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DEVELOPMENT AND EVALUATION OF PROTECTIVE REVETMENTS

Dwayne D. Piepenburg
Lt USAF

TECHNICAL REPORT NO. AFWL-TR-66-47

November 1966

AIR FORCE WEAPONS LABORATORY
Research and Technology Division
Air Force Systems Command
Kirtland Air Force Base
New Mexico

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FOREWORD

This engineering development study was conducted under Program Element 6.44.15.03.4, Project 1383. Inclusive dates of research were December 1965 to June 1966. The report was submitted by the Air Force Weapons Laboratory Project Officer, Lt Dwayne D. Piepenburg (WLDC), in August 1966.

The assistance of the personnel from the Explosive Ordnance Disposal Section, Deputy for Material, Air Force Special Weapons Center, the Photographic Division, Deputy for Test and Engineering, AFSWC, and the Eric H. Wang Civil Engineering Research Facility, Kirtland Air Force Base, New Mexico, is gratefully acknowledged.

This report has been reviewed and is approved.

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ABSTRACT

Revetment wall sections constructed from soil-cement, steel-sheet piling, corrugated asbestos, and fiberglass were evaluated for their effectiveness in providing protection to parked aircraft and equipment against the effects of conventional weapons. The results of this evaluation program indicate that the soil-cement wall provided protection against small arms ammunition, mortar rounds statically detonated at elevations less than 12 feet and at any range, 3.5-inch High Explosive Antitank (HEAT) rockets, and shrapnel resulting from the detonation of a 750-pound bomb 10 feet from the wall. The steel-sheet piling wall provided perforation protection against 30-caliber ball ammunition only, but may result in untrapped ricochets on the front face of the wall. Fifty-caliber and 20-millimeter ammunition and mortar rounds caused perforations in the piling, produced secondary projectiles, untrapped ricochets, and shrapnel on the front face of the wall, and spalled the sheet piling, producing shrapnel and secondary projectiles on the rear face of the wall. The fiberglass wall provided protection against small arms ammunition and mortar rounds statically detonated at elevations less than 11 feet and at any range. The fiberglass wall did not prevent the perforation of the core from a 3.5-inch HEAT rocket. The corrugated asbestos wall provided protection against 30-caliber and 50-caliber ammunition. Twenty-millimeter ammunition and 3.5-inch HEAT rockets did considerable damage to the wall.

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ILLUSTRATIONS (cont'd)

ILLUSTRATIONS (cont'd)

ILLUSTRATIONS (cont'd)

TABLES

SECTION I

INTRODUCTION

This report covers the testing of protective revetments for aircraft during the period from 20 December 1965 to 15 June 1966.

On 20 December 1965, a letter was received from Headquarters Air Force Systems Command requesting that conventional weapon tests be conducted on representative sections of a solid soil-cement revetment wall and a single layer of Z-32 steel-sheet-piling wall.

Following the above request, a program was initiated by Headquarters Tactical Air Warfare Center to evaluate revetments for navigational aids. As part of the program, the Air Force Weapons Laboratory was asked to evaluate revetments constructed from corrugated asbestos and Mo-Shel, a waffled fiberglass and resin material.

The purpose of these tests was to evaluate the protection afforded aircraft, equipment, and personnel by the specified revetment concepts. To fulfill this purpose, wall sections were constructed at the revetment test site and tested with conventional weapons including small arms, mortars, rockets, and bombs.

SECTION II

OBJECTIVE

The objective of this study was to investigate the performance and to acquire data on the effectiveness of vertical and sloping wall revetments in providing protection for tactical aircraft, support equipment, and personnel against ground-fired conventional weapons.

Specific objectives of this phase of the project include:

a. The investigation of a solid soil-cement revetment wall constructed from portland cement and indigenous soil.

b. The investigation of a revetment wall constructed from a single layer of Z-32 interlocking-type steel-sheet piling. No earth fill is associated with this specific revetment wall.

c. The investigation of an earth-filled fiberglass revetment wall.

d. The investigation of an earth-filled A-frame wall faced with corrugated asbestos.

SECTION III

BACKGROUND

The effects of current conventional weapons and methods for protecting against such weapons have become important items of research and development because of the current commitment of United States military forces in Southeast Asia. A brief summary of conventional weapon-effects studies was presented in reference 1 along with a detailed discussion of the test and evaluation of revetments constructed from timber, stabilized earth blocks, plain and stabilized sandbags, and cement blocks coated with sulphur and fiberglass.

Reference 2 discusses the test and evaluation of an "Armco Bin" type of revetment. These revetments have been constructed in large numbers in Southeast Asia to provide protection for tactical aircraft and support equipment.

SECTION IV

HISTORICAL INFORMATION ON SOIL-CEMENT REVETMENTS

Prior to the erection of the "Armco Bin" type of revetment in Vietnam, solid soil-cement revetments were constructed at the air bases located at Tan Son Nhut, Da Nang, and Bien Hoa.

The cross section of the soil-cement revetment wall is as shown in figure 1. The materials used to construct these revetments included Type I portland cement from Thailand, native soil, and water.

At Tan Son Nhut, the soil was a sand with the following grain size distribution:

Screen size	Percent passing
4	100.0
8	99.5
16	91.7
30	40.5
50	8.0
100	1.0

The soils used at Da Nang and Bien Hoa were local beach and river-run sand respectively. No sieve analysis is available for these sands, but it is known that approximately 90 percent of the river-run sand at Bien Hoa passes the No. 50 sieve.

Prior to the construction of the soil-cement revetments in Southeast Asia, sample soil-cement cylinders (6 inches in diameter and 12 inches in length) were tested. The results of these tests indicated a 28-day compressive strength of 460 pounds per square inch.

The soil-cement mixture consisted of approximately 10-percent by weight of total mix Type I portland cement. At Bien Hoa, the reported moisture content was 4.8 gallons per cubic meter or a water-cement ratio of approximately 0.145. This is approximately 1.0 to 1.5 percent water by weight of total mix.

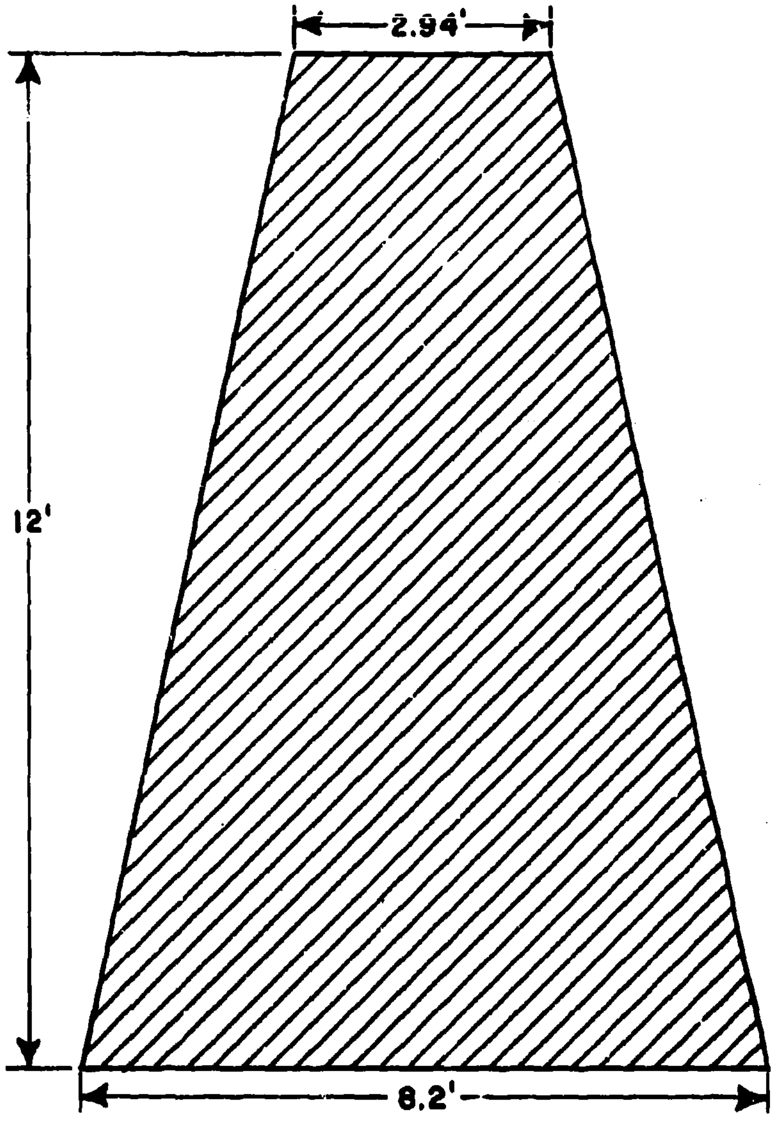


Figure 1. Soil-Cement Revetment

A concrete mixer was used to prepare the soil-cement material and a front-end loader, or a crane and concrete bucket, was used to place the material in the forms. The material was placed in 6-inch lifts and was compacted by hand-rodding and tamping procedures.

SECTION V

LABORATORY STUDIES

Soil-cement test cylinders, simulating the strength characteristics of the soil-cement mixtures used in Vietnam, were prepared and tested.

1. Objective

The purpose of the laboratory studies was to develop a soil-cement mixture consisting of Type 3 portland cement (high early strength), fine concrete aggregate (sieve analysis data which approximates that at Tan Son Nhut, figure 2), and water, and having a 7-day compressive strength of approximately 460 pounds per square inch. By developing this soil-cement mixture, using high early strength cement in lieu of standard Type 1 cement, the time required to erect and test a representative section of a revetment wall was reduced from 30 days to 9 days.

2. Procedure

Soil-cement test cylinders (6 inches in diameter and 12 inches long) were prepared, using Type 3 portland cement, fine concrete aggregate, and various percentages of water. The materials used for each test mixture are tabulated in table I. The cylinders were prepared by filling the cylinders in 4-inch lifts and then rodding and tamping the material or by filling the complete cylinder and then vibrating it. Special care was exercised when rodding the cylinders to ensure a good bond between lifts. The cylinders were then cured in the open air for 7 days and tested in a universal testing machine at a loading rate of 0.2 inches of loading head movement per minute.

3. Results

Given a quantity of fine concrete aggregate and a specified quantity of Type 3 portland cement, test results indicated that the strength of the mixture will depend upon the quantity of water added (table II). For this specific revetment wall test, a mixture consisting of 80.9 percent by weight fine concrete aggregate, 8.3 percent by weight Type 3 portland cement, and 10.8 percent

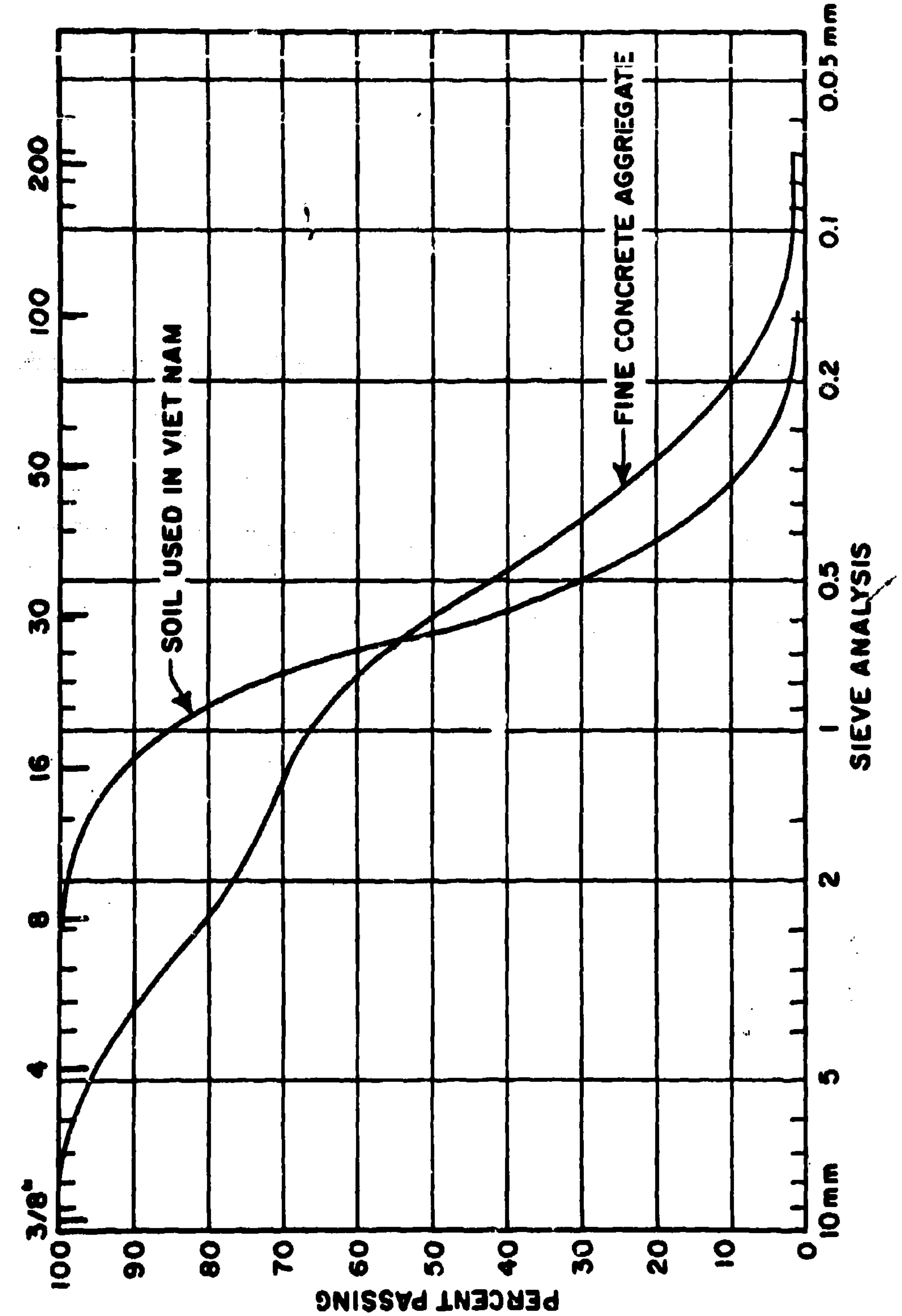


Figure 2. Sieve Analysis

Table I

MATERIALS USED FOR SOIL-CEMENT CYLINDERS

Series No.	Batch No.	Concrete sand dry weight (lb)	Type III cement (lb)	Water Weight (lb)	Water Percent
1	1	68.6	7	4.4	5.5
	2	68.6	7	5.9	7.24
	3	68.6	7	7.65	9.19
	4	68.6	7	9.15	10.79
	5	68.6	7	10.65	12.34
	6	68.6	7	12.15	13.84
2	1	68.95	7	8.8	10.38
	2	68.95	7	7.8	9.32
	3	68.95	7	6.55	7.94
	4	68.95	7	5.05	6.23
	5	68.95	7	3.30	4.17

Table II

SOIL-CEMENT CYLINDER-TEST RESULTS

Series No.	Batch No.	Water Percent	Water/Cement ratio	No. cylinders tested	Average compressive strength, 7 days (psi)
1	1	5.50	0.628	0	---
	2	7.24	0.842	0	---
	3	9.19	1.092	1	689
	4	10.79	1.307	3	473
	5	12.34	1.522	3	338
	6	13.84	1.735	3	259
2	1	10.38	1.255	1	609
	2	9.32	1.115	1	680
	3	7.94	0.936	2	875
	4	6.23	0.722	1	948
	5	4.17	0.471	1	694

by weight water was selected to provide a 7-day compressive strength of approximately 400 pounds per square inch (figure 3).

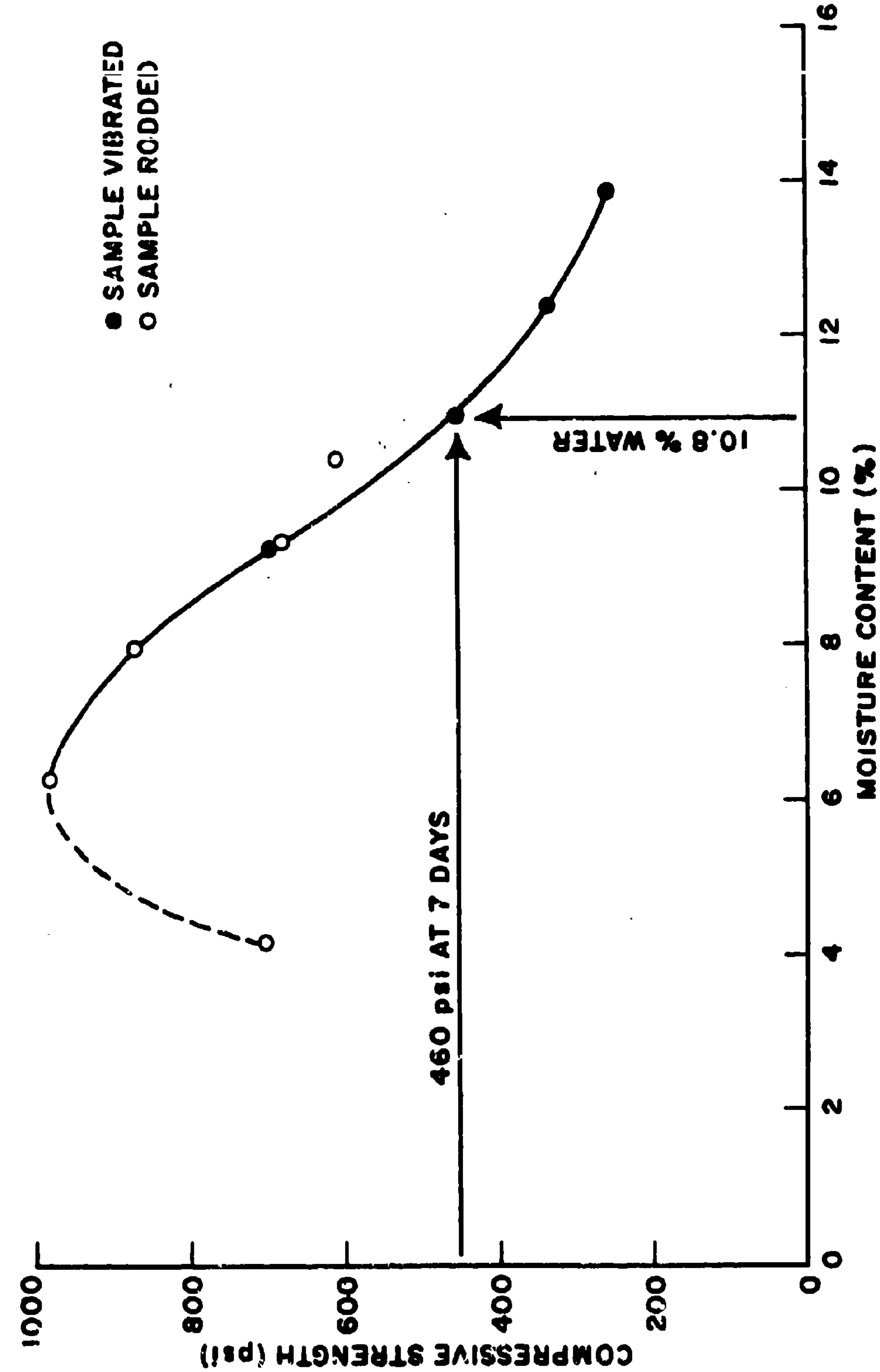


Figure 3. Soil-Cement Test Cylinders

SECTION VI

WALL PANEL TESTS--FIELD TESTING

Representative wall sections of soil-cement, steel-sheet piling, fiberglass, and corrugated asbestos revetments were constructed and tested (figures 4 and 5). The cross sections and dimensions of each wall are presented in figures 6, 7, 8, and 9.

1. <u>Materials</u>

a. Soil-Cement

As stated in Section V, a soil-cement mixture consisting of 80.9 percent by weight fine concrete aggregate, 8.3 percent by weight type 3 portland cement, and 10.8 percent by weight water resulted in a 7-day compressive strength of approximately 460 pounds per square inch. This was the mixture used to construct the soil-cement test wall.

b. Steel-Sheet Piling

The steel-sheet piling wall was constructed from Z-shaped, interlocking piling having the following section properties: a length of 18 feet, a weight of 32 pounds per square foot of wall, and a section modulus of 38.3 inches cubed per linear foot of wall (figure 10).

The steel channels which were attached to the piling as batten plates were 10 inches wide with a weight of 15.3 pounds per linear foot.

Structural grade steel having a yield strength of approximately 33,000 pounds per square inch was used for both the sheet piling and channels. Table III tabulates the section properties of the steel-sheet piling sections and the 10-inch channel sections.

c. Waffled Fiberglass

The fiberglass revetment wall was erected from sheets of fiberglass material having a uniform thickness of 0.085 inches. The sheets of material were bolted together with 1/2-inch-diameter nylon bolts to form cylinders.

Figure 4. Steel-Sheet Piling and Soil-Cement Revetment Wall Sections

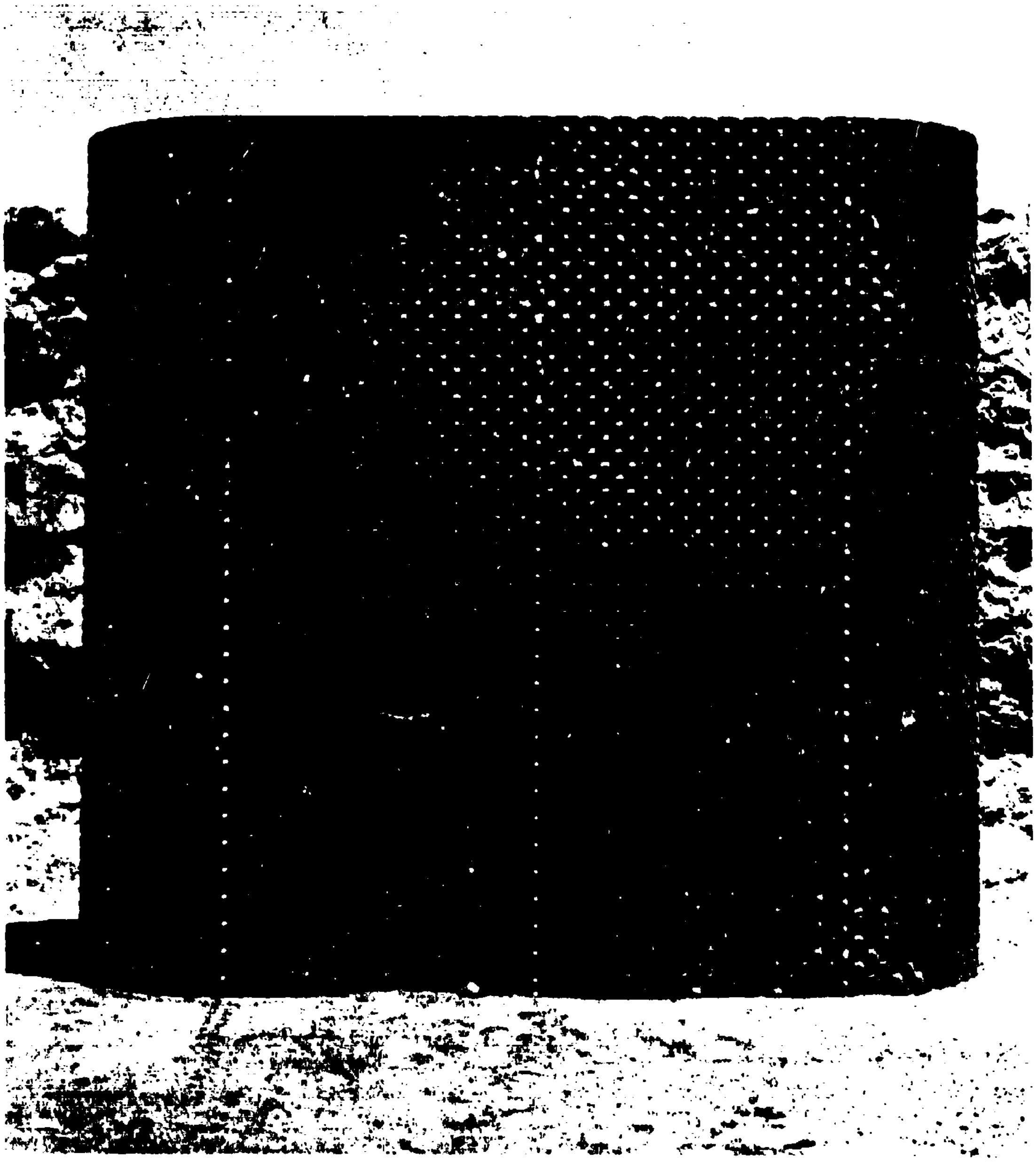


Figure 5. Fiberglass Revetment Wall Section

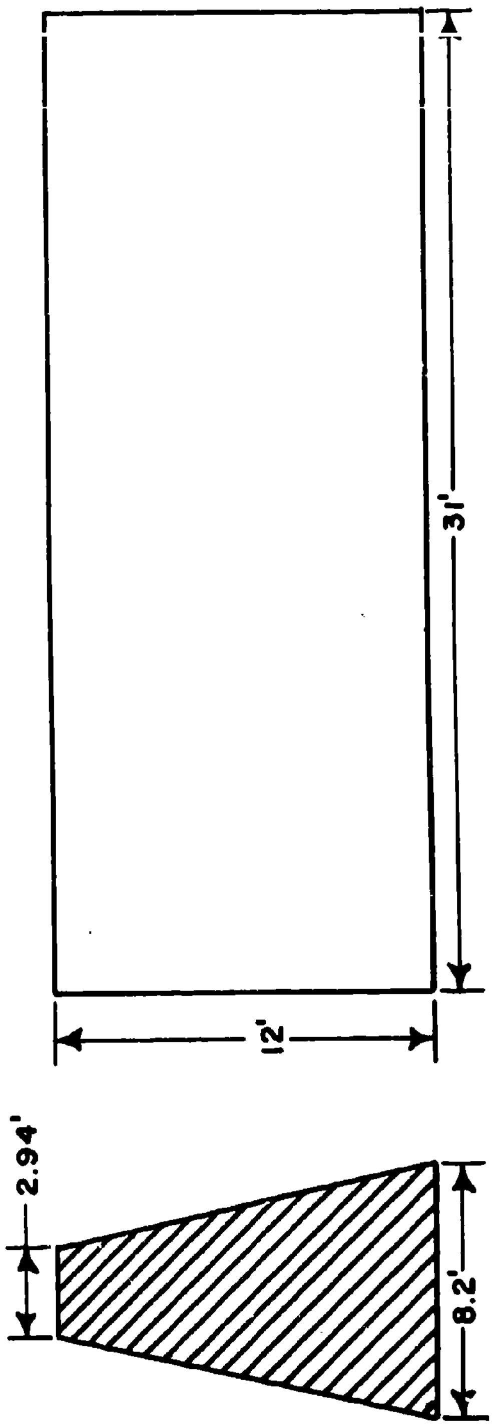


Figure 6. Soil-Cement Revetment

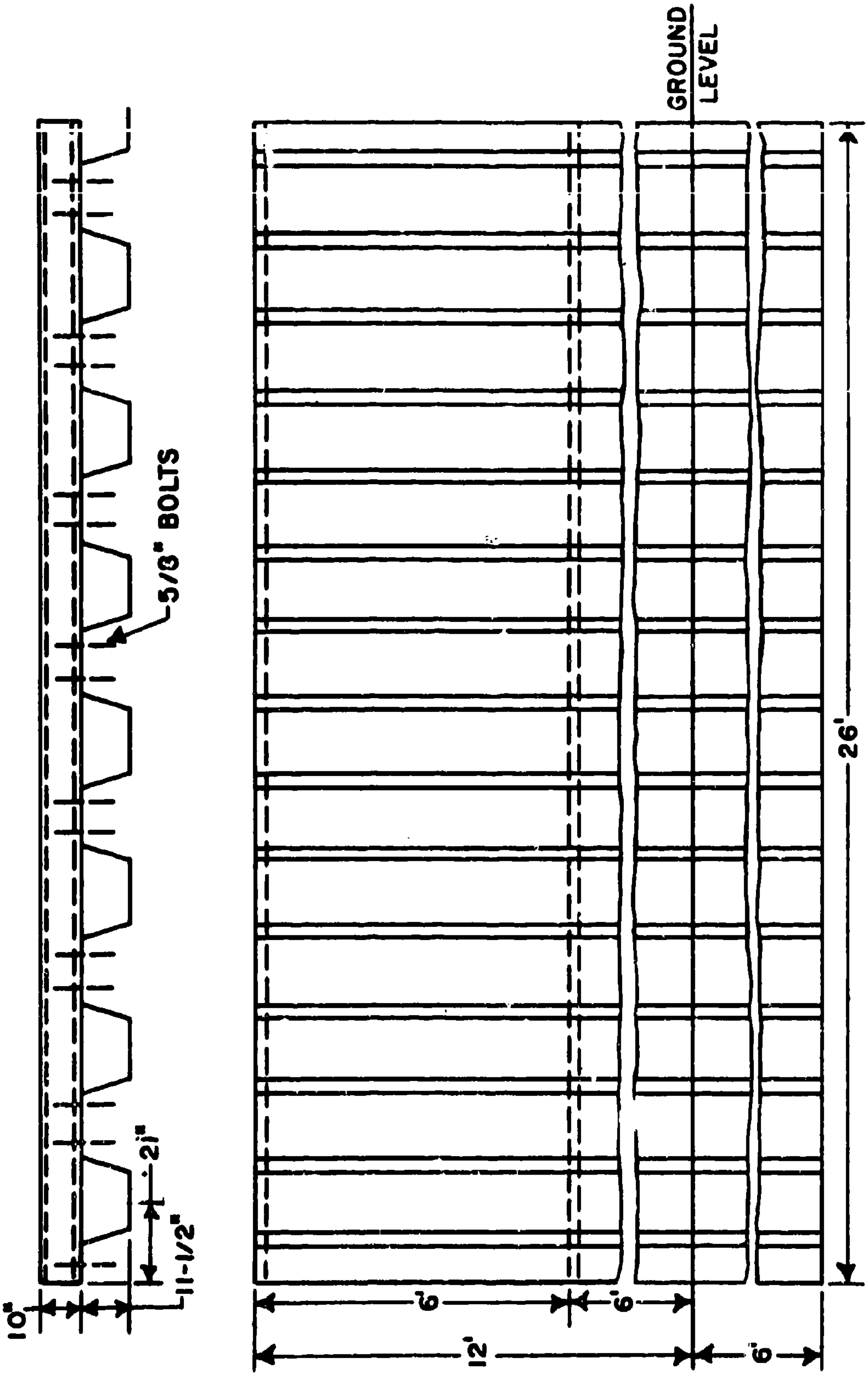


Figure 7. Interlocking Sheet-Piling Revetment

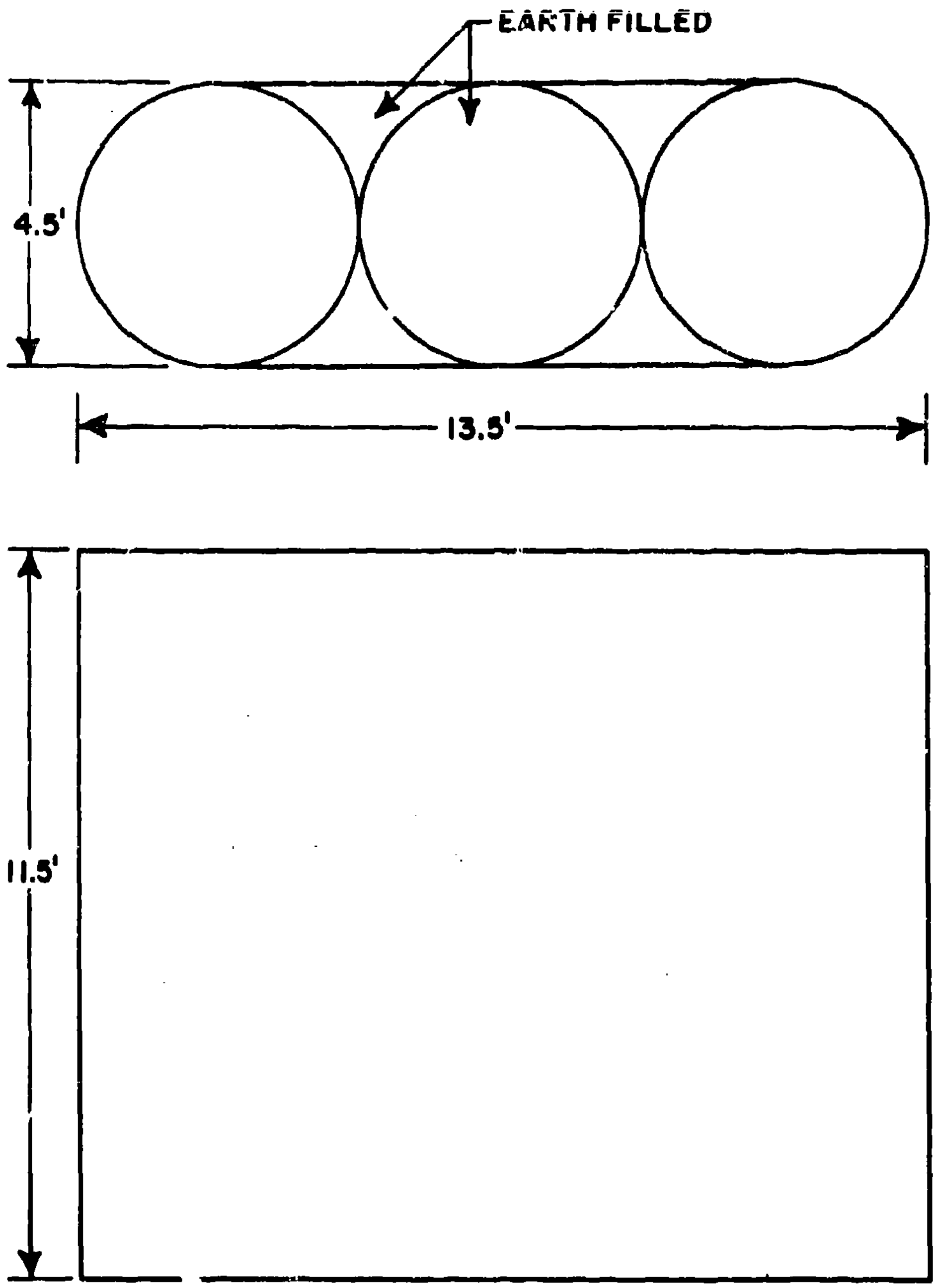
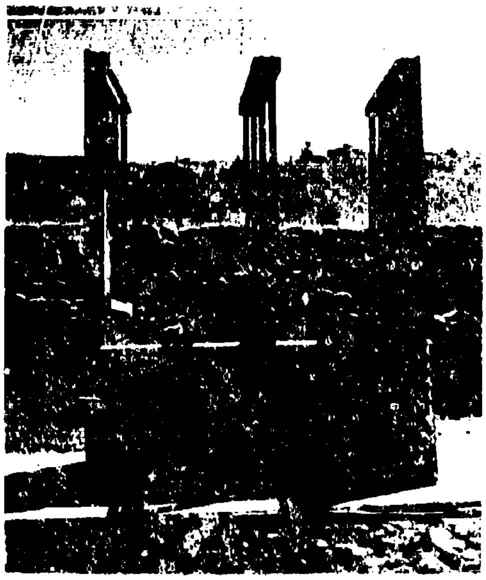


Figure 8. Fiberglass Revetment



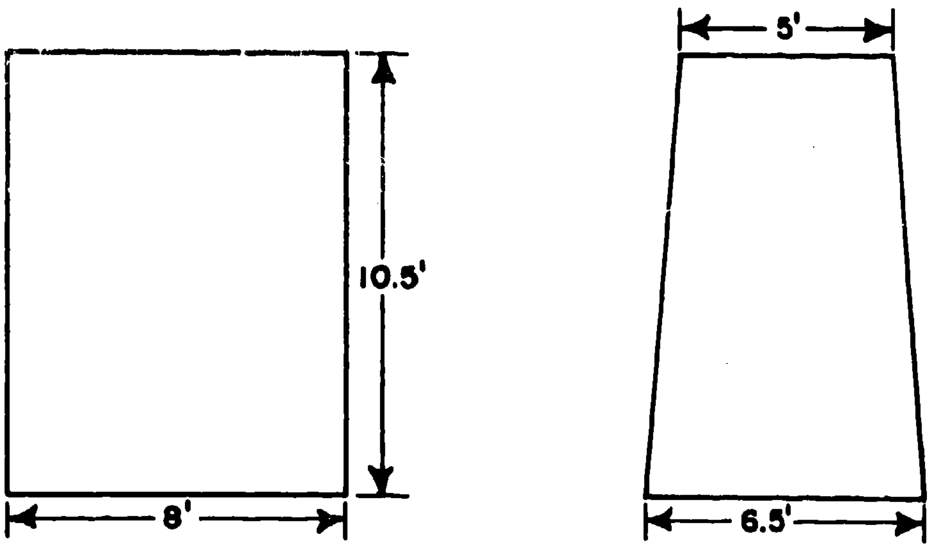


Figure 9. Corrugated Asbestos Revetment

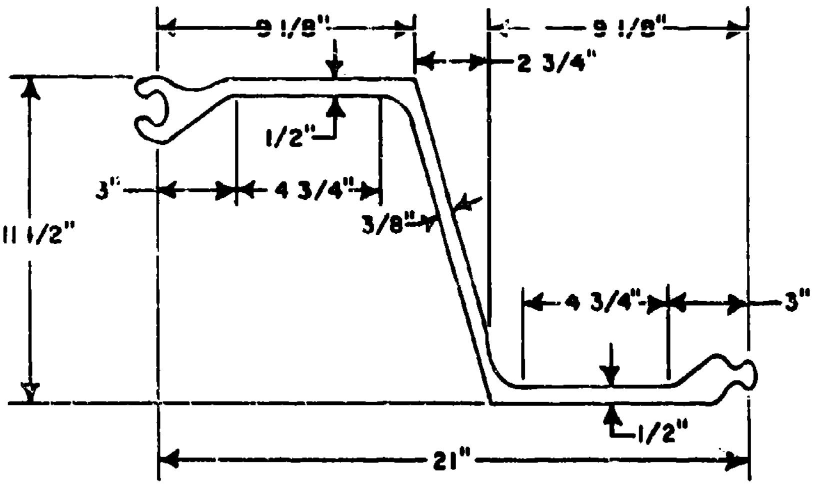


Figure 10. Cross Section of Z-32 Sheet Piling

Table III

STEEL SECTION PROPERTIES

Z-32 Sheet Piling

Section number	Z-32
Web thickness	3/8 inch
Flange thickness	1/2 inch
Weight per linear foot of piling	26.0 pounds
Weight per square foot of wall	32.0 pounds
Section modulus per pile	67.0 inches cubed
Section modulus per foot of wall	38.3 inches cubed
Area	16.47 square inches
Moment of inertia	385.7 inches fourth

10-Inch Channel

Nominal size	10 x 2-5/8 inches
Weight per linear foot	15.3 pounds
Area	4.47 square inches
Depth of section	10.00 inches
Flange width	2.600 inches
Average flange thickness	0.436 inches
Web thickness	0.240 inches
Moment of inertia, X-X axis	66.9 inches fourth
Moment of inertia, Y-Y axis	2.3 inches fourth

A mixture of reject concrete sand, sand having excess fines for concrete work, and native New Mexico soil was used to fill the interior voids of the wall.

d. Corrugated Asbestos

Corrugated asbestos, having a uniform thickness of 1/2 inch and a spacing of 4 inches between corrugations, was used to face a timber A-frame wall section. The remaining three sides of the wall were faced with 3/4-inch plywood. Native soil and reject concrete sand was used to fill the A-frame wall.

2. Construction Procedures

a. Soil-Cement Wall

The soil-cement wall was constructed in two phases. Phase one was the fabrication and erection of the wood forming. The forming was prefabricated at the Eric H. Wang Civil Engineering Research Facility, Albuquerque, New Mexico, in sections 12 feet long and 8 feet wide from 3/4-inch plywood with 2-inch by 4-inch lumber spaced on 2-foot centers and nailed to the plywood. The forming was then hauled to the test site where it was erected. Each section of the form was put into position with hand labor and braced with 2-inch by 4-inch lumber (figure 11).

Phase two was the placing of the soil-cement ready-mix fill material. The first ready-mix truck arrived on the site at 0800 hours and pouring operations began at 0810 hours. Trucks carrying 8-cubic yards of material arrived at 50-minute intervals thereby permitting continuous pouring operations. The soil-cement material was placed with a crane and a 1-cubic-yard concrete bucket. The bucket was filled directly from the turck and then lifted to the top of the form where it was dumped into the forming (figure 12). The fill material was permitted to drop 12 feet with no apparent separation of mixture constituents (figure 13).

The fill material was placed in 6-inch lifts with each lift thoroughly hand-rodded and foot-tamped to produce a relatively voidless and well-bonded structure. Special effort was required to ensure that rodding was deep enough to pass through the top 6-inch lift and well into the preceding lift, thereby bonding the lifts together (figure 14).

Two sample cylinders were prepared from each of the 11 ready-mix trucks. These cylinders were prepared in 4-inch lifts with each lift thoroughly rodded and tamped (figure 15).

Figure 11. Erection of Forming for Soil-Cement Test Wall

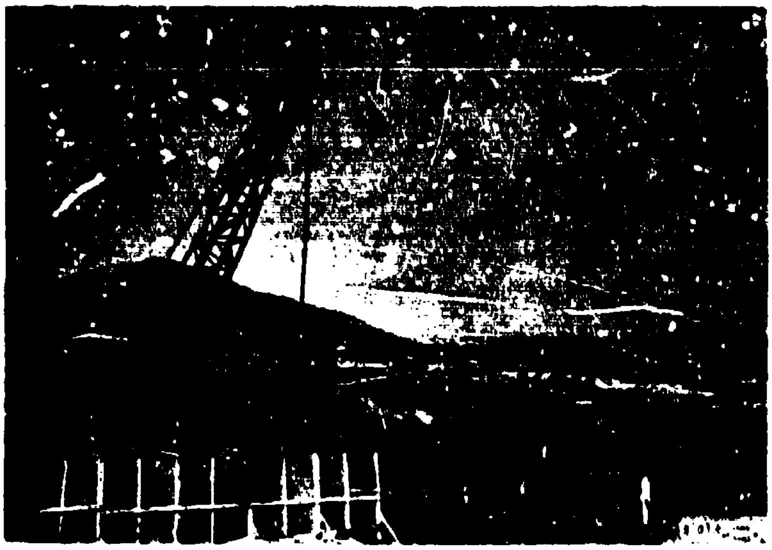


Figure 12. Placing of Soil-Cement Fill Material in Forming

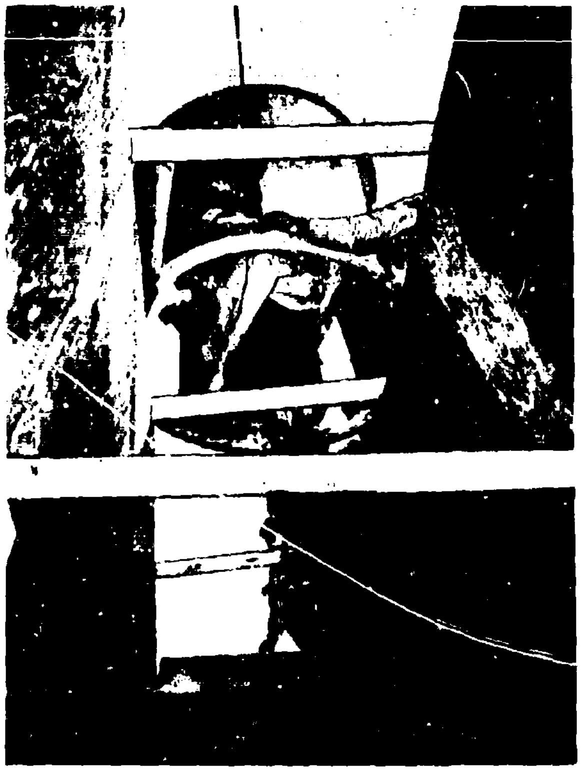


Figure 13. Dropping of Fill Material

Figure 14. Rodding and Tamping of Soil-Cement Material

Figure 15. Preparing Test Cylinders from Ready-Mix Soil-Cement Material

Upon completing the pour operations, the complete structure, except one end, was covered with canvas and two kerosene heaters were used to maintain a minimum air temperature of 40 degrees Fahrenheit around the form. The heaters, each having a capacity of 75,000 BTU per hour, were used continuously for 3 days with periodic temperature checks made at 0800, 1600, and 2400 hours each day. Table IV tabulates the temperature readings recorded during this 3-day curing period.

On the third day, the wood forming was removed and the structure again covered to reduce the effects of severe temperature changes. No heat was applied after the forming was removed.

b. Steel-Sheet Pile Wall

Prior to the arrival of the steel-sheet piling, a trench 30-feet long, and 2 feet wide was excavated to a depth of 6 feet, using a tractor and backhoe (figure (16).

The sheet piling was placed with a crane in the following manner: first, one sheet of piling was placed in the trench and braced, then a second sheet of

Table IV

CURING TEMPERATURE DATA*

Date	0800	Time 1600	2400
11 Jan	**	Heaters started	50°F
12 Jan	55°F	50°F	50°F
13 Jan	40°F	64°F	54°F
14 Jan	54°F	Forms removed	---

*Average of two readings, one on each side of wall.

**Pouring operations began at 0810 hours and were completed by 1700 hours, 11 January 1966.

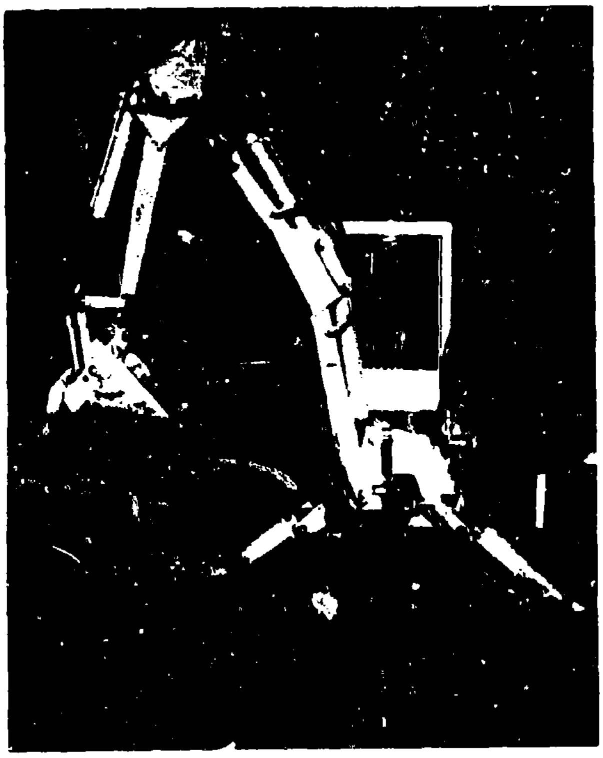


Figure 16. Excavating for Steel-Sheet Piling

piling was elevated to a position directly above the first sheet and slowly lowered until the two sheets of piling interlocked (figure 17). At this time the lowering process continued until firm contact was made with the ground. This process was repeated until fifteen sheets of piling had been positioned.

The bucket of a front-end loader was used to position a man near the top of the sheet piling wall where accurate and rapid alignment could be made to interlock the sheet piling. A timber or steel scaffolding could also have been used for this operation.

As shown in figure 18, the front-end loader served a dual role by also moving the necessary fill material for tamping around the piling.

Following the placement of the third sheet of piling, the wall was plumbed and backfilling operations begun by placing approximately 6 inches of native soil around the first piling. This material was then compacted with a 6-inch-diameter, compressed-air-operated tamper (figure 19). Additional 6-inch lifts of earth fill were placed and tamped. This process was repeated until the bottom 6 feet of each sheet piling was embedded in the trench.

The 10-inch steel channels were secured to the piling at the specified elevations of 6 and 12 feet by first elevating the channels to their respective positions with a front-end loader and then cutting 5/8-inch-diameter holes through the channel and piling with an acetylene cutting torch. Each section of piling was secured to the channels with a 5/8-inch-diameter black-steel machine bolt having an approximate allowable tensile strength of 14,000 pounds per square inch of cross section (figure 20). For ease in securing the channels, special attention was and should be given to the alignment of the steel-piling sections relative to each other.

c. Fiberglass Wall

The fiberglass sheets were first separated into cylinder pieces and outside facing pieces. Then two cylinder pieces, each having a length of 11.5 feet and a width of 7 feet, were bolted together with nylon bolts to form a 4.5-foot-diameter cylinder. This procedure was repeated until three cylinders were prepared.

Following this, the cylinders were positioned side by side so that the greater number or more concentrated sections of bolts were at the same end, the bottom. Then an outside facing piece of material was bolted to the cylinders. Next, the wall section was tipped over and the opposide outside facing was

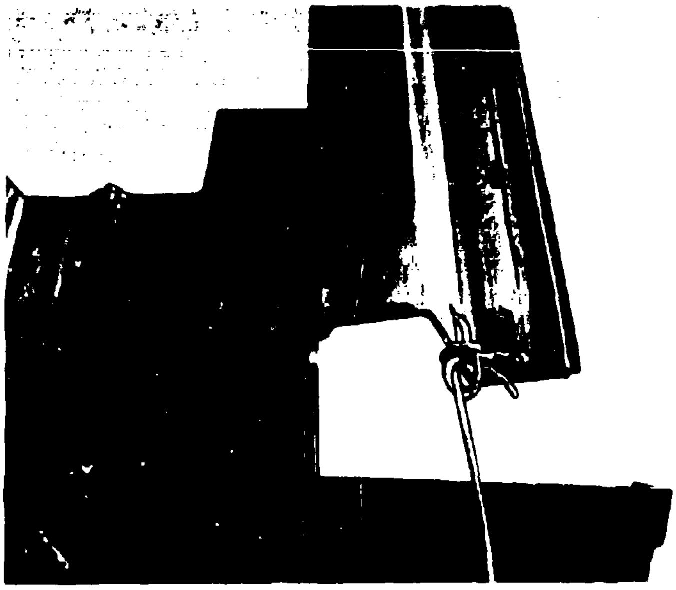


Figure 17. Interlocking of Sheet-Piling Sections

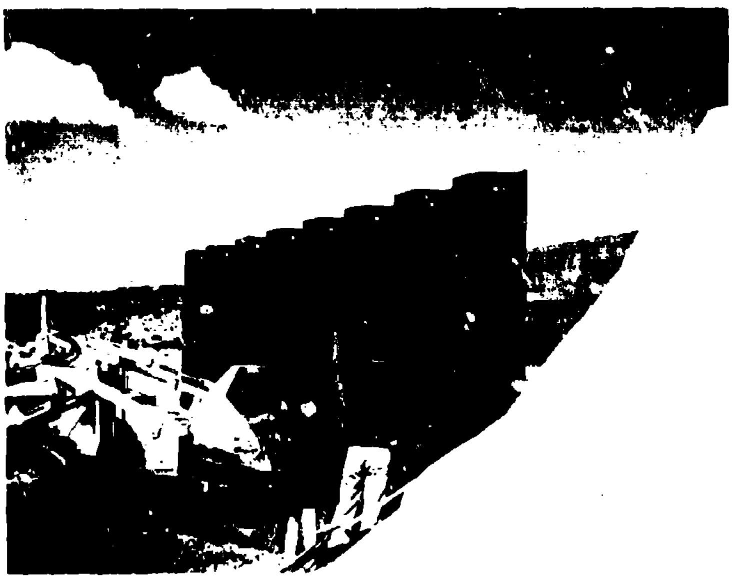


Figure 18. Placing of Earth Fill Around Sheet Piling

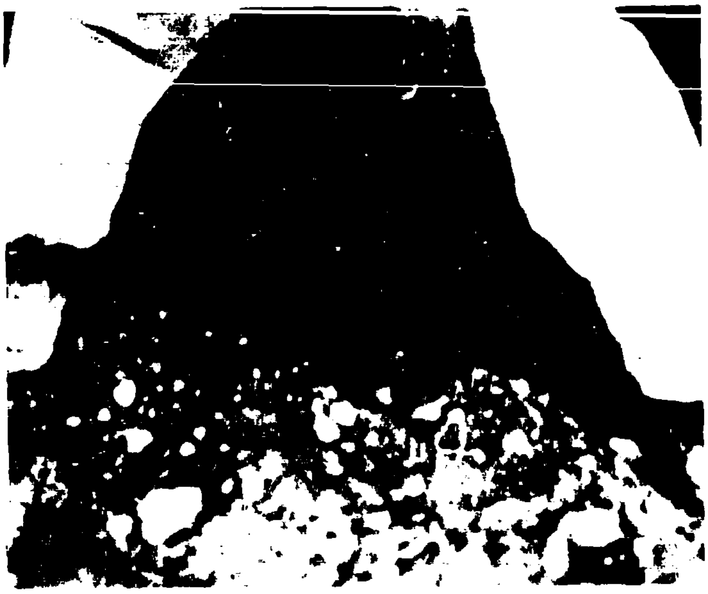


Figure 19. Compacting Fill Material with 6-Inch-Diameter, Air-Operated Tamper

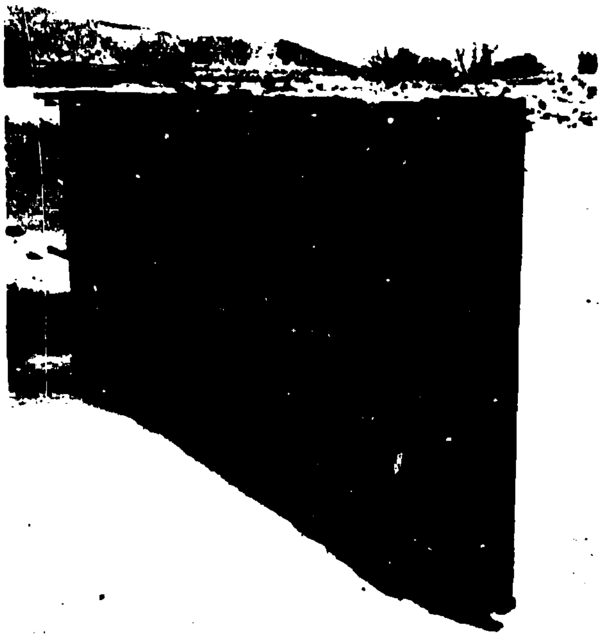


Figure 20. Steel Channels Secured to Rear Face of Wall

bolted on. All bolts were tightened to 60 inch-pounds of torque.

As stated in Section VI,1c, the fill material consisted of reject sand and native soil. This material was randomly placed in the wall with a front-end loader and conveyer. No effort was made to compact the soil. However, an effort was made to fill all of the wall compartments uniformly.

d. Corrugated Asbestos Wall

The A-frames were constructed from 2-inch by 4-inch lumber nailed with 16d cement-coated nails. Three A-frames were fabricated and positioned at 4 feet on centers on a concrete support pad. Following this, 3/4-inch plywood was nailed to the end and rear sides of the wall.

Prior to nailing the asbestos to the timber A-frames, 3/16-inch-diameter holes were drilled in the asbestos to permit ease in nailing. Cement-coated 16d common nails were used in groups of two with the nails spaced 3 inches on centers horizontally and each group spaced 4 inches on centers vertically.

The material and procedures used to fill this wall were the same as those used to fill the fiberglass wall section.

3. Construction Time and Costs

The information presented in this section is for a one-time, no-prior-experience operation. It must be pointed out that it was necessary to purchase sand for the soil-cement mixture and also that ready-mix delivery, which was used for this project, may be slightly more expernsive than military or other contractual services. In addition, if sheet piling is used in overseas areas, transportation costs may be an important part of the total cost.

Tables V, VI, VII, and VIII summarize the number of manhours, types of equipment used, and construction costs for each of the test walls.

4. Testing Procedures

As stated previously, the soil-cement wall section was designed to be tested on the seventh day following construction. To verify that the proper strength had been attained, a number of sample cylinders which were prepared during the construction of the wall were tested in a universal testing machine. The loading rate was 0.2 inches of loading head movement per minute.

Upon determining that the proper strength had been attained (table IX), the testing of the soil-cement wall was initiated with a 30-caliber rifle fired at a range of 150 feet from the wall. Following this, the wall was tested with

Table V

CONSTRUCTION TIME AND COST FOR SOIL-CEMENT WALL

Materials: Required	Materials: Cost	Manpower: Required	Manpower: Cost	Time for construction: Manhours total	Time for construction: Manhours per linear foot	Total	Cost Per linear foot
30 sheets of 3/4 in. plywood	$ 180	5 men for 2 days to erect forming	$ 240	80	2.6	$ 636	$ 21
1540 linear feet of 2x4 lumber[1]	216						
84 cubic yards per 31-linear-foot section[2]	1260	10 men for 1 day plus overtime	480	120	3.9	1824	59
Crane	Owned by Air Force	1 man for 12 continuous hours	48	12	0.4		
Concrete bucket	$36 (rental fee)						

[1]Lumber for forming is a one-time expense since it can be reused. Plywood estimated at $6 per 4x8 sheet and 2x4 lumber estimated at $14 per 100 linear feet.

[2]Ready-mix material estimated at $15 per cubic yard (within 15-mile-delivery radius) locally procured.

Table VI

CONSTRUCTION TIME AND COST FOR STEEL-SHEET PILING WALL

Materials Required	Materials Cost	Manpower Required	Manpower Cost	Time for constrcution: Manhours total	Time for constrcution: Manhours per linear foot	Total	Cost Per linear foot
Trenching with backhoe	Owned by Air Force	1 man for 6 hours	$ 18	6	0.2	$2764	$ 89
Sheet piling	$2223	7 men for 1 day to place piling	168	56	1.8		
Steel channels, 54 linear feet	180	4 men for 1/2 day to install channels	48	16	0.5		
Tamping equipment[1]	127						

[1]Tamping equipment, including air compressor, two 6-inch-diameter air tampers, and 100 feet of hose (rental fees).

Table VII

CONSTRUCTION TIME AND COST FOR FIBERGLASS WALL

Materials Required	Materials Cost	Manpower Required	Manpower Cost	Time for construction: Manhours total	Time for construction: Manhours per linear foot	Total	Cost Per linear foot
6 sheets of cylinder material with associated 2 side panels, nylon bolts included	$2250	3 men for 4 hours to assemble cylinders and attach side panels	$ 36	12	0.80	$2331	$155
Conveyor	$36 (rental fee)	1 man for 1.5 hours to place fill material	4	1.5	0.1		
Front-end loader	Owned by Air Force	1 man for 1.5 hours to operate vehicle	5	1.5	0.1		

Table VIII

CONSTRUCTION TIME AND COST FOR CORRUGATED ASBESTOS WALL

Materials		Manpower		Time for construction			
Required	Cost	Required	Cost	Manhours total	Manhours per linear foot	Total	Cost Per linear foot
3 sheets of asbestos	$ 60	3 men for 3.5 hours to construct A-frames and erect wall	$ 31	10.5	1.3	$ 214	$ 27
8 sheets of 3/4-inch plywood	48						
225 linear feet of 2x4 lumber	32						
Nails, 16d cement-coated							
Conveyor	$36 (rental fee)	1 man for 1 hour to place fill material	3	1.0	0.125		
Front-end loader	Owned by Air Force	1 man for 1 hour to operate vehicle	4	1.0	0.125		

[1]Plywood estimated at $6 per 4x8 sheet; 2x4 lumber estimated at $14 per 100 linear feet.

Table IX

TEST RESULTS OF SOIL-CEMENT CYLINDERS*

Truck No.	Cylinder No.	Day of test following erection wall	Load before failure (lb)	Cylinder strength Compressive strength (psi)	Avg compressive strength (psi)
1	B	3	12,850	454	
2	A	3	8,700	308	
4	A	3	6,750	239	302
6	A	3	6,900	244	
8	A	3	7,550	267	
4	B	4	12,000	424	438**
6	B	4	12,800	452	(394)
3	B	7	12,200	431	
9	A	7	12,450	440	
1	A	7	14,300	505	445
5	B	7	11,350	401	
3	A	45	18,900	668	
8	B	45	20,400	720	694

*Cylinders 2B, 5A, 7A, 7B, 9B, 10A, and 10B were damaged during transportation from field site to testing machine or during capping operations.

**These cylinders were exposed to a heavy frost 3 hours prior to testing. Therefore, this load carrying capacity should be reduced by 10 percent assuming the temperature at time of test to be near 35°F. See appendix I for further discussion.

ammunition fired from a 50-caliber machine gun and a 20-millimeter, ground-mounted aircraft cannon. These weapons were fired from a range of 480 feet. For these tests, the 20-millimeter cannon's ground mount was positioned on a concrete pad 5 feet wide and 6 feet long. This pad aided the accuracy of the weapon during rapid fire.

The next ordnance used in the test program was 81-millimeter morter shells statically detonated at ranges of 10 and 5 feet from the face of the wall. These rounds were positioned vertically on the ground and detonated with an electric blasting cap.

Following these tests, an 81-millimeter mortar shell was positioned against the soil-cement wall at midheight and statically detonated (figure 21). The reason for positioning the mortar round against the wall was to simulate the detonation of a live mortar shell impacting against the wall.

Upon completing the static detonation of the 81-millimeter mortar shells, the foregoing procedure was repeated with 4.2-inch mortar shells.

To evaluate the effectiveness of the soil-cement wall in preventing the perforation of rockets and recoilless rifle ammunition, high explosive anti-tank (HEAT) rockets were fired from a 3.5-inch rocket launcher. These shells were live fired at a range of 480 feet from the wall.

The final tests conducted on the soil-cement wall section were static detonations of 750-pound general purpose bombs (figure 22). Two tests were conducted, each using one bomb containing 331 pounds of Composition C-4 explosive hand-placed by Explosive Ordnance personnel. The use of Composition C-4 explosive was dictated by the current demand for 750-pound bombs in Southeast Asia.

Following the testing of the soil-cement wall with 3.5-inch rockets and prior to the detonation of 750-pound bombs, the steel-sheet piling revetment wall section was tested with 30-caliber, 50-caliber, and 20-millimeter ammunition, and 81-millimeter and 4.2-inch mortar shells.

After the soil-cement and steel-piling walls were tested, the steel-piling wall was dismantled and the fiberglass and corrugated asbestos walls were erected.

The fiberglass wall was tested with 30-caliber, 50-caliber, and 20-millimeter ammunition, 81-millimeter and 4.2-inch mortar shells, and a 3.5-inch rocket.

Figure 21 Position of Mortar Shell Prior to Static Detonation

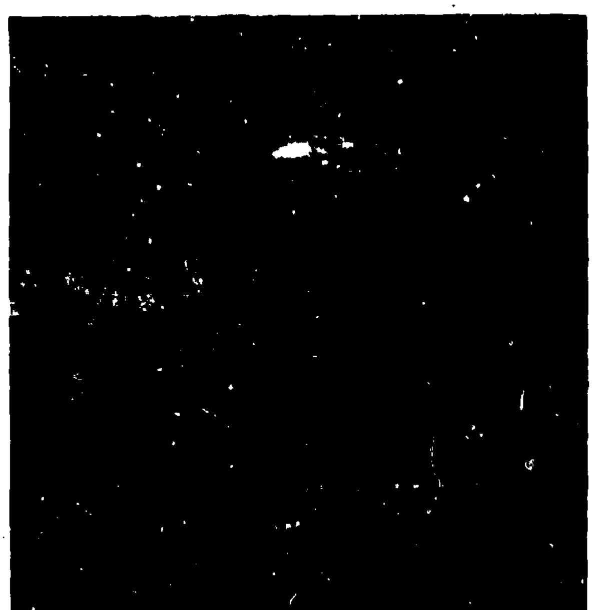


Figure 22. Position of 750-Pound Bomb Prior to Static Detonation

The sequence of operations and overall test procedure for the steel wall, the fiberglass wall, and the corrugated asbestos wall were the same as for the soil-cement wall.

Table X presents a summary of the weapons and ammunition used to test each of the wall sections. More detailed characteristics of the weapons and ammunition are tabulated in Appendix II.

5. Test Results

During the testing of the four wall sections, damage estimates and test results were recorded following the firing of each type of small arms ammunition, mortar shell, rocket, and bomb.

Tables XI, XII, XIII, and XIV are presented to summarize the test results of the soil-cement, steel-sheet piling, fiberglass, and corrugated asbestos revetment wall sections, respectively.

6. Discussion of Results

Each of the revetment wall sections were damaged to some degree by each of the weapons and types of ammunition used during the evaluation of weapon effects.

a. Soil-Cement Wall

As indicated in table XI, the major type of damage suffered by the soil-cement wall during the small arms and mortar tests was the spalling of the soil-cement material from the front face of the wall. However, because of its overall mass and density, the wall was able to effectively absorb the energy from the projectiles and fragments and prevent their perforating the wall. Although the tensile strength of the wall section was low, approximately 46 pounds per square inch, the wall had sufficient strength to prevent tensile cracks from forming due to small arms projectiles and fragments from mortar shells. Also, the wall retained the projectile jackets and other pieces of shrapnel, thereby significantly reducing secondary projectiles and ricochets.

The soil-cement wall received only minor cracking on the rear face of the wall along with a 3.5-inch-diameter penetration hole into the front face of the wall as a result of the tests conducted with 3.5-inch high explosive anti-tank (HEAT) rockets. The 3.5-inch rockets impacted on the front face of the wall at an elevation of 10 feet above the ground. It is considered that the cracking of the rear face of the wall would be eliminated if the rockets impacted against the wall at an elevation of less than 8 feet, where the wall

Table X

TESTING SEQUENCE, RANGES, AND AMMUNITION

Sequence	Ammunition (type)	Range (ft)	Soil cement	Number of rounds Steel piling	Fiberglass	Corrugated asbestos
1	30-caliber ball	150	48	8	40	24
2	50-caliber ball	480	60	20	30	30
3	50-cal armor-piercing incendiary (API)	480	48	20	46	32
4	50-cal armor-piercing incendiary tracer (APIT)	480	12	7	12	8
5	20-millimeter ball	480	20	10	20	20
6	20-millimeter armor-piercing incendiary (API)	480	20	10	20	20
7	20-millimeter high-explosive incendiary (HEI)	480	20	10	20	9
8	81-millimeter mortar	10	1	1	1	0
		5	1	1	1	0
		0*	1	1	1	0
9	4.2-inch mortar	10	1	1	1	0
		5	1	1	1	0
		0*	1	1	1	0
10	3.5-inch rocket high-explosive antitank (HEAT)	480	3	0	1	1
11	750-lb general purpose bomb containing 331 lb of composition C-4 explosive	10 Elevation of 4 feet	2	0	0	0

*Contact detonation at midheight of wall.

Table XI

SOIL-CEMENT WALL TEST RESULTS

Weapon	Effect on front face	See figure number
30-cal ball	Eight rounds in close proximity caused spalling over an 8-inch diameter circular area to a depth of 4 inches.	23
50-cal ball	Individual rounds penetrated to a depth of about 6 inches with spalling over a 5-inch diameter circular area to a depth of 2 inches.	None
50-cal API 50-cal APIT	Rounds penetrated to a depth in excess of 10 inches with spalling over an 8-inch diameter circular area to a depth of 4 inches	24
20-mm ball	Rounds penetrated to an approximate depth of 11 inches with spalling over a 10-inch diameter circular area to a depth of 5 inches.	None
20-mm API	Rounds penetrated to an approximate depth of 15 inches with spalling over a 10-inch diameter circular area to a depth of 7 inches.	25
20-mm HEI	Rounds penetrated to a depth of 6 inches with spalling over a 12-inch diameter circular area to a depth of 2 inches.	26 27
81-mm mortar detonated at 10 and 5 feet	Maximum damage caused by these shells was small, 3-inch diameter circular areas spalled to a depth of 1 inch.	None
81-mm mortar at midheight on wall	Shrapnel and blast caused spalling over an 18-inch diameter circular area to a depth of 6 inches maximum.	28
4.2-inch mortar detonated at 10 and 5 feet	Larger pieces of shrapnel had same effect on wall as did the 81-mm in contact with wall.	None
4.2-inch mortar at midheight on wall	Shrapnel and blast caused spalling over a 42-inch diameter circular area to a maximum depth of 8 inches.	28
3.5-inch rocket (HEAT)	Projectile produced a 301/2-inch hole to a depth of 3 feet. Some cracking was visible on back face of wall because impact was made near top of wall.	29

Table IX (cont'd)

Weapon	Effect on front face	See figure number
750-lb bomb Test 1	The front face of the wall was spalled uniformly to a depth of 2 inches. Vertical cracks formed through wall at quarter and midpoints of wall. No shrapnel perforated wall.	30(a) 30(b)
750-lb bomb Test 2	Additional spalling of front face; increased width of previous cracks; no shrapnel performated wall.	30(c)

Figure 23. Effect of 30-Caliber Ball Ammunition on Soil-Cement Wall

Figure 24. Effect of 50-Caliber API and APIT Ammunition on Soil-Cement Wall

Figure 25. Effect of 20-Millimeter API Ammunition on Soil-Cement Wall

Figure 26. Effect of 20-Millimeter HEI Ammunition on Soil-Cement Wall

Figure 27. Soil-Cement Wall Following Testing with 30-Caliber, 50-Caliber, and 20-Millimeter Ammunition

Figure 28. Damage Caused by Contact Detonations of 81-Millimeter and 4.2-Inch Mortar Shells on Soil-Cement Wall

Figure 29. Effect of 3.5-Inch HEAT Rocket Fired at Soil-Cement Wall

a. Before

b. After Bomb Test #1

c. After Bomb Test #2

Figure 30. Damage on Rear Face of Soil-Cement Wall Caused by 750-Pound Bomb Detonated 10 Feet from Front Face of Wall

Table XII

STEEL-SHEET PILING WALL TEST RESULTS

Weapon	Effect on wall	See figure number
30-cal ball	6 rounds resulted in 1/4-inch-deep penetrations of front face and 2 rounds ricocheted.	31
50-cal ball	9 rounds perforated wall with 11 rounds ricocheting. Some of the ricocheting rounds were later entrapped by the steel wall. Bullet holes in wall were 1/2 inch in diameter with part of brass cover remaining in wall.	32 33
50-cal API	16 rounds perforated wall leaving a 1/2-inch diameter, brass-lined hole. 4 rounds ricocheted with 2 of these later entrapped by wall.	34
50-cal APIT	All rounds perforated wall leaving a 1/2-inch diameter, brass-lined hole.	35
20-mm ball	9 rounds perforated the wall by punching out a 20-mm-diameter piece of steel resulting in 18 lethal projectiles leaving rear face of wall. 1 round ricocheted.	36 37
20-mm API	8 rounds perforated the wall leaving a 20-mm-diameter hole. 2 rounds ricocheted.	38 39
20-mm HEI	5 rounds perforated the wall leaving a 20-mm-diameter hole. 4 rounds partially perforated wall and 1 round ricocheted. All rounds detonated and produced a 3-inch-diameter shrapnel pattern on face of wall.	40 41
81-mm and 4.2-inch mortar shells at 10 and 5 feet	These shells resulted in much scarring of the front face of the wall. Larger pieces of shrapnel perforated wall or caused spalling on rear face of wall.	42 43 44
81-mm mortar shell in contact with wall	A hole 10 inches wide and 16 inches long was blown through the wall. Steel was flared back with no large pieces of steel torn from wall as secondary projectiles.	45 46

Table XII (cont'd)

Weapon	Effect on wall	See figure number
4.2-inch mortar shell in contact with wall	Three large holes were blown through wall with large pieces of steel torn from wall as secondary projectiles. Secondary projectiles were found at ranges of 30 feet from rear face of wall and 150 feet from front face of wall. Dimensions of largest hole are 19 inches wide and 28 inches long.	45 47

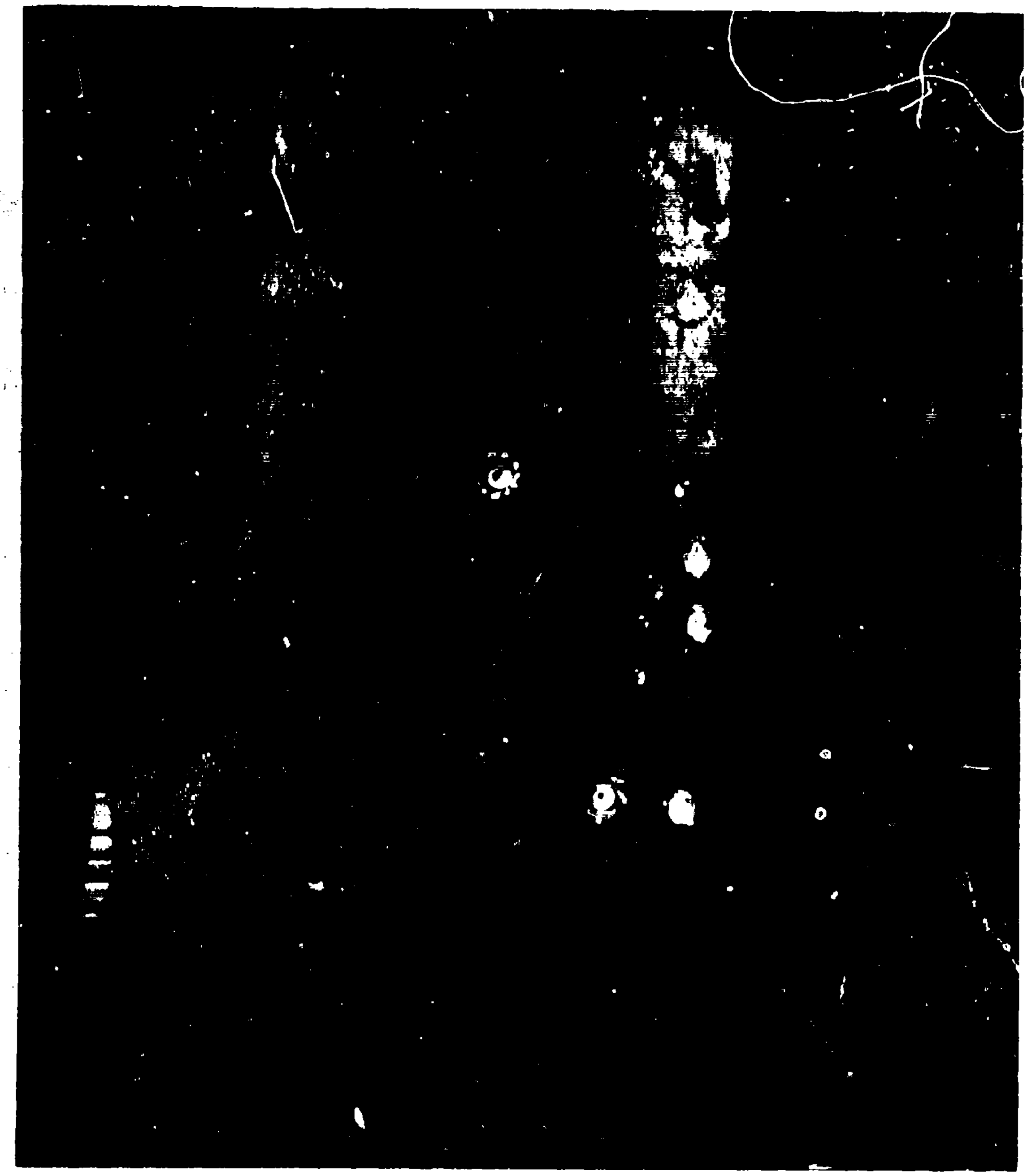


Figure 31. Effect of 30-Caliber Ball Ammunition on Steel-piling Wall

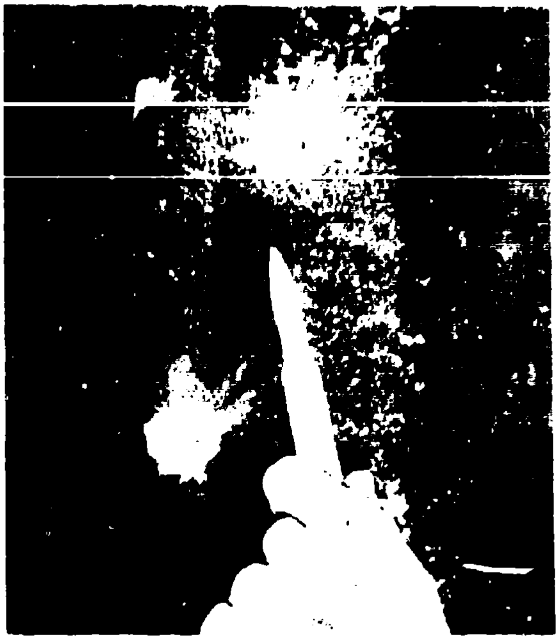


Figure 32. Effect of 50-Caliber Ball Ammunition on Front Face of Steel-Piling Wall

Figure 33. Effect of 50-Caliber Ball Ammunition on Rear Face of Steel-Piling Wall

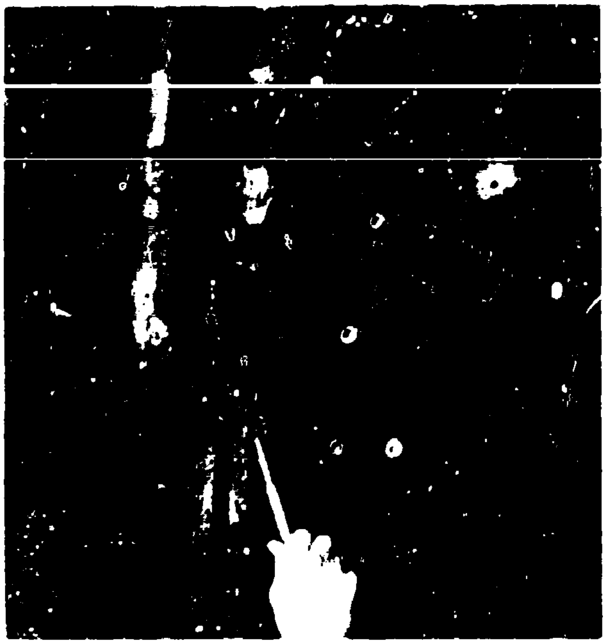


Figure 34. Effect of 50-Caliber API Ammunition on Front Face of Steel-Piling Wall

Figure 35. Effect of 50-Caliber APIT Ammunition on Front Face of Steel-Piling Wall

Figure 36. Effect of 20-Millimeter Ball Ammunition on Front Face of Steel Piling Wall

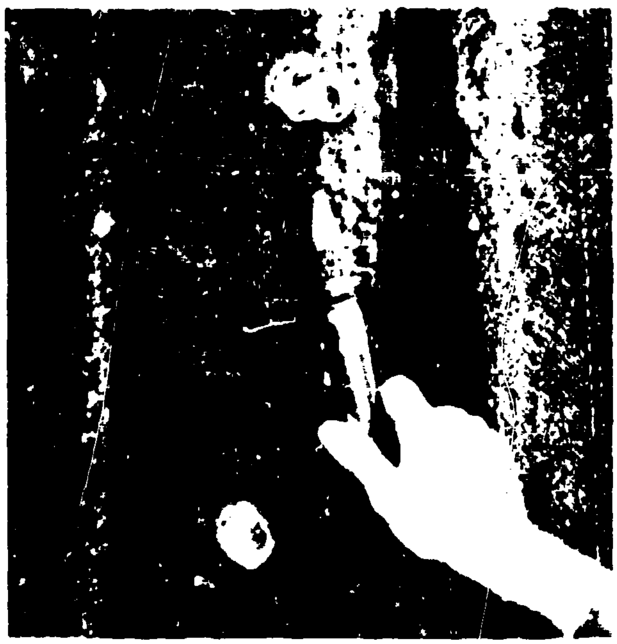


Figure 37. Effect of 20-Millimeter Ball Ammunition on Rear Face of Steel-Piling Wall

Figure 38. Effect of 20-Millimeter API Ammunition on Front Face of Steel-Piling Wall

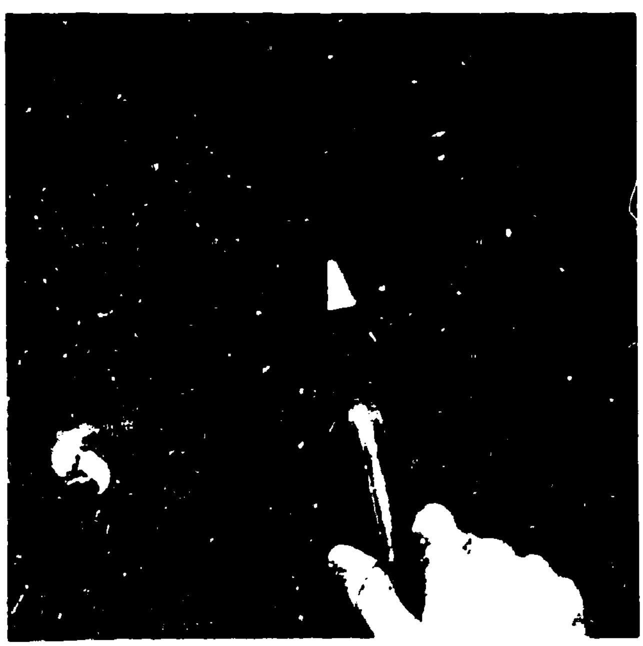


Figure 39. Effect of 20-Millimeter API Ammunition on Rear Face of Steel-Piling Wall

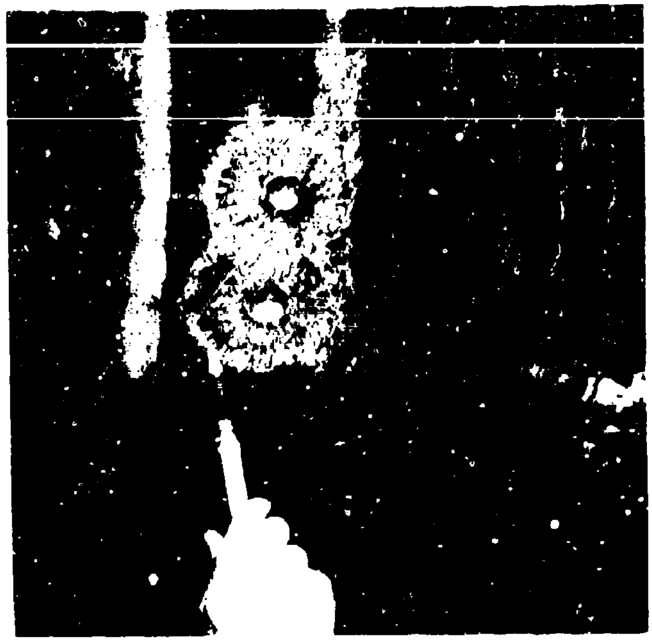


Figure 40. Effect of 20-Millimeter HEI Ammunition on Front Face of Steel-Piling Wall

Figure 41. Effect of 20-Millimeter HEI Ammunition on Rear Face of Steel-Piling Wall

Figure 42. Effect of 81-Millimeter Mortar Shell Statically Detonated 10 Feet from the Face of Steel Wall

Figure 43. Effect of 4.2-Inch Mortar Shell Statically Detonated at Range of 10 Feet from Face of Wall

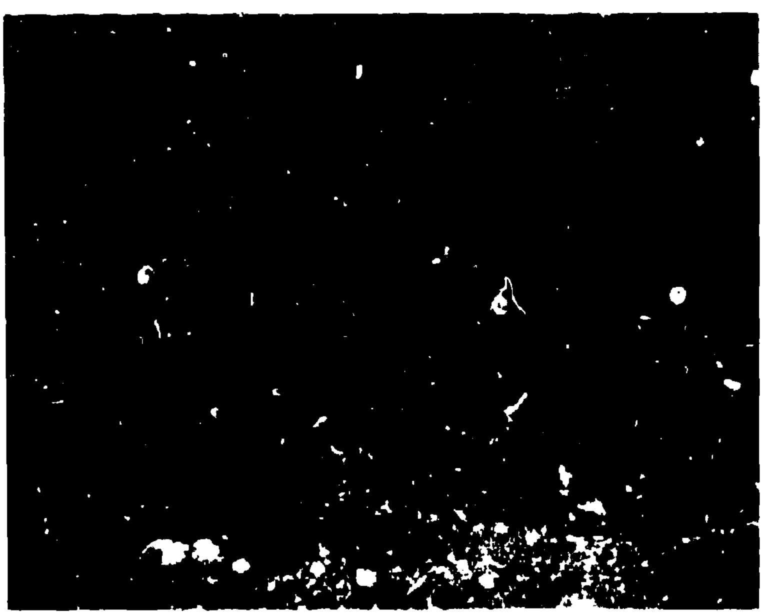


Figure 44. Spalling on Rear Face of Steel-Piling Wall Caused by Mortar Rounds

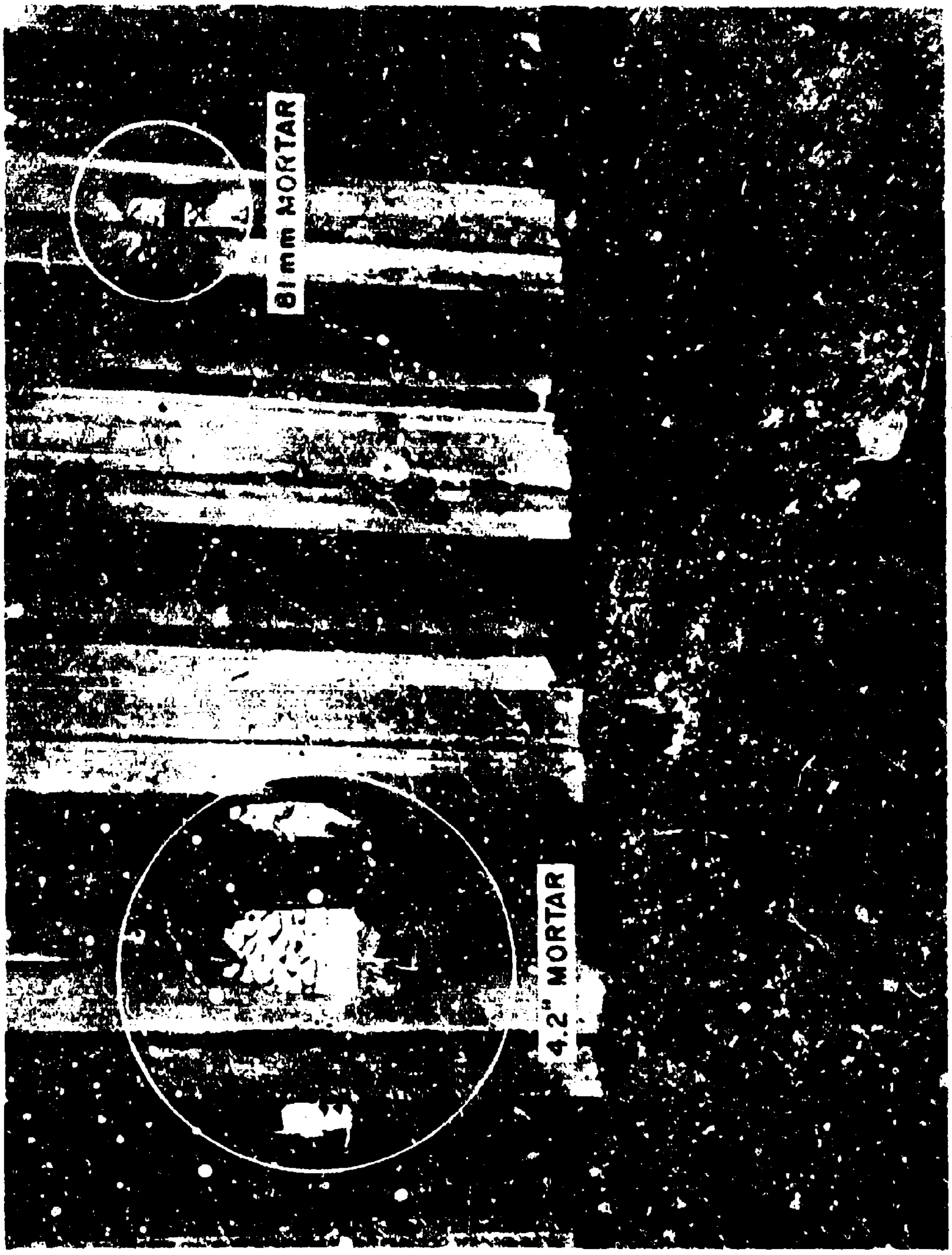


Figure 45. Damage Caused by 81-Millimeter and 4.2-Inch Mortar Shells Contact-Detonated on Front Face of Steel-Piling Wall

Figure 46. Rear Face of Steel Wall Following 81-millimeter Mortar Shell Tests

Figure 47. Damage on Rear Face of Steel Wall

TABLE XIII

FIBERGLASS WALL TEST RESULTS

Weapon	Effect on front face	See figure number
30-cal ball	Projectile penetrated into wall with 30-cal-diameter hole and slight peeling of outer face of wall.	48
50-cal ball	Projectile penetrated into wall with peeling of outer face of wall.	49
50-cal API 50-cal APIT	Projectine penetrated into wall with peeling of outer face of wall.	50
20-mm ball	Projectile penetrated into wall with peeling of outer face of wall.	51
20-mm API	Projectile penetrated into wall with peeling of outer face of wall. Impact of projectiles destroyed 21 nylon bolts which were used to attach the side panel to interior cylinders.	52
20-mm HEI	Projectile penetrated into wall following surface detonation. Twenty holes were placed in the face of the wall ranging from 4 inches to 6 inches square. Note holes were square, not round. An additional 8 bolts were destroyed. Outer sheet of fiberglass was severely damaged and almost ready to fall away from the interior cylinders. Some loss of fill material.	53
81-mm morter and 4.2-inch mortar detonated at 10 and 5 feet from wall	Small performations of the outer surface of the wall.	None
81-mm mortar against wall	Outer surface of wall destroyed and interior cylinder badly damaged in vicinity of mortar round. Some loss of fill material.	54
4.2-inch mortar against wall	End cylinder was split at bolted seam, some loss of fill material and wall tilted as result of cylinder buckling. Buckling considered as a wall panel end effect.	55 56

Table XIII (cont'd)

Weapon	Effect on front face	See figure number
3.5-inch rocket (HEAT)	The core from the rocket perforated the wall. Hole on front face of wall was approximately 4 inches square and hole on rear face of wall was approximately 1 inch square. Both wall surfaces were peeled by the rocket. The shrapnel from the rocket badly damaged the front face of the wall.	57 58

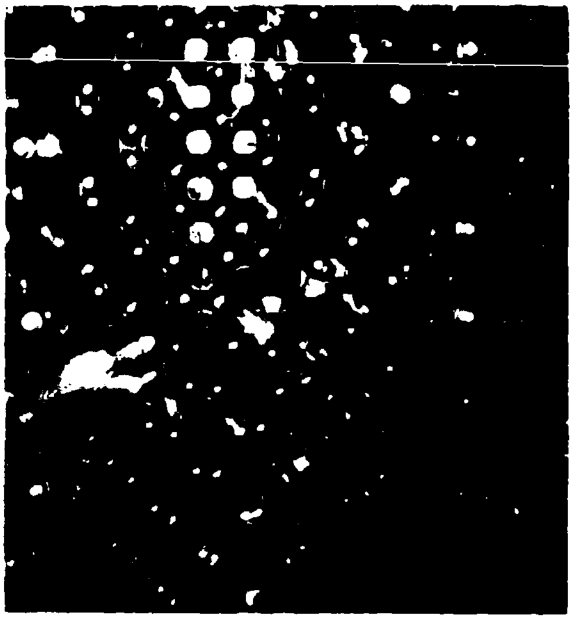


Figure 48. Effect of 30-Caliber Ball Ammunition of Fiberglass Wall

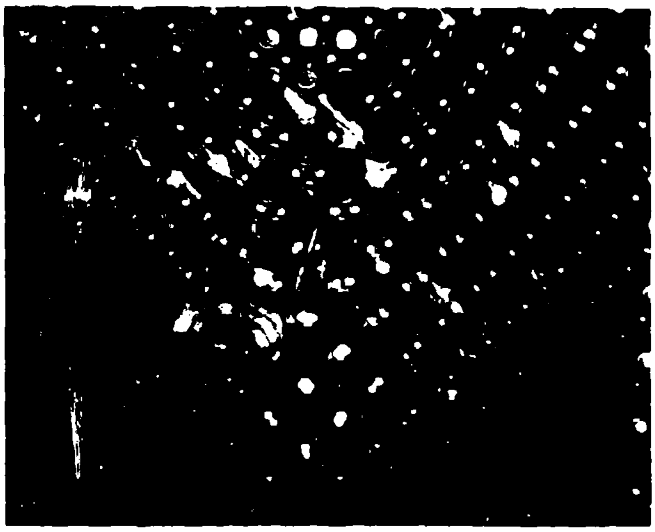


Figure 49. Effect of 50-Caliber Ball Ammunition on Fiberglass Wall

Figure 50. Effect of 50-Caliber API and APIT Ammunition on Fiberglass Wall

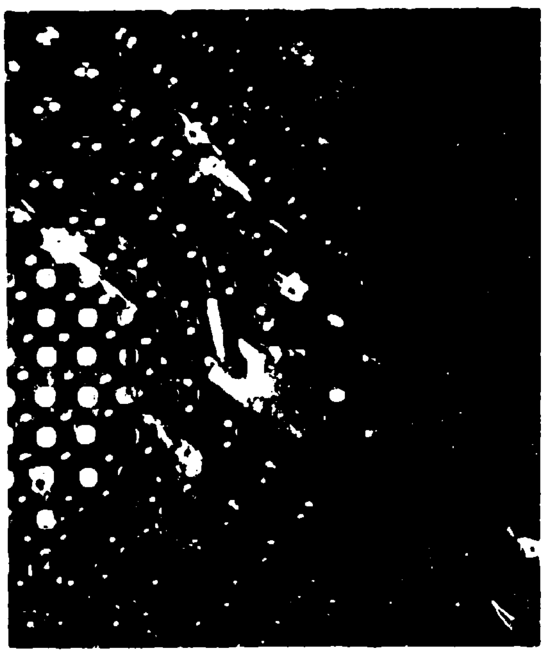


Figure 51. Effect of 20-Millimeter Ball Ammunition on Fiberglass Wall

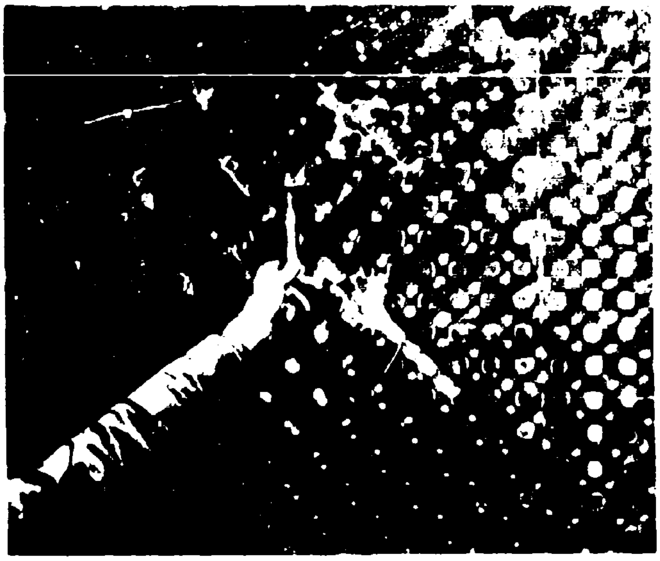


Figure 52. Effect of 20-Millimeter API Ammunition on Fiberglass Wall

Figure 53. Effect of 20-Millimeter HEI Ammunition on Fiberglass Wall

Figure 54. Damage Resulting from an 81-Millimeter Mortar Shell Detonated in Contact with Fiberglass Wall

Figure 55. Damage Resulting from a 4.2-Inch Mortar Shell Detonated in Contact with Fiberglass Wall

Figure 56. Buckling and Tilting of the Fiberglass Wall Produced by a 4.2-Inch Mortar Shell Detonated in Contact with the Wall

Figure 57. Damage Resulting from a 3.5-Inch HEAT Rocket Impacting Against Fiberglass Wall

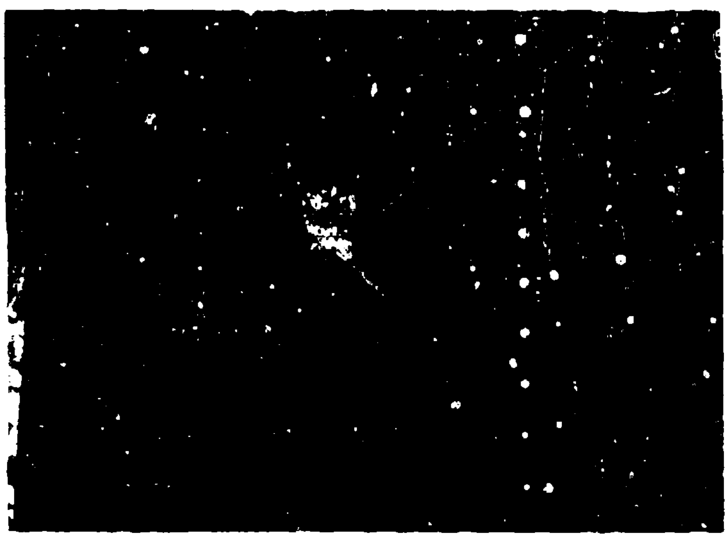


Figure 58. Damage on Rear Face of Fiberglass Wall as a Result of HEAT Rocket Core Perforating the Wall

Table XIV

CORRUGATED ASBESTOS WALL TEST RESULTS

Weapon	Effect on front face	See figure number
30-cal ball 50-cal ball 50-cal API 50-cal APIT	Projectile penetrated into wall with respective size caliber holes. No external surface damage and no loss of fill material.	 59 60
20-mm ball	Projectile penetrated into wall with 20-mm hole with no loss of fill material.	61
20-mm API	These rounds resulted in cracking and loss of facing material and loss of earth fill.	62
20-mm HEI	These rounds severely damaged 6- and 8-inch areas of the asbestos facing material. several rounds impacted in one general area with a 2x2-foot area of facing completely destroyed. Considerable quantities of fill material were lost.	None
3.5-inch rocket	Rocket completely destroyed front face of wall. Rocket core perforated the rear face of the wall.	63

Figure 59. Effect of 30-Caliber Ball Ammunition on Front Face of Corrugated Asbestos Wall

Figure 60. Effect of 50-Caliber Ball Ammunition on Front Face of Corrugated Asbestos Wall

Figure 61. Effect of 20-Millimeter Ball Ammunition on Corrugated Asbestos Wall

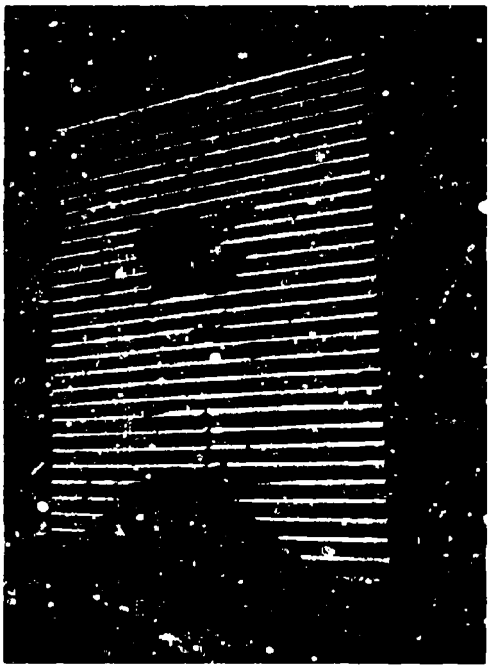


Figure 62. The Asbestos Facing Material Cracked and Totally Destroyed by 20-Millimeter API and HEI Ammunition

Figure 63. Final Configuration of Corrugated Asbestos Wall Following Testing with Small-Arms Ammunition and a 3.5-Inch HEAT Rocket

thickness is approximately 5 feet or more.

Each of the 750-pound bomb tests damaged the soil-cement wall by spalling material from the front face of the wall and by creating vertical cracks through the wall at the quarter and midpoints of the wall. The cracking of the wall was a result of the high air-overpressure which caused the wall to: (1) tend to overturn and (2) bend similar to a beam with a blast load applied at the center (Appendix III).

It is important to note that the soil-cement wall section was not repaired following any of the tests. Therefore, the second bomb test was conducted on a wall which had previously been cracked and weakened.

b. Steel-Sheet Piling Wall

As indicated in table XII, the steel-sheet piling wall was very ineffective in preventing the performation by small arms ammunition. This ineffectiveness can probably be attributed to the small wall mass and thickness available to absorb the energy from the projectiles and fragments. The high density of the steel wall was also detrimental because it permitted a great deal of the projectile energy to pass through the wall resulting in spalling and secondary projectiles.

An additional item of interest is the fact that untrapped ricochets were prevalent with the steel wall. When a projectile impacted on the front face of the wall, the brass jacket around the center core of the projectile was ripped off by the steel, resulting in ricocheting shrapnel in all directions at ranges up to 50 yards.

c. Fiberglass Wall

The weapons test results, as tabulated in table XIII, indicate that the fiberglass wall received little damage from small arms fire (excluding 20-millimeter high explosive incendiary ammunition) and mortar shells detonating at ranges greater than 5 feet from the wall. Only the 20-millimeter high explosive incendiary ammunition produced large holes (4 to 6 inches square) in the front face of the wall with a loss of earth fill material. The square hole could be considered characteristic of fiberglass because the material is formed by placing layers of glass fibers at 90 degrees to each other.

Three important observations made during the weapons testing were that the glass fibers had a tendency to close up the small arms projectile and shrapnel holes, that the peeling of the face of the wall occurred near every projectile hole, and that the impacting projectiles caused the nylon bolts to fail in tension. However, the peeling of the wall and loss of bolts was not considered to be of sufficient magnitude to reduce the structural strength or protective properties of the wall. Also by increasing the number of bolts per row, the damage resulting from the loss of bolts should be greatly reduced.

Mortar rounds detonated in contact with the wall produced damage over localized areas only, again, of insufficient magnitude to reduce the protection offered. The damage produced by the contact-detonated 4.2-inch mortar shell may be greatly reduced if the mortar shell is detonated one or more cylinder diameters from the end of the wall.

Only the 3.5-inch rocket perforated the entire wall. The damage to the front and rear faces of the wall was not considered severe; however, the rocket core did perforate the wall as a result of insufficient wall thickness to absorb the rocket core energy.

Throughout the testing of the fiberglass wall, the wall prevented the perforation of small arms fire and shrapnel from mortar shells and absorbed the projectile jackets and other pieces of shrapnel, thereby reducing lethal secondary projectiles.

Field repair techniques, using epoxy and nylon rivets, proved inadequate because the old material was badly damaged and did not lend itself to smooth, close contact between the sheets of material. This method may work for repairing small areas of damage.

Wall repair on a large scale (entire front face) was accomplished by using metal toggle bolts with no special effort to obtain close contact between sheets of material. The bolts were placed in single rows at the cylinder contact points and spaced 8 inches on center.

d. Corrugated Asbestos Wall

Although the corrugated asbestos wall prevented the perforation of small arms fire, the front face of the wall received severe damage from 20-millimeter armor piercing incendiary and high explosive incendiary ammunition. This damage can be described as a brittle failure of the corrugated asbestos.

The failure of the wall section following the impact of the 3.5-inch rocket was for the most part caused by the direct hit on the interior A-frame support. As with the fiberglass wall, the rocket core perforated the wall as a result of insufficient earth thickness to absorb the kinetic energy of the rocket core.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

The results from the series of tests indicate that a soil-cement revetment wall is effective in preventing perforation by small arms ground fire, 30-caliber, 50-caliber, and 20-millimeter ammunition; shrapnel from mortar shells detonating at elevations less than 12 feet (or height of wall) at any horizontal distance relative to the wall; 3.5-inch high explosive antitank rockets; and shrapnel from 750-pound bombs detonating at distances of 10 feet or more from the face of the wall.

It is considered feasible to construct soil-cement revetment walls to a height of 16 feet while retaining a base thickness of 8 feet and a top thickness of 3 feet. The thickness of the wall may feasibly be reduced to a uniform thickness of 4 feet 6 inches if the height of the wall is reduced to 8 feet or less.

While this soil-cement wall section was erected with ready-mix or batch-type equipment and placed in the form with a crane and bucket, alternate methods of erecting soil-cement revetments are: (1) to place the materials (soil and cement) dry in the form, hand-mix, water, and compact or (2) to place the materials dry on the ground, mix with a grader or tractor and blade, place in the form with a front-end loader, water, and compact.

The test results indicate that a steel-sheet piling revetment wall with no earth fill is very ineffective in stopping small arms ground fire and shrapnel from mortar rounds.

It is recommended that the use of steel for revetment structures be limited to light gage (10 gage or less) material with earth fill. This configuration would eliminate projectile and shrapnel ricochets and perforations. The adequacy of this concept was established at Eglin Air Force Base, Florida, during the testing of the "Armco Bin" type of revetment.

A fiberglass revetment wall will provide complete protection against small arms fire and shrapnel from mortar rounds detonating at any range from the wall and at an elevation less than the height of the wall.

It is recommended that the thickness of the wall section be increased to 6 feet as a minimum to increase the protection offered against 3.5-inch high explosive antitank rockets. Also, it is recommended that the bolts used to splice the cylinder material and secure the side panels be steel bolts whenever possible and that the bolts be uniformly spaced at 4 inches on centers with two rows staggered and spaced 2 inches on centers. This should greatly reduce the overall wall damage and increase the protection offered by the wall section.

The corrugated asbestos wall provided protection against small arms fire only. However, the wall should provide protection against shrapnel from mortar rounds detonating at ranges of 15 feet or more from the wall and at elevations less than the height of the wall

This material is not recommended for protective revetments as it is very brittle and can be easily damaged by equipment hitting the wall or by enemy fire.

Table XV summarizes the protection offered by each of the revetment wall test sections against the threat presented.

Future studies of protective revetments will be conducted by the Civil Engineering Branch of the Air Force Weapons Laboratory under a new project entitled "Protective Shelters for Tactical Aircraft."

Table XV

SUMMARY OF PROTECTION PROVIDED FOR THREAT PRESENTED*

	Revetment wall test material			
Weapon	Soil-cement	Steel-sheet piling	Fiberglass	Corrugated asbestos
30-cal ball	yes	yes Projectile may ricochet	yes	yes
50-cal ball	yes	no	yes	yes
50-cal API	yes	no	yes	yes
50-cal APIT	yes	no	yes	yes
20-mm ball	yes	no	yes	yes
20-mm API	yes	no	yes	yes
20-mm HEI	yes	no	yes	yes Considerable damage
81-mm mortar	yes	no Some protection against mortars greater than 5 feet from wall	yes	Not tested
4.2-inch mortar	yes	no Some protection against mortars greater than 10 feet from wall	yes	Not tested
3.5-inch rocket	yes	Not tested	no	no
750-pound bomb	yes	Not tested	Not tested	Not tested

*Yes indicates that the wall prevented perforation by the weapon used.

APPENDIX I

TEMPERATURE EFFECTS ON CONCRETE CYLINDERS

"The temperature of specimen at time of test has a marked influence on indicated strength; the higher the temperature, the lower the indicated strength. Compression tests of concrete at the University of California indicate in a typical case that the compressive strength at 25°F is 40 percent higher, and at 130°F is 15 percent lower, than that of corresponding specimens tested at 70°F. Flexure tests of mortar at the University of Texas indicate that the modulus of rupture at 50°F is 12 percent higher, and at 100°F is 20 percent lower, than that at 70°F. Thus, on the average, a variation of 1 to 4°F in testing temperature results in a difference in strength of 1 percent." (Reference 3)

APPENDIX II

WEAPONS AND AMMUNITION CHARACTERISTICS

The weapons used to evaluate the revetment wall sections included a 30-caliber rifle, a 50-caliber machine gun, a 20-millimeter aircraft cannon, a 3.5-inch rocket launcher, 81-millimeter and 4.2-inch mortars, and 750-pound general-purpose bombs. Figure 64 shows the relative size of the small arms ammunition and mortar rounds used in the test program. Tables XVI, XVII, and XVIII tabulate the weapon and ammunition characteristics.

The above listed weapons were obtained from the Small Arms Training Group, Kirtland Air Force Base, New Mexico (30-caliber rifle), the US Marine Reserve Center, Albuquerque, New Mexico (50-caliber machine gun), the 150 TAC Fighter Air National Guard, Albuquerque, New Mexico (20-millimeter cannon), and the New Mexico National Guard, Albuquerque, New Mexico (3.5-inch rocket launcher).

As stated in Section VI, the 750-pound bomb contained 331 pounds of Composition C-4 explosive. This quantity of explosive is considered to be equal to 386 pounds of 80-20 Tritonal (reference 9).

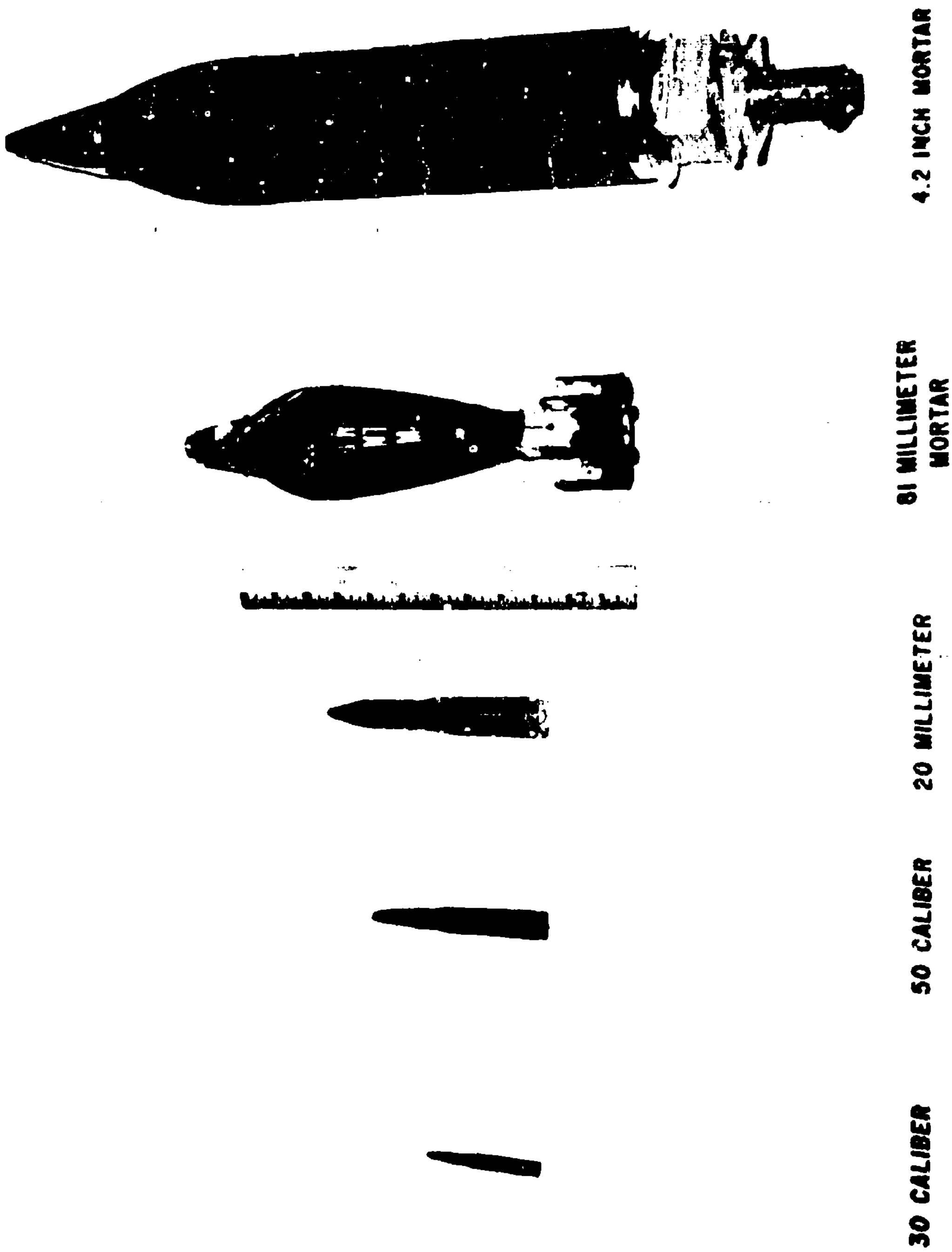


Figure 64. Ammunition Used in Revetment Test Program

Table XVI

WEAPONS CHARACTERISTICS

	M-1	M-2 (Ref. 4)	M-39 (Ref. 5)	M-29 (Ref. 6)	M-30 (Ref. 6)	M-20 A1 B1 (Ref. 7)
Unloaded weight (lb)	9.5	126	179	93	640	14
Loaded weigth (lb)	10.0	---	---	---	---	23.02
Length (inches)	43.0	65.0	72.4	50-1/3	60	60-1/4
Operation	Semi-automatic	Semi-automatic	Electrical (automatic)			Electrical
Type of feed	8-round clip	Belt, metallic link	Disintegrating metallic belt	Single round	Single round	Single round
Caliber	30	50	20-mm	81-mm	4.2-inch	3.5-inch
Cyclic rate of fire (rnd/min)	32-40 max	450-500	1500-1700	24 max	30 max	---
Max effective rate of fire (rnd/min)	16-24	100	---	---	---	---
Sustained rate of fire (rnd/min)	8-10	40	50	2	3	---
Max range (yd)	3,500	7,400	---	4,000	6,000	960
Max effective range (yd)	500	2,000	1,600	---	---	---
Min range (yd)	---	---	---	330	880	---

Table XVII

SMALL ARMS AMMUNITION CHARACTERISTICS

Type ammunition	Weight (grains) Round	Projectile	Muzzle velocity (ft/sec)
30-caliber ball (M-2)	---	152	2800
50-caliber ball (M-2)	1768	661.5	2930
50-caliber tracer (M-17)	1742	648	3030
50-caliber API (M-8)	1739	622	3050
50-caliber APIT (M-20)	1698	624	3050
20-mm ball (M-55)	3920	1540	3300
20-mm API (T221E3)	3990	1540	3300
20-mm HEI (M56A1)	3920	1540	3300

Table XVIII

ROCKETS, MORTARS, AND BOMB CHARACTERISTICS

Weapon	Characteristics
3.5-inch HEAT rocket (M28A2) (Ref. 8)	Length of round: 23.6 inches Round weight: 9.02 lb Explosive weight: 1.90 lb Type explosive: Comp B Velocity: 317 ft/sec Range: 945 yd Burning time of rocket: 0.015 to 0.045 sec
81-mm teardrop HE mortar shell	Average weight: 9.5 lb Explosive charge: 1.23 lb Muzzle velocity: 180 to 800 ft/sec
4.2-inch HE mortar shell	Average weight: 25 lb Explosive charge: 8.1 lb Muzzle velocity: 300 to 1000 ft/sec
750-pound general purpose bomb (M117)	Bomb diameter: 16 inches Length of bomb: 51 inches Length of bomb with tail: 89.43 inches Bomb weight: 820 lb Explosive weight: 386 lb Type explosive: 80-20 tritonal

APPENDIX III

COMPUTATION OF 750-POUND-BOMB BLAST-LOADING ON SOIL-CEMENT WALL SECTION

Miss Nancy R. Smith
Civil Engineering Branch
Air Force Weapons Laboratory

Approach

The problem of finding the pressures resulting from a bomb detonation at various points on a wall was solved using vector analysis.

The dimensions of the wall are illustrated in figure 65. The slope of the wall is

$$\frac{\Delta Z}{\Delta X} = \frac{-12}{2.63}$$

Therefore, the normalized vector representing the direction of the wall is

$$\vec{w}_n = \frac{-2.63\vec{i} + 12.0\vec{k}}{\sqrt{150.9169}}$$

If S is the scalar representing the vertical distance along the wall (S = 0 at the base of the wall), then the product

$$S\vec{w}_n = \vec{s} = \frac{-2.63S\vec{i} + 12.0S\vec{k}}{\sqrt{150.9169}}$$

is a vector of length S with the same orientation as $\vec{w}_n$. Thus

$$\vec{s} \cdot \vec{i} = \frac{-2.63S}{\sqrt{150.9169}}$$

is the projection of $\vec{s}$ on the x axis and

$$\vec{s} \cdot \vec{k} = \frac{12.0S}{\sqrt{150.9169}}$$

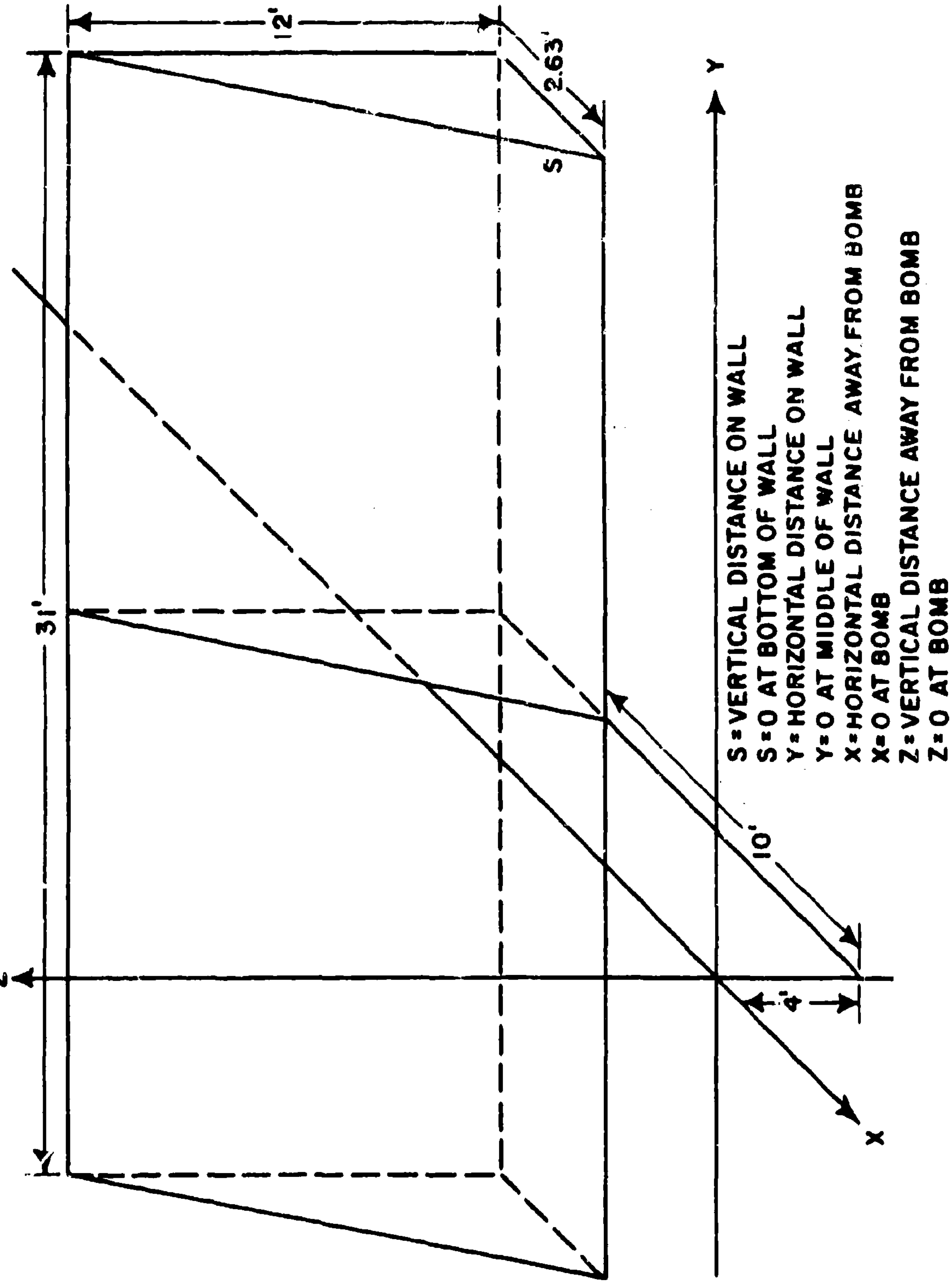


Figure 65. Coordinate System

is the projection of $\vec{s}$ on the z axis. With the coordinate system as illustrated in figure 65, the x coordinate of a point S feet from the base of the wall is

$$x = -10 - \frac{2.63S}{\sqrt{150.9169}} = -\left(10 + \frac{2.63S}{\sqrt{150.9169}}\right)$$

The -10 is necessary because the base of the wall is 10 feet from the z axis (figure 66). Similarly,

$$Z = \frac{12.0S}{\sqrt{150.9169}} - 4$$

In the computer program Y and S were incremented and X and Z computed until the wall was covered with a mesh of points. The radius or distance from the bomb to the wall, the incident overpressure, the angle of reflection, and the reflected pressure were then calculated at each point.

The radius, R, is equal to

$$|\vec{r}| = \sqrt{X^2 + Y^2 + Z^2}$$

where

$$\vec{r} = X\vec{i} + Y\vec{j} + Z\vec{k}$$

Also, the vector normal to the wall is

$$\vec{n} = \frac{12.0\vec{i} + 2.63\vec{k}}{\sqrt{150.9169}}$$

and

$$\vec{n} \cdot \vec{r} = |\vec{n}|\ |\vec{r}| \cos \theta$$

where θ is the angle of reflection. Thus,

$$\theta = \cos^{-1}\left[\frac{12.0X + 2.63Z}{\sqrt{150.9169\ (X^2 + Y^2 + Z^2)}}\right]$$

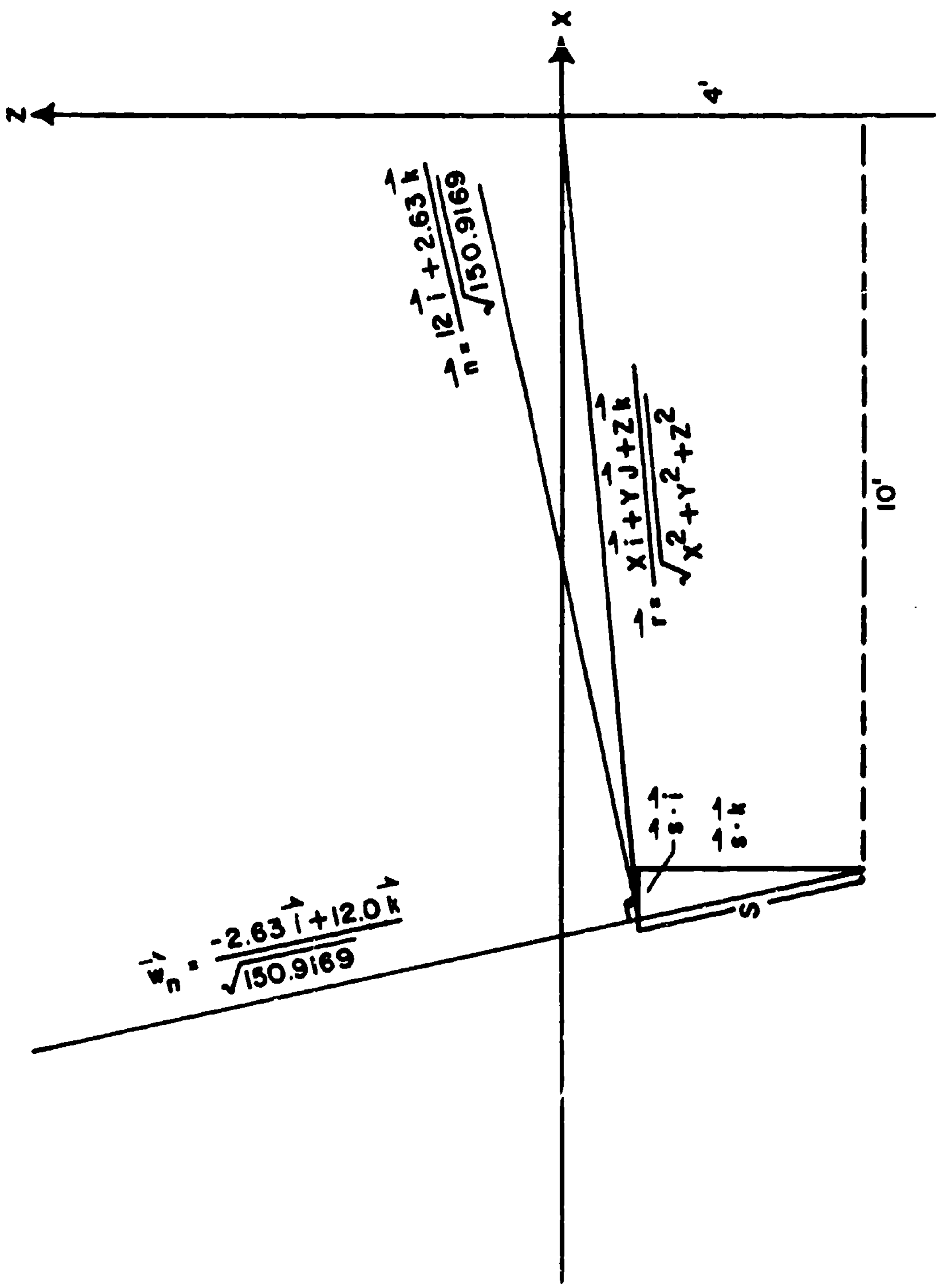


Figure 66. Vector Diagram

The incident overpressure was determined as a function of radius using a polynomial fit to pressure versus scaled distance as calculated in reference 10 (figure 67).

According to reference 11, page 3-50,

$$U \alpha \sqrt{W/C}$$

where

U = initial velocity of bomb fragments

W = yield

C = weight of case

Using the data in the above reference, the constant was calculated to be 9460 ft/sec.

$$U = 9460 \text{ ft/sec} \sqrt{\frac{331}{434}} = 8500 \text{ ft/sec}$$

The energy of the case is

$$E_c = \frac{1}{2} CU^2$$

$$E_c = \frac{(434 \text{ lb})(72.2 \times 10^6 \text{ ft}^2/\text{sec}^2)}{2(32.2 \text{ ft/sec}^2)}$$

$$E_c = 487 \times 10^6 \text{ ft-lb}$$

The energy available in the bomb is

$$E_w = \frac{(331 \text{ lb})(3.98 \times 10^9 \text{ Btu/kt})(778 \text{ ft-lb/Btu})(1.14)}{(2 \times 10^6 \text{ lb/kt})}$$

$$E_w = 584 \times 10^6 \text{ ft-lb}$$

The constant 1.14 is the equivalence factor between Composition C-4 and TNT.

Thus, the amount of TNT available for airblast is

$$\frac{1.14(W)\left(E_w - E_c\right)}{E_w} = \frac{1.14(331 \text{ lb})(5.84 - 4.87)}{5.84} = 62.6 \text{ lb}$$

Using this result, the airblast parameters are calculated. The scaling factor, S_d, for distance (reference 10) is

$$S_d = \left[W\left(\frac{14.7}{P_a}\right)\right]^{1/3}$$

where P_a is ambient atmospheric pressure

$$S_d = \left[\left(\frac{62.6}{2}\right)\left(\frac{14.7}{12}\right)\right]^{1/3} = 3.37$$

The factor of two in the denominator is necessary because the yield was calculated for a hemispherical charge in which none of the airblast is absorbed by the ground. However, in this particular instance, the bomb was detonated 4 feet above the ground. The distance is then

$$R = S_d\lambda = 3.37\lambda$$

From the geometry of the problem, it is evident that the radius and therefore, the angle of reflection and the incident overpressure, are constant in concentric circles with their center calculated to be 1.77 feet above the center of the base of the wall.

With the angle of reflection and the incident overpressure known, the reflected pressure was calculated from figures 3.2 and 3.3 of reference 12.

Using figure 3 in reference 13, distance in feet was calculated and plotted as a function of time in milliseconds. This reference showed the space-time diagram as τ versus λ where

$$\tau = \frac{TC_o}{\alpha}$$

and

$$\lambda = R/\alpha$$

making it necessary to calculate α.

$$\alpha = \left[\frac{W}{P}\right]^{1/3}$$

$$\alpha = \left[\frac{(62.6\ \text{lb})\left[(3.98 \times 10^9\ \text{Btu})/\text{kt}\right](778\ \text{ft-lb/Btu})}{(12\ \text{lb/in}^2)(2 \times 10^6\ \text{lb/kt})(144\ \text{in}^2/\text{ft}^2)}\right]^{1/3}$$

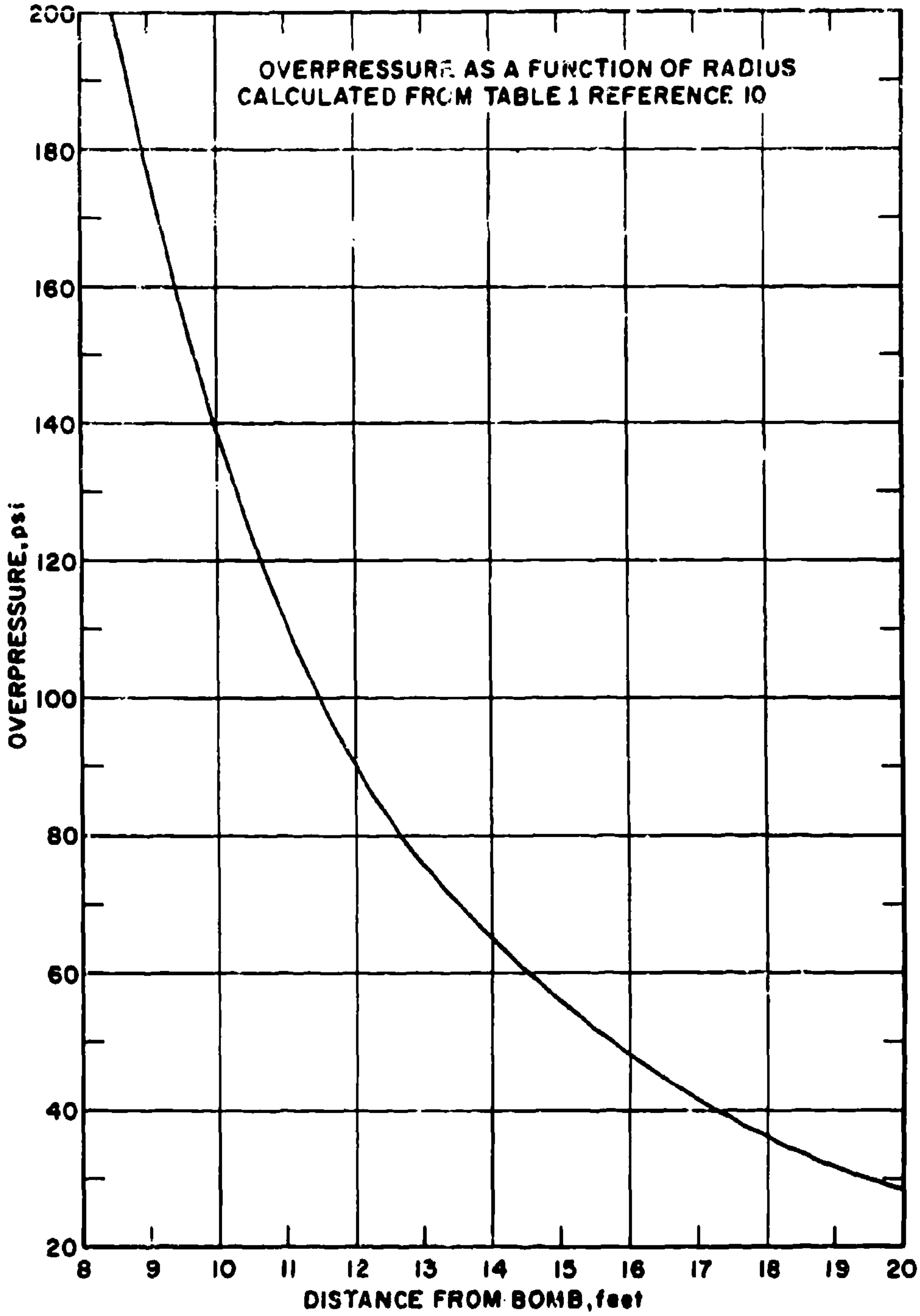


Figure 67. Overpressure versus Distance from Bomb

$$\alpha = 38.3 \text{ ft}$$

$$t = \frac{\alpha\tau}{C_o}$$

$$t = \frac{(38.3 \text{ ft})(1000 \text{ ms})}{(1100 \text{ ft/sec})(\text{sec})} \tau$$

$$t = 34.8 \ \tau \text{ ms} \tag{1}$$

$$R = \alpha\lambda$$

$$R = 38.3 \ \lambda \text{ ft} \tag{2}$$

From figure 17 of reference 13 and equation (1) above, a typical pulse shape with a duration of 2.08 milliseconds was obtained.

Using the above two graphs (figures 72 and 74), the pulse shape and its position were determined for various times. The position of the shock front was determined from the distance-time relationship of figure 72. The tailend of the rarefaction acts as a perturbation of zero magnitude and moves at the speed of sound, C_o = 1100 ft/sec. Using this velocity, the position of the tail as a function of R, the distance from the bomb was calculated. From figure 75, distance from the bomb versus distance on the wall, the position of the tail on the wall was obtained. It should be noted that the increased velocity due to the Mach reflection was not taken into account in calculating the pulse shapes.

Once the pulse shapes at various times were determined, the force as a function of time was calculated by:

a. Finding the area, A, of the appropriate concentric ring in figure 68 for each time.

b. Multiplying the area, A, of each concentric ring by the reflected pressure, $\overline{P}$, in the middle of the ring.

c. Summing the products, $A\overline{P}$, over the concentric rings for each specific time.

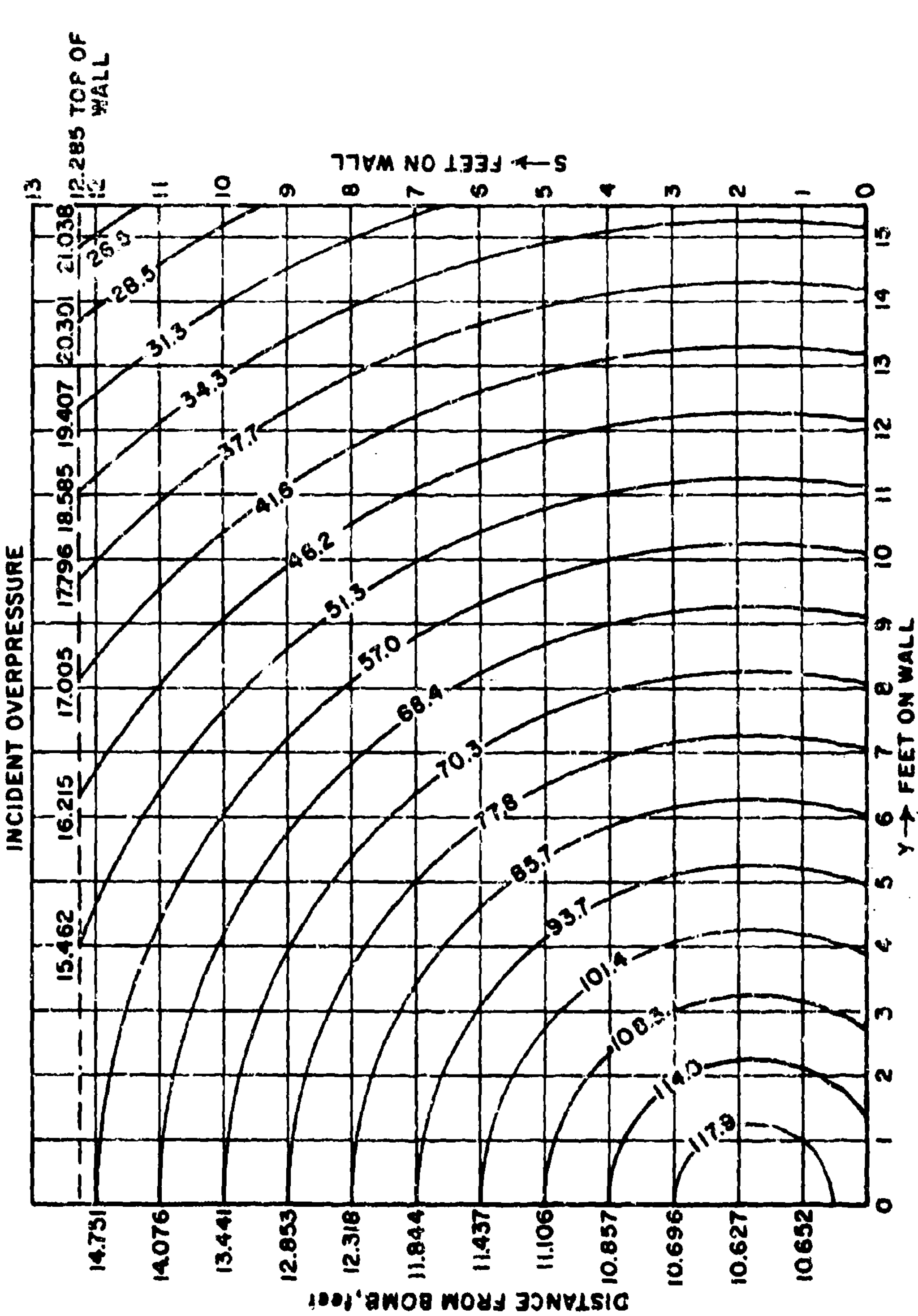


Figure 68. Overpressure at Various Points on the wall

Results

In figures 68 and 69, incident overpressure as a function of distance, it is evident that the peak incident overpressure of 120 psi occurs at the point of minimum distance from the bomb. This point is 1.77 feet above the center of the base of the wall. Similarly, in figures 70 and 71, reflected pressure as a function of distance, the peak reflected pressure of 612 psi occurs at the same point.

Distance as a function of time is plotted in figure 72. The minimum distance from the bomb to the wall is 10.61 feet. Therefore, it takes 1.72 milliseconds after detonation for the shock front to reach the wall.

In figure 73, pressure is plotted as a function of time at scaled distance $R/\alpha = \lambda = 0.35$. Since $\alpha = 38.3$, $R = 38.3 \times 0.35$ or $R = 13.405$ feet. The duration of the pulse is 2.08 milliseconds. This pulse shape, calculated from figure 17, reference 13, was assumed to be typical (figure 74) and was used to calculate the pulse shapes in figure 76 and consequently, to calculate force as a function of time in figure 77.

In figure 76, the pulse shape is plotted for various times. From this figure, the force for each time was calculated and plotted in figure 77. Peak force occurs at ?.0 milliseconds. Further, the force drops to zero at 12.12 milliseconds when the tail of the rarefaction has moved off of the wall.

It should be emphasized that the areas necessary in calculating the force were estimates and for this reason, the accuracy diminishes as the distance increases. Also, the increased velocity due to the Mach reflection was not accounted for in calculating the velocity of the shock front.

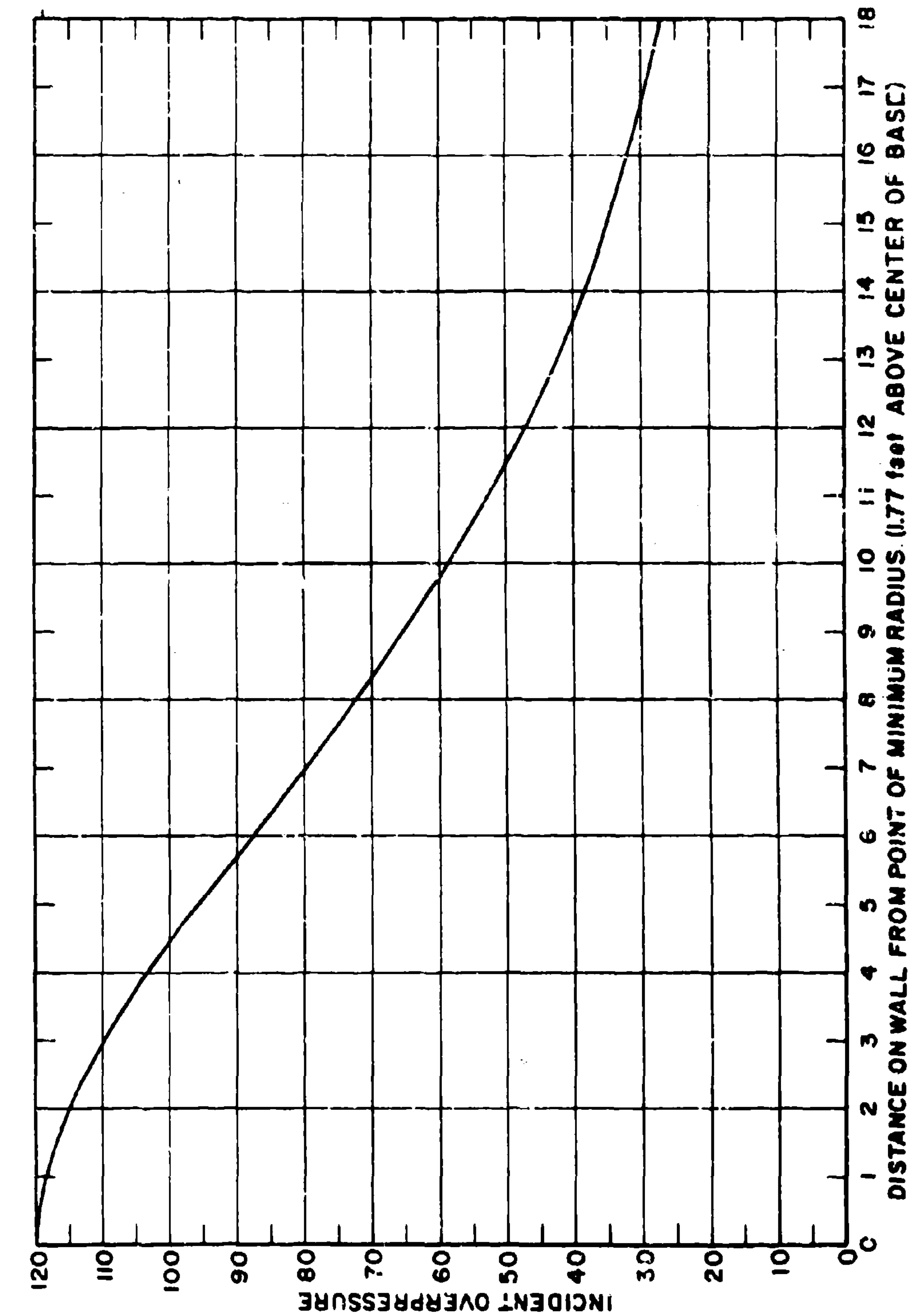


Figure 69. Overpressure versus Distance on Wall from Point of Minimum Radius

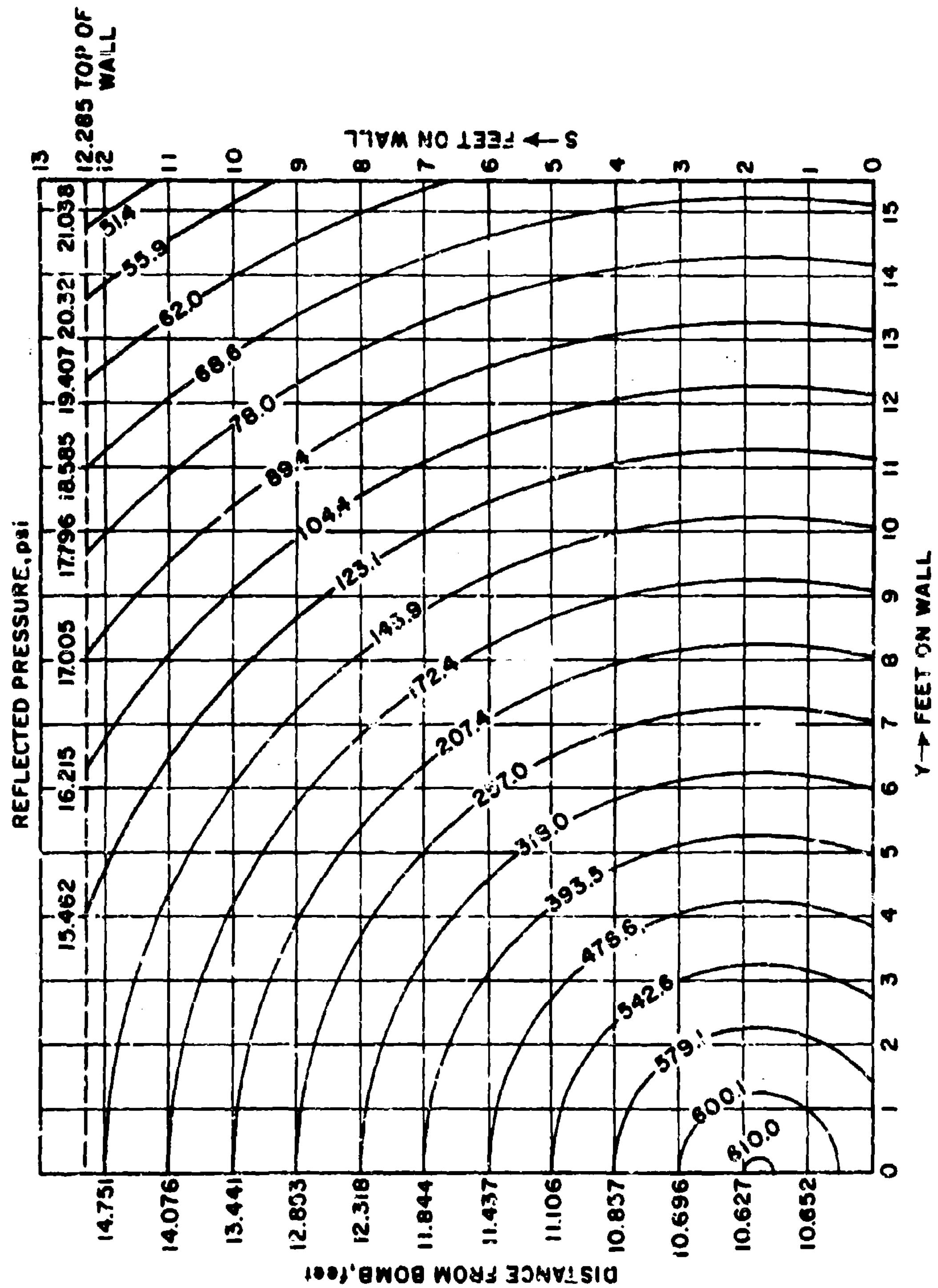


Figure 70. Reflected Pressure at Various Points on the Wall

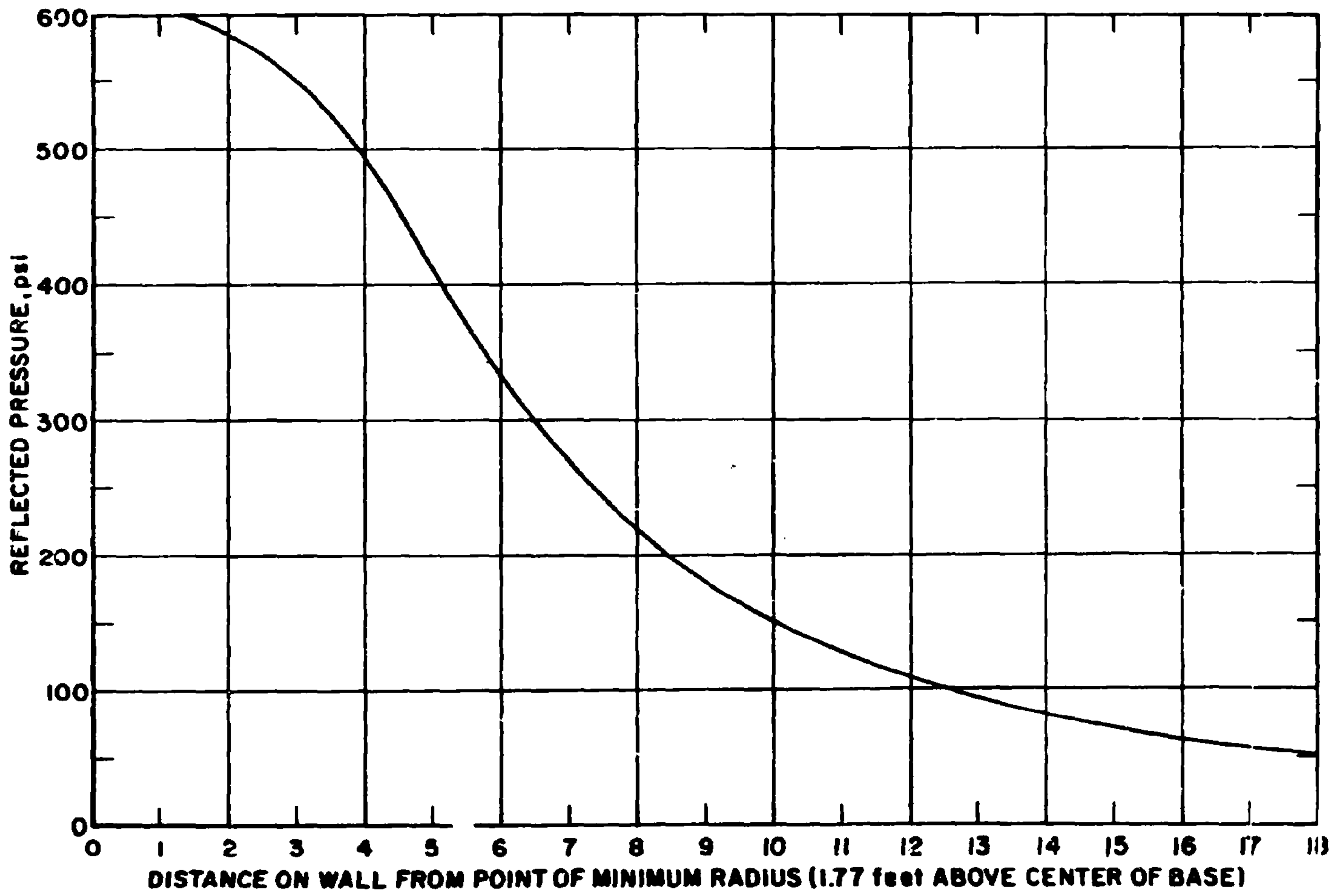


Figure 71. Reflected Pressure versus Distance on Wall from Point of Minimum Radius

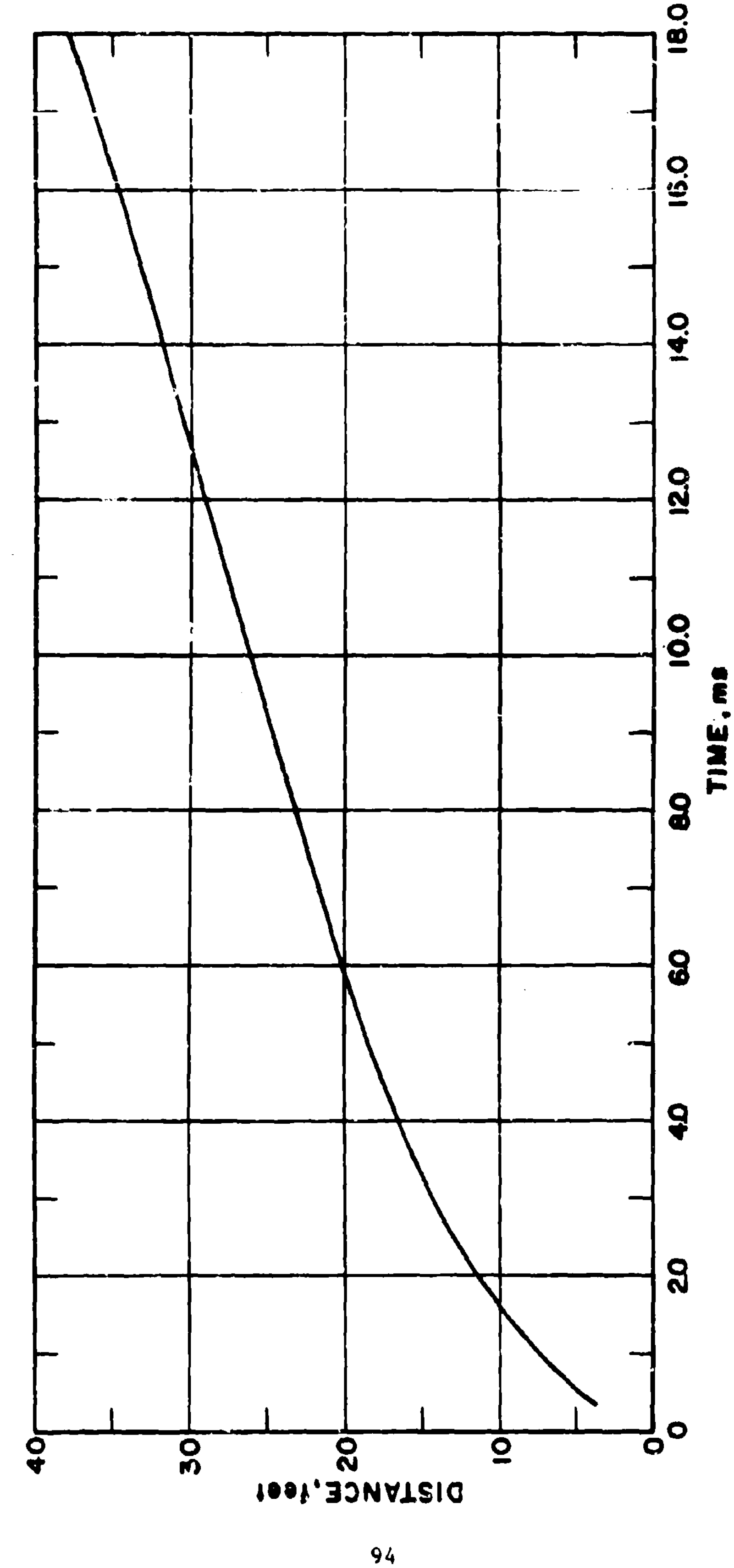


Figure 72. Distance Traveled by Shock Front versus Time

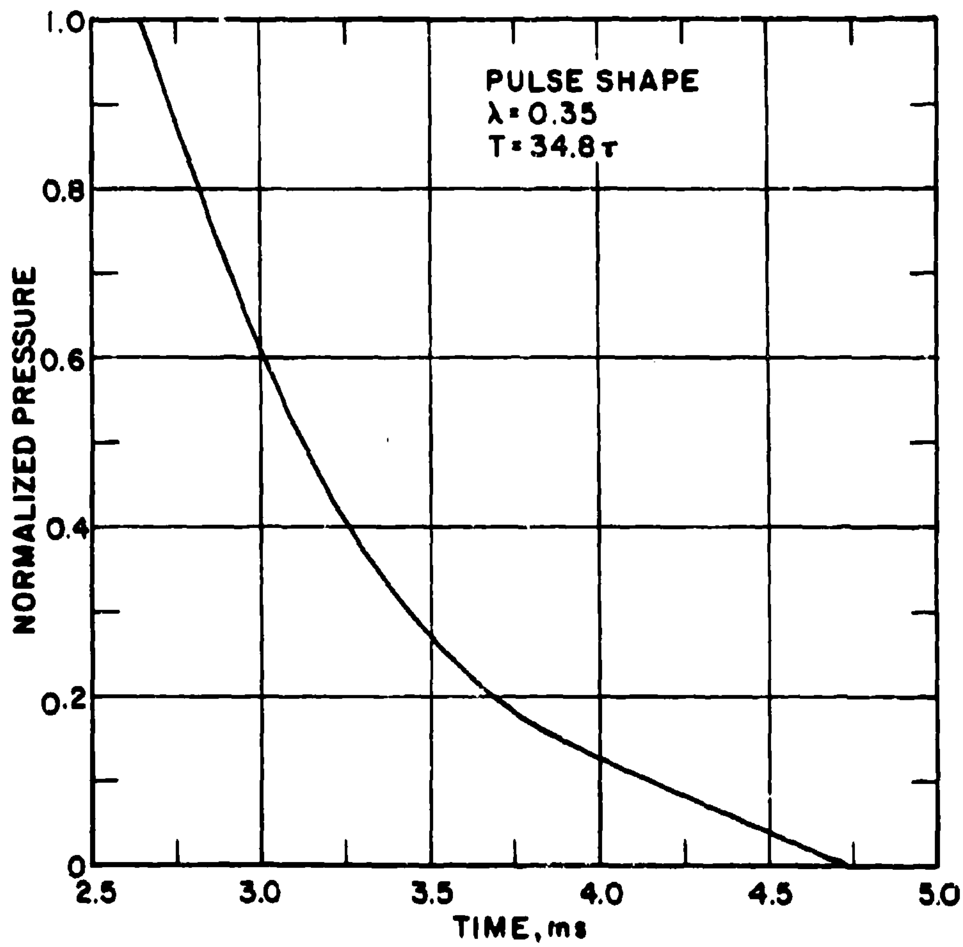


Figure 73. Pulse Shape for a Radius of 13.405 Feet

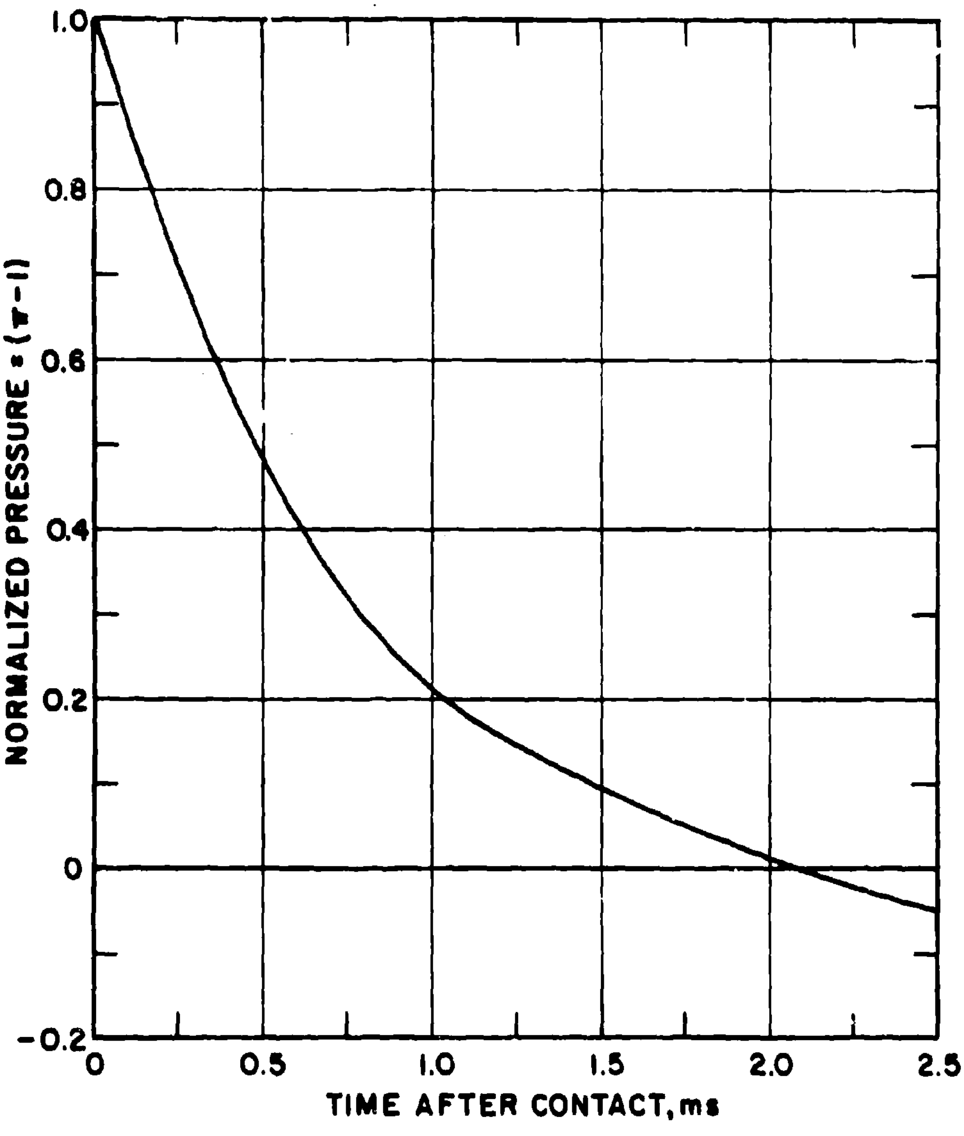


Figure 74. Typical Pulse Shape

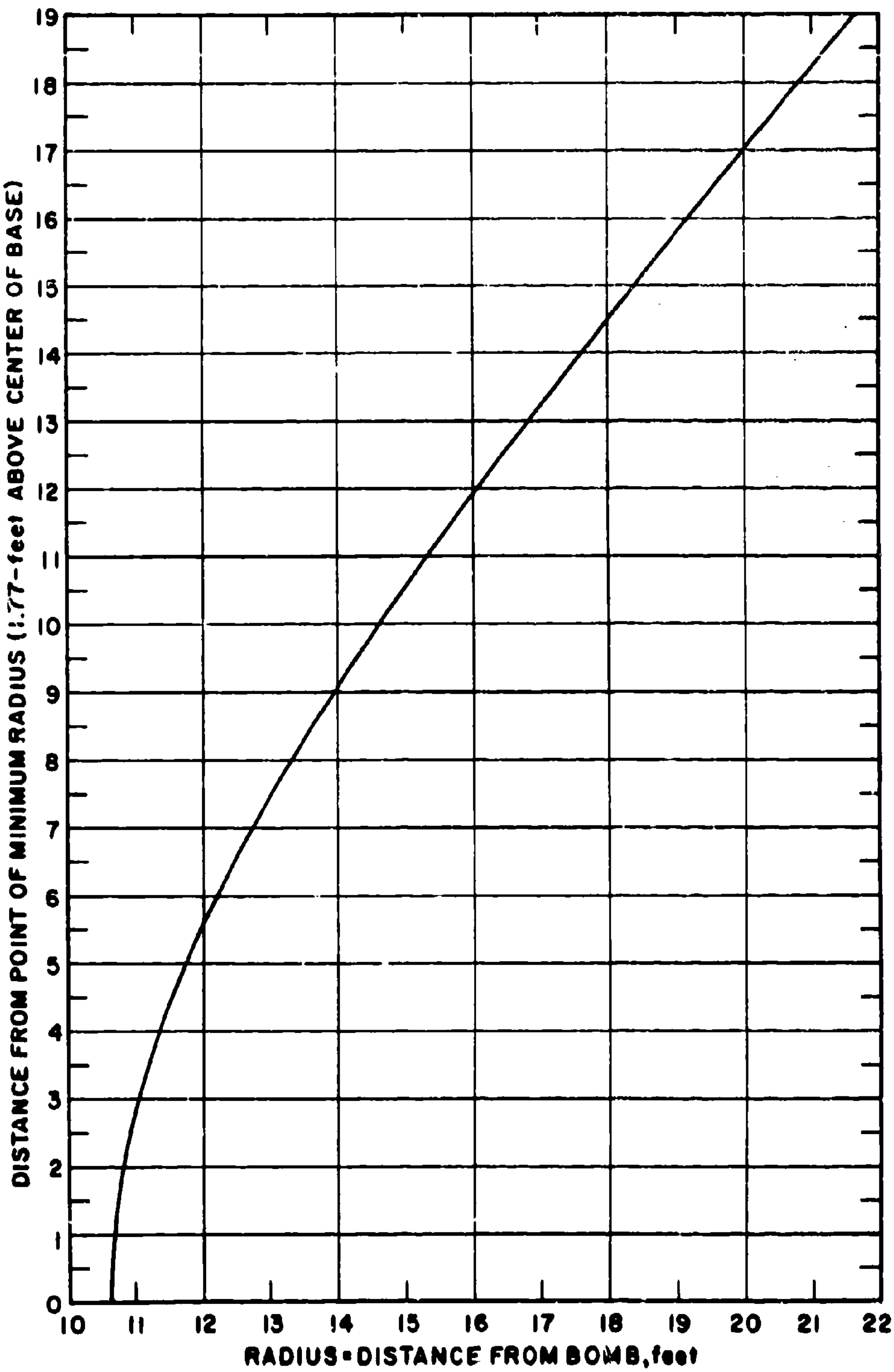


Figure 75. Distance on Wall versus Distance from Bomb

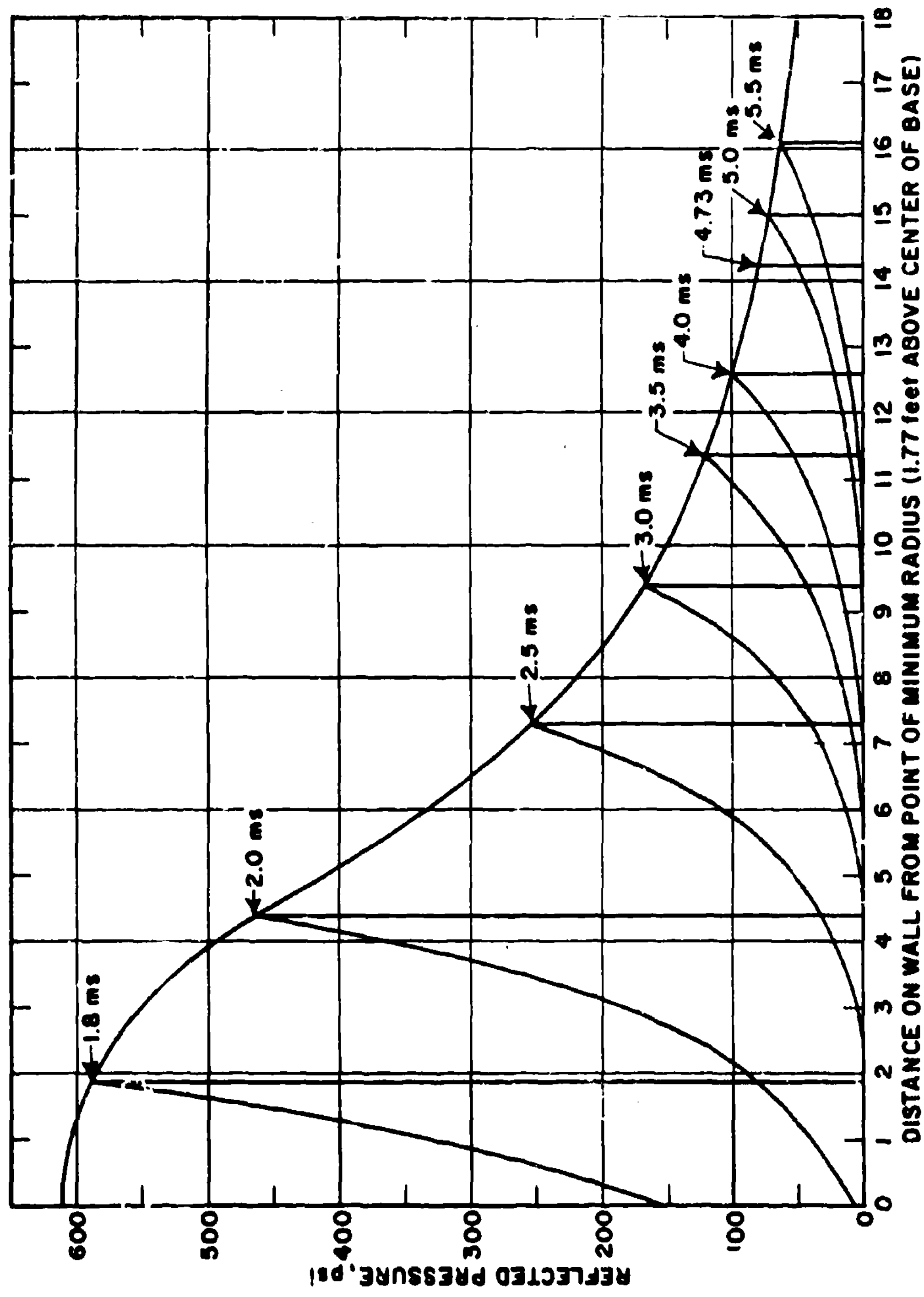


Figure 76. Pressure Pulses on Wall for Various Times after Detonation

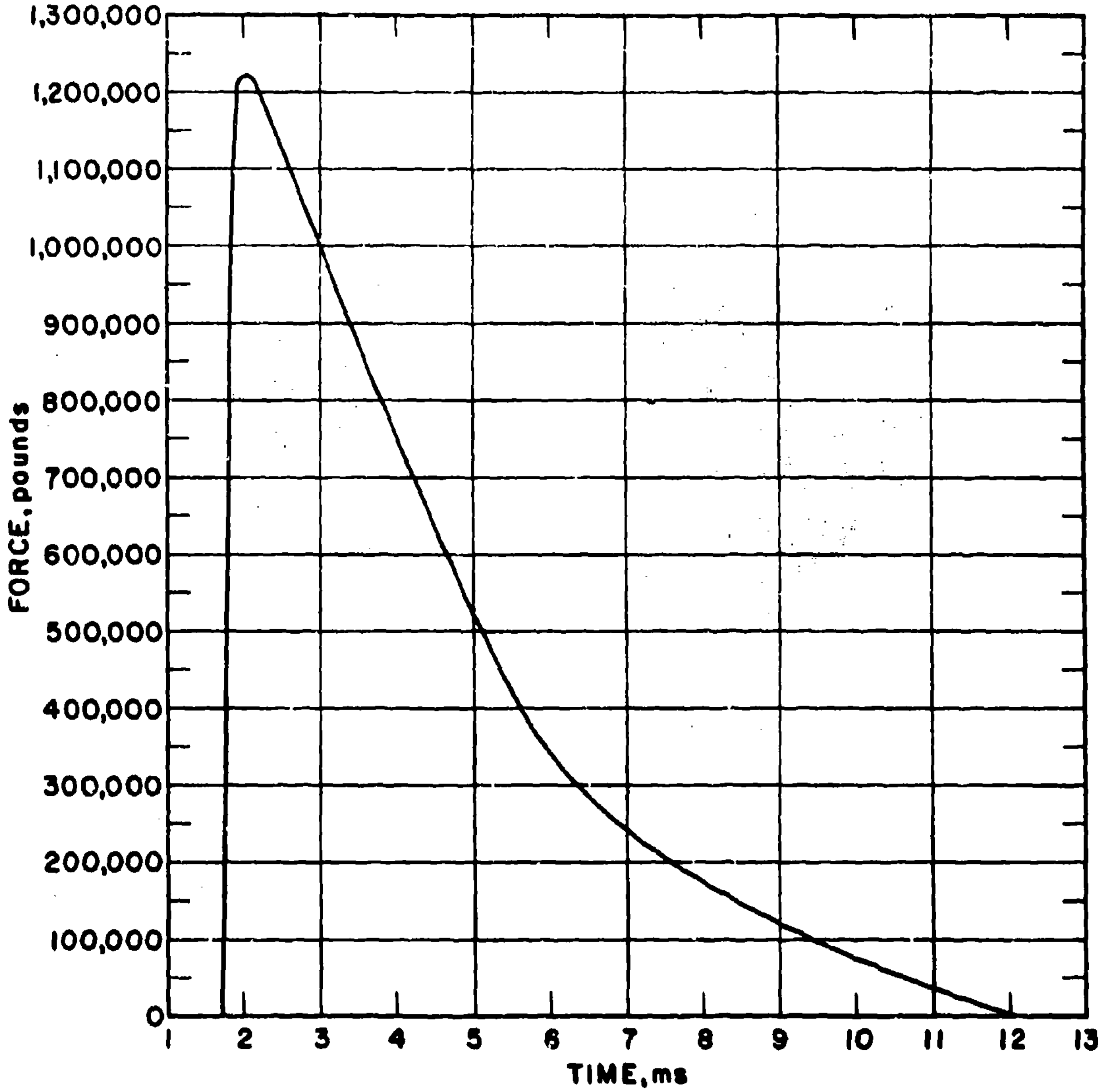


Figure 77. Force as a Function of Time

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13. ABSTRACT Revetment wall sections constructed from soil-cement, steel-sheet piling, corrugated asbestos, and fiberglass were evaluated for their effectiveness in providing protection to parked aircraft and equipment against the effects of conventional weapons. The results of this evaluation program indicate that the soil-cement wall provided protection against small arms ammunition, mortar rounds statically detonated at elevations less than 12 feet and at any range, 3.5-inch High Explosive Antitank (HEAT) rockets, and shrapnel resulting from the detonation of a 750-pound bomb 10 feet from the wall. The steel-sheet piling wall provided perforation protection against 30-caliber ball ammunition only, but may result in untrapped ricochets on the front face of the wall. Fifty-caliber and 20-millimeter ammunition and mortar rounds caused perforations in the piling, produced secondary projectiles, untrapped ricochets, and shrapnel on the front face of the wall, and spalled the sheet piling, producing shrapnel and secondary projectiles on the rear face of the wall. The fiberglass wall provided protection against small arms ammunition and mortar rounds statically detonated at elevations less than 11 feet and at any range. The fiberglass wall did not prevent the perforation of the core from a 3.5-inch HEAT rocket. The corrugated asbestos wall provided protection against 30-caliber and 50-caliber ammunition. Twenty-millimeter ammunition and 3.5-inch HEAT rockets did considerable damage to the wall.

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Conventional weapons effects						
Penetration resistance of soils and steel						
Cement as soil stabilizing material						
Navigational aid revetments						

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14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

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