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RAPID CONSTRUCTION FOR HARDENING ABOVE-GROUND FACILITIES TO SMA--ETC(U)
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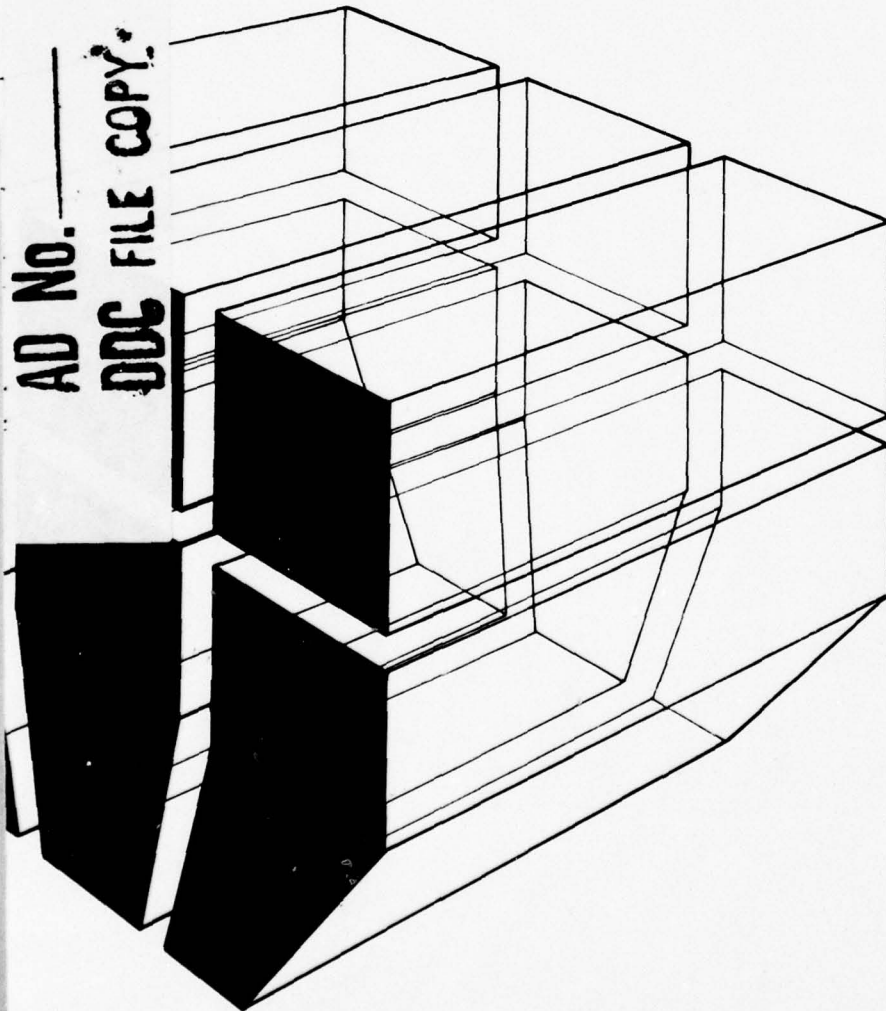
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TECHNICAL REPORT M-230
April 1978
Rapid Construction of Hardened Shelters
in the T/O with New Material Systems

RAPID CONSTRUCTION FOR
HARDENING ABOVE-GROUND
FACILITIES TO SMALL ARMS FIRE

AD NO. _____

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P. X. Bellini
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The purpose of this research was to develop an efficient structural system for the rapid construction of above-ground hardened shelters in the theater of operations. This system would have a short construction time, use unskilled labor, and be capable of resisting small arms fire and bomb blast concussion and fragmentation. Two material systems were considered: (1) standard concrete block with a surface bond material using no conventional mortar joints, and (2) ferrocement—several layers of wire mesh impregnated with Portland cement mortar. →		

Block 20 continued.

↙ The standard concrete block system was chosen based on results of a series of laboratory tests, and a full-scale shelter was designed, constructed, and tested to determine its actual protective capabilities.

It was found that surface-bonded concrete walls having block cells filled with mortar or pea gravel provide complete protection from weapons such as the M16, M1911, and M60; in addition, such structures can be built rapidly by unskilled workers. Lightweight concrete blocks having cells filled with steel-fiber mortar will provide complete protection from M14 and M16 rifles, M1911 pistols, and M2 machine guns. ↗

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FOREWORD

This study was conducted for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE). The research was funded under RDT&E Program 6.27.19A, Project 4A762719AT41, "Design, Construction and Operations and Maintenance Technology for Military Facilities," Task T5, "Research for Base Development in the Theater of Operations," Work Unit 003, "Rapid Construction of Hardened Shelters in the T/O with New Material Systems." The OCE Technical Monitor was Mr. R. H. Barnard, DAEN-FEP.

The report was prepared by the Engineering and Materials Division (EM), U. S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL. CERL personnel directly concerned with the work were Mr. Ray Aufmuth, Mr. David Morse, Mr. Alvin Smith, and Dr. Paul Bellini. Dr. Gil Williamson is Chief of EM, COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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RAPID CONSTRUCTION TECHNIQUES FOR HARDENING ABOVE-GROUND FACILITIES TO SMALL ARMS FIRE

1 INTRODUCTION

Problem Statement

Methods and procedures must be developed for rapid construction of above-ground hardened shelters in the theater of operations. These structures must be sufficiently hardened to resist small arms fire. In addition, they must be constructed with ordinary materials and equipment by means of unskilled labor.

Background

Two recently developed material systems conform to the above criteria. The first is concrete block coated with a surface bonding material of Portland cement, hydrated lime, and alkali-resistant fiberglass strands; its commercial name is "BlocBond." It is commonly referred to as glass fiber reinforced cement (GFRC).¹ This system eliminates the requirement of the mortar joint connection, and greatly reduces the amount of technical skill and erection time required for fabrication. A publication by Busching and Hamilton² outlines the current use of surface bonding material on concrete block structures and summarizes the current state of the art. A recent report by the National Concrete Masonry Association³ discusses tests conducted to determine the compressive, flexural, and racking strengths of hollow concrete masonry walls coated with a fiberglass-reinforced surface bonding material.

The second material system is ferrocement, which consists of a series of layers of wire mesh impregnated with Portland cement mortar. A relatively small thickness of this material develops high tensile strength and maintains a given shape without complicated formwork. A series of static and dynamic load tests was conducted on ferrocement panels by Lin and Associates⁴ to eval-

uate their protective potential for military structures. Shah⁵ conducted a static analysis of ferrocement in which elastic, cracking, and ultimate load behavior were studied. Braver conducted an extensive laboratory investigation which analyzed flexure, impact shear, tensile, creep, and compression strengths,⁶ and also published a state-of-the-art survey of ferrocement.⁷ More recently, Sargent⁸ presented a lengthy summary of the factors affecting the fatigue strength of ferrocement. A 5-year study of the properties of ferrocement has been summarized and interpreted by Greenius.⁹

The construction techniques outlined above are applicable to the construction of barracks, equipment buildings, warehouses, and other similar structures.

Objective

The objective of this investigation was to develop both a material system and an associated rapid construction procedure for above-ground, hardened shelters in the theater of operations; these structures were to be capable of rapid erection by unskilled labor and had to possess sufficient strength to withstand small arms fire.

Approach

Both surface-bonded concrete block and ferrocement satisfy the rapid construction requirements. To determine which system requires the lower level of labor skill for assembling the finished shelter and which is more structurally effective in resisting small arms fire, a set of test specimens was fabricated for each system and subjected to static strength tests, including tension, flexure, and shear; and to dynamic tests, including localized impact and ground shock.

Based on the level of technical skill required for assembling the finished structure, the simplicity of the construction process, and the static and dynamic char-

¹"How to Work with BlocBond," Pub. No. 1-SB-5734-A (Owens-Corning Fiberglas Corporation, December 1972).

²H. W. Busching and D. H. Hamilton, "Surface Bonded Concrete Block Panels," Vol 100, No. EM2 (American Society of Civil Engineers, April 1974), pp 359-374.

³National Concrete Masonry Association, *Structural Properties and Moisture Resistance of Surface Bonded Concrete Masonry Walls*, Pub. No. 12-SB-5767:2 (Owens-Corning Fiberglas Corporation, 1971).

⁴T. Y. Lin and Associates, *Ferrocement Panels*, No. CR69.008 (Naval Civil Engineering Laboratory, November 1968).

⁵S. P. Shah, *Ferrocement as a New Engineering Material*, No. 70-11 (University of Illinois, November 1970).

⁶F. E. Braver, *The Mechanical Properties of Ferrocement*, No. 3588 (Naval Ship Research and Development Center, August 1972).

⁷F. E. Braver, *State-of-the-Art Survey of Ferrocement*, No. 8-529 (Naval Ship Research and Development Center, January 1971).

⁸D. P. Sargent, Jr., *Factors Affecting the Fatigue Strength of Ferrocement*, Master's Thesis (Naval Postgraduate School, December 1974).

⁹A. W. Greenius, *Ferrocement for Canadian Fishing Vessels*, Report No. 86 (B. C. Research, March 1975).

acteristics of structural strength, the surface-bonded BlocBond material system was chosen as the most advantageous. Using this material system, a full-scale shelter was designed, constructed, and tested.

2 MODE OF TECHNOLOGY TRANSFER

The information obtained in this study has application to TM 5-855-1, *Fundamentals of Protective Design (Non-Nuclear)* (July 1965) and TM 5-742, *Concrete and Masonry* (June 1970). Appendix D is suggested for incorporation into TM 5-742 as Section IV of Chapter 8 (Concrete Masonry); included is a description of the materials and procedures for the expedient construction of conventional or hardened shelters, using a system requiring ordinary building materials and low-skill labor. This system uses surface bonding of concrete block to construct both above- and below-grade walls that can be either load-bearing or non-load-bearing. Protection against small arms fire can be achieved by filling the cells of the blocks with earth, gravel, mortar, or concrete. Other material suggested for possible inclusion in both TM 5-855-1 and TM 5-742 is the following:

Construction

a. **Materials and Tool Requirements:** The materials required to construct a building using the surface bonding technique include concrete for the footing, concrete block, glass fiber reinforced cement (trade name BlocBond), and wire mesh and mortar for the roof, if a ferrocement roof is desired; however, any conventional roofing system can be used. The tools required are shovels, plaster trowels with rounded corners, block trowel, string line, hand level, mortar mixer, and scaffolding.

b. **Procedure:** A concrete footing is placed and leveled as for any building type. The first course of block is laid in a bed of mortar and carefully aligned and leveled (Figure 1). The corner units should usually be laid first. When the first course is set, the remaining block units can be placed. Starting at the corners, the blocks are stacked tightly together, one on top of another, without any mortar. At every third course, the wall should be checked for alignment, grade, plumbness, and levelness. It may be necessary to smooth the top and bottom of each block by scraping two blocks together to remove the excess material. If leveling is required, sheet metal shims, sand, or mortar may be

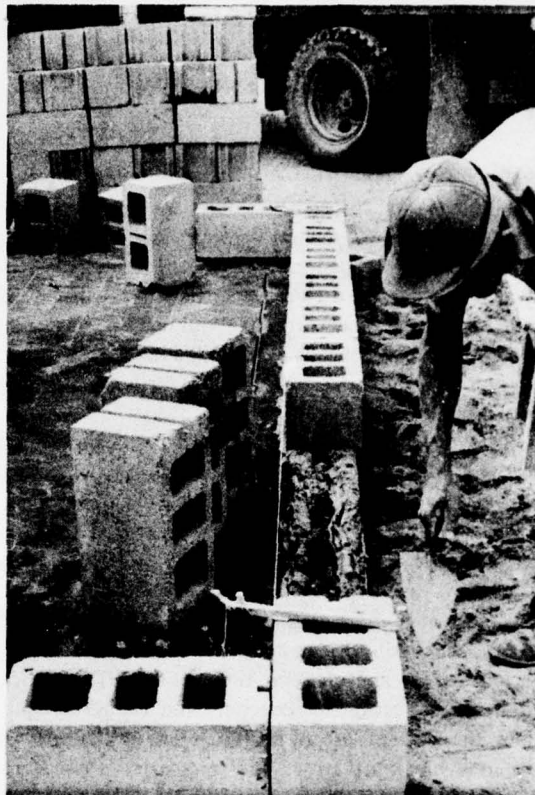


Figure 1. The first course of block is laid in a full bed of mortar and carefully aligned and leveled.

used. Blocks may be laid to a height of 10 ft (3 m) before applying the glass fiber cement parging (Figure 2); however, safety precautions should be taken when leaving a non-bonded wall for extended periods to prevent the blocks from falling due to high winds, etc. Once the blocks have all been placed, leveled, and aligned, the walls are ready for parging with the glass fiber cement. The material can be mixed by hand but is best mixed with a mortar mixer. Four gallons (.015m³) of water are required for each 80-lb (36.3-kg) bag. The water and the glass fiber cement are mixed for 2 to 3 min until all the material is wetted thoroughly. Overmixing will cause lumps to form. The material should have a mortar-like consistency, which may require additional water. The mixer should be washed out occasionally to insure uniform, lump-free mixes.

Before applying the glass fiber cement, make sure the wall is free of dirt, oil, paint, or other foreign



Figure 2. Blocks can be laid to a height of 10 ft (3 m) before applying the glass fiber cement parging.

material. Then wet the wall thoroughly, maintaining complete wetness until just prior to application of the material. Using a trowel with rounded corners, apply the mix smoothly to both sides of the wall to a thickness of at least 1/8 in. (3 mm). Press the mix in firmly to insure a good bond (Figure 3). When application is discontinued for more than 1 hour, the joint in the BlocBond must not coincide with the joints in the blocks; therefore, the material should be stopped at mid-height of a block to maintain the structural integrity of the parging.

BlocBond, which is comprised of Portland cement, lime, and glass fibers, must be cured like any other cementitious material. The best way to do this is to spray the material with a garden hose after it has set and then cover it with a polyethylene sheet. If rain is expected, the wall should be protected with a waterproof cover for at least 8 hours.

If a repair is required, the surface material can be chiseled off and new material applied after thoroughly wetting the surface.

Protection from small arms fire can be achieved by filling the cells of the blocks with soil, gravel, mortar,

or concrete as the blocks are being stacked (Figure 4). Care must be taken not to knock the wall out of alignment. The roof can be made of either conventional roofing materials or ferrocement, which consists of two to six layers of chicken wire or fine wire mesh (hardware cloth) plastered with mortar. A wooden frame or small-diameter reinforcing bars can be used to shape the roof and attach the wire mesh. When the mesh is in place, it is parged with mortar to a thickness sufficient to cover the wire. The roof is cured in the same manner as the walls. Figure 5 shows the completed structure.

Ballistic Resistance

The surface-bonded concrete block construction described in this report will provide protection against the following weapons:

1. M16 Rifle, 5.56-mm, at 164 ft (50 m), ball ammunition.
2. M1911 Pistol, .45-caliber, at 33 ft (10 m), ball ammunition.
3. M60 Machine Gun, 7.62-mm, at 164 ft (50 m), ball ammunition (when cells are filled with mortar or pea gravel).



Figure 3. Stacked block being parged with glass-fiber-reinforced cement.



Figure 4. Protection from small arms fire can be achieved by filling the cells of the blocks with soil, gravel, mortar, or concrete.

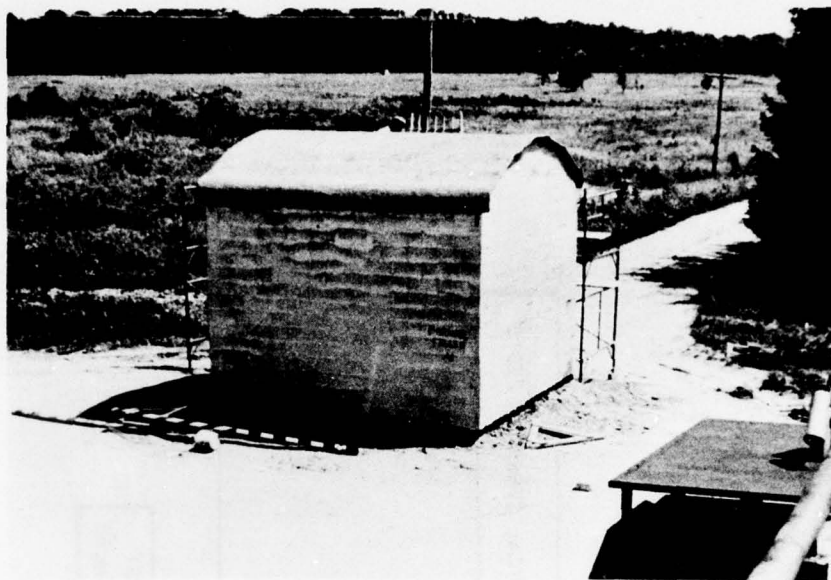


Figure 5. Completed structure—shows the ferro-cement roof.

3 DESCRIPTION OF TESTING PROGRAM AND TEST SPECIMENS

Description of Testing Program

To facilitate choice of the more efficient material system, a testing program was formulated (Figure 6) to develop the necessary information for comparing skill levels, construction procedures, and structural strength.

The test program was divided into three phases. The first phase (Chapter 4) consisted of a series of static tests to determine material characteristics in tension, flexure, dynamic, and shear; and a series of dynamic (ballistic) tests to determine the effects of high-velocity, local impact by various sizes of weapons. The effects of distributed impulsive dynamic stress were observed by using a ground shock loading method. The second phase of the test program (Chapter 5) compared the labor skill requirements, construction requirements, and erection procedures with the strength test results. The preferred material system was then determined. In the third phase of the program (Chapter 6), a full-scale, semi-hardened shelter was designed and constructed in an actual field situation, with a time study analysis made of the construction process. Ballistic tests

were performed on the field structure to determine its actual protective characteristics and capabilities.

Description of Test Specimens

Test Specimen Material Variables

The variables of the concrete block and ferro-cement material systems were defined to optimize the systems' structural capacities to resist load.

For the concrete block system (all blocks were nominal $8 \times 8 \times 16$ in. [$203 \times 203 \times 406$ mm]), three general parameters were considered: (1) the surface bonding material, (2) the block core filler material, and (3) the block joint material (see Figure 7). The surface bonding agent was glass-fiber-reinforced cement (Bloc-Bond). The block core filler material was either conventional mortar or fibrous mortar (a mixture of cement, fine aggregate, and discontinuous discrete steel fibers). The block joint material was either conventional Portland cement mortar or glass-fiber-reinforced Portland cement mortar. Various combinations of these parameters were considered to determine strength variations.

For the ferro-cement system, two general parameters were investigated: (1) the type and quantity of reinforcing steel, and (2) the type of mortar used for bond-

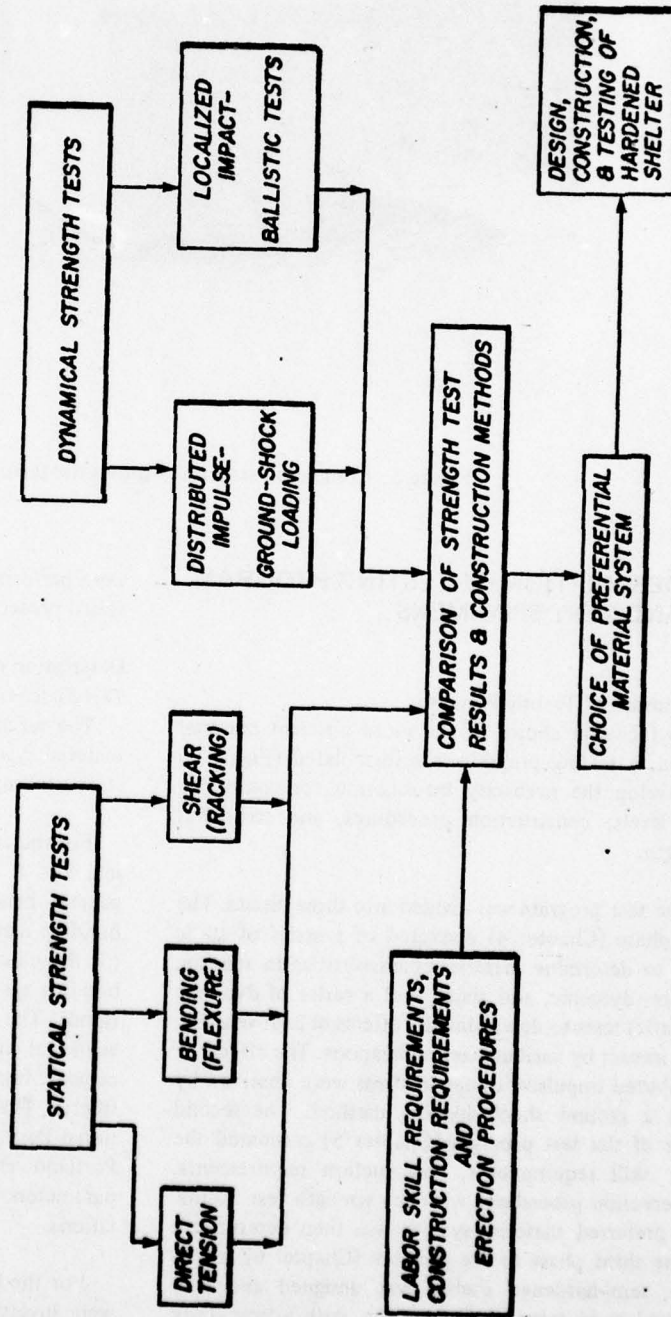


Figure 6. Test program flow diagram.

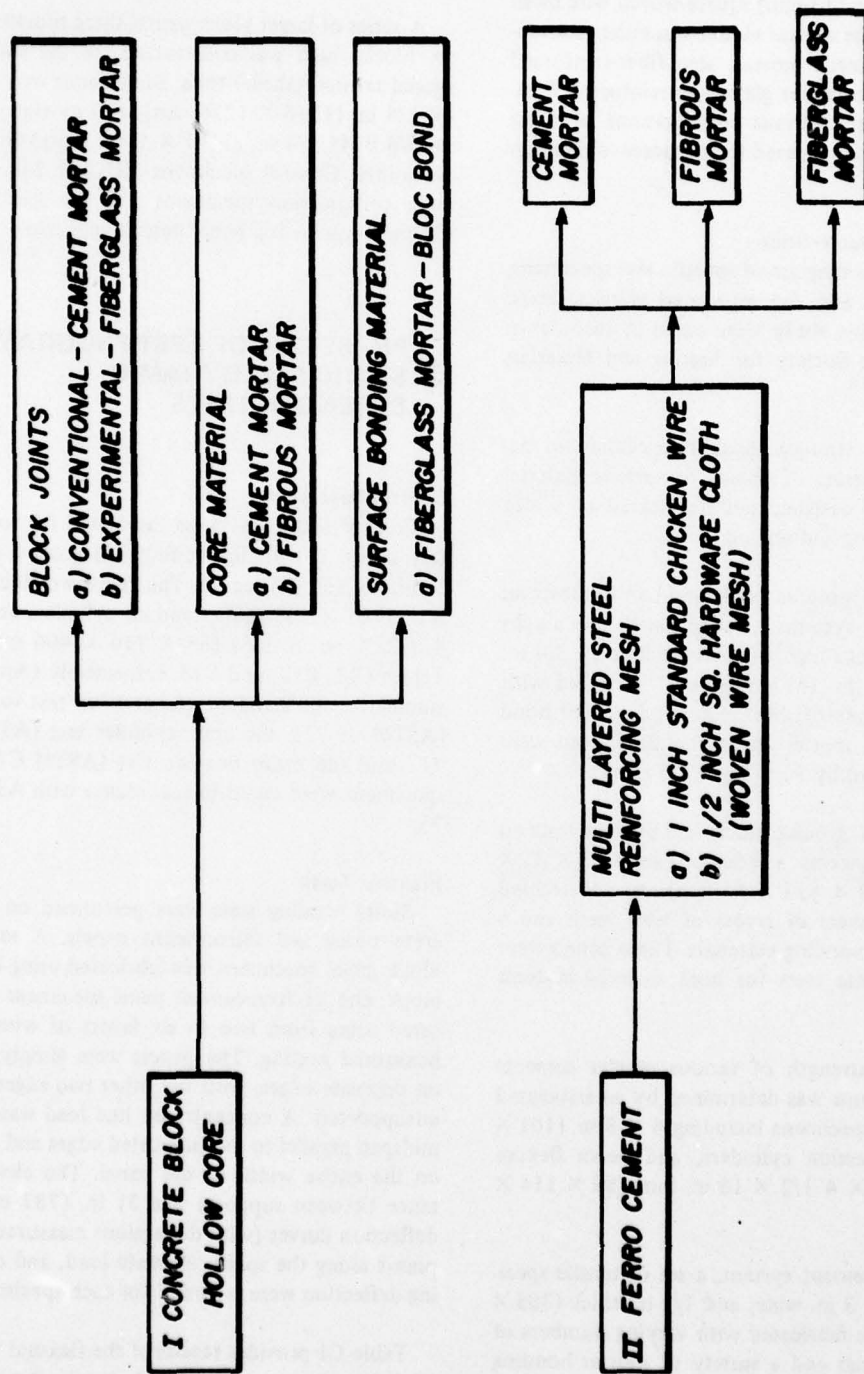


Figure 7. Test specimen material variables. (SI conversion factor: 1 in. = 25.4 mm)

ing it. Two types of reinforcing steel were used: (1) standard 1-in. (25-mm) hexagonal netting (chicken wire), and (2) 1/2-in. (13-mm) square-woven wire mesh (hardware cloth). The mortar binder was either conventional Portland cement mortar, steel-fiber-reinforced Portland cement mortar, or glass-fiber-reinforced Portland cement mortar. Various combinations of these material types were considered for purposes of comparison.

Test Specimen Characteristics

Figure 8 is a flow diagram of specific test specimens, control specimens, and the associated physical tests. All specimens in this study were cured in accordance with the American Society for Testing and Materials (ASTM) C511-75.¹⁰

To compare the strength capabilities of the two material systems, a series of panels of various material combinations was designed and fabricated in a size efficient for handling and testing.

For the flexural, ground shock, and ballistic tests on the concrete block systems, a set of panels two blocks wide and four blocks high with dimensions 31 3/4 in. (806 mm) by 32 in. (813 mm) was fabricated with various combinations of joint, core, and surface bond materials. Without mortar joints, the dimensions were 31 1/4 in. (794 mm) by 30 1/2 in. (775 mm).

For the flexural, ground shock, and ballistic tests on the ferrocement systems, a series of panels 32 × 32 × 1/2 in. thick (813 × 813 × 13 mm) was constructed with varying numbers of layers of wire mesh and a variety of mortar bonding materials. These panels were used in the ballistic tests for both material systems (Figure 8).

The material strength of various mortar cements used in both systems was determined by an associated series of control specimens including 4 × 8 in. (101 × 203 mm) compression cylinders, and beam flexure specimens 3 1/2 × 4 1/2 × 16 in. long (89 × 114 × 406 mm).

For the ferrocement system, a set of tensile specimens 12 in. long, 3 in. wide, and 1/2 in. thick (305 × 76 × 13 mm) was fabricated with varying numbers of layers of wire mesh and a variety of mortar bonding

materials. These specimens were used to determine the material's tensile characteristics and properties.

A series of larger block panels three blocks wide and six blocks high was constructed for the standard diagonal tension (shear) tests. Dimensions were 47 7/8 × 48 1/4 in. (1216 × 1226 mm) with mortar joints and 46 7/8 × 45 3/4 in. (1191 × 1162 mm) without mortar joints. Control specimens included 2-in. (51-mm) cube compression specimens and the standard 1-in. (25-mm)-square dog bone* tensile specimen.

4 PHASE ONE OF TEST PROGRAM— STATIC AND DYNAMIC STRENGTH TESTS

Control Specimens

Control specimens were fabricated for four general test series: (1) static bending, (2) ground shock, (3) ballistics, and (4) tensile. The specimens included 4 × 8 in. (101 × 203 mm) standard cylinders and 3 1/2 × 4 1/2 × 16 in. long (89 × 114 × 406 mm) beams. Tables C11, C12, and C13, respectively (Appendix C), summarize the standard compression test for cylinders (ASTM 39-72), the split cylinder test (ASTM C496-71), and the beam flexure test (ASTM C78-64). All specimens were cured in accordance with ASTM C511-75.

Flexural Tests

Static bending tests were performed on both concrete block and ferrocement panels. A series of 13 block panel specimens was fabricated using lightweight block, and 21 ferrocement panel specimens were fabricated using from two to six layers of wire mesh and hexagonal netting. The panels were simply supported on opposite edges, with the other two edges remaining unsupported. A concentrated line load was applied at midspan parallel to the supported edges and distributed on the entire width of the panel. The clear span distance between supports was 31 in. (787 mm). Load-deflection curves (with deflections measured at quarter points along the span), ultimate load, and corresponding deflection were recorded for each specimen.

Table C1 provides results of the flexural tests on the 13 lightweight concrete block panels. Panels made by parging with glass-fiber-reinforced cement (GFRC)

*Test specimen is shaped like a dog bone.

¹⁰Moist Cabinets and Rooms Used in the Testing of Hydraulics, ASTM C511-75 (American Society for Testing and Materials [ASTM], 1975).

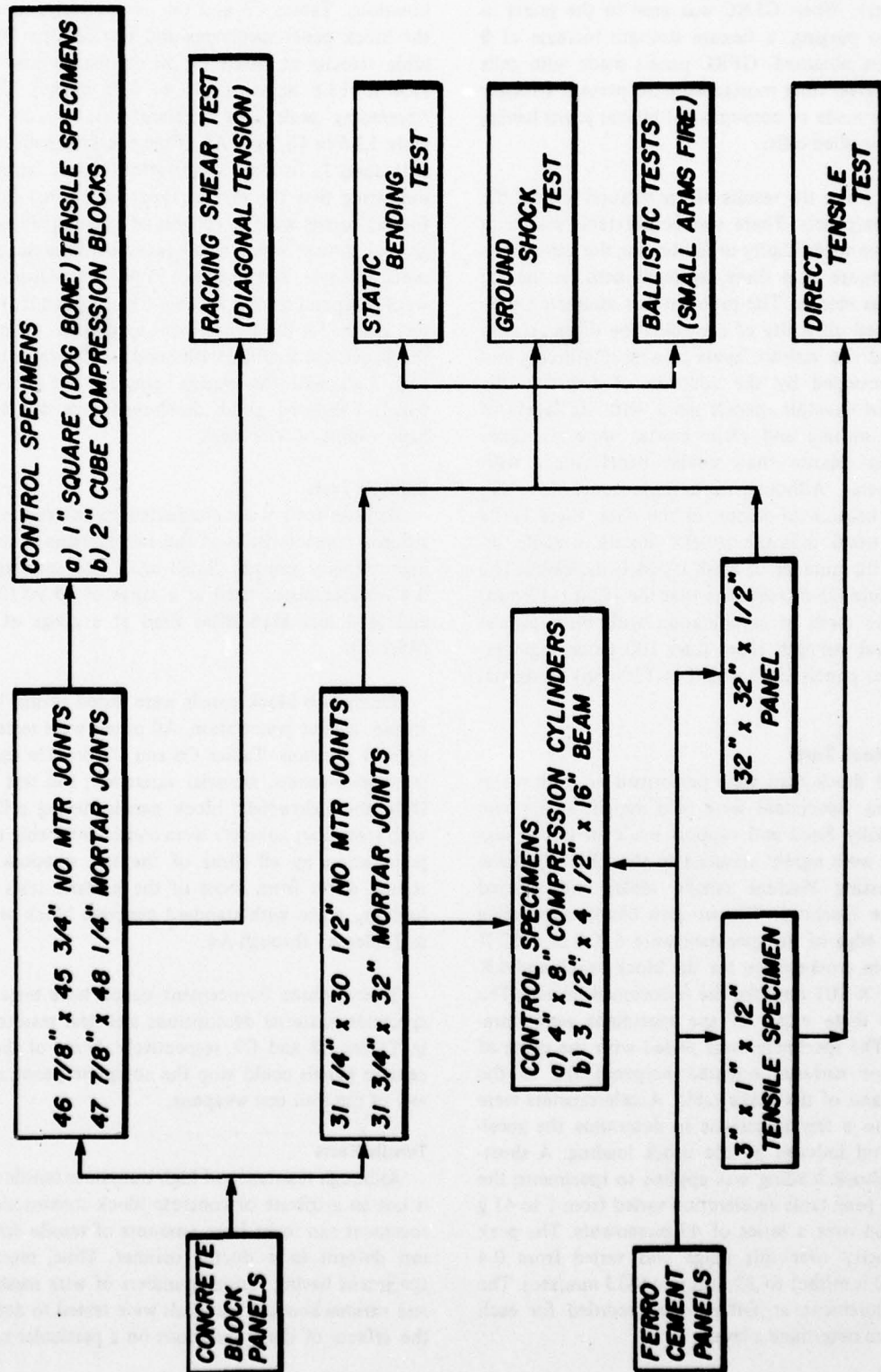


Figure 8. Physical test flow diagram. (SI conversion factor: 1 in. = 25.4 mm)

were 12 percent stronger in flexure than panels made with conventional mortar joints and cells filled with plain mortar. When GFRC was used in the joints in addition to parging, a flexure strength increase of 8 percent was obtained. GFRC panels made with cells filled with steel fiber mortar were 30 percent stronger than panels made of conventional mortar joints having plain-mortar-filled cells.

Table C2 lists the results of the flexural tests of the ferrocement panels. There was considerable scatter in the data due to difficulty in fabricating the panels that contained more than three layers of mesh, or the use of a fibrous mortar. The problem was associated with the increased difficulty of consolidating the mortar in and around the various layers of wire reinforcing and was compounded by the addition of fibers to the mortar. For example, panels made with six layers of hexagonal netting and plain mortar were six times stronger in flexure than similar panels made with GFRC mortar. Although no definite conclusions can be drawn because of scatter in the data, there is the expected trend that the panel's flexure strength increases as the number of mesh layers is increased. The data in Table C2 also indicate that the 1/2-in. (13-mm) square wire mesh in combination with plain mortar had flexural strength more than 100 percent greater than similar panels made with 1-in. (25-mm) hexagonal netting.

Ground Shock Tests

Ground shock tests were performed on both material systems. Specimens were held upright at the base by a partially fixed end support made of timber sections that were rigidly attached to the CERL Bi-Axial Shock Testing Machine (shake table) and wedged against the specimen. The wooden blocks supporting the entire edge of the specimen were 6 × 6 in. (152 × 152 mm) in cross-section for the block panels and 4 × 4 in. (101 × 101 mm) for the ferrocement panels. The remaining three edges of the specimens were unrestrained. The specimens were tested with the plane of their major surfaces oriented perpendicular to the surface plane of the shake table. Accelerometers were attached to a few specimens to determine the acceleration level induced by the shock loading. A short-duration shock loading was applied to specimens; the maximum peak table acceleration varied from 1 to 41 g acceleration over a series of 43 increments. The peak table velocity over this range was varied from 0.4 in./sec (10 mm/sec) to 32.8 in./sec (833 mm/sec). The loading increment at failure was recorded for each specimen to determine g levels.

Seven block panels and 10 ferrocement panels were tested in shock loading for a variety of material combinations. Tables C3 and C4, respectively, summarize the block panel specimens and test results. The peak table velocity at failure for all the panels ranged from 12.4 to 13.6 in./sec (0.31 to 0.35 m/sec). The corresponding peak table acceleration at failure ranged from 13.6 to 18.7 g's. All of the specimens successfully withstood 11 or more accelerations before failure, thus indicating that the various types of construction used for the panels were all capable of resisting considerable ground shock when small-panel configurations were used; however, this does not imply that full-scale walls would respond similarly. Table C5 of Appendix C shows test results for the ferrocement specimens. Again, all of the panels successfully withstood accelerations of more than 9 g's, with the average being 18. The ferrocement panels exhibited good shock-resistance due to their high volume of wire mesh.

Ballistic Tests

Ballistic tests were conducted to determine the resistance characteristics of the two systems to localized high velocity impact. Small arms fire consisted of a 0.45-caliber pistol fired at a range of 25 yd (22.9 m) and M14 and M16 rifles fired at a range of 50 yd (45.7 m).

Thirty-two block panels were tested against ballistic impact and/or penetration. All panels were tested in an upright position. Tables C6 and C7 provide the specimen descriptions, material variations, and test results. Only the lightweight block panels having cells filled with steel fiber concrete were consistently able to resist penetration by all three of the test weapons. These results differ from those of the ballistic tests on the building made with standard concrete block as shown in Tables A1 through A4.

Twenty-three ferrocement panels were tested, with specimen material descriptions and test results shown in Tables C8 and C9, respectively. None of the ferrocement panels could stop the complete penetration of any of the four test weapons.

Tensile Tests

Although resistance of high transverse tensile stresses is not an attribute of concrete block construction, ferrocement can resist large amounts of tensile stress and can deform in a ductile manner. Thus, tensile test specimens having various numbers of wire mesh layers and various bonding materials were tested to determine the effects of these variations on a particular material

composition. A set of three specimens was fabricated and tested for each material combination. A cross-sectional area of $3 \times 1/2$ in. (76×13 mm) was used in each case. A total gage length of 6 in. (152 mm) was common to each specimen. Twenty-one material combinations were tested; Table C10 of Appendix C provides data and test results.

Shear Test of Block Walls

Background

The predominant structural mechanism for resisting a time-varying load induced by impact, blast, wind, or seismic effects is shear wall stiffness. Thus, a prime consideration in the design of surface-bonded concrete block walls is the wall panel's ability to resist in-plane shear forces. The standard racking test for masonry is described in ASTM E72-68.¹¹ This method requires application of a "hold-down" force that will prevent the specimen from rotating as shear force is applied. Determining the stress distribution within the specimen is extremely difficult, if not impossible, due to the difficulty of measuring the "hold-down" force accurately and the interaction of the internal stress with the boundary conditions. Block panels approximately 4×4 ft (1.2×1.2 m) were tested using a more recent test procedure described in ASTM E519-74.¹² The panels were loaded in compression along the main diagonal of the panel. This loading condition induced a failure mode of stepwise shear along the block joints, or direct tension failure of the individual blocks. The stress distribution within the test specimen using this test method has been discussed by Mayes et al.¹³ The National Concrete Masonry Association¹⁴ conducted a few of these tests on surface-bonded concrete block walls.

Test Specimen Fabrication Procedures

This test series compared shear strength characteristics of surface-bonded (glass-fiber-reinforced cement), hollow concrete block panels with (1) the shear strength of mortar-jointed (conventional) block panels; (2) the

variation in thickness of the surface bonding material; and (3) the variation of block strength considering both standard block and lightweight concrete block.

The testing program used 32 block panels fabricated of standard and lightweight concrete block (see Table B1). Each panel was three blocks wide and six block courses high. Measurements were $47 \frac{7}{8} \times 48 \frac{1}{4}$ in. (1216×1226 mm) for panels with mortar joints, and $46 \frac{7}{8} \times 45 \frac{3}{4}$ in. (1191×1162 mm) for specimens without mortar joints. Twenty panels were constructed with conventional mortar joints only, five with external surface joints smeared with surface bonding material, and one with internal block joints coated with surface bonding material. Table 1 summarizes test specimens and material variations. The five panels with external smeared joints were constructed to establish a lower limit on failure load. The panel with internal smeared joints was fabricated to observe the failure mode; its internal joints were held as tightly butted as possible during construction.

The two-core concrete masonry units used for the shear test panels were manufactured by a local producer (nominal $8 \times 8 \times 16$ in. [$203 \times 203 \times 406$ mm]). Properties of these units as determined by ASTM C140-75¹⁵ are given in Table B6 and summarized in Table 2.

For the panels using conventional mortar joint construction, type S mortar (ASTM C270-73)¹⁶ was in the following volume: one-half part Portland cement, one part masonry cement, and three parts loose sand. All mortar joints were full-bedded, with a joint thickness of approximately $1/2$ in. (13 mm). Three 2-in. (51-mm) cube compression specimens (ASTM C109-75)¹⁷ were formed from each set of three mortar joint panels, including standard block and lightweight block (see Table B3). These specimens were used to determine the ultimate compression strength of the cement mortar.

All block panels with conventional mortar joints and all mortar control specimens were placed in a moist cure control room (meeting ASTM C511-75) for a minimum of 28 days of cure time before testing. All specimens were tested no later than 30 days after fabrication.

¹¹ *Conducting Strength Tests of Panels for Building Construction*, ASTM E72-68 (ASTM, 1968).

¹² *Test for Diagonal Tension (Shear) in Masonry Assemblages*, ASTM E519-74 (ASTM, 1974).

¹³ R. L. Mayes et al., "Cyclic Tests on Masonry Piers," *New Zealand Society Earthquake Eng Bull*, Vol 7n (3 September 1974).

¹⁴ National Concrete Masonry Association, *Structural Properties and Moisture Resistance of Surface Bonded Concrete Masonry Walls*, No. 12-SB-5767:2 (Owens-Corning Fiberglas Corporation, 1971).

¹⁵ *Sampling and Testing Concrete Masonry Units*, ASTM C140-75 (ASTM, 1975).

¹⁶ *Mortar for Unit Masonry*, ASTM C270-73 (ASTM, 1973).

¹⁷ *Test for Compressive Strength of Hydraulic Cement Mortars*, ASTM C109-75 (ASTM, 1975).

Table 1
Shear Test Specimens of Hollow Concrete Block
(SI conversion factor: 1 in. = 25.4 mm)

Panel Designation	Number of Panels	Block Type	Thickness of BlocBond (in.)	Thickness of Mortar Joints (in.)
1/16 LW	5	Lightweight	1/16	None
1/16 STD	3	Standard	1/16	None
1/8 LW	3	Lightweight	1/8	None
1/8 STD	3	Standard	1/8	None
1/4 LW	3	Lightweight	1/4	None
1/4 STD	3	Standard	1/4	None
LWMJ	3	Lightweight	None	1/2
STDMJ	3	Standard	None	1/2
LWSJ	2	Lightweight	Smearred	None
STDSJ	3	Standard	Smearred	None
BBJF	1	Lightweight	None	Smearred

Symbol Identification—

Blocks:

LW — Lightweight Block (cinder)

STD — Standardweight Block

Block Joints:

MJ — Mortar Joints

BBFJ — BlocBond Joints (BlocBond placed between tightly butted block joints)

SJ — Smearred Joints (external parging of joints only)

Table 2
Material Properties of Concrete Masonry Units
(SI conversion factors: 1 in. = 25.4 mm; 1 lb = 0.454 kg; 1 lb/cu ft = 16.02 kg/m³; 1 sq in. = 6.45 × 10⁻⁴ m²; and 1 psi = 6.894 × 10³ Pa.)

Type	Dimensions		Faceshell Thickness (in.)	Oven Dry Weight (lbs)	Absorption (lbs/cu ft)	Area (sq in.)		Compressive Stress Gross Area (psi)
	Nominal (in.)	Actual (in.)				Gross	Area	
LW*	8 × 8 × 16	7.63 × 7.63 × 15.63	1.25	25.9	10.88	119.3	62.5	1592
STD**	8 × 8 × 16	7.56 × 7.56 × 15.63	1.25	38.1	6.99	118.2	66.4	2878

* LW — Lightweight Block

**STD — Standardweight Block

The surface bonding material used for all block panels was BlocBond. The recommended standard amount of water—4 gal (33.4 lb [15.1 kg]) per bag (80 lb [36.3 kg]) of BlocBond—was used for all panels fabricated. A set of three standard (dog bone) tensile specimens (ASTM C190-72)¹⁸ and three 2-in. (51-mm)

¹⁸Test for Tensile Strength of Hydraulic Cement Mortars, ASTM C190-72 (ASTM, 1972).

cube compression specimens (ASTM C109-72) was formed from the surface bonding material for seven panels, including standard block with 1/4-in. (6-mm) coating and lightweight block with 1/16- and 1/4-in. (1.7- and 6-mm) coatings (see Table B4). These companion specimens were used to compare the strength of the wall as a unit with the tensile and compressive strengths of the surface bonding material.

All surface-bonded panels and control specimens were air-dried for a maximum of 12 hours after fabrication, and then placed in a moisture control room (ASTM C511-75) for at least 28 days before testing. All specimens were tested within 30 days after fabrication.

Two steel loading shoes were fabricated as specified by ASTM E519-74. Each specimen was held in a centered plumb position and lowered into the shoe containing a bed of high-strength gypsum plaster "hydro-stone." The specimen was rotated and the opposite corner was capped with an identical loading shoe.

Test Procedures

The shear test was performed on test specimens cured for at least 28 days but not more than 30 days (see Table B2). Crack load and ultimate load were recorded for each specimen, and horizontal elongation of all wall panels was recorded using a gage length of 60 in. (1524 mm). A Physi-Tech electro-optical tracking system accurate to 1 percent over a range of 0.002 in. (0.05 mm) to 50.0 ft (15.2 m) was used. The vertical contraction of the wall panel was recorded by accurate control of the hydraulic machine head movement. Both the horizontal elongation and the vertical contraction were recorded concurrently with the first crack load (see Table B2).

Cube compression tests for both cement mortar and BlocBond specimens were conducted after a minimum of 28 days cure time (see Table B3). Tensile specimens of the surface bonding material were tested after 28 days of curing time (see Table B4).

Test Results

Table B5 summarizes test results for each panel tested. Parameters recorded were ultimate load, mode of failure, computations of the vertical and horizontal longitudinal strains at first crack, average shear strain at first crack, shear strength of the wall per unit length of wall, and ultimate shear stress based on the gross area of the wall.

Table 3 summarizes test results for both lightweight and standard concrete block; the average values of ultimate load, shear strain at first crack, average shear strength per foot of wall, and average values of ultimate shear stress are shown for each material combination. The percentage strength ratio of the surface-bonded walls to the conventional mortar jointed walls was also computed and recorded.

Control specimens for the Portland cement mortar (see Table B3) provided an average ultimate compressive stress of 4400 psi (30.3 MPa). For the BlocBond control specimens, an average ultimate compressive

Table 3
Summary of Shear (Racking) Test Results
(SI conversion factors: 1 kip = 4.448 × 10³ N;
1 lb/sq ft = 14.59 N/m; and 1 psi = 6.894 × 10³ Pa.)

Block Type	Bonding Material Type	Average Ult. Load kips	Average Shear Strain 1st Crack × 10 ⁻⁴	Average Shear Strength lb/ft of wall	Average Shear Stress (Gross Area) psi	Percent Stress Efficiency Actual/Conventional
Lightweight	Smeared BB* Joints	14.3	9.44	2588	28.6	37
	1/16 BBSB**	19.5	6.98	3532	39.0	50
	1/8 BBSB	29.0	--	5255	58.1	75
	1/4 BBSB	32.7	10.1	5925	65.5	85
	Mortar Joints	40.1	8.46	6955	77.3	100
Standard	Smeared BB Joints	12.0	6.16	2172	24.2	26
	1/16 BB	31.0	8.97	5611	62.6	67
	1/8 BB	42.6	8.11	7710	86.0	92
	1/4 BB	39.3	6.86	7107	79.3	85
	Mortar Joints	48.3	9.66	8384	93.1	100

*BlocBond

**Surface bonded with BlocBond

stress of 3900 psi (26.9 MPa) and an average ultimate tensile stress of 530 psi (3.6 MPa) were obtained (see Tables B3 and B4, respectively).

Figure 9 is a plot of the ultimate load versus the thickness of the surface bond material, together with the ultimate load for conventional mortar joint construction. In all tests performed for both the lightweight and standard blocks, the conventional mortar joint panels were stronger in shear (diagonal tension) than the surface-bonded panels for all thicknesses of BlocBond.

For the lightweight block, there was a maximum of 85 percent efficiency with a 1/4-in. (6-mm) coating of BlocBond, and a 75 percent efficiency with a 1/8-in. (3-mm) coating. For the standard concrete block, a maximum efficiency of 92 percent was obtained for a 1/8-in. (3-mm) coating.

Doubling of the coating thickness from 1/8 in. (3 mm) to 1/4 in. (6 mm) increased the shear carrying capacity by only 10 percent for the lightweight block; however, for the standard concrete block, the capacity decreased by 7 percent, which can be attributed to the failure mode of the panels (see Table B5). For the 1/8-in. (3-mm) and 1/16-in. (6-mm) thick surface-bonded specimens, the mode of failure was diagonal tension; however, for the 1/4-in. (12-mm) thick bonded specimens the mode of failure was diagonal tension accompanied by crushing of the corner half block due to the high compression stress concentrations directly under the loading shoe (see Figure 10).

5 PHASE TWO OF TEST PROGRAM— MATERIAL SYSTEM EVALUATION

Evaluation Criteria

The material systems were evaluated on the basis of two categories of parameters which are critical to the project objective.

Category I: Fabrication Characteristics

- Ease of construction
- Labor skill level
- Logistics constraints
- Construction time

Category II: Material Properties

- Flexure tests

Ground shock tests

Ballistic tests

Evaluation of Category I parameters was based on actual panel construction in a laboratory environment and the extensive construction experience of research personnel. Category II parameters were evaluated on the basis of the material property testing program described in Chapter 3.

Evaluation Analysis

A rating system was devised to compare and contrast the two material systems based on the two parameter categories. This system was based on a numerical scale of one through six, in which a low score designates a superior condition. Table 4 summarizes the rating results.

The rating for flexural resistance of both the block panels and the ferrocement panels is based on test data contained in Tables C1 and C2, respectively. The rating values for ground shock resistance are obtained by comparing test results for block panels given in Table C4 with those in Table C5 for ferrocement panels. The ballistic resistance of the two systems was rated according to the results presented for block panels in Table C7 and for ferrocement panels in Table C9.

Material System Selection

The two material systems were compared on the basis of Category I criteria, which showed that the four criteria are more uniquely satisfied by using BlocBond surface material in a concrete block system. The ferrocement system requires a higher level of labor skill, a longer construction time, and a more complicated construction procedure.

When evaluated in terms of Category II criteria, the concrete block system was again rated much higher than the ferrocement system, partly because the thickest ferrocement panel tested was approximately 1/2 in. (12 mm). Increasing the panel thickness or using a multi-layered panel system will increase the system's ability to resist load and hence yield a higher Category II rating; however, this will also lower the Category I rating.

The overall conclusion based on the rating system shown in Table 4 was that the BlocBond system has the highest potential for simultaneously satisfying the greatest number of requirements and constraints for both the construction process and the required material strength. The BlocBond system was therefore selected for use in full-scale shelter construction.

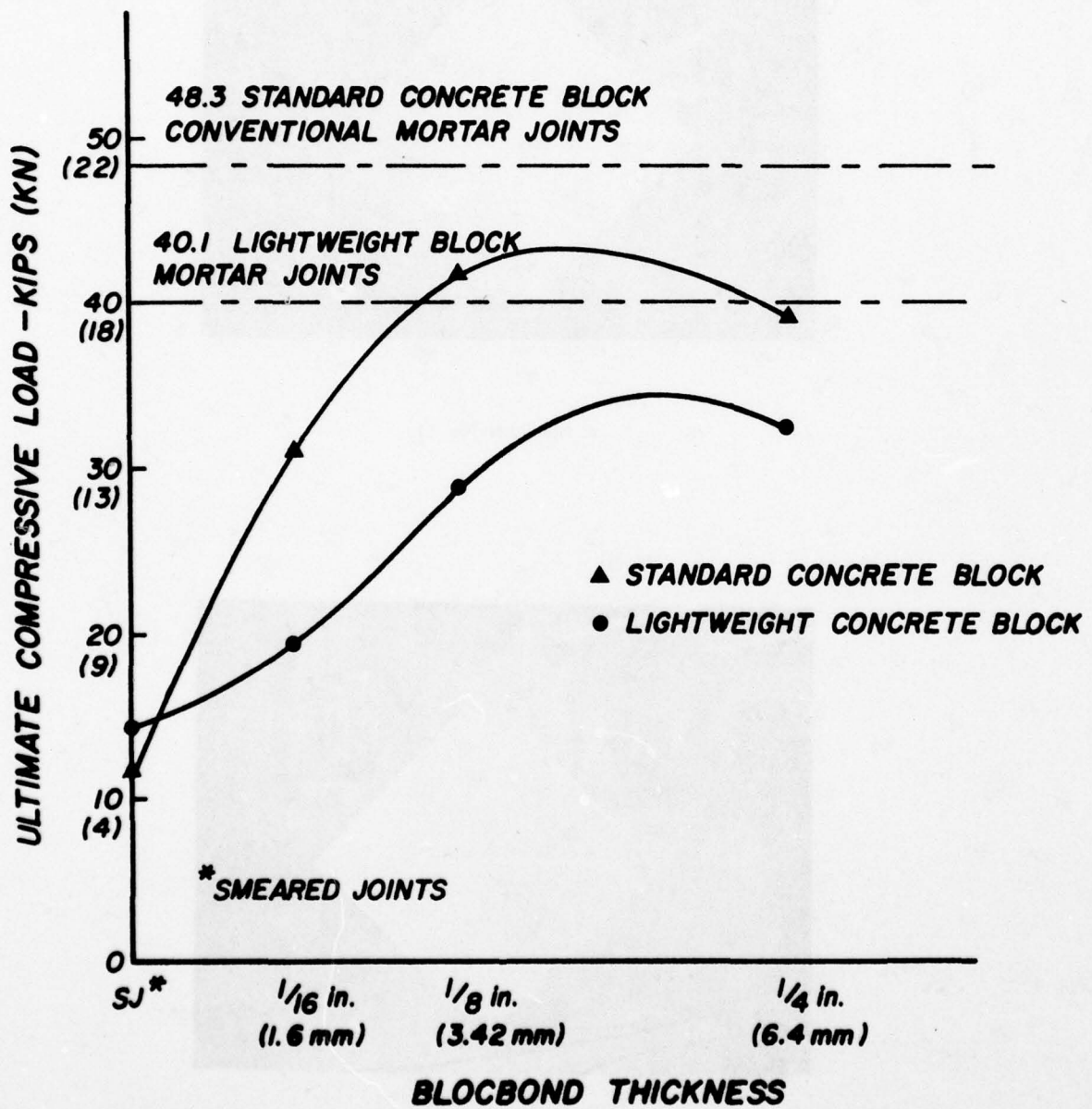
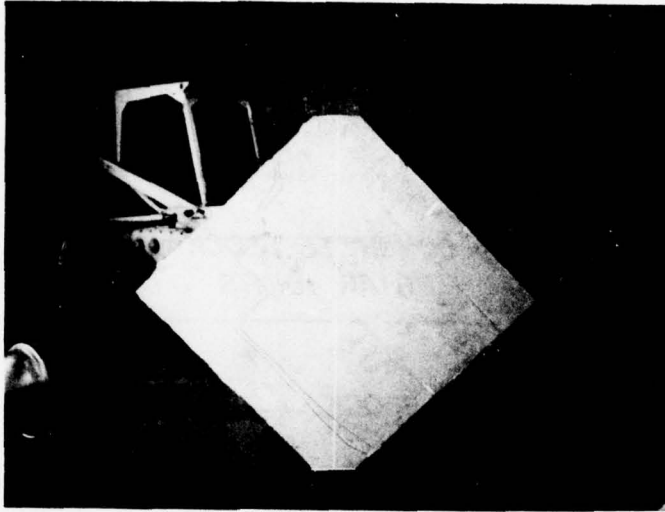
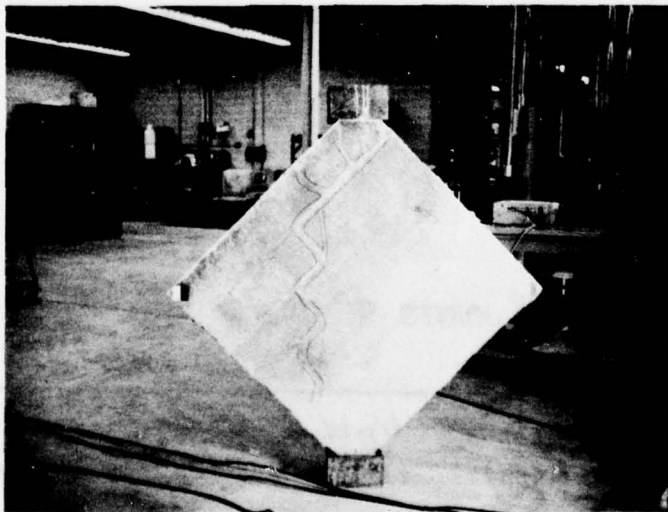


Figure 9. Ultimate compression load vs. BlocBond thickness for shear panels.
(SI conversion factor: 1 kip = 4.45×10^3 N)

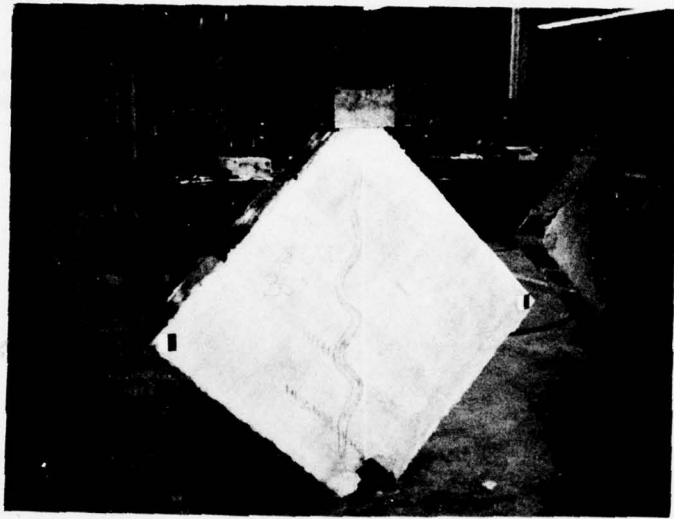


a. Specimen No. 11.

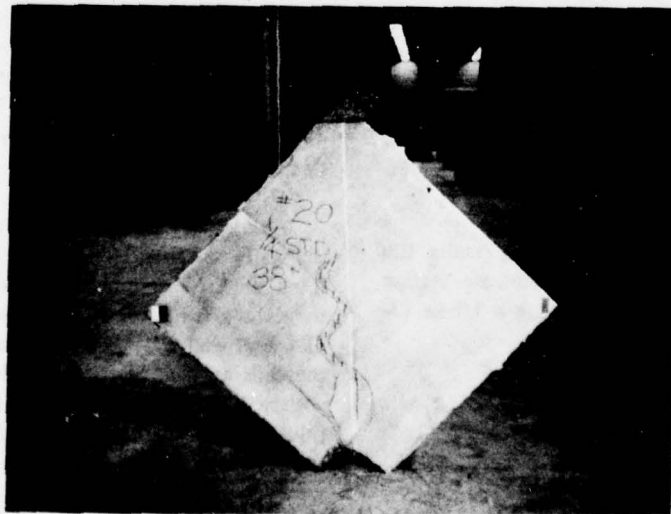


b. Specimen No. 15.

Figure 10. Failure modes of typical shear panel specimens.



c. Specimen No. 19.



d. Specimen No. 20.

Figure 10 (cont)

Table 4
Material Systems Rating Chart

Material System	Category I					Category II				Rating
	Ease of Construction	Labor Skill Level	Logistic Constraints	Construction Time	Sub-Total	Flexural Resistance	Ground Shock Resistance	Ballistic Resistance	Sub-Total	
Lightweight Block Panels										
(a) Mortar Joints										
1. Only	2*	2	1	2	7	3	1	2	6	13
2. Mortar Cores	3	2	1	2	8	2	1	1	4	12
3. Fibrous Mortar Cores	3	2	1	2	8	2	1	1	4	12
(b) BlocBond										
1. No Mortar Joints										
1. No Mortar Joints	1	1	2	1	5	1	2	2	5	10
2. Foam Blocks	2	1	2	2	7	2	1	6	9	16
Ferrocement Panels										
(a) Mortar	4	3	2	4	13	4	1	4	9	22
(b) Fibrous Mortar	5	3	2	4	14	4	1	4	9	23
(c) BlocBond	6	3	2	4	15	4	2	4	10	25

*A low number indicates a superior condition

All block panel tests used lightweight concrete block, which produced a material stiffness less than that of standard concrete block. The shear tests are indicative of a system's ability to carry dynamic load; these tests showed that a 32 percent increase in shear carrying capacity could be obtained for the same thickness of BlocBond (1/8 in. [3 mm]) using standard block rather than lightweight block. In addition, the standard block-BlocBond system attained a 92 percent efficiency in shear load carrying capacity when compared with conventional mortar joints, while the lightweight block-BlocBond system reached only an 85 percent efficiency.

Based on these observations and rating results, the material system chosen for initial full-scale testing operations was standard concrete having a 1/8-in. (3-mm) layer of BlocBond on both sides.

6 PHASE THREE OF TEST PROGRAM—CONSTRUCTION OF A FULL-SCALE SHELTER

Construction Details

A full-scale, surface-bonded, standard concrete block shelter was constructed "on-site" at the Jefferson Proving Ground in Madison, IN, between 21 June 1975 and

1 July 1976. The shelter dimensions were approximately 13 ft (3.96 m [10 blocks]) long, 13 ft (3.96 m [10 blocks]) wide, and 9 1/2 ft (2.89 m [15 courses]) high. The foundation of the structure was a 6-in.- (152-mm-) thick armor plate resting on a leveled sand bed. The lowest course of blocks was set in a mortar bed and carefully plumbed. Subsequent block courses were dry-bedded, and the block joints were tightly butted. No conventional mortar joints were used. The walls were coated with a 1/8-in. (3-mm) layer of BlocBond on both sides following procedures and techniques specified by the manufacturer.¹⁹

A variety of block cell filler materials were used in the wall construction. The cells in the north wall were filled with a 3/8-in. (10-mm) pea gravel poured into the cells as each block course was placed in position. The west wall was filled with pulverized soil placed in the cells at each block course level and hand-tamped with a blunt instrument. The east wall was mortar-filled with S-type mortar poured into the cells at every second block course. The block cells in the south wall were empty.

The end walls were peaked using an additional set of three block courses. Ten 4 in. X 4 in. X 13 ft long

¹⁹How to Work with BlocBond, Pub. No. 1-SB-5734-A (Owens-Corning Fiberglas Corporation, December 1972).

(101 mm × 101 mm × 3.96 m) wood beams, placed one block length on center (see Figure 11d) formed the basic support structure for the ferrocement roof. The wood beams were attached to the structure by metal straps wrapped around the beam and nailed to the concrete blocks. The ferrocement roof was fabricated with two layers of 1/4-in.-square (6-mm) wire mesh (hardware cloth) fastened with 3/4-in. (19-mm) staples to the cross-beam. The wire mesh was covered with a 1/2-in. (13-mm) layer of S-type mortar which penetrated both layers.

A three-block-wide, six-course-high opening was formed at ground level of the south wall to provide access into the shelter. A 3 × 3 × 48 in. (76 × 76 × 1212 mm) angle iron was placed over the opening and cut into the blocks. The opening was protected externally by an L-shaped wall which was coated with BlocBond.

A vertical-mounted 1/2-in. (13-mm) steel plate was positioned inside the shelter on a rotation pivot, which allowed for 360 degrees of rotation. The plate was 9 × 9 1/2 ft (2.74 × 2.89 m) and was equipped with a locking pin mechanism to prevent rotation caused by projectile impact. The plate prevented projectiles penetrating the masonry walls from striking the opposite wall.

Figure 11 shows four views of the shelter at various stages of construction. Table 5 gives a complete list of material requirements for total construction of a semi-hardened structure, and Table 6 summarizes construction equipment requirements.

Construction Time Study

The shelter was built between 21 June and 1 July 1976 by two semi-skilled workers who were not familiar with the surface-bonded concrete block construction technique. Work activity was supervised at the site by a CERL engineer. The average working day was 8 1/2 hours, from 7:30 a.m. to 4:00 p.m. Considering travel time to and from the construction site, lunch, and break periods, each man worked 6 hours daily on actual construction operations. Two days of construction time were lost due to inclement weather. Table 7 summarizes the construction process on a time basis.

Seventy-six man-hours were required to build the entire structure, including the walls with filler material and surface bonding, the roof, and the entry; however, this number of hours is based on having all required materials readily available at the site and an adequate, level foundation provided.

Since the two-man labor team was unfamiliar with the technique of placing BlocBond, the internal walls were coated relatively slowly; however, the external walls were completed in one-half this time as the workmen became more familiar with the technique (Table 7).

Ballistic Resistance

Four different types of weapons were used to determine the ballistic resistance of the surface-bonded building: M16 rifle, 5.56 mm ammunition; M1911 pistol, .45-caliber; M60 machine gun, 7.62 mm; and M2 machine gun, .50-caliber. Tables A1 through A4 give the results of the tests.

M16 Rifle, 5.56 mm, 1193 Ball Ammunition

Three rounds were fired at each of the four types of walls: cells were mortar-filled, earth-filled, pea-gravel-filled, or not filled) from distances of 164 ft (50 m), 328 ft (100 m), and 656 ft (200 m). Only the outer cell wall was penetrated at all ranges. Therefore, it can be concluded that total protection from weapons equivalent to the M16 rifle can be achieved from this type of construction.

M1911 Pistol, .45-Caliber, 1911 Ball Ammunition

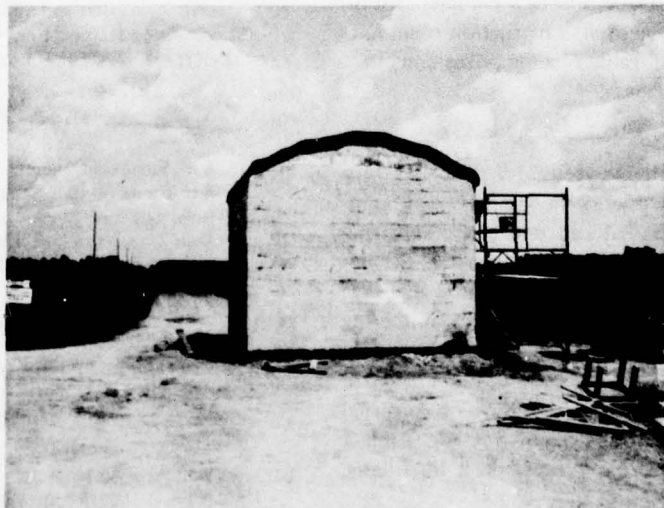
Three rounds were fired at each of the four types of walls from distances of 33 ft (10 m) and 82 ft

Table 5
Shelter Material Requirements
(SI conversion factors: 1 in. = 25.4 mm; 1 ft = 0.3048 m;
1 cu ft = 2.83 × 10⁻² m³; and 1 ton = 907.185 kg.)

Item No.	Material Type	Amount Required
1	8-in. Standard Concrete Block	660 units
2	8-in. Standard Half Concrete Block	20 units
3	Solid Concrete Block 4 × 8 × 16 in.	25 units
4	Solid Concrete Block 4 × 4 × 8 in.	25 units
5	Wood Posts 4 in. × 4 in. × 14 ft	10 units
6	Steel Angle Iron 1L 3 × 3 × 48 in.	2 units
7	1/4-in. Square Hardware Cloth - 6 ft wide	100 ft
8	BlocBond (80-lb sack)	15 sacks
9	Cement Mortar - Roof and Bedding Joints @ 11 cu ft	
	Portland Cement	2 sacks
	Masonry Cement	4 sacks
	Sand	1/2 ton
10	Wall Filler Material (Considering all four walls are to be filled with one of the given material types)	
	a. 3/8-in. Pea Gravel	10 tons
	b. Loose Pulverized Soil (S. G. = 2.3)	1 1/2 tons
	c. Cement Mortar @ 156 cu ft	
	1. Portland Cement	24 sacks
	2. Masonry Cement	48 sacks
	3. Sand	6 tons

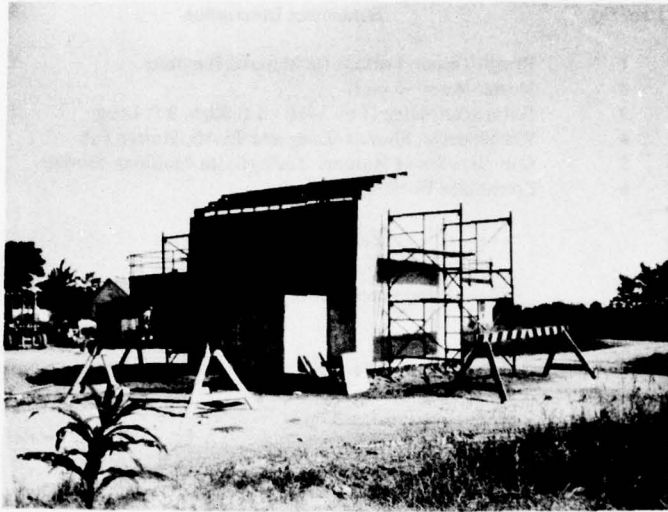


a. North wall.

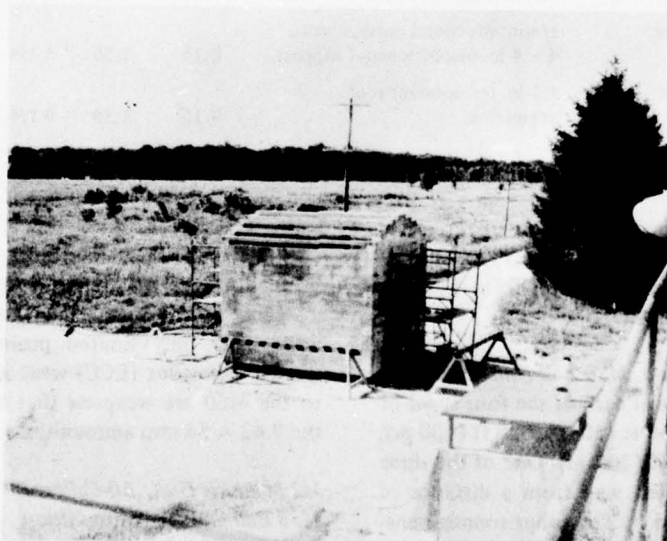


b. West wall.

Figure 11. Four views of the hardened shelter.



c. South and east walls.



d. North and west walls.

Figure 11 (cont)

Table 6
Shelter Construction Equipment Requirements
(SI conversion factors: 1 cu ft = 2.83×10^{-2} m³ and 1 ft = 0.3048 m.)

Item No.	Equipment Description
1	Rough Terrain Forklift for Material Handling
2	Mortar Mixer - 5 cu ft
3	Metal Scaffolding (Two Sets) - 4 ft High, 8 ft Long
4	Wheelbarrow, Shovels (Long and Short), Mortar Tub
5	Complete Set of Masonry Tools (Extra Finishing Trowel)
6	Pressurized Watering System

Table 7
Shelter Construction Time Study
(SI conversion factor: 1 in. = 25.4 mm)

Day No.	Date	Construction Details	Time		Working Hours	Man-Hours
			Start	End		
1	21 June 1976	Foundation prepared; sandbed and armor plate.	10:30	11:30	--	--
		First block course placed and leveled in mortar bed.	11:30	3:15	3 1/4	6 1/2
2	22 June	All walls up seven courses, core fill material in place.	8:15	3:15	6	12
3	23 June	Stacking of north and west walls completed, including filler.	8:15	3:15	6	12
4	24 June	Stacking of east and south walls completed, including filler.	8:15	3:15	6	12
5	29 June	1/8-in. BlocBond coating completed (interior only).	8:15	2:30	5 1/4	10 1/2
6	30 June	1/8-in. BlocBond outside walls, 4 x 4 in. placed for roof support.	8:15	2:30	5 1/4	10 1/2
7	1 July	1/2-in. ferrocement roof completed.	8:15	3:30	6 1/4	12 1/2
Total Man-Hours						76

(25 m). Only the outer surface bonding material was penetrated at both ranges. Therefore, this type of construction can provide total protection from weapons equivalent to the M1911 pistol.

M60 Machine Gun, 7.62 mm, M80 Ball Ammunition

Three rounds were fired at each of the four types of walls from distances of 164 ft (50 m), 328 ft (100 m), 492 ft (150 m), and 656 ft (200 m). One of the three rounds fired at the unfilled wall from a distance of 492 ft (150 m) penetrated it. The other rounds penetrated the outer cell wall only. One of the three rounds fired at the earth-filled wall from 164 ft (50 m) produced a small amount of spalling on the interior face. The other rounds penetrated only the outer cell wall. Only the outer cell walls of the mortar-filled and pea-gravel-filled walls were penetrated for all ranges. There-

fore, it was concluded that filling the cells of the concrete block with mortar or pea gravel will provide protection against weapons equivalent to the M60 machine gun, but that the earth-filled and unfilled walls offer only limited protection. Eurasian Communist Countries (ECC) weapons that are comparable to the M60 are weapons that use 7.72 x 39 mm and the 7.62 x 54 mm ammunition.

M2 Machine Gun, .50-Caliber; M33 Ball and AP Ammunition

Three rounds were fired at each of the four walls from 656 ft (200 m); all of the walls were penetrated completely. Therefore, it was concluded that the surface-bonded concrete block construction described in this study offers no protection against the M2 .50-caliber machine gun.

Data on the ballistic resistance of concrete block (Tables A1 through A4 and C7 and C8) show that heavier and denser standard concrete block provides a greater resistance to penetration than lightweight block; however, it is interesting to note that the lightweight block having cells filled with steel-fiber mortar was not penetrated by ball ammunition from the .50-caliber machine gun, although the standard block filled with plain mortar was. These data indicate that a standard concrete block with steel-fiber mortar fill should successfully resist penetration by a .50-caliber machine gun.

7 CONCLUSIONS

The surface bonding technique is a rapid, low-skill procedure for constructing concrete block buildings for use as hardened shelters in the theater of operations.

Surface-bonded concrete walls whose block cells are filled with either mortar or pea gravel will provide complete protection against weapons comparable to the M16 rifle, the M1911 pistol, and the M60 machine gun.

Surface-bonded lightweight concrete block having cells filled with steel-fiber mortar will provide complete protection against weapons comparable to M14 and M16 rifles, the M1911 pistol, and the M2 machine gun.

The standard concrete block-Blocbond System has a shear strength efficiency of 92 percent when compared to a conventional wall with mortar joints.

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**APPENDIX A:
BALLISTIC TEST DATA
FOR FULL-SCALE SHELTER**

**Table A1
Ballistic Resistance of Concrete Block Building
M16 Rifle, 5.56 mm; M193 Ball Ammunition**

Range Meters	Wall	Fill Material	Penetration
50	North	Pea Gravel	Outer cell wall
100	North	Pea Gravel	Outer cell wall
200	North	Pea Gravel	Outer cell wall
50	South	None	Outer cell wall only
100	South	None	Outer cell wall only
200	South	None	Outer cell wall only
50	East	Mortar	Outer cell wall only
100	East	Mortar	Outer cell wall only
200	East	Mortar	Outer cell wall only
50	West	Earth	Outer cell wall only
100	West	Earth	Outer cell wall only
200	West	Earth	Outer cell wall only

Note: The data for each range represents the results of three firings.

**Table A2
Ballistic Resistance of Concrete Block Building
M1911 Pistol, .45-Caliber, M1911 Ball Ammunition**

Range Meters	Wall	Fill Material	Penetration
10	North	Pea Gravel	Outer surface bonding material only
25	North	Pea Gravel	Outer surface bonding material only
10	South	None	Outer surface bonding material only
25	South	None	Outer surface bonding material only
10	East	Mortar	Outer surface bonding material only
25	East	Mortar	Outer surface bonding material only
10	West	Earth	Outer surface bonding material only
25	West	Earth	Outer surface bonding material only

Note: The data for each range represents the results of three firings.

Table A3
Ballistic Resistance of Concrete Block Building
M60 Machine Gun, 7.62 mm, M80 Ball Ammunition

Range Meters	Wall	Fill Material	Penetration
50	North	Pea Gravel	Outer cell wall only
100	North	Pea Gravel	Outer cell wall only
150	North	Pea Gravel	Outer cell wall only
200	North	Pea Gravel	Outer cell wall only
50	South	None	Outer cell wall only
100	South	None	Outer cell wall only
150	South	None	One of three penetrated completely
200	South	None	Outer cell wall only
50	East	Mortar	Outer cell wall into mortar
100	East	Mortar	Outer cell wall into mortar
150	East	Mortar	Outer cell wall into mortar
200	East	Mortar	Outer cell wall into mortar
50	West	Earth	One of three produced slight spalling inside
100	West	Earth	Outer cell wall into earth
150	West	Earth	Outer cell wall into earth
200	West	Earth	Outer cell wall into earth

Note: The data for each range represents the results of three firings. Weapons comparable to the M60 include the 7.62 x 39 mm and the 7.62 x 54 mm of the Eurasian Communist countries.

Table A4
Ballistic Resistance of Concrete Block Building
M2 Machine Gun, .50-Caliber, M33 Ball and AP Ammunition

Range Meters	Wall	Fill Material	Ammo	Penetration
200	North	Pea Gravel	Ball	Complete
200	South	None	Ball	Complete
200	East	Mortar	Ball	Complete
200	East	Mortar	AP	Complete
200	West	Earth	Ball	Complete

Note: The data for each range represents the results of three firings.

**APPENDIX B:
TEST DATA AND ANALYSIS FOR BLOCK PANEL SHEAR TESTS**

The following are definitions of abbreviations used in Appendix B:

- LW** – Lightweight Block (cinder)
- STD** – Standardweight Block
- JF** – Joints Filled (BlocBond placed between tightly butted block joints)
- SJ** – Smearred Joints (external parging of joints only)
- MJ** – Mortar Joints
- BB** – Fiberglass Cement (BlocBond)

Table B1
Shear Panel Fabrication Data
(SI conversion factor: 1 cu in. = 1.64×10^{-5} m³.)

Spec. No.	Type	Fab. Date*	Vol. of BlocBond Per Side - cu in.	Companion Specimens	
				Compression	Tension
1	1/8 LW	24 MAR	261.5	---	---
2	1/8 LW	29 MAR	261.5	---	---
3	1/8 LW	29 MAR	261.5	---	---
4	1/8 STD	29 MAR	261.5	---	---
5	1/8 STD	30 MAR	261.5	---	---
6	1/8 STD	30 MAR	261.5	---	---
7	1/16 STD	30 MAR	130.8	---	---
8	1/16 LW	31 MAR	130.8	---	---
9	1/4 STD	31 MAR	523.1	---	---
10	1/16 STD	31 MAR	130.8	---	---
11	1/16 STD	31 MAR	130.8	---	---
12	1/16 LW	31 MAR	130.8	---	---
13	1/16 LW	31 MAR	130.8	---	---
14	1/16 LW	5 APR	130.8	3	3
15	1/16 LW	5 APR	130.8	3	3
16	1/4 LW	7 APR	523.1	3	3
17	1/4 LW	7 APR	523.1	3	3
18	1/4 LW	7 APR	523.1	3	3
19	1/4 STD	8 APR	523.1	3	3
20	1/4 STD	8 APR	523.1	3	3
21	LWJF	12 APR	NA	---	---
22	LWSJ	15 APR	22.0	---	---
23	LWSJ	15 APR	22.0	---	---
24	STDSJ	15 APR	22.0	---	---
25	STDSJ	20 APR	22.0	---	---
26	STDSJ	20 APR	22.0	---	---
27	LWMJ	3 MAY	None	3	---
28	LWMJ	4 MAY	None	3	---
29	LWMJ	5 MAY	None	3	---
30	STDMJ	6 MAY	None	3	---
31	STDMJ	10 MAY	None	3	---
32	STDMJ	12 MAY	None	3	---

*1976

Table B2
Laboratory Test Data - Shear Panels
(SI conversion factors: 1 kip = 4.45×10^3 N, and 1 in. = 25.4 mm.)

Spec. No.	Type	Date* Fab.	Age Days	Ult. Load (kips)	1st Crack Load (kips)	Horiz. Elong. 1st Crack (in.)	Vert. Contract 1st Crack (in.)
1	1/8 LW	24 MAR	21 APR	28	28.5	28.9	---
2	1/8 LW	29 MAR	26 APR	28	28.5	31.2	0.045
3	1/8 LW	29 MAR	26 APR	28	24.0	27.0	0.053
4	1/8 STD	29 MAR	27 APR	29	47.0	53.8	0.065
5	1/8 STD	30 MAR	27 APR	28	26.0	35.0	0.055
6	1/8 STD	30 MAR	27 APR	28	36.4	39.0	0.045
7	1/16 STD	30 MAR	28 APR	29	31.0	32.0	0.045
8	1/16 LW	31 MAR	29 APR	29	14.5	16.4	0.03
9	1/4 STD	31 MAR	29 APR	29	31.0	43.8	0.043
10	1/16 STD	31 MAR	20 APR	20	30.5	36.2	0.055
11	1/16 STD	31 MAR	29 APR	29	24.8	24.8	0.055
12	1/16 LW	31 MAR	29 APR	29	17.5	22.4	0.04
13	1/16 LW	31 MAR	30 APR	30	13.5	20.8	0.045
14	1/16 LW	5 APR	3 MAY	28	9.0	14.1	0.039
15	1/16 LW	5 APR	3 MAY	28	20.0	23.9	0.059
16	1/4 LW	7 APR	5 MAY	28	33.2	35.4	0.080
17	1/4 LW	7 APR	5 MAY	28	26.8	30.8	0.055
18	1/4 LW	7 APR	5 MAY	28	26.0	32.0	0.045
19	1/4 STD	8 APR	6 MAY	28	30.5	35.9	0.043
20	1/4 STD	8 APR	6 MAY	28	34.0	38.1	0.040
21	LWJF	12 APR	10 MAY	28	54.8	54.8	0.077
22	LWSJ	15 APR	13 MAY	28	6.0	12.8	0.06
23	LWSJ	15 APR	14 MAY	29	13.0	15.8	0.044
24	STDSJ	15 APR	14 MAY	29	9.0	10.4	0.025
25	STDSJ	20 APR	18 MAY	28	12.5	13.3	0.037
26	STDSJ	20 APR	18 MAY	28	8.5	12.3	0.034
27	LWMJ	3 MAY	1 JUN	29	25.5	28.1	0.035
28	LWMJ	4 MAY	2 JUN	29	49.2	49.2	0.077
29	LWMJ	5 MAY	3 JUN	29	42.9	42.9	0.071
30	STDMJ	6 MAY	4 JUN	29	42.8	42.8	0.052
31	STDMJ	10 MAY	7 JUN	28	48.9	48.9	0.061
32	STDMJ	12 MAY	9 JUN	28	53.2	53.2	0.054

*1976

Table B3
Laboratory Test Data - Compression Cubes
(SI conversion factors: 1 kip = 4.45×10^3 N, and 1 ksi = 6.89×10^6 Pa.)

Spec. No.	Date* Fab.	Age Days	Ult. Comp. Load (kips)			Avg Load (kips)	Average Comp. Str. (ksi)
			a	b	c		
14	5 APR	3 MAY	28	13.93	18.25	17.74	16.64
15	5 APR	3 MAY	28	14.39	14.67	15.88	14.98
16	5 APR	3 MAY	28	14.78	15.63	14.64	15.02
17	7 APR	5 MAY	28	19.19	16.77	16.68	17.55
18	7 APR	5 MAY	28	12.28	13.80	14.58	13.55

*1976

Table B3 (cont)

Laboratory Test Data – Compression Cubes
(SI conversion factors: 1 kip = 4.45×10^3 N, and 1 ksi = 6.89×10^6 Pa.)

Spec. No.	Date* Fab.	Test	Age Days	Ult. Comp. Load (kips)			Avg Load (kips)	Average Comp. Str. (ksi)
				a	b	c		
19	8 APR	6 MAY	28	17.24	15.68	18.24	17.05	4.26
20	8 APR	6 MAY	28	14.26	13.92	15.09	14.42	3.61
27	3 MAY	1 JUN	29	13.00	16.26	17.28	15.51	3.88
28	4 MAY	2 JUN	29	21.80	21.00	22.20	21.67	5.42
29	5 MAY	3 JUN	29	9.40	22.40	20.00	17.27	4.32
30	6 MAY	4 JUN	28	16.70	17.10	18.10	17.30	4.33
31	10 MAY	7 JUN	28	15.40	14.60	16.00	15.33	3.83
32	12 MAY	9 JUN	28	18.30	18.90	18.00	18.40	4.60

*1976

Table B4

Laboratory Test Data – Tensile Specimens
(SI conversion factors: 1 lb = 4.45 N, and 1 psi = 6.89×10^3 Pa.)

Spec. No.	Date* Fab.	Test	Age Days	Ult. Tensile Load (lb)			Avg Load (lb)	Average Tensile Strength (psi)
				a	b	c		
14	5 APR	3 MAY	28	698.	703.	616.	672.	672.
15	5 APR	3 MAY	28	591.	522.	191.	435.	435.
16	5 APR	3 MAY	28	629.	553.	655.	612.	612.
17	7 APR	5 MAY	28	491.	305.	475.	424.	424.
18	7 APR	5 MAY	28	432.	536.	474.	481.	481.
19	8 APR	6 MAY	28	621.	519.	680.	607.	607.
20	8 APR	6 MAY	28	469.	532.	481.	494.	494.

*1976

Table B5

Data Analysis – Shear Panels
(SI conversion factors: 1 lb/ft = 1.46 N/m, and 1 kip = 4.45×10^3 N.)

Spec. No.	Type	Ult. Load (kips)	Vert Strain $\Delta V/64.7 \times 10^{-4}$	Hor Strain $\Delta H/60 \times 10^{-5}$	Shear Strain $\times 10^{-4}$	Racking Strength (lb/ft of wall)	Ult. Shear Strength (gross area)	Failure Mode
								1. Diag Ten. B.B. 2. Crush End Bik 3. Shear in Joints 4. Ten in Blk & Jt
8	1/16 LW	16.4	4.64	5.0	5.14	2968	32.8	1
12	1/16 LW	22.4	6.18	2.5	6.43	4054	44.8	1
13	1/16 LW	20.8	7.11	—	—	3764	41.6	1
14	1/16 LW	14.1	6.03	6.67	6.70	2551	28.2	1
15	1/16 LW	23.9	9.12	5.33	9.65	4326	47.8	1
7	1/16 STD	32.0	7.42	7.50	8.17	5792	64.6	—
10	1/16 STD	36.2	8.50	10.8	9.58	6552	73.1	1
11	1/16 STD	24.8	8.50	6.67	9.17	4489	50.1	1

Table B5 (cont)

Data Analysis - Shear Panels

(SI conversion factors: 1 lb/ft = 1.46 N/m, and 1 kip = 4.45 × 10³ N.)

Spec. No.	Type	Ult. Load (kips)	Vert Strain $\Delta V/64.7 \times 10^{-4}$	Hor Strain $\Delta H/60 \times 10^{-5}$	Shear Strain $\times 10^{-4}$	Racking Strength (lb/ft of wall)	Ult. Shear Strength (gross area)	Failure Mode
								1. Diag Ten. B.B. 2. Crush End Blk 3. Shear in Joints 4. Ten in Blk & Jt
1	1/8 LW	28.9	---	---	---	5231	57.8	1
2	1/8 LW	31.2	6.96	---	---	5647	62.4	1
3	1/8 LW	27.0	8.19	---	---	4887	54.0	1
4	1/8 STD	53.8	10.0	---	---	9737	108.6	1
5	1/8 STD	35.0	8.50	4.17	8.92	6335	70.7	1
6	1/8 STD	39.0	6.96	3.33	7.29	7059	78.8	1
16	1/4 LW	35.4	12.4	5.83	12.98	6407	70.8	1, 2
17	1/4 LW	30.8	8.50	9.17	9.42	5575	61.6	1
18	1/4 LW	32.0	6.96	9.17	7.88	5792	64.0	1
9	1/4 STD	43.8	6.65	3.33	6.98	7927	88.4	1, 2
19	1/4 STD	35.9	6.65	4.17	7.09	6498	72.5	1, 2
20	1/4 STD	38.1	6.18	3.33	6.51	6896	76.9	1, 2
27	LWMJ	28.1	5.41	5.0	5.91	4878	54.2	3
28	LWMJ	49.2	11.9	6.67	6.09	8540	94.9	3
29	LWMJ	42.9	12.0	13.70	13.37	7447	82.7	3
30	STDMJ	42.8	8.04	10.9	9.13	7429	82.5	3
31	STDMJ	48.9	9.43	5.0	9.93	8488	94.3	3
32	STDMJ	53.2	8.35	5.83	8.93	9235	102.6	3
22	LWSJ	12.8	9.27	1.67	9.44	2316	25.6	1
23	LWSJ	15.8	6.80	---	---	2860	31.6	1
24	STDSJ	10.4	3.86	---	---	1882	21.0	1
25	STDSJ	13.3	5.72	5.0	6.22	2407	26.9	1
26	STDSJ	12.3	5.26	8.33	6.09	2226	24.8	1
21	LWJF	54.8	11.9	10.67	12.97	9918	109.6	4

Table B6

Material Properties of Concrete Masonry Units

(SI conversion factor: 1 lb/ft³ = 16.01 kg/m³, and 1 psi = 6.892 × 10³ Pa.)

Spec. No.	Dimensions Inches		Faceshell Thickness (in.)	Oven Dry Weight (lb)	Absorption (lb/cu ft)	Area (sq in.)		Comp. Stress Gross Area (psi)
	Nominal	Actual				Gross	Net	
L1	8 × 8 × 16	7 5/8 × 7 5/8 × 15 5/8	1.25	25.77	10.92	119.3	62.9	1559
L2	8 × 8 × 16	7 5/8 × 7 5/8 × 15 5/8	1.25	26.19	10.87	119.3	62.5	1680
L3	8 × 8 × 16	7 5/8 × 7 5/8 × 15 5/8	1.25	25.89	10.84	119.3	62.0	1538
H1	8 × 8 × 16	7 9/16 × 7 9/16 × 15 5/8	1.25	38.15	6.95	118.2	66.6	2838
H2	8 × 8 × 16	7 9/16 × 7 9/16 × 15 5/8	1.25	37.93	7.06	118.2	66.1	2868
H3	8 × 8 × 16	7 9/16 × 7 9/16 × 15 5/8	1.25	38.20	6.96	118.2	66.4	2927

**APPENDIX C:
TEST DATA FOR STATIC BENDING TESTS, GROUND
SHOCK TESTS, BALLISTIC TESTS, AND TENSILE TESTS**

The following are definitions of abbreviations used in this appendix:

Block Core Filler Material:

- MC** – Cement Mortar (sand, Portland cement, and water)
- FC** – Fibrous Cement (sand, Portland cement, water, and steel fibers)

Surface Bond Material:

- BB1** – BlocBond, one side only
- BB2** – BlocBond, two sides

Blocks:

- CB** – Lightweight Block (cinder)
- STD** – Standardweight Block

Reinforcement:

- WM** – 1/2-in. (12-mm) square woven wire mesh
- CW** – 1-in. (25-mm) hexagonal netting (chicken wire)

Ferrocement Mortar:

- MM** – Cement Mortar (sand, Portland cement, and water)
- FC** – Fibrous Cement (sand, Portland cement, water, and steel fibers)
- BB** – Fiberglass Cement (BlocBond) (Portland cement, lime, water, and glass fibers). (Also abbreviated GFRC.)

Blocks:

- LW** – Lightweight Block (cinder)
- STD** – Standardweight Block

Block Joints:

- MJ** – Mortar Joints
- BBJ** – BlocBond Joints
- SJ** – Smearred Joints (external parging)

Table C1
Static Bending Tests – Block Panels – Test Data
(SI conversion factor: 1 lb = 4.448 N.)

Spec. No.	Specimen Designation	Block Type	Joint Material	BlocBond No. of Sides	Core Mat'l, Mortar Type	Max. Appl. Load at Failure (lb)	Center Line Defl. at Max. Load (in.)
5	CB-BB2	Lightweight	---	2	---	8060	0.034
6	CB-BB2	Lightweight	---	2	---	7100	0.036
7	CB-BB2	Lightweight	---	2	---	6600	0.024
8	CB-BB1-BBJ	Lightweight	BlocBond	1	---	7540	0.040
9	CB-BB1-BBJ	Lightweight	BlocBond	1	---	7620	0.030
10	CB-BB1-BBJ	Lightweight	BlocBond	1	---	7880	0.066
11	CB-BB1-BBJ	Lightweight	BlocBond	1	---	8240	0.051
12	CB-BB2-FC	Lightweight	---	2	Fibrous	8760	0.046
13	CB-BB2-FC	Lightweight	---	2	Fibrous	7920	0.031
15	CB-MJ-MC	Lightweight	Mortar	---	Mortar	6060	0.084
16	CB-MJ-MC	Lightweight	Mortar	---	Mortar	6160	0.026
17	CB-MJ-MC	Lightweight	Mortar	---	Mortar	6680	0.010
18	CB-MJ-MC	Lightweight	Mortar	---	Mortar	6740	0.014

Table C2
Static Bending Tests – Ferrocement Panels – Test Data
(SI conversion factors: 1 lb = 4.448 N, and 1 in. = 25.4 mm.)

Spec. No.	Specimen Designation	Material Type		No. of Mesh Layers	Max. Appl. Load at Failure (lb)	Centerline Defl. at Max. Load (in.)
		Cement	Wire			
1	6MMCW	Mortar	Hex. Netting	6	1935	2**
2	6MMCW	Mortar	Hex. Netting	6	650	2+
3	6BBCW	BlocBond	Hex. Netting	6	210	2+
4	6BBCW	BlocBond	Hex. Netting	6	250	1.95
5	6BBWM	BlocBond	Mesh	6	155	2+
6	4FCCW	Fibrous	Hex. Netting	4	240	1.40
7	4FCCW	Fibrous	Hex. Netting	4	220	2+
8	4BBCW	BlocBond	Hex. Netting	4	155	2+
9	4BBWM	BlocBond	Mesh	4	200	1.80
10	4MMCW	Mortar	Hex. Netting	4	115	1.20
11	4MMWM	Mortar	Mesh	4	430	2+
12	4MMCW	Mortar	Hex. Netting	4	115	1.20
13	3FCWM	Fibrous	Mesh	3	100	2+
14	3FCCW	Fibrous	Hex. Netting	3	180	1.70
15	3BBWM	BlocBond	Mesh	3	90	2+
16	3BBCW	BlocBond	Hex. Netting	3	50	1.0
17	3MMWM	Mortar	Mesh	3	570	2+
18	3MMCW	Mortar	Hex. Netting	3	235	2+
19	2BBWM	BlocBond	Mesh	2	60	1.60
20	2MMWM	Mortar	Mesh	2	130	2+
21	2MMWM	Mortar	Mesh	2	250	1.95

*2+ Indicates a deflection greater than 2 inches which is beyond the limits of the recording instruments.

Table C3
Shock Table Tests – Block Panels – Specimens

Spec. No.	Specimen Designation	Block Type	Joint Material	BlocBond No. of Sides	Core Filler Material
1	CB-BB1	Lightweight	---	1	---
2	CB-BB2	Lightweight	---	2	---
3	CB-BB1-BBJ	Lightweight	BlocBond	1	---
4	CB-MJ-FC	Lightweight	Mortar	---	Fibrous Cement
5	CB-MJ-MC	Lightweight	Mortar	---	Mortar Cement
6	CB-BBJ	Lightweight	BlocBond	---	---
7	CB-MJ-MC-RB*	Lightweight	Mortar	---	Mortar Cement

*Vertical rebars through blockcells

Table C4
Shock Table Tests – Block Panels – Test Data
(SI conversion factor: 1 in./sec = 2.54×10^{-2} m/sec.)

Spec. No.	Test No. at Visual Failure	Peak Table Vel. at Failure (in./sec)	No. of Table Accelerations at Failure	Peak Table Acc. at Failure (g)
1	21	12.4	15	13.6
2	26	12.8	20	17.3
3	21	12.4	15	13.6
4	23	13.6	17	13.9
5	27	13.6	21	18.7
6	21	12.4	15	13.6
7	27	13.6	12	18.7

Table C5
Shock Table Tests – Ferrocement Panels – Test Data

Spec. No.	Specimen Designation	Material Type		No. of Mesh Layers	No. of Table Accelerations at Failure	Max. Specimen Acceleration at Failure/g
		Cement	Mesh			
1	6MMCW	Mortar	Hex. Netting	6	20	21
2	6MMCW	Mortar	Hex. Netting	6	7	9.6
3	6BBCW	BlocBond	Hex. Netting	6	10	13
4	4FCCW	Fibrous	Hex. Netting	4	14	13
5	4MMWM	Mortar	Wire	4	13	17
6	3MMCW	Mortar	Hex. Netting	3	20	15
7	3MMWM	Mortar	Wire	3	6	55
8	3FCCW	Fibrous	Hex. Netting	3	18	20
9	3FCWM	Fibrous	Wire	3	5	9
10	2MMWM	Mortar	Wire	2	3	9

Table C6
Ballistic Tests – Block Panels – Specimens

Spec. No.	Specimen Designation	Block Type	Joint Material	BlocBond No. of Sides	Core Filler Material
7	CB-L-S	Lightweight	---	---	Soil
8	CB-BB2-FC	Lightweight	---	2	Fibrous Mortar
9	CB-BB1-BBJ-FC	Lightweight	BlocBond	1	Fibrous Mortar
10	CB-MJ	Lightweight	Mortar	---	---
11	CB-BB2	Lightweight	---	2	---
12	CB-MJ-FC	Lightweight	Mortar	---	Fibrous Mortar
13	CB-MJ-MC	Lightweight	Mortar	---	Mortar
14	CB-MJ	Lightweight	Mortar	---	---
15	CB-BB1	Lightweight	---	1	---
16	CB-BB2	Lightweight	---	2	---
17	CB-BB2-S	Lightweight	---	2	Soil
18	CB-MJ-MC	Lightweight	Mortar	---	Mortar
19	CB-BB1-S	Lightweight	---	1	Soil
20	CB-MJ-FC	Lightweight	Mortar	---	Fibrous Mortar
21	CB-BB2-S	Lightweight	---	2	Soil
22	CB-MJ-MC	Lightweight	Mortar	---	Mortar
23	CB-BB2-BBJ	Lightweight	BlocBond	2	---
24	CB-BB2	Lightweight	---	2	---
25	CB-MJ	Lightweight	Mortar	---	---
26	CB-MJ-S	Lightweight	Mortar	---	Soil
27	CB-BB1-FC	Lightweight	---	1	Fibrous Mortar
28	CB-MJ-MC	Lightweight	Mortar	---	Mortar
29	CB-BB1-MC	Lightweight	---	1	Mortar
30	CB-MJ	Lightweight	Mortar	---	---
31	CB-BB2-BBJ	Lightweight	BlocBond	2	---
32	CB-BB1	Lightweight	BlocBond	---	---

Table C7
Ballistic Tests – Block Panels – Penetration Data

Specimen Designation	Specimen No.(s)	Weapon			0.50 Cal. MZ
		0.45 Cal. M1911	M14	M16	
CB-MJ	10, 14-25, 30	pt	a(cw)	pt	pt
CB-MJ-FC	13, 30	a	a	pt	pt
CB-MJ-MC	13, 18, 22, 28	a(mJ)	a	pt	pt
CB-BBJ	32	a(mJ)	a(cw)	pt	pt
CB-MJ-S	26	pt	pt	pt	pt
CB-BB2	11, 16, 24	pt	pt	pt	pt
CB-BB2-S	17, 21	a	a	pt	pt
CB-BB1	15	pt	pt	pt	pt
CB-BB1-S	19	a(cw)	pt	pt	pt
CB-BB1-BBJ	23, 31	pt	a	pt	pt
CB-BB1-MC	29	a	pt	a(s)	pt
CB-BB1-BBJ-FC	9	a	a	a	a
CB-BB2-FC	8	a	a	a	a(s)
CB-BB1-FC	27	a	a	a	---

Abbreviations used in this table:
pt - passed through
a - arrested

cw - penetration of cell wall
mJ - penetration of mortar joint
s - severe spalling

Note: All weapons were fired at a range of 50 yards (46 m) except the .45 caliber pistol, which was fired at 25 yards (23 m). Ball ammunition used throughout.

Table C8
Ballistic Tests - Ferrocement Panels - Specimens

Specimen Designation	Material Type		Number of Mesh Layers
	Cement	Wire	
6MMCW	Mortar	Hex. Netting	6
6MMWM	Mortar	Mesh	6
6FCCW	Fibrous	Hex. Netting	6
6FCWM	Fibrous	Mesh	6
6BBCW	BlocBond	Hex. Netting	6
6BBWM	BlocBond	Mesh	6
4MMCW	Mortar	Hex. Netting	4
4MMWM	Mortar	Mesh	4
4FCCW	Fibrous	Hex. Netting	4
4FCWM	Fibrous	Mesh	4
4BBCW	BlocBond	Hex. Netting	4
4BBWM	BlocBond	Mesh	4
3MMCW	Mortar	Hex. Netting	3
3MMWM	Mortar	Mesh	3
3FCCW	Fibrous	Hex. Netting	3
3FCWM	Fibrous	Mesh	3
3BBCW	BlocBond	Hex. Netting	3
3BBWM	BlocBond	Mesh	3
2MMCW	Mortar	Hex. Netting	2
2MMWM	Mortar	Mesh	2
2FCCW	Fibrous	Hex. Netting	2
2FCWM	Fibrous	Mesh	2
2BBWM	BlocBond	Mesh	2

Table C9
Ballistic Tests - Ferrocement Panels - Penetration Data

Specimen Designation	Weapon			
	0.45 Cal.	M14	M16	0.50 Cal.
6MMCW	pt*	pt	pt	pt
6MMWM	pt	pt	pt	pt
6FCCW	a**	pt	pt	pt
6FCWM	a	pt	pt	pt
6BBCW	pt	pt	pt	pt
6BBWM	pt	pt	pt	pt
4MMCW	pt	pt	pt	pt
4MMWM	pt	pt	pt	pt
4FCCW	pt	pt	pt	pt
4FCWM	a	pt	pt	pt
4BBCW	pt	pt	pt	pt
4BBWM	pt	pt	pt	pt
3MMCW	pt	pt	pt	pt
3MMWM	pt	pt	pt	pt
3FCCW	pt	pt	pt	pt
3FCWM	pt	pt	pt	pt
3BBCW	pt	pt	pt	pt
3BBWM	pt	pt	pt	pt
2MMCW	pt	pt	pt	pt
2MMWM	pt	pt	pt	pt
2FCCW	pt	pt	pt	pt
2FCWM	pt	pt	pt	pt
2BBWM	pt	pt	pt	pt

pt* - Passed through
a** - Arrested

Table C10

Tensile Tests - Ferrocement Panels - Test Data
(SI conversion factors: 1 psi = 6.894 × 10³ Pa, and 1 lb = 0.454 kg.)

Spec. No.	Specimen Designation	Material Type		Age Days	Ultimate Load (lb)			Avg Ult Load (lb)	Ult Tension Strength (psi)
		Cement	Mesh		1	2	3		
1	6MMCW	Mortar	Hex. Net.	104	1292	1263	1196	1250	833
2	6FCCW	Fibrous	Hex. Net.	95	3078	2706	2700	2828	1885
3	6FCCW	Fibrous	Hex. Net.	90	1199	1104	1278	1194	796
4	6BBWM	BlocBond	Wire	75	2481	2440	2485	2469	1664
5	6BBCW	BlocBond	Hex. Net.	102	1364	1320	1239	1308	872
6	4MMCW	Mortar	Hex. Net.	104	951	986	838	925	617
7	4FCCW	Fibrous	Hex. Net.	96	1315	1274	1002	1295	863
8	4BBCW	BlocBond	Hex. Net.	103	859	975	877	907	603
9	3MMCW	Mortar	Hex. Net.	106	705	655	741	700	467
10	3FCWM	Fibrous	Wire	93	1540	1648	---	1594	1063
11	3FCWM	Fibrous	Wire	94	1779	---	---	1779	1186
12	3FCCW	Fibrous	Hex. Net.	97	990	946	990	975	650
13	3BBWM	BlocBond	Wire	75	1475	1355	924	1415	943
14	3BBCW	BlocBond	Hex. Net.	75	621	663	748	677	451
15	2MMWM	Mortar	Wire	122	881	842	774	832	555
16	2MMCW	Mortar	Hex. Net.	112	538	506	568	537	358
17	2MMCW	Mortar	Hex. Net.	132	507	451	499	486	324
18	2FCWM	Fibrous	Wire	93	1658	1750	---	1704	1136
19	2FCCW	Fibrous	Hex. Net.	97	1074	805	871	917	611
20	2BBWM	BlocBond	Wire	74	1271	1157	1298	1242	828
21	2BBCW	BlocBond	Hex. Net.	105	687	524	679	596	397

Table C11

Cylinder Compression Tests - Test Data
(SI conversion factors: 1 psi = 6.894 × 10³ Pa, and 1 kip = 4.45 × 10³ N.)

Spec. No.	Material Type	Associated Specimen	Age Days	Ultimate Load (kips)			Avg Ult Load (kips)	Ult Comp Stress (psi)
				1	2	3		
1	Fibrous Cement	6FCCW	28	71.9	76.8	79.4	76	6,050
2	Fibrous Cement	6FCCW	64	135	128	125.5	129.5	10,257
3	Fibrous Cement	4FCCW	41	123.5	124	117	121.5	9,643
4	Fibrous Cement	4FCCW	32	127	127.5	121	125	9,921
5	Fibrous Cement	3FCW	33	127	132	131.5	130	10,317
6	Mortar Cement	3MMCW	42	124.5	127	128	126.5	10,040
7	Mortar Cement	3MMWM	26	122	112	117	117	9,286
8	Fibrous Cement	2FCCW	32	121	128	135	128	10,160
9	Mortar Cement	2MMWM	59	118.5	126	120.5	121.6	9,651
10	Mortar Cement	2MMCW	48	121	128	128.5	125.8	9,984
11	BlocBond	---	63	56	58.5	52.5	55.6	4,413

Table C12
Split Cylinder Tests – Test Data
(SI conversion factors: 1 psi = 6.894×10^3 Pa, and 1 kip = 4.45×10^3 N.)

Spec. No.	Material Type	Associated Specimen	Age Days	Ultimate Load (kips)			Avg Ult Load (kips)	Ult Tension Stress (psi)
				1	2	3		
1	Mortar Cement	2MMWM	41	32	26.5	27.8	28.7	570
2	Mortar Cement	3MMCW	25	27.4	24.6	32.5	28.2	560
3	Fibrous Cement	4FCCW	18	51.5	57.6	58.0	55.7	1107
4	Fibrous Cement	6FCCW	14	53.8	38.7	37.5	43.3	861
5	BlocBond	---	44	3.6	32.6	27.7	21.3	423
6	BlocBond	---	31	38.1	30.7	33.7	34.2	680

Table C13
Beam Flexure Tests – Test Data
(SI conversion factors: 1 psi = 6.894×10^3 Pa, and 1 lb = 0.454 kg.)

Spec. No.	Material Type	Associated Specimen	Age Days	Ultimate Load (lb)			Avg Ult Load (lb)	Modulus of Rupture (psi)
				1	2	3		
1	BlocBond	---	49	5380	3320	5660	4800	1015
2	Mortar Cement	2MMWM	47	3200	3760	4380	3780	800
3	Mortar Cement	2MMCW	36	4900	5630	6520	5980	1265
4	Mortar Cement	3MMCW	30	3600	4340	3900	3950	834

**APPENDIX D:
MATERIAL SUGGESTED FOR
INCORPORATION INTO TM 5-742**

The following text is suggested for incorporation into TM 5-742, *Concrete and Masonry* (June 1970), as section iv of chapter 8, beginning p 8-16.

**SECTION IV. SURFACE-BONDED BLOCK
CONSTRUCTION**

8-17. Use.

Concrete block walls can be fabricated by coating them with a surface bonding material, consisting of Portland cement, hydrated lime, and alkali resistant fiberglass strands (commonly called glass fiber reinforced cement [GFRC]). This system eliminates the requirement for mortar joints and greatly reduces the amount of technical skill and erection time required for fabrication of load-bearing and non-load-bearing walls.

8-18. Estimating.

Because the surface-applied bonding materials eliminate all but the first mortar joint, more blocks are needed for a given area of wall, unless full size 8 X 8 X 16 in. blocks are used. Table 8-4 demonstrates how the elimination of mortar joints affects a wall laid dry with standard size blocks. In estimating requirements, check not only the length and height dimensions, but also all door openings and windows to allow for elimination of the mortar joint.

8-19. Mixing.

GFRC comes in bags premixed and ready for use with the addition of water. It is packaged in 50 and 70 lb bags depending on the manufacturer, and can be purchased with sand already mixed in if desired. GFRC is sold in two colors, gray and white.

a. Addition of Water.

When mixing GFRC for general and trial application, place 2.5 gallons of water per 50-lb bag of GFRC with sand, or 3 gallons of water per 70-lb bag without sand. Use only clean water. Blend for 2 to 3 minutes, or until all materials are thoroughly wet. Do not exceed a total mixing time of 5 minutes. Additional water may be added to achieve mortar-like consistency. Avoid excessive mixing because it may cause lumps in the mix. Wash out the mixer periodically to assure uniform, lump-free mixes.

b. False Set.

(1) The material may occasionally reach a false set. If this occurs, mix a new batch for about 1 minute, then stop mixing and wait until the material turns dull, indicating a false set. Mix through the false set for an additional 2 minutes.

(2) If the mixture begins to set, or if the mixed batch is not used within 1 hour, discard it. If the mixture has stiffened due to evaporation before 1 hour, but has not set, it can be retempered to restore workability.

*Table 8-4
Dry Stacked Wall Dimensions
(Using Standard Units)*

No. Units	Length of Wall	Height of Wall
1	1' - 3 5/8 in.	0' - 8 in.
2	2' - 7 1/4 in.	1' - 3 5/8 in.
3	3' - 10 7/8 in.	1' - 11 1/4 in.
4	5' - 2 1/2 in.	2' - 6 7/8 in.
5	6' - 6 1/8 in.	3' - 2 1/2 in.
6	7' - 9 3/4 in.	3' - 10 1/8 in.
7	9' - 1 3/8 in.	4' - 5 3/4 in.
8	10' - 5 in.	5' - 1 3/8 in.
9	11' - 8 5/8 in.	5' - 9 in.
10	13' - 0 1/4 in.	6' - 4 5/8 in.
11	14' - 3 7/8 in.	7' - 0 1/4 in.
12	15' - 7 1/2 in.	7' - 7 7/8 in.
13	16' - 11 1/8 in.	8' - 3 1/2 in.
14	18' - 2 3/4 in.	8' - 11 1/8 in.
15	19' - 6 3/8 in.	9' - 6 3/4 in.

8-20. Application.

a. Preparation.

Before applying GFRC, make sure the wall is free of dirt, oil, paint, or other foreign matter. Then wet the wall down thoroughly, making sure it is sufficiently wet so that all blocks are the same color. If the blocks appear to be drying at the joints, rewet the wall before applying GFRC.

b. Applying Mix.

Using a small trowel with rounded corners, apply the mixture smoothly onto both sides of the wall to a thickness of at least 1/8 in. Press the mix in firmly to insure a good bond (Figure 8-25). If the GFRC mixture has begun to set, or if the mixed batch is not used within 1-1/2 hours, discard it. If the mixture has stiffened due to evaporation before 1-1/2 hours, but has not set, it can be retempered to restore workability.

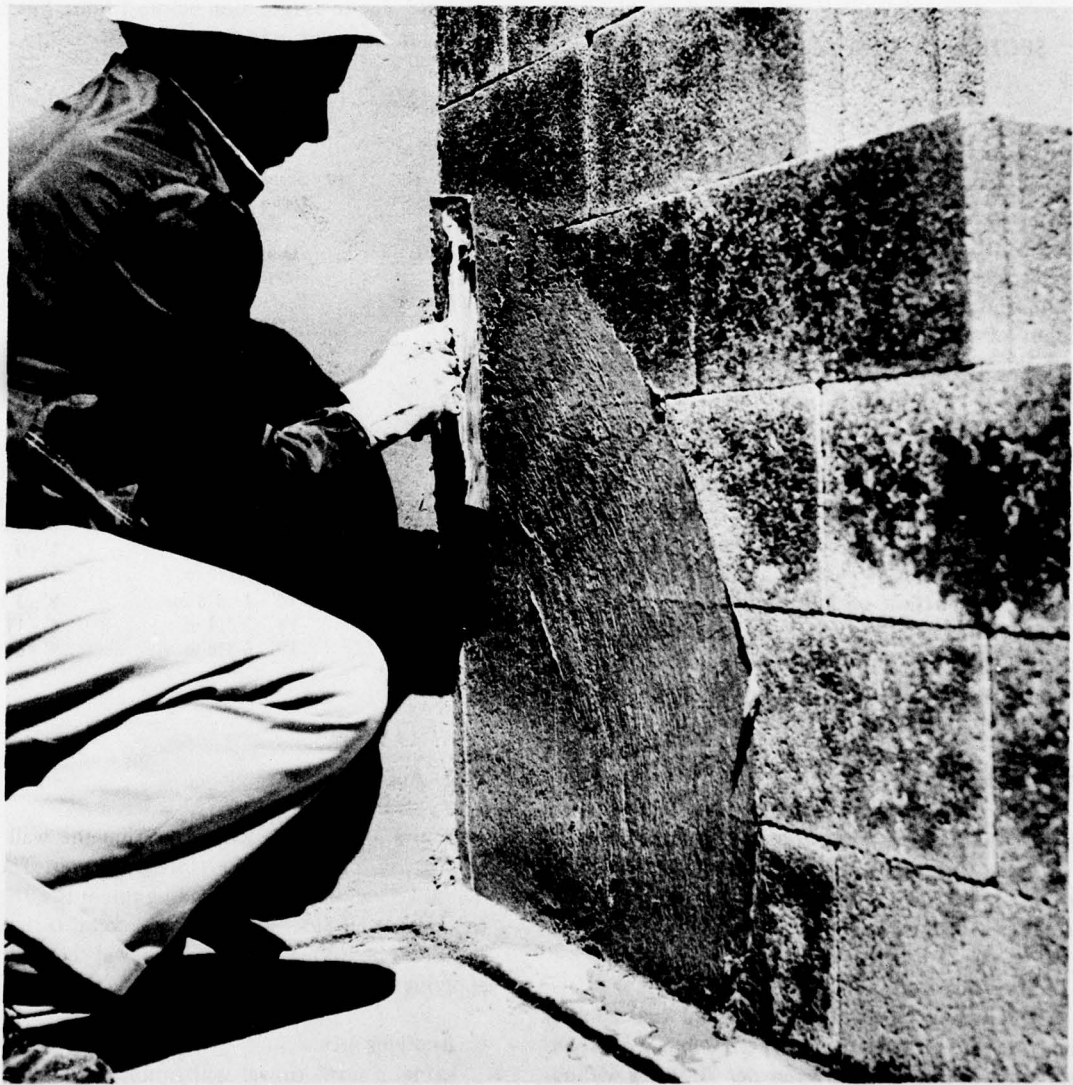


Figure 8-25. Applying mix.

c. Breaks in Application.

Always apply GFRC up to the middle of a course before a break of more than 1 hour. If application is discontinued for more than 1 hour, do not allow the joint in the GFRC to coincide with the joints between the blocks. This will insure the structural integrity of the wall. When block laying is resumed, lay the unit dry, then apply GFRC from the point left off.

d. Hot Weather Application.

(1) To provide high-quality construction during hot weather or in arid climates, normal procedures and practices must be supplemented with additional techniques. Hot weather causes a significant increase in the rate of surface evaporation of the water required for hydration. Excessive evaporation can cause dry out and cracking. Premature dry out causes a powdery surface which cannot be adequately hydrated; if a second coat of material is applied, it will not bond properly and cracking will occur.

(2) The following precautions are recommended to minimize the chance of dry out and cracking. A specific job might require one or more of these precautions.

(a) Pre-wet the wall surface more than normal to cool the block surface.

(b) Cover water hoses with dirt or boards to shade them from the sun.

(c) Cool the water.

(d) Mix and store material in a shaded area using cool water.

(e) Add extra water to the mix if humidity is below 50 percent.

(f) Erect wind breaks to reduce wind velocity over the surface.

(g) Erect sun shades to reduce the surface temperature, or work at night.

(h) Reduce the time between coats and/or between the applications and the start of curing.

(i) Minimize evaporation by enclosing the wall surface and maintaining a humid condition in the enclosure.

e. Cold Weather Procedures.

(1) The GFRC should be checked prior to use to insure that water did not enter the package and freeze during storage. When the weather is extremely unfavorable and protection requirements are most stringent, the units can be laid up dry and GFRC can be applied later when the weather is favorable. However, be sure that a dry laid wall is properly braced and protected at the top to prevent moisture such as rain, snow, or sleet from entering the masonry. In addition, safety precautions are necessary when a nonbonded wall is left at the end of the day's construction.

(2) GFRC must never be applied to a frozen surface. When the temperature is below 32°F, pre-wet the concrete masonry units with hot water if possible. When the temperature is 32°F or below, omit the post wetting procedure for GFRC. At the end of each work day, protect the top of all walls and GFRC surfaces applied that day from moisture such as rain, snow, or sleet. Cover GFRC masonry surfaces deemed unsatisfactory because of surface hardness with plastic and provide with sufficient heat and moisture for 48 hours to allow further strength development. The use of an accelerator such as calcium chloride is not recommended. Table 8-5 gives cold weather instruction and protection requirements.

8-21. Curing.

a. Protection.

If rain is expected, protect the wall with a waterproof cover until the GFRC has cured for at least 8 hours.

b. Damp Walls.

Sometime between 4 and 24 hours, depending on wind and sun effects, dampen the wall with a water mist. This will prevent the material from premature drying and aid in the curing process. Perform this wetting only if the temperature is expected to remain above 32°F for 12 hours.

c. Cold Weather.

In cold climates, when the temperature is below 40°F, allow a minimum of 7 days curing time. Be sure that all GFRC surfaces are hard before continuing construction or backfilling.

d. Normal Weather.

At normal temperature, allow walls to cure for 24 hours before continuing structural work. Cure for at

least 48 hours before backfilling and for at least 2 weeks before using mechanical compaction.

e. Arid Climates.

In arid climates, or where intense direct sunlight or winds exist, additional wetting and curing time must be allowed.

*Table 8-5
Cold Weather Requirements*

Temperature	Construction Requirements	Protection Requirements*
Above 40°F	Follow normal procedures.	Cover walls with plastic or canvas at end of work day to prevent water from entering masonry.
40° to 32°F	Heat water for prewetting units from 100° to 140°F.	Cover walls with plastic or canvas at end of wall section or work day to prevent water from entering masonry.
32° to 20°F	Heat water for prewetting units from 100°F to 140°F. Heat water for GFRC mixtures to 100° to 140°F. Maintain GFRC temperature on boards above 40°F.	With wind velocities over 5 miles per hour, provide windbreaks during the work day and cover walls at the end of wall section or work day to prevent water from entering masonry. Maintain masonry above freezing for 16 hours using auxiliary heaters under the covers.
20° to 0°F and below.	Heat water for prewetting units from 100° to 140°F. Maintain GFRC temperature on boards above 40°F.	Provide enclosures and supply sufficient heat to maintain masonry enclosure above 32°F for 24 hours.

8-22. Construction.

a. Layout.

(1) Lay the corner units first, making sure they are level and aligned. Then lay the first course, using great care so that you can build the succeeding courses into a straight, plumb, and level wall (Figure 8-26).

(2) The layout of the first block course in a running bond is very important because it will help you determine whether it will be necessary to cut an odd-size unit for the enclosure.

(3) When laying the first course, place a full mortar bed on the foundation the full thickness of the wall (Figure 8-27). Begin laying the units after the first course is set in mortar. Start at the corners and lay up the units to the desired heights, stepping back each course by half a unit length. On every third course, use a level to check the units for alignment, grade, and plumbness. Next, fill in the wall between the stepped corners. Use a mason's line for the corner to corner to insure that the top outside edge of each unit is layed level and plumb (Figure 8-28).

(4) If necessary, smooth the top and bottom of each unit by scraping two blocks together to eliminate excess material or burrs. Because concrete blocks may vary in size, shimming may be required to maintain a level and plumb wall. When shimming, use sheet metal, mortar, or GFRC (Figure 8-29).

b. Control Joints.

(1) Control joints are set in a wall at any point where horizontal strain may cause a crack. The control joint reduces the strain by allowing the wall, or structural elements adjacent to the wall, to move.

(2) Control joints are necessary at the following locations:

- (a) At changes in wall height or thickness.
- (b) At construction joints in the foundation, roof, or floor.
- (c) At chases or recesses for piping column fixtures, etc.
- (d) At abutments or walls in columns.
- (e) At one or both sides of wall openings.

(3) A control joint is generally placed at one side of an opening less than 6 ft wide, and at both jams of openings over 6 ft wide.

(4) Provide a horizontal slip plane where a reinforced lintel beam terminates at a control joint.

(5) When a flat concrete roof is poured directly on a masonry wall, both initial shrinkage and temperature changes in the slab can cause sufficient movement to crack the wall, particularly at corners. A horizontal slip plane at the junction of the roof and wall running 12 to 15 ft back from corners would permit sliding of



Figure 8-26. Lay the corner units first, making sure they are level and aligned.

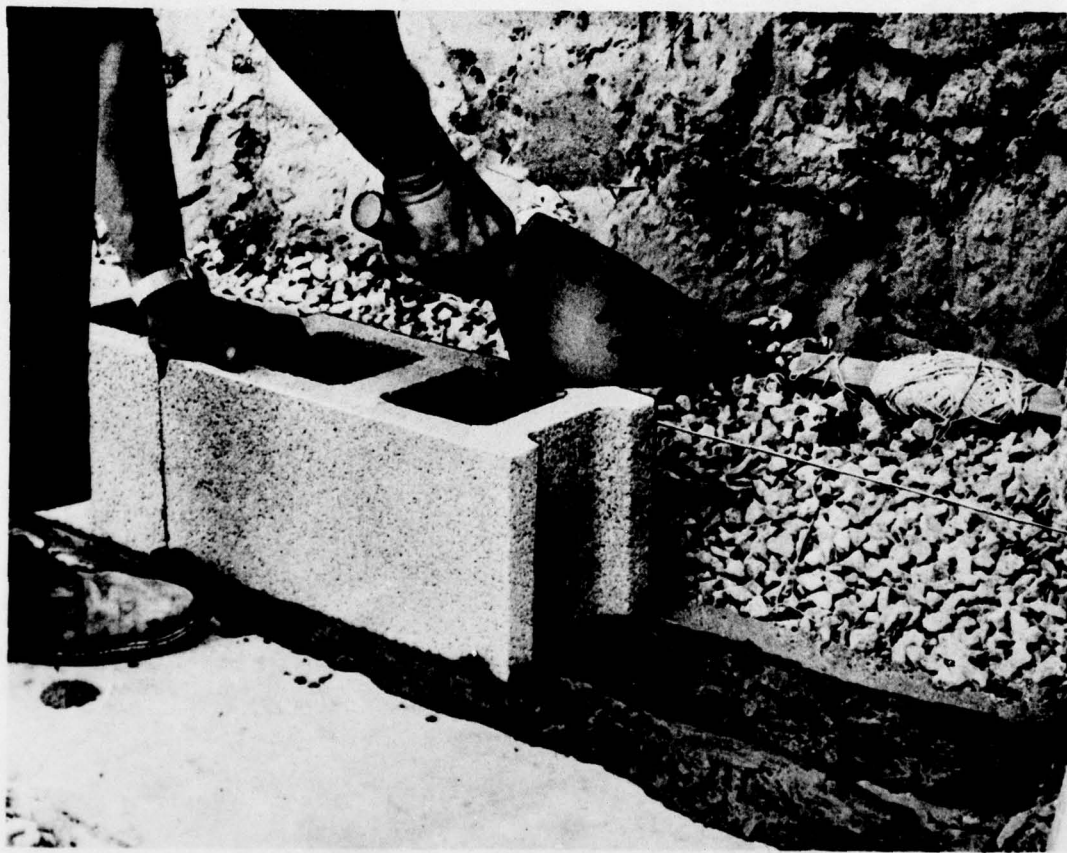


Figure 8-27. Place a full mortar bed on the foundation the full thickness of the wall.

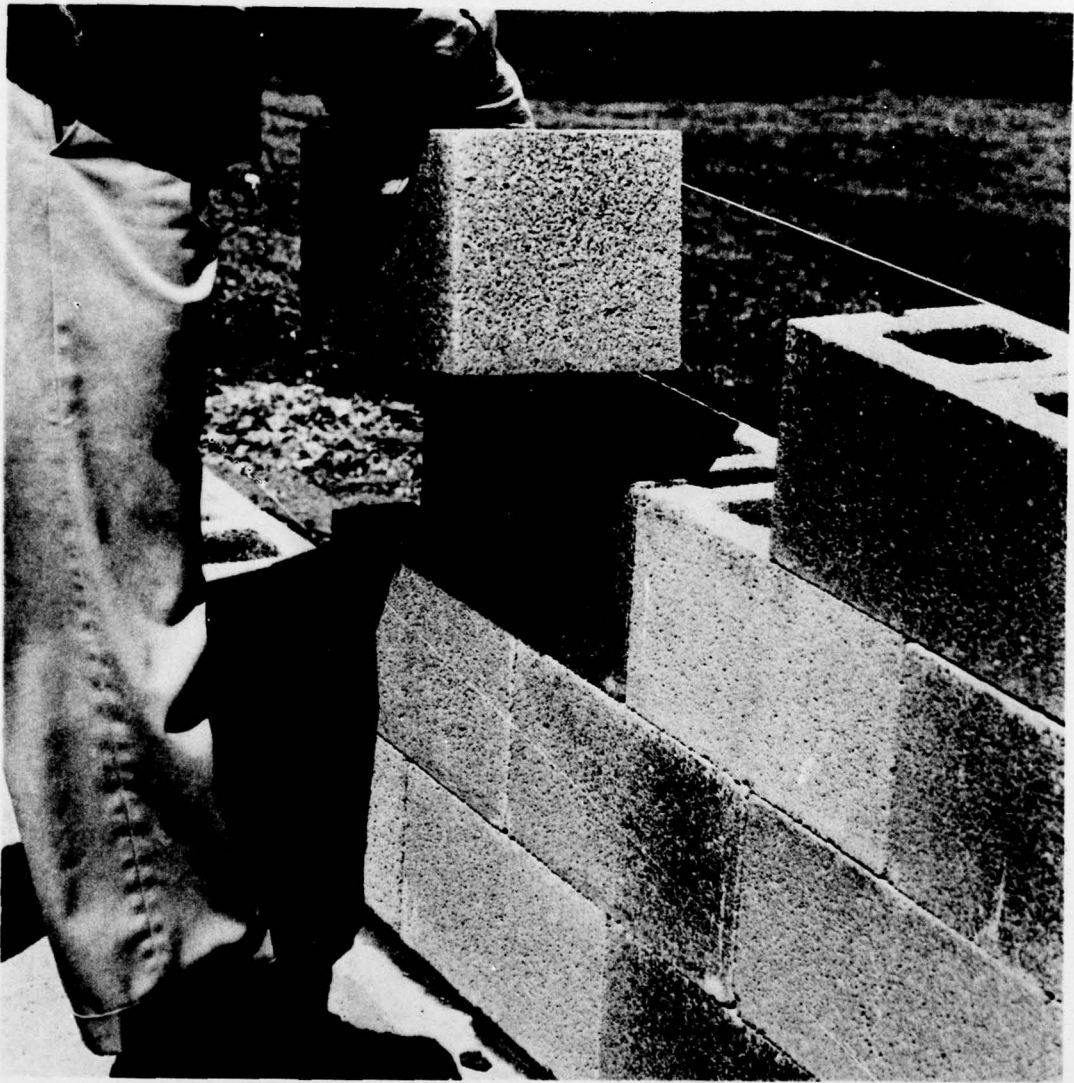


Figure 8-28. Use a mason's line for the corner to corner to insure that the outside edge of each unit is level and plumb.

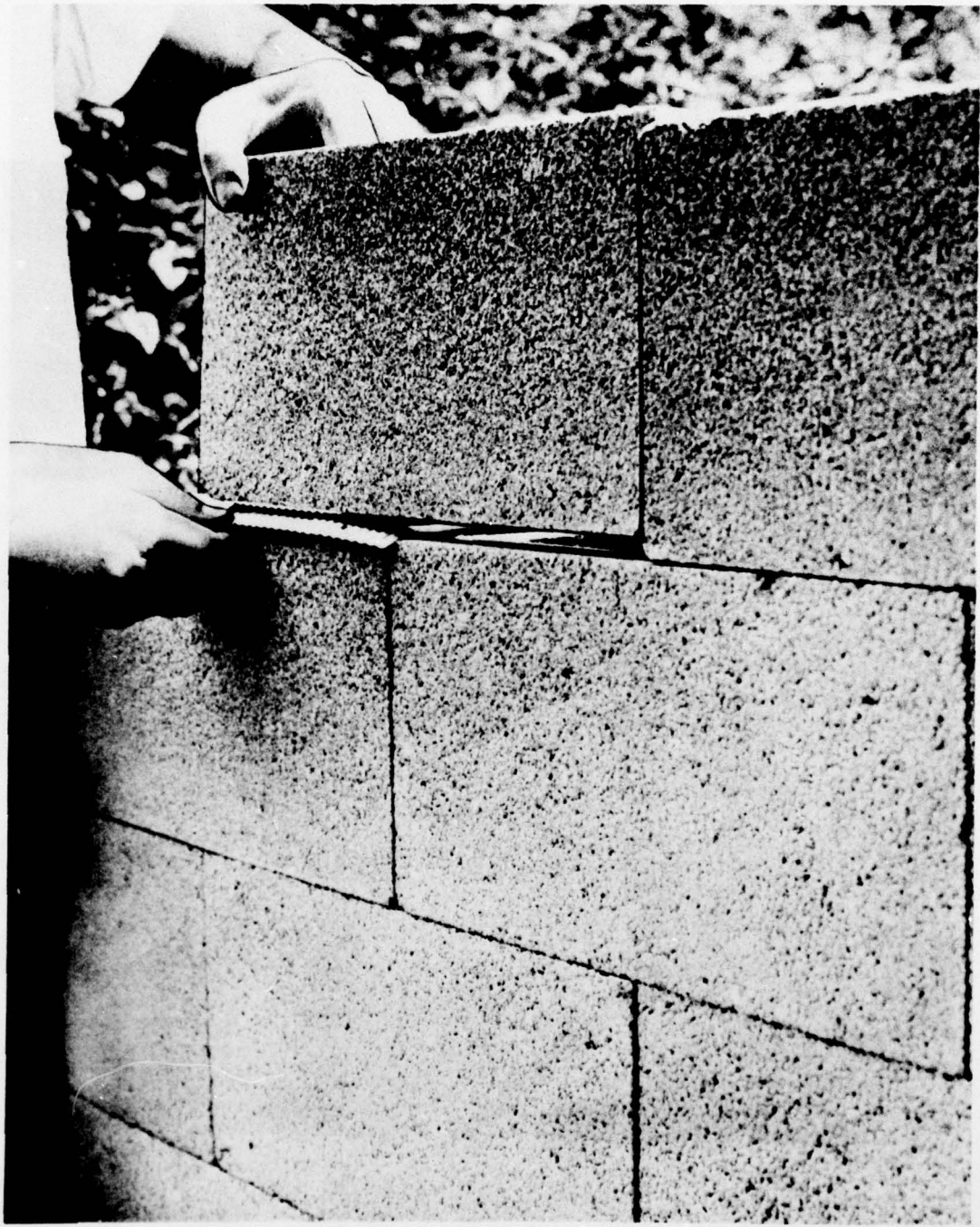


Figure 8-29. Shimming.

the roof at these points (where movement is greatest) and relieve the wall from much strain. The slip plane should terminate at a control joint.

(6) Build control joints into the wall as with a mortared wall. Use standard construction materials such as building paper and concrete, preformed gasket and sash units, or special control joint units (Table 8-6, Figure 8-30).

(7) Rake the GFRC joints; on exterior walls caulk the joint, making sure the joint is watertight. Silicone or urethane caulking compounds are recommended because they have good elastic properties and are weather resistant. Caulk depth should not be less than 1/2 in. Instead of caulked joints, special metal joint material can be attached to block surface similar to that of plaster applications.

(8) When bond beams are provided for crack control, control joints should extend through them. If there is a structural reason for a bond beam, run the steel continuously through the joint.

Table 8-6

Recommended Control Joint Spacing

	With an L (Length) H (Height) ratio of	With a Max L (Length) of
For Type I CUM's	2	40'
For Type II CUM's	2	20'
With Bond Beams 4'0.C.	4	60'

(9) To avoid cracks caused by differential movement between concrete masonry and structural framing members, such as columns, a space should be provided between the masonry and the member to allow free movement. A control joint should be located at the column.

(10) When a concrete masonry wall is reduced in thickness across the face of the column, a control

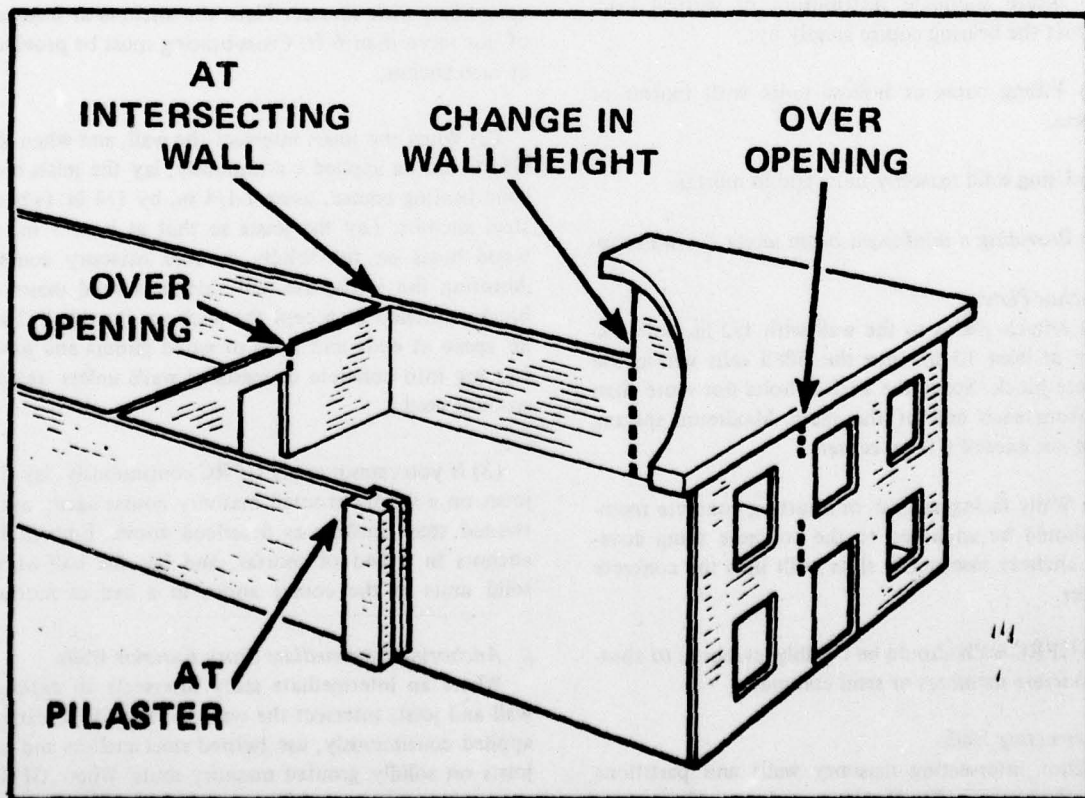


Figure 8-30. Typical control joint locations.

joint should be placed along one or both sides of the column. Thin concrete masonry across the column face should be tied to the column by means of dovetail anchors or another suitable device.

c. Temporary Bracing.

(1) Temporary bracing may consist of wood planks or steel members placed vertically against the wall. Spacing between braces will depend on the forces anticipated but should not exceed 8 ft.

(2) Temporary bracing should be provided to above-grade or below-grade walls to prevent their collapse during high winds or from other forces. Lack of adequate bracing can cause death or injury, property damage, or construction delay.

(3) Above-grade GFRC walls require temporary bracing in the same manner as mortared walls. Unless the below-grade walls are permanently anchored and the first story is in place, temporary bracing before backfilling is required.

d. Bearing Course.

To insure adequate distribution of vertical load, construct the bearing course solidly by:

(1) Filling cores of hollow units with mortar or concrete.

(2) Using solid masonry units laid in mortar.

(3) Providing a reinforced beam along the wall top.

e. Anchor Plates.

(1) Attach plates to the wall with 1/2 in. bolts extended at least 15 in. into the filled cells within the concrete block. Space the anchor bolts not more than 1 ft from each end of the plate. Maximum spacing should not exceed 6 ft on centers.

(2) Walls facing against or abutting concrete members should be anchored to the concrete using dovetailed anchors inserted in slots built into the concrete member.

(3) GFRC walls should be flexibly anchored to abutting concrete members or steel columns.

f. Intersecting Walls.

Anchor intersecting masonry walls and partitions where they join walls, floors, or columns if they are depended on for lateral support. Walls should be tied

together in a toothed masonry bond only at corners. Place intersecting walls separately and anchor them with rigid steel anchors embedded in the horizontal joint. Set the hook ends of the anchor into cores filled with mortar or GFRC. Because there is no mortar joint in GFRC construction, notch the webs of the block to accept the anchor.

g. Changes in Wall Thickness.

If a change in wall thickness is specified, cap the lower portion in the same way as the top course of a wall. Then, start the first course of the upper portion in a mortar bed.

h. Intersecting Floors or Roofs.

When constructing structural members such as floors, roof joists, concrete slabs, or lintels, place the members on hollow masonry with cells filled with mortar, or a bond beam, on a bearing course of solid masonry units at least 4 in. thick.

i. Anchoring Wood Joists.

(1) When the joists run parallel to the wall, use wall anchors with the anchored end bent down into a block core filled with mortar. Place the anchors at intervals of not more than 6 ft. Cross-bracing must be provided at each anchor.

(2) When the joists intersect the wall, and when the GFRC can be applied continuously, lay the joists on a solid bearing course, using 1-1/4 in. by 1/4 in. twisted steel anchors. Lay the joists so that at least 3 in. of wood bears on the solidly grouted masonry course. Abutting the joists, use half thickness solid masonry blocks notched to accept the anchors. Provide 1/2 in. air space at ends and sides of wood girders and joists framing into concrete or masonry walls unless treated wood is used.

(3) If you cannot apply GFRC continuously, lay the joists on a solidly grouted masonry course again, using twisted steel anchors as described above. Embed the anchors in a bed of mortar, and lay the half-width solid units in the course above in a bed of mortar.

j. Anchoring Intermediate Story Exterior Walls.

Where an intermediate story intersects an exterior wall and joists intersect the walls so that GFRC can be applied continuously, use twisted steel anchors and lay joists on solidly grouted masonry units. Where GFRC cannot be applied continuously, lay the half-width solid units and the course in a bed of mortar.

8.23. Finishing.

A trowel with rounded edges can be used to achieve a smooth or rough surface. A smooth finish is best obtained with a standard paring trowel, as is a stucco finish (Figure 8-31). A wood float can be used for a stipple finish, while a brush is best for producing a swirl finish (Figure 8-32). Supplemental finishes such as paint, plaster or stucco can also be used, but the walls must be hard and free of loose material before application. Surfaces that are dusty to the touch have received too little water for proper curing; supplemental finishes should not be applied to such walls until the surface has thoroughly hardened through additional wetting. When using paints, follow TM 5-618 (Paints and Protective Coatings) or manufacturer's recommendations for painting concrete surfaces. A bonding agent is recommended for plaster or stucco applications unless the surface is coarse or rough.

8-24. Repairs.

a. Repair Methods.

If a unit is knocked out of alignment, or a crack appears because of foundation settlement, repair the wall using one of the following methods: (1) if the GFRC material is still workable, scrape it off and re-apply GFRC, or (2) if it has set, chip out a 1-in. strip of GFRC from either side of the damaged area, clean and dampen the area, then apply a new layer of GFRC.

b. Bonding.

Damage to GFRC that has set can also be repaired by removing any loose material around the damaged area. Then trowel or spray GFRC over the damaged area. GFRC will not adhere to cured GFRC without the aid of a suitable bonding agent. The bonding agent can be mixed with the GFRC, applied to the wall and allowed to dry before the GFRC is applied, or GFRC can be applied before the bonding agent/GFRC mix dries.



Figure 8-31. A stucco effect can be obtained with a standard paring trowel.

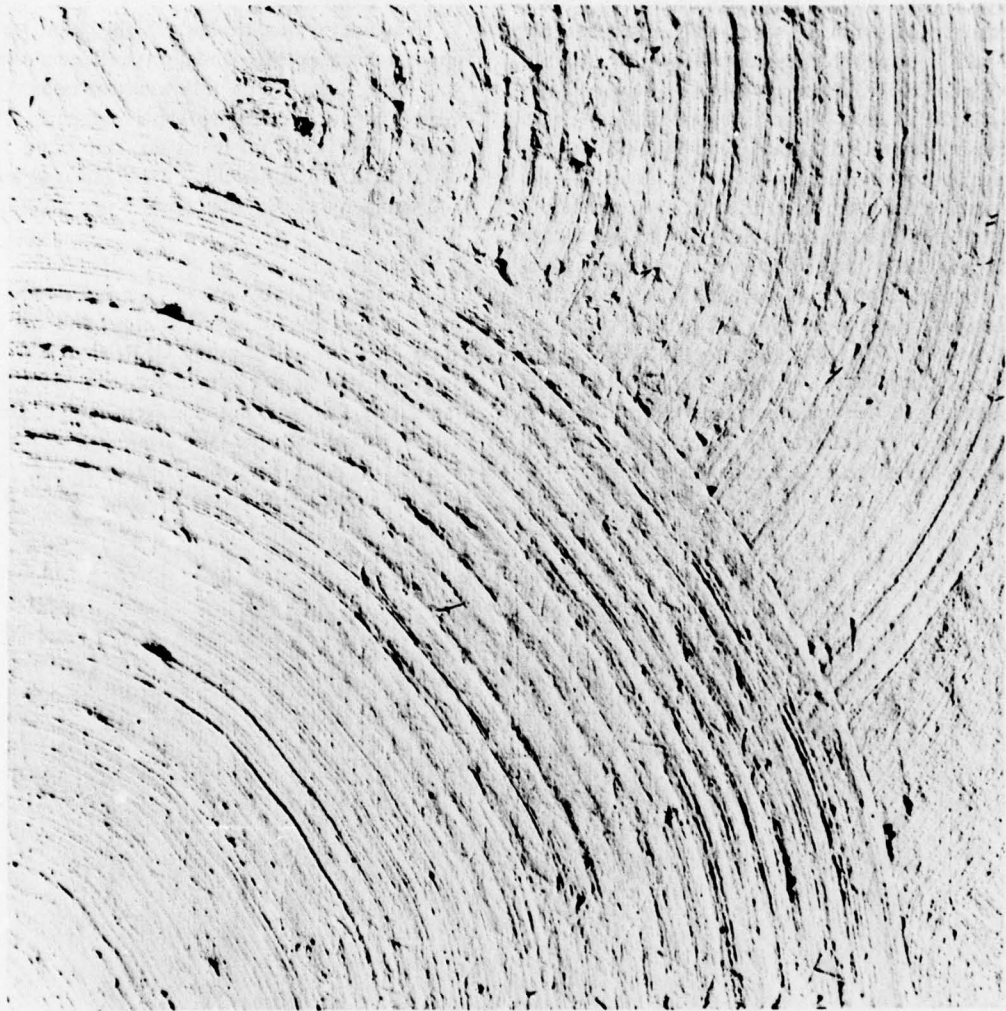


Figure 8-32. A swirled effect is best obtained with a brush.