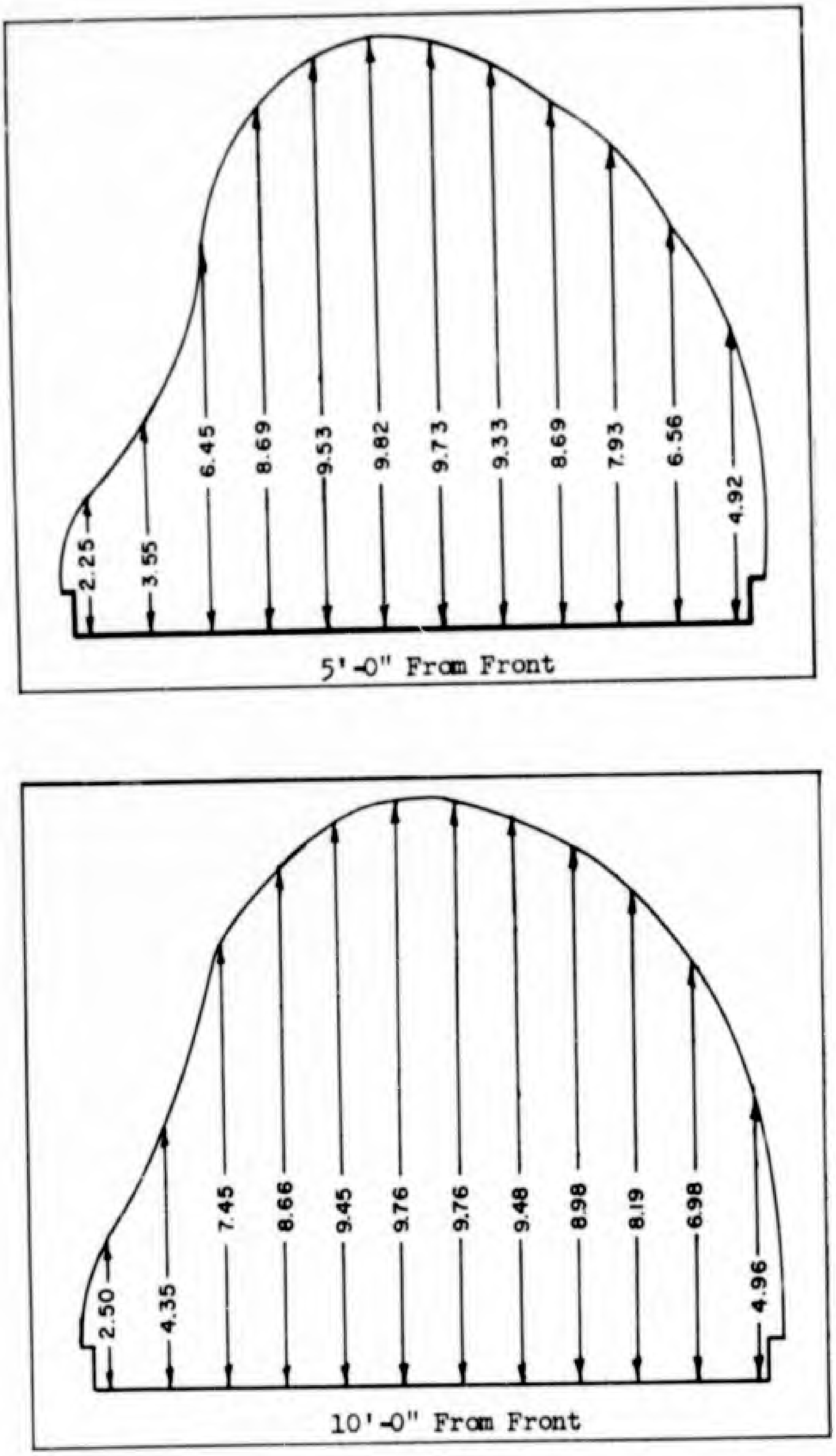


FIG. 57. Igloo C Arch Distortion (5 Ft From Front and 10 Ft From Front).

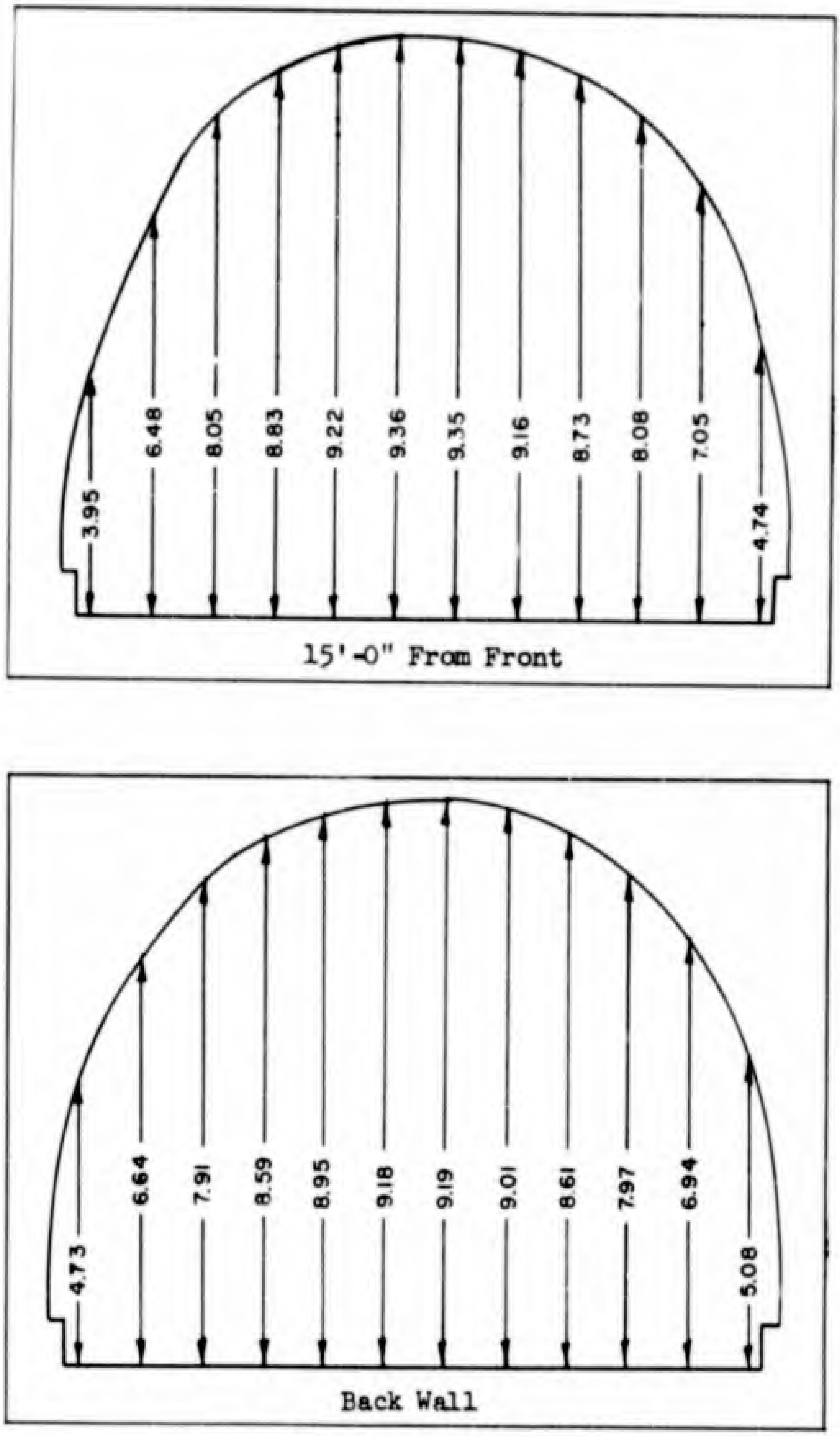
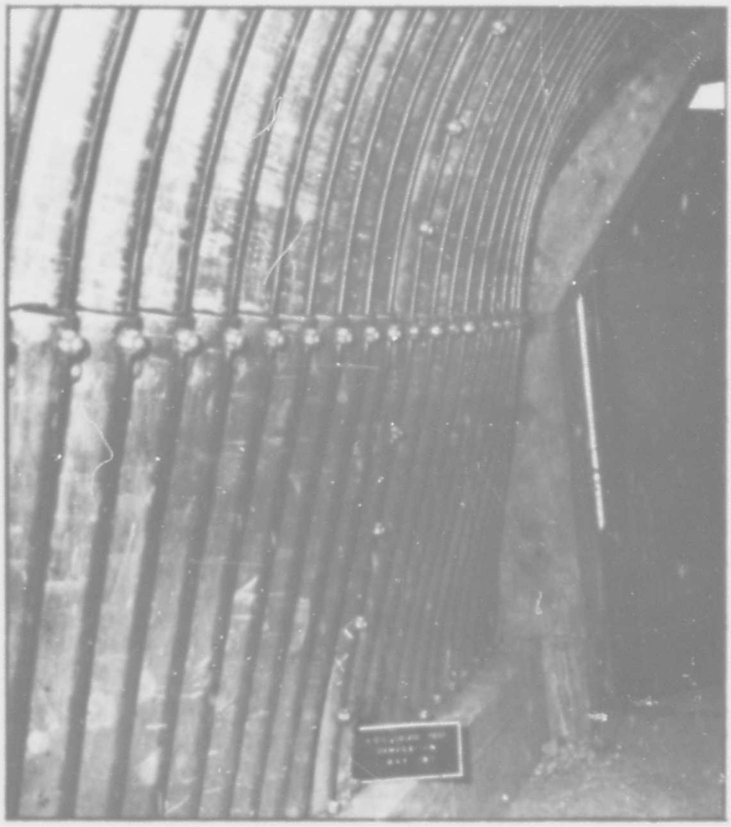


FIG. 58. Igloo C Arch Distortion
(15 Ft From Front, Back Wall).



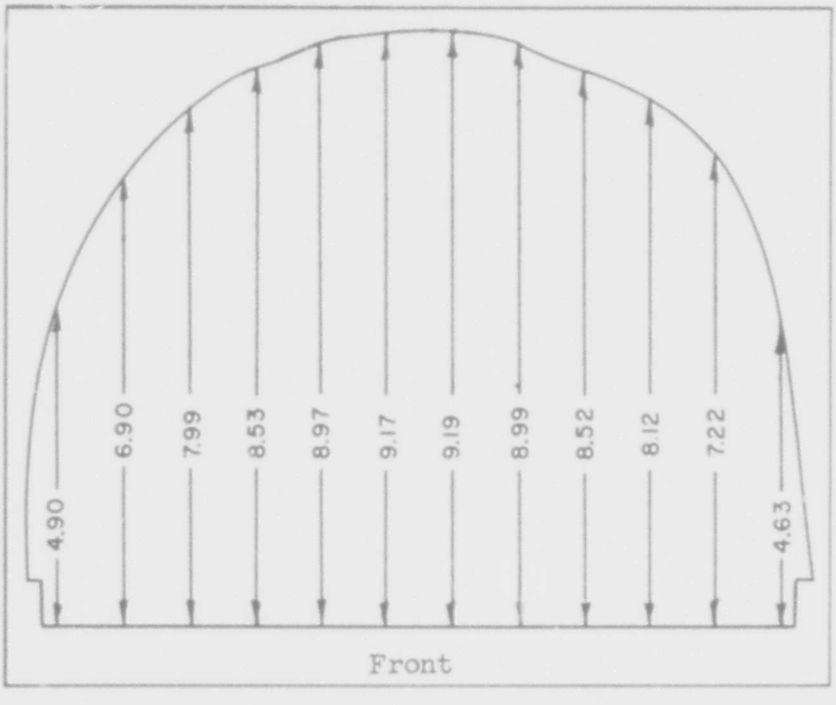
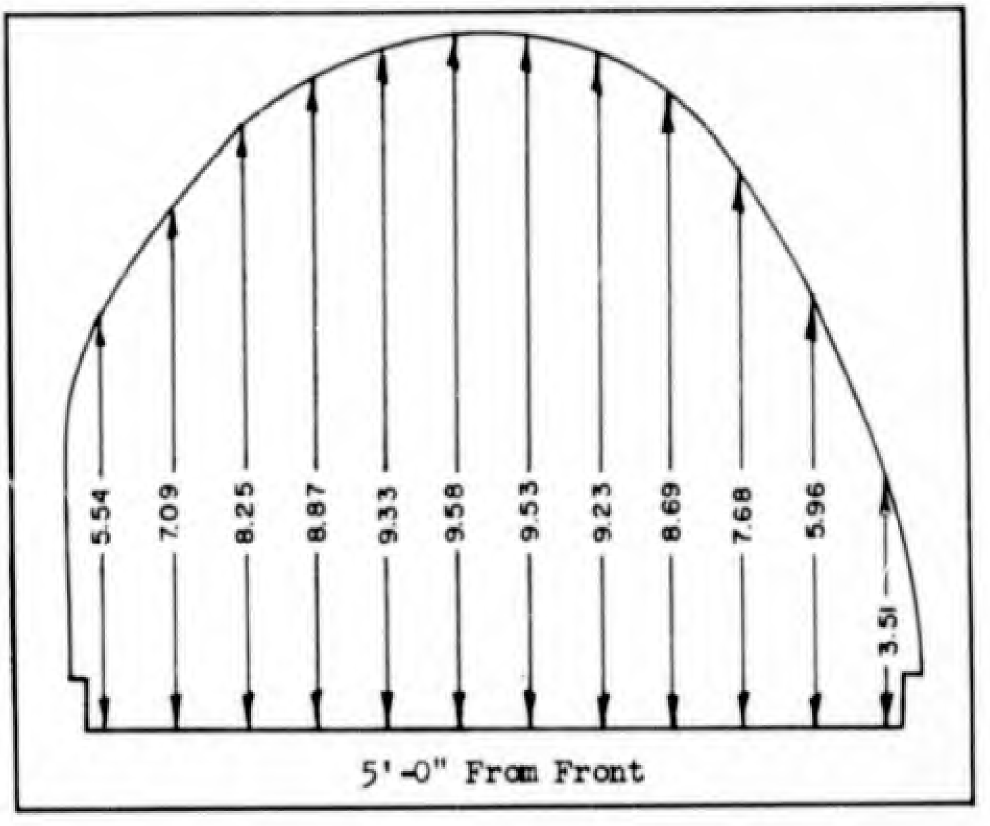


FIG. 59. Igloo B Arch Distortion
(Photo and Front View).



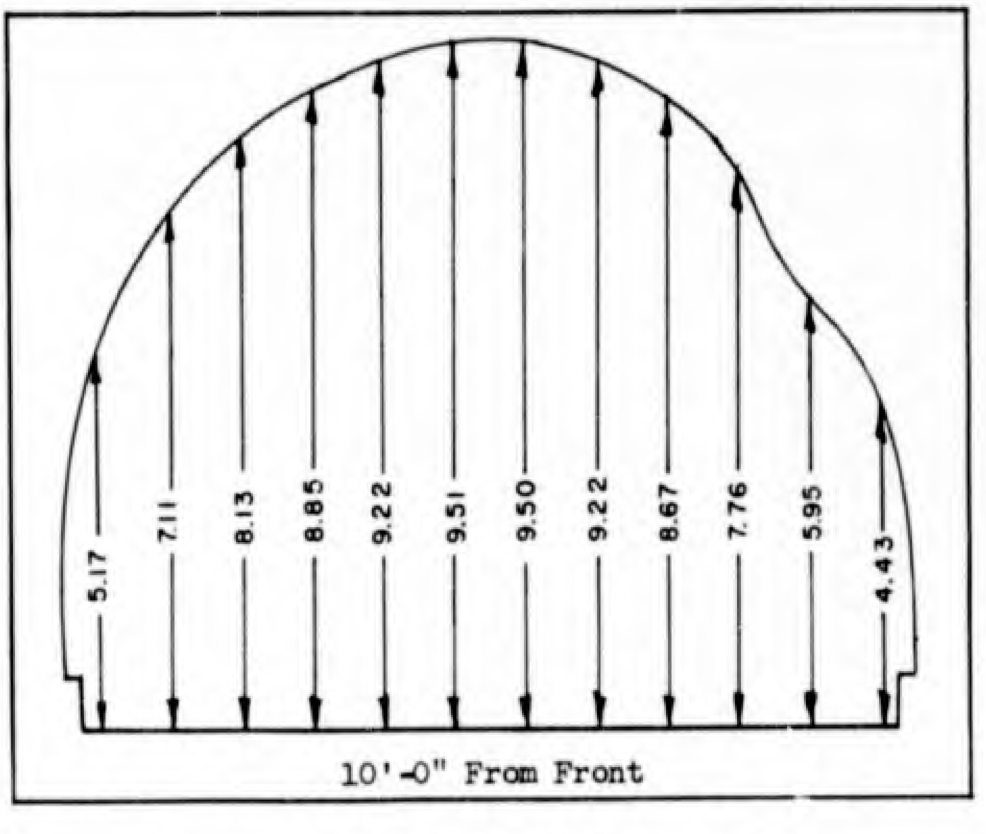


FIG. 60. Igloo B Arch Distortion (5 Ft From Front and 10 Ft From Front).

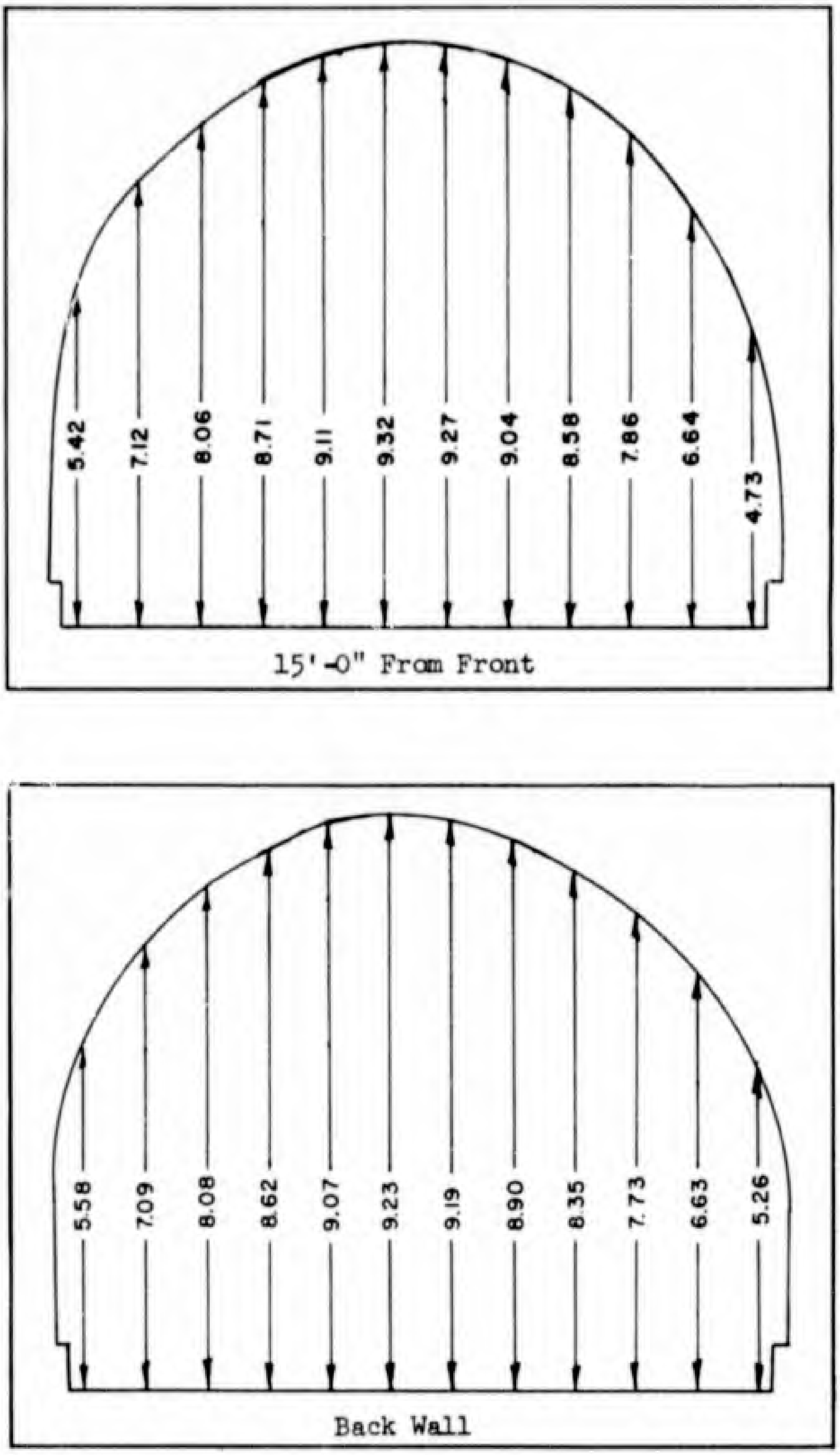
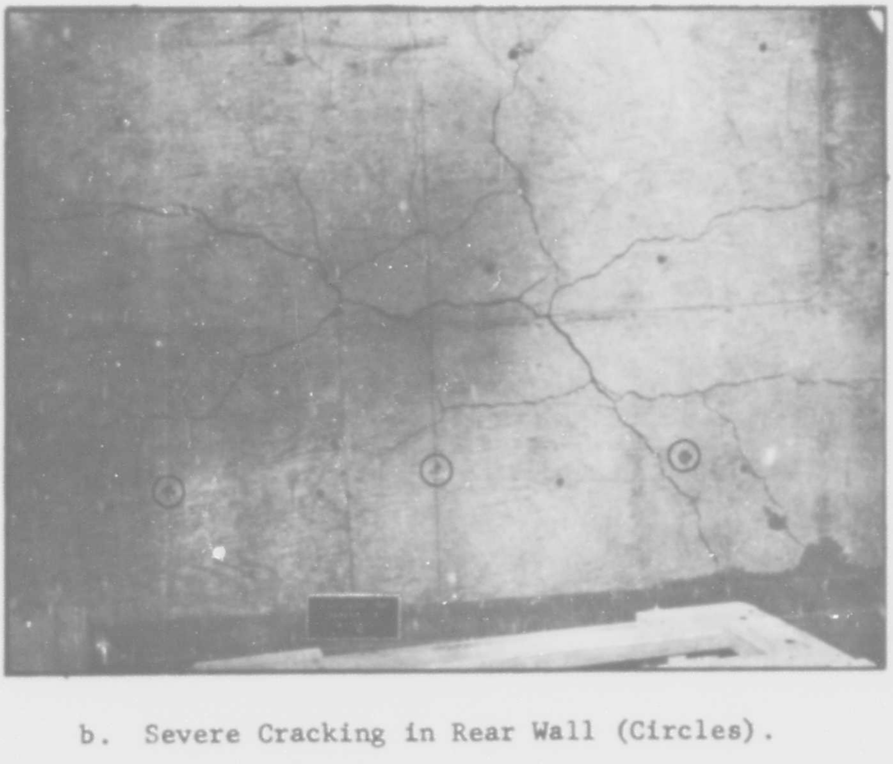


FIG. 61. Igloo B Arch Distortion
(15 Ft From Front, Back Wall).

a. Damage to Wing Wall.



b. Severe Cracking in Rear Wall (Circles).

FIG. 62. Damage in Igloo D.

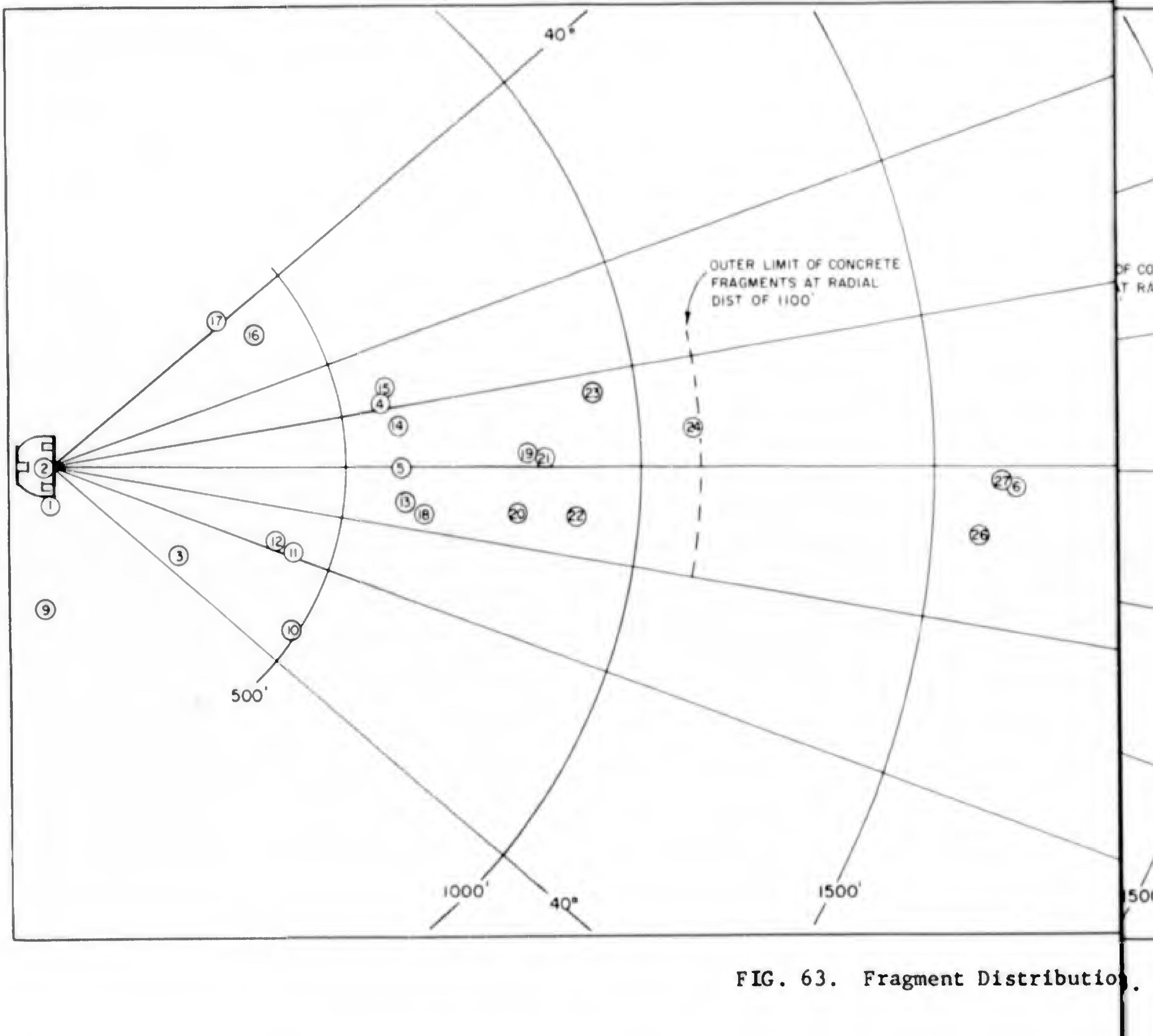
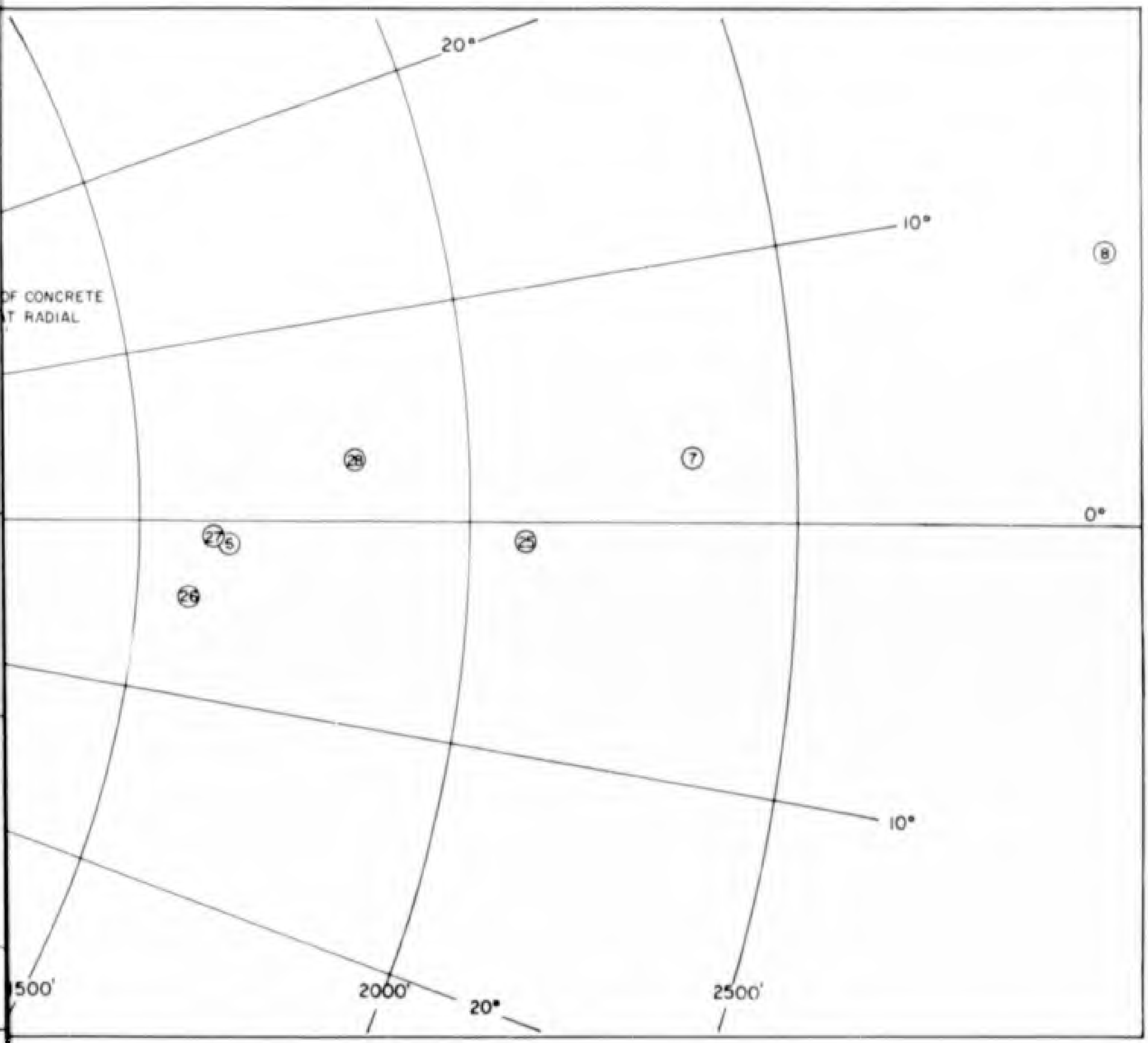


FIG. 63. Fragment Distributio

A



. Fragment Distribution.

B

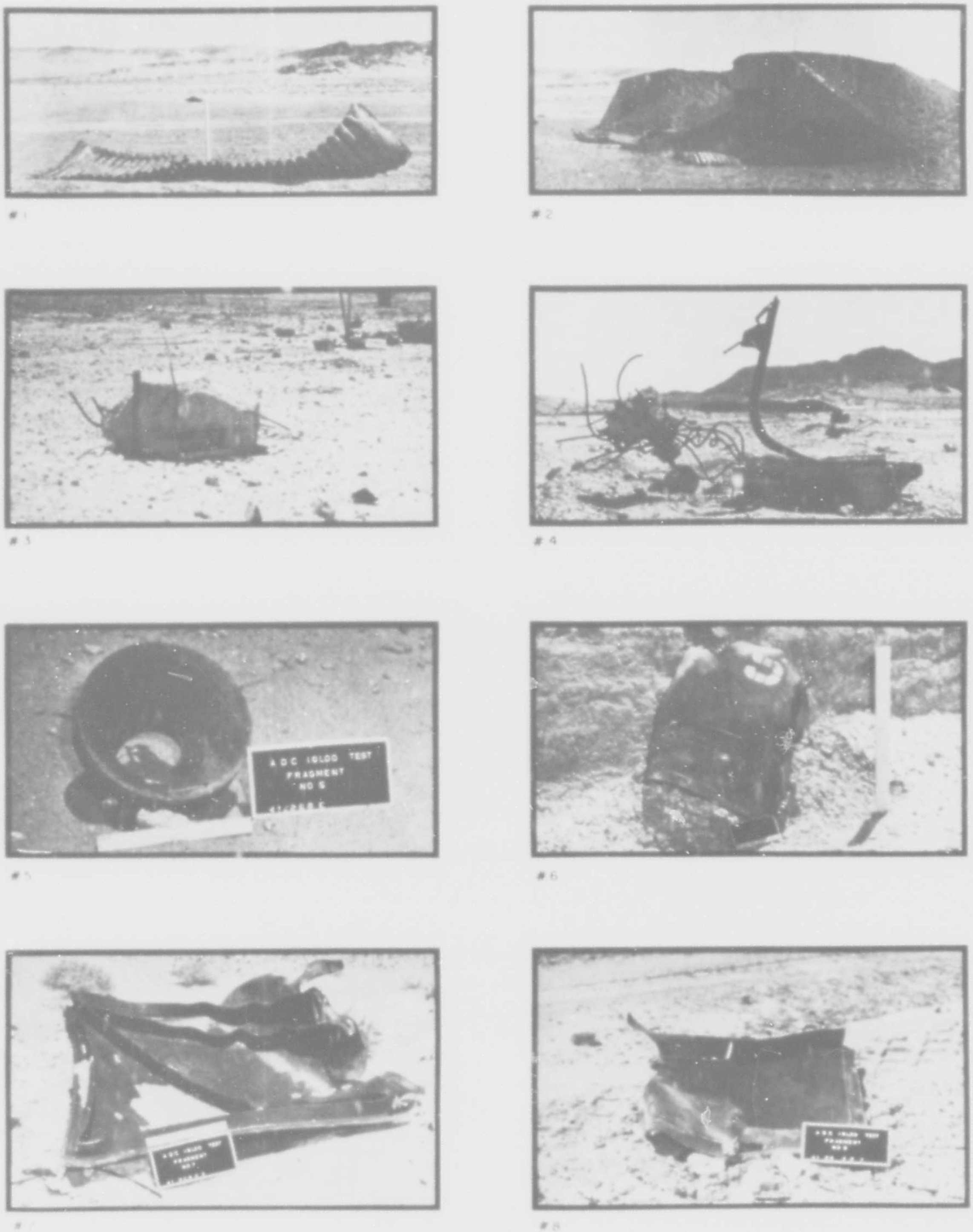


FIG. 64. Fragment Distribution.

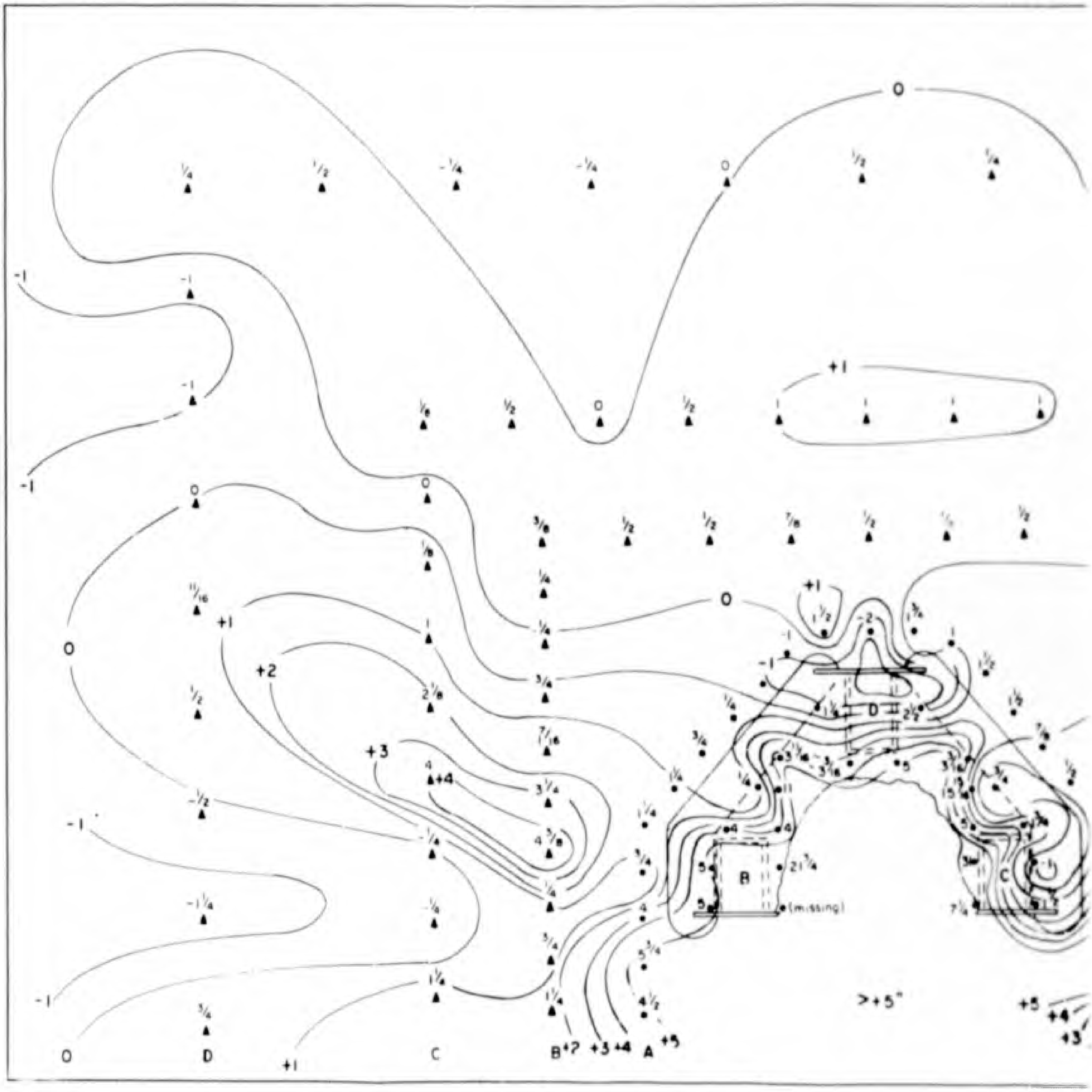


FIG. 65. Soil Deposition.

A

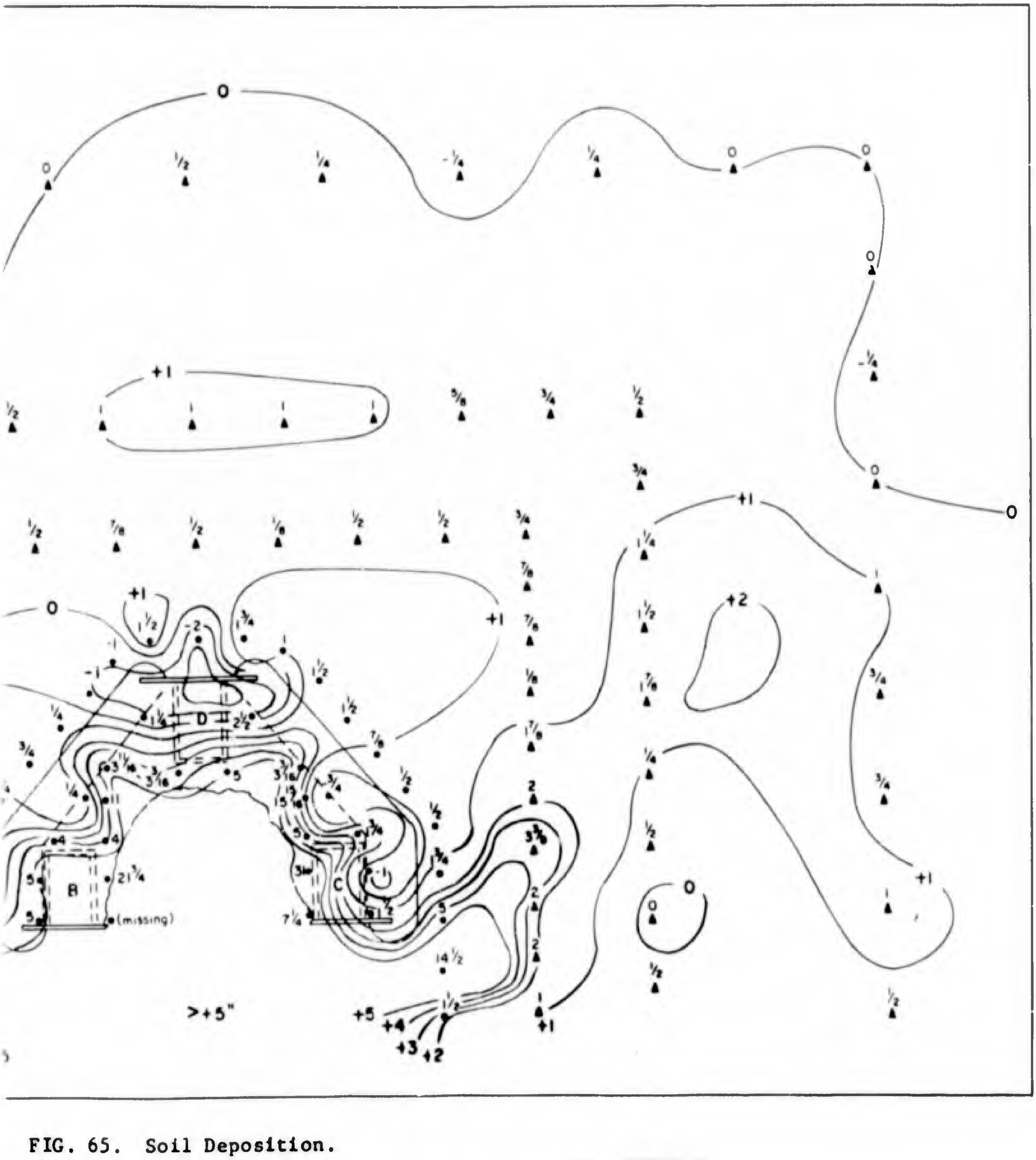


FIG. 65. Soil Deposition.

B

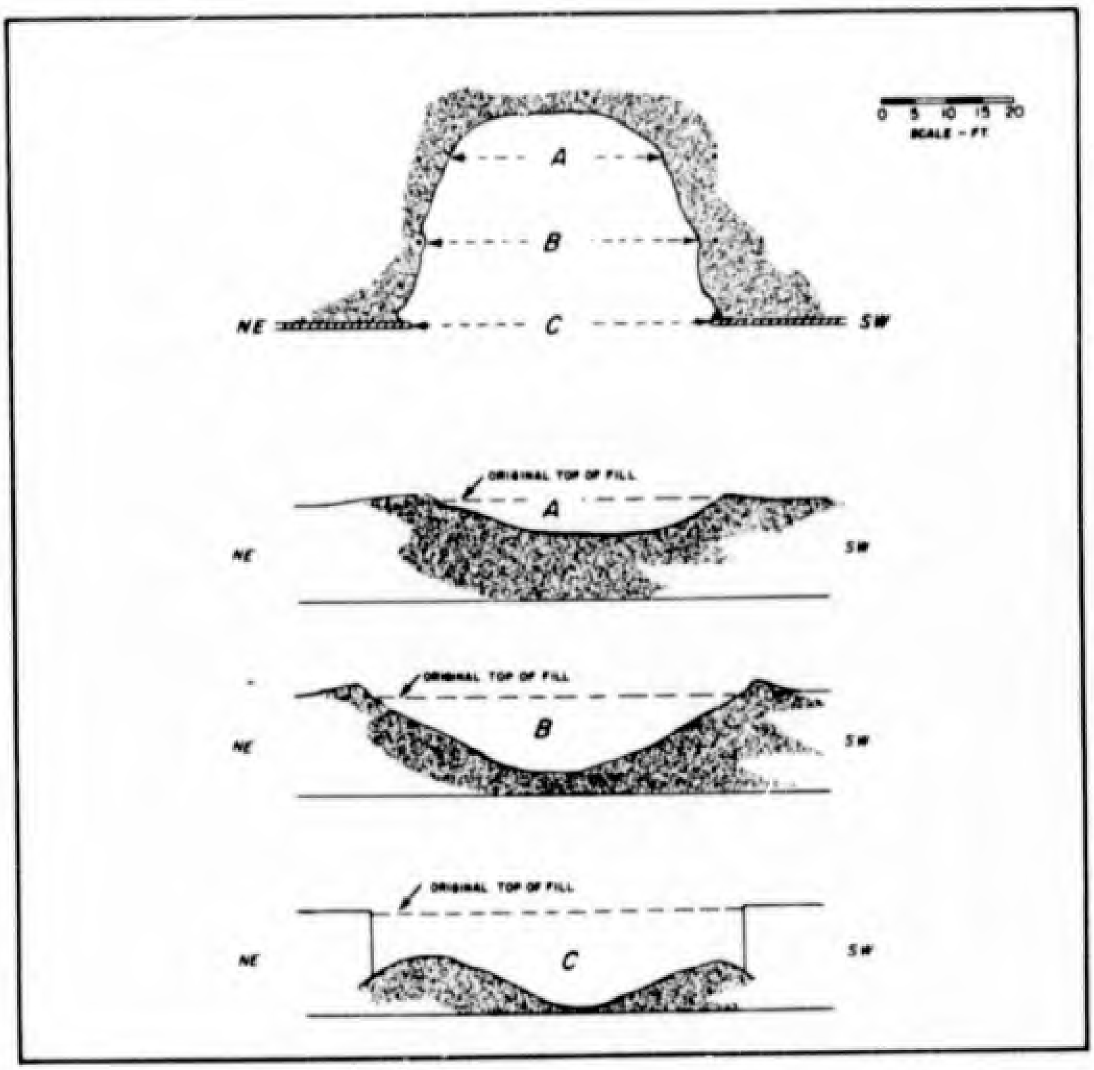


FIG. 66. Crater Measurements.

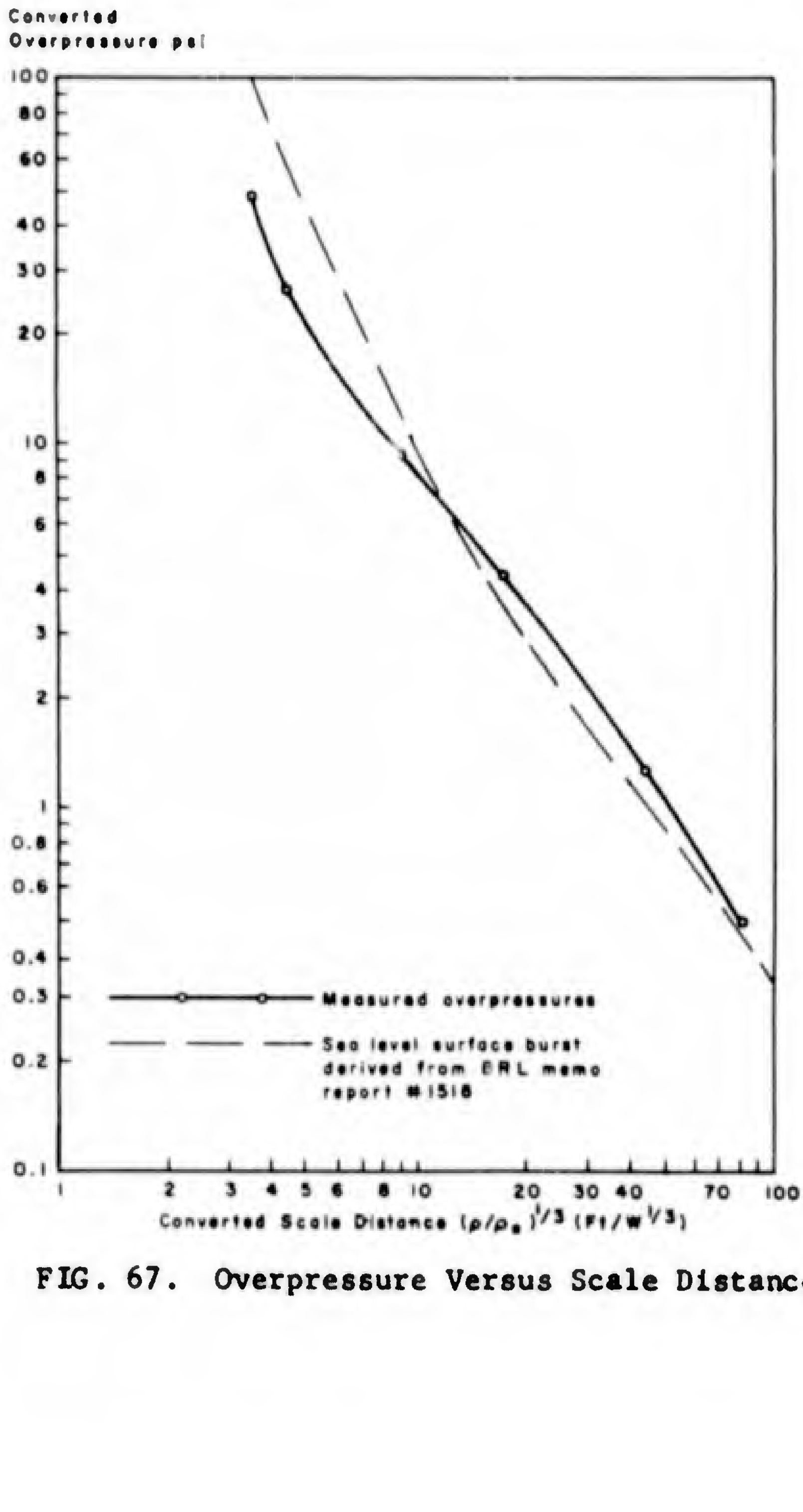


FIG. 67. Overpressure Versus Scale Distance.

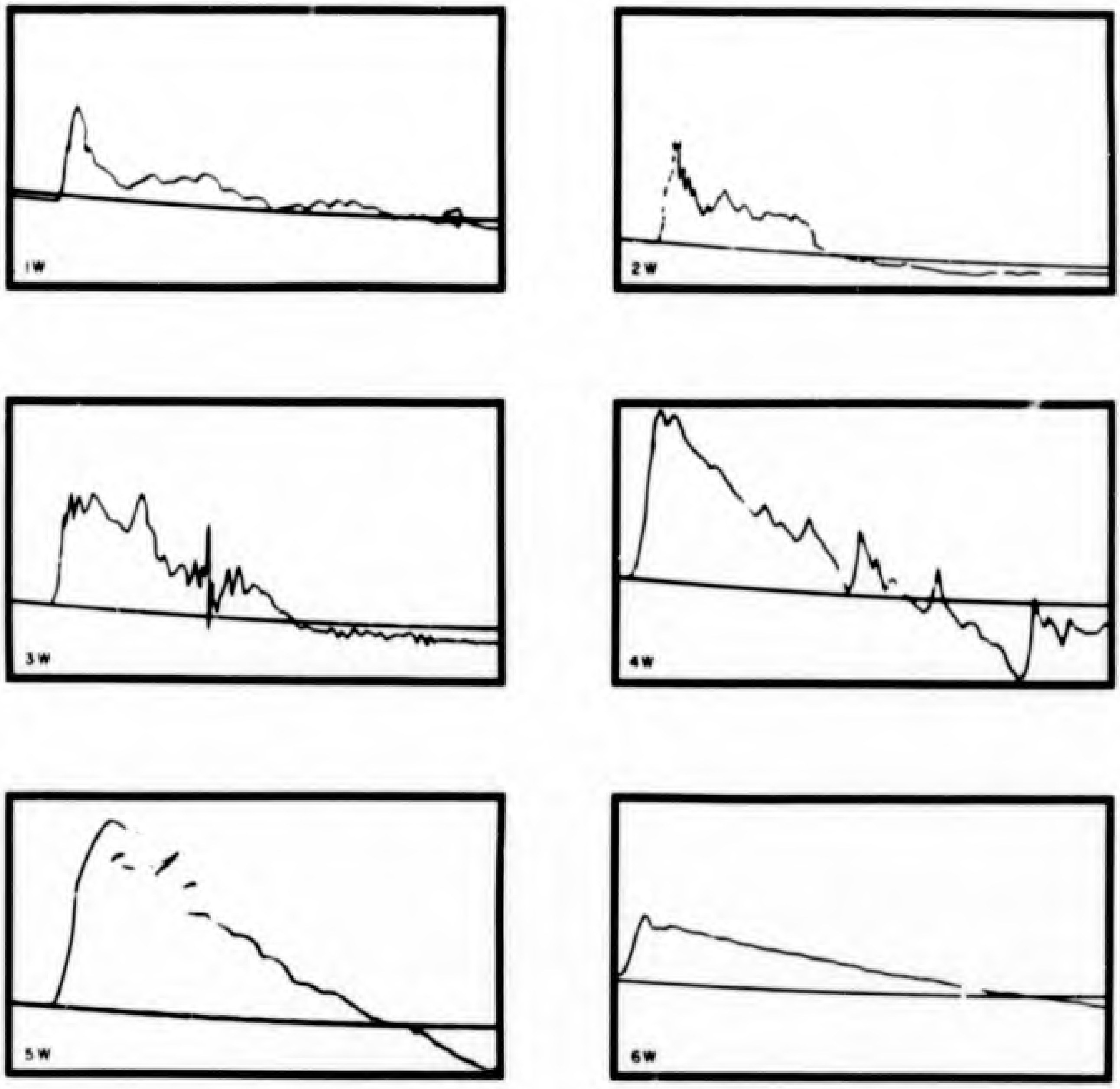


FIG. 68. BRL Gage Records (Donor Front).

SECTION FIVE

TEST NO. 6 (E-3005)

The igloo test program to this point had shown that the side-to-side spacing factor between buried igloos could be established at 1.5 x $W^{1/3}$, and Test No. 5 indicated that it could be reduced to 1.25 x $W^{1/3}$ for test conditions as described. However, all the tests had been accomplished with explosive donor charge weights under 2,500 lb, and it was uncertain whether the same results would be obtained from significantly larger donor charges. Also, the mixture of high explosive and rocket propellant comprising the donor charge for the fifth test gave ambiguous results, decreasing confidence in the 1.25 x $W^{1/3}$ factor. To eliminate these doubts and definitely determine the lower safe limit of clear distance between magazines, Test No. 6 was authorized using two acceptor igloos located with spacing factors of 1.25 x $W^{1/3}$ and 1.50 x $W^{1/3}$ to each side of the donor igloo containing 100,000 lb of high explosive. The test was conducted at 1300 hours PST on 18 December 1963, at the NOTS Randsburg Wash Test Range.

TEST STRUCTURES

The three steel-arch igloos were constructed of one-gage corrugated steel in accordance with O.C.E. specification 33-15-64-62 as approved by ASESB, and covered with essentially separate compacted earth mounds, two feet thick at the top, with side slopes of one in two. Each igloo was 14 ft 4 inches high inside, 25 ft wide at the curbs and 59 ft long. The clear separation distance between the center igloo and the west acceptor igloo was 58 ft (1.25 x $W^{1/3}$), and between the donor igloo and the east acceptor igloo it was 70 ft (1.50 x $W^{1/3}$).

To assure that the earth cover was at least 90% compacted, earth samples were tested during the fill operation, and the earth was re-compacted when necessary. Concrete core samples were obtained during construction, the average 28-day compressive strength being 3,559 psi.

To obtain additional information on the effectiveness of barricades in reducing fragment throw and overpressures, an earth barricade was constructed in front (to the north) of the donor igloo, with a distance of 25 ft between the igloo and the toe of the barricade. The barricade was three feet thick at the top, about 14 ft high, had side slopes of one in two, and was long enough to subtend a full 60° angle to the door of the donor igloo. The only compaction of the soil was that incidental to the passage of earth-moving equipment during construction. The completed igloos and barricade are shown in Fig. 69.

DONOR CHARGE

It had been suggested that the donor charges of Tests 1 and 2 distributed about the donor igloo, and the elongated charges (warheads and rocket motors) of Test No. 5, had less than the maximum blast effect on the igloo walls. To eliminate this possibility and to simulate the block storage system for bulk explosives, the donor charge for this test was concentrated in a single stack.

The charge consisted of 100,000 lb ($W^{1/3} = 46.4$) of Composition B packed in 2,106 sealed, 9.5-inch cubical cans, with 47.5 lb of explosive in each container. The cans were stacked in the center of the donor igloo for maximum blast effect, as shown in Figs. 70 and 71. Detonation was accomplished by two Engineer's Specials installed with Composition C-3 primer in two-inch holes bored six inches deep in twelve blocks of explosive. The 12 detonation points were located at the upper corners of the stack at about mid-height on the vertical corners and near the center of each side, as illustrated in Fig. 71.

ACCEPTOR CHARGES

Eight spherical acceptor charges, consisting of standard 100-lb dividing wall acceptors with a full complement of detonators, were arranged in each acceptor igloo essentially four feet apart on wood stands in a row three feet from the wall adjacent to the donor, as indicated in Fig. 70. Figure 72 shows the acceptor charges in place.

INSTRUMENTATION

Eight 16mm cameras operated at 2,000 to 8,000 frames per second were located 1,500 ft from the front, rear, and both sides of the igloos to obtain coverage of the fireball expansion and the smoke and dust cloud growth. An M-45 tracking mount, incorporating two cameras operated at 120 and 1,000 frames per second, was located about four miles away to obtain overall coverage. All cameras used color film.

To measure the earth and air pressures impressed upon the igloos, and the accelerations of the igloos, 21 gages were installed about the magazine complex. The overpressure wave resulting from the detonation was measured by 18 BRL gages installed in the ground flush with the surface on lines extending 3,630 ft in front (north), 1,855 ft behind (south), and 1,855 ft to the side (west) of the magazines.

Atmosphere and wind characteristics were obtained preceding and following the test for prediction and avoidance of hazardous focusing effects and for correlation with the smoke and dust cloud dispersion.

Seismological data were provided by the Division of Geological Sciences Seismological Laboratory of the California Institute of Technology from three seismographs located at China Lake (32 miles at 310° from the test site), Goldstone (21 miles at 136° from the test site), and Lake Isabella (73 miles at 278° from the site).

TEST RESULTS

Detonation of the 100,000-lb donor (Fig. 73) resulted in complete destruction of the donor magazine (Fig. 74) without uncovering or seriously damaging either acceptor igloo. No propagation to any acceptor charges occurred. Measurement of the crater provided the contours of Fig. 75, which includes the donor igloo location.

Although no acceptor charges were ignited by the blast, most were slightly displaced with their wood stands, and one acceptor near the doors in each igloo was upset from its stand (Fig. 76). It is probable that these were upset by the doors falling inside, rather than by the blast.

West Igloo Damage. Both doors of the west acceptor igloo were bowed inward by the blast. While one was broken entirely away, falling immediately inside the doorway, the other door broke loose only from the bottom hinge and remained standing, supported by the top hinge. The east wingwall was separated from the head wall at the shear joint, being pushed forward about eight inches at the top and about 4-1/2 inches at the bottom.

The entire west igloo was displaced to the west, and the floor was distorted vertically, as indicated in Fig. 77, and sustained numerous random fine criss-cross cracks. The side of the steel arch nearest the donor was visibly distorted, but to such a minor degree that no actual measurements were attempted.

East Igloo Damage. Both doors of the east acceptor igloo were also bowed inward, and both were torn loose. One door fell immediately inside the doorway, while the other was found about 50 ft in front of the igloo. The west wingwall (nearest the donor) moved slightly away from the head wall, leaving a small gap at the shear joint.

The entire igloo was moved east, away from the donor, but to a lesser degree than the west igloo movement. The floor was distorted vertically (Fig. 77) and was cracked in a random criss-cross pattern, as in the west igloo. The steel arch did not appear to be distorted.

Fragment Dispersion. A limited survey showed that four main types of fragments were thrown to the longer ranges. These were fragments of steel reinforcing bars, steel arch, concrete, and clods of earth. Earth clods were the most numerous to the rear and side, and accounted for the maximum range of 3,300 feet. The clod traveling 3,300 ft broke into smaller pieces at impact. The total weight before impact was estimated at 15 lb, which was typical of many other clods. The larger steel arch pieces (50% to 80% of a complete panel) were limited to a radius of 1,600 ft, while one 24 x 24-inch fragment was found 2,900 ft in front of the igloos. The bulk of the larger concrete fragments were scattered to 800 ft forward, with the main concentration in zones of 25° to 50° from the igloo center line.

The earth barricade effectively intercepted most of the steel door fragments and limited their travel to approximately 200 ft beyond the barricade; however, a few small door or door-frame fragments were found 2,000 to 2,450 ft in front of the magazines.

The fragment dispersion shown in Table 10 gives the maximum distances at which various types of fragments were found. It should be noted that these represent fragments found, and a more extensive search might possibly have disclosed fragments thrown to greater distances.

TABLE 10. Fragment Dispersion, Test No. 6, E-3005

Type of fragment	Maximum distance thrown (ft)	Direction
Reinforcing steel	2,740	Rearward (south)
Concrete	2,530	" "
Steel arch	2,410	" "
Earth fill	2,500	" "
Steel arch	1,400	Sideward (east)
Earth fill	2,100	" "
Reinforcing steel	2,300	Forward (north)
Concrete	1,600	" "
Steel door	2,450	" "
Steel arch	2,900	" "
Steel arch	1,400	Sideward (west)
Earth fill	3,300	" "

Camera Data. Complete still and motion-picture coverage was obtained, and a technical motion picture (No. 146, "Earth-Covered Magazine Test 100,000-Pound Donor") was produced.

Meteorology. Surface and upper-air observations of pressure, temperature, relative humidity, and wind direction and speed were made at Fire Control at regular intervals preceding and immediately following the test. These data are presented in Appendix J.

Spectators on the roof of the Michelson Laboratory, approximately 30 miles away, saw the dust column but did not hear or feel the detonation. In the town of Trona, approximately 17 miles away, the blast was audible as a double shock.

Seismology. The results from the seismographs located at China Lake, Goldstone, and Lake Isabella, are shown in Fig. 78. Of interest is the fact that C.I.T. personnel located the source of the disturbance at 35°35'N latitude, 117°10'W longitude (±5 miles). The actual location was 35°31'N, 117°10'W.

Igloo Instrumentation. Twenty-one air blast and earth-pressure gages and accelerometers were located about the igloos as shown in Fig. 79. The instruments at locations (1), (2), and (5) were eight feet below the surface of the earth fill midway along the sides of the igloos. The gages at locations (3) and (9) were at the rear of the igloos, eight feet deep. The instruments at locations (4) were attached to the center of the igloo floors. The gages at locations (6) were attached to the middle of the doors, on the outside. The instruments at location (7) were at the surface of the earth fill over the middle of the igloos.

The data from the earth pressure gages are presented in Table 11, the accelerometer results are in Table 12, and Table 13 presents the results of the air blast pressure gages.

TABLE 11. Earth Pressure Data, Test No. 6, E-3005

Location	Gage	Range (psi)	Peak pressure (psi)	Arrival time (msec)
(1) West igloo	Bongo[1]		12 Hor.	56
(1) West igloo	Bongo		11 Ver.	54
(1) East igloo	Microducer	25	---[2]	--
(1) East igloo	Microducer	25	---[2]	--
(1) East igloo	Microducer	10	9 Hor.	46
(1) East igloo	Microducer	10	15 Ver.	28
(2) West igloo	Microducer	25	5 Hor.	30
(3) West igloo	Microducer	25	-2 Ver.[3]	39

[1]NOTS experimental gage.

[2]No data, reason unknown.

[3]Data unreliable.

TABLE 12. Acceleration Data, Test No. 6, E-3005

Location	Gage	Range (g)	Peak acceleration (g)	Arrival time (msec)	Duration (msec)
(4) West igloo	Wiancko	50	9 Hor.	10	130
(4) West igloo	"	50	21 Ver.	9	98
(4) East igloo	"	50	4.9 Hor.	29	56
(4) East igloo	"	50	10.1 Ver.	31	41
(5) East igloo side	"	50	--- Hor.	--[1]	--
(5) East igloo side	"	50	49 Ver.	39[2]	85
(9) East igloo rear	"	25	1.5 Hor.	--[2]	89
(9) East igloo rear	"	25	--- Ver.	--[1]	--

[1]No data, blast destroyed line.
[2]Data unreliable.

TABLE 13. Air Pressure Data, Test No. 6, E-3005

Location	Gage	Range (psi)	Peak pressure (psi)	Arrival time (msec)
(6) West igloo	Photocon	100	54	21
(6) East igloo	Photocon	100	54	27
(7) West igloo	Photocon	100	--[1]	--
(7) East igloo	Photocon	100	100+[2]	10
(8) Barricade toe	Waincko	500	125[3]	8

[1]No data, blast destroyed line.
[2]Pressure exceeded gage limit, possibly due to debris.
[3]Data unreliable, gage destroyed during recording.

Eighteen BRL gages were installed on three lines as shown in Fig. 80. The gage results are listed in Table 14, and the gage identification is listed in Appendix K. The measured overpressures converted to sea level conditions are presented as a function of scale distance in Fig. 81, where an explosive weight of 100,000 lb was used in determining scale distance. Since the Composition B used for the donor charge is 13% more energetic than TNT, the donor weight could more properly have been considered as 113,000 pounds. However, this would reduce the scale distances by only 4%, causing no significant change in the curves of Fig. 81.

TABLE 14. BRL Gage Data for Test No. 6, E-

Ambient Conditions: 935.0 mbar, 57.6°F

Station	Direction from donor	Distance (ft)	Peak over-pressure (psi)	Converted scale distance	Overpressure converted to sea level (psi)	Impulse (psi-msec)	Impulse converted to sea le (psi-msec
[1]N-1	Front	300	20.98	6.29	22.75	----	----
N-2	Front	500	8.87	10.48	9.62	284.14	299.0
N-2A	Front	500	6.57	10.48	7.12	188.81	198.8
N-3	Front	750	3.67	15.72	3.98	173.28	182.3
N-4	Front	1000	2.50	20.95	2.71	151.82	159.8
N-5	Front	1855	1.22	38.85	1.32	92.07	96.9
N-6	Front	3630	0.40	76.10	0.43	39.45	41.5
S-1	Rear	300	10.20	6.29	11.06	219.70	231.5
S-2	Rear	500	4.69	10.48	5.09	136.98	144.2
S-3	Rear	750	2.48	15.72	2.69	106.31	112.0
S-4	Rear	1000	1.79	20.95	1.94	91.30	96.1
[2]S-5	Rear	1855	0.55	38.85	0.60	----	----
[2]W-1	Side	300	7.74	6.29	8.39	----	----
W-2	Side	500	5.49	10.48	5.95	239.96	252.5
W-2A	Side	500	5.65	10.48	6.12	243.99	256.7
W-3	Side	750	3.73	15.72	4.04	138.94	146.2
[1]W-4	Side	1000	2.24	20.95	2.43	----	----
W-5	Side	1855	0.91	38.85	0.99	69.83	73.5

[1]Gage ran early.
[2]Gage failed to run.

A

BRL Gage Data for Test No. 6, E-3005

Conditions: 935.0 mbar, 57.6°F.

Overpressure converted to sea level (psi)	Impulse (psi-msec)	Impulse converted to sea level (psi-msec)	Scale impulse	Pulse duration (msec)	Pulse duration converted to sea level (msec)	Scale duration
22.75	----	----	----	----	----	----
9.62	284.14	299.0	6.45	93.00	90.5	1.95
7.12	188.81	198.8	4.29	78.33	76.1	1.64
3.98	173.28	182.3	3.93	159.86	155.3	3.35
2.71	151.82	159.8	3.45	189.06	184.0	3.97
1.32	92.07	96.9	2.09	215.73	209.8	4.53
0.43	39.45	41.5	0.90	240.80	234.2	5.05
11.06	219.70	231.5	4.99	63.00	61.2	1.32
5.09	136.98	144.2	3.11	84.66	82.3	1.78
2.69	106.31	112.0	2.41	109.73	106.8	2.30
1.94	91.30	96.1	2.07	176.53	171.7	3.70
0.60	----	----	----	----	----	----
8.39	----	----	----	----	----	----
5.95	239.96	252.5	5.45	109.86	106.8	2.30
6.12	243.99	256.7	5.54	116.00	112.8	2.43
4.04	138.94	146.2	3.15	107.86	104.8	2.26
2.43	----	----	----	----	----	----
0.99	69.83	73.5	1.59	175.06	170.2	3.67

B

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It can be seen that the overpressures developed off the front of the igloos were of the same magnitude as would be expected from detonating the same explosive in the open, while the overpressures to the rear and side were only slightly less. The contrast between these results and those of the first two tests may be due to the relatively higher ratio of explosive weight to the amount of earth cover used on this test. While the igloos were covered to the same depth, the volume was significantly less in proportion to the weight of explosive, developing less focusing effect. Additionally, previous tests had used an earth fill common to acceptor and donor igloos. This could also explain the relatively smaller difference in the overpressures between the front, side, and rear of the magazines.

Another explanation might be that these effects were caused by the earth barricade acting to reduce the overpressure along the extended line in front of the igloos and increasing the overpressure to the sides and rear. Further tests would be required to determine which of these explanations is correct.

The records from the BRL gages along the north line are reproduced in Fig. 82. It can be seen that these gages again recorded small overpressures ahead of the main pressure rise, but they were of less relative magnitude than those of the first two tests. Once again, these minor shocks were not apparent to the rear (Fig. 83) or to the side of the magazines (Fig. 84).

Figure 82 also shows a second positive pulse that becomes of substantial size with increasing distance from the explosion. This second pulse was present to the rear of the igloos, but was of less magnitude (Fig. 83) and it apparently did not occur to the side (Fig. 84). It is not known at this time whether the second impulse is an inherent characteristic of the explosion, or whether it was generated by reflections from the local uneven terrain.

CONCLUSIONS

This test confirmed the factor 1.25 x $W^{1/3}$ for determining the side-to-side clearance between earth-covered, steel-arch igloo magazines while reasonably assuring prevention of explosion propagation; and also demonstrated that any possible upper limit to the quantity of the stored explosive when using this guide is at least as high as the equivalent of 100,000 lb of TNT. It should be noted that damages to steel-arch structures and to head walls, excluding the doors, was less for the 100,000 lb of explosive than was the corresponding damage for the smaller amounts of explosive, thus suggesting that extrapolation beyond 100,000 lb quantities is warranted. Direct comparison between effects of smaller quantities and those of the 100,000-lb donor charge is clouded somewhat by the previously noted differences in the configuration of the earth cover.

Figures 69 through 84 illustrate the characteristics and results of Test No. 6, conducted under E-3005.

FIG. 69. Magazines and Barricade.

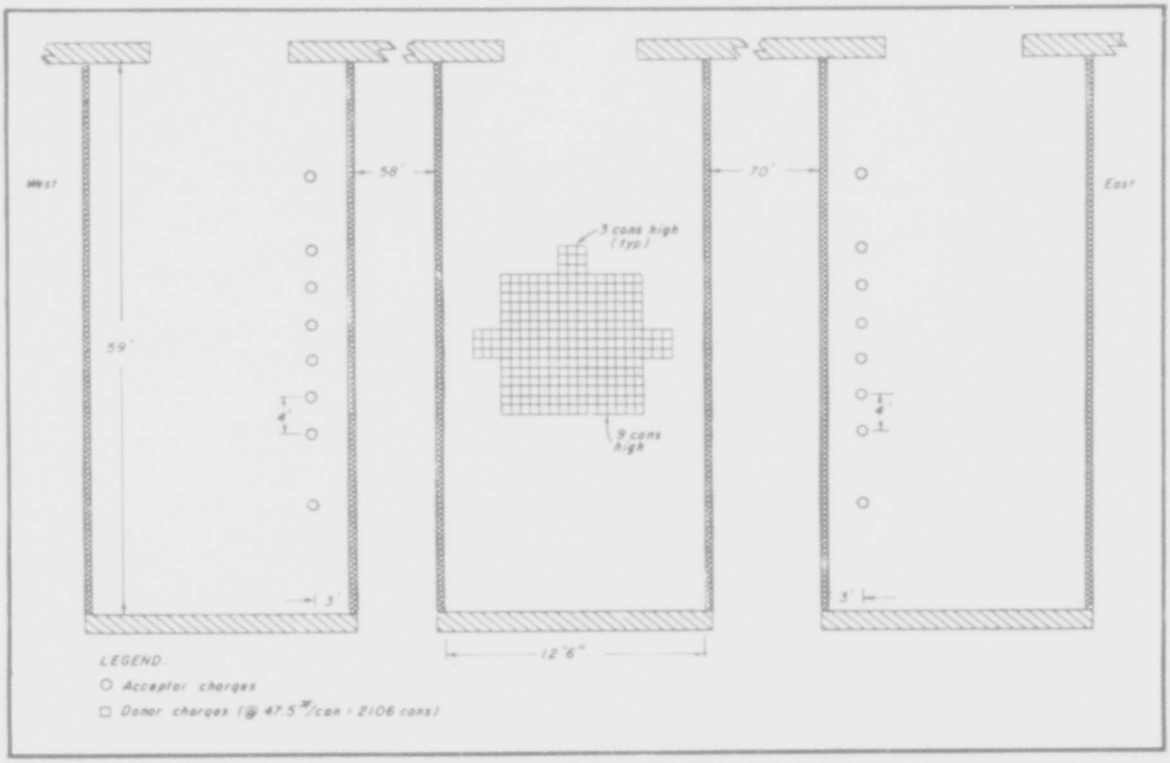


FIG. 70. Test Complex Layout.

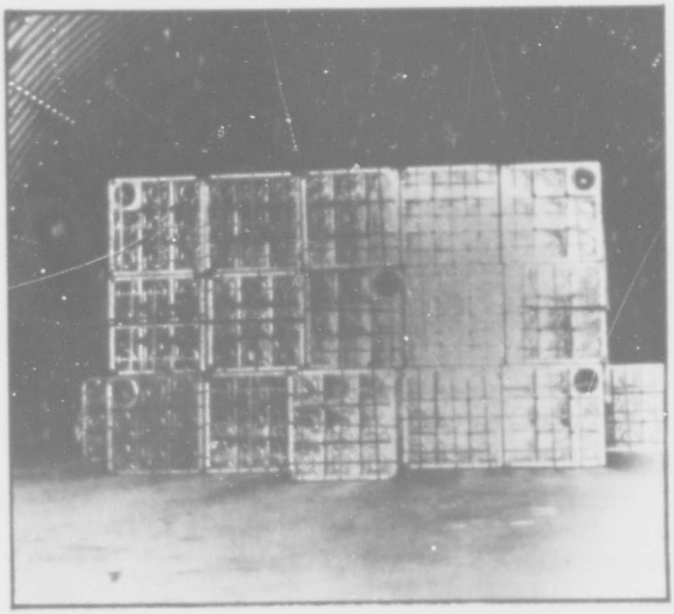
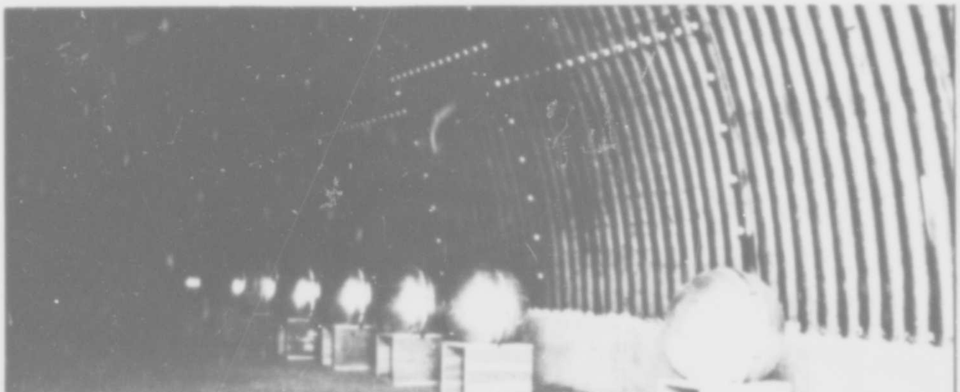


FIG. 71. 100,000-Pound Donor Charge.

a. West Igloo.



b. East Igloo.

FIG. 72. Acceptor Charges.

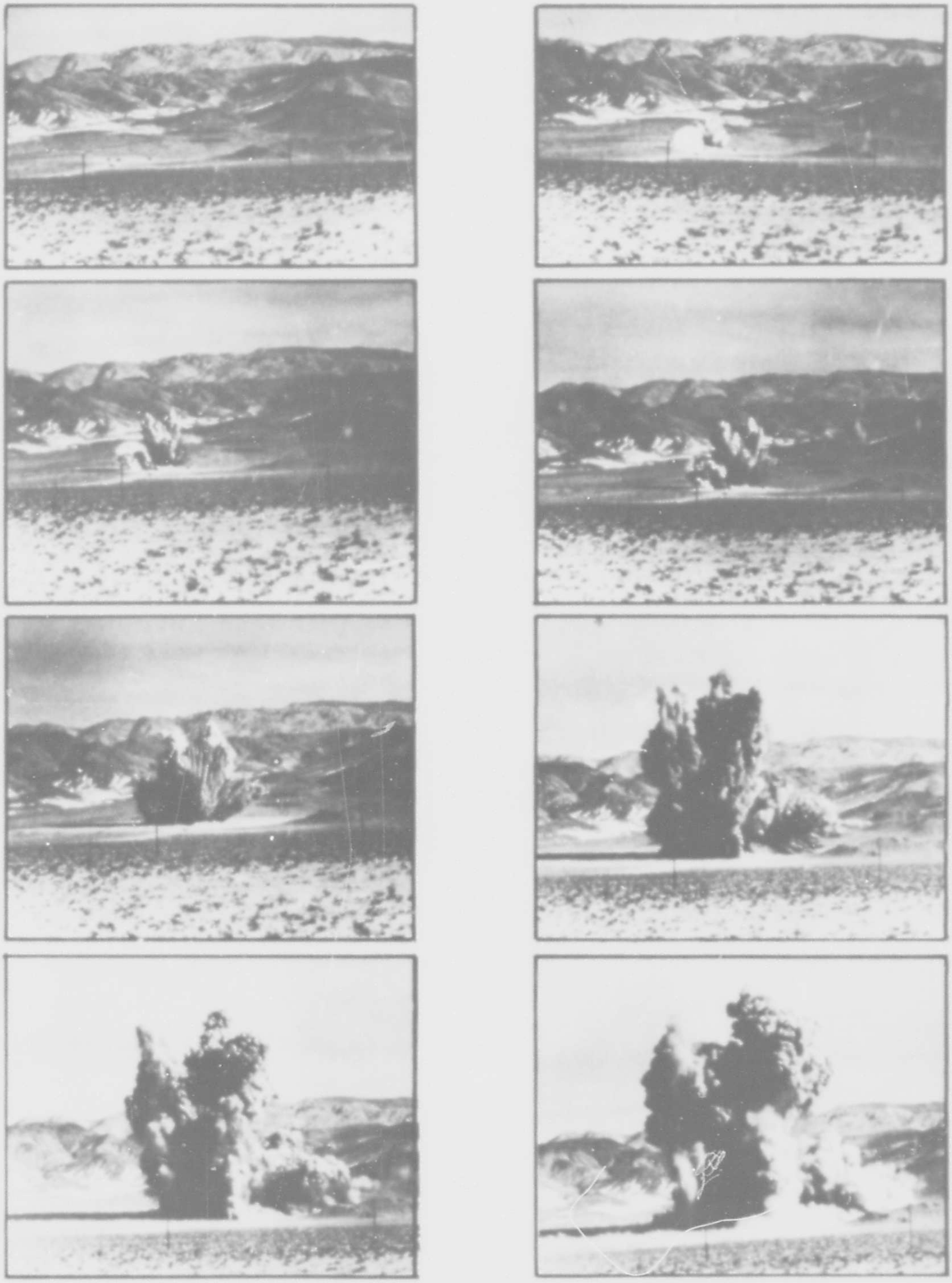


FIG. 73. 100,000-Pound Detonation.

FIG. 74. Igloo Complex Following Test.

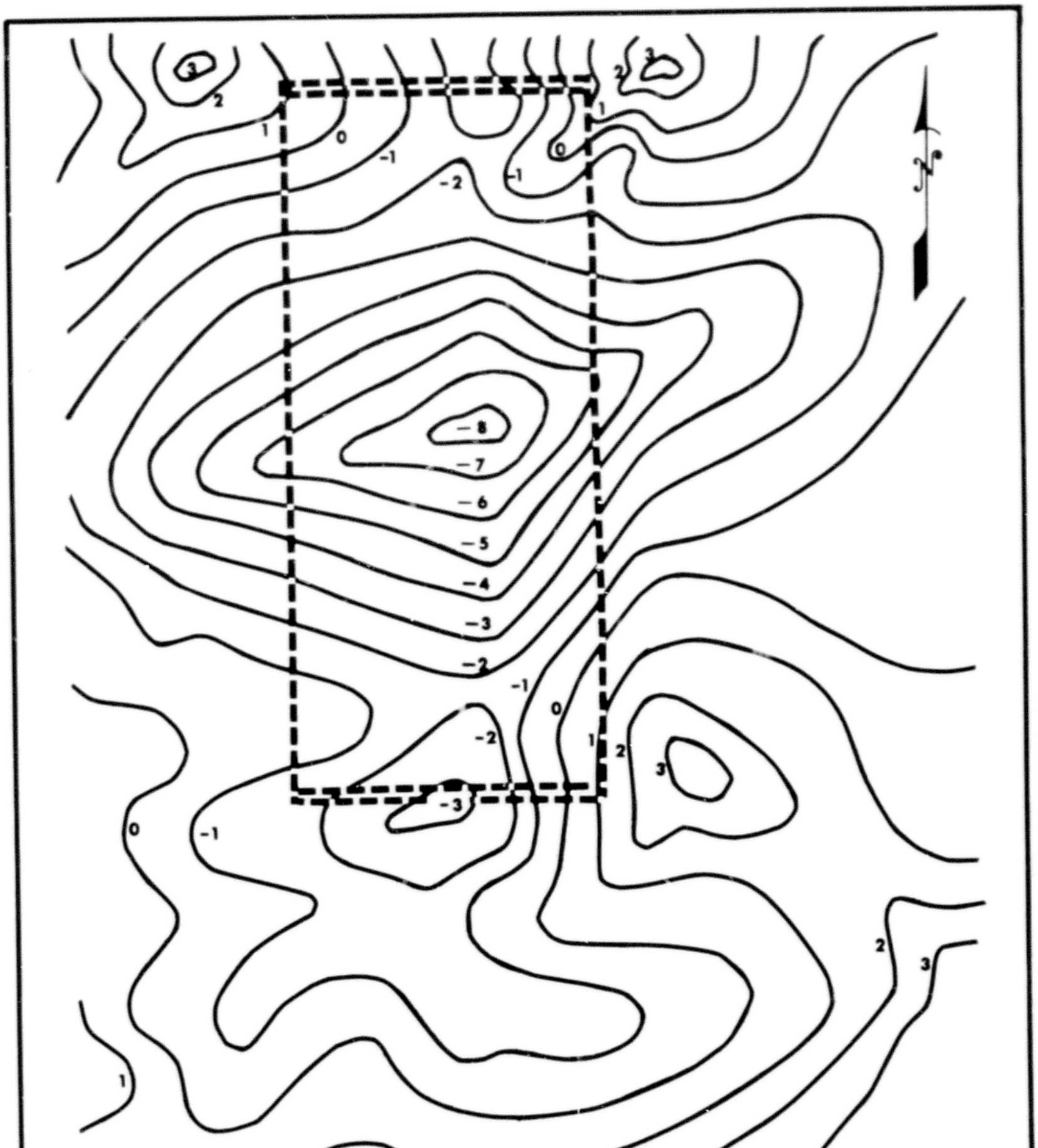
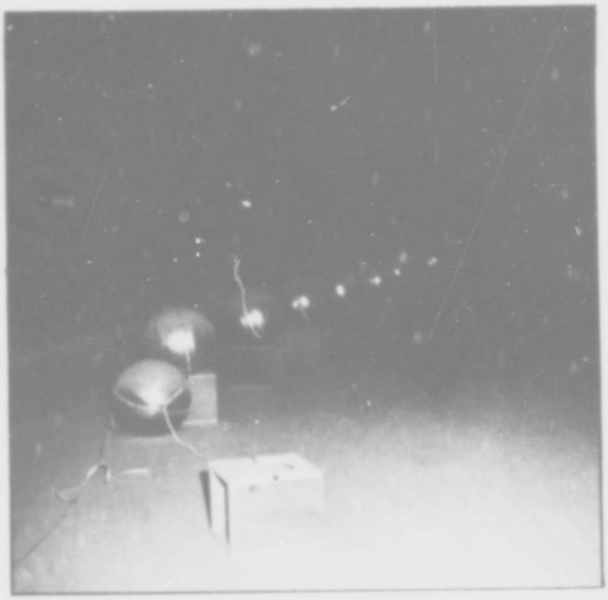
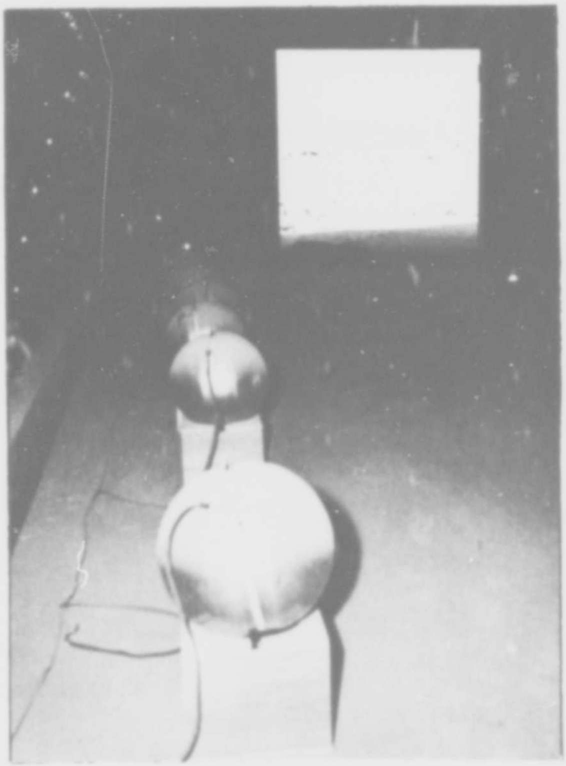


FIG. 75. Approximate Crater Dimensions.



a. West Igloo



b. East Igloo

FIG. 76. Acceptor Charges Following Test.

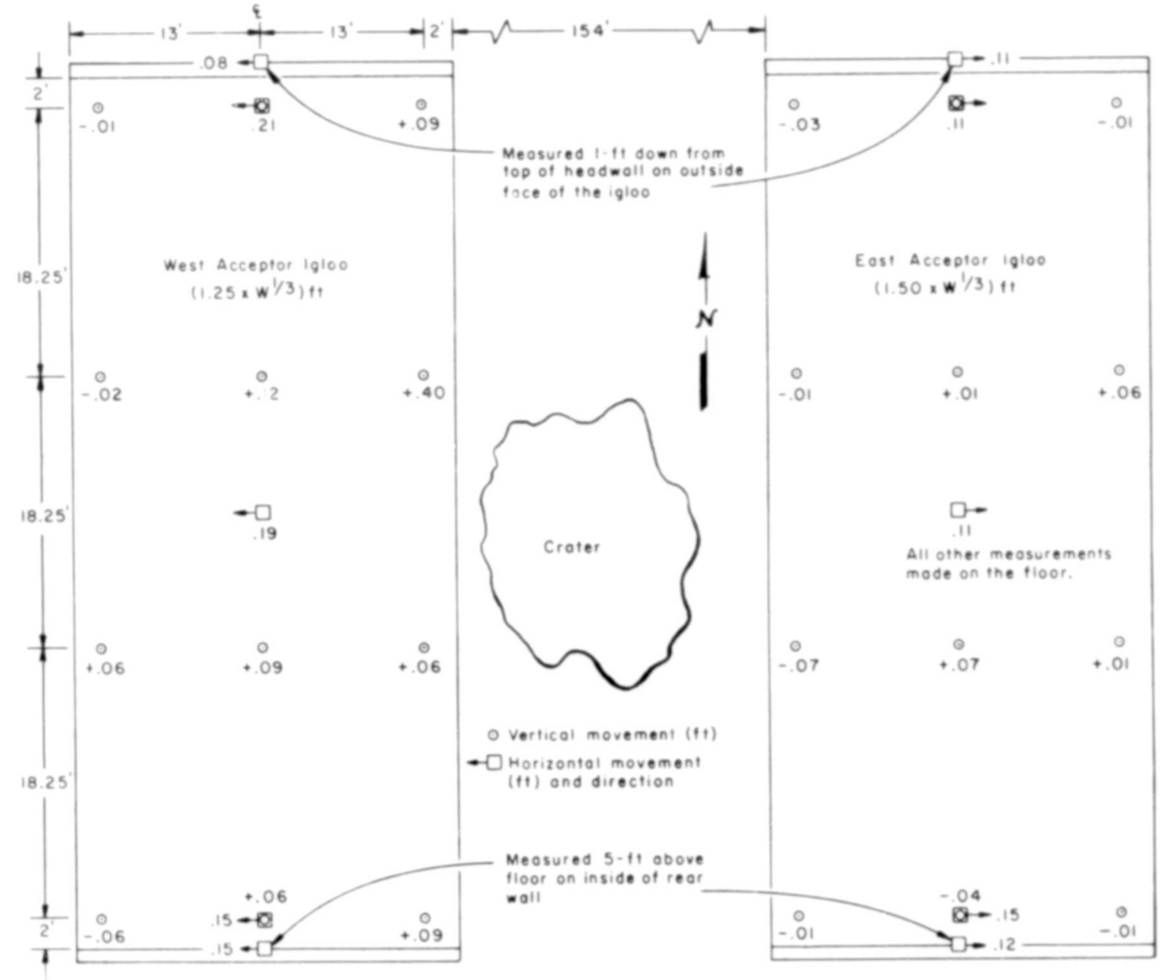


FIG. 77. Horizontal and Vertical Movements of Acceptor Igloos.

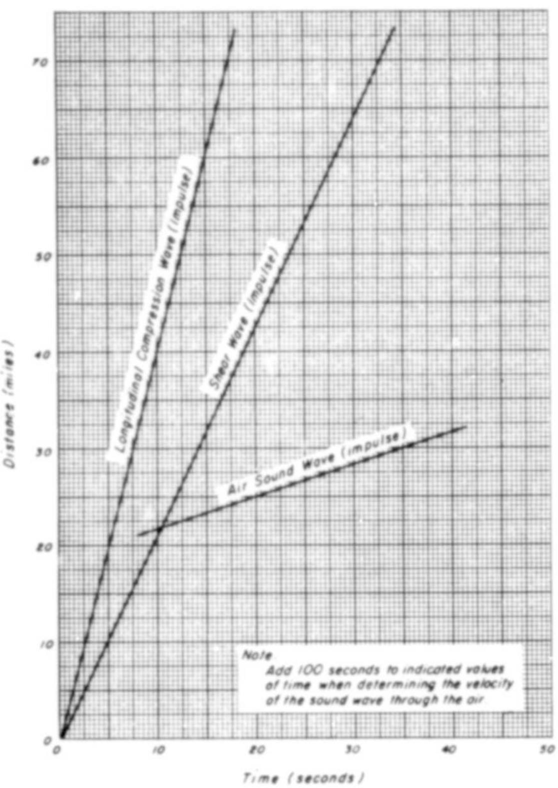


FIG. 78. Seismological Data.

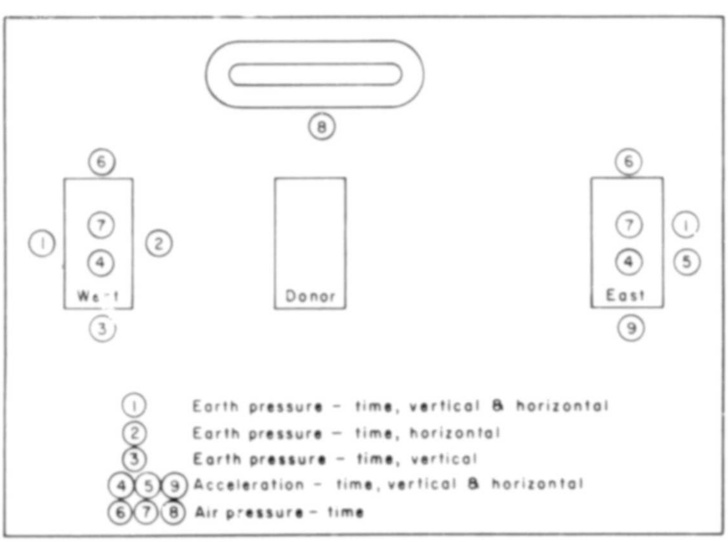


FIG. 79. Instrumentation.

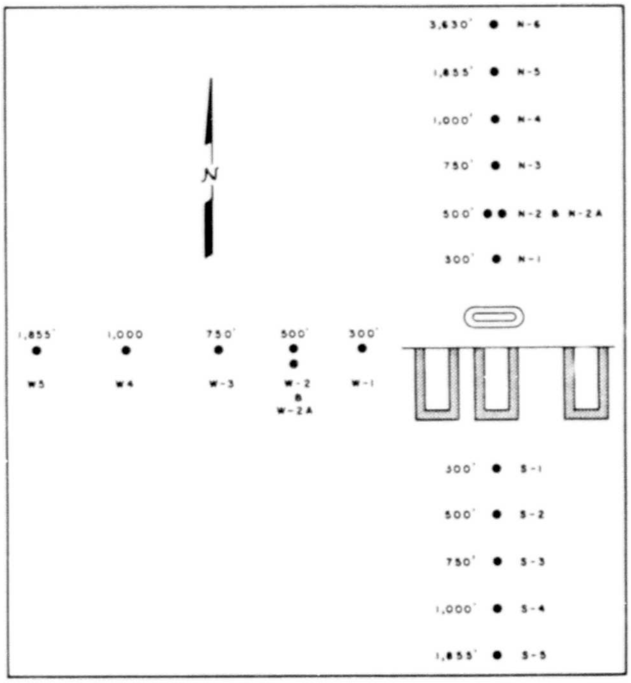


FIG. 80. BRL Pressure Gage Locations.

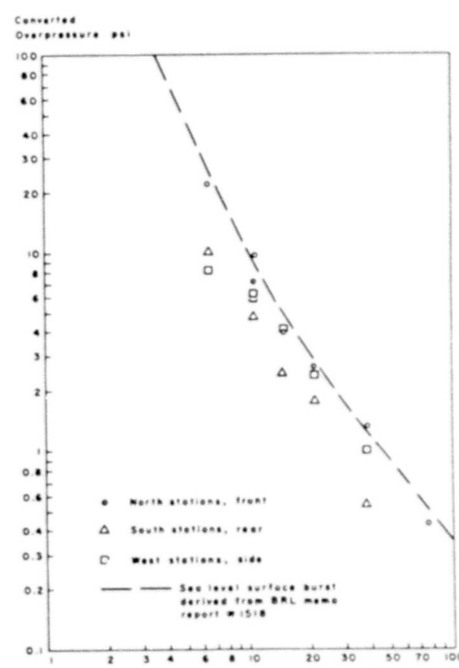


FIG. 81. Overpressure Versus Scale Distance.

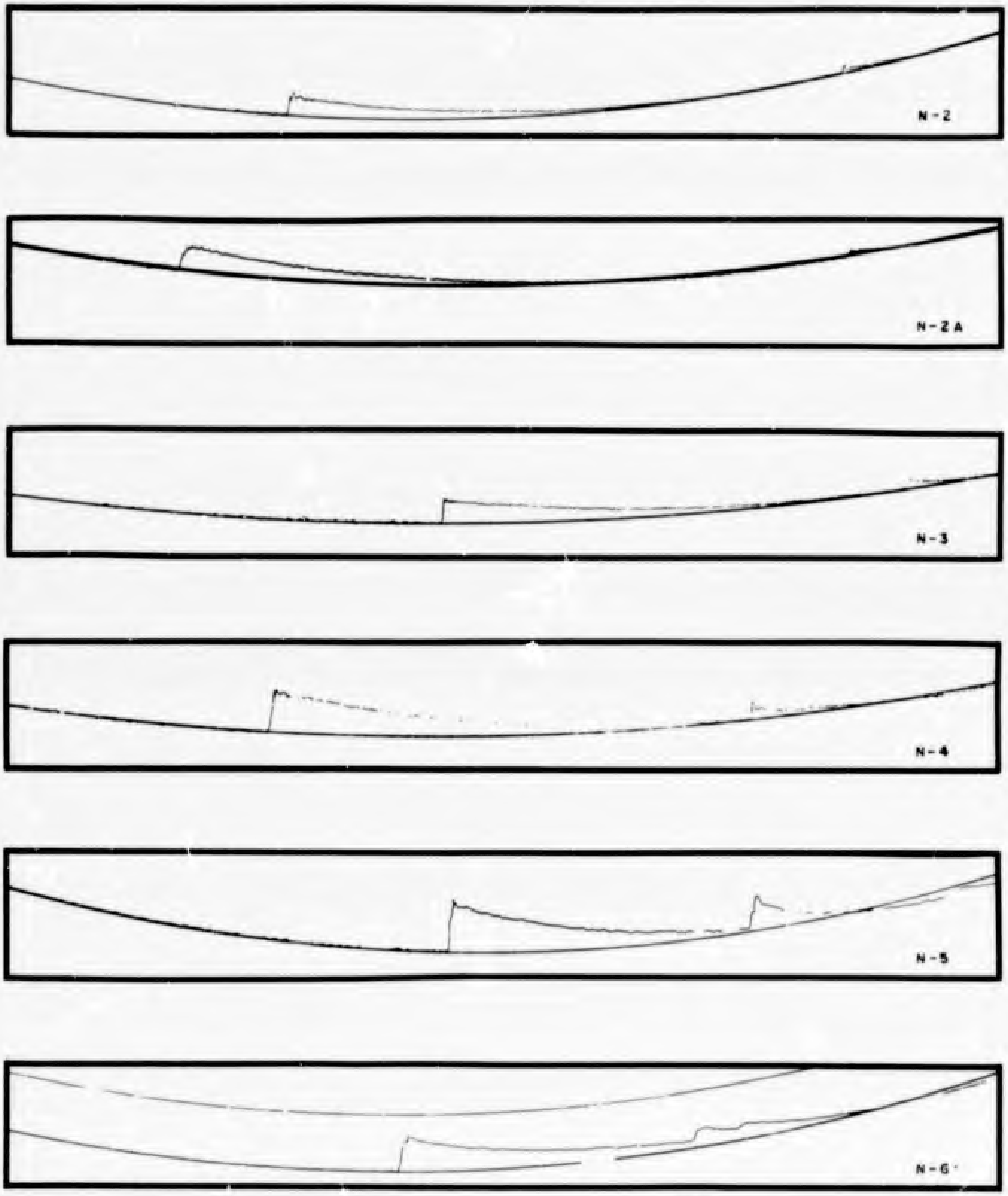


FIG. 82. North BRL Gage Records (Donor Front).

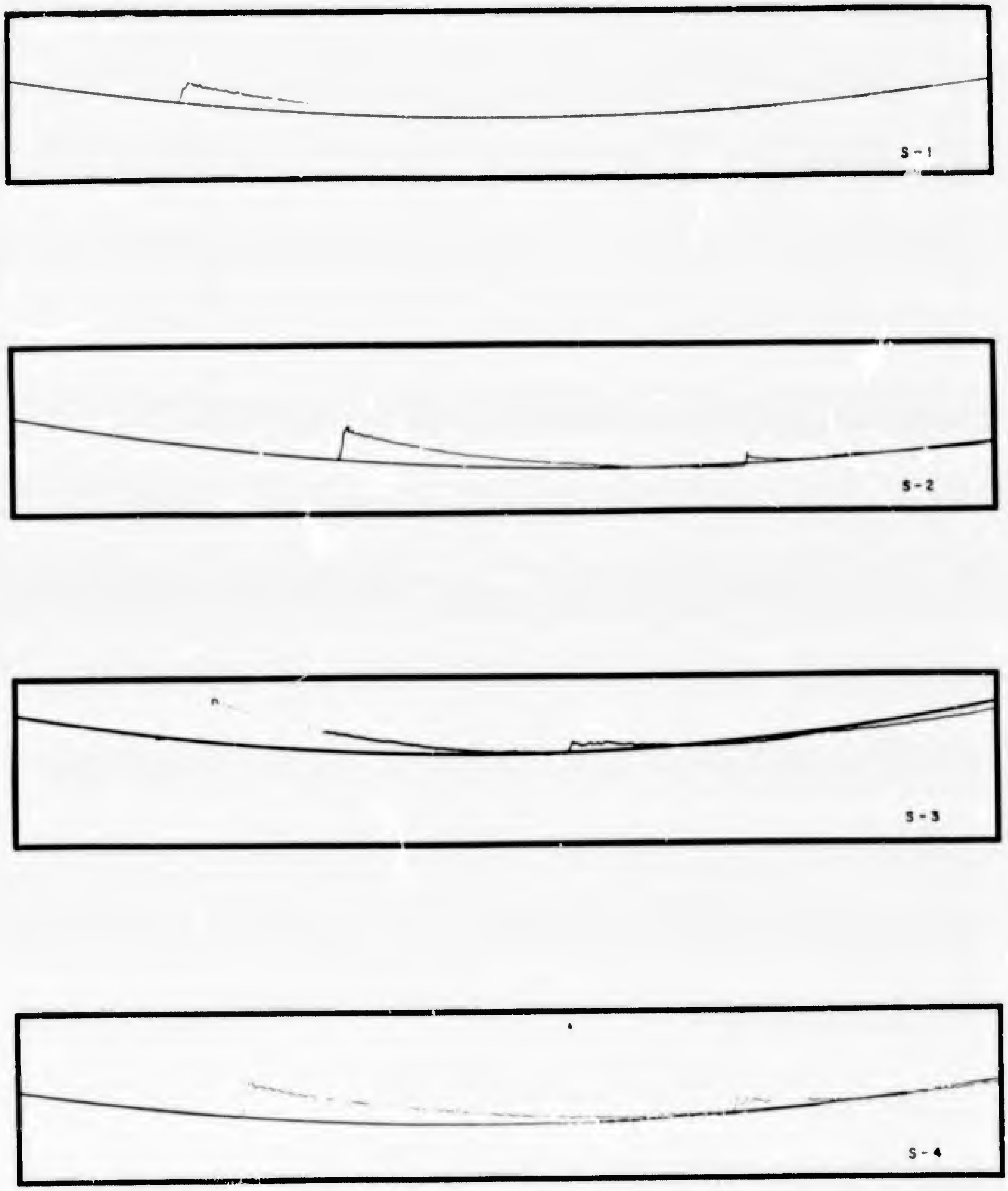


FIG. 83. South BRL Gage Records (Donor Rear).

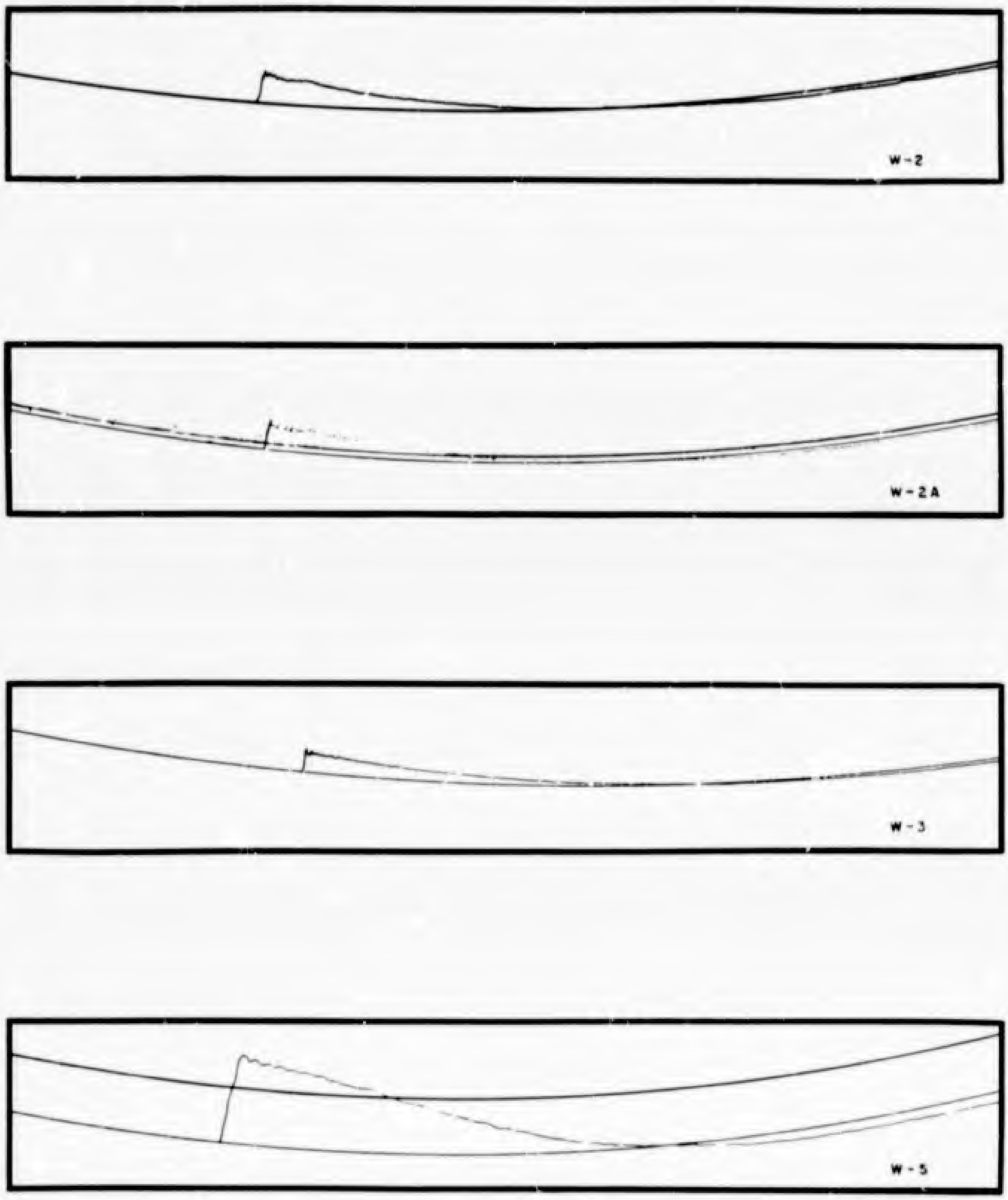


FIG. 84. West BRL Gage Records (Donor Side).

SECTION SIX

TEST NO. 7 (ROLLER COASTER)

Project Roller Coaster was a series of tests conducted jointly by several organizations, including DASA. The Clean Slate III event of Project Roller Coaster is identified as Test No. 7 for this report. The participation by NOTS in Test No. 7 consisted of providing and operating blast pressure gages and accelerometers to measure the effects of the explosion.

Test No. 7 was conducted at 0330 hours PDT, 9 June 1963, at the test site located at latitude 37°45'33"N, longitude 116°40'48"W, near Tonopah, Nevada.

TEST STRUCTURES

The test structures pertinent to Test No. 7 consisted of a donor steel-arch igloo and an acceptor igloo covered by a common earth fill to an eight-foot depth at the highest point of the arches, Fig. 85. The igloos were of typical steel-arch construction, 6.5 ft high, 11 ft wide, and 36 ft 4 inches long. The clear separation distance between the igloos was 18 ft, with a spacing factor of 1.5 x $W^{1/3}$.

DONOR CHARGE

The donor explosive for this test consisted of 19 charges spaced about three feet apart in the donor igloo. The total explosive was equivalent to 2,000 lb of TNT. No acceptor charges were used in the acceptor igloo.

INSTRUMENTATION

The primary purpose of this test was the measurement of the dispersion of earth and dissemination of dust resulting from the explosion in the earth-covered donor igloo. Air and earth sampling equipment was installed according to plans approved by DASA, and results were accumulated by DASA.

The overpressure wave was measured by BRL blast gages installed on a line extending 1,200 ft forward from the donor igloo. The horizontal and vertical components of earth pressure were measured by Wiancko earth pressure gages installed in the earth fill on each side of the acceptor igloo just behind the head wall, at a depth appropriate for recording the pressures impressed upon the arch, as indicated in Fig. 86. Due to the circumstances of the test, it was possible to install only the horizontal pressure gage on the side toward the donor charge, the vertical gage being omitted. An attempt was made to adapt the vertical gage to a higher pressure range, and use it for measuring horizontal pressure on the acceptor side away from the donor. A vertical and a horizontal accelerometer were installed at the center of the acceptor igloo floor. Two Wiancko air blast gages were also used, one on the outside of the acceptor igloo doorway (normal to the igloo face), and one at the surface of the earth fill above the center of the acceptor igloo (normal to the surface). A photocell near the acceptor igloo provided a zero-time indication.

TEST RESULTS

Detonation of the donor charges resulted in destruction of the donor igloo (Fig. 87).

The data obtained from the earth and air blast pressure gages are listed in Table 15. The accelerometers recorded the start of accelerations six milliseconds after zero time, as recorded by the photocell. It was also noted that the three earth pressure gages on the side of the acceptor igloo away from the donor and the air blast gage at the acceptor igloo doorway, all registered varying small pressures starting six milliseconds after zero time. It is not known whether these were real pressures or the effects of acceleration on the gages. The air blast gage on the earth fill and the horizontal earth pressure gage nearer the donor igloo did not record these effects.

TABLE 15. Earth and Air Pressure Data, Test No. 7, Roller Coaster

Gage	Range (psi)	Location	Peak pressure (psi)	Arrival time (msec)	Duration time (msec)
Hor. earth pres.	50	(b) Away from donor	20	96	235
Hor. earth pres.	[1]--	(b) Away from donor	[1]--	107	230
Ver. earth pres.	25	(b) Away from donor	20	33	40
Hor. earth pres.	25	(b) Toward donor	14	7	95
Air blast pres.	50	(d) On earth fill	10	24	50
Air blast pres.	50	(d) At doorway	25	15	[2]22

[1]No usable data obtained.

[2]Extrapolated. Apparent cable break after 16 ms of duration.

The results obtained from the BRL overpressure gages are presented in Table 16, and the gage identifications are listed in Appendix L. The overpressure data is presented as a function of scale distance in Fig. 88. The data have not been converted to sea level conditions, but this does not change the trend of the curve, since the conversion would make but a small shift of the individual points. It is apparent that the earth cover over the igloo has increased the overpressure wave off the front of the igloo, compared to the results to be expected from the detonation of the same explosive in the open.

TABLE 16. BRL Gage Data, Test No. 7, Roller Coaster

Station	Direction from donor	Distance (ft)	Peak overpressure (psi)	Scale distance	Impulse (psi-msec)	Scale impulse	Pulse duration (msec)	Scale pulse duration
1	Front	100	18.20	7.93	237.01	18.82	40.0	3.17
[1]2	Front	225	---	---	---	---	---	---
3	Front	300	3.08	23.8	66.14	5.24	54.9	4.36
4	Front	500	[2]1.34	39.7	18.07	1.44	32.0	2.54
5	Front	900	0.86	71.4	27.45	2.18	84.8	6.73
[1]6	Front	1200	---	---	---	---	---	---

[1]Gage recording lost during post test clean-up operation.

[2]1.446 psi overpressure occurred 36.133 msec earlier.

The BRL gages also recorded varying shocks ahead of the principal overpressure pulse (Fig. 89). These advance shocks seem to have yielded relatively higher impulses, compared to the earlier tests. This was probably due to the greater weight of earth cover (eight feet of thickness rather than two feet) increasing the apparent focusing effect out the front of the igloo.

It is evident that the pulse duration and impulse derived from the BRL gage located at Station 4 are inconsistent. Apparently the gage was running slow, possibly because of low battery power.

CONCLUSIONS

This series of tests has demonstrated that an acceptably low probability of explosion can be maintained when the minimum side-to-side clear space between earth-covered, steel-arch magazines is determined by the equation

$$\text{Distance (in feet)} = 1.25W^{1/3}$$

where W is the weight in pounds of the high explosive being stored, and the earth covers the igloos to a two-foot depth, with the sides and rear graded to a slope of one to two.

The tests also showed that the distance through continuous earth fill between the concrete rear walls of steel-arch magazines can be determined by the equation

$$\text{Distance} = 1.5W^{1/3}$$

It was demonstrated by Test No. 1 that the spacing from the rear wall of an earth-covered igloo to the unprotected concrete face of another covered igloo can be determined by the equation

$$\text{Distance} = 4.5W^{1/3}$$

where W is the weight of high explosive contained in the igloo whose rear wall is being considered.

As a result of the tests, the ASESB has approved the spacing criteria as presented in Appendix M.

Figures 85 through 89 illustrate the characteristics and results of Test No. 7, the Clean Slate III event of Project Roller Coaster. Test No. 7 was conducted near Tonopah, Nevada.

FIG. 85. Igloos Covered With Eight Feet of Earth, Roller Coaster Test.

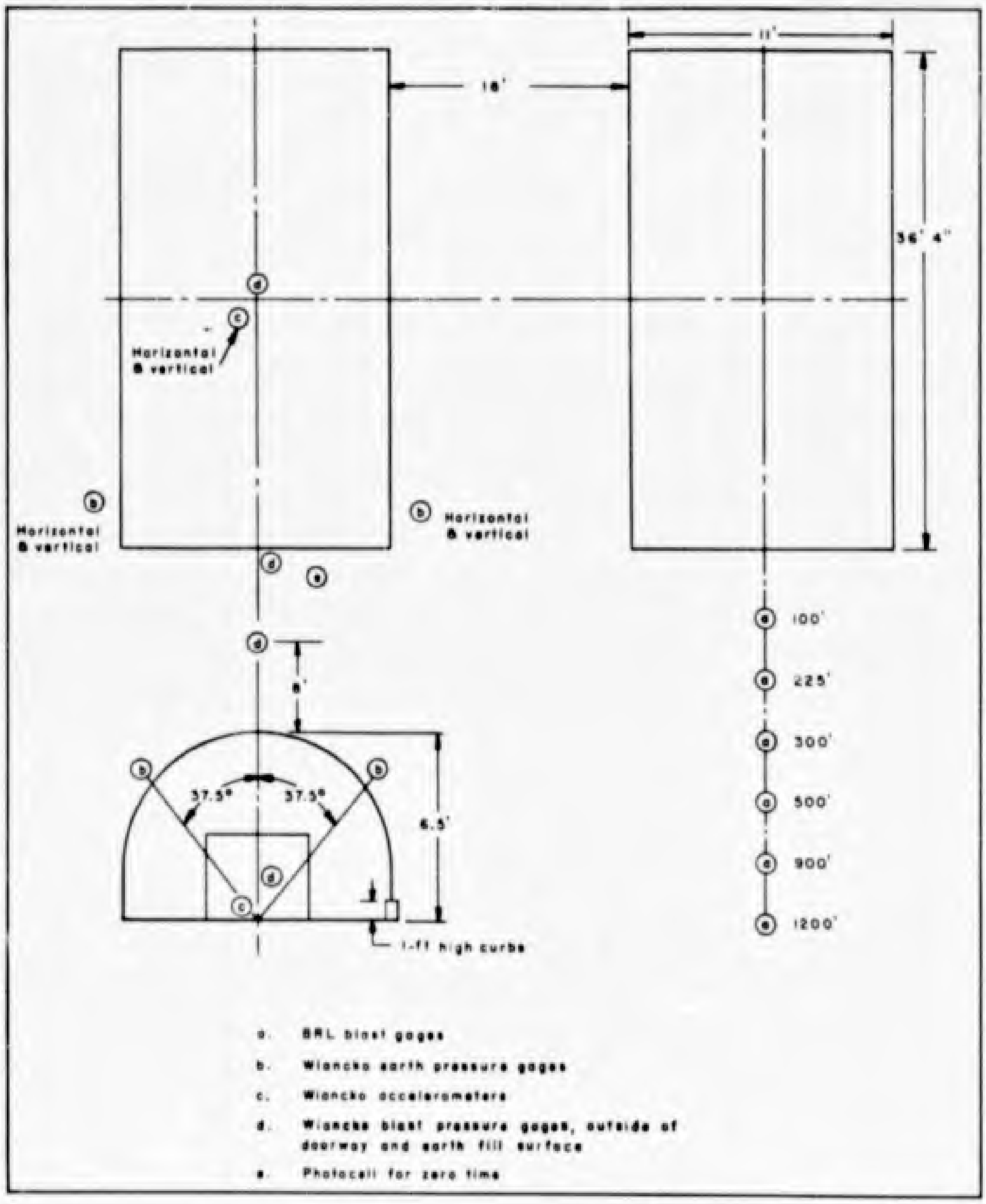


FIG. 86. Instrumentation.

FIG. 87. Donor and Acceptor Igloos Following Test.

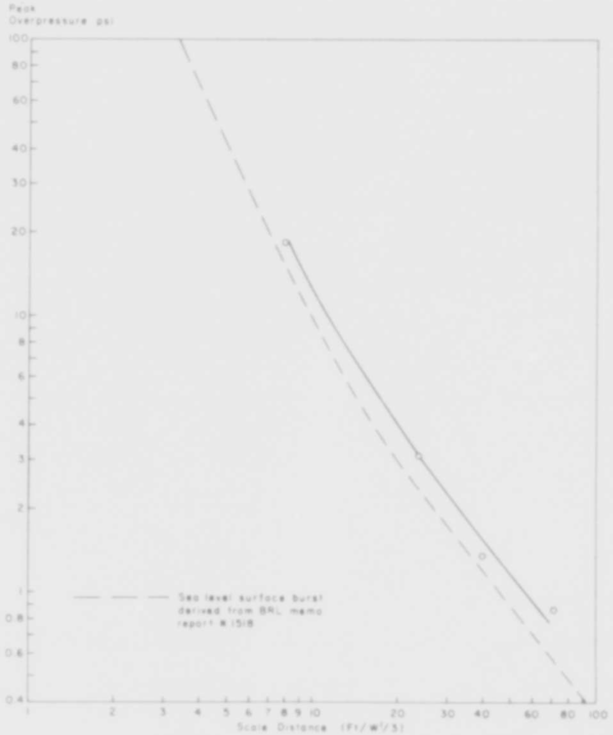


FIG. 88. Peak Overpressure Versus
Scale Distance.

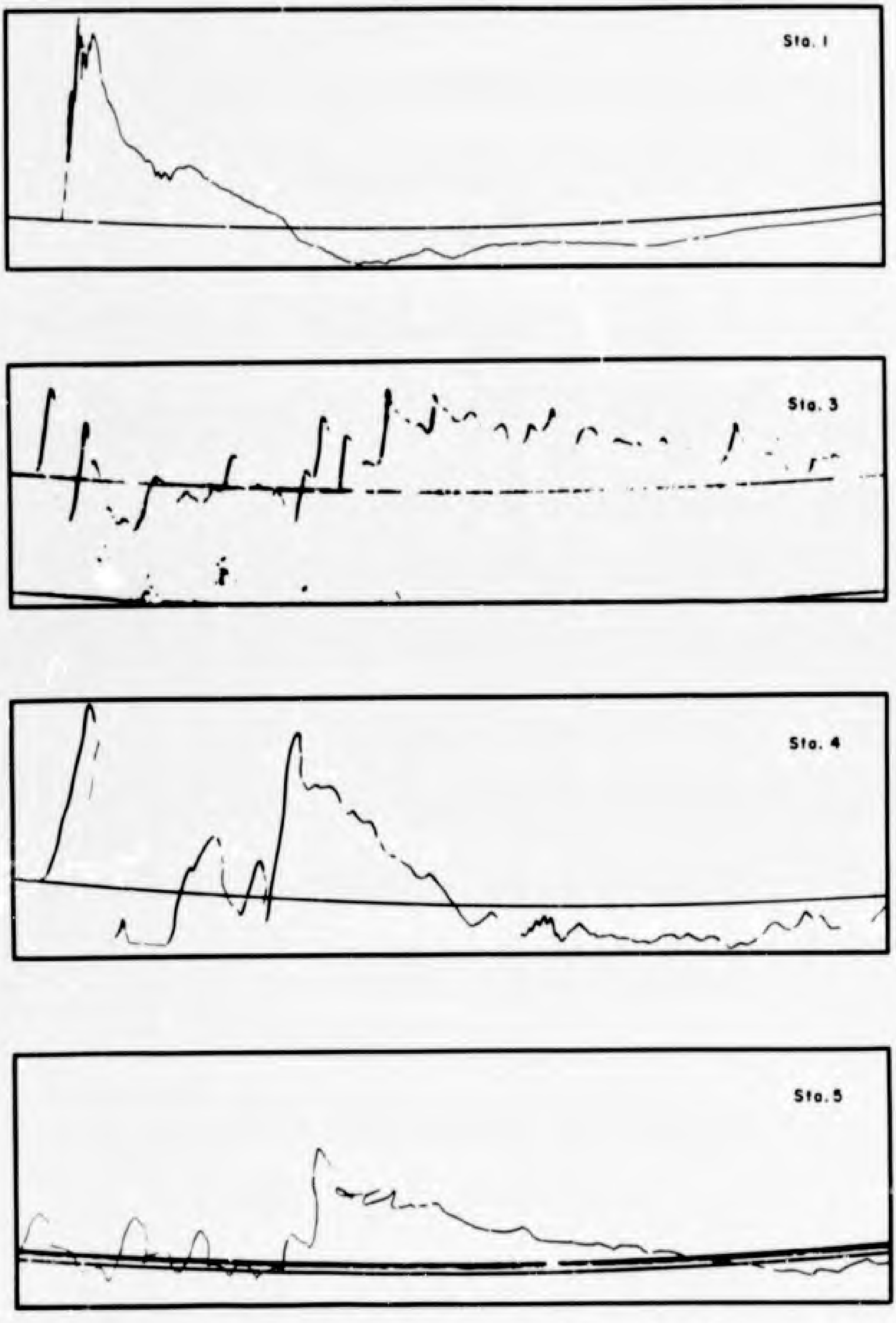


FIG. 89. BRL Gage Records (Donor Front).

Appendix A

BRL GAGE IDENTIFICATION, TEST NO. 1, E-6819

Station	Distance (ft)	Capsule number	Capsule range (psi)	Motor number	Gage number
N-1	65	911	50	10-40-H	318
N-2	590	1169	0.5	10-7-H	343
N-3	1180	1173	0.5	10-136-L	322
E-1	65	901	50	20-104	324
E-2	590	1181	0.5	10-2-L	372
E-3	1180	1171	0.5	10-9-L	332
NE-1	59	995	100	10-12-L	359
NW-1	65	895	50	10-12-H	316
NW-2	130	622	5	20-109	314
SE-1	65	898	50	10-11-L	384
SE-2	130	15-1	15	10-2	601
A-2 OUT	50	976	100	20-111	348
A-1 IN	50	900	50	10-106-L	330
SW-1	65	970	100	20-110	406
SW-2	130	1511	25	10-109-L	615
B-2 OUT	280	1506	5	10-112	602
B-1 IN	280	619	5	10-8-L	369
B-3 IN	285	1505	1	10-127-L	606
SW-3A	290	617	5	10-6-L	349
SW-3B	290	625	5	10-115	337
SW-4	590	631	5	10-114	301
SW-5	1180	1186	1	10-4-L	373

Appendix B

BRL GAGE IDENTIFICATION, TEST NO. 2, E-6923

Station	Distance (ft)	Capsule number	Capsule range (psi)	Motor number	Gage number
S-1	65	800	25	20-110	406
S-2	130	844	25	10-12-H	316
S-3A OUT	131	804	25	10-106-L	330
S-3A IN	131	625	5	10-115	337
S-4	149	802	25	10-11-L	384
S-5	290	690	15	10-8-L	369
S-B2 OUT	366	617	5	10-6-L	349
S-B1 IN	366	631	5	10-114	301
S-B3 OUT	376	1186	1	10-4-L	373
S-B4 IN	371	622	5	10-40-H	318
S-6	590	1188	1	20-111	348
S-7	1180	1169	0.5	10-7-H	343
N-1	59	806	25	20-109	314
N-2	130	630	5	20-104	324
N-3	290	624	5	10-12-L	359
N-4	590	1173	0.5	10-136-L	322
N-5	1180	1171	0.5	10-9-L	332

Appendix C

METEOROLOGY DATA, TEST NO. 4, E-7093

29 Aug 1962 - 1120 PDT

Altitude (ft/above surface)	Pressure (milli-bars)	Temperature (°C.)	Humidity (%)	Wind	
				Direction (degrees)	Speed (ft/sec)
Surface	932.0	34.5	5	175	16
100	929	33.5	*	175	15
200	925	32.5	*	175	15
300	921	31.5	*	176	14
400	918	30.7	*	177	13
500	915	30.4	*	178	12
600	912	30.2	*	179	12
700	909	29.9	*	180	12
800	906	29.7	*	181	11
900	902.5	29.4	*	182	10
1,000	899	29.2	*	183	9
1,100	896	29.0	*	184	7
1,200	893	28.8	*	190	7
1,300	890	28.6	*	197	7
1,400	887	28.4	*	204	7
1,500	884	28.2	*	211	6
1,600	881	28.0	*	218	6
1,700	878	27.7	*	225	6
1,800	875	27.5	*	232	6
1,900	872.5	27.2	*	239	5
2,000	870	27.0	*	246	5
2,100	867	26.8	*	254	5
2,200	864	26.5	*	261	5
2,300	861	26.2	*	266	5
2,400	858	26.0	*	271	6
2,500	854.5	25.7	*	276	7
2,600	851	25.5	*	281	7
2,700	848	25.3	*	285	8
2,800	845	25.1	*	289	9
2,900	842	24.8	*	294	10
3,000	839	24.6	*	299	11

*Below the sensitivity of the instrument.
Wind data taken at 1030 PDT.

Appendix D

DISPERSION OF STRUCTURAL DEBRIS FROM IGLOO TESTS 1 THROUGH 4

Description of debris	Weight (lb)	Distance from igloo (ft)	O'clock position in which 6 o'clock = forward extension of igloo center line	Remarks
Concrete still bonded to 2 - #4 bars 12' long and 1 #6 bar 4' long	65 (Est)	2,900	6:00	Old, probably Test No. 1 or 2
10" Channel 4' long with est. 25# conc. and 3 steel anchors attached. (Part of door frame)	85 (Est)	2,020	5:45	Believed new, Test No. 3 or 4
10" Channel 6' - 3" long, twisted (part of door frame)	90 (Est)	1,850	6:30	Recent ground marks to north
3' x 3.5' x 3/8" steel plate bent and perforated (part of magazine door)	155 (Est)	2,900	5:30	Old, Test No. 1 or 2
Concrete fragment	4.2 (Meas)	2,900	5:30	Association with particular E.S. undetermined
Metal fragment 6" x 7" x 0.25" - possible bomb fragment	2.8 (Meas)	2,900	6:00	" " "

Concrete fragment with 1' long No. 4 bar projecting	23.3 (Meas)	2,650	5:50	Association with particular E.S. undetermined
Concrete fragment	19.7 (Meas)	2,800	6:00	" " "
Concrete fragment	10.4 (Meas)	1,800	7:00	" " "
Fragment of corrugated metal arch	2.2 (Meas)	1,100	7:00	" " "
2 - 10" x 2" x 1/2" steel anchors	3.0 ea (Meas)	1,820	5:45	" " "
Multiple fragments collected in area 100' wide and 150' long. Largest single fragment 14.3 lb	67 (Meas) Total	2,525 to 2,675	6:00	" " "

NOTES:

1. Found no concrete fragments on 7:00 o'clock line beyond 1,800' and relatively few fragments from 1,100' to 1,800'.
2. Found no evidence of concrete fragments, earth clods or metal fragments on small alkali flat approximately 100' x 100' at 7:00 o'clock 1,200' radial distance.
3. Occurrence of fragments was frequent on 6:00 o'clock line out to 2,700 feet.

Appendix E

BRL GAGE IDENTIFICATION, TEST NO. 3, E-7093

Station	Distance (ft)	Capsule number	Capsule range (psi)	Motor number	Speed (rpm)	Gage number
1	462	1188	1	A-5903	10	342
2	922	1166	0.5	G-5836	10	347

Appendix F

SOIL DATA, TEST NO. 5, E-7520

The Office of the Chief of Engineers, Department of the Army, requested the following information on the earth fill over and between the magazines that comprised the test structure:

1. A description of a standard classification for the earth fill over the test structure. MIL-STD 619A, 20 Mar 62.

2. The moisture content at time of the test for varying distances in the fill. MIL-STD 621 (CE) 18 May 61.

3. The maximum density obtainable for laboratory method S-1, CE 55.

4. The actual or field density of the fill.

5. A field determination of the vertical modulus of soil reaction five feet below ground surface of the fill.

6. A field determination of the horizontal modulus of soil reaction five feet below ground surface of the fill.

7. Unconsolidated-quick triaxial shear test to maximum range of chamber pressures available on undistributed sample of field compacted material. (EM 1110-345-147) 15 Aug 61.*

*This information was not obtained because soil samples obtained were too small to test with test device provided by the U. S. Naval Civil Engineering Laboratory.

U. S. NAVAL CIVIL ENGINEERING
LABORATORY
Port Hueneme, California

In Reply Refer to:
L53/JAB/od

C O P Y

From: Commanding Officer and Director
To: Commanding Officer, U. S. Naval Ordnance Test Station, China Lake, California

Subj: Soil Tests; results of

Ref: (a) BUDOCKS ltr 74B/jmc:js of 20 Mar 1963 w/encl (1) and (2)
(b) Conference of 19 Mar 1963 among Messrs. Weals, Casaroli of Naval Ordnance Test Station, China Lake and Bishop of NCEL

Encl: (1) Curve, "Plate Bearing Test at China Lake"
(2) Curve, "Lateral Plate Bearing Test at China Lake"

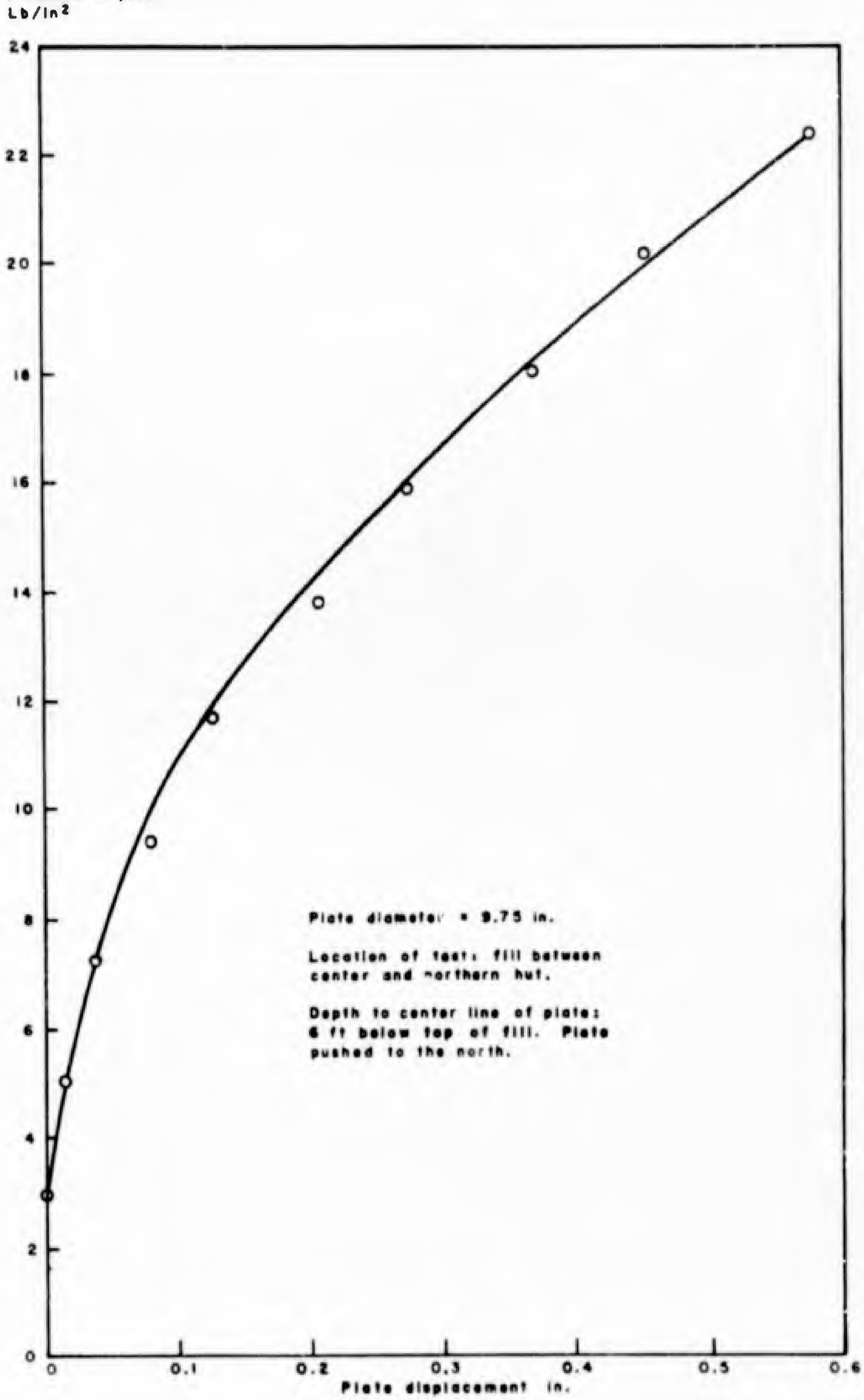
1. References (a) and (b) requested the assistance of NCEL in the conduct of some of the soils work at Naval Ordnance Test Station, China Lake defined by enclosure (1) of reference (a). In accordance with these requests technicians from NCEL conducted vertical and lateral plate bearing tests at Naval Ordnance Station, China Lake, during the period 26 - 29 March 1963 in areas specified and prepared by Naval Ordnance Test Station personnel.

2. Results of the plate bearing tests are forwarded as enclosures (1) and (2). It appears from enclosure (1) that the vertical modulus of soil reaction (at 0.1 inch) is slightly in excess of 500 psi per inch. From enclosure (2) the lateral modulus (also at 0.1) is calculated to be 110 psi per inch. It is suggested however that in view of the method used for placing the soil around the pile used for the lateral plate test the "k" value of 110 may not be particularly meaningful. It is very probable that the lack of control on the placement of the soil resulted in its having a substantially different density than the surrounding soil and this would, of course, influence the "k" value obtained.

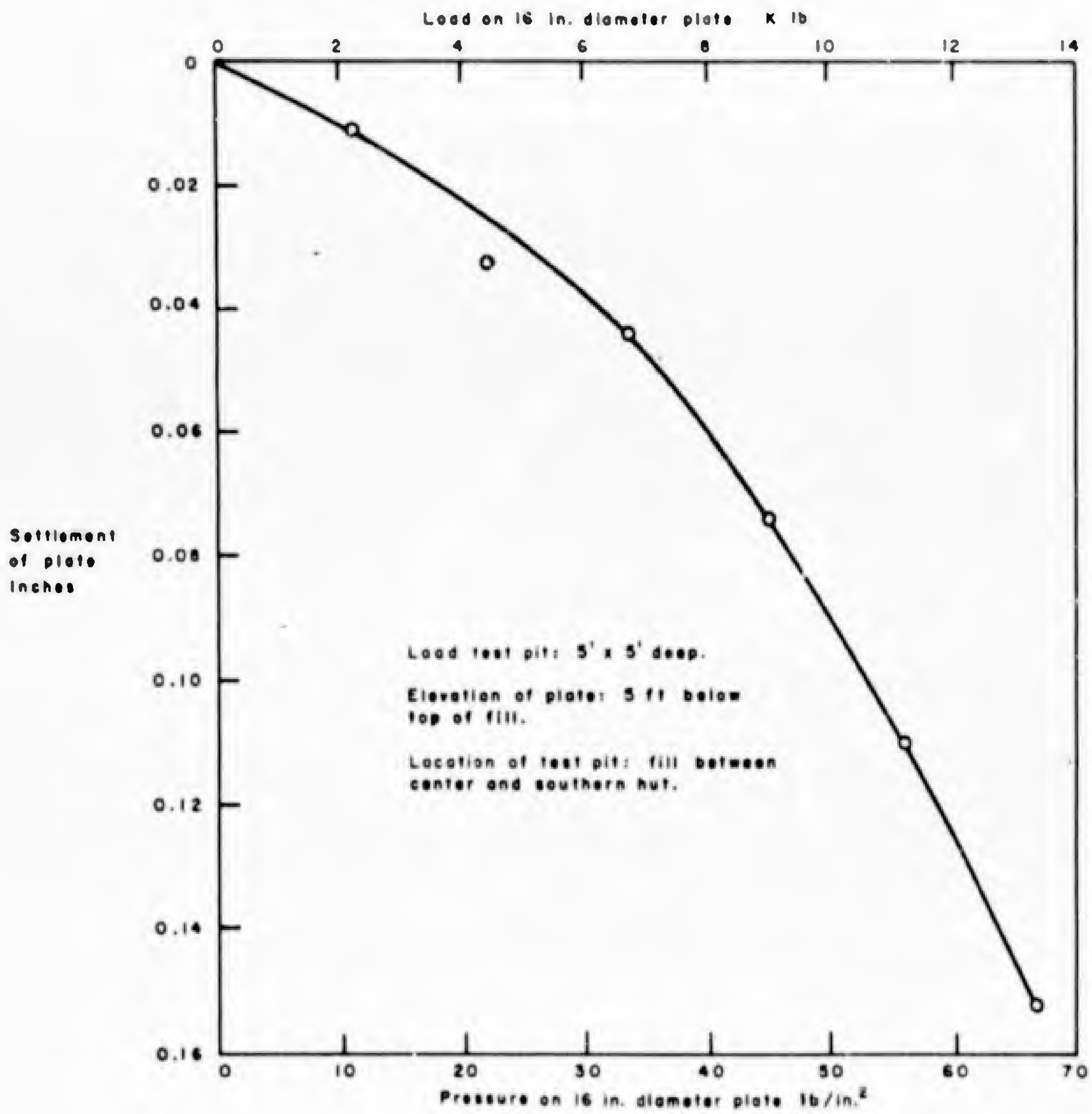
3. NCEL will make a machine available within the next week for use by Naval Ordnance Test Station for determination of the triaxial shear strengths desired.

W. F. BURKART
By direction

Copy to:
BUDOCKS (Code 70)


Pressure on plate
Lb/In²
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Plate displacement in.
Plate diameter = 9.75 in.
Location of test: fill between center and northern hut.
Depth to center line of plate: 6 ft below top of fill. Plate pushed to the north.

ENCLOSURE (1)


Load on 16 in. diameter plate K lb
0
2
4
6
8
10
12
14
Settlement of plate Inches
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Load test pit: 5' x 5' deep.
Elevation of plate: 5 ft below top of fill.
Location of test pit: fill between center and southern hut.
0
10
20
30
40
50
60
70
Pressure on 16 in. diameter plate lb/in.²

ENCLOSURE (2)

U. S. NAVAL ORDNANCE TEST STATION
China Lake, California

7036/EDC:gtl
19 April 1963

C O P Y

From: Code 7036 (Casaroli)
To: Code 3012 (Fred Weals)

Subj: Transmittal of Test Results for: Soil Densities
Project: A.D.C. - J.O. 306-178

1. The following samples have been received, and the test results for the above project are tabulated below:

Location	Depth of sample above fin floor	Date sampled 1963	Field		Lab Opt.		
			% Mst	Den (PCF)	% Mst	Den (PCF)	% Comp.
Midway	0" to 6"	3-22	11.7	105.1	9.5	128.5	82
	3' to 3'-6"	3-23	9.0	107.4	9.5	128.5	84
between	4' to 4'-6"	3-23	10.5	115.3	9.7	130.0	89
	6'-6" to 7'	3-23	8.2	111.0	9.7	130.0	85
Mag	8' to 8'-6"	3-25	9.2	109.4	9.7	130.0	84
	10' to 10'-6"	3-26	8.3	121.6	8.0	131.5	92
A&C	11'-6" to 12'	3-26	9.7	119.0	8.0	131.5	91
Midway	4' to 4'-6"	3-23	11.3	107.0	9.7	130.0	82
between							
Mag A-D	8' to 8'-6"	3-25	9.1	112.6	9.7	130.0	87
Midway	1' to 1'-6"	3-23	8.5	108.3	9.5	128.5	84
	3' to 3'-6"	3-23	9.9	115.0	9.5	128.5	89
between	5' to 5'-6"	3-23	9.7	111.3	9.7	130.0	86
	6' to 6'-6"	3-23	9.6	110.0	9.7	130.0	85
Mag	8' to 8'-6"	3-25	9.7	110.2	9.7	130.0	85
	10' to 10'-6"	3-26	9.2	113.1	8.0	131.5	86
A-B	11'-6" to 12'	3-26	10.5	114.0	8.0	131.5	87

/s/ E. D. CASAROLI

U. S. NAVAL ORDNANCE TEST STATION
Public Works
SOIL-ASPHALT-CONCRETE TESTING LABORATORY
Mechanical Analysis of Soil

A.D.C. Proj.
19 April 1963

DEPTH OF SAMPLE

Mechanical analysis cumulative % passing sieves	Borrow pit material	Between A&C 4' above floor elevation	Between A&B 5½' above floor elevation	Between A&B 10' above floor elevation
3/8"	100	100	100	100
No. 4	97.9	97.9	98.0	96.6
No. 10	90.8	94.8	92.6	94.7
No. 40	70.8	74.8	68.0	73.4
No. 60	60.9	31.6	54.9	41.4
No. 100	33.5	26.8	23.6	31.3
No. 200	22.7	23.8	20.8	23.3
Gravel % plus 4	2.1	2.1	2.0	3.4
Coarse sand %	7.1	3.1	5.4	1.9
Mud sand %	20.0	20.0	24.6	21.3
Fine sand %	48.1	51.0	47.2	50.1
Clay & silt %	22.7	23.8	20.8	23.3
*Textural classification	S.M.	S.M.	S.M.	S.M.
Liquid limit	18	17	18	19
Plastic index	NP	NP	NP	NP
Field den (PCF)		115.3	111.3	113.1
Field moist. %		10.5	9.7	9.2
**Opt. density (P.S.F.) mod.	128.5	130	130	131.5
**Opt. moisture %	9.5	9.7	9.2	8.0
% Rel. comp.		89	86	86

*Un. soil class. system

/s/ E. D. CASAROLI
E. D. CASAROLI

Appendix G

METEOROLOGICAL DATA, TEST NO. 5, E-7520

Altitude (ft/above surface)	Wind Direction (degrees)	Wind Speed (knots)	Altitude (ft/above surface)	Wind Direction (degrees)	Wind Speed (knots)
1227 PST			1244 PST		
Surface	150	5.0	Surface	155	2.4
500	123	3.9	500	180	3.5
1,000	104	2.8	1,000	204	4.6
1,500	109	2.2	1,500	192	4.1
2,000	114	1.6	2,000	180	3.6
2,500	133	1.8	2,500	241	2.5
2,600	137	1.8	2,600	233	2.3
1300 PST			1314 PST		
Surface	250	3.0	Surface	290	3.8
500	227	3.5	500	247	3.6
1,000	204	4.0	1,000	204	3.4
1,500	196	2.8	1,500	217	3.1
2,000	188	1.6	2,000	231	2.8
2,500	162	1.9	2,500	167	1.9
2,600	157	2.2	2,600	154	1.7
1344 PST			1400 PST		
Surface	278	2.0	Surface	280	2.4
500	260	2.4	500	276	1.8
1,000	241	2.8	1,000	272	1.2
1,500	209	2.4	1,500	251	2.3
2,000	177	2.0	2,000	231	3.4
2,500	151	2.2	2,500	213	3.0
2,600	146	2.2	2,600	210	2.9

Wind instrument oriented on true north.

Altitude (ft/above surface)	Wind		Altitude (ft/above surface)	Wind	
	Direction (degrees)	Speed (knots)		Direction (degrees)	Speed (knots)
1420 PST (Firing Time)			1435 PST		
Surface	210	4.0	Surface	300	3.0
200	217	4.0	200	292	3.3
400	226	4.0	400	285	3.5
600	235	4.0	600	278	3.7
800	243	4.0	800	270	3.8
1,000	250	4.0	1,000	263	3.8
1,200	248	4.1	1,200	256	3.8
1,400	244	4.2	1,400	248	3.8
1,600	241	4.4	1,600	241	3.8
1,800	238	4.6	1,800	234	3.8
2,000	236	4.8	2,000	227	3.8
2,200	235	4.5	2,200	205	4.0
2,400	234	4.2	2,400	182	4.4
2,600	234	3.8	2,600	160	4.8
1450 PST			1505 PST		
Surface	330	1.6	Surface	270	3.0
200	318	2.8	200	270	3.0
400	296	4.3	400	269	3.1
600	279	5.4	600	268	3.2
800	271	6.2	800	267	3.3
1,000	267	6.6	1,000	266	3.4
1,200	266	6.6	1,200	263	3.7
1,400	266	6.6	1,400	260	4.0
1,600	266	6.6	1,600	258	4.3
1,800	266	6.5	1,800	254	4.7
2,000	266	6.4	2,000	250	5.4
2,200	267	6.2	2,200	243	5.5
2,400	267	5.9	2,400	235	5.6
2,600	268	5.6	2,600	224	5.6

Wind instrument oriented on true north.

Altitude (ft/above surface)	Pressure (millibars)	Temp (°C)	Humidity (%)
0730 PST - Taken at T-8, G-1 Range			
Surface	948.8	9.6	45
200	941	8.2	33
400	933	9.5	33
600	926	9.5	32
800	920	9.5	30
1,000	913	9.4	29
1,200	907	8.9	28
1,400	900	8.4	27
1,600	893	8.0	27
1,800	886	7.5	27
2,000	880	7.1	26
2,200	874	6.7	26
2,400	868	6.3	25
2,600	861	5.9	25
0802 PST - Taken at T-5, G-2 Range			
Surface	949.0	10.8	50
200	942	9.7	43
400	936	8.8	38
600	929	11.7	37
800	921	11.2	37
1,000	914	10.7	37
1,200	907	10.0	36
1,400	901	9.6	35
1,600	895	9.2	35
1,800	888	8.6	34
2,000	881	8.0	33
2,200	875	7.6	32
2,400	869	7.1	32
2,600	862	6.6	30
1425 PST - Taken at T-5, G-2 Range			
Surface	945.4	20.6	15
200	938	17.4	*
400	931	17.0	*
600	924	16.6	*
800	917	16.0	*
1,000	910	15.4	*
1,200	904	14.8	*
1,400	899	14.2	*
1,600	893	13.6	*
1,800	886	13.0	*
2,000	880	12.5	*
2,200	874	11.7	*
2,400	867	11.2	*
2,600	861	10.7	*

*Below the sensitivity of the instrument.

Appendix H

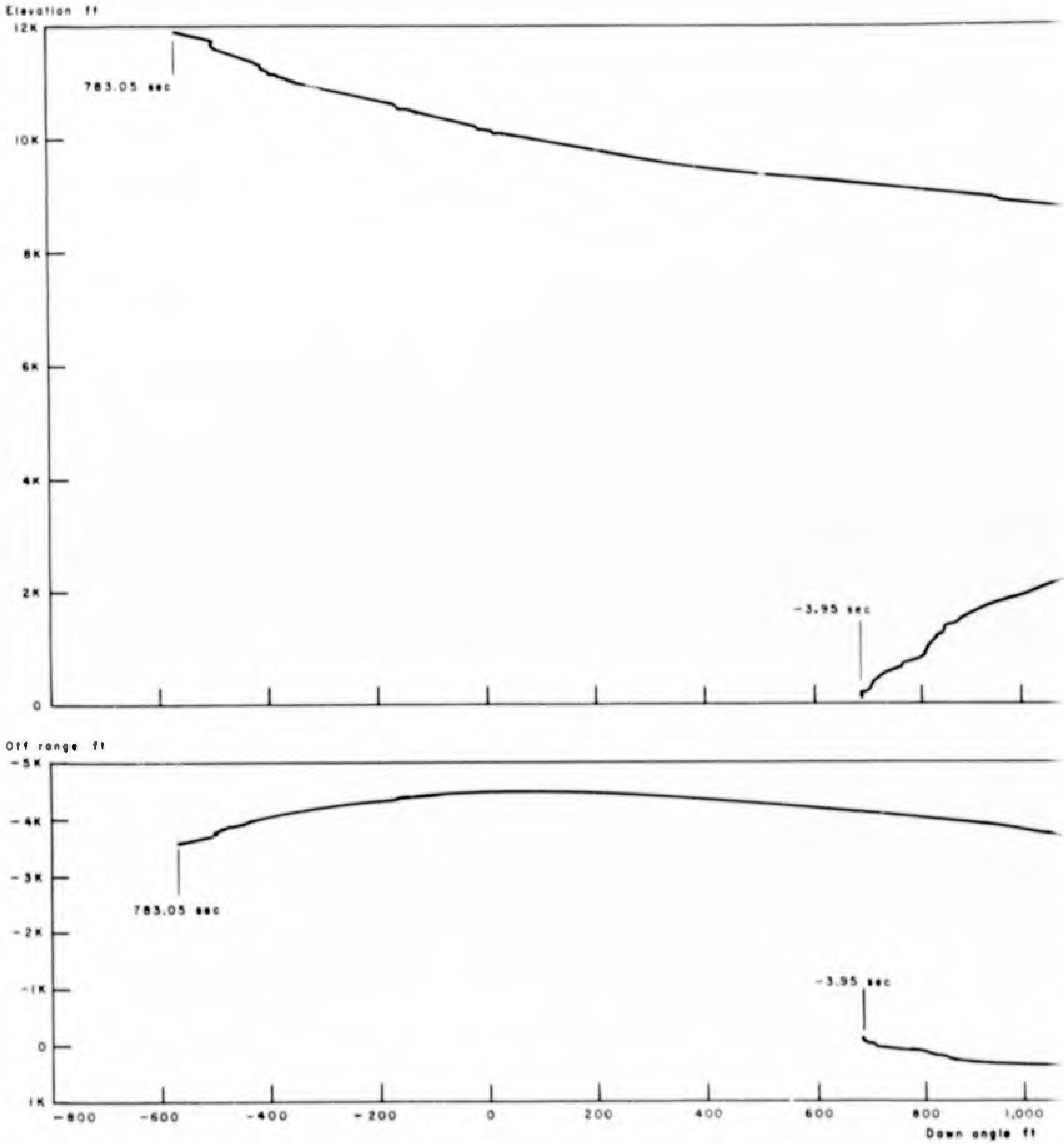
THEODOLITE DATA, TEST NO. 5, E-7520

Flight test data are submitted in a right-handed coordinate system with Y axis parallel to the gravity vector at L-20 (G-1 range origin), reference axis X, direction exactly true north, and off range axis, Z, normal to the XY plane. The origin is located at the door of the center igloo involved in the test.

Balloon trajectory data were derived from a least squares treatment of theodolite measurements based on a three-station solution. The resulting position data were subjected to a sliding polynomial fit of second order over five position points. The output time was substituted into the computed polynomials and their derivatives to evaluate the submitted functions.

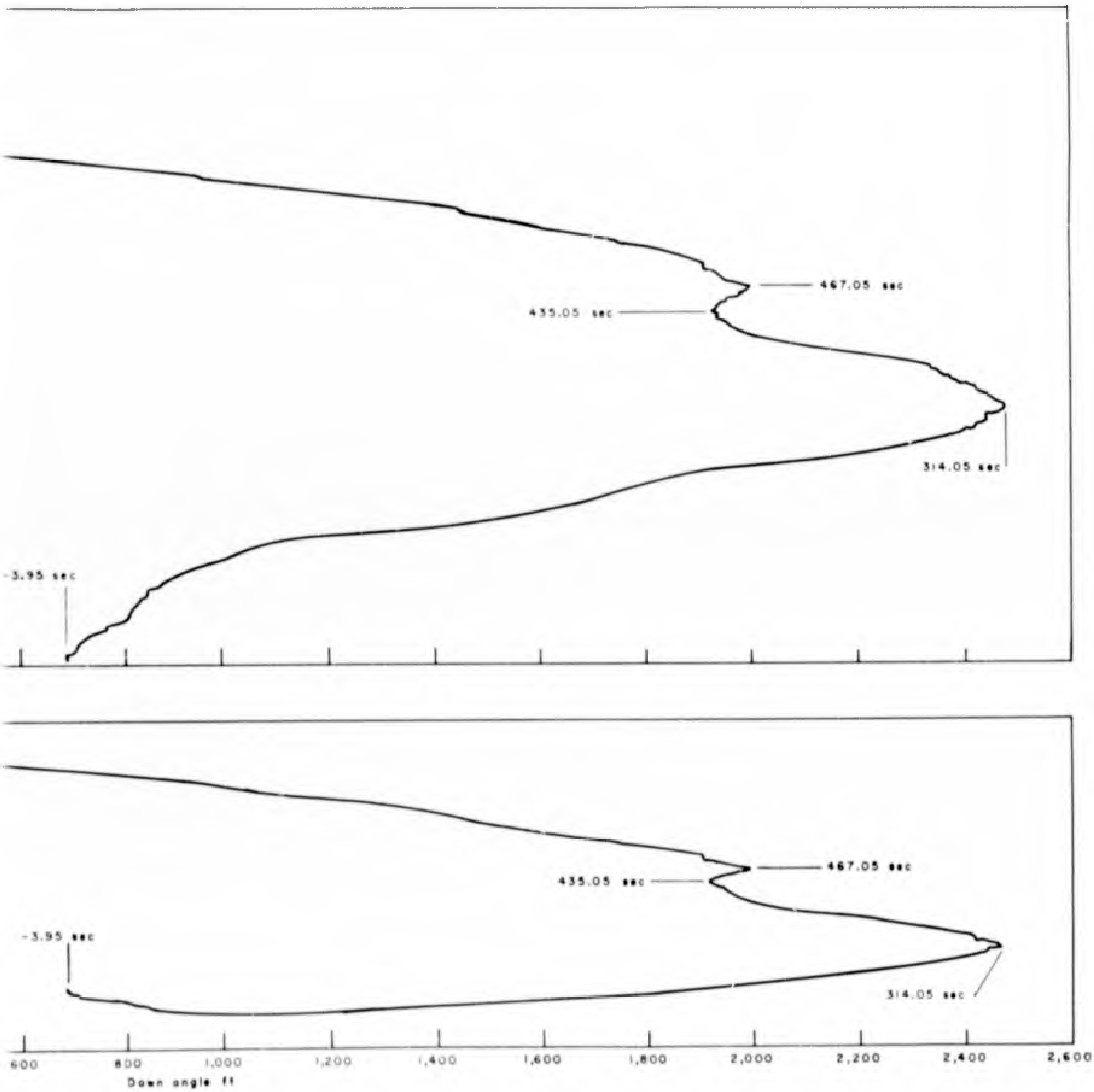
The submitted functions include position (X, Y, Z), Direction of Motion Component Angles (AZ, EL) defining the velocity direction.

Time is given with respect to detonation.



BALLOON POSITION (THEODO

A



..LLOON POSITION (THEODOLITE DATA)

B

Appendix I

BRL GAGE IDENTIFICATION, TEST NO. 5, E-7520

Station	Distance (ft)	Capsule number	Capsule range (psi)	Motor number	Gage number
1-W	40	976	100	104-20	324
2-W	50	905	50	1061-10	330
3-W	100	713	15	40H-10	318
4-W	200	617	5	115-10	337
5-W	500	1145	1	-10	339
6-W	920	1188	1	-10	342

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Appendix J

METEOROLOGICAL DATA, TEST NO. 6, E-3005

Altitude (ft)	Pressure (millibars)			Temperature (°C.)			Rel. Hum. (%)	Wind velocity (fps)		
Time	1028	1200	1314	1028	1200	1314	1314	1028	1200	1314
Surface	937.3	935.8	935.0	10.0	12.5	14.2	28	360°/5	325°/5	330°/7
100				6.9						
390					8.9					
500			917			10.5	27			010°/5
650						9.8				
1,000	903	902	900	7.8	9.7	9.8	25	046°/7	040°/5	042°/4
1,500			884			9.7	24			055°/5
1,730				8.6	10.5					
1,950						9.7				
2,000	870	870	869	8.2	9.9	9.7	23	075°/13	101°/10	072°/6
2,500			852			8.5	*			093°/7
2,990						7.3				
3,000	837	836	835	6.5	7.5	7.3	*	112°/14	130°/15	124°/9
3,430				5.7						
3,500			820			6.6	*			140°/10
3,630					6.0					
4,000	806	806	805	5.3	5.4	5.8	*	135°/12	142°/15	156°/12
4,500			790			4.9	*			166°/17
5,000	777	777	775	4.5	3.9	4.1	*	152°/13	166°/14	176°/22
5,500			760			3.2	*			177°/28
6,000	749	749	746	3.6	2.2	2.3	*	160°/24	172°/25	179°/34
6,500			732			1.5	*			181°/37
7,000	720	720	718	0.8	0.3	0.6	*	162°/38	171°/40	183°/39
7,500			705			-0.2	*			188°/39
8,000	694	693	692	-1.0	-1.3	-1.0	*	163°/48	181°/43	193°/40
8,500			679			-1.8	*			197°/41
9,000	668	668	667	-3.0	-3.0	-2.5	*	168°/50	193°/44	201°/43
9,500			654			-3.5	*			204°/48
10,000	643	642	641	-5.2	-4.8	-4.5	*	175°/53	199°/44	208°/44
11,000	618	617		-7.2	-6.6			182°/54	217°/49	
12,000	594	594		-9.3	-7.3			189°/53	223°/64	
13,000	571	571		-11.8	-8.1					
14,000	549	549		-13.2	-9.9					

*Below the sensitivity of the instrument.

Wind directions relative to true north.

Appendix K

BRL GAGE IDENTIFICATION, TEST NO. 6, E-3005

Station	Distance (ft)	Capsule number	Capsule range (psi)	Motor number	Gage number
N-1	300	989	50	20-202	382
N-2	500	804	25	20-211	308
N-2A	500	802	25	20-207	375
N-3	750	713	15	10-3-L	390
N-4	1,000	654	5	10-106-L	324
N-5	1,855	1192	1	10-339	339
N-6	3,630	1168	0.5	10-18-L	366
S-1	300	901	50	20-206	405
S-2	500	723	15	10-390	410
S-3	750	617	5	10-396	320
S-4	1,000	630	5	10-203	396A
S-5	1,855	1198	1	10-129	342
W-1	300	815	25	20-210	383
W-2	500	732	15	10-8-L	313
W-2A	500	727	15	10-109-L	330
W-3	750	722	15	10-112	404
W-4	1,000	658	5	20-104	337
W-5	1,855	401	0.5	10-115	318

Appendix L

BRL GAGE IDENTIFICATION, TEST NO. 7, ROLLER COASTER

Station	Distance (ft)	Capsule number	Capsule range (psi)	Motor number	Gage number
1	100	713	15	10-40H	318
2	225	617	5	10-115	337
3	300	631	5	20-104	324
4	500	1198	1	10-106	330
5	900	1145	1	10-	339
6	1,200	1188	1	10-	342

Appendix M

EARTH-COVERED, STEEL-ARCH MAGAZINE SPACING CRITERIA

1. The test program for evaluation of the steel-arch magazines is essentially complete unless further evaluation of specific problems is requested by one of the sponsoring agencies of the Dividing Wall Program.

2. Based upon the results achieved in this test series, the 225th meeting of the Armed Services Explosives Safety Board approved siting criteria for these magazines as follows:

a. Structures must be at least equivalent in strength to those shown on Corps of Engineers Drawings Nos. AW 33-15-63 (5 March 1963), AW 33-15-64 (10 May 1963), 33-16-65 (10 January 1963), and the Corps of Engineers standard specifications cited therein.

b. The earth fill or earth cover between these steel-arch magazines may be either solid or sloped in accordance with the requirements of other construction features, but a minimum of two feet of earth cover must be maintained over the top of each magazine and a minimum slope of two horizontal to one vertical starting directly above the spring line of each arch must be maintained.

c. The spacing of adjacent magazines will be computed from the following formulae, where D represents the distance in feet, and W represents the net weight of the explosive in pounds.

EXCEPTION: No magazines shall be spaced one from the other at a distance of less than seven feet.

(1) Spacing is to be $D = 1.25W^{1/3}$ between sides or between a side and rear wall.

(2) Spacing is to be $D = 1.5W^{1/3}$ between rear walls when siting is back-to-back.

(3) Spacing is to be $D = 4.5W^{1/3}$ between front walls and rear wall or side.

d. Explosive weight, W, will be computed as follows:

(1) When all explosives in the magazine are mass detonating: W will be the total weight of explosives.

REFERENCES

1. Underwater Explosives Research Laboratory. Test on Scale-Model Igloo-Type Storage Magazines, by W. D. Kennedy and W. E. Curtis. Woods Hole Oceanographic Institution, Woods Hole, Mass., 1 August 1946.

2. Naval Proving Ground, Arco, Idaho. Igloo Tests (Technical Paper No. 3), revised by S. W. Thompson. Armed Services Explosives Safety Board, Washington, D. C., 6 November 1947.

3. ------. Scale Model Igloo Magazine Explosion Tests (Technical Paper No. 4), by Cdr R. L. Mann. Armed Services Explosives Safety Board, Washington, D. C., 12 June 1947.

4. ------. Igloo and Revetment Tests (Technical Paper No. 5). Armed Services Explosives Safety Board, Washington, D. C., October 1946.

5. Kinney, G. F. Explosive Shocks in Air. New York, Macmillan, 1962. Pp. 90.

(2) When explosives in the magazine are combinations of solid rocket and missile propellants and/or warheads: W will be the sum of the weights of mass detonating explosives and the expected yield from those propellants that have been determined by appropriate service tests or analogy to contribute to high explosive yields; on new propellants where no data exists as to high explosive equivalencies, contribution of the total weight of the propellant will be used.

4. These criteria are only for prevention of propagation of explosions between adjacent steel-arch magazines, and will not necessarily prevent damage to acceptor magazines and their contents.

5. The above criteria are recommended for use on all magazines referenced in paragraph 2 above; no upper limit on explosives weights has been established.

6. These criteria are the minimum permitted. In cases where explosives of greater-than-normal sensitivity (e.g., liquid nitroglycerin) present maximum risk of initiation, these criteria will require review to determine the need, if any, for increased spacing.