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Report 1557-TR

PROTECTION AFFORDED BY FIELD FORTIFICATIONS AGAINST NUCLEAR WEAPONS EFFECTS (U)

Project 8-12-95-400 (formerly 8-12-75-001)

8 December 1958

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Report 1557-TR

PROTECTION AFFORDED BY FIELD FORTIFICATIONS AGAINST NUCLEAR WEAPONS EFFECTS (U)

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REGRADED UNCLASSIFIED
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BY [illegible] ON [illegible]

Nathaniel J. Davis, Jr
Special Projects Branch
Military Engineering Department
U. S. Army Engineer Research and Development Laboratories
Corps of Engineers
Fort Belvoir, Virginia

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PREFACE

The test of field fortifications in Exercise DESERT ROCK VII was conducted under the authority of Project 8-12-95-400 (formerly 8-12-75-001).

This report was prepared by Nathaniel J. Davis, Jr., Project Engineer, under the supervision of Frederick A. Pieper, Chief, Technical Analysis Section, and under the general supervision of Dr. Thomas G. Walsh, Chief, Special Projects Branch, U. S. Army Engineer Research and Development Laboratories (USAERDL), Fort Belvoir, Virginia. The Chemical Warfare Laboratories (CWL) and the Ballistic Research Laboratory (BRL) provided instrumentation for nuclear radiation and blast measurements, respectively. William H. Van Horn, sub-project officer, and 1st Lt. Craig Miller, both from the USAERDL but assigned to the CWL for the test, provided essential support. Construction of the fortifications was the responsibility of Camp Desert Rock and was performed by Company B of the 84th Engineer Battalion (Construction).

CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY

This report covers a field fortification test conducted as a part of Exercise DESERT ROCK VII during Operation PLUMBBOB. The test objectives were (1) to determine if increased protection could be obtained by using a shelter-type entrance in conjunction with a 7-ft by 7-ft machine gun emplacement; (2) to determine the vulnerability of a laminated roof to blast from atomic weapons; (3) to determine the effect of partial cover (varying the size of entrance opening) and orientation on the attenuation of prompt gamma and neutron radiation in various types of hasty fortifications; and (4) to determine the protection afforded by the offset foxhole against blast and nuclear radiation.

The fortifications were exposed to peak overpressure of from 9.0 to 42.7 psi from the Priscilla shot, a 37-KT weapon, burst at a height of 700 ft.

The report concludes that:

a. Access construction for the 7-ft by 7-ft machine gun emplacement is less vulnerable to blast for all orientations if it is placed with the roof at grade level rather than at the same elevation as the emplacement; it will afford a greater degree of protection to occupants from blast-driven debris than will the emplacement.

b. The shelter used in conjunction with the 7-ft by 7-ft machine gun emplacement provided better shielding against nuclear radiation than the emplacement, but the additional shielding obtained may not be sufficient to justify the construction effort.

c. The 7-ft by 7-ft machine gun emplacement can withstand blast effects of up to approximately 40 psi peak overpressure only if it is facing away from the burst. It appears to be extremely vulnerable to blast when oriented side-on to ground zero and facing ground zero.

d. On relatively open fortifications, a laminated roof of the design tested appears capable of sustaining loads resulting from incident peak overpressure of up to about 40 psi.

e. The initial gamma transmission factor of the standard, open, two-man foxhole ranged from 0.067 for the side-on orientation to 0.131 for the end-on orientation. The addition of 2/3 cover reduced the factor by about 50 percent while full cover reduced it by about 70 percent.

f. The neutron transmission factor of the standard, open, two-man foxhole was 0.29. The addition of 2/3 cover reduced this factor by about 65 percent.

g. The modified, two-man foxhole (1/2 covered) provided more shielding than the 1/3 covered and less shielding than the 2/3 covered, standard, two-man foxholes similarly oriented.

h. The initial gamma transmission factor of the horizontal tunnel of the offset foxhole ranged from 0.006 to 0.008 at 2280 ft from ground zero and from 0.003 to 0.005 at 3900 ft from ground zero. The factors for the open, offset foxhole and the covered, offset foxhole with firing step were about the same.

i. The neutron transmission factor of the tunnel of the offset foxhole was 0.003 at 2280 ft from ground zero.

j. Pressure multiplication in the tunnels of the offset foxholes caused peak overpressures which ranged from 1.8 to 2.6 times the incident peak overpressure.

k. The circular foxhole appeared to be less vulnerable to blast than the standard two-man foxhole. Meager test evidence does not justify further conclusions about its vulnerability.

PROTECTION AFFORDED BY FIELD FORTIFICATIONS

AGAINST NUCLEAR WEAPONS EFFECTS (U)

I. INTRODUCTION

1. Subject. This report covers Project 50.6, a field fortifications test conducted as a part of Exercise DESERT ROCK VII, Operation PLUMBBOB. The objectives of this project were (1) to determine if increased protection could be obtained by using a shelter-type entrance in conjunction with the 7-ft by 7-ft machine gun emplacement; (2) to determine the vulnerability of a laminated roof to blast from atomic weapons; (3) to determine the effect of partial cover (varying the size of entrance opening) and orientation on the attenuation of prompt gamma and neutron radiation in various types of hasty fortifications; and (4) to determine the protection afforded by the offset foxhole against blast and nuclear radiation.

2. Background and Previous Investigation. Standard 7-ft by 7-ft machine gun emplacements having standard covered trench entrances with approximately 5 ft of earth cover were tested during Exercise DESERT ROCK VI. At overpressures where these emplacements received only light damage (approximately 35 psi), nuclear radiation inside the emplacements was sufficiently high to have caused death to all occupants. Fast rise times and relatively high overpressures were also recorded inside the emplacement. The structure projected above ground surface over the entire plan area, and damage from lateral loading was very evident. For DESERT ROCK VII, it was desired to test a machine gun emplacement which incorporated modifications indicated by the previous test to provide more protection from atomic effects. It was believed that this could be accomplished with only a slight increase in the materials required by designing the entrance to provide more protection. In effect, the structure would serve as a combination shelter-fighting emplacement. Furthermore, it was desired to test on the emplacement proper a laminated roof of the type on which the Demolitions and Fortifications Branch, USAERDL, Fort Belvoir, Virginia, had conducted high explosive experiments. These experiments were aimed at developing a roof that was not as vulnerable as the stringer-type roof to blast from high explosive shells. The results of tests had been very encouraging. In fact, in tests conducted at Fort Sill, Oklahoma, by personnel from the above branch with the cooperation of the Guided Missile and Artillery School, this type of roof with only 2 ft of earth cover sustained repeated direct hits with 155-mm howitzer shells fuzed with 0.05 second delay fuzes. Such hits would have caused solid timber roof stringers to fail. It was, therefore, desirable to get a comparative evaluation of the response of this type roof to the impulse from atomic weapons.

In the fall of 1955, the Panel on the Organization of the Ground was convened at the U. S. Army Engineer School, Fort Belvoir, Virginia. During the course of this meeting, it was determined that approximately 18 in. of cover on emplacements would be all that could be expediently used and that under the current concept of protection against atomic attack in the forward area, maximum use of protective-type shelters would be sacrificed in favor of mobility and dispersion. Also, questions arose with reference to the degree of additional protection from nuclear radiation, especially residual radiation, which could be furnished by partially covering hasty emplacements of the foxhole type. To a large extent, the hasty emplacements in this project stemmed from the Panel on the Organization of the Ground and were proposed for test by the U. S. Army Engineer School. It was realized when this project was initiated that a contaminating burst from which to obtain data on residual radiation probably would not be available; however, the investigation of the shielding afforded by partially covered foxholes against prompt gamma and neutron radiation was considered of importance. Furthermore, prior to Operation TEAPOT, most of the neutron data measured included only the high and low ends of the neutron spectrum and not the intermediate neutron energies (4 Kev to 3 Mev). Discussion with DOD Project 2.4 personnel at the CWL, Army Chemical Center, Maryland, revealed that shielding data, particularly for neutrons, on several of the Project 50.6 fortifications were especially desirable for analysis and inclusion in the report of the 2.4 project. As a result, the Project 50.6 fortifications were incorporated in the neutron and gamma shielding tests of Project 2.4.

II. INVESTIGATION

3. Description of Test. Twenty-seven fortifications were exposed at Frenchman Flat to the Priscilla Shot, a 37-KT weapon, burst at a height of 700 ft. The fortifications were 7-ft by 7-ft machine gun emplacements with entrance shelters, standard two-man foxholes, modified two-man foxholes, open offset foxholes, covered offset foxholes, and 6-ft by 8-ft hasty shelters. These are shown in Figs. 1 through 8 respectively.

The machine gun emplacement was basically the same design as shown in Engineer Technical Bulletin 117 and was the one tested in Exercise DESERT ROCK VI. The primary difference was in the roof design. Fig. 1 shows a laminated roof (7 layers of 1-in. by 12-in. planks) on the emplacement instead of the normal 6-in. by 6-in. timber stringers. The entrance (Fig. 2) used with the emplacement was non-standard but had one span (5 ft 4 in.) of approximately the same design as the standard trench cover section (see reference 4). The position of the emplacement relative to the entrance is shown in

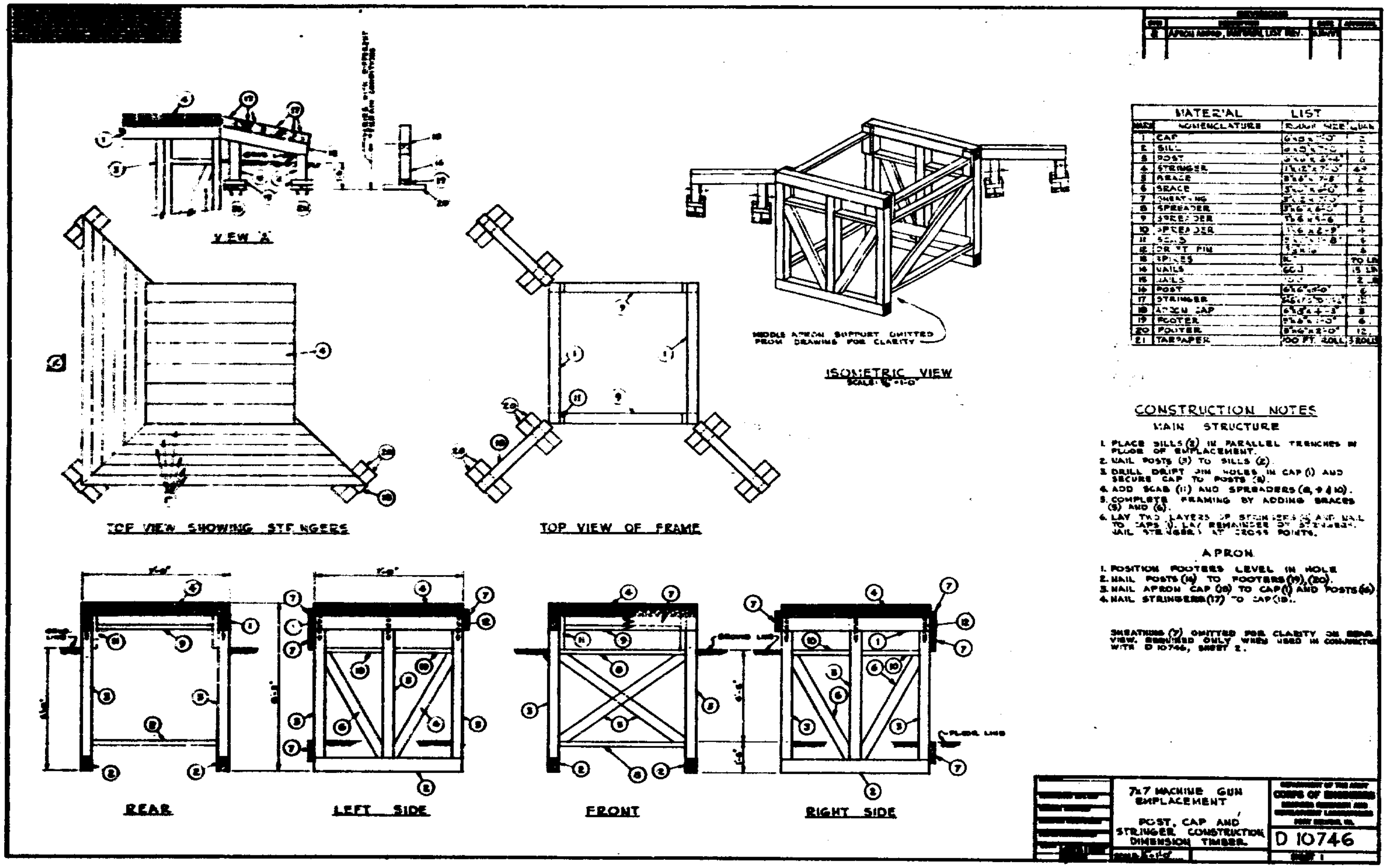

Fig. 1. 7' x 7' machine gun emplacement.

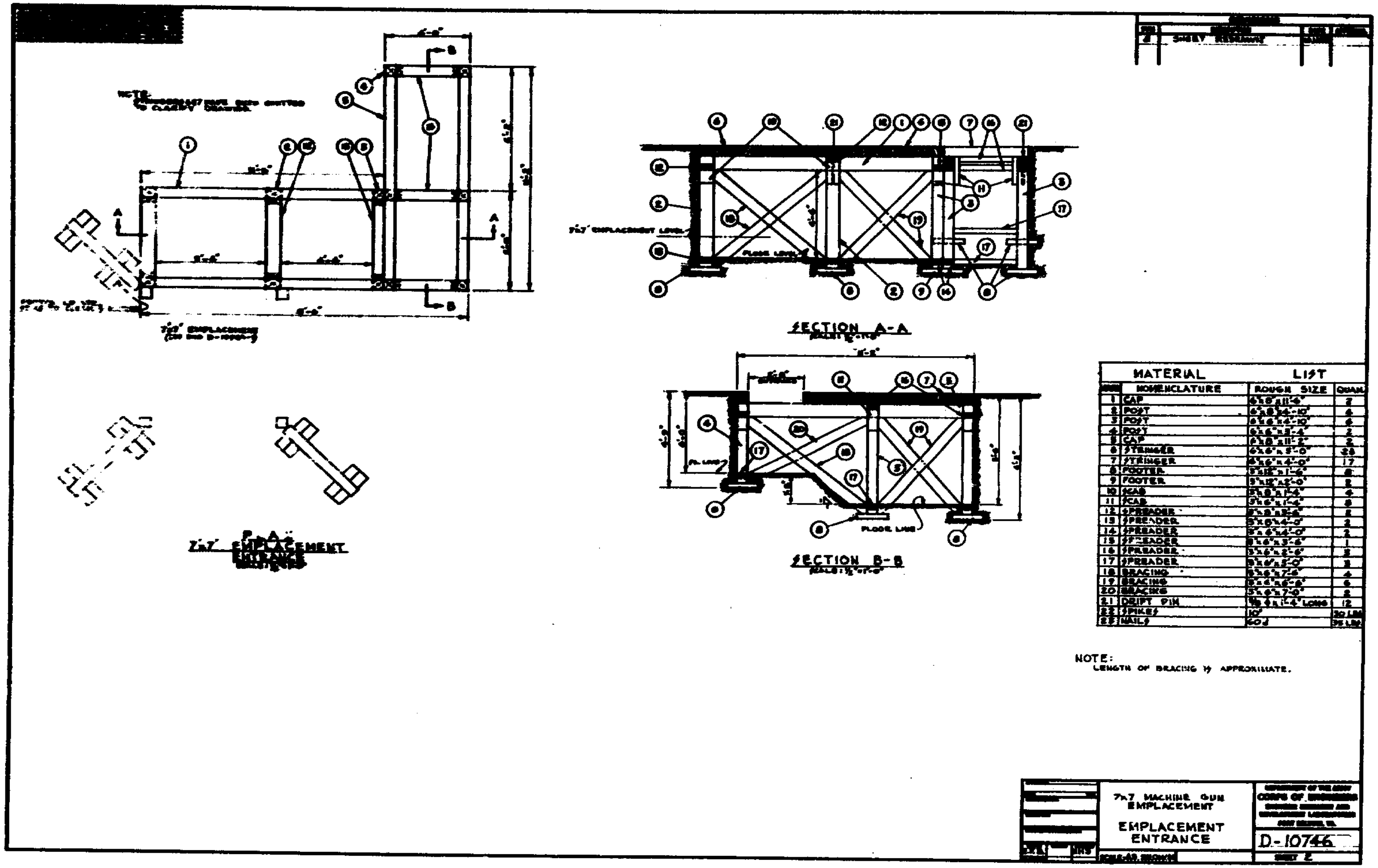

Fig. 2. 7' x 7' machine gun emplacement entrance.

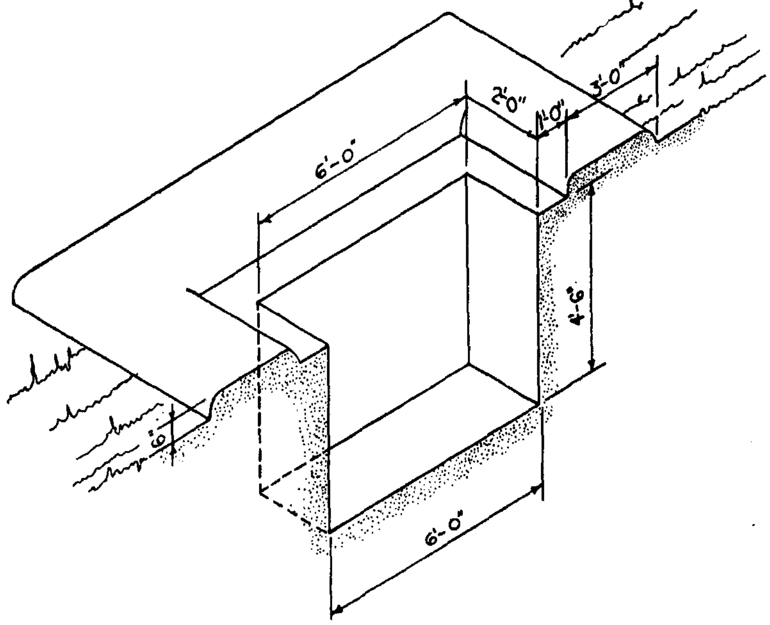

Fig. 3. Standard two-man foxhole.

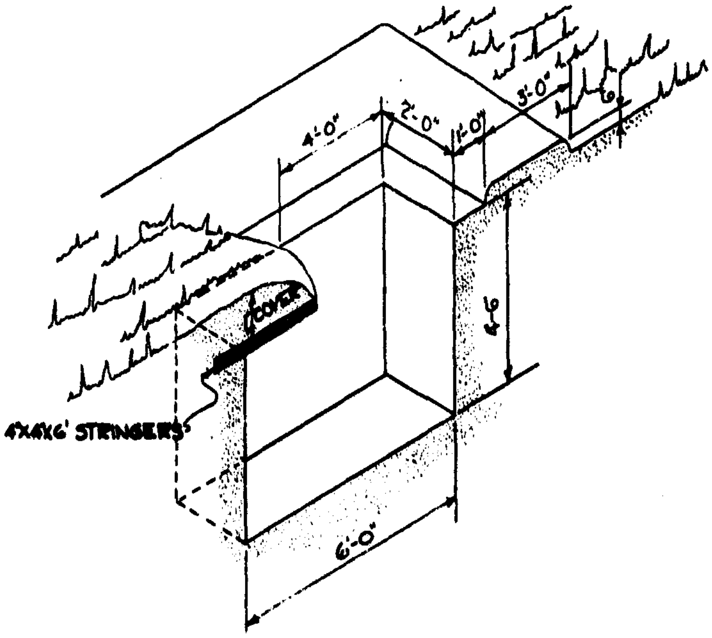

Fig. 4. Standard two-man foxhole, 1/3 covered.

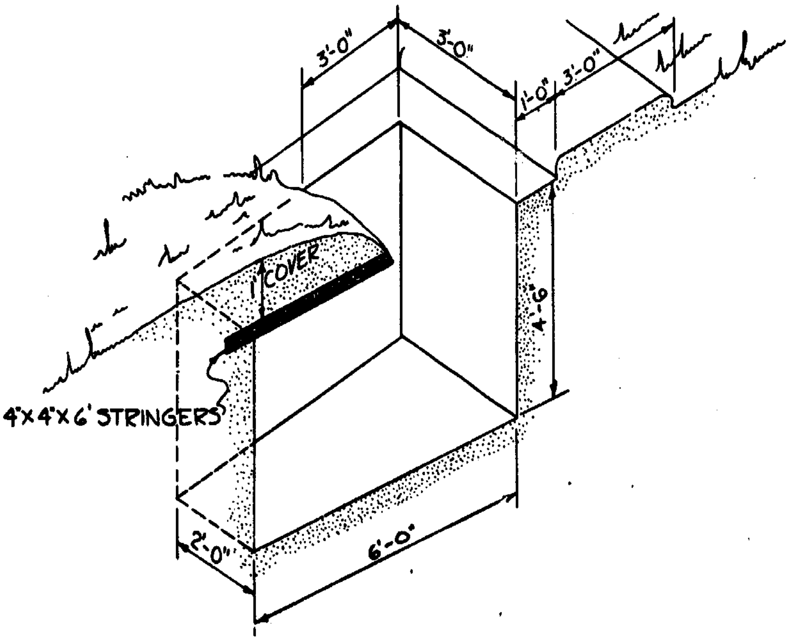

Fig. 5. Modified two-man foxhole.

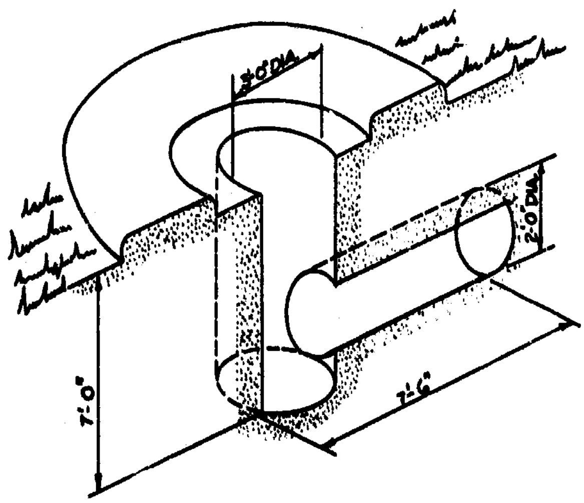

Fig. 6. Open offset foxhole.

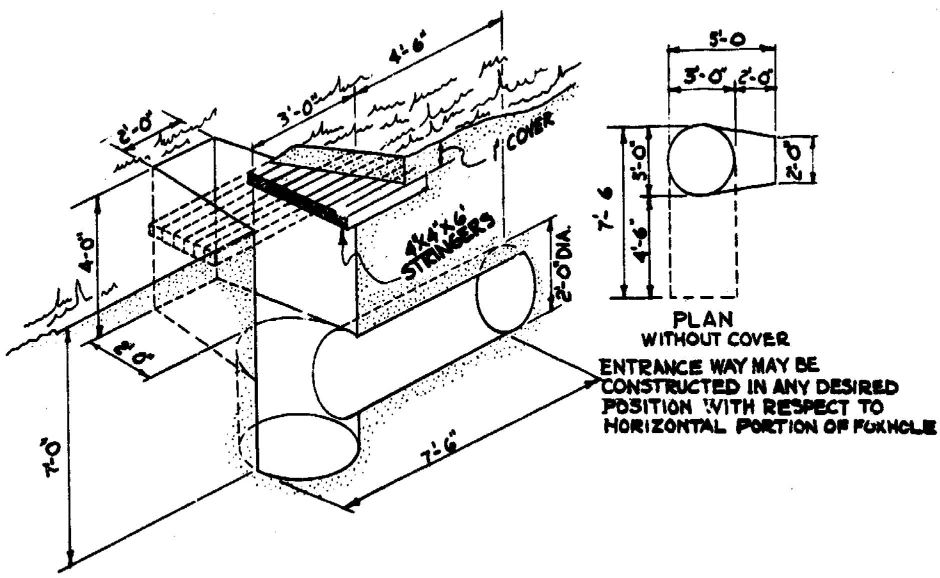

Fig. 7. Covered offset foxhole.

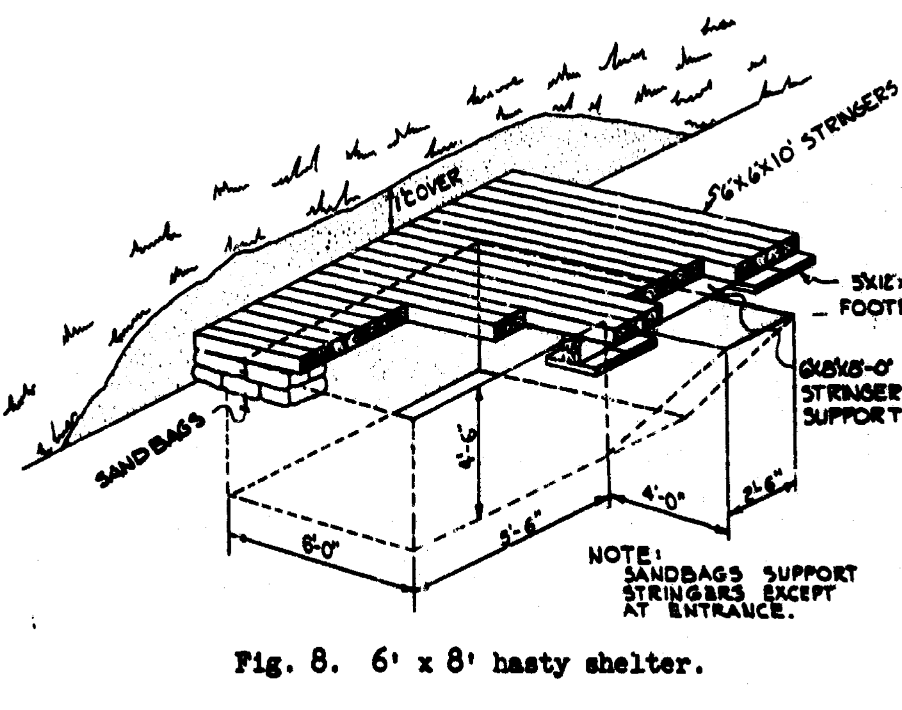

Fig. 8. 6' x 8' hasty shelter.

Fig. 2 (plan view). The entrance structure, which had its roof stringers flush with the surface of the ground, was covered with 5 ft of earth cover; however, the emplacement projected above the surface of the ground and had only 2 ft 9 in. of earth cover. These fortifications were sheathed with 24-gage, corrugated steel. They were exposed in two orientations (1) with the front firing port facing away from ground zero (rear-on) and (2) with the side firing port facing ground zero (side-on). The machine gun emplacement is best described by Figs. 9 through 16.

The rest of the fortifications can be classed as hasty fortifications. These were covered with 1 ft of earth cover supported by 4-in. by 4-in. timber stringers on the foxholes and by 6-in. by 6-in. timber stringers on the shelters. Two-man foxholes were exposed side-on and end-on to ground zero; no cover, one-third cover, two-thirds cover, and full cover were used to determine the effect of partial cover on the attenuation of prompt gamma and neutron radiation. Fig. 4 shows the two-man foxhole one-third covered. When the two-man foxhole is partially covered, it tends to become a one-man foxhole in the sense that two men cannot effectively fight from it at the same time; hence, the modified two-man foxhole shown in Fig. 5. One end of this emplacement was made 3 ft wide to enable two men to stand abreast. Two of these foxholes were exposed, one with the covered end toward ground zero and one with the open end toward ground zero. Both were one-half covered. The two-man foxholes (Figs. 3, 4, and 5) were tested with flat floor surfaces; that is, the water sumps were omitted. The open and covered offset foxholes (Figs. 6 and 7) were tested with the horizontal tunnels oriented side-on to ground zero, toward ground zero, and away from ground zero; different materials were used to revet the tunnels. Those tunnels oriented side-on to ground zero and away from ground zero were revetted with sections of oil drums and with arched sticks, respectively. No revetment was used in the tunnels oriented toward ground zero. Two hasty shelters (Fig. 8) were constructed; the entrance of each faced ground zero. The earth cover on the shelters was as previously stated for the hasty fortifications; however, the entrance of each shelter was treated differently. One was left open; the other was closed with sandbags which were arranged to simulate the closure that could be accomplished by a person from within. Figs. 17 through 26 show photographs of the hasty fortifications.

The fortifications were constructed at ranges where overpressure between 45 and 8 psi was expected. Table I summarizes the emplacements and gives orientation, amount of entrance opening covered, and overpressure location for each. Fig. 27 shows the layout. To avoid excessive spread, the fortifications were offset 10 ft on each side of the 3900-ft arc rather than being all in one line (see

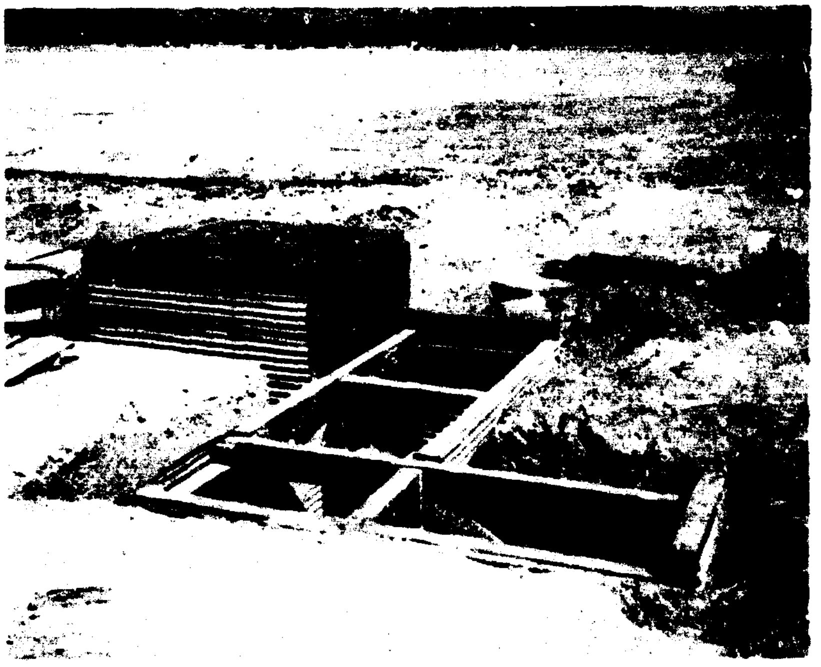

Fig. 9. 7' x 7' machine gun emplacement under construction.

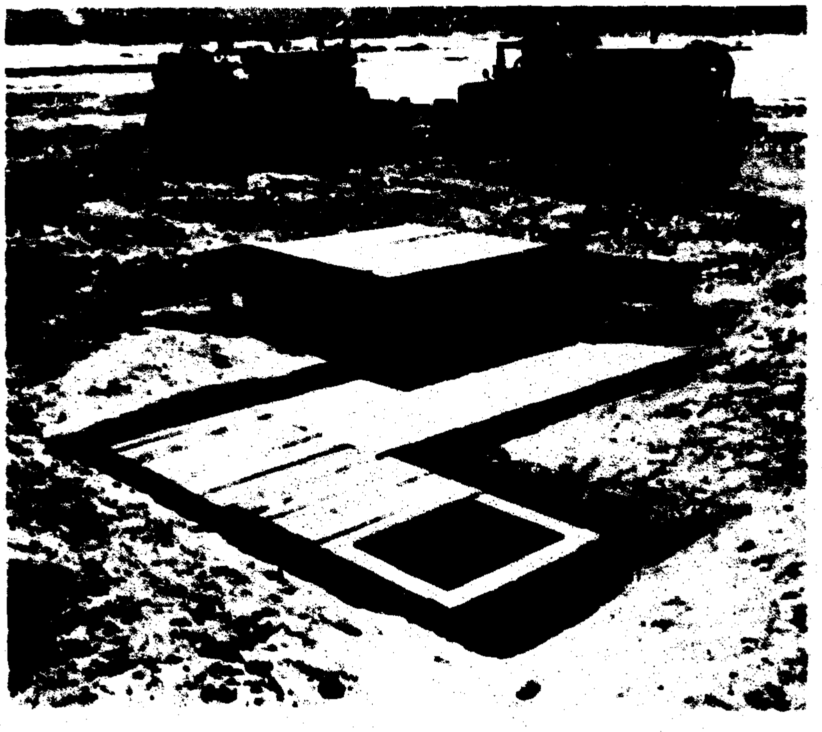

Fig. 10. 7' x 7' machine gun emplacement completed except for backfill and cover.

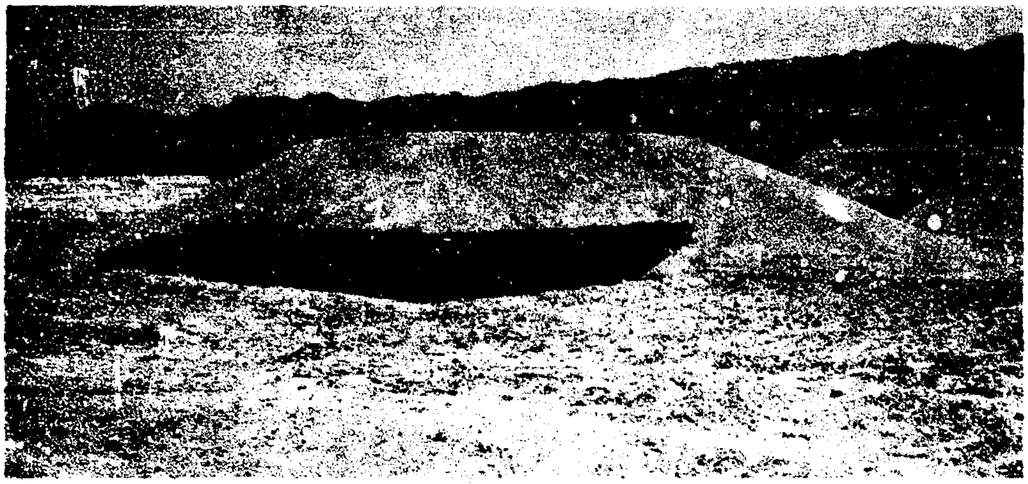

Fig. 11. Frontal view of 7' x 7' machine gun emplacement, front firing port to the right, side firing port to the left.

Fig. 12. View of 7' x 7' machine gun emplacement, looking toward side firing port.

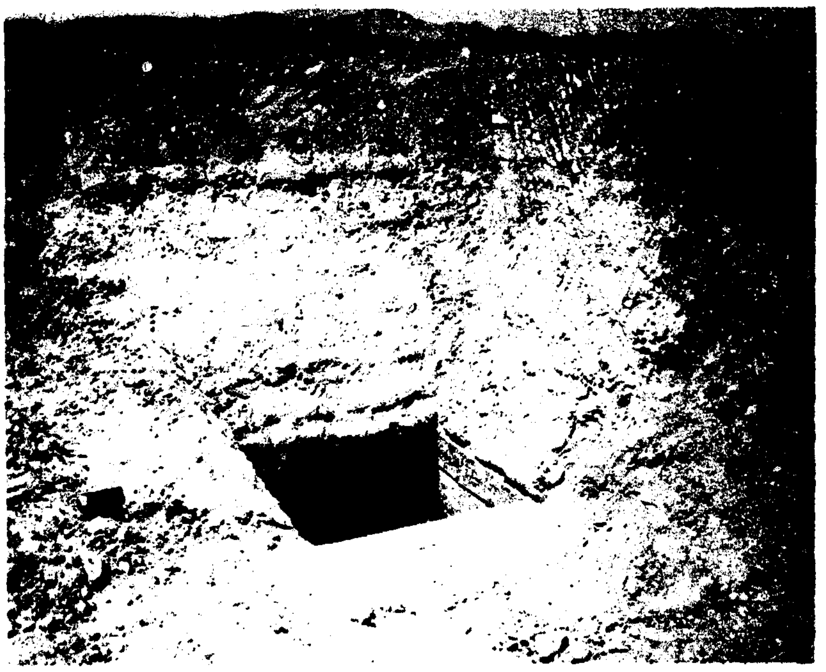

Fig. 13. Close-up view of entrance opening to 7' x 7' machine gun emplacement.

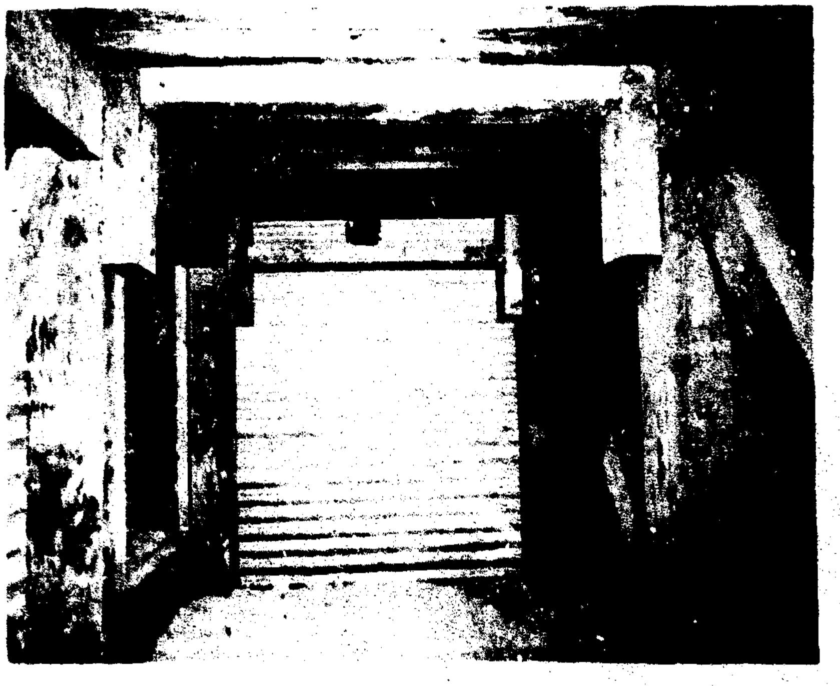

Fig. 14. View of shelter adjacent to 7' x 7' machine gun emplacement.

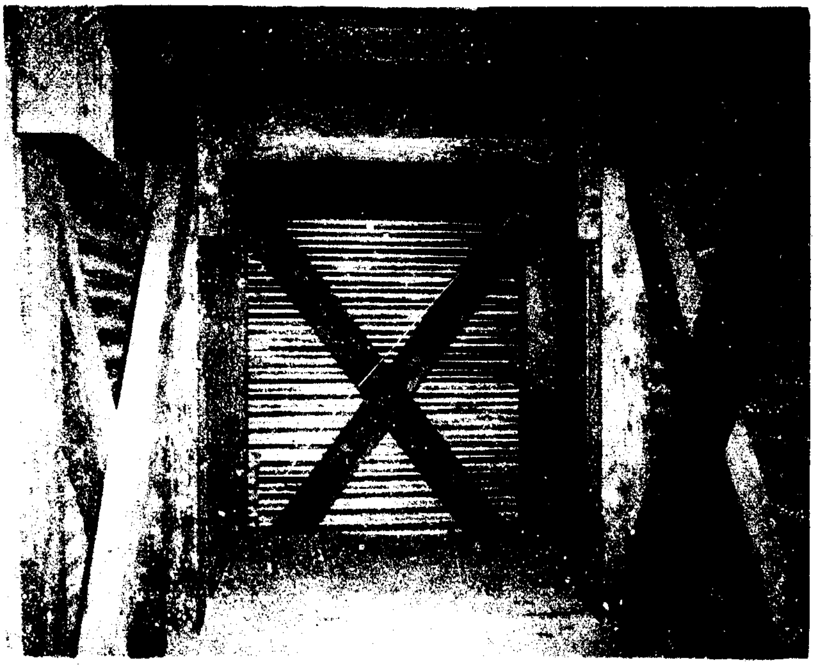

Fig. 15. View through shelter toward entrance from a point in the shelter adjacent to the emplacement.

Fig. 16. View through entrance toward entrance opening.

Fig. 17. Standard two-man foxhole, open.

Fig. 18. Standard two-man foxhole, 2/3 covered.

Fig. 19. Modified two-man foxhole.

Fig. 20. Open offset foxhole.

Fig. 22. Covered offset foxhole.

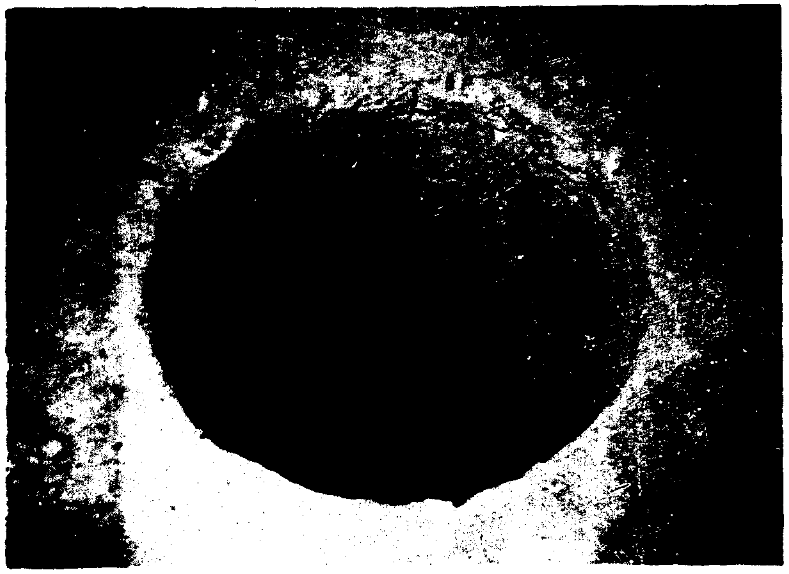

Fig. 21. Close up view of open offset foxhole, no revetment in tunnel.

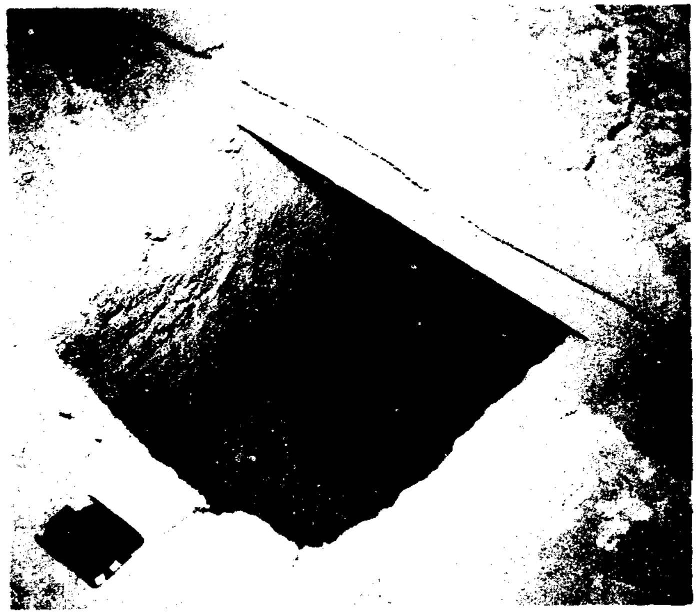

Fig. 23. Close up view of covered offset foxhole, oil drum revetment in tunnel.

[redacted]

Fig. 24. 6' x 8' hasty shelter, open entrance.

Fig. 25. 6' x 8' hasty shelter, closed entrance.

Fig. 26. Entrance to 6' [redacted] shelter viewed from inside.

Table I. Summary of Field Fortifications Tested

Fortification Designation	Fortification	Orientation to GZ	Amount of Entrance Opening Covered	Distance from GZ (')	Predicted Peak Overpressure (psi)
A1	7' x 7' MG emplacement	Rear-on	Open	1430	45
A2	7' x 7' MG emplacement	Rear-on	Open	1720	30
A3	7' x 7' MG emplacement	Side port to GZ	Open	1720	30
A4	7' x 7' MG emplacement	Rear-on	Open	2280	15
A5	7' x 7' MG emplacement	Side port to GZ	Open	2280	15
B1	Two-man foxhole	End-on	Open	2280	15
B2	Two-man foxhole	End-on	Open	3900	8
B3	Two-man foxhole	Covered end-on	1/3	3900	8
B4	Two-man foxhole	Covered end-on	2/3	2280	15
B5	Two-man foxhole	Covered end-on	2/3	3900	8
B6	Two-man foxhole	End-on	Covered	3900	8
B7	Two-man foxhole	Side-on	Open	3900	8
B8	Two-man foxhole	Side-on	1/3	3900	8
B9	Two-man foxhole	Side-on	2/3	3900	8
B10	Two-man foxhole	Side-on	Covered	3900	8
C1	Modified two-man foxhole	Open end-on	1/2	3900	8
C2	Modified two-man foxhole	Covered end-on	1/2	3900	8
D1	Offset foxhole, open, tunnel not revetted	Tunnel forward	Open	3900	8
D2	Offset foxhole, open, tunnel revetted with oil drums	Tunnel side-on	Open	2280	15
D3	Offset foxhole, open, tunnel revetted with oil drums	Tunnel side-on	Open	3900	8
D4	Offset foxhole, open, tunnel revetted with sticks	Tunnel rearward	Open	3900	8
E1	Offset foxhole, covered, tunnel not revetted	Tunnel forward	Open	3900	8
E2	Offset foxhole, covered, tunnel revetted with oil drums	Tunnel side-on	Open	2280	15
E3	Offset foxhole, covered, tunnel revetted with oil drums	Tunnel side-on	Open	3900	8
E4	Offset foxhole, covered, tunnel revetted with sticks	Tunnel rearward	Open	3900	8
F1	6' x 8' Hasty shelter	Side-on	Open	3900	8
F2	6' x 8' Hasty shelter	Side-on	Closed	3900	8

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Fig. 27). This is permissible in view of the fact that at this distance from ground zero, the few feet involved would have a negligible effect.

Based on DESERT ROCK VI results, it was expected that 45-psi overpressure would cause only moderate damage to the machine gun emplacement oriented rear-on to ground zero and that 15 psi would cause only superficial damage. This emplacement had not previously been exposed in the side-on orientation, but it was acknowledged to be more vulnerable to blast and radiation in this orientation.

4. Field Procedure. Except for the offset foxholes, all of the fortifications were excavated with a rubber-tired ditching machine which was undergoing tests by the USAERDL at the test site during the DESERT ROCK exercise. The rather large excavations required for the machine gun emplacements were accomplished with the ditcher by successively digging short, parallel trenches from one end of the required excavation to the other. This machine was especially suitable for the two-man foxholes since it digs a trench 2 ft wide. A 20-in. earth auger was used to bore a pilot hole for the offset foxholes. These holes were then enlarged with hand tools to the required 3-ft diameter. The horizontal portion of the offset foxholes was dug, tunnel fashion, with hand shovels and entrenching tools. Those tunnels designated for oil drum revetment were revetted with three, 18-in.-long, cylindrical sections placed end to end. (Note: Because of its length, the 55-gal. oil drum cannot be inserted in the tunnel without cutting it first.) The stick revetment was 1/2 to 1 in. diameter willow limbs pre-cut, bent, and bound at Fort Belvoir into semi-circular shaped sections, each 18 in. long. Three sections were required in each tunnel. A small space between the walls of the tunnels and the revetment could not be avoided. This was backfilled with earth and tamped. Because of its high strength characteristics, the Frenchman Flat soil is not a desirable type soil in which to determine blast damage criteria for revetments. This is especially true in the case of the revetment in the tunnels of the offset foxholes; as work on these tunnels progressed, it became increasingly doubtful whether revetment was actually needed to prevent collapse of the tunnels even at 15-psi overpressure.

An analysis of the laminated roof is beyond the scope of this report; but it would appear that its success against the impulsive load from HE shells can be attributed principally to its deflective characteristics which enable it to absorb energy and, to a much lesser degree, to the load distribution capability afforded by the particular construction (crossed planking). The former would also apply for atomic blast; however, the latter would apply only for the more concentrated blast from HE shells as atomic blast would be uniformly distributed over the surface of the roof. When the HE

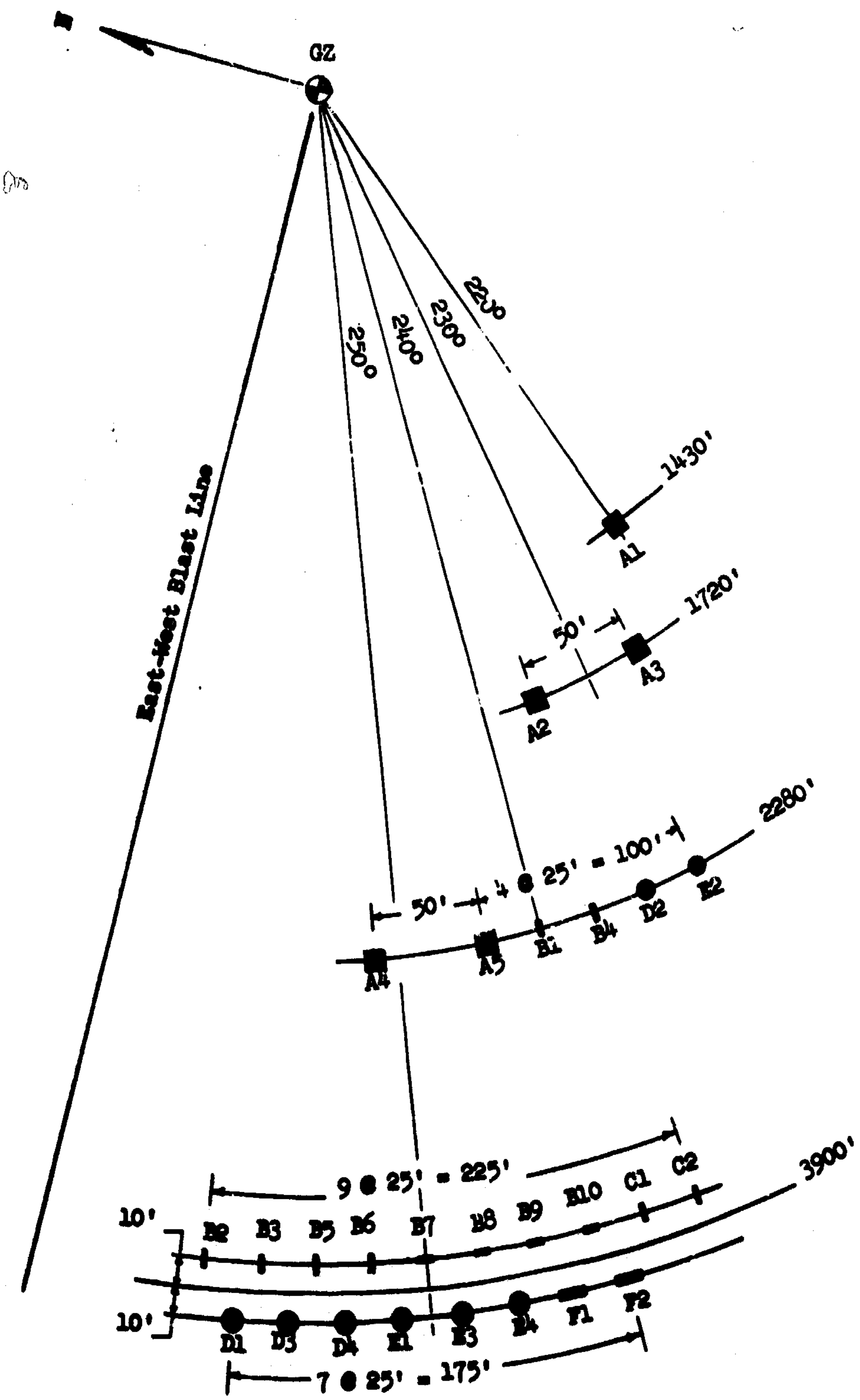


Fig. 27. Layout of fortifications.

tests were conducted by the Demolitions and Fortifications Branch, USAERDL, the ends of the laminated roof were not fastened to the supporting structure in order that the ability to deflect would not be impaired. For the same reason, it was desired that little or no restraint be used on the roof for the atomic test; but the more complex loading (drag and peak overpressure inside as well as outside the structure) demanded that the roof be fastened to the supporting structure. Several methods of fastening were considered, but all were subsequently discarded in favor of a simple method similar to one used successfully in the DESERT ROCK VI test. The roof was nailed to the inside top edge of the caps with 60d nails (two per foot of cap) driven through the two bottom layers of planks. The layers of planks were nailed together with 8d nails, two per square foot of plank.

5. Instrumentation. Instrumentation was provided to obtain measurements of peak overpressure and nuclear radiation. Overpressure measurements were obtained with BRL self-recording, pressure-time (pt) gages. A gage embedded flush with ground surface recorded free-field pressure at each of the distances from ground zero. Two gages were mounted on the floor of each machine gun emplacement and held in place with sandbags. These recorded pressures at approximately 20 in. above the floor. The only other pressure measurements were made in the horizontal tunnels of offset foxholes E2 and E3 where a gage was mounted flush with the bottom of the middle section of revetment.

Measurements of gamma radiation and neutron flux at locations of interest in the fortifications were the responsibility of Project 2.4 and were obtained with the National Bureau of Standards-Evans Signal Laboratory (NBS-ESL) film packet, the United States Air Force School of Aviation Medicine (AFSAM) chemical dosimeters, and neutron threshold detectors. This instrumentation is described in Reference 3. The location and extent of the instrumentation for both blast and radiation is summarized in Table II.

6. Test Results. The peak overpressures recorded at ground surface by the pt gages are shown in Table III. This table also gives, for the respective distances, the dynamic pressures recorded at a 3-ft height along the blast line by DOD Project 1.1. Pressure-time curves for the pt gages are shown in Fig. 28. The gage at 3900 ft recorded a peak pressure only. All of the emplacements were within those limits where a precursor was in evidence. Project 1.1 data shows that at approximately 3900 ft, the distance at which most of the hasty fortifications were constructed, the precursor was present but the wave form had almost "cleaned up" or reverted back to the classical shape.

Table II. Summary of Instrumentation

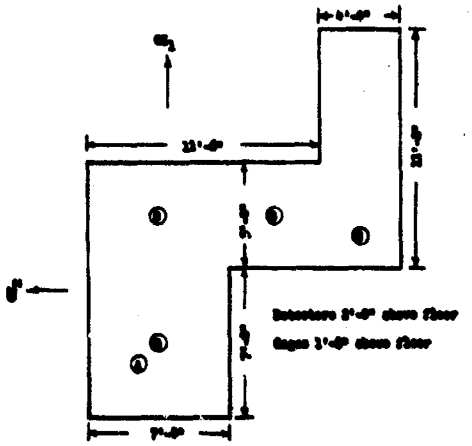
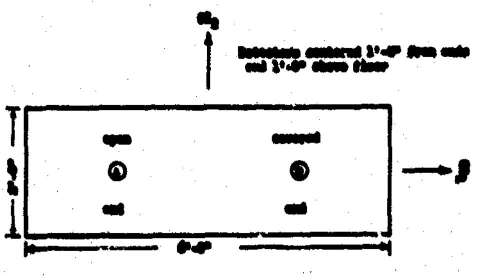
Plan View Sketch Showing Location of Instrumentation	Fortification Designation	Orientation	Location	Film Badge	Chemical Dosimeter (G)	Threshold Detector	Chemical Dosimeter (N)	Pressure Gage
				Instrumentation				
 7' x 7' MG emplacement	A1, A2, and A4	GZ_1	A	X	X	X	X	
			B	X	X		X	
			C	X	X		X	
			G					X
	A3 and A5	GZ_2	A	X	X	X	X	
			B	X	X		X	
			C	X	X		X	
			G					X
 Two-man foxhole, open and covered	B1	GZ_1	A	X	X	X	X	
			B	X	X		X	
	B2	GZ_1	A	X		X		
			B	X	X		X	
	B3	GZ_1	A	X	X		X	
			B	X	X		X	
	B4	GZ_1	A	X	X	X	X	
			B	X	X		X	
	B5	GZ_1	A	X	X	X	X	
			B	X	X		X	
	B6	GZ_1	A	X				
			B	X				

Table II (cont'd)

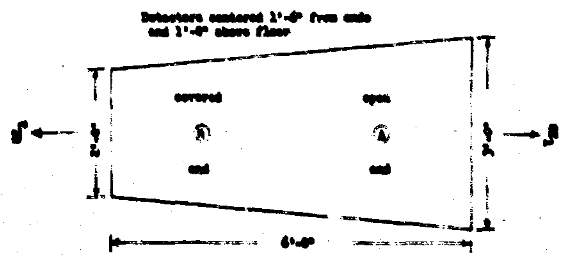
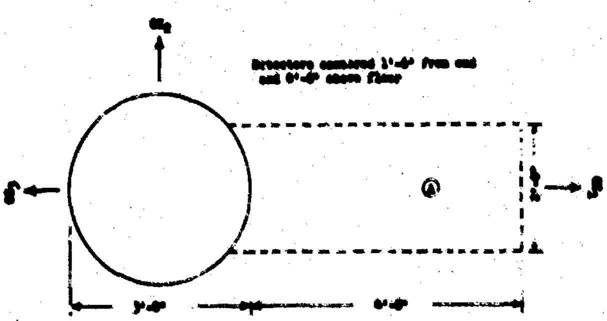
Plan View Sketch Showing Location of Instrumentation	Fortification Designation	Orientation	Location	Instrumentation: Film Badge	Chemical Dosimeter (G)	Threshold Detector	Chemical Dosimeter (N)	Pressure Gage
	B7	GZ_2	A	X				
			B	X	X		X	
	B8	GZ_2	A	X	X		X	
			B	X	X		X	
	B9	GZ_2	A	X	X		X	
			B	X	X		X	
Two-man foxhole, open and covered (cont'd)	B10	GZ_2	A	X				
			B	X				
	C1	GZ_1	A	X	X		X	
			B	X	X		X	
	C2	GZ_2	A	X				
Modified two-man foxhole			B	X	X		X	
	D1	GZ_1	A	X	X		X	
	D2	GZ_2	A	X		X		
	D3	GZ_2	A	X		X		
Open offset foxhole	D4	GZ_3	A	X	X		X	

Table II (cont'd)

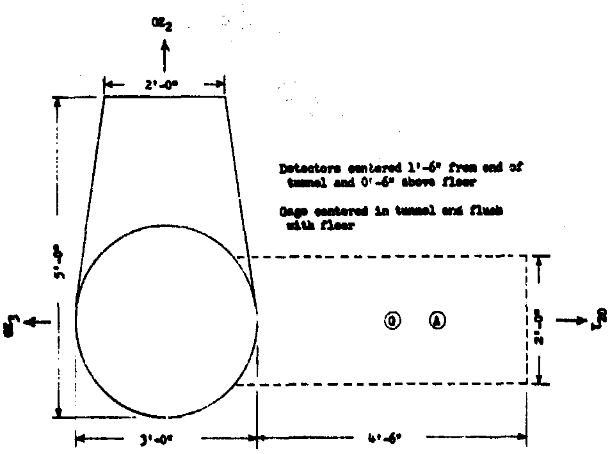
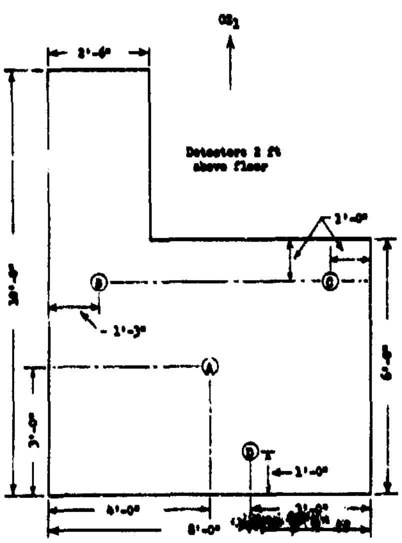
Plan View Sketch Showing Location of Instrumentation	Fortification Designation	Orientation	Location	Instrumentation: Film Badge	Chemical Dosimeter (G)	Threshold Detector	Chemical Dosimeter (N)	Pressure Gage
 Covered offset foxhole	E1	GZ_1	A	X	X		X	
			G					
	E2	GZ_2	A	X		X		
			G					X
	E3	GZ_2	A	X		X		
			G					X
	E4	GZ_3	A	X	X		X	
			G					
 6' x 8' Hasty shelter	F1	GZ_1	A	X	X	X	X	
			B	X	X		X	
			C	X	X		X	
			D	X	X		X	
	F2	GZ_1	A	X		X		
			B	X	X		X	
			C	X				
			D	X	X		X	

Table III. Surface Pressures

Distance from GZ (ft)	Predicted Peak Overpressure (psi)	Measured Peak Overpressure (psi)	Dynamic Pressure (psi)
1430	45	42.7	175
1720	30	28.8	120
2280	15	11.8	47
3900	8	9.2	2

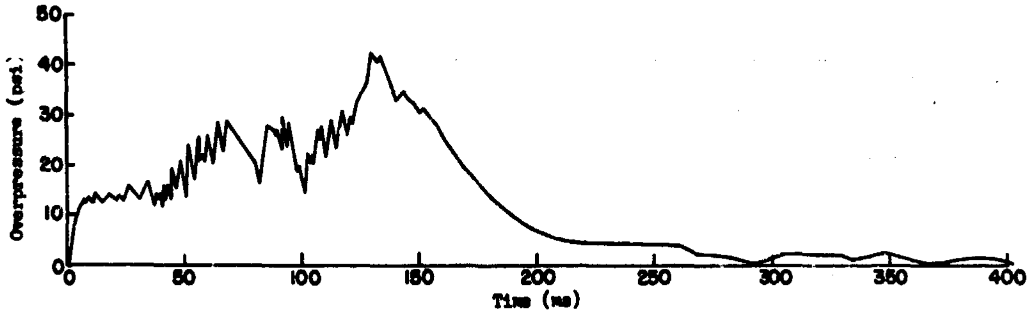
a. 7-Ft by 7-Ft Machine Gun Emplacement. For purposes of clarity, this fortification will be considered as having three parts: (1) the emplacement or gun location; (2) the shelter, consisting of the two spans of the entrance structure with caps running at right angles to the caps of the emplacement; and (3) the entrance, consisting of the remaining two spans of the entrance structure with caps running parallel to the caps of the emplacement.

Figs. 29 through 35 show damage to the A1, A2, and A4 emplacements which were oriented rear-on to ground zero. (In the captions for several of these figures and succeeding figures, the reader is referred to the appropriate figure for a pre-test view of the subject being considered.) Rearward displacement (displacement away from ground zero) of the laminated roof on A1 was 5 in. relative to the cap at the side firing port while the opposite side seemingly remained fastened to the cap. The roofs on A2 and A4 were partially and completely removed, respectively, with the one on A2 being rotated counter clockwise approximately 45 degrees and the one on A4 being rotated counter clockwise approximately 90 degrees (see Figs. 32 and 34). The laminated roofs did not fail in bending. The emplacements of A1, A2, and A4 were leaning away from ground zero, and the amount of displacement at the caps increased from about 2 in. for A1 to about 4 in. for A4. Post failure was limited to one post, this being in the emplacement of A1 (see Fig. 31).

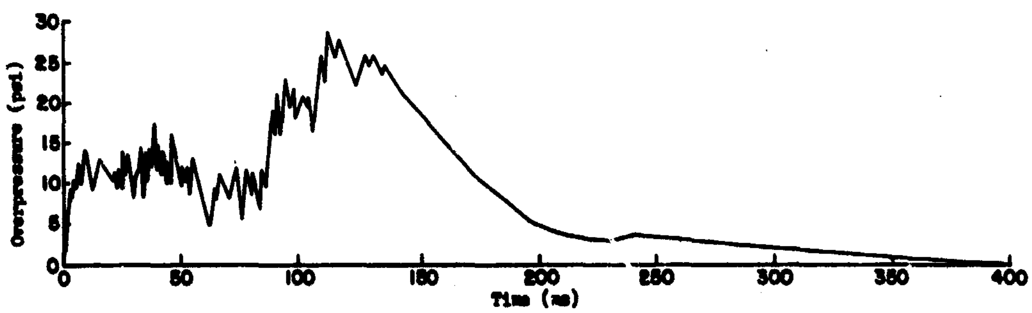
The emplacements of A3 and A5, which were oriented with the side firing ports toward ground zero, were destroyed. Figs. 36 and 37 show the damage to these emplacements. Fig. 38 shows the bottom of the laminated roof from A3. It had been standing on end and leaning against the leeward wall of the emplacement, but instrument recovery made it necessary to remove the roof before photographs were taken.

[redacted]

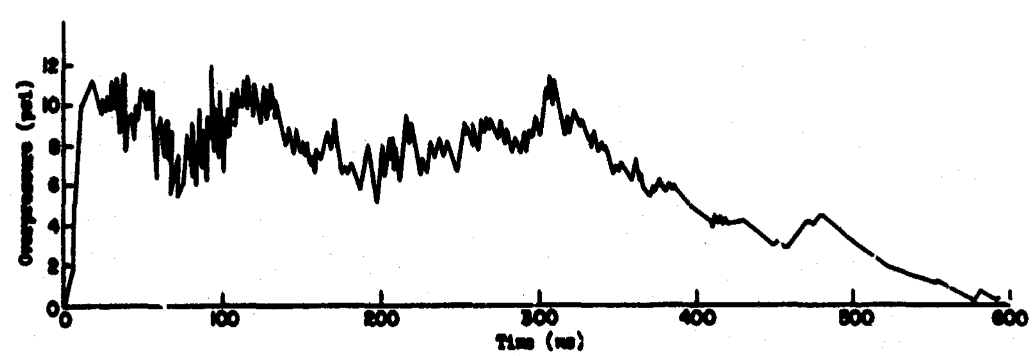
[redacted]



Distance from ground zero 1430 ft



Distance from ground zero 1720 ft



Distance from ground zero 2280 ft

Fig. 28. Pressure-time curves for surface gages.

[redacted]

Fig. 29. Frontal view of A1, post shot, ground zero in direction of left background (see Fig. 11).

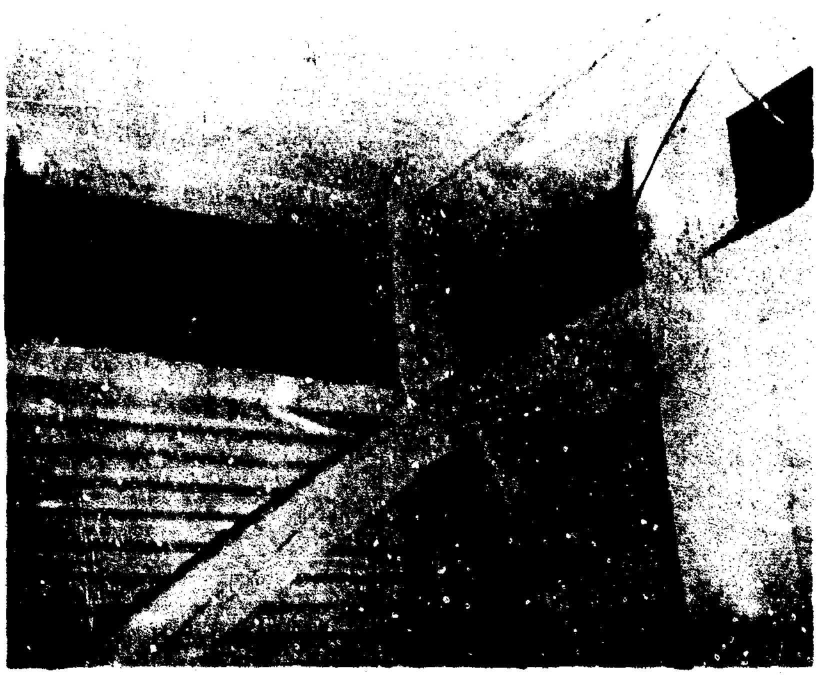


Fig. 30. Firing ports and roof of A1, post shot.

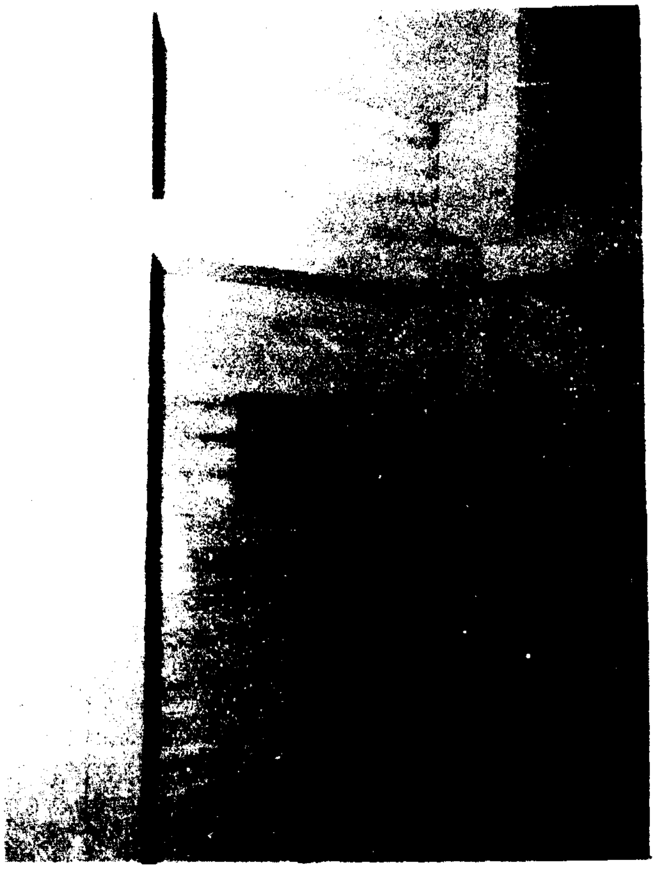


Fig. 31. Wall opposite side firing port of A1, post shot.

Fig. 32. Side view of A2, post shot, ground zero to left (see Fig. 12).

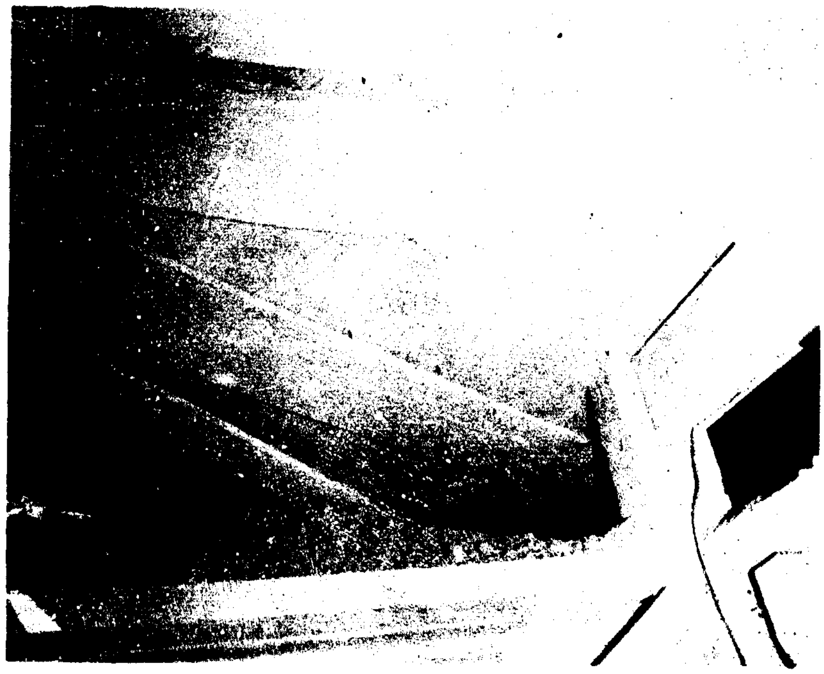


Fig. 33. Firing ports and roof of A2, post shot, looking from the direction of ground zero.

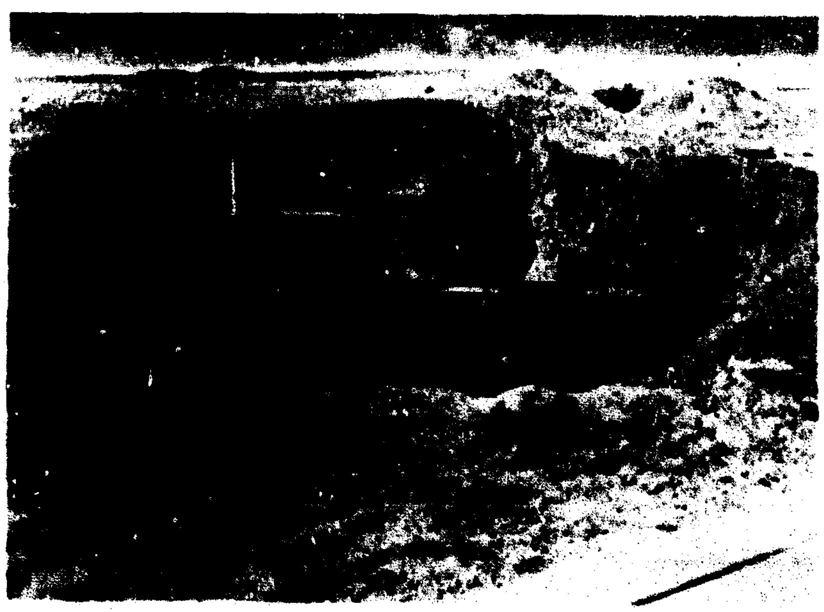


Fig. 34. Side view of A4, post shot (see Fig. 12).

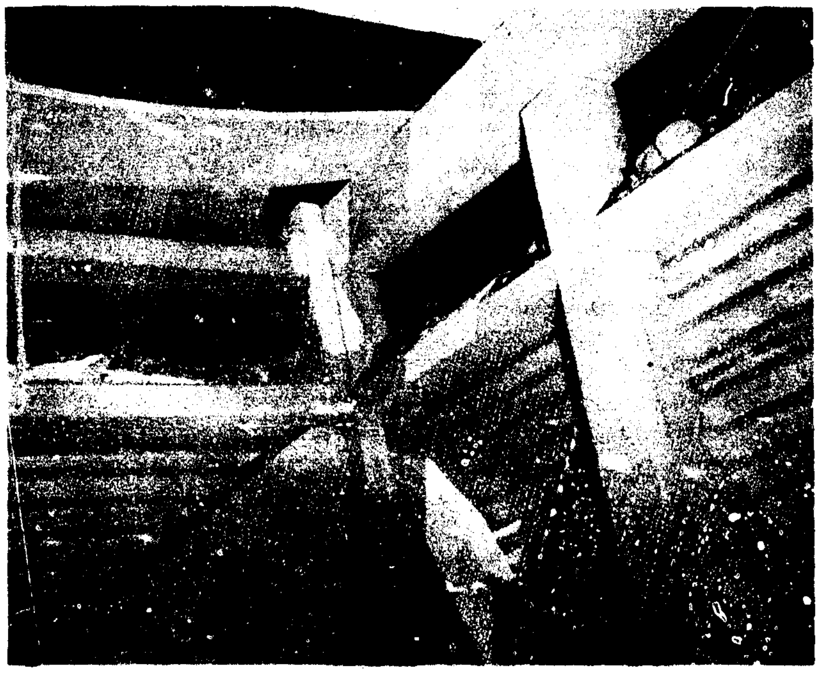


Fig. 35. Firing ports and roof of A4, post shot, looking from the direction of ground zero.

The firing port aprons on all of the emplacements were destroyed. In most instances, this destruction could be described as separation and gross displacement without breakage; but in the case of the side firing port aprons (those facing ground zero) on the emplacements of A3 and A5, the apron stringers were broken and forced against and into the emplacements.

Figs. 39 through 52 describe the damage to the entrances and shelters of the machine gun emplacement. The entrance and part of the adjacent shelter of A1 were severely damaged (Fig. 39). Both caps along the entrance opening of A2 collapsed. Fig. 41 shows part of this debris but does not show the damaged section. The entrances of A3, A4, and A5 received minor structural damage; nevertheless, all entrance openings were nearly blocked by caved cover material. Figs. 50 and 51 show that the 6-in. by 6-in. roof stringers on the entrance of A5 were lifted from the caps; however, it should be pointed out that the supply of spikes which had been used to fasten these members to the caps were depleted, and for this fortification about one-half of the roof stringers were only toe nailed to the caps.

Shelter damage consisted of one broken cap in each of the sections of shelter adjacent to the emplacement of A1, A2,

Fig. 36. Frontal view of A3, post shot (see Fig. 11).

Fig. 37. Frontal view of A5, post shot (see Fig. 11).

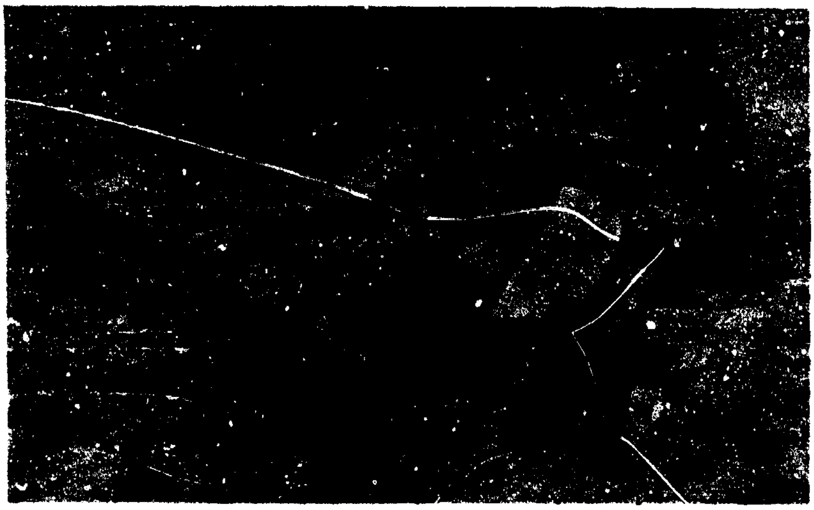


Fig. 38. Emplacement roof of A3, post shot.

Fig. 39. Damage to entrance and shelter of A1 as seen from a point in the shelter adjacent to the emplacement, post shot (see Fig. 15).

Fig. 40. View of shelter adjacent to emplacement of A1, post shot (see Fig. 14).

Fig. 41. Damage to entrance of A2 as seen from a point in the shelter adjacent to the emplacement, post shot (see Fig. 15).

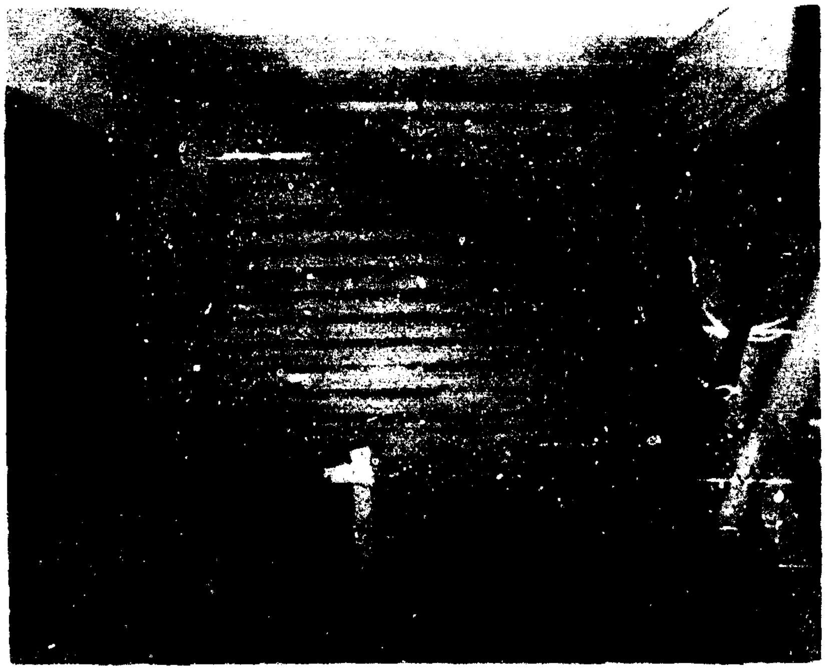


Fig. 42. View of shelter adjacent to emplacement of A2, post shot (see Fig. 14).

Fig. 43. Entrance opening to A3, post shot (see Fig. 13).

Fig. 44. Entrance opening to A3 as seen from inside structure, post shot (see Fig. 16).

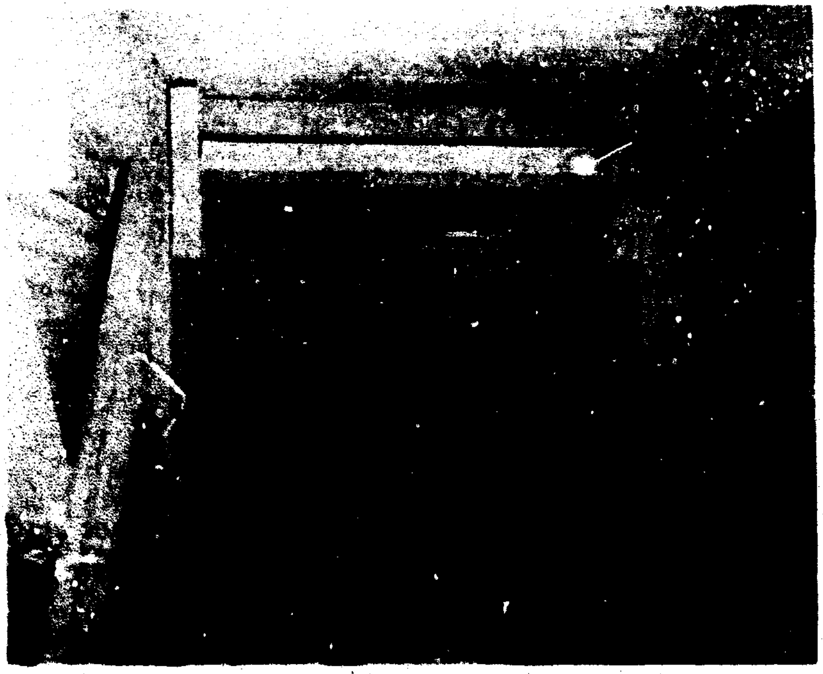


Fig. 45. View toward entrance of A3 as seen from a point in the shelter adjacent to emplacement, post shot (see Fig. 15).

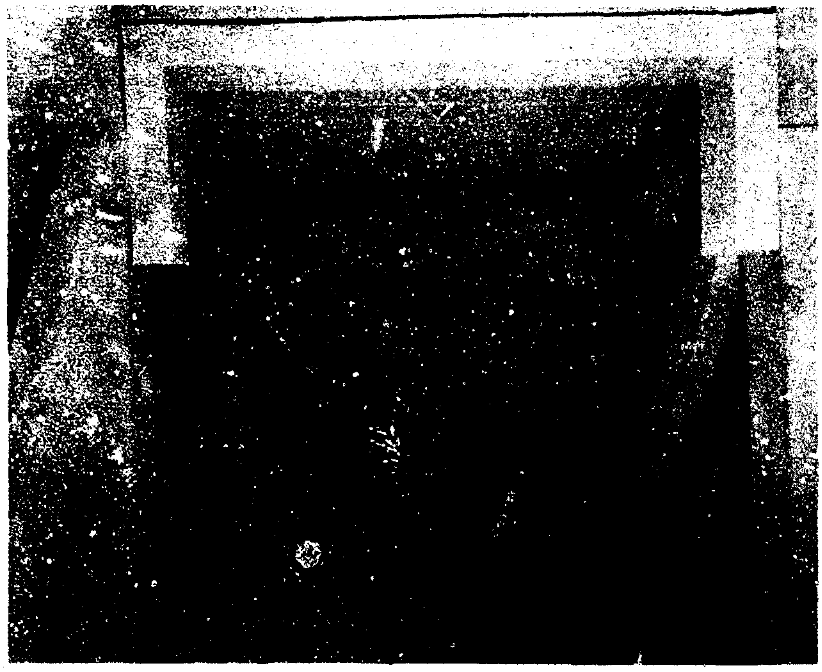


Fig. 46. View of shelter adjacent to emplacement of A3, post shot (see Fig. 14).

Fig. 47. Entrance opening to A4, post shot (see Fig. 13).

Fig. 48. Entrance opening to A4 as seen from inside structure, post shot (see Fig. 16).

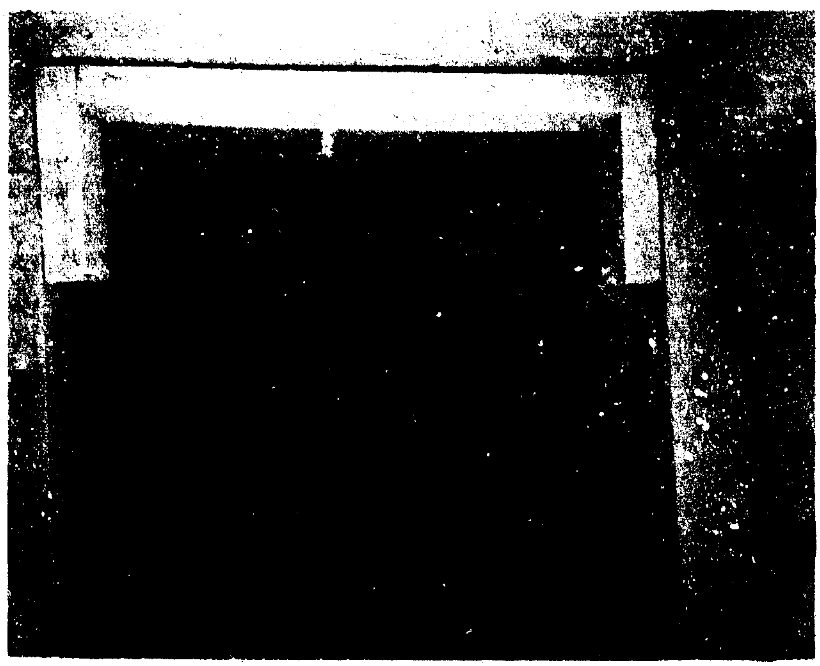


Fig. 49. View of shelter adjacent to emplacement of A4, post shot (see Fig. 14).

Fig. 50. Entrance opening to A5, post shot (see Fig. 13).

Fig. 51. Entrance opening to A5 as seen from inside structure, post shot (see Fig. 16).

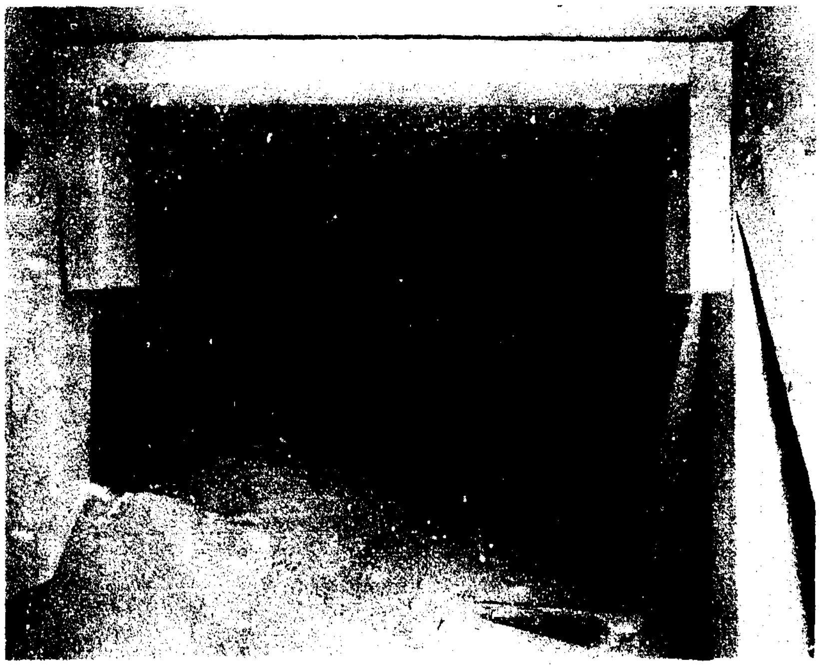


Fig. 52. View of shelter adjacent to emplacement of A5, post shot (see Fig. 14).

and A3 (Figs. 40, 42, and 46). Rearward displacement (leaning) of the shelter of A1 was negligible. In A2 and A4, this displacement was noticeable but less than that of the emplacement. In the shelter of A3 and A5, the cross bracing between posts was in the direction of loading and displacement was negligible.

Nine of the ten pt gages in these fortifications recorded peak overpressure, but only five measured the duration. The peak overpressure measurements are summarized in Table IV. The pressure-time curves are presented in Fig. 53.

Table V summarizes the gamma and neutron doses in the machine gun emplacements and also gives the transmission factors which can be defined as the quotients obtained by dividing the inside doses by the outside dose. This table contains considerable data, primarily from chemical dosimeters, which was not available for the interim test report of Project 2.4 but which was subsequently made available for this report. Data are missing for all five of the emplacements because some detectors were either lost in the debris or destroyed by secondary blast effects. Three of the threshold detectors were recovered too late to provide measurements of neutron flux.

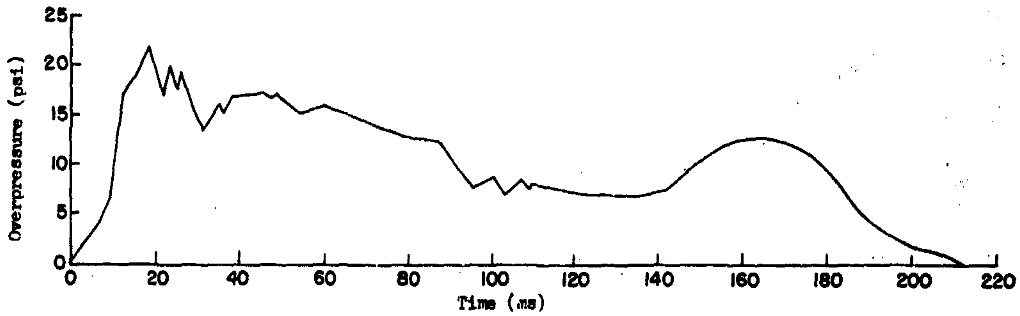
[redacted]

Table IV. Peak Overpressure in Machine Gun Emplacements

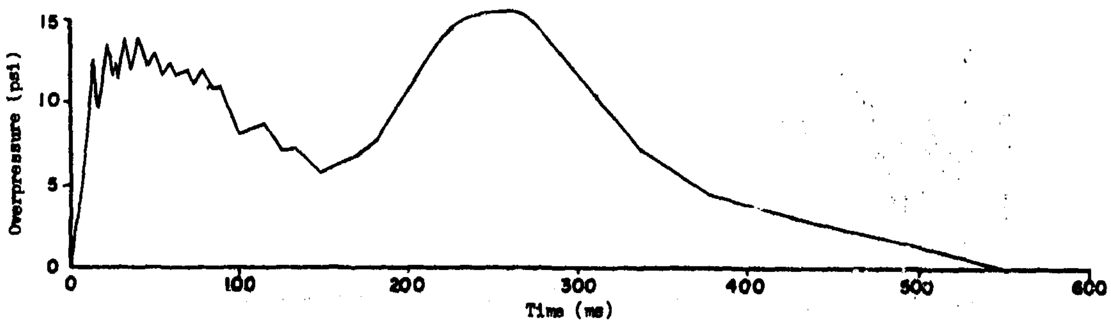
Fortification Designation	Orientation	Distance from GZ (ft)	Measured Surface Overpressure (psi)	Overpressure Inside Fortification (psi) Gage Location *	
				Emplacement	Shelter
A1	Rear to GZ	1430	42.7	21.7	24.8
A2	Rear to GZ	1720	28.8	13.4	**
A3	Side port to GZ	1720	28.8	19.2	15.6
A4	Rear to GZ	2280	11.8	13.0	14.7
A5	Side port to GZ	2280	11.8	14.7	14.6

* See Table II.
** No record.

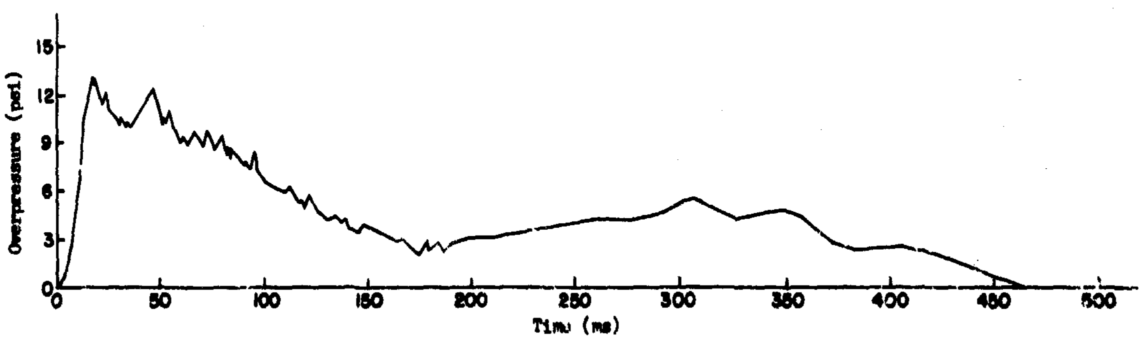
[redacted]



Fortification A1, emplacement, 1430 ft



Fortification A3, shelter, 1720 ft

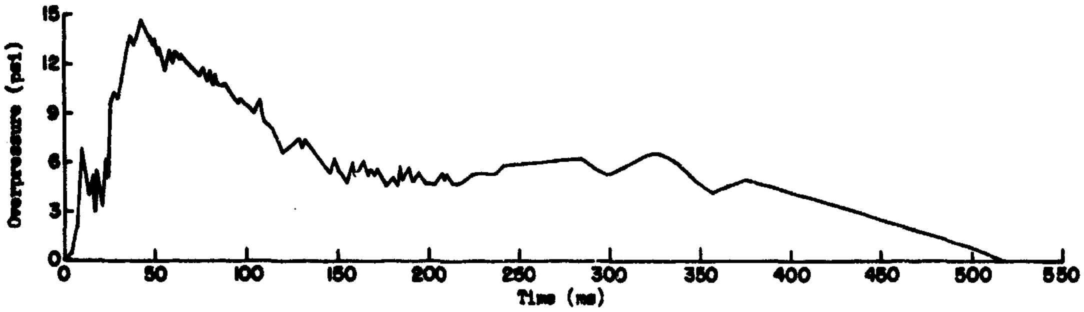


Fortification A4, emplacement, 2280 ft

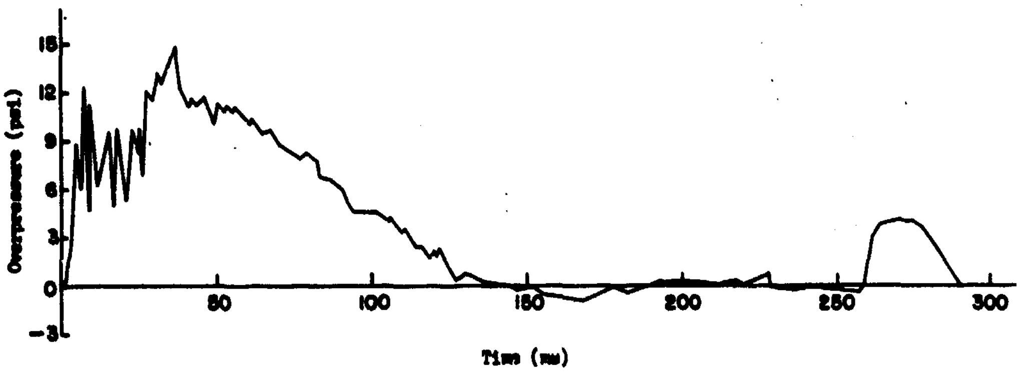
Fig. 53. Pressure-time curves for machine gun emplacements.

[redacted]

 [redacted]



Fortification A4, shelter, 2280 ft



Fortification A5, emplacement, 2280 ft

Fig. 53. (cont'd)

Table V. Shielding Characteristics of Machine Gun Emplacements

Fortification Designation	Orientation	Detector Location*	Dose: Gamma, Film (r)	Dose: Gamma, Chemical Dosimeter (r)	Dose: Neutron, Threshold Detector (rep)	Dose: Neutron, Chemical Dosimeter (rep)	Transmission Factor: Gamma, Film	Transmission Factor: Gamma, Chemical Dosimeter	Transmission Factor: Neutron, Threshold Detector	Transmission Factor: Neutron, Chemical Dosimeter
A1	Rear to GZ	Free field	91,000	88,300	72,600	68,100				
		A	170	11,000	**	4,000	0.0018	0.12	--	0.059
		B	140	5,000	***	1,600	0.0015	0.057	--	0.023
		C	**	**	***	**	--	--	--	--
A2	Rear to GZ	Free field	52,000	49,300	37,500	29,800				
		A	160	6,200	2,200	7,000	0.0031	0.13	0.059	0.24
		B	1,100	2,500	***	3,400	0.021	0.051	--	0.11
		C	**	**	***	**	--	--	--	--
A3	Side port to GZ	Free field	52,000	49,300	37,500	29,800				
		A	**	**	**	**	--	--	--	--
		B	**	**	***	**	--	--	--	--
		C	>1,000	3,300	***	2,400	>0.019	0.067	--	0.081
A4	Rear to GZ	Free field	20,000	17,200	11,000	10,100				
		A	**	**	359	**	--	--	0.033	--
		B	210	3.3	***	<50	0.011	0.020	--	<0.005
		C	**	2,550	***	2,200	--	0.148	--	0.22
A5	Side port to GZ	Free field	20,000	17,200	11,000	10,100				
		A	**	2,140	**	1,600	--	0.124	--	0.16
		B	720	1,400	***	400	0.036	0.081	--	0.04
		C	450	790	***	160	0.023	0.046	--	0.016

* See Table II.
** Detector not recovered.
*** Location not instrumented.

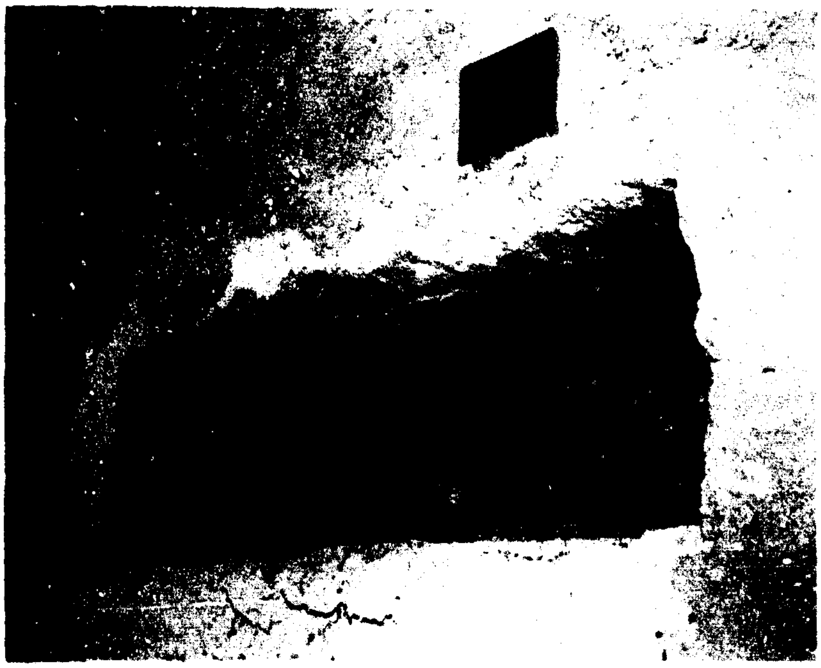


Fig. 54. View of B2, post shot (see Fig. 17).

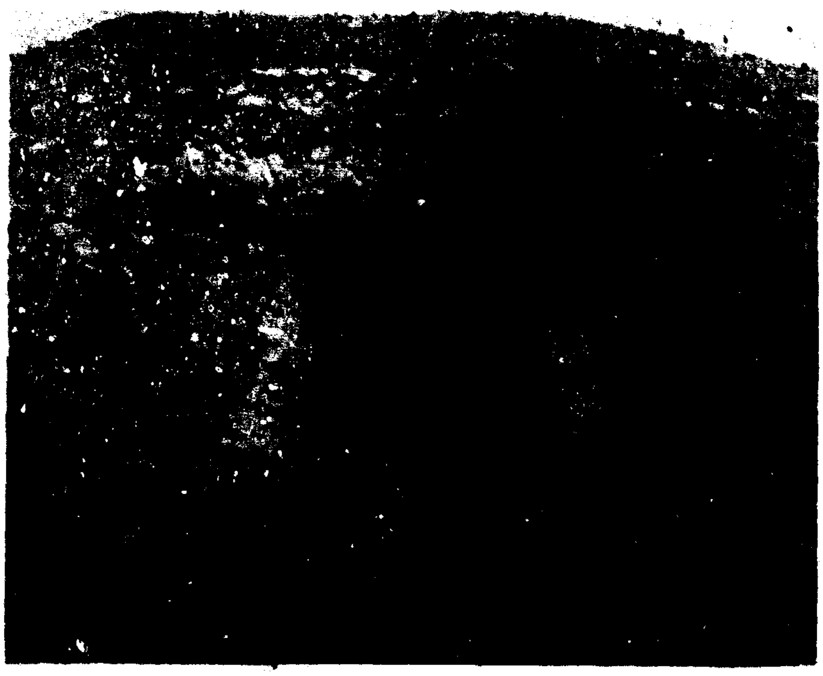


Fig. 55. View of B3, post shot.

Fig. 56. View of B4, post shot (see Fig. 18).

Fig. 57. View of B8, post shot.

Fig. 58. View of C1, post shot (see Fig. 19).

Fig. 59. View of earth walls and tunnel entrance of D1, post shot (see Fig. 21).

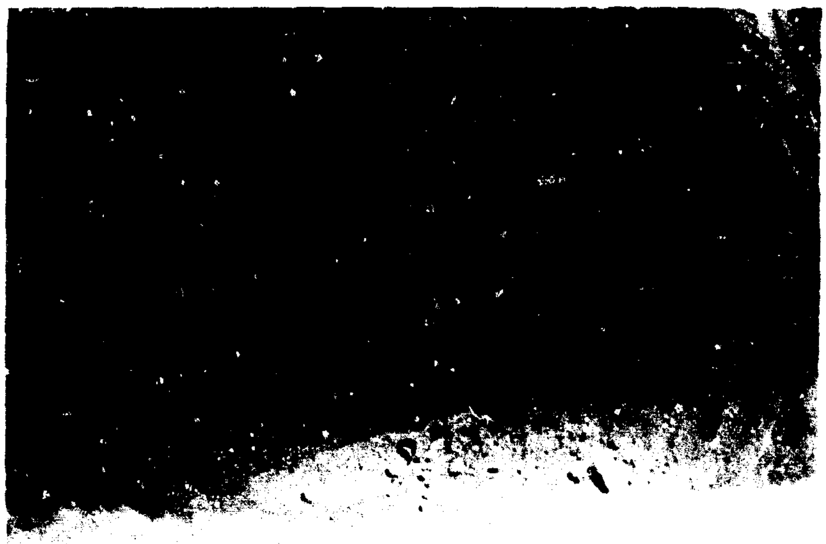


Fig. 60. Looking toward ground zero and into tunnel of D1, post shot.

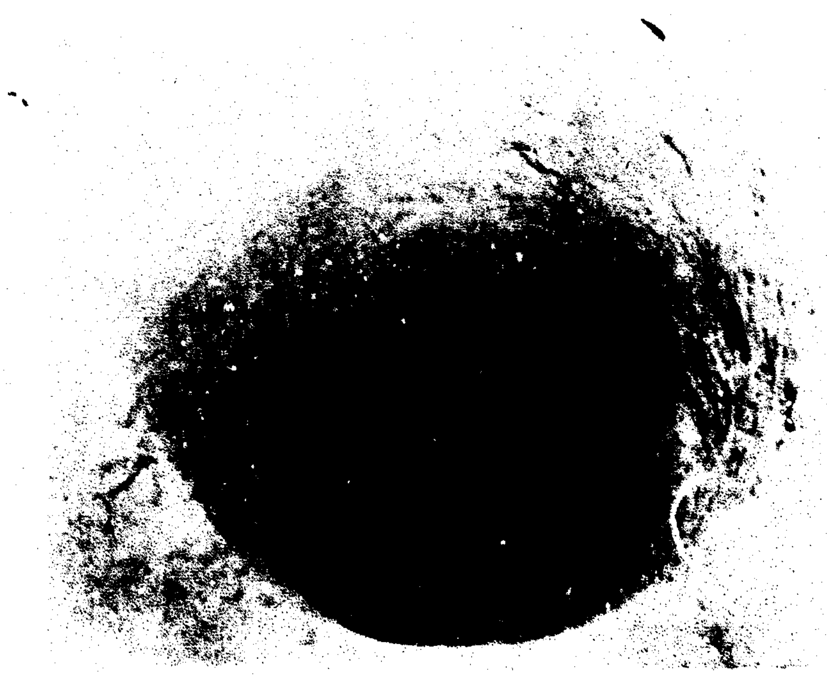


Fig. 61. View of earth walls and tunnel entrance of D3, post shot, ground zero to left.

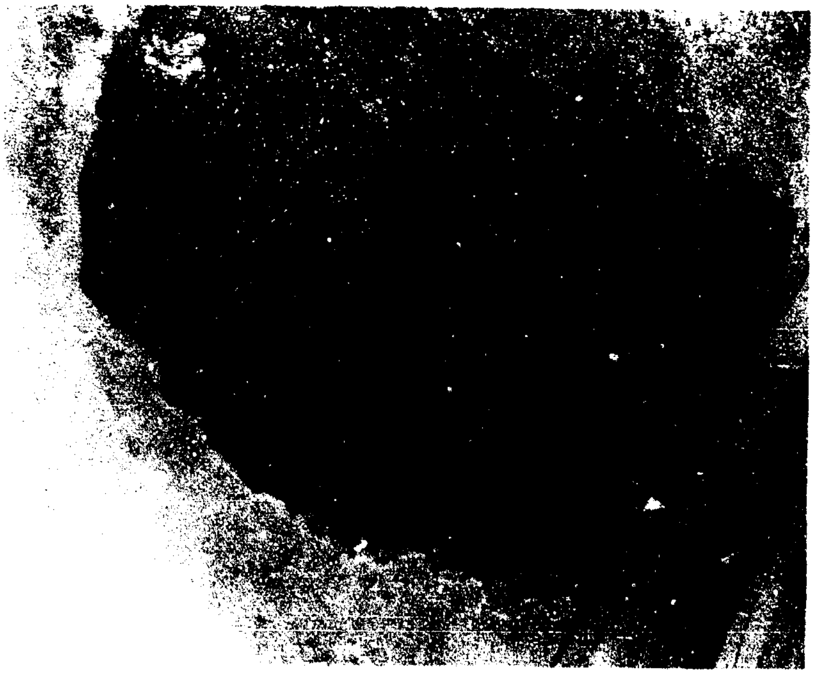


Fig. 62. View of E2, post shot (see Fig. 23).

Fig. 63. View of E3, post shot, fortification facing ground zero (see Fig. 23).

Fig. 64. View of F1, post shot, entrance facing ground zero (see Fig. 24).

Fig. 65. View of F2, post shot, sandbags removed from entrance, entrance facing ground zero (see Fig. 25).

b. Hasty Fortifications. Figs. 54 through 65 are photographs which show the effects of blast on some of the hasty fortifications. Not all of the fortifications are shown because the condition of any one fortification was representative of the condition of similar fortifications at the same distance from ground zero. Note in the figures listed above that some of the foxholes showed wall-spalling while others did not. The condition of the revetted tunnels of the offset foxholes is not apparent from the photographs. About one-half of the backfill material was removed from around the revetment in these tunnels. Damage to the earth arches at both distances (2280 and 3900 ft) appeared to be about the same as that to the unrevetted tunnel of D1 shown in Fig. 60. Blast within the tunnels caused no damage to the stick revetment in D4 and E4, but almost blew the end (bottom of oil drum) out of the rearmost section of revetment in E2. In E3, the end was fully rounded but completely intact. The peak overpressures recorded by the pt gages in the tunnels of E2 and E3 are given in Table VI. A pressure-time record was obtained in E3 (Fig. 66), but the gage in E2 recorded peak pressure only. Radiation measurements for the hasty fortifications are presented in Table VII.

Table VI. Peak Overpressure in E2 and E3

Fortification Designation	Distance from GZ (ft)	Surface Overpressure (psi)	Inside Overpressure (psi)
E2	2280	11.8	30.5
E3	3900	9.2	16.6

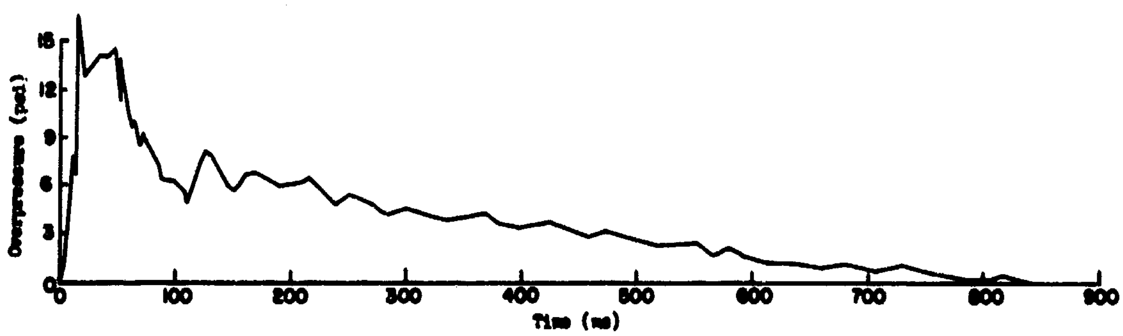


Fig. 66. Pressure-time curve for E3, 3900 ft.

UNCLASSIFIED

Table VII. Shielding Characteristics of Hasty Fortifications

Fortification Designation	Distance from GZ (ft)	Orientation to GZ	Cover	Detector Location*	Dose: Gamma, Film (r)	Dose: Gamma, Chemical Dosimeter (r)	Dose: Neutron, Threshold Detector (rep)	Dose: Neutron, Chemical Dosimeter (rep)	Transmission Factor: Gamma, Film	Transmission Factor: Gamma, Chemical Dosimeter	Transmission Factor: Neutron, Threshold Detector	Transmission Factor: Neutron, Chemical Dosimeter
	2280			Free field	20,000	17,200	11,000	10,100				
B1	2280	End-on	Open	A	>1000	8000	**	6000	>0.050	0.460	**	0.59
				B	>1000	6500	***	3000	>0.050	0.380	***	0.30
B4	2280	End-on	2/3	A	>1000	3500	813	1400	>0.050	0.200	0.074	0.14
				B	1050	1800	***	lost	0.053	0.100	***	lost
D2	2280	Side-on	Open	A	165.0	***	****	***	0.0081	***	****	***
E2	2280	Side-on	Yes	A	115.0	***	34	***	0.0058	***	0.0031	***
	3900			Free field	1570	1230	463	474				
B2	3900	End-on	Open	A	205	***	136	***	0.131	***	0.29	***
				B	120	173	***	<50	0.076	0.141	***	< 0.10
B3	3900	End-on	1/3	A	112	145	***	< 50	0.071	0.118	***	<0.10
				B	76	118	***	< 50	0.048	0.096	***	<0.10
B5	3900	End-on	2/3	A	90	132	46	< 50	0.057	0.107	0.099	<0.10
				B	49	93	***	< 50	0.031	0.076	***	<0.10
B6	3900	End-on	Full	A	64	***	***	***	0.041	***	***	***
				B	32	***	***	***	0.020	***	***	***
B7	3900	Side-on	Open	A	105	***	***	***	0.067	***	***	***
				B	110	123	***	80	0.070	0.100	***	0.17
B8	3900	Side-on	1/3	A	82	306	***	< 50	0.052	0.249	***	< 0.10
				B	100	122	***	< 50	0.064	0.099	***	< 0.10
B9	3900	Side-on	2/3	A	54	84	***	< 50	0.034	0.068	***	< 0.10
				B	60	80	***	< 50	0.044	0.072	***	< 0.10

B4	2280	End-on	2/3	A	>1000	3900	813	1400	>0.050	0.200	0.074	0.14
				B	1050	1800	***	lost	0.053	0.100	***	lost
D2	2280	Side-on	Open	A	165.0	***	****	***	0.0081	***	****	***
E2	2280	Side-on	Yes	A	115.0	***	34	***	0.0058	***	0.0031	***
	3900			Free field	1570	1230	463	474				
B2	3900	End-on	Open	A	205	***	136	***	0.131	***	0.29	***
				B	120	173	***	<50	0.076	0.141	***	<0.10
B3	3900	End-on	1/3	A	112	145	***	<50	0.071	0.118	***	<0.10
				B	76	118	***	<50	0.048	0.096	***	<0.10
B5	3900	End-on	2/3	A	90	132	46	<50	0.057	0.107	0.099	<0.10
				B	49	93	***	<50	0.031	0.076	***	<0.10
B6	3900	End-on	Full	A	64	***	***	***	0.041	***	***	***
				B	32	***	***	***	0.020	***	***	***
B7	3900	Side-on	Open	A	105	***	***	***	0.067	***	***	***
				B	110	123	***	80	0.070	0.100	***	0.17
B8	3900	Side-on	1/3	A	82	306	***	<50	0.052	0.249	***	<0.10
				B	100	122	***	<50	0.064	0.099	***	<0.10
B9	3900	Side-on	2/3	A	54	84	***	<50	0.034	0.068	***	<0.10
				B	69	89	***	<50	0.044	0.072	***	<0.10
B10	3900	Side-on	Full	A	30	***	***	***	0.019	***	***	***
				B	28	***	***	***	0.018	***	***	***
C1	3900	Open end-on	1/2	A	105	137	***	<50	0.067	0.111	***	<0.10
				B	150	177	***	90	0.096	0.144	***	0.19
C2	3900	Closed end-on	1/2	A	102	***	***	***	0.065	***	***	***
				B	75	50	***	<10	0.048	0.041	***	<0.02
D1	3900	Forward	Open	A	5.2	<5	***	<10	0.0033	<0.004	***	<0.02
D3	3900	Side-on	Open	A	7.0	***	****	***	0.0045	***	****	***
D4	3900	Rearward	Open	A	4.8	<5	***	<10	0.0031	<0.004	***	<0.02
E1	3900	Forward	Yes	A	4.9	<5	***	<10	0.0031	0.004	***	0.02
E3	3900	Side-on	Yes	A	5.6	***	****	***	0.0036	***	****	***
E4	3900	Rearward	Yes	A	5.0	<50	***	<50	0.0032	<0.04	***	<0.10
F1	3900	Front-on	Entrance open	A	55	92	37	<50	0.035	0.075	0.08	<0.10
				B	180	182	***	<50	0.115	0.148	***	<0.10
				C	225	34	***	<30	0.143	0.028	***	<0.063
				D	188	79	***	<30	0.120	0.064	***	<0.063
F2	3900	Front-on	Entrance closed	A	255	***	13	***	0.162	***	0.028	***
				B	760	125	***	<30	0.484	0.102	***	<0.063
				C	205	***	***	***	0.131	***	***	***
				D	760	107	***	<30	0.484	0.087	***	<0.063

* See Table II.
** Detector recovered late.
*** Location not instrumented.
**** Insufficient activity in threshold detector.

III. DISCUSSION

7. 7-Ft by 7-Ft Machine Gun Emplacement. The data obtained from the test of this fortification is considered in the following subparagraphs.

a. Overpressure Measurements. Four of the five pressure records obtained in the fortifications appear to be good records. Perhaps because of the severe damage to the emplacement of A5, the gage at this location produced a poor record. However, there appears to be no reason to question the first 50 milliseconds (ms) of this record. The rate of pressure rise in the fortifications ranged from about 1.0 psi per ms in A1 to about 0.7 psi per ms in A4. The results in Table IV show that in the fortifications at the greater distances from ground zero, the difference between internal and external peak overpressure decreased. The average of the peak overpressure measurements in fortifications A1, A2, and A3 ranged from about 50 to 60 percent of the outside peak overpressure. In A4 and A5, the average peak overpressure measurement exceeded the outside peak measurement by about 2.0 and 2.9 psi, respectively. The foregoing are comparisons of peak values only. The gage records must be compared to obtain the difference between inside and outside overpressure at a specific time of loading. Such comparisons are made in the discussion of the damage to the emplacements.

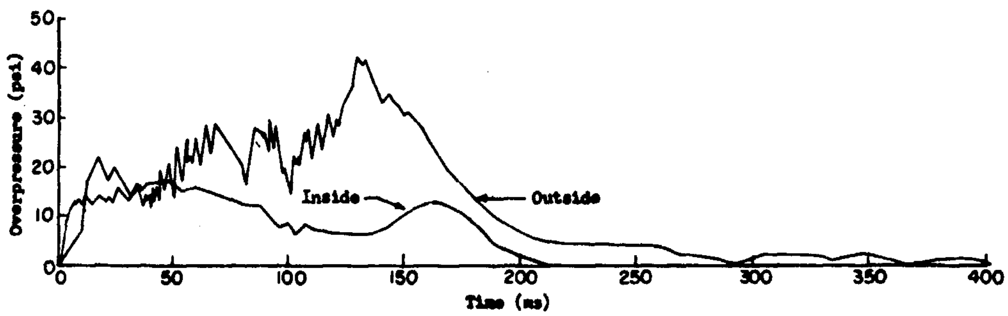
b. Blast Damage. As stated previously, the fortifications will be considered in three parts: the emplacement, the shelter, and the entrance.

(1) Emplacement. Since the emplacement, excluding the laminated roof, had been tested rear-on to ground zero in DESERT ROCK VI, not much additional information was expected regarding blast damage to A1, A2, and A4. A1 and A2 were located at a distance where they would receive approximately the same as two of the emplacements in the previous test, while A4 was located at a distance where little blast damage was expected. Only the emplacement of A1 received peak overpressure comparable to the DESERT ROCK VI test (others received less), and dynamic pressure was less on all three. Even so, the firing port aprons were destroyed on all of the emplacements. This indicates that the partially above grade level entrances tested at DESERT ROCK VI afforded protection from blast winds for the aprons and gave a false impression of apron vulnerability. Lowering the entrance construction is believed to have had no adverse effect on the substructure of the emplacement (that part which supported the roof). Post displacement (leaning rearward), which increased as distance from ground zero increased, is believed to have been caused by roof movement and by blast loading other

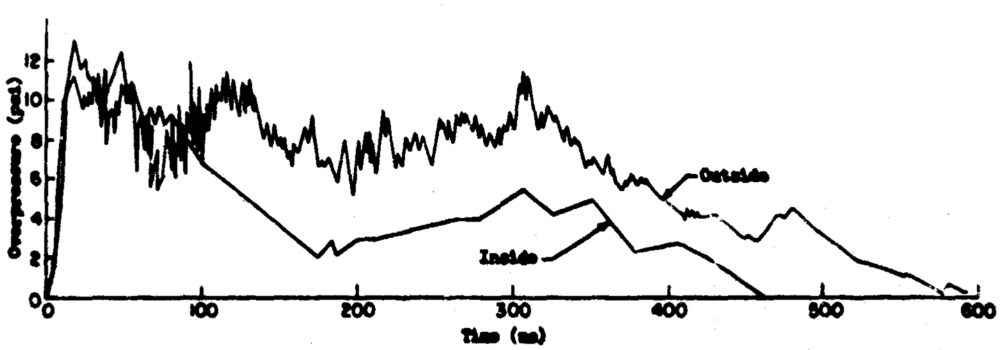
than that transmitted by the entrance construction which contributed to the damage to the emplacements in the DESERT ROCK VI test. Although post displacement was as much as 4 in. for A4, no other damage was caused the substructure. Some lateral displacement is to be expected for construction of this type, and the amount obtained may be acceptable.

Although the closed side to ground zero orientation would have shown some improvement because of the mass of the earth cover on that side, the emplacement design is obviously inadequate to withstand much blast from either side direction as shown by the results to A3 and A5 (see Figs. 36 and 37). Prospects of the emplacement withstanding blast when oriented with the front firing port facing ground zero are also rather poor. Destruction of the front apron would appear to be a certainty, and the impact of this debris against the emplacement would cause severe damage.

No information was obtained about the vulnerability to blast of the laminated roofs on the emplacements of A3 and A5 because of the severe damage caused these emplacements by lateral forces. Damage to the roof on A3 (Fig. 38) may have been caused when the roof was slammed against the wall and floor of the emplacement. The laminated roofs on A1, A2, and A4 appear to have withstood the downward load of the blast overpressure to which they were exposed, but only the roof on A1 remained on the emplacement for the duration of the external load. Fig. 67 shows the inside overpressure records for the emplacements of A1 and A4 plotted on the outside overpressure records. (A pressure record was not obtained in the emplacement of A2.) The differences in arrival times of the blast wave at the gages at each distance would be slight, perhaps 6 or 8 ms, and are neglected in the figure. The figure shows that the peak inside overpressure was reached early in the loading phase and that it exceeded the outside overpressure, which had not yet reached a maximum, by roughly 4 psi for about 40 ms for A1 and by roughly 1.5 psi for about 75 ms for A4; but the total impulse resulting from this internal loading should not have been sufficient to cause removal of the roofs. Also, the fact that roof planks remained on the emplacement caps of A2 and A4 (see Figs. 32 and 34) indicates removal of the roof by other than internal pressure. The roofs on A1, A2, and A4 showed lateral displacement accompanied by rotation in the counter clockwise direction. It appears then that roof displacement was caused by drag winds impinging along the edge of the roof at the side firing port. This would not have occurred until after the roof was bared to these winds by the removal of the side firing port aprons. The roofs would have been more



Fortification A1, 1430 ft



Fortification A4, 2280 ft

Fig. 67. Comparison of inside and outside overpressure records for the emplacements of A1 and A4.

vulnerable to lateral loads when frictional resistance to sliding between the roof and caps was least. This was when the internal pressure was a maximum, but it is unlikely that the sides of the roofs were exposed to drag forces this early as a result of apron failure.

On fortifications of the type tested (relatively open and partially above ground), the laminated roof appears to be more vulnerable to drag or dynamic pressure then to overpressure. Obviously, it must be securely fastened to the emplacement. Drift pins through the roof and into the caps should be adequate fastening.

(2) Shelter. Lowering the shelter roof to grade level effectively minimized dynamic pressure as a serious damage producing effect. Cap failures, which occurred only in the section adjacent to the emplacement, were not severe enough to cause collapse. In A2 and A3, these failures (one in each shelter) were effected by a peak incident overpressure of 28.8 psi. Failure was no more extensive in this part of A1 which received a peak overpressure of 42.7 psi. The shelter of A4 and A5 was not damaged by 11.2-psi peak overpressure. It should be noted that the caps with the 4-ft 4-in. span length withstood the blast in all cases.

In contrast to the emplacement, orientation had little effect on the amount of damage caused the shelters. It was noted that with the emplacement in the rear-on orientation the caps on the down range side of the shelter (next to the emplacement) were broken, while with the emplacement in the side-on orientation the cap on the opposite side of the shelter was broken (compare Figs. 40 and 42 with Fig. 46). In A1, the damage to the end of the shelter next to the entrance is attributed to faults of the entrance design which are discussed later.

Even with the entrance damage experienced by A1 and A2, the missile hazard in the shelter appeared least when the emplacement was oriented rear-on to ground zero or down wind from the shelter. When in either side-on orientation or the front-on orientation, the emplacement itself is a source for missiles in the shelter. The possibility of missiles entering the shelter through the firing ports also presents a hazard where the ports are oriented toward ground zero; however, such missiles were not detected in the shelters of A3 and A5.

(3) Entrance. A comparison of the entrances of A2 and A3, both at 1720 ft from ground zero, shows that orientation

influenced damage to this part of the fortification. Oriented side-on to ground zero, the entrance of A3 displayed no timber failure; but oriented with the opening toward ground zero, the entrance of A2 showed both caps to be broken in the longer span. The entrance of A1, oriented the same as A2, was severely damaged. From comparisons of the damage, it is believed that because of the shape of the cover (see Fig. 13), pressure multiplication occurred at the entrance opening of A1, A2, and A4. Better shaping of the cover material at the entrance may have improved the aerodynamic characteristics and thus decreased reflected pressure thereby causing less damage to the entrance.

c. Shielding Characteristics. The film badge measurements of gamma radiation in A1 and at location A in A2 are exceptionally low and must be considered incorrect (see Table VI). Since much of the film badge data were lost, better comparisons of gamma doses are obtained by using the chemical dosimeter data. It should be noted, however, that the gamma doses recorded in the fortifications by the chemical dosimeters are greater than the doses recorded by the film badges. The chemical dosimeter data obtained in fortification A1 and A2 show that the gamma dose received in the shelters at detector location B was roughly 55 percent less than the dose received in the emplacement. Because of the loss of data, similar comparisons cannot be made for A3 and A4. The gamma dose received in the shelter of fortification A5, which was oriented side-on to ground zero, was 33 percent less than the dose received in the emplacement. However, the gamma dose in this shelter (A5) was a factor of 4 greater than the dose in the shelter of A4 which was located at the same distance from ground zero but oriented rear-on to the burst. This comparison gives the only indication of how orientation of the fortification affected the attenuation of gamma radiation in the shelters.

Much of the neutron data was also lost; nevertheless, similar comparisons can be made using the chemical dosimeter data given in Table VI. No explanation is offered for the neutron doses in A2 being higher than those in A1.

d. DESERT ROCK VII vs DESERT ROCK VI Results. No specific comparisons can be made of the results from these tests; however, general comparisons which provide indications of relative effectiveness or vulnerability are justified. General comparisons of structural damage show that the response from vertical loading was about the same. As for lateral forces, much less damage was caused fortification A1 in the DESERT ROCK VII test than was caused one of the DESERT ROCK VI fortifications which was exposed to roughly the same peak blast phenomena. In this instance, overall rearward displacement was reduced from about 1 ft at the earlier test to about 2 in. at the later test. Also, joint separations were much less in evidence at the DESERT ROCK VII test. Further, the more recent test indicates that for all orientations a higher degree of blast protection can be obtained for a fortification by lowering the entrance construction to grade level and thus providing a more sheltered area.

Compared with peak incident overpressures, the overpressure measurements inside the DESERT ROCK VII fortifications did not vary significantly from the measurements obtained at DESERT ROCK VI. Rate of rise to peak pressure inside the fortifications was also about the same for the two tests.

Comparisons of shielding against nuclear radiation for the two tests have little meaning. The many factors involved, such as radiation energy, density and depth of cover material, and weapon design, make comparisons invalid. Although it is not possible to say definitely that the DESERT ROCK VII fortification provided better shielding from nuclear radiation, there are no indications that it provided less shielding. Indications are that the fortification tested at DESERT ROCK VII will afford better shielding in all orientations than the fortification exposed in the earlier test. The fact that the results for the two tests show that neither type fortification attenuated nuclear radiation to a survival level is of considerably more import than their relative shielding capabilities.

8. Hasty Fortifications. Blast effects and radiation shielding characteristics of the hasty fortifications are discussed in the following sub-paragraphs.

a. Blast Effects. The peak overpressure at the two test distances, 11.8 psi at 2280 ft and 9.2 psi at 3900 ft, caused about the same amount of earth wall damage to the B and C foxholes. Spalling of the side walls occurred at both distances, but generally the walls remained standing in the foxholes at 3900 ft (see Figs. 54, 55, 57, and 58) and collapsed in foxholes at 2280 ft (see Fig. 56). The photographs (Figs. 54 through 63) show that spalling at both test distances was confined to those emplacements having flat wall surfaces. The spalling which occurred in E2 (Fig. 62) was limited to the flat wall surface at the firing step. Thus, it appears from the test that because of the geometrical shape, more blast (air blast and air induced ground shock) is required to cave in the walls of a circular foxhole. It would appear that the circular hole is more resistant for two reasons: (1) the shock front which is a plane wave reflects from the curved surface creating tensile stresses the resultant of which may be non-directional and (2) the arching action of the soil around the periphery of the hole. Additional investigation is required to determine how much more resistant the circular foxhole is to blast than the rectangular one.

The results showed that only a slight amount of earth cover on the foxholes at 3900 ft was removed by the blast winds (dynamic pressure 2 psi); but at 2280 ft, the earth cover and stringers were removed from E2 (Fig. 62) and about one-half of the earth cover on B4 (Fig. 56) was blown away. Dynamic pressure at 2280 ft was 47 psi.

The skepticism over the likelihood of failure of the horizontal tunnels in the offset foxholes proved correct as none of the tunnels collapsed. The test of these foxholes provided little useful information about the vulnerability to blast of the tunnels. Their vulnerability will vary with soil type and construction technique. Because of the strength characteristics of the Frenchman Flat soil, it is felt that no particular significance should be attached to the lack of tunnel damage. The pressure gage results show that comparatively high peak overpressure can be expected in the offset foxhole. This is obviously due to pressure reflections off the rear wall of the tunnel. The peak overpressure in E2 and E3 was greater than the surface peak overpressure by factors of 2.6 and 1.8, respectively. The high overpressure in E2 was probably as much responsible as blast wind for the removal of the stringers and earth cover on this foxhole.

Figs. 64 and 65 show that the damage to the hasty shelters amounted to removal of cover material from the front and sides. Apparently, the sandbags used to close the entrance of F2 (Fig. 65) prevented the blast from separating the roof stringers as it did at the entrance of F1 (Fig. 64).

b. Shielding Characteristics. The film badge data obtained at the 3900-ft distance show that the average gamma dose received in 1/3, 2/3, and fully covered standard, two-man foxholes oriented end-on to ground zero was 42, 57, and 70 percent less than that received in the open foxhole. The effect of the cover reduced the doses at both detector locations within each foxhole somewhat in the same proportion. For the side-on orientation, the dose was 19, 45, and 74 percent less than that received in the open foxhole. This shows that the dose reduction was slightly better in the end-on foxholes. However, the average gamma shielding characteristics of the side-on foxhole were somewhat better than those of the end-on foxhole for all cover conditions. At the 3900-ft distance, the average gamma transmission factor of the side-on, two-man foxhole was 33, 3, 11, and 40 percent lower than the end-on foxhole for open, 1/3, 2/3, and full cover, respectively. This is understandable since more of the direct radiation has to travel through a greater slant thickness in order to reach the detector in the side-on orientation than in the end-on orientation. No shielding comparisons can be made of similar foxholes at the two test distances because of overexposure of the film badges in the foxholes at 2280 ft.

The chemical dosimeter data show that the average gamma dose received in the end-on, 2/3 cover, two-man foxhole (B4) was 63 percent less than that received in the open foxhole (B1) at the same distance, 2280 ft. When the chemical dosimeter data is again used, the average gamma transmission factor for B4 is found to be a factor of about 1.6 higher than its counterpart, B5, at 3900 ft. This is understandable for at the closer range the radiation energy would be higher and the angle of sight would be larger.

The gamma transmission factor for the different locations within each fortification varied. In the end-on, two-man foxholes at 3900 ft, the gamma transmission factor obtained from the film badge data for location A (the end away from ground zero) was greater than that of location B, as could be expected from a comparison of the line of sight or slant thickness of the earth for the two locations.

The neutron transmission factor of location A of the 2/3 covered foxhole (B5) was 66 percent less than that of the open foxhole at 3900 ft. It appears that a lower neutron transmission factor resulted as foxhole position receded from ground zero.

The 1/2 covered, modified, two-man foxhole with covered end toward ground zero (C2) had an average transmission factor less than the 1/3 covered and greater than the 2/3 covered, standard, two-man foxholes similarly oriented. The orientation of this foxhole affected the gamma transmission factors. For example, the average gamma transmission factor for the covered-end-on orientation was about 30 percent lower than the factor for the open-end-on orientation (C1). With the open end toward ground zero, the modified, two-man foxhole provided less shielding than any of the two-man foxholes with covered end toward ground zero but had an average transmission factor about 21 percent less than the end-on, open, two-man foxhole (B2).

It appears that the offset foxhole provided much better protection than the standard two-man foxhole against neutron as well as gamma radiation. For instance, the average of the gamma transmission factors obtained in the tunnels of offset foxholes D1, D3, and D4 is 0.0037 which is a factor of about 18 less than the average gamma transmission factor of the side-on, open, two-man foxhole. The offset foxholes at 2280 ft had transmission factors about twice as large as those at 3900 ft. The effect of cover in reducing the gamma dose in the offset foxholes was negligible. However, this statement may be misleading in that the covered and open offset foxholes differed in construction. The covered foxholes had a step opening that would tend to increase the transmission factor. The effect of orientation was not so striking in the case of the offset foxholes. The foxholes with tunnels forward or rearward had almost identical gamma transmission factors that are smaller than the transmission factors of the oil-drum-revetted offset foxholes with tunnels side-on.

The closed 6-ft by 8-ft hasty shelter had higher gamma transmission factors than the open shelter. This is unexplainable. Variations with detector location were expected in these shelters, but the data appear questionable and do not seem consistent enough to permit the drawing of conclusions.

IV. CONCLUSIONS

9. Conclusions. It is concluded that:

a. Access construction for the 7-ft by 7-ft machine gun emplacement is less vulnerable to blast for all orientations if it is placed with the roof at grade level rather than at the same elevation as the emplacement; it will afford a greater degree of protection to occupants from blast-driven debris than will the emplacement.

b. The shelter used in conjunction with the 7-ft by 7-ft machine gun emplacement provided better shielding against nuclear radiation than the emplacement, but the additional shielding obtained may not be sufficient to justify the construction effort.

c. The 7-ft by 7-ft machine gun emplacement can withstand blast effects of up to approximately 40-psi peak overpressure only if it is facing away from the burst. It appears to be extremely vulnerable to blast when oriented side-on to ground zero and facing ground zero.

d. On relatively open fortifications, a laminated roof of the design tested appears capable of sustaining loads resulting from incident peak overpressure of up to about 40 psi.

e. The initial gamma transmission factor of the standard, open, two-man foxhole ranged from 0.067 for the side-on orientation to 0.131 for the end-on orientation. The addition of 2/3 cover reduced the factor by about 50 percent while full cover reduced it by about 70 percent.

f. The neutron transmission factor of the standard, open, two-man foxhole was 0.29. The addition of 2/3 cover reduced this factor by about 65 percent.

g. The modified, two-man foxhole (1/2 covered) provided more shielding than the 1/3 covered and less shielding than the 2/3 covered, standard, two-man foxholes similarly oriented.

h. The initial gamma transmission factor of the horizontal tunnel of the offset foxhole ranged from 0.006 to 0.008 at 2280 ft from ground zero and from 0.003 to 0.005 at 3900 ft from ground zero. The factors for the open, offset foxhole and the covered, offset foxhole with firing step were about the same.

i. The neutron transmission factor of the tunnel of the offset foxhole was 0.003 at 2280 ft from ground zero.

j. Pressure multiplication in the tunnels of the offset foxhole caused peak overpressures which ranged from 1.8 to 2.6 times the incident peak overpressure.

k. The circular foxhole appeared to be less vulnerable to blast than the standard two-man foxhole. Meager test evidence does not justify further conclusions about its vulnerability.

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