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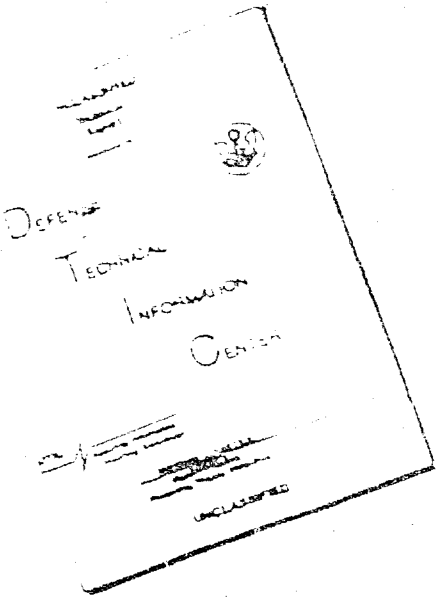
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OPERATION BUSTER

PROJECT 9.1 a

F.C.D.A. FAMILY SHELTER EVALUATION

by

ARCHIE P. FLYNN

MARCH 1952

FEDERAL CIVIL DEFENSE ADMINISTRATION

Washington 25, D. C.

PREFACE

This report covers tests conducted as Project 9.1 a BUSTER to determine the effects of atomic explosions on small shelters. It details organization and conduct of the tests, factors influencing results, and evaluates the degree of protection afforded by simple shelter structures.

The shelters selected for the tests were similar in design to those recommended by the Lehigh University Institute of Research for use by the Federal Civil Defense Administration. However, the test structures were varied in building detail and, as a consequence, factors of strength were considerably altered. Protective values were not intended to conform with those of basic designs considered for general use by the public.

The writer gratefully acknowledges the assistance of personnel of the Atomic Energy Commission and the Armed Forces Special Weapons Project. Many members of the Federal Civil Defense Administration helped with the project: Dr. H. Kenneth Gayer, Admiral Garret L. Schuyler, Mr. Ellery Husted, and Mr. A. S. Neiman in arranging and planning the test; Mr. Benjamin Taylor in field operations, and other members of the staff in the preparation of the report.

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ABSTRACT

Project 9.1 a BUSTER was designed to determine the effects of atomic explosions on small civil defense shelters for family use. Since limited participation in the program did not permit tests of all proposed shelter designs, data developed by Lehigh University Institute of Research served as a guide in selecting four types of shelters. They were: (1) covered-trench, (2) metal-arch, (3) wood-arch, and (4) basement lean-to.

Twenty-nine simple structures were built along an arc 1200 ft. from the target point. Construction was varied without regard to protective values and only to obtain technical data for design purposes. These structures were subjected to Shots Baker, Charlie, and Dog.

Soil at the test site, when moved, lacked cohesive properties and, consequently, much of the earth cover on the shelters was removed by the first shot. Since a change in test operations prevented the planned restoration of structures and replacement of cover after each blast, this reaction materially influenced test results. Effects of the first explosion added considerably to the damage normally resulting from the succeeding shots and cumulative damage was all that could be appraised. This limited the use of test data from the second and third explosions.

Test structures were severely damaged by the three explosions, but considerable useful data was obtained. Below-grade covered-trench shelters provided protection against Shot Baker, and withstood the three explosions. Partly above-grade covered-trench shelters provided less protection against blast and gamma radiation tests indicated that they should be used only if below-grade construction is possible. The metal-arch shelter failed before sufficient data could be obtained, but metal-arch shelters set in concrete footing reacted well. The tests indicated that this type of shelter can, with minor modifications in design, provide good protection. Wood-arch shelters survived the first explosion, but collapsed in the second. The wood-arch, as designed, proved unsuitable as a substitute for the metal arch. Because of the inadequacy of the test structures, no information was obtained on the reaction of basement lean-to shelters.

Unusual conditions disclosed a number of weak points in the structures tested which contributed to their failure. Deficiencies were noted in entrance construction, front and end sections, and effective earth cover. These defects can be corrected by changes in design. Damage to the structures was so severe that conclusive data on many items were not obtained. However, knowledge of the reaction of shelters gained under test conditions should be helpful in planning additional tests with improved methods of instrumentation.

The tests showed that smal shelters are potentially capable of providing a degree of protection commensurate with the requirements of civil defense. The information developed should be useful in modifying present designs to provide safer shelters.

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The Federal Civil Defense Administration family shelter evaluation under Project 9.1 a BUSTER was designed to develop information on the degree of protection from atomic explosions afforded by simple structures which could be built by the average householder with available materials. Specifically, information was desired on the degree of protection provided by shelter designs proposed for use by FCDA. Since all shelter designs could not be tested, the following data applicable to all types were desired:

(a) Resistance of small shelters to blast pressures.

1. Degree of protection afforded by basic designs.
2. Reaction of structures above and below-natural grade.
3. Stability of entrance structures.
4. Effects on framing materials of reduced sizes.
5. Reaction of construction materials.

(b) Reaction of earth cover.

1. Earth-arch effect on structural strength.
2. Resistance of mass of overburden to transient loads.
3. Effects of blast on reducing earth cover.
4. Requirements for protection from radiation.

(c) Effects of orientation of structures with respect to ground zero.

1. Resistance of structures.
2. Protection against radiation.

(d) Requirements for sheathing sidewalls.

1. Reaction of concrete-block sidewalls.
2. Substitution of chicken wire and tarpaper for wood sheathing.
3. Method of fastening sheathing.

(e) Reaction of lean-to shelters fastened to basement walls.

1.2 HISTORICAL

In November, 1950, the Corps of Engineers, acting for FCDA negotiated a contract with Lehigh University Institute of Research for preparation of a series of manuals on shelter protection. With the assistance of FCDA and a panel of technical consultants, Lehigh University Institute of Research developed design and construction data on a number of family shelters. Before officially approving this data, FCDA desired to determine reactions of the proposed structures to the effects of an atomic explosion.

Provision was made for a limited test of these small structures under Project 9.1 a BUSTER. Since limited participation and fixed test conditions did not permit inclusion of all proposed shelter designs, the data developed by the Lehigh University Institute of Research served as a guide for selecting a number of simple structures which had not previously been tested. These structures included four basic types: (a) covered-trench, (b) metal-arch, (c) wood-arch and, (d) basement lean-to shelters.

With the exception of the wood-arch, these designs were typical of those under consideration for recommendation to the public. In addition several reduced-strength structures were used, not to provide any degree of protection but, to develop technical data for design purposes.

1.3 THEORETICAL PREPARATION

T. family shelters were not intended to provide absolute protection against atomic explosions. The Lehigh University Institute of Research criteria for a nominal bomb exploded at optimum height is as follows:

(a) Metal-arch shelters

1. Structural resistance at ground zero (maximum peak overpressure of 52 pounds per square inch).

2. Radiation dosage
   a. 100 r at 2100 ft. from ground zero.
   b. 200 r at ground zero.

(b) Covered-trench shelters

1. Structural resistance at about one-half mile from ground zero.

2. Radiation dosage
   a. 100 r at 2100 ft. from ground zero.
   b. 200 r at ground zero.

These designs were based on information contained in The Effects of Atomic Weapons and one or more of the following assumptions:

(a) Structural resistance of small shelters must be provided by the structure and will be only slightly affected by the mass or ductility of the shelter.

(b) Effects of pressure relief, due to the blast filling the structure will be omitted in calculating resistance of the shelters.

(c) All structural resistance of the covered-trench shelters must be provided by the action of the roof joists. Effect of interaction between the joists and roofing, as well as earth-arch action, was omitted to compensate for the possibility of poor workmanship.

(d) Structural resistance of the metal-arch shelter will be provided largely by the earth arch formed over the steel shell. The steel shell must be capable of providing sufficient support to confine the earth during construction. For earth-arch action to occur, each type of soil must satisfy certain minimum criteria. Granular soil, forming a 3 ft. earth arch (on a 4' 6" diameter steel shell) must meet either of the following requirements:

1. Minimum cohesive strength - 7 pounds per square inch. Minimum internal friction angle - 30 degrees.

2. No cohesive strength. Minimum internal friction angle - 35 to 40 degrees.

Test structures were selected to provide further information on these assumptions, as well as other factors influencing the reactions of small shelters to the effects of atomic explosions. The structures were to be subjected to atomic explosions of varying intensities covering a range of pressures extending considerably beyond design values. All were to be located equidistant from the ground zero of three successive bombs of increasing size. After each shot it was planned to readjust earth cover and partially rehabilitate the structures to reduce the build-up of effects from successive explosions.

CHAPTER 2

PROCEDURES

2.1 CONSTRUCTION

A total of 29 simple structures spaced 25 ft. apart were built along an arc 1200 ft. from the target point. The first structure was located 30 ft. south of a line due east of the target point. These are shown in U. S. Atomic Energy Commission, Santa Fe Operations Office drawings N.T.S. 9.1-1198, dated September 22, 1951.

Eighteen of the structures were the covered-trench; five, metal-arch; four, wood-arch; and two, basement lean-to type. Structural strength, materials, amount of earth cover, elevation and orientation were varied for test purposes. These variations are summarized in Table 2.1, and details of design of the various structures are contained in drawings N.T.S. 9.1-1198; N.T.S. 9.1-1199; N.T.S. 9.1-1200; N.T.S. 9.1-1201; and N.T.S. 9.1-1202.

2.1.1 Covered-trench Shelters

Structures for the covered-trench shelters (type-A) were prefabricated by the contractor in a field shop. (Fig. 2.1). These structures were small enough to be moved by truck and lowered into position by an A-frame. (Fig. 2.2). The covered-trench or type-A shelters were placed both below and partly above the natural grade. (Figs. 2.3 and 2.4).

Figures 2.5 and 2.6 show identical structures, one covered with 3 ft. of earth and the other with 2 ft. A bulldozer was used to place earth cover and no special provisions were made to compact backfill. To obtain sufficient cover for some of the above-grade structures, the area surrounding structures A-15, A-17, and A-18 was cut slightly below grade. In backfilling operations the bulldozer cracked a stud in the entrance structure of A-15, and the center 2 x 4 roof joist in A-6.

Considerable difficulty was experienced in protecting the entrance construction with earth cover, since the soil lacked cohesive properties after being moved. This was not as serious in below-grade structures as in those built partly-above grade (Figs. 2.6 and 2.7).

2.2 INSTRUMENTATION

Since this project was a late addition to the test program, facilities were not available for complete instrumentation of the test structures. Therefore, it was necessary to improvise some of the methods of instrumentation. The following provisions were made to obtain data:

(a) Radiation Measurements - Gamma Film Badges.

1. Range 50 r to 300 r - Dupont Adlux No. S2 film badges located in entrance and within shelter areas.

2. Range 1/10 r to 300 r - No. 606 badges located within shelter areas.

3. Range 50,000 r - No. 548 badges attached to structures located at ends and center of 1200 arc.

4. Range - Dupont 554 and 556 film badges, shielded in National Bureau of Standards (lead, tin, bakelite) film holder and calibrated against Co^{60}, used for reference purposes by Project 6.1 b BUSTER, placed in high, medium, and low positions in some structures.

(b) Deflection Measurements - Improvised Deflection Devices.

1. Rough devices similar to wooden jacks built on site of 2 x 4 scrap lumber, placed at ends and center of roof joists and at center of studs and arches.

(c) Pressures Inside Shelters - Land Mine Fuses.

1. A limited number of land mine fuses, tested by the Corps of Engineers (Project 3.5) placed in a few structures.

The location at which these readings were taken within the shelters are shown in Fig. 2.18. Figure 2.19 shows the details of the devices to measure deflection of structural members.

2.3 SITE CONDITIONS

Yucca Flat is an alluvium-filled valley. The alluvium varies in character from clay and silt-sized particles, to cobbles and boulders. The composition of this material is chiefly limestone and volcanic tuff with smaller amounts of other volcanics, quartzite, conglomerate and sandstone. The alluvium is poorly consolidated except where the particles are cemented by caliche or where beds of caliche exist. Density of the alluvium varies from 1.3 to 1.8 kilograms per liter. There were no determinations made of the cohesive properties of the soil either before or after it was disturbed.

After being disturbed, the soil had practically no cohesive properties. The low cohesive value of the material used in backfilling made it difficult to compact the earth cover on the structures. It was also impossible to protect above-grade entrance construction because of the tendency of the material to flow freely. Intermittant showers two days before the first explosion contributed little to the stability of the earth cover. Since no special provisions were taken to compact backfill, the structures were subjected to unusually severe test conditions.

The function of the earth cover on the structure is of particular importance. However, it was impossible to completely evaluate this function since an unavoidable change in the test schedule did not permit carrying out plans to replace the earth cover and partially restore the shelters after each blast. Considerable earth cover was removed by each explosion and the effects of the first explosion contributed greatly to the damage resulting from succeeding explosions. This limited the use of test data from the second and third explosions in evaluating the protection afforded by test structures.

2.1.2 Metal-arch Shelters

Only one complete metal-arch shelter was included in the test. This shelter was built in accordance with plans prepared by the Lehigh University Institute of Research. (Figs. 2.8 and 2.9).

One of the studs in the entrance section of shelter B-1 was cracked in backfilling and additional spreaders were placed as shown. (Fig. 2.10).

Twelve and 16 gauge corrugated-metal sections were also set in concrete footings to determine the reaction of metal-arch sections under 2 and 3 ft. of cover. (Figs. 2.11 and 2.12).

2.1.3 Wood-arch Shelters

With a view to the possibility of conserving critical materials 4 wood-arch shelters were also built. (Figs. 2.13 and 2.14).

2.1.4 Basement Lean-to Shelter

Two structures simulating conditions for use of basement lean-to shelter were built to determine whether the top of the lean-to should be attached to the wall. (Figs. 2.15, 2.16 and 2.17).

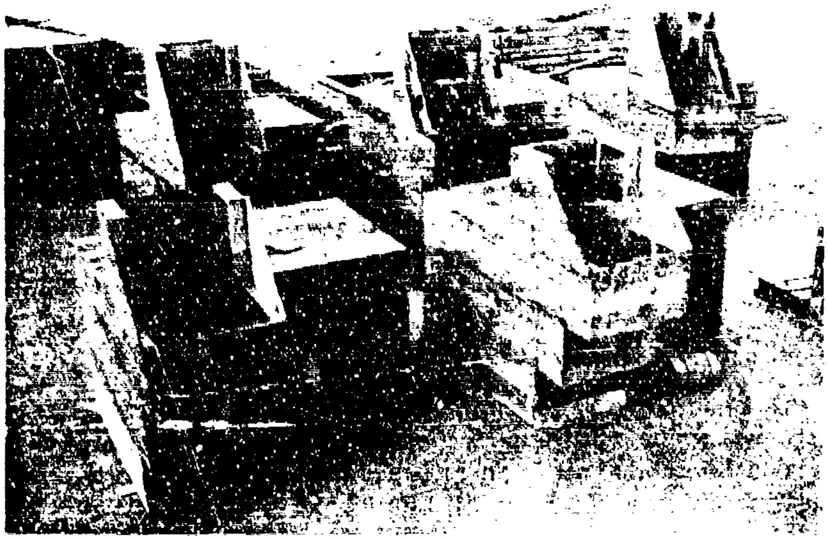


Fig. 2.1 Prefabricated Structures for Covered-trench Shelters (carpentry yard)

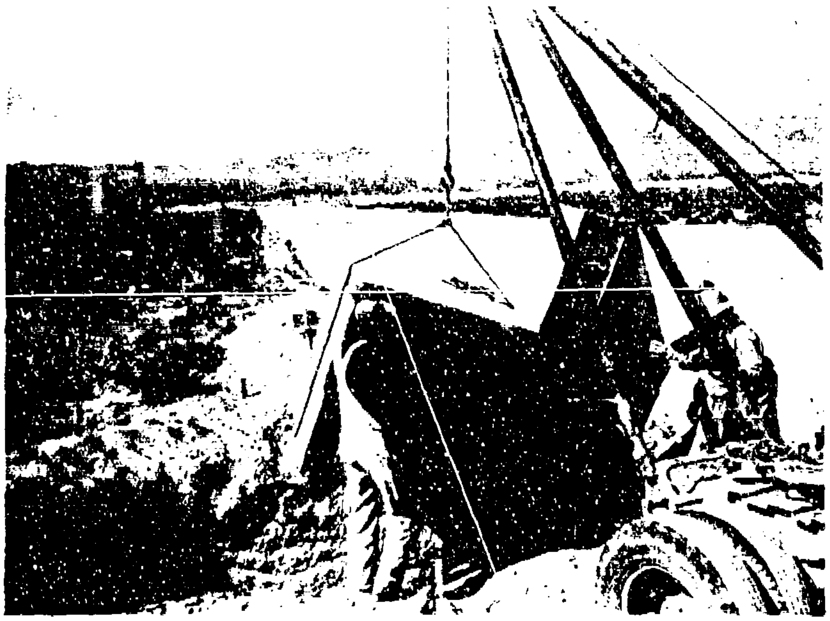


Fig. 2.2 Placing Structure in Position for Shelter A-1

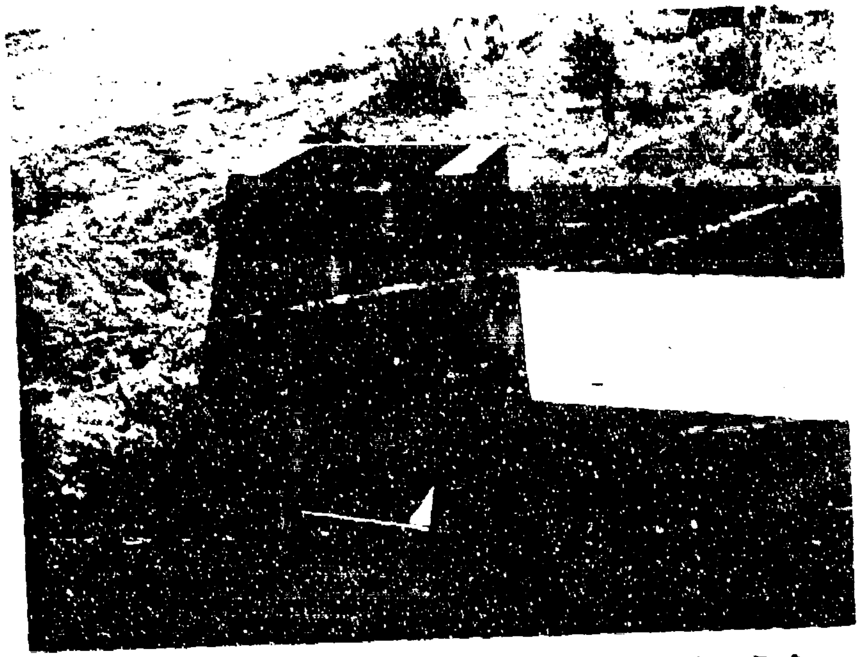


Fig. 2.3 Shelter Structure A-13 in Position Before Backfilling (below grade)

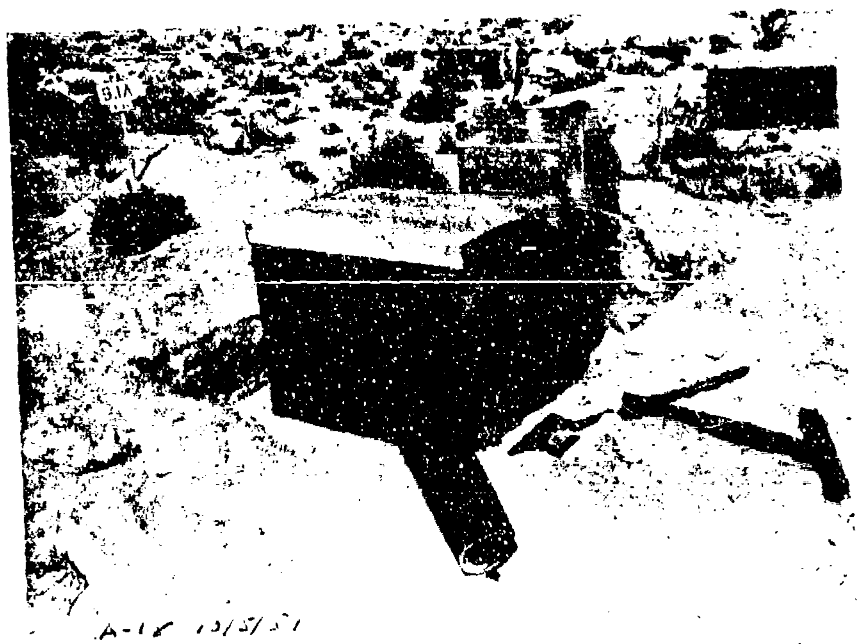


Fig. 2.4 Shelter Structure A-18 in Position Before Backfilling (partly above grade)

Fig. 2.5 Shelter A-1 Completed with 3 Ft. of Earth Cover (below grade)

Fig. 2.6 Shelter A-2 Completed with 2 Ft. of Earth Cover (below grade)

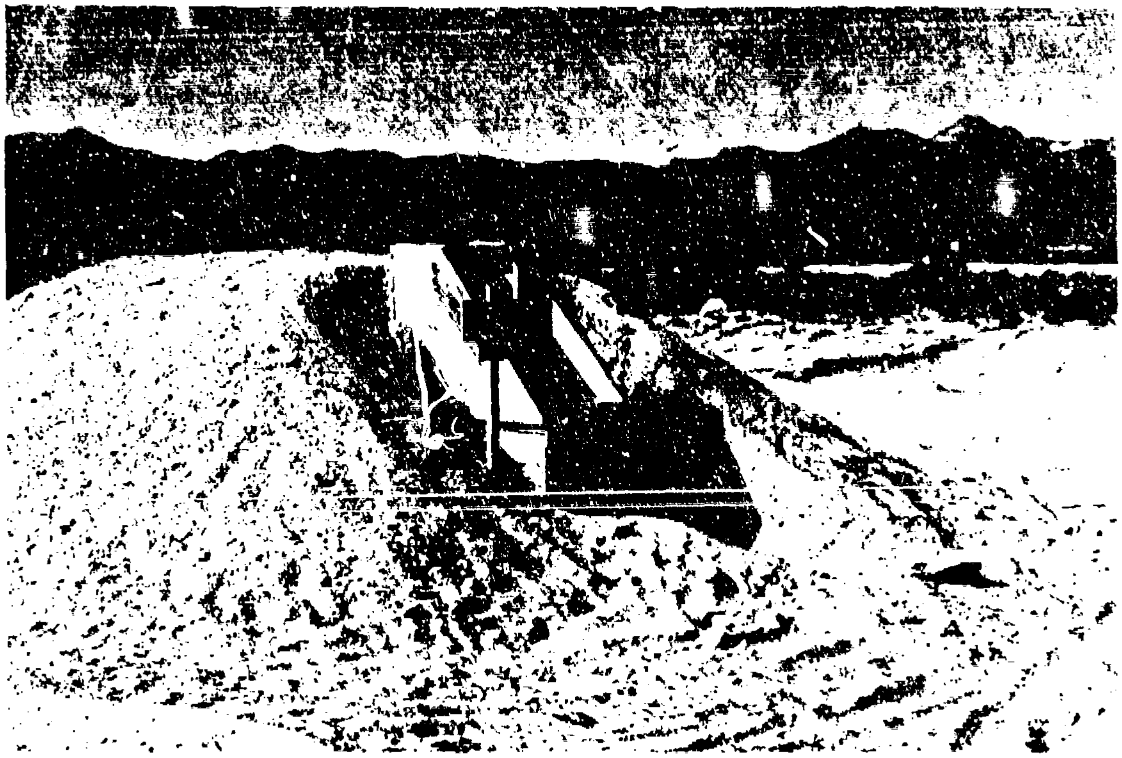


Fig. 2.7 Shelter A-17 Completed (partly above grade)

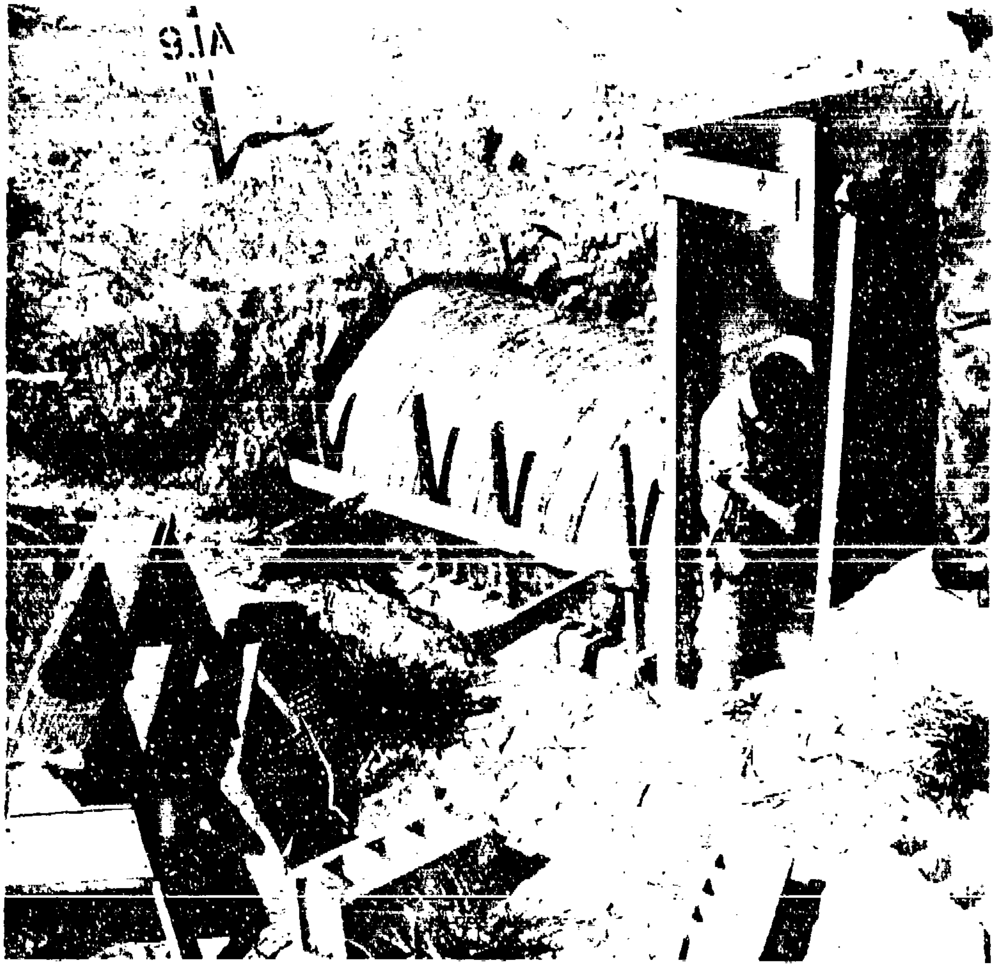


Fig. 2.8 Metal-arch Shelter B-1 Under Construction

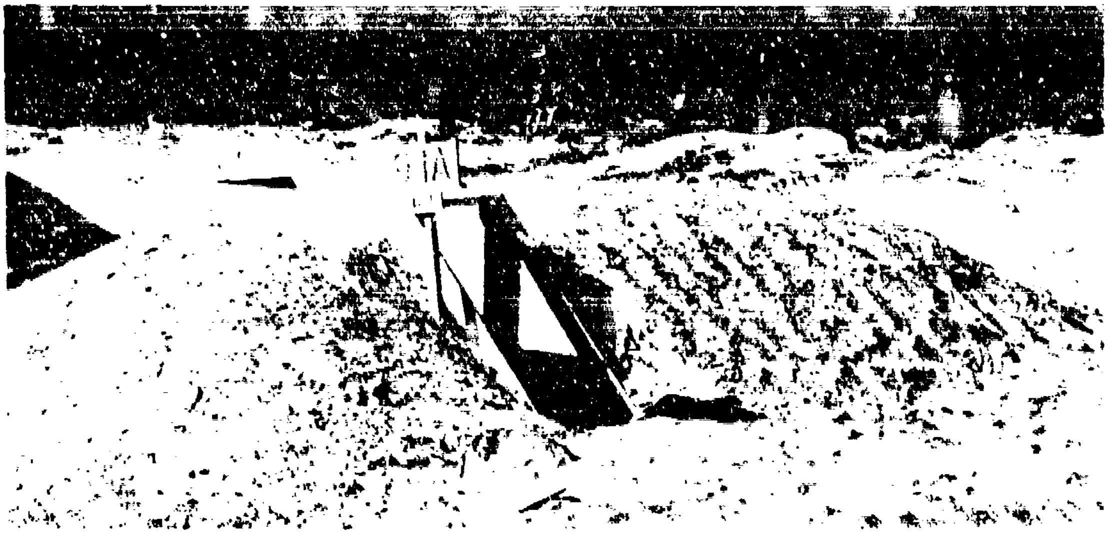


Fig. 2.9 Shelter B-1 Completed

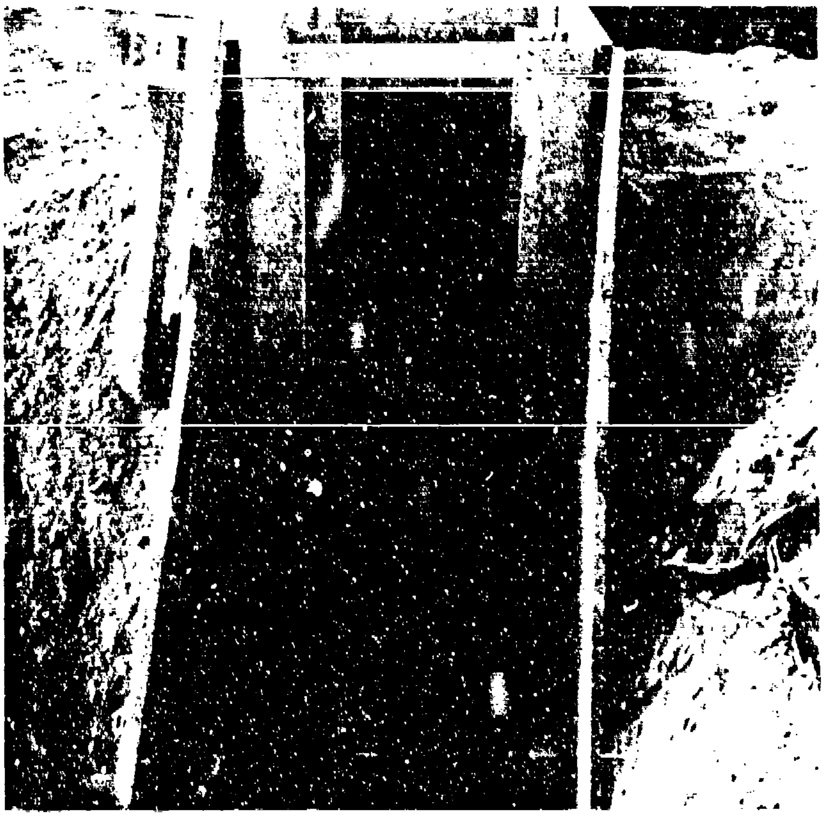


Fig. 2.10 Entrance Details of Shelter B-1

Fig. 2.11 Metal-arch Structure B-5 Set in Concrete Footing

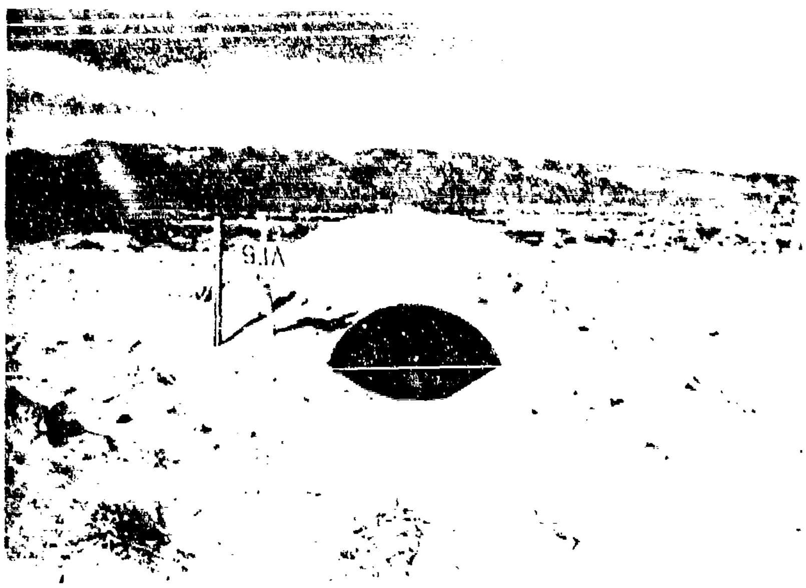


Fig. 2.12 Completed Structure B-3 with 2 Ft. of Earth Cover

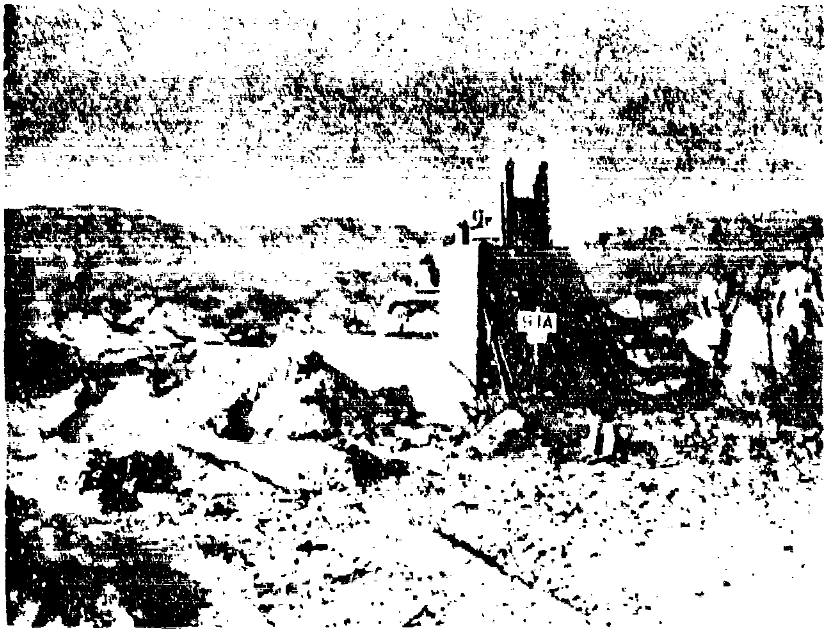


Fig. 2.13 Wood-arch Shelter C-4 (under construction)

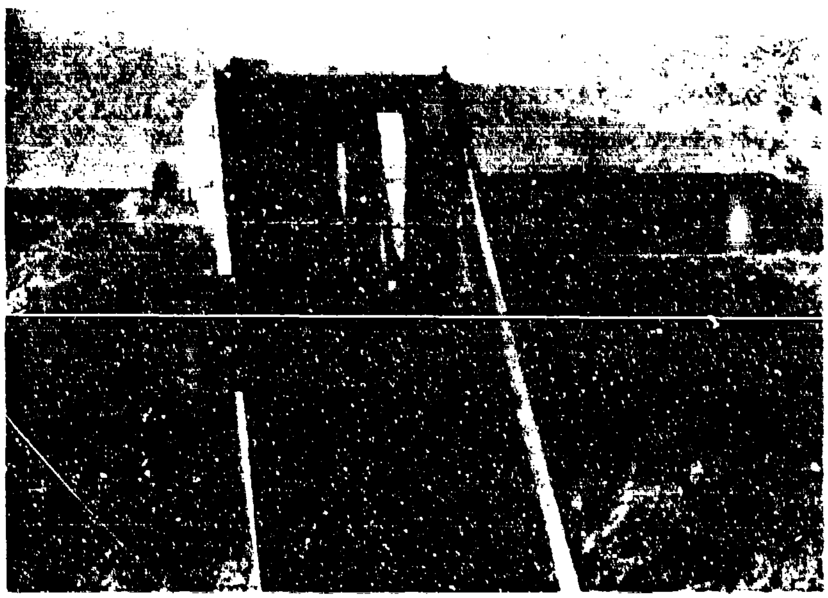


Fig. 2.14 Shelter C-1 Under Construction

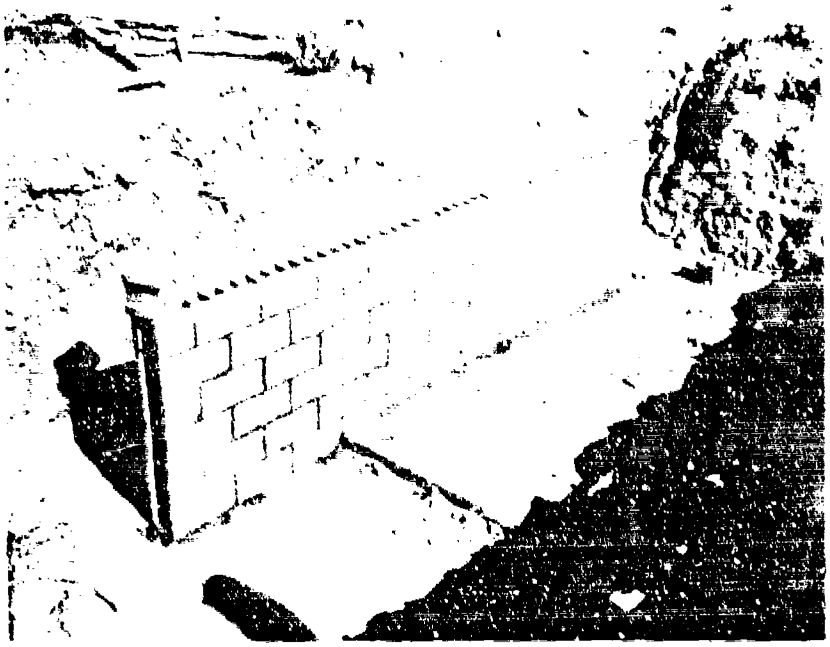


Fig. 2.15 Foundation and Wall for Basement Lean-to Structure

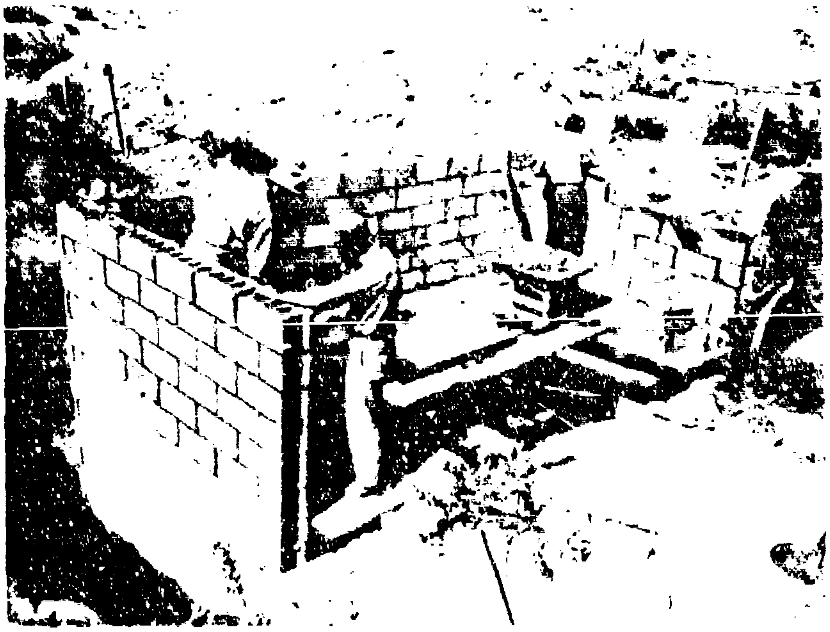


Fig. 2.16 Construction of Structure for Test of Basement Lean-to Shelters

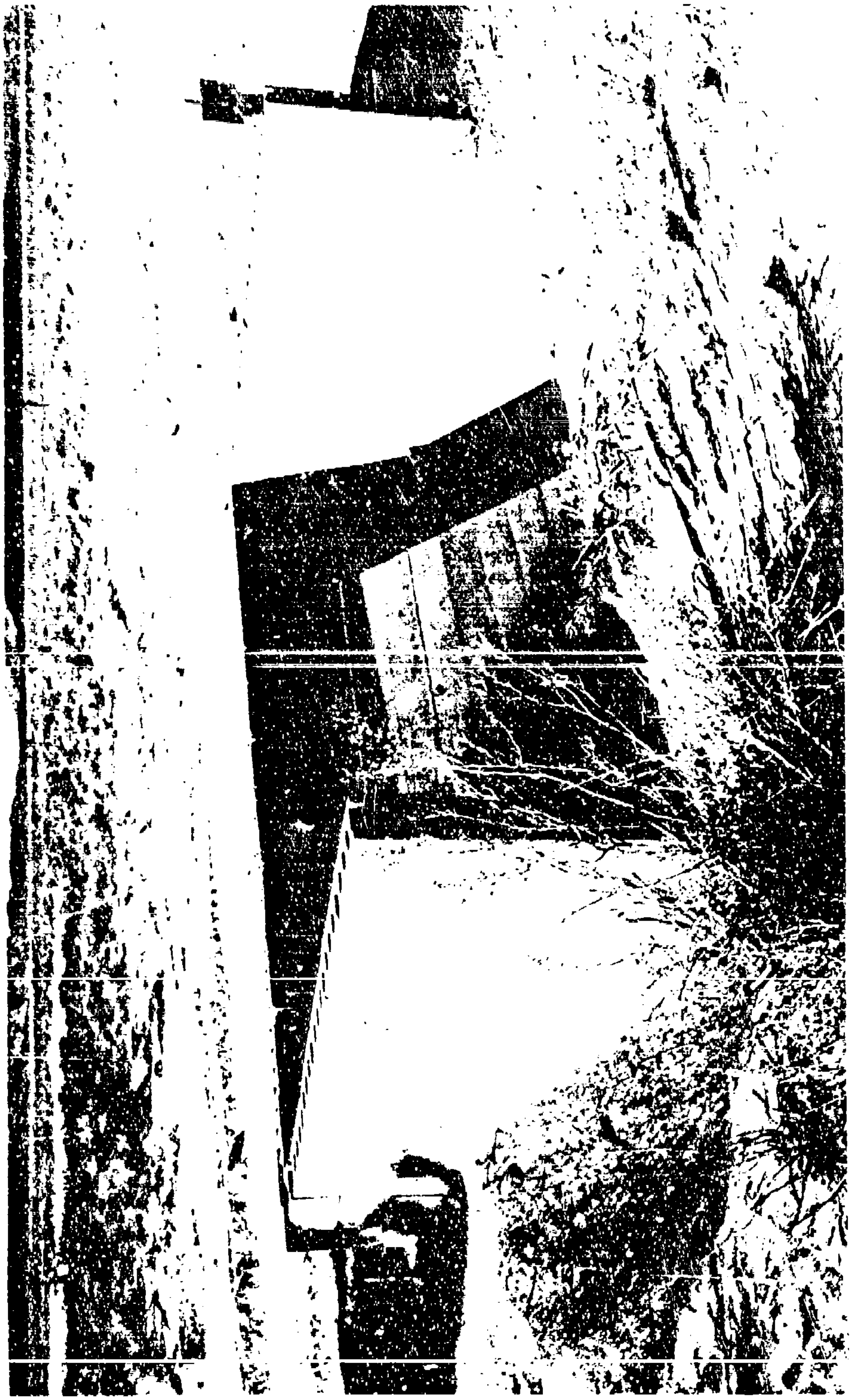
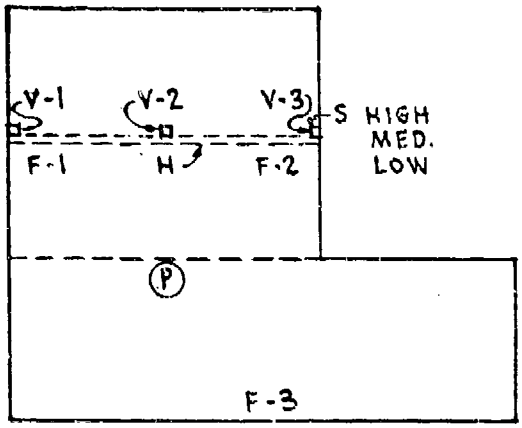
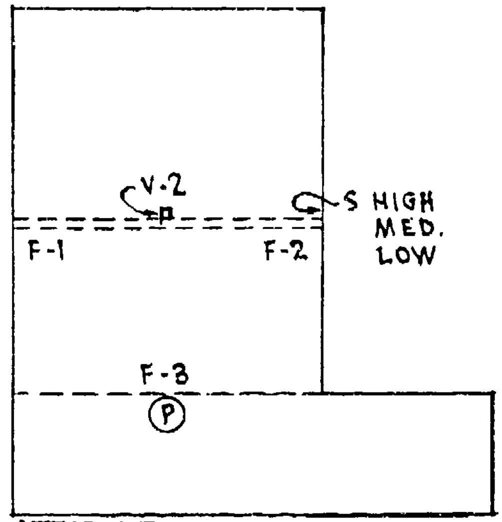


Fig. 2.17 Structure for Test of Basement Lean-to Shelter



COVERED-TRENCH SHELTER



METAL AND WOOD-ARCH SHELTER

KEY

F-1 Film Badge Dupont Adlux No. 52
F-2 Film Badge Dupont No. 553
F-3 Film Badge Dupont Adlux No. 52

(High - N.B.S. Shielded Dupont 554 or 556 at Roof
S(Medium - N.B.S. Shielded Dupont 554 or 556 Midway Between Floor & Roof
(Low - N.B.S. Shielded Dupont 554 or 556 3" to 6" Above Floor

H Horizontal Jack Between Studs)
V-1) Vertical Jacks to) Deflection
V-2) Measure Deflection of) Devices
V-3) Roof Joists or Arch)

P Land Mine Fuses to Measure Pressures Inside Structure

Fig. 2.18 Location of Shelter Instrumentation

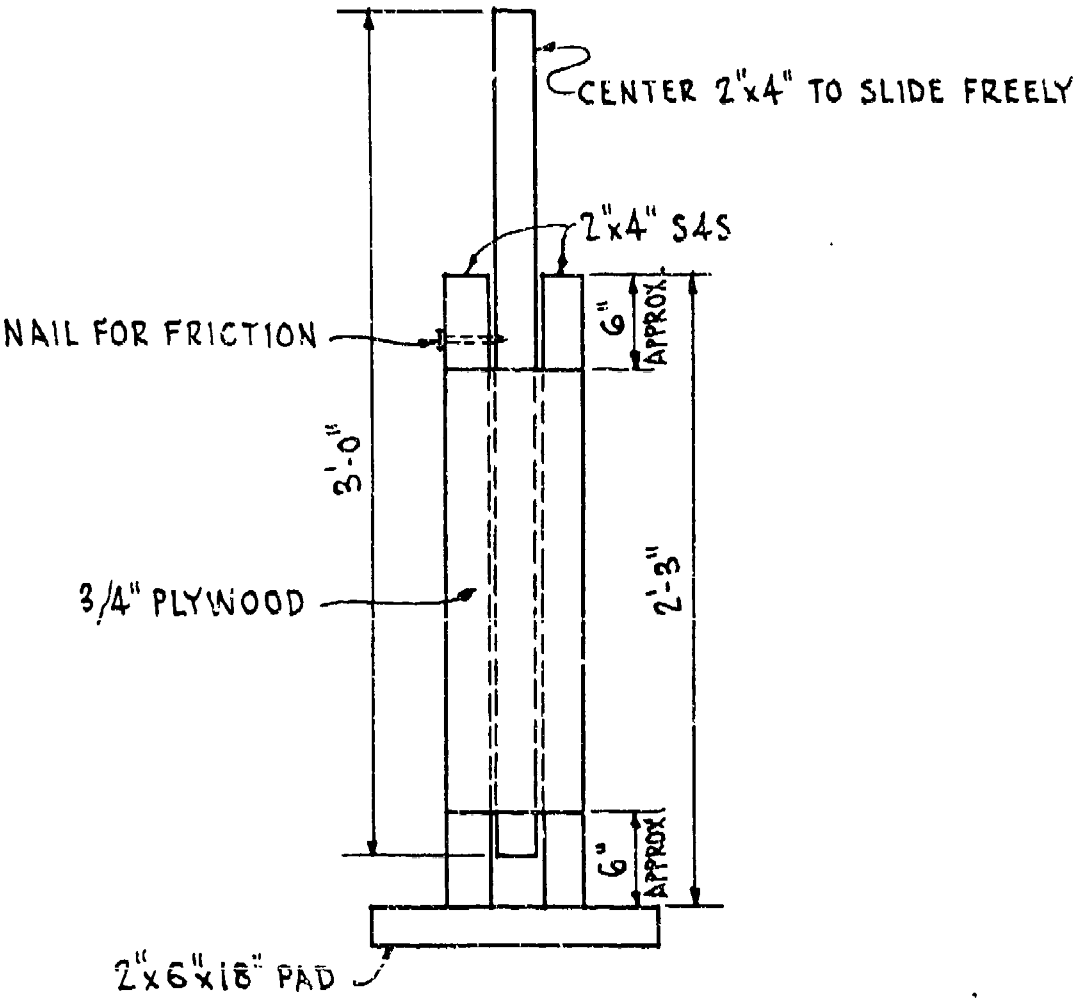


Fig. 2.19 Device to Measure Deflection of Structural Members

TABLE 2.1

Shelter Test Structures - Type A - Covered-trench

Shelter Number	Orientation	Earth Cover	Roof Joists	Studs	Wood Sheathing
Group I - Below Grade - Basic Lehigh Shelters					
A-1	Back to Ground Zero	3'	2x6 @ 3 3/4"	2x4 @ 16"	1x6
A-2	Back to Ground Zero	2'	2x6 @ 3 3/4"	2x4 @ 16"	1x6
A-3	Long Side to GZ	2'	2x6 @ 3 3/4"	2x4 @ 16"	1x6
A-4	Front to GZ	3'	2x6 @ 3 3/4"	2x4 @ 16"	1x6
Group II - Below Grade - Lightened Frame					
A-5	Back to Ground Zero	3'	2x4 @ 24"	2x4 @ 24"	1x6
A-6	Back to Ground Zero	2'	2x4 @ 24"	2x4 @ 16"	1x6
A-7	Back to Ground Zero	3'	2x4 @ 16"	2x4 @ 16"	1x6
A-8	Back to Ground Zero	2'	2x4 @ 16"	2x4 @ 16"	1x6
A-13	Back to Ground Zero	3'	2x4 @ 8"	2x4 @ 8"	1x6
A-14	Back to Ground Zero	2'	2x4 @ 8"	2x4 @ 8"	1x6
A-15	Back to Ground Zero	3'	2x6 @ 5"	2x4 @ 12"	1x6
A-16	Back to Ground Zero	2'	2x6 @ 5"	2x4 @ 12"	1x6
Group III - Semi-buried - Lightened Frame					Wood Roof*
A-9	Back to Ground Zero	2'	2x4 @ 8"	2x4 @ 8"	1x6
A-10	Back to Ground Zero	3'	2x4 @ 8"	2x4 @ 8"	1x6
A-11	Back to Ground Zero	2'	2x4 @ 16"	2x4 @ 16"	1x6
A-12	Back to Ground Zero	3'	2x4 @ 16"	2x4 @ 16"	1x6
A-17	Back to Ground Zero	3'	2x6 @ 5"	2x4 @ 12"	1x6
A-18	Back to Ground Zero	2'	2x6 @ 5"	2x4 @ 12"	1x6

* Chicken wire and tarpaper sides

TABLE 2.1

Shelter Test Structures

Type B - Metal-arch

Shelter Number	Orientation	Earth Cover	Roof Arch	Walls
Group I - Below Grade - Basic Design				
B-1	Back to Ground Zero	3'	12 Gauge	Concrete Block
Group II - Arch on Concrete Footing - Shelter not Completed				
B-2	Back to Ground Zero	2'	12 Gauge	Concrete Footing
B-3	Back to Ground Zero	2'	16 Gauge	Concrete Footing
B-4	Back to Ground Zero	3'	16 Gauge	Concrete Footing
B-5	Back to Ground Zero	3'	12 Gauge	Concrete Footing
Type C - Wood-arch				
Group I - Above Grade				
C-1	Back to Ground Zero	2'	2x4 @ 8"	Concrete Block
C-2	Back to Ground Zero	3'	2x4 @ 8"	Concrete Block
C-3	Back to Ground Zero	2'	2x4 @ 16"	Concrete Block
C-4	Back to Ground Zero	3'	2x4 @ 16"	Concrete Block

Type D - Basement Lean-to

Shelter Number	Orientation	Foundation Wall	Lean-to Const. 1" Sheathing	Type of Fastening
D-1	Wall to Ground Zero	Conc. Block	2x6 @ 5"	Bottom-bolted Top-toenailed
D-2	Wall to Ground Zero	Conc. Block	2x6 @ 5"	Bottom-bolted Top Free

CHAPTER 3
RESULTS

3.1 BASIC TEST DATA

The shelter structures were subjected to Shots Baker, Charlie, and Dog. Bombing data for these three air bursts have not been listed, but Table 3.1 gives the computed distances of the structures from the actual explosions. The distance of each structure from the explosions varied, but this variation was not great enough to significantly affect the intensities of pressure and radiation. Hence, average values for representative structures were used in evaluation of effects of the three explosions.

3.2 WEAPONS EFFECTS

Peak overpressures, thermal radiation, and gamma radiation readings were based on actual recorded data. However, pressures for Shot Dog were estimated. These readings are summarized in Table 3.2.

3.3 REACTION OF SHELTER STRUCTURES

The effects of the explosions on the shelters have been listed separately to assist in evaluating their reaction to each shot. Recorded data and structural damages have been summarized in tabular form. In classifying structural damage no consideration has been given to radiation hazards or other effects of the explosions.

Structural damage has been classified as either light, moderate, heavy, severe, or complete destruction. These categories were defined as follows:

(a) Light Damage.--Superficial damage confined largely to exposed or above-grade portions of the structure, sufficient to nullify its protective value.

(b) Moderate Damage.--Shelter pr[illegible] in good shape with structural failure confined to shattering or p[illegible] demolition of above-grade entrance construction.

(c) Heavy Damage.--Structura[illegible] shelter proper insufficient to cause failure, but serious damage [illegible]ove-grade entrance construction, in some cases blocking access.

(d) Severe Damage.—Partial or complete collapse of the structure sufficient damage to indicate failure to provide protection.

(e) Complete Destruction.--Demolition of structures.

Only in case of severe damage or complete destruction should structural failure be sufficient to result in death or serious injury to persons within shelters. Since, the effect of blast damage and radiation dosages were equally as dangerous, other hazards were considered separately.

TABLE 3.1

Location of Shelters with Respect to Explosions

Structure Number	SHOT BAKER Distance GZ	SHOT BAKER Slant Height	SHOT CHARLIE Distance GZ	SHOT CHARLIE Slant Height	SHOT DOG Distance GZ	SHOT DOG Slant Height
A-1	1224	1658	1312	1733	1240	1883
A-2	1227	1660	1316	1736	1241	1883
A-3	1230	1662	1319	1738	1242	1884
A-4	1233	1664	1321	1740	1243	1885
A-5	1236	1666	1324	1742	1244	1886
A-6	1239	1668	1327	1745	1245	1886
A-7	1241	1671	1330	1747	1246	1887
A-8	1244	1673	1333	1749	1247	1888
A-9	1247	1675	1336	1751	1248	1888
A-10	1250	1677	1338	1753	1249	1889
A-11	1252	1679	1340	1755	1250	1889
A-12	1255	1681	1343	1757	1251	1890
A-13	1257	1683	1346	1758	1252	1891
A-14	1260	1685	1348	1760	1253	1892
A-15	1263	1687	1350	1762	1253	1892
A-16	1265	1688	1352	1764	1254	1892
A-17	1268	1690	1355	1765	1255	1893
A-18	1270	1692	1357	1767	1256	1893
B-1	1272	1694	1360	1769	1256	1894
B-2	1275	1696	1361	1770	1257	1894
B-3	1277	1698	1363	1772	1258	1895
B-4	1280	1700	1363	1773	1258	1895
B-5	1282	1704	1367	1775	1259	1896
C-1	1285	1704	1368	1776	1260	1896
C-2	1287	1705	1370	1777	1260	1897
C-3	1290	1706	1371	1779	1261	1897
C-4	1291	1708	1373	1780	1261	1897
D-1	1293	1710	1375	1781	1262	1897
D-2	1295	1711	1376	1782	1262	1898

TABLE 3.2

Basic Effects Data for Shelter Structures

Shelter Number	Peak Pressures P. s. i.	Thermal Radiation Calories/cm^2	Gamma Radiation r**
SHOT BAKER			
A-1	8.2	43	
A-10	8.0	42	
A-18	7.9	40	
D-2	7.8	39	
Average Values	8.0	41	9,600
SHOT CHARLIE			
A-1	15.4	118	
A-10	15.0	115	
A-18	14.8	112	
D-2	14.3	110	
Average Values	14.9	114	29,800
SHOT DOG			
A-1	14.7*	155	
A-10	14.7*	155	
A-18	14.7*	155	
D-2	14.7*	155	
Average Values	14.7*	155	50,700

*Estimated Values
**Values Subject to Revision

CHAPTER 4

EFFECTS OF SHOT BAKER

4.1 INTRODUCTION

The pressures from Shot Baker were considerably less than those which the basic shelters were intended to withstand. The effects of Shot Baker on the shelter structures are summarized in Table 4.1. Additional data on structural damage, intensities of radiation and other factors affecting the protective value of the shelters are given in this chapter.

4.2 STRUCTURAL DAMAGE

With the exception of structures simulating the basement lean-to shelters, complete structural failure did not occur. The blast removed considerable earth cover and, possibly because of poorly placed backfill, slightly shifted or twisted some shelters. Above-grade entrance construction was badly damaged particularly where not fully protected by earth cover. Although partial failure occurred in some structures, deflection devices and other materials placed within them were not disturbed. A group by group analysis follows:

4.2.1 Covered-trench Shelters

The basic covered-trench shelters (A-1 through A-4) which conformed with designs prepared by Lehigh University Institute of Research fared well with damage confined to above-grade entrance construction. Earth cover was lowered 6 to 12 inches. The extent of damage to basic below-grade structures is shown in Figs. 4.1, 4.2, 4.3, and 4.4. Greatest damage was suffered by Shelter A-4, the entrance facing the blast. With the exception of A-4, damage to entrance construction was confined to spreaders and batterboards (Fig. 4.4). The entrance of A-1 which suffered more damage than A-2 was not as well protected with earth cover (Figs. 4.1, 4.2, 2.5 and 2.6).

Below-grade covered-trench shelters, weakened by increased spacing and reduced structural members, did not fail, but were damaged more than the basic structures. Front and end walls showed a tendency to give where they were joined to the roof section. Some roof joists were cracked and in two shelters studs on the front side were broken. Structure A-6, designed to carry little more than the dead load of earth cover, continued to hold although its center roof joist had been cracked in backfilling operations. Figures 4.5, 4.6, 4.7, and 4.8 show the nature of external damage suffered by these structures.

Fig. 4.1 Damage to Structure A-1 Due to Shot Baker (covered-trench below-grade)

Fig. 4.2 Shelter A-2 After Shot Baker (covered-trench below-grade)

Fig. 4.3 Shelter A-3 After Shot Baker (covered-trench below-grade)

Fig. 4.4 Shelter A-4 After Shot Baker (covered-trench below-grade) Front Side Facing Ground Zero

Fig. 4.5 Shelter A-5 After Shot Baker (below-grade lightened-frame)

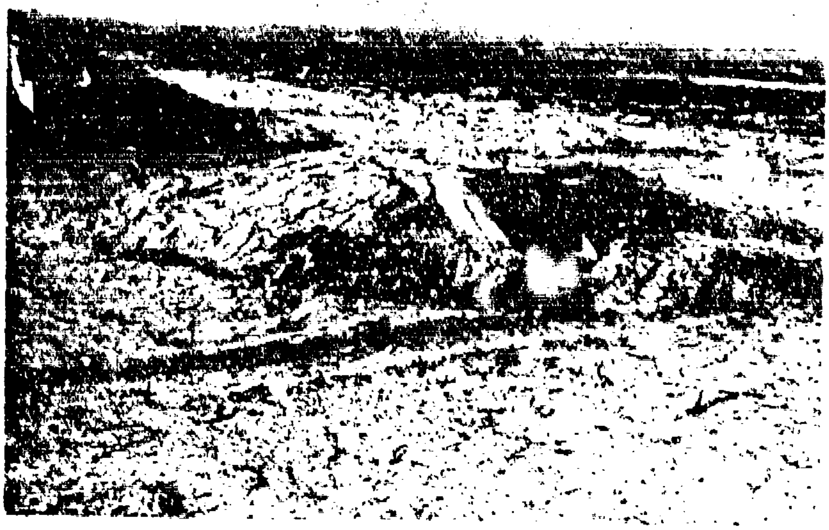


Fig. 4.6 Shelter A-8 After Shot Baker (below-grade lightened-frame)

Fig. 4.7 Shelter A-14 After Shot Baker (below-grade lightened-frame)

Fig. 4.8 Shelter A-15 After Shot Baker (below-grade lightened-frame)

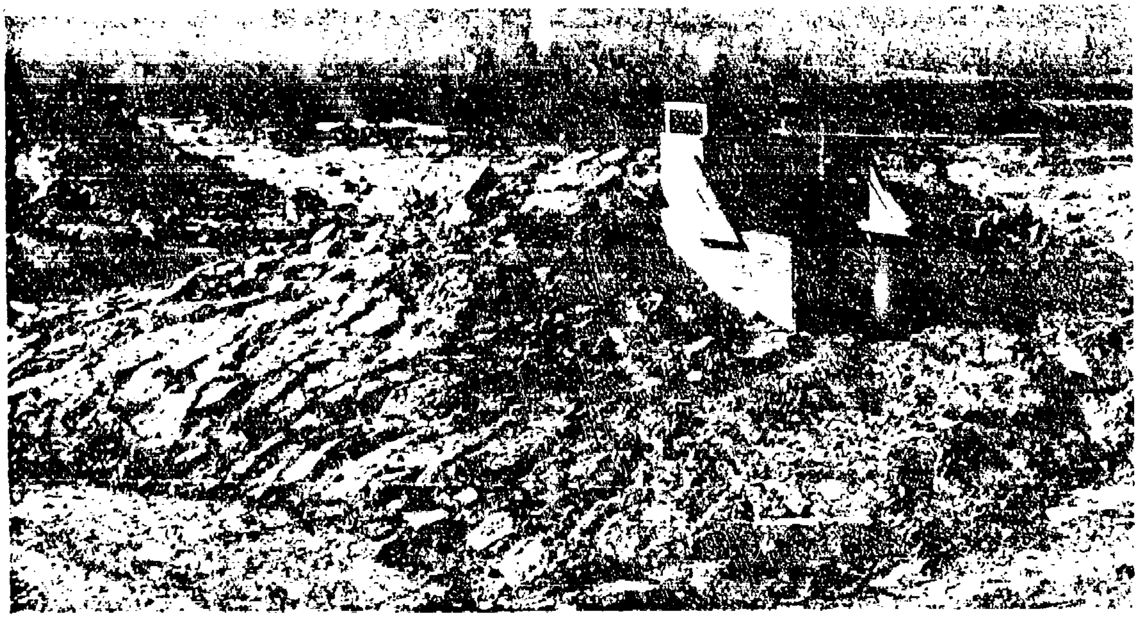


Fig. 4.9 Shelter A-9 After Shot Baker (partly above-grade lightened-frame)

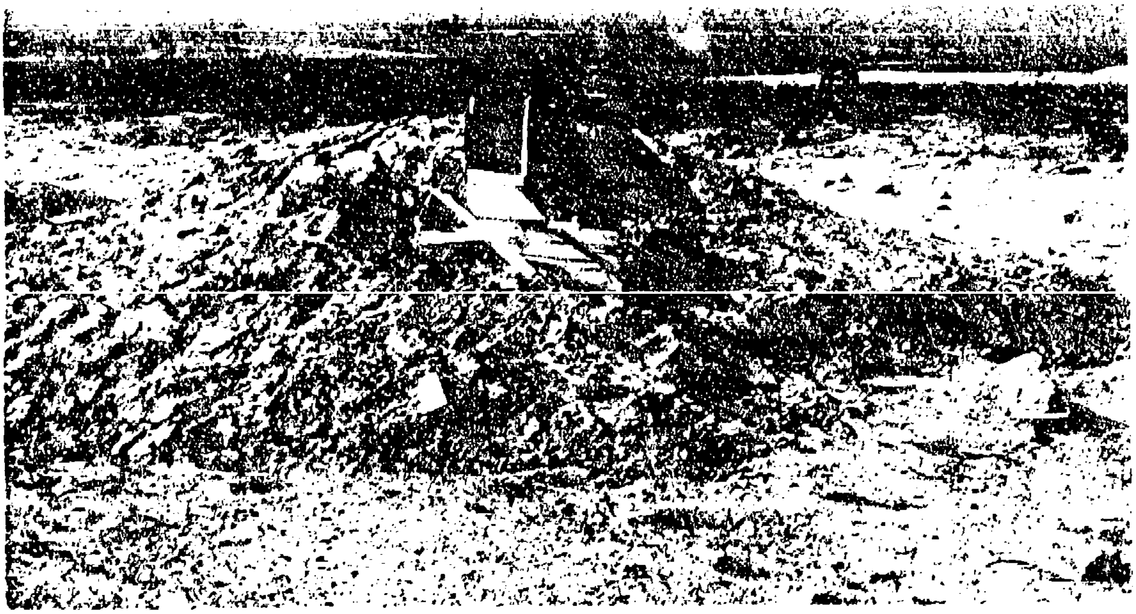


Fig. 4.10 Shelter A-11 After Shot Baker (partly above-grade lightened-frame)

Fig. 4.11 Shelter A-12 After Shot Baker (partly above-grade lightened-frame)

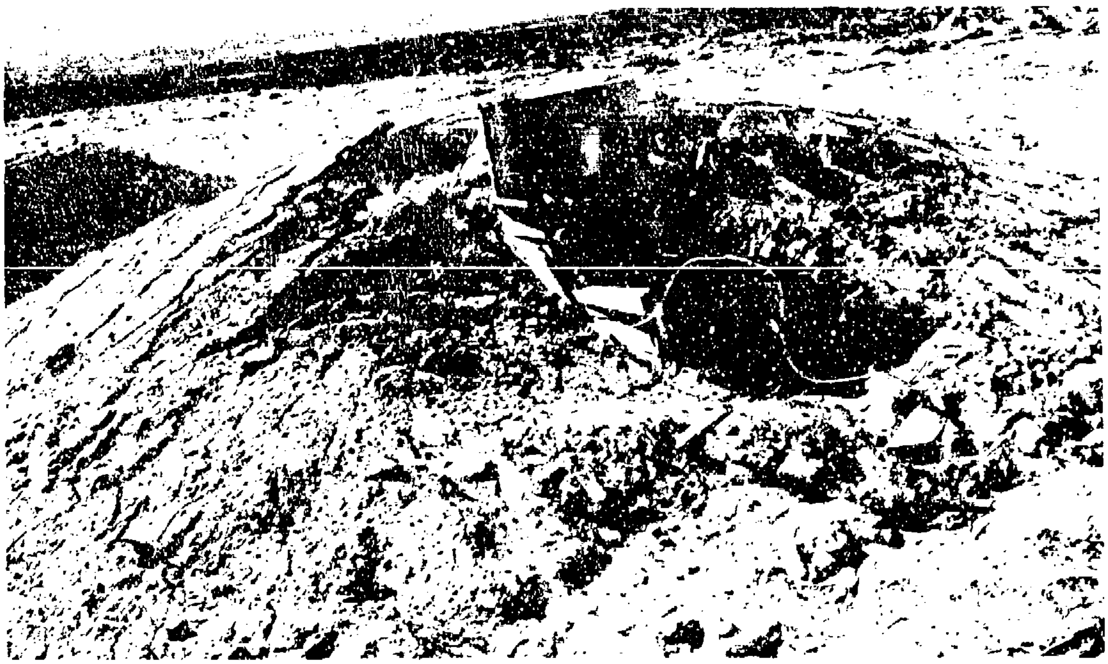


Fig. 4.12 Shelter A-17 After Shot Baker (partly above-grade lightened-frame)

4.2.2 Metal-arch Shelters

In addition to extensive damage to entrance construction, partial failure occurred in the end section of the only completed metal-arch shelter. There was also evidence of a slight shifting or twisting of the arch on its foundation, but structural damage was insufficient to prove hazardous to an occupant. Figure 4.13 shows collapsed entrance structure and spreading of earth cover. Effects of blast on metal-arches are shown on Fig. 4.14. The earth cover on this structure was lowered appreciably.

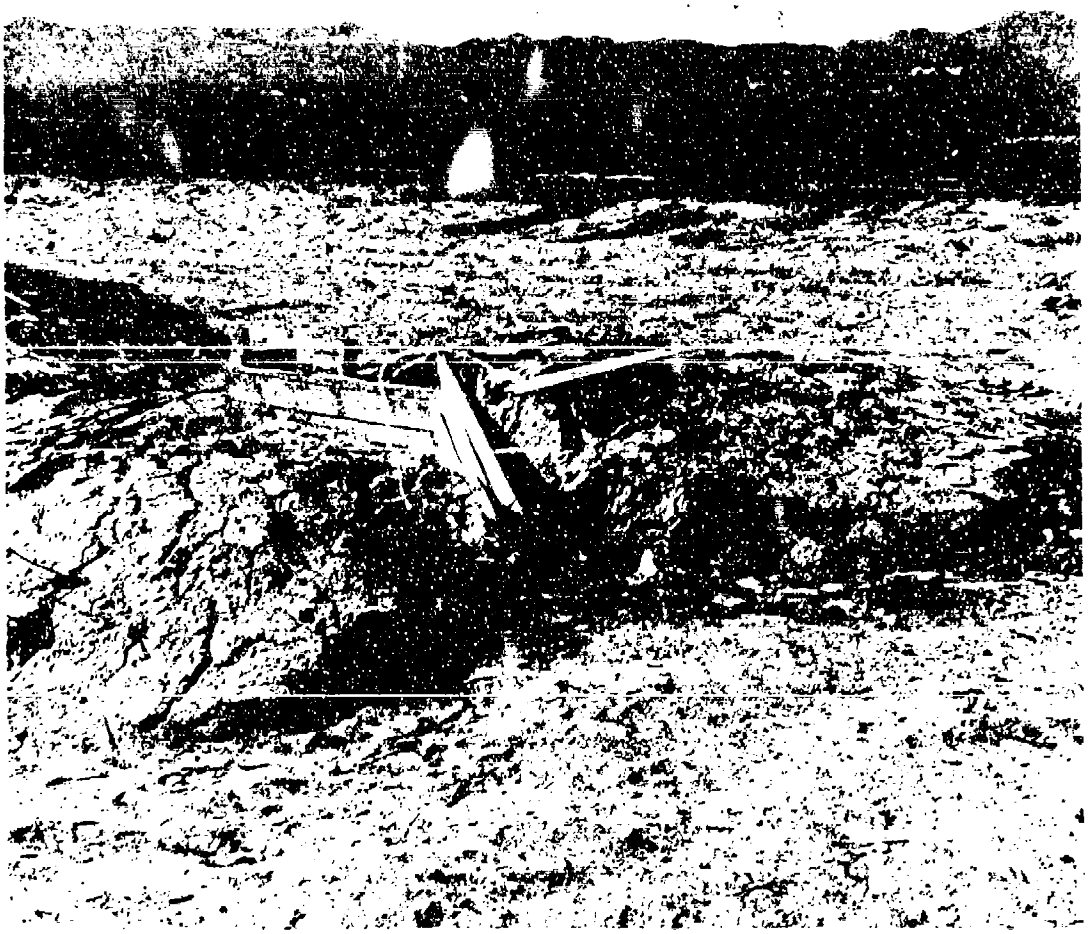


Fig. 4.13 Shelter B-1 After Shot Baker (basic below-grade metal-arch shelter).

Fig. 4.14 Structure B-4 After Shot Baker (metal-arch, 16 gauge with 3 ft. of earth cover)

4.2.3. Wood-arch Shelters

Damage to wood-arch shelters is partially shown in Figs. 4.15, 4.16, and 4.17. Entrance structures were severely damaged and were almost impassable. The wood-arch and wall of all structures remained intact, but in C-4, the end section gave way.

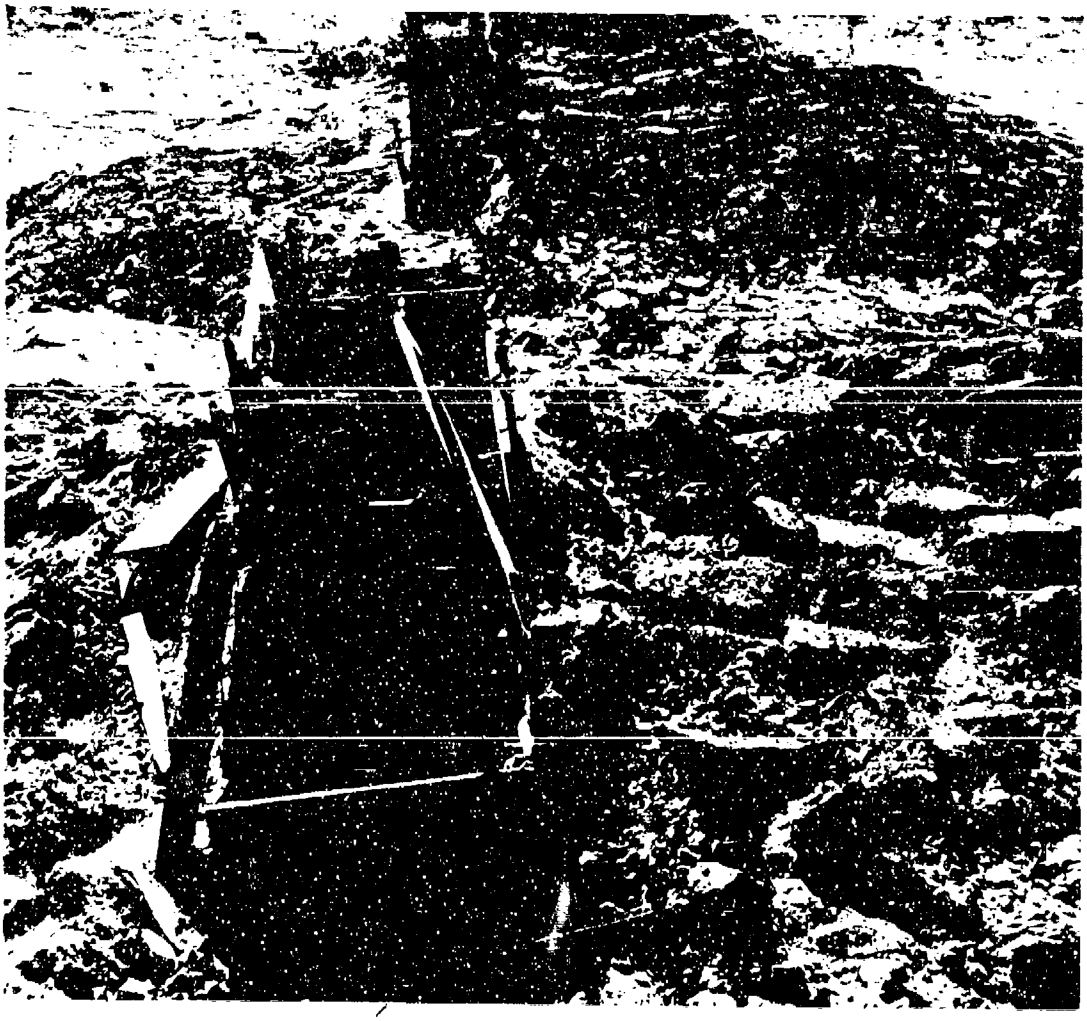


Fig. 4.15 Entrances to Wood-arch Shelters After Shot Baker

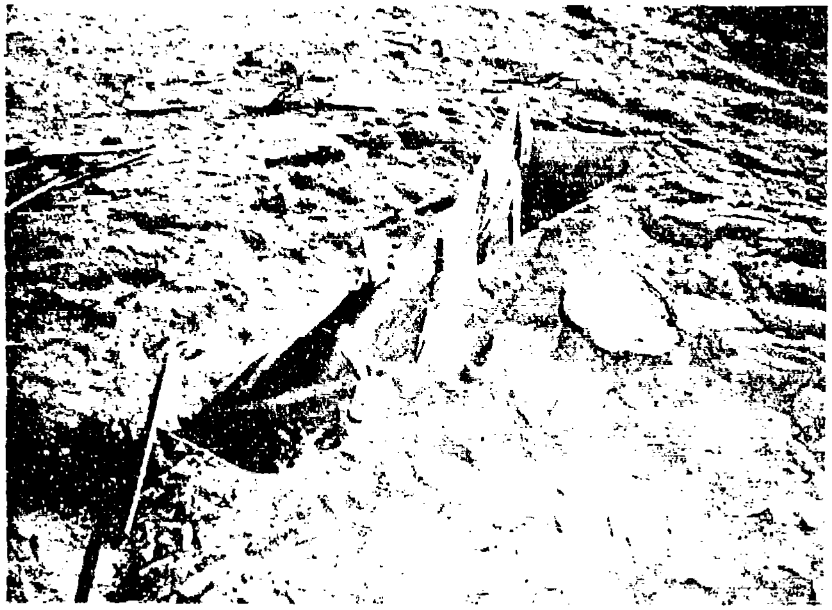


Fig. 4.16 Entrance to C-3 After Shot Baker (wood-arch)

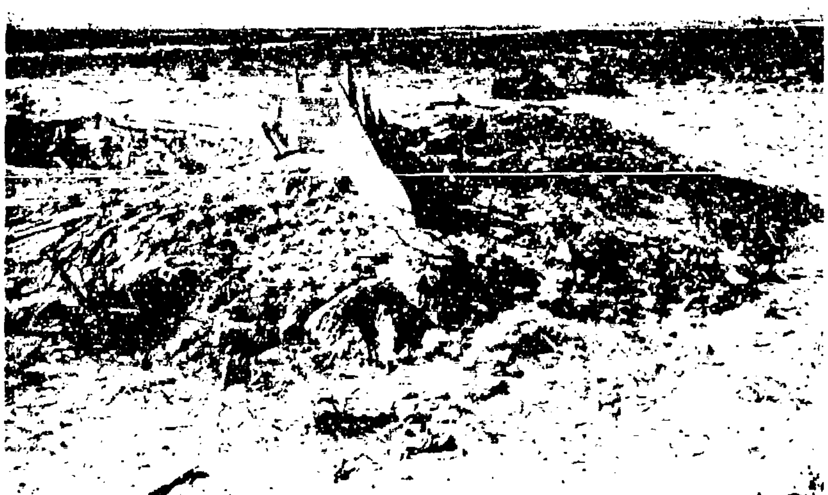


Fig. 4.17 Structure C-4 After Shot Baker (wood-arch)

4.2.4 Basement Lean-to Structures

The complete destruction of simulated basement lean-to shelters (D-1 and D-2) is shown in Fig. 4.18. These structures were designed to determine whether fastening a lean-to section to a basement wall would afford greater protection than if the top of the lean-to were left free. However, destruction was so complete, no information could be obtained on wall failure or reaction of the lean-to.

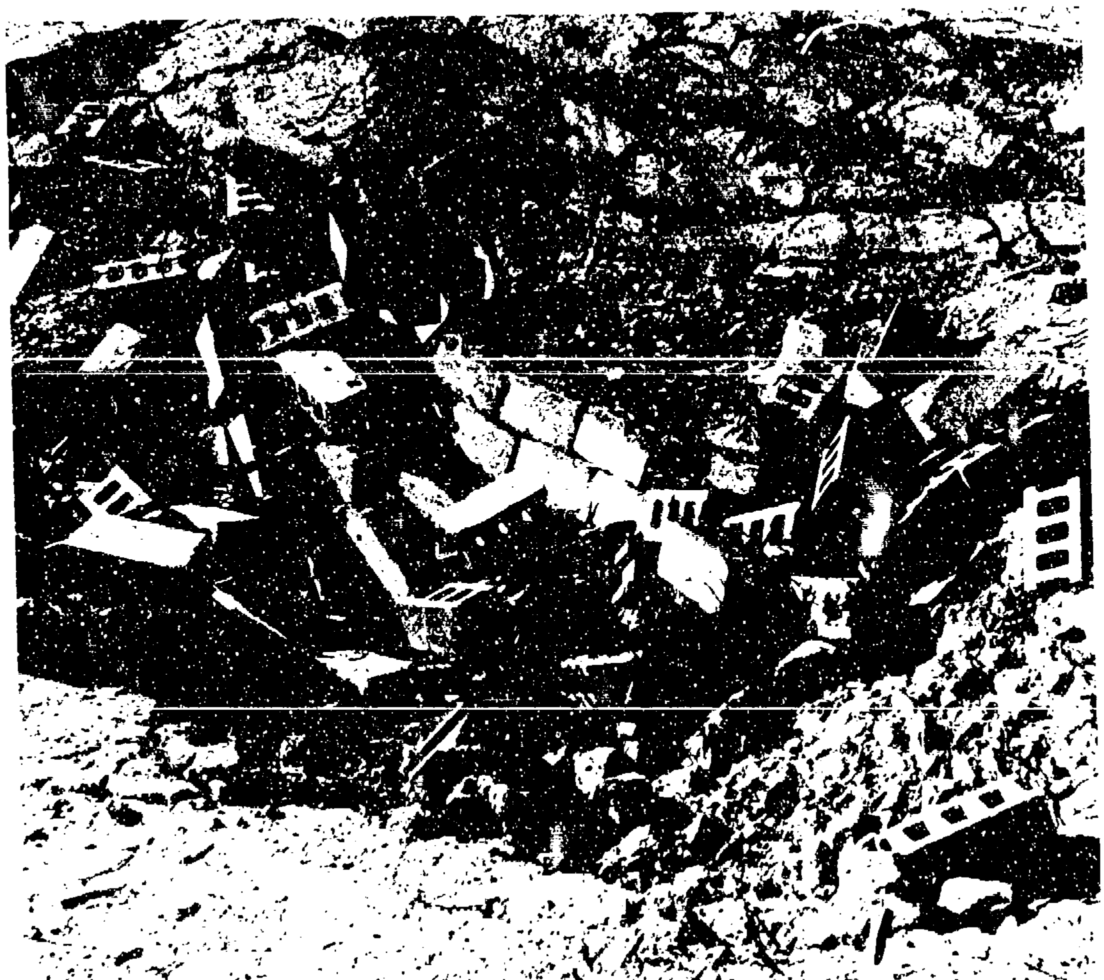


Fig. 4.18 Remains of Structure D-1 After Shot Baker (simulated basement lean-to)

TABLE 4.1

Effects of Shot B* on Shelter Structures

Shelter Number	Earth Cover	Gamma Radiation F-1	Gamma Radiation F-2	Gamma Radiation F-3	Deflections Inches Joists	Deflections Inches Studs	Pressures Inside p.s.i.	Effects on Shelter
Type A - Covered-trench								
Group I - Below Grade - Basic Lehigh Design								
A-1	3'	120	130 (H-113 S(M-77 (L-50	190	0.063	0.063	4.7	Light Damage. No effects on shelter proper. Damage confined to side-boards on above grade entrance structure. Cover reduced 9" to 12".
A-2	2'	190	240	250		1.016	3.5	Light Damage. Shelter in good shape. Studs in end section pushed in enough to crack top piece of sheathing. Above-grade entrance sideboards damaged. Cover reduced 6" to 12".
A-3	2'	110	150	180	0.063	0.078		Light Damage. Shelter in good shape. Entrance damage minor out spreader blown off. Cover reduced 6" to 12".
A-4	3'	130 (H-500 S(M (L-49	270	190	0.109	0.031		Light Damage. Shelter in good shape. Sides of entrance facing target blown away. Above-ground and other side shattered. Cover reduced 12" to 15".

*Baker

TABLE 4.1

Effects of Shot B on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Deflections Inches Joists	Studs	Pressures Inside p.s.i.	Effects on Shelter
				Type A - Covered-trench				
Group II - Below Grade - Lightened Frame								
A-5	3'	150	180	220				Heavy Damage. Shelter holding. Two roof joists cracked. Front side pushed in and sheathing cracked. Entrance stud cracked; one sideboard missing on each side. Cover reduced 12" to 18"
A-6	2'	170	160	340				Moderate Damage. Shelter holding despite construction damage. Front side giving slightly. Entrance damage minor; one stud cracked. Cover reduced 9" to 12".
A-7	3'	130	130					Moderate Damage. Shelter damage minor. Front side giving way. Entrance studs broken; sideboards blown away. Cover reduced 12" to 18".
A-8	2'	140	140	230				Moderate Damage. Shelter damage minor. Structure twisted away from GZ. Entrance damaged but intact. Cover reduced 9" to 12".

TABLE 4.1

Effects of Shot B on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	Gamma Radiation F-2	Gamma Radiation F-3	Deflections Inches Joists	Deflections Inches Studs	Pressures Inside p.s.i.	Effects on Shelters
								Type A - Covered-trench
Group II - Below Grade - Lightened Frame								
A-13	3'	180	160	200				Moderate Damage. Roof joist broken. Entrance damage minor; stud cracked; sideboard on each side missing. Cover reduced 9" to 12".
A-14	2'	140	150	230				Moderate Damage. Two roof joists split. Entrance damage minor; spreader and sideboard missing. Cover reduced 9" to 12".
A-15	3'	120	120	190				Moderate Damage. Shelter damage minor. Entrance structure damaged and 2x4 smashed. Cover reduced 12" to 18".
A-16	2'	220	270					Light Damage. Shelter damage minor. Entrance structure damaged with spreader batterboards missing. Cover reduced 12" to 18".

TABLE 4.1

Effects of Shot B on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	Gamma Radiation F-2	Gamma Radiation F-3	Deflections Inchs Joists	Deflections Inchs Studs	Pressures Inside p.s.i.	Effects on Shelter
Type A - Covered Trench								
Group III - Semi-buried - Lightened Frame								
A-9	2'	290	290	430				Moderate Damage. Shelter proper in good shape. Front section giving way; entrance sideboard blown away. Cover reduced 12" to 24".
A-10	3'		220	250				Moderate Damage. Shelter proper in good shape. Studs in entrance side giving way; entrance partially demolished above grade. Cover reduced 15" to 24".
A-11	2'	250	320					Moderate Damage. Shelter proper holding, tilted slightly. Entrance partly demolished but usuable. Cover reduced 12" to 18".
A-12	3'	190	240	270				Moderate Damage. Shelter proper holding. Above-grade entrance structure shattered and partially collapsed. Cover reduced 24" to 30".

TABLE 4.1

Effects of Shot B on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	Gamma Radiation F-2	Gamma Radiation F-3	Deflections Inches Joists	Deflections Inches Studs	Pressures Inside p.s.i.	Effects on Shelter
Type A - Covered Trench								
Group III - Semi-buried - Lightened Frame								
A-17	3'	210 (H-265 S(M-48 (L-48	170					Heavy Damage. Shelter proper holding, but slightly twisted. Front section giving a little. Above-grade entrance structure demolished. Cover reduced 18' to 24".
A-18	2'		300					Heavy Damage. Shelter proper holding, but slightly twisted. Entrance severely damaged, but passable. Cover reduced 15" to 18"

TABLE 4.1

Effects of Shot B on Shelter Structures

Shelter Number	Earth Cover	Gamma Radiation F-1	Gamma Radiation F-2	Gamma Radiation F-3	Deflection of Arch Vertical	Deflection of Arch Horizontal	Pressures Inside p.s.i.	Effects on Shelters
Type B - Metal Arch								
Group I - Below Grade - Basic Lehigh Design								
B-1	3'						4.8	Heavy Damage. End section pushed in at bottom. Arch twisted 6" to 12" out of line but intact. Entrance almost impassable--folded. Cover reduced 18" to 24".
Group II - Arch on Concrete Footing								
B-2	2'		320	230	0.250	0.219		Arch twisted to north. Cover reduced 15" to 18".
B-3	2'		300		0.344	1.00		Cover reduced 15" to 18". No damage.
B-4	3'		280		0.313	0.563		Cover reduced 24" to 27". No damage.
B-5	3'				0.094	0.656		Cover reduced 24" to 27". No damage.

TABLE 4.1

Effects of Shot B on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Deflection of Arch Vertical	Horizontal	Pressures Inside p.s.i.	Effects on Shelter
					Type C - Wood Arch			
Group I - Semi-buried - Concrete Block Walls								
C-1	2'				0.375	1.25		Heavy Damage. Shelter proper in good shape. Entrance collapsed, almost impassable. Cover reduced 12" to 15"
C-2	3'							Heavy Damage. Shelter proper in good shape. Entrance collapsed, almost impassable. Cover reduced 18" to 24".
C-3	3'							Heavy Damage. Shelter proper in fair shape. Entrance shattered, almost impassable. Cover reduced 12" to 18".
C-4	3'							Severe Damage. End section gave way. Arch and walls intact. Entrance shattered, almost impassable. Cover reduced 18" to 24".

TABLE 4.1

Effects of Shot B on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Deflection of Arch Vertical	Horizontal	Pressures Inside	Effects on Shelter
				Type D - Basement Lean-to				
D-1								Complete Destruction. Lean-to completely shattered, entire wall thrown in. No examination possible.
D-2								Complete Destruction. Lean-to demolished, entire wall thrown in. Blocks thrown 25'. No observation possible.

Total Radiation - Film badge at structure B-5 8000R
Test data for shelter sites 9600R

4.3 RADIATION MEASUREMENTS

Total gamma radiation at the site of the shelters was approximately 9,600 roentgens. A film badge placed at the top of the entrance to structure C-4 recorded 8,000 r. Readings for gamma radiation listed in Table 4.1 were taken from film badges placed at entrance sections and inside shelters. Film-badge data on metal-arch and wood-arch shelters were not available.

Readings for total gamma radiation were comparatively uniform for similar types of structures. Average values for the covered-trench shelters are listed in Table 4.2. This table gives total radiation dosages in below-grade and partly above-grade shelters with 2 ft. and 3 ft. of earth cover. In addition to values for the shelter proper, average readings are also provided for the entrance areas.

TABLE 4.2

Total Gamma Radiation in Covered-trench Shelters

Average Readings for Buster Shot Baker

	Earth Cover - 2 ft.		Earth Cover - 3 ft.	
Shelters	Shelter Area	Entrance Area	Shelter Area	Entrance Area
Below-grade	173	246	151	198
Partly above-grade	290	430	206	320

Table 4.2 indicates the difference in intensity of radiation in below-grade and partly above-grade shelters. Differences were possibly due to entrance damage and the greater amount of earth cover removed from partly above-grade shelters by the blast. A comparison of structures with 2 and 3 ft. of earth cover indicates that the extra foot of cover did not reduce radiation as much as anticipated. Radiation data on high, medium and low positions in 4 shelters show total gamma ray dosage is much higher near the top of the shelter than at the bottom (Table 4.1).

In A-1 where the back of the shelter faced ground zero the average reading was 125 roentgens. In contrast the corresponding reading was 200 roentgens in an identical shelter, A-4, where the entrance side faced ground zero.

4.4 OTHER EFFECTS

Thermal radiation at the shelter site was approximately 41 calories per square centimeter. There was no indication of thermal effects within the shelters, and it appeared that protection was adequate. Exposed sections of the wood structures were charred as shown in Figs. 4.1, 4.5, and 4.8, but there were no signs of continued combustion.

Pressures inside the structures measured with land mine fuses were based on a limited number of readings. They averaged 4 pounds per square inch. This figure is of considerable interest, but in view of the limitations of the measuring devices is not conclusive.

The deflection measurements of structural members of the shelters are listed in Table 4.1. They show some variation due probably to the shifting and twisting of structures, as well as the inaccuracy of measuring devices.

CHAPTER 5

EFFECTS OF SHOT CHARLIE

5.1 INTRODUCTION

Shelters were seriously damaged by Shot Charlie, largely because damage sustained on the previous explosion had not been repaired and because the earth cover removed by the Baker blast had not been replaced. Pressures again were considerably less than those the structures were intended to withstand. On the other hand, the intensity of gamma radiation was much greater than that against which the original shelters were intended to provide protection. Test results for Shot Charlie are summarized in Table 5.1. In reviewing this data consideration should be given to the reduction of earth cover by Shot Baker, exposing structures and reducing their ability to provide protection against gamma radiation.

5.2 STRUCTURAL DAMAGE

All shelters suffered considerable structural damage and the metal-arch and wood-arch shelters were completely destroyed. Partly above-grade shelters were damaged sufficiently to indicate failure to provide protection against blast. The shelters were stripped of practically all cover and considerable soil poured into the entrance sections.

5.2.1 Covered-trench Shelters

Damage to basic below-grade covered-trench shelters (A-1 through A-4) was confined principally to above-grade entrance construction (Figs. 5.1 and 5.2). Shelter A-4, with the front end facing the blast, was damaged slightly more than shelters of similar construction. In reduced strength below-grade shelters blast had approximately the same effect on earth cover and entrances (Fig. 5.3). Although, none of these structures failed, studs and roof joists were broken. There was also evidence of weakness where studs in the front and end sections were tied into the roof section.

The partly above-grade covered trench shelters suffered much more damage. Although the structures remained intact, earth cover was swept down to natural grade (Fig. 5.4). Entrances suffered greater damage (Figs. 5.5 and 5.6).

Fig. 5.1 Shelter A-2 After Shot Charlie (covered-trench below-grade)

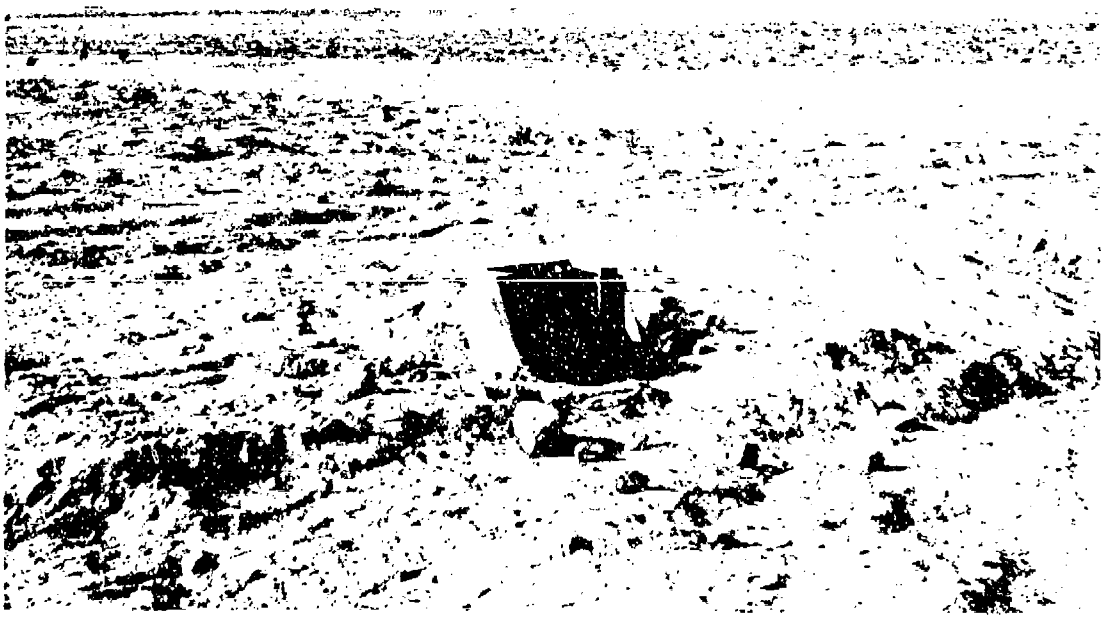


Fig. 5.2 Shelter A-3 After Shot Charlie (covered-trench below-grade)

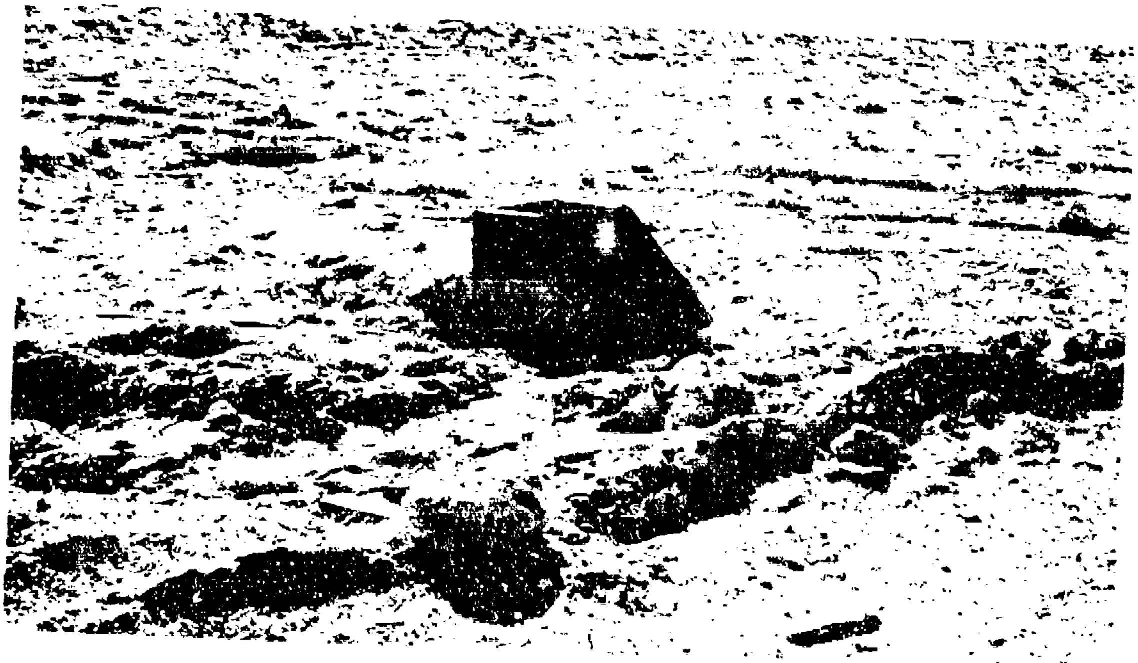


Fig. 5.3 Shelter A-6 After Shot Charlie (lightened-frame below-grade)

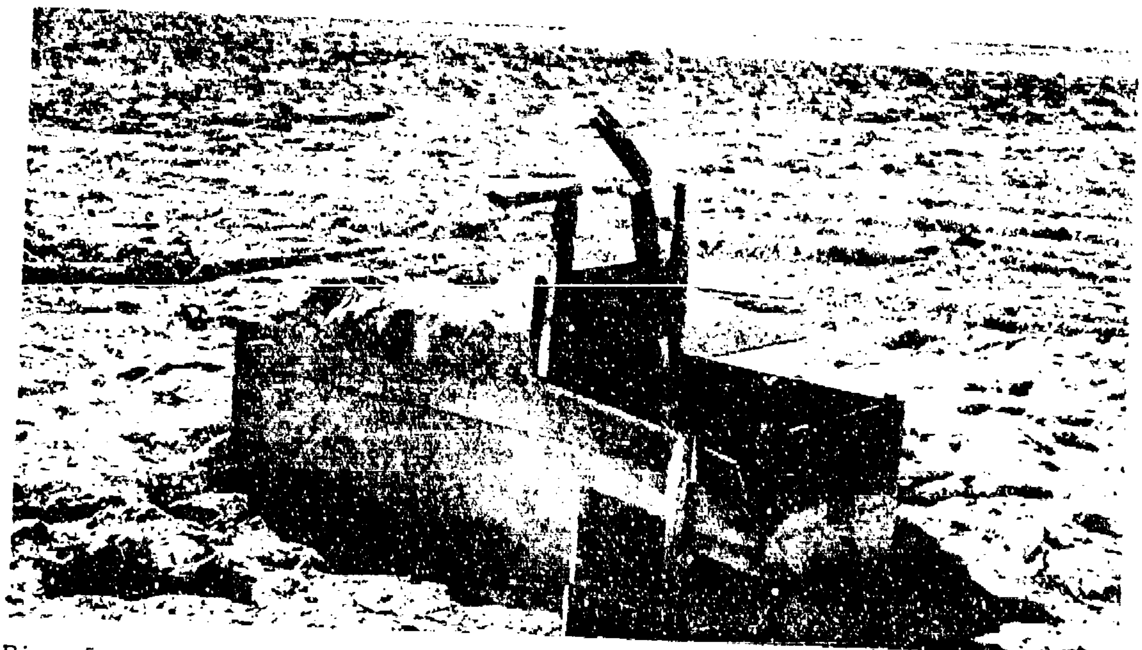


Fig. 5.4 Shelter A-9 After Shot Charlie (partly above-grade lightened-frame)

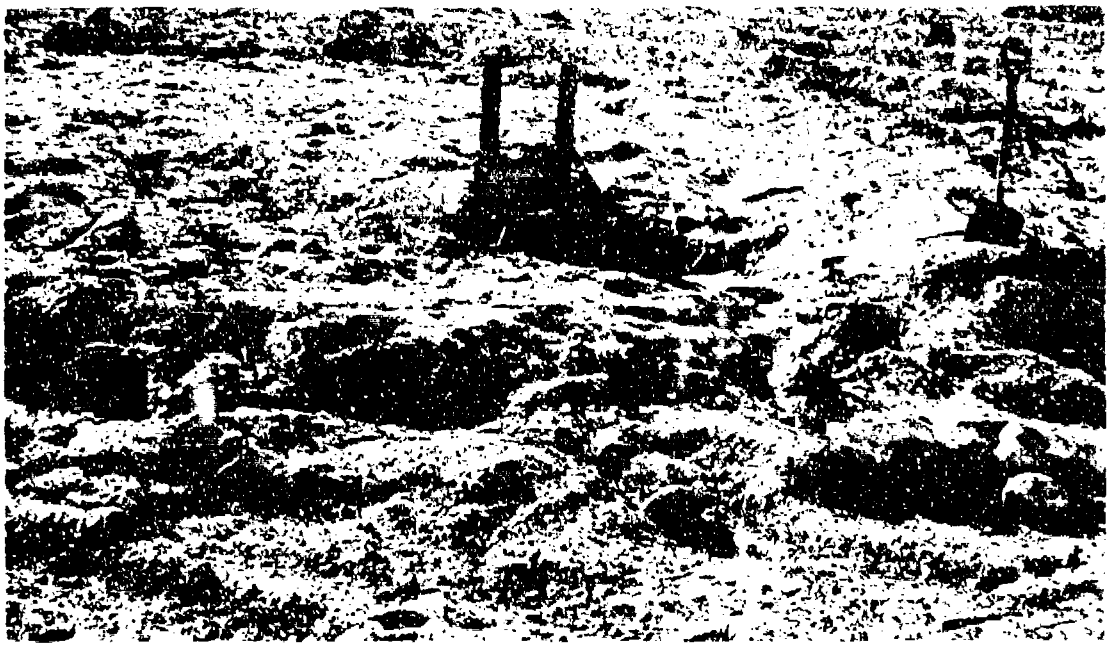


Fig. 5.5 Shelter A-11 After Shot Charlie (partly above-grade lightened-frame)

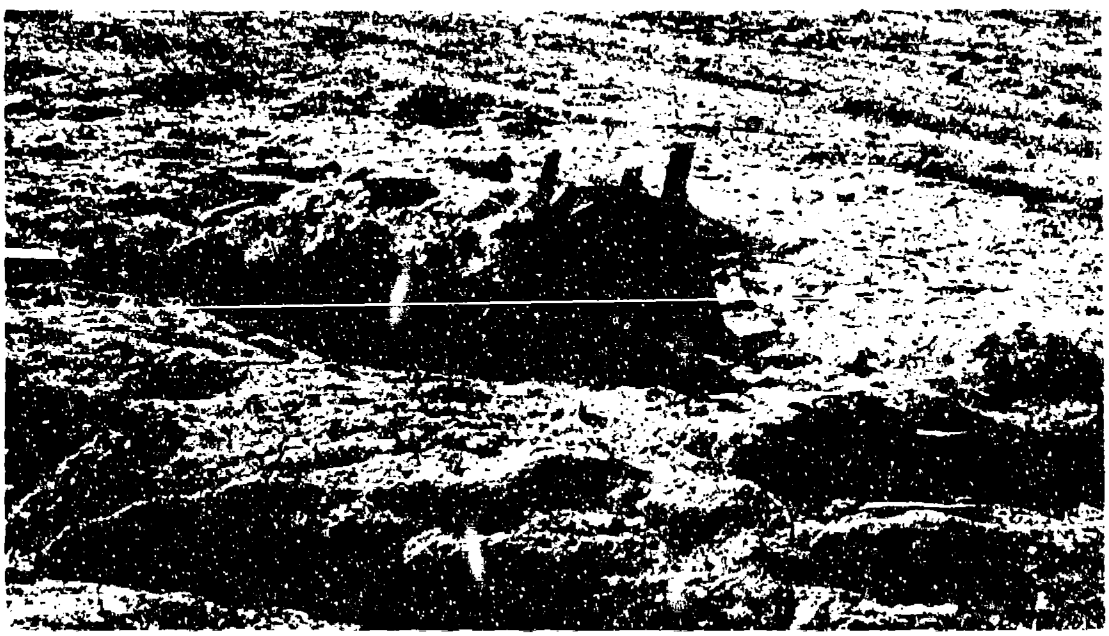


Fig. 5.6 Shelter A-13 After Shot Charlie (lightened-frame below-grade)

5.2.2 Metal-arch Shelters

Failure of stakes to hold the end section of the metal-arch shelter in the previous explosion contributed to its destruction (Fig. 5.7). Entrance sections were weaker than those of the covered-trench type, but the metal-arch and walls survived.

Figures 5.8 and 5.9 show effects of the blast on metal-arch sections in a ground level concrete footing. Virtually all cover was swept away, but the metal arch was not affected by blast.

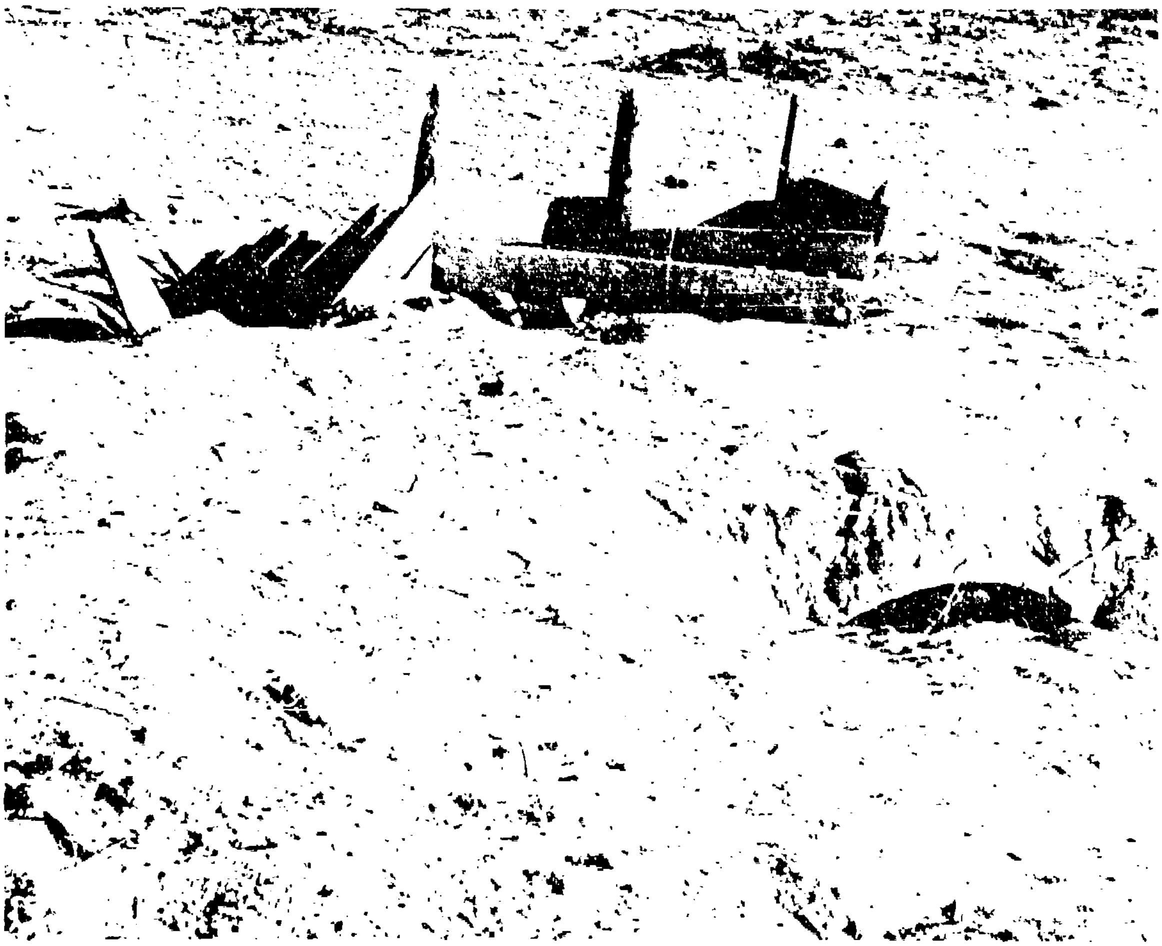


Fig. 5.7 Shelter B-1 After Shot Charlie (metal-arch shelter below-grade)

Fig. 5.8 Structure B-2 After Shot Charlie (metal-arch - 2 ft. of earth cover)

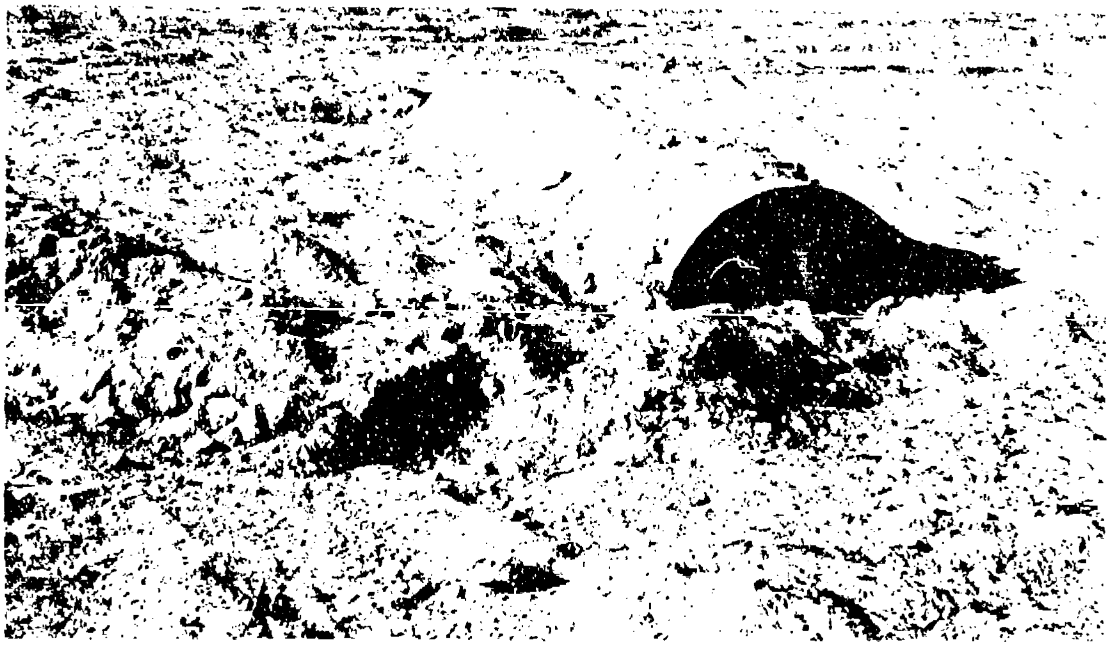


Fig. 5.9 Structure B-4 After Shot Charlie (metal-arch - 3 ft. of earth cover)

5.2.3 Wood-arch Shelters

Earth cover was swept away to ground level and wood-arch shelters collapsed completely as a result of Shot Charlie (Figs. 5.10 and 5.11). Arch folded and in some cases pulled sidewalls in with them.

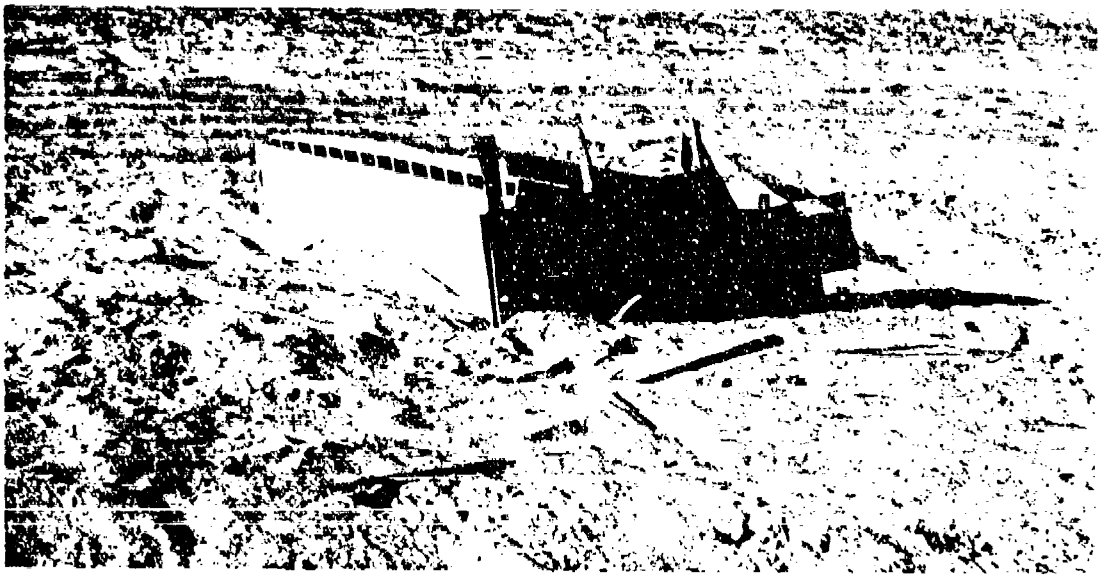


Fig. 5.10 Shelter C-1 After Shot Charlie (wood-arch)

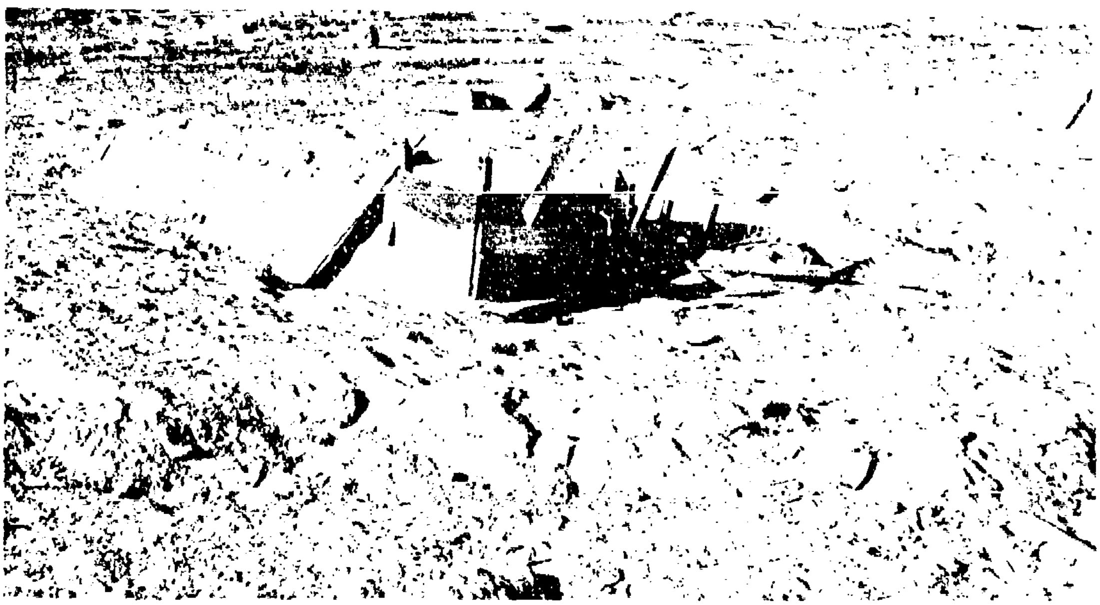


Fig. 5.11 Shelter C-3 After Shot Charlie (wood-arch)

TABLE 5.1

Effects of Shot C* on Shelter Structures

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Effects on Shelter
					Type A - Covered-trench
Group I - Below Grade - Basic Lehigh Design					
A-1	3'	760	590	1200	Moderate Damage. Shelter in good shape. Studs in front side pushed in 3/4". Entrance structure above grade smashed; debris partially blocking passage. Cover down 24".
A-2	2'	2500	920	2500	Moderate Damage. No additional damage to structure proper. Above-grade entrance construction demolished on blast side, other side damaged. Shelter accessible. Cover down 12" to 18"
A-3	2'	1000	760	1400	Light Damage. Shelter in good shape with only slight damage to entrance. Cover down 12" to 18". (Fig. 5.2).
A-4	3'	980	820	1400	Moderate Damage. Shelter proper in good shape. Above-grade entrance construction smashed. Shelter accessible but debris in entrance. Cover down 18" to 24".

*Charlie

TABLE 5.1

Effects of Shot C on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Effects on Shelters
					Type A - Covered-trench
Group II - Below Grade - Lightened Frame					
A-13	3'	980	580	1200	Heavy Damage. Structure intact. Entrance severely damaged. Cover down 24" to 30".
A-14	2'	700	600	1000	Heavy Damage. Front and end walls giving slightly. Cover reduced 15" to 18".
A-15	3'				Heavy Damage. Structure proper in fair shape. Front side giving way. Entrance completely collapsed and impassable. Cover reduced 24" to 30"
A-16	2'	3000	900	3400	Moderate Damage. Structure intact. No appreciable damage. Entrance in fair shape. Cover reduced 18".

TABLE 5.1

Effects of Shot C on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Effects on Shelter
					Type A - Covered-trench
Group III - Semi-buried - Lightened Frame					
A-9	2'	4000	1000	4000	Severe Damage. Shelter intact; top of entrance structure demolished; cover reduced to natural grade. Structure exposed.
A-10	3'	4000	1000	4000	Severe Damage. Shelter intact; top of entrance structure demolished; cover reduced to natural grade. Structure exposed.
A-11	2'	4000	1000	4000	Severe Damage. Shelter proper intact; entrance demolished; cover reduced to natural grade. Structure exposed.
A-12	3'	4000	1000	4000	Severe Damage. Shelter proper intact; entrance demolished; cover reduced to natural grade. Structure exposed.
A-17	3'	3400	900	2700	Severe Damage. Shelter proper intact; front section giving slightly but holding. Above-grade top of structure demolished; cover reduced to natural grade.
A-18	2'				Severe Damage. Shelter crushed, short side damaged; entrance structure on blast side completely demolished; cover reduced to natural grade. Structure exposed.

TABLE 5.1

Effects of Shot C on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Effects on Shelter
Type B - Metal Arch					
Group I - Below Grade - Basic Lehigh Design					
B-1	3'				Complete Destruction. End section and entrance demolished. Shelter filled with material.
Group II - Arch on Concrete Footing					
B-2	2'	1000	4000		No change in position of arch; arch completely stripped; some soil blown in open end.
B-3	2'	1000			End wall uncovered and opened up. Partially filled with soil; practically all cover removed.
B-4	3'	1000			Arch twisted to north; end section demolished; practically all cover removed.
B-5	3'	1000	3400		No change in arch; partly filled with soil; practically all cover removed.

TABLE 5.1

Effects of Shot C on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	Gamma Radiation F-2	Gamma Radiation F-3	Effects on Shelter
					Type C - Wood Arch
Group I - Semi-buried - Concrete Block Walls					
C-1	2'	1000			Complete Destruction. Arch folded completely with short side collapsed; walls intact; entrance completely demolished; cover reduced to natural grade. Structure exposed.
C	3'	1000			Complete Destruction. Arch folded in; both sides giving way. Concrete-block wall partially pushed in.
C-3	2'				Complete Destruction. Arch folded in; both sides giving way; cover reduced to natural grade. Structure exposed.
C-4	3'	1000			Complete Destruction. Arch folded in; both sides giving way; cover reduced to natural grade. Structure exposed.

5.3 RADIATION MEASUREMENTS

Gamma radiation readings at the shelters are shown in Table 3.2. Radiation dosages within the shelters were far above lethal (Table 5.1). Average readings are summarized in Table 5.2. These figures are of minor significance because of removal of cover and serious damage to shelters.

TABLE 5.2

Total Gamma Radiation in Covered-trench Shelters

Average Reading for Shot Charlie

Shelters	Original Earth Cover - 2 ft.		Original Earth Cover - 3 ft.	
	Shelter Area	Entrance Area	Shelter Area	Entrance Area
Below-grade	1210	2000	840	1340
Partly above-grade	2310	3800	2380	3570

Gamma radiation dosages recorded within shelters were far in excess of those normally occurring with the amount of earth cover remaining after Shot Baker. Since the shelters were approximately 1750 ft. from the bomb, the shock front, which arrived in less than a second, stripped additional cover from them before receipt of total dosage of radiation.

5.4 THERMAL RADIATION

The intensity of thermal radiation at equivalent distances to those of the shelters was 114 calories per square centimeter. Wood surfaces were charred and entrance panels showed indication of reflected heat. However, protection inside the shelters that survived appeared adequate. Action of thermal radiation prior to removal of earth cover by blast is shown in Figs. 5.2, 5.3, and 5.4. There were no signs of continued combustion.

CHAPTER 6

EFFECTS OF SHOT DOG

6.1 INTRODUCTION

Shelters were in poor shape for Shot Dog. The two previous explosions had stripped all earth cover and damaged structures. This greatly influenced the results and limited the use of data on this shot. Peak overpressures and radiation dosages from Shot Dog were greater than those from the previous explosions.

6.2 TEST RESULTS

The below-grade covered-trench, as well as the metal arches set in concrete, withstood the blast in spite of the lack of protective covering. All other structures were almost completely demolished. Damage is shown in Figs. 6.1, 6.2, and 6.3.

In below-grade covered-trench shelters, entrance construction, which was above the natural grade, was almost completely blown away. Considerable material was blown into the shelters and soil seeped through damaged structures. Debris, however, was stopped in the entrance areas. Deflection devices were generally not disturbed. In reduced-strength shelters partial failure of the front and end sections occurred when studs were joined to the roof section.

The cover was swept from metal arches and their end enclosures facing the blast were demolished. Destruction of the end sections permitted faster equalization of pressures and undoubtedly contributed to the resistance of the arches. Arch sections were tilted slightly, but otherwise undamaged.

Total radiation for Shot Dog is listed in Table 3.1. Radiation readings within shelters are listed in Table 6.1, but this information is of little value due to the lack of protective cover.

Thermal radiation intensities at distances equivalent to that of the shelters were approximately 155 calories per square centimeter. However, exposed wood sections did not burn.

Fig. 6.1 Below-grade Covered-trench Shelters After Shot Dog. Structure A-1 in Foreground

Fig. 6.2 Metal-arch Shelters After Shot Dog

Fig. 6.3 Metal-arch Shelters After Shot Dog

TABLE 6.1

Effects of Shot D*on Shelter Structures

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Effects on Shelter
Type A - Covered-trench					
Group I - Below Grade - Basic Lehigh Design					
A-1	3'				Heavy Damage. Shelter proper intact; studs in front side holding but pushed in 4" to 6". Entrance structure demolished above grade and shelter 1/3 filled with soil. Access blocked.
A-2	2'	4000	1000	4000	Heavy Damage. Shelter proper intact; studs in front and end sections holding but pushed in slightly. Entrance structure above grade demolished and considerable soil deposited in shelter entrance.
A-3	2'	4000	1000	4000	Heavy Damage. Shelter proper intact; studs in front and end sections giving slightly, but holding. Entrance structure above grade severely damaged permitting soil to flow in.
A-4	3'				Heavy Damage. Shelter proper intact; front section pushed in slightly. Entrance severely damaged; below-grade construction splintered, blocked; considerable soil in shelter.

*Dog

TABLE 6.1

Effects of Shot D on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Effects on Shelter
Type A - Covered-trench					
Group II - Below Grade - Lightened Frame					
A-5	3'				Severe Damage. Shelter intact. Entrance collapsed completely; not accessible. Considerable material in shelter.
A-6	2'				Severe Damage. Shelter filled to roof with material. Although apparently intact inspection impossible. Entrance on blast side failed completely.
A-7	3'	2700	1000	3500	Severe Damage. Partial collapse of front side. End studs giving way. Entrance above grade demolished, below grade in good shape. Considerable material in shelter.
A-8	2'	3000	940	2700	Severe Damage. Shelter intact. Entrance above grade demolished; stud on entrance side split. Considerable material in shelter.

TABLE 6.1

Effects of Shot D on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	Gamma Radiation F-2	Gamma Radiation F-3	Effects on Shelter
					Type A - Covered-trench
Group II - Below Grade - Lightened Frame					
A-13	3'	3000	960	2700	Severe Damage. Shelter intact but front and end sides giving way. Top of entrance demolished. Considerable material in shelter.
A-14	2'				Severe Damage. Roof and wall damage slightly increased. Top of entrance demolished. Considerable material in shelter.
A-15	3'				Severe Damage. Shelter exposed. Up-ended 15 degrees from ground zero.
A-16	2'				Severe Damage. Shelter exposed. Up-ended 20 degrees from ground zero.

TABLE 6.1

Effects of Shot D on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Effects on Shelter
Type A - Covered-trench					
Group III - Semi-buried - Lightened Frame					
A-9	2'				Complete Destruction. Entrance folded; remainder demolished.
A-10	3'				Complete Destruction. Entrance folded; remainder demolished.
A-11	2'				Complete Destruction. Only scattered lumber left to mark entrance; trench completely filled.
A-12	3'				Complete Destruction. Only scattered lumber left to mark entrance; trench completely filled.
A-17	2'				Complete Destruction. Structure demolished; trench filled in.
A-18	2'				Complete Destruction. Structure demolished; trench filled in.

TABLE 6.:

Effects of Shot D on Shelter Structures (Con't.)

Shelter Number	Earth Cover	Gamma Radiation F-1	F-2	F-3	Effects on Shelter
Type B - Metal Arch					
Group I - Below Grade - Basic Lehigh Design					
B-1	3'				Complete Destruction. No change; structure completely stripped.
Group II - Arch on Concrete Footing					
B-2	2'				Arch tilted away from ground zero; end section demolished; partially filled with material.
B-3	2'				Arch tilted away from ground zero; end section demolished; completely filled with material.
B-4	3'				Arch tilted towards ground zero; end section demolished; partly filled with soil.
B-5	3'				End section demolished; completely filled with soil.

CHAPTER 7

DISCUSSION

7.1 REACTION OF SHELTERS

Since structures tested in Shots Baker, Charlie, and Dog were not located with a view toward providing protection, an understanding of the reasons for their behavior under test conditions is of primary importance.

7.2 EARTH-ARCH ACTION

The covered-trench shelters were designed to resist blast pressures by beam action of the roof alone. It was assumed that practically all resistance to the pressures in metal-arch shelters would come from arch action, but it appears reasonable to believe that such action did occur.

The soil at the test site lacked cohesive properties after being disturbed. However, the natural angle of repose of earth cover was at least 45 degrees. This would indicate an internal friction angle of at least 35 to 40 degrees, sufficient for the soil to carry the necessary compressive stress for earth-arch action.

If earth-arch action occurred, its effectiveness was greatly reduced by the amount of earth cover removed by each explosion and structures were stripped by the second. This would partially account for the poor resistance of arch-type shelters. Covered-trench shelters which did not depend on arch action were less seriously affected by successive explosions and indicated ability to resist pressures corresponding to the theoretical values for which they were designed.

7.3 PROTECTIVE VALUE OF COVER

Additional test data is needed on the reaction of earth cover. The test results do not show the effect of earth-arch action or whether the resistance of the mass of the earth cover contributed to the ability of structures to withstand blast. However, results did show that damage to structures was less severe when protected by even a small amount of cover. This was particularly evident where entrance structures were poorly protected but survived when covered. It appeared that if earth cover were below natural grade, it would not be greatly affected by blast. Thus lowering grade level of shelters would add considerably to their safety.

The reaction of the earth cover affected not only the structural resistance of the shelters, but also their ability to protect against radiation. Reduced cover on the second and third explosions greatly increased radiation dosages within the shelters. Test structures were located sufficiently close to the three explosions to receive the shock an appreciable interval before all gamma radiation was absorbed. On Shot Baker, shelter A-1 was 1,658 ft. from the explosion (Table 3.1). It is estimated [1] that the shock front should have arrived at the structure in approximately 0.6 seconds. Since only 50 percent of total radiation dosage is received in one second, [2] the removal of one foot of cover by blast action undoubtedly affected total radiation in the shelter. This may have increased radiation dosages and partially account for unusually high readings on Shots Charlie and Dog.

7.4 DEFLECTION OF STRUCTURAL MEMBERS

Data obtained on deflection of structural members of shelters was of limited value. They undoubtedly were affected by shifting and twisting of the shelters and inaccuracy of improvised method of instrumentation. It has been possible to check some of these readings with the computed values for the covered-trench shelter. These results show a possible error of 50 percent. For example, a center line deflection of 2/32 of an inch in the roof joists of shelters A-1 and A-3 should result from a pressure of 10 pounds per square inch. Actual deflection on Shot Baker for a pressure of 8 pounds per square inch was 2/32. When the effect of partial elastic action of the wood is included, this discrepancy amounts to an error of approximately 50 percent. However, partially because of variation in amounts of earth cover removed, readings provide no indication of earth-arch action or protective value of earth cover.

7.5 PRESSURES INSIDE SHELTERS

Design of the shelter structures was based on the assumption that no resistance was provided by pressures developed within the shelter. If resistant pressures of the magnitude recorded were effective, they would have considerably increased the resistance of the shelters. However, instruments used to record these readings are not considered reliable and further tests should be made to check the accuracy of these data.

---

[1] The Effects of Atomic Weapons, Page 54, Fig. 3.13 f.

[2] The Effects of Atomic Weapons, Page 238, Fig. 7.46.

CHAPTER 8

CONCLUSION

8.1 PROTECTIVE VALUE OF SHELTERS

The below-grade covered-trench shelters provided protection against blast and thermal effects of Shot Baker. Total gamma radiation dosage within the shelters (average 150 - 175 r) exceeded a desirable value of 100 r, but was considerably below the median lethal dosage. Structurally, basic designs of this type of shelter withstood the effects of the three explosions, but gamma radiation for Shots Charlie and Dog would have been fatal to an occupant. Discounting the damage resulting from accumulated effects of successive explosions, the basic shelters resisted peak pressures of approximately 15 pounds per square inch. They should be capable of withstanding blast effects at one-half mile from the ground zero of a nominal bomb exploded at optimum height. At this location the 3 ft. of earth cover would be less than required to reduce total gamma radiation to 100 r.

In the partly above-grade covered-trench shelters, radiation dosages from Shot Baker increased to between 200 and 300 r. These shelters were capable of providing protection against blast and thermal effects, but damage was more severe. Under conditions limiting construction, shelters of this type should be used only with the knowledge that the degree of protection has been considerably reduced.

Partial failure of the end section of the metal-arch shelter occurred in Shot Baker. This failure would not have imperiled the life of an occupant, but it contributed to the destruction of the shelter in Shot Charlie. Despite the failure of the test structures, this type of shelter should provide good protection.

Wood-arch shelters collapsed completely in Shot Charlie, partly because of the reaction of the earth cover. Their failure, however, indicated that the proposed design of the wood arch should be modified.

Information on the reaction of the basement lean-to shelter was not obtained due to the inadequacy of the test structures. The structure simulating the basement of a private house should be redesigned, and additional tests made to determine the resistance of shelters of this type.

8.2 RESISTANCE OF STRUCTURES

Wood shelters offered good resistance to blast provided they were properly protected by earth cover. They did not burn and their resiliency permitted them to absorb shock without failing completely. Corrugated metal pipe sections also resisted greater pressures than anticipated, as evidenced by the arch sections set in a concrete foot[illegible]

The tests indicated that reducing the strength of the shelters was not justified. The increased spacing in studs and joists in the covered-trench shelters caused some of the structures to twist. Structural members were cracked, and end and front sections showed a greater tendency to fail. Savings on lumber were minor, and test structures failed to withstand the three explosions.

The partly above-grade shelters offered considerably less protection from blast than the below-grade type, and nuclear radiation dosages were much higher. Damage to entrance structures was particularly severe because of the reaction of the earth cover.

The entrances of all structures were considerably weaker than the shelters proper. Entrances to the arch-type shelters proved weaker than other types. They collapsed completely on Shot Baker. On the next two shots practically all above-grade entrance construction was demolished and blown away. Gamma radiation readings showed that these areas could not be used for shelter purposes. They did, however, effectively block off thermal radiation and there was no indication of material being disturbed within the shelters. Debris thrown into the shelters was trapped in entrances and would not have injured occupants. It did block access to many of the shelters and escape would have been hazardous. Some of the damage to the entrances was superficial and did not affect the protective value of the shelters, but all should be redesigned to provide resistance comparable with the capabilities of the rest of the structures.

The end and front sections of the covered-trench shelters showed a tendency to fail where they were joined to the roof sections. Since these structures were tied together only by toenailing wall studs to the roof joists, failure was more severe where the spacing of the studs was increased. This weakness can and should be corrected.

Various sections of the metal-arch shelter showed a tendency to pull apart. They should be joined more securely. End sections partially gave way in Shot Baker because of the failure of supporting stakes. Since this also occurred in one of the wood-arch shelters, it was not attributed to faulty construction, but rather to design. Supporting members were not tied into the structure.

8.3 REACTION OF EARTH COVER

Large quantities of earth cover were removed by each explosion. Amounts of cover blown off by Shot Baker varied from 30 to 60 percent of the total cover. These quantities varied with elevation of structures with respect to natural grade. Partly above-grade shelters were affected to a greater extent. This undesirable reaction was serious for it not only affected protection against radiation, but also resistance of the structures to blast

Total gamma radiation dosages from test shots were sufficiently large that the 3 ft. of earth cover did not provide desired protection. Even in terms of one-half mile from a nominal bomb at optimum height, radiation dosages were such that 3 ft. of earth cover was slightly less than required. Since the blast preceded total gamma radiation dosages, only a portion of the earth cover was effective. This may have slightly increased radiation dosages within the shelters.

Test results did not show whether earth-arch action occurred in the cover over the shelter structures. Indications are that conditions would permit such action. However, it was impossible to determine whether earth-arch action was effective because of blast action of successive shots. Whether the mass of earth cover contributed anything to resistance of the shelters to blast pressures is not substantiated by data. The protective cover did, however, greatly reduce damage to shelter structures.

8.4 ORIENTATION OF SHELTERS

Orientation of the covered-trench shelters had a major effect on their protective value only where the front faced the explosion. Since this was the weakest side of the structure, this shelter suffered considerably more damage than others of similar construction. Radiation dosages within this shelter were also considerably higher than in shelters facing in other directions. Greater damage to the entrance was the probable cause.

Scorching of parts of the entrance panels not directly exposed to the blast indicated the possibility of heat reflection of some magnitude. However even in the shelter where the entrance side faced the blast, there was no evidence of heat entering the shelter proper. Hence, entrances as designed should provide protection against thermal radiation even if facing the blast.

8.5 SHEATHING REQUIREMENTS

The results obtained from the substitution of materials were satisfactory. Chicken wire and tarpaper sheathing for the sides of shelters were adequate where the spacing of supporting members was not too great. Reduction in the rigidity of the shelter, because of the substitution of chicken wire and tarpaper for one inch wood sheathing, is not considered serious in structures of basic design. The method of joining wood sheathing to other types of materials, such as the metal arch, should be improved. Concrete-block sidewalls of wood-arch shelters also proved satisfactory when built below grade. Walls of the wood-arch shelters (concrete-block set in mortar) failed. This was partially due to the collapse of the wood arches, but use of unreinforced concrete-block walls is not recommended.

CHAPTER 9

RECOMMENDATIONS

9.1 INTRODUCTION

Damage to the test shelters was so severe that data was not conclusive on all items. This data should be obtained by additional tests with improved methods of instrumentation. The unusual test conditions also disclosed a number of weak points in the structures which contributed to their failure.

9.2 DESIGN RECOMMENDATIONS

A number of minor modifications in the shelters should improve their ability to provide protection. It is recommended that the following be considered in redesigning shelters:

(a) Effective thickness of earth cover.

1. Removal of cover by blast action.
2. Practical methods of stabilizing earth cover.

(b) Entrances.

1. Increased strength of entrance construction.
2. Utilization of protection from earth cover and below-grade construction.
3. Elimination of long unsupported studs.
4. Improved methods of fastening batterboards and spreaders.

(c) Design of end and front sections.

1. Provision of bearing for studs in joining end and front sections to the roof of the covered-trench shelters.
2. Proper fastening of structural members in the end sections of the arch shelters to the rest of the structure.

(d) Elevation of shelters.

1. Methods of avoiding an abrupt change in grade.
2. Lowering the grade of metal-arch shelters.

9.3 TEST REQUIREMENTS

Knowledge gained of the reaction of the shelters under the unusual conditions at the test site should be helpful in planning future tests. Additional tests should be made to obtain conclusive data on the following:

(a) Effect of pressures inside the shelters.
(b) Resistance provided by earth-arch action.
(c) Resistance of the mass of earth cover to transient loads.
(d) Shielding against neutron and thermal radiation.
(e) Adequacy of concrete-block construction.
(f) Reaction of strengthened entrance structures.
(g) Protective value of metal-arch shelters.
(h) Effect of the blast on typical basement construction.
(i) Reaction of other types of family shelters.

9.4 CONCLUSION

The tests showed that small shelter structures are potentially capable of providing a degree of protection commensurate with the requirements of civil defense. They are not as easy to build as generally believed, but they are of a type that can be built by the average householder. The test structures can be modified to avoid much of the damage that occurred in the tests. This should provide much safer shelters for civil defense purposes.

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