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INTERIM FIELD PROCEDURE FOR BOMB DAMAGE REPAIR -USING CRUSHED LIME STONE FOR CRATER REPAIRS AND SILIKAL® FOR SPALL REPAIRS

MICHAEL T. McNERNEY
ENGINEERING DIVISION,
RAPID RUNWAY REPAIR SECTION

APRIL 1979

INTERIM REPORT
JUNE 1978 - MARCH 1979

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This report describes a recommended procedure for performing repairs of large and small bomb craters using crushed stone as the repair material. The report also describes a rapid spall repair technique using a proprietary polymer concrete product. The repair techniques are described to determine the equipment, manpower, and time required to affect repairs. The report gives a brief description of the results of field tests using the crushed stone and polymer concrete techniques.

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PREFACE

This report was prepared by the Air Force Engineering and Services Center, Engineering and Services Laboratory at Tyndall AFB, Florida under Job Order Number 21042B22 Materials Fields Test for Bomb Damage Repair. This report is prepared to give the operational commanders interim guidance on two bomb damage repair techniques that are currently under investigation.

This report discusses the use of a proprietary polymer-concrete repair material. This report does not constitute an endorsement of this product by the Air Force nor can it be used to advertise the product.

This report has been reviewed by the information office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public including foreign nations.

This report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

1.0 Background

The Air Force Engineering and Services Center is currently engaged in a research and development program to upgrade the Air Force rapid runway repair (RRR) capability. Field tests at the Tyndall AFB small crater facility are in progress at this time. One repair technique that is being tested uses crushed limestone. This technique permits flush repairs to large and small craters with currently available equipment. The purpose of this report is to give guidance which will enable the users to make successful repairs to airfield pavements using the crushed stone method. This report also discusses a technique for rapid spall repair using a material that is commercially available.

The rapid repair of bomb damaged airfields has become an item of increasing concern throughout the Air Force. The repair of airfield pavements damaged by various enemy weapons must be completed rapidly following an attack in order to launch combat aircraft. The requirement for an immediate bomb damage repair capability is absolutely vital to the Air Force mission. The current repair procedure as described in AFR 93-2, Disaster Preparedness and Base Recovery Planning. (Reference 1) directs the use of AM-2 aluminum matting for repair of 750-lb bomb craters. The AFR 93-2 repair procedure is to push the crater ejecta and debris back into the crater to within one foot of the surface. Then select fill is placed in the top 12 inches and compacted with a vibratory compactor. It should be noted that the NATO accepted standard requires 60 cm (24 inches) of select fill. AM-2 matting is then towed over the repair and anchored on top of the existing concrete. AFR 93-2 does not address the repair of small craters or spall damage. Also, the AM-2 mat system described in AFR 93-2 is limited to the quantity of AM-2 mat at each base (currently, 9 patches).

There may be occasions where rapid runway repairs are required and AM-2 matting cannot be used due to unacceptable roughness of the repair or unavailability of the mats.

This interim report gives instructions for the repair of large and small craters using crushed limestone without AM-2 matting and gives instructions on the rapid repair of spall damage.

1.1 Limitations

This report is not a revision to AFR 93-2 and therefore is not directive in nature. This report gives the operational Base Civil Engineer and Red Horse Squadron instructions for an alternate repair procedure for large craters and instructions for small crater and spall repairs to supplement the procedures outlined in AFR 93-2. This report is interim in nature as the research and development effort is continuing with additional field tests planned in 1979. A small crater repair manual is planned for 1980 with revision to AFR 93-2 to include the recommended small crater repair procedures.

1.2 Unresolved Questions

The repair procedures described in this report have not been tested under operational conditions or with actual trafficking of jet aircraft and therefore present some unresolved questions. The crater repair procedure uses crushed limestone for a wearing surface which has not been flight tested with current fighter aircraft to evaluate foreign object damage, jet blast erosion, or aircraft handling and roughness characteristics.

There is some debate whether or not some type of cover over crushed stone repairs is needed to prevent pieces of stone from being ingested into jet engines, cutting aircraft tires or damaging the aircraft skin or external stores. The majority opinion is that no operational jet aircraft will suck into its intake any rocks laying motionless on the surface. However if the rocks or debris are set in motion by the jet blast of another aircraft or an aircraft nosewheel there is a possibility that the rocks or debris could be ingested if near the jet intake. A field test was conducted using a cold mix asphalt as a FOD cover over a crushed stone repair, but this proved unsuccessful because the asphalt was easily dislodged by loadcart traffic. Research is continuing to determine ways of providing possible FOD covers for this repair method. One possible way this repair technique could be used is as a temporary repair and when flight operations permit such as during the night a layer of hot-mix asphalt could be applied to stabilize the surface and prevent FOD.

The effects of operating fighter-type aircraft over crushed stone surfaces are not fully known at this time. We know that the cargo type aircraft routinely operate over gravel runways in Alaska but gravel deflectors are used on the landing gear. It is interesting to note that the MIG 23 and MIG 25 also have gravel deflectors on their nosewheel gears. The failure criteria for cargo aircraft is specified by the USA Corps of Engineers as three inches of rutting but no criteria is established for fighter type aircraft (Reference 2). Field tests conducted at Tyndall AFB have used the three-inch rut as part of the failure criteria for all F-4 loadcart tests. The effects of aircraft braking or nosewheel steering has not been studied yet and are not addressed in this repair procedure. This report provides guidance only on what is known about the structural capacity of field repairs using crushed stone. The decision to use this repair technique must be made by the operational commander due to the unknowns that still require further research.

SECTION II

SPECIFICATIONS

2.0 Crushed Limestone Specifications

Field tests at Tyndall AFB have used well-graded one and one-half inch minus crushed limestone which meets Corp of Engineers specifications for base course material as specified in AFM 88-6, Chapter 2, Section 6 (Table 1). It is important to meet these specifications. Every effort should be made to obtain crushed limestone, but if it cannot be obtained locally a suitable substitute conforming to AFM 88-6 base course material should be obtained. It is extremely important that less than 10 percent of the material pass the number 200 sieve. If crushed limestone is not obtained, tests for suitability must be performed locally.

TABLE 1. GRADATION OF AGGREGATES FOR GRADED CRUSHED AGGREGATE BASE COURSE

Sieve Designation	Percentage by Weight Passing Square-Mesh Sieve		
	No. 1	No. 2	No. 3
2-inch	100	-	-
1-½-inch	70-100	100	-
1-inch	45-80	60-100	100
½-inch	30-60	30-65	40-70
No. 4	20-50	20-50	20-50
No. 10	15-40	15-40	15-40
No. 40	5-25	5-25	5-25
No. 200	0-10	0-10	0-10

2.1 Moisture Limitations

The crushed limestone must be stockpiled in such a way that the moisture content of the material remains less than 5 percent by weight. This can normally be achieved by allowing the stockpile freedom to naturally drain excess water. The decision to cover the stockpile must be made locally based on weather patterns.

2.2 Compaction Required

The crushed limestone repair is critically dependent on proper compaction and failure to meet the requirements will adversely affect the repair performance. Failure of the repair on the first aircraft pass could easily result from insufficient compaction. Compaction requirements are a function of the aircraft loads. The ability to meet the compaction requirements are a function of the compactor used, the soil being compacted, and the moisture content of the soil. The recommended repair procedure uses a 19,000-lb minimum weight, self-propelled vibratory roller to achieve an average density exceeding 100 percent of CE-55 density in the top 12 inches. Smaller sized compactors will require two or more lifts and consequently require longer repair times (up to 12 hours for compaction alone using hand-held tamping compactors). Larger size compactors appear to give little or no increase in density and should also be used as specified in Section III. Density is not easily and quickly measured in the field without a nuclear moisture-density gage, and therefore the compaction requirements are specified as the number of passes that the vibratory compactor makes over each area of the repair.

2.3 Equipment Required

It is assumed for this repair procedure that all equipment and personnel currently assigned to Bomb Damage Repair (BDR) by AFR 93-2 are available although the mat assembly crew and their related equipment are not required. It is also assumed that the self-propelled vibratory roller in the BDR equipment allowance meets the following specifications:

Vibratory steel drum
Minimum weight: 19,000 lb
Frequency range: 1200-1500 vpm
Minimum drum width: 80 inches
Minimum dynamic force: 35,000 lbs
Minimum combined compactive force: 500-lb/in of drum width

For this repair procedure any equipment in addition to that listed in AFR 93-2 is identified as additional equipment.

2.4 Silikal® Specifications

Silikal® is a proprietary product of Karl Ullrich & Co of Germany. This company has several licensees who produce this material in the United States and Germany. A list of American manufacturers and licensees is listed in the Appendix. The German army has a special version called Silikal® R7/Bw which is made only for the German army for BDR spall repair and is currently stockpiled at German bases.

Silikal® is a methyl methacrylate-based polymer mortar. The civilian patching material is called Silikal® R-17. The civilian material has a shelf life of 18 months, but the specially packaged German army material reportedly has a shelf life of 5 years.

Silikal® R-17 is a two-component mix of dry powder and sand, and a liquid polymer. In addition the polymer mortar can be extended with aggregate such as pea gravel to make a polymer concrete. The pea gravel should be a clean, hard, durable aggregate suitable for normal concrete. The gradation should limit the maximum aggregate size to one-half inch (three-eighths inch preferred) and minimum aggregate size should be retained on a #4 sieve. Additional fines below a #4 sieve should be avoided as the sacked Silikal® contains the optimum fines using quartz sand. With Silikal® R-17, the pea gravel should be as dry as possible. Do not exceed 1 percent moisture in the pea gravel when extending the polymer mortar by 100 percent by weight or 2 percent moisture when extending the polymer mortar by 50 percent by weight. Silikal® R7/Bw can reportedly tolerate up to 6 percent moisture in the coarse aggregate.

2.6 Silikal® Equipment Required

Silikal® is a methyl methacrylate polymer and all personnel should be protected from the toxic chemicals with eye goggles and rubber gloves. The liquid is a Class I flammable material and should be transported and handled in the same manner as gasoline. No smoking in the immediate area. Avoid prolonged breathing of the vapors. Respirators are not required but are recommended when in enclosed areas without adequate ventilation. It is useful to have an air hammer to remove all loose or unsound concrete and an air compressor to run the air hammer and to blow away the loose debris. If these tools are not available use whatever tools are available to do these tasks. A screed and trowel are also required to level and finish the repair.

SECTION III

CRUSHED STONE REPAIR FIELD PROCEDURES

3.0 Field Procedures

This section discusses the field procedures necessary for rapidly repairing small and large craters with crushed limestone. This repair has the limitations discussed in Section I.

3.1 Crater Preparation

The repair of the runway starts in the same fashion as the procedure described in AFR 93-2. The first task on the critical path is to survey and establish the runway centerline; the next step is to select the craters to be repaired. The next step in the AFR 93-2 repair procedure is to push the debris into the crater and compact the debris with a tracked dozer working in the crater. For a small crater it may not be possible to use a dozer to compact inside the crater. The backfill operation remains the same for the crushed stone repair and can still be accomplished within two hours after start of repair. The difference between AFR 93-2 and the crushed stone repair is that for the crushed stone procedure or the NATO procedure the top of the debris must be at least 24 inches below the original pavement surface. This primary change critically impacts the next task, hauling the select fill (crushed limestone) from the stockpile to the repair site.

3.2 Crater Backfill and Compaction

3.2.1 Hauling Select Fill. In AFR 93-2 the haul of 12 inches select fill is scheduled from 0:25 to 2:00 hours following start of the repair. The hauling of 24 inches of select fill with the currently used 5-cu yd dump trucks will now take three to four hours to fill the needed repair area, assuming 0.8 mile haul distance. If the 24 inch thickness is not carefully measured and is actually six inches deeper, as happened in the Tyndall AFB field tests in 1974, the actual time to haul material from a stockpile 0.8 miles away to the crater will be four to five hours (Reference 3). Hauling the select fill is now the critical path for minimum time.

3.2.2 Backfill of Select Fill. The next step can be accomplished while the trucks are delivering the material to the site after the debris has been pushed into the crater. The select fill must be placed into the crater. All select fill delivered after the crater is prepared can be dumped directly into the crater by the dump trucks. It is assumed for this manual that all material is placed into the crater by the time the last select fill arrives. The crater must be overfilled six inches (Figure 1). The loader should be used to level the material approximately six inches higher than the pavement (Figure 2).

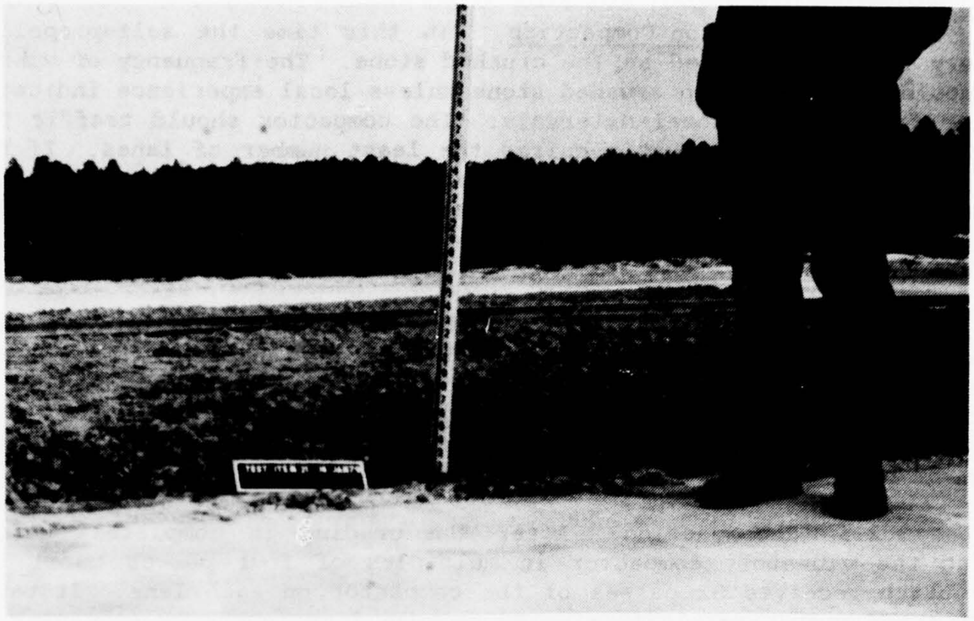

Figure 1
Crater Over-filled with Six Inches of Uncompacted Crushed Stone

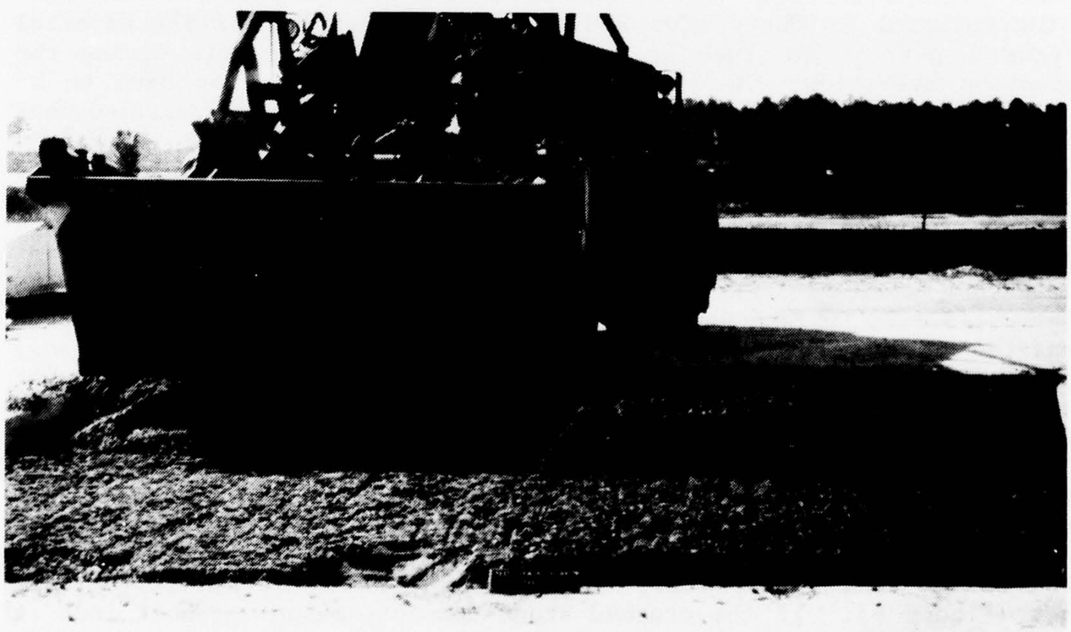

Figure 2
Using the Front End Loader to Level the Uncompacted Crushed Stone

3.2.3 Vibration Compaction. At this time the self-propelled vibratory roller is placed on the crushed stone. The frequency of vibration should be 1500 vpm on crushed stone unless local experience indicates a better frequency on local materials. The compactor should traffic the repair in the direction that requires the least number of lanes. If the repair exceeds 50 ft in diameter, compact only the portion within the emergency launch strip using the minimum number of lanes (Figure 3). Compact the repair four passes at a time on each lane, then move to the next lane (Figure 4).

3.2.4 Grading. After four passes of the compactor have been applied to each lane the patch should be releveled to approximately one and one-half inches above the concrete. The easiest way to do this is to use an experienced grader operator to grade the patch (Figure 5). An experienced operator can do this in a single pass per lane with only a minimum of hand work with shovels required.

3.2.5 Recompaction. After the grading is complete continue applying the vibratory compactor in multiples of four passes until the entire patch receives 32 passes of the compactor on each lane. It takes one compactor approximately 12 minutes to make four coverages (4 passes on each lane) on a 50 foot by 65 foot repair using eight lanes. This operation is on the critical path for minimum repair time and two compactors should be used if available.

3.2.6 Moisture Content. Experience gained from field tests indicates the crushed stone should be kept very slightly wet with no visible puddles of water (approximately 2 to 5 percent moisture content). If the material is dusty dry, add a little water, but if the material exceeds 5 percent moisture or puddles of water are visible during the compaction operation, the top four inches of material may have to be removed and replaced with drier material. Field tests have verified that the surface appearance of the material cannot be used to accurately predict aircraft traffic load bearing performance. However, if an area is obviously very spongy under the weight of a person's foot, that area should definitely be replaced with the driest material available, and thoroughly compacted.

3.2.7 Surface Roughness. After the crushed limestone has been compacted it must be inspected for surface roughness. Currently only conservative interim surface roughness criteria has been established but testing is in progress. As a guide, the following recommendations are made in lieu of formal criteria to be established later. The crushed stone should not exceed one inch in height above the adjacent concrete or extend below the adjacent concrete by two inches. Careful attention must also be given to the joint between the crushed stone and the existing concrete such that the crushed stone never falls one-half inch below the level of the concrete creating a sharp bump which could damage the aircraft (Figure 6). If the crushed stone compacts below one-half inch at the concrete joint, additional material should be added and compacted. Careful attention to this roughness criteria during the initial compaction cycle will result in no additional grading required after compaction.

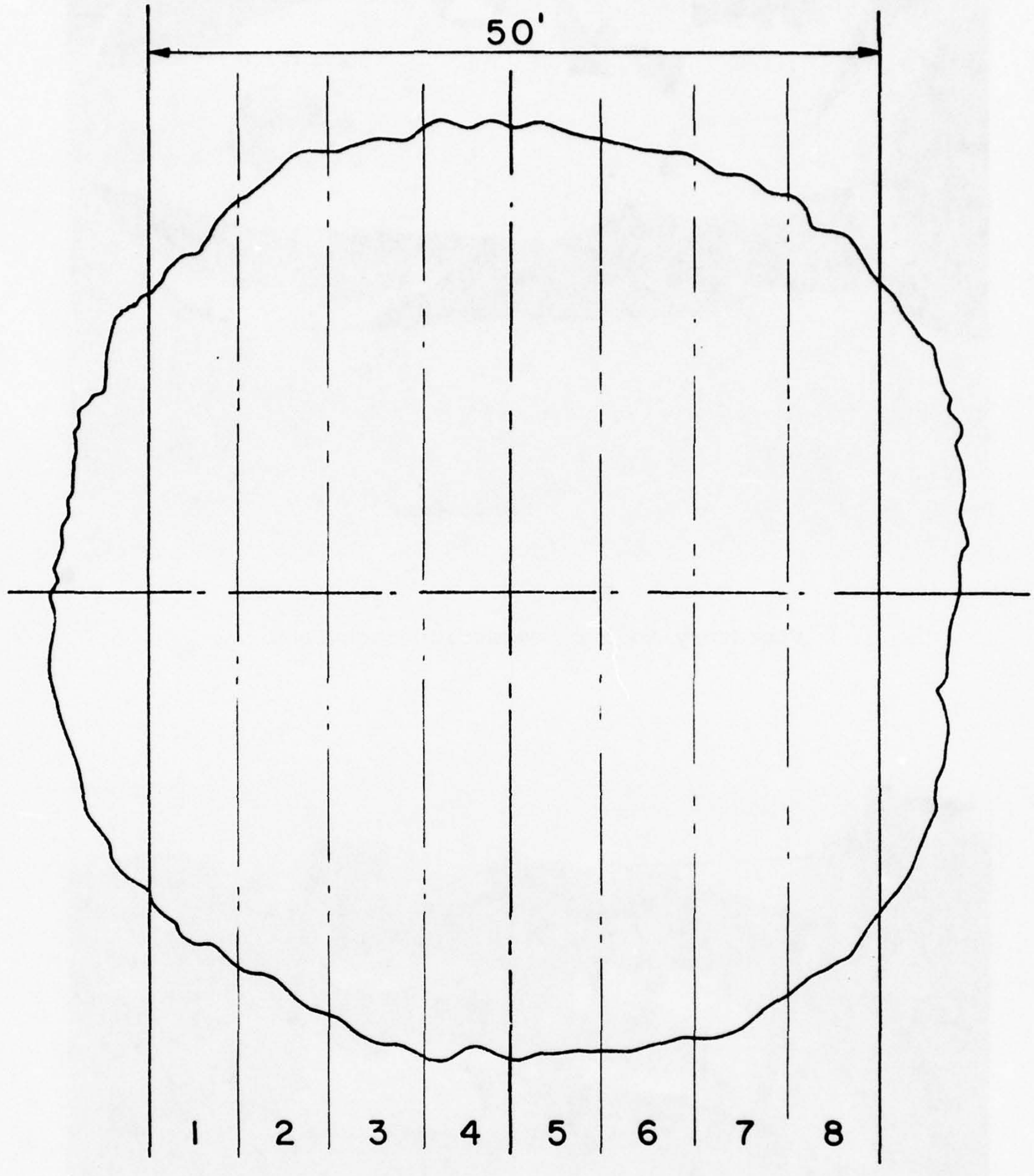

Figure 3. Compacting Lanes for Typical
750-Pound Bomb Crater

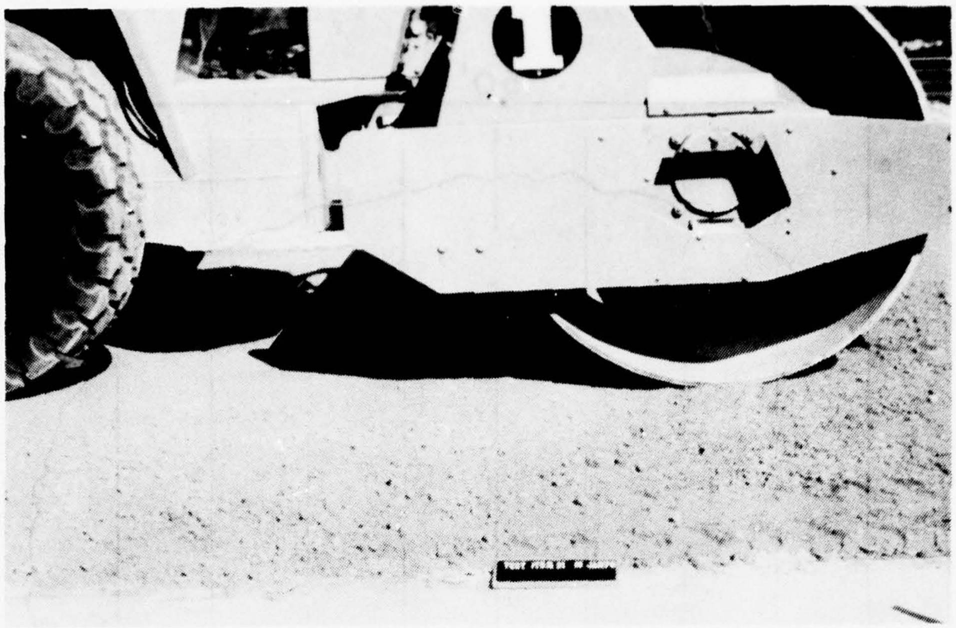

Figure 4

Vibratory Roller Compacting Each Lane

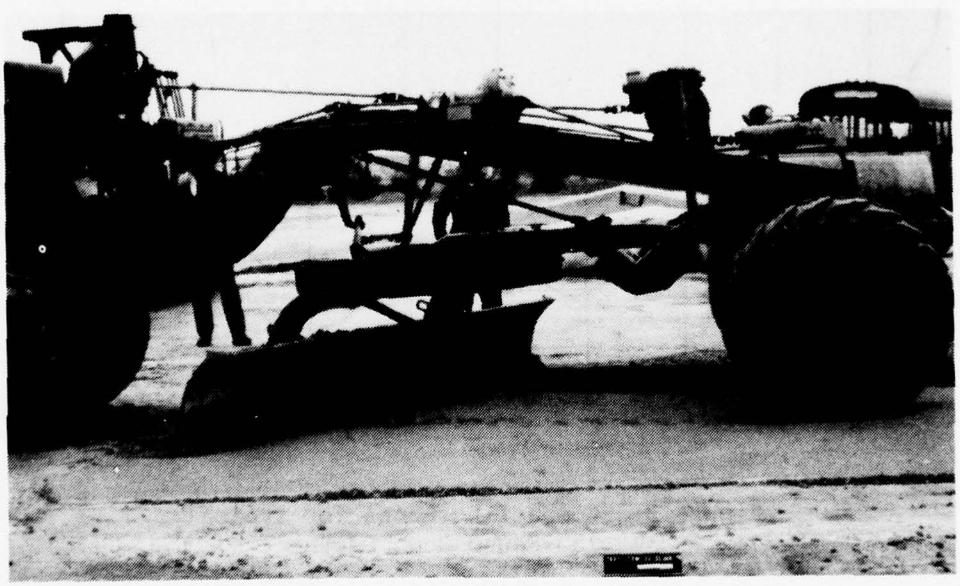

Figure 5
Grader Operator Grades the Patch After Four Coverages of the Vibratory Roller

Figure 6
Consolidation of Crushed Stone at Edge of Concrete

3.2.8 <u>Cleanup</u>. The final step is cleanup. The excess material that is pushed onto the existing concrete must be picked up either with a sweeper, loader, or grader. This material must be cleaned up to prevent damage to the aircraft. This operation can be accomplished simultaneously with the compaction operation. After the cleanup and painting of the centerline stripe the repair is ready for aircraft trafficking.

3.3 Time Analysis

The current equipment list in AFR 93-2 includes the following major items for one crater:

5 dump trucks	5 ton
2 front end loaders	2½ cu yd
1 grader	Size 2
1 dozer	Size 4 (150 hp)
1 vibratory compactor	Self-propelled

and at the stockpile for three crater teams:

1 front end loader	2½ cu yd

Assuming a 0.8-mile haul distance from the stockpile to the crater, the repair time for this method for one 65-ft diameter repair with current equipment (when the new compactors arrive) would be seven to eight hours under ideal conditions (Figure 7). The repair time is mostly a function of equipment size and numbers.

If the following larger equipment were available for one crater:

5 dump trucks	30 ton
2 front end loaders	12 cu yd
1 dozer	300 hp
1 grader	Size 2
2 vibratory compactors	Self-propelled

and at the stockpile for three crater teams:

1 front end loader	12 cu yd

Assuming a 0.8 mile haul distance from the stockpile to the crater, the repair time using the larger equipment for one 65-foot diameter crater would be approximately three hours under ideal conditions (Figure 8).

These time estimates are for a 65-foot diameter repair such as the one repaired at the Tyndall AFB field test in 1974, (Reference 3). The repaired surface in that test was 3334 sq ft and would require 500 tons of select fill if the depth had been 2 feet 0 inches. If the repair depth was exceeded by six inches (as happened in the 1974 tests) it would require 625 tons of select fill. It is imperative for strength that the minimum thickness of select fill not be less than 24 inches when the debris backfill is weak (CBR 4 to 10).

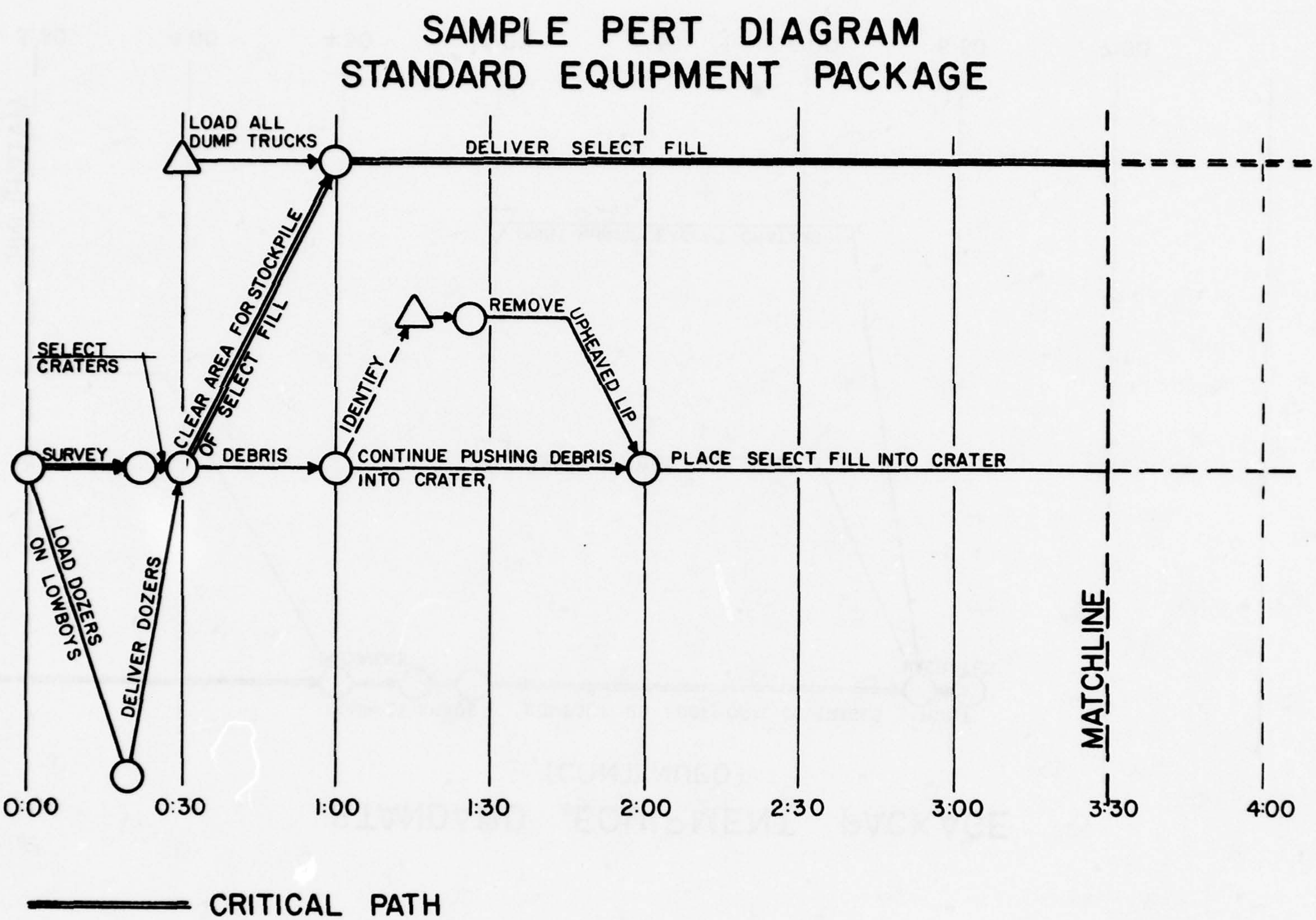

Figure 7. Sample PERT Diagram Standard Equipment Package

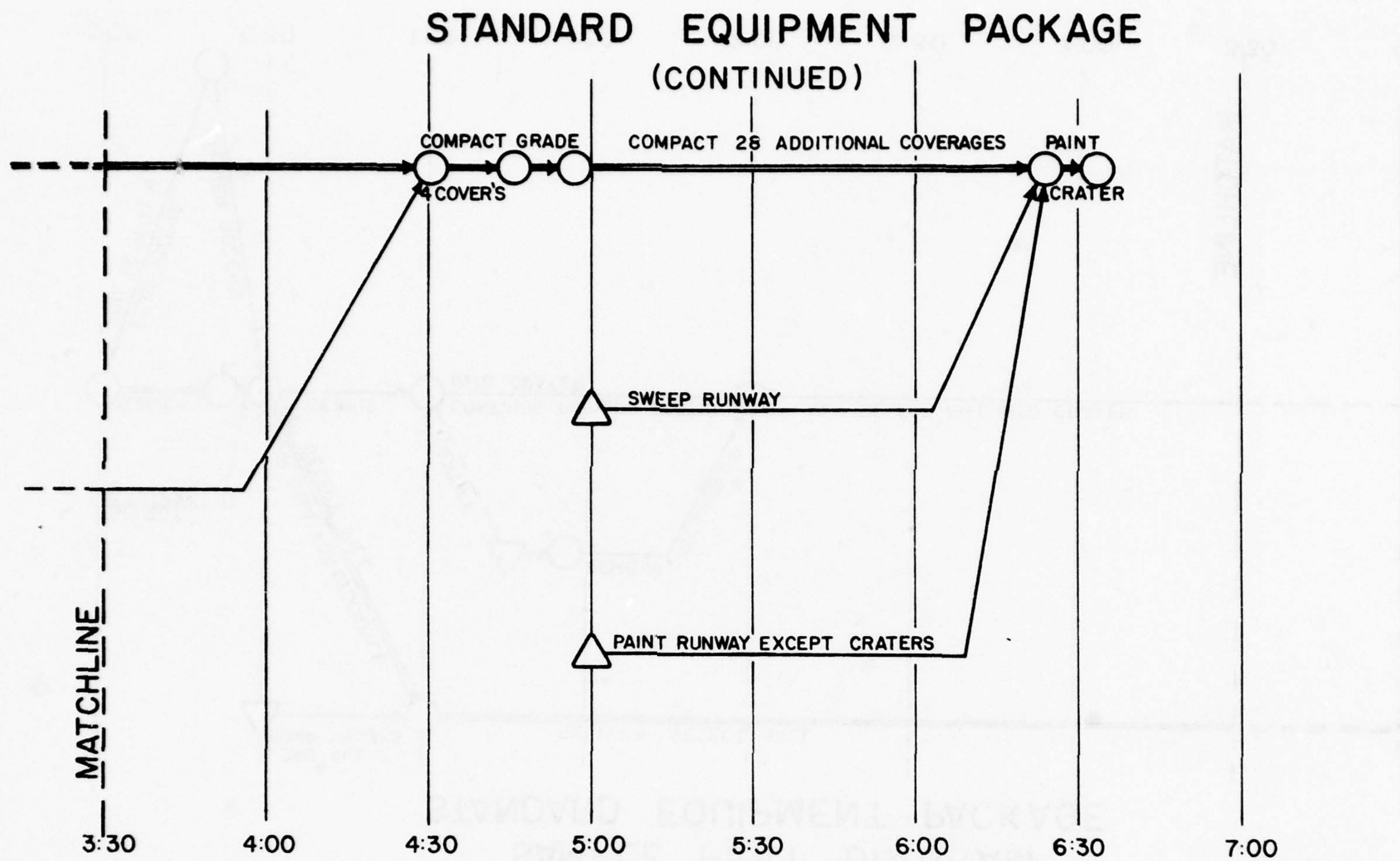

Figure 7. cont'd. Standard Equipment Package

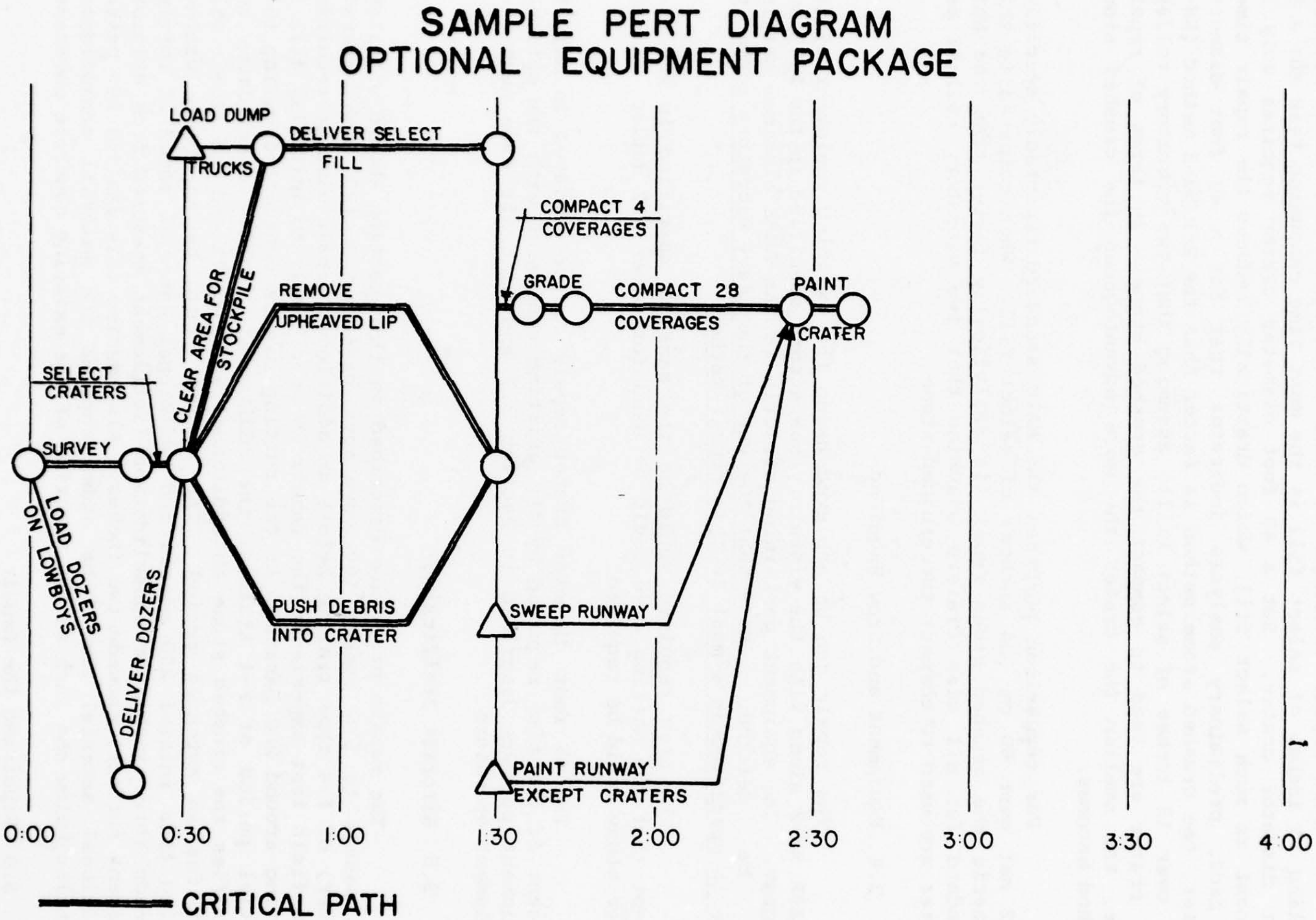

Figure 8. Sample PERT Diagram Optional Equipment Package

This repair technique is most advantageous for small craters. Hauling 24 inches of select fill is the most time consuming task for a 65 foot diameter crater. But a 40 foot diameter crater requires only 38 percent as much select fill, which drastically reduces the repair time. In fact, preliminary analysis indicates that for a 40 foot diameter crater, the crushed stone method is faster than the AFR 93-2 method (AM-2 mat over 12 inches of select fill), assuming that two vibratory rollers per crater are used to compact the crushed stone. In terms of repair time, the smaller the crater the more advantageous the crushed stone method becomes.

For comparison purposes the NATO standard reportedly specifies AM-2 mat over 60 cm (24 inches) of select fill. When compared to this criteria the crushed stone repair is analytically faster than the NATO standard for all size craters assuming that two vibratory rollers per crater are used to compact the crushed stone.

3.4 Equipment and Crew Required

The repair can be achieved using the existing equipment listed in AFR 93-2 along with the vibratory compactors specified in the FY79 buy program. The equipment pertaining strictly to the AM-2 aluminum matting can be deleted. <u>Note that the use of the heavy vibratory compactor here in specified is a must to this repair method</u>.

The crew required would be the same as specified in AFR 93-2 except that the matting crew could be used for other RRR duties. A manpower study would be required.

The 65 foot diameter crater repair can be achieved in only 43 percent of the time required by the existing equipment with the optional equipment package described in Section 3.3 and with the same number of equipment operators.

3.5 Aircraft Trafficking

The repair procedure described in this section should withstand 200 passes to 576 passes (60 coverages based on a 120 inch aircraft wander) of F-4 type traffic before an additional repair will be required. From field test experience the repair is most likely to initially fail in rutting around 200 passes. If the rutting can be controlled during this initial period of F-4 traffic, the additional traffic consolidates and densifies the crushed stone an additional 5 lbs/cu ft and the repair will last for an extended period. The repair should be carefully watched during this initial 200 passes and additional material added if rutting exceeds three inches or consolidation (settlement measured from original pavement surface) exceeds two inches. Also during this initial 200 passes additional material should be added anytime the material consolidates (settles)below one inch at the junction of the existing concrete pavement.

3.6 Repairing the Repair

If repairs are required due to rutting or consolidation of the crushed limestone, they should be made in much the same manner as the original repair. If high water content is a problem, it will be necessary to remove some surface material with a front end loader or dozer. If moisture is not a problem just add new material directly to the repaired crater and compact with the vibratory compactor for 24-32 coverages. When possible it is highly advisable to scarify the old limestone surface before adding new material. This will aid in preventing the new lift of crushed limestone from separating into layers and peeling off.

3.7 Limitations

3.7.1 Operational

The crushed limestone repair procedure is usable for F-4 fighter aircraft loads for craters of all sizes. It is also usable for all other fighter aircraft with the possible exception of the F-111. No data or field tests have been conducted for the F-111. Field tests indicate that a C141 can be supported after the 20'diameter repair has been densified by 150 coverages of the F-4 aircraft. However, tests are planned to determine if the repair is totally adequate for C141 traffic.

If the repair is left unsurfaced, take offs and taxiing should be separated to prevent FOD to the following aircraft. Formation take offs or taxiing are NOT recommended on unsurfaced repairs.

3.7.2 Materials

The crushed limestone should meet the specifications listed in section 2.0. The moisture content of the crushed limestone should be less than 5.0 percent.

3.7.3 Compactor required

The large vibratory compactor must meet the specifications listed in section 2.3. Smaller vibratory compactors cannot meet the compaction requirements in one 24 inch lift of crushed stone. If smaller vibratory compactors are used tests must be completed to determine the number of lifts and number of passes of the compactor required to achieve adequate density. If larger vibratory compactors are used the compaction should remain at 32 passes per lane over the width of the repair.

SECTION IV

SPALL REPAIR FIELD PROCEDURES

4.0 Field Procedures

This section discusses the field procedures necessary for rapidly repairing spall damage using a commercially available proprietary polymer concrete, Silikal® R-17. This method is routinely used for repairing portland cement concrete, however, asphalt overlayed concrete can also be repaired with this procedure. For spalls in only asphalt, repairs might be possible with cold mix asphalts.

4.1 Concrete Spall Preparation

It is necessary to remove all loose debris, unsound concrete, and all asphalt from the spalled area. If an air compressor is available, it should be used to remove the loose debris. Unsound concrete should be removed by an air hammer, if available, or else by a hammer and chisel. The spalled area should be free of asphaltic or oil base contaminants and moisture to the maximum extent practical. If the concrete surface requires drying, this can best be accomplished by applying a butane-fired heater such as the one shown in Figure 9 which can be manufactured locally. A typical drying time for the heater pictured is 4-8 minutes, with 10-15 minutes concrete cooling time required.

4.2 Spall Repair

4.2.1 Material

After the spall has been prepared, a crew of two is required to repair the spall. Silikal® R-17 consists of a large paper bag containing one polyethylene mixing bag and 30 pounds of the powder component. The second component is a half-gallon of liquid. The company presently does not package the liquid in individual containers for each bag, but this can be done locally.

4.2.2 Mixing Procedure

Person A opens the paper bag and removes the polyethylene mixing bag. Person B pours the powder mixture into the polyethylene mixing bag which is held open by Person A (Figure 10). Person B then adds one-half gallon of liquid into the polyethylene mixing bag (Figure 11). Person A now closes the bag by twisting the open end, leaving a small open space above the surface of the mortar (Figure 12). Holding the bag closed with one hand, he grasps the bag at a bottom corner and kneads, rolls, and shakes the contents until thoroughly mixed for about 1-2 minutes (Figure 13). If the spall is two or more inches deep, up to 30 pounds of dry pea gravel may be added to the mixing bag at this time. If the pea gravel is added, continue mixing for another minute, (Figure 14).

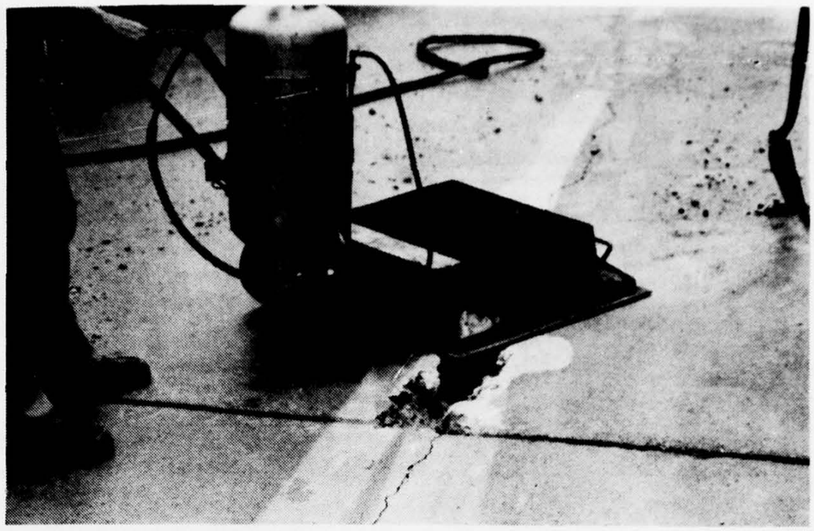

Figure 9
Butane-Fired Heater Used to Dry Concrete

Figure 10
Pouring the Powder into the Mixing Bag

Figure 11
Adding One-Half Gallon of Liquid to the Powder

Figure 12
Closing the Mixing Bag Leaving Only a Small Space
Above the Polymer Mortar

Figure 13
Thoroughly Mixing the Polymer Mortar

Figure 14
Adding Pea Gravel to the Mortar

4.2.3 Material Placement

Over the repair area, the bag with the mortar is slit open with a trowel. The mortar is poured out and trowelled down with a steel trowel (Figures 15 and 16). The mortar has a working life of 10-15 minutes and is fully cured in 60-90 minutes. Trowels should be cleaned before the mortar sets by soaking in the liquid hardener, trichloroethylene, or methyl methacrylate.

4.2.4 Cold Weather Repair

For temperatures below freezing one of two things must be done to achieve proper curing and polymerization of Silikal®. One solution is to add the special accelerator developed for the German Army which will give cure times of 60-90 minutes in below freezing temperatures. The other solution is to add heat after the Silikal® is placed or heat the Silikal® and aggregate to room temperature before using. The cure times of these procedures are variable and they must be used with some caution. Chemical acceleration is the preferred method.

4.3 Time Analysis

All spalls should be trafficable by aircraft two hours after the spall has been cleaned and the repair begins. A typical spall can be repaired in 10-30 minutes with a 60-90 minute cure time.

4.4 Equipment and Crew Required

For maximum efficiency a crew of four is recommended. The first two crew members would be the spall preparation team. The spall preparation team will require the following equipment:

1 pickup truck w/o catalytic converter
1 air compressor
1 jack hammer
1 propane heater
2 rolls polyethylene
miscellaneous hand tools (e.g. hammer, chisel, broom)

The second two crew members would be the spall repair team and would require the following equipment:

1 pickup truck w/o catalytic converter
2 pr rubber gloves
2 eye goggles
2 trowels
1 screed beam
Silikal® repair material
buckets of dry pea gravel

The recommended procedure is for the spall preparation team to start preparing spalls and the spall repair team following in their tracks. Once a

Figure 15
Slitting the Mixing Bag Open with a Trowel

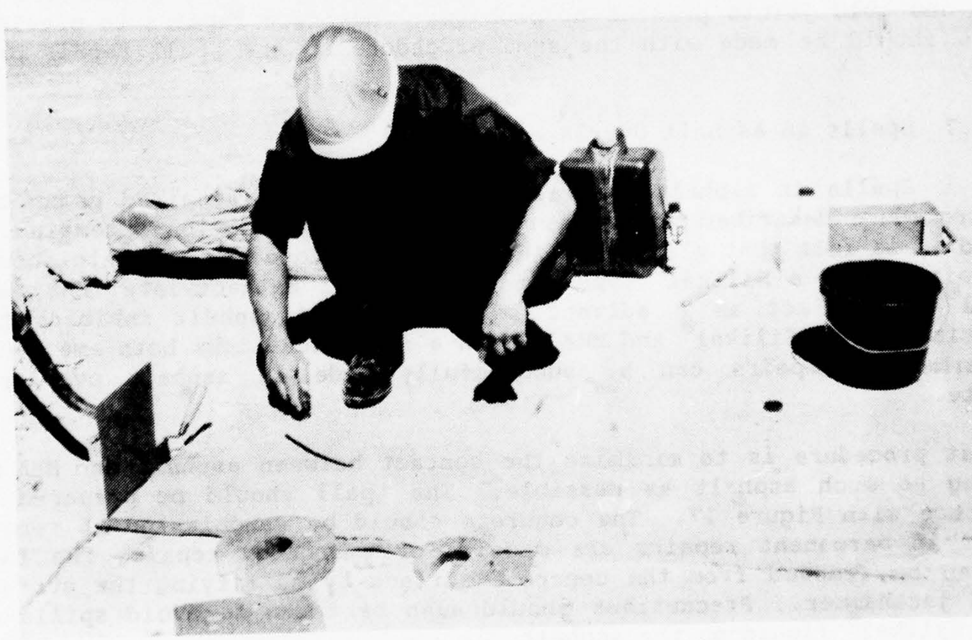

Figure 16
Trowelling the Concrete Down Smooth

spall is prepared, the spall preparation team goes to the next spall while the spall repair team completes the repair. The number of multiple crews required would depend on the number of spalls to repair and the time available.

4.5 Aircraft Trafficking

The strength of Silikal® and all polymer concretes is directly proportional to the temperature of the material. At 130°F the material has only half the strength it has at 75°F, (Reference 4). Once polymerization has occurred Silikal® may be trafficked. As a general rule Silikal® may be trafficked according to the following table:

Ambient Temperature	Cure Time and Traffic Time
75°F	60 minutes
50°F	90 minutes
32°F	120 minutes
32°F w/Accelerator added	60 minutes
0°F w/Accelerator added	90 minutes

4.6 Repairing the Repair

Spall repairs done with Silikal® R-17 and dry aggregate should require no maintenance. Silikal® would in fact make excellent routine permanent repairs, exceeding the strength of ordinary concrete. If repairs do become necessary, Silikal® has excellent bond properties to itself and cold joints present no problems; therefore repairs to previous repairs should be made with the same procedure as the spall repair procedure.

4.7 Spalls in Asphalt Overlayed Concrete

Spalls in asphalt overlayed concrete can be repaired using the same procedure described in Section 4.2. Although additional testing is planned it is felt that all spalls that penetrate into the concrete should be repaired with a Silikal® type product. Methyl Methacrylate (MMA) and Silikal® liquid act as a solvent to asphalt and asphalt inhibits the polymerization of Silikal® and MMA. With a few precautions both emergency and permanent repairs can be successfully made in asphalt overlayed concrete.

The best procedure is to minimize the contact between asphalt and MMA by removing as much asphalt as possible. The spall should be prepared in accordance with Figure 17. The concrete should be sandblasted to remove asphalt if permanent repairs are made. For emergency repairs the tack coat can be removed from the concrete surface by scarifying the surface with a jackhammer. Precautions should also be taken to avoid spills of MMA or Silikal® liquid on the asphalt.

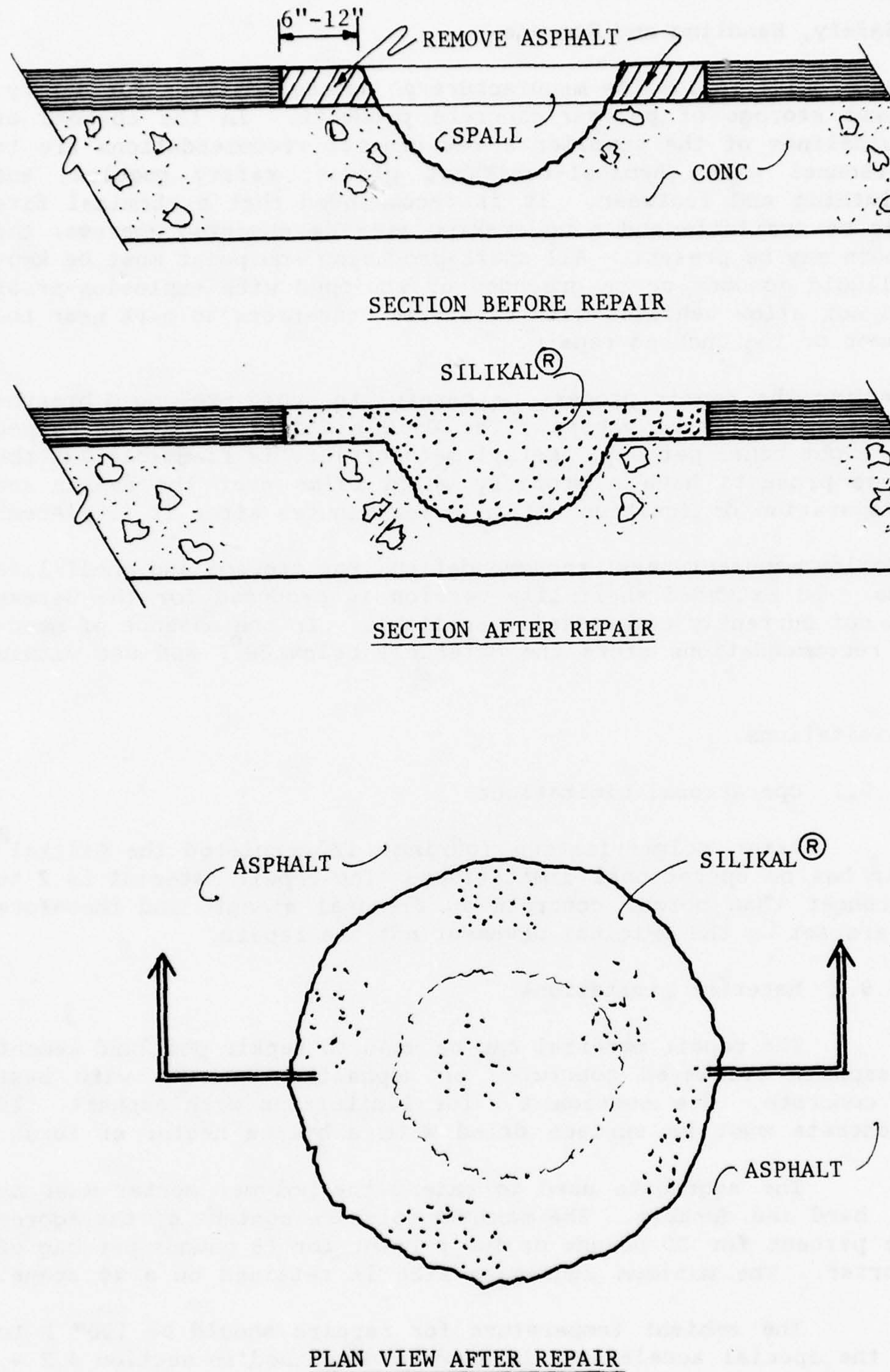

Figure 17 Proper Spall Preparation for Asphalt Overlayed Concrete

4.8 Safety, Handling and Storage

As a guide follow the manufacturers' recommendations for safety, handling, and storage of polymer-concrete products. In the absence of specific guidelines of the supplier a few general recommendations are to protect personnel with chemical-resistant gloves, safety goggles, and suitable clothing and footwear. It is recommended that a chemical fire extinguisher be available and a *no smoking area* be observed wherever the polymer vapors may be present. All spark-producing equipment must be kept away from liquid monomer or be grounded or equipped with explosion-proof motors. Do not allow vehicles with catalytic converters to park near the liquid monomer or the uncured repair.

During the repair process be careful to avoid prolonged breathing of methyl methacrylate vapors. The OSHA standard is 100 parts per million for eight hours per day. Methyl methacrylate is flammable but the Silikal® type products have a property which films over the repair and prevents evaporation or ignition within a few minutes after it is placed.

Follow manufacturers' recommendations for storage and shelf-life requirements. An extended shelf-life version is produced for the German Army but is not currently commercially available. In the absence of manufacturers' recommendations store the materials below 80°F and use within 18 months.

4.9 Limitations

4.9.1 Operational Limitations

After polymerization (curing) is completed the Silikal® spall repair has no operational limitations. The repair material is 2 to 3 times stronger than normal concrete in flexural stength and therefore the limits are set by the original pavement not the repair.

4.9.2 Material Limitations

The repair material can be used to repair portland cement concrete, asphalt overlayed concrete, or asphaltic concrete with best results in concrete. See section 4.7 for limitations with asphalt. If wet, the concrete must be surface dried with a butane heater or torch.

The aggregate used to extend the polymer mortar must be dry, clean, hard and durable. The maximum moisture content of the aggregate is one percent for 30 pounds or two percent for 15 pounds per bag of Silikal® mortar. The minimum aggregate size is retained on a #ϕ scene.

The ambient temperature for repairs should be 100° F to 20° F. If the special accelerator is used as described in section 4.2.4, the ambient temperature may extend below 0° F.

The liquid material and its vapors must be kept away from sources of ignition or open flames. The material is toxic and should be handled with the same precautions as gasoline. If contact with the skin occurs, flush with water.

SECTION V

TYNDALL AFB FIELD TESTS

5.0 This section will give a short review of some of the Tyndall AFB field tests using the crushed stone and Silikal® repair procedures conducted as part of the on-going research effort to improve BDR procedures. The results of the field tests and the lessons learned give additional information on the performance of repairs using these repair procedures.

5.1 Crushed Stone Tests

Approximately eleven field tests have been conducted to date using crushed limestone as the repair material over a compacted heavy clay subgrade with a CBR of 4-7. Table 3 gives a short summary of the results of these tests. The performance of typical field tests meeting these repair specifications would be similar to test items 22 or 26.

Field experience has shown that even good repairs such as test item 26 will show evidence of rutting during the initial aircraft traffic (Figure 18). Additional F-4 traffic will tend to further compact the material and rutting will tend to diminish (Figure 19). After 150 coverages (1440 passes) of F-4 traffic the repair will reach near maximum consolidation and rutting will be even less of a problem (Figure 20). Failure due to rutting was considered to be a three-inch rut. Figures 21, 22 and 23 are photographs of actual field test item failures due to rutting.

Besides rutting, there are two other conditions in a crushed stone patch that require repair. One condition is general consolidation of 1 to 2 inches. Until further data from aircraft testing is available, it is recommended that patches with 1 to 2 inches of consolidation be repaired by adding more material and compacting with 12 to 20 coverages of the vibratory roller (Figure 24). The other condition is the movement of material out of the patch, creating a lip along the edge of the patch (Figure 25). This is a hazard to aircraft due to possible FOD ingestion of loose rocks or cutting of the aircraft tires due to on the concrete surface or the lip itself. This should be repaired by sweeping the loose debris up and adding more material at the junction of the existing concrete.

5.2 Silikal® Field Repairs

Two Silikal® spall repairs were performed at Tyndall AFB. One was maintenance to the Tyndall AFB main runway beneath the BAK-12 arresting cable. The other repair was a spall repair test at the small crater test facility.

The first repair was to the runway beneath the arresting cable. This particular area is where the BAK-12 arresting cable impacts the runway during every aircraft pass, wearing away the concrete. A cold mix

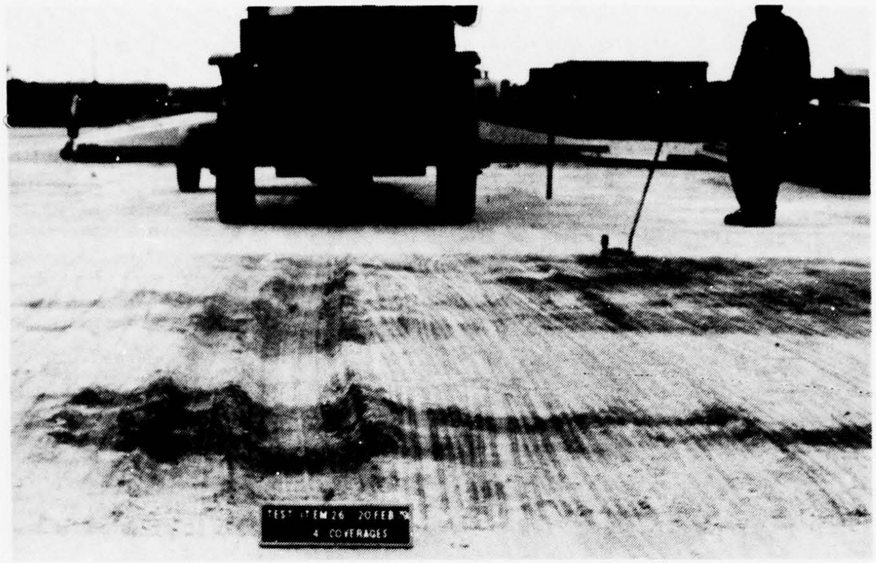

Figure 18
Typical Initial Rutting on Satisfactory Repairs

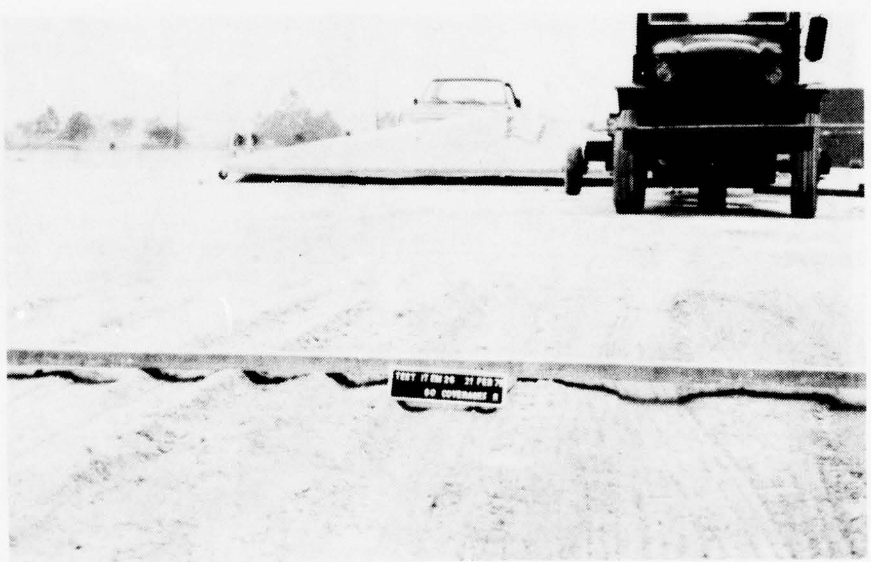

Figure 19
Typical Rutting After 60 Coverages (576 Passes)

Figure 20
Typical Rutting After 150 Coverages (1440 Passes)

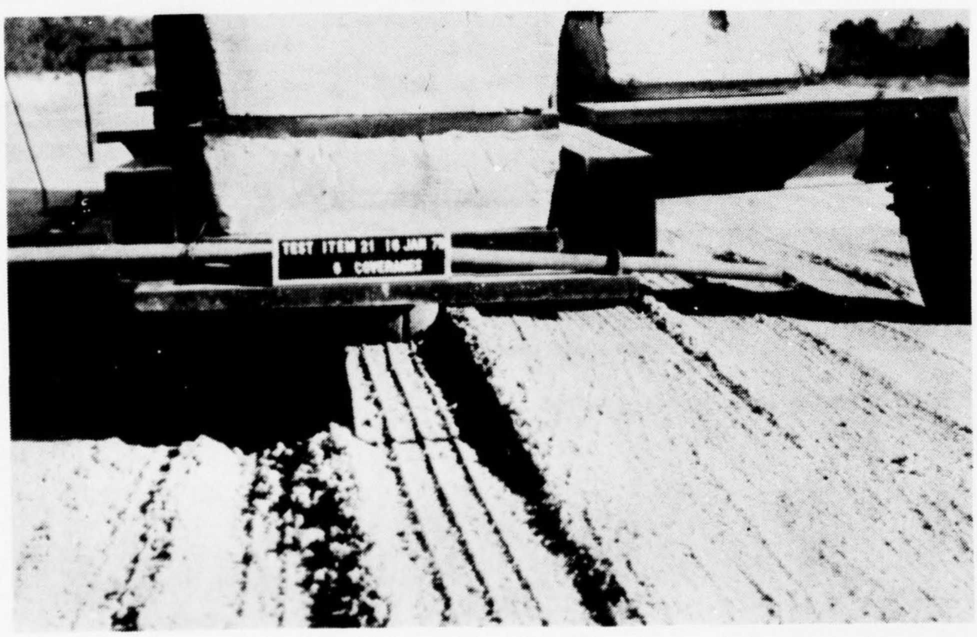

Figure 21
Actual Failure Due to Rutting

Figure 22
Actual Failure Due to Rutting

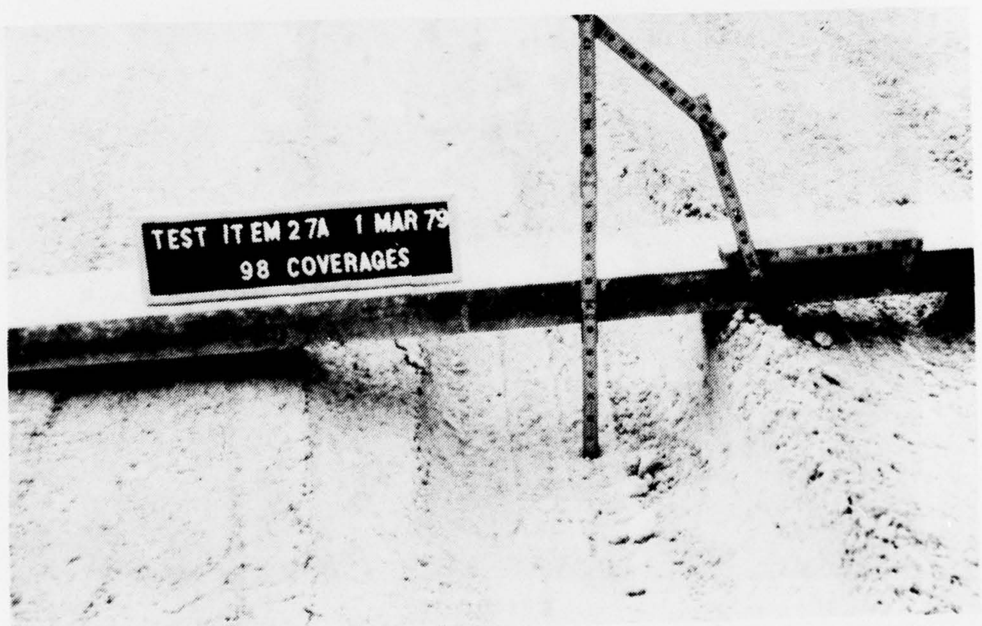

Figure 23
Actual Failure Due to Rutting

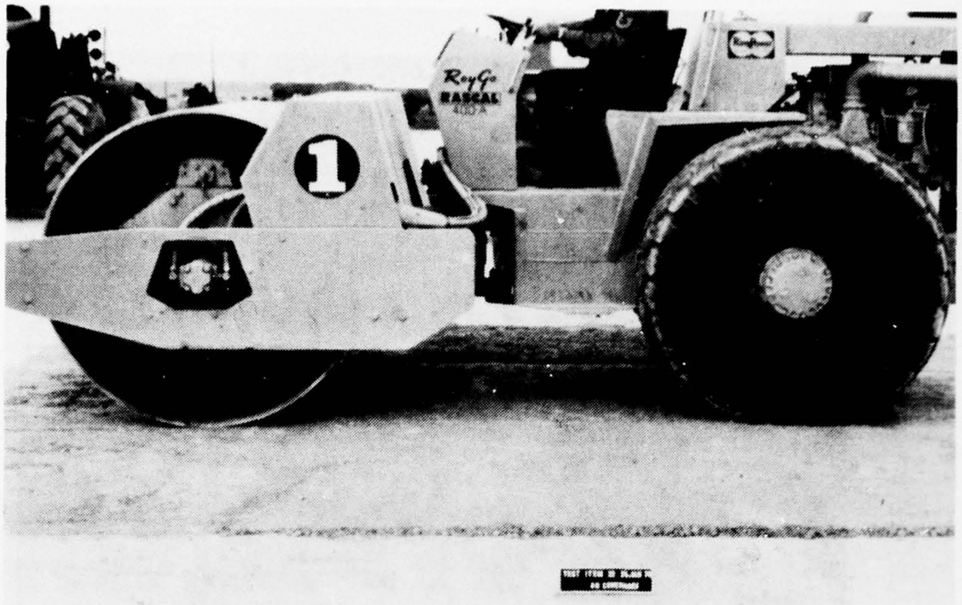

Figure 24
Repairing Patch by Adding More Material and Recompacting

Figure 25
Lip Created at Edge of Patch by Movement of Crushed Stone

asphalt was being used as a temporary solution, but was seriously deteriorating (Figure 26). A repair was made using Silikal® R-17 patching material and Silikal® R-7 overlay material. Because this was a permanent repair, two things were done differently from the procedures outlined in Section IV. After the asphalt and unsound concrete were removed, the cleaned concrete surface was primed using Silikal® R41S primer to improve the bond to the concrete (Figure 27). This is not required during emergency repairs, but can be used during routine maintenance repairs. The second change was the use of Silikal® R-7 overlay material for a thin surfacing to protect the existing concrete from further damage.

Problems encountered were minimal. Two of the Silikal® kits did not include polyethylene mixing bags. The experience level of the repair crew was minimal, ranking from staff sergeant to airman basic. No one in the crew had used the material before, but no problems were encountered. Someone mistakenly added the pea gravel to the Silikal® before adding the liquid, but this proved not to be a problem. Currently the repair has been in service for six weeks and is performing satisfactorily (Figure 28).

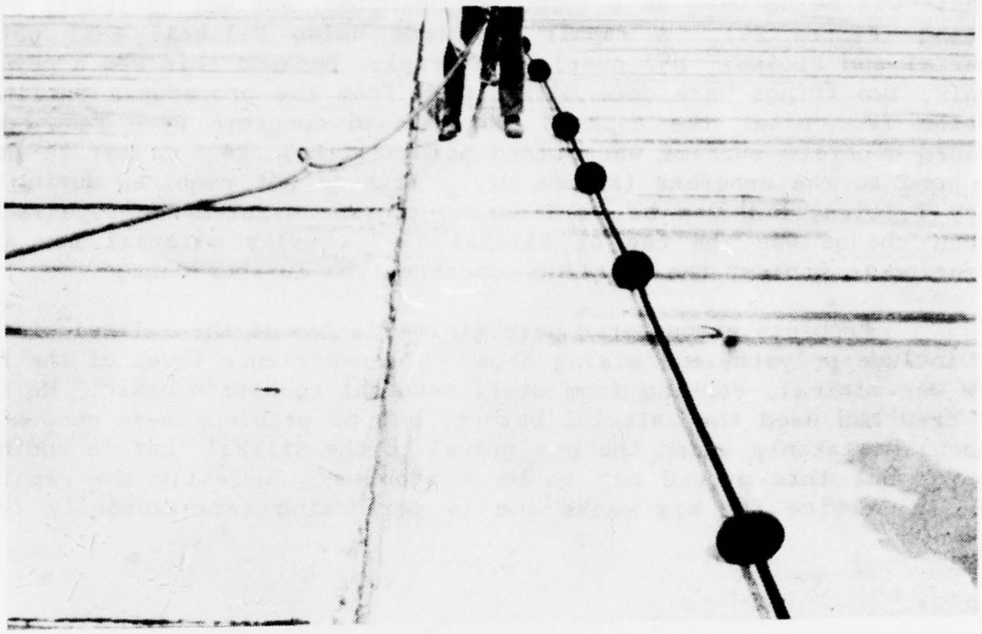

Figure 26
Spalling Under BAK-12 Arresting Barrier Cable

Figure 27
Primer Added to Insure Bond to Concrete to be Overlayed

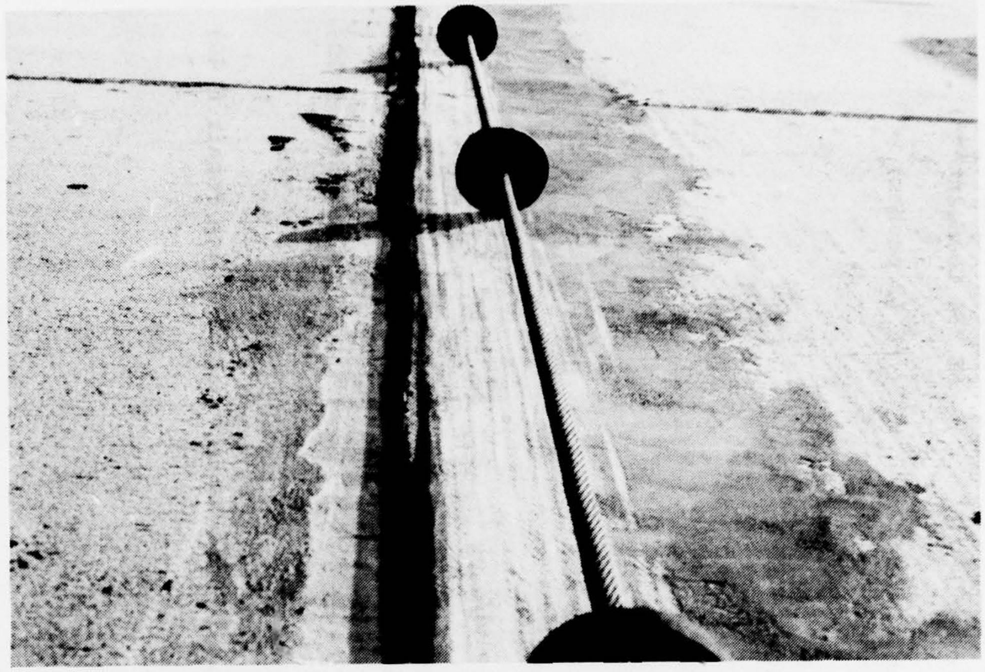

Figure 28
Silikal[R] Repair After Three Weeks of Service Under Arresting Barrier Cable

Figure 29
Spall at Small Crater Test Facility

TABLE 2. SUMMARY OF CRUSHED STONE FIELD TESTS AT TYNDALL AFB

Item Number	Thickness of Base Course	No. & Thickness of Each Lift	Moisture Content	Compactor	Traffic (Coverages of F-4 Loadcart***)
1	13.0 in*	2 @ 6.5"	-	Vibrating Plate & Towed Vibratory	0 (2 passes)
2	14.5 in	5 @ 3"	-	Whacker & Vibrating Plate	3
4	25	3 @ 4" over 2 @ 6"	(dry)	Whacker	150+
13	24	4 @ 6	-	Whacker	2
13A	24**	4 @ 6"	-	Whacker & 12-Ton Steel Wheel	150+
19	24	1 @ 24"	5.3%	RayGo 510	150+ (with repairs @ 30 and 60)
21	24	1 @ 24"	5.5%	RayGo 400	6
22	24	1 @ 24"	3.8%	RayGo 400	150+ (with repair @ 40)
25	24	1 @ 24"	6.5%	RayGo 510	26
26	24	1 @ 24"	3.0%	RayGo 400	150+ (with repair @ 40)
27	24	1 @ 24"	5.5%	RayGo 510	98
28	24	1 @ 24"	5.5%	RayGo 400	2

* 1 inch of cold mix asphalt was applied over this test.
** This was item 13 recompacted with 12-ton steel-wheel roller.
*** One coverage = 9.6 passes of the F-4 loadcart.

The second repair was a patch to small crater test facility where the vibratory compactor had cracked the existing concrete. Although this was a permanent repair, no deviations were made from the field procedure described in Section IV. The existing concrete was removed with an air hammer and cleaned with compressed air (Figure 29). A cardboard form was used to preserve an expansion joint and form an open side. The Silikal® was mixed in bags and extended 100 percent by weight with pea gravel. The repair took 30 minutes from start of mixing until cleanup. An hour and a half after cleanup (two hours after start of mixing) the repair was trafficked with 20 passes of the F-4 loadcart (Figure 30). The repair worked perfectly and is in better condition than when it was new (Figure 31).

Figure 30
Spall Repair Under F-4 Loadcart Traffic

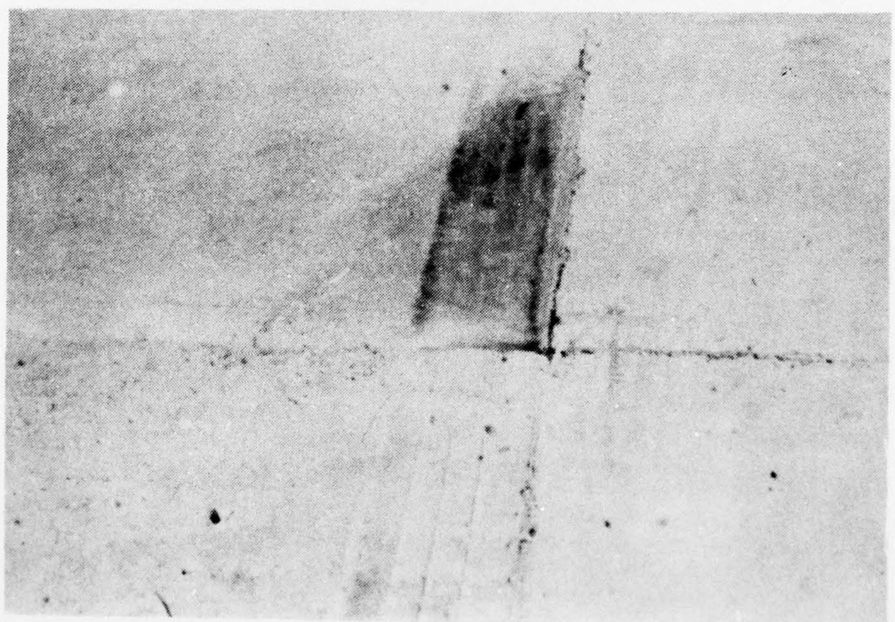

Figure 31
Spall Repair After 20 Passes of F-4 Loadcart Showing
No Damage

SECTION VI

SUMMARY OF REPAIR STEPS

6.0 Crushed Limestone Crater Repair Steps

Step 1. Select the area to be repaired in accordance with AFR 93-2.

Step 2. Clear an area near the crater for a stockpile of the select fill using the front end loader.

Step 3. Push debris into the crater using front end loaders. The debris should be 24 inches below the pavement surface.

Step 4. Remove upheaved concrete using the tracked dozer as per AFR 93-2.

Step 5. Place select fill into the crater using front end loaders and dump trucks. The front end loader is used to level the crushed limestone approximately 6 inches above the pavement surface.

Step 6. Using the large vibratory roller compact the crushed limestone for 4 passes per lane over the width of the area to be repaired.

Step 7. Using a motor grader, cut the crushed limestone down to 1½ inches above the pavement surface.

Step 8. Compact the crushed limestone for 28 additional passes per lane over the width of the repair area.

Step 9. Clean up the loose material using the vacuum and rotary sweepers around the crater and paint the center line stripe.

Step 10. Ready for aircraft traffic but keep additional material handy for repairing the patch.

6.1 Spall Repair Steps

Step 1. Remove loose concrete and debris using an air hammer and jets of air.

Step 2. If the concrete is wet, dry with a butane heater and allow to cool to approximately 100°F.

Step 3. Mix the Silikal® in the mixing bag.

Step 4. If the repair is greater than 1 inch deep, add 30 pounds of dry pea gravel to the Silikal® mortar.

Step 5. Place the Silikal® and pea gravel into the spall and trowel smooth.

Step 6. Clean up the debris with a sweeper.

Step 7. Wait until polymerization has taken place before trafficking with aircraft.

REFERENCES

1. AFR 93-2, Disaster Preparedness and Base Recovery Planning, Department of the Air Force, Washington, D.C., July 1974.

2. Ladd, D. M., Soil Strength Criteria for Operation of Fighter Aircraft on Unsurfaced Airfields, Miscellaneous Paper 5-70-24, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, September 1970.

3. Hokanson, Lawrence D. and Raymond S. Rollings, Field Test of Standard Bomb Damage Repair Techniques for Pavements, AFWL-TR-75-148, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, October 1975.

4. McNerney, Michael T., An Investigation of the Use of Polymer-Concrete for Rapid Repair of Airfield Pavements, CEEDO-TR-78-10, Det 1, Armament Development Test Center, Tyndall AFB, Florida, January 1978.

APPENDIX

LIST OF MANUFACTURERS

List of Manufacturers

Adhesive Engineering Company
1411 Industrial Road
San Carlos CA 94070
Product Name: Concressive 2020, "Multi-Purpose Polymer Concrete"

Rohm and Haas Company
Independence Mall West
Philadelphia PA 19105
Product Name: Plexicrete A-121 Liquid; Plexicrete B-200 Powder

Silikal® North America, Inc
111 Cedar Street
New Rochelle NY 10801
Product Name: Silikal® R7/R17 Powder; Silikal® R17 Liquid

Transpo Materials, Inc
111 Cedar Street
New Rochelle NY 10801
Product Name: Silikal® R7/R17 Powder; Silikal® R17 Liquid

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INITIAL DISTRIBUTION

HQ USAF/LEE	1
HQ USAF/LEEM	1
HQ MAC/DEE	1
HQ MAC/DEM	1
HQ AFSC/DEE	1
HQ AFSC/DEM	1
HQ AFSC/DLW	1
HQ TAC/DRP	1
HQ TAC/DEE	1
HQ TAC/DEM	1
HQ AUL/LSE 71-249	1
AFIT, Tech Library	1
AFIT/DET	1
HQ USAFE/DEE	2
HQ USAFE/DEM	2
HQ USAFE/DEX	2
HQ PACAF/DEE	2
HQ PACAF/DEM	2
ADTC/DLOSL (Tech Library)	1
TAWC/RX	1
DDC/DDA	2
HQ AFESC/DEO	2
HQ AFESC/DEM	10
HQ AFESC/TST	1
HQ AFESC/RDCR	10
USN Civil Engineering Laboratory	2
USA Waterways Experiment Station	4
US Army Standardization Group, UK	2
AFML/MXE	1
HQ AFLC/DEE	1
HQ AFLC/DEM	1
DOT/HDV-22	1
HQ AFESC/RDCT	2
HQ AFESC/OLB	2
HQ SAC/DEM	1
HQ SAC/DEE	1
HQ ATC/DEE	1
HQ ATC/DEM	1
EOARD/LNA	2
AFRES/DEM	1
ANGSC/DEM	1

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