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VOL I OF II

EXPEDIENT REPAIR OF STRUCTURAL FACILITIES (ERSF) - VOLUME I: ERSF SYSTEM DEVELOPMENT (VOLUME I OF II)

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The objective of this effort was to develop expedient systems to repair conventional weapon damage to mission-critical facilities at United States Air Forces in Europe (USAFE) and Pacific Air Forces (PACAF) forward operating bases (FOBs) in a postattack environment. Several of the developed expedient repair of structural facilities (ERSF) systems were demonstrated in the field to determine their effectiveness. Included in the development of each ERSF system was identification of the personnel, equipment, materials and procedures required to support it.

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EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this effort was to develop expedient systems to repair conventional weapon damage to mission-critical facilities at United States Air Forces in Europe (USAFE) and Pacific Air Forces (PACAF) forward operating bases (FOBs) in a postattack environment. Included in the development of each repair system was identification of the personnel, equipment, materials, and procedures required to support it.

B. BACKGROUND

To fulfill its mission after an attack, an airbase must be able to quickly generate aircraft sorties, and then sustain them. To generate sorties, an airbase must have a usable and accessible runway surface. To sustain them, an airbase's mission-critical facilities must be operational.

During the SALTY DEMO air base survivability exercise in 1985, when damage assessment teams (DATs) in the field informed the Damage Control Center (DCC) of a damaged mission-critical facility, the DCC could give them little or no guidance on how to repair the facility. This highlighted the fact that the Air Force did not have systems in-place at FOBs to expediently repair mission-critical facilities. Without such a capability, airbase mission fulfillment is jeopardized. Consequently, the expedient repair of structural facilities (ERSF) development effort described here was undertaken by the Air Force Engineering and Services Center (AFESC) Engineering Research Division's Airbase Structures and Weapon Effects Branch (RDCS).

C. SCOPE

This technical report consists of two volumes. Volume I documents the development and screening of candidate ERSF systems for expected expediently repairable damage modes to mission-critical structures. This development and screening process allowed the most promising system(s) for each damage mode to be identified. Volume I also contains results from field demonstrations of several of the developed ERSF systems. Additionally, Volume I presents recommendations for further development and fielding of ERSF systems. Volume II describes ERSF system requirements with respect to the personnel, equipment, supplies, and training needed to support each recommended ERSF system.

D. EVALUATION METHODOLOGY

ERSF systems to repair expected damage modes to mission-critical structural facilities were developed, and underwent a preliminary, subjective screening process. During this screening process, systems were modified, if possible, to improve their viability. Based on this screening and refinement process, the most viable candidate ERSF systems to repair each damage mode were identified. These candidate ERSF systems were then evaluated in-depth for effectiveness, and ranked in order of merit using evaluation matrices. Each system was evaluated in operational, structural, and logistic categories for criteria such as manpower, simplicity, strength, durability, storage life, and cost. Each system was assigned a score for each criterion. Scores ranged from one (poor) to five (excellent). A system's criterion scores in each category were summed, and the sum multiplied by a weight factor to obtain the system's category score. The three weighted category scores for the system were then summed to obtain the system's total evaluation score. Based on this score, the system was ranked against other repair systems for the same damage mode.

E. RESULTS

Identified damage modes to structural facilities, and the candidate ERSF system(s) to repair each damage mode are presented below. Recommended systems and backup systems are denoted by the symbols (R) and (B), respectively.

Damage Mode	Repair Method
Damaged Steel Frame	Cutting And Welding (R)
Destroyed Column	Shoring Jack (R)
	Glulam Timber Column (R)

Damage Mode	Repair Method
Cracked Column	Column Splint (R)
Damaged Beam/Girder	Vertical Shoring (R)
	King Post (B)
Destroyed Wall	Plywood Backing (R)
	Earth Berm (B)
	Precast Slabs (B)
	Shotcrete[1] Repair
	Masonry Blocks
Wall Breach	Plywood Backing (R)
	Earth Berm (B)
	Precast Slabs (R)
	Shotcrete[1] Repair
	Masonry Blocks
Floor/Roof Breach	Plywood And Rolled Roofing (R)
	Rapid Set Concrete (R)
	Shotcrete[1] Repair
	Seal Stairs (B)
Damaged Overpressure Door	Canvas/Sheeting Covering (R)
	Third Door Insertion (B)
	Door Replacement (B)
	Seal Door Opening (B)
Stuck Blast Door	Pry Open Door (R)
Destroyed Window	Plastic Sheeting (R)
	Acrylic Panel Replacement (R)

1 - Shotcrete System is still under development by AFESC/RDCS.

Damage Mode	Repair Method
Fractured Aircraft Shelter Floor Slab	AM2 Panel Ramp (R) Rapid Set Concrete Ramp (B) Shotcrete[1] Ramp

1 - Shotcrete System is still under development by AFESC/RDCS.

F. CONCLUSIONS

Effective expedient repair systems can be fielded to repair a wide range of conventional weapon damage to mission-critical structural facilities. The majority of the systems are simple, ease to use, and inexpensive. A shotcrete-based expedient repair system needs further development to identify suitable equipment and determine material storage requirements. However, an ERSF shotcrete system holds great promise, because of its wide range of uses, and the structural strength, durability, blast resistance, fragment penetration resistance, and airtightness of the resulting repairs.

G. RECOMMENDATIONS

Full-scale development of recommended ERSF systems should be undertaken. Engineering development of an ERSF shotcrete system should be continued to identify suitable equipment, procedures, and material storage requirements. If this engineering development effort is successful, full-scale development of the shotcrete system should be undertaken.

PREFACE

This report was prepared by Applied Research Associates, Inc. (ARA), under contract F08635-88-C-0067, for the Air Force Engineering and Services Center (AFESC), Engineering and Services Laboratory, Tyndall Air Force Base, Florida.

This report summarizes work done between 1 December 1987 and 30 October 1990. LT William R. Burkett (USN) and Capt Richard A. Ried were the AFESC/RDCS Project Officers for the subtasks under which this work was accomplished.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be abailable to the public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this report is to provide a preliminary Expedient Repair of Structural Facilities (ERSF) system user's manual for field use. The intended use and limitations of each developed ERSF system are discussed. Also, items such as personnel requirements, training, repair procedures, required equipment, materials, and supplies are discussed for each ERSF system. When possible, a repair time estimate is also given for each system.

B. BACKGROUND

This is Volume II of the two-volume technical report documenting the development of ERSF systems by the Air Force Engineering and Services Center (AFESC). ERSF is an important component of the Air Base Operability (ABO) concept in a postattack environment, that is Base Recovery After Attack (BRAAT). Just as Rapid Runway Repair (RRR) is critical to a Forward Operating Base (FOB) in fulfilling its mission of sortie generation after an attack, expedient repair of mission-critical facilities is necessary for the same reason. Even if an airbases runways are repaired, aircraft sorties cannot be sustained if critical support facilities, such as the Wing Operations Center (WOC), Base Civil Engineer (BCE) Damage Control Center (DCC), Survival/Recovery Center (SRC), and fueling and arming facilities are damaged and not functioning.

The SALTY DEMO air base survivability exercise at Spangdahlem AB, FRG in 1985 demonstrated that the Air Force could not expediently repair damaged mission-critical facilities. Due to this lack of capability, Damage Assessment Teams (DATs) in the field could not be given timely, specific guidance by the DCC with respect to repair procedures, equipment, and supplies when they reported damage to mission-critical facilities. The ERSF concept was developed to solve this problem.

ERSF can be viewed as first aid to mission-critical facilities. The intent of ERSF is not to completely repair all badly damaged facilities, but to accomplish only those minimal repairs to moderately damaged facilities needed to permit resumption of mission-critical functions. ERSF methods include wall breach repair, wall replacement, column replacement, and beam/girder shoring. Such repairs will allow damaged mission-critical facilities to continue to house their function, or at least allow mission-critical resources to be removed from the facility.

C. SCOPE

Volume I identifies expediently repairable structural damage modes of mission-critical facilities. Then ERSF systems to repair each damage mode are developed and evaluated. Based on this development and evaluation process, the best ERSF system(s) for each damage mode were selected. In this volume, Section II presents general ERSF system requirements. Subsequent sections present ERSF system descriptions, consisting of system-specific resource requirements and step-by-step repair procedures for each ERSF system selected in Volume I. These ERSF system guidelines are grouped by damage mode.

SECTION II

ERSF OVERVIEW AND GENERAL SYSTEM REQUIREMENTS

A. ERSF OVERVIEW

As planned, the ERSF process will work with the POST-DAM personal computer-based damage assessment system through the DCC. After an attack, personnel at a mission-critical facility inform the DCC that they cannot accomplish their mission because of structural damage. The DCC then dispatches a DAT to the facility. If communications are down, the DCC will use its facility priority list to dispatch DATs to facilities.

Once at the damaged facility, the DAT uses the remote component of POST-DAM to evaluate the damage and develop recommended expedient repair strategies. This information is sent to the DCC over the Survivable BRAAT Communication System (SBCS). If SBCS is not available, the civil engineering radio net will be used for communication. At the DCC, the host component of the POST-DAM system determines whether the required resources (supplies, equipment, and personnel) are available, and if so, schedules the necessary repairs. Upon direction by the SRC commander, the DCC dispatches an ERSF team to the damaged facility to accomplish the repair(s), using the systems described in this report.

Exceptions and/or additions to the general system requirements presented below are addressed in subsequent sections of this report, where individual ERSF systems are discussed.

B. GENERAL SYSTEM REQUIREMENTS

1. Personnel

The suggested standard ERSF team has five personnel. The personnel and their corresponding Air Force Specialty Codes (AFSC) are given in Table 1.

TABLE 1. ERSF TEAM COMPOSITION AND AIR FORCE SPECIALTY CODES (AFSC).

Position	Number	AFSC
Structural Technician	1	55270
Structural Specialist	3	552X0
Sheet Metal Specialist	1	55252
Equipment Operator*	1	551X1

* The equiment operator is not part of the basic five person ERSF team. The equipment operator is only needed for certain tasks, such as driving a front-end loader to form an earth berm.

2. Communication

Communication between an ERSF team in the field or staging area and the DCC will be over SCBS or, if SBCS is not available, the civil engineering radio net. Using SCBS or the radio net, the DCC will direct the DARTs and the ERSF teams to damaged facilities, and ERSF teams will inform the DCC of the status of repairs.

3. Transportation

The primary transportation mode for an ERSF team is a six-pax truck with a pintel hook trailer hitch, or some similar vehicle. The hitch is used to tow a trailer carrying bulky supplies, an air compressor, or other required pieces of equipment. Specialized supplies, such as precast concrete slabs, will require a different vehicle for transportation; for example a flatbed truck. Specialized equipment, such as the shotcrete machine described in Section VII, is self-propelled or towable.

4. Supplies, Materials, And Equipment

A list of the general supplies, materials, and equipment required by an ERSF team is given in Table 2. This list does not include specialized items required to support specific ERSF systems. Such items are addressed in the discussion of each applicable system.

5. Training

If possible, ERSF team training should be integrated with other ABO training, using existing facilities. However, it may be necessary to construct a simple framed structure at a base training area, so that different ERSF systems, such as column replacement, can be practiced.

For each ERSF method described in this report, training should include: classroom instruction, by which personnel can become familiar with the purpose of the repair and associated procedures; one to two walk-through repairs; and at least one actual repair. If possible, training should be

TABLE 2. ERSF TEAM SUPPLIES, MATERIALS, AND EQUIPMENT[1]

Item	Quantity
Rope, 1/4-Inch Diameter	100 Feet
8-Foot Step Ladders	2
Acetylene Torch Unit	1
Wire Cutters	2
Brooms	3
Coal Shovels	3
Protective Eye Wear	5
Portable Electric Generator	1
Electric Rotary Saw, With Spare Blade(s)	1
Electric Drills, With Various Sized Bits	2
Towable Air Compressor	1
Jackhammer And Bits	1
Pneumatic Concrete Dills, With Various Sized Bits	2
Stud Guns, Ramset	2
Cartridges For Stud Gun	100
Collapsible Sawhorses	2
Tape Measures, 50-Foot	2
Carpenter's Ruler	1
Carpenter's Square	1
Marker Pen	3
Carpenter's Level	1
1-Inch Adjustable Wrenches	2
Crowbar	1
Carpenter's Hammer	4
Nails, 8d, 20d, 60d (2.5 to 6 Inches Long)	200 each
Tarp, 10' x 10', With Grommets And Tie-Downs	1
Work Gloves	5 Pairs
Boards, 2- by 4-Inch, 8 Feet Long	10
Board, 4- by 4-Inch, 12 Feet Long	10
POST-DAM Remote Computer And Associated SBCS	
SBCS Communication Gear (If Available)	1
Sledge Hammer	1
Wrecking Bar	1
Bolt Cutters	1
Extra Fuel For Generator And Air Compressor	---
Lubricating Oil	---
Hard Hats	5
Work Shoes	5 Pairs

1 - For additional information on supplies, materials, and equipment carried by ERSF team members (AFSCs 552X0, 552X2, and Civil Engineering squadron personnel) as part of standard team kits see AFR 93-3, "Air Force Civil Engineering Emergency Force (BEEF) Program", Attachements 29, 32, and 38.

conducted at least every 6 months. Additional training requirements for the ERSF shotcrete system are discussed in Section VII.

6. Chemical/Biological Agents

An ERSF team must be able to function with personnel wearing chemical/biological protective clothing. However, under this condition ERSF system performance will probably be degraded with respect to repair time and team fatigue. This holds true especially for systems requiring high physical exertion.

7. ERSF Repair Limitations

As already mentioned, ERSF is only first aid to damaged mission-critical structures. ERSF does not aim to restore a damaged structure to its original structural or protective condition. Nor are ERSF repairs necessarily permanent. When time permits, a damaged structure can be permanently repaired, using standard techniques.

8. Nighttime Operations

If security conditions permit, all ERSF systems described in this report can be used at night, with appropriate lighting. The same lighting system used for nighttime RRR activities is suitable for ERSF nighttime activities.

9. Inclement Weather

All ERSF systems described in this report, except the shotcrete system, can be used without modification in rain, snow, sleet, hail, fog, cold/heat, or other inclement weather as specified in the ERSF System Specification (Reference 2 of Volume I). The shotcrete system is sensitive to moisture and cold. However, these problems can be overcome by protecting the shotcrete material from moisture during storage, and while it is being loaded in the shotcrete machine. In cold weather, the shotcrete material can be used by heating the mix water.

10. Storage

ERSF system supplies, materials, and most equipment should be stored in the War Readiness Material (WRM) inventory, thus their use will be governed by the rules and monitoring procedures associated with WRM resources. If possible, complex, specialized equipment, such as the shotcrete machine, should be used for routine base civil engineering activities, and thus stored when not in use in the Civil Engineering Squadron's equipment park. Frequent use of complex, specialzed equipment will increase operational and training proficiency, and help keep the equipment well maintained.

As already mentioned, the shotcrete material must be protected from moisture during storage. Preferably, the shotcrete material should be stored in double-lined bags, such as supersacks, under environmentally controlled conditions, such as a warehouse with controlled temperature and humidity.

C. REPAIR METHODS

In the following sections of this report, ERSF systems are described, and step-by-step procedures are given for their use. Personnel and specialized resources required by the systems are also presented, with repair time estimates, when possible. However, these ERSF system descriptions assume only one repair is needed. In a real postattack situation, the BCE must decide how many repairs can be accomplished by an ERSF team before resupply is required. Also, staging and directing the ERSF team, and deciding how resupply will occur, how multiple repairs of different types will be accomplished by one team, and other similar decisions are base-specific matters, and are best left to the discretion of the BCE.

Repair time estimates given in the following sections do not include travel time. Times are measured from the moment an ERSF team arrives at a damaged structure until the repair is completed, assuming the repair being timed is the only repair to be accomplished. Repair time estimates include setup, actual repair operations, and cleanup.

Specific ERSF supply details given in the following sections, such as lumber dimensions and quantities, are recommendations. These details can be changed for logistical or other reasons, at the discretion of the BCE.

SECTION III

DAMAGED STEEL FRAMED STRUCTURE

A. OVERVIEW

The repair of a damaged steel-framed structure is accomplished by welding steel sections over or in place of the damaged area(s), as described below. Other repair methods, such as column replacement, shotcrete, and beam/girder shoring, described in other sections of this report, can also be used when applicable, and/or when welding is unsuitable.

B. SYSTEM REQUIREMENTS

1. Personnel

The standard ERSF team described in Section II can accomplish this repair.

2. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, the welding repair method requires:

- a portable welding unit, the size and type of which will be determined by the BCE;
- appropriate eye shielding and protective clothing;
- welding electrodes (probably E8013);
- two, 1-foot long, stiff wire brushes;
- ten, 4-foot long, 1-foot high, 0.5-inch thick, steel plates (approximately 82 pounds each); and
- sections of scaffolding that can be assembled into a working platform with dimensions of approximately 8 feet by 4 feet, and up to 12 feet high.

C. SYSTEM DESCRIPTION

1. Purpose And Use

The purpose of this repair is to shore or strengthen a damaged steel framed structure. This repair method applies when sections of a steel frame are damaged, and the damaged area is accessible and can be strengthened or replaced with steel plate. If large sections of the frame are damaged or, if the damaged area is not accessible, other repair methods, such as shotcrete wall replacement or shoring by column replacement, should be considered, or the structure abandoned.

2. Repair Procedure

The repair is accomplished using the following steps:

a. Debris Clearance

Using brooms and shovels, remove loose debris from the repair area to obtain a clean and level working space. If necessary, remove damaged and/or interfering sections of the steel frame or other parts of the structure from the area, using the acetylene torch and/or jackhammer. Finally, if necessary, remove rust or other fine debris and/or contaminants from locations where welds will be made, using wire brushes.

b. Erect scaffolding

If necessary, erect scaffolding next to the area to be repaired, to provide access. Scaffolding will be required mainly when overhead beams/girders or the upper portions of columns must be repaired.

c. Positioning Steel Sections

Position the steel plates required to repair the damaged area. If necessary, trim the plates with the acetylene torch. As required, brace the plates with 2- by 4-inch boards to hold them in position prior to welding.

d. Welding

If possible, make fillet and/or butt welds along all four edges of each steel plate. Make the welds along the entire length of each edge, except where damage to the existing structure prevents it. Once welding is completed, remove the bracing boards (if used), and take down the scaffolding. This completes the repair process.

e. Shoring

If damage is extensive, and space permits, the repaired area should also be shored or strengthened with a replacement column (see Section IV), beam/girder shoring (see Section V), and/or shotcrete (see Section VII). A completed welded plate repair is illustrated in Figure 1.

3. Repair Time

Repair time depends strongly upon the type and extent of damage. Typically, a single repair requiring welding two steel plates on an overhead beam, should take approximately 60 to 90 minutes to complete, including erection and disassembly of scaffolding. This repair time estimate does not include additional shoring by other ERSF methods.

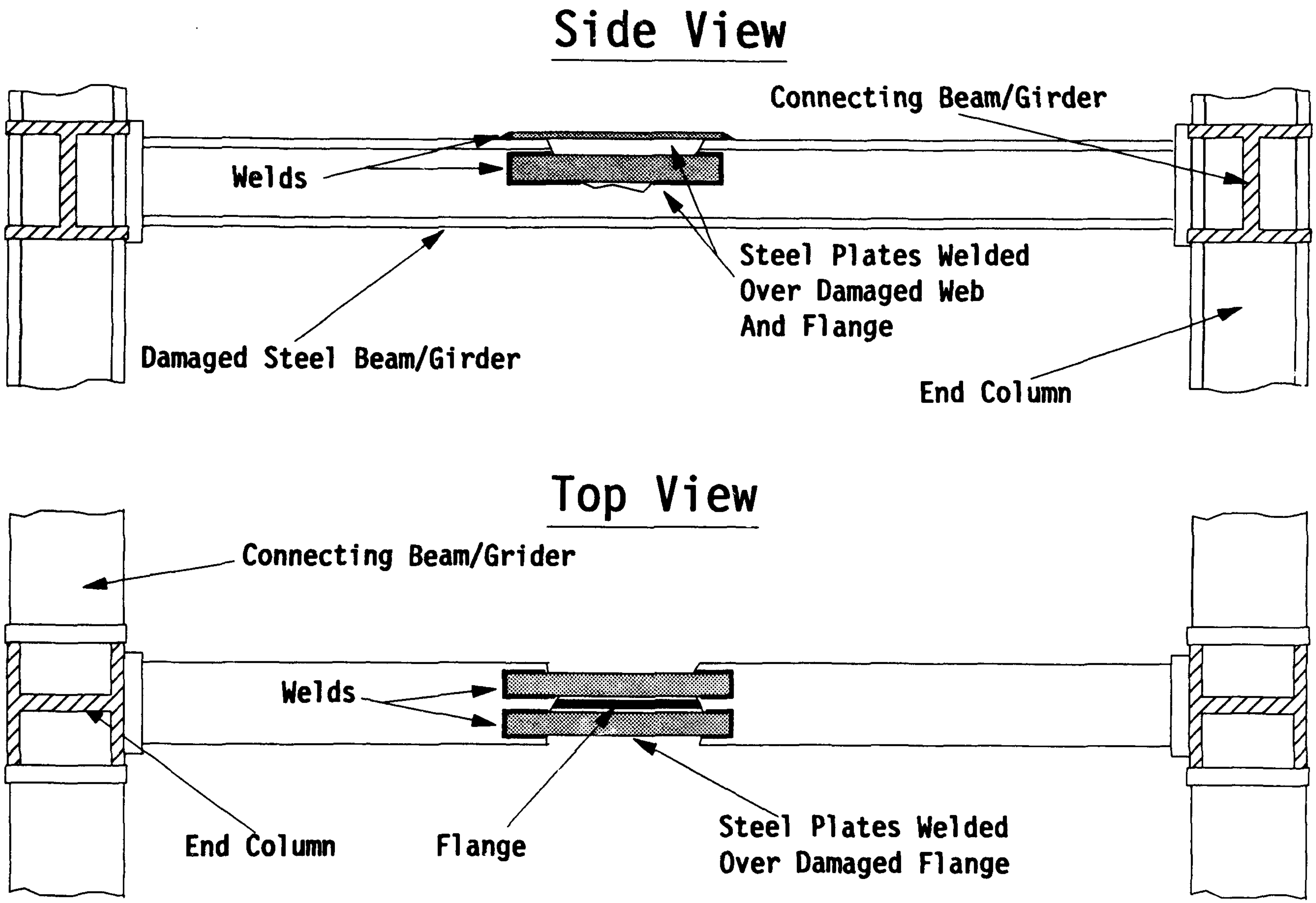


Figure 1. Steel Frame Welded Plate Repair.

SECTION IV

DESTROYED COLUMN

A. OVERVIEW

Two methods of replacing a destroyed column were identified and evaluated in Volume I: (1) glued, laminated timber (glulam) column insertion and (2) mechanical shoring jack insertion. Both systems were ranked essentially equally after evaluation, so both methods are described here. The final choice of which method should be selected for a given base, or whether both methods should be used, is best left to the BCE.

B. GLULAM COLUMN

1. System Requirements

a. Personnel

The standard ERSF team described in Section II can accomplish this repair.

b. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, the glulam column replacement method requires:

- two, 12-foot long, 12-inch square, glulam columns (having a capacity of over 165,000 pounds each; see Volume I);
- mechanical shoring jack having at least a 40,000-pound capacity, with a maximum extended height of at least 12 feet (see Table 3 for a list of shoring jack manufacturers);
- chainsaw with a spare blade and 2-cycle oil;
- twenty wooden wedges, each 6 inches long, 4 inches wide, and 0.75 to 0.25 inches thick;
- telescoping measuring rod, such as the telescoping rods used by power line maintenance personnel; and

TABLE 3. SHORING JACK MANUFACTURERS (SOURCE: THOMAS REGISTER, VOL. 7, 1989).

1) Beerman Precision, Inc.
P.O. Drawer 53432
New Orleans, LA 70153
Phone: 504-486-9391

2) CF Industrial Division of Hein-Werner Corp.
1005 Perkins Ave.
Waukesha, WI 53186
Phone: 414-542-6611

3) Duff Norton Co.
Dept. T
P. O. Box 7010
Charlotte, NC 28241
Phone: 704-588-0300

4) Elgood Mayo Corp.
P.O. Box 1413
1817-T Colonial Village Lane
Lancaster, PA 17603
Phone: 717-397-6201

5) Ellis Manufacturing Co., Inc.
4803-T N Cooper
Oklahoma City, OK 73118
Phone: 405-528-4671

6) Indianapolis Industrial Products, Inc.
1428 Sadler Circle, E. Drive
Indianapolis, IN 46221-0008
Phone: 317-359-3078

7) Milwaukee Tool & Equipment Co., Inc.
2773 S. 29th Street
P.O. Box 2039
Milwaukee, WI 53201
Phone: 414-645-2982

8) Richard Dudgeon, Inc.
7A Market Street
Stamford, CT 06902
Phone: 203-327-7217

- two rubber-headed mallets.

2. System Description

a. Purpose And Use

The purpose of this repair is to replace a badly damaged reinforced concrete column or, in certain circumstances, a steel column. The replacement column is placed as close as possible to the destroyed column, so that it will support the same overhead beam/girder as did the destroyed column. If this is not possible, two replacement columns should be placed so that they support adjoining beams/girders.

This repair method is appropriate when the damaged column can no longer support a significant structural load. If the column is cracked, but appears otherwise structurally sound, it should be splinted, using the repair method described in Section V.

b. Repair Procedure

The repair is accomplished using the following steps:

(1) Debris Clearance

Using brooms and shovels, remove loose debris from the repair area. If necessary, remove interfering concrete and protruding rebar with the jackhammer, acetylene torch, or bolt cutters, to provide a level surface at the floor and roof locations where the replacement column will be inserted. This should also provide adequate working space around the destroyed column.

(2) Trim Column

Using pieces of lumber to lift the glulam column, place it on two saw horses. Using the telescoping measuring rod, measure the distance between the floor and ceiling beam next to the damaged column. Using this measurement as a reference, measure and mark the glulam column at the appropriate length with a carpenter's square and marker pen. The marked length of the column should be 3/4-inch less than the measured distance between the floor and ceiling beam to allow the glulam column to be tilted upward into position (see below), and also allow space for the wooden wedges. Use the chainsaw to trim the glulam column to the marked length.

(3) Jack Structure

While the glulam column is being trimmed, place the mechanical shoring jack close to where the replacement column will go. Then extend the jack until its capacity is reached or it meets refusal, whichever comes first.

(4) Position Column

Again using pieces of lumber to lift the glulam column, move it to the location selected for insertion. Lay the column on the floor, then tilt it upward into position. After column placement, there should be a 3/4-inch gap between the top of the column and the overhead beam. Use the rubber-headed mallets to pound as many wooden wedges as possible into this gap, to secure the column in position.

(5) Jack Removal

Once the column is wedged into position, the shoring jack can be unloaded and removed. By removing the jack, a load is transferred to the glulam column.

(6) Brace Column

Attach 2- by 4-inch wood sills to the floor around the column, using the ramset stud gun. Attach bracing lumber to the column and the sills with hammer and nails. If space permits, the column should be braced in both the "x" and "y" directions. A completed glulam column replacement repair is illustrated in Figure 2.

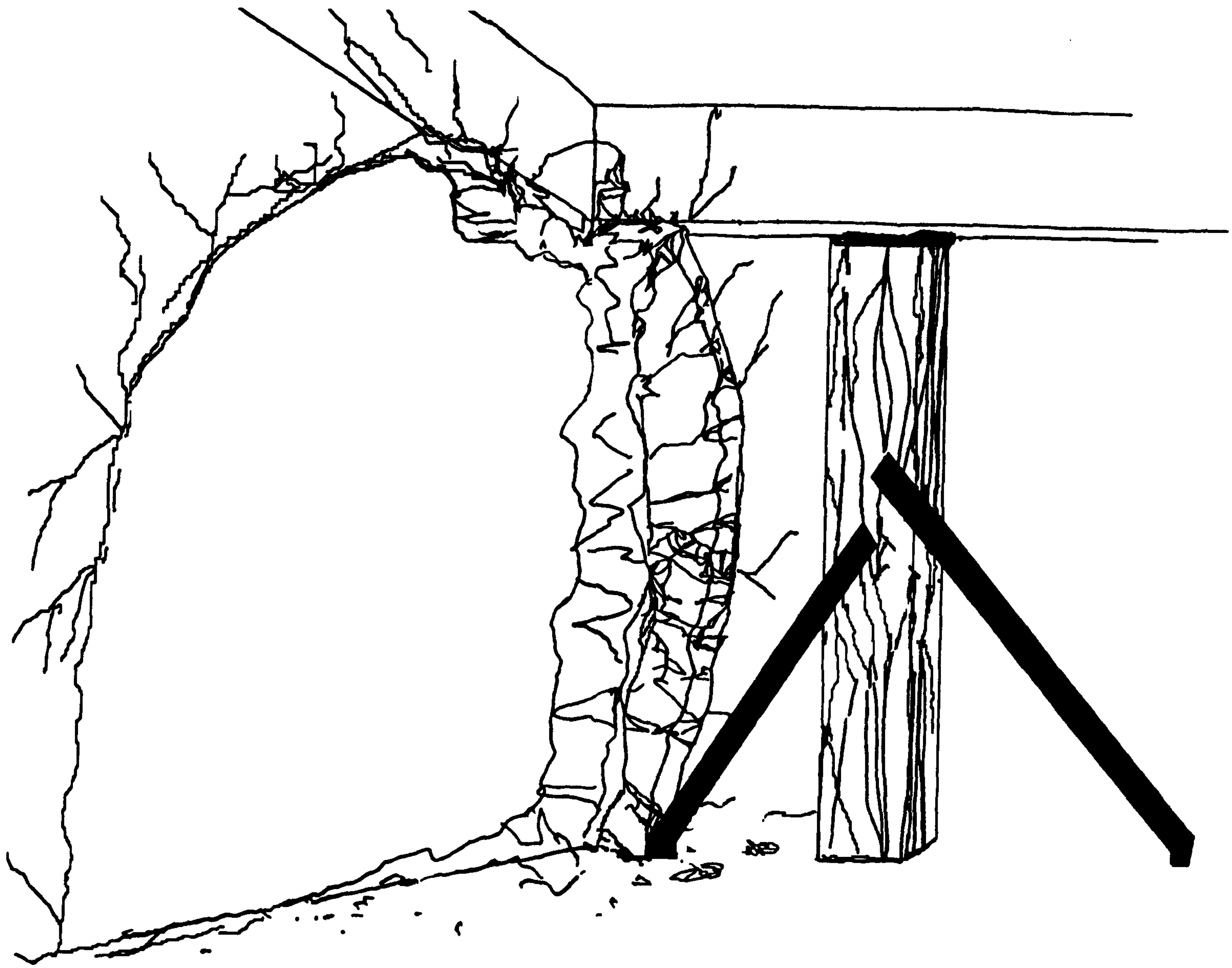


Figure 2. Completed Glulam Column Replacement Repair.

c. Repair Time

The glulam column replacement method was demonstrated in the field as part of the ERSF system development effort (see Volume I). Based on this demonstration, repair time under good conditions should range between 15 and 30 minutes. This time estimate assumes no interfering concrete or rebar need be removed to obtain level floor/roof working surfaces or an adequate working area. Add 30 to 60 minutes to the repair time estimate if interfering rebar and/or concrete must be removed from the repair area.

C. SHORING JACK

1. System Requirements

a. Personnel

The standard ERSF team described in Section II can accomplish a shoring jack column replacement repair. However, if personnel are scarce, the repair can be done with fewer personnel because a heavy timber column does not have to be handled.

b. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, the shoring jack repair method requires:

- two mechanical screw jacks, each having at least a 40,000-pound capacity and a maximum extended height of at least 12 feet (see Table 3 for a list of jack manufactures);
- metal plates, with at least two 3/4-inch diameter holes pre-drilled in them, that are attached at several points to the jacks so bracing members can be secured to jacks; and
- ten, 6-inch long, 3/4-inch diameter hex-head bolts and nuts to secure wood braces to the jack plates.

2. System Description

a. Purpose And Use

See Subsection IV-B.2.a. for details on the purpose and use of this repair method.

b. Repair Procedure

The repair is accomplished using the following steps:

(1) Debris Clearance

See Subsection IV-B.2.b.(1) for details on debris clearance.

(2) Position And Extend Jack

Position the mechanical shoring jack next to the destroyed column so that it will support the same ceiling beam/girder. Then extend the jack until it is securely wedged in position. The jack should not be extended until refusal or its capacity is reached. By only wedging the jack in position, the jack retains a reserve of structural capacity, which can be used if additional damage occurs to the structure. If the jack cannot be positioned to support the same beam/girder framing into the destroyed column, place two jacks so they support adjoining beams/girders.

(3) Brace Jack

Attach 2- by 4-inch wood sills to the floor around the jack using the ramset stud gun. Attach 2- by 4-inch wood braces to the jack plates by drilling 3/4-inch holes through the boards, and placing 3/4-inch diameter hex-head bolts through the holes in the boards and plates and tightening nuts on the ends of the bolts. Using hammer and nails, secure the boards attached to the jack to the wood sills. If space permits, the jack should be braced in both the "x" and "y" directions. A completed shoring jack column replacement repair is illustrated in Figure 3.

c. Repair Time

Judging from the glulam column replacement demonstration results already mentioned, shoring jack repair time under good conditions should range between 10 and 20 minutes. As stated for the glulam column method, this time estimate assumes no interfering concrete or rebar need be removed to obtain level floor/roof working surfaces or an adequate working area. Add 30 to 60 minutes to the repair time estimate if interfering rebar and/or concrete must be removed from the repair area.

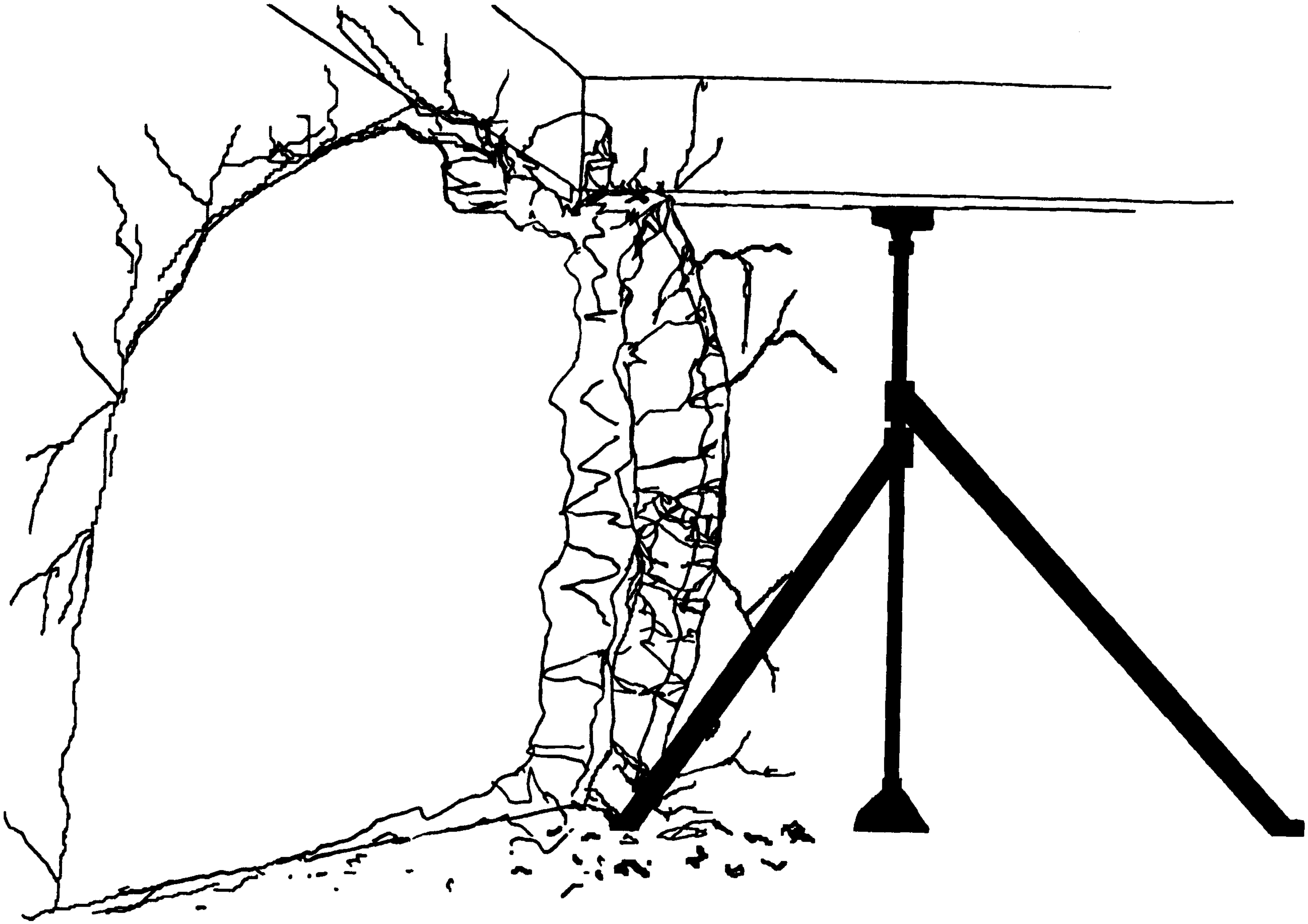


Figure 3. Completed Shoring Jack Column Replacement Repair.

SECTION V

CRACKED COLUMN

A. OVERVIEW

One method of splinting a cracked reinforced concrete column was identified and evaluated in Volume I. In this method, a splint consisting of two parallel, slotted steel plates, threaded rods, and nuts is placed around a cracked column. The splint illustrated in Figures 4 through 6 has a capacity of 28,000 pounds, and can easily be fabricated from basic construction materials available on an airbase.

B. SYSTEM REQUIREMENTS

1. Personnel

Two persons are required to accomplish this repair. From the standard ERSF team described in Section II, choose two of the structural specialists (AFSC 552X0).

2. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, the column splint repair method requires the splint already described. A repair team should carry several splints, so a column with cracks at differing locations can be completely repaired.

C. SYSTEM DESCRIPTION

1. Purpose And Use

In this repair, the cracked column is splinted at the location of the crack(s), to provide a lateral restraining force which prevents the column from slipping along the cracks. If there are cracks at several locations, multiple splints can be used. The column splint repair method is preferred

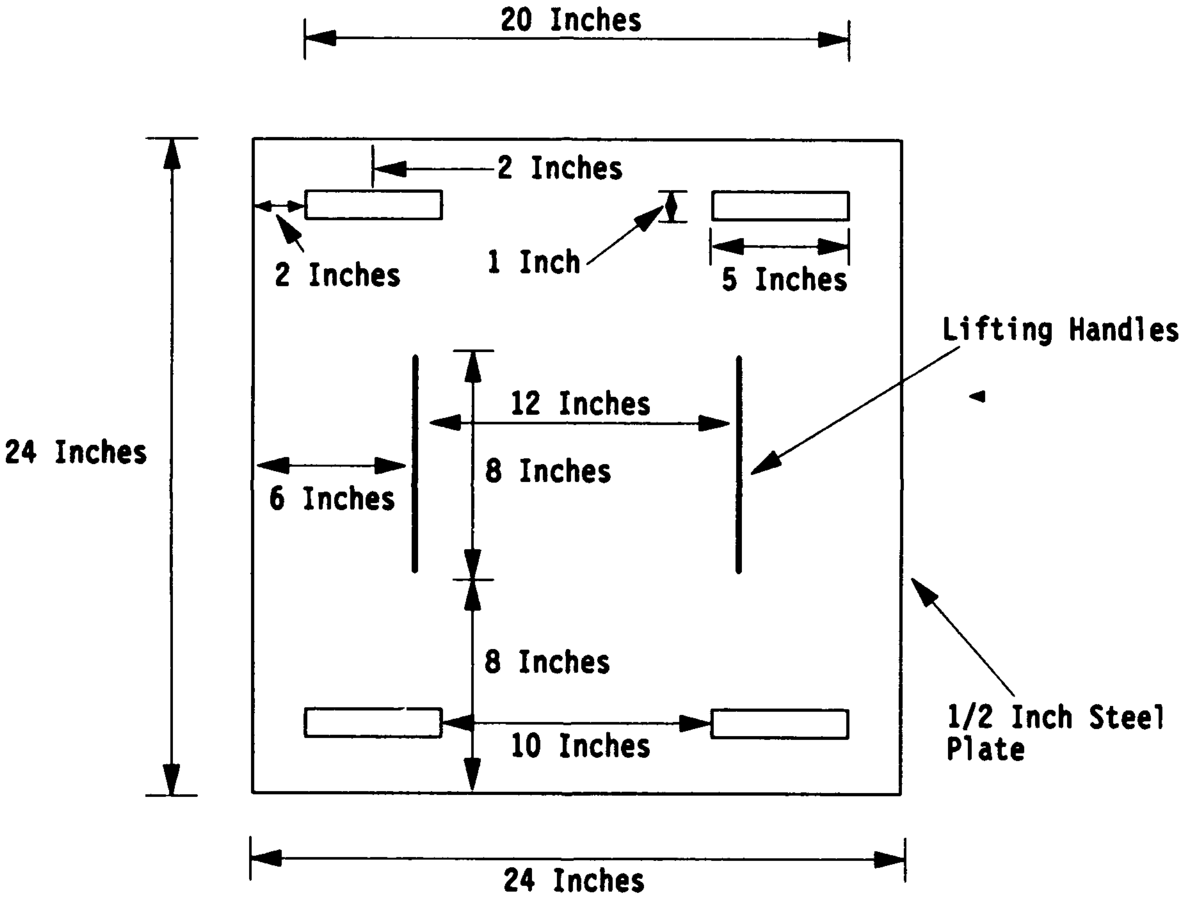


Figure 4. Detail Of Column Splint Plate.

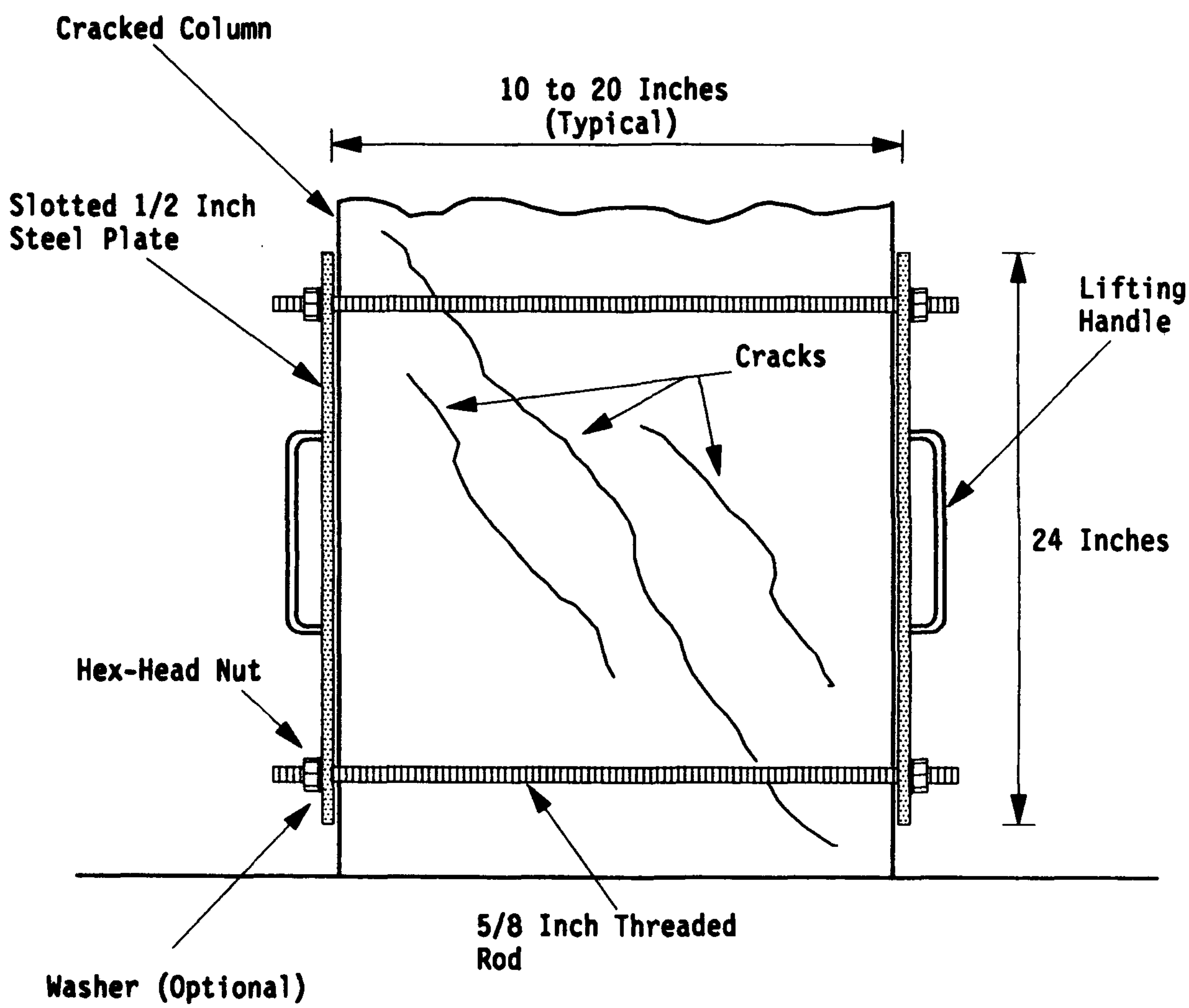


Figure 5. Side Elevation Of Column Splint.

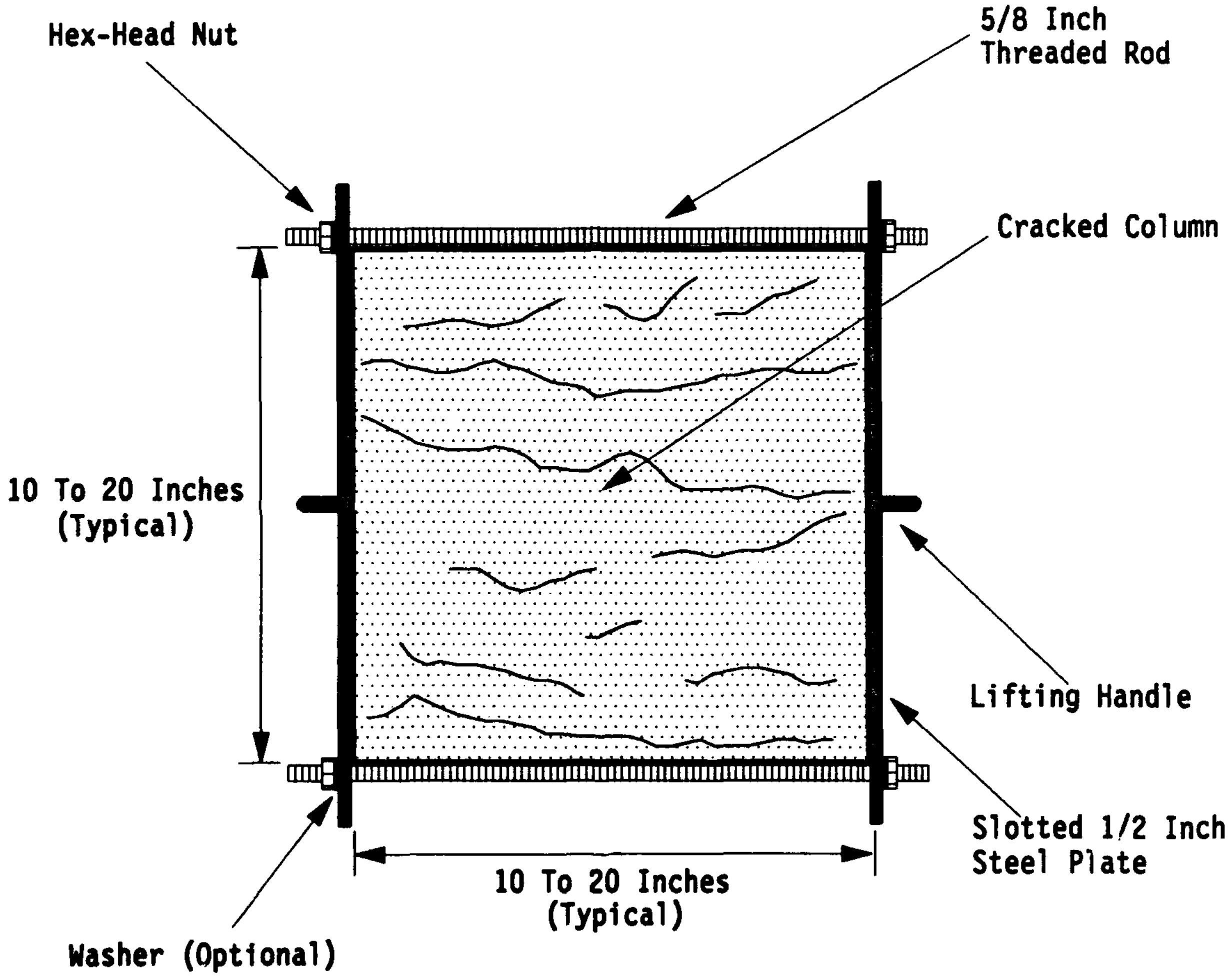


Figure 6. Plan View Of Column Splint.

over column replacement when a damaged column is still capable of carrying a significant load, because it requires less manpower and is faster. However, if a column is damaged to the extent of near collapse, column replacement methods described in Section IV should be used.

2. Repair Procedure

The repair is accomplished using the following steps:

a. Debris Clearance

Using brooms and shovels, remove loose debris from around the column to provide a clear working area. If necessary, remove loose debris from the cracked area(s) of the column.

b. Position Steel Plates

Position the two steel plates on opposite sides of the column, so they will apply a compressive force component normal, i.e., perpendicular, to the crack surface(s). Use 2- by 4-inch boards to support the plates at the correct height. Trim the boards to the correct height, and bind them to the sides of the column with rope. The plates can then be placed on top of the boards, and against the sides of the column.

c. Placement Of Threaded Rods

Place a nut and washer (optional) on one end of each of the four threaded rods. Run a threaded rod through each slot in one plate, and through the corresponding slot in the opposite plate. Place a second nut and washer (optional) on the free end of each rod. Slide each rod in the slots until the rod contacts a side of the column, as shown in Figure 5. Hand tighten all eight nuts to snug the plates to the sides of the column. Be sure each nut has at least 1/2 inch of free thread.

d. Tighten Nuts

Use a ratcheted socket wrench to tighten each nut in an alternating sequence, to ensure the plates are in even and firm contact with the sides of the column. If the length of the free ends of the threaded rods passing through the nuts prevents the use of a ratcheted socket wrench, use an open ended wrench to tighten the nuts. After tightening the nuts, remove the bracing lumber to complete the repair. A completed column splint repair is illustrated in Figure 7.

3. Repair Time

The column splint repair method was demonstrated in the field as part of the ERSF system development effort (see Volume I). Based on this demonstration, repair time under good conditions, for each cracked area of a column, should range between 5 and 15 minutes.

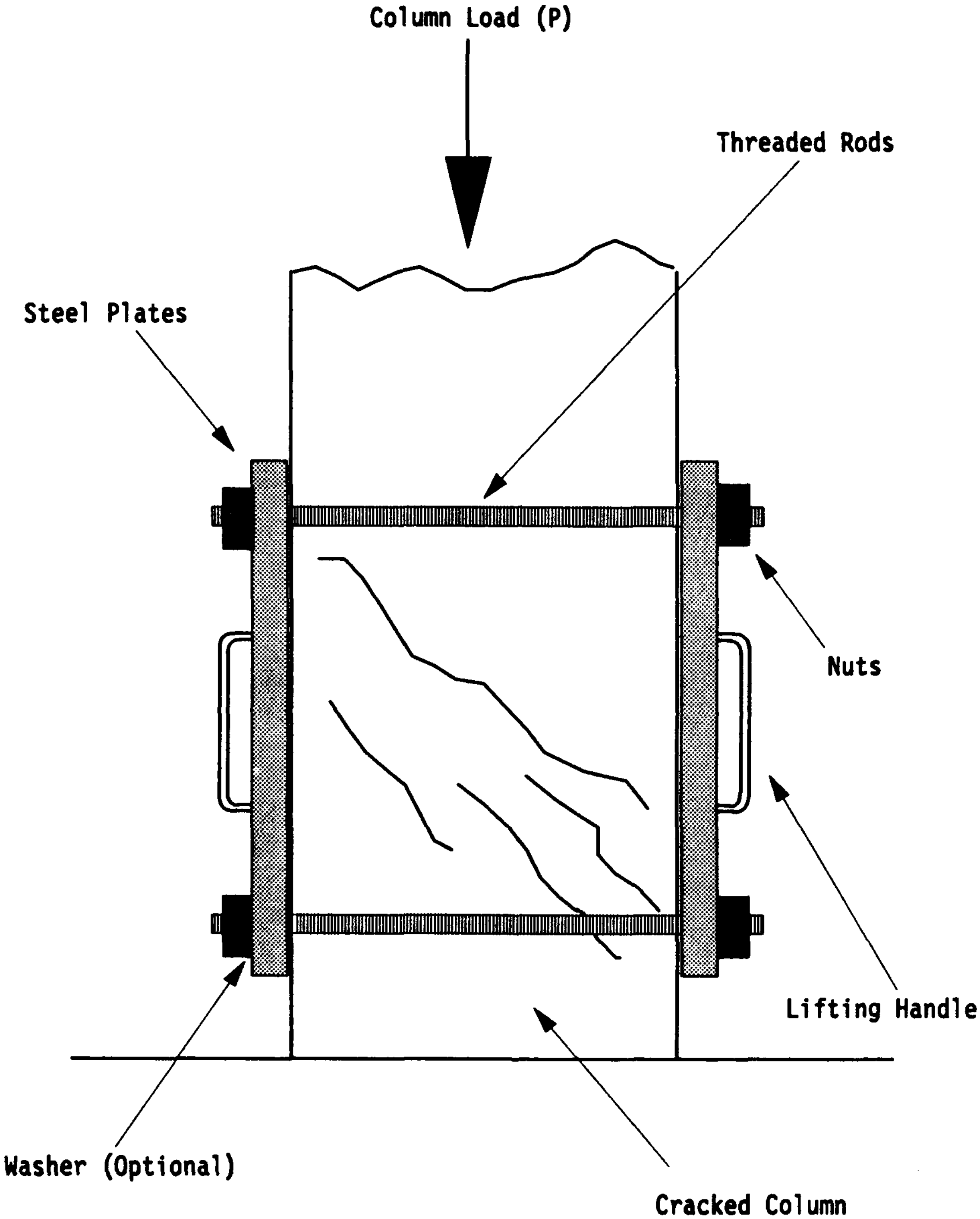


Figure 7. Completed Column Splint Repair.

SECTION VI

BEAM/GIRDER SHORING

A. OVERVIEW

Two methods for shoring a damaged beam/girder were identified and evaluated in Volume I: (1) vertical shoring, and (2) a king post device. Of these two systems, vertical shoring ranked the highest. The king post, due to concerns about the potentially high tension forces in its chain, and possible slipping of the chain anchors, scored much lower than vertical shoring. However, if damage around the beam/girder prevents the use of vertical shoring, the king post system could be used. Vertical shoring is the preferred system, with the king post method considered a backup.

B. VERTICAL SHORING WITH GLULAM COLUMN OR SHORING JACK

These repair methods are essentially the same as those used for column replacement (see Section IV). The main exception is that instead of placing the new column next to a destroyed column, the glulam column or shoring jack is placed at the weakest point of the damaged beam/girder. To prevent increasing the damage to the beam/girder, and to avoid forming a jagged transition along the beam at the location of the damage, the beam should be jacked symetrically prior to inserting the shoring member. This can be accomplished by placing jacks on both sides of the damaged area of the beam, and then raising the jacks in unision. If damage to the beam/girder is extensive, multiple shoring columns and/or jacks should be used.

C. KING POST

1. System Requirements

a. Personnel

The standard ERSF team described in Section II can accomplish this repair.

b. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, the king post method requires:

- a king post (see Figure 8);
- rapid-setting epoxy tape (potential source: McMaster-Carr Part Number 7462A24);
- 50 feet of chain (40,000-pound capacity, potential source: McMaster-Carr Part Number 3587T21) and a chain cutter;
- a ratchet-action load binder (40,000-pound capacity, potential source: McMaster-Carr Part Number 2967T9);
- a calibrated, hand-operated, torque wrench with a dial indicator (potential source McMaster-Carr Part Number 5718A14);
- two connection plates (see Figure 9);
- eight, 3/4-inch diameter rock bolts, 6 inches long;
- two chain shackles (40,000-pound capacity, potential source McMaster-Carr Part Number 3558T59); and
- sections of scaffolding that can be assembled to provide an approximately 8- by 4-foot working platform at a height of up to 12 feet.

If a steel member is to be repaired, the welding equipment listed in subsection III-B.2. will be required.

A possible source for the rock bolts is Hilti Inc. (phone 918-627-9711, TELEX: 96-5951). Hilti Inc. has provided 3/4-inch rock bolts for the fiberglass mat crater repair system used in RRR. These rock bolts have a tension pullout strength of approximately 20,000 pounds in concrete, when installed with a torque of between 70 and 100 foot-pounds. McMaster-Carr's mailing address is P.O. Box 4355, Chicago, IL 60680-4355 (phone 312-833-0300, TELEX: 2-53632).

2. System Description

a. Purpose And Use

The purpose of this repair is to shore a damaged reinforced concrete beam/girder, or in certain circumstances a steel beam/girder, by

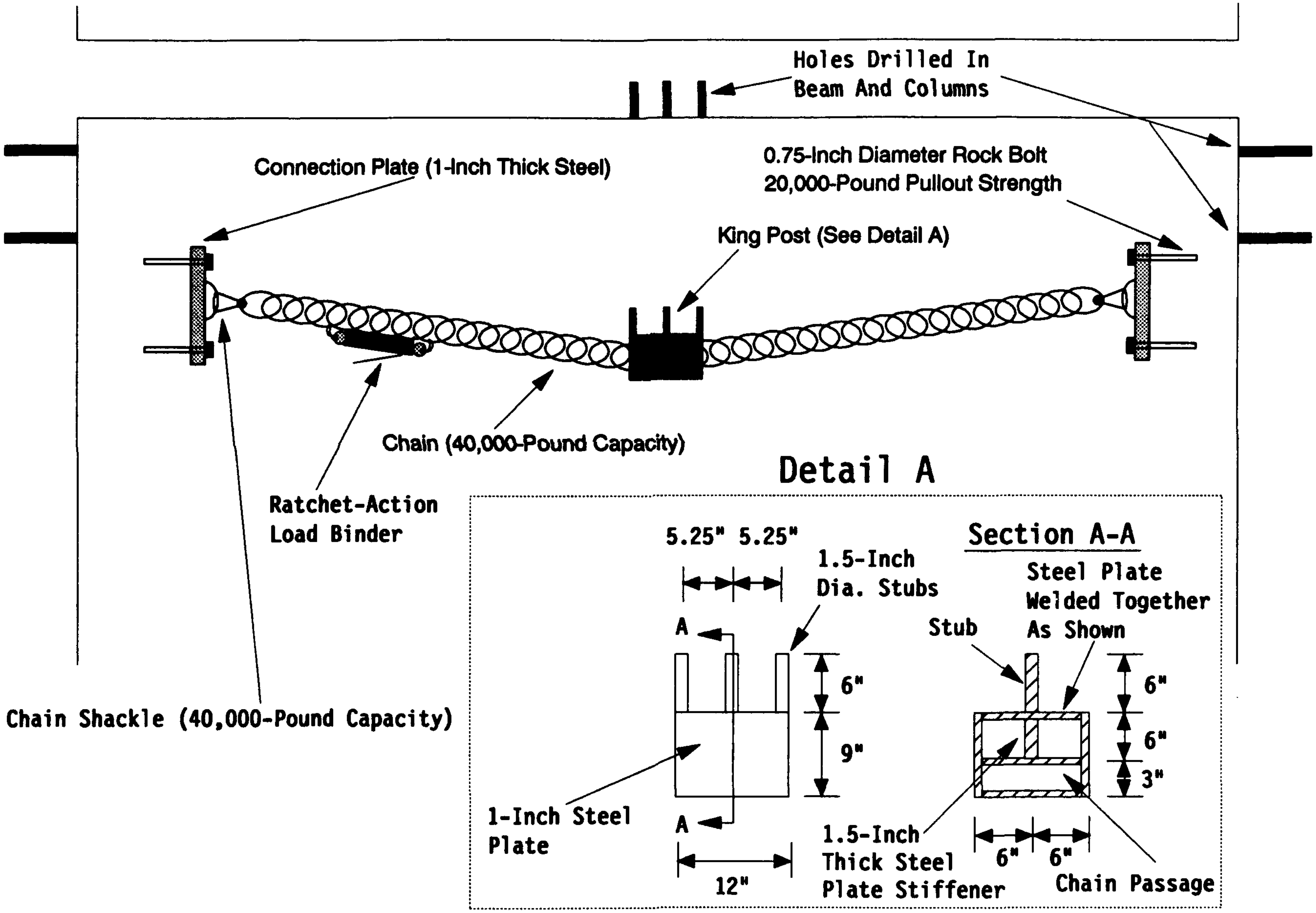
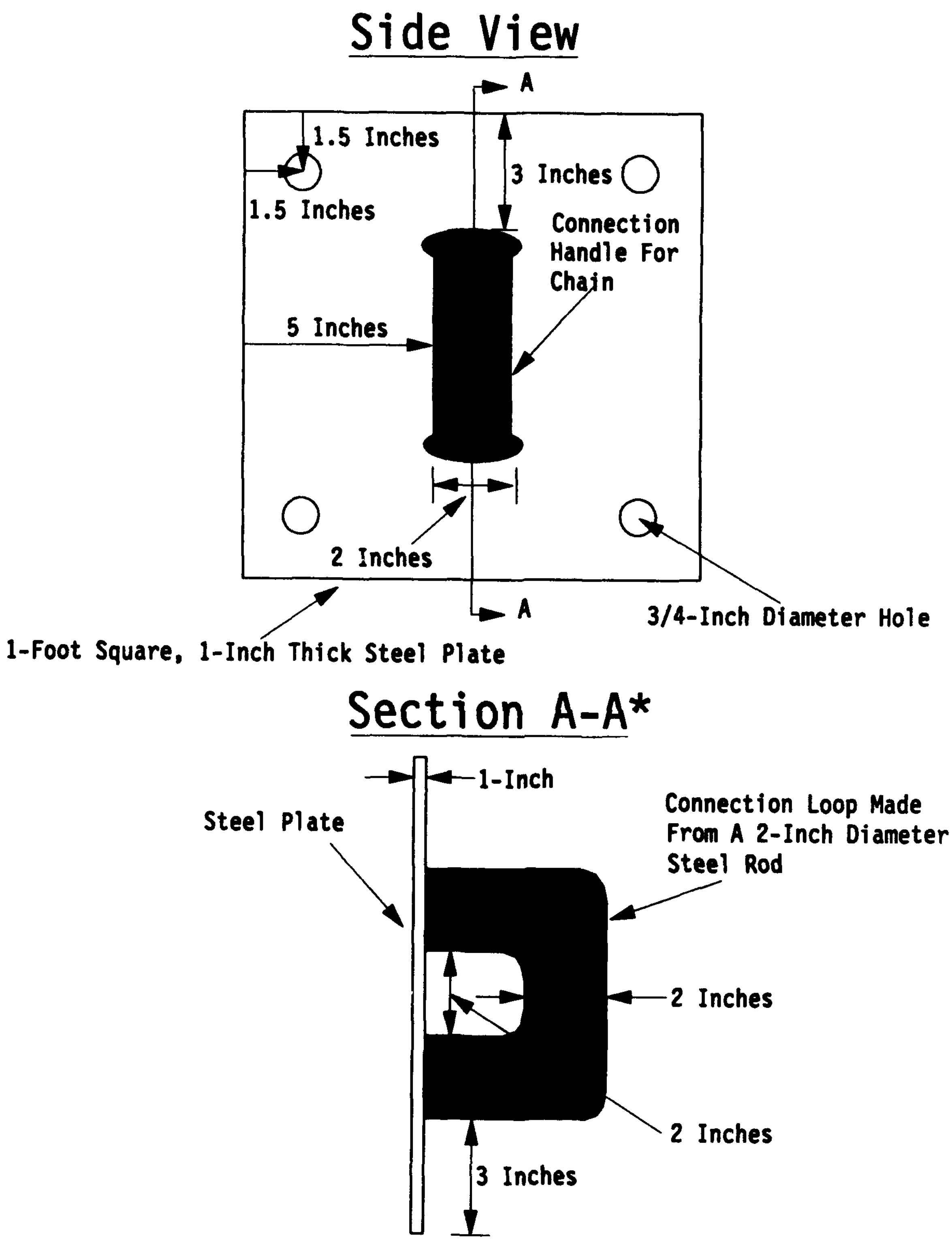


Figure 8. King Post Device.



* - Splint capacity is 40,600 pounds. Capacity determined using SAP 90 structural analysis program with failure criteria of 0.9Fu.

Figure 9. King Post Device Connection Plate.

attaching a king post device (see Figure 8) to the beam/girder. A chain is placed through a king post located at the midpoint of the member. The chain is attached to anchor plates, which are secured with rock bolts to the end columns supporting the member. A ratchet-action load binder is used to put the chain into tension. Unlike vertical shoring, the king post acts as a tension member along the entire bottom of the damaged beam/girder. Consequently, it is not necessary to place the king post at the weakest point of the member.

It is not the intent of a king post repair to uplift a sagging, damaged beam/girder towards its original position. Instead, the purpose of a king post repair is to provide additional structural capacity to a damaged beam/girder. This additional structural capacity will provide a safety factor if additional damage occurs to the structure. Only a small amount of tension must be placed in the chain of the king post, to prevent snap loading of the chain from additional structural deformation, for the king post to fulfill its function.

b. Repair Procedure

The repair is accomplished using the following steps:

(1) Debris Clearance

Using brooms and shovels, remove loose debris from the repair area. If necessary, remove loose concrete in the overhead damaged member that could pose a safety hazard.

(2) Erect Scaffolding

Erect scaffolding under the damaged member to provide access. Move the scaffolding as required to obtain access to other portions of the member or its end columns.

(3) Insert The King Post

From the scaffolding, drill three 1.5-inch diameter holes in the bottom of the member along its longitudinal centerline. The center to center spacing of the holes should be 5.25 inches (see Figure 8). Attach the epoxy tape to the three stubs protruding from the king post. Then force the king post stubs into the drilled holes. By forcing the stubs into the holes, the epoxy resin and hardener are mixed. Brace the king post with lumber to hold it in position until the epoxy hardens. If the damaged member is made of steel, remove the king post stubs and then weld it in position.

(4) Insert Rock Bolts

From the scaffolding, and using as a template a 1-foot square piece of plywood with holes pre-drilled at the correct locations (see Figure 9), drill four, 6-inch deep, 3/4-inch diameter holes in the columns supporting the ends of the damaged member. The holes should be as high up on the columns as possible, along its vertical centerline. Insert four rock bolts through the anchor plate holes and into the holes drilled in each column. Secure the anchor plate to the column by tightening the bolts to the correct torque. If the end columns are steel, weld the connection plates along all four edges to the columns.

(5) Attach Chain

Measure the chain length required to go from one of the anchor plates through the king post to the other anchor plate. Using this measurement as a reference, cut a segment of chain with the chain cutter. Using a chain shackle, attach one end of the chain to one of the anchor plates, and thread the chain through the chain passage of the king post. Attach the free end of the chain to the other anchor plate with another chain shackle.

(6) Tension Chain

Once the chain is through the king post and attached to both anchor plates, put the chain into tension. This is done by attaching the ratchet-action chain binder to a portion of the chain, then working its handle to remove slack in the chain. Continue this process until the chain is taut. If it is desired to reuse the ratchet-action chain binder, a turnbuckle, or something similar, can be attached to the chain and tightened. Then the ratchet-action chain binder can remove without loosing the tension force within the chain. Disassemble and remove the scaffolding to complete the repair process. A completed king post repair is illustrated in Figure 10.

c. Repair Time

Repair time depends on the type and extent of damage and ease of access to the repair area. As an estimate, a typical single king post repair should take between 90 and 150 minutes to complete, including erection and disassembly of scaffolding.

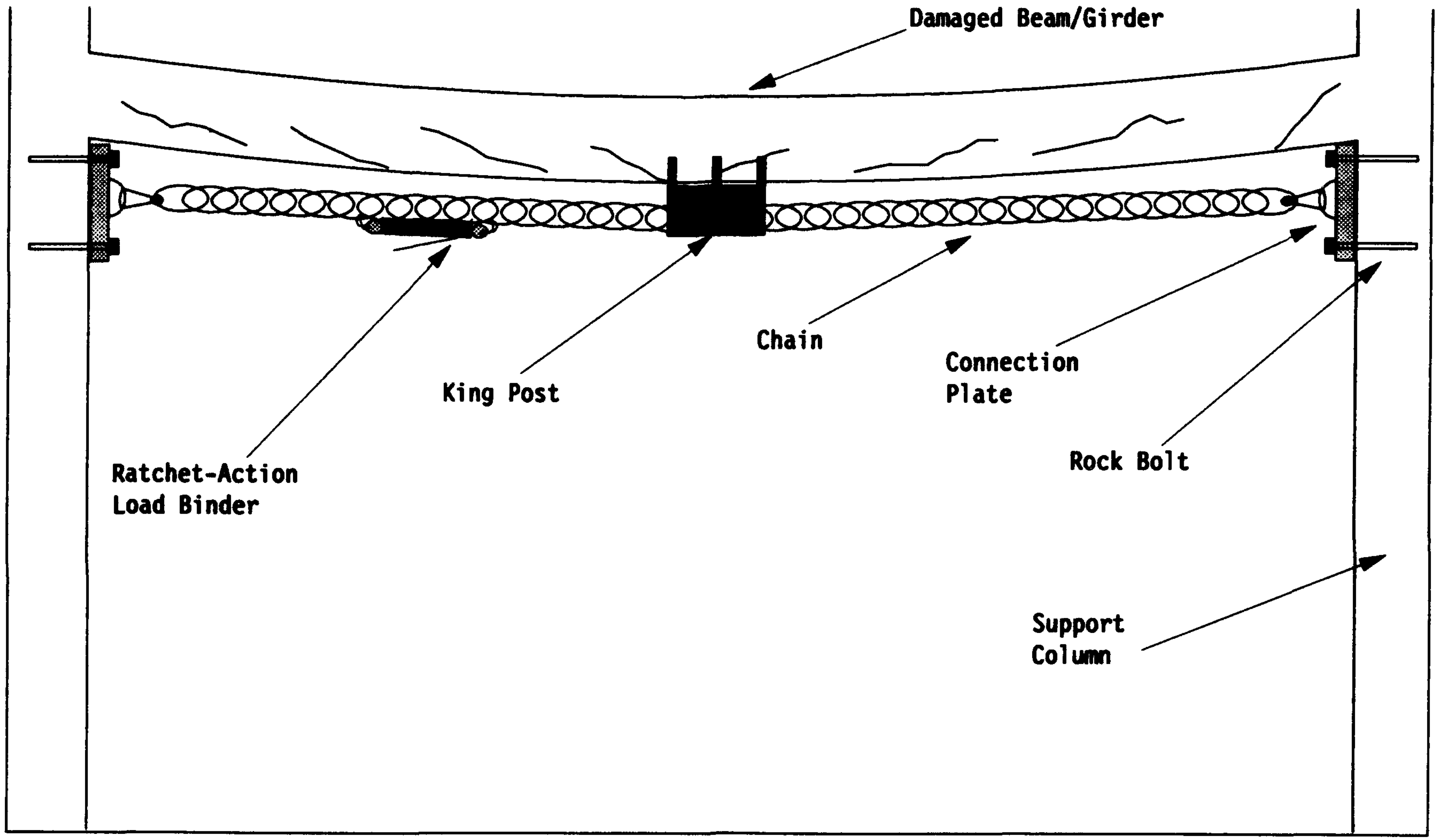


Figure 10. Completed King Post Beam/Girder Repair.

SECTION VII

DESTROYED WALL

A. OVERVIEW

Five methods of replacing a destroyed wall were identified and evaluated in Volume I: (1) shotcrete, (2) earth berm, (3) masonry blocks, (4) precast concrete slabs, and (5) plywood. Of these repair systems, the plywood system ranked highest, with the earth berm and concrete slab systems recommended as backups. Due to concerns about repair flexibility and crew fatigue, the masonry block system was dropped from further consideration.

The shotcrete system is versatile, and provides very strong, blast-resistant repairs. However, it scored poorly on several operational and logistical factors, such as complexity, need for special equipment, high number of components, and cost. An effort is currently under way by AFESC/RDCS to identify an off-the-shelf, mobile, dry-mix shotcrete machine with an automated arm controlling the nozzle, that has on-board shotcrete material and water storage, and on-board water heating capability (see Volume I). Such equipment would overcome most of the operational and logistical problems associated with the shotcrete wall replacement system. Consequently, the shotcrete system was not dropped from consideration, and is described here, along with the earth berm, and precast concrete slab wall replacement systems. The plywood system is essentially part of the other three systems, and therefore is not discussed separately.

The final choice of method or methods to be used at a particular base is best left to the discretion of the BCE.

B. SHOTCRETE

1. System Requirements

a. Personnel

The standard ERSF team described in Section II can accomplish this repair.

b. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, the shotcrete method requires:

- a mobile, dry-mix shotcrete machine with an automated arm controlling the nozzle, on-board shotcrete material and water storage, and on-board water heating capability;
- AFESC/RDCM-developed, steel fiber reinforced, dry-mix shotcrete material in ten, 2,500-pound supersacks (a detailed description of the development and composition of this material is given in Reference 18 of Volume I);
- twenty, 4- by 8-foot sections of 3/8-inch plywood;
- twenty, 2- by 4-inch boards, 8 feet long;
- (optional) forty, Number 4 rebars 10 feet long, and a bar cutter; or 300 square feet of rolled Number 10 gage wire mesh;
- (optional) 100 rebar ties; and
- in some cases, a bulldozer, front-end loader, and flatbed truck.

c. Training

Since a new piece of equipment is required to accomplish this repair, and since placing dry-mix shotcrete is a new process for airbase personnel, specialized training is required. A shotcrete training program is outlined in Table 4. Personnel must be familiar with the mobile shotcrete equipment so they can use it properly and with maximum efficiency without causing operator-induced breakdowns. If possible, the mobile shotcrete equipment and material should be used for routine airbase civil engineering tasks, so personnel can maintain proficiency with it.

2. System Description

a. Purpose And Use

The purpose of this repair is to replace a badly damaged reinforced concrete wall or wall of a steel framed structure. The replacement

TABLE 4. SHOTCRETE TRAINING PROGRAM OUTLINE.

1. <u>Classroom, Day 1 (Morning)</u>

Course objectives and orientation:
- Explanation of course purpose and content
- What shotcrete is and how it can be used
- Why shotcrete is used for expedient repair of facilities

Description of shotcrete equipment and material:
- Shotcrete equipment components and function
- On-board storage of shotcrete material and water
- Shotcrete composition (cement, aggregate, steel fibers, etc.)
- Shotcrete supersack purpose and use
- Shotcrete material storage requirements
- Water addition
- Safety requirements for shotcreting
- Operation of shotcrete equipment and required maintenance

2. <u>Field Workshop, Day 1 (Afternoon)</u>

Operating principles of the shotcrete equipment

Set-up and familiarization with the shotcrete equipment:
- Shotcrete nozzle and boom with keyboard controls
- Shotcrete gun and material feed system
- Water storage, pump, heater, and flow controls
- Electrical generator
- Air Compressor
- Hoses and connectors
- Other controls
- System flushing, cleanup, and maintenance

Trial run of equipment

Recap of day's training

3. <u>Field Training, Day 2</u>

Quick review of previous day's information

Demonstration of shotcrete repair by instructors

Repair of three, 4-foot high, 8-foot wide, 1-foot deep test panels by team members.
- One at ground level
- One 10 feet above ground level
- One 20 feet above ground level

Repair of actual breach in training structure, including backing the breach with plywood, and if desried, placement of rebar by tying it to exposed rebar wall is non-load-bearing, but does provide significant blast resistance and structural redundancy, in case of another attack, and seals the structure against environmental and chemical/biological agent intrusion. If necessary (see Subsection VII-B.2.b.(2) below), plywood backing is placed behind the damaged area before shotcrete placement. If used (see Subsection VII-B.2.b.(3) below), rebar or wire mesh is placed in the damaged area and tied to the existing exposed rebar. The mobile shotcrete equipment then sprays shotcrete onto the backing until the desired thickness has built up. If possible, the repair thickness should be at least 12 inches. The AFESC/RDCM-developed dry-mix shotcrete material obtains a compressive strength of over 4,000 psi in one hour.

b. Repair Procedure

The repair is accomplished using the following steps:

(1) Debris Clearance

(a) Damaged Structure

If required, use the jackhammer, acetylene torch, and bulldozer or front-end loader to remove parts of the damaged wall and surrounding members that are still attached to the structure and will interfere with the repair. However, if the damaged wall is badly cracked and fractured, but still essentially in place, do not remove it. Instead, use the wall instead of plywood as backing for placing the shotcrete.

(b) Loose Debris

Use brooms and shovels to remove loose debris from the repair area to provide a clean and level working surface. If necessary, remove large chunks of debris by pushing them to the side with the bulldozer or front-end loader.

(2) Place Plywood Backing

If required, place plywood backing behind the wall opening. Measure the wall opening, and cut plywood sections with an electric rotary saw to cover the opening, leaving approximately a 1-foot overlap all around, if possible. Join the sections of plywood with 2- by 4-inch boards, using hammer and nails. All boards should be placed on the same side of the plywood, and boards should be placed around the perimeter of the plywood sections to stiffen them. Trim the boards as needed, with the rotary saw.

Secure the fabricated plywood backing behind the wall opening, using ramset studs driven through the plywood and boards into the concrete surrounding the opening. The boards used to hold the plywood together should face the interior of the structure. Brace the plywood backing at 4-foot horizontal intervals, using 2- by 4-inch diagonal bracing lumber and hammer and nails. Attach the diagonal braces to wood sills, secured to the floor with ramset studs. If there is no surrounding concrete to which to anchor the sills, such as in a steel-framed structure, anchor them to whatever flooring exists.

(3) Rebar Placement (Optional)

Rebar is optional, and should only be used if repair time does not need to be minimized and/or the strength of the repair must be maximized. If rebar is used, trim and tie together lengths of Number 4 rebar to fit in the repair area. If possible, tie the rebar to existing exposed rebar around the wall opening. When possible, maintain a 2-foot spacing between rebars. If there is no exposed rebar, drill 4-inch deep, 1/2-inch diameter holes on 2-foot centers in the surrounding concrete, and place the ends of the rebar in the holes. In overhead holes, wedge the rebar in place with nails. In some cases, the rebar will have to be spliced within the repair area. Rebar should span the wall opening in both the horizontal and vertical directions. Where horizontal and vertical rebar cross, they should be tied together.

If wire mesh is used, cut and tie sections of mesh until a section large enough to cover the entire wall opening is obtained. Then tie the edges of the mesh to existing exposed rebar. If there is no exposed rebar, drill 4-inch deep, 1/2-inch diameter holes on 2-foot centers in the surrounding concrete, and place 8-inch long rebar sections in the holes. Wedge the rebar in the holes with nails. Then tie the wire mesh to the rebar.

If possible, place the rebar or wire mesh so there is a 1-inch gap between the repair backing and the rebar/mesh, to provide adequate concrete cover.

(4) Place Shotcrete Material

Position the mobile shotcrete equipment next to the prepared wall opening. Spray shotcrete material onto the prepared backing until the repair reaches the desired thickness. If possible, the repair thickness should be at least 12 inches. Shotcrete depth can be measured with a 2- by 4-inch board and a ruler, using the nearby undamaged outside wall surface as a reference. As an estimate, the volume of shotcrete material, in cubic feet, required to complete a repair equals: average height (ft) x average width (ft) x (desired depth (inches) /12) x 1.2. If the amount of material required to complete a repair exceeds the storage capacity of the shotcrete equipment, additional material should be brought to the repair area in 2,500-pound supersacks (1 yd^3 per sack) on a flatbed truck, dump truck, or other suitable vehicle. The sacks can be lifted off the flatbed using a front-end-loader with boom attachment. The sacks should be positioned over the mobile shotcrete equipment material tank, and the material fed into the tank through the drawstring funnel at the bottom of the sack. A shotcrete wall repair operation is illustrated in Figure 11.

c. Repair Time

A shotcrete wall replacement repair was demonstrated in the field as part of the ERSF system development effort (see Volume I). However, because the equipment used in the demonstration was undersized, demonstration results did not accurately reflect the time required to complete a shotcrete repair using adequate equipment. Until an appropriate piece of shotcrete equipment is identified and tested during the effort under way by AFESC/RDCS, it will not be feasible to estimate repair time. Additionally, repair time will depend on the size of the repair, whether backing is required, and

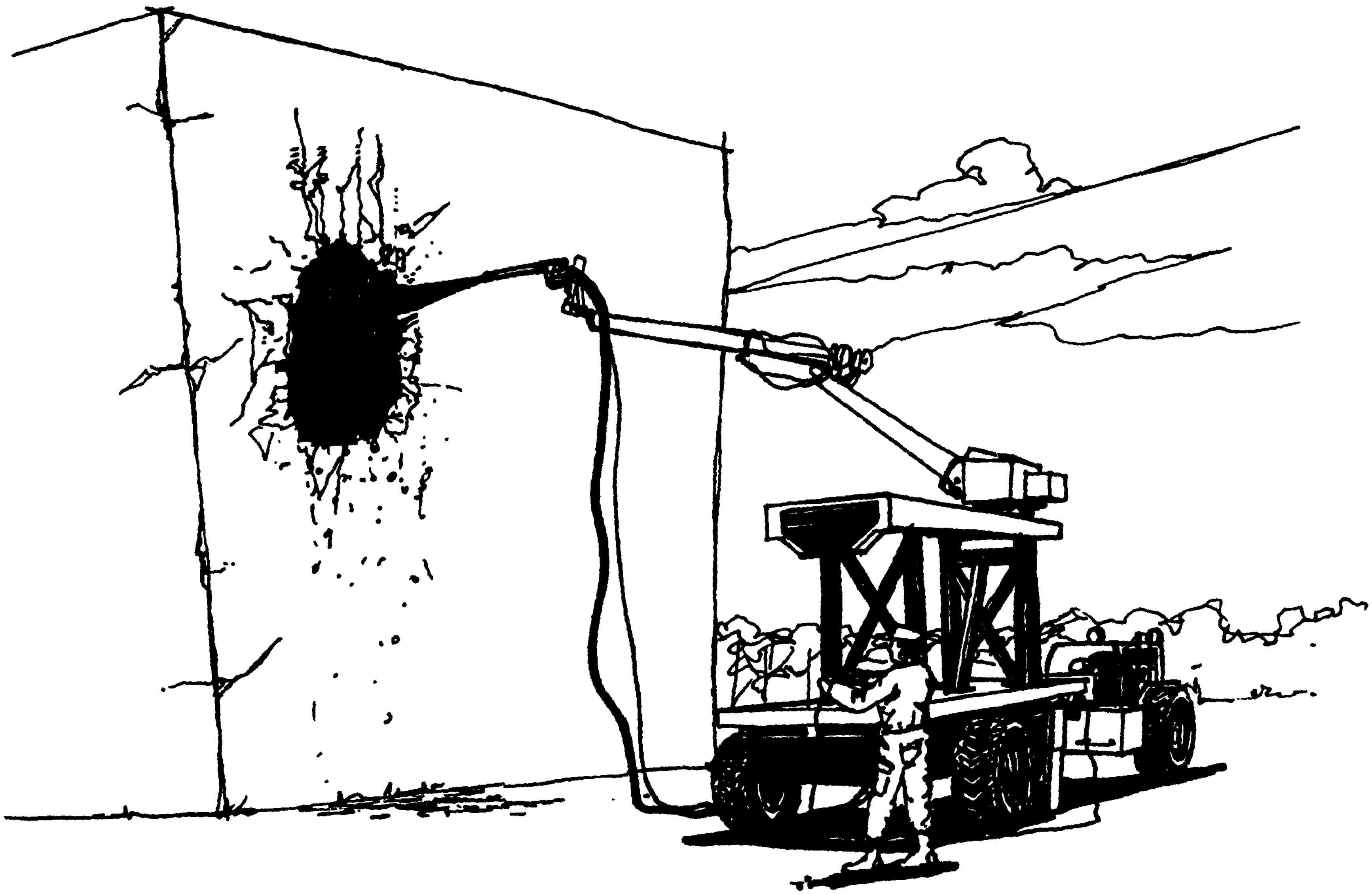


Figure 11. Shotcrete Wall Repair In Progress.

whether reinforcement is used. Presently, a repair time estimate based on repair volume and material placement rate is the most appropriate estimate.

C. EARTH BERM

1. System Requirements

a. Personnel

The standard ERSF team described in Section II can accomplish this repair.

b. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, the earth berm repair method requires:

- a bulldozer, front-end loader, or other suitable piece of equipment to form the berm;
- twenty, 4- by 8-foot sections of 3/8-inch plywood;
- twenty, 2- by 4-inch boards, 8 feet long; and
- 2-meter square, 8-inch thick, precast, reinforced concrete slabs.

The slabs are to be tilted-up against the damaged wall. The number of slabs required depends upon the size of the wall opening. The slabs can be transported to the repair area on a flatbed truck or other suitable vehicle. Once at the repair area, a front-end loader is needed to lift and position the slabs.

2. System Description

a. Purpose And Use

The purpose of this repair is to shield a badly damaged exterior wall with an earth berm. The repair is non-load-bearing, but does provide significant blast resistance. If necessary, a backing of plywood is placed behind the damaged wall to prevent the material that forms the berm from entering the structure. Precast slabs are then tilted-up against the damaged wall (see Subsection VII-C.2.b.(1)(a) below). A bulldozer or front-end-loader is then used to mound earth against the precast slabs to form a berm. This repair method can only be used for ground floor exterior walls.

b. Repair Procedure

The repair is accomplished using the following steps:

(1) Debris Clearance

(a) Damaged Structure

If required, use the jackhammer, acetylene torch, and bulldozer or front-end-loader to remove parts of the damaged wall and surrounding members that are still attached to the structure and will interfere with repair operations. However, if the damaged wall is badly cracked and fractured but still essentially in place, do not remove it. Instead, use the wall itself, instead of plywood and tilted-up precast slabs as backing for the berm.

(b) Loose Debris

Use brooms and shovels to remove loose debris from the repair area, to provide a clean and level working surface. If necessary, remove large chunks of debris by pushing them to the side with the bulldozer or front-end-loader.

(2) Place Backing

(a) Plywood

Measure the wall opening, and cut plywood sections with the rotary saw to cover the opening, leaving approximately a 1-foot overlap all around, if possible. Join sections of plywood with 2- by 4-inch boards, using hammer and nails. As required, trim the boards with the rotary saw. All boards should be placed on the same side of the plywood, and boards should be placed around the perimeter of the plywood sections to stiffen them. Trim the boards as needed, with the rotary saw.

Secure the fabricated plywood backing behind the wall opening, using ramset studs driven through the plywood and boards into the concrete surrounding the opening. The boards used to hold the plywood together should face the interior of the structure. Brace the plywood backing at 4-foot intervals, using 2-by 4-inch diagonal bracing lumber, and hammer and nails. Attach the diagonal braces to wood sills secured to the floor with ramset studs. If there is no surrounding concrete to which to anchor the sills, such as in a steel framed structure, anchor them to whatever flooring exists.

(b) Precast Slab Backing

Bring the precast slabs to the repair site on a flatbed truck or other suitable vehicle. Use a front-end loader with the slab lifting frame to lift and maneuver the slabs off the truck, and tilt them up against the outside of the structure to cover the opening. Place the slabs as close together as possible.

(3) Form Berm

Use a bulldozer or front-end loader to mound earth against the precast slabs to form a berm. The berm base length needed to obtain the necessary height to cover the opening will depend upon the angle of repose of the material used to form the berm. The lower the angle of repose, the greater the berm base length. A nearly completed earth berm repair is illustrated in Figure 12.

c. Repair Time

Repair time depends upon the size of the wall opening, the type of backing, and the berm material. However, it is estimated that an earth berm repair should take between 90 and 150 minutes to complete.

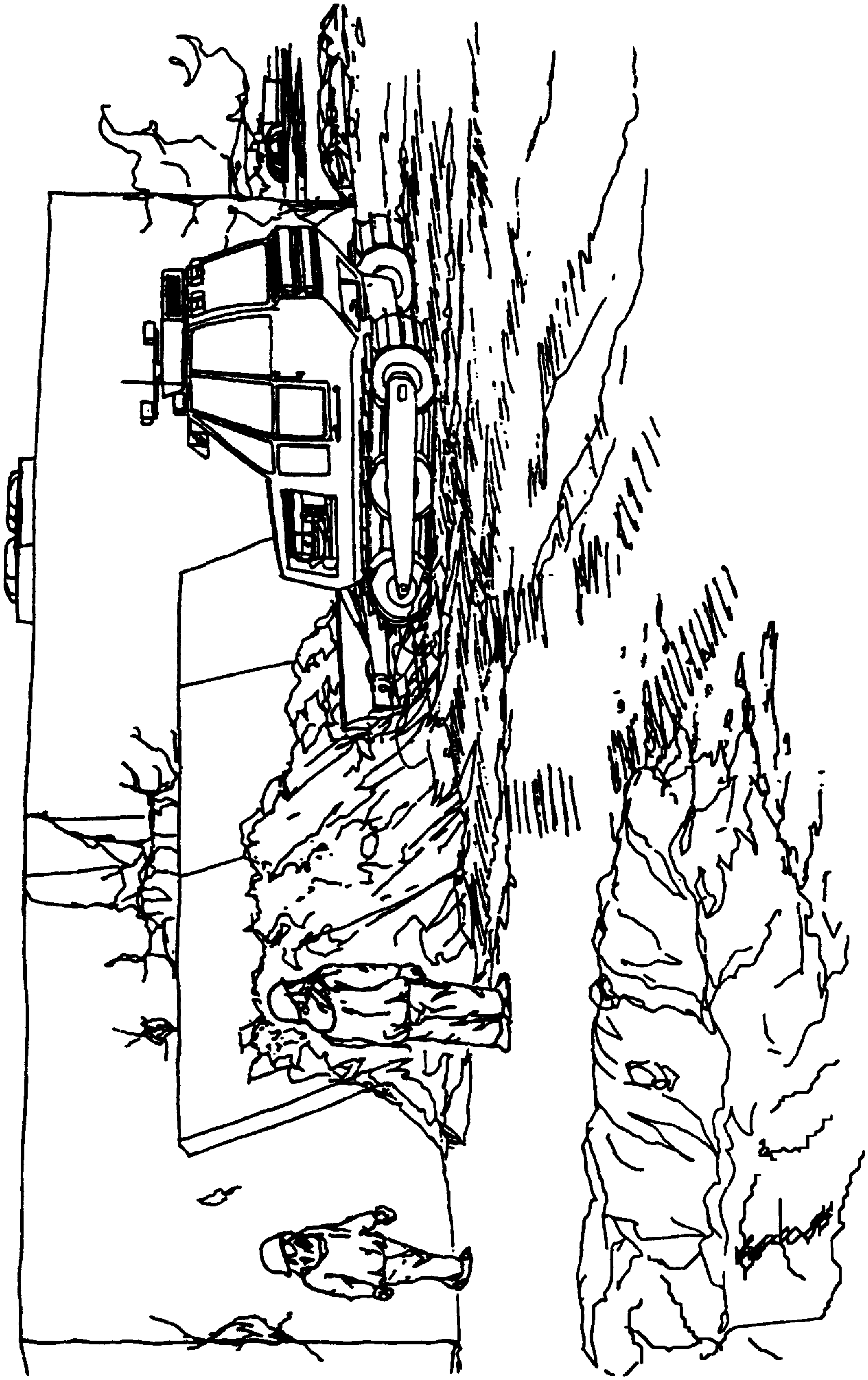


Figure 12. Nearly Completed Earth Berm Wall Repair.

D. PRECAST SLAB

1. Repair Description

The precast slab repair is essentially an earth berm repair without the earth berm. The process is the same as described in Subsections VII-C.1.a. to C.2.b.(2)(b). A precast slab repair will provide some blast resistance, but adds no structural redundancy, and does not seal the structure. As with the earth berm repair, this repair method can only be used on ground floor exterior walls.

2. Repair Time

Completion of a precast slab repair should take between 60 and 120 minutes to complete.

SECTION VIII

WALL BREACH

A. OVERVIEW

The same five wall replacement repair methods identified in Section VII for wall replacement were also evaluated as wall breach repair methods in Volume I of this report. The repair systems are: (1) shotcrete, (2) earth berm, (3) masonry blocks, (4) precast concrete slabs, and (5) plywood. The relative ranking of the five systems is the same as for wall replacement (see Section VII-A). The shotcrete, earth berm, and precast concrete slab systems are briefly discussed here. For detailed descriptions of these three repair methods, see Section VII. The plywood system is not discussed separately here or in Section VII, because it is essentially part of the other three systems. Essentially, a plywood repair is accomplished when the plywood backing is placed behind the damaged area during shotcrete, earth berm, and precest slabs repairs.

B. REPAIR DESCRIPTION

The shotcrete, earth berm, and precast concrete slab wall breach repair systems are essentially identical with their wall replacement counterparts. The only significant differences are: (1) the area to be repaired will be smaller, so repair time under most circumstances should be less; (2) if a breach occurs high up on an exterior wall, the precast slab method will not work; and (3) if a breach is high up on an exterior wall, and the angle of repose of the material used to form a berm repair is small, repair time may become excessive because a great deal of material must be moved to form the berm, in proportion to the area to be repaired. The second and third differences just described can be overcome by using the shotcrete system.

SECTION IX

FLOOR/ROOF BREACH

A. OVERVIEW

Methods to repair a floor/roof breach are divided into two categories. The first category applies when the damage to a floor/roof can be repaired. The second category applies when damage to a floor/roof is too severe to be repaired, and the access stairs to the heavily damaged portion of the structure must be sealed. Each of these repair categories is discussed below.

1. Repair Breach

Three methods were identified and evaluated in Volume I to repair a floor/roof breach: (1) shotcrete, (2) plywood and rolled roofing, and (3) rapid-setting concrete. Of these three repair systems, plywood and rapid-setting concrete were ranked essentially equally. The shotcrete system was ranked lower then those two systems, due to the operational and logistical concerns discussed in Section VII-A. However, because work is being done to overcome these problems, a shotcrete floor/roof breach repair is discussed here, along with plywood and rolled roofing, and rapid-setting concrete repairs.

2. Seal Stairs

For the case in which the floor/roof breach cannot be repaired, two methods were identified and evaluated in Volume I to seal the access stairs to the heavily damaged portion of the structure: (1) shotcrete, and (2) plywood. Of these two systems, the plywood system ranked highest. The shotcrete system ranked lower than the plywood system, but for reasons given in the preceding paragraph is discussed here.

Each repair method is discussed below, by repair category. The choice of method in each category to be used at a particular airbase is best left to the discretion of the BCE.

B. REPAIR FLOOR/ROOF BREACH

If none of the repair methods described below is to be used to repair a breach, and access stairs to the damaged area are not going to be sealed, traffic cones or rope should be used to cordon off the damaged area, as a safety precaution. This procedure should only be considered as a stopgap measure when there is no time and/or resource available to carry out a repair.

1. Shotcrete

a. System Requirements

(1) Personnel

The standard ERSF team described in Section II can accomplish this repair.

(2) Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, and the additional supplies described in Subsection VII-B.1.b., the shotcrete floor/roof repair method requires:

- a mobile, dry-mix shotcrete machine with automated arm controlling the nozzle, on-board shotcrete material and water storage, and on-board water heating capability;
- AFESC/RDCM-developed, steel fiber reinforced, dry-mix shotcrete material in ten, 2500-pound supersacks (a detailed description of the development and composition of this material is given in Reference 18 of Volume I);
- twenty, 4- by 8-foot sections of 3/8-inch plywood;
- twenty, 2- by 4-inch boards, 8 feet long;
- forty, Number 4 rebars 10 feet long, and a rebar cutter: or 300 square feet of rolled Number 10 gage wire mesh;
- 100 rebar ties; and
- possibly a front-end-loader and flatbed truck.

(3) Training

See Subsection VII-B.1.c. for shotcrete training requirements.

b. System Description

(1) Purpose And Use

The purpose of this repair is to fill in a breach in a floor/roof. This method should not be used to completely replace a destroyed floor/roof. For that degree of damage, the stair-sealing repair method is recommended. This repair method is very similar to the shotcrete wall replacement repair method, with most of the repair steps being identical. However, because the repair occurs on a horizontal instead of a vertical surface, backing of the repair prior to placing shotcrete is different.

(2) Repair Procedure

The repair is accomplished using the following steps:

(a) Debris Clearance

See Subsections VII-B.2.b.(1)(a) and VII-B.2.b.(1)(b) for details on debris clearace.

(b) Rebar Placement

See Subsection VII-B.2.b.(3) for details on placement of rebar or wire mesh in the breach. For this type of repair, rebar or wire mesh must be used because of strength requirements.

(c) Construct Formwork

Next to the breach, fabricate formwork to cover the breach from panels of plywood and 2- by 4-inch boards. Measure the breach, and assemble plywood panels with 2- by 4-inch framing, large enough so the resulting formwork will overlap the existing concrete by 1-foot all around the breach. Cut the plywood panels and boards with the rotary saw to obtain the correct fit. Ensure the formwork has 2- by 4-boards running around its perimeter to act as reinforcement. The board's 4-inch dimension should be parallel to the plywood surface, and all boards used during the fabrication process should be on the same side of the formwork.

(d) Install Formwork

Place the formwork over the breach, with the 2- by 4-inch framing facing upward. Secure the plywood section around its perimeter with ramset studs driven through the plywood and boards into the concrete.

(e) Place Shotcrete Material

Shotcrete material is sprayed from underneath the breach onto the plywood backing until the desired repair thickness is reach. See Subsection VII-B.2.b.(4) for details on placement of the shotcrete material. Usually, to gain access to the repair area, the hose and nozzle attachment of the mobile shotcrete equipment will be used instead of its automated arm. After the shotcrete has reached its design strength in 1 hour, the plywood formwork can be removed. A nearly completed shotcrete floor/roof breach repair is illustrated in Figure 13.

(3) Repair Time

See Subsection VII-B.2.c. for details on estimating repair time.

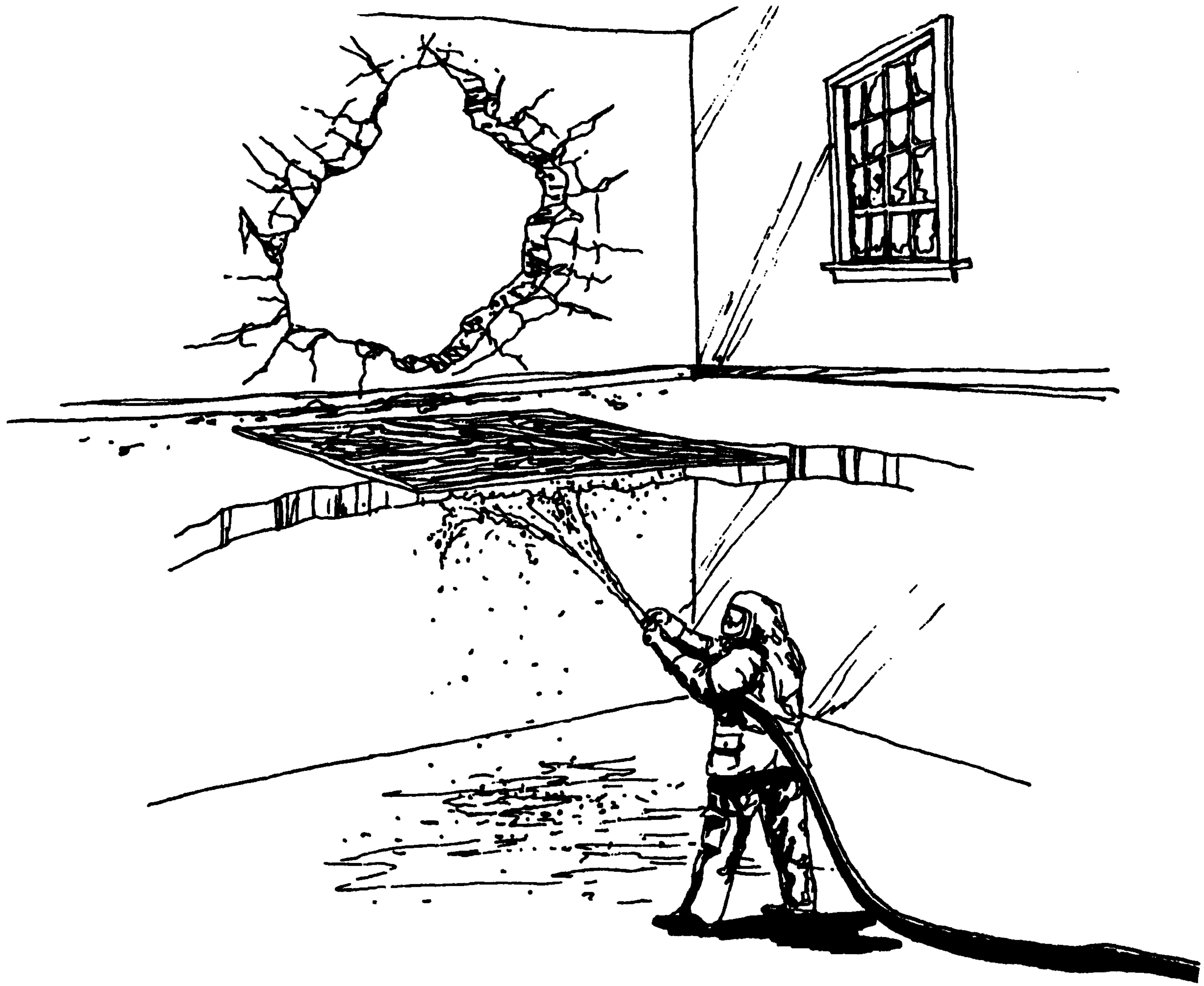


Figure 13. Nearly Completed Shotcrete Floor/Roof Repair.

2. Rapid-Setting Concrete

a. System Requirements

(1) Personnel

The standard ERSF team described in Section II can accomplish a rapid-setting concrete floor/roof breach repair.

(2) Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, the rapid-setting concrete floor/roof repair method requires:

- 2 cubic yards of rapid-setting grout and the appropriate amount of accelerator;
- a small towable concrete mixer with a concrete pump and 100 feet of hose;
- a water buffalo;
- a dump truck load of pea gravel;
- five finishing squeegees;
- twenty, 4- by 8-foot panels of 3/8-inch plywood;
- twenty, 2- by 4-inch boards, 8 feet long;
- forty, Number 4 rebars 10 feet long, and a rebar cutter; or 300 square feet of rolled Number 10 gage wire mesh;
- seven, mechanical shoring jacks having at least a 5,000-pound capacity, with a maximum extended height of at least 12 feet (see Table 3 for a list of shoring jack manufacturers); and
- sections of scaffolding that can be assembled to provide approximately 4- by 8-foot working platform at a height of up to 12 feet;

b. System Description

(1) Purpose And Use

The purpose of this repair is to fill in a breach in a floor/roof. This method should not be used to completely replace a destroyed floor/roof. For that degree of damage, the stair-sealing repair method is recommended. This repair method is very similar to the shotcrete floor/roof breach repair method just described, with most of the repair steps being identical. The only significant difference involves mixing and placing the concrete. Instead of being sprayed into the repair area, the concrete is mixed with water and aggregate in a concrete mixer, and then poured into the repair area.

(2) Repair Procedure

The repair is accomplished using the following steps:

(a) Debris Clearance

See Subsections VII-B.2.b.(1)(a) and VII-B.2.b.(1)(b) for details on debris clearance..

(b) Erect Scaffolding

Erect scaffolding under the roof/floor breach to provide access for formimg. When needed, move the scaffolding to obtain access to different areas of the concrete surrounding the breach.

(c) Place Plywood Backing

Place plywood formwork on the floor beneath the breach. Measure the breach, and fabricate formwork from plywood panels and 2- by 4-inch framing. Assemble the formwork so it overlaps the existing concrete around the breach by 1-foot all around. All framing boards used to construct the formwork should be on the same side of the plywood. Cut the plywood panels and boards with the rotary saw to obatin the correct fit.

Attach rope to the formwork a several locations. Pass the rope through the breach. Then from above the breach use the rope to pull the formwork upward from the floor underneath the breach until in comes in contact with the concrete surrounding the breach. Secure the ends of the rope to hold the formwork in position. Secure the formwork underneath the breach using ramset studs driven through the framing boards and plywood into the concrete surounding the breach. After the formwork is secured, remove the rope.

Brace the formwork with the shoring jacks. Evenly space the shoring jacks beneath the formwork so there is one jack for each 20 square feet of repair area. Extend the jacks until the heads of the jacks are in firm contact with formwork.

(d) Rebar Placement

See Subsection IX-B.1.b.(2)(b) for details on placing rebar or wire mesh in the breach.

(e) Place Rapid-Setting Concrete

Use the concrete mixer to mix the rapid-setting grout, aggregate, accelerator, and water (from the water buffalo) in ratios recommended by the grout manufacturer. The amount of accelerator can be varied to obtain more rapid set times, or to account for cold weather or mix water. From the mixer, pour, or if necessary pump, the concrete into the prepared breach. Use the squeegees and shovels to trowel the concrete into all areas of the breach. A fairly high slump concrete mix should be used to ease finishing of the concrete. Continue this process until the breach is completely filled. After the concrete has reached its design compressive strength, usually within 1 hour, the plywood backing and shoring jacks can be removed.

c. Repair Time

Repair time will vary depending on breach volume. As an estimate, it should take between 90 and 120 minutes to complete a breach repair that requires 1 cubic yard of concrete.

3. Plywood And Rolled Roofing

a. System Requirements

(1) Personnel

The standard ERSF team described in Section II can accomplish this repair.

(2) Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, this repair method requires:

- twenty, 4- by 8-foot sections of 3/4-inch plywood;
- twenty, 2- by 4-inch boards, 8 feet long;
- seven, 6- by 6-inch boards, 12 feet long;
- chainsaw with spare blade and 2-cycle oil;
- telescoping measuring rod, such as the telescoping rods used by power line maintenance personnel;
- 100, 2-inch long, 3/8-inch diameter wood screws; and
- 200 square feet of rolled roofing material.

b. System Description

(1) Purpose And Use

The purpose of this repair is to cover a breach in a floor/roof. This method should not be used to completely replace a destroyed floor/roof. For that degree of damage, the stair-sealing repair method is recommended. The plywood and rolled roofing method will cover the damaged area, and eliminate a safety hazard as personnel walk through the structure. This repair method will not provide blast resistance or structural redundancy to the structure, nor will it seal the structure. In this repair, a fabricated section of plywood is placed over the breach, and anchored around its perimeter to the underlying concrete with ramset studs. The plywood section is braced underneath by 6- by 6-inch timbers.

(2) Repair Procedure

The repair is accomplished using the following steps:

(a) Debris Clearance

If required, use the jackhammer and acetylene torch to remove parts of the damaged floor/roof and surrounding members that will interfere with repair operations. Use brooms and shovels to remove loose debris from the repair area to provide a clean and level working surface.

(b) Fabricate Plywood Section

Next to the breach, fabricate a section of plywood to cover the breach. Measure the breach, and assemble plywood panels with 2- by 4-inch framing, large enough so the entire section will overlap the existing concrete by 1-foot all around the breach. Cut the plywood panels and boards with the rotary saw to obtain the correct fit. Ensure the fabricated section has 2- by 4-boards running around the perimeter of the section to act as reinforcement. The board's 4-inch dimension should be parallel to the plywood surface, and all boards used during the fabrication should be on the same side of the plywood section.

(c) Install Plywood Section

Place the plywood section over the breach, with the 2- by 4-inch framing facing downward. Secure the plywood section around its perimeter with ramset studs driven through the plywood and boards into the concrete.

(d) Brace Plywood Section

Measure the distance between the floor and the overhead plywood cover, using the telescoping measuring rod. Using this distance as a reference, trim the 6- by 6-inch boards with the chainsaw, so they fit snugly underneath the cover to act as post shores. Position the post shores underneath the plywood backing in an evenly spaced pattern. Place one post shore under the breach for each 20 square feet of repair area. Attach the shores to the cover above and the floor below using wood sills. Take 6-inch long sections of 2- by 4-inch boards and secure them to the floor around the base of the post shore along all four sides with ramset studs. Place the sills so their 2-inch dimension is perpendicular to the floor. At the top of the post shores, secure the sills to the plywood around all four sides of the post shores using the 2-inch long wood screws. Place the sills so their 2-inch dimension is perpendicular to the plywood. Use at least 2 screws per sill.

(e) Place Rolled Roofing

If the repair is on the exterior of a structure, rolled roofing should be placed over the plywood section to seal it from the elements. Place strips of the rolled roofing over the plywood section, and secure them with hammer and nails. Start at one edge of the plywood section, and trim and secure a strip of rolled roofing to the plywood. Trim and secure another strip of rolled roofing so it overlaps the previous strip by 6 inches. Continue to trim and position strips of rolled roofing until the plywood section is completely covered.

(3) Repair Time

Depending upon the size of the floor/roof breach, the estimated repair time will range between 90 and 120 minutes.

C. SEAL STAIRS

This repair method is used when the upper levels of a structure are damaged beyond the point of expedient repair, but lower levels of the structure have not been severely damaged. To seal the remaining portion of the structure off from the damaged area, the shotcrete or plywood wall replacement repair methods can be used.

1. Shotcrete

The personnel, supplies, and procedures needed to accomplish this repair are the same as described in Subsections VII-B.1.a to VII-B.2.b.(4) for a shotcrete repair, except for the four exceptions described below.

First, since no exposed rebar is likely to be found in a stairway opening, a method is required to tie the shotcrete repair into the existing structure. This can be accomplished in two ways. If there is a steel door frame in the stairway opening, Number 4 rebar can be butt and fillet welded to the backside of the frame on all four sides, at 1-foot intervals, so the rebar protrudes 6 inches into the stairway opening. If the sides of the opening are concrete, 1/2-inch diameter, 4-inch deep holes can be drilled in all four sides of the opening on 1-foot centers, and 10-inch long Number 4 rebars wedged in the holes with nails.

Second, depending on the depth of the stairway opening, it may not be possible to achieve a repair thickness of at least 12 inches. The repair thickness should equal the depth of the opening, with the desired thickness being at least 12 inches.

Third, this type of repair will usually occur in the interior of a structure, where blast resistance is not critical. In this case, to save time, rebar need only be used if deamed necessary to hold the repair in position.

Fourth, again because the repair will most likely occur in the interior of a structure, the shotcrete material will most likely have to be placed by hand, using the nozzle/hose attachment of the mobile shotcrete equipment.

2. Plywood

If plywood is used to seal the stairs, follow the procedures described in Subsections VII-B.1.a to VII-B.2.b.(2).

SECTION X

DAMAGED CHEMICAL/BIOLOGICAL OVERPRESSURE DOOR

A. OVERVIEW

Four methods for repairing a damaged chemical/biological overpressure door were identified and evaluated in Volume I: (1) shotcrete, (2) third door insertion, (3) door replacement, and (4) canvas covering. Of these methods, the canvas covering ranked highest, with the door replacement, third door insertion, and shotcrete repair methods recommended as supplements to the canvas system. All four repair methods are described here. However, as indicated previously, the shotcrete system is still under development, and its recommendation as a repair method is preliminary and subject to change.

Descriptions of these repair methods must consider the fact that use of three of the systems (third door insertion, door replacement, and shotcrete) is damage-dependent. If only a door has been damaged, the door replacement system is used. If the door's frame is damaged, the third door insertion system is used. If the entire door system is severely damaged, the shotcrete system is used to seal the doorway. So these methods should be viewed as components of a single overpressure door repair system. The canvas system can be used for all the damage modes just described. Consequently, the following descriptions of overpressure door repair methods are divided into two categories: the canvas system, and damage-dependent systems.

The choice of which repair system should be used at a particular base is best left to the discretion of the BCE.

B. CANVAS REPAIR SYSTEM

1. System Requirements

a. Personnel

The standard ERSF team described in Section II can accomplish this repair.

b. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, this repair method requires:

- two, 10-foot square, heavy-weight, zippered pieces of water-proof canvas;
- two sailmaker's knives for trimming the canvas;
- a heavy-duty staple gun with 300 staples;
- 50 feet of 1/2-inch wide, 1/4-inch thick, adhesive, rubber weatherizing material;
- twenty, 2- by 4-inch boards, 8 feet long; and
- a caulking gun with five tubes of caulk.

2. System Description

a. Purpose And Use

The purpose of this repair is to cover a damaged overpressure door with a zippered, water-proof, heavy-weight, piece of canvas. The canvas cover will minimize the overpressure loss inside the building, while still allowing entry into and egress from the building using the zipper. A wood frame is fabricated from 2- by 4-inch lumber, and attached to the wall around the doorway with ramset studs. The frame is sealed to the wall with caulk. The canvas cover is attached to a wood frame with a staple gun. Weatherizing strips placed between the canvas cover and wood frame form a seal.

b. Repair Procedure

The repair is accomplished using the following steps:

(1) Debris Clearance

If required, use the jackhammer and/or acetylene torch to remove parts of the damaged structure surrounding the doorway that will interfere with repair operations. Use brooms and shovels to remove loose debris from the repair area to provide a clean and level working surface.

(2) Fabricate And Install Wood Frame

Measure the height and width of the doorway, and fabricate a door frame from 2- by 4-inch lumber. The wood frame should be sized to overlap the wall around the doorway, as shown in Figure 14. Once fabricated, attach the frame to the exterior wall around the doorway by driving ramset studs through the frame into the wall. Seal the frame to the wall with caulk.

(3) Attach Canvas Cover

Attach weatherizing strips to the wood frame, as shown in Figure 14. Trim a piece of canvas to fit the wood frame, using a sailmaker's knife. Attach the canvas to the wood fame over the weatherizing strips with a staple gun. The zipper should be oriented so it runs vertically.

c. Repair Time

A canvas covering overpressure door repair is estimated to take between 60 and 90 minutes.

C. DAMAGE-DEPENDENT REPAIR SYSTEMS

1. Shotcrete

a. System Requirements

(1) Personnel

See Subsection VII-B.1.a. for details on personnel requirements.

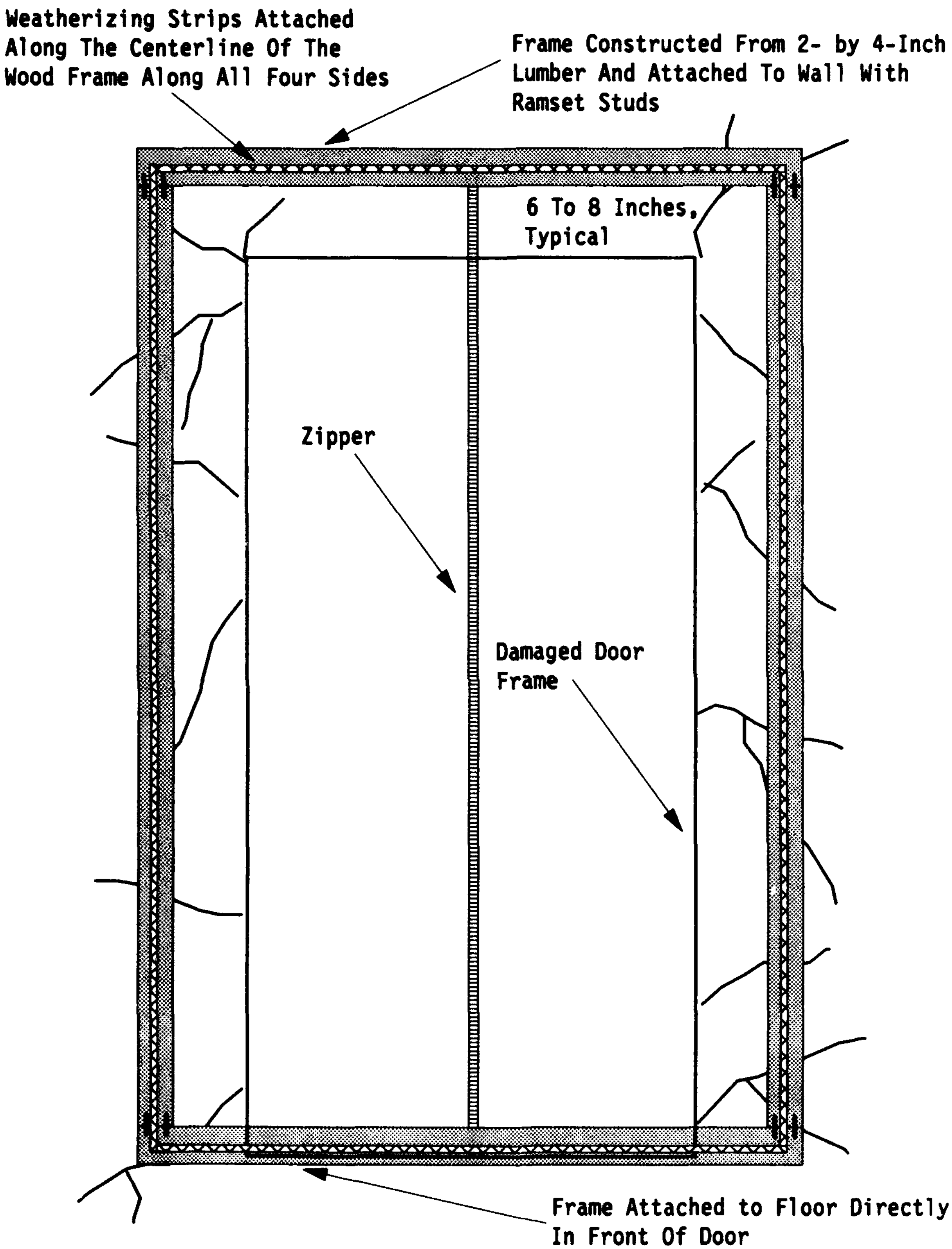


Figure 14. Wood Frame Location On Damaged Structure For Canvas Overpressure Door Repair.

(2) Supplies, Materials, And Equipment

See Subsection VII-B.1.b. for details on supplies, materials, and equipment requirements.

(3) Training

See Subsection VII-B.1.c. for shotcrete training requirements.

b. System Description

(1) Purpose And Use

The purpose of this repair is to fill with shotcrete a severely damaged overpressure door system to seal a structure. The repair process is the same as used for a shotcrete wall replacement or wall breach repair.

(2) Repair Procedure

See Subsection VII-B.2.b. for details on repair procedures.

(3) Repair Time

See Subsection VII-B.2.c. for details on estimating repair time.

2. Third Door Insertion

a. System Requirements

(1) Personnel

The standard ERSF team described in Section II can accomplish this repair.

(2) Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, this repair method requires:

- a portable welding unit, the size and type of which will be determined by the BCE;
- appropriate eye shielding and protective clothing;
- welding electrodes (probably E8013);
- four, 10-foot long, 0.25-inch thick angle iron sections with 4-inch legs;
- six, 4- by 8-foot sections of 3/8-inch plywood;
- ten, 2- by 4-inch boards, 8 feet long;
- 50 feet of 1/2-inch wide, 1/4-inch thick, adhesive, rubber weatherizing material;
- a caulking gun with five tubes of caulk;
- two door hinges and a door handle;
- a calibrated, hand operated, torque wrench with a dial indicator (see Subsection VI-C.1.b. for suggested source); and
- twelve, 3/4-inch diameter, 6-inch long rock bolts (see subsection VI-C.1.b for potential source).

b. System Description

(1) Purpose And Use

The purpose of this repair is to replace a badly damaged overpressure door and frame. A new door and frame are inserted behind the damaged door and frame, allowing the two-door overpressure entry system to continue to function, but with reduced efficiency. Consequently, a more permanent repair should be accomplished as soon as possible.

A new door frame is fabricated from angle iron, and attached to the door passageway immediately behind the damaged door. Caulk is used to create a seal around the frame. A door is fabricated from plywood and lumber.

Seams in the door are sealed with caulk. The door is attached to the frame with hinges. Rubber strips are attached to the edges of the door to act as weather and hostile agent seals.

(2) Repair Procedure

The repair is accomplished using the following steps:

(a) Debris Clearance

If required, use the jackhammer and/or acetylene torch to remove parts of the damaged structure surrounding the doorway that will interfere with repair operations. Use brooms and shovels to remove loose debris from the repair area to provide a clean and level working surface.

(b) Fabricate And Install Door Frame

Measure the height and width of the doorway, and fabricate a door frame to the correct dimensions from angle iron, as shown in Figure 15. Once fabricated, attach the frame to the doorway immediately behind the damaged door. If the frame is attached to metal, weld the frame in position. If the frame is attached to concrete, drill 6-inch deep, 3/4-inch diameter holes through the frame into the concrete, and secure the frame to the concrete with rock bolts. Use three bolts per side, and install them to the correct torque with the dial torque wrench. Seal the frame around the edges with caulk.

(c) Fabricate Door

Measure the inside dimensions of the installed door frame. Using these dimensions for reference, assemble sections of 2- by 4-inch boards and plywood into a door, as shown in Figure 16. During fabrication, seal wood seams with caulk. Using hammer and nails, attach rubber weatherizing strips along all four edges, inside and out.

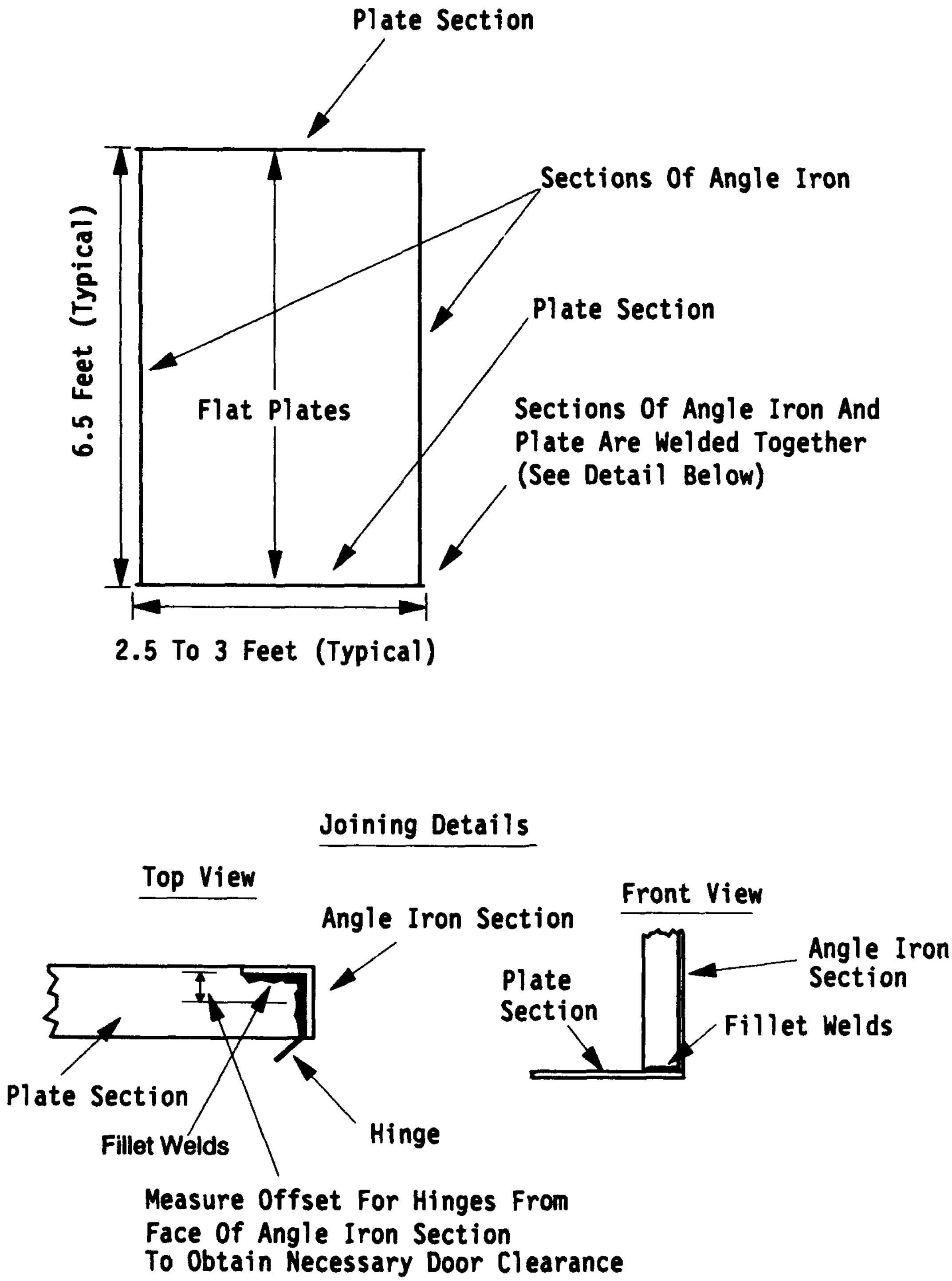


Figure 15. Door Frame Fabricated From Angle Iron.

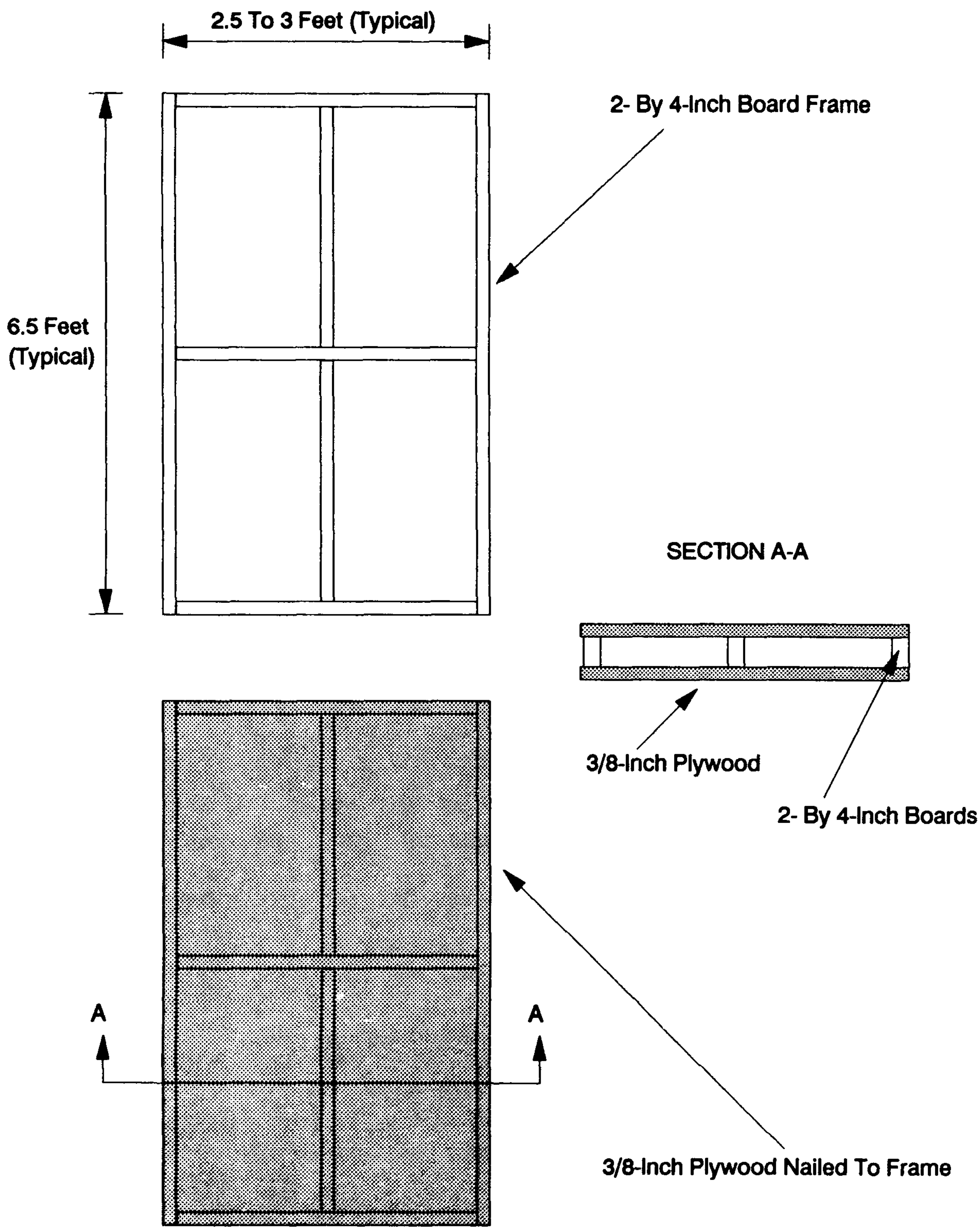


Figure 16. Door Fabricated From Plywood And Boards.

(d) Attach Door To Frame

Measure the door thickness. Using this measurement as an offset, weld two hinges to the frame, as shown in Figure 15. Then attach the door to the hinges, and the door handles to the door with wood screws. A nearly completed third door insertion repair is illustrated in Figure 17.

(3) Repair Time

A third door insertion repair is estimated to take between 60 and 120 minutes.

3. Door Replacement

a. System Requirements

(1) Personnel

The standard ERSF team described in Section II can accomplish this repair.

(2) Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, this repair method requires:

- a portable welding unit, the size and type of which will be determined by the BCE;
- appropriate eye shielding and protective clothing;
- welding electrodes (probably E8013);
- six, 4- by 8-foot sections of 3/8-inch plywood;
- ten, 2- by 4-inch boards, 8 feet long;
- 50 feet of 1/2-inch wide, 1/4-inch thick, adhesive, rubber weatherizing material;
- a caulking gun with five tubes of caulk; and

Figure 17. Nearly Completed Third Door Insertion Repair.

- two door hinges and a door handle.

b. System Description

(1) Purpose And Use

The purpose of this repair is to replace a badly damaged overpressure door. The damaged door is removed from its frame and a new door attached, allowing the two-door overpressure entry system to continue to function, but with reduced efficiency. A more permanent repair should be accomplished as soon as possible.

A door of appropriate dimensions is fabricated from plywood and lumber. Seams in the door are sealed with caulk. The damaged door, including hinges, is removed from its frame. The fabricated door is then attached to the frame with new hinges. Rubber strips are attached to the edges of the door to act as weather and hostile agent seals.

(2) Repair Procedure

The repair is accomplished using the following steps:

(a) Debris Clearance

If required, use the jackhammer and/or acetylene torch to remove parts of the damaged structure surrounding the doorway that will interfere with repair operations. Use brooms and shovels to remove loose debris from the repair area, to provide a clean and level working surface. Remove the damaged door and its hinges from the door frame.

(b) Fabricate Door

Measure the inside dimensions of the existing door frame. Based on these measurements, assemble sections of 2- by 4-inch boards and plywood into a door as shown in Figure 16. During fabrication, seal seams in the door with caulk. Using hammer and nails, attach rubber weatherizing strips along all four edges, inside and out.

(c) Attach Door To Frame

Measure the door thickness. Using this measurement as an offset, weld two hinges to the frame as shown in Figure 15. Then attach the door to the hinges, and the door handles to the door with wood screws.

(3) Repair Time

A door replacement repair is estimated to take between 30 and 90 minutes.

SECTION XI

STUCK BLAST DOOR

A. OVERVIEW

In Volume I of this report, systems for opening stuck aircraft shelter blast doors and other hardened structure blast doors were investigated. The result of this investigation was a recommendation that a heavy piece of equipment, such as a bulldozer, be attached to the door with heavy chains and shackles to pry the door open. It is not the intent of this process to repair the door so it can be opened and closed in a normal manner. Instead, the purpose of this method is to open the door, even if that means damaging it further, so critical resources can be removed from within the structure.

B. REPAIR DESCRIPTION

1. System Requirements

a. Personnel

The standard ERSF team described in Section II can accomplish this repair.

b. Supplies, Materials, And Equipment

Besides the standard supply listing given in Table 1, this repair method requires:

- a bulldozer or other piece of heavy tracked construction equipment;
- three, 30-foot lengths of heavy chain (each with a 20,000-pound working capacity);
- a portable welding unit, the size and type of which will be determined by the BCE;
- appropriate eye shielding and protective clothing;
- welding electrodes (probably E8013);

- three, 1-foot square, 3/4-inch thick steel plates, each with a with 6-inch diameter round hole in the middle; and
- three, large, double-ended chain hooks (each with a 20,000-pound capacity, potential source: McMaster-Carr Part Number 3889T64).

2. Repair Procedure

The repair is accomplished using the following steps:

a. Debris Clearance

If required, use the jackhammer and acetylene torch to remove parts of the damaged structure surrounding the blast door that will interfere with opening it. Using the acetylene torch, cut away any welds caused by fragment impact that interfere with opening the door. If the blast door is not an aircraft shelter door, cut the hinges with the acetylene torch.

b. Attach Connection Points

Attach three connection points to the door by welding the steel plates to the door. Position the plates so an even prying force can be obtained. Fillet weld the plates to the door along all four edges. The hole in each plate should be oriented so a chain can be passed through it in the direction from which the bulldozer will pull to open the door (see Subsections XI-B.2.c. and XI-B.2.d..

c. Connect Chains

Loop a chain around a hard point on the bulldozer, through the hole in one of the plates welded to the door, and back to the bulldozer. Attach the chain to itself using one of the double ended chain hooks. Repeat this process until all three chains are attached to the door and bulldozer.

d. Open Door

Using the bulldozer, slowly apply a prying force to the door until it opens wide enough to remove the desired resources from within the structure. If the door will not open, try cutting additional points around the door that may interfere with its opening. Then try opening the door again with the bulldozer. Continue this process until the door is opened, or team personnel are directed by the DCC to terminate repair operations. Opening a stuck aircraft shelter blast door is illustrated in Figure 18.

3. Repair Time

As seen from the repair procedures described above, it is difficult to estimate the time required to open a struck blast door. As a guide for planning, assume a repair time between 60 and 90 minutes for a normal blast door, and 120 and 180 minutes for an aircraft shelter blast door.

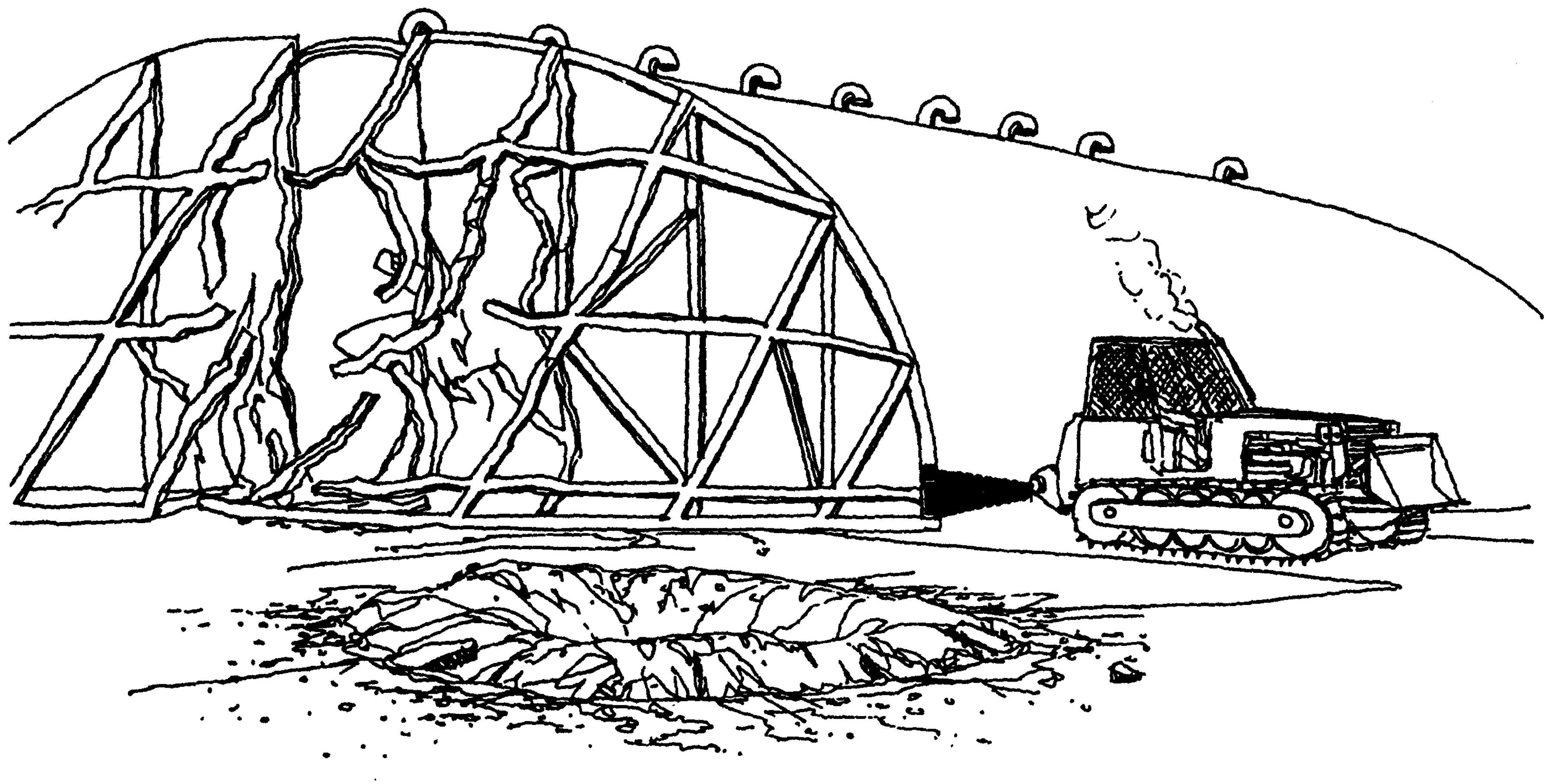


Figure 18. Opening Stuck Aircraft Shelter Blast Door.

SECTION XII

DESTROYED WINDOW

A. OVERVIEW

Two methods of repairing a destroyed window were identified and evaluated in Volume I: (1) acrylic panels, and (2) clear polyethylene sheeting. After evaluation, both systems ranked essentially equally. The sheeting repair is simple, but should be viewed only as a very temporary repair. It therefore will not be discussed here. Resource and personnel requirements and repair procedures for the acrylic panel window repair are presented in this section.

B. REPAIR DESCRIPTION

1. System Requirements

a. Personnel

Two ERSF personnel can accomplish this repair, preferably two of the structural specialists (AFSC 552X0).

b. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, this repair method requires:

- four, 4- by 8-foot, 1/2-inch thick acrylic panels;
- one gallon of clear, fast-setting epoxy cement;
- a caulking gun with five tubes of caulk; and
- twenty, 1/2-inch diameter wood screws, 4 inches long.

2. System Description

a. Repair Purpose And Use

The purpose of this repair is to replace a destroyed window. Such a repair could be critical in a postattack environment. Power may be off or intermittent, and sunlight may be the only source of illumination for periods of time. Further, the window opening should be covered to keep the elements and/or chemical and biological agents from entering the structure.

A wood frame is fabricated from 2- by 4-inch lumber, and attached to the wall around the damaged window with ramset studs. The frame is sealed to the wall with caulk. Acrylic panels are then placed on the frame, and secured to it with screws. Caulk is then applied to the frame/panel interface.

b. Repair Procedure

The repair is accomplished using the following steps:

(1) Debris Clearance

If required, use the jackhammer and/or acetylene torch to remove parts of the damaged structure surrounding the window opening that will interfere with repair operations. Use shovels and brooms to remove loose debris to provide a clean and level working area.

(2) Fabricate And Install Wooden Frame

Measure the height and width of the window opening, and fabricate a window frame from 2- by 4-inch lumber. The wood frame should be sized to overlap the wall around the window opening, as shown in Figure 19. Once fabricated, attach the frame to the exterior wall of the building around the opening by driving ramset studs through the frame into the wall. Seal the frame around its edges with caulk.

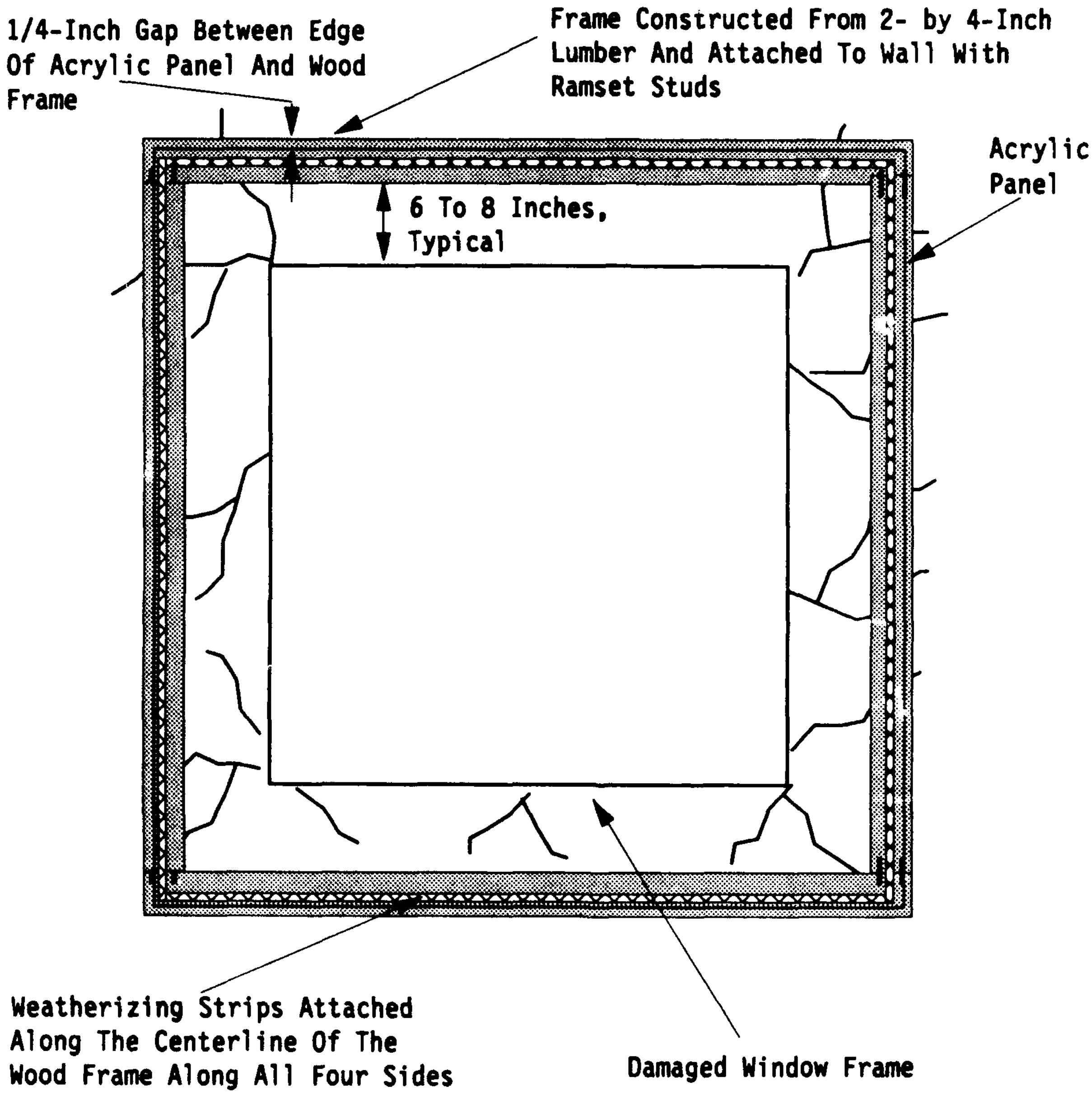


Figure 19. Wood Frame Location On Damaged Structure For Acrylic Panel Window Repair.

(3) Fabricate Acrylic Section

Fabricate an acrylic section to cover the wood frame. Trim panels by placing them on sawhorses and cutting them with a rotary saw. Join panels with rapid-setting epoxy cement. The dimensions of the acrylic section should allow a 1/4-inch gap to exist between the edge of the panel and the outside edge of the wood frame, along all four sides (see Figure 19).

(3) Attach Acrylic Section

Center the acrylic section over the frame, and secure it to the frame with wood screws. Holes should be predrilled in the panel where the screws will be located. Place the screws at 1-foot intervals around all four sides of the acrylic section. Seal the acrylic panel to the wood frame by running a bead of caulk along the interface between the panel and frame, along all four edges. A nearly completed acrylic panel window repair is shown in Figure 20.

c. Repair Time

An acrylic panel window replacement repair is estimated to take between 60 and 90 minutes.

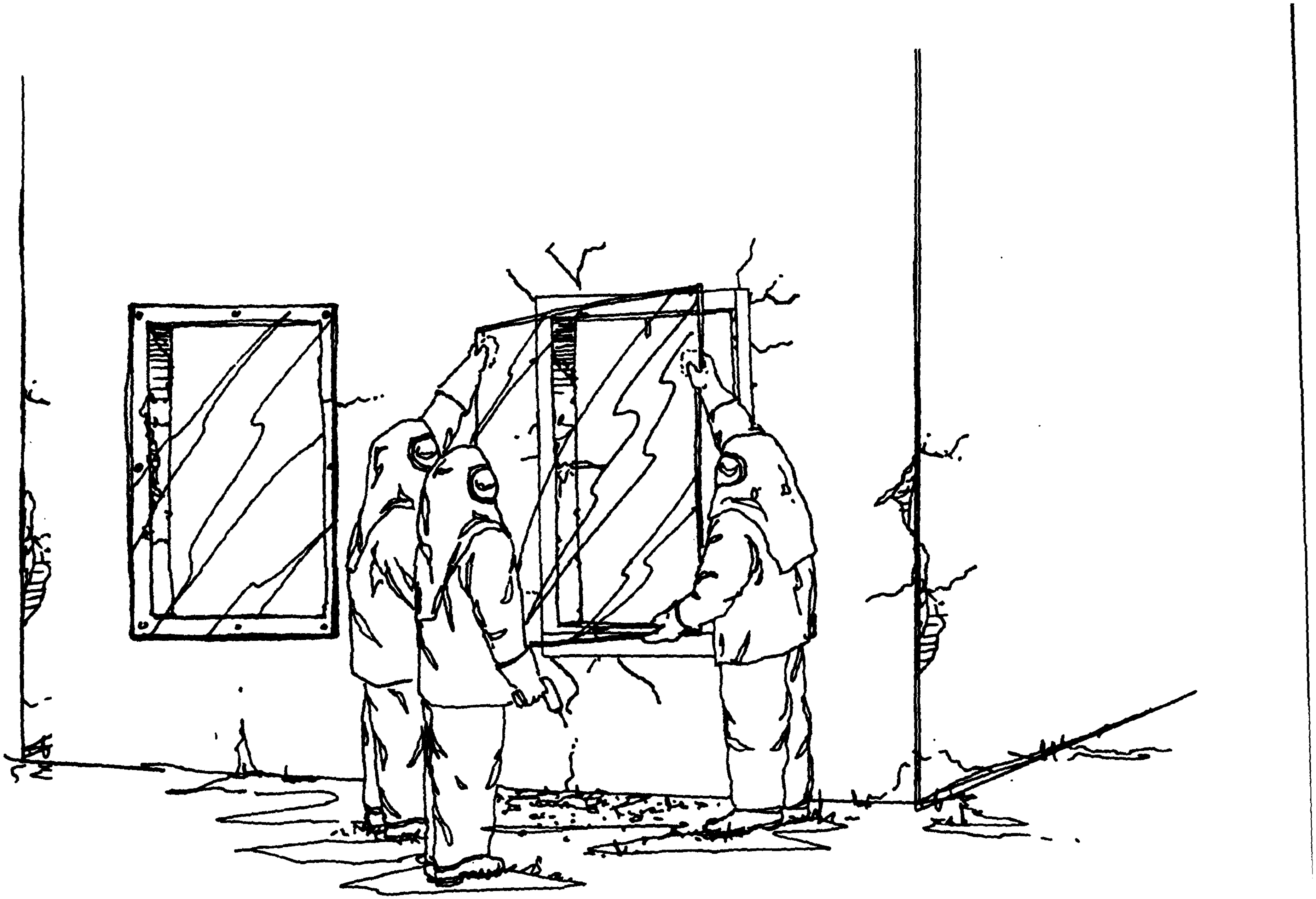


Figure 20. Nearly Completed Acrylic Panel Window Repair.

SECTION XIII

BUCKLED AIRCRAFT SHELTER FLOOR SLAB

A. OVERVIEW

In Volume I, one of the structural damage modes identified as expediently repairable involved a buckled aircraft shelter floor slab. The buckled slab prevents the aircraft within the shelter from exiting. Three methods were identified and evaluated for repairing such a damage mode: (1) shotcrete, (2) rapid-set concrete, and (3) AM2. All three systems involve forming a ramp to allow an aircraft to taxi over the buckled pavement. Of the three, the AM2 system ranked highest and should be used when the required ramp height is not excessive (see below) in relation to the panels 6-foot length. The rapid-set concrete ranked nearly as well as the AM2, and should be used when the required ramp height is large. Both the AM2 and rapid-set concrete systems are discussed in this section. The shotcrete system, due to concerns already mentioned in previous sections, did not score as well as the other two systems. However, because work is being done to overcome these concerns, the shotcrete system is also described in this section.

It is assumed that all three tactical aircraft wheels must traverse the buckled pavement, so three ramps must be formed. The distance between the ramps must conform to the aircraft gear-truck configuration and dimensions. The typical gear-truck configuration for tactical aircraft is shown in Figure 21. Gear-truck dimensions for common tactical aircraft are given in Table 5.

If positioned correctly, ramps need only be 2 feet wide to accommodate an aircraft wheel. Ramp length depends on the height of the buckled pavement. Based on this height, the length of a ramp should be such that the ramp grade is 30-percent (1 to 3) or less.

If only a small portion of the floor slab is buckled, fewer ramps can be used than indicated above and described below, because part of an aircraft gear-truck can then traverse undamaged pavement.

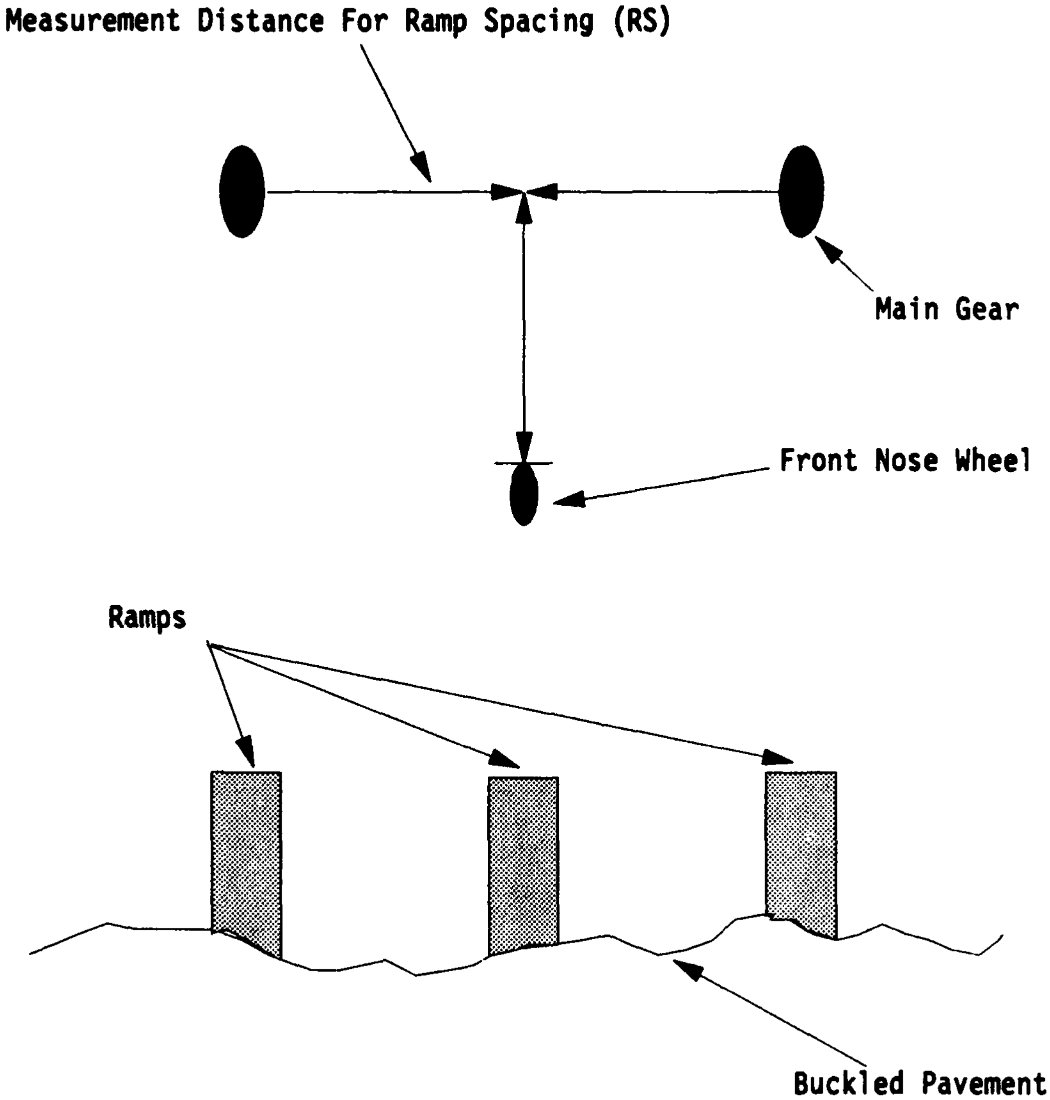


Figure 21. Ramp Spacing Versus Typical Tactical Aircraft Gear-Truck Configuration.

TABLE 5. GEAR-TRUCK DIMENSIONS FOR COMMON TACTICAL AIRCRAFT.

AIRCRAFT	RS IN FEET AND INCHES[1]
F-15	4' 6.5"
F-16	3' 10.5"
F-111	5' 0"
F-4E	8' 11.5"
F-5A	5' 6.5"
A-10	7' 7.4"2[2] 9' 7.6"[2]

1 - RS is one half the distance between an aircraft's main gear (see Figure 22).
2 - Looking forward, the nose gear of the A-10 is offset to the right 12.1 inches.

B. SHOTCRETE

1. System Requirements

a. Personnel

The standard ERSF team described in Section II can accomplish this repair.

b. Supplies, Materials, And Equipment

See Subsection VII-B.1.b. for details on supplies, materials, and equipment.

c. Training

See Subsection VII-B.1.c. for shotcrete training requirements.

2. System Description

a. Purpose And Use

The purpose of this repair is to form three ramps over a buckled aircraft shelter floor slab, using the mobile shotcrete equipment to place shotcrete material into prepared formwork.

b. Repair Procedure

The repair is accomplished using the following steps:

(1) Debris Clearance

See Subsection VII-B.2.b.(1) for details on debris clearance.

(2) Measurements

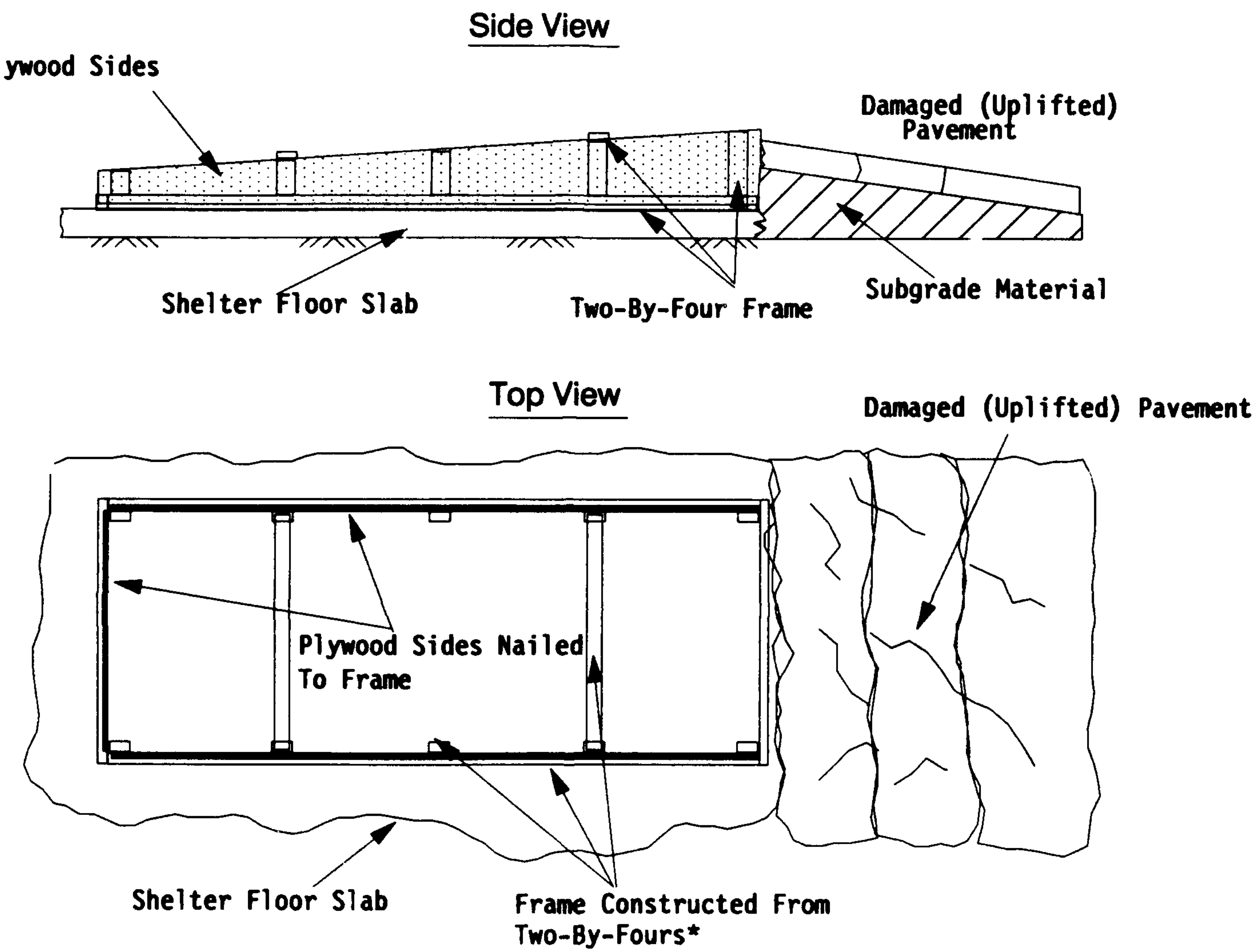
From Table 5, determine the transverse distance between the main gear and nose gear for the aircraft to be moved. If the aircraft is not listed in the table, measure the distance. This distance will be the spacing between the longitudinal centerline of each ramp. Measure the height of the buckled pavement where each ramp is to be placed. Divide these heights by 0.30 to obtain the minimum length of each ramp. Round each ramp length up to the nearest foot.

(3) Construct Formwork

Using 4- by 8-foot plywood sections, 2- by 4-inch boards, and hammer and nails, fabricate three sections of the formwork shown in Figure 22. The formwork consists of a frame of 2- by 4-inch boards with plywood sides. The high end of the formwork should be positioned directly against the buckled pavement.

(4) Place Shotcrete Material

See subsection VII-B.2.b.(4) for general details on placing shotcrete. Usually, to reach the repair area, the hose and nozzle attachment of the mobile shotcrete equipment will be used instead of its automated arm. Application of shotcrete within the formwork should start at the location of the uplifted pavement and slowly move backwards, until the ramp is completed. The boards along the top of the formwork can be used as height guides, to ensure the correct ramp grade is obtained and the ramp surface is free of large undulations. If desired, the formwork can be removed immediately after placement of shotcrete is completed. Traffic over the ramps can begin 1 hour after placement is completed, when the shotcrete has reached its design compressive strength. A completed aircraft shelter floor slab repair is illustrated in Figure 23.



* - Place Two-By-Fours At 3-Foot Intervals Across The Top Of The Formwork To Prevent The Sides From Bulging Once The Concrete Is Placed.

Figure 22. Ramp Formwork.

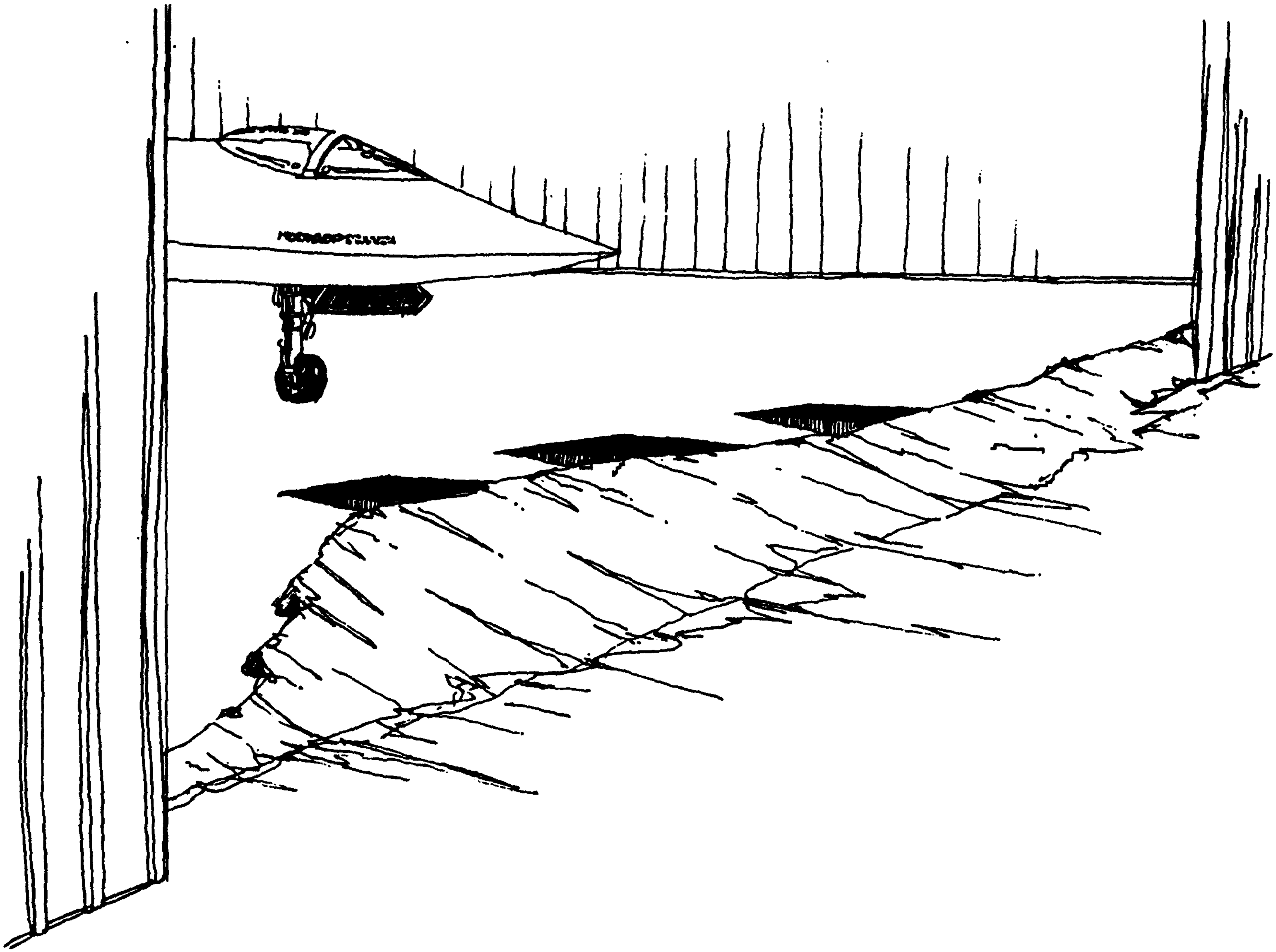


Figure 23. Aircraft Shelter Floor Slab Ramp Repair.

c. Repair Time

See Subsection VII-B.2.c. for details on estimating repair time.

C. RAPID-SETTING CONCRETE

1. System Requirements

a. Personnel

The standard ERSF team described in Section II can accomplish this repair.

b. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, this repair method requires:

- 2 cubic yards of rapid-setting grout and the appropriate amount of accelerator;
- a small, towable concrete mixer;
- a water buffalo;
- a dump truck load of pea gravel;
- five finishing squeegees;
- twenty 4- by 8-foot panels of 3/8-inch plywood; and
- twenty 2- by 4-inch boards, 8 feet long.

If desired, Number 10 gage wire mesh can be used as reinforcing material in the ramps.

2. System Description

a. Purpose And Use

The purpose of this repair is to form three ramps over a buckled aircraft shelter floor slab, using rapid-setting grout mixed with pea gravel, water, and an accelerator, in a small concrete mixer. The concrete is poured into formwork and trowled into position with squeegees.

b. Repair Procedure

The repair is accomplished using the following steps:

(1) Debris Clearance

See Subsection VII-B.2.b.(1) for details on debris clearance.

(2) Measurements

See Subsection XIII-B.2.b.(2) for details on required measurements.

(3) Construct Form Work

See Subsection XIII-B.2.b.(3) for details on formwork construction.

(4) Place Rapid-Setting Concrete

Use the concrete mixer to combine the rapid-setting grout, aggregate, accelerator, and water (from the water buffalo) in ratios recommended by the grout manufacturer. The amount of accelerator can be varied to obtain more rapid set times, or to account for cold weather or mix water. From the mixer, pour the concrete into the formwork. Use the squeegees and shovels to trowel the concrete into all areas of the formwork. If necessary, as the lower portion of the formwork becomes filled with concrete, nail a piece of plywood across the formwork at this location to keep the concrete from overflowing. If necessary, seal the bottom edges of the formwork with caulk, or a similar material, to prevent the concrete from seeping out the bottom of the formwork during placement. A low stump concrete mix should be used to minimize concrete overflow and seepage. Continue this process until the formwork is completely filled. Repeat this process until the other two formwork sections are filled. After the concrete hardens to its design compressive strength, usually within 1 hour, traffic over the ramp can begin. If desired, at this time the formwork can be removed from around the ramp.

c. Repair Time

Repair time will vary depending on ramp volumes. As an estimate, it should take between 30 and 60 minutes to construct one ramp.

D. AM2

1. System Requirements

a. Personnel

Three persons are required to accomplish an AM2 aircraft shelter floor slab repair. Preferably, the structural specialists (AFSC 552X0) should be used.

b. Supplies, Materials, And Equipment

Besides the standard supply list given in Table 1, this repair method requires:

- three, 6-foot long, 2-foot wide AM2 landing mat sections; and
- bracing material consisting of sandbags filled with sand or pea gravel that will be place under the AM2 ramps to keep them from sagging under load.

2. System Description

The purpose of this repair is to form three ramps over a buckled aircraft shelter floor slab. Sections of AM2 matting are placed lengthwise to bridge the buckled pavement. The AM2 panels are supported underneath, as shown in Figure 24, to prevent excessive deformation under load. Support consists of sandbags filled to the correct height with sand or pea gravel. Pieces of 2- by 4-inch boards are secured to the pavement with ramset studs at both ends of the AM2 to act as chocks. This repair technique is only suitable for pavement uplifts up to 1.8 feet, because the length of AM2 matting is 6 feet. An uplift of 1.8 feet, with a 6-foot ramp length, corresponds to a ramp grade of 30-percent. This repair method should be viewed as a rapid, temporary repair, and as soon as time permits, should be replaced with a more durable shotcrete or rapid-set concrete ramp repair. A completed single AM2 ramp repair is shown in Figure 24.

c. Repair Time

Repair time should range between 15 and 30 minutes.

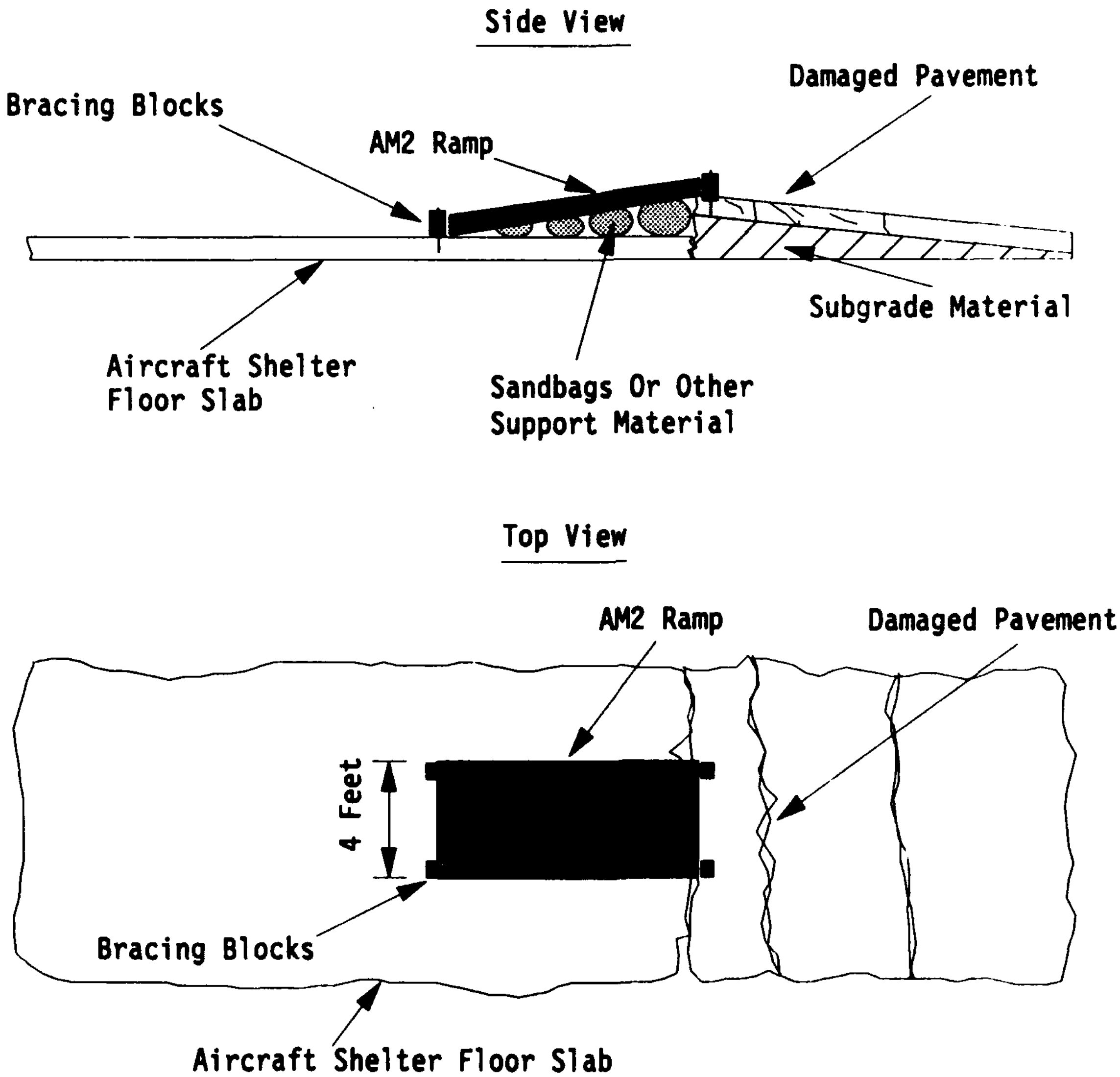


Figure 24. AM2 Aircraft Shelter Floor Slab Ramp Repair.