UNIFIED FACILITIES CRITERIA (UFC)

CONCRETE REPAIR

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U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\\ ... /**1**/)

Change No.	Date	Location
1	16 May 2006	Revised Foreword

The format of this document does not conform to UFC 1-300-1; however, it will be reformatted at the next major revision.

FOREWORD

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The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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CHAPTER 1

INTRODUCTION

1.1. Scope. This handbook describes methods and procedures for maintenance and repair of concrete pavements. Since surface failure must be corrected at the source, probable causes are discussed and repair measures described. The principals outlined apply to reinforced and nonreinforced pavements for roads, airfields, and parking and open-storage areas. Normal maintenance on concrete pavements consists principally of the care of joints, sealing of cracks, replacement of random broken slabs or similar sections, and the correction of minor settlement and drainage faults. Repair consists of the work required to restore a distressed pavement so that it may be used at its original designed capacity and/or accommodate the current mission as provided for by applicable service instruction. Additional information can be found in the literature listed in paragraph 1.3., References. **AF Records Disposition.** Ensure that all records created by this handbook are maintained and disposed of IAW AFMAN 37-139, "Records Disposition Schedule."

1.2. Objective. The objective of this handbook is to provide a simple step-by-step "how to" procedure for concrete pavement repair. Although joint and crack maintenance is one of the most important maintenance functions to be performed, it will not be covered here. For those procedures, another handbook has been developed. This handbook will also cover some of the equipment used in the maintenance and repair of concrete pavements.

1.3. References.

1.3.1. Darter, M. I., Barenberg, E. J., and Yrjonson, W. A. (1985). "Joint Repair Methods for Portland Cement Pavements Research Report, Design, and Construction Guidelines and Guide

Specifications," National Cooperative Highway Research Program, Transportation Research Board. National Research Council, Final Report, Washington, DC.

1.3.2. Darter, M. I., Barenberg, E. J., and Yrjonson, W. A. (1985). "Joint Repair Methods for Portland Cement Concrete Pavements," National Cooperative Highway Research Program Report 281, Washington. DC.

1.3.3. Portland Cement Association. (1967). "Slabjacking Concrete Pavements," Skokie, IL.

1.3.4. Portland Cement Association. (1982). "Cement-Grout Subsealing and Slabjacking of Concrete Pavments," Skokie, IL.

1.3.5. ChemGrout. (1985). "Pavement Undersealing Principals and Techniques," LaGrange Park, IL.

1.3.6. U.S. Department of Transportation, Federal Highway Administration. (1987). "Field Inspection Guide for Restoration of Jointed Concrete Pavements," Washington, DC.

1.3.7. American Association of State Highway and Transportation Officials. (1976). "Maintenance Manual," Washington, DC.

1.3.8. Air Force Civil Engineering Support Center. "Concrete Joint and Crack Repair Field Manual," Tyndall Air Force Base, FL.

1.3.9. American Concrete Institute. (1980). ACI Committee 503, "Use of Epoxy Compounds with Concrete," Detroit, MI.

1.3.10. American Concrete Institute. (1981). ACI Committee 548.1, Chapter 5, "Polymers in Concrete," Detroit, MI.

1.3.11. AFM 85-8, "Maintenance and Repair of Surfaced Areas," (March 1977).

1.3.12. American Society for Testing and Materials. ASTM C-39, "Test Method for Organic Impurities in Fine Aggregates for Concrete," 1996, Philadelphia, PA.

1.3.13. American Society for Testing and Materials. ASTM C-109, "Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-inch or 50-mm Cubes)," 1998, Philadelphia, PA.

1.3.14. American Society for Testing and Materials. ASTM D-1752, "Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction," 1996, Philidelphia, PA.

1.3.15. American Society for Testing and Materials. ASTM D-2628, "Preformed Polychloroprene Elastomeric Joint Sealers for Concrete Pavements," 1998, Philidelphia, PA.

1.3.16. American Society for Testing and Materials. ASTM D-3405, "Joint Sealants, Hot-Applied, for Concrete and Asphalt Pavements," 1996, Philadelphia, PA.

1.3.17. American Society for Testing and Materials. ASTM D-3406, "Joint Sealant, Hot-Applied, Elastomeric-Type, for Portland Cement Concrete Pavements," 1995, Philadelphia, PA.

1.3.18. American Society for Testing and Materials. ASTM D-3569, "Joint Sealant, Hot-Applied, Elastomeric, Jet-Fuel-Resistant-Type for Portland Cement Concrete Pavements," 1995, Philadelphia, PA.

1.3.19. American Society for Testing and Materials. ASTM D-4751, "Test Method for Determining Apparent Opening Size of a Geotexile," 1995, Philadelphia, PA.

1.3.20. American Society for Testing and Materials. ASTM D-5101, "Test Method for Measuring the Soil-Geotexile System Clogging Potential by the Gradient Ratio," 1990, Philadelphia, PA.

1

1.3.21. American Society for Testing and Materials. ASTM D-5893, "Cold-Applied, Single Component Chemically Curing Silicon Joint Sealant for Portland Cement Concrete Pavement," 1996, Philadelphia, PA.

1.3.22. American Society for Testing and Materials. ASTM E-119, "Fire Tests of Building Construction and Materials," 1998, Philadelphia, PA.

1.3.23. CEGS CW-02215, "Geotextiles Used as Filters," (May 1995).

1.3.24. CEGS-02753, "Concrete Pavement for Airfields and Other Heavy-Duty Pavements," (Mar. 1997).

1.3.25. U.S Army Engineer Waterways Experiment Station and American Society for Testing and Materials. (1987). CRD-C 611/ASTM C-939. "Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)," Vicksburg, MS, and Philadelphia, PA.

1.3.26. TM 5-623, "Pavement Maintenance Management," (Nov. 1982).

1.3.27. TM 5-822/AFM 88-6, Chapter 8, "Standard Practice for Concrete Pavements."

1.3.28. TM 5-822-9/AFM 88-6, Chapter 10, "Repair of Rigid Pavements Using Epoxy Resin Grouts, Mortars, and Concretes," (Jan. 1989).

1.3.29. TM 5-822-11/AFM 88-6, Chapter 7, "Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements," (Jan. 1993).

1.3.30. TM 5-825-3/AFM 88-6, Chapter 3, "Rigid Pavement for Airfields," (Aug. 1988).

1.3.31. TM 5-826/AFR 93-5, "Procedures for U.S. Army and U.S. Air Force Airfield Pavement Condition Surveys," (July 1989).

1.3.32. Federal Specification SS-S-200E. "Sealing Compounds, Two-Component, Elastomeric, Polymer Type, Jet-Fuel-Resistant, Cold-Applied."

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CHAPTER 2

SELECTION OF REPAIR MATERIALS

2.1. Description. A variety of concrete repair materials are available on the market today. A properly designed, placed, and cured conventional portland cement concrete remains as one of the most widely used and reliable patching materials for concrete pavements. It is most effective for full-depth patches or complete slab replacement. A high density, very low slump, 0 to 1/2 inch (0 to 13 millimeters) portland cement concrete or mortor patching mix, properly placed, thoroughly compacted by tamping and thoroughly cured, has proved very successful for partial-depth patches. The use of conventional portland cement concrete (PCC) in partial-depth patches has given mixed results, some successful and many not. By using high early-strength cement (Type III) and accelerators, concrete mixes can be produced that will allow traffic in 24 hours or less. There is a wide variety of special products sold under proprietary names for patching concrete. These include both organic and inorganic materials such as epoxies, methacrylates, magnesium phosphate cements, and gypsum-based cements. Most of these products are sold under trade names, and it is often difficult to identify the specific cementitious agent. All claims of performance for these proprietary products *should be treated with caution*, and it is always prudent to *establish the performance of new products through trials prior to committing* to the purchase of large quantities. The selection and evaluation of specific patching materials is a specialized topic and outside the scope of this handbook. Care should be taken to restrict use of impervious materials (epoxies, etc.) in areas large enough to block vapor coming up from below and trapping moisture which can freeze and debond the patch.

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CHAPTER 3

CONCRETE PAVEMENT

3.1. Description and Composition. Concrete is made from portland cement, water, fine aggregate (sand), and coarse aggregate (gravel or crushed rock), with or without additives (air entraining, fly ash, etc.), developed to achieve the strength and durability of natural stone. Concrete generally achieves its initial set within 1 hour after water is added and will become fairly hard within 6 hours of placement. Concrete will continue to gain strength at an ever decreasing rate for many years as long as moisture is retained within the consolidated mass and there is no adverse chemical reaction either internally or due to external action.

3.2. Properties and Behavior.

3.2.1. Performance. A concrete pavement has a relatively long economic life when properly designed, constructed, and maintained. In general, the economic life of a pavement ends when, under the effects of traffic, weather, and/or lack of proper maintenance, it breaks into small unstable sections; surface problems develop; and costly, extensive maintenance is required. Durability is improved by surface maintenance, especially at joints and cracks. Maintaining the joints to minimize the infiltration of water and to prevent the entrance of incompressible material is essential under most conditions for long life. Frequent loadings greater than those for which the pavements were designed will cause early failure of the pavement.

3.2.2. Rigidity. PCC is classified as a rigid pavement. Because of its beam action or resistance to bending, it can bridge small, soft, or settled areas of a subgrade. Overloading of concrete pavements can result from applied loads being greater than the design load, more passes than assumed in the design, or the foundation support being reduced as a result of pumping,

excessive moisture, etc. Usually, once cracking has begun, continued loading will cause additional cracks or breaks until complete failure of the pavement results.

3.2.3. Strength. Concrete pavement design is based on limiting the concrete tensile stresses produced by applied loads. Flexural strength is used in the design of rigid pavement. Loads applied to the pavement surface cause bending with tensile stresses at the bottom or top of the slab and compressive stresses at the top. Since compressive strength of concrete is typically 8 to 10 times greater than the tensile or flexural strength, the ratio of load-induced tensile stresses at the bottom of the slab to the flexural strength of the concrete controls the behavior of concrete pavement.

The relative strength as well as the durability is directly affected by: (1) quality of cement; (2) purity of water; (3) cleanliness, durability, strength, and gradation of the aggregates; (4) water-cementitious material ratio; (5) density of concrete; (6) amount and types of admixtures; (7) proportioning and mixing of materials; (8) placement, finishing, and curing methods.

CHAPTER 4

FULL-DEPTH REPAIR OF PAVEMENTS

4.1. Purpose. When normal maintenance procedures can no longer correct the effects of ordinary pavement wear or use, full-depth repair may become necessary to restore damaged areas to their original condition. Full-depth repairs are generally necessary when slabs have been shattered or have deteriorated to such an extent that the safe support of the required load is no longer possible (Figure 4.1.).

4.2. Need for Full-Depth Repair. There are several types of distress that occur at or near transverse joints which may require full-depth repair when classified as medium- or high-severity level distress. Comprehensive distress manuals (TM 5-623 for vehicular pavements and TM 5-826/AFR 93-5 for airfield pavements) are available which define distress and severity levels. Types of distress that occur in rigid pavements which may justify full-depth repair when classified as medium- or high-severity distresses include:

4.2.1. Blowup.

4.2.2. Corner break.

4.2.3. Durability ("D") cracking.

4.2.4. Patch deterioration.

4.2.5. Shattered slab (A slab broken into four or five pieces with some or all cracks of high severity or a slab broken into six or more pieces with over 15 percent of the cracks of medium or high severity).

4.2.6. Spalling (if spalling is one-half the slab thickness or deeper).

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4.2.7. Punchout.

4.2.8. Railroad crossing distress.

Many rigid pavements are also subject to spalling and faulting at intermediate cracks. This deterioration may be caused by repeated heavy traffic loads, failure of doweled joints to function properly, and/or the intrusion of incompressible materials in the open cracks.

4.3. Selection of Repair Boundaries. First, a detailed survey should be done to accurately identify the required repair areas so that all significant underlying distresses are found. Quite often, and particularly in freeze-thaw climates, the deterioration near joints and cracks is greater at the bottom of the slab than is apparent from the top of the slab Figure 4.2.). In both plain jointed and reinforced jointed concrete pavement, partial-slab replacement is acceptable where the distresses are within one-half of the slab length. Full-width slab patching is required if the original slab length is less than 20 feet (6 meters), or full-depth cracks are located within the interior area of the slab. A minimum slab length is required to avoid rocking and pumping of the repair. General experience indicates that 10 feet (3 meters) or one-half of the slab length, which ever is less, is a minimum length when load transfer is provided.

The recommended minimum patch dimensions are:

4.3.1. Saw cut will be a minimum of 2 feet (600 millimeters) from joint (Figure 4.3.).

4.3.2. If patch is a utility cut, make cut 6 to 12 inches (150 to 300 millimeters) beyond limits of the excavation and any sluffing of the trench (Figure 4.4.).

4.3.3. For continuously reinforced concrete, the disressed portion must be in the middle of the patch area. Patch should be 6 feet (1.8 meters) long if steel is to be tied, and 4 feet (1.2 meters) long, if welded.

4.3.4. Saw cuts shall be straight lines forming rectangles in line with the jointing pattern.

4.4. Sawing of Repair Boundaries. The repair boundaries of mesh reinforced, plain doweled, and plain jointed concrete pavement are typically provided by diamond blade sawing (Fig- ure 4.5.). Sawing is the recommended method. Air hammers should not be used to outline the area. The rough joint formed by air hammers typically spalls in service. It's difficult to lift out the concrete within the repair boundaries or break it up with large pavement breakers. The partial- depth saw cut does provide some aggregate interlock due to a rough face, but microcracking will develop at the bottom of the repair area and the bottom of the slab may spall when using a large pavement breaker to shatter the concrete within the repair boundaries. If this occurs, the saw cut must be made deeper, the size of the pavement breaker should be limited, and the pavement breaker should not be used in the immediate joint area. Normally, pavement breakers should be hand-held and not weigh over 30 pounds, (14 kilograms). The full-depth saw cuts will completely sepa-rate the concrete that is to be removed, leaving verrtical faces, and eliminate unwanted damage at the bottom of the slab; however, it will not provide adequate aggregate interlock for the patch.

The repair boundaries of continuously reinforced concrete pavement are provided by sawing full depth at the repair boundaries. Partial-depth saw cuts above the reinforcing steel are then provided at a distance required by the lap length of the reinforcement (TM 5-825-3/AFM 88-6, Chap. 3) from the repair boundaries (Figure 4.6.). The partial-depth saw cuts should be located at least 18 inches (450 millimeters) from the nearest tight crack and should not cross an existing crack. Should any of the reinforcing steel be cut while sawing, the repair area must be increased by the required lap length of the reinforcement.

4.5. Removal of Existing Concrete. Procedures used for removal must not spall or crack adjacent concrete or significantly disturb the base or subgrade. There are two basic methods to remove concrete pavement:

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4.5.1. Breakup and cleanout method. This is normally accomplished using a pavement breaker with removal by a backhoe (Figure 4.7.). This method usually disturbs the base and requires replacement or filling with concrete.

It also has the potential to damage the adjacent slab if proper sawing procedures are not followed. After the repair is isolated by full-depth saw cuts, additional saw cuts using a wheel saw with at least 1 1/2 inch (38 millimeters) kerf, are made within the repair area, parallel and approximately 1 1/2 feet (450 millimeters) from each perimeter saw cut or joint (Figure 4.8.). Breakup should begin in the center of the removal area within the inner saw cuts. After breakup of the inner area, a backhoe can then be used to gently pull the outer region free of the adjacent slab, or this strip can be broken up with light hand-held jackhammers.

4.5.2. Lift-out method. This is normally accomplished using a crane or front end loader to lift the deteriorated concrete from its position (Figure 4.9.). Lift-out operations should be closely controlled to prevent accidents. This method generally does not disturb the base or damage the adjacent slab. After the repair area is isolated by full-depth saw cuts, holes are drilled through the slab and fitted with lift pins, and the slab is then lifted in one or more pieces. If it is necessary to decrease the load, the slab may be cut into smaller pieces. During hot weather, the sawing equipment may bind during initial transverse sawing procedures. It may be necessary to perform sawing at night when the temperatures are lower and the slabs are contracting. Another solution is to use a carbide-tipped wheel saw to provide a pressure relief cut within the patch area prior to boundary sawing (Figure 4.10.). It is strongly recommended that the wheel saw cut be made no closer than 6 to 8 inches (150 to 200 millimeters) from the proposed patch boundary due to possible damage and microcracking in adjacent concrete. The same procedures may be used for the removal of continuously reinforced concrete. Concrete in the two reinforcing lap areas must be carefully removed so as not to damage the reinforcing and to avoid spalling of the concrete at the bottom of the joint.

4.6. Subgrade and Base Preparation. After the deteriorated and loose concrete has been removed, the base course should be examined. All disturbed material should be removed and the patch area compacted (Figure 4.11.). If excessive moisture exists in the repair area, it should be removed or dried before replacing. It is difficult to adequately compact granular material which may result in settlement of the patch. Replacing some or all disturbed base material with lean concrete or flowable fill may be the best alternative.

4.7. Dowel and Tiebar Placement. In repair of jointed concrete pavements, good load transfer across the transverse repair joints appear to be the most ciritical factor affecting full-depth repair performance. Load transfer is best achieved by properly installed dowel bars of sufficient size and number. Dowels provide load transfer across repair joints while at the same time allowing the joint to open and close as the surrounding pavement expands and contracts in response to temperature and moisture changes. Hence, they are used in joints between slabs. In constrast, tie bars provide both load transfer and prevent movement at the repair interface. Consequently, tie bars are appropriate for repairs with a slab where the structural integrity of the slab is being maintained. Since in repair, both dowels and tie bars have a load transfer role, their dimensions and spacing should be selected based on the design loading. Note that tie bars in joints in new construction function only to restrict movement at the joint, and they are typically relatively small (#5 bar) and widely spaced [30 inches (750 millimeters)]. Both smooth steel dowels (Figure 4.12.) and deformed reinforcement, tie bars, (Figure 4.13.) can be provided in the patch joint. This is accomplished by drilling holes at specified locations into the exposed face of the existing slab. Equipment is available to drill multiple holes simultaneously (Figure 4.14.). The holes should be drilled by placing the drills in a rigid frame to prevent the drill bit from wandering and holds them in a horizontal position at the correct height (one-half the slab thickness). The depth of the holes should be approximately one-half the length of the dowel or tie bar.

Hole diameters exceeding the bar diameter by 1/8 inch (3 millimeters) or less are recommended when using epoxy mortar materials. Care must be exercised in epoxy grouting dowels or tie bars to ensure complete coverage and support of the device. Grout retention devices that fit tightly over the dowel or tie bar and effectively seal the hole should be used to prevent loss of grout or epoxy. Smooth steel dowels are provided in concrete pavement slabs to transfer loads to adjacent slabs and to help maintain the alignment of adjoining slabs. Dowels are placed in joints that are intended to accommodate movement of the adjoining slabs. When using dowels, the end that entends into the repair area should be painted and oiled to prevent bonding with the patch material. Dowels used at expansion joints should be capped at one end, in addition to painting or oiling, to permit further penetration of the dowels into the concrete when the joints close. Deformed tie bars have surface ridges that provide a locking anchorage with surrounding concrete. Tie bars are placed in joints that are not intended to have movement. Any dowels, tiebars, or reinforcement must be clean and free of flaking rust.

4.8. Replacing Reinforcement. Successful performance of continuously reinforced concrete pavements requires good load transfer across all transverse cracks and repair joints. Failure to do so and to carry the longitudinal reinforcing steel through the repair will cause the repair and the surrounding pavement to fail as the cracks begin to open. The longitudinal reinforcing is generally carried through these repairs by careful removal of the old concrete to allow the appropriate length of steel (lap length) from the existing pavement to extend into the repair area. This steel is then tied, welded, or mechanically connected to additional reinforcing steel that extends through the repair area. When replacing reinforcing in the patch area, the type of bars should match the original in grade, quality, and number. The new bar should be placed on bar supports to ensure proper position and cover, they should not extend closer than 2 inches (152 millimeters) to the patch/slab interface. Tied splices should be lapped the proper length (TM 5-825-3/AFM 88-6, Chap. 3) that provides full bar strength. Welded splices should be of the

proper length for the welding procedure chosen and should be lapped at the center of the repair area to avoid the potential buckling of bars on hot days (Figure 4.15.).

4.9. Expansion Joints. Expansion joints are placed in concrete pavements to provide relief for expansion due to temperature changes. Generally, expansion joints are installed at all inter-sections of pavements with structures and may be required within pavement features. Expansion joints may be required if full-depth repairs are made during cool weather when adjacent concrete is in a contracted state, or crushing and spalling of concrete at the joints may occur during subse-quent hot weather when the concrete expands. Expansion joints in pavements should be kept to the minimum necessary to prevent excessive stresses in the pavement. The types of expansion joints are the thickened-edge (Figure 4.16.), the thickened-edge expansion joint (Figure 4.17.), and the doweled type (Figure 4.18.).

4.9.1. The thickened-edge type is suggested for longitudinal expansion joints within pavements. Dowels are not recommended for use in longitudinal expansion joints, because differential expansion and contraction parallel with the joints may develop undesirable localized strains and possibly failure of the concrete, expecially near the corners of slabs at transverse joints.

4.9.2. The thickened-edge expansion joint (without dowels) is normally the best suited expansion joint to surround or separate any structure that projects through, into, or against the pavement (apporaches to buildings, drainage inlets, and hydrant refueling outlets).

4.9.3. Doweled-type, transverse expansion joints should be used within pavements. However, at the angular intersection of pavements, it might be desirable to allow some slippage in the trans-verse joint to prevent the expansion of one pavement from distorting the other. In such instances, the design of the transverse expansion joint should be a thickened-edge slip joint, or thickened-edge expansion joint.

4.10. Filler Material. Filler material for the thickened-edge and doweled-type expansion joint should be a nonextruding type. The type and thickness of a filler material will depend upon the particular case. Usually a preformed material of 3/4-inch (20-millimeter) thickness will be adequate, but in some instances a greater thickness may be required. Filler material for slip joints should be a heavy coating of bituminous material not less than 1/4 inch (6 millimeters) in thickness when the joints match. A normal nonextruding type material not less than 1/4 inch (6 millimeters) in thickness should be used when joints do not match.

4.11. Dowels. Expansion joints where dowels are used require that the dowels be securely and accurately placed. The nonextruding filler material should be drilled or punched to the exact diameter and at the location of the dowels. It should be furnished in lengths equal to the width of the placement. When more than one length is used in a joint, the abutting ends of the filler should be held in alignment. It should be held firmly in place and extend downward completely to the bottom of the slab, and the top edge should be held about 1/2 inch (13 millimeters) below the surface of the pavement. The top edge of the filler material should be protected while the concrete is being placed. The important functions of dowels or any other load-transfer device in concrete pavements are:

4.11.1. Help maintain the alignment of adjoining slabs.

4.11.2. Limit or reduce stresses resulting from loads on the pavement. Different sizes of dowels should be specified for different thicknesses of pavements. (Reference paragraph 10.4.).

4.12. Concrete Placement. As well as many other factors, the concrete mixture selection depends on the curing time to reach required strength before the repair area is opened to traffic. If it is acceptable for the concrete to cure for several days (similar to new construction), regular concrete mixtures can be used. If an earlier opening time (1 to 3 days) is needed, a high early-strength PCC (usually type III cement) can be used, or the cement content should be

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increased, with minimal mixing and an accelerator added. The concrete placement techniques should follow standard procedures.

4.12.1. Extra attention should be given to ensure that the concrete is vibrated well around the edges and beneath the reinforcement. Where new concrete is to be bonded, all exposed concrete faces should be cleaned by sandblasting. Temperatures for the concrete placement should be between 40 and 90 degrees Fahrenheit (4 and 32 degrees Celsius).

4.12.2. Rapid-set proprietary cementitious materials that attain sufficient strength for traffic in as little as 4 hours are available. Rapid-set proprietary patching materials should be used in compliance with the manufacturer's recommendations. This includes bonding, placing, curing, time required before opening to traffic, and temperature ranges.

4.12.3. If cuts are made on each side of a joint and load transfer is required for full-depth repairs, the repair must be done in two pours as described in CEGS 02753 to allow installation of load transfer.

4.13. Concrete Finishing and Texturing. Finishing techniques should follow standard procedures. For repairs less than 12 feet (3.7 meters) in length, the surface of the concrete should be struck off with the screed parallel to the centerline of the pavement. For repairs more than 12 feet (3.7 meters) in length, the surface should be struck off with the screed perpendicular to the centerline of the pavement. Extra attention should be given to ensure that the concrete is not overfinished. Before the concrete becomes nonplastic, the surface should be given a burlap drag or broom finish to approximately match the surface finish of the existing adjacent concrete pavement, unless a grinding operation is to follow.

4.14. Curing. There are many ways to cure concrete. Wet burlap (with or without sand), impervious paper, pigmented curing membranes, and ponding or constant spraying can be used

for curing the repair area. Curing should be started as soon as the concrete has set sufficiently. Good curing is crucial to achieving a good repair.

4.15. Joint Sealing. Any longitudinal or transverse joints must be sealed. This reduces the entry of water, which may cause pumping and faulting, and reduces the incidence and severity of spalling. The transverse and longitudinal joint sealant reservoirs at the repair area may be formed or sawed, while the concrete is green to control cracking. If the concrete cracks before initial sawing, the resulting crack should be prepared and sealed. The initial cuts or dummy joints must be prepared to function as a joint. This preparation begins after the curing period of the concrete has ended. The preparation of joints in newly constructed PCC pavements are the same for both field-molded and preformed materials.

4.15.1. After the initial sawing to control cracking of the concrete, the saw cuts should be inspected for spalling. Spalls that extend more than 1/4 inch (6 millimeters) horizontally from the sidewall of the initial cut should be repaired, since normally they would not be removed during the widening operation. Void areas caused by honeycombing of the concrete must be patched to provide a solid joint sidewall for the sealant to bond.

4.15.2. After the required curing period, the initial saw cut must be widened to the joint width and depth specified in the project specifications using a self-propelled concrete saw. The depth of the cut should be uniform, and the width should not vary along the length of the joint.

4.15.3. Following the sawing operation, the joint should be sandblasted to remove laitance, curing compound, sawing dust, and other foreign debris from the joint sidewalls and from the pavement surface adjacent to the joint to a width of approximately 1 to 2 inches (25 to 50 milli-meters). A multiple pass technique has proven very successful in removing foreign debris. When using the multiple pass technique, the nozzle is directed at one of the joint faces, and that face is sandblasted the entire length of the slab. After one face has been completed, the nozzle is

directed at the other joint face, and it is sandblasted for the entire length of the slab. The pavement surface adjacent to the joint is then sandblasted to remove all surface debris. If waterblasting is used instead of sandblasting, a multiple pass technique should still be employed and the joints will have to be dry before the sealing operation continues. Cleaning the joint is one of the most important steps in obtaining a high-quality sealing project. If the joints are not clean and dry before the sealant is installed, the sealant will usually fail prematurely.

4.15.4. After the joint has been sandblasted, it must be cleaned with compressed air to remove any remaining sand or dust. However, the final air cleaning of the joint should be completed immediately before sealing to prevent more sand and dust from blowing back into the joint. A vacuum sweeper can be used to clean around the joints, which will help reduce the amount of debris that blows back into the joints.

4.15.5. After the joint is cleaned, the backer rod or separating material should be installed. The backer materials should not be left in the joint for an extended period of time before sealing. The materials may work loose and move up or down in the joint or may even come completely out. These materials must not be twisted, stretched, or otherwise damaged when they are installed in the joint. Damaging the backer material can cause sealant failure or a poor quality finished product. The backer rod or separating material should be inspected after installation to ensure that it has been placed at the proper depth and has not been damaged. After installation of the backer or separating material, the joint is ready for the sealant material. However, the joint should be sealed only if all steps have been performed properly.

4.15.6. Sealants must conform to one of the following ASTM specifications: D 1752, D 2628, D 3405, D 3406, D 5893, or D 3569 if the repair is located in an area where fuel, lubricating, or hydraulic fluid spillage may occur.

Figure 4.1. Shattered slab

Figure 4.2. Bottom of deteriorated slab

Figure 4.3. Minimum cut distance (full-depth repair)

Figure 4.4. Utility cut

FULL DEPTH REPAIR

VERTICAL SAWCUT (2-" (50-mm) MIN)
DEPTH, CHIP AND BREAK OUT
CONCRETE FULL DEPTH

2' MIN
(600 mm)

2' MIN
(600 mm)

CORNER BREAK

DRILL AND EPOXY DEFORMED TIE BARS

PAINT AND OIL
DRILL AND EPOXY

DOWEL IF JOINT WAS
ORIGINALLY DOWELED

NEW CONCRETE

REESTABLISH LONGITUDINAL JOINT (KEY OR DOWELS)

(TOP VIEW)

UTILITY CUT REPAIR (RIGID PAVEMENT)

TIE BAR

EXISTING
PCC

NEW
PCC

EXISTING
PCC

6"-12"
(150 - 300 mm)

6"-12"
(150 - 300 mm)

UTILITY CUT ➔

BACKFILL

FROM EDGE OF
SLUFFED SLOPE

PIPE

SAWCUT FULL DEPTH AND REMOVE PAVEMENT 6-12" (150 - 300 mm) AWAY
FROM CUT BACKFILL CUT WITH THE PROPER MATERIAL IN WELL COMPACTED
3" (76 mm) LIFTS TO THE BOTTOM OF THE PAVEMENT. INSTALL TIE BARS
AS REQUIRED BY DRILLING AND EXPXYING INTO EXISTING PCC. IN ORDER
FOR THE TIE BARS TO SUPPORT THE LOAD, THEY SHOULD BE THE SAME
DIAMETER AS THE DOWELS THAT THE LOAD REQUIRES. PLACE FINISH AND
CURE NEW PCC.

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Figure 4.5, Diamond blade sawing

Figure 4.6. Repair boundaries
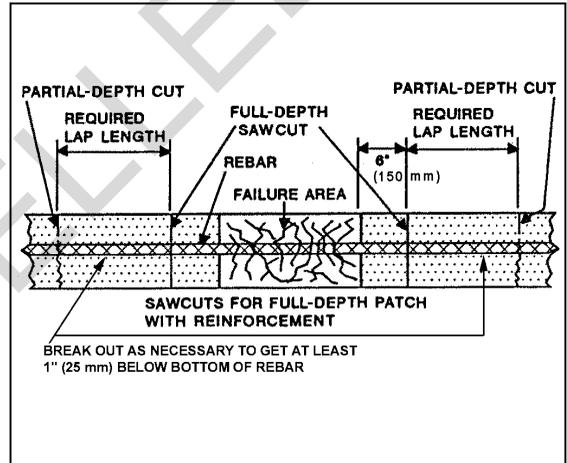
Figure 4.7. Concrete removal

Figure 4.8. Additional saw cuts (breakup method)

LONGITUDINAL JOINT

LONGITUDINAL JOINT
OR ℄ SLAB

TRANSVERSE JOINT

FULL-DEPTH CUTS

FULL-DEPTH CUTS

LONGITUDINAL JOINT

PLAN VIEW OF SAW CUTS FOR BREAKUP METHOD
INNER SAW CUTS TO HAVE 1 1/2" (38 mm) MINIMUM KERF

(TOP VIEW)

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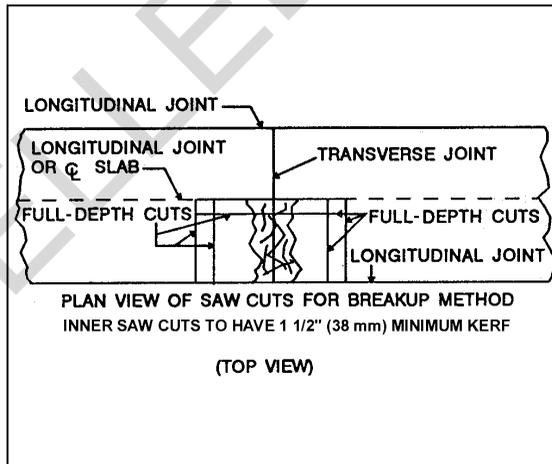
Figure 4.9. Lift-out method

Figure 4.10. Pressure relief cut (lift-out method)

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Figure 4.11. Patch area compaction

Figure 4.12. Smooth steel dowels

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Figure 4.13. Deformed
reinforcement

Figure 4.14. Drilling multiple holes

4

Figure 4.15. Welded reinforcement installation
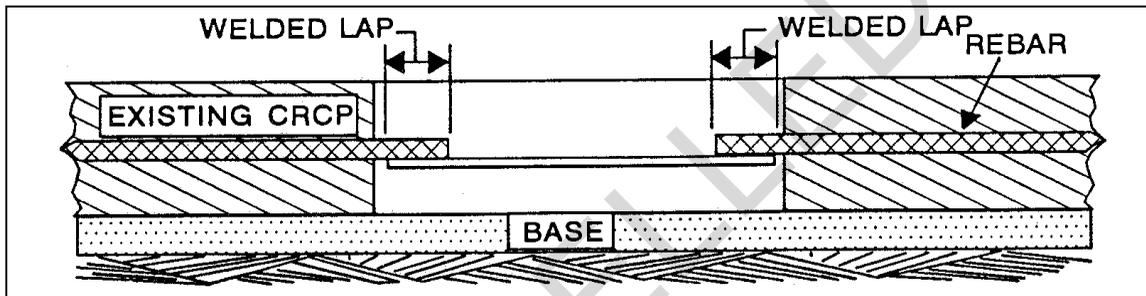
Figure 4.16. Thickened-edge expansion joint
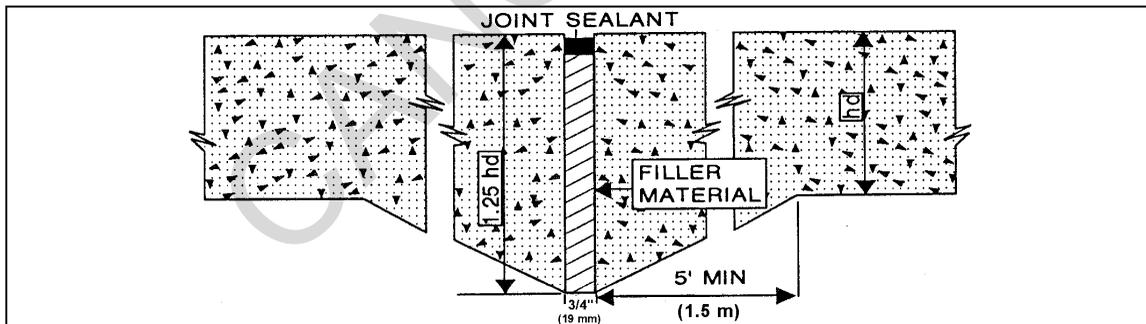
Figure 4.17. Thickened-edge slip joint
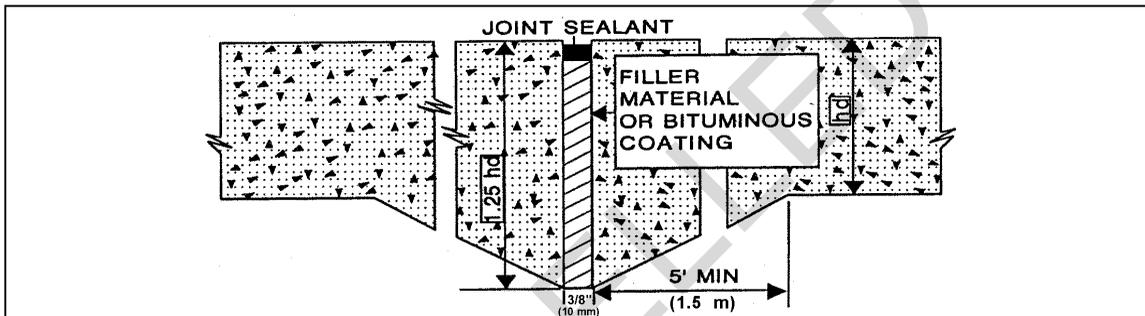
Figure 4.18. Doweled expansion joint

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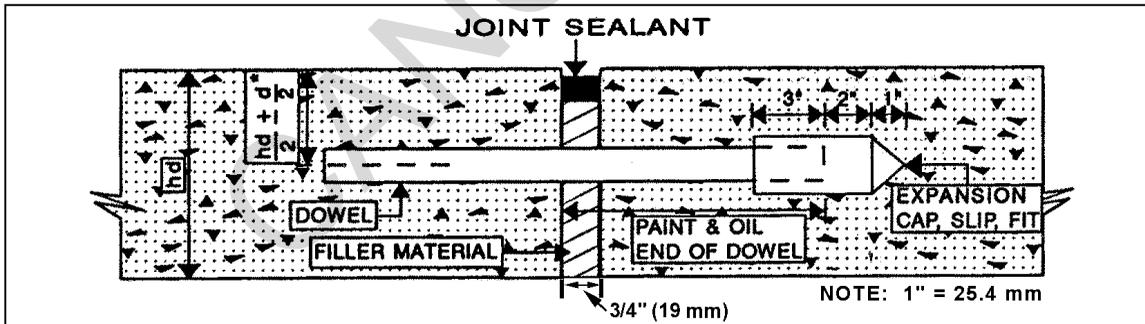
CHAPTER 5

PARTIAL-DEPTH REPAIR OF PAVEMENTS

5.1. Purpose. The purpose of partial-depth repairs is to correct localized areas of concrete pavement distress. Repair of this type restores rideability, deters further deterioration, reduces foreign object damage potential, and provides proper edges so that joints can be effectively resealed.

5.2. Need for Partial-Depth Repair. Partial-depth repair is typically used to repair spalling either at pavement joints (Figure 5.1.) or at midslab locations. Spalling can occur when unsealed joints or cracks are filled with incompressible materials that prevent movement of the slab in hot weather and result in breakage of the concrete. Other caus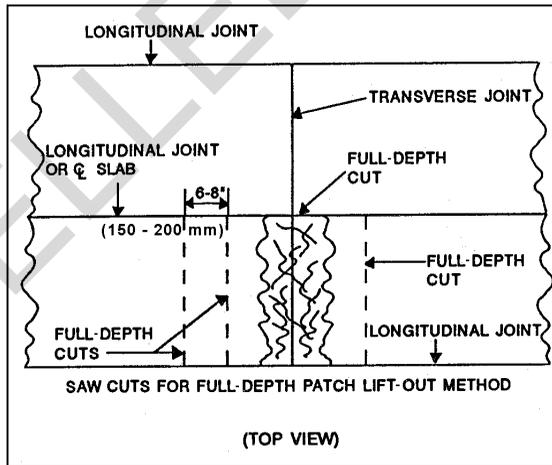es of spalling at joints include: keyway failures (of oversized, poorly designed keyways), poor construction, poor repairs, dowel bar lockup, improperly located dowels, and dowels in reamed-out sockets. Spalling at midslab is generally caused by reinforcement that is too close to the surface, or foreign matter, or poor surface finish, in the original PCC. Spalls create a rough ride and can accelerate deterioration. Spalling is typically a localized distress and, therefore, warrants a localized repair. If several severe spalls are present on one joint, it may be more economical to place a full-depth repair along the entire joint than to repair individual spalls (Figure 5.2.).

5.3. Selection of Repair Boundaries. Prior to commencement of work, a survey to determine areas of unsound or delaminated concrete should be made to establish the repair boundaries. During the survey, all areas of unsound concrete or delamination should be determined by using a sounding technique. Sounding the pavement to find delamination and spall removal areas is accomplished by striking the existing concrete surface with a steel rod or carpenters hammer. Delaminated or unsound concrete will produce a dull or hollow thud, while sound concrete will

produce a sharp metallic ring. The repair boundaries should be extended beyond the detected delaminated or spalled area by 3 inches (76 millimeters) to assure removal of all unsound concrete (Figure 5.3.). The repair boundaries should be kept square or rectangular in line with the jointing pattern to avoid irregular shapes. Irregular shapes may cause cracks to develop in the repair material. If repair areas are closer than 24 inches (600 millimeters) apart, they should be combined. This will help reduce costs and eliminate numerous small patches. The actual construction of the concrete repair should comply with AFM 85-8.

5.4. Removal of Existing Concrete. Removal of existing concrete can be accomplished by sawing and chipping or by a milling process. To remove concrete by sawing and chipping, a minimum 2-inch- (50-millimeter-) deep saw cut should be made (in a rectangular pattern at least 3 inches (150 millimeters) outside all visible deterioration) around the perimeter of the repair area. This will provide a vertical face of sufficient depth to give integrity to the patch (Figure 5.4.). Additional sawcuts may be made within the repair area to speed chipping. A saw cut 2 inches (50 millimeters) away from joints might reduce the possibility of damaging the opposite joint face. A saw cut along the opposite joint face made by skimming the blade along the joint face will remove sealant residue and leave a clean vertical joint face (Figure 5.5.). Concrete within the repair area should be removed to the bottom of the saw cuts or to 1/2 inch (13 millimeters) into visually sound and clean concrete, whichever os deeper, with light pneumatic tools. It is important that the proper tools are used. The recommended maximum size of the chipping hammer for partial-depth repairs is 30 pounds (13.6 kilograms). Concrete within the repair area can also be removed by carbide-tipped cold milling equipment. Cold milling is especially effective where the repair area extends over the majority of the slab width. Milling machines must be equipped with a device for stopping at a preset depth to prevent excessive removal or damage to existing dowel bars or reinforcement. After removal of the concrete in the repair area, the pavement should be sounded again to ensure all unsound or delaminated concrete has been

removed. Occasionally, what appears to be spalling at the surface will actually extend through the full-slab depth or for more than one-half the slab thickness.

Partial-depth repair should not be tried at such locations. The area should be marked and full-depth repair accomplished. Full-depth repair should also be made if the concrete below one-half the slab depth is damaged during chipping or if dowel bars or reinforcing are encountered during removal. Steel that is encountered in spall areas must be completely exposed for 1/2 inch (13 millimeters) cleaned and reembedded in the patch material. *Under no circumstances should partial-depth repair material rest upon dowel bars or reinforcement.*

5.5. Cleaning. Prior to patching, the exposed faces, bottom of the patch area, and any exposed steel should be sandblasted to remove all loose particles, oil, dirt, dust, asphaltic concrete, rust, and other contaminants. As a minimum, air blow, wash with high-pressure water, and air blow again (Figure 5.6.). The prepared surface must be checked prior to placing the new patch material. Any contamination of the surface will reduce the bond between the new material and the existing concrete.

5.6. Joint Preparation. When placing a partial-depth patch adjacent to any joint, there must be no bond of the repair patch to the face of the adjacent concrete.

Elimination of bond can be accomplished by using a compressible insert (styrofoam, asphalt-impregnated fiberboard (Figure 5.7.), and plastic joint inserts are commonly used) along the joint prior to placing the patch material. Patches that abut working joints or cracks that penetrate the full-depth of the slab require a compressible insert or other bond-breaking medium to reform the joint or crack. This will form a uniform face against which the joint or crack can be properly sealed and will separate the patch from the adjacent slab. The new joint should be not less than the same width as the existing joint or crack. Failure to reform the joint or crack as described can result in point bearing and failure by blowup, delamination, or new shear planes sometimes in the

adjacent slab (Figure 5.8.). When placing a partial-depth patch along a shoulder joint, place a piece of joint material along the slab edge even with the surface to prevent the patch material from penetrating the shoulder interface. Otherwide, the material may restrict longitudinal movement of the slab in response to thermal changes and result in damage to the repair or the shoulder.

5.7. Patch Materials. High early-strength PCC (usually Type III cement) should be used when early opening to traffic is required. When using this material, an epoxy bonding agent should be used. The concrete should not be placed until the epoxy becomes tacky.

Normal set Type I PCC can be used when the patch material can be protected from traffic for 24 hours. A light coat of bonding mortar, one part portland cement to one part sand by volume with sufficient water to produce a mortar with a creamy consistency, is applied to the patch area. The concrete must be placed before the grout dries. If the grout dries or hardens prior to place-ment of this concrete, it should be removed by sandblasting. Patches using normal-set concrete should not be placed when the air temperature is below 50 degrees Fahrenheit (10 degrees Celsius). At temperatures below 55 degrees Fahrenheit (13 degrees Celsius), a longer curing period and/or insulation mats may be required. Rapid-set proprietary patching materials should be used in compliance with the manufacturer's recommendations. This includes bonding, placing, time required before opening to traffic, and temperature ranges. Epoxy mortar and epoxy concrete mix designs should be evaluated in the laboratory before use. The epoxy resin catalyst should be preconditioned before blending to produce a liquid blended between 75 and 90 degrees Fahrenheit (24 and 32 degrees Celsius). The epoxy components should be mixed in compliance with the manufacturer's recommendations prior to addition of aggregate. The material should be blended in a suitable mixer until homogenous. Only the quantity of material that can be used within 1 hour (dependent on materials and air temperature, may be less than 1 hour) should be mixed in each batch.

5.8. Placement of Patch Materials, All sandblasting residue should be removed using oil-free airblowing equipment just prior to placing the bonding agent. The bonding agent should be applied with a stiff bristle and scrubbed into the patch area. It should be applied evenly and in a thin coat (approximately 1/16 inch (2 millimeters) thick) and should not be allowed to puddle (Figure 5.9.). The volume of material required for a partial-depth repair is usually less than 2.0 cubic feet (0.056 cubic meters). Therefore, patching material should be mixed on site in a small mobile drum or paddle mixer. Transit mix trucks and other large equipment cannot efficiently produce such small quantities, since maximum mixing times for a given temperature may be exceeded, decrease the quality, and result in waste of material. The repair area should be slightly overfilled to compensate for consolidation. Primary consolidation should be by tamping. The patch material also may be consolidated by small spud vibrators to eliminate voids at the interface of the patch and the existing concrete (Figure 5.10.). Vibrators greater than 1 inch (25 millimeters) in diameter are not recommended for this work. On very small repairs, hand tools should be sufficient to work the repair and attain adequate consolidation.

5.9. Finishing. The finishing area should be finished to the cross section of the existing pavement without leaving excess material on the adjacent pavement surface. The recommended finishing procedure is to screed from the center of the patch area to the patch boundaries. By moving the screed toward the patch boundaries, the material is pushed toward the interface to increase the potential for high bond strength. After finishing, the patch should be given a burlap drag or broom finish to approximately match the surface finish of the existing adjacent concrete pavement, unless a grinding operation is to follow.

5.10. Saw-cut Runouts. Epoxy mortar should be used to fill any saw-cut runouts that extend beyond the patch perimeter at patch corners. The mortar will help to prevent moisture penetration that may undermine the bond.

5.11. Sealing Patch/Slab Interface. An inportant procedure in placement of partial-depth repairs is sealing the patch/slab interface. The patch/slab interface is sealed with a one-to-one cement grout. This grout will form a moisture barrier over the interface and impede delamination of the patch (delamination of the patch can occur if water at the interface freezes during the winter). A joint sealant may also be used.

5.12. Curing. Proper curing of partial-depth repairs is very important due to the large surface of small patches compared to the volume of patch material, as well as the fact that concrete gains bond strength much slower than it gains compressive strength. This relationship is conducive to quick moisture loss and is different from most other concrete applications. Proper curing generally employs the application of curing compound at the time bleed water has evaporated from the surface. Because curing is critical for partial-depth patches, the first 24 hours should be wet cured with burlap or a similar material. The balance of the 7-day curing period may be with liquid membrane compounds. In general, the procedures used for curing full-depth repairs can be considered for partial-depth repairs.

In hot or dry climates, the patches should be cured for 14 days with a double mat of saturated burlap covered with polyethylene sheeting, over which plywood or lumber is placed. The covering should be removed and the burlap resaturated daily and the covering replaced.

5.13. Joint Resealing. Resealing the repair joint is extremely important, because it will help prevent moisture and incompressibles from causing further damage. It is important that the new transverse and longitudinal joints constructed within the patch area be formed or sawed to provide the proper joint seal reservoir, and match surrounding joints. The joint faces must be clean and dry for good sealant performance. Resealing of joints should be done in accordance with the recommendations outlined in AFM 88-6, Chapter 7, and the Concrete Joint and Crack Repair Field Manual.

Figure 5.1. Pavement joint

Figure 5.2. Severe spalling

Figure 5.3. Spall repair

NOTE: 1" = 25 mm

(TOP VIEW)

MAKE VERTICAL SAW CUT 2" MIN DEEP APPROX 3" BEYOND DISTRESS AREA
REMOVE ALL MATERIAL INSIDE SAWN AREA TO 1/2" BELOW SURFACE OF
VISUALLY SOUND CONCRETE (3" MIN DEPTH). USE SEPARATING MEDIUM TO
MAINTAIN JOINT. USE PORTLAND CEMENT BONDING AGENT TO ENSURE
GOOD BOND BETWEEN OLD AND NEW MATERIAL. PATCH WITH 0" SLUMP
CONCRETE, WELL COMPATED, AND CURE. SEAL JOINT WHEN CURED.

Figure 5.4. Clean vertical face

Figure 5.5. Saw cuts

PARTIAL-DEPTH PATCH
SAW CUTS

BOUNDARY SAW CUTS MIN. 2" (50 mm) DEEP,
3" (76 mm) OUTSIDE DISTRESSED AREA
OVERLAP CUTS AT CORNERS AND APPROX.
1" (25 mm) ACROSS JOINT

(TOP VIEW)

SAW CUT APPROX 2"(51mm) AWAY   SAW CUT SKIMMING OPPOSITE
FROM JOINT FOR PROTECTING   JOINT TO PROVIDE CLEAN
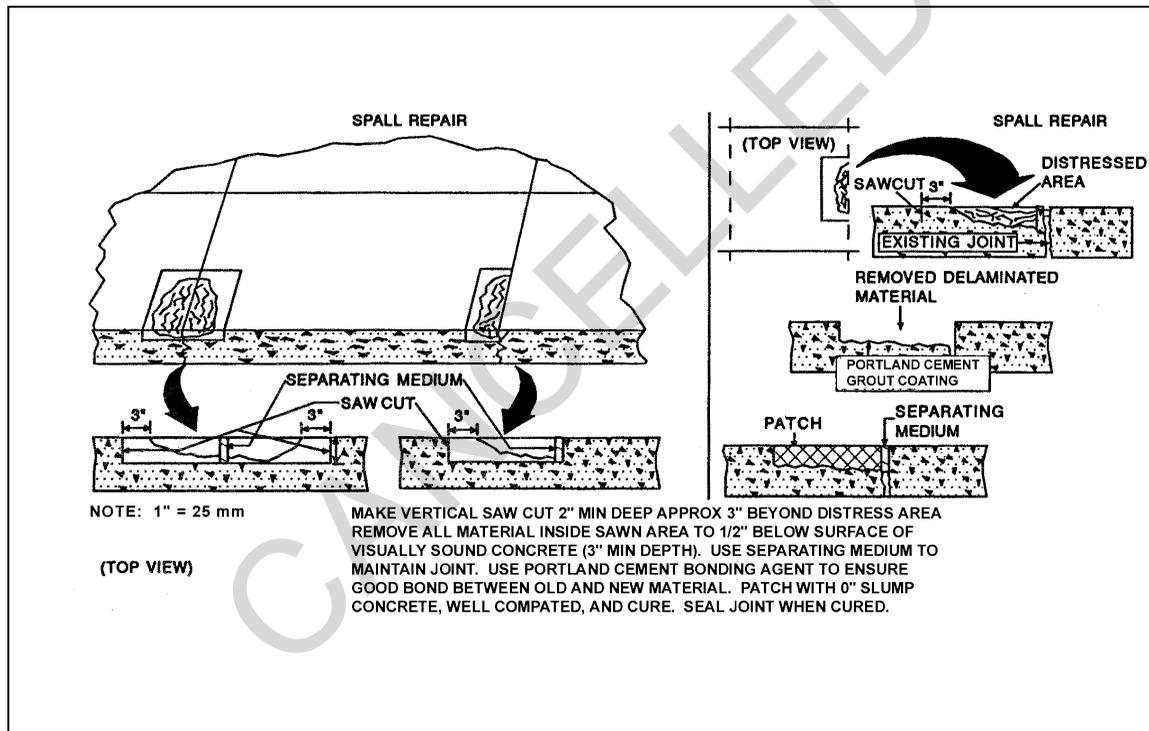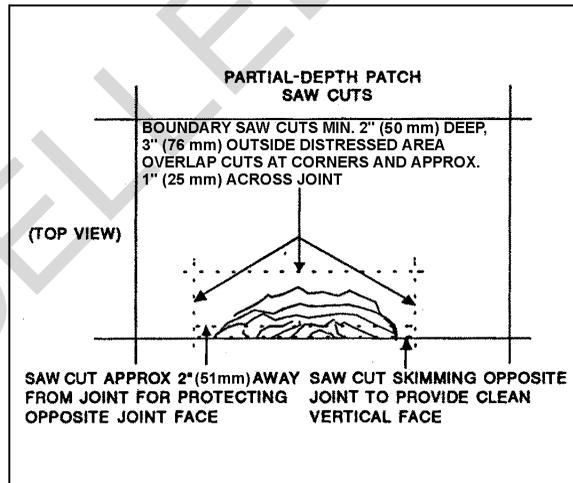OPPOSITE JOINT FACE   VERTICAL FACE

Figure 5.6. Cleaning exposed faces

Figure 5.7. Compressible insert

Figure 5.8. Point bearing causing failure

Figure 5.9 Application of bonding agent

Figure 5.10. Spud vibrator

CHAPTER 6

SLABJACKING

6.1. Purpose. The purpose of slabjacking is to raise a slab in place permanently, prevent impact loading, correct faulty drainage, and prevent pumping at transverse joints by injection of a grout under the slab. The grout fills voids under the slab, thereby restoring uniform support (Figure 6.1.). When necessary, it can also be used to raise the slab. This work must be done by an experienced contractor due to work complexity and specialized equipment required.

6.2. Need for Slabjacking. Slabjacking should be considered for any condition that causes nonuniform slab support, such as embankment settlement, settlement of approach slabs, settlement over culverts or utility cuts, voids under the pavements, differences in elevation of adjacent pavements, joints in concrete pavements that are moving or expelling water or soil fines, and pavement slabs that rock or teeter under traffic.

6.3. Location of Injection Holes. Location of injection holes must be determined in the field. The jacking crew superintendent normally locates the holes and must take into consideration the size or length of the pavement area to be raised, the elevation difference, subgrade and drainage conditions, location of joints or cracks, and the manner in which the slabs will be tilted or raised.

As a general rule, holes should not be placed less than 12 inches (300 millimeters) or more than 18 inches (450 millimeters) from a transverse joint or slab edge. The holes should not be placed more than 6 feet (1.8 meters) center to center, so that not more than approximately 25 to 30 square feet (2.33 to 2.79 square meters) of slab is raised by pumping any one hole. Additional holes may be required if the slab is cracked. The proper location of holes varies according to the defect to be corrected (Figure 6.2.). For slabjacking a joint where faulting has not yet occurred, a minimum of two holes can be used. For slabjacking a joint where one corner of the slab has

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faulted, the hole at the low corner should be set back to avoid raising the adjacent slab. Where the pavement has settled and the slabs are in contact with the subbase, a single hole located in the middle of the panel may be sufficient.

6.4. Drilling Holes. Holes that are 1-1/4 to 2 inches (32 to 50 millimeters) in diameter are drilled by pneumatic drills, core drills, or other devices which are capable of drilling grout injection holes through the concrete pavement and the base material. The equipment must be in good condition and operated in such a manner that the holes are vertical and round. The down feed pressure, whether by hand or mechanical means, should not exceed 200 pounds per square inch (1,379 kilopascals). Where the concrete pavement is tight against the base material, the use of an airline or blow pipe may be necessary to form a cavity under the pavement slab for the grout pressure to take effect. Where the pavement is placed and bonded to a cement treated or other stabilized base material, grout holes should be drilled completely through the base material.

The grout should be injected below the base material rather than between the pavement and base material.

6.5. Grout Mixtures. A variety of grout mixtures have been successfully used for slabjacking. They generally consist of three to seven parts fine aggregates or a mixture of aggregate and pozzolans or flyash to one part portland cement with enough water to produce the desired consistency. Wetting agents or other additives may also be used to increase the flowability. The use of a wetting agent lubricates the grout and permits runs of up to 6 feet (1.8 meters), and it also tends to reduce "pyramiding" (a stiff grout may form a pyramid under the slab, leaving unfilled cavities). A definite method of proportioning the grout mixture should be used to ensure uniform consistency. The proper consistency to be used for any given condition is best determined by experience. Generally, a mix of stiff consistency is used to raise the pavement slabs and a more fluid mix is used for filling voids. The consistency should be checked by a flow

cone (CRD-C 611/ASTM-C-939) at least twice each day. Typical flow-cone times vary between 16 to 30 seconds depending on the type of materials used in the grout mix. Strength require-ments of the grout mixture should be specified. A common requirement is 600 pounds per square inch (4,134 kilopascals) at 7 days as determined by ASTM-C-39.

6.6. Grout Pumping. Pumping and jacking operations should normally start at the lowest point in a depressed area and work outward in both directions (Figure 6.3.). Pumping progresses by lowering into successive holes an injection pipe connected to the discharge hose of the grout pump. An expanding rubber packer is used to seal the open space between the pipe and the drill hole. The injection pipe must not extend below the bottom of the pavement and it must be equipped with a return line to circulate the grout while no grout is being placed. Lifting should be done in increments of about 1/4 inch (6 millimeters) with frequent changes in injection locations to keep slab stresses at a minimum and avoid cracking. The rate of grout injection should be uniform and as slow as possible, usually a minimum of 1/2 cubic foot (0.014 cubic meter) per minute to a maximum of 2 cubic feet (0.056 cubic meter) per minute. Initial pumping is normally at the lower rate and is increased as lifting progresses. As the desired elevation is approached, the lifting rate should be reduced. When grout is extruded from joints, cracks, or from the pavement edge before the target elevation is reached, regrouting in new drill holes and additional slabjacking will be necessary. Gauge pressures for slabjacking are normally in the range of 75 to 200 pounds per square inch (517 to 1,379 kilopascals) with short pressure surges up to 600 pounds per square inch (4,134 kilopascals) to initiate lifting of bonded slabs. Constant observation and analysis of pressure behavior is the most important single factor affecting good slabjacking. A rapid increase could signal a stoppage of flow that could be followed by a buildup of pressure and excessive lift and cracking, if pumping continues.

A sudden reduction of pressure could indicate a loss of lift due to subsurface leakage. In slabjacking operations, the temperature is important when raising slabs to correct faulted joints or

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other elevation differences. If the temperature is high, the concrete may be in compression at the slab ends and may not be free to move. This may require freeing the joints by sawing to complete the lifting process.

6.7. Elevation Control During Jacking. Before slabjacking operations are started, some method of controlling the amount the slab is to be raised and the finished elevation of the pavement should be determined. For correcting faulted slabs, a straight edge may be used. For short dips up to approximately 50 feet (18.3 meters) in length, a tight stringline is adequate provided the joints are true and plane with those of the adjacent pavement (Figure 6.4.). For dips in excess of 50 feet (18.3 meters) in length, an engineer's level and rod should be used to check the profile well beyond the dip. This will avoid building a bulge into the pavement.

6.8. Plugging and Cleanup. After slabjacking has been completed in a hole and the discharge pipe removed, the hole should be plugged immediately. Tapered wooden plugs are temporarily placed into the injection hole to retain the pressure of the grout and stop any return flow of the mixture.

When slabjacking to the desired elevation has been accomplished, the temporary plugs are removed and the injection holes are filled with a stiff one-part-water, three-part-cement grout or approved concrete mixture. These areas are then finished to an approximate match with the existing pavement. Surfaces adjacent to the grouting operation should be kept clean of excess grout and other materials. Grout and cement slurry on the pavement should be broomed and washed off to avoid unsightly discoloration and to remove the grout slurry before it bonds to the surface.

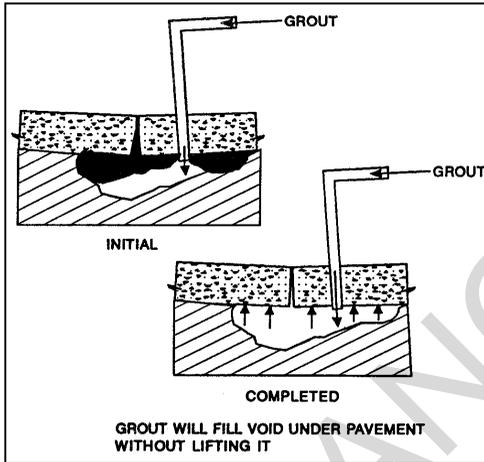Figure 6.1. Injecting grout

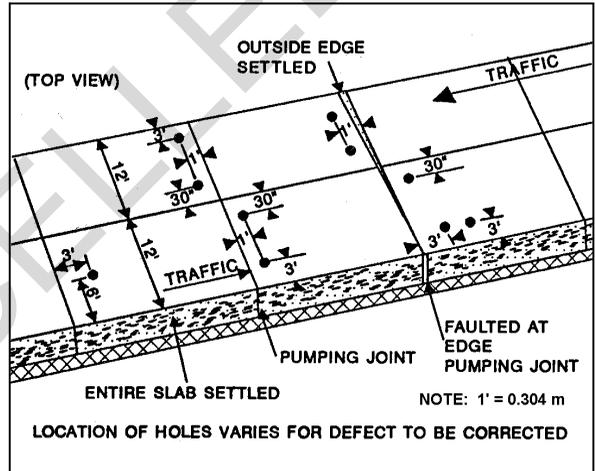Figure 6.2. Location of injection holes
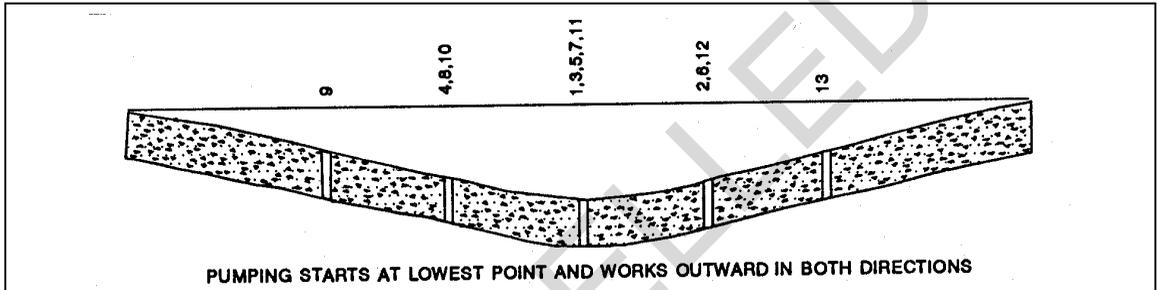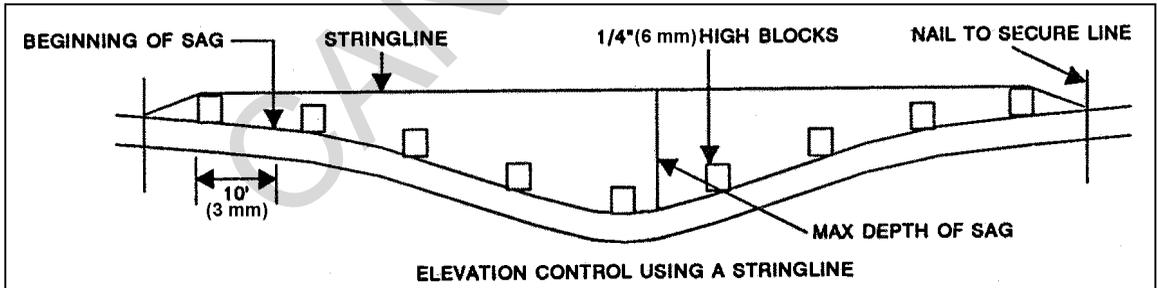

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Figure 6.3. Grout pumping

PUMPING STARTS AT LOWEST POINT AND WORKS OUTWARD IN BOTH DIRECTIONS

Figure 6.4. Elevation control

ELEVATION CONTROL USING A STRINGLINE

CHAPTER 7

SUBSEALING JOINTED CONCRETE PAVEMENTS

7.1. Purpose of Subsealing. The purpose of subsealing is to stabilize the pavement slab by the pressurized injection of a cement grout through holes drilled in the slab. The cement grout will, without raising the slab, fill the voids under it, displace water from the voids, and reduce the damaging pumping action caused by excessive pavement deflections. To ensure that the slab is not raised, straightedges with gauges attached should be placed over the slab to measure any upward movement of the slab. At the first indication of movement, the grout injecting procedure should be stopped.

7.2. Void Detection. A thorough survey should determine the void locations beneath the concrete pavement. Void detection measurements should be taken during the preliminary evaluation and during the repair process. Void detection can be a complicated process as natural wetting and drying cycles and thermal variations can cause slab curling. Several suggested methods follow, but interpretation of field conditions by experienced personnel is always desirable.

Several methods of void detection are in use. Perhaps the simplest is a visual inspection of the pavement to locate areas of distress. The presence of ejected subgrade or base material, staining of pavement surfaces adjacent to joints, vertical movement at joints or cracks, and faulting of joints are evidence of possible voids under the slab. The most common method of determining the presence of voids is called "proof rolling." This is the procedure of slowly driving a heavily loaded vehicle (minimum 18,000-pound (80-kilonewton) axle load) over a transverse joint while observing deflection of the slabs. If deflection can be visually observed, the joint should be undersealed. Deflection can also be measured by devices equipped with sensitive dial

gauges which contact the pavement and are attached to a firm base located off the pavement. The dial gauges can be read visually or recorded electrically. When deflection is measured in this way, any slab showing deflection in excess of 0.015 inch (0.38 millimeter) should be undersealed. Other methods for measuring deflection to locate voids include nondestructive equipment such as the Falling Weight Deflectometer, which measures the deflection response of the pavement under a dynamic load (Figure 7.1.).

7.3. Need for Subsealing. For jointed concrete, pavement subsealing should be accomplished as soon as significant loss of support is detected at slab corners. Symptoms of loss of support include increased deflections, transverse joint faulting, corner breaks, and the accumulation of fines in or near joints or cracks on traffic lanes or shoulders.

Subsealing should also be considered at all existing repairs that show evidence of pumping or settlement. To be effective, subsealing should be performed before the voids become so large that they cause pavement failure.

7.4. Hole Patterns. Hole patterns for effective distribution of cement grout under the pavement are not easily determined in advance. Some preliminary testing is often necessary in advance to locate holes in a way that will ensure good grout distribution. Where a hole pattern is selected for repetition, it should provide sufficient holes to permit grout to reach all voids beneath the pavement. The most common hole pattern is a four hole pattern with two holes on each side of a transverse joint. The holes are located in the wheel tracks, with the approach slab holes nearer the joint than the leave slab holes. Typical distances from the joint are 12 to 18 inches (150 to 450 millimeters) for the approach slab and 18 to 24 inches (450 to 600 millimeters) for the leave slab. Additional holes may be required for voids under the longitudinal joints or at the shoulder. Usually, one hole that is 24 to 36 inches (600 to 900 millimeters) from the shoulder and 4 to 6 feet (1.22 to 1.83 meters) from the transverse joint is adequate. Ideally, the hole should be placed as

far from the adjacent joints and cracks as possible but within the void area, so the grout can flow from the injection hole toward the joint or crack.

7.5. Drilling Holes. Grout holes may be drilled with pneumatic, hydraulic, or diamond core drills. An important factor is hole size. Holes should not be larger than 2 inches (50 millimeters) in diameter. The downward pressure, whether by hand or mechanical means, should be less than 200 pounds (91 kilograms), particularly at the bottom portion of the slab. Excessive down pressure can cause breakout of the concrete adjacent to the injection hole. This breakout can seriously weaken the slab and may result in premature cracking. Usually, the breakout material drops in such a way that it seals the hole, thereby preventing the grout from reaching the void. The grout holes should be drilled vertically and round and to a depth completely through the base material. Grout holes should not be left ungrouted overnight and preferably should be grouted within 4 hours.

7.6. Grout Mixtures. Grout mixtures for subsealing are typically cement grouts consisting of approximately one part portland cement to three parts pozzolan, either natural or artificial, or three parts limestone dust with enough water to achieve the required consistency. Other additives may include super plasticizers, water reducers, fluidifiers, expanding agents, and calcium chloride. Each must be tested and evaluated in the laboratory to ensure compatibility of the materials. Consistency should be checked by a flow cone (CRD-C 611/ASTM-C-939) at least twice each day.

Flow cone time varies between 9 and 20 seconds depending on the types of materials used in the grout mix. Typically flow cone times for limestone grouts are 16 to 22 seconds. Flyash grouts generally have flow times from 10 to 16 seconds. Strength requirements of the grout mixtures should be specified; a common requirement is 600 pounds per square inch (4,134 kilopascals) at 7 days as determined by ASTM-C-109.

7.7. Grout Injection. Grout injection proceeds by lowering into successive holes a pipe connected to the discharge hose of the grout pump. The grout hole is sealed by a device called a packer. Two types are commonly used:

7.7.1. The drive packer consists of a tapered pipe tapped into and out of the grout hole. Drive packers are used with 1-inch- (25-millimeter-) diameter holes.

7.7.2. The expanding rubber packer consists of a threaded inner pipe, a thin-walled steel outer sleeve, and a short rubber sleeve at the bottom. This type of packer is used with 1.5-inch- (33-millimeter-) diameter and larger holes.

Movement of the slabs must be monitored during the grouting operation. To properly monitor movement of the slabs, gauges capable of reading movement of 0.001 inch (0.025 millimeter) have to be used. The base for the gauge should be 3 to 4 feet (0.91 to 1.22 meters) off the slab being monitored. The gauges are set up at the outside edge of the slabs at the joints and are not moved until grouting of the joint is completed. Typical pumping pressure should be in the 40- to 60-pounds per square inch (275- to 413-kilopascals) range. Grout injection should always start with a low pumping rate and pressure. Pumping should stop if the slab begins to rise or when no material is being injected at the maximum allowable pressure of 100 pounds per square inch (689 kilopascals).

Pumping of short surges up to 200 pounds per square inch (1,378 kilopascals) are allowable for the grout to penetrate the void structure. If grout returns through an adjacent hole, pumping should stop, and the packer should be inserted into another hole. If grout is observed flowing from joints or cracks in the pavement, pumping should continue until undiluted grout is observed. Generally when pumping the four-hole pattern, pumping should begin at the centerline holes in each slab first and then continue with the holes closest to the shoulder. This sequence will drive any trapped water to the outside of the slab and through the transverse and shoulder joints.

Where there is an additional shoulder void and extra holes are required, the sequence becomes more complicated. Usually, the shoulder joint is pumped last. If, however, the transverse joint is wider than the shoulder joint, it may be necessary to pump the shoulder hole first.

7.8. Retesting Slab Corners. After a minimum of 24 hours has elapsed following completion of subsealing, testing of the grouted slabs for stability should be accomplished at the same points as previously tested. This testing should also include other joints that were not grouted for use as control. If loss of support still exists after grouting, the slab should be regrouted. In each regrouting, new holes will be needed. It is recommended that if, after three attempts to stabilize the slab, voids are still present, no further regrouting should be attempted. Other methods of repair should then be considered, such as full-depth repair.

7.9. Plugging and Cleanup. After grouting has been completed at any one hole, the packer is removed and the hole is plugged with tapered wooden plugs to permit the grout to set, thus preventing back pressure from forcing the grout back through the hole. The plugs are removed and the hole is filled with a cement grout and finished to match the existing pavement. Surfaces of the pavement adjacent to the holes should be kept clean of excess grout and other materials. Grout and cement slurry on the pavement should be broomed and washed to avoid unsightly discoloration and to remove the grout and slurry before it bonds to the pavement.

Figure 7.1. Falling Weight Deflectometer

CHAPTER 8

ASPHALT UNDERSEALING

8.1. Method. Asphalt undersealing describes the injection of bituminous material under pavements to fill minor voids caused by pumping action. Use of asphalt to fill voids greater than 1 inch (25 millimeters) in depth or to raise slabs is not recommended. Bituminous undersealing is mainly used to fill voids about 1/2 inch (13 millimeters) deep. Only asphalt especially prepared for undersealing should be used. Recommended asphalt should have a penetration range of 15 to 30, a softening point range of 180 to 200 degrees Fahrenheit (82 to 93 degrees Celsius), be of suitable consistency for pumping when heated to a temperature of 400 to 500 degrees Fahrenheit (204 to 260 degrees Celsius), and be resistant to displacement in the pavement when cooled.

8.2. Procedure. The method of placing bituminous undersealing is practically the same as that used for cement grout undersealing. The asphaltic cement should be heated in the bituminous distributor tank to a temperature of between 400 and 450 degrees Fahrenheit (204 to 232 degrees Celsius). All water should be removed from beneath the slab with compressed air prior to pumping of the hot asphalt. The tapered nozzle on the asphalt hose is driven tightly into the drilled hole and asphalt injected under pressure. The nozzle should be allowed to remain in a hole for approximately 1 minute after pumping ceases and pressure is reduced, then removed, and the hole plugged. Pumping pressures should range from 20 to 40 pounds per square inch (138 to 276 kilopascals) under normal conditions.

During pumping, water should be sprayed on the pavement adjacent to the drilled holes to prevent discoloration of the surface. Water saturated with hydrated lime is considered most suitable, since spilled asphalt will chill quickly and can be easily removed. Asphalt seeping through cracks or joints can be quickly chilled and hardened by applying cold water. Extreme

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caution should be taken and appropriate safety equipment should be worn at all times due to the extremely high temperatures of the asphalt.

CHAPTER 9

DIAMOND GRINDING

9.1. Purpose of Grinding. Diamond grinding removes faults, reprofiles pavements, removes surface defects, and restores the pavement to a smooth surface. Because the hardness of the aggregate will influence the grinding operation, the type of aggregate in the PCC pavement should be identified when the work is to be contracted.

9.2. Need for Grinding. When a pavement survey reveals surface defects such as faulted joints in excess of 1/8 inch (3 millimeters), roughness in excess of 1/8 inch (3 millimeters) in a 10-foot (3-meter) length, or rutting up to 3/8 inch (10 millimeters), diamond grinding should be considered. If skid resistance is to be examined, it should be examined on the areas not scheduled for grinding for any of the previously mentioned defects. If a large area requires grinding to improve skid resistance, economics may favor grinding the entire pavement surface.

9.3. Grinding Process. The diamond grinding process is free of impact and does not damage joints. The pavement grinder is similar to a wood plane. The front wheels are designed to pass over a fault or bump, the cutting head shaves it off and the rear wheels ride in a smooth path left by the cutting head.

Diamond grinding requires heavy, specially designed equipment (Figure 9.1.) that uses diamond saw blades gang mounted on a cutting head (Figure 9.2.). Spacers are placed between the saw blades to reduce the amount of cutting that is to be done. This combination of saw blades and spacers gives the pavement the characteristic corduroy texture that improves skid resistance.

9.4. Test Section. Before work begins, the equipment should be used in a test section to ensure that proper blade spacing is being used for the specific aggregate on the project. The width of the spacers between the saw blades is varied depending on the hardness of the aggregates. The

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harder the aggregate, the thinner the spacing between the blades. As the diamond grinding head cuts the surface of the pavement, thin fins of concrete are left between the cutting blades. These fins should break off during the grinding process. If these fins do not break off, a grinding head with thinner spacers should be used. When grinding aggregate susceptible to polishing, the spacing must be wider to provide more an area between the blades. The grinding chip thickness measured at the thickest point should be an 0.080-inch (2-millimeter) minimum and have an average thickness of 0.100 inch (2.5 millimeters). For harder aggregates not subject to polishing, the minimum chip thickness should be 0.065 inch (1.7 millimeters) and an average of 0.080 inch (2 millimeters).

9.5. Grinding Procedure. Roughness removal: When areas have been identified as being too rough, a level of restoration must be set and sections having excess roughness must be ground. Following the grinding, the roughness should be tested again. Testing is typically accomplished using equipment such as the California Profilograph (Figure 9.3.) or the Mays Ride Meter. Prior to grinding, the grade should be established. The old pavement surface should not be used as the reference unless a long beam or skid is used. Where sags in the pavement are encountered, the sags should be removed by slabjacking. Grinding a sag will not remove roughness. The pavement should be reinvestigated following slabjacking to determine if grinding requirements were altered.

Fault removal: Prior to grinding the faulted joints, the slabs should be undersealed to prevent the fault from recurring. The joints must be cleaned, resawn to the proper depth, and resealed. This is necessary to prevent infilration of water from the grinding operation. Grinding should cut into the faulted joints, this produces smoother joints, and a more efficient operation. The fault must be feathered back some distance into the slab. The distance required depends on the allowable roughness. The American Concrete Paving Association has a general guideline of 1 foot

(300 millimeters) for every 0.1 inch (2.5 millimeters) of faulting. This is slightly rougher than 1/8 inch (3 millimeters) in 10 feet (3 meters).

Feathering distances necessary to meet straight-edge requirements of 1/8 inch (3 millimeters) in 10 feet (3 meters) are shown in Table 9.1.

Table 9.1. Feathering Distances

Fault Height inches (millimeters)	Feathering Distance feet (meters)
1/8 (3)	2.5 (0.76)
1/4 (6)	5.0 (1.52)
3/8 (10)	7.5 (2.29)
1/2 (13)	10.0 (3.04)
5/8 (16)	12.5 (3.81)
3/4 (19)	15.0 (4.57)

If the entire slab is to be ground, the depth of cut to remove the fault will be feathered out to the next joint. Skid resistance can be improved by grinding and should only be done on those lanes needing the treatment. The edges of the ground areas should be feathered into the adjoining areas to eliminate a sharp drop off. The pavement should be ground in a longitudinal direction that begins and ends at lines normal to the pavement centerline. The grinding operation should

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produce a uniform finished surface free of joint or crack faults (Figure 9.4.) and provide positive lateral surface drainage. The removal of slurry residue resulting from the grinding operation should be continuous. Grinding slurry should not be permitted to flow across adjacent lanes into gutters or other drainage facilities.

9.6. Acceptance Testing. After completion of the grinding and texturing, the pavement should be tested for smoothness. The pavement should meet the surface tolerance for a new pavement as required by the specifying agency. The test equipment to be used in the acceptance testing should be the same as that used in the initial evaluation and should be specified along with procedures to be followed in acceptance testing. The grinding must not reduce the thickness of the pavement enough to affect the load-carrying capability of the pavement.
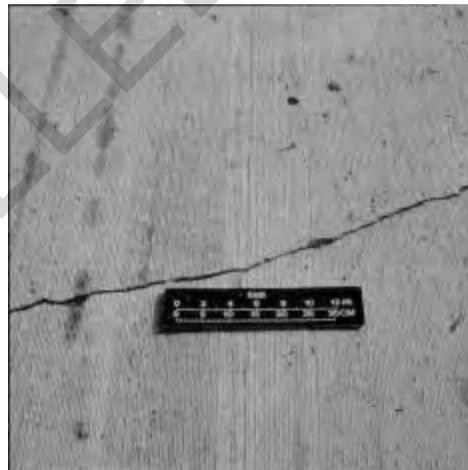
Figure 9.1. Diamond grinding equipment

Figure 9.2. Diamond cutting head

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Figure 9.3. California profilograph

Figure 9.4. Crack fault

CHAPTER 10

LOAD-TRANSFER RESTORATION

10.1. Purpose. New pavement joints typically exhibit good load transfer, particularly if the joints are doweled. However, repeated heavy loads can cause an elongation of the dowel sockets and result in dowel looseness and a reduction of load-transfer efficiency. As load-transfer efficiency decreases, many types of distress rapidly increase, including pumping, spalling, faulting, and slab cracking. Restoration of load transfer is used to retard further deterioration of the concrete pavement by reducing the potential for the distress and the mechanisms previously described.

10.2. Need for Load-Transfer Restoration. Transverse joints or cracks that would benefit improved load transfer can be identified by measuring the existing load-transfer efficiency with heavy-weight, nondestructive, deflection testing devices such as the Falling Weight Deflectometer (Figure 7.1.). These tests must be conducted during periods of cooler temperatures (less than about 80 degrees Fahrenheit (27 degrees Celcius)) when the slab joints and cracks are not tightly closed. Joints or cracks having a measured load-transfer efficiency (ratio of the deflection on the unloaded side of a joint or crack divided by the deflection of the loaded side) of less than 50 percent should be considered for load-transfer restoration.

The deflection measurements should be taken as near as possible to the joint or crack. If a sensor is used, the measurements should be taken in the center of the load plate and 12 inches (300 millimeters) across the joint. The measurements taken in the center of the slab should be corrected for normal slab bending.

10.3. Correction of Deficiencies. Before load-transfer devices are installed, it is necessary to determine the cause of the joint or crack distress. Attempts should be made to correct these deficiencies prior to load-transfer restoration. Heavy distressed slabs may require portions of or

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the entire slab to be replaced. Successful installation of load-transfer devices requires sound concrete adjacent to the joint or crack. If the concrete near the joint or crack is significantly deteriorated, full-depth repair should be placed (with provisions for load transfer) in lieu of load-transfer devices. Additional work that must be performed prior to load-transfer restoration may include:

10.3.1. Subsealing (essential if loss of support exists) to fill voids in the pavement structure and to restore to the pavement slabs.

10.3.2. Full-depth and spall repairs to replace highly distressed joints and slabs with corner breaks, "D" cracking, etc.

10.4. Methods of Load-Transfer Restoration. Two methods of restoring load transfer of existing joint or cracks have been used: dowels and proprietary shear devices. Short-term experience indicates that both methods can be effective in transferring loads across joints and cracks. The important functions of load-transfer devices in concrete pavements are to help maintain alignment of adjoining slabs and to limit or reduce stresses resulting from loads on the pavement.

10.4.1. Dowels. Different sizes of dowels should be specified for different thicknesses of pavements. Dowel size and spacing for construction, contraction, and expansion joints are shown in Table 10.1.

Table 10.1. Dowel Size Requirements

Pavement Thickness inches (millimeters)	Minimum Dowel Length inches (millimeters)	Maximum Dowel Spacing inches (millimeters)	Dowel Diameter and Type
8 (200)	16 (400)	12 (300)	3/4-inch (19-millimeter) bar
8 to 11.5 (200 - 290)	16 (400)	12 (300)	1-inch (25-millimeter) bar
12 to 15.5 (300 -395)	20 (500)	15 (380)	1- to 1 1/4-inch (25- to 32-millimeter) bar or 1-inch (25-millimeter) extra-strength pipe
16 to 20.5 (400 - 520)	20 (500)	18 (450)	1- to 1 1/2-inch (25- to 38-millimeter) bar or 1- to 2 1/2-inch (25- to 64-millimeter) extra-strength pipe
21 to 21.5 (530 - 550)	24 (600)	18 (450)	2-inch (50-millimeter) bar or 2-inch (50-millimeter) extra-strength pipe
>26 (660)	30 (762)	18 (450)	3-inch (75-millimeter) bar or 3-inch (75-millimeter) extra-strength pipe

When extra-strength pipe is used for dowels, the pipe should be filled with a stiff mixture of sand-asphalt or portland cement mortar or the ends of the pipe should be plugged. If the ends of

the pipe are plugged, the plug must fit inside the pipe and be flush with the end of the pipe so that there will be no protruding material to bond with the concrete and prevent free movement of the dowel. When using smooth steel dowels, slots for the dowels are cut using diamond-blade saws. Multiple blade saws may be used to speed operations. The slots should be cut so that the dowels are allowed to rest horizontally and perpendicular to the crack or joint and at middepth of the slab (Figure 10.1.). Light-weight chipping hammers are used to remove the concrete within the slots. The slot is then cleaned by sandblasting or any method that will ensure removal of all sawing residue, dirt, or oil that may prevent bonding of the patch material to the slot faces. Each dowel is placed upon a support chair to allow the patch material to surround the dowel. One end of the dowel is oiled and painted and an expansion cap placed on the end (Figure 10.1.). The dowels must be provided with a filler board or styrofoam material at midlength to prevent intrusion of the patch material into the joint or crack and to form the joint in the slot (Figure 10.2.).

10.4.2. Proprietary Shear Device. Proprietary shear devices such as the Double Vee Device and the Plate Stud Connector have been used and are reported to be effective for load transfer across joints and cracks. The placement of proprietary shear devices must be in accordance with the manufacturer's recommendations. The following are general recommendations for the Double Vee Device: In the coolest weather possible, core a 6-inch- (152-millimeter-) diameter hole centered over the joint or crack (Figure 10.3.), with the core hole extending entirely through the slab depth. The core sidewalls should be grooved to assist in creating a mechanical interlock (Figure 10.4.). The core hole sidewalls are then roughened by sandblasting and brushed clean to keep dust from interfering with bond of the patch material with the existing slab. The joints or cracks and the bottom of the core hole must be completely sealed to prevent loss of the liquid portion of the polymer concrete. The precompressed Double Vee Device is inserted (Figure 10.5.) and properly oriented with the joint or crack at a depth of 1 inch (25 millimeters) below the

slab surface. A joint sealant reservoir must be provided at the top of the slab above the shear device (Figure 10.5.).

10.5. Patching Material. Polymer concretes and high early-strength PCC have been used in most installations to date. The patch material used with load-transfer devices is the most critical factor in performance, particularly with shear devices. Sufficient bond must be established between the device and the patching material as well as between the existing concrete and the patching material.

For this reason, a thorough laboratory evaluation must be made of any patch material utilized for the load-transfer devices. Prime factors which must be evaluated are: working time, rapid early-strength gain, and shrinkage.

10.6. Placing. After the patch area has been properly cleaned, a bonding agent should be applied (Figure 10.6.). The type of bonding agent will depend on the bond development requirements for opening to traffic and type of patching material used. The manufacturer's recommendations should be followed with all patching materials. Bonding agents should be those recommended by the manufacturer for the placement conditions. The patch material should be placed and consolidated to eliminate essentially all voids at the interface of the patch and the existing concrete and at the load-transfer device and the patch.

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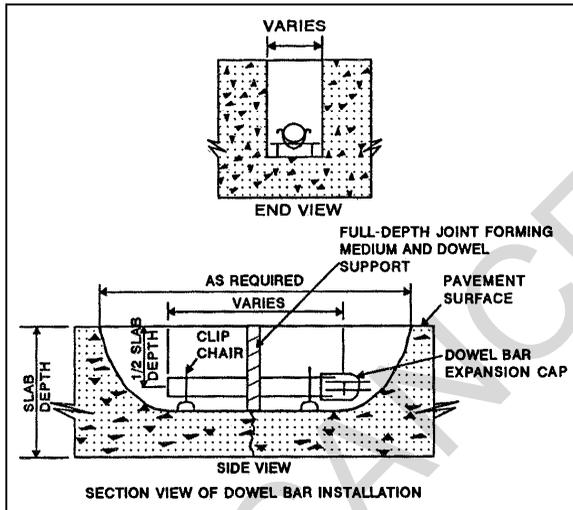Figure 10.1. Dowel installation

Figure 10.2. Forming joint in slot
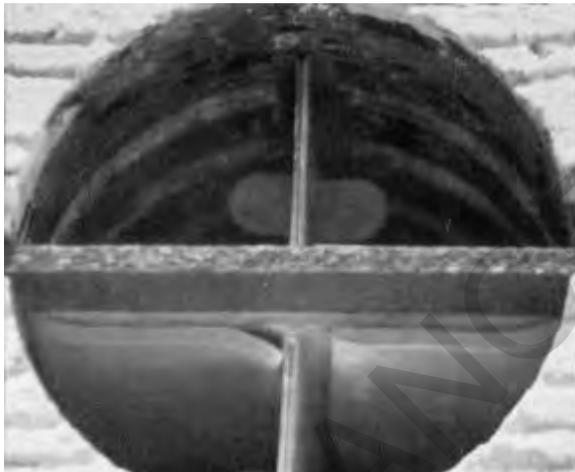
Figure 10.3. Core hole centered over crack

Figure 10.4. Grooving sidewalls

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Figure 10.5. Double Vee Device

Figure 10.6. Cleaned patch area

CHAPTER 11

POLYMER CONCRETE

11.1. Description. There are many kinds of new specialty polymer concretes (PC) such as furan and sulfur concretes, polyester, vinyl ester, vinyl ester novolac polymer concretes, epoxy and epoxy-novolac polymer concretes, etc. Most of the work on PC has been with methyl methacrylate, epoxies, and polyester-styrene resin systems. PC is a composite material in which aggregate is held together in a dense matrix with a polymer binder. The composites do not contain a hydrated cement phase of portland cement; however, they can be used as an aggregate or filler. PC composites can possess a unique combination of properties dependent upon the formulation. These should include:

11.1.1. Rapid curing at ambient temperatures from 0 to 104 degrees Fahrenheit (-18 to 40 degrees Celsius).

11.1.2. High tensile, flexural, and compressive strengths.

11.1.3. Good adhesion to most surfaces.

11.1.4. Good long-term durability with respect to cycles of freezing and thawing.

11.1.5. Low permeability to water and aggressive solutions.

11.1.6. Good chemical resistance.

Application and performance of PC is dependent upon the specific polymeric binder as well as the type of aggregate and its gradation. Copolymerization techniques allow the production of a variety of binders with a wide range of physical properties.

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11.2. Surface Preparation. Prior to starting the work, it is necessary to determine the condition of the surface to be treated and to determine what surface preparation is required. Two surface conditions must be met if repairs are to be successful:

11.2.1. The concrete surface must be strong and sound, and all loose deteriorated and unsound material should be removed. Patching over delaminated areas should not be done. The delaminations can be repaired by epoxy injection or similar techniques, but long-term durability of such patches over repaired delaminations is likely to be impaired. In spalled areas, concrete removal may require the use of chipping hammers, scarifiers, sand blasters, high-pressure water blasters, or a combination of these.

11.2.2. The concrete surface must be dry and clean (free from laitance, dirt, oil, grease, paints, and curing compounds). Moisture on the concrete surface should be removed, unless the adhesion of the PC material to be used is not affected by moisture. Dust and debris may be removed by blowing with clean, dry, compressed air. Mechanical abrasion may also be necessary to achieve the desired bond between the PC and the concrete surface. Any exposed reinforcing steel in the repair area should also be cleaned by mechanical abrasion prior to the application of PC patching material. Mechanical abrasion that results in damage to the reinforcing steel should not be used.

11.3. Polymer Concrete Patching Materials. PC patching materials are particularly useful for the repair of portland cement pavements where traffic conditions allow closing of the repair area for only a few hours. The fast-curing, high-strength characteristics of PC patching materials are well suited on these applications. PC is not limited to that usage, however, and can be formulated for a wide variety of applicaton needs; thus, care must be exercised in selecting the right material for the job it is to perform. Some of the most widely used monomers for PC patching materials include methracylate (MMA), styrene (STY), unsaturated polyester resins

(PEs), vinyl esters (VEs), and high molecular weight methacrylate (HMWM), a relatively new material. Curing of the formulations for PC patching materials is generally an exothermic reaction. The working and curing time for PC is affected by the amount of the promoter and initiator concentrations, the ambient substrate and component temperatures, thickness, and the time required to mix, transport, and place the materials. Many factors affect the performance of these materials so it is essential that the manufacturer's recommendations are carefully followed. Epoxy compounds are generally formulated in two or more parts. Part A is most often the portion containing the resin, and Part B is usually the hardener system. Epoxy systems are formulated for specific uses so the proper epoxy must be selected for the specific job requirements. The ratio of resin to hardener varies considerably with the formulation of the epoxies. The range of curing temperatures also varies depending on the specific formulation.

Curing has taken place at temperatures varying from 140 to 5 degrees Fahrenheit (60 to -15 degrees Celsius) or below. Users of epoxy PC materials should refer to publications issued by ACI Committee 503 for additional guidance. Aggregates used in PC systems should be of the highest quality available. The aggregate must usually be dry and always free of dirt, asphalt, and other organic materials. The required aggregate size distribution is dependent upon the depth of the patch to be made. The maximum size should not be greater than one-third the depth of the patch. The distribution should provide for a minimum void volume. This will minimize the voids and the amount of monomer required to ensure proper bonding of all aggregate particles and will result in a more economical PC.

11.4. Placement. Methods of placing PC patching include:

11.4.1. Dry pack placement. The graded aggregate is placed in the repair area and compacted by tamping. The compacted aggregate is then saturated with the monomer mixture by sprinkling cans or a similar system. Care must be taken to ensure that the aggregate is wetted with

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monomer; therefore, several monomer applications are necessary. This method usually requires a higher concentration of monomer than the premixing methods and is generally limited to monomer systems with viscosities less than 100 cp.

11.4.2. Premix placement. This method is identical to that used for the placement of PCC. The polymer binder is first added directly to the mixer, then the fine aggregates, and finally the coarse aggregates. Mixing is continued until all particles and completely wetted. This method can be used for binders with low or high viscosities with a predetermined quantity of polymer binder. Depending on the product, consolidation of the PC can be obtained by tamping, vibrating screed, or small-diameter vibrators. The repair area is usually primed with the polymer binder prior to placement of the PC patch material.

11.4.3. Prepackaged PC. These systems can be mixed by hand or in mechanical mixers. If a rotating mixer is used, all of the monomer or resin system should be added to the mixer and blended first. The powders and fine aggregates are added, followed by the coarse aggregates, and the entire blend is mixed for the specified time. The entire composite is then placed and consolidated utilizing the manufacturer's recommendations. Once the PC has been placed by any one of the described methods, it can be finished by manual or vibrating screeds, or by manual or power trowels.

11.5. Safety. The chemicals used to produce some PCs may be flammable, volatile, and/or toxic. The degree of hazard is greater for high-vapor pressure materials.

With proper precautionary measures, these materials can be handled safely. The manufacturers of the chemicals and the prepackaged systems will provide recommendations for safe storage, mixing, and handling. Additional safety recommendations are provided in Chapter 5 of ACI 548.1.

CHAPTER 12

PAVEMENT-EDGE DRAIN

12.1. Purpose. Water is a fundamental factor in most problems associated with pavement performance and is responsible directly or indirectly for many of the distresses found in pavement systems. One of the most prevalent sources of pavement distress is the loss of support to the pavement structure caused by removal of underlying fine-grained material by pumping. The infiltration of water through the pavement causes saturation of the base and subbase. When traffic loads are applied, pumping occurs unless these pavement systems are very porous and able to quickly remove the water from the system. Repeated cycles lead to loss of support for the pavement structure with deflection and cracking (Figure 12.1.).

12.2. Need for Pavement-Edge Drainage. Pavement-edge drainage may be required where:

12.2.1. Surface drainage facilities within the vicinity are inadequate.

12.2.2. Water table may rise.

12.2.3. Surface water may enter the pavement system at joints or cracks, at the edges of the surfacing, or percolate through the surfacing and shoulders.

12.2.4. Water may move vertically in capillaries or interconnected water films.

12.3. Drainage Systems. Drainage systems consist of two major classifications: surface or subsurface. When both types are required for efficient maintenance and protection of the pavement, it is generally a good practice for each system to function independently.

12.4. Subsurface Drain Functions. Subsurface drainage is provided to: intercept, collect, and remove any ground water from the subgrade or base, lower high water tables, drain water

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pockets or perched water tables, or a combination of these. Base drainage is required in areas where: frost action occurs in the subgrade beneath the pavement, ground water rises to the base course layer, pavement may become inundated, and free drainage from the base is not possible (Figure 12.2.). Subgrade drainage is required in areas where seasonal fluctuations of ground water may be expected to rise in the subgrade to less than 1 foot (0.305 meter) below the bottom of the base course. Interceptor drainage is required in areas where seeping water in a pervious stratum will raise the ground water table to a depth of less than 1 foot (0.305 meter) below the bottom of the base course. Subsurface drainage collection systems include open jointed, perforated, or porous collector pipes, observation risers and cleanouts, filters, and outlet structures.

12.5. Subsurface Drain Materials.

12.5.1. Pipe. Currently, several different types of perforated pipe of various lengths and diameters are being used in pavement subsurface drainage systems such as: clay tile, concrete tile and pipe, perforated plastic bituminous fiber pipe, perforated corrugated metal pipe, corrugated plastic tubing, and water drains. Most of the newer types of drainage pipe are flexible rather than rigid (Figure 12.3.). The type selected should be based on local requirements such as the condition of the soil, loading and amount of cover, cost and availability of pipe.

12.5.2. Filter material. When possible, locally available processed sands and gravels should be used for economic reasons. Standard concrete aggregate can often be used as a filter, but the filter criteria must be met. A filter material must meet two basic requirements:

12.5.2.1. The filter material must be fine enough to prevent infiltration of the material from which drainage is occurring. The following criteria should be met to avoid contamination of the filter by fines from the material being drained.

$$\frac{\text{d15 percent passing size of filter material}}{\text{d85 percent passing size of material being drained}} < 5$$

and

$$\frac{\text{d50 percent passing size of filter material}}{\text{d50 percent passing size of material being drained}} < 25$$

The criteria should be used when protecting all soils, except that for nondispersive lean clay (CL) or fat clay (CH) soils without sand or silt particles, the 50 percent size relationship can be disregarded.

It is essential that the filter be well graded and have a coefficient of uniformity of not more than 20. The coefficient of uniformity is:

$$\frac{\text{d60 percent passing size of filter material}}{\text{d10 percent passing size of filter material}}$$

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If dispersive clays are encountered, the designer must obtain the services of an expert that has had previous experience with detecting and determining the best way to handle these clays. Dispersive clays normally deflocculate when exposed to water of low salt content, the opposite of aggregated clays that remain flocculated in the same soil-water systems. Generally, dispersive clays are highly erosive, are subject to high, shrink-swell potential, and have lower permeability rates than aggregated clays.

12.5.2.2. The filter material must be much more permeable than the material being drained. The grain size curve of the filter should be smooth (no gap grading) and parallel to or flatter than that of the protected material. The following conditions should be met to permit water movement.

$$\frac{\text{d15 percent passing size of filter material}}{\text{d15 percent passing size material being drained}} > 5$$

To prevent clogging of perforated pipe or screens, the following criteria should be met:

$$\frac{\text{d85 percent passing size of filter material}}{\text{slot or hole diameter}} > 1.2 \times \text{slot width or } 1.0 \times \text{hole diameter}$$

To prevent clogging of the openings in porous pipe, the following criteria should be met:

$$\frac{\text{d15 percent passing size of aggregate in porous pipe}}{\text{d85 percent passing size of filter material}} < 5$$

12.5.3. Filter fabrics. The use of geotextile materials as filters is widely accepted in underdrains. These materials may in some instances be used to replace one or more components of a graded filter. Filter fabrics may be used to wrap the collector pipe (Figure 12.4.), thus permitting a relatively fine backfill material to be used; or line the trench, (Figure 12.5.) allowing a relatively course backfill material to be used (Figure 12.6.). Filter fabrics are rarely used to replace the entire granular filter system. The only instance that a geotextile can completely replace a granular system is with the soil being a clean granular material.

When a geotextile is used to wrap the collector pipe, the following criteria should be met:

12.5.3.1.
$$\frac{\text{d85 percent passing size of granular filter material (mm)}}{\text{Apparent opening size (AOS) of geotextile (mm)}} > 1.0$$

where: gradient ratio is the ratio of the hydraulic gradient through a soil-geotextile system to the hydraulic gradient through the soil alone.

12.5.3.2.   Gradient Ratio < 3

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where: apparent opening size is a property that indicates the approximate largest particle that will effectively pass through the geotextile.

For woven geotextiles, the open area of the cloth should not be less than 4 percent or greater than 36 percent. Where these criteria are met, the criteria given for perforated pipe or screens are no longer applicable. Where geotextiles are used to line the drainage trench, the following criteria should be followed:

12.5.3.3. Geotextile adjacent to granular materials containing 50 percent or less by weight of fines (minus NO. 200 materials):

12.5.3.3.1. $$\frac{d85 \text{ percent size of the material (mm)}}{\text{Apparent opening size (AOS)(mm)}} > 1$$

12.5.3.3.2. Gradient ratio < 3

12.5.3.3.3. For woven geotextiles, open area of the cloth should not be less than 4 percent or greater than 36 percent.

12.5.3.4. Geotextile adjacent to all other types of soil:

12.5.3.4.1. AOS no larger than the opening in the U.S. Standard Sieve No. 70

12.5.3.4.2. Gradient ratio < 3

12.5.3.4.3. For woven geotextiles, open area of the cloth should not be less than 4 percent or greater than 10 percent.

Where these criteria are met, the criteria for stability and permeability are no longer applicable, and the backfill may be selected based on the criteria for perforated pipe or screens. To reduce

the change of clogging, no geotextile should be specified with an AOS smaller than the openings of a U.S. Standard Sieve No. 100. When possible, it is preferable to specify a geotextile with openings as large as allowed by the criteria. Geotextiles should not be used for soils with 85 percent or more passing the No. 200 sieve.

NOTE: Methods for determining the AOS and gradient ratio of geotextile are given in ASTM Specifications D 4751 and D 5101, respectively.

NOTE: Percent open area is defined as the summation of the open areas divided by the total area of the geotextile (refers to woven geotextiles only).

12.6. Subsurface Drain Installation. Subsurface drains are typically installed using trenchers or other suitable equipment (Figure 12.7.). Grade control and elevations are normally obtained from the pavement surface. A minimal slope of 0.15 foot (0.04 meters) in 100 feet (30.4 meters) is recommended for subsurface drains.

A minimum thickness of 6 inches (152 millimeters) of filter material should be placed around all types of subsurface drains. Filter material must not become segregated or contaminated prior to, during, or after installation. Segregation results in zones of material too fine to meet the permeability requirements and other zones too coarse to meet the stability requirements. Contamination can clog voids in the material and render the drainage system useless. Outlets should feed into existing storm drainage manholes where practicable. Outlets, 12 inches (304 millimeters) in diameter and smaller, not terminating in a manhole, should be protected with rodent screens located to prevent surface water from entering the system and protected and marked to prevent damage by mowers or other equipment. The upstream end of drainage pipes not terminating in a structure should be capped or plugged.

12.7. French Drains. French Drains are not recommended and should only be used if a drainage system with a perforated pipe cannot be used. These systems quickly clog if not properly designed and constructed. They are expensive to repair if clogged and cannot be inspected.

If French Drains are required, a double-filter system (Figure 12.8.) should be used and is essential to prevent the drain from clogging after relatively short periods of use. The criteria for the double-filter system are as follows:

$$\frac{\text{d15 percent passing size of filter material}}{\text{d85 percent passing size of protected material}} < 5$$

$$\frac{\text{d50 percent passing size of filter material}}{\text{d50 percent passing size of protected material}} < 25$$

$$\frac{\text{d15 percent passing size of inner material}}{\text{d85 percent passing size of filter material}} < 5$$

$$\frac{\text{d50 percent passing size of inner material}}{\text{d50 percent passing size of filter material}} < 25$$

Figure 12.1. Pavement pumping

Figure 12.2. Inundated pavement

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Figure 12.3. Flexible drainage pipe

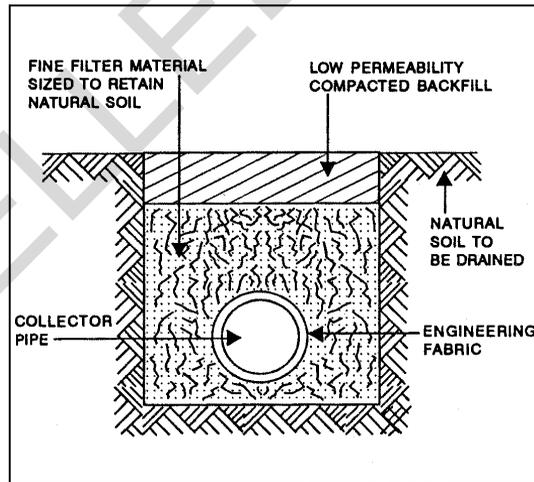Figure 12.4. Filter fabric used to wrap collector pipe
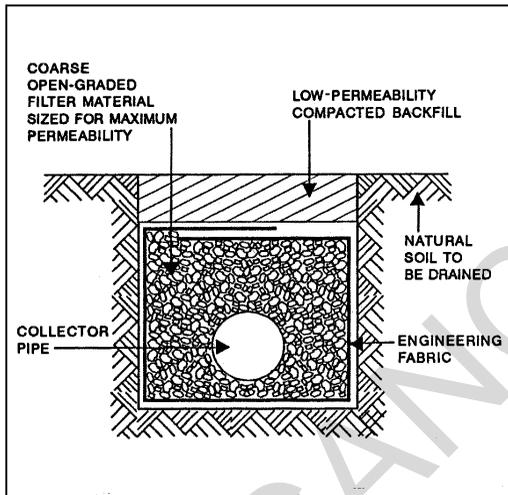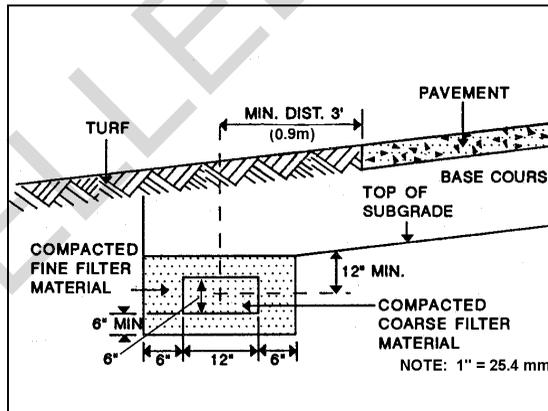
Figure 12.5. Filter fabric used to
line trench

Figure 12.6. Lined trench with
coarse backfill

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Figure 12.7. Trencher

Figure 12.8. French Drain

CHAPTER 13

HEAT-RESISTANT CONCRETE

1**3.1. Description.** Concrete pavement exposed to high temperatures from aircraft jet blast or from auxiliary power units can suffer damage. If the concrete is wet when the heat is suddenly applied, the production of steam within the concrete can cause spalling. If the concrete is dry or the heat is applied slowly, relatively little permanent damage is done with concrete temperatures up to 400 to 500 degrees Fahrenheit (204 to 260 degrees Celsius). At concrete temperatures above this, water of hydration is lost, and the concrete strength decreases. At about 1,000 degrees Fahrenheit (538 degrees Celsius), compressive strength loss can be 55 to 80 percent of the original strength. At the time of heating, the degree of saturation of the concrete influences the severity of strength loss, and repetitions of heating and cooling cycles further degrade the concrete. At a temperature of around 1,060 degrees Fahrenheit (571 degrees Celsius), silica in the concrete aggregates undergoes a crystal change and expands, and in the range of 1,300 to 1,800 degrees Fahrenheit (704 to 982 degrees Celsius), carbonate aggregates undergo a chemical change. As the concrete surface is heated, a large temperature gradient develops between the surface concrete and the cooler slab depths that can lead to separation and spalling. The behavior of concrete exposed to high temperatures is complex. Typical concrete pavement damage resulting from high temperatures of jet blast includes spalling, aggregate popouts, scaling, cracking, and loss of joint sealant. The time that the concrete is exposed to the jet engine or auxiliary power unit exhaust is critical, since there is considerable thermal lag in concrete.

Properly designed pavements generally have not suffered heat damage from aircraft. Power check pads where extensive engine operations occur for maintenance are specially detailed to minimize the exhaust plume's contact with the pavement surface. Where existing pavements,

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particularly if at a shallow slope, are converted to use as power check pads, extensive thermal damage can occur. Particular problems are posed by aircraft with vectored thrust such as the Navy's Harrier or aircraft such as the B-1 or FA-18 with auxiliary power units that exhaust downward on the pavement for extended periods of time. AFCESA and TSMCX should be consulted for the most up-to-date guidance on how to deal with these problems.

13.2. Exposure Time and Temperature. Concrete slabs exposed to an ASTM E119 standard fire for 2 hours indicated that after the temperature of the concrete at about 3/4 inch (19 millimeters) below the surface was 1,200 degrees Fahrenheit (649 degrees Celsius), at 1 1/2 to 2 inches (38 to 51 millimeters) it was 800 degrees Fahrenheit (427 degrees Celsius), and at about 3 1/2 inches (89 millimeters) it was 400 degrees Fahrenheit (204 degrees Celsius). (The atmosphere temperature for a standard ASTM E119 fire rises to 1,000 degrees Fahrenheit (538 degrees Celsius) at 5 minutes, 1,700 degrees Fahrenheit (927 degrees Celsius) at 1 hour, and 2,300 degrees Fahrenheit (1,260 degrees Celsius) at 8 hours.) Normally concrete would not be exposed to jet or auxiliary power unit exhaust for extended periods of time, and any thermal damage will be concentrated in the upper surface concrete. Concrete exposed to high temperatures must be of high quality. It should have a low water/cement ratio, and it must be properly cured. Leaner concrete mixes perform better than richer mixes. Construction must also be of high quality. Proper consolidation and proper finishing are critical. Finishing techniques that cause a paste on the surface will result in scaling. Selection of the proper materials in the concrete also has a dramatic effect on heat resistance. Aggregate selection probably is the most important single materials-related factor; however, no standard specification has been developed for heat-resistant aggregate.

An aggregate with a low coefficient of thermal expansion is generally considered to be desirable, and one rating system roughly groups aggregates as follows in descending order of desirability for heat-resistant concrete, as shown in Table 13.1.

Table 13.1. Aggregate Desirability

Group	Rating	Description	Typical Aggregates
I	Most desirable	Calcareous	Limestone, Dolomite
II	Intermediate	Nonquartzose silicates	Basalt, Dolorite Gabbro, Andesite, Diabase (traprock)
III	Aggregates that spall and crack at high temperature	High silica content quartzose	Granites, High Silica Content Igneous Rocks, Quarts Bearing Schists and Gneisses
IV	Least desirable	Silica not combined to form silicates	Quartzite, Quartz, Chert, Flint

13.3. Aggregate Performances. Lightweight aggregates such as expanded shale tend to perform better than conventional natural concrete aggregates when exposed to high temperatures. Good results have also been reported for air-cooled slag aggregates. Hydrated portland cement that has lower calcium hydroxide content appears to be preferable to those with higher contents for high-temerature applications. Therefore, some benefit may be obtained by using portland cement blended with slag cement. For temperatures of 1,500 degrees Fahrenheit (816 degrees Celsius) or more, high alumina cement will provide superior performance over conventional portland cement. Repair of concrete that has suffered thermal damage is a difficult

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problem. Proper patching procedures for spalls and popouts must be meticulously followed, and the repair material should have similar thermal characteristics to the original concrete. Even so, the repairs may only be temporary. Overlays using heat resistant concrete are a potential repair for scaled areas or for areas with concrete of poor heat resistance. If scaling is due to a paste on a concrete surface that is otherwise acceptable, grinding the surface may be adequate. Joint sealant used in concrete pavements exposed to high temperatures should conform to Federal Specification, SS-S-200E. This specification does require testing of the material at 500 degrees Fahrenheit (260 degrees Celsius) for 2 minutes so that some resistance to high temperatures can be achieved. However, when high temperatures are combined with jet blast, the sealant may still be damaged or blown out of the joint. Under these circumstances, increased periodic resealing must be accepted as routine maintenance. Conventional concrete and joint sealants should provide reasonable service up to concrete temperatures of about 500 degrees Fahrenheit (260 degrees Celsius).

Above this temperature, deterioration of concrete and increased loss of sealant can be expected. High-quality concrete with selected aggregates can reduce the amount of damage. Above 1,000 degrees Fahrenheit (538 degrees Celsius), severe deterioration can be expected, and refractory materials such as high alumina may be needed. Where possible, blast shields, diverters, or increased slope of pavements should be used to allow the maximum dissipation of the exhaust plumes temperature before it impinges on the concrete. Use of continuously reinforced concrete for areas such as power check pads removes the need for joints and joint sealants. In one installation, refractory brick was used to surface a test facility where high-temperature engines were tested and evaluated. Conventional concrete has a limited capability to withstand high temperatures for an extended period of time, and facilities must be designed to accommodate these limitations.