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ESKIMO VII TEST RESULTS

by

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ABSTRACT

ESKIMO VII, seventh in the series of Explosive Safety Knowledge IMprovement Operation Tests, was conducted to determine the safety and performance of Navy box-shaped ammunition storage magazines. The two magazines tested, the Type A (new design) and Type IIB (old design), were the remaining half-scale structures from the July 1980 ESKIMO VI test. The Type A magazine was tested using a foam High Explosive Simulation Technique (HEST) on its roof. The Type IIB magazine was tested one week later using a small hemispherical surface charge of 13,616 pounds of TNT. The two interior columns of the Type A magazine catastrophically collapsed when subjected to a HEST impulse approximately three times greater than the design impulse. Although the yield-line pattern and response predicted for the flat-slab structure never occurred, the roof remained intact while undergoing maximum support rotations of 16 degrees. These data indicate a high probability of eliminating the columns from future magazines by utilizing the tremendous energy absorbing properties associated with tensile membrane behavior of restrained slabs. The redesigned door and headwall system for the Type IIB magazine survived the blast loading conditions approximating those at the minimum side-to-side spacing of earth-covered magazines with only minor structural damage. These data indicate that the structural re-design used in this test is more than adequate to prevent sympathetic detonation.

INTRODUCTION

ESKIMO VII, seventh in the series of Explosive Safety Knowledge IMprovement Operation test events of earth-covered magazine structures was recently completed at the Naval Weapons Center (NWC), China Lake, California. The box magazines tested were the two remaining structures, the Type IIB (designed in the 1950s) and the Type A (designed in the 1970s), from the July 1980 ESKIMO VI test. The Type A magazine was tested first using a foam HEST (High Explosive Simulation Technique) (Ref 1). To obtain a test design impulse of 2,300 psi-msec acting on the roof, a charge density of 0.43 lb/ft^3 was used. The Type IIB magazine was tested 7 days later using a hemispherically shaped surface charge of 13,616 pounds of TNT in a side-to-side orientation. The explosive effects (induced airblast loading, ground motion, debris, etc.) on the Type IIB magazine from the earlier HEST detonation was negligible. Results from ESKIMO VII will be used to evaluate the safety and performance under blast loading of box-shaped (smokeless powder/projectile) storage magazines. A description of the testing procedure and the results of the test are included in this report. If needed, additional pretest information can be found in the ESKIMO VII Test Plan (Ref 2).

Background

The Department of Defense Explosives Safety Board (DDESB) establishes explosives safety standards applicable to the military services and other Department of Defense (DOD) components. The quantity-distance standards for the separation of explosives storage magazines published in DOD Standard 5154.4S (Ref 3) depend on the construction of the magazines. Additionally, DOD 5145.4S allows higher explosive limits (up to 500,000 pounds) in certain standard earth-covered magazines of proven design that may be sited at the minimum intermagazine spacing permitted.*

ESKIMO VI showed that the door system design of Navy Smokeless Powder and Projectile Magazine Type IIB was inadequate to resist the loading resulting from detonation of 350,000 pounds in a similar magazine located at the minimum side-to-side spacing. The test also demonstrated an ample, possibly excessive, margin of safety in the Type A box magazine roof, which had been designed for a maximum support rotation of 2 degrees in accordance with the triservice manual on explosion-resistant structures (Ref 4).

*Prior to ESKIMO VI (1980), box magazines in the field had not been tested or specifically designed for overpressure loads. Safety policy, therefore, had required that they be sited at nonstandard intermagazine separation distances and that their storage capacity be limited to one-half the weight of explosives allowed in a standard magazine.

Objective

The objectives of ESKIMO VII were to:

1. Validate the performance of a redesigned door and headwall system for the Type IIB magazine under blast loading conditions approximating those at the minimum side-to-side spacing of earth-covered magazines.

2. Evaluate the reserve strength inherent in the Type A magazine design at roof slab deformations corresponding to large rotations at supports.

3. Provide test data to support improved load criteria, structural performance requirements, and design methods for the roofs, walls, and doors of more economical box-shaped magazines that can be sited at the minimum separation distances permitted by explosives safety standards.

High-explosive field test events are the only means, except for small-scale model testing, to evaluate the accuracy of calculational and empirical prediction techniques for the blast loading and response of magazine structures.

TEST A-ROOF

Type A Magazine

The Type A magazine (Ref 5) was designed to provide the same interior dimensions as the Type IIB magazine. The Type A magazine roof is supported by two interior circular columns with drop panels (see Figure 1). Aside from the Type A magazine being more massive and designed without pilasters, the major difference between the Type A and the Type IIB magazine is in the headwall design. The Type A magazine employs two sliding (built-up) doors that are supported on all four edges (the door sill, lintel, and jambs) by large beam elements. The two doors are located at the loading platform.

The Type A half-scale test structure duplicates the walls, roof, columns, footings, doors (without hanging mechanisms), and earth cover. The model structure used 1 foot of earth cover. Steel wing walls salvaged from the ESKIMO V test were designed to retain the earth cover. The interior floor slab, ramp, and loading platform in the model were replaced with compacted earth fill without concrete slabs, footings, or steps; all other nonstructural features were deleted. Construction drawings of the Type A structure used in ESKIMO VI are included in Reference 6.

In ESKIMO VI the roof parapet (a low wall used to retain the 1-foot soil cover on the roof) was severely damaged. The parapet was refurbished and increased in height from 1 foot 5 inches to a total height of 2 feet 9 inches. This modification was needed to retain the additional 12 inches of uncompacted native soil overburden required above the foam HEST cavity. The steel wing walls in the region adjacent to the structure were also increased in height (see Figure 2).

Foam HEST Design

To produce the required airblast loading, it was necessary to accurately simulate the overpressure component of the airblast generated by a high-explosive surface burst. A test procedure developed by the Air Force Weapons

TEST IIB-DOORS

Type IIB Magazine

The Type IIB magazine is a smokeless powder and projectile storage magazine in the Naval Facilities Engineering Command (NAVFAC) inventory (Ref 7). The full-scale Type IIB magazine is 52-feet deep and 97-feet wide with an inside height that varies from 13 feet at the rear wall to 15 feet 2 inches at the front wall. It has two interior columns and 10 pilasters with capitals. Three continuous drop panels are provided at the column lines between the side walls. Two doors are located at the loading platform.

The construction drawings for the Type IIB half-scale structure tested in ESKIMO VI are found in Reference 6. This test structure duplicates the walls, roof, columns, pilasters, floor slab, footings, both doors, and earth fill. The model structure used 1 foot of earth cover. Steel wing walls salvaged from the ESKIMO V test were designed to retain the earth fill behind them. The ramp and platform were replaced with compacted earth fill without concrete slabs, footings, or steps and all other nonstructural features were deleted.

The performance of the Type IIB test structure in ESKIMO VI showed that the current double-leaf hinged door design was inadequate for resisting the blast loads. These doors were forced inward, bending past the door stops, and were separated from their hinges, coming to rest in the corresponding rear corners of the magazine. A redesign of the door/ headwall was undertaken in connection with ESKIMO VII. In addition to satisfying explosives safety criteria, the new door design also satisfies physical security criteria for theft (Ref 8). The new door configuration shown in Figure 9 is similar to the sliding single-leaf system of the Type A magazine. The construction drawings for the half-scale components to be tested are shown in Figures 10 and 11. Construction photographs of the modifications are shown in Figures 12 and 13.

Hemispherical Surface Charge

The explosive charge configuration (orientation, size, shape, and range) was designed to provide a blast environment similar to that observed in the ESKIMO VI test. According to these test results, the centerline of the Type IIB headwall was subjected to an impulse of 382 psi-msec and a maximum overpressure of 50 psi. The charge configuration was designed by NCEL using Figure 18 from Reference 9. This figure appears as Figure 14 in this report. As a design aid, the relationship for peak positive incident overpressure (p_{so}) versus scaled unit positive incident impulse ($i_s/W^{1/3}$) was obtained from this figure and then plotted in Figure 15. At the desired peak overpressure level of 50 psi, the corresponding values for $i_s/W^{1/3}$ and scaled ground distance, $R/W^{1/3}$, are 16.2 and 4.6, respectively. Substituting 382 psi-msec for i_s in the first expression results in a desired charge weight (W) of 13,111 pounds. Substituting this value into the second expression results in a charge distance (R) of 108.5 feet from the headwall centerline. These values are valid for the ambient conditions at sea level. However, since the test site is about 2,000 feet above sea level, the mean ambient conditions differ measurably from those at sea level. To account for these differences, a computational procedure outlined in Reference 10 was followed.

Using this procedure the following parameters were obtained at the headwall centerline for W = 13,616 pounds and R = 108.6 feet:

$$p_{so} = 50.2 \text{ psi}$$

$$i_s = 382.4 \text{ psi-msec}$$

The values at both door centerlines were also calculated and are listed in Table 2 and shown in Figures 16 and 17.

The following equation for crater radius was derived from data found in Reference 11:

$$r_c = 0.452\, W^{0.42}$$

where:

r_c = crater radius (ft)

W = charge weight (lb)

The calculated crater radius for a 13,615-pound charge is 24.6 feet. As shown in the proposed test configuration of Figure 18, cratering is of no concern.

The charge was constructed of 8-pound TNT blocks (2 by 6 by 12 inches) and is shown in Figure 19.

Instrumentation

Figure 20 is a schematic of the active instrumentation recording the blast environment at the Type IIB magazine. Surface airblast pressure gauges located along gage lines at 90 and 180 degrees recorded the free-field pressure-time environment (Figure 21, Table 3). These gauges were installed in heavy-gage mounts to read the side-on pressure loads. A detailed description and purpose for each gauge is listed in Table 4. A total of 31 gauges were used.

Motion Picture Photography

The test was recorded photographically by ground and air-based 16mm cameras using color film at speeds ranging from 24 frames/second to 10,000 frames/second. Figure 22 illustrates the locations of the ground cameras.

TEST RESULTS

The analog data signals from the test instrumentation were conditioned and recorded on 1-inch magnetic tapes. The tape recorders were 14-track, intermediate-band, with FM amplifiers, operated at either 60 or 120 ips, providing a maximum frequency response of 20 kHz or 40 kHz, respectively. Each tape contained a IRIG B time signal and a detonation zero signal. Time-history records of all data are not included in this report due to its bulk, but are available from the author on request. High speed films showing test results are located at NCEL. A full documentary film of test results should be available approximately January 1987.

Test A-ROOF

Observed Structural Response. Test A-ROOF took place on 5 September 1985. Figure 23 illustrates the sequence of the foam HEST event. The explosive source was designed to produce a maximum impulse of 2,300 psi-msec on the Type A magazine roof. The average measured impulse of 2,500 psi-msec was only slightly greater than predicted. A post-test view of the magazine interior is shown in Figure 24. Both interior columns catastrophically collapsed, changing the roof configuration from a flat slab to a rectangular two-way slab restrained on four sides. The large dynamic deflections that occurred resulted in the roof acting primarily as a tensile membrane member in the short direction (front to rear). None of the principal steel reinforcing bars were broken or showed signs of necking down. A view of the roof after excavating the left rear quadrant is shown in Figure 25. The permanent deflections of the roof surface measured along nine lines (A through I) are displayed in Figure 26 and listed in Table 5. The permanent center deflection at midspan of the roof was 45.5 inches. The maximum support rotation measured in the short direction along Line E equals 15.8°. The maximum support rotation measured in the long direction along Line 7 equals 9.1°.

Both the backwall and the headwall were forced inward by the tensile membrane action of the roof. The maximum inward displacement of these walls, measured at the magazine centerline near the roof elevation, were 8 inches and 2-1/2 inches for the backwall and headwall, respectively.

Response Instrumentation. Data recovery in general was poor. In view of the catastrophic collapse of the interior columns this loss of data was not unexpected. Data from only three of the recovered airblast pressure gages is considered useful. A summary of the airblast data is listed in Table 6 and a representative time history plot is shown in Figure 27. A summary of data derived from velocity gage output is shown in Table 7. Gage No. A-C2-V3 was attached to the column and was lost immediately confirming the sudden early collapse of the columns. All three vertical roof displacement gages functioned satisfactorily until reaching the established 18-inch limit of gage travel.

Test IIB-DOORS

Observed Structural Response. Test IIB-DOORS took place on 12 September 1985. The explosive source was designed to produce a maximum impulse of 382 psi-msec and peak overpressure of 50 psi on the centerline of the Type IIB magazine headwall. Generally, measurements of blast loading made during the test were slightly lower than the predicted levels. The measured impulse at the headwall centerline was 355 psi-msec with an initial peak overpressure of 58 psi. A comparison of the roof and headwall gage output for ESKIMO's VI and VII is quite similar. Figure 28 shows the magazine being engulfed by the fireball. A post-test view of the magazine and crater is shown in Figure 29. Crater dimensions were 9-foot depth and 20-foot radius. The redesigned door and headwall system remained intact and more than satisfied the explosives safety deficiencies uncovered in ESKIMO VI. Buckling of the exterior steel face plate of the near door is illustrated in Figure 30. Maximum permanent door deflections of the near and far doors were measured as 9/16 inch and 3/16 inch, respectively. The only significant magazine damage observed was to the capital of the near column. Several large concrete pieces had separated as shown in Figure 31.

Response Instrumentation. Data recovery in general was good. A summary of the pressure gage output is listed in Tables 8 and 9 and a representative time history plot is shown in Figure 32. A comparison of the measured airblast impulse versus the predicted (from Ref 9) is shown in Figure 33. A summary of data derived from the velocity gage output is listed in Table 10 and a representative time history plot is shown in Figure 34. Displacment was established by integration of the velocity gage output. Displacement transducers were strategically positioned so as to measure the maximum displacement of the headwall, pilasters, and doors. A summary of the displacement gage data is listed in Table 11 and a representative time history plot is shown in Figure 35. A summary of the strain gage output is listed in Table 12 and a representative time history plot is shown in Figure 36.

DISCUSSION/CONCLUSIONS

Test A-ROOF

Although the intended purpose of the test was not achieved, significant findings in the areas of column design, slab deflection capacity, and tensile membrane behavior were uncovered. The loading capability of the HEST technique was awesome. A total of only 264 pounds NEW of primacord produced an impulse of 2,500 psi-msec on the magazine roof while in ESKIMO VI, 44,000 pounds NEW produced only 656 psi-msec impulse. Since the pressure pulse shapes from this HEST explosion and an HE magazine detonation are similar, the observed test results are considered appropriate. A post-test dynamic analysis of the column for the blast load acting directly on the column indicated column failure. The loaded area in this analysis was limited to the area of the drop panel. The current column design procedures (Ref 4) neglects this "early" loading condition and only considers a loading equal to the ultimate resistance of the roof acting over the tributary area supported by the column. Under most loading conditions, the direct blast loding would not control the column design. However, as demonstrated in ESKIMO VII, it is possible that for a high magnitude blast load acting on a relatively low resistance roof, the column could fail before the flat slab yield line patterns could develop and thus the direct blast loading would control. The column failures immediately transformed the roof slab into a rectangular two-way slab restrained on four sides with an aspect ratio L/H of 1.9. In order for this roof slab to develop tension membrane behavior, adequate lateral restraint of the reinforcement is mandatory. However, external lateral restraint is not required for elements supported on four edges provided the aspect ratio is not less than one-half nor greater than two. Within this range, the inherent lateral restraint provided by the element's own compression ring around its boundary is sufficient lateral restraint to develop tension membrane behavior. The Type A magazine roof satisfies both restraint conditions and thus, tensile membrane behavior is possible. The tensile membrane resistance function for the Type A magazine roof is shown in Figure 37. A dynamic response calculation using this function and the measured roof loading resulted in a predicted maximum displacement of 49.7 inches. This is only slightly greater than the measured post-test permanent displacement of 45.5 inches. Even though no stirrups were used, the concrete on the underside of the roof remained intact except for small regions of the column bands where the bottom steel was cut off.

Test IIB-Doors

The redesigned door and headwall system of the Type IIB magazine was more than adequate to resist the load resulting from the detonation of 350,000 pounds NEW in a similar magazine located at the minimum side-to-side spacing. The pilasters, which were designed for a maximum support rotation of 4 degrees, sustained less than one-fourth-degree of rotation. Figure 38 shows the resistance function for the Type IIB magazine door. Initiation of plastic behavior for the built-up steel channel and face plates is predicted for 21.7 psi and 0.64 inch. The ultimate door resistance is reached when the oak boards rupture at 25.9 psi. The measured maximum strain, deflection, and permanent deflection for the near door are much smaller than predicted for the 12 degree design rotation (8 inches of displacement equals 12 degrees rotation).

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Table 1. Instrumentation for Test A-ROOF

Channel No.	Gauge No.	Measurement	Manufacturer/Model	Location and Purpose of Gauge	Predicted Peaks
1, 2	A-A2-BP1[a]	Airblast Pressure	Kulite/HKS-375-5000	Surface air pressure at center of left bay	800 psi
3, 4	A-A3-BP2	Airblast Pressure	Kulite/HKS-375-5000	Surface air pressure at rear of left bay	800 psi
5, 6	A-B2-BP3	Airblast Pressure	Kulite/HKS-375-5000	Surface air pressure at center of middle bay	800 psi
7, 8	A-D3-BP4	Airblast Pressure	Kulite/HKS-375-5000	Surface air pressure at rear of right bay	800 psi
9, 10	A-D2-BP5	Airblast Pressure	Kulite/HKS-375-5000	Surface air pressure at center of right bay	800 psi
11	A-B3-SE1	Soil Stress	Kulite/LQ-080U	Vertical soil stress at 1-in depth	800 psi
12	A-B2-SE2	Soil Stress	Kulite/LQ-080U	Vertical soil stress at 1-in depth	800 psi
13	A-B1-V1	Velocity	Bell & Howell/364142-0100	Vertical velocity of roof at front of middle bay	800 in/sec
14	A-D1-V2	Velocity	Bell & Howell/364142-0100	Vertical velocity of roof at front of right bay	800 in/sec
15	A-C2-V3	Velocity	Bell & Howell/364142-0100	Vertical velocity of right column below right bay	25 in/sec
16	A-B2-VF1	Velocity	Bell & Howell/364142-0100	Vertical velocity of ground at center of middle bay	25 in/sec
17	A-B1-VF2	Velocity	Bell & Howell/364142-0100	Vertical velocity of ground at front of middle bay	25 in/sec
18	A-D2-VF3	Velocity	Bell & Howell/364142-0100	Vertical velocity of ground at center of right bay	25 in/sec
19	A-B2-D1	Displacement	Bournes/205194I502	Vertical displacement of roof at center of middle bay	16.5 in
20	A-B1-D2	Displacement	Bournes/205194I502	Vertical displacement of roof at front of middle bay	16.5 in
21	A-D2-D3	Displacement	Bournes/205194I502	Vertical displacement of roof at center of right bay	16.5 in

[a] A = Test A-ROOF; A2 = Gauge location (A = headwall position, 2 = sidewall position); BP1 = airblast pressure gauge No. 1.

Table 2. Blast Parameters for W = 13,616 lb at 2,000 Feet Above Sea Level

Blast Parameter	Magazine Location		
	Near Door	Headwall Centerline	Far Door
Charge distance, R (ft)	92.5	108.6	124.7
Scaled distance, Z (ft/lb$^{1/3}$)	3.87	4.55	5.22
"Corrected" scaled distance, Z* (ft/lb$^{1/3}$)	3.78	4.44	5.09
"Corrected"[a] peak positive overpressure, p_{so} (psi)	66.9	50.2	35.0
"Corrected"[b] positive impulse, i_s (psi-msec)	435.1	382.4	332.0
"Corrected"[c] positive duration, t_d (msec)	39.4	38.2	38.2
"Corrected"[c] arrival time, t_a (msec)	18.5	24.7	34.5

[a] Correction factor = 0.929.

[b] Correction factor = 0.959.

[c] Correction factor = 1.032.

Table 3. Free-Field Pressure Gauge Locations on Lines at 90 and 180 Degrees for Test IIB-DOORS

Range, R ft-in	Scaled Distance[a] $Z = R/W^{1/3}$ (ft/lb$^{1/3}$)	"Corrected" Scaled Distance[b], Z* (ft/lb$^{1/3}$)	"Uncorrected" Pressure Parameters[c]				"Corrected" Pressure Parameters			
			Peak Positive Incident Overpressure, P_{so} (psi)	Unit Positive Incident Impulse, i_s (psi-msec)	Arrival Time, t_a (msec)	Positive Duration, t_d (msec)	Peak Positive Incident Overpressure[d], P_{so} (psi)	Unit Positive Incident Impulse[e], i_s (psi-msec)	Arrival Time[f], t_a (msec)	Positive Duration[f], t_d (msec)
71-8	3	2.9	140	573	11.0	39.4	130	550	11.3	40.6
95-6	4	3.9	70	454	19.1	38.2	65	435	19.7	39.4
119-5	5	4.9	43	370	29.9	37.0	40	354	30.8	38.2
143-3	6	5.9	28	310	45.4	39.4	26	297	46.8	40.6
167-2	7	6.8	20	263	52.5	46.6	19	252	54.1	48.0

[a] $W = 13{,}616$ lb; $W^{1/3} = 23.88$ lb$^{1/3}$.

[b] $Z^* = Z\,(13.66/14.70)^{1/3}$.

[c] From Figure 14

[d] Correction factor = 0.929.

[e] Correction factor = 0.959.

[f] Correction factor = 1.032.

Table 4. Instrumentation for Test IIB-DOORS

Channel No.	Gauge No.	Measurement	Manufacturer/Model	Location and Purpose of Gauge	Predicted Peaks
1	90-3-A1[a]	Airblast Pressure	Bytrex/HFG-200	Surface air pressure at scaled distance of 3; 90-deg azimuth	130 psi
2	90-4-A2	Airblast Pressure	Bytrex/HFG-100	Scaled distance of 4; 90-deg azimuth	65 psi
3	90-5-A3	Airblast Pressure	Bytrex/HFG-100	Scaled distance of 5; 90-deg azimuth	40 psi
4	90-6-A4	Airblast Pressure	Bytrex/HFG-100	Scaled distance of 6; 90-deg azimuth	26 psi
5	90-7-A5	Airblast Pressure	Bytrex/HFG-100	Scaled distance of 7; 90-deg azimuth	19 psi
6	180-3-A6	Airblast Pressure	Bytrex/HFG-200	Scaled distance of 3; 180-deg azimuth	130 psi
7	180-4-A7	Airblast Pressure	Bytrex/HFG-100	Scaled distance of 4; 180-deg azimuth	65 psi
8	180-5-A8	Airblast Pressure	Bytrex/HFG-100	Scaled distance of 5; 180-deg azimuth	40 psi
9	180-6-A9	Airblast Pressure	Bytrex/HFG-100	Scaled distance of 6; 180-deg azimuth	26 psi
10	180-7-A10	Airblast Pressure	Bytrex/HFG-100	Scaled distance of 7; 180-deg azimuth	19 psi
11	B-C3A-BP1[b]	Airblast Pressure	Senso-Metrics/SP68	Surface air pressure at center of middle bay	50 psi
12	B-C2A-BP2	Airblast Pressure	Senso-Metrics/SP68	Surface air pressure at front of middle bay	50 psi
13	B-A1D-BP3	Airblast Pressure	Senso-Metrics/SP68	Side-on air pressure on headwall at near door mid-height	67 psi
14	B-C1D-BP4	Airblast Pressure	Senso-Metrics/SP68	Side-on air pressure on headwall at centerline mid-height	50 psi
15	B-F1D-BP5	Airblast Pressure	Senso-Metrics/SP68	Side-on air pressure on headwall at far door mid-height	35 psi
16	B-C4E-BP6	Airblast Pressure	Bytrex/HFG-25	Interior magazine leakage pressure; centerline of floor at rear wall	0 psi
17	B-C2B-V1	Velocity	Bell & Howell/364142-0100	Vertical velocity of roof at front of middle bay	160 in/sec
18	B-D3C-V2	Velocity	Bell & Howell/364142-0100	Vertical velocity of right column at capital	50 in/sec
19	B-C1D-V3	Velocity	Bell & Howell/364137-0100	Horizontal velocity of headwall at centerline mid-height	515 in/sec
20	B-C2E-V4	Velocity	Bell & Howell/364142-0100	Vertical velocity of floor at front of middle bay	50 in/sec

Table 4. Continued

Channel No.	Gauge No.	Measurement	Manufacturer/Model	Location and Purpose of Gauge	Predicted Peaks
21	B-C3B-D1	Displacement	Bournes/2001564W07	Vertical displacement of roof at center of middle bay	1.6 in
22	B-C2B-D2	Displacement	Bournes/2001564W07	Vertical displacement of roof at front of middle bay	1.6 in
23	B-A1D-D3	Displacement	Bournes/2051941502	Horizontal displacement at center of near door; inside face	10.5 in[c] 14.3 in[d]
24	B-B1D-D4	Displacement	Bournes/2001941501	Horizontal displacement of near door pilaster at mid-height; inside face	5.6 in
25	B-C1D-D5	Displacement	Bournes/2001941501	Horizontal displacement of headwall at centerline at mid-height; inside face	6.6 in
26	B-E1D-D6	Displacement	Bournes/2001564W07	Horizontal displacement of far door pilaster at mid-height; inside face	1.6 in
27	B-F1D-D7	Displacement	Bournes/2001941501	Horizontal displacement at center of far door; inside face	4.5 in[c] 5.6 in[d]
28	B-A1D-S1	Strain	Ailtech/SG129-65	Horizontal strain at center of near door; inside face	20,000 μin/in
29	B-A1D-S2	Strain	Ailtech/SG129-65	Vertical strain at center or near door; inside face	10,000 μin/in
30	B-F1D-S3	Strain	Ailtech/SG129-65	Horizontal strain at center of far door; inside face	20,000 μin/in
31	B-F1D-S4	Strain	Ailtech/SG129-65	Vertical strain at center of far door; inside face	10,000 μin/in

[a]90 = 90° azimuth; 3 = scaled distance; A1 = airblast pressure gauge No. 1.

[b]B = Test IIB-DOORS; C3A = gauge location (C = headwall position, 3 = sidewall position, A = elevation position);
BP1 = Airblast pressure gauge No. 1.

[c]Relative displacement.

[d]Gross displacement.

Table 5. Vertical Roof Deflection of the Type A Test Structure

Measurement Point	Vertical Displacement Along These Roof Lines[a] (feet)								
	A	B	C	D	E	F	G	H	I
1	0.26	0.28	0.36	0.45	0.40	0.41	0.58	0.38	0.33
2	0.84	0.85	1.03	1.17	1.14	1.27	1.26	1.05	0.92
3	1.13	1.67	1.93	1.98	1.94	1.97	1.90	1.74	1.15
4	1.26	2.13	2.50	2.70	2.74	2.74	2.38	2.11	1.23
5	1.35	2.25	2.80	3.16	3.28	3.07	2.60	2.23	1.25
6	1.48	2.43	3.00	3.48	3.63	3.27	2.75	2.33	1.29
7	1.61	2.55	3.16	3.61	3.79	3.35	2.88	2.42	1.33
8	1.72	2.72	3.33	3.69	3.77	3.49	3.00	2.54	1.40
9	1.84	2.91	3.13	3.38	3.45	3.24	3.02	2.66	1.46
10	2.00	2.43	2.56	2.93	2.84	2.88	2.49	2.29	1.52
11	1.34	1.66	1.90	2.09	2.15	2.06	1.85	1.58	1.30
12	0.66	0.94	1.13	1.40	1.32	1.33	1.14	0.89	0.60
13	0.27	0.29	0.32	0.71	0.61	0.79	0.56	0.27	0.21

[a]See Figure 26 for location of these displacements.

Table 6. Summary of Airblast Pressure Data for Test A-ROOF

Gage No.	Peak[a] Pressure (psi)	Impulse (psi-msec)
A-A2-BP1	1207/500	3500[b]
A-A3-BP2	Bad Gage	—
A-B2-BP3	Bad Gage	—
A-D3-BP4	1570/400	2500
A-D2-BP5	1180/340	1550[c]

[a]The first value is a maximum value read from the curve. The second value is a linearized estimate of the peak value based on an exponentially decaying pressure pulse.

[b]Residual pressure equals +50 psi. Corrected impulse equals 2500 psi-msec.

[c]Residual pressure equals −50 psi. Corrected impulse equals 2550 psi-msec.

Table 7. Summary of Velocity Data for Test A-ROOF

Gage No.	Peak Velocity (in/sec)[a]	Displacement[a] (in)
A-B1-V1 (roof)	460	37.2
A-D1-V2 (roof)	395	24.6
A-C2-V3 (column)	b	b
A-B2-VF1 (floor)	22	0.4
A-B1-VF2 (floor)	9	0.2
A-D2-VF3 (floor)	17	0.5

[a]Positive values indicate downward motion.

[b]Gage lost during test.

Table 8. Summary of Free-Field Pressure Gage Data for Test IIB-DOORS

Gage No.	Gage Distance From Donor (ft)	Peak Overpressure[a] (psi)	Impulse (psi-msec)
90-3-A1[a]	71.7	192/97	725
90-4-A2	95.6	73/58	403
90-5-A3	119.4	39/25	258
90-6-A4	143.3	24/21	226
90-7-A5	167.2	21/18	200
180-3-A6	71.7	165/90	580
180-4-A7	95.6	75/48	451
180-5-A8	119.4	42/30	258
180-6-A9	143.3	23/20	235
180-7-A10	167.2	18/16	235

[a]The first value is the maximum value read from the curve. The second value is a linearized estimate of the peak value based on an exponentially decaying pressure pulse.

Table 9. Summary of On-Structure Pressure Gage Data for Test IIB-DOORS

Gage No.	Location	Peak[a] Overpressure (psi)	Impulse (psi-msec)
B-C3A-BP1	Roof Centerline	82/46	382
B-C2A-BP2	Roof Centerline	55/41	390
B-A1D-BP3	Near Door	105/74	395
B-C1D-BP4	Headwall Centerline	58/42	355
B-F1D-BP5	Far Door	45/38	230

[a]The first value is a maximum value read from the curve. The second value is a linearized estimate of the peak value based on and exponentially decaying pressure pulse.

Table 10. Summary of Velocity Gage Data for Test IIB-DOORS

Gage No.	Location	Time from Zero to Maximum Peak Displacement (msec)	Peak Velocity[a] (in/sec)	Displacement (in)
B-C2B-V1	Roof Centerline	79	84 (-43)	1.49
B-D3C-V2	Far Column	79	17 (-21)	0.31
B-C1D-V3	Headwall Centerline	59	185 (-154)	2.00
B-C2E-V4	Floor	96	5 (-6)	0.12

[a]Positive values indicate motions vertically down or horizontally toward the structure center.

Table 11. Summary of Displacement Gage Data for Test IIB-DOORS

Gage No.	Location	Time from Zero to Maximum Displacement (msec)	Maximum Displacement (in)
B-C3B-D1	Roof Centerline	75	1.49
B-C2B-D2	Roof Centerline	77	1.49
B-A1D-D3	Near Door	43	1.62
B-B1D-D4	Near Door Pilaster	44	0.16
B-C1D-D5	Headwall Centerline	58	1.77
B-E1D-D6	Far Door Pilaster	53	0.16
B-F1D-D7	Far Door	69	2.24

[a]Positive values indicate motions vertically down or horizontally toward the structure center.

Table 12. Summary of Strain Gage Data for Test IIB-DOORS

Gage No.	Location	Direction	Time from Zero to Maximum Strain (msec)	Peak Strain[a] (μin/in)
B-A1D-S1	Near Door	Horizontal	44	3270
B-A1D-S2	Near Door	Vertical	-	-
B-F1D-S3	Far Door	Horizontal	57	1895
B-F1D-S4	Far Door	Vertical	-	-

[a]Positive values equal tension; negative values equal compression.

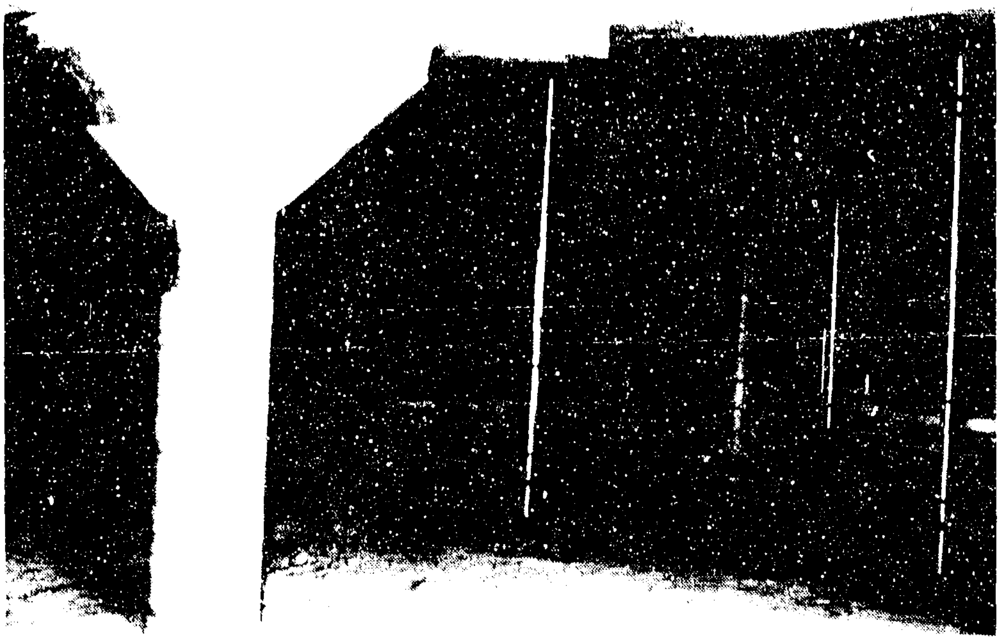


Figure 1. Interior view of Type A magazine before test.

Figure 2. Exter : view of Type A magazine before test.

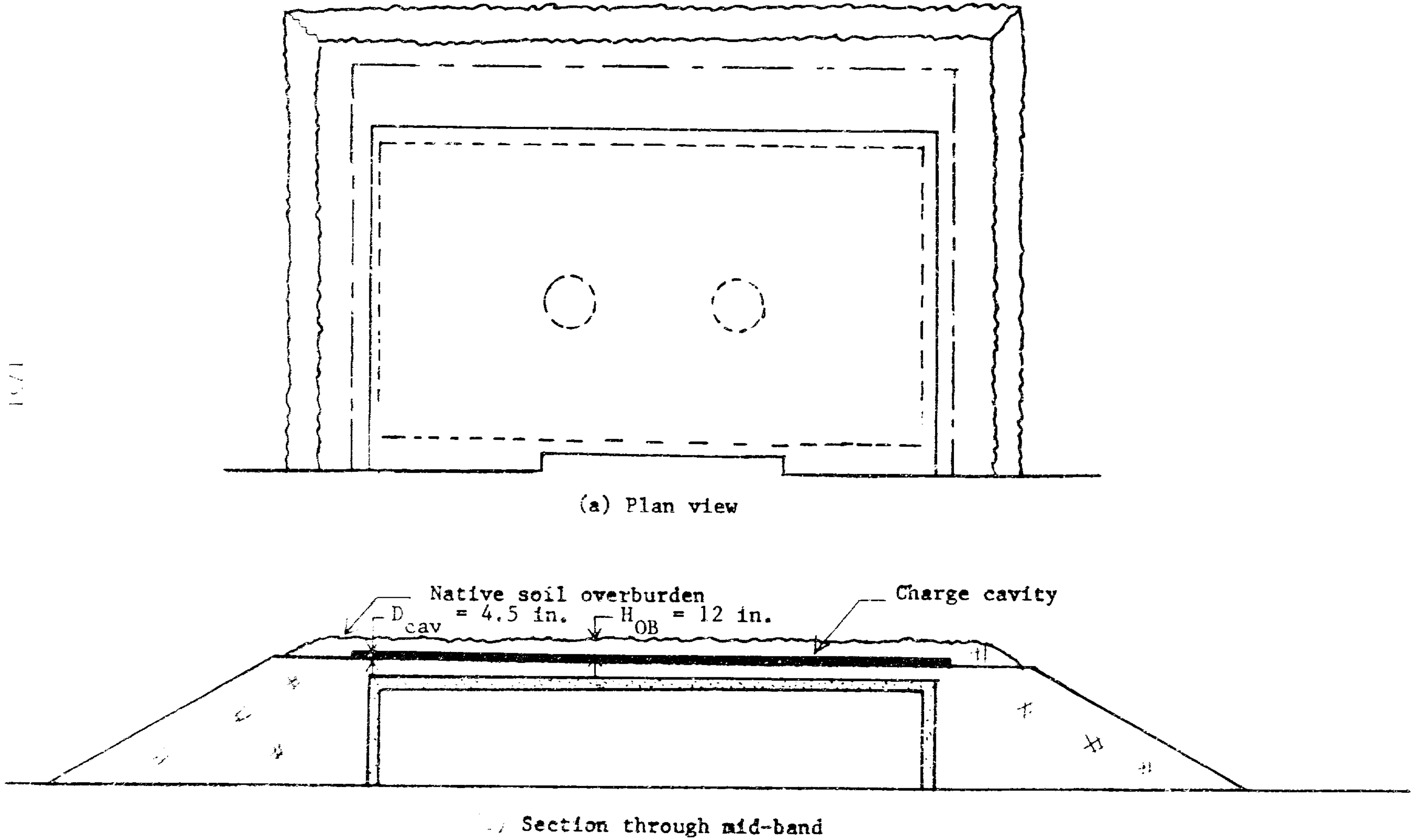


Figure 3. Foam HEST configuration and placement.

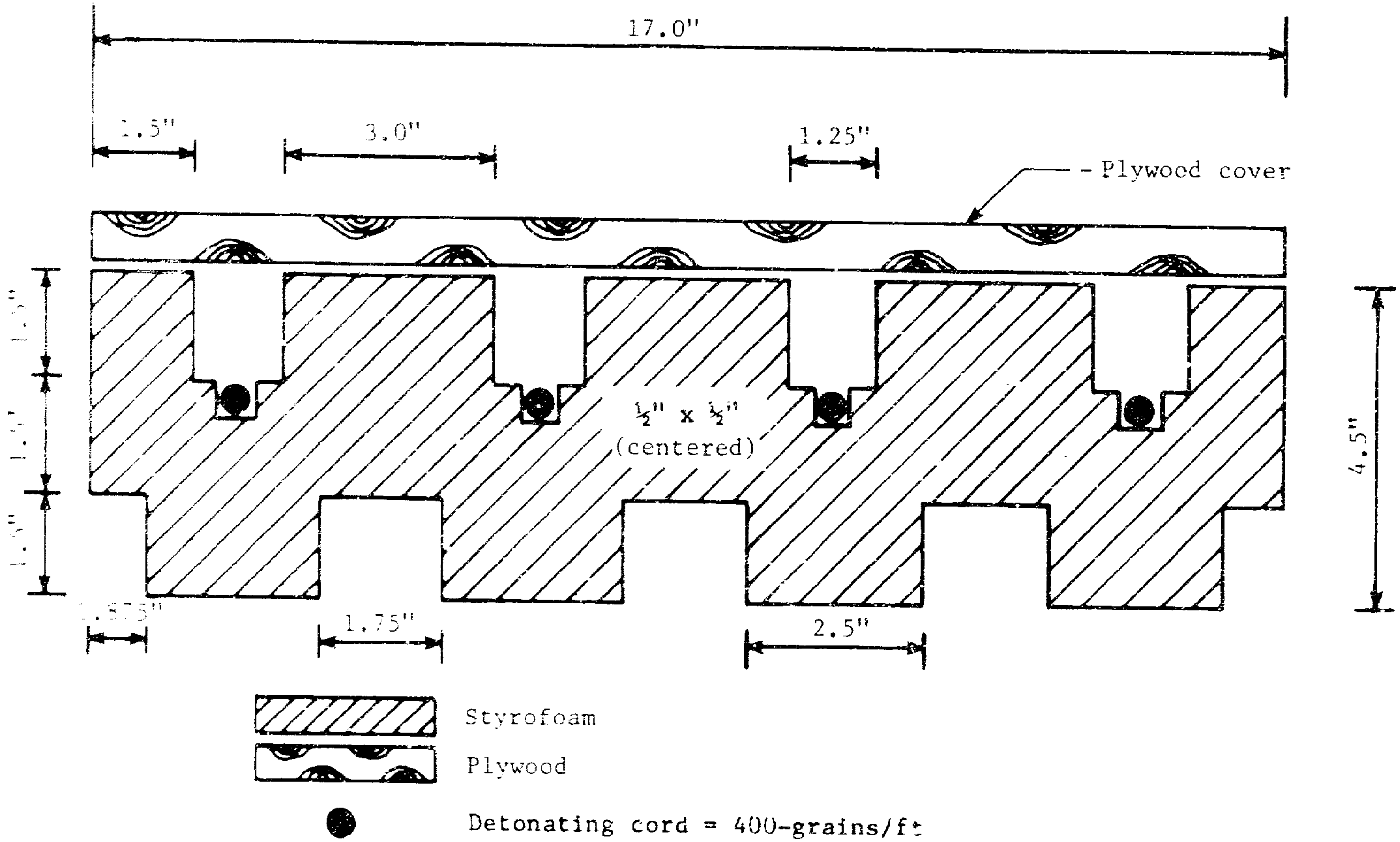


Figure 4. Charge cavity for foam HEST.

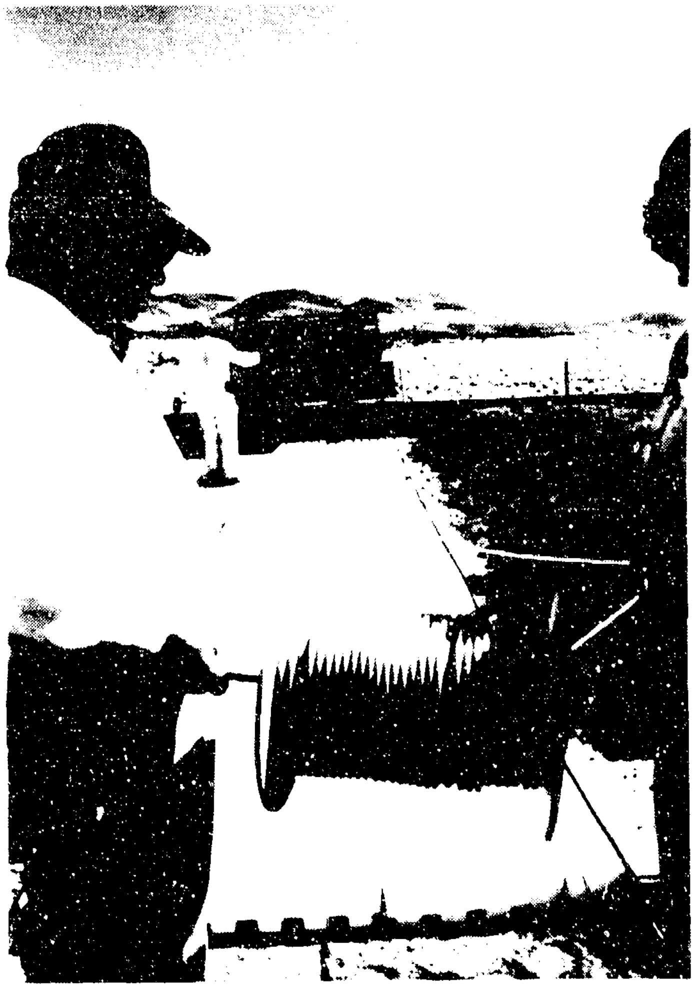


Figure 5. Construction of foam HEST charge cavity above Type A magazine roof.

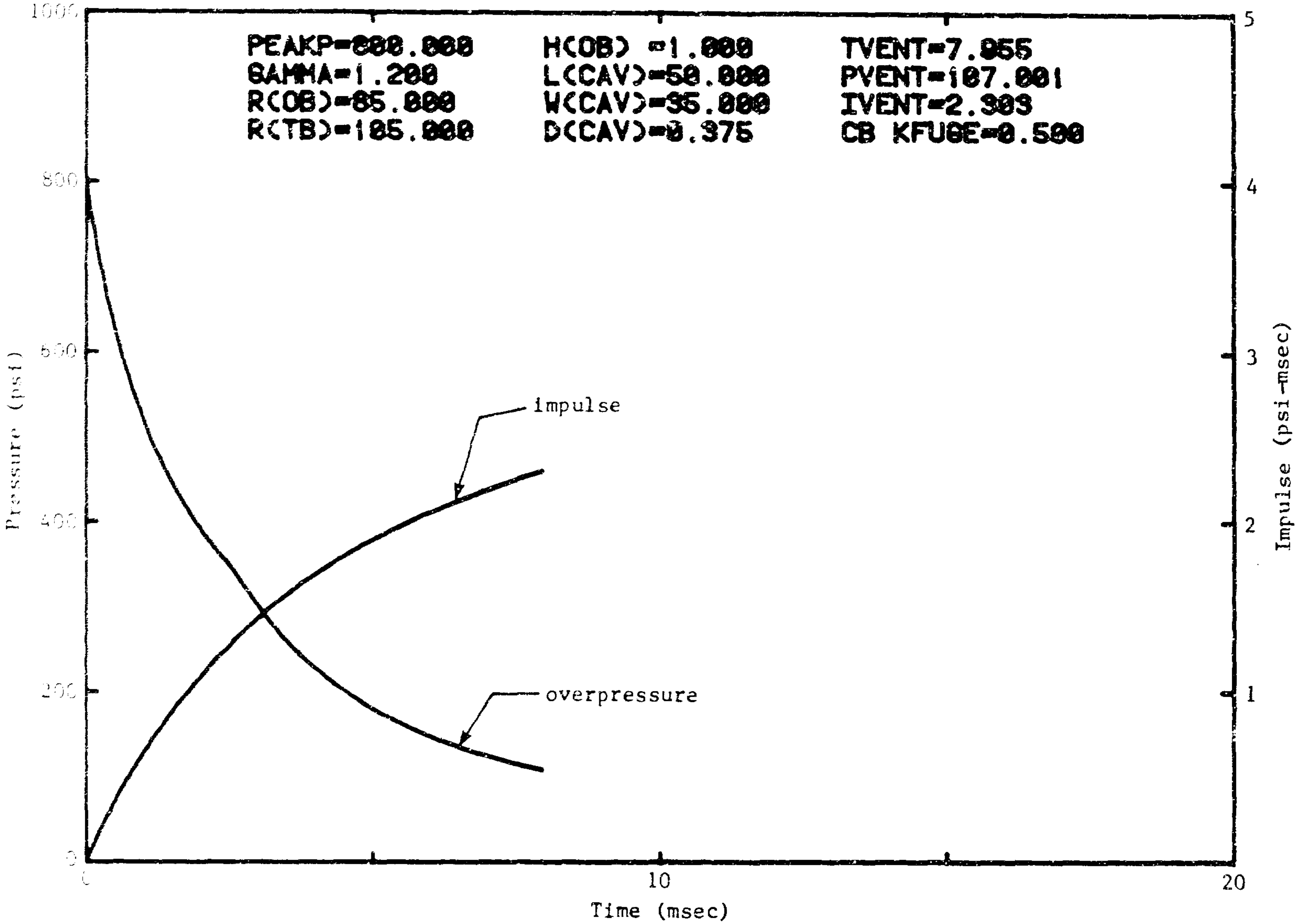


Figure 6. HEST design code output for foam HEST A-ROOF parameters.

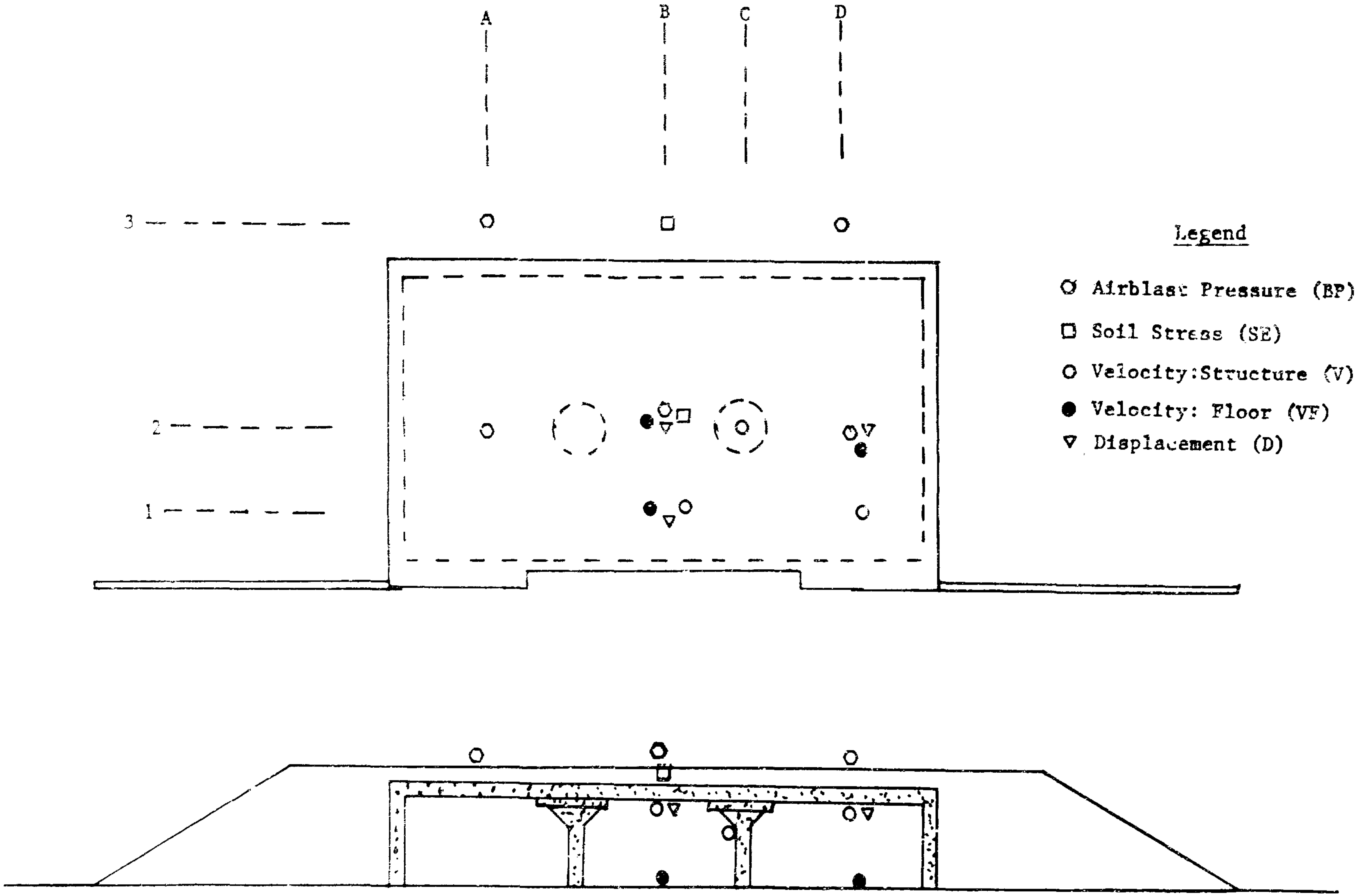


Figure 7. Type A magazine gauge locations for Test A-ROOF.

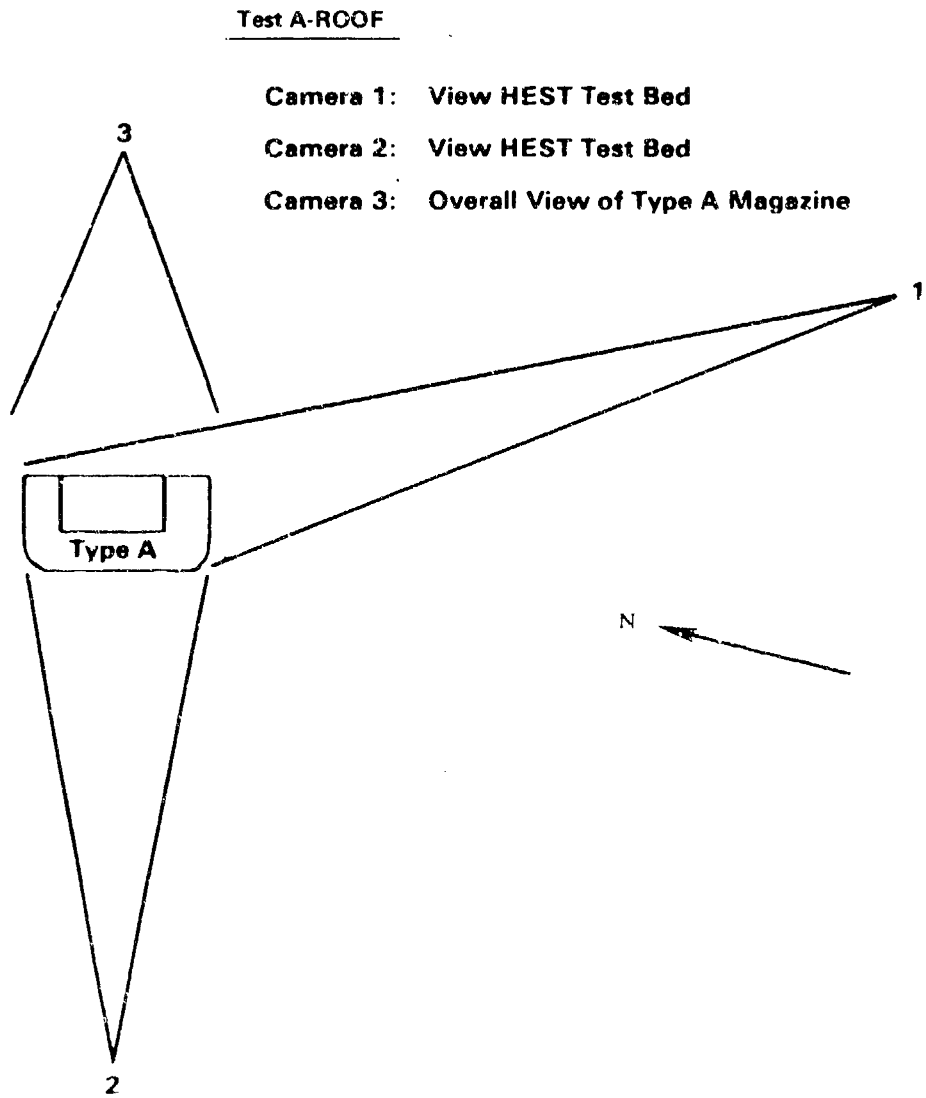
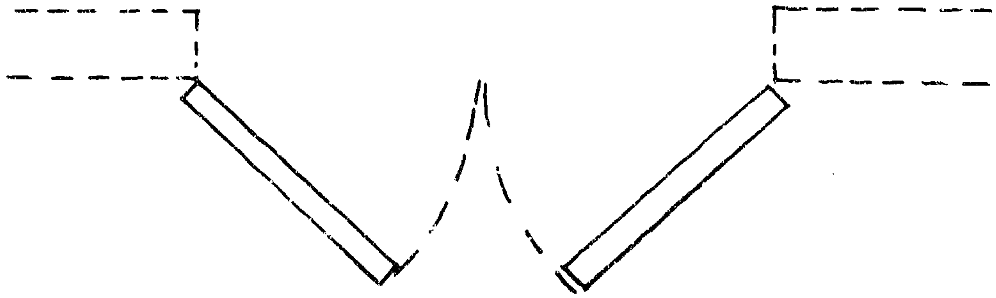
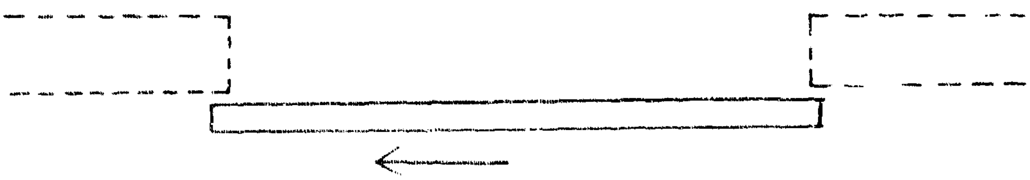


Figure 8. Test A-ROOF camera locations and field-of-view definition.



(a) ESKIMO VI: Double leaf/hinged



(b) ESKIMO VII: Single leaf/sliding

Figure 9. Type IIB magazine door.

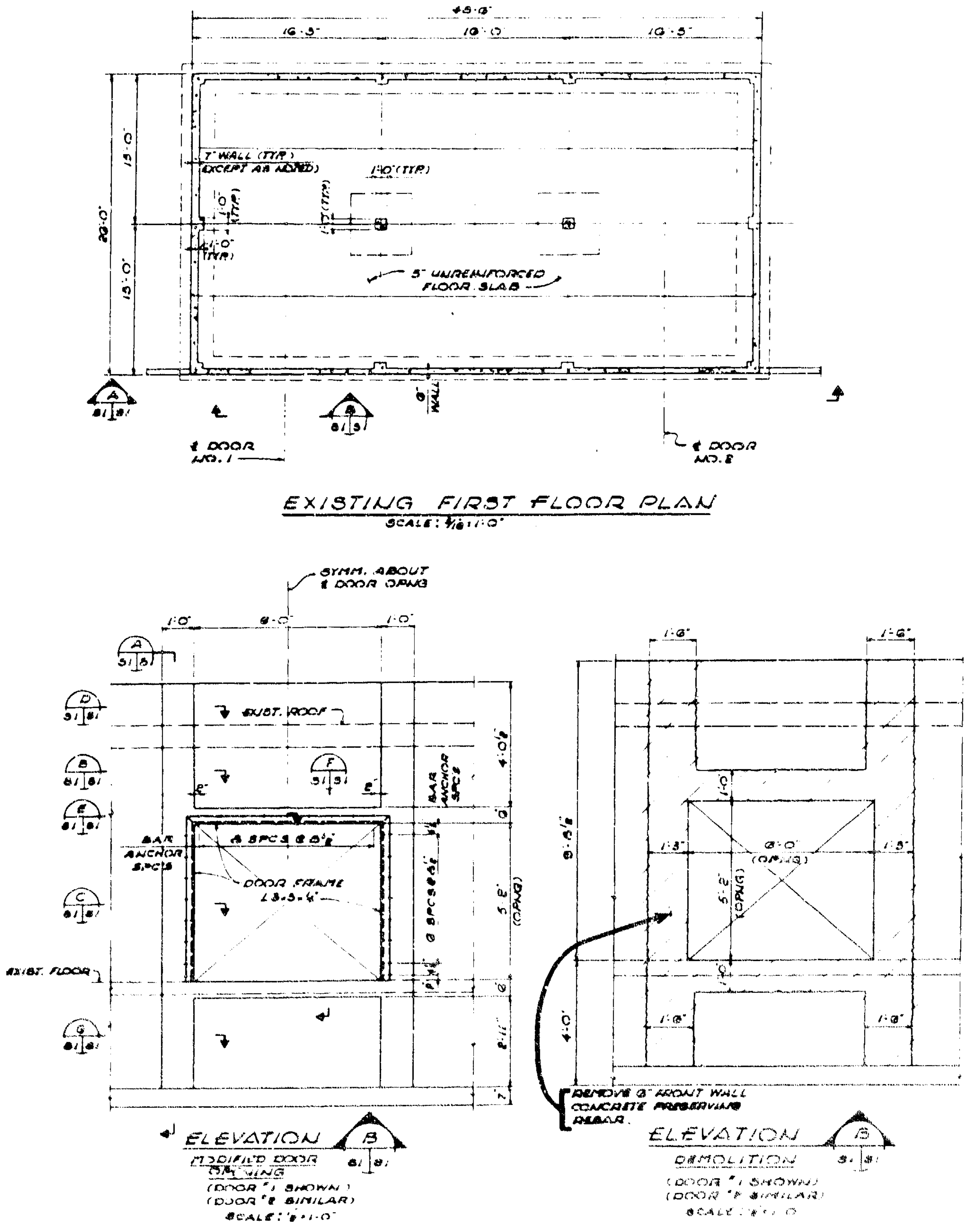


Figure 10. Construction drawing of half-scale Type IIB magazine headwall modifications.

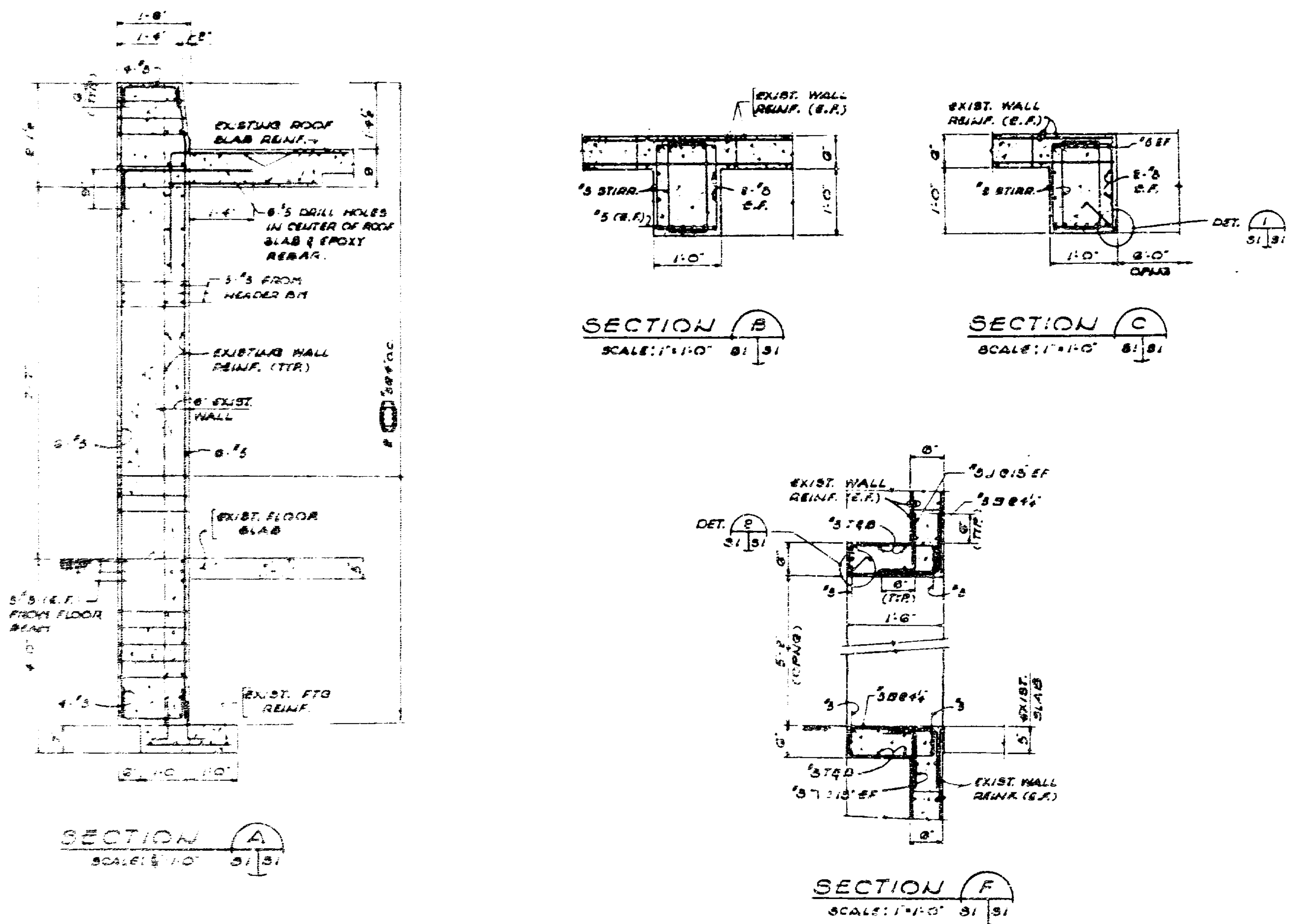


Figure 10. (Continued from previous page.)

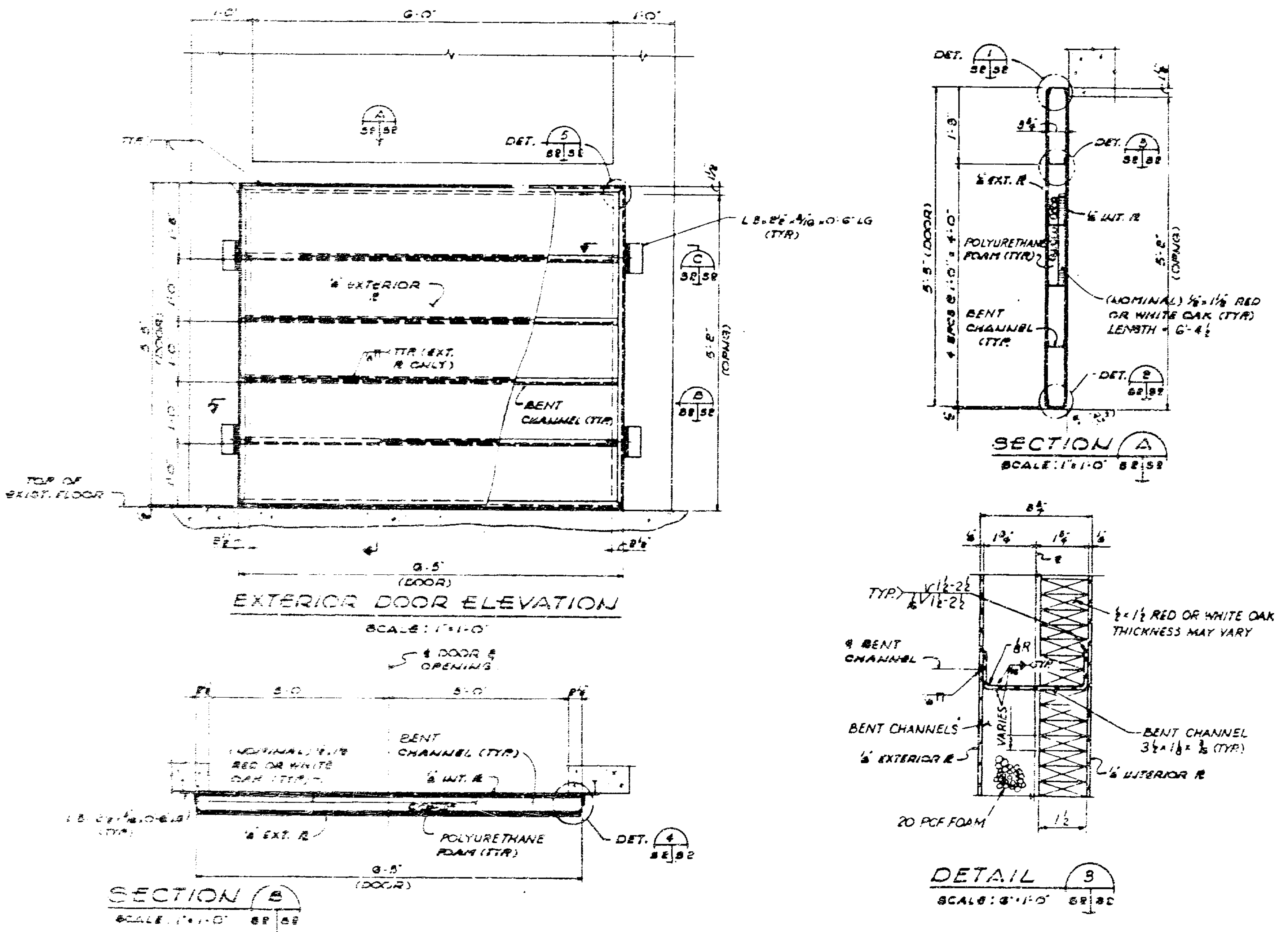


Figure 11. Construction drawing of half-scale Type IIB magazine door.

Figure 12. Pilaster and lintel beam reinforcement of the Type IIB test structure.

Figure 13. Completed headwall modifications of Type IIB test structure.

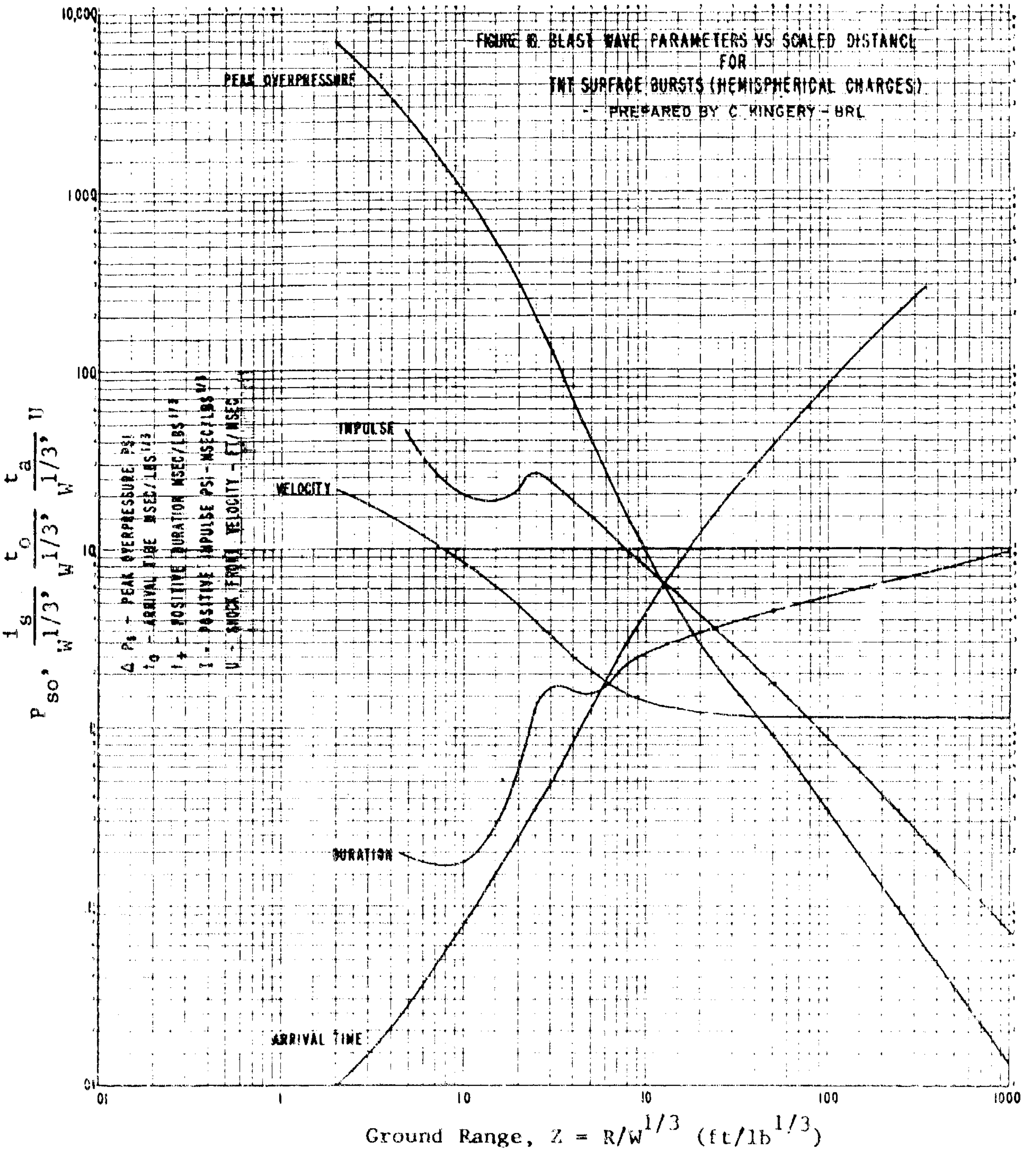


Figure 14. Blast wave parameters versus scaled distance for hemispherical TNT surface bursts (Ref 9).

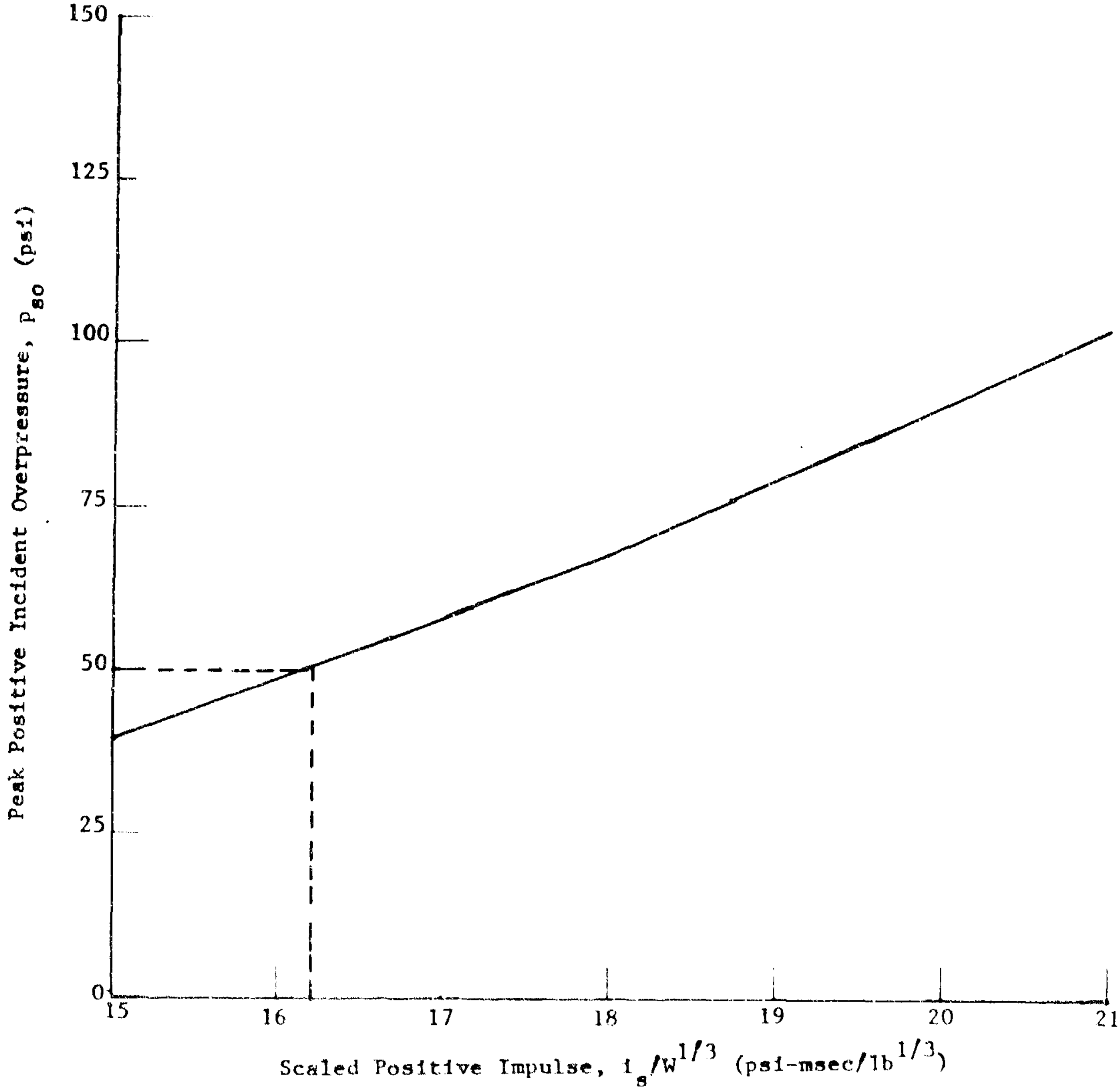


Figure 15. Peak positive incident overpressure versus scaled unit positive incident impulse for hemispherical charge (Ref 9)

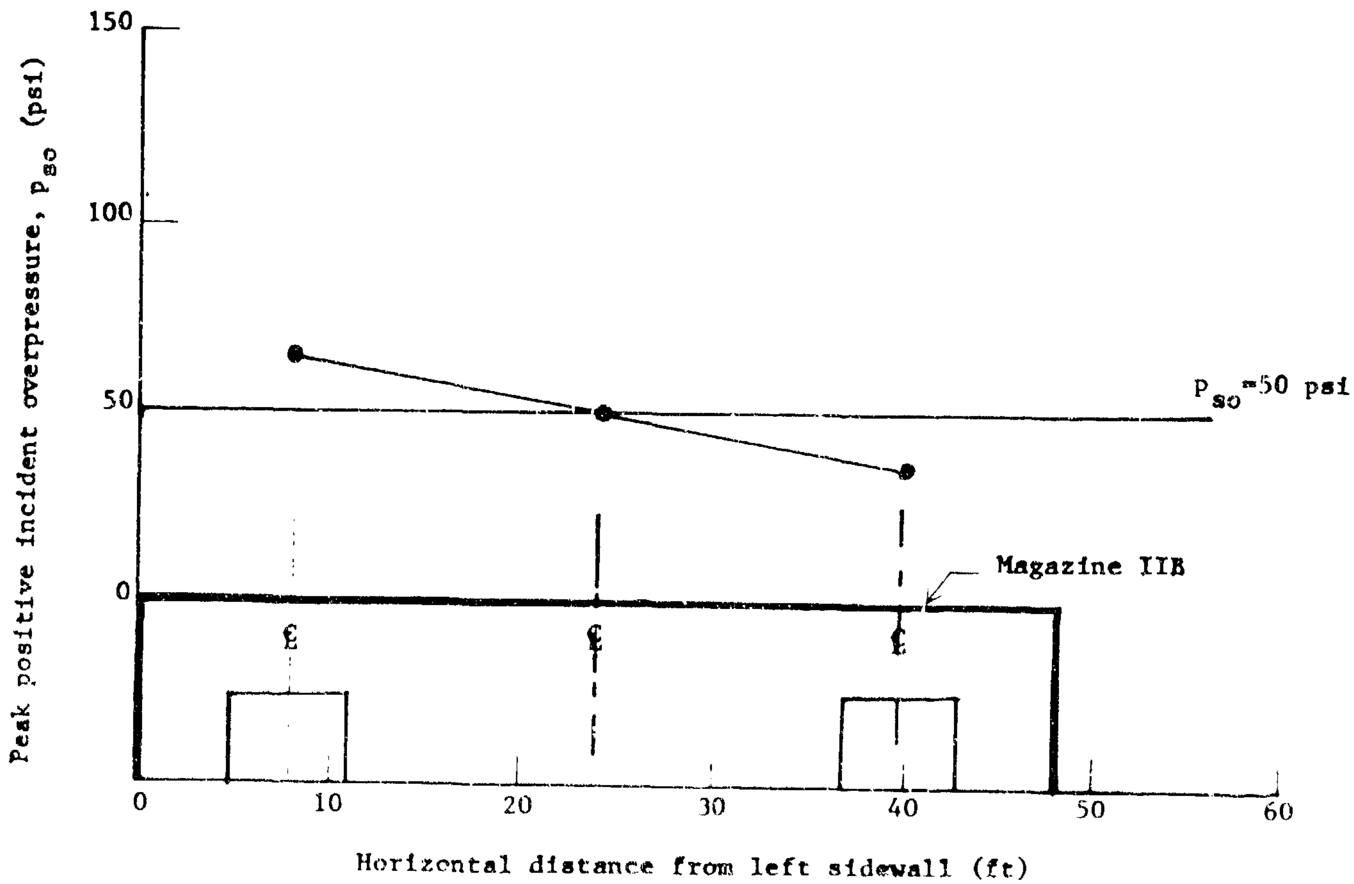


Figure 16. Peak positive overpressure acting along Type IIB magazine; W= 13,616 lb.

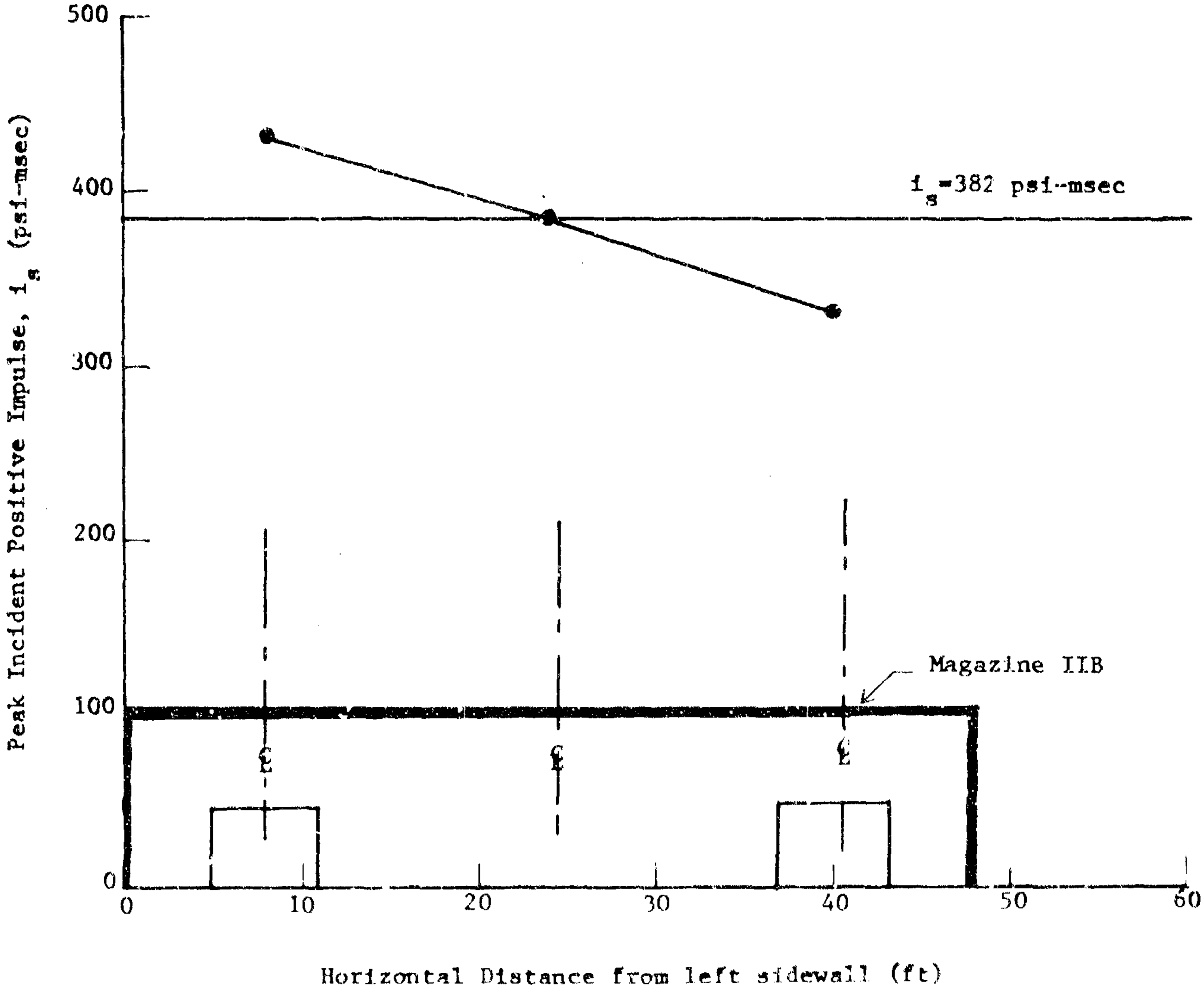


Figure 17. Impulse acting along Type IIB magazine; W= 13,616 lb.

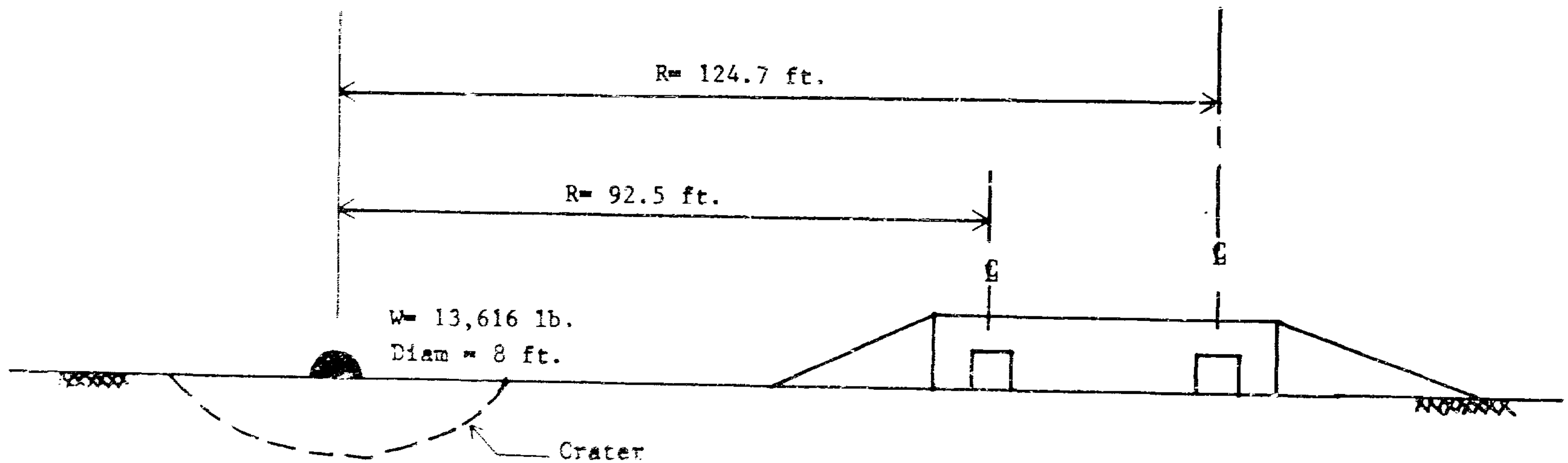


Figure 18. Test IIB-DOORS layout configuration.

Figure 19. Type IIB test structure and hemispherical surface charge.

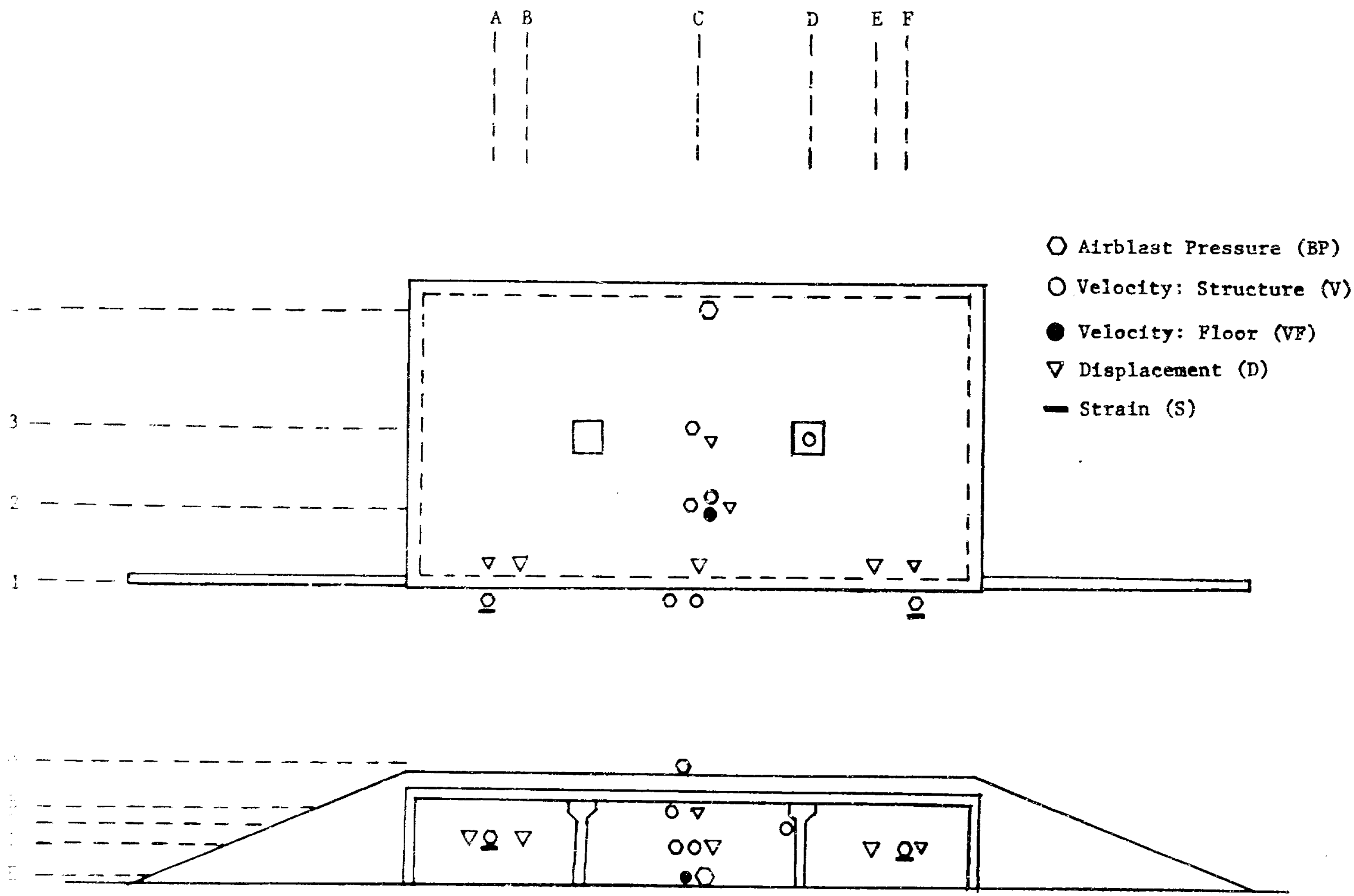


Figure 20. Type IIB magazine gauge locations for Test IIB-DOORS.

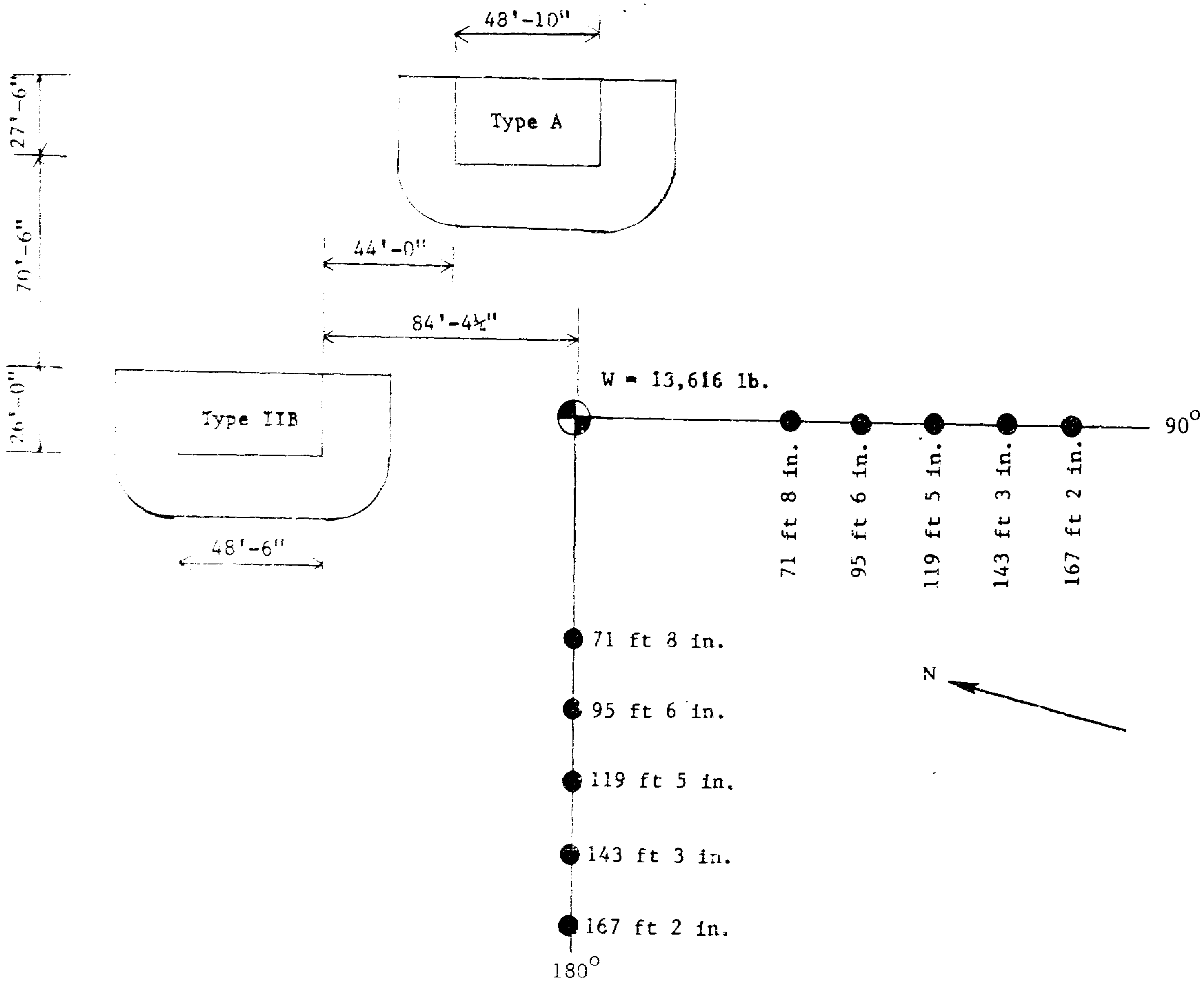


Figure 21. Free-field pressure gauge locations for Test IIB-DOORS.

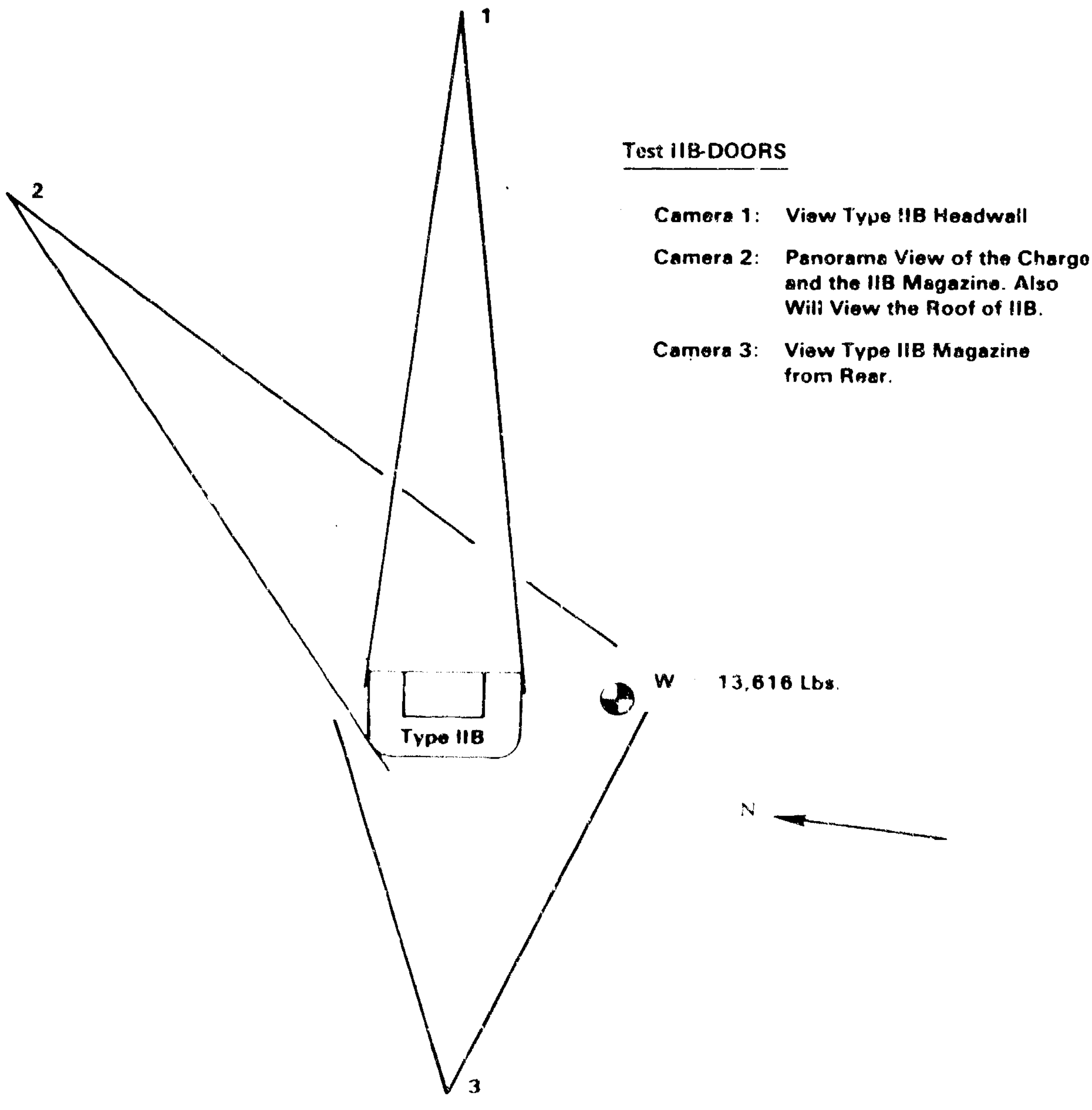


Figure 22. Test IIB-DOORS camera locations and field-of-view definition.

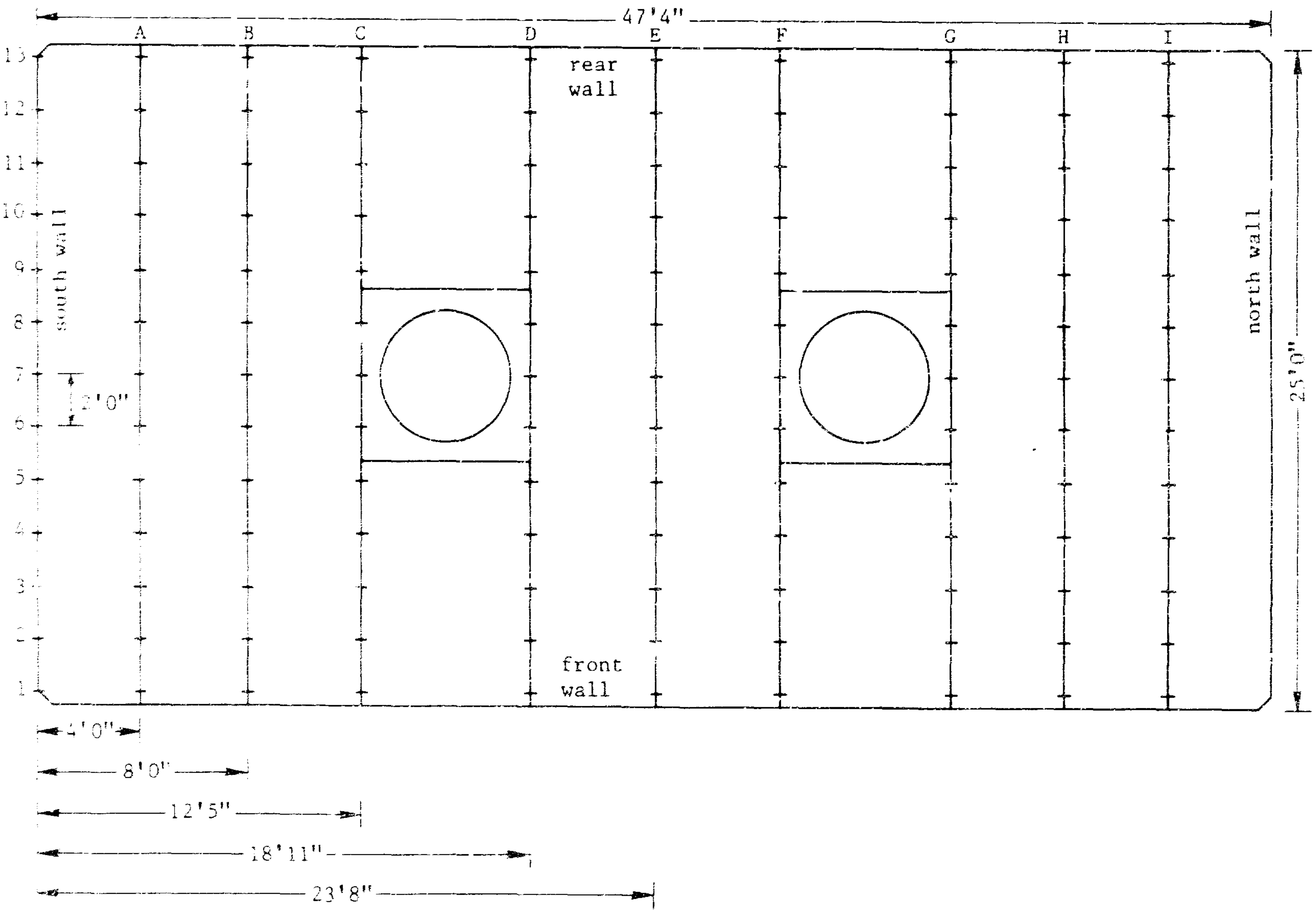


Figure 26. Deflection measurement locations and roof slab profiles for the Type A structure.

Figure 24. Post-test interior view of Type A test structure.

Figure 25. Post-test exterior view of the Type A test structure roof quadrant taken from the south wall.

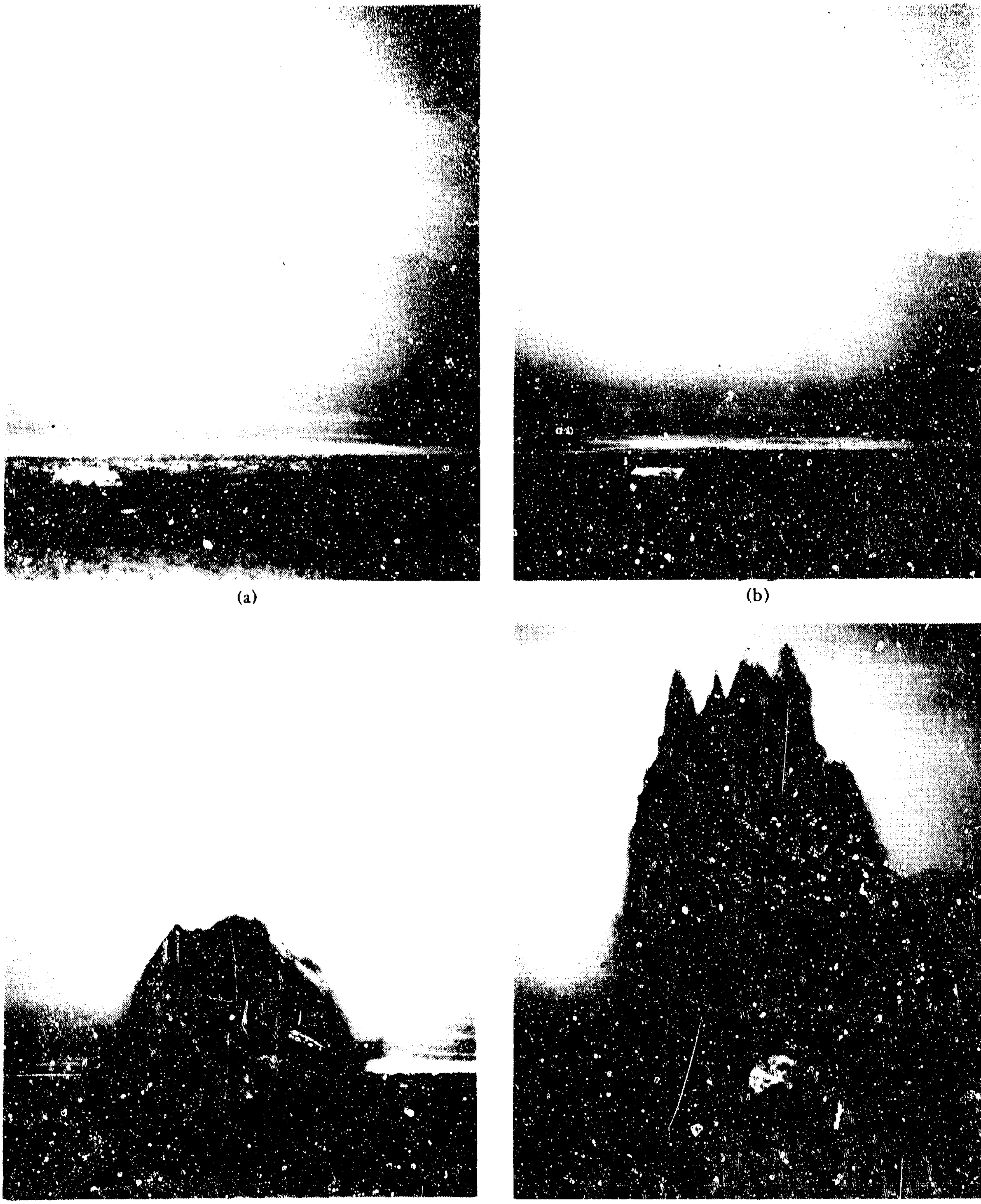


Figure 23 Test A - ROOF detonation sequence.

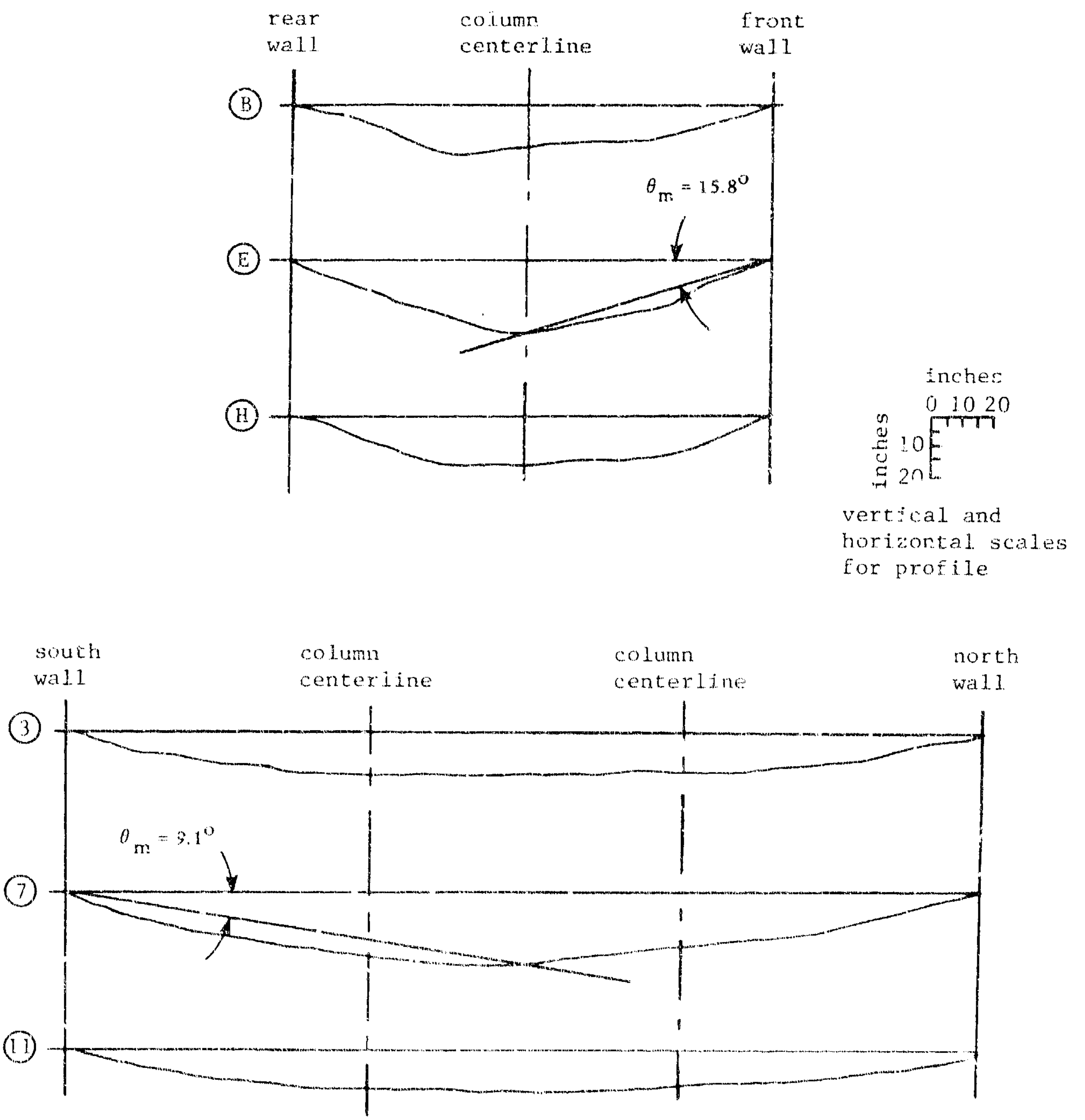


Figure 26. Continued.

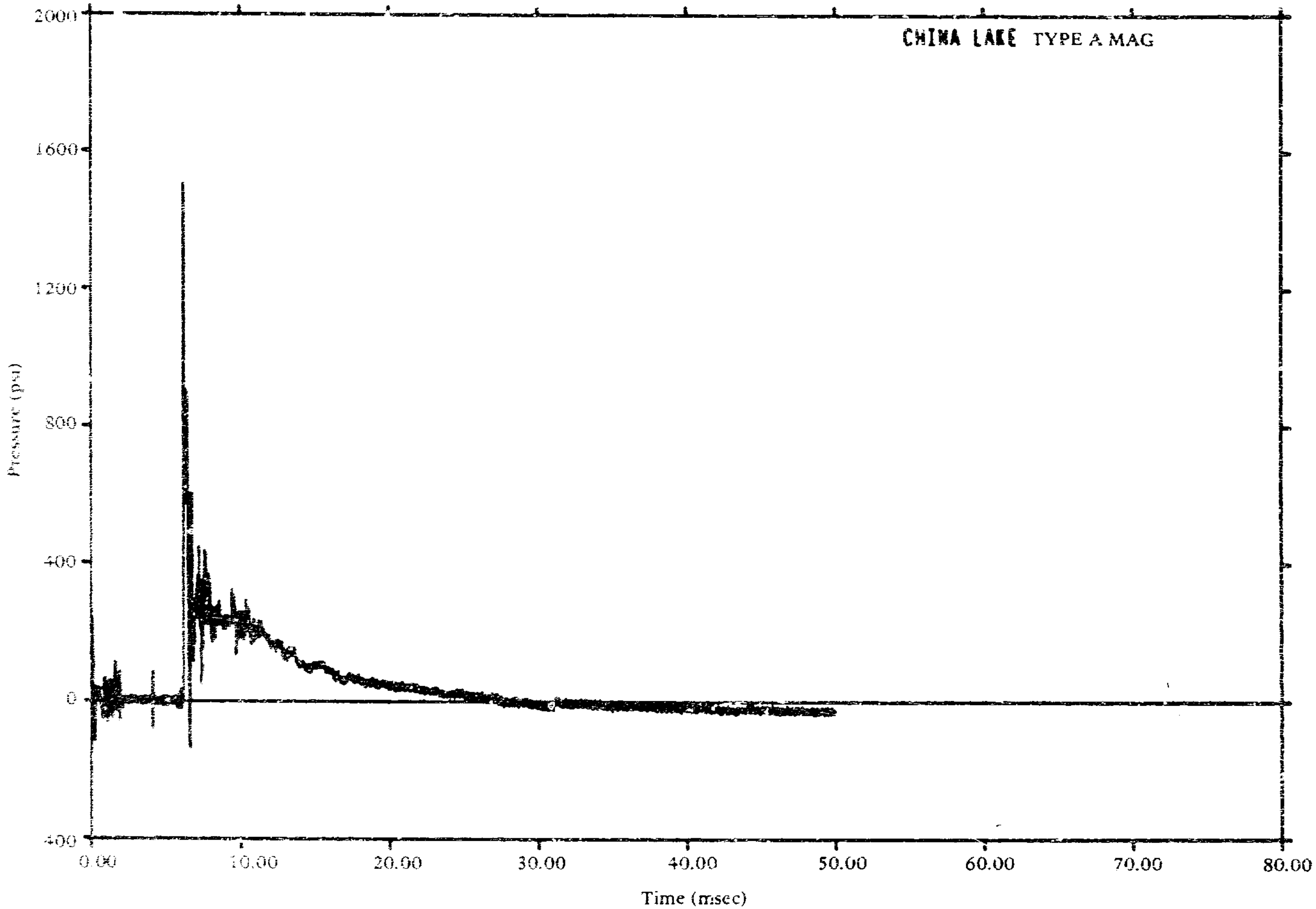


Figure 27. Typical airblast pressure gage output for Test A-ROOF, Gage No. A-D3-BP4.

Figure 28. Test IIB-DOORS fireball.

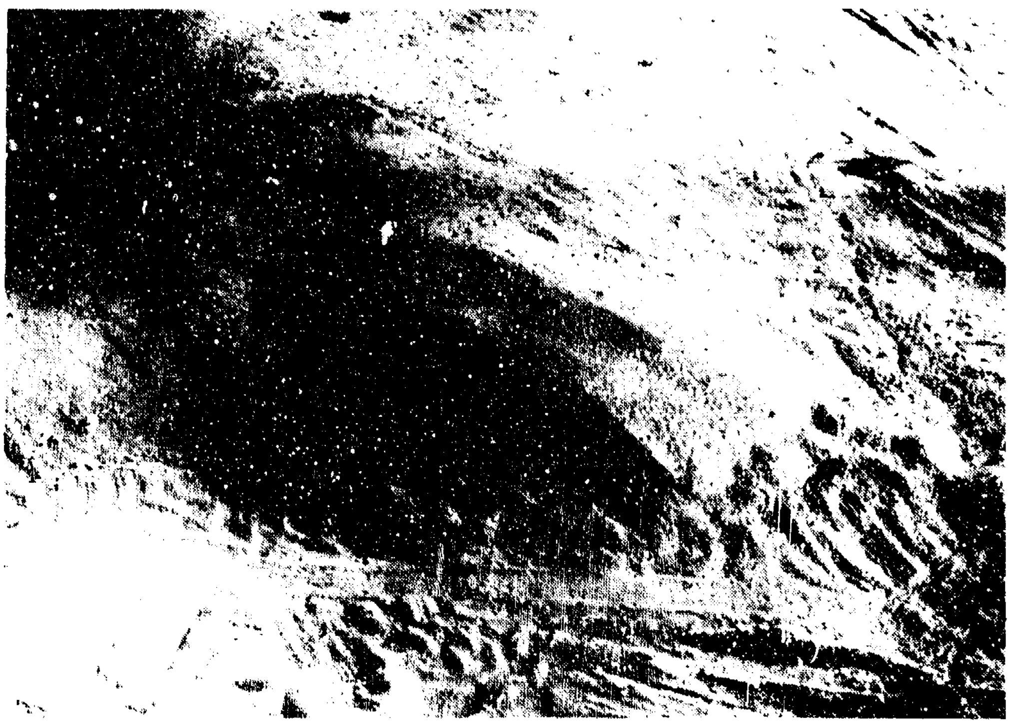


Figure 29. Post-test view of Type IIB test structure and crater.

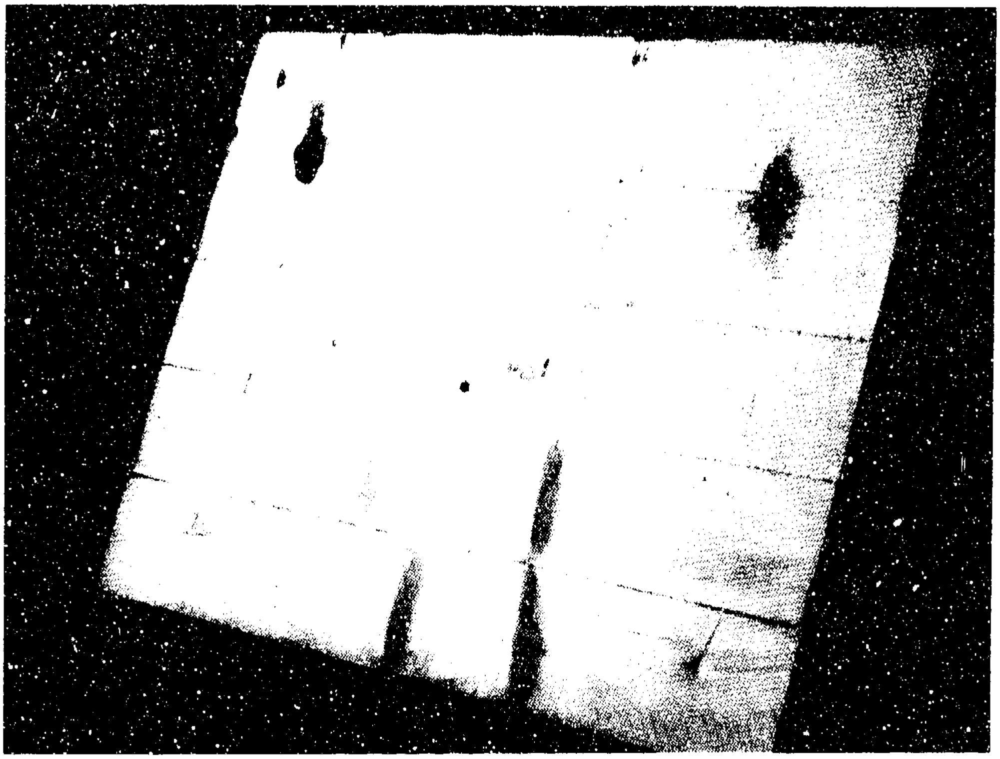


Figure 30. Post-test view of near door of Type IIB test structure.

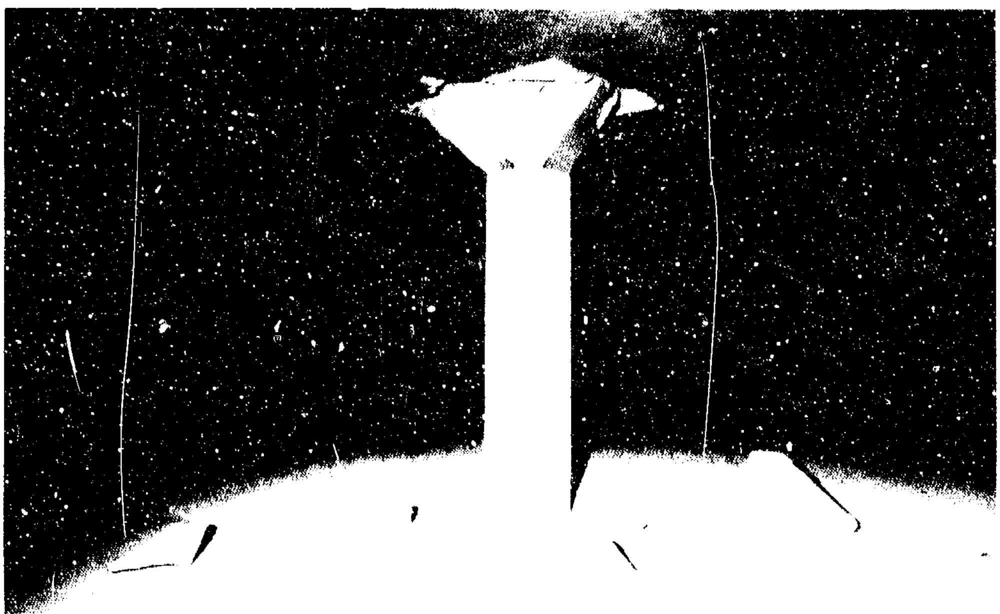


Figure 31. Post-test interior view of Type IIB test structure.

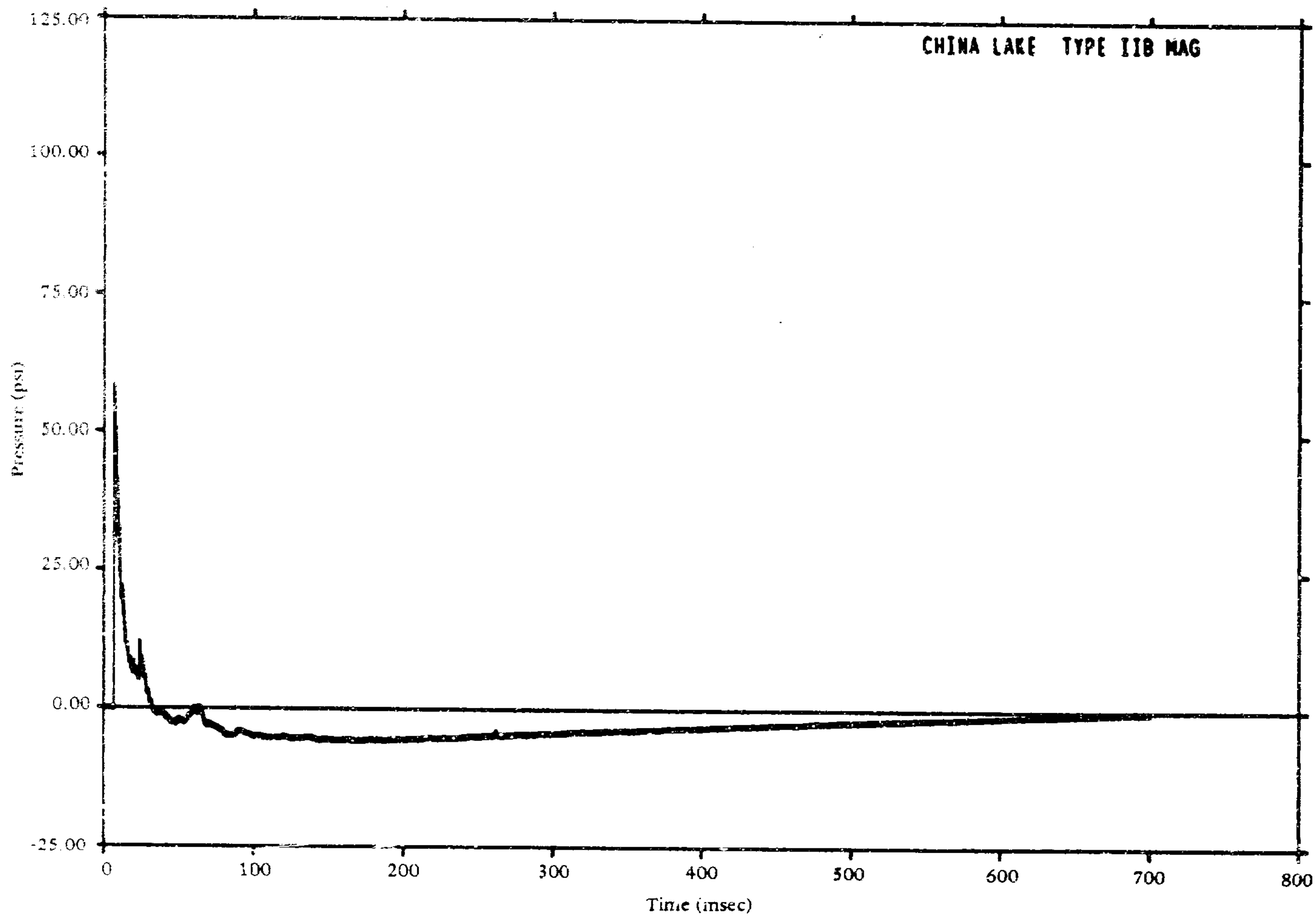


Figure 32. Typical airblast gage output for Test IIB-DOORS, Gage No. B-CID-BP4: headwall centerline.

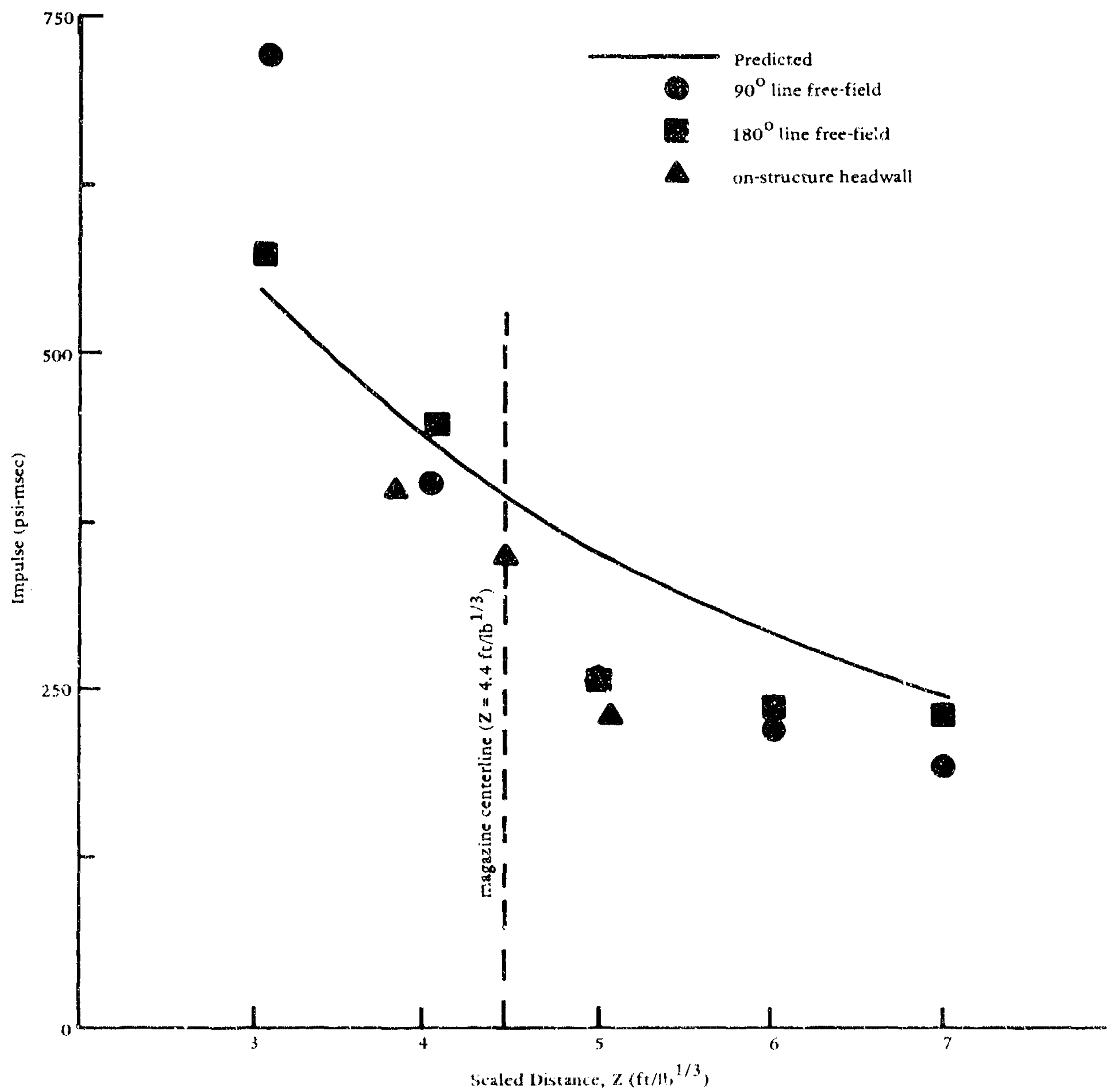


Figure 33. Measured versus predicted airblast loading for Test IIB-DOORS.

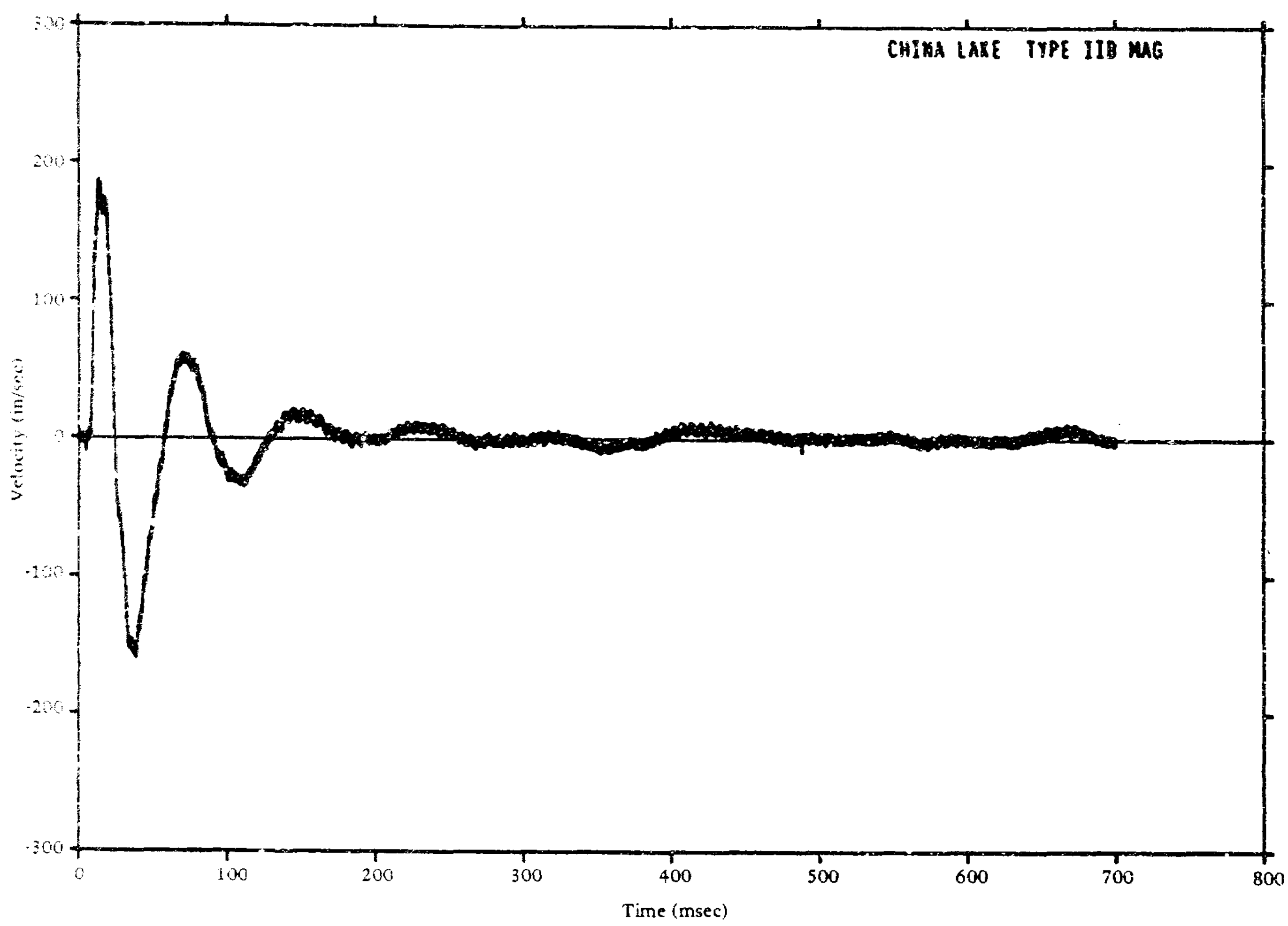


Figure 34. Typical velocity gage output for Test IIB-DOORS, Gage No. B-CID-V3: headwall centerline.

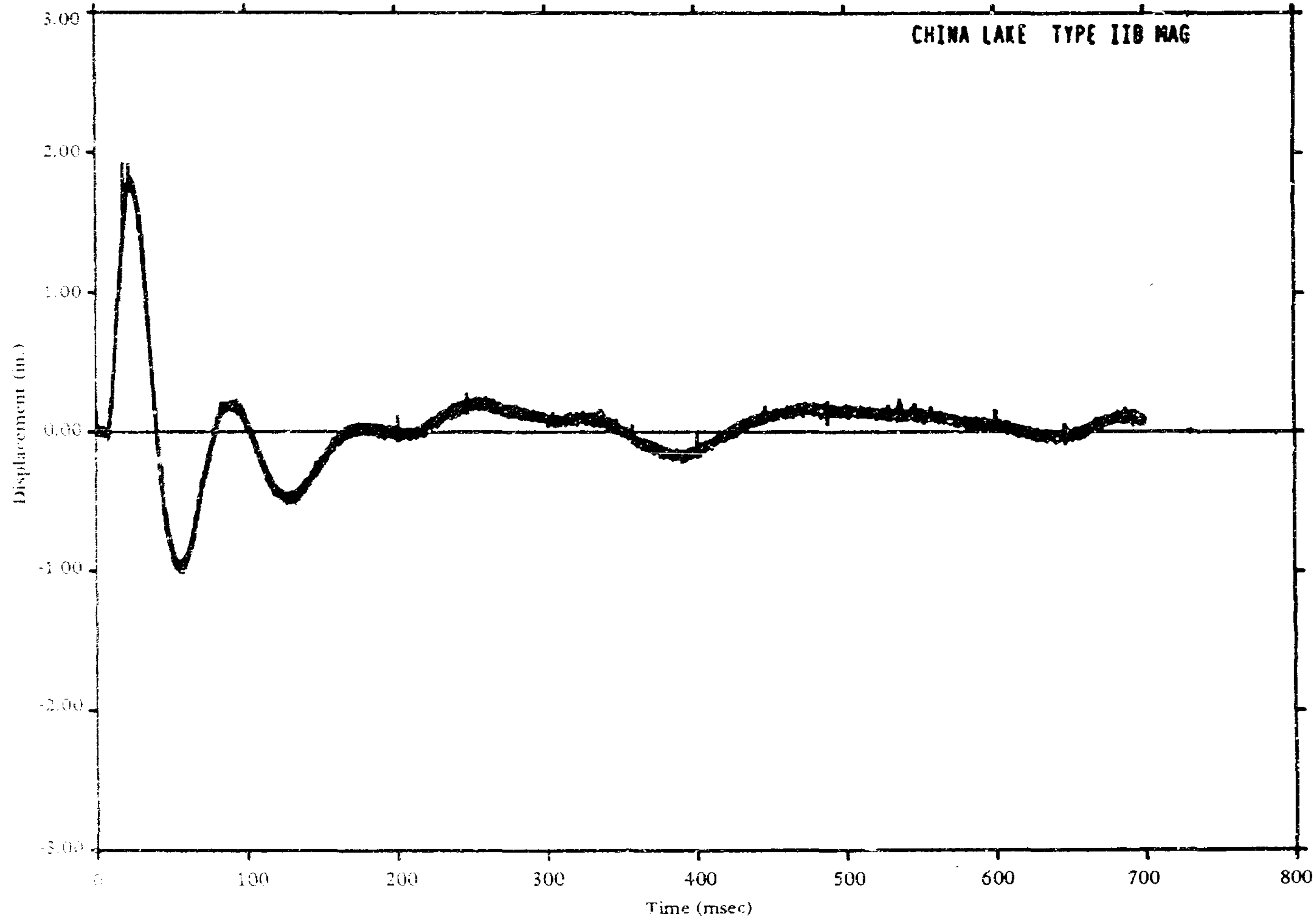


Figure 35. Typical displacement gage output for Test IIB-DOORS, Gage No. B-CID-D5: headwall centerline.

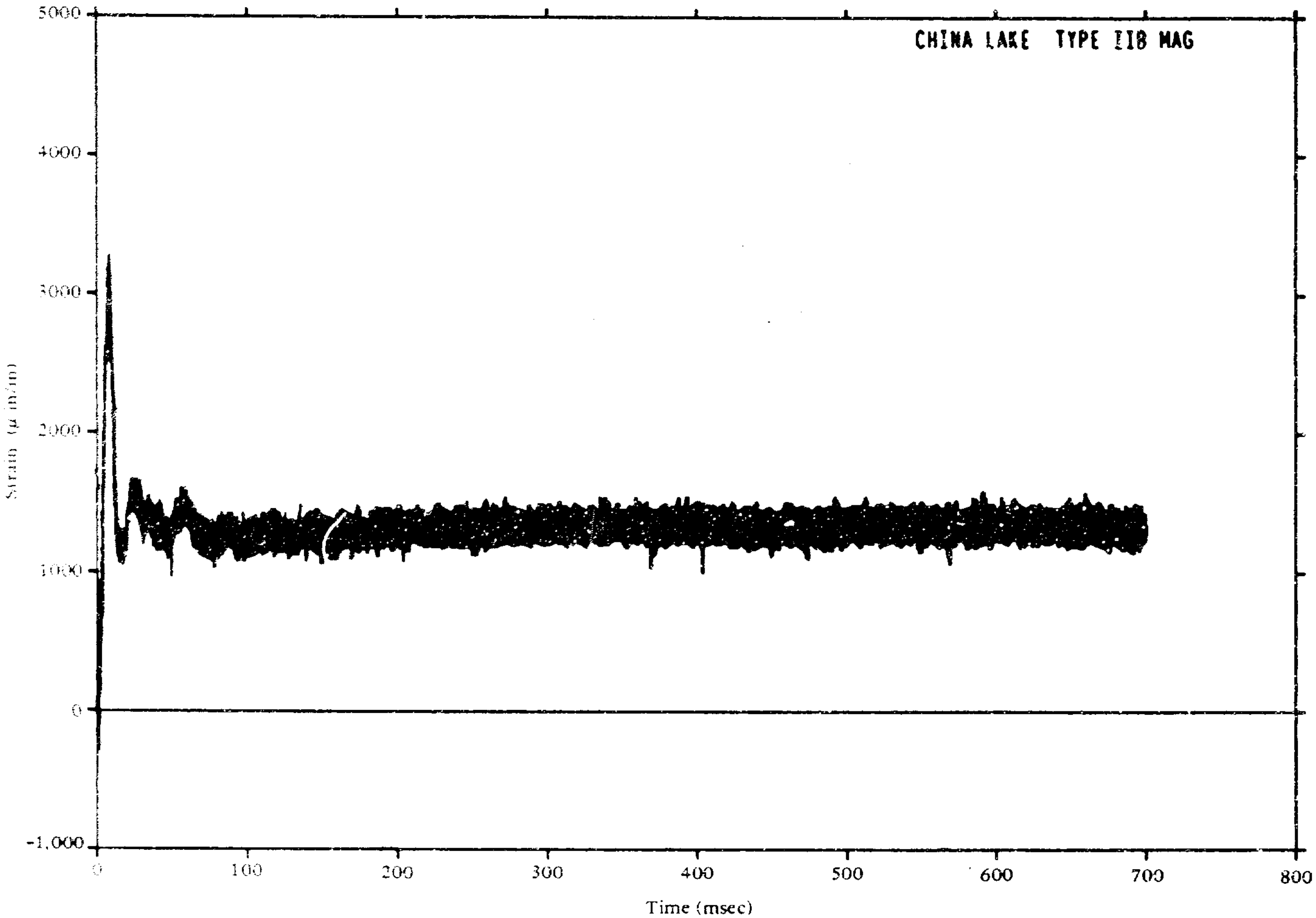


Figure 36. Typical strain gage output for Test IIB-DOORS; Gage No. B-AID-S1.

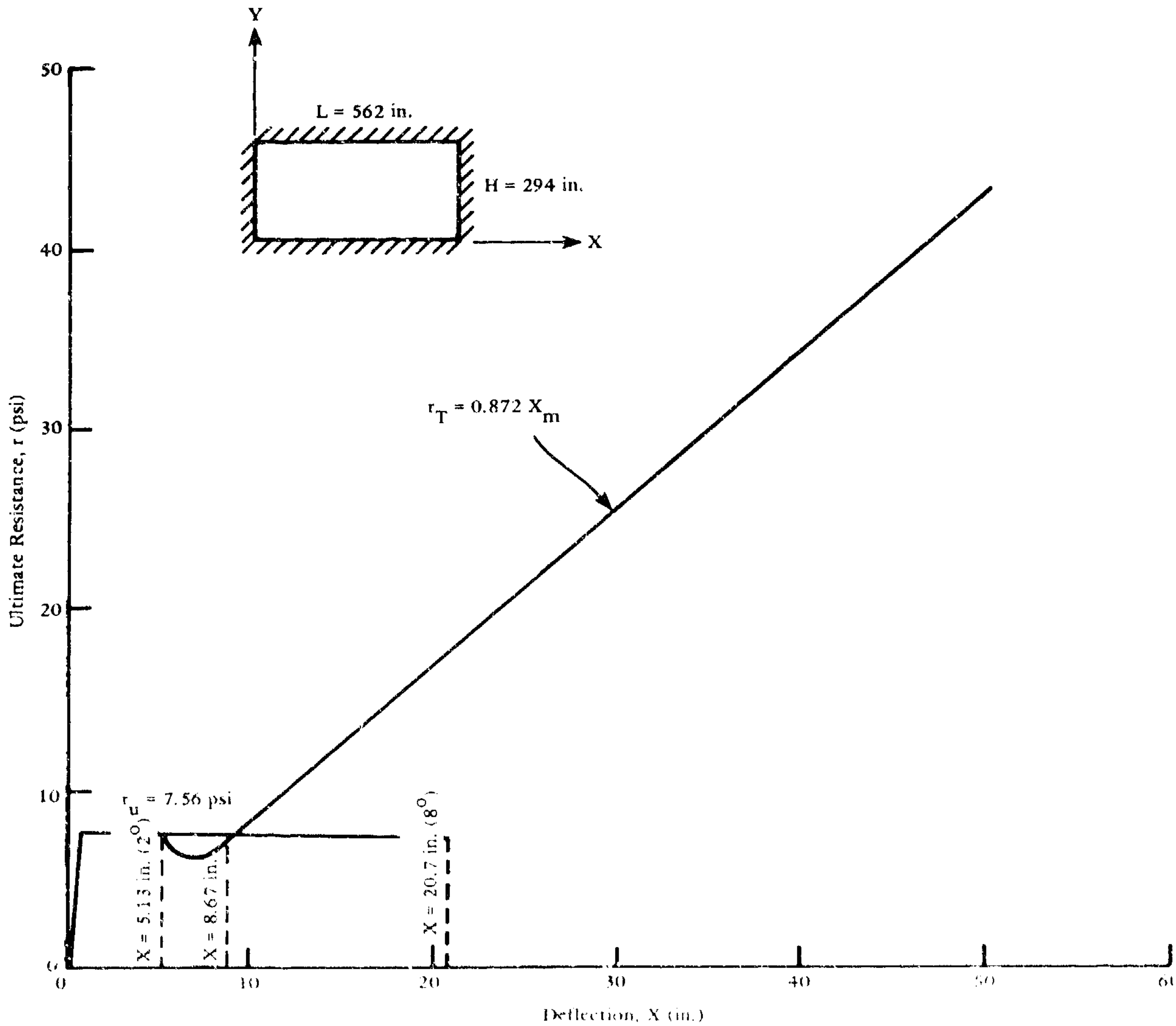


Figure 37. Available resistance deflection curve for half scale Type A magazine roof after column failure; two way restrained slab.