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TR 1468-TR (EX)

EXTRACTED VERSION

AD A995098

FIELD FORTIFICATIONS TEST EXERCISE DESERT ROCK VI

Project 8-12-75-001

2 November 1956

Nevada Test Site

NOTICE

This is an extract of TR 1468-TR, Field Fortifications Test Exercise Desert Rock VI, which remains classified RESTRICTED DATA as of this date.

Extract version prepared for:

Director
DEFENSE NUCLEAR AGENCY
Washington, D.C. 20305

1 January 1981

DEFENSE NUCLEAR AGENCY
WASHINGTON, D.C. 20305

TITL

SUBJECT: Corrections for Extract Version of Classified Reports

Defense Technical Information Center
ATTN: Mr. Charles E. Gould
Cameron Station
Alexandria, Virginia 22314

1. Reference is made to the following versions of classified reports recently distributed to you:

AD-A995098 TR 1468-TR (EX), Field Fortification Test Exercise Desert Rock VI Project 8-12-75-001

AD-A995094 Operation Sandstone Nuclear Explosions - 1948, Scientific Director's Report - Volume 1, General Report.

2. The following corrections to these reports are requested:

Block 9 of the DD Form 1473 for report TR 1468-TR (EX) should be changed from Los Alamos Scientific Laboratory, Albuquerque, New Mexico to Engineer Research and Development Laboratories, Fort Belvoir, Virginia.

Block 9 of the DD Form 1473 for Operation Sandstone should read Los Alamos Scientific Laboratory, Albuquerque, New Mexico.

FOR THE DIRECTOR:

Sandra G. [illegible]
BETTY L. FOX
for Chief
Technical Library Division

Corrections made.
Per: [illegible]
DTIC/DDA 2
19 Jun '81

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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18. SUPPLEMENTARY NOTES

This report has had the classified information removed and has been republished in unclassified form for public release. This work was performed by the General Electric Company-TEMPO under contract DNA001-79-C-0455 with the close cooperation of the Classification Managment Division of the Defense Nuclear Agency.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Desert Rock VI
Instrumentation
Test Results
Air Blast Evaluation
Nuclear Radiation
Structural Damage
Damage Criteria

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

* Per: telecon w/Betty Fox, Chief, DNA Tech Libr'y. Div.: the Classifed References contained herein may remain. 5 Sept.'79
Vic LaChance
DDA-2

**Verified for Extracted Versions.
9 July'80
pfcooper, DTIC/DDA-2

FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is all currently classified as Restricted Data or Formerly Restricted Data under the provision of the Atomic Energy Act of 1954, (as amended) or is National Security Information.

This report has been reproduced directly from available copies of the original material. The locations from which material has been deleted is generally obvious by the spacings and "holes" in the text. Thus the context of the material deleted is identified to assist the reader in the determination of whether the deleted information is germane to his study.

It is the belief of the individuals who have participated in preparing this report by deleting the classified material and of the Defense Nuclear Agency that the report accurately portrays the contents of the original and that the deleted material is of little or no significance to studies into the amounts or types of radiation received by any individuals during the atmospheric nuclear test program.

Pages i and ii deleted

PREFACE

Authority was obtained for participation in Operation TEAPOT at the Nevada test site in 1955 under Project 8-12-75-001, "Tessie Jones."

Investigations of field fortifications as a part of Exercise DESERT ROCK VI, Operation TEAPOT, were made under the supervision of Mr. Nathaniel J. Davis, Jr., Project Engineer, in conjunction with other field work under the direction of Mr. John G. Lewis, both of whom are employed in Special Projects Branch, Engineer Research and Development Laboratories, Fort Belvoir, Virginia. Troops from the 95th Engineer Combat Battalion, Camp Desert Rock, performed the required construction with 1st Lt Guy E. Jester, from the Field Fortifications Section, The Engineer School, providing valuable assistance. The Ballistic Research Laboratories, the Chemical and Radiological Laboratories, the Evans Signal Laboratory, and the Naval Ordnance Laboratories provided essential support. Grateful acknowledgment is made to Dr. T. G. Walsh, Special Projects Branch, for contributing that portion of the discussion on nuclear radiation and to Mr. F. A. Pieper, Special Projects Branch, for contacts and planning required to establish blast instrumentation and for his assistance relative to evaluation of data therefrom.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SUMMARY

This report covers a field fortifications test conducted as a part of Exercise DESERT ROCK VI, Operation TEAPOT. The test objectives of this project were: to determine the protection afforded against atomic weapons by new field works which were designed for use against conventional weapons; to obtain data for modifications to these designs to gain better protection against atomic weapons; and to study design criteria, improve construction techniques, and develop concepts of tactical employment for field works applicable to future warfare.

The fortifications exposed to TEAPOT shot No. 12 (code named MET), a 400-ft tower burst with an expected yield of 28±3 KT, were machine gun emplacements and shelters. Post, cap, and stringer-type construction predominated. Peak overpressures to which the fortifications were actually subjected were 65, 48, and 37 psi.

Measurements of peak overpressures, gamma radiation, and neutron flux were made at several locations in the structures.

Tests revealed that the degree of structural damage at a given distance from ground zero (GZ) depends largely upon the elevation of the structure in relation to ground surface. The vulnerability of structures in descending order is: (1) structures located on the ground surface; (2) structures located partially below the ground surface; and (3) structures located totally below the ground surface. The damage to surface and semisurface structures from lateral or drag forces is at least equal to or more severe than the damage caused by vertical forces. Joints and fastenings play as significant a role in structure survival as do the materials themselves. Operation TEAPOT showed that field fortifications, especially below-grade-level shelters, can be constructed to withstand blast effects of moderate intensity, but the effects of both prompt nuclear radiation and, to a lesser extent, blast pressure inside the structures, will dictate the range at which occupants of these structures will survive. It appears that fighting emplacements of the semisurface type can survive at 30 to 40 psi overpressure; and that, depending on the entrances, shelters can withstand almost twice this amount. Current blast damage prediction methods in TM 23-200 are either overly pessimistic or do not include information on the damage to heavy timber structures of the type exposed in this project.

FIELD FORTIFICATIONS TEST

EXERCISE DESERT ROCK VI (U)

I. INTRODUCTION

1. Subject. This report covers a field fortifications test conducted as a part of Exercise DESERT ROCK VI, Operation TEAPOT, under Project 8-12-75-001, "Tessie Jones." The test objectives were: to determine the protection afforded against atomic weapons by new field works which were designed for use against conventional weapons; to obtain data for modifications to these designs to gain better protection against atomic weapons; and to study design criteria, improve construction techniques, and develop concepts of tactical employment for field works applicable to future warfare.

2. Background and Previous Investigation. Efforts to obtain atomic effects information on field fortifications began with Operation BUSTER JANGLE, one of the first of the atomic tests at the Nevada test site, in the fall of 1951. Prior to this Operation, atomic weapons effects on field fortifications were approximated by applying knowledge obtained from atomic detonations outside the continental limits of the United States (detonations over Japan and at the Marshall Islands). The U. S. Army began Exercise DESERT ROCK (its designation for participation in the atomic tests) with the Operation just mentioned. Exercise DESERT ROCK I through V was conducted in conjunction with Operation BUSTER JANGLE and with the two succeeding Operations, TUMBLER-SNAPPER and UPSHOT-KNOTHOLE. As a part of each of these exercises, field fortifications were exposed at varying distances from ground zero (GZ). Although these exercises furthered knowledge in this field, the recording of the effects on these fortifications was a mission secondary to troop indoctrination and observer orientation; as a consequence, the reports on the exercises included only a minimum of detailed information.

UPSHOT-KNOTHOLE Project 3.9 was an AFSWP field fortifications test conducted during continental atomic tests in the spring of 1953. In this test, considerable emphasis was placed on the importance of obtaining detailed information on the effectiveness of various materials used as revetment and overhead cover. The emplacements which were selected to provide this information were small command posts, machine gun emplacements, and two-man foxholes. The report on Project 3.9 (2) contains a summary of the reports on the DESERT ROCK exercises, as well as summaries of other related structure tests that have been conducted in conjunction with the various Operations, and the reader is referred to the aforementioned report for further information on past tests. Considered collectively, the tests prior to Operation TEAPOT determined, together with the objectives, distances from ground zero at which occupants of emplacements were considered to be safe. It was further determined that field fortifications provided protection, but only a limited quantity of conclusive information was obtained on the amount of protection afforded. Because of the need for additional information, this test, Project 40.15 was initiated. Project 40.15 originated as a result of coordinated efforts by the OCE and OCAFF whereby the Corps of Engineers would provide plans, materials, and construction supervision for a field fortifications project as a part of Exercise Desert Rock VI. It was intended that such a project would fulfill Exercise DESERT ROCK VI requirements for troop indoctrination and observer orientation and also would provide the Corps of Engineers with data from which to arrive at balanced field fortification designs. A balanced field fortification design is considered to be one capable of providing adequate protection from HE bursts as well as blast, radiation, and thermal effects of an atomic burst.

II. INVESTIGATION

The test was comprised of twenty fortifications exposed to TEAPOT shot No. 12 (code named MET), a 400-ft tower burst with an expected yield of 28±3 KT. Distances from ground zero were selected so that the structures would be subjected to peak overpressures of approximately 60, 40, and 20 psi. These values were considered of the right magnitude to cause varying amounts of damage from which the aforementioned objectives could be accomplished.

3. Description of Structures. The structures tested are listed in Table I; in this table, I, J, and K are three types of corrugated steel shelters which were positioned one each, of the three types, at each of the three ranges. These designs were included for test in the DESERT ROCK Exercise by the Exercise Director and have been made a part of this report. In general, these have been referred to as the Sixth Army structures.

Structures A, B, C, E, G, and TCS were constructed from plans drawn by the Field Fortifications Section, Pioneer Branch, The Engineer School (TES), Fort Belvoir, Virginia. These structures were designed for protection against conventional weapons only. The Type D structure was designed by the Pioneer Development Section, TES, Fort Belvoir, Virginia, to withstand approximately 23 psi peak overpressure from an atomic burst. The corrugated metal arch and the plywood dome, Types F and H, are ERDL designs. The former was included in the test to provide blast effects information on a structure constructed of materials normally available to Engineer troops in the field, and the latter was tested to provide data

Table I. Structures and Ranges

Type	Description	Expected Overpressure (psi)	Distance from GZ (')
A	7' x 7' Machine gun emplacement, dimension timber	60 40 20	1000 1150 1400
B	8' x 12' Modular shelter, dimension timber (two 8' x 6' sections)	60 40 20	1000 1150 1400
C	7' x 7' Machine gun emplacement, notched dimension timber	60 40 20	1000 1150 1400
D	9' x 20' CP type underground shelter, dimension timber	60 40	1000 1150
E	7' x 7' Machine gun emplacement, round timber	60 40 20	1000 1150 1400
F	5' Diameter arch emplacement, corrugated metal culvert, 12' long	60 20	1000 1400
G	8' x 12' Modular shelter, round timber (two 8' x 6' sections)	60 20	1000 1400
H	9' Diameter, prefabricated plywood dome	60 20	1000 1400
TCS	Covered trenches to provide entrance to types A, B, E, and G		
I	4' Diameter shelter, corrugated culvert, 10' long	60 40 20	1000 1150 1400
J	9½' Diameter arch shelter, corrugated metal, multiplate, 12' long	60 40 20	1000 1150 1400
K	14' Diameter section of Armco building, corrugated metal, 10' long	60 40 20	1000 1150 1400

which would serve as a guide for the development and design of new portable fortifications. Figs. 1 through 7 are isometric drawings of structures A, B, C, E, F, G, and H, respectively. Fig. 8 is a photograph of a scaled model of the Type D structure. For those structures requiring them, trench cover sections (TCS) are shown. Three bays of TCS were used in the entrance construction for both the modular shelters and the machine gun emplacements. The TCS were arranged so as to afford a right angle turn in the entrance to the modular shelters. Those structures that were constructed from TES plans required, in some instances, minor changes in design at the test site. These changes are reflected in the drawings.

Structures A, D, E, and G (entrances included) were sheathed with 24-gage, galvanized, corrugated steel (depth of corrugation ½ in. with 2-2/3 in. to the corrugation). The entrances to the B structures were also sheathed with corrugated metal; however, the shelters themselves were sheathed with 3-in. planking. A brief description of the primary structural components of each type structure is contained in Table II.

All dimension timber structures were constructed of No. 2 common or better, rough, yellow pine timbers. The greater number of these timbers were green as they had been cut only a few weeks before shipment to the test site. The round timber structures (E and G) were constructed of Douglas fir logs. These logs, although acceptable for construction of this type but not recommended for test purposes, left much to be desired. They appeared to be well seasoned (quite old), and if brittleness is considered as an indication of moisture, had a low moisture content. This condition is normally suggestive of increased strength, but here, certain conditions, probably weathering, had caused a prevalence of "checks" and "shakes." Checks and shakes do not affect members subjected to longitudinal compression, but they are detrimental in members subjected to bending in that they reduce the shear value.

Drawings of the Sixth Army structures are not available for inclusion in this report, but it is believed that the photographs of these structures together with a brief description are sufficient to portray to the reader the designs tested. Hollow bulkheads (2-in. by 4-in. studding sheathed on both sides with 1-in. by 6-in. plank) were constructed on both ends of the I and J structures and doors were provided in the entrance-end bulkhead. Both ends of the K structures were furnished with garage-type, metal doors; however, only one end afforded access because the other was backfilled. The K structures were further provided with 6-in. by 6-in. center posts at each end and separated by a 6-in. by 6-in. spreader that ran the length of the structure. These posts were intended to afford lateral support for the doors. The corrugated metal in the structures measured approximately 3/32 in. thick and was considered to be 12 gage.

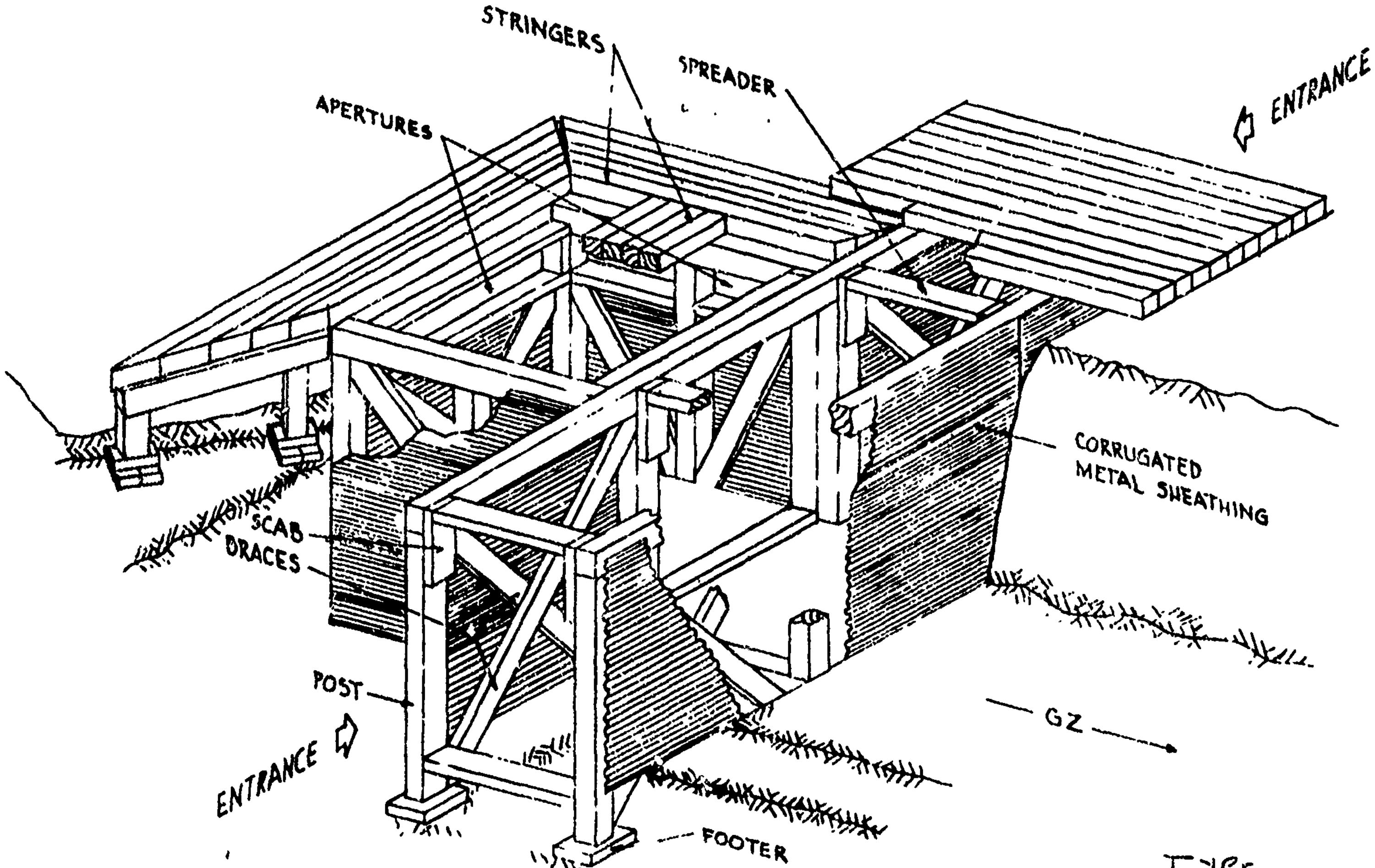

Fig. 1. 7' x 7' machine gun emplacement, dimension timber.

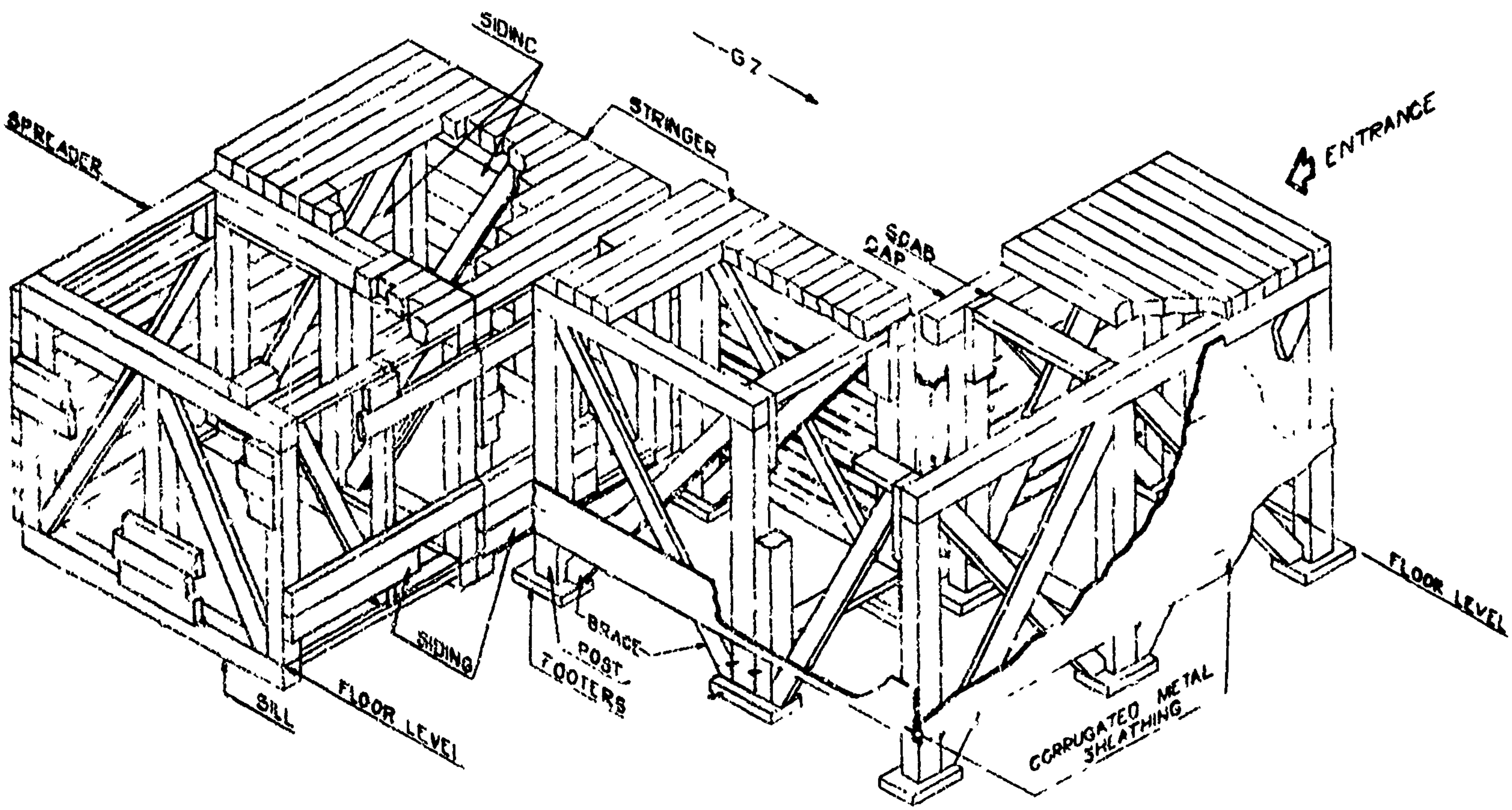

Fig. 2. 8' x 12' modular shelter, dimension timber (two 8' x 6' sections).

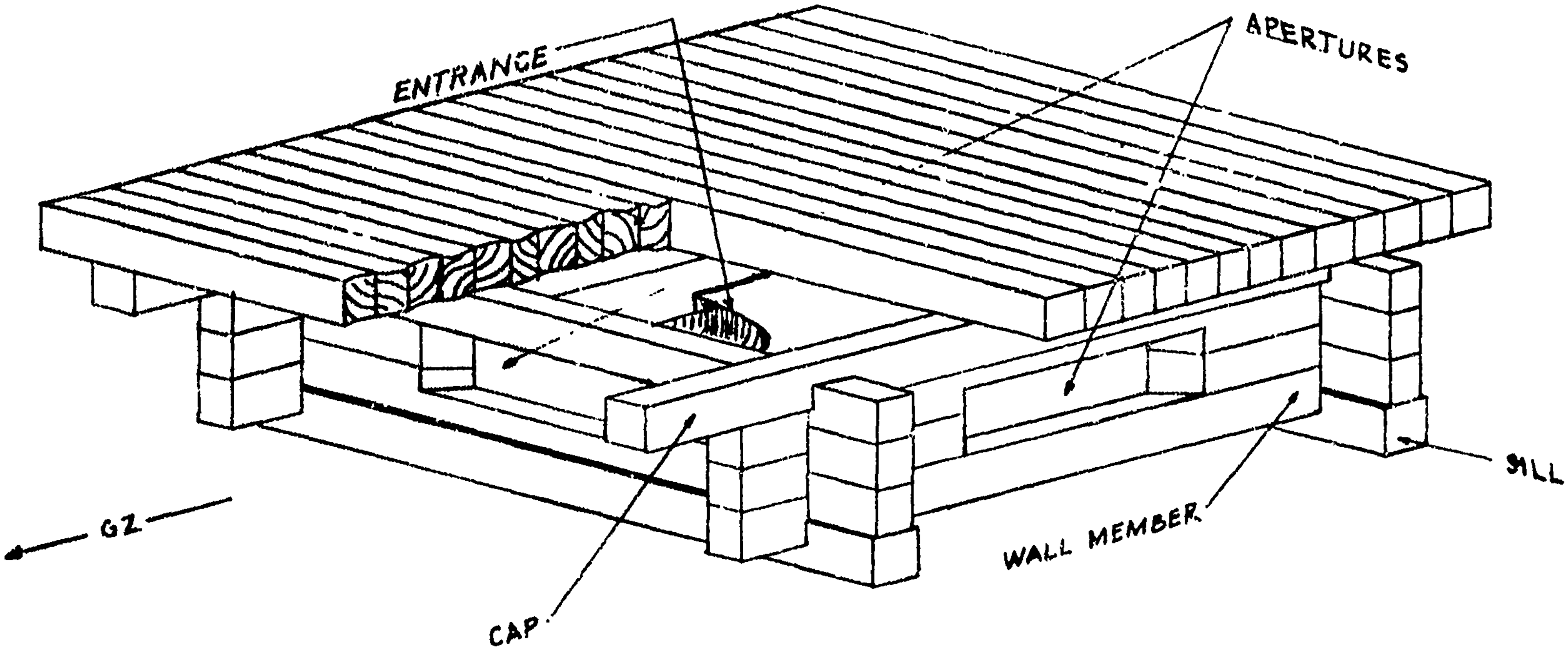

Fig. 3. 7' x 7' machine gun emplacement, notched dimension timber.

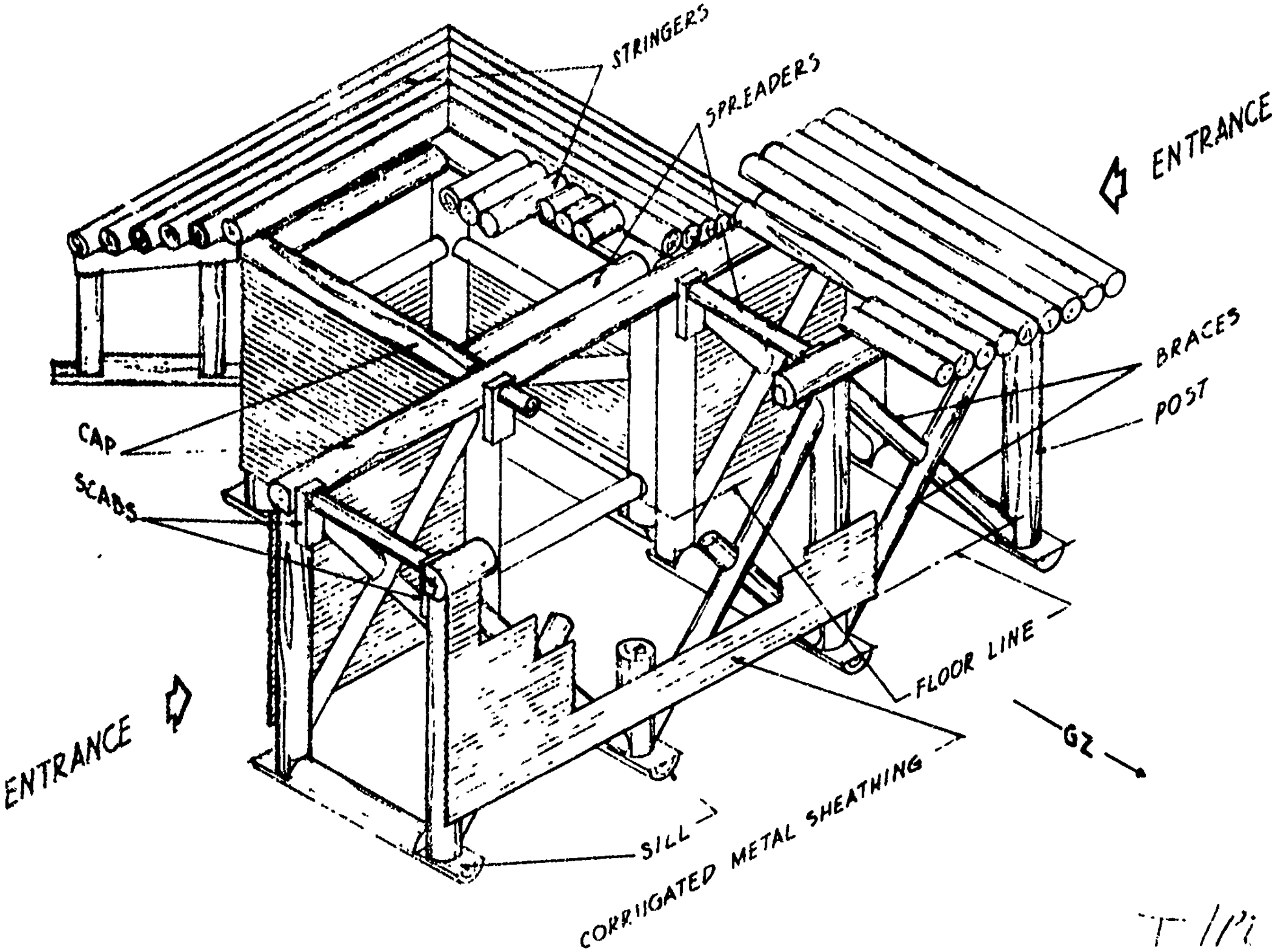

Fig. 4. 7' x 7' machine gun emplacement, round timber.

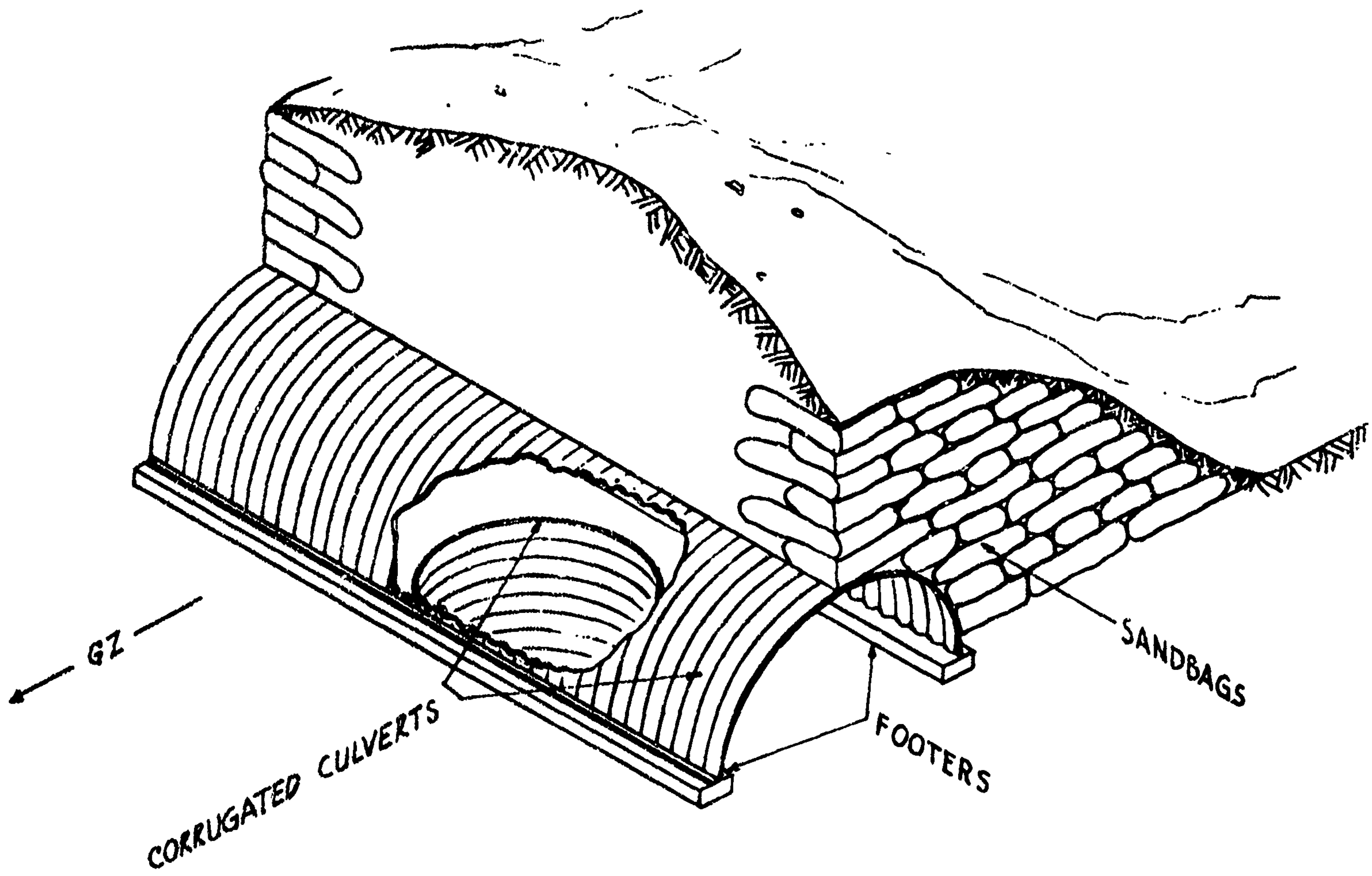

Fig. 5. 5' diameter arch emplacement, corrugated metal culvert sections, 12' long.

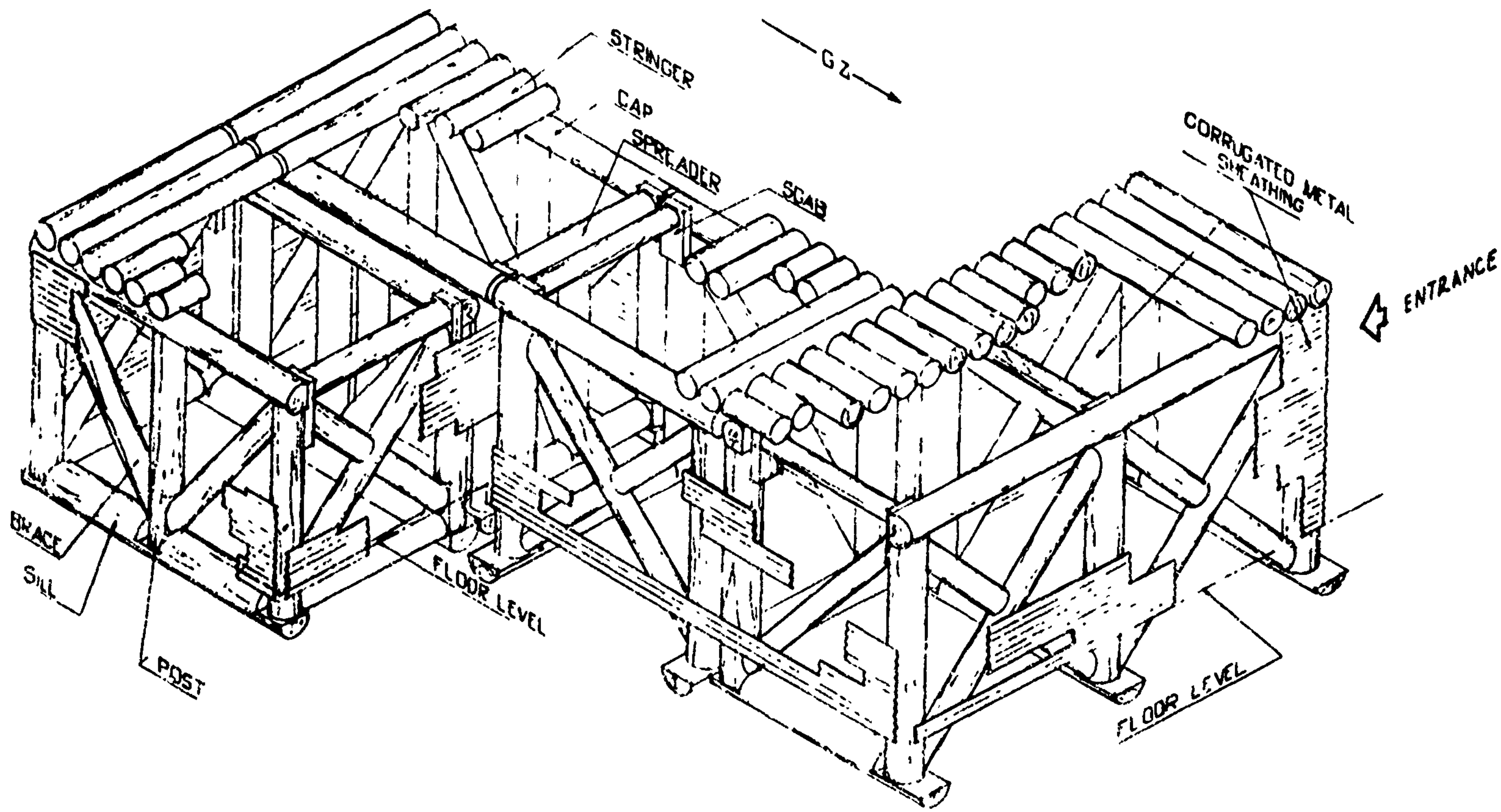

Fig. 6. 8' x 12' modular shelter, round timber (two 8' x 6' sections).

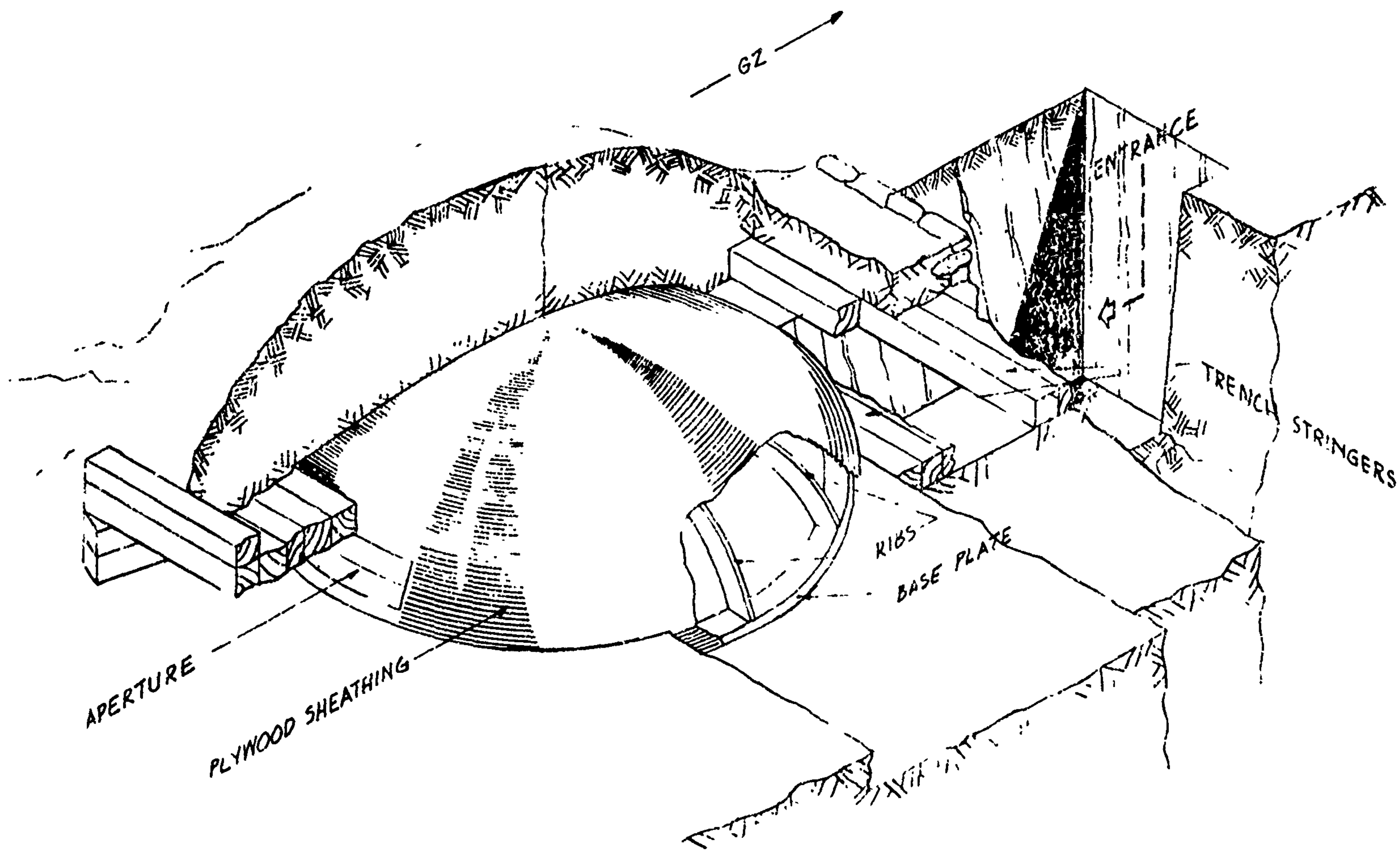

Fig. 7. 9' diameter, prefabricated plywood dome.

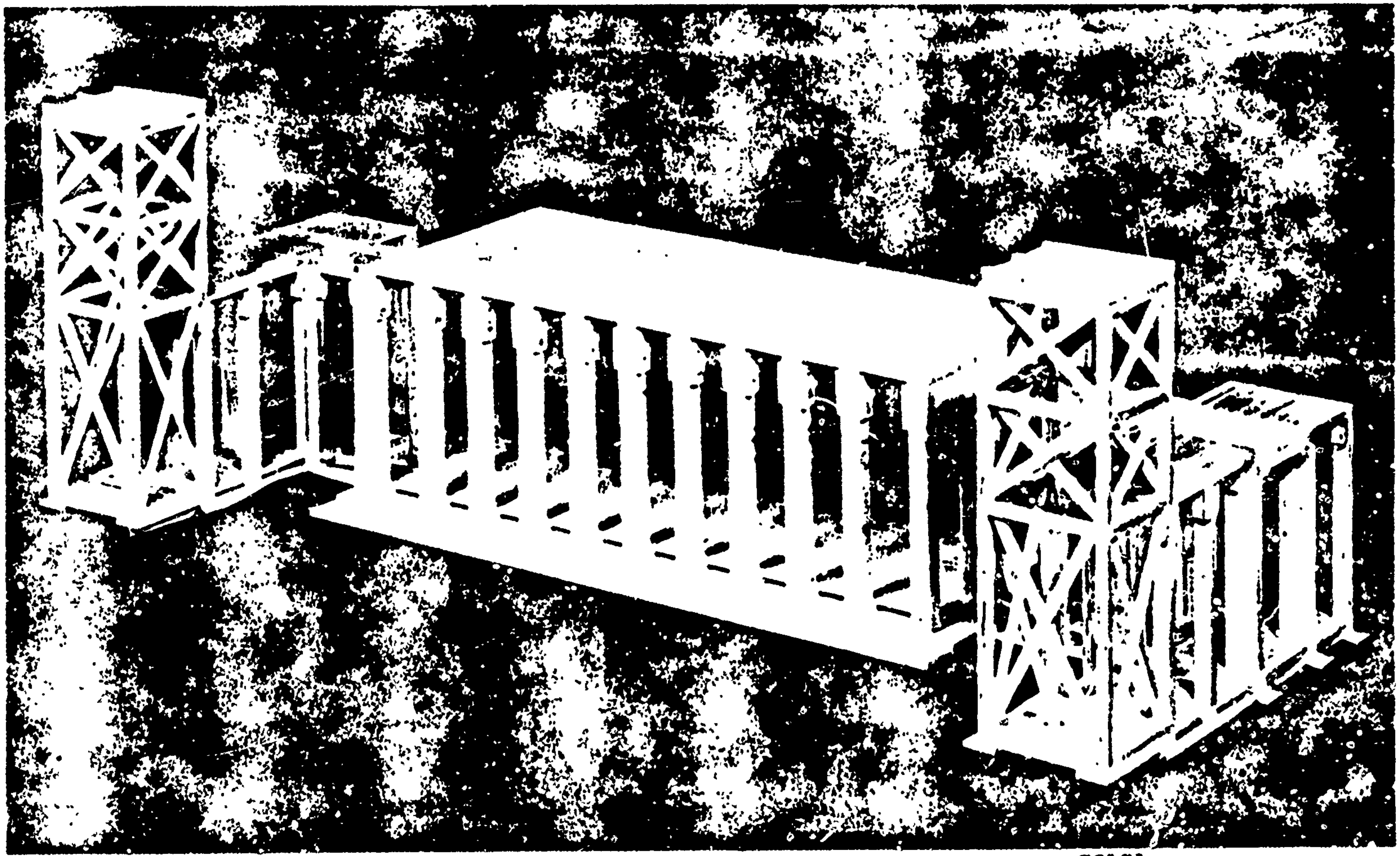

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Fig. 8. 9' x 20' CP type underground shelter, dimension timber.

Table II. Description of Primary Structural Components

Structure	Item	Description*
A	Cap	6" x 8" x 7'-0"
	Sill	6" x 8" x 7'-0"
	Post	6" x 6" x 6'-4"
	Stringer	6" x 6" x 7'-0"
	Spreader	3" x 6" x 6'-0"
	Drift pin	½" x 16"
B	Cap	6" x 8" x 8'-0"
	Sill	6" x 8" x 8'-0"
	Post	6" x 6" x 5'-10"
	Stringer	6" x 6" x 6'-0"
	Siding	3" x 6" planking
	Drift pin	½" x 14"
C	Cap	8" x 8" x 11'-6"
	Sill	8" x 8" x 10'-0"
	Wall member	6" x 8" x 10'-0"
	Stringer	6" x 8" x 10'-0"
D	Cap (room)	8" x 10" x 10'-4"
	Post (room)	8" x 8" x 6'-10"
	Footers (room)	2" x 12" plank placed on 3" x 8" x 4'-0" subfooters
	Cap (passage)	6" x 6" x 4'-0"
	Post (passage)	6" x 6" x 6'-6"
	Post (shaft)	4" x 4" x 13'-2" 4" x 4" x 6'-8"
	Spreader (shaft)	4" x 4" x 3'-4"
	Bracing (shaft)	2" x 4"
	Roofing	2" x 6" planking
E	Cap	11" dia. x 7'-0"
	Sill	13" dia. x 8'-0"
	Post	12" dia. x 6'-8"
	Stringer	9" dia. x 7'-0"
	Drift pin	½" x 16"
F	Metal arch	Composed of three 5' dia. 10-gage corrugated steel culvert sections, flanged, 4' long
	Vertical culvert lining	4' dia. 12-gage corrugated steel culvert, 4' long
	Footers	3" x 6" x 12'

Table II (cont'd)

Structure	Item	Description*
G	Cap	10" dia. x 8'-0"
	Sill	13" dia. x 8'-0"
	Post	10" dia. x 6'-0"
	Stringer	9" dia. x 6'-0"
	Drift pin	½" x 16"
H	Plywood covering	Total thickness 3/4" (3 layers of ¼" plywood)
	Ribs	Laminated construction, 2-3/8" x 4-1/8"
	Base plate	Laminated construction, 2-3/8" thick, 6" wide
	Cable	Base of dome encircled by ¼" steel cable
	Entrance roof stringers	6" x 6" x 5'-0" (stringers bearing on soil, span approx. 30")
TCS (dimension timber)	Cap	6" x 8" x 12'-8" (continuous through two spans)
		6" x 8" x 6'-4" (one span only)
	Post	6" x 8" x 7'-2"
	Spreader (top)	3" x 8" x 3'-6"
	Scab	3" x 8" x 2'-0"
	Stringer	6" x 6" x 10'-0" (clear span 4', overhang 2½')
	Footer	3" x 12" x 1'-6"
	Drift pin	5/8" x 16"
TCS (round timber)	Cap	11" dia. x 19'-0"
	Post	12" dia. x 7'-4"
	Spreader	7" dia. x 3'-6"
	Scab	3" x 8" x 1'-6" (cut from log)
	Stringer	9" dia. x 10'-0" (clear span 4', overhang 2½')
	Footer	12" dia. x 6'-8"
	Drift pin	½" x 16"
I	Contained elsewhere in this paragraph	
J	Contained elsewhere in this paragraph	
K	Contained elsewhere in this paragraph	

* Log diameters are average dimensions and exceed from 1" to 3" the diameters normally recommended for these structures.

4. Site Layout and Orientation of Structures. The MET shot was conducted on Frenchmen Flat. The structures were placed along three concentric arcs centered at ground zero with radii corresponding to the desired ranges. The layout of fortifications at the three ranges is shown in Fig. 9.

With the exception of the 7-ft by 7-ft notched dimension timber machine gun emplacement, Type C, those structures with firing

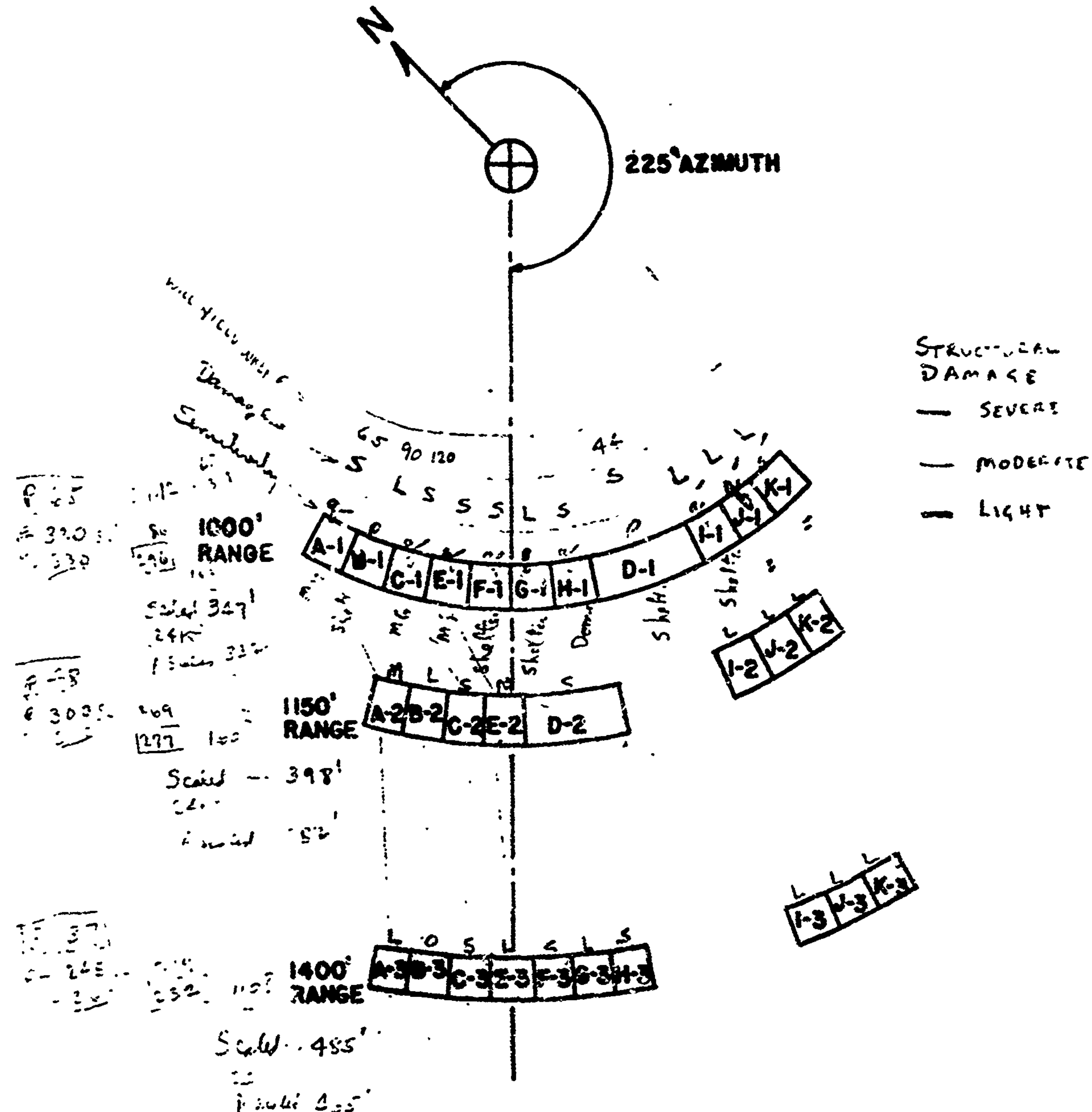


Fig. 9. Layout of fortifications relative to ground zero.

ports were oriented with firing ports facing away from ground zero; thus, the overhanging roof stringers over the front firing port were exposed to the full effects of the blast. Structures D and F were oriented with their principal axes normal to the line of blast with the vertical entrance shafts on the D structure toward ground zero. The Sixth Army structures were positioned with the entrances facing 90° away from, or normal to, the shock front.

5. Construction Techniques. All construction was performed by A Company, supplemented by a platoon from C Company, of the 95th Engineer Combat Battalion, Camp Desert Rock.

Before authority to begin construction at the test site was granted, the decision was made that some of the construction could be accomplished at another location and hauled to the site on a later date. Accordingly, Types A, B, and C, minus the entrance trenches, were constructed at Camp Desert Rock and hauled to the test site on 20-ton trailers. Handling and placement of the structures was accomplished with an M-59 wrecker. Some conjecture was made as to whether the hauling (to a distance of approximately 17 miles) and additional handling would weaken the structures, but subsequent inspections revealed no ill effects.

Excavation and construction at the test site was begun on 25 January 1955 and completed on 17 February 1955 at which time construction of Types I, J, and K was begun. The construction crew averaged approximately 65 men per day. Except for the excavations for the Type D structures which were slot dozed, all excavating was accomplished with hand tools. Air compressor tools, especially the clay spades, were used extensively. A clam shell was available but its use was limited to removal of loosened soil from the relatively deep excavations required for the modular structures.

Excavations for the Type D structures were slot dozed oversize to allow ample working space around the structure. The excavations for the other timber structures were dug 6 to 12 in. larger than the over-all dimensions of the structure with earth walls vertical and undisturbed. This did not allow sufficient work space to nail corrugated metal sheathing on that portion of structure below ground surface; consequently, the sheathing on the log emplacements and the dimension timber TCS was nailed only at above ground locations and at below ground locations accessible because of structure configuration.

The structures were backfilled and covered with the dry, noncohesive, desert soil. The backfill material was tamped dry; thus, tamping did little more than assure that no large voids existed behind the sheathing. Most of the cover was placed on the structures with equipment, final shaping being accomplished by hand.

Table III. Average Construction Time per Structure in Man-Hours and Equipment Hours

Structure	Excavation		Construction		Cover		Total	
	M-H per Structure	EH per Structure	M-H per Structure	EH per Structure	M-H per Structure	EH per Structure	M-H per Structure	EH per Structure
A	92.5	13.2C	117.5	5.2C	14.2	2.4D	224.2	18.0C 2.8D
B	264.7	6.0S 30.2C	240.5	2.0W 10.8C	2.3	2.3D	507.5	2.8D 6.0S 2.0W 2.3D
C	23.0	0.8C	40.5	1.5C	32.7	--	96.2	2.3C
D	79.5	2.0C 16.8D	444.3	12.0C	16.8	6.5D	540.3	14.0C 23.3D
E	93.8	81.2C	377.5	1.2C 6.0X	40.8	0.2D	512.2	6.0X 0.2D 9.3C
F	35.8	0.5C	14.5	--	33.0	2.5L	83.3	0.5C 2.5L
G	239.3	40.8C 14.0S	372.5	15.8C 11.5X	26.5	0.5D	633.3	51.5C 14.0S 11.5X 0.5D
H	37.5	5.8C	28.8	--	11.5	0.7D	77.8	5.8C 0.7D

Key to symbols:
C - air compress[illegible] [illegible]ith standard tools; S - 3/4-yd clam shell; X- gasoline-powered chain saw;
W - M-59 wrecker; [illegible] bulldozer; L - D-4 front loader.

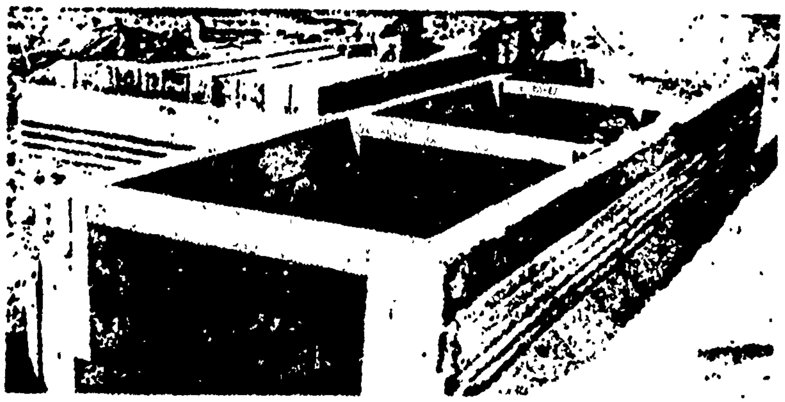
Note: Timbers for [illegible]es A, B, C, and D were cut at ERDL; M-H are not included.

It was intended that protection from radiation would be provided to the extent of that afforded by 5 ft of cover material. A cover design typical of that used for protection from HE shell bursts was not used, only soil. A layer of roofing paper was placed over each structure to prevent cover material from sifting through cracks into the structures. To attain and keep 5 ft of the dry, powdery soil over the center of many of the emplacements meant diverging somewhat from recommended sandbag placement. A rain near the completion of the construction phase of the test was beneficial because it caused the outer layer of cover material to crust and remain in place until test time.

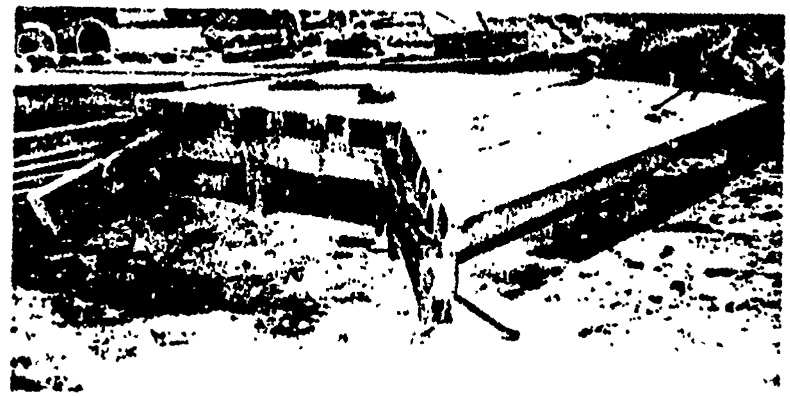
Day-to-day accounts were kept of the man-hours and equipment hours consumed in constructing each structure. The total requirements for the various structures have been averaged and presented in Table III to show the average effort required for one structure. Figs. 10 through 23 show random photographs taken during and after completion of the construction phase.

6. Instrumentation. Various fortifications were instrumented with available instrumentation to obtain measurements of air blast and nuclear radiation. No instrumentation was provided to measure thermal radiation.

a. Air Blast. Pressure measurements were made with BRL pressure-time (p-t) gages and NOL indenter gages. Twenty p-t gages were placed in eleven of the structures by personnel from the Ballistic Research Laboratories. It was desirable to use more than this number of p-t gages, but the supply was limited. These twenty gages were allocated to all but the log and Type C structures. Further, this meant that only one or two pressure-time records could be obtained per structure, except for the D structures which were allotted three gages each. The gages were placed on the floors of the structures and held in place with sandbags. The indenter gages, which measured peak pressure only, were mounted in the log structures (Types E and G) and the Type B structure, at 1400 ft. Indenter gages were also used to supplement the p-t gages in several of the other structures, namely, the two Type D structures and the Type A, at 1150 ft. Furthermore, placement of the indenter gages with the more accurate p-t gages would provide by comparison of pressure measurements, some indication of the dependence that should be placed on the indenter gage measurements in the log structures. The Type C structures were believed to be especially vulnerable to drag and therefore were not instrumented. The indenter gages were mounted in clusters of four with faces parallel to the floor surface on threaded lag screws in 6-in. by 6-in. wooden post mounts. These mounts were imbedded in, or firmly attached to, the floors of the structures. No gages were available for use with the Sixth Army structures.

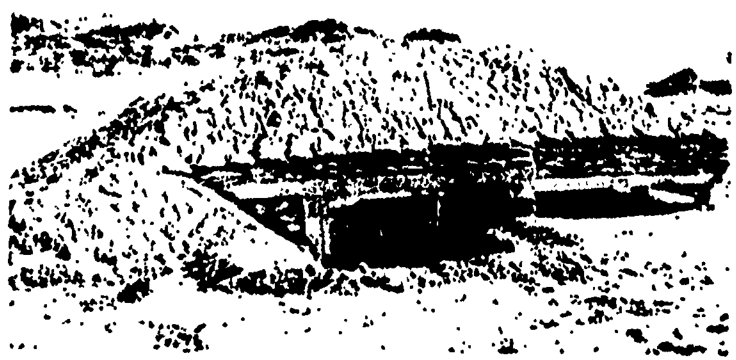


A12996
TCS construction, right entrance

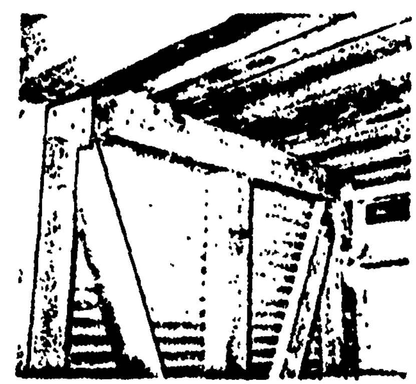


A12980
Looking toward front and side firing ports

A12878
Left to right through TCS

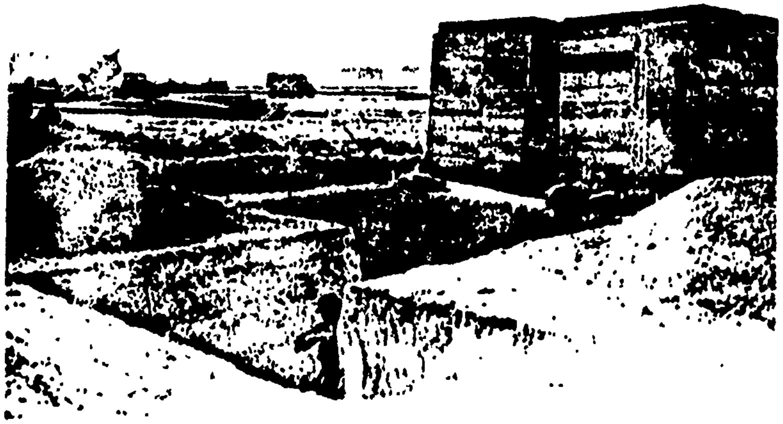


A13058
Left entrance, GZ. to left



A12881
Wall opposite side firing port

Fig. 10. Type A, various stages of construction.

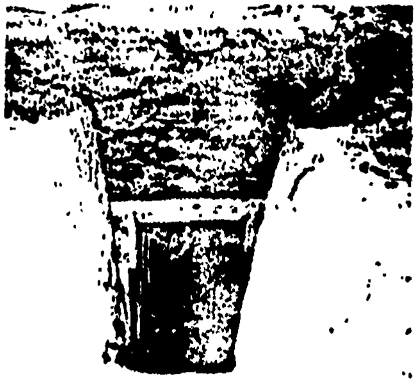


A12965
Modular sections complete, excavation in progress

A13113
Completed shelter

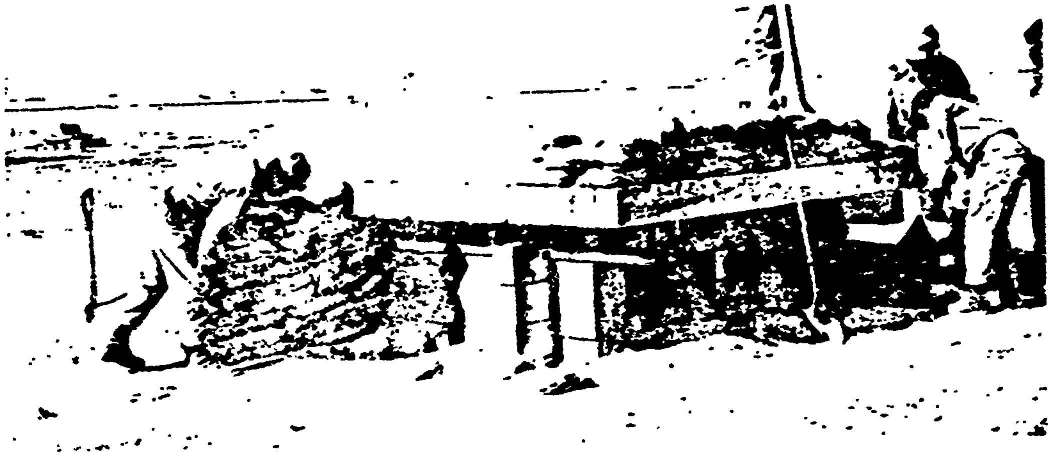
A12884
From TCS toward first modular section

A12885
Inside looking out



A12886
Entrance, GZ to left

Fig. 11. Type B, various views of structure.



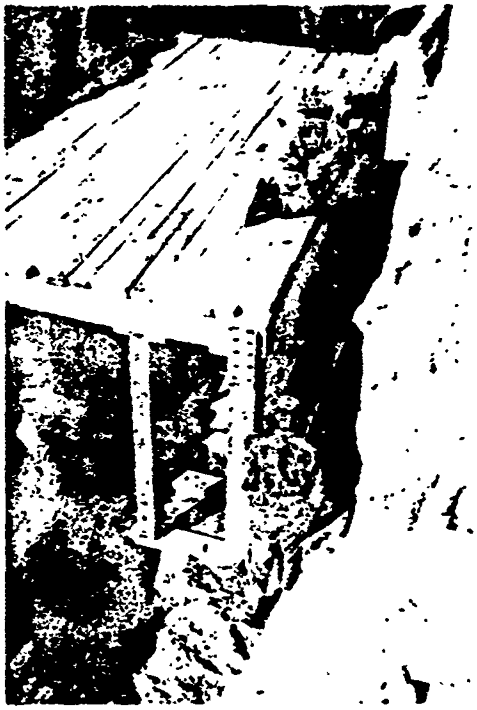
A12962

Nearing completion, GZ in direction of right foreground (note rabbit hole entrance under solid wall)

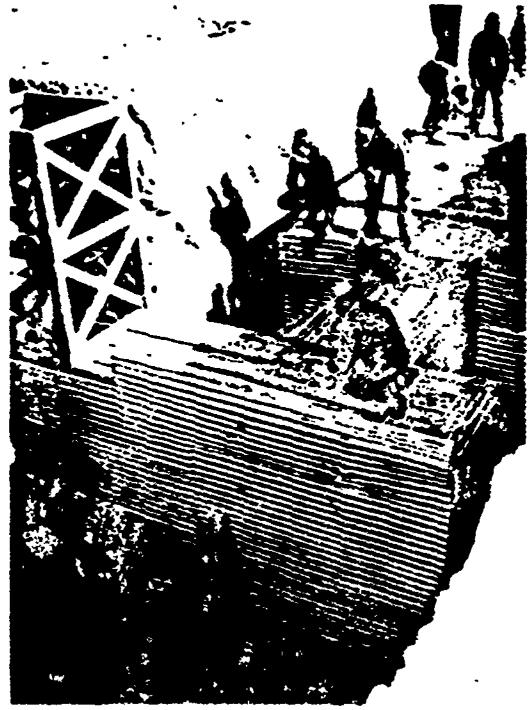
A13114

Completed, GZ in direction of left foreground

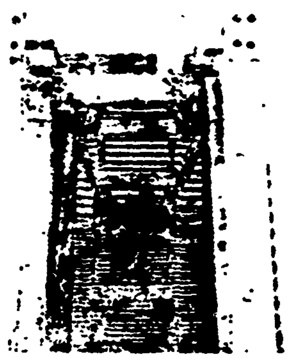
Fig. 12. Type C Structure.



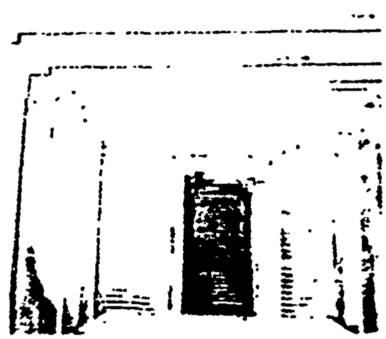
A13014
9' x 20' room, GZ to right



A13033
Entrance construction nearing completion, GZ in direction of left background



A12915
Entrance passage, looking toward vertical shaft and GZ

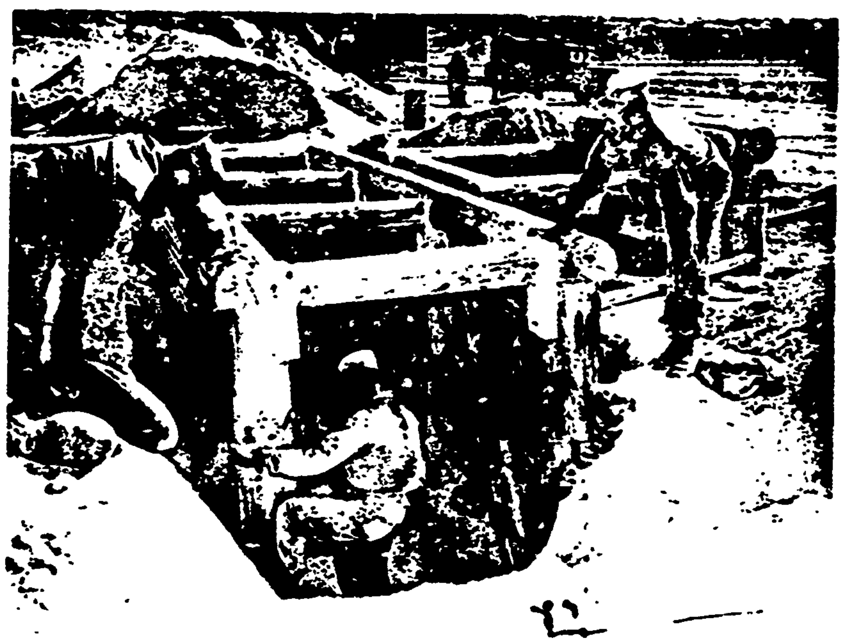


A12902
Interior of 9' x 20' room

Fig. 13. Type D, various views of construction.

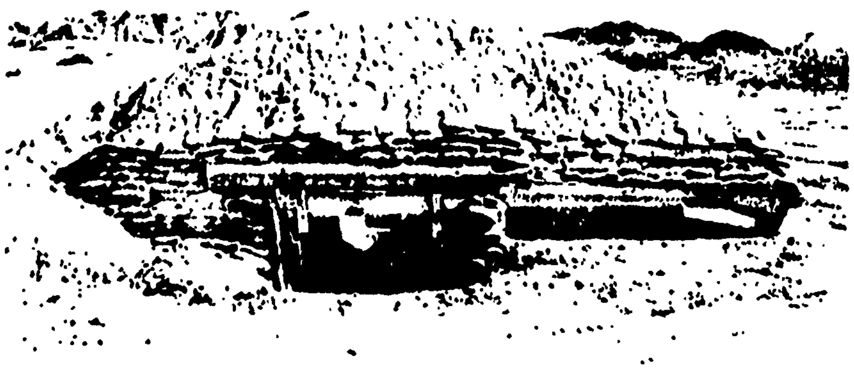
A13108

Fig. 14. Type D structure, before test, looking away from GZ (doors closed for test).



A13039

Fig. 15. Type E, under construction.

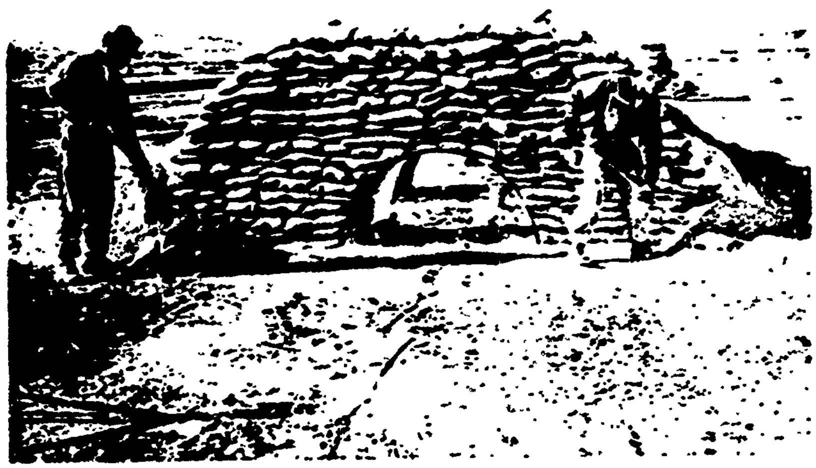


Left entrance, GZ to left A13061

A12890
Right to left through TCS,
GZ to right

Fig. 16. Type E, construction completed.

Under construction A12937



Nearing completion, GZ to right A12955

Fig. 17. Type F structure.

A12916
From TCS toward first modular section

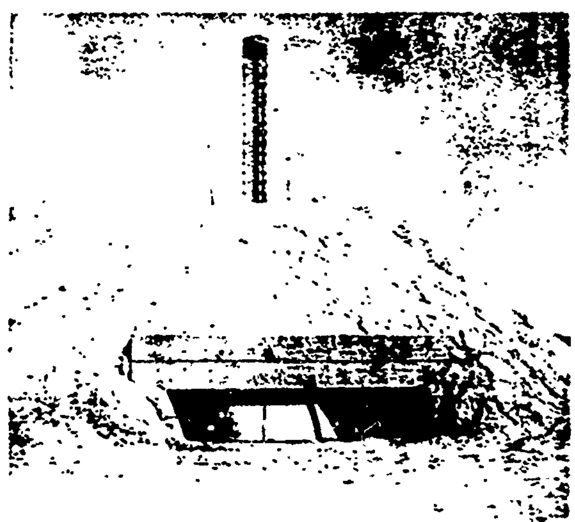
A12921
Entrance, GZ to left

Fig. 18. Type G structure.

A13023
Fig. 19. Type H, showing rib construction.

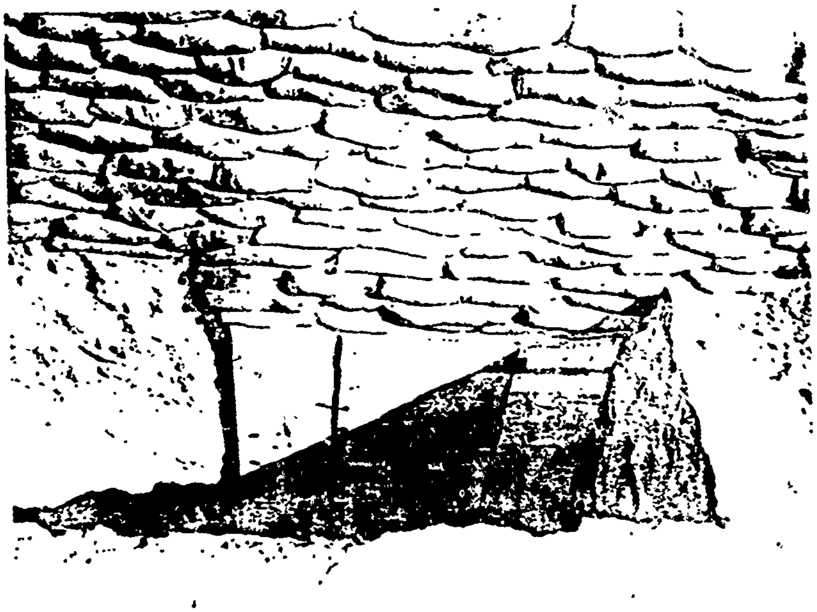
A13020
Placing cable around base of dome

A13016
Entrance



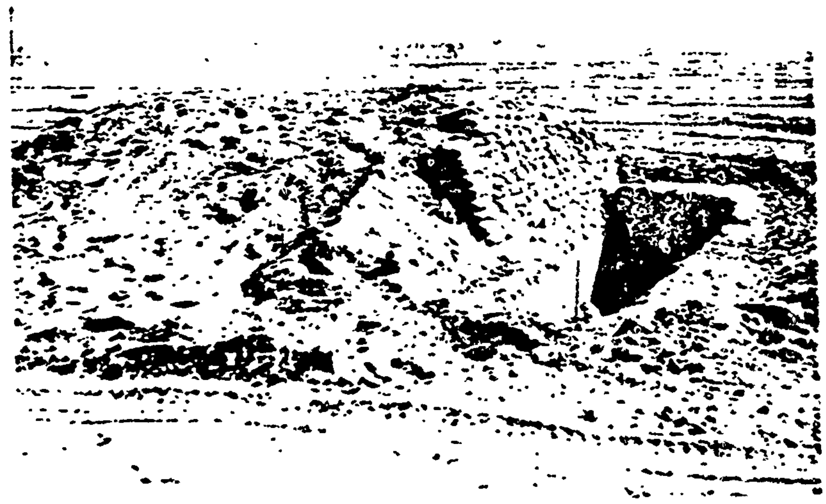
A12900
Structure completed, GZ in background

Fig. 20. Type H, various views of structure.



A13215

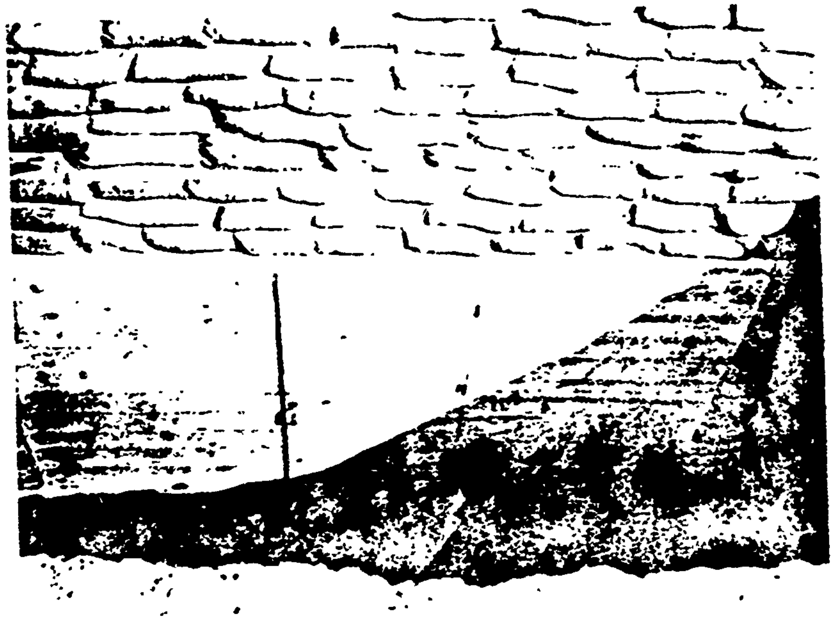
Entrance view, GZ to left



A13120

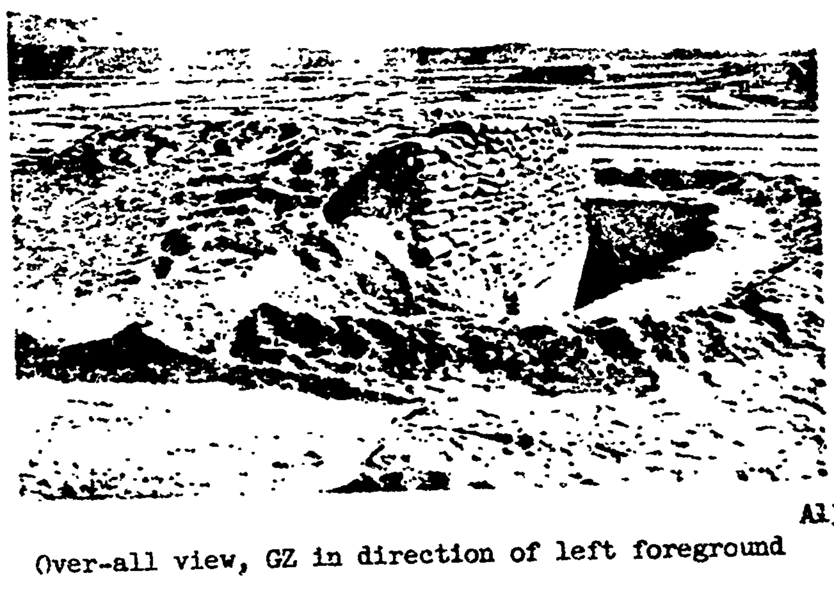
Over-all view, GZ in direction of left foreground

Fig. 21. Type I structure.



A13216

Entrance, GZ to left



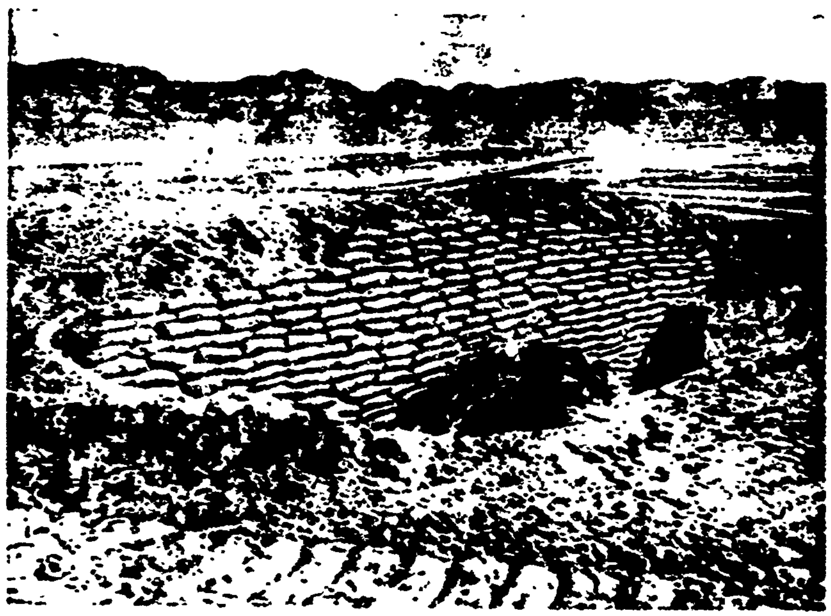
A13110

Over-all view, GZ in direction of left foreground

Fig. 22. Type J structure.

A13217

Entrance, GZ to left



A13103

Over-all view, GZ in direction of left foreground

Fig. 23. Type K structure.

The gages were located within the structures at the positions indicated in Fig. 24. No instrumentation was provided for measuring pressure on the outside. It was intended that overpressure and dynamic pressure measurements at distances of interest to the project would be obtained from other sources, principally the desert blast line.

b. Nuclear Radiation. Measurements of both gamma radiation and neutron flux at several locations in the structures were made by personnel of the Army Chemical Corps. Gamma radiation was recorded by means of NBS film dosimeters and three different types of chemical dosimeters; the film dosimeters measured exposures in the 500 r to 40,000 r region, while the chemical dosimeters measured exposures in the region of 200,000 r. Neutron fluxes were recorded by means of gold, fission threshold, and sulfur detectors; gold recorded the thermal neutrons; fission threshold, the neutrons of intermediate energies (4 Kev to 3 Mev); and sulfur, the high energy neutrons (greater than 3 Mev).

7. Test Results. The MET shot was fired on 15 April 1955. The yield of the weapon as determined by radiochemistry was 22 KT, 6 KT less than the predicted yield, and definite evidence of precursor formation was noted. Peak overpressures at ground surface along the desert blast line were approximately 65, 48, and 37 psi at the 1000-, 1150-, and 1400-ft ranges, respectively. The dynamic pressure measurements at a 3-ft height over the desert surface along the main blast line revealed pressures of well over 160 psi at the 1000- and 1150-ft ranges and approximately 110 psi at the 1400-ft range.

First efforts toward recovery of effects-measuring instruments were attempted on D-day and D+1 by the agencies concerned. Heavy contamination at these relatively close ranges and the condition of the structures impeded this operation to the extent that some of the instrumentation, primarily that at the 1000-ft range, had to be recovered on subsequent days. Because of a stiff breeze which formed dense dust clouds of the disturbed soil in this close-in area, photography and detailed examination of the damage were not completed until several days after the shot, at which time the remaining p-t gages and indenter gages were recovered. This recovery delay in no way impaired the quality of the gage recordings.

a. Pressure Measurements. Maximum pressures recorded by the BRL p-t gages and the indenter gages are presented in Table IV. The p-t records were read and interpreted by BRL personnel and made available for this report. They are described in greater detail in ITR-1155 (1). Reproductions of these records are shown in Fig. 25. The indenter gage pressures listed in Table IV were obtained by averaging the readings of gages in the clusters described in paragraph 6a.

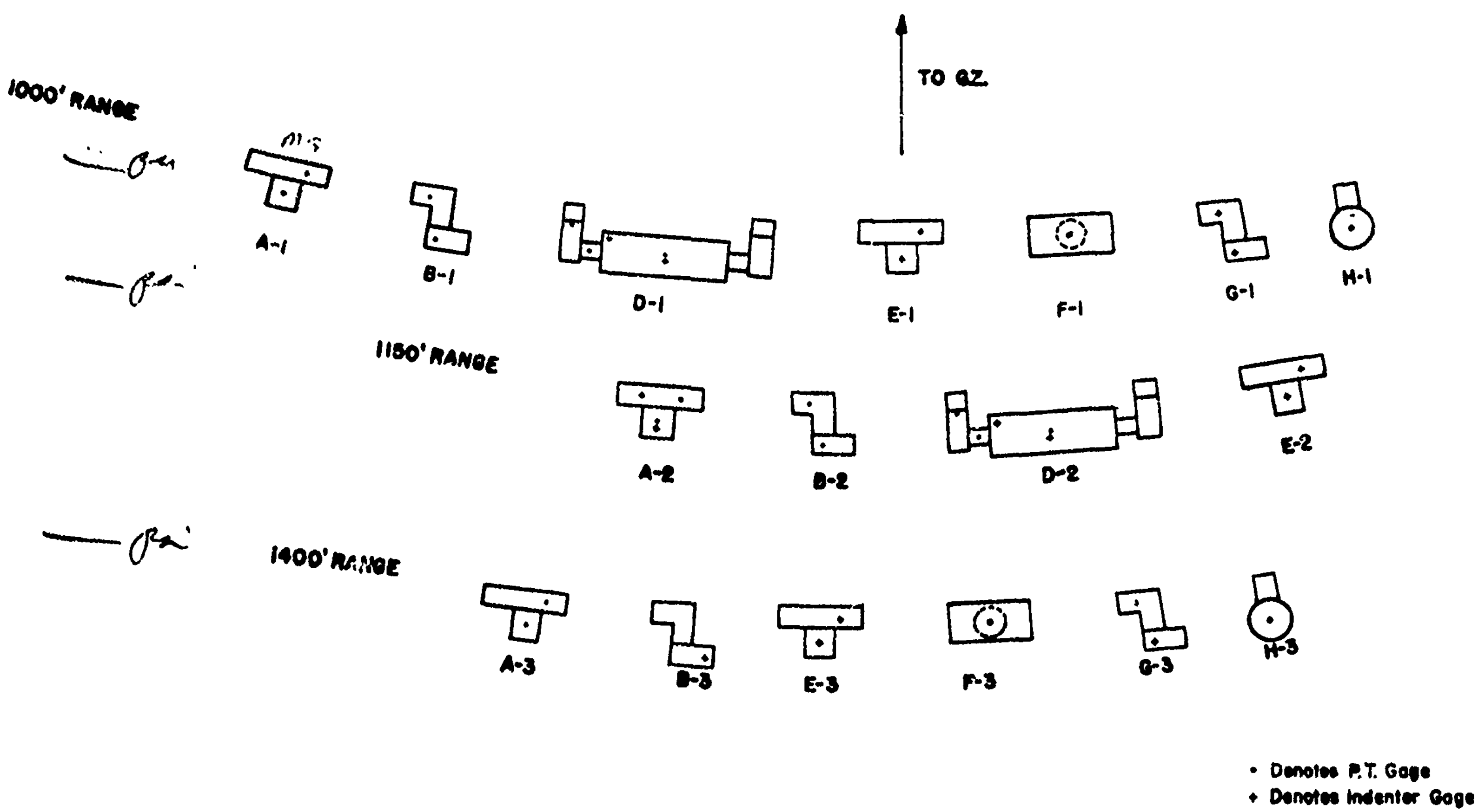
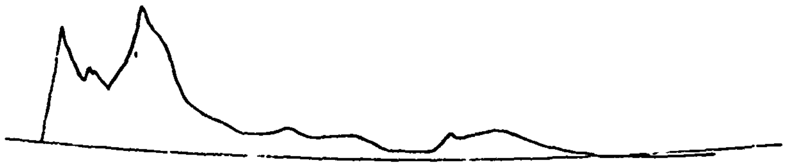


Fig. 24. Gage locations in fortifications.

Table IV. Peak Pressures Recorded in Structures

Range	1000'		1150'		1400'	
Psi at Ground Surface Main Blast Line	65		48		37	
Structure and Gage Locations	Gage Pressure (psi)		Gage Pressure (psi)		Gage Pressure (psi)	
	p-t	Indenter	p-t	Indenter	p-t	Indenter
A TCS	49.9		30.8	41.6	16.8	
Center of emplacement	40.0		22.8	28.8	15.8	
B TCS	*		30.6			
First modular section	38.5		33.0			11.6***
D Bottom of shaft	*		19.8			
Intermediate passage	15.0		13.4			
Center of room	14.6	16.8	16.3	16.5		
Corner of room		19.3		16.8		
E TCS		*		54.5		34.6
Center of emplacement		*		37.0		30.6
F Center	50				27.1	
G TCS		73.7**				19.9
First Modular section		37.4				16.6
H Center	46.8				14.3	

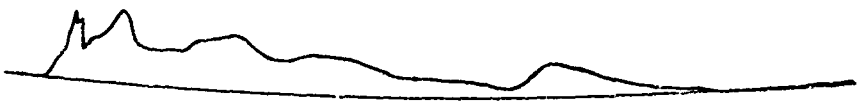
* Not recovered or no record.
** Not considered reliable.
*** Gage mounted in inner modular section. Structure was modified for use by the Chemical Corps.



A-1, TCS, 49.9 psi, 401 msec

A-1, center of emplacement, 40.0 psi, 398 msec

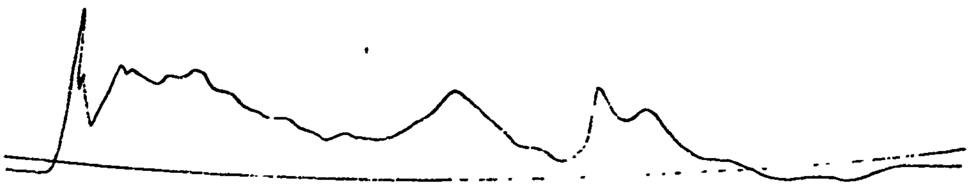
A-2, TCS, 30.8 psi, 422 msec



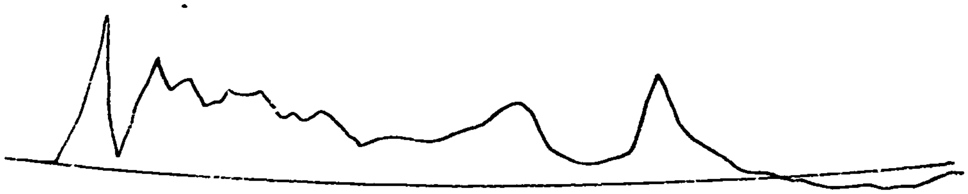
A-2, center of emplacement, 22.8 psi, 467 msec

100 msec

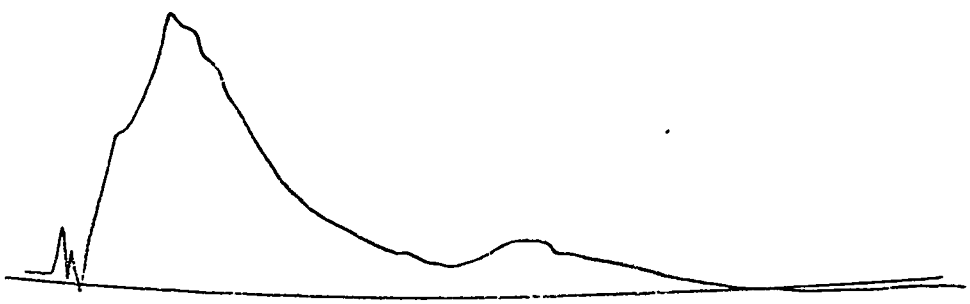
Fig. 25. Tracings of p-t gage records.



A-3, TCS, 16.8 psi, 482 msec



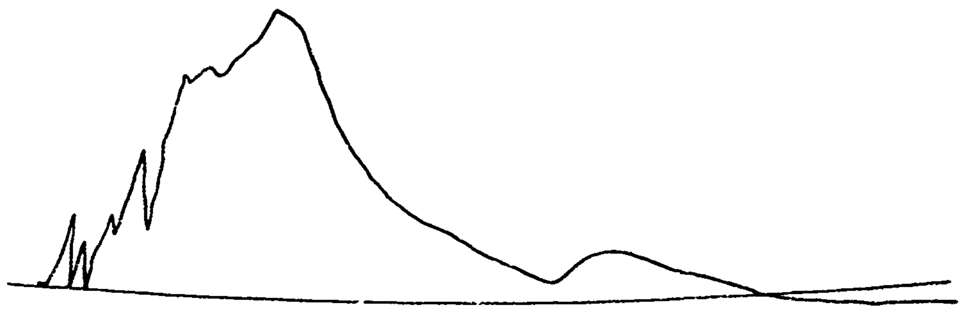
A-3, center of emplacement, 15.8 psi, 497 msec



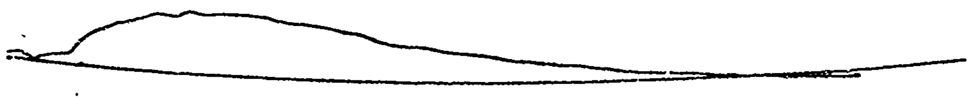
B-1, first modular section, 38.5 psi, 471 msec

Fig. 25. (cont'd)

B-2, TCS, 30.6 psi, 482 msec



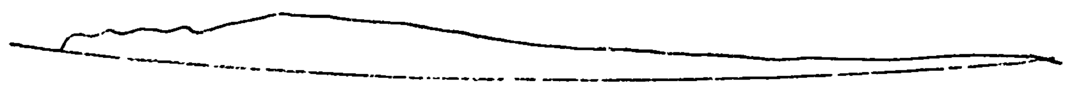
B-2, first modular section, 33.0 psi, 462 msec



D-1, intermediate passage, 15.0 psi, 508 msec

100 msec

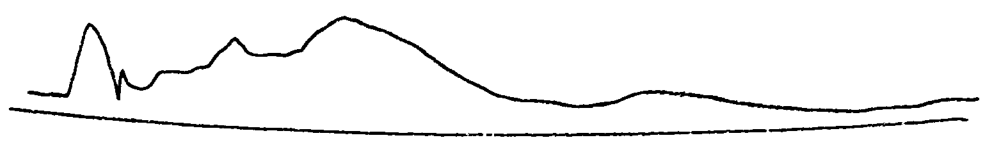
Fig. 25. (cont'd)



D-2, bottom of shaft, 19.8 psi, 673 msec

D-2, center of room, 16.3 psi, 674 msec

F-1, center, 50 psi, 228 msec



F-3, center, 27.1 psi, 546 msec

100 msec

Fig. 25. (cont'd)

b. Radiation Measurements. The gamma ray and neutron measurements are presented in Tables V and VI, respectively. These results were obtained from ITR-1121, the report for Project 2.7 (3).

c. Structural Damage. Structural damage varied from very light damage to complete destruction, and the overpressure obtained at the selected ranges was considered satisfactory to attain the objectives of this test. Structures partially or completely above the ground surface suffered much more damage than did those placed entirely below ground. Structures which were built entirely above ground were severely damaged by drag forces, and evidence of the effects of these forces was readily apparent in most of those structures partially above ground. Table VII summarizes the damage to the structures. The effects of the blast on each structure are described in detail as follows:

(1) Damage to 7-Ft by 7-Ft Machine Gun Emplacement, Dimension Timber (Type A). This structure was located at each of the three pressure ranges.

(a) 1000-Ft Range. Although access was possible through both entrances, this structure was severely damaged. Fig. 26 and 27 show damage to the right and left entrances, respectively. (Note: To understand such directions as right, left, and rearward, the reader should assume the observer was facing GZ.) The front and rear TCS caps (6-in. by 8-in. by 64-in. span) were broken in every span, and the cross bracing was pulled from the posts, and, in several instances, broken. Fig. 28, which is a photograph of the interior of the TCS looking from left to right, gives some idea of the extent of the damage. The caps failed in a surprising number of ways: (1) typical bending failure (Fig. 29); (2) bending failure caused by the horizontal component of the loading (upper left corner of the photograph in Fig. 28); (3) horizontal shear through the vertical dimension (end of the cap showing in the photograph in Fig. 26); and (4) a splitting or tension failure in the rear cap over an interior post which may have been started, initially, by horizontal shear. The splitting failure was a longitudinal separation of the cap along its vertical dimension and can be attributed to two opposing forces: (1) the rearward force transmitted to the cap by the roof stringer spikes; and (2) the restraining action of the drift pin which fastened the cap to the post.

Post damage was limited to that shown in the photograph in Fig. 28. One post in each entrance was blown completely out of position; but as the posts were

Table V. Gamma Shielding Measurements

Type of Forti-fication	Distance from GZ (')	Type of Detector*	Gamma Readings (r)							
			Inside							Outside
			Distance Above Floor							
			Interior			Entrance Way		Forward Wall		
			8"	26"	44"	29"	47"	Pb	No Pb	
A-1	1000	CCDos	--	24.0K	--	42.0K	--	--	--	238K
		FDNoLi	--					unrec.	unrec.	
B-1	1000	CCDos	--	<300	--	8.0K	--	--	--	238K
		FBNoLi	--					unrec.	unrec.	
F-1	1000	FBNoLi				--	--	--	--	238K
H-1	1000	FBNoLi				--	--	--	--	238K
D-1	1000	FBNoLi	--			--				238K
I-1	1000	FBNoLi	--	unrec.	--	--	--	--	--	238K
J-1	1000	FBNoLi	--	unrec.	--	--	--	--	--	238K
K-1	1000	FBNoLi	--	unrec.	--	--	--	--	--	238K
A-2	1150	CCDos	--	24.0K	--	51.0K	--	--	--	162K
		CDos		9.5K	--	--	--	--	--	
		FBLi1/8"	--	5.9K	--	24.2K	--	--	--	
		FBLi1/2"	--	5.3K	--	22.0K	--	--	--	
		FBLi1"	--	4.0K	--	--	--	--	--	
		FBNoLi	--	7.0K		27.2K	28.0K	7.1K	9.1K	

Table V (cont'd)

Type of Forti-fication	Distance from GZ (')	Type of Detector*	Gamma Readings (r)							
			Inside							Outside
			Distance Above Floor							
			Interior			Entrance Way		Forward Wall		
			8"	26"	44"	29"	47"	Pb	No Pb	
B-2	1150	CCDos	--	<300	--	~5.0K	--	--	--	162K
		CDos	--	100	--	3.4K	--	--	--	
		FBLi1/8"	--		50	1090	--	--	--	
		FBLi1/2"	--		48.5	1000	--	--	--	
		FBLi1"	--		45.5	--	--	--	--	
		FBNoLi	--	59.0	51	1.6K	1.6K	1390	1370	
D-2	1150	CCDos	--	< 300	--	--	unrec.**	--	--	162K
		CDos	--	< 50	--	--	unrec.**	--	--	
		FBLi1/8"	--	--	39	--	unrec.**	--	--	
		FBNoLi	--	40.5	35.3	--	unrec.**	23.5	32.3	
		FBLi1/2"	--	--	38	--	unrec.**	--	--	
I-2	1150	FBNoLi	--	unrec.	--	--	--	--	--	162K
J-2	1150	FBNoLi	--	unrec.	--	--	--	--	--	162K
K-2	1150	FBNoLi	--	unrec.	--	--	--	--	--	162K
A-3	1400	CCDos	--	7.6K	--	>600	--	--	--	
		CDos	--	3.8K	--	7.2K	--	--	--	89.4K
		FBLi1/8"	--	2.6K	--	8.0K	--	--	--	
		FBNoLi	--	2.9K	3.9K	8.2K	9.3K	2.9K	4.1K	
B-3	1400	CCDos	--	< 50	--	unrec.	--	--	--	
		CDos	--	<50	--	1320	--	--	--	
		FBLi1/8"	--	26.6	--	750	--	--	--	
		FBLi1/2"	--	26.9	--	600	--	--	--	89.4K
		FBNoLi	--	24.3	29	900	954	--	830	

Table V (cont'd)

Type of Forti-fication	Distance from GZ (')	Type of Detector*	Gamma Readings (r)							
			Inside							Outside
			Distance Above Floor							
			Interior			Entrance Way		Forward Wall		
			8"	26"	44"	29"	47"	Pb	No Pb	
C-3	1400	FBNoLi	unrec.	--	unrec.	--	--	--	--	89.4K
F-3	1400	FBNoLi	unrec.	--	--	--	--	--	--	89.4K
G-3	1400	FBNoLi	--	38..	38.3	1250	1150	728	942	89.4K
H-3	1400	FBNoLi	unrec.	2.0K	2.5K	--	--	--	--	89.4K
I-3	1400	FBNoLi	--	1.4K	--	--	--	--	--	89.4K
J-3	1400	FBNoLi	--	unrec.	--	--	--	--	--	89.4K
K-3	1400	FBNoLi	--	unrec.	--	--	--	--	--	89.4K

* CCDos = Chemical Corps "Tactical E-1" two phase dosimeter.
CDos = Laboratory type, full range, anhydrous chloroform dosimeter.
FBLi1/8" = NBS-ESL Film Badge, covered with 1/8" of lithium metal.
FBLi1/2" = NBS-ESL Film Badge, covered with 1/2" of lithium metal.
FBLi1" = NBS-ESL Film Badge, imbedded with Li_2CO_3 powder equivalent to 1" of lithium metal.
FBNoLi = NBS-ESL Film Badge, in interior facing ground zero, in entrance way facing opening, no lithium cover.

** These readings were taken at about 60" above the floor.

Table VI. Neutron Shielding Measurements

Type of Forti-fication	Dis-tance from GZ (')	Type of Detector	Neutron Flux (neut/cm²)					
			Inside					Outside
			Distance Above Floor					
			Interior			Entrance Way		
			8"	26"	44"	29"	47"	
A-1	1000	Au	--	unrec	unrec	unrec	unrec	$3.57x10^{13}$
		S	--	unrec	unrec	unrec	unrec	
B-1	1000	Au	--	unrec	unrec	unrec	unrec	$3.57x10^{13}$
		S	--	unrec	unrec	unrec	unrec	
F-1	1000	Au	unrec	unrec	unrec	--	--	$3.57x10^{13}$
		S	unrec	unrec	unrec	--	--	
H-1	1000	Au	unrec	unrec	unrec	--	--	$3.57x10^{13}$
		S	unrec	unrec	unrec	--	--	
D-1	1000	Au	--	unrec	unrec	--	unrec	$3.57x10^{13}$
		S	--	unrec	unrec	--	unrec	
I-1	1000	Au	--	unrec	--	--	--	$3.57x10^{13}$
		S	--	unrec	--	--	--	
J-1	1000	Au	--	$8.86x10^{12}$	--	--	--	$3.57x10^{13}$
		S	--	$5.3x10^{11}$	--	--	--	
K-1	1000	Au	--	unrec	--	--	--	$3.57x10^{13}$
		S	--	unrec	--	--	--	
A-2	1150	Au	--	$7.07x10^{12}$	$7.72x10^{12}$	$2.07x10^{13}$	$1.72x10^{13}$	$2.39x10^{13}$
		Pu	--	$3.48x10^{11}$	--	$7.48x10^{12}$	--	$1.22x10^{14}$
		Np	--	$2.23x10^{11}$	--	--	--	$7.20x10^{13}$
		U	--	$7.94x10^{10}$	--	$9.96x10^{11}$	--	$2.71x10^{13}$

Table VI (cont'd)

Type of Forti-fication	Dis-tance from GZ (')	Type of Detector	Neutron Flux (neut/cm^2)					
			Inside					Outside
			Distance Above Floor					
			Interior			Entrance Way		
			8"	26"	44"	29"	47"	
A-2	1150	S	--					
B-2	1150	Au	--	4.25×10^{10}	5.13×10^{10}	3.00×10^{12}	2.98×10^{12}	2.39×10^{13}
		Pu	--	--	6.41×10^{8}	2.79×10^{11}	--	1.22×10^{4}
		Np	--	--	--	--	--	7.20×10^{13}
		U	--	--	--	4.19×10^{10}	--	2.71×10^{13}
		S	--					
D-2	1150	Au	--	4.65×10^{9}	4.14×10^{9}	--	5.68×10^{11}	2.39×10^{13}
		Pu	--	1.56×10^{9}	--	--	1.58×10^{10}	1.22×10^{14}
		Np	--	--	--	--	--	7.20×10^{13}
		U	--	2.17×10^{9}	--	--	5.93×10^{9}	2.71×10^{13}
		S	--					
I-2	1150	Au	--	unrec	--	--	--	2.39×10^{13}
		S	--	unrec	--	--	--	
J-2	1150	Au	--	unrec	--	--	--	2.39×10^{13}
		S	--	unrec	--	--	--	
K-2	1150	Au	--	1.30×10^{13}	--	--	--	2.39×10^{13}
		S	--		--	--	--	
A-3	1400	Au	--	3.16×10^{12}	3.76×10^{12}	8.70×10^{12}	8.47×10^{12}	1.24×10^{13}
		Pu	--	2.09×10^{11}	--	2.08×10^{12}	--	5.30×10^{13}
		NP	--	8.33×10^{10}	--	--	--	3.00×10^{13}
		U	--	3.42×10^{10}	--	2.50×10^{11}	--	1.20×10^{13}
		S	--					

Table VI (cont'd)

Type of Fortification	Distance from GZ (')	Type of Detector	Neutron Flux (neut/cm^2) Inside, Distance Above Floor, Interior 8"	Interior 26"	Interior 44"	Entrance Way 29"	Entrance Way 47"	Outside
B-3	1400	Au	--	1.76×10^{9}	1.98×10^{9}	9.77×10^{11}	1.19×10^{12}	1.24×10^{13}
		Pu	--	2.46×10^{8}	--	2.17×10^{11}	--	5.30×10^{13}
		Np	--	--	--	--	--	3.30×10^{13}
		U	--	5.82×10^{9}	--	3.28×10^{10}	--	1.20×10^{13}
		S	--					
C-3	1400	Au	unrec	--	unrec	--	--	1.24×10^{13}
		Su	unrec	--	unrec	--	--	
F-3	1400	Au	unrec	unrec	unrec	--	--	1.24×10^{13}
		S	unrec	unrec	unrec	--	--	
G-3	1400	Au	--	1.5×10^{10}	1.48×10^{10}	1.67×10^{12}	1.89×10^{12}	1.24×10^{13}
		Pu	--	unrec	--	2.51×10^{11}	--	5.30×10^{13}
		Np	--	--	--	--	--	3.00×10^{13}
		U	--	unrec	--	3.3×10^{10}	--	1.20×10^{13}
		S	--					
H-3	1400	Au	unrec	1.26×10^{12}	1.15×10^{12}	--	--	1.24×10^{13}
		S	unrec			--	--	
I-3	1400	Au	--	1.06×10^{11}	--	--	--	1.24×10^{13}
		S	--		--	--	--	
J-3	1400	Au	--	unrec	--	--	--	1.24×10^{13}
		S	--	unrec	--	--	--	
K-3	1400	Au	--	5.41×10^{12}	--	--	--	1.24×10^{13}
		S	--		--	--	--	

Table VII. Summary of Structural Damage

Type of Forti- fication	Distance from GZ (')	Damage	Remarks
A-1	1000	Structure almost totally destroyed. TCS caps broken in every span. Emplacement roof and caps displaced rearward approximately 4'. Structure leaning rearward approximately 3'. Numerous joint failures.	Not repairable.
B-1	1000	No major damage. Entrance 2/3 filled with dirt. Sheathing at doorway blown into structure. Posts, caps, and roof stringers structurally sound.	Repairs possible and practicable.
C-1	1000	Structure blown away.	Not repairable.
D-1	1000	Both entrances severely damaged. All caps failed. No post damage.	Not repairable.
E-1	1000	Completely collapsed. Many broken timbers.	Not repairable.
F-1	1000	Corrugated metal collapsed rearward over emplacement. Emplacement filled with dirt.	Not repairable.
G-1	1000	Entrance 2/3 filled with dirt. Structure in excellent condition.	Minor repairs necessary.
H-1	1000	Completely collapsed. Excavation filled with dirt.	Not repairable.
I-1	1000	Entrance works blown into shelter. No noticeable arch deflection. Entrance filled with dirt.	Terrific missile hazard.
J-1	1000	Entrance works blown into shelter. Arch pushed inward approximately 1' on GZ side. Entrance filled with dirt.	Terrific missile hazard.

Table VII (cont'd)

Type of Forti-fication	Distance from GZ (')	Damage	Remarks
K-1	1000	Entrance doors blown into shelter. End bulkhead pushed into shelter approximately 18". Approximately 1" permanent arch deflection.	Terrific missile hazard.
A-2	1150	Major damage but fewer timber failures than in A-1. One span of TCS cap broken. Firing ports and aprons destroyed. Structure leaning rearward approximately 1'. Roof stringers and caps removed from emplacement posts. Joint failures.	Repairs possible but impracticable.
B-2	1150	Similar to B-1 damage. Sheathing at doorway blown into structure.	Repairs possible and practicable.
C-2	1150	Structure blown away.	Not repairable.
D-2	1150	Damage about the same as D-1. Cap fractures not so bad as those in D-1.	Not repairable.
E-2	1150	Entire structure severely damaged. Three posts broken. One TCS cap splintered. TCS roof moved rearward about 2'. Emplacement stringers removed.	Repairs possible but impracticable.
I-2	1150	Same as I-1.	Terrific missile hazard.
J-2	1150	Same as J-1 except no arch damage.	Terrific missile hazard.
K-2	1150	Entrance doors blown into shelter. End bulkhead pushed into shelter approximately 8". No arch damage.	Terrific missile hazard.

Table VII (cont'd)

Type of Forti-fication	Distance from GZ (')	Damage	Remarks
A-3	1400	Right entrance constricted by collapse of rear TCS wall. One span of TCS cap broken. Emplacement in relatively good condition. Entire structure leaning rearward about 4".	Repairs possible and practicable.
B-3	1400	Structure modified and equipped with blast door for use by Chemical Corps. Door removed by blast. Portions of diffusion board damaged. Negligible damage to basic structure.	Repairs possible and practicable.
C-3	1400	Structure blown away.	Not repairable.
E-3	1400	Superficial damage.	Minor repair necessary.
F-3	1400	Corrugated metal collapsed rearward over emplacement. Emplacement half filled with dirt.	Not repairable.
G-3	1400	Entrance 2/3 filled with dirt. One post pushed inward by lateral earth pressure. No cap failure.	Minor repairs necessary.
H-3	1400	Structural damage throughout. Partially blown away.	Not repairable.
I-3	1400	Same as I-1.	Terrific missile hazard.
J-3	1400	Same as J-2.	Terrific missile hazard.
K-3	1400	Same as K-2 except end bulk-head damaged less.	Terrific missile hazard.

not broken, this damage is considered to be joint failure. Joint failure was noticeable throughout the structures. No roof stringer failures occurred.

Damage to the corrugated metal sheathing on the rear wall of the entrance trench was severe, but it is believed that much of this damage was caused as a result of timber joint failures.

The emplacement proper suffered damage comparable to that of the trench cover section with the exception that the caps did not fail. Instead, they were forced from the posts with roof stringers intact and moved rearward approximately 4 ft. Fig. 30 is a photograph of the damaged right wall of the emplacement which collapsed rearward. The left wall, having added strength because of the firing port member, was not damaged as thoroughly as the right. No post failures occurred in the emplacement. Both firing ports were destroyed and the aprons were blown about 25 ft to the rear.

About $3\frac{1}{2}$ ft of earth cover remained over the trench cover section. A more uniform covering would have resulted, but displacement and structural failure of timbers permitted the powdery cover material to fall into the structure. The emplacement proper was approximately two-thirds filled.

(b) 1150-Ft Range. Damage to the Type A structure at this range was similar to the damage at the 1000-ft range; however, severe damage was noticeably less and more localized. Figs. 31 and 32 show damage to the right and left entrances, respectively, and Fig. 33 is a view of the interior of the trench cover section looking toward the badly damaged right entrance which was approximately one-half filled with cover and backfill material. Only one cap failed in the entire structure. This was a bending failure of the right front span. The only post failure, apparently a bending failure, is shown in Fig. 34 which is a photograph of the left rear wall of the trench cover section.

Damage to the emplacement proper is shown in Figs. 35 and 36. The caps and roof stringers were not moved to the extent they were at the 1000-ft range. Displacement was approximately 1 ft to the left rear. This displacement caused about 2 cu yd of earth cover to fall into the structure. Both firing ports and the aprons were destroyed. Fig. 37, a view of the structure looking toward the aprons, shows the over-all damage to the earth cover as well as the susceptibleness to blast of the sandbags used at the entrance and firing ports.

(c) 1400-Ft Range. Significant structural damage at 1400 ft was confined to the right side of the trench cover section (Fig. 38). The right entrance was constricted by the collapse of the rear wall, apparently as a consequence of post-to-cap joint failure, but the left entrance was in relatively good condition (Fig. 39). Fig. 40 is a photograph of the right rear wall taken from inside the trench cover section. This same figure shows the only broken cap which was opposite the collapsed rear wall. Fig. 41 is a closeup of this cap failure. The entire structure was out of plumb about 4 in., and as a result, early stages of joint failure were evident. (Note the loosened scabbing in Fig. 40 and the cap in Fig. 42 which was raised off the post about 1 in. by the diagonal brace. Fig. 43 shows a portion of the two walls which contain the firing ports. Two firing port members, one in each wall, were canted slightly from the effects of the blast within the structure. One end of each lower apron stringer was loosened; otherwise, the aprons were undamaged. Only a small amount of cover material obstructed the fields of fire.

(2) Damage to 8-Ft by 12-Ft Modular Shelter, Dimension Timber (Type B). Structural damage to the three Type B structures did not vary significantly at the different ranges. As a result of caving of the entrance ramp walls and cover material, the entrances into the trench cover sections were partially filled with earth, thereby decreasing the clear height to approximately 24 in. Figs. 44 through 46 show the entrance damage at the three ranges. Fig. 47 shows the entrance to B-1 from inside the trench cover section. This was representative of the condition of the entrances at all three ranges.

The principal damage to B-1 and B-2 was to the exposed section of wall at the doorway into the shelter proper. Failure of the door stud allowed the sheathing to be blown inward. Although the same repair problems were presented at both ranges, the damage at 1150 ft was not so severe as that which occurred at 1000 ft. Figs. 48 and 49 show the damaged wall in B-1. The wood sheathing on B-1 was forced outward $\frac{1}{4}$ to 1 in. from the posts on all but one side of the shelter. Inspection revealed that the roof had not raised. The modular structure at the 1400-ft range was modified to permit the Chemical Corps to evaluate CBR protection afforded by diffusion board lining in this type of shelter.[1] The modifications consisted of a blast door and baffle wall installed to protect the diffusion board from blast pressures. Damage incurred by this structure consisted of the removal of the blast door (Fig. 50) and destruction of portions of the diffusion board liner. Damage to the basic shelters and entrance trench was negligible.

(3) Damage to 7-Ft by 7-Ft Machine Gun Emplacement, Notched Dimension Timber (Type C). Little can be said for the Type C structures other than that they were completely destroyed by being blown away. Figs. 51 through 53 show the remains of the structures. (Note the scattered, broken timbers in the background in Fig. 53.)

(4) Damage to 9-Ft by 20-Ft Underground Shelter, Dimension Timber (Type D). Damage to the two Type D structures was so nearly the same that a consolidated description of the damage will suffice. Because of entry difficulties and the almost identical damage, it was decided that photographs of the damage inside of both structures would not be necessary; therefore, interior photographs were made of D-1 only.

Before entering D-1 it was apparent from the sunken condition of the ground surface that the structure had been damaged. A dish-shaped depression, approximately 2 ft deep, was observed in the ground over the D-1 structure; the depression was only approximately 1 ft deep over the D-2 structure. A brief examination of the vertical entrance shafts to both structures revealed that they were severely damaged and the trap-door-type entrance coverings destroyed. No part of the doors could be identified in the debris at the bottom of the shafts; and, although a hinge from one of the doors was found 1400 ft from ground zero, this is not felt to be sufficient evidence from which to determine how the doors responded. Most of the damage to the entrance shafts appeared to have been caused as a result of lateral pressure exerted by the backfill material against the sheathing which, in turn, pushed the braces and spreaders into the shafts, thus promoting severe displacement or failure of the 4-in. by 4-in. corner posts. In all instances, the upper halves of the shafts were badly damaged. Damage to two of the entrances was such as to allow considerable quantities of backfill material to fall into the shafts. Subsequent sluffing of the earth at one entrance almost sealed off a horizontal passage in the D-2 structure. The access ladders, which had been constructed on the front walls of the shafts, were completely destroyed. Figs. 54 through 57 show the damaged entrance shafts.

1. E. H. Engquist, Evaluation of CBR Protective Shelter, Project 40.14, Operation TEAPOT, 1955, cited in (3) in Bibliography.

An inspection of the interior of the structures revealed that all 6-in. by 6-in. caps in the passages and all 8-in. by 10-in. caps in the 9-ft by 20-ft rooms were broken. No failures other than bending failures were noted. All of the 8-in. by 10-in. caps and several of the 6-in. by 6-in. caps in the D-1 structure were completely separated at the fractures, whereas, in the D-2 structure the fractures were not so severe. Figs. 58 and 59 show the broken caps in the room and the right entrance passage, respectively.

All of the 2-in. by 6-in. roofing in the entrance passages of D-1 failed (Fig. 59) except that in the outer passage at the junction of the connecting passage. At this junction, crossed, double roofing was used, and no failures occurred in either structure. The only roofing failures in D-2 were over the blast pocket at the ends of the two outer passages. Here, the roofing span was only 2 ft, 6-in. less than another span which did not fail. The 2-ft span, however, was simply supported, and the longer span was continuous through two spans of 2½ and 2 ft. A brief investigation of the spans revealed that the extreme fiber stress in bending, from unit loading, would be greater in the 2-ft simply supported span.

Fig. 60 is a photograph of the 8-in. by 8-in. posts in the front wall of D-1. No damage to posts was incurred in either structure other than the crushing effect of the sagging caps on the inside top edges. If the posts were out of plumb it was not perceptible. The 6-in. by 6-in. passage posts were not damaged in either structure; they also appeared to be plumb.

Several pieces of scabbing were split by the sagging caps in the main room of the structures; however, the scabbing did not fail to carry out the purpose for which it was intended. Little or no horizontal movement of the caps occurred.

The only sheathing damage of any significance, other than that in the entrance shafts, was in the blast pockets. The sheathing across the ends of the blast pockets, a 3-ft span, was bulged inward considerably on both structures, but in only the left blast pocket of the D-1 structure was it bulged sufficiently to allow the dry, noncohesive, backfill material to enter the structure. The funneling of this material into the structure caused a cavity on the outside which eventually reached ground surface. In the center background of Fig. 55 can be seen a cavity that was formed as a result of the failure of the 8-in. by 10-in. cap at the entrance to the room. The failure of this cap combined with the lateral earth pressure caused an inward displacement of one of the sheathing nailing posts at the entrance, thereby forming an opening through which backfill material flowed into the structure. Inspection revealed that blast had not caused any direct damage to the flooring in either of the structures; and indications were that the footings were not damaged in any way.

(5) Damage to 7-Ft by 7-Ft Machine Gun Emplacement, Round Timber (Type E). The round timber machine gun emplacements, which were oriented and constructed in a manner similar to the dimension timber machine gun emplacements, suffered more damage at the 1000- and 1150-ft ranges than did the dimension timber emplacements. Damage at the 1400-ft range was comparable to that inflicted on the dimension timber structure at this range. A description of the damage follows:

(a) 1000-Ft Range. The emplacement at this range was incapable of even partially withstanding the effects of the blast. Destruction was complete and in no way localized. Some idea of the extent of damage can be obtained from Fig. 61.

(b) 1150-Ft Range. Damage to the structure at this range was in excess of that caused to the dimension timber emplacement at the same range; in fact, it was comparable to that inflicted on the dimension timber emplacement at the 1000-ft range. Damage to the right and left entrance is shown in Figs. 62 and 63, respectively. Perhaps the most impressive damage caused to any of the structures is the two broken posts shown in Fig. 64 which is a view from right to left through the entrance trench. This damage is indicative of the loads transmitted from the forward wall to the rear wall of the entrance trench by the spreaders between the posts. The front cap in the entrance trench was badly shattered (Fig. 65); and, although the rear cap did not fail, it was moved rearward approximately 3 ft. The roof was completely removed from the emplacement proper (Fig. 66). Post displacement in the emplacement was negligible as compared to the displacement of the posts in the dimension timber emplacement. The emplacement was approximately two-thirds filled with cover material.

(c) 1400-Ft Range. The log machine gun emplacement at this range suffered only light damage throughout. No failures occurred to critical members. Figs. 67 and 68 show the damage to the right and left entrances, respectively. Wall members (posts and crossbracing) in the entrance trench withstood the effects of the blast well.

The only noticeable displacement in this structure was approximately a 2-in. rearward movement of one end of the rear cap (Fig. 68). Only one sheathing failure occurred in the entrance trench, namely, the one in the rear wall and adjacent to the side firing port apron. Other sheathing, although bulged inward, was effective in holding the backfill material. Except for severely bulged sheathing on one wall, the emplacement proper was not damaged (Fig. 69). Fig. 70 is an over-all view of the structure which shows the general condition of the cover material and the firing port aprons.

(6) Damage to 5-Ft Diameter Corrugated Metal Arch (Type F). Little difference was noted in the amount of damage to the two emplacements. At both the 1000- and 1400-ft ranges, the corrugated metal arches were flattened rearward over the excavated portion of the emplacements (Figs. 71 and 72). The corrugated metal culverts used to revet the walls of the excavations were not damaged significantly; however, the excavations were over one-half filled with cover material which entered through the parted sections of the flattened overhead culvert.

(7) Damage to 8-Ft by 12-Ft Modular Shelter, Round Timber (Type G). Approximately the same damage was inflicted on the entrances to both structures, namely, caving of entrance ramp walls and entrance cover material (Figs. 73 and 74). The entrance timbers to neither structure were damaged except for the removal of a roof stringer. Structural damage to G-1 was nonexistent; whereas, lateral earth pressure on an exterior wall bent of G-3 forced the upper end of the center post inward approximately 18 in. (Fig. 75). Examination of the post revealed that the drift pin had not been centered and that the pie-shaped segment of the post split along well-defined checks in the wood. No other damage resulted because of the failure of this post. As the sheathing was omitted at the left of the doorway, the outer modular section was not damaged as was the dimension timber structure. The corrugated metal sheathing, which was used throughout this type shelter, was bulged inward more on the entrance trench than on the modular sections; but, as a whole, it was in good condition.

(8) Damage to 9-Ft Diameter, Prefabricated Plywood Dome (Type H). The plywood dome at the 1000-ft radius was destroyed beyond recognition and the excavation was filled with dirt. Fig. 76 is a view, looking toward GZ, of the remains of the emplacement. At the 1400-ft range, approximately one-third of the dome was destroyed. The remaining two-thirds was intact but severely damaged (Fig. 77). The portion that was destroyed

contained the firing port and faced away from GZ. Failure of the laminated ribs and the sole plate were noted throughout the structure. Almost all these failures occurred at a joint in the lamination (Fig. 78). The firing port apron on both structures was blown rearward and destroyed. All of the 6-in. by 6-in. roof stringers on the simple, crawl-type entrance to the H-1 structure were broken, whereas on H-3 only the stringer supporting that portion of the dome that spanned the entrance trench was broken.

(9) Damage to Sixth Army Structures (Types I, J, and K). From the standpoint of arch failure these structures withstood the blast pressure well; however, entrance damage to all structures was severe. Arch damage occurred in only two structures. The worst was a 1-ft depression in the GZ side of J-1, while in K-1, the 6-in. by 6-in. timber spreader was knocked out and the top of the arch was depressed approximately 1 inch. No other permanent arch deflections were noted. The most significant damage to these structures was the failure of the entrance bulkheads and doors. All or part of the entrance works in every structure were blown inward and in most structures against the opposite wall. The entrance excavations contained considerable amounts of loose soil, most of which had been cover material, and two of the entrance arches were covered when examined. The bulkheads in the rear of the I and J structures withstood the pressure transmitted by the backfill material; however, the metal doors opposite the entrance on K-1 and K-2 were forced inward approximately 18 and 8 in., respectively. Figs. 79 through 82 show damage to the Sixth Army structures.

III. DISCUSSION

A considerable amount of valuable information was obtained from this test. Ultimately, the data obtained should provide a basis for new designs as well as modifications to present designs. Furthermore, the test will be a source of data for improvements in construction techniques, utilization of construction materials, and concepts of tactical employment.

Although overpressures were generally higher than intended, that is, as much as 70 percent at the 1400-ft range, this condition was not detrimental to the success of the test. For the group of structures as a whole, a finite bracket on blast (and prompt radiation) damage was obtained, supported by several instances of progressive failure over the three ranges. A milder effects level would have caused less damage and made discrimination of the degree of damage more difficult, particularly between the 1150- and 1400-ft ranges.

8. Air Blast Evaluation. The pressure data recorded in the structures must be accepted with caution. The gages performed as well as could be expected; but, if one considers the conditions under which some data were recorded (high dust concentration and flying debris), much data would be termed suspect. More gage locations and duplication of gages at locations would have provided more confirmed pressure data. The p-t gage recordings (Fig. 25) show several malfunctions. The gage in H-1 and H-3 recorded a peak pressure but failed to record pressure as time passed. (Records from these gages were not legible, and no tracings were made for inclusion in the figure.) It is apparent that the p-t recording obtained in F-1 is incorrect. The positive phase duration was only 228 msec as compared to 546 msec in F-3. This short duration was probably caused by dirt clogging the pressure orifice, an occurrence which was likely, considering the position of the gage. Some shock wave arrival time data in the structures was obtained and examined, but the precision with which the p-t gages measured the arrival time was not sufficiently accurate for making valid comparisons. Many of the indenter gage discs registered multiple indentations, some of which were distorted. Any deviation from a single, uniform indentation makes interpretation of records more difficult, and, consequently, causes more scatter in the final data. Of all the emplacements instrumented, the shelters (Types B, D, and G) probably provided the most reliable data. The amount of data obtained in Types B and G provided only limited comparisons of pressure between structures; however, no evidence indicated that the data obtained were not of the right magnitude. The indenter and p-t gage measurements compare favorably in both Type D Structures, with the indenter gages registering slightly higher pressures. The indenter gages mounted in A-2 recorded pressure 25 to 33 percent higher than did the p-t gages. The indenter gages in E-2 recorded pressure approximately 30 percent higher than did the indenter gages in A-2, and the indenter gage measurements obtained in E-3 were approximately twice the p-t gage readings in A-3. The difference between indenter gage readings and p-t gage readings can be attributed to several factors which can be considered as acting independently or in combination. Among these factors would be the relative sensitivity to short duration reflected pressures, the relative sensitivity to acceleration pulses, and other differences in the physical characteristics of two types of gages.

Records show that interiors of structures which were relatively open were subjected to pressures of approximately the same magnitude, rise time, and duration as recorded on the outside. Structures with limited access (Types B, D, and G) showed considerable modification of the shape of the blast wave which reached their interiors. Significant reductions of peak overpressures occurred. The longest rise times and greatest pressure reductions were observed in the D structures which had the smallest openings compared to internal volume. Long rise times are significant. According to White in his report on biological effects of blast (9), from the standpoint of casualties, it is important to consider the rate of pressure rise as well as peak overpressure.

9. Nuclear Radiation Evaluation. Radiation measurements taken inside Type A revealed that, although the structure withstood external pressures of 37 psi, both the gamma and neutron doses far exceeded lethal values, being about 2600 r and 1000 rem, respectively. If an attenuation factor is defined as the internal dose divided by the external dose, and the measurements made with no lithium shielding on the film badges are used for determining gamma attenuation, and the measurements made with gold detectors are used for determining neutron attenuation, limited data reveal that the Type A structure provides an attenuation factor of about 0.063 to gamma radiation and about 0.280 to neutrons. Thus, it is clearly pointed out that when weapons of kiloton yields are used, protection from overpressure cannot be considered as the sole parameter for determining the protection afforded by structures. However, when weapons of megaton yields are employed, the nuclear radiation at the distance to which 37 psi extends would probably be insignificant, and overpressure would be the predominant factor for determining the degree of protection obtained.

Type B structure afforded good protection from nuclear radiation although significant doses, approximately 100 rem from gamma rays plus neutrons, were recorded inside the structure at the 1150-ft range. The attenuation factors for Type B were about 0.001 for gamma radiation and varied from 0.002 to 0.0002 for neutrons. Type C structure, which was a duplicate of Type B except that it was constructed of logs instead of dimension timbers, displayed the same characteristics as to nuclear radiations. Its attenuation factors were measured as 0.001 for both gamma radiation and neutrons.

The Type D structure permitted 150 rem total dose of gamma radiation and neutrons to be recorded on the inside at a range of 1150 ft. Its attenuation factors were 0.001 for gamma radiation and 0.0001 for neutrons. In Types F and H, the instruments were not recovered, because both structures were severely damaged by the blast pressures. Consequently, no attenuation factors can be presented for those types. The factors for Types I, J, and K were approximately 0.002, 0.2, and 0.5, respectively.

10. Structural Damage Evaluation. The results show that the degree of structural damage depends largely on the elevation of the structure in relation to ground surface. Accordingly, the structures can be classified as (1) surface, that is, structures located on ground surface; (2) semisurface, that is, structures located partially above ground surface; and (3) subsurface, that is, structures located totally below ground surface.

a. Surface Structures (Types C and F). Damage to these structures indicates that any practical surface fortification would probably have been severely damaged at these test locations. At all ranges these structures were sensitive to drag. The C structure was almost completely removed, even at the 1400-ft range, and the overpressure at which it would have survived cannot be determined. The F structure, which was flattened rearward at both locations, afforded only little more protection than did Type C. Survival would not have been possible in C and probably not in F. Test results on Type F do not necessarily give a true indication of the performance that can be expected of a partially buried corrugated metal arch structure designed as a machine gun emplacement and should not serve to obviate further work on structures of this type. As a fighting emplacement, the corrugated metal structure still possesses a definite potential which can be exploited more fully by reducing the height of the arch above ground surface as much as possible and thus lessening the cross-sectional area exposed to drag.

b. Semisurface Structures (Types A, E, and H). In general, the A and E structures showed comparable damage from the blast at the 1400-ft range, but the E structures at the 1000- and 1150-ft ranges showed more damage. Structural damage to both types of structures at the 1000- and 1150-ft ranges was sufficient to have made casualties of any occupants. It would not have been possible to repair either of the structures at the 1000-ft range; and, although repairs to both structures at 1150 ft would have been possible, they would not have been practicable. Both structures at this location, however, were still capable of affording a limited amount of protection from the hazards of conventional warfare and could have been remanned for an expected assault after clearing some debris. It is unlikely that serious casualties would have resulted from flying debris in either A-3 or E-3, and both structures could have been repaired with no great amount of difficulty. It would not have been necessary to make repairs in either of these structures immediately. The comments in this paragraph regarding casualties caused by structural failures have been made simply to convey to the reader additional information as to the seriousness or extent of damage. The pressures recorded in these structures were sufficiently high to cause serious bodily injury, and measured prompt radiation was well into the lethal range.

Several points regarding worthwhile design changes were noted as a result of well-defined progressive failures obtained between ranges for both the A and E structures. Most notable of these is perhaps the spreader arrangement between the walls of the entrance trench. From Fig. 10 it can be seen that the spreaders were located between and at the top of the caps, and it is believed that many of the joint failures or separations can be traced to this arrangement. The lateral forces imparted to the ground zero side of the entrance trench by the shock wave and the ensuing drag forces would be transmitted to the opposite wall of the trench by the spreaders and to a lesser extent by the roof stringers. Thus, forces which caused a moment type loading in the post were transmitted not directly by the spreader but by means of the drift pin and scabbing which connected the cap to the post. Such transmission is conducive to joint separation. Figs. 27, 31, 32, and 38 in the appendix show damage believed to have been influenced by this wedging action of the spreader between the caps. Figs. 28, 30, and 40 show several stages of joint separation of interior joints. (Note the damaged post in Fig. 28 which is believed to have been caused by the scabbing, shown in horizontal position on the adjacent post, overriding the post.) Because only oversized spreaders were available for the E structures, more of the load was transmitted directly to the posts by the spreaders, and the resulting damage differed somewhat from that of the A structures. Figs. 62, 63, and 68 show damage similar to that of the A structures, but the effects of the oversized spreader can be noted, especially in Fig. 68. As evidenced by Fig. 64 broken posts can be expected when larger, lowered spreaders are used. The aforementioned post and cap-to-post joint failures tend to point out the necessity for lowering the entrance trench in relation to ground surface, thus minimizing the effect of drag forces. If this were accomplished, probably no precise elevation for the entrance trench in relation to the emplacement proper would exist. If the entrance trench were constructed flush with the surface of the ground its elevation relative to the emplacement would be dependent on the slope of the ground. It should be remembered that the machine gun emplacements in this test were exposed on flat, desert ground and were probably damaged more then they would have been if constructed on average, rolling terrain and exposed to the same burst. Greater damage to the E structures can by no means be attributed solely to a difference of materials or slight variations in design. Much of the damage can be attributed to the E structures extending approximately 36 in. above ground surface, cover excluded, as compared to approximately 26 in. for the A structures. The additional height increased considerably the cross-sectional area exposed to the drag forces. Little advantage is derived from the use of entrance trench roof stringers which extend as much as 2½ ft past the caps. Against atomic bursts the loading would be approximately uniform; thus, this amount of overhang would about double the load on the caps. One advantage of the long roof stringer was noted. Where caps did fail the roof stringer was supported by the soil and complete collapse of the structure was prevented (see Figs. 26 and 27).

So far, this discussion has dealt only with the entrances to the A and E structures. However, these entrances are considered important, and it is believed that had different entrances or even a lowered entrance of this same design been used, damage to the emplacements proper at 1000 ft and 1150 ft would have been considerably less. The interior posts, caps, and roof stringers in the rear wall of the entrance trench were in contact with the emplacement, and an undeterminable but large portion of the lateral forces imparted to the entrance trench were transmitted to the emplacement causing considerable post displacement. Less displacement in E-2 can be attributed to better bracing, namely, stronger spreaders in both side walls.

It is obvious that the design strength of the H structure was insufficient to withstand the pressures to which it was subjected. In the surface and semisurface structures, drag damage was apparent; however, in the H structure, it was not possible to associate much of the damage with drag forces. Certainly, displacement of the firing port aprons can be attributed to drag, but structural failures to both domes appears to have been purely a result of overpressure. This was substantiated in part, at least, by the failure of the roof stringers on the entrance to H-1. Unlike the entrance to the A and E structures the geometry of the opening apparently provided a lag in pressure rise which caused a pressure differential sufficiently high to effect failure. Unfortunately, the p-t gage in each of these structures provided a peak pressure measurement only and no pressure-time history. If a better bracket on blast damage had been obtained, the vulnerability of this particular shape to drag forces might have been indicated. It may be significant that the remaining part of the H-3 structure that was not destroyed was not displaced laterally.

c. Subsurface Structures (Types B, D, G, I, J, and K). The noticeable absence, and in the D structure, the difference, in significant structural damage to these structures in comparison with those previously discussed emphasizes the amount of damage that can be attributed to drag. Both modular shelters (B and G) were capable of withstanding the overpressure to which they were subjected. With the possible exception of the caps in B-1, cap failures in the Type B modular sections were not expected; however, failure of some of the entrance trench caps was expected. The expected response of the G structures was uncertain because of the condition of the logs. A comparison of the response of the entrance trench caps with the entrance stringers of H-1, which were only 10 in. below ground surface, indicates a more significant amount of pressure attenuation through the cover material of the modular structures than had been expected. Damage to the sheathing at the doorway into B-1 and B-2 came as no surprise because the stud was not designed to take any loading other than that of static lateral pressure from backfill material. This damage is of little consequence as it could be prevented by designing the stud to withstand the pressure; however, the simplest solution would be to omit the sheathing. Sheathing at this location was not included on the G structures; consequently, no damage occurred at the doorway. The absence of doorway damage made it appear that B-1 and B-2 were inferior to G-1 when actually neither of the two basic structures was damaged. The pressure buildup in B-1 was not appreciably higher than that in B-2 (see Table IV); nevertheless, the differential pressure in B-1 was sufficiently high at some time, presumably during the decay phase, to force the sheathing outward from the posts. This was the only conclusive evidence of a structure tending to blow apart. The "pushed-in" posts in G-3 clearly demonstrated the importance of good materials and quality workmanship. It is interesting to note that the cap was not damaged as a result of the loss of this support or that the sheathing did not bulge sufficiently to cause failure.

Although the Type D structure was nothing more than a series of two-post bents (minus the sills and placed on continuous footers), connected by plank roofing on the top and corrugated metal sheathing on the sides, the absence of post displacement indicated that this amount of lateral support was sufficient. These shelters showed damage different from, and in excess of, the other timber shelters in that cap failures were extensive. A glance at the p-t curves (Fig. 25) for these structures makes apparent the reason for these cap failures. The p-t curves obtained in these structures showed a slow pressure rise and a considerable difference between peak overpressure inside and outside of the structures. (The outside pressure considered is the peak overpressure recorded at the same ranges on the desert blast line.) The differences in these pressure-time histories can be attributed to the combined effects of the blast door and the entrance area-shelter volume ratio. These phenomena resulted in a diffraction type loading which caused the failures noted. The contrast in damage between this and the other timber shelters (B and G) at these ranges illustrates the effect of fast and slow pressure rise in the structures. In B-1 and B-2, for example, had it not been for a faster rise to a relatively high inside pressure, caps in the entrance trench probably would have failed. From the standpoint of withstanding lateral pressure exerted by backfill material, the entrance shaft design appeared inadequate. From observation of the damage to D-2 it is felt that these shafts were probably the weakest parts of the structure. Damaged vertical entrances are more difficult and possibly more dangerous to exit through than are damaged horizontal entrances and, therefore, should be at least as strong, preferably stronger, than the rest of the structure. Damage to the shafts might have been less had there been no blast doors, but with or without doors the necessity for a different shaft design is indicated.

The most significant damage to the Sixth Army structures was the failure of the entrance bulkheads and doors. It would have been virtually impossible for an occupant to have survived the missile hazard associated with the damage. This damage further emphasizes that against atomic weapons the entrances should be given as much design consideration as the structure. Arch damage (noted in only J-1 and K-1) was less to the Sixth Army structures than to the F structures because the Sixth Army structures were subjected to peak overpressure only and not to a combination of overpressure and drag pressure. These structures were placed from 6 in. to 2 ft below ground surface and were covered similarly to the previously mentioned shelters with 4 to 5 ft of earth cover. It is believed that pressure instrumentation in these structures would have revealed as a result of entrance failures, relatively fast rise times to high overpressures which probably prevented further arch damage, especially to J-1 and K-1.

11. Damage Criteria. The weapons effects information currently published in TM 23-200 does not adequately cover the structures exposed in this project. Recent developments have been made in design and construction of fighting emplacements and personnel shelters (7). Tests on structures representative of these designs (Types A, B, E, and G) indicate that current blast damage prediction methods are either overly pessimistic or do not include information on the damage to structures of this type. For purposes of predicting safety to personnel, blast damage to structures must be considered concurrently with blast pressure and radiation levels expected inside the structures. This implies that simple scaling of blast effects to determine safe distances for field fortifications will not hold. Thus, weapons effects predictions in terms of safety to personnel rather than probability of structural damage would appear to have more significance.

IV. CONCLUSIONS

12. Conclusions. It is concluded that:

a. The degree of structural damage at a given distance from ground zero depends largely upon the elevation of the structure in relation to ground surface. The vulnerability of structures in descending order is (1) structures located on ground surface; (2) structures located partially below ground surface; and (3) structures located totally below ground surface.

b. The damage to surface and semisurface structures from lateral or drag forces is at least equal to or more severe than the damage caused by vertical forces.

c. Joints and fastenings play as important a role in structure survival as do the materials themselves.

d. Field fortifications, especially below-grade-level shelters, can be constructed to withstand blast effects of moderate intensity, but the effects of both prompt nuclear radiation and, to a lesser extent, blast pressure inside the structures, will dictate the range at which occupants of these structures will survive. It appears that fighting emplacements of the semisurface type can survive at 30 to 40 psi overpressure; and that, depending on the entrances, shelters can withstand almost twice this amount.

e. Current blast damage prediction methods in TM 23-200 are either overly pessimistic or do not include information on the damage to heavy timber structures of the type exposed in this project.

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APPENDIX

SUPPLEMENTARY DATA

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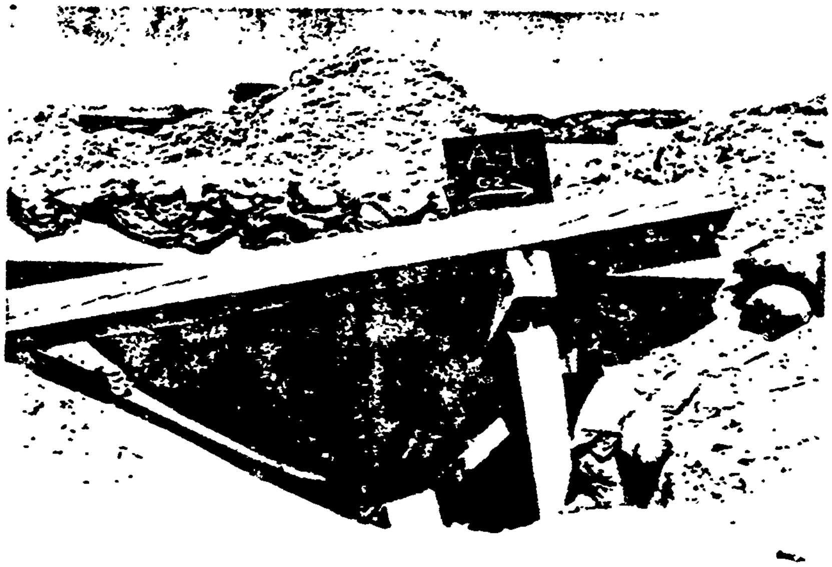

A13277

Fig. 26. A-1 structure, right entrance.

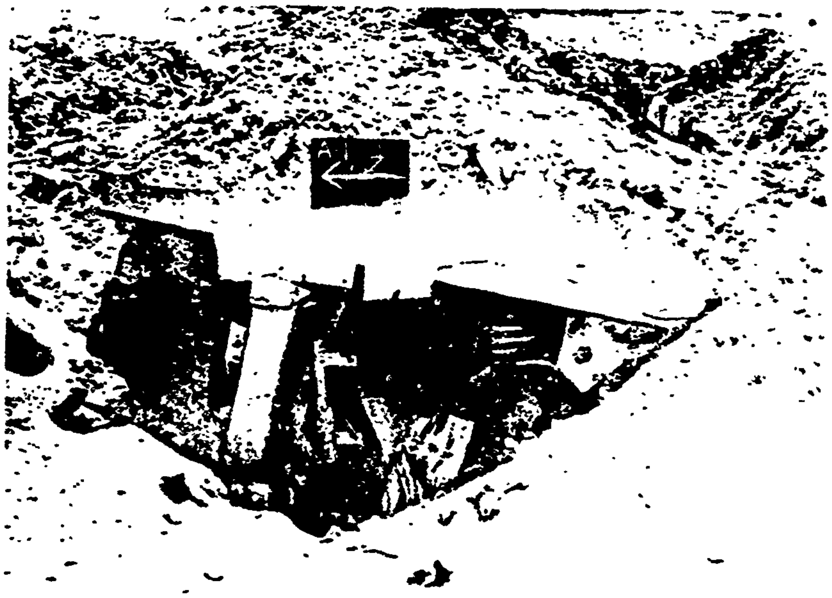

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Fig. 27. A-1 structure, left entrance.

A13226

Fig. 28. A-1 structure, looking from left to right through TCS (GZ to left).

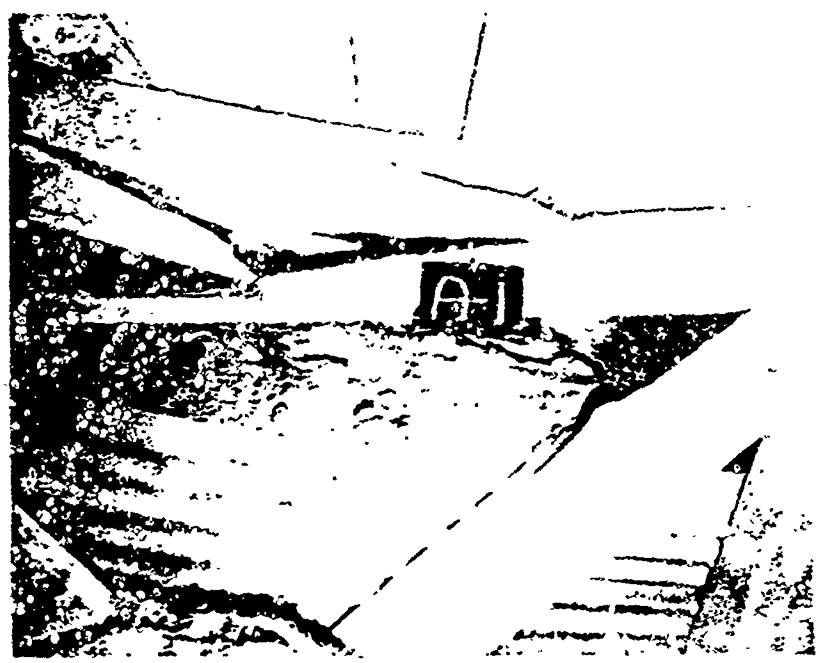

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Fig. 29. A-1 structure, center span TCS (looking toward GZ).

A13228

Fig. 30. A-1 structure, emplacement wall (GZ in direction of left foreground).

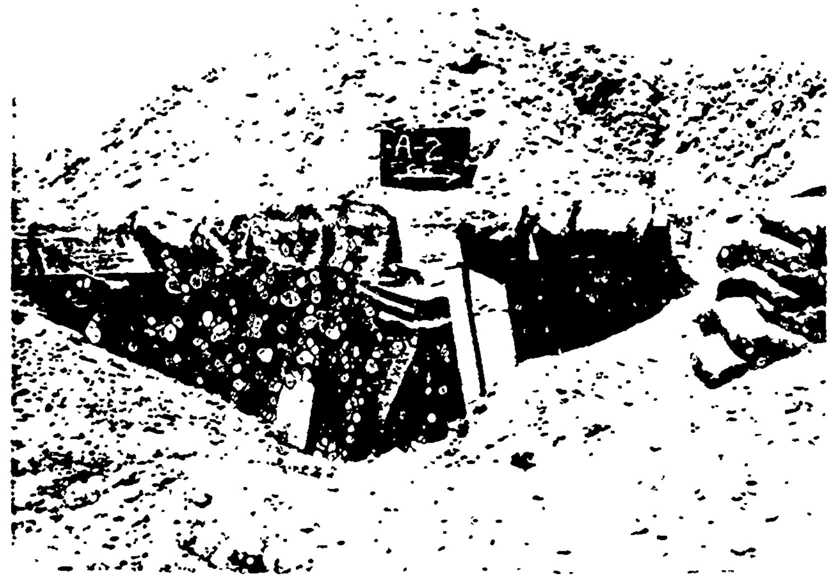

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Fig. 31. A-2 structure, right entrance.

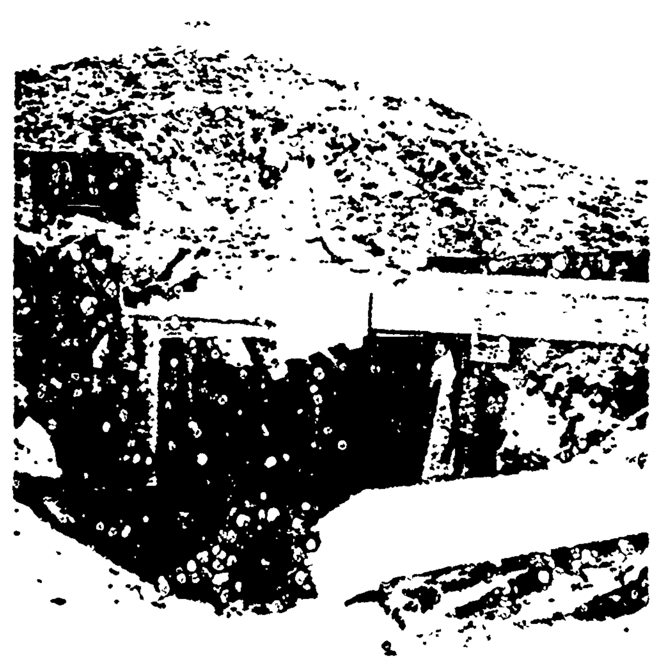

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Fig. 32. A-2 structure, left entrance.

A13300

Fig. 33. A-2 structure, looking toward right entrance (GZ to left).

A13230

Fig. 34. A-2 structure, rear wall, left entrance (GZ to right).

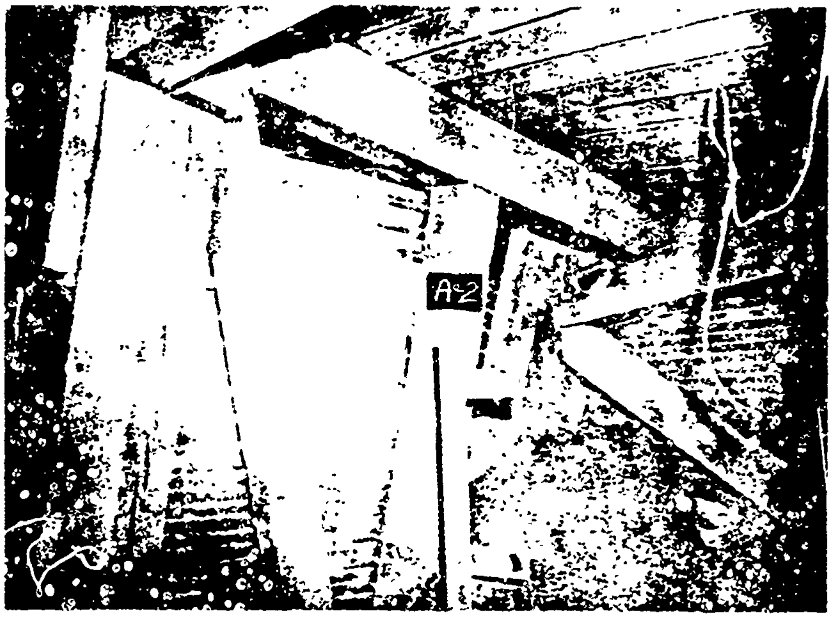

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Fig. 35. A-2 structure, emplacement wall (GZ in direction of left foreground).

A13009

Fig. 36. A-2 structure, front and side firing port walls (looking from GZ).

A13301

Fig. 37. A-2 structure, looking toward firing port aprons (GZ to left background).

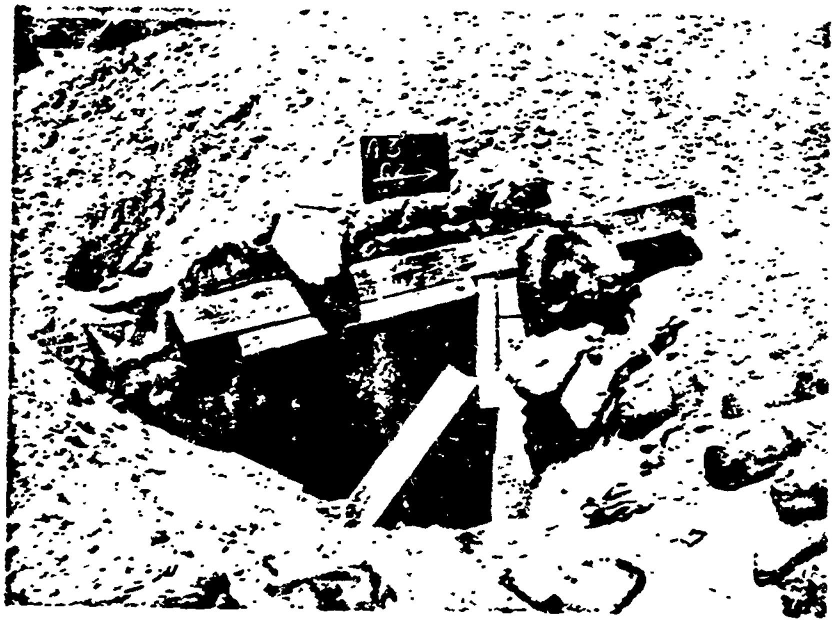

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Fig. 38. A-3 structure, right entrance.

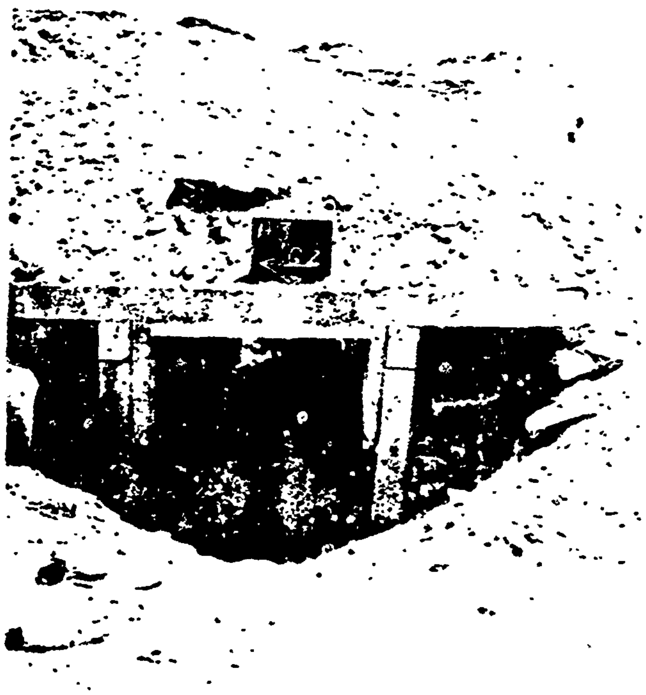

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Fig. 39. A-3 structure, left entrance.

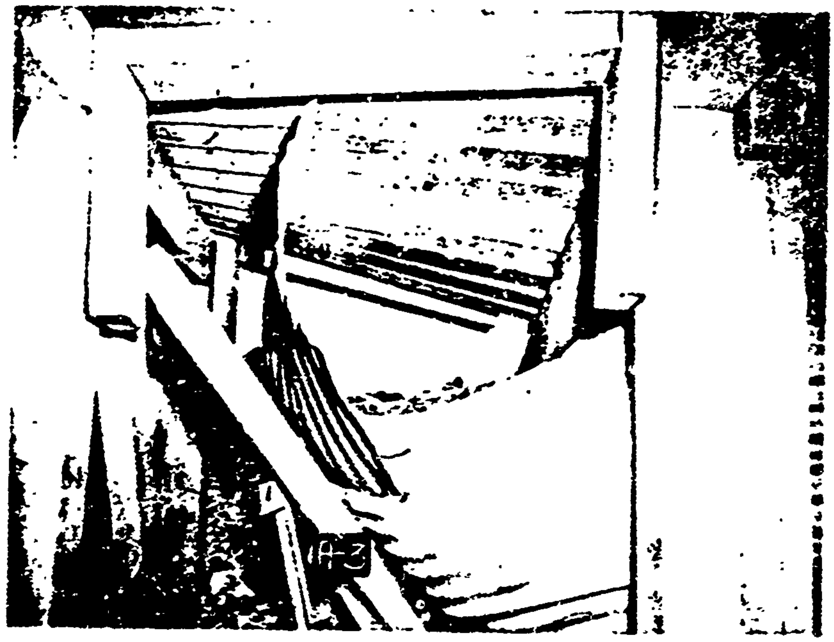

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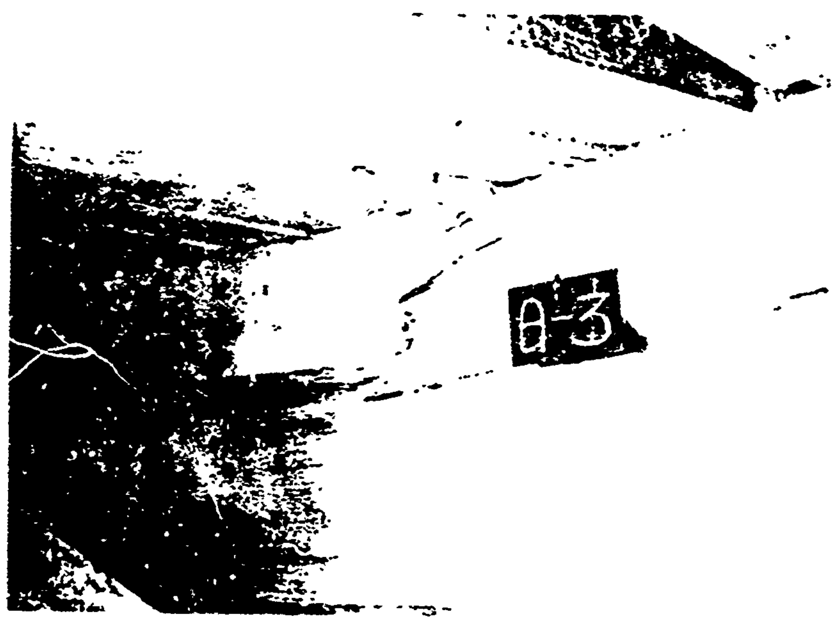
Fig. 40. A-3 structure, looking toward right entrance (GZ to left).



A13237

Fig. 41. A-3 structure, right front TCS cap (looking toward GZ).

A13238

Fig. 42. A-3 structure, emplacement wall right, TCS left (GZ in direction of left background).

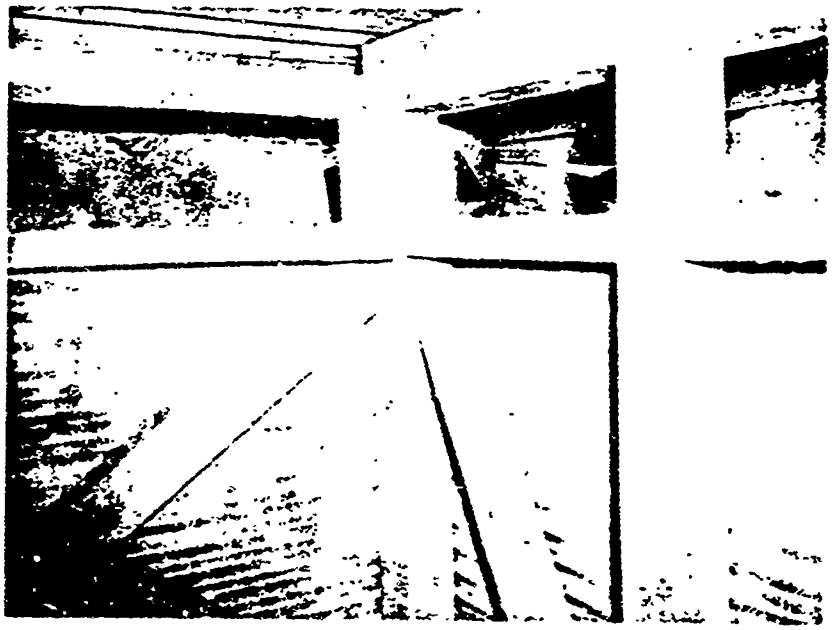


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Fig. 43. A-3 structure, front and side firing port walls (looking from GZ).

A13273

Fig. 44. Entrance to B-1 structure.

A13296

Fig. 45. Entrance to B-2 structure.

A13305

Fig. 46. Entrance to B-3 structure.

A13279

Fig. 47. Entrance to B-1 structure from inside (GZ to right).

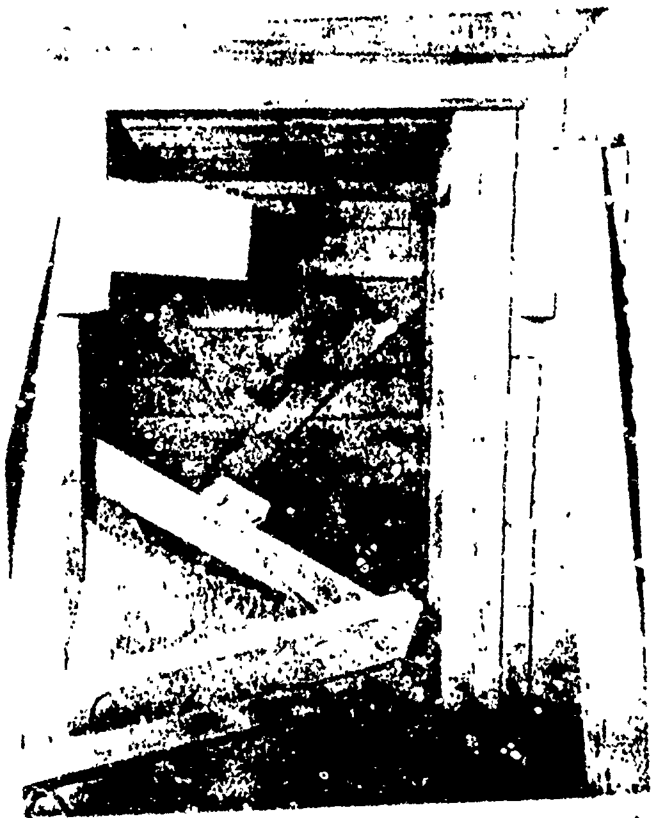

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Fig. 48. B-1 structure, entrance to first modular section (looking from GZ).

A13281

Fig. 49. B-1 structure, forward walls of modular sections, entrance from TCS at left.

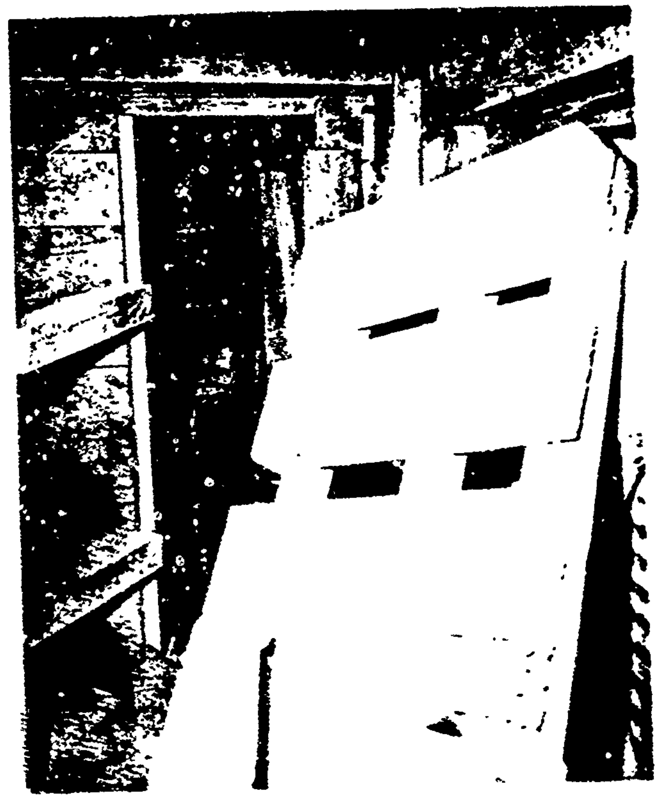

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Fig. 50. B-3 structure, blast door damage (looking from GZ).

A13282

Fig. 51. C-1 structure.

A13295

Fig. 52. C-2 structure.

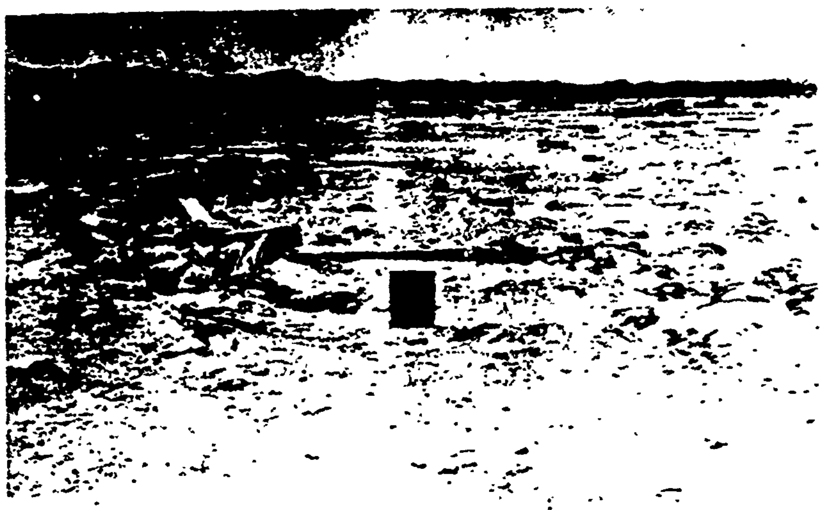

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Fig. 53. C-3 structure.

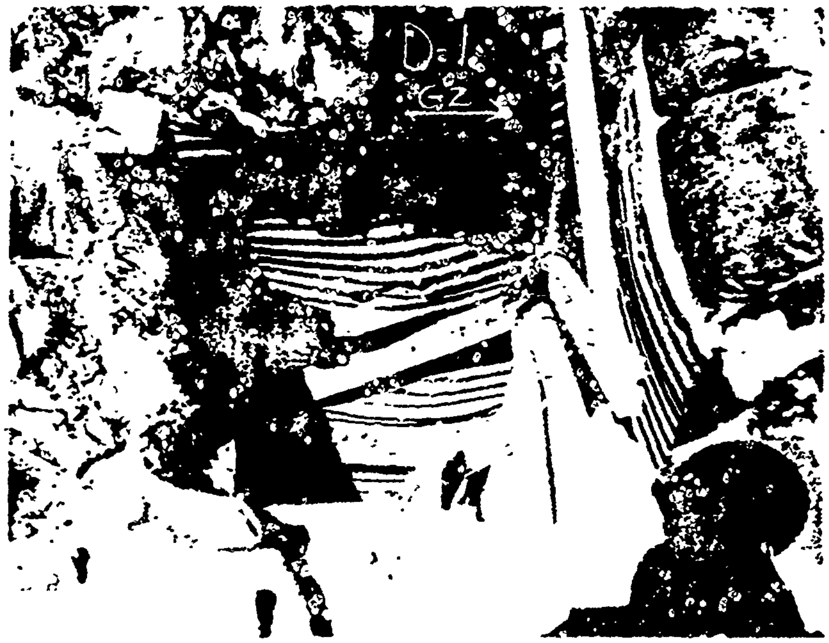

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Fig. 54. Right entrance shaft, D-1 structure.

A13287

Fig. 55. Left entrance shaft, D-1 structure.

A13289

Fig. 56. Right entrance shaft, D-2 structure.

A13290

Fig. 57. Left entrance shaft, D-2 structure.

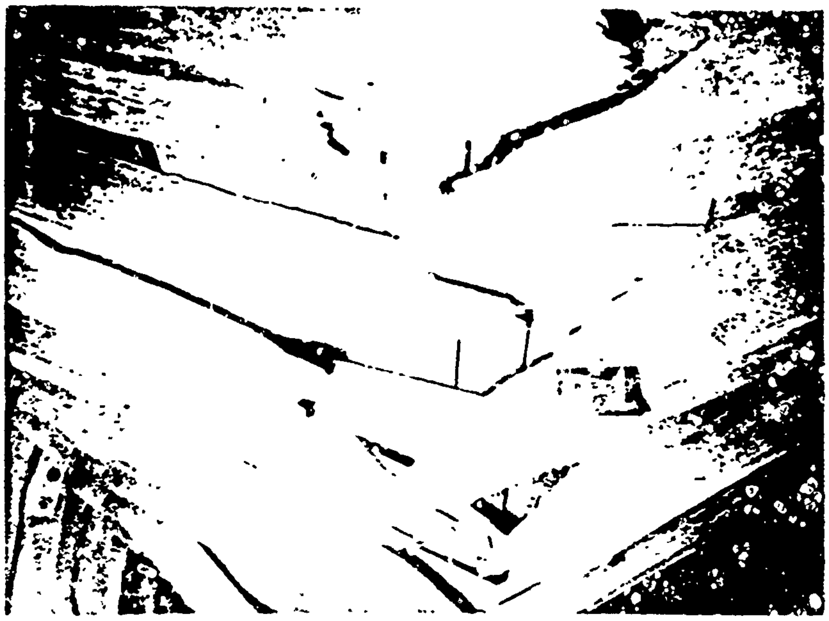

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Fig. 58. Cap damage in D-1 structure (GZ to right).

A13236

Fig. 59. Entrance passage in D-1 structure (looking toward GZ and vertical entrance shaft).

A13234

Fig. 60. Front wall of room in D-1 structure (GZ in direction of right background).

A13283

Fig. 61. Left side of E-1 structure.

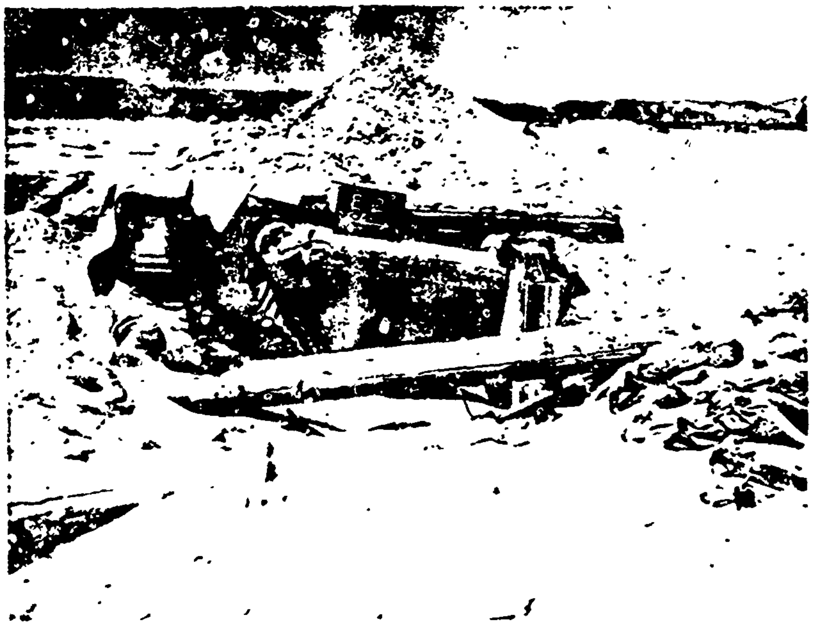

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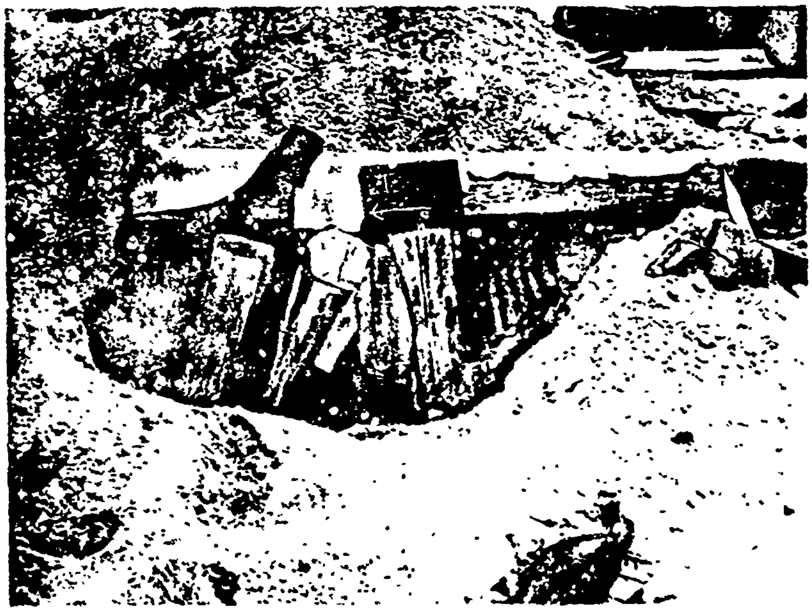
Fig. 62. E-2 structure, right entrance.



A13293

Fig. 63. E-2 structure, left entrance.

A13292

Fig. 64. E-2 structure, looking from right to left through TCS (GZ to right).

A13232

Fig. 65. E-2 structure, portion of right side of front TCS wall (GZ in direction of right background).

A13294

Fig. 66. Top view of E-2 emplacement (GZ to left).

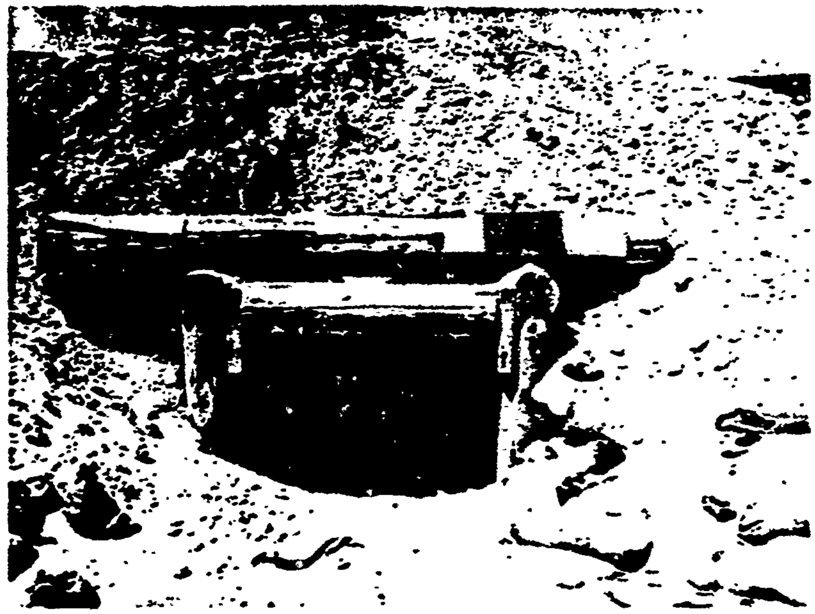


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Fig. 67. E-3 structure, right entrance.

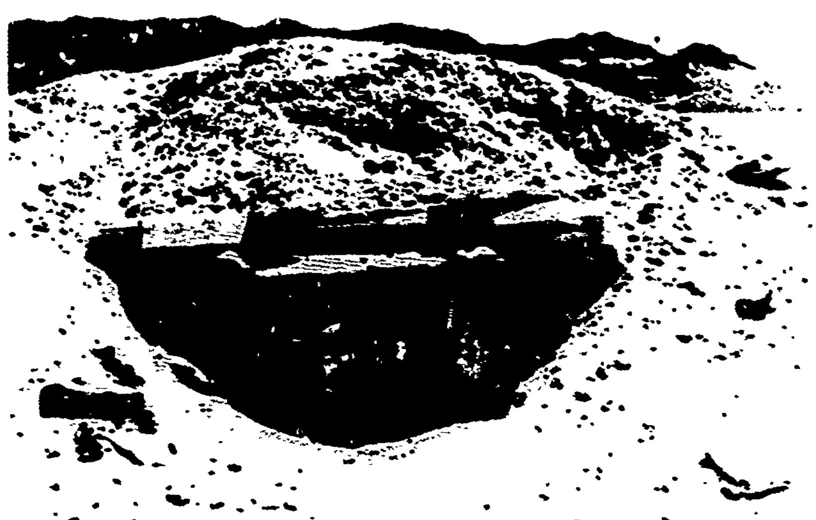

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Fig. 68. E-3 structure, left entrance.

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Fig. 69. E-3 structure, emplacement wall (GZ in direction of left foreground).

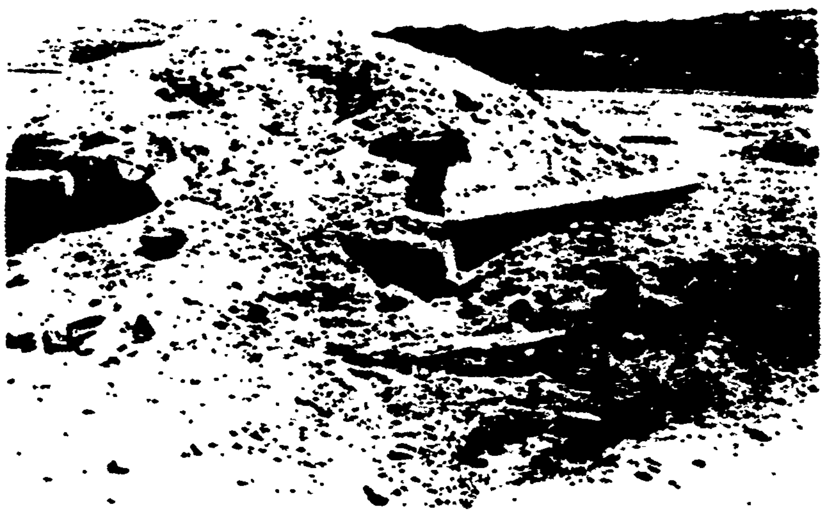

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Fig. 70. E-3 structure, looking toward firing port aprons (GZ to left background).

A13284

Fig. 71. F-1 structure, left entrance.

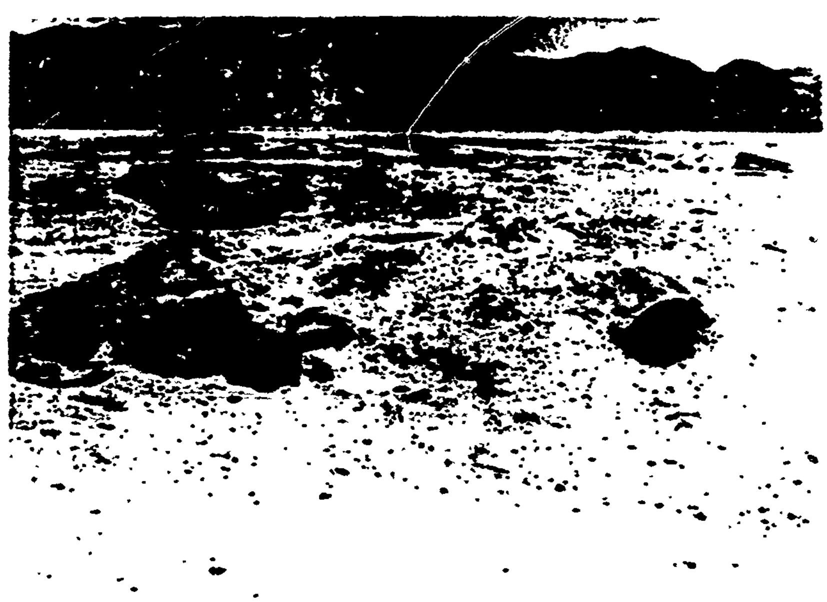

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Fig. 72. F-3 structure, left entrance.

A13285
Fig. 73. Entrance to G-1 structure.

A13339
Fig. 74. Entrance to G-3 structure.

A13341

Fig. 75. Post damage in G-3 structure.

A13286

Fig. 76. H-1 structure.

A13340

Fig. 77. H-3 structure.

A13243

Fig. 78. Structural failure in plywood dome, H-3 structure (looking toward GZ).

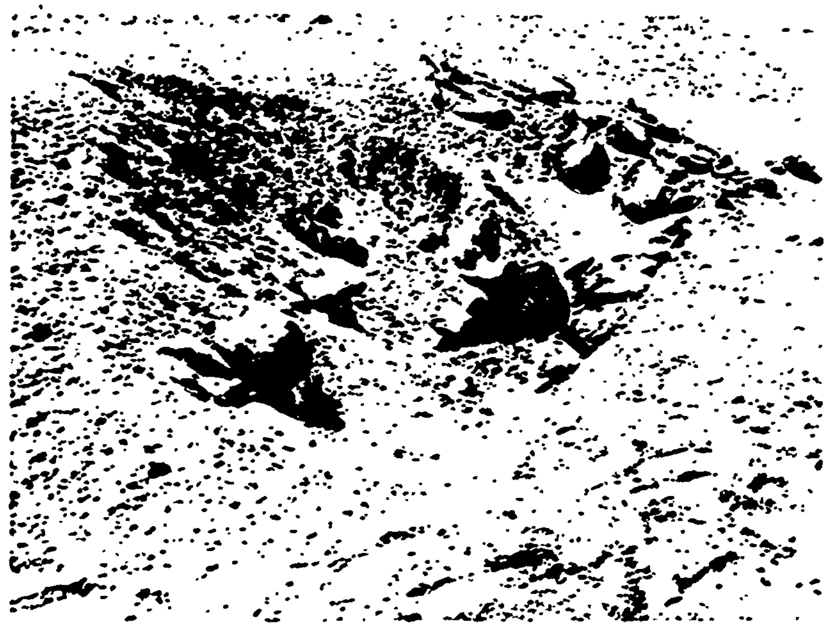

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Fig. 79. I-3 structure, general view of entrance (GZ in direction of left foreground).

A13269

Fig. 80. J-2 structure, general view of entrance (GZ in direction of left foreground).

A13261

Fig. 81. K-3 structure, general view of entrance (GZ in direction of left foreground).

A13264

Fig. 82. K-3 structure, interior view (arch toward GZ).

APPROVAL OF

Report 1468-TR

DESERT ROCK VI (U)

2 November 1956

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18 February 1957

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SUBJECT: Transmittal for Approval of Report No. 1468TR, Desert Rock VI. (u)

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Department of the Army
Washington 25, D. C.
ENGTN

Report No. 1468TR, dated 2 November 1956, and its Proposed Distribution List are submitted for approval.

2 Incls
1. Proposed distr list
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H. F. S[illegible]
Colonel,
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SUBJECT: Transmittal for Approval of Report No. 1468TR, Desert Rock VI

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TO: Commanding General, Engineer Research and Development Laboratories, Fort Belvoir, Virginia

1. Report No. 1468TR, Field Fortification Test, Exercise Desert Rock VI, 8 November 1956, Project 8-12-75-001, is approved.

2. Distribution is authorized as per inclosed revised distribution list.

FOR THE CHIEF OF ENGINEERS:

H. E. BROWN
Colonel, Corps of Engineers
Chief, Engineer Research and
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