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PRESSURE RELIEF AND

OTHER JOINT REHABILITATION TECHNIQUES

APPENDICES

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APPENDIX A

DESIGN AND CONSTRUCTION GUIDELINES AND GUIDE SPECIFICATIONS FOR PRESSURE RELIEF JOINTS

PRESSURE RELIEF IN CONCRETE PAVEMENTS

PART 1: DESIGN AND CONSTRUCTION GUIDELINES

Section 1 — INTRODUCTION

Pressure buildup develops over time in some concrete pavements until significant damage occurs in the form of spalling, blowups and/or bridge pushing. Pressure relief can be accomplished in these pavements through the placement of pressure relief joints at appropriate intervals and between the ends of pavement sections and fixed structures. Removal of incompressibles from transverse joints and wide cracks (through cleaning in cooler weather) accompanied by resealing is also beneficial in reducing pressure buildup.

These guidelines present important background information for engineers and technicians involved in designing and constructing projects where pressure relief is under consideration.

1.1 NEED FOR PRESSURE RELIEF

A buildup of compressive stresses in a concrete pavement can be caused by two major factors: (1) the entry of incompressibles in joints and cracks (due to inadequate sealant materials and maintenance practices) which prevents the normal thermal expansion of the pavement, and (2) the expansion of reactive aggregates in the concrete. With either of these causes, compressive pressure in the slab increases over time until blowups, spalling or the "pushing" of bridges or other abutting structures occurs. These distresses normally begin to develop seven to ten years after construction.

Appropriate use of pressure relief in concrete pavements exhibiting pressure buildup will accomplish the following:

1. Reduce the expansive pressure in the pavement to prevent blowups and spalling without causing increased amounts of other types of distress (such as widening and faulting of transverse cracks and joints).

2. Protect bridge abutments and other fixed structures adjacent to the mainline pavement from damage due to expansion of the mainline pavement.

Determination of the need for and type of pressure relief should consider several factors including the past occurrence of blowups, amount of incompressibles in the joints, pavement age, presence of reactive aggregates, joint spacing, truck traffic level, extent of existing full-depth repairs and history of pressure damage in pavements of similar design and construction in the area. Specific engineering guidelines for determining the need for pressure relief joints are given in Section 3.

1.2 LIMITATIONS

The purpose of pressure relief is to reduce compressive stresses in concrete pavements that result in spalling and blowups at joints and cracks and damage to fixed structures. Pressure relief should be considered only where excessive compressive stress exists or is expected. Experience has shown that the unwarranted use of pressure relief joints very often causes more deterioration than is prevented by allowing adjacent joints and cracks to open and fault and by accelerating joint sealant deterioration at these widened joints and cracks. These are serious problems requiring expensive repairs.

The following items are examples of inappropriate uses of pressure relief joints.

1. The use of pressure relief joints as a substitute for good joint sealant maintenance is poor engineering practice and definitely not cost-effective.

2. Pressure relief joints must not be constructed in jointed plain or continuously reinforced concrete pavements because they result in the violation of the principal design assumptions of such pavement types (i.e., aggregate interlock load transfer in jointed plain pavements and continuity of reinforcement and pavement support in continuously reinforced pavements). However, the use of pressure relief joints near bridges and other fixed structures may be appropriate on these types of pavements.

3. Pavements that do not include reactive aggregate and are more than 20 years old should not need pressure relief joints because they have probably reached a state of equilibrium with the environment and have already developed most of the distress that can be expected to occur. The development of this state of equilibrium is contingent upon good joint sealant maintenance to prevent pavement "growth" due to the infiltration of incompressibles.

4. Pressure relief joints should not be placed within 1000 feet [305 m] of full-depth repairs that are placed across all tied lanes. The placement of these full-depth repairs is likely to have relieved any excess compressive stress that was present in the pavement. However, if the repairs are very old and incompressibles are present in the joints, pressure damage might still occur.

5. Undowelled pressure relief joints should not be installed in conjunction with full-depth repairs because the absence of load transfer will cause premature failure of the repair, particularly under heavy traffic.

6. Pressure relief joints should not be constructed within 1000 feet [305 m] of recent blowup locations because these distresses relieve the compressive stresses locally.

7. When the pavement is to be overlaid, special consideration must be given to reflection of the pressure relief joints through the overlay and their deterioration under heavy truck traffic. "Heavy-duty" relief joint designs may be necessary to avoid deterioration of the overlay directly over the relief joint.

1.3 EFFECTIVENESS

The effectiveness of pressure relief is dependent on many factors. Some of the key factors include the following:

1. Truck traffic. Heavy truck traffic typically causes serious damage to individual pressure relief joints (particularly under an AC overlay) and adjacent joints and cracks that lose load transfer. Deterioration is typically much lower on pavements that experience a lower volume of heavy truck traffic.

2. Existing joint and crack deterioration and previous pavement repairs. If joint deterioration (spalling) is substantial and many full-depth repairs have already been installed, some of the pressure buildup has probably been relieved and additional pressure relief may not be needed at all.

3. Degree of load transfer across the pressure relief joint. Poor load transfer results in pumping, faulting and corner breaks on pavements without overlay and deteriorated transverse reflective cracks on pavements with AC overlays. High volumes of heavy truck traffic require the use of a special heavy-duty pressure relief joint design to provide good load transfer. As an alternative, dowels placed in kerfs across the relief joint could be installed on an experimental basis.

4. Existing transverse joint spacing. JRCP with joint spacings exceeding 35 feet [10.7 m] typically develop serious pressure buildup problems and may benefit from the use of pressure relief joints. Pavements with short slabs (e.g., JPCP with joint spacings less than 20 feet [6.1 m]) typically do not experience pressure buildup problems and may suffer considerable damage if pressure relief joints are installed.

5. Joint sealant condition and infiltration of incompressibles. If the transverse joint sealant is allowed to deteriorate to a poor condition, permitting substantial infiltration of incompressibles, pressure relief joints will only relieve pressure temporarily. Their use will allow the joints to open further and more incompressibles will infiltrate quickly if the joints are not cleaned and resealed properly.

6. Presence of expansive reactive aggregate. The presence of expansive or reactive aggregate presents an entirely different situation. Pressure relief joints may be needed on a continuing basis.

The proper consideration of all of the above factors will result in the use of pressure relief joints only where they are truly needed -- where pressure buildup itself is the problem, rather than a symptom of other problems, such as poor joint maintenance practices. Properly used, pressure relief joints will relieve compressive stress in the mainline pavement and protect bridge abutments and other secondary structures without adversely affecting pavement condition.

Section 2 — CONCURRENT WORK

Some types of repair should be considered along with pressure relief techniques. The actual need for concurrent work depends largely upon specifics such as existing pavement distress, original pavement design, present and projected traffic volume and type, subgrade and materials properties, and climate considerations. As a minimum, the following work items should be considered:

1. Full-depth repair and spall repair of joints and cracks exhibiting deterioration.

2. Cleaning of incompressibles from joints and open cracks followed by immediate resealing, including provision of an appropriate joint sealant reservoir shape factor.

Section 3 — DESIGN

The design of a pressure relief project requires a determination of the need for pressure relief through an examination of the existing pavement design and condition, previous and concurrent full-depth repair work, and other important factors.

3.1 PAVEMENT DESIGN

The following should be determined from as-built plans and design documents:

1. Type of concrete pavement (JPCP, CRCP, JRCP).

2. Transverse joint spacing and sealant reservoir dimensions.

3. Cross-section of the pavement illustrating slab thickness, base/subbase type and thickness, shoulder design, transverse slope, and subdrainage provisions.

4. The horizontal layout of the highway throughout the length of the project, including locations of bridges and other structures.

5. Age of the pavement.

6. Current and forecasted average daily truck traffic.

7. Terminal joint details near bridges and other structures.

3.2 PAVEMENT CONDITION AND PREVIOUS REPAIR

The following should be determined during a field survey of the pavement:

1. Extent of infiltration of incompressibles into transverse joints. This can only be accurately determined through observations of the joints, removal of small sections of sealant, and cutting cores through representative joints to determine the amount of incompressibles throughout the depth of the joints.

2. Location of full-depth repairs throughout the section (lane by lane).

3. Location of any blowups that have occurred.

4. Severity and location of joint spalling and transverse crack deterioration throughout the project.

5. Examination of bridges and other structures that abut the mainline pavement to determine if pressure problems exist. Examination of on- and off-ramp adjacent joints should also be accomplished.

6. Presence of either reactive aggregate distress or "D" cracking in the concrete slab.

3.3 DETERMINING THE NEED FOR PRESSURE RELIEF IN THE MAINLINE PAVEMENT

The need for and most appropriate type of pressure relief (and other related rehabilitation work) can be determined by using the decision chart shown in Figure A-1. This chart was developed by a panel of experienced engineers, but should be considered only as a guide. Extensive engineering judgment must be applied to ensure the appropriateness of these recommendations for the specific project being evaluated and to fill in many additional details important to the design of the rehabilitation techniques.

Pavement design and condition inputs are used to work through the decision chart. Key decision points are explained as follows:

1. Overlay planned --

   No: the pavement will not be overlaid soon (e.g., within 5 years)
   Yes: the pavement will be overlaid soon

2. Pavement type --

   JPCP: short-jointed plain concrete pavement
   JRCP: long-jointed reinforced concrete pavement

PROJECT LEVEL PRESSURE RELIEF DECISION TREE

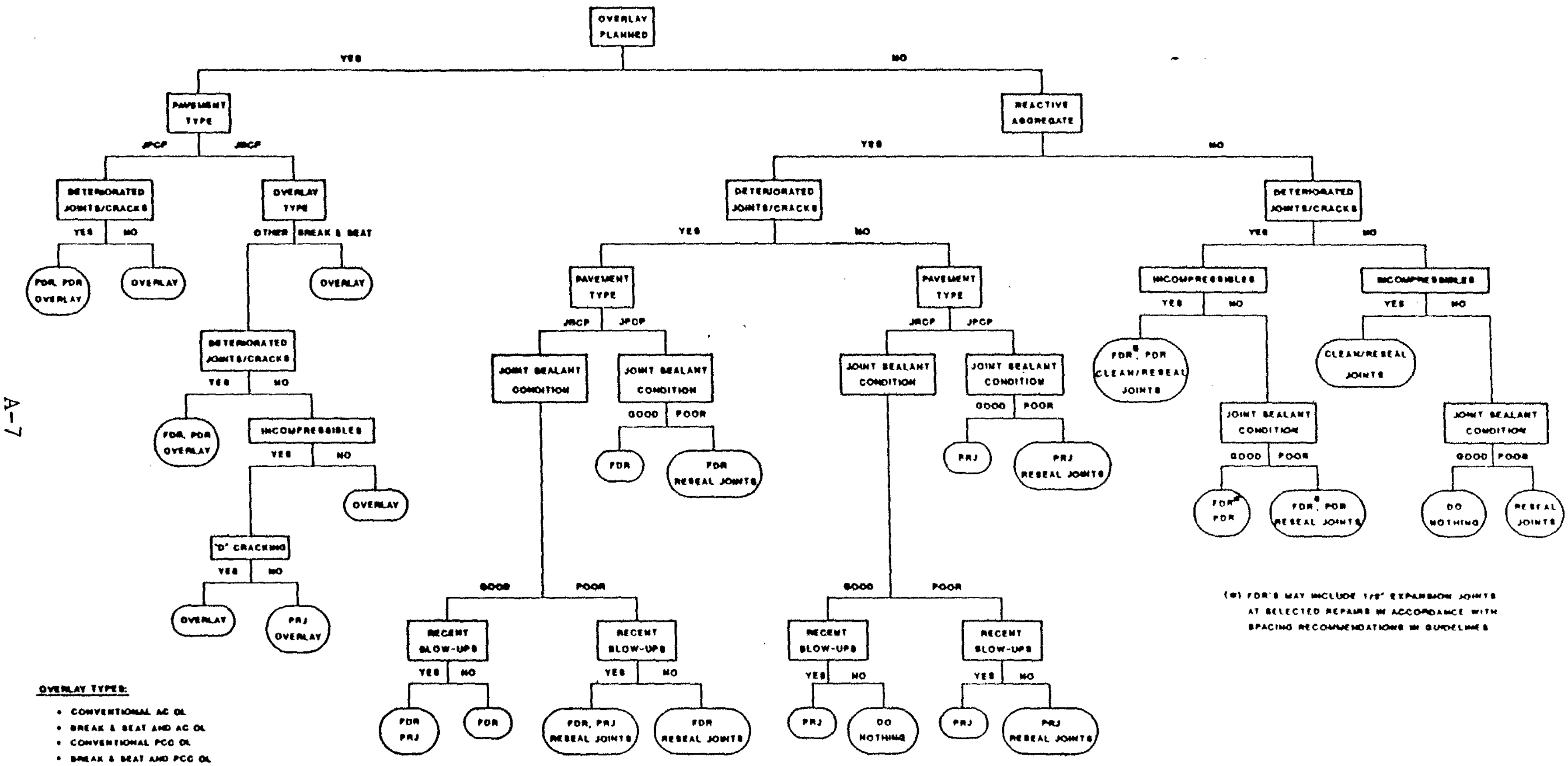

Figure A-1. Guideline for Use of Pressure Relief and Other Joint Rehabilitation Techniques.

3. Evidence of pressure damage due to expansion of reactive aggregate --

No: visual inspection reveals no evidence of the presence of reactive or expansive aggregates
Yes: reactive aggregate cracking, spalling and longitudinal cracks have developed

4. Deteriorated joints and cracks --

No: five (5) or fewer joints per mile exhibit medium- or high-severity spalling
Yes: more than five (5) joints per mile exhibit medium- or high-severity spalling

5. Incompressibles in joints --

No: an examination of the joints and cores taken at the joints shows that only a small amount of incompressibles (i.e., sand and rocks) have lodged in the joints
Yes: an examination of the joints and cores taken at the joints shows that a substantial amount of incompressibles have infiltrated either the top or the bottom of the joints

6. Joint sealant condition --

Good: sealant is in place and has few if any adhesion or cohesion failures, hardening of the sealant or signs incompressibles being trapped
Poor: sealant has significant adhesion or cohesion failures, hardening of the sealant, or entrapped incompressibles

7. Presence of "D" cracking --

No: "D" cracking does not exist or, if it does, no spalling has taken place in the slab
Yes: spalling has taken place and the distress has advanced to a serious degree

8. Recent blowups --

No: less than 2 blowups per mile have occurred in the mainline pavement
Yes: 2 or more blowups per mile have occurred in the mainline pavement

9. Overlay type --

Break and seat and overlay: the existing pavement will be broken into small pieces and seated with a heavy roller before an overlay is placed
Other: any other overlay type is planned

Use of the flowchart for a given project will result in one or more of the following recommendations for pressure relief and other related rehabilitation techniques:

Do nothing. No pressure relief or other rehabilitation technique is needed at the present time.

Reseal joints. Clean the joint sealant reservoir and transverse joint through the depth of the slab, if possible. Resawing of the joint may be required to obtain a proper joint sealant reservoir shape factor.

FDR. Full-depth repair of significantly deteriorated joints and cracks.

PDR. Partial-depth repair of spalled joints.

Overlay. Asphalt concrete or Portland cement concrete overlay.

PRJ. Cut pressure relief joints near the center of slabs at 1000-foot [305-m] intervals. Do not place pressure relief joints within 1000 feet [305 m] of recently placed full-depth repairs that have been placed across all lanes, or locations where blowups have previously occurred.

These guidelines should be applied only by experienced engineers with the understanding that they are not intended to provide exact solutions in all cases. Extenuating circumstances may exist that require different or additional pressure relief techniques to be applied.

3.4 DETERMINING THE NEED FOR PRESSURE RELIEF AT STRUCTURES

The condition survey should include an examination of the adjacent pavement slabs, approach slabs, backwall and abutment of every structure along the pavement. The width of and extent of incompressibles in any existing expansion joints should be determined. Any signs of pressure distress should be noted. The joints and cracks in the pavement slabs adjacent to the structure should be examined to see if they are significantly wider than those that are farther away. This would indicate that the slabs are pushing the structure, which could cause serious structural problems in the backwall and abutments of the structure.

3.5 PRESSURE RELIEF JOINT DIMENSIONS AND SPACING

The joint must be cut full-depth through the concrete slab and across all tied traffic lanes. A maximum width of 2 inches [51 mm] is recommended for all pavements that do not contain reactive aggregates. It is believed that this width is adequate to relieve pressure and that a greater width simply promotes excessive widening of adjacent joints and cracks. The traditionally used width of 4 inches [102 mm] has often resulted in large openings in nearby joints and cracks.

Pavements containing reactive aggregates may require 4-inch [102-mm] wide expansion joints, depending on the degree of reactivity or expansion potential present. The use of 4-foot [1.2-m] wide bituminous concrete-filled expansion joints is not recommended due to the likelihood of "humping" or settling over time.

The joint filler should be installed in a slightly compressed state and should extend from the bottom of the cut joint to 1 inch [25 mm] below the pavement surface.

It is recommended that a joint sealant be installed on top of the pressure relief filler to inhibit infiltration of incompressibles. The sealant should be designed with a proper shape factor and recessed at least 0.25 inch [6 mm] below the pavement surface. These dimensions will protect the sealant protection from the damaging effects of traffic and joint closure.

Spacing of pressure relief joints is critical and depends on several factors. The objective is to place the relief joints along the project so that compressive stresses will be relieved and blowups and spalling damage will not occur. However, each pressure relief joint is a potential problem in itself and may cause excessive opening of joints and cracks within 200 feet [61 m] or more on either side of it. Overuse of expansion joints will result in more damage to the pavement than would occur without the pressure relief joints. Some general guidelines for locating pressure relief joints are as follows:

1. Expansion joints near structures may provide relief to the mainline pavement as far as 2000 feet [610 m] away.

2. Installation of full-depth repairs across all tied lanes provides relief of pressure and decreases the need to install pressure relief joints near the repairs for several years.

3. Good results have been obtained with pressure relief joints spaced at approximately 1000-foot [305-m] intervals in pavements without expansive reactive aggregates and placed on bases with relatively low sliding friction coefficients (e.g., granular bases). Good results have also been obtained with pressure relief joint spacings of 2000 feet [610 m] on pavements with reactive aggregate and granular bases. However, local experience and the extent of friction between the slab and the base may dictate a different spacing.

3.6 HEAVY-DUTY PRESSURE RELIEF JOINT

When an AC overlay is to be placed and it is determined that pressure relief joints are needed, serious deterioration of the reflection crack will occur if heavy truck traffic exists. It may be necessary to utilize a heavy-duty pressure relief joint that incorporates load transfer devices to reduce deterioration under very heavy traffic conditions.

The Illinois Department of Transportation has successfully used the design shown in Figure 2 for many years on expressways carrying truck traffic from 3000 to 7000 trucks per day per traffic lane.

Section 4 - CONSTRUCTION

4.1 MATERIALS

It is recommended that a pressure relief joint contain a suitable compressible filler and a sealant on top of the filler to inhibit infiltration of incompressibles.

a. Joint Fillers.

The joint filler is placed to fill the void between the subbase and the joint sealant and to provide support for the placement of the joint sealant. It also provides the appropriate joint sealant reservoir dimensions and shape factor to reduce tensile strain failures of the sealant. The filler should be able to accommodate repetitions of compression and rebound over the range of expected joint movement.

Different types of compressible fillers have been used successfully, including various preformed closed-cell plastic joint fillers. The filler must be able to accommodate compression to less than 50 percent of its original installed width.

The filler must be a flexible, compressible, nonshrinking, nonreactive and nonabsorptive material. The filler should be at least 25% larger than the joint width so that if fits tightly in the joint and is not easily displaced.

Joint filler types are recommended in the Guide Specifications.

b. Joint Sealants.

Sealants that have been shown to provide at least 5 years of acceptable performance should be considered. The accommodation of potentially large movements and the cost of joint preparation, traffic control, etc., require that the sealant be of high quality to last at least 5 years and preferably longer.

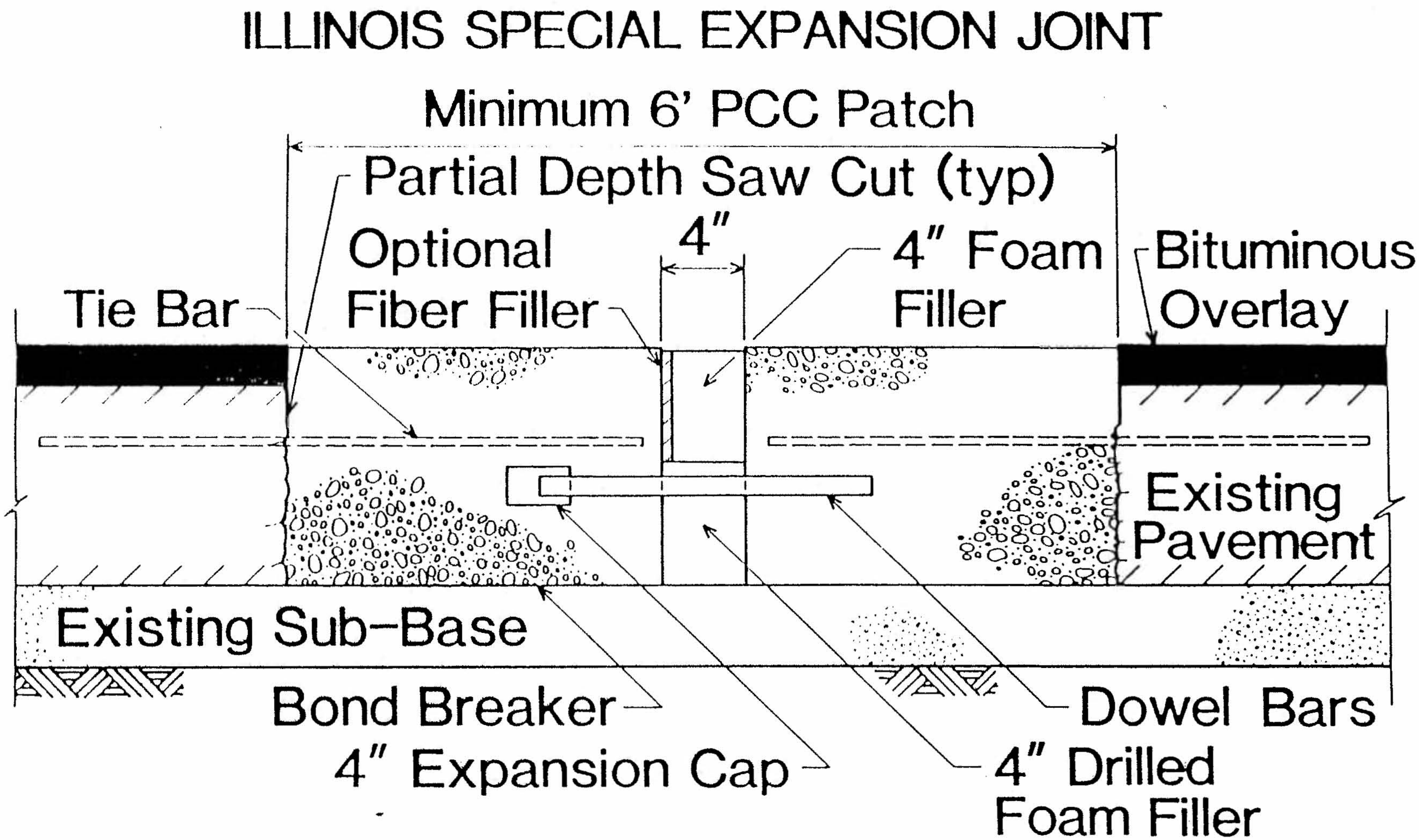

Figure A-2. Illinois DOT pressure relief joint for very heavy traffic conditions.

4.2 JOINT PREPARATION

Two different methods have been successfully used to cut pressure relief joints. In the first method, diamond blade saws are used to make two full-depth cuts to form the edges of a pressure relief joint of the specified width. The material between the cuts is removed using light jackhammers and a crowbar.

In the other method, a carbide tooth wheel saw (sometimes called a rock saw) is used to make one full-depth cut across the pavement at the specified width. The use of this saw should be considered carefully, since it may produce an unacceptable amount of spalling at the pavement surface and create significant traffic control problems.

The faces of the joint are cleaned of all loose particles and dust. When a joint sealant is to be used on top of the filler, the top of the joint must be cleaned by sandblasting to remove saw residue and any other material. After sandblasting, the joints should be further cleaned with a high pressure air jet just before sealing.

4.3 INSTALLATION OF JOINT FILLER

After the joint has been cleaned and immediately before installation of the joint filler, a lubricant/adhesive should be applied to the joint faces. The lubrication aids in the insertion of the joint filler and cures to form a weak adhesive that helps to prevent the filler material from floating out under a heavy rain. The joint filler should be installed just before the sealing operation starts. Special hydraulic equipment is often used to compress and install the filler properly.

4.4 JOINT SEALING

When the joints have been properly prepared and the material and equipment approved, the actual sealing can begin. It must be emphasized that the joint preparation and sealing operation are a continuous process. This prevents unnecessary intrusion of moisture, incompressibles and dust. <u>The joints must not be left unsealed overnight</u>. Preparation must not be done on more joints than can be sealed during the working day.

Air entrapment in the sealant can be avoided by applying the sealant under pressure from the bottom up. The joint must not be overfilled. A standard recess of at least 0.25 inch [6 mm] is required. This will prevent damage to the sealant by traffic.

4.5 INSPECTION

The contractor must be aware that he will be required to repair or replace anything found out of specification, regardless of when the error is found during the construction operation.

Examine all pressure relief joints for the following features:

1. No excessive spalling from the sawing operation.
2. Clean and dry joint face before sealant application.
3. No filler material floating in the sealant.
4. Joints not underfilled or overfilled.
5. Joint sealant is not tacky.
6. Sealant has adhered to the face of the joint.
7. Spilled sealant has been removed.
8. No debris is left on pavement surface.
9. No air or moisture is trapped in the sealant during installation.

Section 5 — PREPARATION OF PLANS & SPECIFICATIONS

The plans should clearly show the locations of the pressure relief joints to be constructed, and should include a diagram showing the saw cuts required, joint filler placement, and joint sealant and reservoir dimensions.

The Guide Specifications accompanying these Design and Construction Guidelines are recommended for use after they have been revised to reflect local conditions.

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PRESSURE RELIEF JOINTS IN CONCRETE PAVEMENTS

PART 2: GUIDE SPECIFICATIONS

Section 1 — GENERAL

1.1 DESCRIPTION OF WORK. The work performed under these specifications shall consist of constructing pressure relief joints in concrete pavements.

1.2 LOCATION. All joints to be installed are indicated on the plans.

1.3 STANDARD SPECIFICATIONS. The standard specifications which are applicable to the work on this project are as published in the current edition of (Local, State, Special) "Standard Specifications."

1.4 SUBMITTALS.

a. MATERIALS. Joint sealant and filler material shall be inspected, tested and approved by the Engineer before incorporation in the work. The Contractor shall give sufficient notice in advance of placing orders to permit the completion of tests before the materials are incorporated in the work, and shall afford such facilities as the Engineer may require for collecting and forwarding samples and making inspections. All samples shall be furnished without charge to the Agency.

Any work in which untested and unaccepted materials are used without approval or written permission of the Engineer shall be performed at the Contractor's risk and may be considered as unacceptable and unauthorized, and will not be paid for. Unless otherwise designated, tests in accordance with the most recent cited standard methods of AASHTO or ASTM, which are current on the date of advertisement for bids, or with other standard methods of sampling or testing adopted by the Engineer, will be made by and at the expense of the Agency. Samples will be taken by a qualified representative of the Agency. All materials being used are subject to inspection, test or rejection at any time. When requested by the Agency, the Contractor shall furnish a complete written statement of the origin, composition, and manufacture of any or all materials that are to be used in the work.

b. EQUIPMENT. A list and description of the equipment to be used and a statement from the supplier of the joint sealant and filler materials that the proposed equipment is acceptable for installing the specified joint sealant and filler shall be submitted. All other equipment will be approved by the Engineer, prior to use on the project.

c. MANUFACTURER'S RECOMMENDATIONS. Where installation procedures or any part thereof are required to be in accordance with recommendations of the manufacturer of sealing compounds and filler materials, copies of the recommendations shall be submitted before installation of the material is begun.

1.5 DELIVERY AND STORAGE. Materials delivered to the site shall be inspected for damage, and carefully unloaded and stored with a minimum of handling. Joint sealants shall be delivered in the original sealed containers and protected from freezing. Storage facilities shall be provided at the job site for maintaining materials at temperatures recommended by the manufacturer.

Section 2 — MATERIALS

2.1 JOINT SEALANT. See agency "Standard Specifications."

2.2 JOINT FILLER. Several products may provide satisfactory performance. The following are two examples of specifications in current use.

(1) Illinois:

The joint filler shall be preformed closed-cell plastic joint filler, and shall consist of an extruded, low-density, expanded polyethylene plastic foam. It shall have a closed-cell structure that is chemically inert and has no food value that would attract or support plant or animal life. The plastic foam shall be odorless and nontoxic, remaining flexible over a wide range of temperatures, and be resistant to chemicals and solvents.

The filler shall comply with the following requirements:

Physical properties and methods of tests

1. compression, psi [MPa] ASTM D 1056
   - at 10 % deflection . . . . . not less than 5 [0.04]
   - at 80 % deflection . . . . . not greater than 125 [0.86]
2. moisture vapor permeability, inches [mm] ASTM E 96
   - permeability . . . . less than 0.4 [10.2]
3. water absorption ASTM C 272
   - % by volume . . . . less than 0.5
4. density ASTM D 1564
   - pcf [kg/m^3] . . . . not less than 2.4 [38.4]

Dimensions and tolerances

Measurements for conformance to dimensional specifications must be made on a unit of stock which has been allowed to condition for one hour or longer at a temperature of 73 ± 10°F [23 ± 5°C]. If the unit of stock is packaged or is a part of a pallet, it must be removed from the package or pallet and allowed to condition free from the insulating effect of the package or pallet.

1. The thickness shall have a tolerance of + 1/2 inch [13 mm] and minus 0.
2. The width shall have a tolerance of + 1/2 inch [13 mm] and minus 0.
3. The length shall be such that sufficient coverage is allowed so that both ends can be squared and cut to the required length.

Appearance

1. Each piece of plank shall not contain more than 3 percent voids or hard spots.
2. The surface shall be smooth and reasonable free of dents or appendages. All packaged products will be free of surface dirt and packaging damages.
3. The planks shall have no kinks or other deformities affecting straightness.

(2) Nebraska:
The joint filler shall be preformed urethane foam (inverted V-shaped) conforming to the following specifications:

Typical properties

Material type . . . . Preformed cellular
Density, pcf [kg/m^3] . . . . 7 - 10 [112 - 160]
Weight, lb/ft [kg/m] . . . . 1.6 - 2.0 [2.4 - 3.0]
Compressive strength, psi [MPa]:
25 percent deflection . . . . 3 - 10 [0.02 - 0.07]
65 percent deflection . . . . 8 - 16 [0.06 - 0.11]
Recovery after 65 percent deflection compressive strength test and one minute relaxation, percent of original . . . . 90 min.
Water absorption, 1-inch [25-mm] thick sample, percent by volume . . . . 30 max.
Color . . . . cement gray

Testing Requirements
The preformed polyurethane joint filler (inverted V-shaped) shall be tested in accordance with the following methods of test.

Density. The density shall be determined in accordance with ASTM D 1564.
Compressive strength. The compressive strength shall be determined in accordance with ASTM D 2406 with the following modifications:

1. Rate of compression-- two inches per minute, preflexed to 75 percent deflection.
2. Sample size-- 4 inches by 4 inches by 1 inch [102 mm by 102 mm by 25 mm] cut from top of molded piece at least 1/4 inch [6 mm] below any molded surface.

Water absorption. The water absorption shall be determined in accordance with AASHTO T 42.

The manufacturer shall furnish a suitable lubricant-adhesive material for installing the preformed material.

Section 3 — EQUIPMENT

3.1 GENERAL. The contractor shall furnish all necessary accessories to saw the pressure relief joints, clean and prepare joint faces, insert joint filler materials and install joint sealants. Machines, tools, and other equipment used in performance of the work shall be maintained in proper working conditions at all times, and are subject to approval by the Engineer.

3.2 JOINT SAWING AND CLEANING EQUIPMENT.

a. CONCRETE SAW. A water-cooled, self-propelled power saw with diamond saw blades shall be used, which is designed for sawing hardened concrete, to construct the pressure relief joints as specified without damaging the sides, bottom, or top edge of joints. Blades may be single or gang type with one or more blades mounted in tandem for fast cutting. The saw shall be adequately powered to cut the full depth specified opening with not more than two passes of the saw through the joint.

b. CARBIDE TOOTH WHEEL SAW (ALTERNATE). A carbide tooth wheel saw (sometimes called a rock saw) shall be used to make one full-depth cut across the slab at the specified width. This method to cut the pressure relief joints shall be prohibited if an unacceptable amount of spalling at the pavement surface exists.

c. SANDBLASTING EQUIPMENT. Sandblasting equipment shall be capable of removing any oil or other foreign material which may prevent bond of new sealer. Equipment shall include an air compressor, hose and nozzles of proper size, shape and opening. An adjustable guide must be attached to the nozzle or nozzles that will hold the nozzles aligned with the joint about one inch [25 mm] above the pavement surface. Adjust, as necessary, the height, angle of inclination, or size of nozzles to sandblast the joint faces and not the bottom of the joint.

d. AIR COMPRESSOR. A portable air compressor shall be used which is capable of operating the sandblasting equipment and capable of blowing out sand, water, dust adhering to sidewalls of concrete, and other objectionable materials from the joints. The compressor shall furnish air at a pressure not less than 90 psi [0.62 MPa] and a minimum volume of 150 cubic feet [4.2 cubic meters] of air per minute at the nozzles, free of oil and moisture.

e. VACUUM SWEEPER. A self-propelled, vacuum pickup sweeper capable of completely removing all loose sand, water and debris from the pavement surface shall be used.

f. HAND TOOLS. When approved, hand tools may be used in small areas for repairing or cleaning the joint faces. Hand tools shall consist of brooms, chisels, and other hand tools required to accomplish the work specified.

3.3 JOINT FILLER EQUIPMENT

a. LUBRICANT-ADHESIVE APPLICATOR. This applicator shall be able to provide an even coat of adhesive to promote a positive bond between the joint faces and joint filler material. Equipment shall include an air compressor, hose and nozzles of proper size, shape and opening.

b. JOINT FILLER COMPRESSION EQUIPMENT. This machine shall be capable of compressing the joint filler material to the full depth of the pavement so that it can be inserted into the joint without damaging the adjacent joint walls or severely disturbing the lubricant-adhesive on the joint walls.

3.4 JOINT SEALING EQUIPMENT.

See current edition of (Local, State, Special) "Standard Specifications."

Section 4 — CONSTRUCTION METHODS

4.1 JOINT CONSTRUCTION AND PREPARATION.

a. GENERAL JOINT PREPARATION. Unless otherwise indicated, all joints shall be sawed, cleaned and resealed. The final cleaning operations shall not be accomplished more than one working day in advance of sealing. Cleaning procedures which damage joints or previously placed repairs by chipping or spalling shall not be permitted.

b. SAWING OF JOINTS. All joints shall be sawed in a straight line perpendicular to the longitudinal alignment of the pavement. Immediately after each joint is sawed, the saw cut and adjacent concrete surface shall be cleaned thoroughly by flushing with water under pressure, and simultaneously blowing out the water with compressed air until all waste from sawing is removed from the joints.

c. FINAL CLEANING OF JOINTS. Final cleaning shall be conducted using sandblasting and airblasting.

Sandblasting methods shall be used to clean the newly exposed concrete joint faces and pavement surfaces extending one inch from the edges of the joint. Sandblasting shall be continued until surfaces are free of any traces of old sealant, of saw-cutting fines, or of any dirt deposited after initial preparation. Sandblasting equipment shall provide a minimum of 150 cubic feet [4.2 cubic meters] per minute of air at a nozzle pressure of 90 psi [0.62 MPa] for final cleaning. After final cleaning and immediately prior to sealing, the joints shall be blown out with compressed air using the specified air compressor to remove all sand and water to insure that the joints are dry, dust free, and clean at the time of sealing.

d. JOINT FILLER. After the joints have received the final cleaning and are dry, the lubricant adhesive shall be applied to the joint walls and the joint filler material installed as indicated in the bottom of the joint with an approved device so that it is a uniform distance from the top of the slab. These materials shall not be stretched or twisted during installation.

e. RATE OF PROGRESS. The final stages of joint preparation, which include placement of joint fillers, shall be limited to only that linear footage of joint that can be resealed during the same work day.

f. DISPOSAL OF DEBRIS. Power sweepers or hand brooms shall be used to sweep from the pavement surface all excess dirt, water, sand, and other debris. Debris shall be removed immediately to an area designated by the Engineer.

4.3 INSTALLATION OF SEALANT.

See the agency "Standard Specifications."

Section 5 — WEATHER CONDITIONS

Work shall not proceed when weather conditions detrimentally affect the quality of forming joints and applying joint sealants. Hot-poured sealants shall be applied only if the air temperature is at least 50°F [10°C] and rising. The minimum placement temperature for silicone sealant is 40°F [4°C]. Surfaces shall be dry and component materials shall be protected from free moisture.

Section 6 — ACCEPTANCE

The completed pressure relief joint installation shall:

1. Prevent intrusion of incompressibles and be free of materials foreign to the manufactured material delivered to the project site.

2. Conform to the locations, sizes and dimensions shown or otherwise specified.

3. Exhibit bond with sidewalls of the joint.

4. Not crack, bubble or blister.

5. Not have cohesive failures within the joint sealant.

6. Retain resilient, rubber-like quality.

7. Not be picked up, or spread upon adjacent horizontal pavement surfaces, by rubber-tired vehicular traffic or by the action of power vacuum rotary brush pavement cleaning equipment.

8. Provide a finished, exposed joint surface that is non-tacky and will not permit the adherence of dust, dirt, small stones, and similar contaminants.

9. Contain backfill material exhibiting good bonding to the adjacent concrete with no breakup or cracking of the backfill material itself.

Section 7 — MEASUREMENT & PAYMENT

7.1 MEASUREMENT. This work shall be measured by the number of linear feet of pressure relief joints constructed. No separate measurement will be made of joints resealed at the direction of the Engineer due to improper installation or damage to the sealant.

7.2 PAYMENT. Payment shall be made at the contract unit bid price per linear foot of pressure relief joint and shall include the cost of all labor and materials and the use of all equipment and tools required to complete the work.

APPENDIX B

DESIGN AND CONSTRUCTION GUIDELINES AND GUIDE SPECIFICATIONS FOR FULL-DEPTH REPAIRS

Acknowledgment

These guidelines and specifications were originally prepared under NCHRP Project 1-21 conducted at the University of Illinois and published in NCHRP Report No. 281, Transportation Research Board, 1985. The guidelines have been updated in 1987 based upon the findings and results from the study entitled "Pressure Relief and Other Joint Rehabilitation Techniques" under contract DTFH61-83-C-00111 between the Federal Highway Administration and ERES Consultants, Inc. On-going research concerning this rehabilitation technique is being performed at the University of Illinois under FHWA Contract DTFH61-85-C-00004, "Determination of Rehabilitation Methods for Rigid Pavements."

FULL-DEPTH REPAIR OF JOINTED CONCRETE PAVEMENT

PART 1: DESIGN AND CONSTRUCTION GUIDELINES

Section 1: — INTRODUCTION

These guidelines present important background information for engineers and technicians involved in designing and constructing projects where full-depth repairs will be placed. These guidelines will also be useful to maintenance engineers and technicians in placing full-depth concrete repairs as part of good pavement maintenance procedures. This document is intended to provide guidance in the preliminary engineering phase and to explain portions of the Guide Specifications.

The procedures and specifications included herein are intended for full-depth repairs and slab replacements which are to be subjected to medium-to-heavy truck traffic for a design life of 10 years or more. These procedures and specifications are applicable to repair projects both with and without overlay.

1.1 NEED FOR FULL-DEPTH REPAIRS

There are several types of deterioration which occur at or near transverse cracks and joints which justify full-depth repair or slab replacement to restore rideability and structural integrity to the concrete pavement. The design engineer must conduct a preliminary condition survey of the project (which may require some coring of representative areas) and identify the specific locations and approximate quantities that must be repaired.

The engineer must first assess the causes of joint/crack deterioration. Some typical types of joint/crack deterioration and their causes are as follows.

1. Faulting: Heavy truck axle loads cause large differential deflections across joints/cracks where poor load transfer exists (typically where no dowels exist), which results in a high potential for pumping and erosion of material beneath the slab and/or stabilized base. If dowels exist, the differential deflection is much lower and thus pumping and faulting is decreased. However, depending upon dowel design, heavy loads can cause high bearing stresses between the dowels and concrete. The result of many repeated heavy loadings can cause the enlargement of the dowel socket, resulting in eventual faulting of the joint. Corrosion of the dowel bars may also be a factor contributing to faulting.

2. Spalling: The deterioration of a joint or crack through spalling can be caused by several factors. The major factors are described as follows.

   a. Infiltration of incompressibles into the joint: This common occurrence results in much of the spalling at joints. The extent of incompressibles in the joint can be determined by visual observations of joints and digging into the joint sealant reservoir with a knife, but is best determined by coring directly through the joint and opening the core to examine the joint faces. Incompressibles can infiltrate from both the top and bottom of the joint.

b. Disintegration of concrete at the bottom of the joint (non "D" cracked concrete): This is caused by infiltration of incompressibles and large horizontal joint movements. This occurs predominantly in long-jointed reinforced concrete pavement (40-100 feet [12-30 m]), but can also develop in short-jointed plain concrete pavements where infiltration of incompressibles is extensive. This distress is not initially visible at the surface, but eventually develops into a spall that can be seen at the surface.

 Coring of typical joints prior to full-depth repair to observe the amount of incompressibles and the deterioration at the bottom of the joint greatly assists in identifying this problem.

 Disintegration of the bottom of the slab contributes to a high potential for blowups because less vertical cross-sectional area is available at the joint to bear compressive stress in the slab.

c. "D" cracking or reactive aggregate spalling: "D" cracking is a pattern of cracks caused by freeze-thaw expansion of the aggregate. Reactive aggregate is a cracking pattern caused by the reaction of the aggregate in an alkaline environment. The disintegration and spalling associated with these distresses normally begins near the joints. Cores should be taken to determine the depth of deterioration at different distances from the joint. Four-inch [102-mm] diameter cores taken at distances of 0, 12, 24, 36, and 48 inches [0, 305, 610, 914, 1219 mm] from several typical joints will often provide a good visual indication of the extent of deterioration in the vicinity of the joints. These results may also show that partial-depth repairs may be acceptable in certain instances (Ref. 9).

d. Joint Lock-up: Corrosion of the dowels or other load transfer devices can eventually lead to nonworking or "frozen" joints. This may be manifested in the following ways:

 A transverse crack can develop across the slab parallel to the joint near the end of the dowels. The area between this crack and the joint often spalls and breaks up, requiring full-depth repair.

 Lock-up of joints from corrosion can also result in the opening of nearby transverse cracks causing the reinforcing steel to rupture in JRCP and resulting in eventual spalling and faulting of the crack. These cracks then act as joints and require full-depth repair.

Corrosion and lock-up of mechanical load transfer devices can also lead to joint spalling due to expansive pressures or other stresses.

e. Joint inserts: Certain types of joint inserts (e.g., Unitubes) cause spalling of the joint through corrosion, entrapment of incompressibles or other means.

3. Slab breakup such as corner breaks or diagonal cracks near the joint: This is caused by a loss of slab support. Faulting of the slab near the joint in the cracked area and fines on the shoulder are definite indicators of pumping. Another early indicator of pumping is the development of a small depression (blowhole) of the asphalt shoulder near the joint or crack where base materials are pumped out.

4. Breakup of the slab in several pieces: This is typically caused by repeated heavy truck loads and loss of support from beneath the slab from pumping. Another cause is movement of the foundation from frost heave or swelling soils. If slab breakup is occurring only in the lane with the heaviest truck traffic, fatigue damage is the likely cause, but if slab breakup occurs in all lanes then foundation problems are likely.

The severity of the deterioration of the joint or crack is the main criterion by which the engineer decides if a repair is needed and determines its required size. A comprehensive distress identification manual is available that includes descriptions of joint and crack distress at low, medium and high severity levels (Refs. 1, 2).

Low severity level: does not require full-depth repair within the next two years.

Medium severity level: may or or may not require repair depending on several factors. Quite often a joint having only medium-severity spalling on the top of the slab is seriously deteriorated at the bottom of the slab. This should be investigated through selective coring near representative joints. The time interval between the preliminary condition survey and the actual construction must be considered. The preliminary survey is conducted for the purpose of making an estimate for bidding purposes. Therefore, if more than one year will pass before construction will begin, most of the medium-severity distress and all of the high-severity distress should be programmed for repair. The medium-severity distress is likely to deteriorate into high-severity distress before the construction begins in one or more years. Estimated quantities should also be increased by 10-20 percent per year of delay before repair, to allow for the additional deterioration.

High severity level: is a safety hazard and definitely requires repair.

If a typical asphalt concrete overlay of 1 to 6 inches [25 to 152 mm] in thickness is to be placed, it is recommended that there be no difference in the amount of full-depth repair done prior to overlay than would be done if no overlay were placed, because deteriorated joints and cracks will quickly reflect through the overlay and cause premature deterioration and failure of the overlay.

The need for full-depth repair at individual joints can be assessed using the decision chart shown in Figure B-1. Specific guidelines for repairing individual joints are provided in Section 3 -- DESIGN.

1.2 LIMITATIONS AND EFFECTIVENESS

Full-depth concrete repairs that are properly designed and constructed (particularly with good load transfer at the joints) will provide good long-term performance (e.g., 10 or more years).

Poor load transfer design and poor construction techniques has been responsible for much of the faulting and breakup of full-depth repairs. It has also been responsible for the serious deterioration of reflective cracks over repairs in asphalt concrete overlays. The construction of successful full-depth repairs requires high-quality construction quality control, supervision and inspection, particularly in the installation of dowels or other load transfer devices.

Section 2 -- CONCURRENT WORK

In addition to full-depth repair, other types of rehabilitation may be required. A general flow chart for determining joint rehabilitation needs is provided in the design guidelines for pressure relief joints (Figure A-1). Repair of spalls by partial-depth repair is economical when the distress has not penetrated beneath the midpoint of the slab. Deflection tests should be conducted at the joints and corners to determine existing load transfer and the existence of voids. Subsealing of slabs where pumping has eroded the base is essential to prevent rapid slab cracking. Also, subdrainage should be provided in wet climates with fine-grained soils and high truck traffic volumes.

Where poor load transfer exists at original contraction joints, consideration should be given to the reestablishment of good load transfer (by using dowels placed in kerfs or shear devices) to reduce deflections and stresses. The reduction of free water beneath the slab through joint/crack sealing or the incorporation of underdrains is also very important. If the joint deterioration is due to the infiltration of incompressibles or water into the joint, cleaning and resealing of the transverse joints is necessary.

When a particular JRCP has a history of blowups, construction of pressure relief joints at 1000- to 2000-foot [305- to 610-m] intervals should be considered. However, these joints should be placed not less than 1000 ft [305 m] from the nearest proposed full-depth repair, since the repair itself is a form of pressure relief. Expansion joints should definitely be located at bridge ends, where serious damage to bridge decks and abutments can occur from pavement "growth." Finally, a smooth surface may be restored to the pavement by diamond grinding.

TRANSVERSE JOINT EVALUATION AND REHABILITATION SELECTION FOR JOINTED CONCRETE PAVEMENTS

(BASED ON VISUAL INSPECTION OF INDIVIDUAL JOINTS)

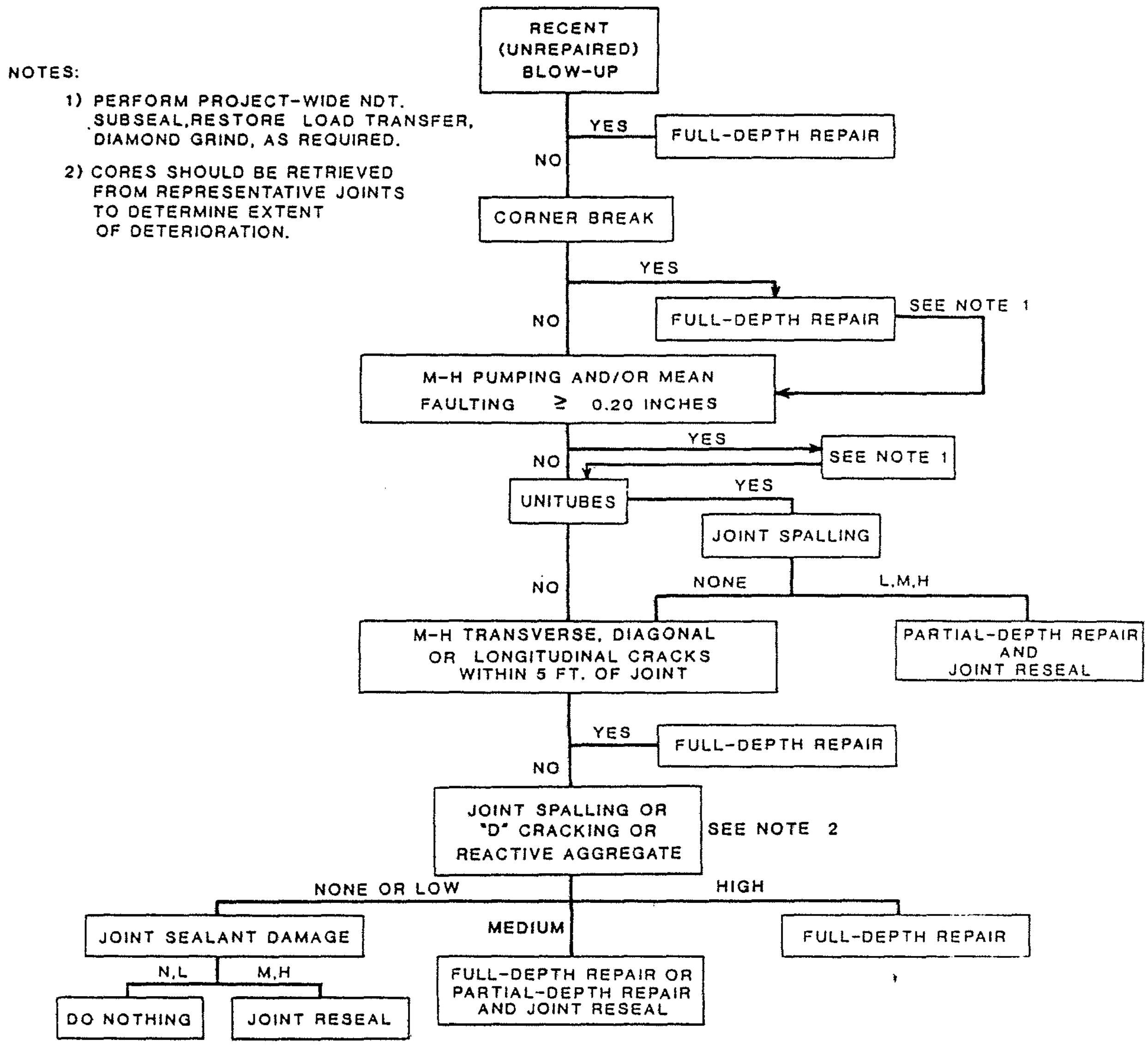


Figure B-1. Transverse Joint Evaluation and Rehabilitation Selection for Jointed Concrete Pavements.

If an overlay is to be placed, almost all of the same repairs should be performed (except grinding). It is important to realize that medium- to high-severity distress or poor load transfer at joints or cracks that are not repaired will rapidly reflect through the overlay.

Section 3 — DESIGN

3.1 GENERAL

Full-depth repairs should be designed for specific project conditions. The desired life of the repair and the level of traffic loadings will dictate the design details of the repair. The longer the design life and the larger the truck volumes, the more critical the structural design of the repair becomes. A number of full-depth repair projects have not performed as desired because the effect of heavy truck traffic was not fully considered in the design of repairs.

Other items to be considered in the design of full-depth repairs are available lane closure time, environmental conditions, subgrade drainability, design of existing pavement, existence of "D" cracking or reactive aggregate in the existing concrete slab and performance history of various repair designs under similar conditions.

3.2 LOAD TRANSFER

A high degree of load transfer across the transverse joints of the repair is very important in reducing deterioration where heavy truck traffic exists. Poor load transfer results in premature failure of the repair in the form of pumping, faulting, spalling, rocking and breakup. Poor load transfer may be caused by insufficient number or size of dowel bars, poor construction techniques, or a wet climate coupled with poor subbase/subgrade/shoulder drainability. Poor subdrainage greatly increases the potential for pumping, erosion and faulting of the full-depth repair.

Analysis of data from many full-depth repairs in the central U. S. for pavements with poor drainage conditions and granular bases has shown that faulting of full-depth repair joints will, on the average, exceed 0.2 inches [5 mm] if 100 or more commercial trucks per day use the traffic lane over a ten-year period (Ref. 13). Transverse joint faulting that exceeds 0.2 inches [5 mm] is definitely noticeable to drivers. Less precipitation and stabilized bases may allow for much higher truck traffic loadings.

Three different approaches have been used to provide load transfer across full-depth repair joints: (1) aggregate interlock, (2) undercutting and filling with concrete, and (3) dowels and rebars.

Aggregate interlock provides minimal load transfer and is not generally reliable. However, aggregate interlock may be sufficient where the following conditions exist: low volumes of heavy truck traffic (e.g., less than 100 trucks per day in the traffic lane in a wet climate), a nondeteriorated stabilized subbase, good subdrainage, and expansion of the slab due to reactive aggregates, resulting in the repair joints being in compression most of the time.

Undercutting alone does not provide adequate load transfer and should not be used in deep frost areas because the existing slab may heave more than the repair, causing severe roughness. Its reliability in nonfrost areas has not been established, but load transfer is often poor due to poor consolidation of concrete in the undercut area, and pumping is often observed in conjunction with such repairs.

The most reliable and recommended method of providing load transfer is to drill dowels or heavy tie bars into the face of the slab (Refs. 5, 7, 8, 9, 10, 13).

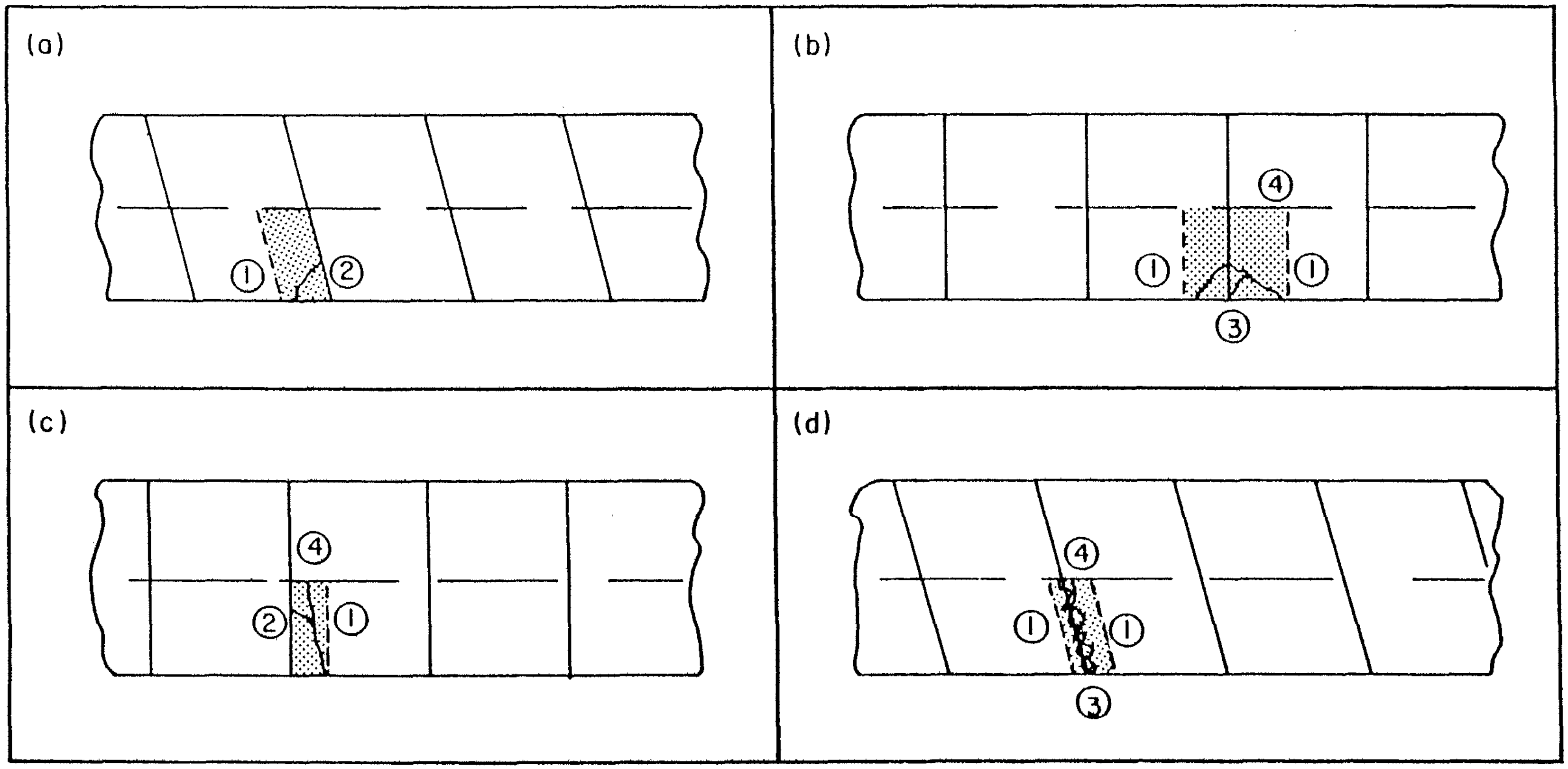
The recommended full-depth repair designs that will provide adequate horizontal movement and load transfer for the indicated situations are shown in Figure B-2 (for jointed plain concrete pavement) and Figure B-3 (for jointed reinforced concrete pavement). A detailed layout of the dowels or rebars is shown in Figure B-4, which shows the load transfer devices located in the wheel paths, where they are needed the most (Refs. 5, 11).

The number, spacing and diameter of the dowels will determine the amount of future faulting of the transverse joints. An approximate design procedure (prepared using a relationship between joint faulting, equivalent single axle loads (ESAL) and dowel/concrete bearing stress) is provided in Reference 5. The required dowel design determined by this procedure is an iterative process considering the following factors:

1. Dowel diameter.
2. Number of dowels in each wheel path (spaced at 12 inches [305 mm]).
3. Future ESAL in design lane.
4. Allowable faulting of the repair transverse joint.

The major uncertainty in using this procedure is that the relationship was developed from in-service pavement joints featuring cast-in-place dowels that are <u>fully supported by the surrounding concrete</u>. Thus, it is essential that good grouting or epoxying of the dowels is performed to achieve the predicted results.

The use of 1.5-inch [38.1-mm] diameter dowels is recommended in most instances due to the very beneficial effect of reducing faulting for a small increase in cost of the dowel. In addition, it is generally recommended that smooth dowel bars be utilized for load transfer. This provides for a working joint (particularly for JRCP) on both sides of the repair and avoids the potential problem of joint damage due to pullout, which is associated with deformed bars. However, in some cases it may be desirable to provide one or more nonworking joints through the use of large deformed rebar. The size of the deformed rebar can be determined through an analysis similar to that for dowel bars, with a minimum No. 8 bar (1 in [25 mm] diameter) recommended.



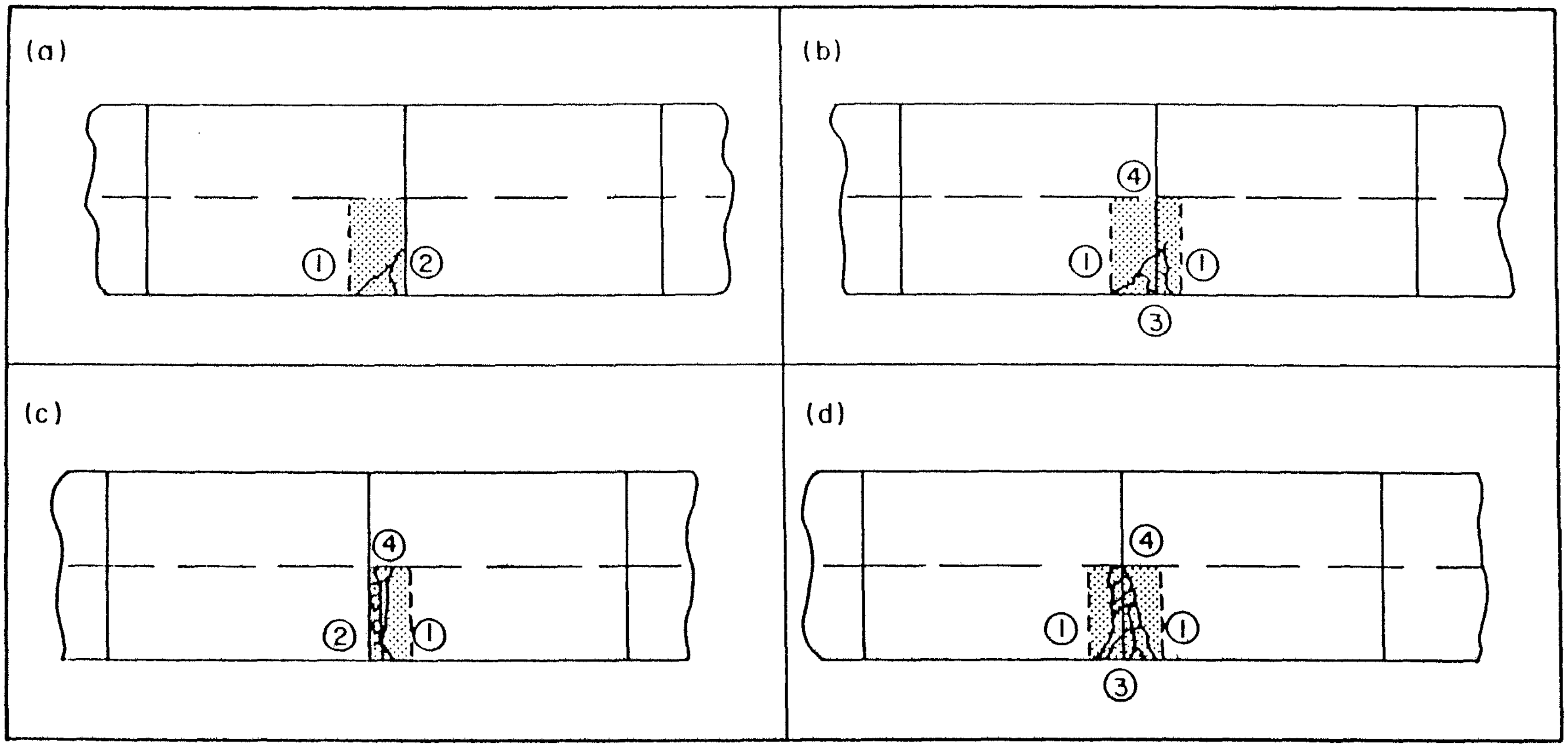
① Full Depth Saw Cut With Deformed Tie Bars or Dowels

② Existing Joint

③ Transverse Joint not Required at This Point Unless Tie Bars/Epoxy are Used at ① Joints, or if Length is > 12 Ft.

④ Sawing of Joint may be Required to Cut Tie Bars and Key-Way. Tie Bars not Required. Bond Breaker Material Must be Placed Along Longitudinal Joint.

Figure B-2. Full Depth Repair Recommendations for Plain Jointed Concrete Pavements Under Heavy Traffic.



(1) Full Depth Saw Cut With Smooth Dowel Bars

(2) Butt Type Joint-Dowels Left in Place or as Shown in Figure (b) If Concrete Deteriorated

(3) Transverse Joint not Required at Point Unless Repair > 12 Ft. Long

(4) Sawing of Joint May be Required to Cut Tie Bars and Key-Way. Tie Bars not Required. Bond Breaker Material Must be Placed Along Longitudinal Joint.

Figure B-3. Full Depth Repair Recommendations For Reinforced Jointed Concrete Pavements Under Heavy Traffic.

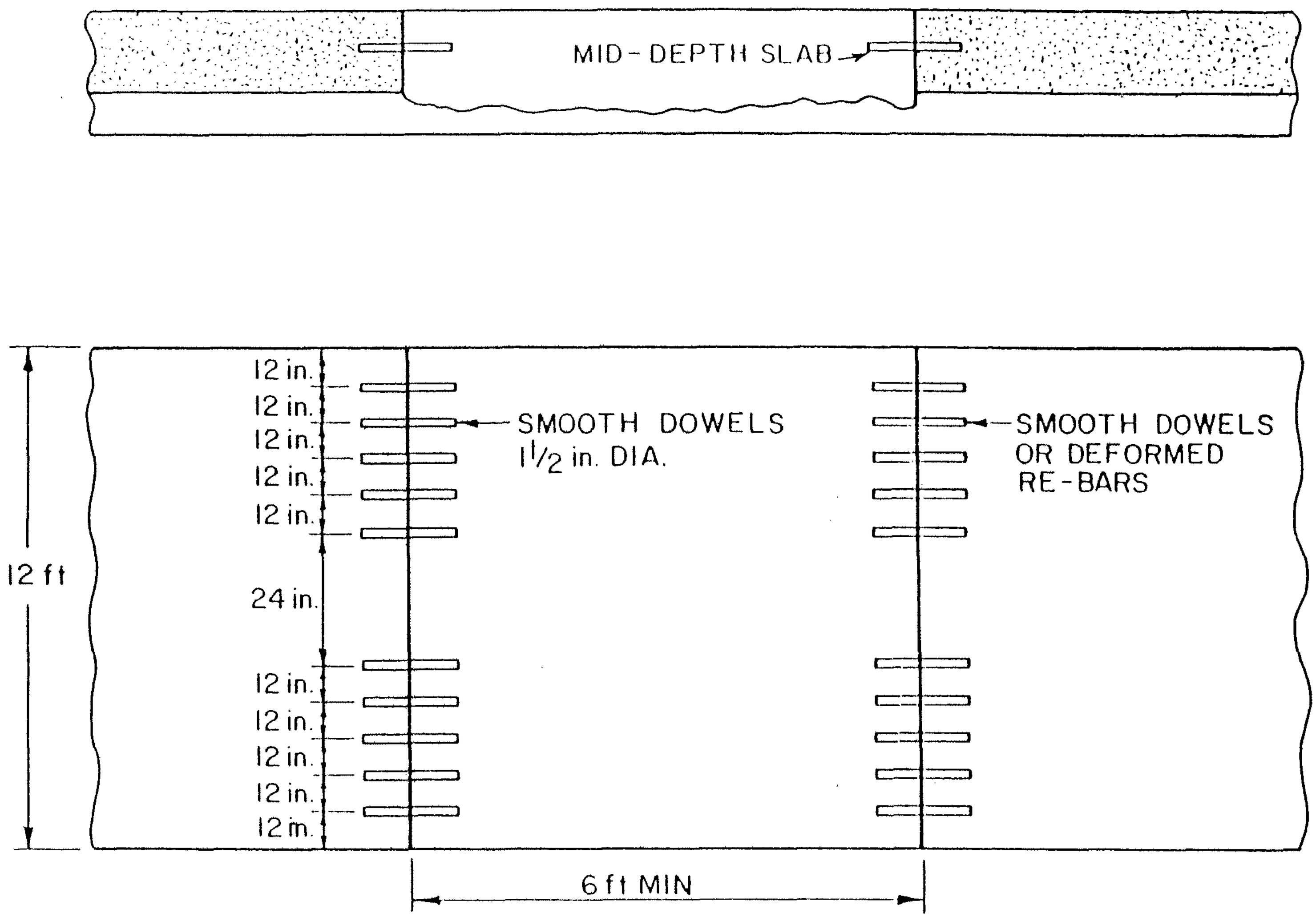


Figure B-4. Recommended Dowel Bar Spacing.

3.3 SELECTION OF BOUNDARIES

It is important that the boundaries be located so that all significant distress is removed. In general, deterioration near joints and cracks is greater at the bottom of the slab than at the top of the slab. Special attention should be paid to distress caused by "D" cracking or reactive aggregate because of the difficulty in determining their extent beneath the surface of the slab.

The location of repair boundaries also depends on the level of load transfer which is to be provided. The repairs must be of sufficient size to eliminate rocking and longitudinal cracking of the repair. A minimum repair length of 6 feet [1.8 m] and repair width of 12 feet [3.6 m] is recommended to provide stability under heavy traffic (as shown in Figure B-4) and to prevent longitudinal cracking. In the case of short plain jointed slabs with high-severity distress, it is normally recommended that the entire slab be replaced.

Reinforcement is needed in JRCP where the repair length is greater than about 15 feet [4.6 m] to avoid transverse cracking of the repair. It may be more economical to place additional dowelled transverse joints at about 15 feet [4.6 m] intervals than to place reinforcement.

Example repair layouts are shown in Figure B-5 for plain jointed concrete pavements (JPCP) and Figure B-6 for reinforced jointed concrete pavements (JRCP).

3.4 THICKNESS OF REPAIR

The repair should normally be the same thickness as the existing slab. However, under certain conditions a thicker repair may be warranted. If truck traffic is very heavy and there has been a history of cracked repairs after a few years, it may be necessary to place the repairs 2 to 4 inches [51 to 102 mm] thicker than the existing slab. Also, if the contractor disturbs the base, the disturbed material should be removed and the area filled with concrete during the repair placement.

Section 4 — CONSTRUCTION

4.1 MATERIALS

The concrete should be obtained from a nearby approved ready-mix plant or from an on-site mixing plant, and should have the following properties:

1. A cement content of 658-846 pounds (7 - 9 sacks) of Portland cement type I, II, or III per cubic yard [390-501 kg per cubic meter] of concrete can be used, depending upon the need for rapid strength gain to achieve early opening to traffic. A mix containing approximately 658 pounds per cubic yard [390 kg per cubic meter] is sufficient for most repair work.

2. An approved air-entraining agent in an amount such that 6.5 ± 1.5 percent of air is entrained in the concrete.

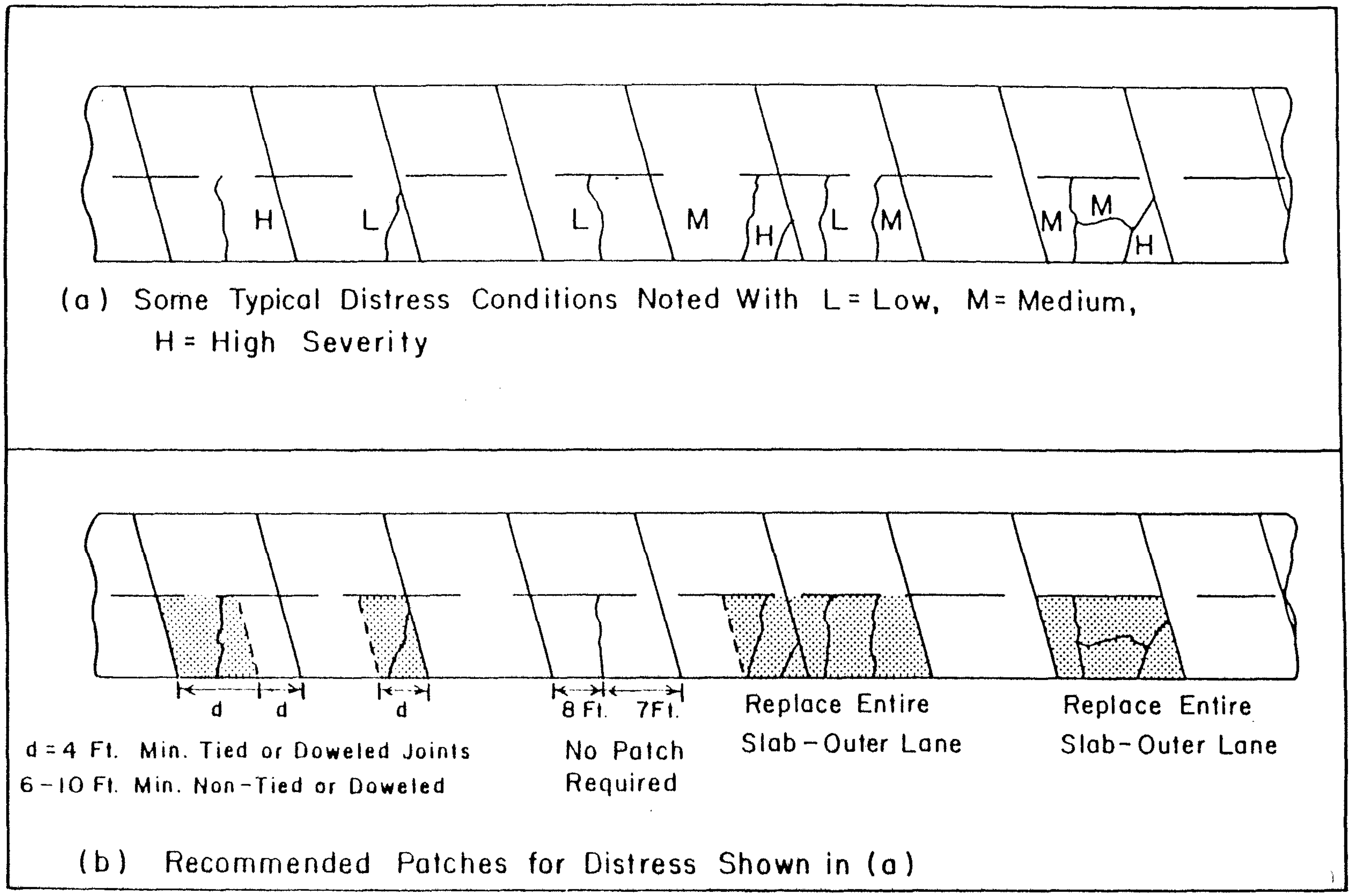


Figure B-5. Recommended Designs for Partial and Full Lane Width Patches for Plain Jointed Concrete Pavements (See Fig.B-4 for load transfer).

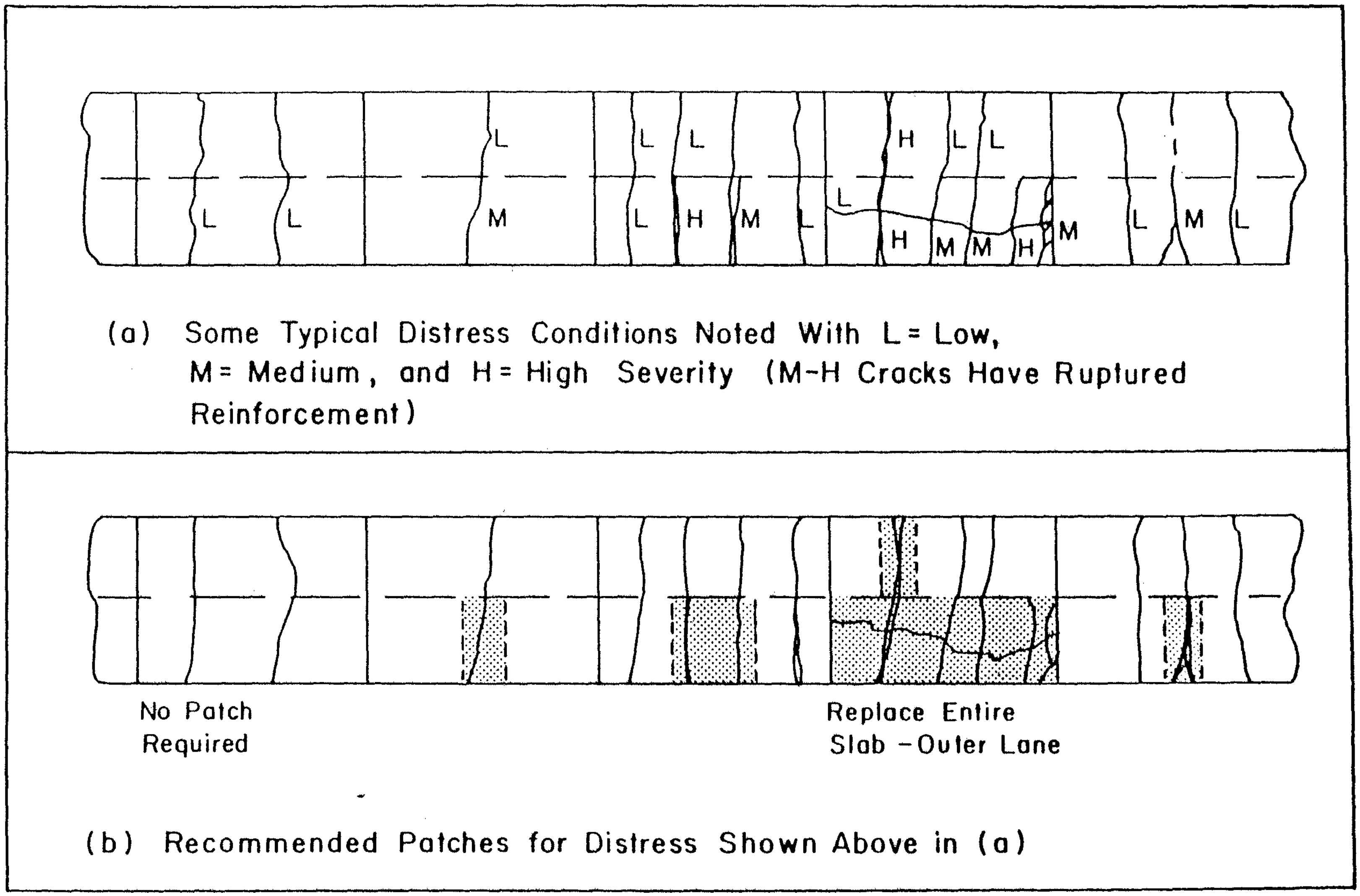


Figure B-6. Illustrations of Patching Recommendations for Reinforced Concrete Pavements (See Fig. B-4 for load transfer).

Calcium chloride or another accelerating chemical admixture is recommended for use as an accelerator in the repair concrete, provided that it is added as specified. It is recommended that no more than 1 percent be used when the ambient temperature is above 80°F [27°C] because greater amounts can bring on flash set. The maximum percentage is generally limited to 2 percent by weight of cement. On warm days, the initial set of the concrete can occur as soon as 30 minutes after the addition of calcium chloride.

The concrete in the ready-mix truck must be mixed an additional 40 revolutions after the addition of the calcium chloride in solution at the site. Higher early strength can be obtained by the addition of a water reducing agent, or a combination of water reducing and set controlling admixtures, or an approved superplasticizer.

The superplasticizer should be added at the site because of the limited time of its effectiveness. It should be added in accordance with the instructions supplied by the manufacturer to provide a 6-inch [152-mm] maximum slump concrete.

If both calcium chloride or other accelerating admixtures and superplasticizer are to be added, the calcium chloride should be added before the superplasticizer. The superplasticizer should be added immediately after the calcium chloride has been thoroughly mixed.

If calcium chloride or other accelerating admixtures are being added at the plant and the concrete consistently arrives at the site too stiff, then the calcium chloride should be added at the site. If, after the addition of calcium chloride at the site, the concrete is still too stiff, the ready-mix plant operator should be notified to increase the slump an appropriate amount, provided that the maximum w/c ratio is not exceeded. Concrete containing one or more chemical admixtures may have these added to the concrete at the batch plant, provided short haul to job site and cool temperatures exist.

Trial mixes using all proposed ingredients should be tested in the laboratory prior to use in the field.

4.2 PROCEDURES

a. Sawing of Repair Boundaries

Repair transverse boundaries must be sawed <u>full depth</u> with diamond saw blades. The only exception to this is where a wheel saw (having carbide steel tips) may be used to make wide cuts <u>inside</u> the full-depth diamond saw cuts so that the center portion can be lifted out. The sawcuts must not intrude on the adjacent lane if that lane is not slated for repair. If the wheel saw cut(s) are made, diamond saw cuts must then be made at least 18 inches [457 mm] outside the wheel saw cuts. The wheel saw cuts produce a ragged edge that promotes excessive spalling along the joint. The wheel saw must not penetrate more than 1/2 inch [13 mm] into the subbase. The longitudinal joint between lanes should be sawed full depth.

Full-depth sawing creates a smooth joint face with no load transfer capacity, and hence high deflections will occur if no mechanical load transfer is provided. Thus, it is very important to limit the traffic loadings between the time of sawing and removal. It is recommended that no traffic be allowed over the sawed repairs before removal procedures begin, to avoid pumping and erosion beneath the slab.

b. Removing Existing Concrete

Removal procedures must not spall or crack adjacent concrete or disturb the base course. This requires the following considerations:

1. Heavy drop hammers should not be allowed on the job.

2. Hydro hammers (large automated jackhammers) must not be allowed near a sawed joint.

3. Whenever the temperature is such that the sawed joint closes up, saw cuts can be made to relieve pressure and spalling when the existing slab is broken up or lifted out. A relief cut pattern that will eliminate spalling is shown in Figure B-7.

Procedures used for removal must not disturb the subbase or subgrade. The common practice of disturbing and then replacing the subbase does not work well because it is extremely difficult to adequately compact the replaced material. If the contractor disturbs the subbase, he should be required to remove all disturbed material and fill the area with concrete at his own expense when the repair is placed.

There are two basic methods for removing the existing deteriorated concrete within the repair area. These include (1) the breakup-and-cleanout method and (2) the lift-out method. Advantages and disadvantages of each method are given in Table B-1. The lift-out method generally provides the best results and the highest production rates for the same or lower cost, and with the least disturbance of the base. Contractors will develop lifting equipment that provides for safe and rapid removal whenever a substantial amount of work is available.

After the existing concrete has been removed, the subbase/subgrade should be examined to determine its condition. All material that has been disturbed or is loose should be removed. If excessive moisture exists in the repair area, it should be removed or dried up before the concrete is placed. Sometimes there is so much water in a given repair area that a lateral side drain must be cut through the shoulder for drainage. The entire foundation should also be compacted before the concrete is placed to minimize the potential of slab settlement.

c. Dowel and Rebar Placement

Either smooth steel dowels or deformed rebars can be installed in the repair joints. For long-jointed reinforced jointed pavement, it is recommended that smooth dowels be used at both ends to allow free movement (especially if the repair thickness is greater than the existing slab thickness). When deformed rebars are used at one end, they should be placed in the approach joint because this joint tends to become very tight due to the action of truck wheels pushing the repair backwards.

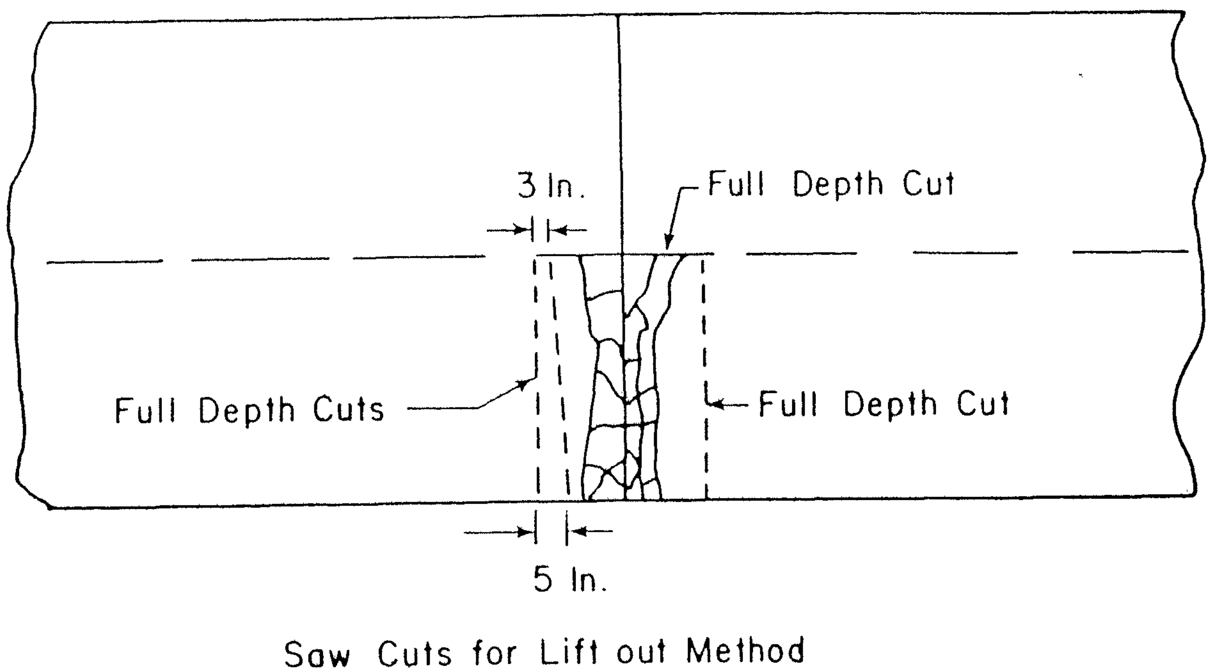


Figure B-7. Saw Cut Locations for Lift Out Method of Concrete Removal. (Note: Due to equipment lift out limitations, it may be necessary to cut the slab into smaller pieces).

Table B-1. Advantages and Disadvantages of Methods for Removal of Concrete in Patch Area.

Method

1. Breakup and Cleanout

   a. Advantages - Pavement breakers can efficiently breakup the concrete and a backhoe having a bucket with teeth can rapidly remove the broken concrete and load it onto trucks.

   b. Disadvantages - This method usually greatly disturbs the subbase/subgrade, requiring either replacement of subbase material or filling with concrete. It also has considerable potential to damage the adjacent slab.

2. Lift-Out

   a. Advantages - This method does not disturb the subbase and does not damage the adjacent slab. It generally permits more rapid removal than the breakup and cleanout method.

   b. Disadvantages - Disposal of large pieces of concrete may pose a problem. Lifting pins and heavy lifting equipment are required for the lift out, or the slab must be sawed into smaller pieces so that they can be lifted out with a front-end loader.

Installation is accomplished by drilling holes into the exposed face of the slab at specified locations. The holes can be drilled rapidly by placing several drills in a frame that holds them in a horizontal position at the correct height. The dowels must be carefully aligned with the direction of the pavement to provide easy movement.

The dowels should be located to provide the most benefit. Placing the bars in and near the wheel paths and the outer edges of the slab is believed to be the most effective. This minimizes the number of bars yet provides load transfer in the wheel paths. Figure B-4 provides the recommended design spacing for bars.

A quick-setting, non-shrinking mortar or epoxy resin can be used to permanently anchor the dowel or rebar in the hole. It is strongly recommended that even smooth dowels be grouted or epoxied into the existing slab to provide a secure fit and reduce potential for faulting.

The grout or epoxy must be placed into the back of the hole so that when the dowel is inserted it will force the material forward to cover and support the entire dowel. This process requires that the anchor material be sufficiently fluid to be pumped or placed at the back of the hole, but sufficiently stiff to keep from running out of the hole after the dowel has been inserted. Achieving such a grout consistency can be difficult, but is extremely important so that good dowel support is achieved. Plastic or nylon disks that fit tightly over the dowel and effectively seal the gap around the hole have been used successfully to prevent flowable anchor materials from running out of the hole (Ref. 15).

The placement of grout at the back of the dowel hole can be achieved by using a type of flexible funnel with a long nose so that grout can be poured into the funnel end, and it will run by gravity out the nose which is placed in the end of the dowel hole. A grout as flowable as this may not stay in the hole and provide good dowel support, however. Stiffer grouts can be pumped to the back of the dowel holes. Placement of epoxy-type anchor materials can be achieved by requiring the manufacturer to provide a system for mixing, proportioning and placing the material at the back of the hole. At least one manufacturer provides a caulking gun type of arrangement that dispenses the components from cartridges, through a long mixing nozzle, and out into the back of the dowel hole.

The dowel bar should be inserted into the hole with a twisting motion so that the material on the bottom of the hole is forced up and around to cover the entire bar. During insertion of the bar, the grout or epoxy typically runs out the end at the face of the slab and wastes, and a gap typically exists around the dowel at this critical bearing stress point (at the face of the slab). This loss of material can be avoided and a very effective face obtained all the way around the dowel at the entrance to the dowel hole through use of a simple thin plastic disk (Ref. 15), as mentioned above. This disk may be about three inches [76 mm] in diameter and manufactured to fit snugly over the bar and slide up against the face of the slab when the bar is being inserted into the hole. The disk will keep all of the material in the dowel hole and provide an excellent bearing surface at the face of the slab (Ref. 15).

When using dowels, the end that extends into the repair area should be lightly greased to provide ease in movement. A high level of inspection and care must be exercised in grouting or epoxying dowel/tie bars to ensure complete coverage of the bars.

Load transfer or tie bars across the longitudinal joint are not normally required.

d. Concrete Placement and Finishing

Critical aspects of concrete placement and finishing include (1) attaining adequate consolidation, (2) avoiding a mix that is either too stiff or has too high a slump, and (3) ensuring a level (flush) finish.

The concrete should be consolidated around the edges of the repair (particularly corners) and internally. The concrete mixture should have a slump of approximately 2 to 4 inches [51 to 102 mm] at the repair site for best placement. However, this may vary depending on admixtures used and construction conditions. A mix that is too stiff or too fluid could cause serious placement problems. The use of a superplasticizer, as discussed in Section 4.1, will help in providing a workable mixture. Work crews should not add excessive water just to get a highly flowable mix as this will weaken the concrete and cause higher shrinkage.

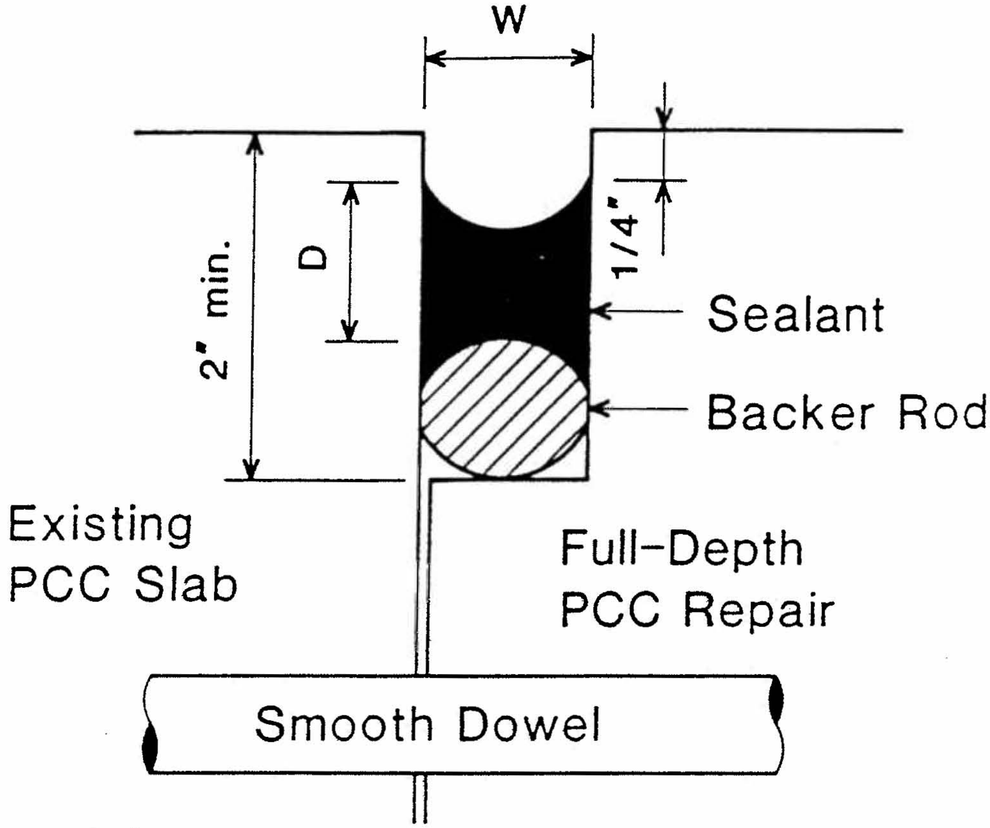
The repair must be finished level with the existing concrete. This can be accomplished by screeding in a transverse direction (to follow any ruts in existing pavement), a double strike-off of the surface, followed by further transverse finishing with a straight edge (Ref. 3). The surface should then be textured similarly to the existing slab surface. Where an overlay will not be placed and diamond grinding will not soon follow, any ruts in the wheel paths caused by studded tires must be incorporated into the surface of the repair.

e. Joint Sealing

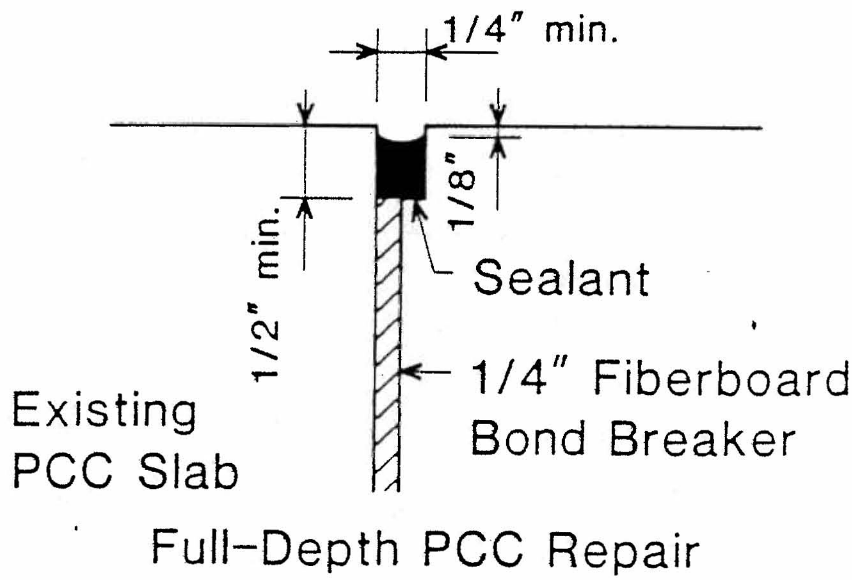
Experience has shown that transverse joints at full-depth repairs must be formed and sealed. This will substantially reduce spalling of the joints. A reservoir (dimensions depending on joint sealant specified, climate, and joint spacing) should be either formed or cut in the new concrete. It should be at least 2 inches [51 mm] deep to avoid point-to-point contact at the top of the slab, thus reducing spalling potential. After cleaning, a backer rod and the sealant should be placed. The width of the joint should be determined as recommended under the Design Guidelines for Resealing Joints. The longitudinal joint should also be sealed to reduce potential for spalling and water infiltration. Figure B-8 shows a typical diagram for transverse and longitudinal joints that could be placed in the project plans with appropriate dimensions.

f. Curing and Opening to Traffic

Ambient temperature at placement and within the next few hours has been found to be the most influential factor in the strength development of concrete repairs (Refs. 4, 6). The temperature in the repair concrete slab will be higher than ambient or cylinder/beam temperatures. This



(a) Transverse Joint Design (Ward 1) to be Determined From Joint Opening and Sealant Properties



(b) Longitudinal Joint Between Lanes

Figure B-8. Transverse and Longitudinal Joint Reservoir designs.

difference ranges from 10 to 20°F [5 to 10°C] at 4 hours after placement for non-insulated repairs. If an insulation blanket is placed over the repair, the temperature difference may be as high as 40 to 60°F [22 to 33°C].

Thus, for rapid curing (particularly in cold weather) it is strongly recommended that insulation blankets be placed over repairs (Ref. 6). Polyethylene sheeting should be placed on the concrete surface under the insulation. However, wet burlap has also been used as a curing agent.

Water/cement ratio and admixtures also have a significant effect on strength development during the first few hours after placement. The shortest curing time can be obtained by using a combination of calcium chloride, superplasticizer and insulation blankets. Table B-2 provides recommendations on early opening of full-depth concrete repairs.

Section 5 — PREPARATION OF PLANS AND SPECIFICATIONS

It is recommended that when a substantial amount of repair work is needed, aerial photography be used to clearly delineate the repair locations and estimated quantities. The photographs of the roadway can be cut out and mounted on plan sheets where quantities and locations can be identified.

Diagrams of typical repairs and removal procedures should be included (see Figures 3, 5, and 6).

Since unit costs between small-area repair and larger area slab replacements differ, two or more pay items should be set up. For example, one agency has the following three sizes: Type I, less than 5 square yards [4.2 square meters]; Type II, 5-15 square yards [4.2-12.5 square meters]; and Type III, greater than 15 square yards [12.5 square meters].

Either of two different methods may be used to specify when repairs can be opened to traffic.

1. Specified minimum strength of beams or cylinders. The minimum required strength before a repair can be opened to traffic has not been fully established, and it varies widely among agencies. A modulus of rupture of 300 psi [2.1 MPa] for center-point loading, or 250 psi [1.7 MPa] for third-point loading, or 1000 to 2000 psi [6.9 to 13.8 MPa] for compressive strength of specimens cured similarly to the repair are fairly common specifications for opening to traffic (Refs. 3, 4, 5). The actual strength of the repair will be higher than the beams or cylinders because the temperature in the repair will be higher than that in the beam or cylinder.

2. Specified minimum time to opening. The agency may specify the mixture design and curing procedures, and then based on ambient temperature at placement and slab thickness, set the minimum time to opening to traffic. The recommendations provided in

Table B-2. Early Opening Guidelines for Full-Depth Repairs
[1 in = 25.4 mm; $^{o}C = (^{o}F-32)5/9$] (Ref. 6).

Slab Thickness (inches)	Ambient Temperature At Placement (^{o}F)	Full-Depth Repair Mixtures/Curing* (hours after placement) A	B	C	D	E	F
7	40	203	90	69	29	28	7
	50	125	60	41	21	20	5
	60	80	45	28	17	16	4
	70	60	38	21	14	13	3
	80	48	35	17	13	11	3
	90	40	30	13	13	9	3
8	40	145	59	55	24	24	6
	50	82	40	35	18	17	5
	60	58	31	24	13	13	4
	70	42	26	17	11	10	3
	80	35	23	13	10	9	3
	90	29	22	11	9	8	3
9	40	82	34	37	15	16	5
	50	51	25	23	12	13	3
	60	28	19	16	9	9	3
	70	25	16	12	8	7	3
	80	20	14	10	6	6	3
	90	17	12	8	5	5	3
10	40	45	18	23	9	9	3
	50	30	14	14	7	7	3
	60	20	10	9	5	5	3
	70	15	9	7	4	4	3
	80	12	7	5	4	4	3
	90	9	6	4	3	3	3

*All mixtures contain 650 pounds cement per cubic yard [386 kg per cubic meter] and 2% CaCl.

Mixture Characteristics:	A	B	C	D	E	F
water/cement ratio	0.42	0.42	0.35	0.42	0.35	0.35
cement type	I	I	I	III	I	III
superplasticizer	no	no	yes	no	yes	yes
fiberglass insulation	no	yes	no	yes	yes	yes

Note: These results are based on research done at the University of Illinois, Department of Civil Engineering, using a computer program written in the Microsoft BASIC language. They are intended as guidelines and should only be used after careful evaluation (Reference 6).

Table B-2 are based on analytical and field tests (Refs. 4 and 6). These recommendations should be carefully evaluated by an agency before adoption, and adjusted to local conditions where needed.

There are several impact hammers available for determining the approximate in-place compressive strength of the full-depth repairs. They have been found to be accurate within 15% and provide quick readings in the field. However, they must be calibrated with cylinders and it is important that, once correlated, their testing be performed only on repairs with the same mix design as the cylinders. One such test method is described in detail in ASTM C805.

The Guide Specifications accompanying these Design and Construction Guidelines are recommended for use after they have been revised to reflect local conditions.

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FULL-DEPTH REPAIR OF JOINTED CONCRETE PAVEMENTS

PART 2 — GUIDE SPECIFICATIONS

Section 1 — DESCRIPTION OF WORK

1.1 DESCRIPTION. The work performed under these specifications shall consist of constructing Portland cement concrete pavement full-depth repairs with or without reinforcement, as required, and with the design specified.

1.2 LOCATION. The locations and approximate surface areas of the repairs are shown on the plans. However, the final locations and boundaries of each repair will be designated by the Engineer.

1.3 STANDARD SPECIFICATIONS. The standard specifications which are applicable to the work on this project are as published in the current edition of (Local, State, Special) "Standard Specifications."

Section 2 — MATERIALS

2.1 CONCRETE REPAIRING MIXTURE. Concrete for repairing shall consist of a mixture of Portland cement, fine aggregate, coarse aggregate, water and admixture when required or permitted, combined in the proportions as hereinafter specified for the various grades of concrete required.

a. The concrete shall be obtained from an approved plant with the following properties:

1. 658 to 846 pounds (7 - 9 sacks) of Type I, II or III Portland cement per cubic yard [390 to 501 kg per cubic meter] of concrete (see Guidelines).

2. An approved air-entraining agent in amounts such that 6.5 percent air is entrained in the concrete with a tolerance of 1.5 percent plus or minus, determined according to AASHTO T 152 prior to addition of calcium chloride.

3. The material proportions shall be in accordance with the approved mixture design which gives a slump of 2 to 4 inches [51 to 102 mm].

b. If calcium chloride is used as an admixture, the following conditions apply:

1. The calcium chloride shall be added in solution to the concrete at the site when the ambient temperature is above 70°F [21°C]. When the temperature is below 70°F [21°C], the calcium chloride can be added at the site or at the plant, as long as the length of time from mixing to delivery is less than 15 minutes.

2. At all times the percentage of calcium chloride by weight of cement is limited to a maximum of 2 percent.

c. If a superplasticizing admixture is used, the following conditions apply:

1. The concrete mix shall be altered so as to produce a 1-inch [25-mm] slump before adding the superplasticizer.

2. At all times the superplasticizer should be added at the site. If calcium chloride is also being added, it should be added according to the provisions of Section 2.1b before the addition of the superplasticizer. The superplasticizer shall be added immediately after the calcium chloride has been thoroughly mixed.

3. The superplasticizer shall be added in accordance with the instructions supplied by the manufacturer to provide a maximum 6-inch [152-mm] slump concrete for easy placement. If the concrete begins to stiffen up by the time the second or third repair is to be placed, an additional reduced dose of superplasticizer may be added according to manufacturer's recommendations.

The concrete must be mixed a minimum of 30 revolutions at mixing speed after every addition of the superplasticizer.

If any chemical admixtures, ASTM C 494, are used, the following conditions apply:

1. All admixtures may be added at the batch plant.

2. Dosage rates of admixtures may be varied to give required time of set and strength development as job site and weather conditions dictate.

2.2 STEEL REINFORCEMENT. Welded wire fabric shall conform to the requirements of AASHTO M55. Bar mat fabric shall conform to the requirements of AASHTO M54.

2.3 DOWEL BARS. Steel for dowel bars shall conform to the requirements of AASHTO M227, grades 70 through 80. The entire length of each dowel bar shall be precoated to protect against corrosion in accordance with AASHTO M254. The dowels shall be 18 inches [457 mm] long and of the diameter specified on the plans.

2.4 TIE BARS. Steel for transverse tie bars shall conform to the requirements of AASHTO M31 or M53.

2.5 JOINT SEALANT MATERIALS. (see Standard Specifications)

2.6 CURING MATERIALS. (see Standard Specifications)

2.7 EPOXY ADHESIVE. (For use in attaching the dowels in the existing slab) The epoxy adhesive shall meet the requirements of AASHTO M 235.

2.8 NON-SHRINK GROUT. (Used to anchor the dowels in the existing slab and is prepackaged.) Non-shrink grout shall be a flowable nonmetallic grout and non-shrink when tested in accordance with the applicable portions of the Corps of Engineers "Specification for Non-Shrink Grout," CRD-C621. The maximum expansion allowable in this test at 3, 14 and 28 days is 0.4 percent. The expansion at 3 and 14 days shall not be greater than the expansion at 28 days. The grout shall have a compressive strength of not less than 3000 psi [20.7 MPa] at an age of 24 hours when tested using applicable portions of ASTM C-109. The compressive strength specimens shall be produced from a mixture of the dry grout and sufficient water to produce a flowable mixture. The initial set shall not be less than 60 minutes when tested under CRD-C82, "Method of Test for Time of Setting of Grout Mixtures," Corps of Engineers.

2.9 CIRCULAR DISKS FOR DOWELS. (Used to hold in dowel anchoring material as dowel is being inserted into hole and to provide smooth face and bearing surface at face of the slab.) Circular disks shall be provided that will slide onto the dowel bars to their midpoint. They must fit tightly over the dowel bars. These disks shall have an outside diameter of three inches [76 mm] and a hole cut in the center with a diameter equal to that of the dowel bar diameter. A small (0.125 to 0.250-in [3 to 6-mm] diameter) "weep hole" shall be provided adjacent to the center dowel hole to allow excess material to extrude from the dowel hole and behind the disk as the disk and dowel assembly are forced against the face of the slab. The thickness of the disk shall be of a suitable thickness and manufactured of suitable material so that the disk has adequate stability for installation in the field.

Section 3 — EQUIPMENT

3.1 GENERAL. The Contractor shall furnish and maintain such equipment as necessary to complete the work in accordance with the specifications.

3.2 CONCRETE SAW. The concrete saw shall be equipped with a diamond blade or approved equal. The saw blade shall be of sufficient size to saw slabs to the required depth.

3.3 EQUIPMENT AND DEVICES FOR REMOVING EXISTING CONCRETE. The Contractor may select either the breakup-and-cleanout method or the lift-out method. Equipment for breaking the concrete shall be limited to drop hammers, hydrohammers and jack hammers. No ball drop breakers may be used. The equipment must not damage the existing slab that is not to be removed, or the subbase and subgrade in the repair area. Other light and similar equipment may be used with approval of the Engineer.

3.4 VIBRATORY COMPACTOR. A subgrade/subbase compactor shall be provided to assure uniform foundation beneath the repair (see Standard Specifications).

3.5 HOLE DRILLING EQUIPMENT. The equipment used for drilling the dowel holes in the face of the slab shall be capable of drilling the size and depth of holes shown on the plans. The equipment shall produce holes that are parallel to the grade and centerline of the pavement with a tolerance of 1/8 inch in 12 inches [3 mm in 305 mm]. The drill shall not crack or spall the adjacent concrete. A drill support system, using the pavement surface as a reference for drill bits, shall be required to assure hole alignment. Hand-held drills will not be allowed.

3.6 INSERTION OF GROUT/EPOXY MATERIALS IN DOWEL HOLES. Equipment must be provided that will insert the specified dowel anchoring material into the back of the drilled dowel hole.

3.7 FORMS, METAL OR WOOD. (see Standard Specifications)

3.8 CHAIRS. (See Standard Specifications).

3.9 INTERNAL VIBRATOR. Internal vibrators for consolidating the concrete shall be of an approved mechanical spud type. The vibrators must be capable of visibly affecting the concrete for a distance of 12 inches [305 mm] from the vibrator head.

3.10 FINISHING AND FLOATING EQUIPMENT AND STRAIGHTEDGES. The finishing and floating equipment shall be capable of consolidating, screeding, and floating the concrete. A dense, homogeneous concrete patch must be produced, and finished to the same surface slope as the existing concrete slab. A minimum of hand finishing should be used. Hand floats and straightedges shall be at least 10 feet [3 m] in length and shall be rigid and free from warp. The handles shall be of sufficient length to permit finishing the width of the patch being placed. Hand floats shall be of the box or channel type. The floating face shall be at least 6 inches [152 mm] in width.

3.11 PRESSURE HAND SPRAYER FOR MEMBRANE CURING COMPOUND. Manually operated spray equipment may be used to apply curing compound.

3.12 INSULATING BLANKETS. When required, 2-inch [51-mm] thick minimum insulation blankets (such as fiberglass, rock wool or other approved commercial insulation material) shall be provided with a protective covering to avoid disintegration if wet.

Section 4 — CONSTRUCTION METHODS

4.1 GENERAL. Full-depth repair shall be performed in accordance with the details, and at the locations shown on the plans. As specified, final locations and dimensions will be designated by the Engineer in accordance with existing conditions of the pavement.

4.2 REMOVAL OF CONCRETE IN REPAIR AREA. The boundaries of the repair shall be sawed as indicated in the plans and marked on the pavement as required. The full-depth sawing operations shall not precede the removal operations by more than two days, unless approved by the Engineer. The concrete in the repair area shall not be removed until the day the repair is placed, unless approved by the Engineer. Concrete between narrowly spaced saw cuts at the end of a repair shall be removed with air hammers and hand tools.

Either of the following two methods are acceptable for the removal of the concrete within the repair area.

a) BREAKUP-AND-CLEANOUT METHOD. The breaking operation shall proceed from the center of the repair area toward the saw cuts at the ends. The pieces of concrete shall then be removed by hand or with equipment that does not damage the subbase.

b) LIFT-OUT METHOD. Whenever lifting devices are used, the slab shall be lifted in one or more pieces without disturbing the subbase and subgrade. The area shall then be cleaned out with hand tools.

Any subbase or subgrade material that is disturbed below the desired level of cleanout must be removed and the repair area compacted to the satisfaction of the Engineer. No new subbase material will be allowed in the repair area. The Contractor shall be required to fill in any area that was disturbed with concrete when the repair is placed. The excess concrete shall be at the expense of the Contractor.

Where reinforcement is required, it shall be supported during concrete placement by the use of bar chairs or other means approved by the Engineer.

Where required in the plans, bondbreaker material shall be placed along the longitudinal joint with the next lane.

Side forms shall overlap the ends of the existing slab. They shall be securely fastened so as not to move when concrete is placed. In order to accommodate forms for the repair, the Contractor shall saw the shoulder full depth along the edge at such a width necessary to accommodate edge forming. The shoulder material along the edge may then be removed and the side forms placed. After removal of the forms, the excavated shoulder area shall be backfilled using asphalt concrete hot mix. Compaction must be satisfactory to the Engineer.

In the event a concrete shoulder exists, the longitudinal joint between the traffic lane and shoulder must be sawed (including the tie bars). The joint will then serve as a form for the repair.

4.3 DRILLING OF HOLES FOR REINFORCEMENT OR DOWELS AND ANCHORING THEM INTO THE EXISTING SLAB

When specified, holes shall be drilled into the face of the existing slab at the specified diameter with a tolerance of 1/8 inch in 12 inches [3 mm in 305 mm]. They must be blown out with compressed air prior to placing the grout or epoxy material. They shall be spaced at mid-depth of the slab and located as indicated on the plans. The diameter of the holes shall be 1/8 inch [3 mm] larger than the dowels or rebar.

For epoxy and non-shrink grouts, the material shall be injected to the rear of the hole and must be dispersed along its length to insure that the bars are completely covered and no voids exist. The bars shall be fitted with thin circular disks and inserted with a twisting motion and seated in place by tapping. The disk shall be pushed against the face of the slab to prohibit material from leaking. After curing the disks shall be removed. Procedures used must be approved by the Engineer.

The ends of the dowels (but not deformed rebars) protruding out into the repair area shall be lightly greased.

4.4 PLACEMENT OF CONCRETE PATCH. Each repair shall be cast in one continuous full-depth operation. The concrete shall be consolidated in place by use of an internal type vibrator, particularly near the edges and corners.

4.5 FINISHING REQUIREMENTS. The surface shall be struck off at least twice with a screed flush with the existing pavement at the repair limits. Floating in lieu of striking off with a screed will not be acceptable. For repairs 12 feet [3.7 m] or less in length, the screed shall be placed parallel to the centerline of the roadway. For repairs over 12 feet [3.7 m] in length, the screed shall be placed perpendicular to the centerline.

While the concrete is still plastic, the Contractor shall test the repair surface for trueness and for being flush with the edges of the repair by use of a straightedge and in accordance with the following:

For repairs 10 feet [3 m] or less in length, the straightedging shall be done by placing the straightedge parallel to the pavement centerline with the ends resting on the existing pavement and drawing the straightedge across the repair. The straightedge shall be in contact with the existing pavement while drawing it across the repair and any high or low spots exceeding 1/8 inch [3 mm] shall be corrected. If any corrections are made, the Contractor shall recheck the surface and eliminate irregularities.

4.6 TRANSVERSE AND LONGITUDINAL JOINTS. The transverse and longitudinal joints shall be formed or sawed to the dimensions shown on the plans. Where full-depth repairs are to be placed in more than one lane at a time, longitudinal joints shall be constructed in line with the existing longitudinal joints and to a depth of one-third the thickness of the repair, either by sawing or by forming. The joint shall be sawed within 24 hours after placement.

4.7 TEXTURING. The surface of the concrete shall be textured to match the surrounding pavement, except when a grinding operation will follow.

4.8 CURING. Concrete curing compound shall be added as soon as the concrete surface has set sufficiently to apply the curing agent without damage. The curing compound shall be applied immediately after texturing at the rate of 150 square feet/gallon [3.7 square meters/liter].

When the ambient temperature at the time of placement is below 90 $^{\circ}$F [32 $^{\circ}$C], insulation blankets having a minimum thickness of 2 inches [51 mm] may be placed over the concrete repair as soon as the curing compound has been applied. Edges and seams in the blanket shall be secured to prevent penetration of wind.

When test beams or cylinders are used they shall be cured similarly to the way that the repair is cured (insulated box).

4.9 SHOULDER REPLACEMENT. Prior to opening to traffic, the shoulder shall be restored to the existing line and grade using asphalt concrete. The asphalt concrete shall be compacted to the satisfaction of the engineer. The mainline concrete repair must not protrude into the shoulder area.

4.10 OPENING TO TRAFFIC. The concrete repairs may be opened to traffic when (specify either of the following alternative methods):

1. The concrete beams or cylinders have attained an average modulus of rupture of ____ psi (300 psi [2.1 MPa] recommended) as determined from center-point loading beam tests, or ____ psi (250 psi [1.7 MPa] recommended) for third-point loading, or ____ psi (1000 to 2000 psi [6.9 to 13.8 MPa] recommended) compressive strength.

2. The time specified has elapsed (for a given ambient temperature at placement of the repair, concrete mixture, and curing condition).

Section 5 — WEATHER CONDITIONS

5.1 Portland cement concrete repairs shall not be placed when the air or pavement temperatures are below 40°F [2°C]. Insulation may be used to improve the rate of strength gain.

Section 6 — MEASUREMENT AND PAYMENT

6.1 MEASUREMENT AND PAYMENT. The completed work as measured for Full-Depth Repair of Jointed Concrete Pavement will be paid for at the contract unit prices for square yards of repair of Type I, II or III as follows: Type I, less than 5 square yards [4.2 square meters]; Type II, 5 to 15 square yards [4.2 to 12.5 square meters]; and Type III, greater than 15 square yards [12.5 square meters]. The square yards of repair will be measured at the surface of the pavement.

APPENDIX C

DESIGN AND CONSTRUCTION GUIDELINES AND GUIDE SPECIFICATIONS FOR PARTIAL-DEPTH REPAIRS

Acknowledgment

These guidelines and specifications were originally prepared under NCHRP Project 1-21 conducted at the University of Illinois and published in NCHRP Report No. 281, Transportation Research Board, 1985. The guidelines have been updated in 1987 based upon the findings and results from the study entitled "Pressure Relief and Other Joint Rehabilitation Techniques" under contract DTFH61-83-C-00111 between the Federal Highway Administration and ERES Consultants, Inc. On-going research concerning this rehabilitation technique is being performed at the University of Illinois under FHWA contract DTFH61-C-85-00004, "Determination of Rehabilitation Methods for Rigid Pavements."

PARTIAL-DEPTH REPAIR OF JOINTED CONCRETE PAVEMENTS

PART 1: DESIGN AND CONSTRUCTION GUIDELINES

Section 1 — INTRODUCTION

These guidelines cover permanent partial-depth repair of jointed Portland cement concrete (PCC) pavements. This type of rehabilitation involves the repair of spalls at joints and/or cracks and other distresses which can be addressed by partial-depth repairs.

1.1 NEED FOR PARTIAL-DEPTH REPAIRS

Partial-depth repairs can be used to extend Portland cement concrete pavement life by repairing surface spalls, scaling and potholes. When these repairs are placed along pavement joints and combined with an appropriate joint maintenance and resealing program, the infiltration of moisture and incompressibles can be reduced and pavement life may be extended.

Spalls are often caused by the infiltration of incompressible materials into joints. This type of spalling is common on pavements with long joint spacing, where larger joint movements occur. Dowel bar misalignment may also cause joint spalling.

Transverse joint spalling in some states has been caused by the use of metal joint forming inserts (Unitubes) in areas where the hardness of the aggregate makes sawing of joints very difficult and expensive. These inserts often corrode and entrap incompressibles, resulting in widespread joint spalling.

Other sources of spalling and scaling include reactive aggregates and "D" cracking, spalls over reinforcing steel that has been placed too near the surface, and locally weak concrete (due to overfinishing and a high water/cement ratio). The need for partial-depth repair at individual joints can be assessed using the decision chart shown in Figure C-1.

1.2 EFFECTIVENESS

Partial-depth repairs extend the life of Portland cement concrete pavements by restoring ride quality that has been lost due to spalling at joints and cracks and scaling of the pavement slabs. Restoration of a uniform joint sealant reservoir in conjunction with partial-depth repair further increases pavement life. When properly placed with an appropriate and durable repair material and combined with good joint maintenance practices, the life of a partial-depth repair should equal the remaining life of the pavement.

The performance of partial-depth repairs has been excellent on many projects; however, high rates of partial-depth repair failure have been observed on other projects. These failures are commonly caused by:

1. Inappropriate use of partial-depth repairs (e.g., where full-depth repairs are needed).

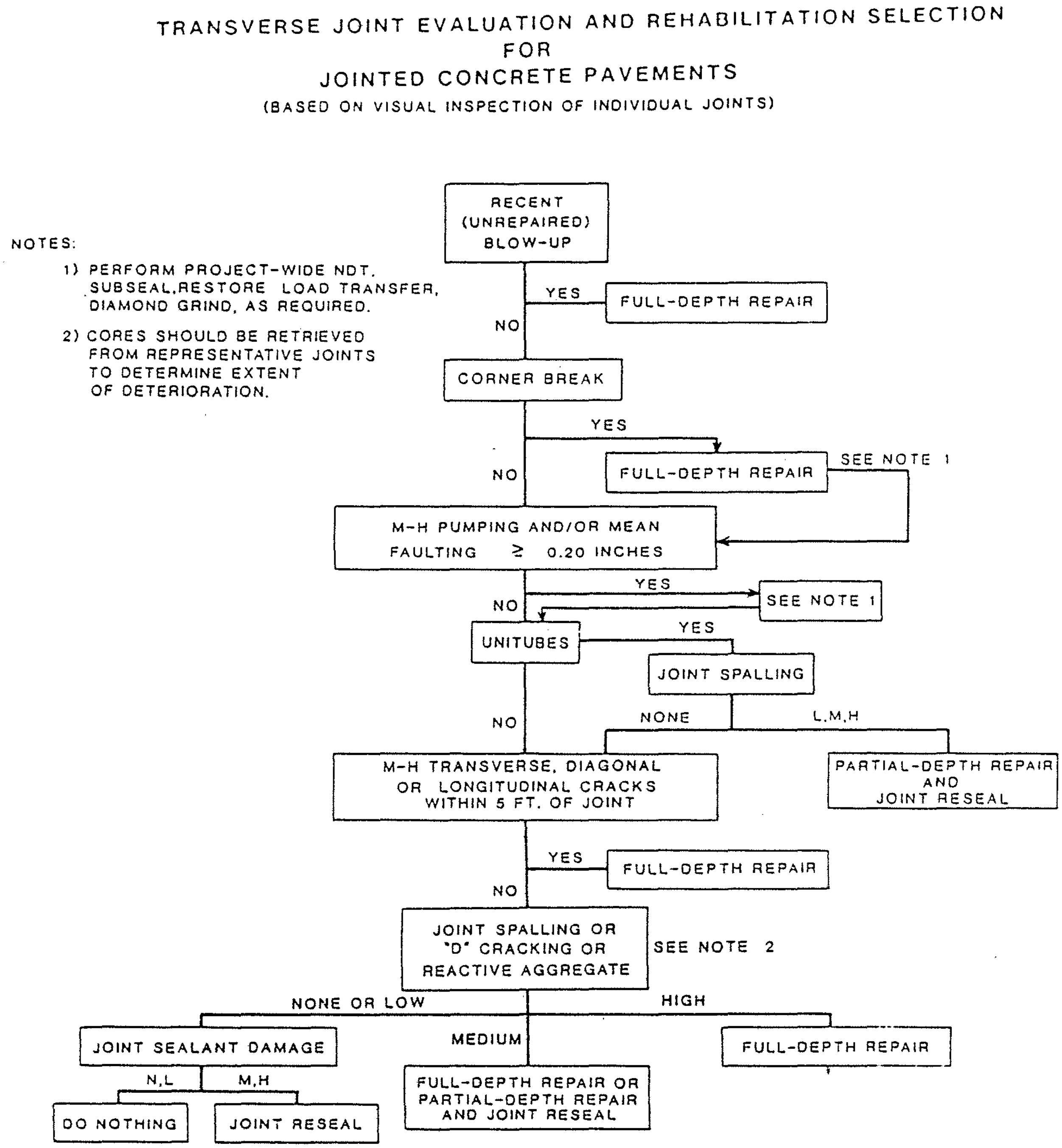


Figure C-1. Transverse Joint Evaluation and Rehabilitation Selection for Jointed Concrete Pavements.

2. Poor construction techniques (failure to remove all deteriorated materials, failure to provide vertical saw cuts at the repair boundaries, failure to provide a compressible material in joints and cracks adjacent to or within the patch area, inadequate surface preparation and bonding provisions, insufficient repair material consolidation).

3. Compression failures (caused by repair material entering working cracks and joints, thereby restricting slab expansion).

4. The use of inappropriate, thermally incompatible or variable-quality repair material.

1.3 LIMITATIONS

Partial-depth repairs are not suitable for spalls that extend deeper than one half the slab thickness because the removal of deteriorated concrete below this depth is often hampered by the presence of reinforcing bars and dowels. Furthermore, sound concrete at the bottom of the repair is more easily damaged as the depth of removal increases. Full-depth repairs should be placed in these cases.

Partial-depth repairs are not suitable for working cracks or joints unless the crack or joint is reestablished through the repair directly above the discontinuity in the underlying slab. Full-depth repairs should be considered at such locations.

If several spalls are present on one joint, it may be more economical to place a full-depth repair along the entire length of the joint than to repair individual spalls.

Partial-depth repair costs are highly dependent upon the size, number and location of repair areas. Spalls are often filled with a temporary repair material (such as bituminous concrete) to reduce further deterioration until a sufficient number of spalls develop to justify a repair contract. Lane closure time, construction conditions and traffic volume also influence production rates and costs.

Section 2 — CONCURRENT WORK

Slab stabilization should be accomplished prior to placing partial-depth repairs so that any spalls which might develop from accidental lifting or movement of the slabs can be repaired.

Full-depth repairs should be accomplished concurrently with or after the placement of partial-depth repairs so that unexpected areas of deep deterioration can be identified and corrected.

Diamond grinding should be accomplished after the completion of all activities which might increase the roughness of the pavement surface (including slab stabilization and partial- and full-depth repairs).

Joint cleaning and resealing should be accomplished last to prevent damage of the new sealant by repair and grinding operations and to assure the proper shape factor and recession of the sealant within the reservoir.

Section 3 — DESIGN AND CONSTRUCTION

3.1 MATERIALS

Selection of appropriate repair materials depends upon many factors, including amount of time available before opening to traffic, ambient temperature, cost, and size and depth of repairs.

Many repair projects require that the pavement be reopened to traffic within 4 to 6 hours. A wide variety of rapid-setting and/or high-early-strength repair materials are available to meet this challenge.

Type III Portland cement (with and without admixtures) has been used for partial-depth repairs longer and more widely than most other materials. It is relatively low in cost, readily available, simple to use, and the most compatible material to the existing slab. Type III cement with 2% $CaCl_2$ (by weight of cement) set accelerator has been successful in providing early openings and durable repairs, particularly when rich mixtures (up to 8 sacks [752 pounds] of cement per cubic yard [446 kg per cubic meter] of concrete) are placed in warm weather and bonded with epoxy. Strength gain of such mixtures in cool or cold weather may be too slow to permit quick opening to traffic.

When using a proprietary patching material, it is essential that the manufacturer's recommendations are followed closely. Handling, mixing, placement, consolidation, screeding and curing of the repair material must be in accordance with the manufacturer's written instructions. The specifying agency should investigate the various repair materials available to determine their suitability for application and environment (Ref. 1). Other valuable information on repair material performance can be obtained from agencies that have used the material (Ref. 1). The working tolerances of some of the proprietary repair materials are too tight for most repair projects (i.e., ambient temperature range for placement and curing, exact measurements of quantities, etc.).

Epoxy resin repair mortars and concretes have also been used. Available epoxy resins have a wide range of setting times. The epoxy concrete mix designs must be compatible with the concrete in the pavement. Large differences in the coefficients of thermal expansion can cause debonding and repair failures. Deep repairs may have to be placed in two or more lifts to control heat development.

Calcium aluminate cement (also called high-alumina cement) has been used for partial-depth repairs where high early strength and/or sulfate resistance was desired, but has generally not provided good performance (Ref. 3). This is due to a chemical conversion which occurs in calcium aluminate cement which can cause substantial strength loss. This conversion occurs rapidly at temperatures greater than 86°F [30°C], but also occurs, albeit more slowly, even at temperatures below 68°F [20°C]. If the temperature of concrete made with calcium aluminate cement exceeds 77°F [25°C] <u>at any time</u> in its life, substantial conversion and subsequent strength loss is likely to occur. Temperature in excess of 77°F [25°C] for even a few hours during initial curing can cause severe strength loss resulting in failure of the concrete. The concrete's sulfate resistance is also substantially diminished by the loss in strength. For these reasons, calcium aluminate cement is prohibited for structural use in many countries. Calcium aluminate cement is not recommended for partial-depth repairs.

A grout mixture of Type III Portland cement and sand has provided good bonding between the repair and original slab where the repairs have been protected from traffic for 24 to 72 hours. For best results, a rich (7 sack [658 pounds] of cement per cubic yard [390 kg per cubic meter] of concrete) mixture and 72-hour curing period are recommended. The use of Portland cement grout bonding agents for repairs that must be opened to traffic in 4 to 6 hours is questionable even in hot weather. Although a Portland cement grout can develop an adequate bond, it does take more time to develop the needed bond strength.

3.2 PROCEDURES

The success of partial-depth repairs depends upon many factors, including the removal of all deteriorated concrete, development of an adequate bond with the existing concrete and proper placement, and consolidation and curing of the repair material. The achievement of these factors is discussed in detail herein. Figure C-2 shows an illustration of the general procedures.

a. Delineation and Preparation of Repair Area

The first step in constructing a successful partial-depth repair is the identification and removal of all deteriorated concrete. Unsound concrete is commonly located by "sounding out" the delaminated area with a steel rod, carpenter's hammer, chain or other device. The rod, hammer and chain will produce a clear ring when used on sound concrete and a more dull response on deteriorated concrete. The repair limits should be extended about 2 to 6 inches [51 to 152 mm] beyond the delaminated area to insure removal of all unsound concrete. If the concrete has spalled and tests indicate sound concrete at the spall limits, the saw cut can be made about 2 inches [51 mm] from the spall.

A 2-inch [51-mm] deep vertical saw cut should be made around the perimeter of the repair area to provide sufficient repair thickness to allow the easy placement of repair materials with coarse aggregate up to 0.75 inch [19 mm] in diameter. However, some agencies have reported good success with a 45° sawcut along the boundaries (Ref. 5). Care must be taken to ensure that there is no feathering of repair edges which may result in spalling. Where extremely hard aggregate exists, a 1-inch [25-mm] deep saw cut is adequate and the top size of the repair material coarse aggregate should be reduced accordingly. The "run-out" of the saw cuts in the existing slab should be filled with mortar from the repair material.

Concrete within the repair area should be removed using pneumatic tools until sound and clean concrete is exposed. It is important that properly sized concrete removal tools be used. The use of large jackhammers may damage otherwise sound concrete and necessitate the removal of additional material or the placement of full-depth repairs. Pneumatic hammer size should be limited to 30 pounds [13.6 kg] (lighter for very small repairs).

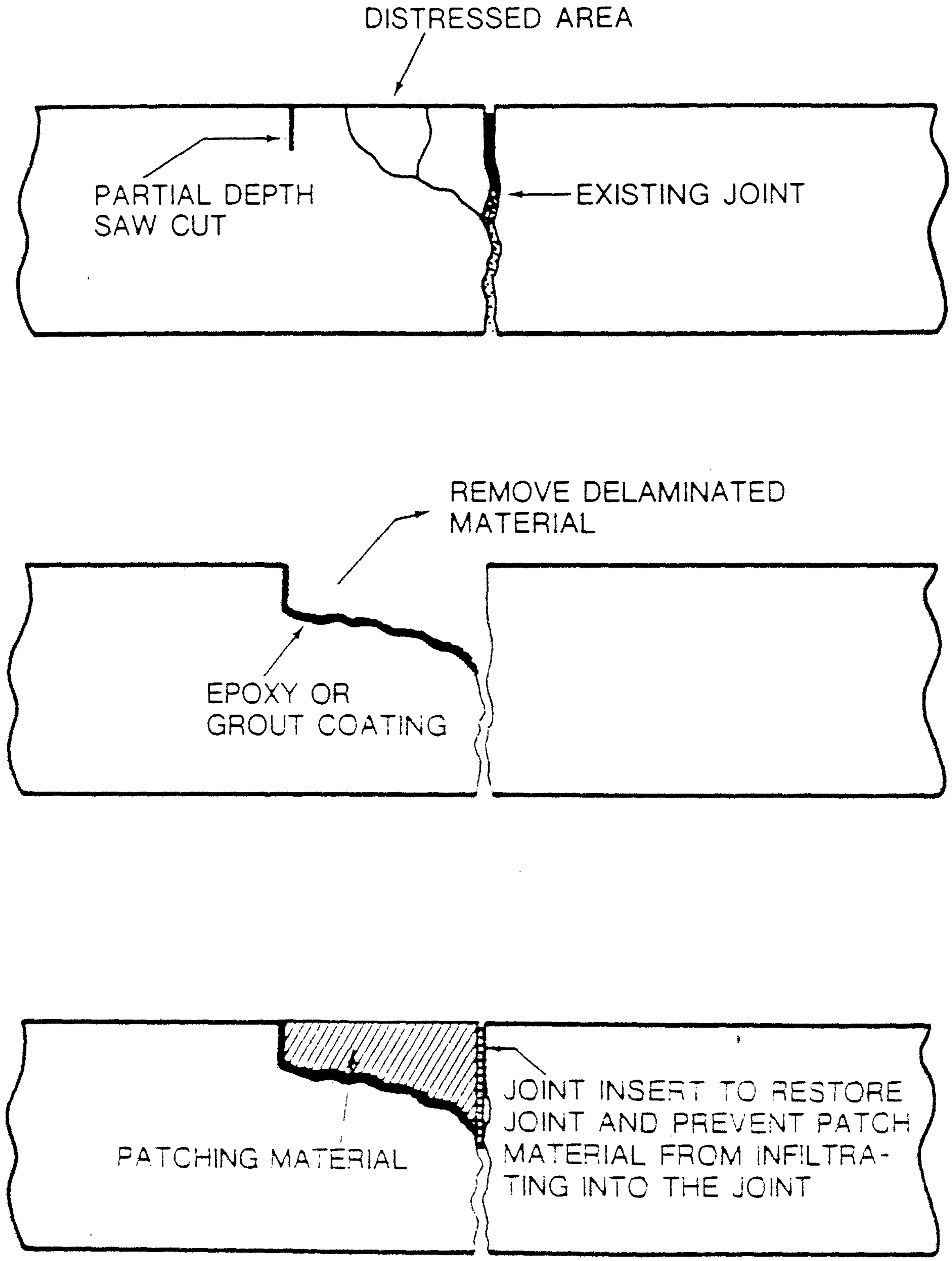


Figure C-2. Steps for Partial-Depth Repairs.

Some states have permitted concrete removal through the use of self-propelled cold milling machines. These have been used primarily on pavements with joint distress caused by "D" cracking or alkali-aggregate reactivity.

If the deteriorated concrete is found to extend below the dowels or other large diameter reinforcement or through more than one half of the slab thickness, strong consideration should be given to the use of full-depth repairs. Coring of representative joints is recommended to determine the depth of deteriorated concrete and assess the suitability of partial-depth repairs.

After removal of the concrete, the surface of the area to be repaired must be cleaned and free of loose particles, oil, dust, traces of asphalt concrete and other contaminants that would inhibit the development of a good bond between the repair material and the underlying slab. Sandblasting is the preferred technique for accomplishing this cleaning; waterblasting has also been used successfully. Air blasting has also been used with less success and additional sandblasting or waterblasting is often required. Sources of compressed air used in the cleaning should be checked for oil leakage (which would contaminate the repair area and inhibit bonding) by placing a clean cloth over the nozzle, releasing air through the cloth and visually inspecting the cloth for evidence of oil.

One of the most common sources of partial-depth repair failure is excessive compressive stresses. Such failures may occur when the repair is cast directly against existing adjacent slabs and insufficient room is provided for daily thermal expansion and contraction slab movements. They may also occur when the repair material is allowed to infiltrate the joint or crack below the bottom of the repair, thereby preventing the crack or joint from functioning and restraining the slabs from moving. In either case, spalling or failure of the repair may result. The risk of such failures can be reduced during the preparation of the repair area by placing compressible inserts in the cracks and joints (from the pavement surface to below the bottom of the repair) to prevent the repair material from restricting slab movement. Plastic sheeting can also be used to isolate the repair from adjacent panels that are not likely to crush the repair (along the longitudinal joint).

Where spalling has been caused by the corrosion or entrapment of incompressibles in a metal joint forming insert (such as a Unitube), the spalls usually start at the bottom fin of the insert, about 2.5 inches [64 mm] below the surface. When repairing this type of spall, it is recommended that the insert be sawed out along the entire length of the joint to avoid further spalls. Small spall areas along joints generally do not require repair (unless preformed compression seals are to be used, in which case <u>all</u> spalls must be repaired) and minimum spall sizes to require repair can be established. For instance, areas less than 6 inches [152 mm] in length and 1.5 inches [38 mm] in width at the widest point may not require repairs but could be filled with a sealant. After the repairs have been placed and the sealant reservoirs have been reestablished, the joints can be resealed.

b. Placing Repair Materials

1. Portland Cement Concrete Repair Material

After the repair area is properly cleaned, a bonding agent should be applied. The type of bonding agent will depend upon the bond development requirements for opening to traffic. If early opening is required (4 to 6 hours), an epoxy agent should be used. A prime coat of epoxy resin binder, thinned with 3 parts toluene to 7 parts epoxy binder by volume, should be applied to the dry, cleaned surface and sides of the repair area except for the adjacent joint face or crack. The prime coat should be applied in a thin coating and scrubbed into the surface with a stiff-bristled brush. Placement of the concrete should be delayed until the epoxy becomes tacky.

When repairs can be closed to traffic for a longer period of time (24 to 72 hours), a sand-cement-slurry mixture may be used for bonding the repair. The bonding grout should be composed of 1 part sand and 1 part cement by volume, with sufficient water to produce a mortar with a thick, creamy consistency. The grout should be scrubbed evenly over the dry surface of the repair area. Excess grout should not be permitted to collect in pockets. The concrete repair material should be placed before the bonding grout dries.

If the spalled area abuts a working joint or crack which penetrates the full depth of a slab, an insert or other bond-breaking medium should be used to maintain working joints or cracks.

Portland cement concrete repairs should not be placed when the air temperature or pavement temperature is below 40°F [4°C]. At temperatures below 55°F [13°C], a longer cure period may be required. An insulation covering may be placed to accelerate curing.

The concrete for repairing spalls should have a minimum compressive strength of 3,000 psi [20.7 MPa] in 24 hours when early opening is required. This accelerated strength gain can be obtained by using not more than 8 bags of Type III cement per cubic yard and calcium chloride in an amount not to exceed 2 percent by weight of the cement, or other accelerating admixtures. Where longer cure periods are permissible, a concrete strength of 3,000 psi [20.7 MPa] at the time of opening to traffic or within 3 days should be specified.

Partial-depth repairs (all materials) placed across working joints or cracks must include reestablishment of the joint or crack directly above the existing joint or crack in the underlying slab to percent cracking of the repair.

2. Rapid-Setting Repair Materials

These materials include rapid-setting and/or high-early-strength repair materials which are available on the market. Before specifying any of these products for use on a large project, it is recommended that their reliability be tested on an experimental basis over a minimum 2-year time period.

The manufacturer's recommendations should be closely followed with regard to mixing and placing the repair material. Bonding agents should be those recommended by the manufacturer for the placement conditions.

3. Epoxy Repair Materials

Epoxy repair materials should be used in accordance with the manufacturer's recommendations. Prior to placing the repair, the cavity should be primed with a thin coating of epoxy resin binder scrubbed into the surface. The epoxy concrete or mortar should then be placed in the cavity in layers not exceeding 2 inches [51 mm]. The time interval between placing of additional layers should be such that the temperature of the epoxy resin concrete does not exceed 140°F [60°C] at any time during hardening. A mechanical plate, screed float vibrators or hand tamper should be used to consolidate the concrete or mortar.

c. Curing

The proper curing of partial-depth repairs is crucial to obtaining good repair performance because shrinkage and curling stresses in partial-depth repairs can cause bond failure and delamination of the repairs. These stresses may be very high in partial-depth repairs because they typically have a relatively small mass in which to retain their heat of hydration and a large surface area through which to lose this heat. The following paragraphs discuss appropriate curing techniques for various materials.

1. Portland Cement Concrete Repair Materials

Various curing methods have been specified for concrete repairs, including white pigmented curing compound, wet sand, burlap or polyethylene sheeting. Where longer cure periods are specified (24 to 72 hours) the use of the curing compound method is recommended.

The use of white pigmented curing compound is the most positive curing method available. A heavy coat (150 square feet/gallon [3.7 square meters/liter] maximum) should be applied to the partial-depth repair immediately after texturing to retain moisture for adequate hydration of the cement.

The use of wet sand or burlap requires re-wetting for proper cure. Traffic in the adjacent lane can also accelerate drying and make holding the burlap or polyethelyne sheeting on the repair difficult.

In cold weather, insulation of the repairs is essential to proper curing.

2. Proprietary Repair Materials

Proprietary repair materials should be cured as recommended by the manufacturer of the product.

3. Epoxy Repair Materials

Epoxy repair materials should be cured as recommended by the manufacturer of the product.

Section 4 — PREPARATION OF PLANS AND SPECIFICATIONS

When there is a substantial amount of partial-depth repair (or full-depth repair) work to be done, a condition survey capable of identifying repair locations and providing accurate quantity estimates should be conducted. This can be accomplished through manual surveys, aerial photographs or automated survey equipment.

The Guide Specifications accompanying these Design and Construction Guidelines are recommended for use after they have been revised to reflect local conditions.

REFERENCES

1. Baker, W.M. and R. G. Price, "Concrete Patching Materials," Federal Highway Administration Report No. FHWA-RD-74-55, 1980.

2. Tyner, H.L., "Concrete Pavement Rehabilitation -- Georgia Methodology," National Seminar On Portland Cement Concrete Pavement Recycling And Rehabilitation, Transportation Research Board, St. Louis, Mo., 1981.

3. Mindess, S. and J. F. Young, Concrete, copyright 1981 by Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

4. Darter, M. I., E. J. Barenberg, and W. A. Yrjanson, "Joint Repair Methods for PCC Pavements--Design and Construction Guidelines," NCHRP Report No. 281, Transportation Research Board, 1985.

5. Ortiz, D., E. J. Barenberg, M. I. Darter, and J. Darling, "Effectiveness of Existing Rehabilitation Techniques for Jointed Concrete Pavements," Federal Highway Administration Report No. FHWA/IL/UI-215, 1986.

PARTIAL-DEPTH REPAIR OF JOINTED CONCRETE PAVEMENTS

PART 2: GUIDE SPECIFICATIONS

Section 1 — GENERAL

This specification covers the use of Portland cement concrete, proprietary rapid-setting materials and epoxy resin for making partial-depth repairs to concrete pavements.

1.1 DESCRIPTION OF WORK. This work shall consist of partial-depth repairs of spalls, potholes, scaling or other surface distress in Portland cement concrete pavements. The repair area shall be prepared by removal of asphalt concrete, or broken, damaged or disintegrated concrete from the area indicated. Repairs shall be made with approved repair materials in accordance with this specification and in close conformity with the existing pavement cross-section.

1.2 LOCATION. The locations and approximate areas of the repairs are shown on the plans. However, the final locations and boundaries of each repair will be designated by the Engineer.

1.3 STANDARD SPECIFICATIONS. The standard specifications applicable to the work on this project are as published in the current edition of (Local, State, Special) "Standard Specifications."

Section 2 — MATERIALS

2.1 MATERIAL SPECIFICATIONS.
The materials used shall meet the requirements of the following AASHTO specifications:

Portland Cement	M-85
Aggregates	M-80 & M-6
Curing Compound	M-148
Concrete Admixtures	M-194
Calcium Chloride	M-144
Epoxy Resin Adhesives (Class I & III)	M-235
Rapid-Setting Patching Materials	approved list
Fine Aggregate for Epoxy Concrete gradation specified by epoxy manufacturer	
Coarse Aggregate - Size 89 AASHTO	M-43

2.2 REPAIR MIXTURES.

a. Accelerated-Strength-Gain Portland Cement Concrete Mixture

Accelerated strength gain shall be obtained by using Type I or Type III Portland cement and calcium chloride or other accelerator to obtain a minimum strength of 3,000 psi [20.7 MPa] in 24 hours. The plastic concrete shall have an air content of 6.5 percent ± 1.5 percent. The slump shall be 1 to 3 inches [25 to 76 mm] at time of placing.

b. Portland Cement Concrete Mixture

Normal-setting Portland cement concrete mixture shall have a minimum compressive strength of 3,000 psi [20.7 MPa] in 3 days or when opened to traffic. The plastic concrete shall have an air content of 6.5 percent ± 1.5 percent and a slump not to exceed 3 inches [76 mm] at time of placing unless a higher-range water reducing system is used.

c. Rapid-Setting Repair Materials

Rapid-setting repair materials shall have a minimum compressive strength of 3,000 psi [20.7 MPa] in 24 hours.

d. Epoxy Resin Repair Mortars

Epoxy resin repair mortars shall be prepared in accordance with the manufacturer's recommendations regarding suitable aggregates and gradation of aggregate.

Section 3 — EQUIPMENT

3.1 GENERAL. The contractor shall furnish and maintain such equipment as necessary to complete the work in accordance with the specifications.

3.2 CONCRETE SAW. The concrete saw shall be equipped with a diamond blade or approved equal. The saw shall be capable of sawing concrete to the specified depth.

3.3 CONCRETE REMOVAL EQUIPMENT. The contractor shall provide equipment capable of removing the concrete in the repair area to the depth required without damaging sound concrete below the deteriorated concrete.

3.4 PROPORTIONING AND MIXING EQUIPMENT. The proportioning and mixing equipment shall meet the appropriate specifications and be capable of uniformly producing a concrete mixture adequate in quality and consistency. Mobile mixing equipment shall be permitted subject to the appropriate specifications.

3.5 FINISHING AND FLOATING EQUIPMENT AND STRAIGHTEDGES. The finishing and floating equipment shall be capable of consolidating, screeding, and floating the concrete. A dense, homogeneous concrete repair must be produced, and finished to the same surface slope as the existing concrete slab.

3.6 PRESSURE HAND SPRAYER FOR MEMBRANE CURING COMPOUND. Manually operated spray equipment may be used to apply curing compound.

3.7 INSULATING BLANKETS. Two-inch [51-mm] thick minimum insulation blankets shall be provided with a protective covering to avoid disintegration.

Section 4 — CONSTRUCTION METHODS

4.1 DETERMINATION OF REPAIR AREAS. Areas to be repaired shall be determined by the Engineer using a rod, hammer or other device to determine defective or delaminated areas. The extent of the repair area will be marked by the engineer. Areas less than 6 inches [152 mm] in length and 1.5 inches [38 mm] in width at the widest point shall not be repaired under this specification but shall be filled with a joint sealant material in accordance with the standard specifications.

4.2 PREPARATION OF REPAIR AREAS. A saw cut shall be made around the perimeter of the repair area to provide a vertical face at the edges and sufficient depth for the repair. The saw cut shall have a minimum depth of 2 inches [51 mm].

Concrete within the repair area shall be broken out to a minimum depth of 2 inches [51 mm] with pneumatic tools until sound and clean concrete is exposed. The maximum size pneumatic hammer shall be 30 pounds [13.6 kg]. The proper size tools must be used to prevent fracture of the sound concrete below the repair area.

The exposed faces of the concrete shall be sandblasted free of loose particles, oil, dust, traces of asphalt concrete and other contaminants before placement of repair material. All sandblasting residue must be removed just prior to placement of the concrete bonding agent. Air hoses may be used for this purpose.

4.3 PLACING REPAIR MATERIAL

a. Accelerated Portland Cement Concrete Patch Mixtures

Accelerated-strength-gain Portland cement concrete (3,000 psi [20.7 MPa] in 24 hours) repair mixtures can be used where early opening (4 to 6 hours) to traffic is required. An epoxy bonding agent is required when placing high-early-strength PCC repairs for early opening to traffic. The epoxy prime coat shall be applied in a thin coating and scrubbed into the surface with a stiff bristled brush. Placement of the concrete should be delayed until the epoxy becomes tacky.

Where repairs are opened to traffic in 24 hours or more after placement, a sand-cement grout may be used for bonding the patch. The bonding grout shall be composed of 1 part Portland cement to 1 part sand by volume with sufficient water to produce a mortar with thick, creamy consistency. The grout shall be scrubbed evenly over the surface of the patch. Excess grout shall not be permitted to collect in pockets. The concrete repair material shall be placed before the bonding grout dries.

The repair mixture shall be placed and consolidated to eliminate essentially all voids at the interface of the repair and the existing concrete. If a partial-depth repair area abuts a working joint or crack which penetrates the full depth of the slab, an insert or other bond-breaking medium shall be used to maintain working joints or cracks. Contact between the repair and any adjacent slab which could cause compression or other types of failure in the repair must be prevented.

High-early-strength PCC repairs should not be placed when the air or pavement temperature is below 40°F [4°C]. At air temperatures below 55°F [13°C], a longer cure period may be required. All repairs shall be finished to the cross-section of the existing pavement. The repair shall be textured with a stiff-bristled brush or other means to conform to that on the existing pavement.

The curing compound shall be applied immediately after texturing at the rate of 150 square feet/gallon [3.7 square meters/liter].

b. Normal-Set Portland Cement Concrete Repair Materials

Normal-setting (3,000 psi [20.7 MPa] in 3 days) Portland cement concrete repair materials may be used where the repair is protected from traffic for 24 hours or more. The sand-cement grout discussed in part (a) of this section may be used as a bonding agent. The repair mixture shall be placed and consolidated to eliminate essentially all voids at the interface between the repair and adjacent concrete. All repairs shall be finished to the cross-section of the existing pavement.

The repair shall be textured with a stiff-bristled brush or to conform to that on the existing pavement. The curing compound shall be applied immediately after texturing at the rate of 150 square feet/gallon [3.7 square meter/liter].

c. Rapid-Setting Repair Materials

Rapid-setting repair materials shall be installed in accordance with the manufacturer's written instructions. The preparation of the repair area surface shall be as outlined under accelerated PCC repair material except where written instructions specify otherwise. The method of bonding, placing and curing shall be as recommended by the manufacturer. The time period recommended before opening to traffic shall also be observed.

d. Epoxy Resin Repair Mortars or Epoxy Concrete

Epoxy mortar and epoxy concrete mix designs shall be submitted to the laboratory for verification and approval. Those designs determined to be compatible with concrete pavement will be approved.

The epoxy resin and the catalyst shall be preconditioned before blending to produce a blended liquid that is between 75°F and 90°F [24°C and 32°C]. The epoxy components shall be mixed in strict compliance with the manufacturer's mixing recommendations before aggregates are added to the mixture. The mixture shall be blended in a suitable mixer (as specified) to produce a homogenous mass. Only that quantity of material that is usable in one hour shall be mixed at one mixing. Material that has begun to generate appreciable heat shall be discarded.

The entire surface of the repair area shall be primed with neat blended epoxy immediately before the mixture is placed. Priming shall include overlapping the surface of the area adjacent to the repair. The mixture shall be placed and tamped with sufficient effort to eliminate voids and to thoroughly compact the product. The surface shall be screeded and textured to produce the required finish. The repaired area shall be allowed to remain undisturbed for at least 3 hours before it is subjected to traffic.

e. The saw cut "run-outs" in the existing slab shall be filled with the mortar phase of the repair material.

Section 5 — WEATHER CONDITIONS

Portland cement concrete repairs should not be placed when the air or pavement temperatures are below 40°F [4°C]. At temperatures below 55°F [13°C], a longer cure period may be required. Insulation may be used to improve the rate of curing.

Section 6 — MEASUREMENT AND PAYMENT

6.1 MEASUREMENT. The area measured for payment will be the number of square feet of surface area of partial-depth repair completed in place and accepted.

6.2 PAYMENT. The area measured as provided above will be paid for at the Contract Unit Price per square foot. Such payment shall be full compensation for: any required sawing; removing asphalt concrete patching material or spalled, broken or damaged Portland cement concrete; cleaning the surface by sandblasting; furnishing, placing, finishing and curing the concrete repair; and forming a new transverse and longitudinal joint, including all equipment, tools, labor and incidentals necessary to complete the work.

Payment will be made under:

Partial-depth repair of Portland cement concrete pavement ___ per square foot.

APPENDIX D

DESIGN AND CONSTRUCTION GUIDELINES AND GUIDE SPECIFICATIONS FOR JOINT RESEALING

Acknowledgment

These guidelines and specifications were originally prepared under NCHRP Project 1-21 conducted at the University of Illinois and published in NCHRP Report No. 281, Transportation Research Board, 1985. The guidelines have been updated in 1987 based upon the findings and results from the study entitled "Pressure Relief and Other Joint Rehabilitation Techniques" under contract DTFH61-83-C-00111 between the Federal Highway Administration and ERES Consultants, Inc. On-going research concerning this rehabilitation technique is being performed at the University of Illinois under FHWA contract DTFH61-85-C-00004, "Determination of Rehabilitation Methods for Rigid Pavements."

RESEALING JOINTS IN CONCRETE PAVEMENTS

PART 1: DESIGN AND CONSTRUCTION GUIDELINES

Section 1 — INTRODUCTION

These guidelines present important background information for engineers and technicians involved in designing and constructing projects where transverse joints are to be resealed. These guidelines will also be useful to maintenance personnel in resealing joints as part of effective preventive maintenance practice.

1.1 NEED FOR RESEALING

Effective resealing of transverse joints in plain and reinforced jointed concrete will accomplish the following:

1. Clean out existing incompressibles in the joint and provide an improved seal to reduce further infiltration. Many jointed concrete pavements have been observed in all areas of the U.S. to be suffering from the effects of infiltration of incompressibles. Distress manifestations include joint spalling and blowups. Jointed reinforced concrete pavements (JRCP) particularly show these distresses because of the large joint movements. Blowups have begun to occur in JRCP in many states in as few as 7 years after construction because of the failure of the sealant to keep out incompressibles.

   Even short-jointed plain concrete pavements (JPCP) have been observed to develop substantial joint spalling where extensive incompressibles exist (e.g., mountain grades where sand is used for traction).

   The policy of using pressure relief joints as a substitute for careful joint maintenance (to solve the problem of a buildup of compressive forces due to incompressibles in the joints) has been found to have very detrimental effects to pavements and hence should only be used as described in Appendix A.

2. Provide a seal to reduce water infiltration (and chlorides in freeze areas) into the joint. Free water beneath the slab or subbase results in pumping of fines which lead to joint faulting and corner breaks and slab breakup. Pavements located in freeze areas also suffer from freeze-thaw damage from saturated PCC near the joints (particularly where freeze-thaw-susceptible aggregate has been used in the PCC, resulting in "D" cracking).

   For joints with mechanical load transfer devices (dowels), the infiltration of water and chlorides causes the steel to corrode. The dowels lock up and prevent the joint from functioning properly. As a result, transverse cracks open up and function as joints. This may also cause spalling near the joints from large compressive and tensile forces.

The determination of sealing needs should consider the amount of distress caused by moisture and incompressibles. If it is determined that moisture could cause or is causing a serious problem, sealing of all joints and cracks should be considered (including the lane/shoulder joint).

1.2 LIMITATIONS

The major purpose of resealing joints is to extend the life of the pavement joints. However, very little, if any, extended life will be obtained if resealing is performed under the following conditions.

1. The pavement is already badly deteriorated. Only with extensive rehabilitation in addition to joint resealing might this be effective.

2. The pavement has good subdrainage or is located in an area with very little moisture. However, incompressibles may still cause serious problems, in which case joint resealing would be very beneficial (particularly for long-jointed JRCP).

3. The pavement carries very little heavy truck traffic. Incompressibles may still be a serious problem, however, and resealing would then be beneficial.

4. Poor quality sealant or poor construction techniques are used to reseal the joints, or the joint sealant reservoir is not properly designed.

5. The pavement has too many pressure relief joints. This can result in slab movements larger than can be accommodated by the sealant.

1.3 EFFECTIVENESS

Proper resealing of joints will lead to an extension of pavement joint life. The life extension need only be a few years to pay for the joint reseal. A few agencies have recognized the cost-effectiveness of preventive maintenance and have developed a regular resealing program on their jointed concrete pavements. Results from NCHRP Project 1-19 showed that proper joint sealing reduced joint deterioration by 50 percent (Ref. 5).

Of course, the cost-effectiveness of joint resealing is dependent on the specific pavement condition and on other rehabilitation work performed concurrently. Obviously, joint resealing must be timely to ensure that optimum effectiveness is obtained. This requires that resealing be performed before serious joint deterioration has occurred.

Section 2 — CONCURRENT WORK

Several types of repair should be considered along with joint resealing. The actual need depends upon the specific existing design, distress, traffic, subgrade, and climate. However, the following work items should be considered.

1. Full-depth repair of badly deteriorated joints and cracks.

2. Partial-depth spall repair where the deterioration does not extend below mid-slab.

3. Resealing of other joints (longitudinal, lane/shoulder) and working cracks.

4. Subdrainage improvement.

5. Restoration of load transfer where poor load transfer exists.

6. Subsealing of voids beneath the joints and cracks.

If grinding of the surface is to be accomplished, it must be performed <u>before</u> the resealing operation so that the seal can be properly recessed beneath the top of the ground slab.

Section 3 — DESIGN

The design of a joint resealing project requires a determination of the purposes of resealing, examination of the existing joint sealant, selection of sealant type, selection of joint reservoir dimensions, and repair of existing joints.

3.1 PURPOSE AND EXISTING CONDITIONS

The following questions should be asked when joint resealing is being considered:

1. What is the designated purpose of the sealant? It may be to protect against water infiltration, to protect against incompressible intrusion, or both.

2. What is the condition of the present sealant? By conducting a thorough examination of the present sealant condition, future failures might be avoided. Pavements exhibiting a substantial amount of high-severity sealant damage should be programmed for resealing as soon as possible. Low-severity sealant damage does not warrant resealing work. Joints exhibiting medium-severity sealant damage should be resealed within the next two years, depending on the proportion of joints that are near the high-severity condition.

3. What is the condition of the joint? The joint condition affects how the sealant will perform in the future and also indicates the relative need for resealing. Several distress types such as

spalling, faulting, settlement/heave and corner breaks may have to be repaired prior to effectively resealing the joint.

Joint condition also influences the selection of the sealant used in resealing the joint. A field-molded sealant may perform satisfactorily in a joint with small spalls while a preformed compression sealant will not.

4. What is the existing joint sealant reservoir shape factor? A small segment of the sealant should be removed from several joints and the joint sealant reservoir width and depth measured. The pavement temperature must also be measured at the time the reservoir width and depth are measured.

5. What concurrent work must be accomplished so that the sealant can perform satisfactorily? Very often other repair techniques (i. e., partial-depth spall repair, restoration of load transfer, subsealing, etc.) should be performed to ensure the success of the joint sealing operation.

3.2 SELECTION OF SEALANT TYPE

The sealant selected must have the capability to withstand:

1. Horizontal movement and vertical shear if poor load transfer exists at all temperatures encountered.

2. Effects of the environment such as ultraviolet light, extreme temperatures, moisture, etc.

Three different types of sealants are recommended in Section 4.1 MATERIALS and in the Guide Specifications:

1. Hot-poured, elastomeric type materials.

2. Low-modulus silicone.

3. Preformed compression sealant.

These sealant types have given good performance for periods ranging from 4 to 15 years when installed properly. Other sealants used by an agency that have shown at least 5 years of acceptable performance should also be considered. The cost of joint preparation, traffic control, etc., requires that the sealant be of sufficiently high quality to last at least 5 years and preferably much longer.

A life-cycle cost comparison should be performed among the sealants considered acceptable for the project. The sealant type having the lowest average annual cost should be selected (assuming it meets other constraints) and specified in the plans and specifications.

3.3 JOINT SEALANT RESERVOIR DIMENSIONS

The performance of field-molded sealants is heavily dependent on the shape and dimensions of the joint reservoir. <u>The ratio of depth (D) to</u>

width (W) is known as the sealant shape factor. Research studies have shown that, for hot-poured and elastomeric sealants, the closer D/W is to one, the lower the stresses and strains and the better the subsequent performance of the sealant. For low-modulus silicones, the best sealant reservoir shape factor is 0.5.

A sufficient depth of sealant is also required to ensure adequate adhesion between the joint face and the sealant. Most manufacturers recommend a minimum sealant depth. For hot-poured elastomeric sealants, a depth of 0.5 to 1 inch [13 to 25 mm] is normally recommended to provide adequate adhesion with the joint sidewalls. For silicone sealants, a minimum depth of 0.25 inch [6 mm] to a maximum 0.5 inch [13 mm] is recommended.

Most existing joints have very poor shape factors and will therefore require widening to provide for a better shape factor and adequate depth for field-molded sealants.

The required width of the joint is dependent upon the horizontal movement. The width must be adequate to accommodate an acceptable level of tensile strain in the sealant in cold weather. Horizontal movement is caused primarily by daily and seasonal variations in temperature. The amount of opening or closing of any discontinuity (i.e., joint or crack) depends on change in temperature, spacing between working joints or cracks, friction between the slab and base, the ability of the joint load transfer devices to allow opening and closing, and the thermal coefficient of expansion of the concrete.

For design purposes, the mean transverse joint opening (change in joint width) that occurs over a time interval can be estimated using the following expression (Ref. 2).

$$DL = C\,L\,[\,a\,DT + e\,]$$

where:

DL = mean change in joint width, inches;

C = an adjustment factor to account for subbase/slab friction restraint (use 0.65 for stabilized subbase, 0.80 for granular base);

L = joint spacing, inches;

a = thermal coefficient of contraction or expansion for Portland cement concrete ($5\text{-}6 \times 10^{-6}/^{o}F$ [$9\text{-}10.8 \times 10^{-6}/^{o}C$]);

DT = change in temperature, ^{o}F (could be estimated as the difference between the mean monthly temperature in the month the refacing will likely be performed and the lowest and highest mean monthly temperature for the year); and

e = the drying shrinkage coefficient of the PCC slab ($0.5\text{-}2.5 \times 10^{-4}$ strain), which can be neglected in resealing work.

For example, if a JRCP had a joint spacing of 35 feet [10.7 m] and a cement-stabilized base course, the following mean joint opening would be computed for a temperature drop of 65°F [18°C]:

$$DL = 0.65*35.0*12.0 \; [\; 6*10^{-6} *65 + 0 \;]$$

$$= 0.11 \text{ inches } [3 \text{ mm}]$$

For a given project there are many joints and each opens a different amount for any given drop in temperature. However, for design purposes computing the mean opening in this manner provides reasonable results.

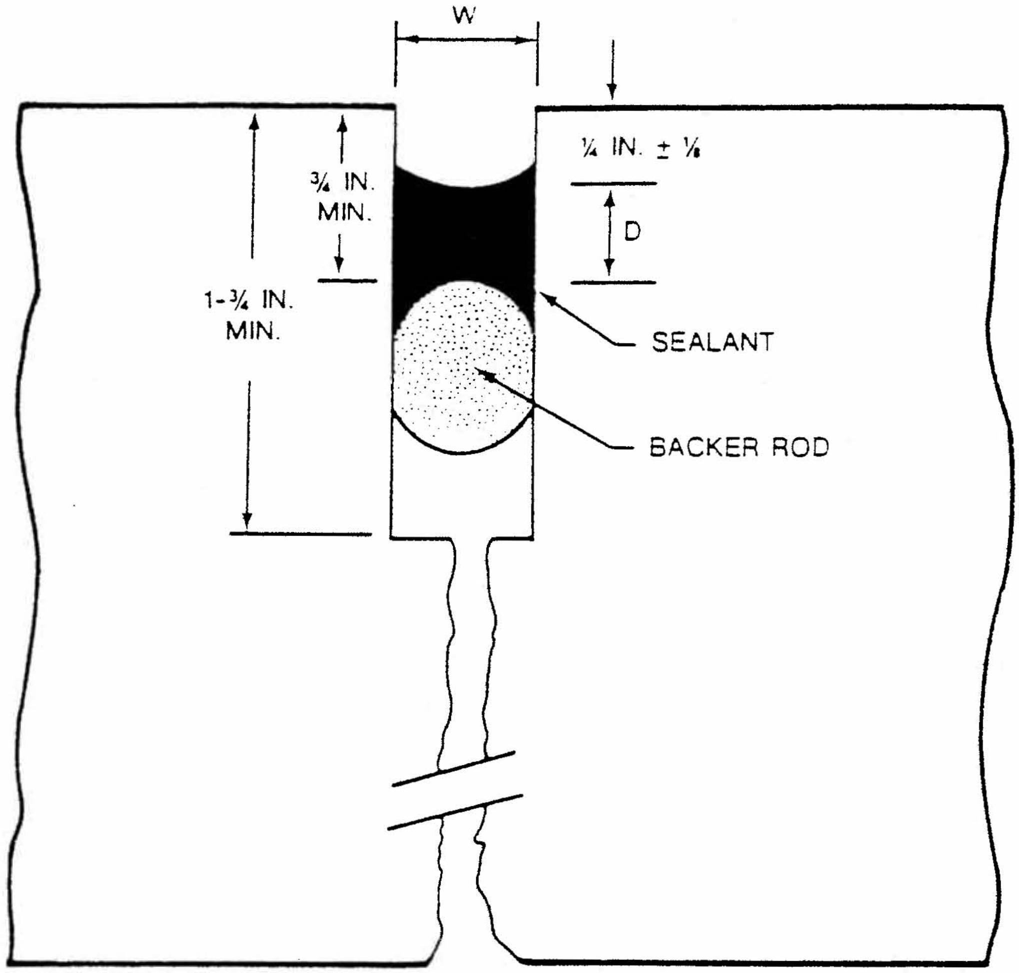
The required width of the joint can then be computed for a given sealant type. For example, if the sealant can handle 20 percent tensile strain, the required width for 0.11 inches [3 mm] of opening is computed as follows:

$$\text{JOINT WIDTH} = 0.11 \;/\; 0.2 = 0.55 \text{ inches } [14 \text{ mm}]$$

This value could be rounded to .625 inches [16 mm] for construction purposes. If a depth of sealant of 0.75 inch [19 mm] was recommended by the manufacturer for adhesive bond to the slab, a shape factor of 0.75 / 0.625 = 1.2 is obtained, which is acceptable. Some typical joint widths and depths for hot-poured sealants (20 percent allowable tensile strain) and for low-modulus silicone sealants (50 percent allowable tensile strain) are given in Figures D-1 and D-2, respectively. The freeze area widths are slightly greater because the temperature drop is greater. Additional example calculations are provided in Reference 2.

A backer rod is strongly recommended with hot-poured sealants to provide the desired shape factor and prevent three-sided adhesion. A maximum reservoir width of one inch is recommended to prevent direct traffic exposure. Most of the field-molded sealants can either be tracked out of a wide joint by traffic or wear away because they are not very abrasion-resistant. For this same reason, sealants must be recessed approximately 0.25 inch [6 mm] below the surface (depending on the season of installation). Joint widths greater than this also cause significant roughness.

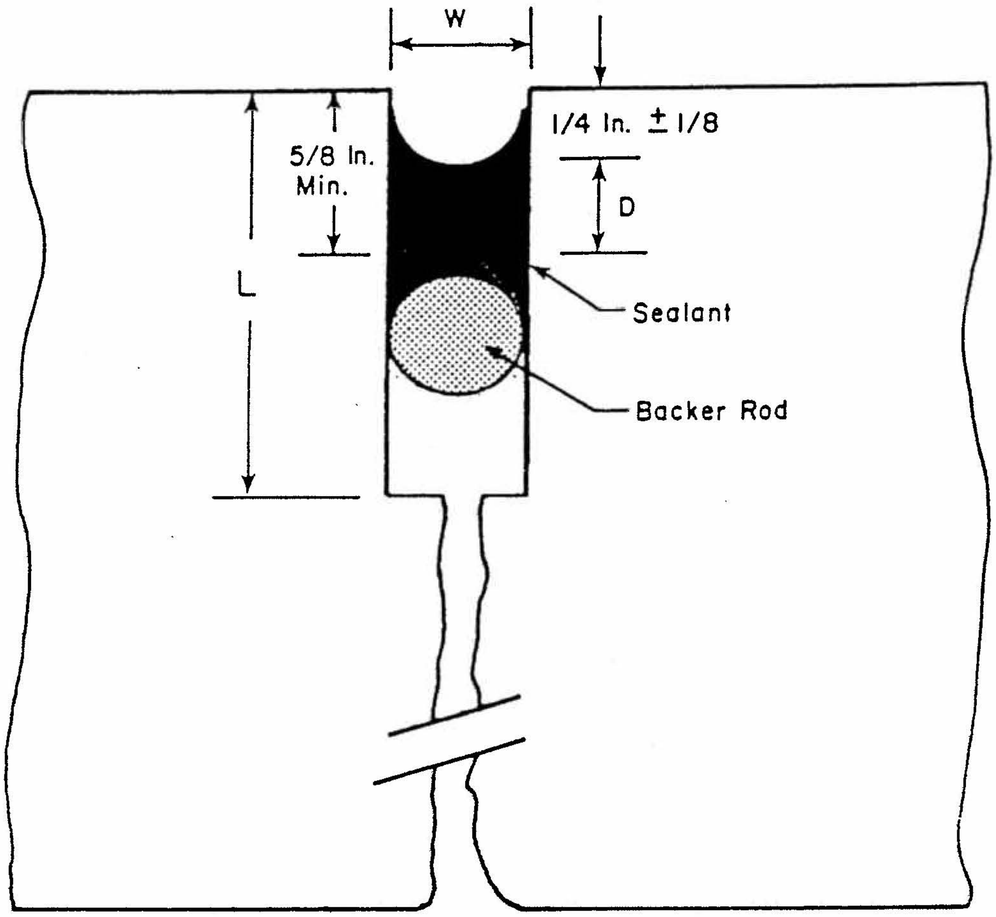
Preformed compression seals rely only on compressive forces to keep them in place. There is little or no bond between the seal and the joint face. If the joint opens too wide, the seal will either fall into the joint or be pulled out by traffic. If the sealant is compressed too much, it will take on a compression set and not be able to open up when the joint opens again. Manufacturer's requirements normally call for a design working range of 50 to 80 percent of the original preformed compression seal width. For example, the working range of a 1-inch [25-mm] wide original uncompressed sealant is 0.5 to 0.8 inches [13 to 20 mm]. Therefore, if the joint opened to a width of 0.9 inches [23 mm] in the winter the sealant may likely drop into the joint due to insufficient compression. A joint width of 0.35 inches [9 mm] during the summer may result in compression set of the sealant, and it may then drop into the joint the next winter when the joint opened again. Determining the most appropriate joint width and sealant width for a given resealing project is a trial-and-error procedure.



JT. SPACING (FT.)	D (INS.)	FREEZE AREA W (INS.)	NON-FREEZE AREA W (INS.)
≤ 20	½ - 1	½	⅜
21 - 40	½ - 1	¾	½
41 - 60	½ - 1	1	¾
61 - 100	*	*	*

* REQUIRED JOINT WIDTH EXCEEDS 1 IN. TO MAINTAIN STRAIN BELOW 20% IN SEALANT.

Figure D-1. Hot Pour Sealant Recommendations.



Jt. Spacing (Ft.)	D (Ins.)	L (Ins.)	Freeze Area W (Ins.)	Non-Freeze Areas W (Ins.)
≤ 20	1/4	1-1/4	1/4	1/4
21-40	1/4	1-1/2	1/2	3/8
41-60	3/8	1-3/4	5/8	1/2
61-80	1/2	2	3/4	5/8
81-100	1/2	2-1/2	1	3/4

Figure D-2. Silicone Sealant Recommendations.

For example, consider the following design situation for the previous pavement conditions:

1. Assume that it was practical to reface the joint to a 0.5 inch [13 mm] width.

2. A 0.75-inch [19 mm] wide preformed compression sealant will be tested to determine its adequacy.

3. The maximum joint width that the preformed compression sealant could withstand is 0.8 * 0.75 = 0.60 inches [15 mm] to keep the seal within the joint.

4. The minimum joint width that the sealant could withstand is 0.5 * 0.75 = 0.375 inches [10 mm] to keep the seal from having compression set.

5. Assume that the mean temperature in June, when the refacing will be done, is 80°F [27°C].

6. Assume that the lowest mean monthly temperature is 15°F [-9°C] in January. The joint will open 0.11 inches [3 mm] and result in a joint width of 0.61 inches [15.5 mm], which is very close to the 0.60 inch [15 mm] width maximum and thus acceptable.

7. Assume that the maximum mean monthly temperature is 90°F [32°C] in July. The joint will close 0.02 inches [0.5 mm] and result in a joint width of 0.48 inches [12 mm] which is well above the 0.375 inches [10 mm] minimum width.

Thus, this sealant width and joint width would be acceptable for this design situation and climate. It should be emphasized that actual joint movements be measured on projects with similar design to determine required sealant properties.

The sealing of longitudinal joints is different because much less movement occurs at this location. A minimum width of 0.25 inch [6 mm] recommended. It is considered very important to seal the longitudinal joints since a substantial amount of water infiltrates through these joints (including the lane/shoulder joint).

3.4 REPAIR OF AN EXISTING JOINT

Spalling along a joint can cause problems with the sealant. The preformed compression seal will not perform well if the joint is uneven and spalled. Therefore, if preformed sealants are to be used, careful consideration must be given to the repair of all spalling along the joint. Field-molded sealants can handle more spalling, but major spalls (greater than 1.5 inches [38 mm] in width) must be repaired before sealing.

Section 4 - CONSTRUCTION

4.1 MATERIALS

a. Sealants.

The following basic sealant types are recommended in the Guide Specifications:

1. Hot-poured, elastomeric-materials that meet ASTM D3406. This specification requires that the material pass an artificial weathering test among other tests. This test provides an indication of the ability of the sealant to withstand environmental effects (ultraviolet light).

2. Low-modulus silicone that meets specifications similar to those of the Georgia Department of Transportation. This is a relatively new material but service lives of over 5 years have been consistently obtained. ASTM is currently working on a specification.

3. Preformed polychloroprene elastomeric seals that meet ASTM D2628 or AASHTO M220. This material has provided over 10 years of service when used in new pavements, and if joint spalls are repaired, should show similar performance in existing pavements. However, this sealant should not be used if the joint is uneven and moderately spalled.

   The other major problem with this seal is the presence of pressure relief expansion joints. These joints close, and any transverse joints within 200 to 300 feet [61 to 91 m] will typically open allowing the sealant to drop down into the joint. Therefore, this type of sealant should not be used if there are pressure relief joints along the project (pressure relief joints at structures do not usually cause major problems).

4. Field-poured, hot-applied thermoplastic asphalt-rubber sealant compounds that meet ASTM D3405. These sealants provide the shortest life but are economical.

Other sealants used by an agency that have been shown to provide at least 5 years of acceptable performance should also be considered. The cost of joint preparation, traffic control, etc., requires that the sealant be of sufficiently high quality to last at least 5 years and preferably longer.

b. Backer Rod (Field-Molded Sealants Only).

Backer rod material provides support to the sealant material to provide uniform thickness and to prevent sagging and indentation in the field-poured, field-molded sealants. They provide the proper shape factor for the sealant, and they help minimize bonding between the new sealant and any old sealant remaining in the lower portion of the joint reservoir.

The backer material must be a flexible, compressible, non-shrinking, non-reactive, and non-absorptive material such as closed cell polyethylene rod or foam rubber rod. Hard rubber rods, or any material that will absorb water and swell, must not be used. The backer rod should not limit the joint movement (mostly compression), and should preferably have minimal interaction with the seal, so as not to restrict its movements. The backer rod should be at least 25% larger than the joint width so that it fits tightly in the joint and is not displaced.

c. Lubricant for Preformed Seals.

The lubricant/adhesive is applied to the joint and/or seal to assist in making the seal insert easier with less force. After a time, the lubricant cures and forms a weak adhesive designed only to assist the seal in maintaining its position. The adhesive is very weak, and will not resist a tensile stress.

4.2 JOINT PREPARATION.

a. Removal of old sealant.

Any old sealant remaining in the joints must first be removed prior to resealing. Field-molded sealant is normally removed with a plow tool, although high-pressure water blasting has also been used effectively on airfield pavements. V-shaped plow tools <u>must not</u> be allowed as these will spall the concrete and not remove all of the old sealant. The most effective removal tool is a <u>rectangular</u> steel section that fits loosely in the joint. The contractor should have different sizes available where joint widths vary.

Widening or refacing of the joint through diamond sawing also removes the old sealant in one operation and is recommended where a widened reservoir is needed.

Preformed compression seals can normally be removed by hand.

b. Refacing the joint sidewalls.

Refacing provides a clean surface for the sealant for bonding and can be used to improve the shape factor by increasing the joint width if necessary. Joint widths must not be increased greater than 1 inch [25 mm], however, for reasons stated earlier. The concrete saw should be a self-propelled, water-cooled power saw using diamond saw blades to cut the concrete without spalling it. This provides a clean surface with no sealant present. Sawing is not normally required where the existing preformed compression seal is being replaced with a new preformed seal, unless the joint faces are uneven.

c. Sawing.

Many factors contribute to the efficiency of sawing. The following are listed:

1. Blades may be ganged together to achieve the necessary width. This is usually more economical than expensive wide blades.

2. The more maneuverable saws can more accurately follow initial cut or old joint centerlines.

3. Cutting pressure, which is also a function of forward speed, should be controlled so that the saw does not try to ride out of the joint. Also, crowding of the saw may cause the saw to lead to the left or right. Warping or dishing of blades may also result.

4. Accurate operation of the saw is essential. The minimum width is desirable, and to follow the joint accurately enough to cut 1/16 inch [2 mm] or less on each face requires very precise sawing. Small saws have relatively good maneuverability.

5. Uneven wearing of the drive wheels will cause a saw to lead to left or right and make the saw more difficult to control.

6. A guide or template should be used to insure accurate alignment of the saw in the joint.

d. Reconstructing defective joints.

Joints with widths in excess of 1 inch [25 mm] or that are severely spalled should be considered for reconstruction. Unspalled, clean joint sidewalls are particularly important when preformed compression seals are being installed.

e. Cleaning.

Once the old sealant has been removed and the joints have been refaced and rebuilt, the joints are ready for cleaning. Sandblasting is _strongly recommended_ for field-molded sealants to remove saw residue and any other foreign material (Ref. 4). After sandblasting, the joints should be further cleaned just before sealing with a high-pressure air jet.

It is extremely important that all joints be free of any dirt, previous sealant remains, or any loose, unsound materials. In addition, the joints should always be completely dry immediately before sealing. As a check, the joints can be wiped with a finger across the face to see if any residue remains.

4.3 INSTALLATION OF BACKER ROD

Backer rod materials are installed just before sealing. The backer material will work loose and possibly come out if it is left in the joint for an extended period of time prior to sealing. The backer materials should be examined before sealing and reseated if necessary. The backer rod must not be stretched or twisted during installation. Deformities from material relaxation will cause premature sealant failure. The backer rod depth must be such that the design thickness of the sealant plus 1/4 inch [6 mm] is obtained beneath the slab surface. Care in installation of the rod is very important. The skin on these rods should not be punctured or abraded.

4.4 JOINT SEALING.

When the joints have been properly prepared and the material and equipment approved, the actual sealing can begin. It must be emphasized that the joint preparation and sealing operation is a continuous process. The joints should not be left unsealed overnight; preparation must not be done on more joints than can be sealed during the day. This prevents unnecessary intrusion of moisture, incompressibles and dust.

Air entrapment can be prevented by applying the sealant under pressure from the bottom up. The joint should not be overfilled. A standard recess of 0.25 inches [6 mm] is required. This will prevent damage to the sealant from traffic.

HOT-POURED SEALANT. Regularly check temperature indicators to make certain they are recording properly and that the heating system is maintaining the temperature required by the manufacturer of the sealant. The pumps should be continuously circulating the heated sealant through the hoses to the applicator head and back to the melting kettle. The continuous stirrers should be observed, particularly the agitator in the hot oil bath, to ensure that overheating does not occur.

SILICONE SEALANT. Silicone may be pumped directly from the storage containers through compressed-air-powered pumping equipment designed for use with moisture curing silicone sealants. Sealant application nozzles should be designed so that sealant is applied within the confines of the joint slot and sealant should be applied so that it is held below the surface of the slab, yet completely filling the width of the joint.

Immediately after the sealant is applied it <u>must be tooled</u> to provide firm contact with the joint edges and to form the 0.25 inch [6 mm] recess below the slab surface. The depth of sealant over the crown of the backer rod should be 0.25 to 0.5 inch [6 to 13 mm].

Silicone skins over quickly at temperatures above 40°F [4°C] and cures through to the recommended depth within seven days at temperatures above 40°F [4°C]. If sealant is applied in joints where no rocking or slab deflection is expected, traffic may be allowed over the sealed areas within one hour of application. If large vertical deflection due to slab movement is expected, sealant should be allowed to cure for a longer period of time to prevent displacement of the sealant due to backer rod movement and to obtain adhesion to the primed joint surface.

An overnight cure is usually adequate for all but extreme movement conditions or for temperatures below 45°F [7°C].

PREFORMED COMPRESSION SEALS. The preformed sealants are designed with the intent that the seal will always be in compression. The preformed seals must be free from twisting and stretching. A maximum of 5 percent stretch is allowed. Joint faces must be surface dry and the atmospheric and pavement temperatures should be above 50°F [10°C] at the time of installation to assure proper adhesion. The seal should be inserted at a depth of 0.25 inch [6 mm] plus 0.125 inch [3 mm] or minus 0.0625 inch [2 mm] below the pavement surface.

4.5 INSPECTION.

Each of the steps mentioned above must be performed many times under varying circumstances and conditions. When the inspector is continually present, problems can be corrected as they occur. If the inspector is not continually present, he will frequently be telling the contractor to redo items that are complete but which may not be correct. While this is the correct procedure, it does make for hard feelings for all parties.

Continual observation of the operation to ensure the contractor is following his quality assurance plan will minimize the amount of work that must be repeated. Because all operations will be occurring simultaneously the inspector must be moving continuously from one operation to another.

The contractor must be aware that he will be required to repair or replace anything found out of specification regardless of when the error is found during the sealing operation.

Examine all joints for the following features:

1. FOR FIELD-MOLDED SEALANTS:

    1. Joint face is clean and dry before sealant application.

    2. No backer material floating in the sealant.

    3. Joints not underfilled or overfilled.

    4. Joint sealant is not tacky.

    5. Sealant has adhered to the face of the joint.

    6. Spilled sealant has been removed.

    7. No debris is left on pavement surface.

2. FOR PREFORMED SEALANTS:

    1. Joint face is clean and dry before sealant application.

    2. Seal is properly compressed (i.e., seal is in contact with both joint faces).

    3. Seal is not stretched or twisted in the joint.

    4. Seal is located at proper depth.

Section 5 — PREPARATION OF PLANS & SPECIFICATIONS

The plans should clearly show the joints to be resealed. A diagram similar to Figures 1 and 2 should be provided to show the contractor the exact saw cuts required, reservoir shape, sealant depth, and backer rod placement.

The Guide Specifications accompanying these Design and Construction Guidelines are recommended for use after they have been revised to reflect local conditions.

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RESEALING JOINTS IN CONCRETE PAVEMENTS

PART 2: GUIDE SPECIFICATIONS

Section 1 — GENERAL

1.1 DESCRIPTION OF WORK. The work performed under these specifications shall consist of sealing joints in concrete pavements as designed.

1.2 LOCATION. All joints to be sealed are indicated on the plans.

1.3 STANDARD SPECIFICATIONS. The standard specifications which are applicable to the work on this project are as published in the current edition of (Local, State, Special) "Standard Specifications."

1.4 SUBMITTALS.

a. MATERIALS. Sealant material and backer rod shall be inspected, tested and approved by the Engineer before incorporation in the work. The Contractor shall give sufficient notice in advance of placing orders to permit tests to be completed before the materials are incorporated in the work, and he shall afford such facilities as the Engineer may require for collecting and forwarding samples and making inspections. All samples shall be furnished without charge to the Agency.

Any work in which untested and unaccepted materials are used without approval or written permission of the Engineer shall be performed at the Contractor's risk and may be considered unacceptable and unauthorized, and will not be paid for. Unless otherwise designated, tests in accordance with the most recent cited standard methods of AASHTO or ASTM, which are current on the date of advertisement for bids, or with other standard methods of sampling or testing adopted by the Engineer, will be made by and at the expense of the Agency. Samples shall be taken by a qualified representative of the Agency. All materials being used are subject to inspection, test or rejection at any time. When requested by the Agency, the Contractor shall furnish a complete written statement of the origin, composition, and manufacture of any or all materials that are to be used in the work.

b. EQUIPMENT. The contractor shall submit a list and description of the equipment to be used and a statement from the supplier of the joint sealant that the proposed equipment is acceptable for installing the specified sealant. All other equipment shall be approved by the Engineer prior to use on the project.

c. MANUFACTURER'S RECOMMENDATIONS. Where installation procedures or any part thereof are required to be in accordance with recommendations of the manufacturer of sealing compounds, catalog data and copies of recommendations shall be submitted before installation of the material is commenced.

1.5 DELIVERY AND STORAGE. Materials delivered to the site shall be inspected for damage, and carefully unloaded and stored with a minimum of handling. Joint sealants shall be delivered in the original sealed containers and protected from freezing. Storage facilities shall be provided at the job site for maintaining materials at temperatures recommended by the manufacturer.

Section 2 — MATERIALS

2.1 JOINT SEALANT. The sealant shall meet the requirements of one of the following specifications:

a. HOT-APPLIED

AASHTO M282 or ASTM D3406 Joint sealants, hot-poured, elastomeric-type for Portland cement concrete pavements.

ASTM D3408 Testing joint sealants, hot-poured, elastomeric-type for Portland cement concrete pavements.

ASTM D3405 Joint Sealants, hot-poured for concrete and asphalt pavements.

b. COLD APPLIED SILICONE

Georgia Department of Transportation
Supplemental Specification, 833.06 Silicone Sealant (latest version)

c. PREFORMED

ASTM D2628 Preformed polychloroprene elastomeric joint seals for concrete pavements.

AASHTO M220 Preformed elastomeric compression joint seals for concrete.

2.2 PRIMER. If required, select a concrete primer recommended by the manufacturer of the proposed joint sealant.

2.3 BACKER ROD. Backer rod shall be compressible, nonshrinkable, nonabsorptive, and nonreactive with joint sealant, such as upholstery cord, cotton, jute, neoprene foam rubber, or closed cell polyethylene foam rod. The material shall be slightly larger than the width of the joint, and such that when placed in the joint space, it will support the sealant at its proper depth. The backer rod used shall be that recommended by the sealant manufacturer.

2.4 LUBRICANT FOR INSTALLATION OF ELASTOMERIC JOINT SEAL.

ASTM D2835 Lubricant for installation of preformed compression seals in concrete pavements.

Section 3 — EQUIPMENT

3.1 GENERAL. The contractor shall furnish all necessary accessories to clean, and widen (if required) existing joints and install joint sealants. Machines, tools, and other equipment used in performance of the work shall be maintained in proper working conditions at all times, and are subject to approval by the Engineer.

3.2 JOINT CLEANING EQUIPMENT.

a. ROUTING TOOL. To remove old sealant from joints, a routing tool shall be used to remove the old sealant to varying depths as required, not wider than the existing joint, and of such dimension that will not strike and damage the sides of joints. V-shaped tools or rotary impact routing devices will not be permitted. The equipment must be capable of maintaining accurate cutting depth and width.

b. CONCRETE SAW. A water-cooled, self-propelled power saw with diamond saw blades shall be used to reface, widen, or deepen existing joints as specified without damaging the sides, bottom, or top edge of joints. Blades may be single or gang type with one or more blades mounted in tandem for fast cutting. Select a saw adequately powered to cut specified opening with not more than two passes of the saw through the joint. A concrete saw will remove old sealant and reface joint in one operation.

c. SANDBLASTING EQUIPMENT. Sandblasting equipment shall be capable of removing any residual sealant, oil, or other foreign material which may prevent bond of new sealer. Equipment shall include an air compressor, hose and nozzles of proper size, shape and opening. An adjustable guide shall be attached to the nozzle or nozzles that will hold the nozzles aligned with the joint about 1 inch [25 mm] above the pavement surface. Adjust, as necessary, the height, angle of inclination, and size of nozzles shall be adjusted as necessary to sandblast the joint faces and not the bottom of the joint.

d. AIR COMPRESSOR. A portable air compressor shall be used which is capable of operating the sandblasting equipment and capable of blowing out sand, water, dust adhering to sidewalls of concrete, and other objectionable materials from the joints. The compressor shall furnish air at a pressure not less than 90 psi [0.62 MPa] and a minimum volume of 150 cubic feet [4.2 cubic meters] of air per minute at the nozzles, and free of oil and moisture.

e. JET WATERBLASTING. A high-pressure water jet machine which shall include a compressor, pressure pumps, hose, water jets and controls capable of discharging water up to 10,000 psi [69 MPa] pressure at 22 gallons [83 liters] per minute may be used for cleaning purposes. Use adjustable nozzles to control nozzle pressure between 7,000 and 10,000 psi [48 and 69 MPa]. Select high-pressure hoses with burst pressures from 20,000 psi to 30,000 psi [138 to 207 MPa].

f. VACUUM SWEEPER. A self-propelled, vacuum pickup sweeper capable of completely removing all loose sand, water, joint material and debris from pavement surface shall be used.

g. HAND TOOLS. When approved, hand tools may be used in small areas for removing old sealant from joints and repairing or cleaning the joint faces. Hand tools shall consist of brooms, chisels, and other hand tools required to accomplish the work specified.

3.3 JOINT SEALING EQUIPMENT.

a. HOT-POURED FIELD-MOLDED SEALANT. Hot-poured sealant materials shall be installed with unit applicators which will heat and extrude the sealant in one operation. The mobile units shall be equipped with double-wall agitator type kettles with an oil medium in the outer space for heat transfer, a direct-connected pressure-type extruding device with nozzle or nozzles shaped for insertion in the joints to be filled, and positive temperature devices for controlling the temperature of oil and sealant. The applicator shall be designed so that the sealant will circulate through the delivery hose and return to the kettle when not sealing a joint. The applicator wand shall be insulated for its entire length from the kettle to the nozzle. Dimensions of the nozzles shall be such that the tip of the nozzle will easily feed sealant into the void space of the joint. The nozzle tip shall be equipped with a metal cross-bar to insure that the top of the sealant fed into the joint is level and within the indicated tolerance below the pavement surface.

b. COLD-APPLIED SILICONE SEALANT. The equipment shall be designed to install cold-applied silicone joint sealant materials. Equipment shall conform to the manufacturers recommendations and shall also be subject to approval by the Engineer.

c. PREFORMED POLYCHLOROPRENE SEALANT. A joint seal installation machine to install polychloroprene compression seals shall be either of the types described below. The machine shall be capable of installing the compression seal to the prescribed depth within specified tolerances, without cutting, nicking, twisting, or otherwise damaging the seal, and shall be capable of not stretching the compression seal more than five percent during installation. Simple hand tools of the single-axle type should not be permitted; this tool tends to cause excessive stretching and may cut or distort the seal.

1. Self-propelled gasoline-powered machines shall include a reservoir for lubricant, a device for conveying lubricant in the proper quantities from the reservoir to the point of application to the sides of the compression seal, a reel capable of holding one full spool of compression seal, power-driven apparatus for feeding the joint seal through a compression device and inserting the seal in the joint, and guides to maintain the proper course along the joint being sealed.

2. Semiautomatic machines shall be hand-powered, two-axle, four-wheel devices which include means for compressing and inserting the compression seal into the joint. Auxiliary equipment shall be provided to coat both sides of the joint with lubricant just ahead of installation of the compression seal.

Section 4 — CONSTRUCTION METHODS

4.1 JOINT PREPARATION.

a. GENERAL JOINT PREPARATION. The sequence of operations shall be as follows: removal of existing material in the joint, refacing and widening saw cuts, cleaning, and resealing. The contractor shall not proceed with cleaning operations by more than one working day in advance of the sealing operation. Cleaning procedures which spall joints shall not be permitted.

b. REMOVAL OF EXISTING MATERIAL. A major portion of the in-place sealants shall be removed by using the specified (rectangular) routing tool. The sealant shall then be removed to the depth required to accommodate the bond breaking material and to maintain the specified depth for the new sealant to be installed. The in-place sealant shall be removed to the depth (as shown, or of the joint, which is ________ inch, plus or minus 0.125 inches [3 mm]). At the completion of routing operations, the pavement surface shall be cleaned with a vacuum sweeper and the joint opening cleaned by blowing with compressed air.

c. REFACING OF JOINTS. The concrete joint walls shall be refaced by using a power-driven concrete saw as specified to remove all residual sealant and provide exposure of newly cleaned concrete. If required, joints shall be refaced to widen the joint to the width and depth shown on the plans. All irregularities shall be removed from both joint faces. Immediately after each joint is sawed, the saw cut and adjacent concrete surface shall be cleaned thoroughly by flushing with water under pressure, simultaneously blowing out the water with compressed air until all waste from sawing is removed from the joints. Adjacent joint spaces shall be protected from water and debris during the cleaning operation.

d. FINAL CLEANING OF JOINTS. Final cleaning shall be conducted using sandblasting.

Using sandblasting, the newly exposed concrete joint faces and pavement surfaces extending 0.5 inch to 1 inch [13 mm to 25 mm] from the edges of the joint shall be cleaned. Continue sandblasting until surfaces are free of any traces of old sealant and free of saw-cutting fines. Select sandblasting equipment as specified to provide a minimum of 150 cubic feet [4.2 cubic meters] per minute of air at a nozzle pressure of 90 psi [0.62 MPa] for final cleaning. After final cleaning and immediately prior to sealing, the joints shall be blown out with compressed air using the specified air compressor to remove all sand and water and insure that the joints are dry, dust free, and clean at the time of sealing.

e. BACKER ROD. After the joints shall be installed have received the final cleaning and are dry, backer rod material as indicated in the bottom of the joint with a steel wheel or other approved device so that it is a uniform distance from the top of the slab. Do not stretch or twist these materials during installation.

f. RATE OF PROGRESS. The final stages of joint preparation, which include placement of bond breakers (backer rod or tape) if required, shall be limited to only that linear footage of joint that can be resealed during the same day.

g. DISPOSAL OF DEBRIS. By means of power sweepers or hand brooms, sweep from the pavement surface all excess joint material, dirt, water, sand, and other debris. Remove the debris immediately to an area designated by the Engineer.

4.2 PREPARATION OF SEALANT.

a. HOT-POURED TYPE. Heat hot-poured sealing materials in accordance with safe heating temperature ranges recommended by the manufacturer. Sealant that has been overheated or subjected to heating for over 3 hours or that remain in the applicator at the end of the day's operation shall be withdrawn and wasted. Heat the sealant in the specified equipment.

b. Cold-applied silicone sealants and preformed sealants require no specific preparations. They should, however, be carefully inspected prior to installation to insure effective seal performance.

4.3 INSTALLATION OF SEALANT.

a. TIME OF APPLICATION. Seal the joints immediately following the final cleaning and placing of the bond breakers if these are required. When the walls of the concrete joint are dust-free and dry, and when the air temperature meets the requirements of Section 5, commence sealing the joints. If the above conditions cannot be met, or if rains interrupt sealing operations, reclean the open joints prior to installing the sealant.

b. SEALING THE JOINTS.

1. FIELD-MOLDED JOINT SEALANTS. No joint sealant shall be installed until the joints to be sealed have been inspected and approved. If recommended by the manufacturer, a primer shall be applied to the joint faces in a thin film by brush or airless spray equipment. The primer shall completely wet the surface to be sealed and shall dry tack free prior to installation of the backer rod. Install bond breaker just prior to pouring sealant. Completely fill the joints with sealant from the bottom up until the joints are uniformly filled solid from bottom to top using the specified equipment for the type of sealant required. Fill the joints to 0.25 inch [6 mm] below the top of the pavement within the tolerances as specified, and without formation of voids or entrapped air.

For silicone sealant, immediately after it is applied, it shall be tooled to provide firm contact with the joint faces and to form the required 0.25 inch [6 mm] recess below the slab surface.

Remove excess sealant that has been inadvertently spilled on the pavement surface. Do not permit traffic on the newly sealed pavement for at least one hour.

2. PREFORMED JOINT SEALANT.

i) The joint seal shall be installed using equipment specified as per EQUIPMENT for "Joint Seal Installation Machine" as follows: the sides of the joint seal and/or the sides of the joint shall be covered with a coating of lubricant and the seal installed in such a manner as to conform to requirements specified above. Butt joints and intersections shall be coated with liberal applications of lubricants. Excess lubricant spilled on the pavement shall be removed immediately to prevent setting on the pavement. The in-place joint seal shall be in an upright position and free from twisting, distortion, or stretching that exceeds five percent. The joint seal shall be placed to a uniform depth within the tolerances specified. Joint seals in place which fails to meet specified requirements shall be removed and replaced in a satisfactory manner at no additional cost to the Agency.

ii) Unless otherwise directed, where joints have vertical sides, the joint seal shall be installed to a depth of 0.25 inch [6 mm], plus or minus 0.125 inch [3 mm]. The seal shall be installed continuously along the transverse joints.

4.4 TRIAL JOINT INSTALLATION.

Before allowing the resealing of joints for the entire project, the Contractor shall select a minimum of 15 transverse joints in an approved location and clean and seal the joints with the specified sealant in a manner proposed for resealing joints for the entire project. Following the sealing of the trial joints, and before any other joint is sealed, the trial joint installation shall be inspected to determine that the sealant and installation meet the requirements specified herein. If it is determined that the material or installation do not meet the requirements, the Contractor shall remove the material and again clean and prepare the joints for resealing. After approval of the trial joints, the Contractor shall clean and seal all other joints in a similar manner and subject to approval.

Section 5 — WEATHER CONDITIONS

Work shall not proceed when weather conditions detrimentally affect the quality of forming joints and applying joint sealants. Apply hot-poured sealants only if the air temperature is at least 50°F [10°C] and rising. The minimum placement temperature for silicone sealant is 40°F [4°C] . Surfaces shall be dry and component materials shall be protected from free moisture.

Section 6 — ACCEPTANCE

The completed joint sealant installation shall:

1. Prevent intrusion of incompressibles and be free of materials foreign to the manufactured material delivered to the project site.

2. Conform to the sizes and dimensions shown or otherwise specified.

3. Exhibit bond with sidewalls of the joint.

4. Not crack, bubble or blister.

5. Not have cohesive failures within the joint sealant.

6. Retain resilient, rubber-like quality.

7. Not be picked up, or spread upon adjacent horizontal pavement surfaces, by rubber-tired vehicular traffic or by the action of power vacuum rotary-brush pavement cleaning equipment.

8. Provide a finished, exposed joint surface that is non-tacky and will not permit the adherence of dust, dirt, small stones, and similar contaminants.

Section 7 — MEASUREMENT & PAYMENT

7.1 MEASUREMENT. This work shall be measured by the number of linear feet of joints sealed. No separate measurement will be made of joints resealed at the direction of the Engineer due to improper installation or damage to the sealant.

7.2 PAYMENT. Payment shall be made at the contract unit bid price per linear foot of joint and shall include the cost of all labor and materials and the use of all equipment and tools required to complete the work.

APPENDIX E

REHABILITATION COST ANALYSES FOR SELECTED PROJECTS

APPENDIX E. REHABILITATION COST ANALYSES FOR SELECTED PROJECTS

The goal of any rehabilitation technique is to obtain a cost-effective design, i.e., one that performs satisfactorily over the design period at a reasonable cost. In an effort to determine the approximate cost-effectiveness of different types of rehabilitation on different projects, a cost analysis was performed on several projects with available cost information.

The intent was to investigate the approximate equivalent uniform annual cost (EUAC) of the applied rehabilitation over the analysis period which is defined as follows:

> The time from when the first rehabilitation was performed on the original pavement to the time the final rehabilitation was expected to last.

It was decided by the panel members to present this cost information as an annual cost per two-lane mile and and annual cost per two-lane mile per million ESALs. An effective discount rate of 6% was assumed (interest rate - inflation rate).

Since maintenance cost was not included in the cost analysis, and since cost information can vary from state to state and project to project, it should be emphasized that the results presented here only represent a small sample and no major conclusions can made. Their use here was solely for the purpose of identifying general trends and effects.

The spreadsheet summarizing the cost analyses is given in Table 1. A breakdown and description of each column is provided below.

COLUMN NO.	COLUMN DESCRIPTION
1	Project ID - projects included were those with available cost information.
2	Pavement Age From New Construction to First Rehabilitation - the length of time before the original pavement required rehabilitation.
3	Initial Rehabilitation Technique - earliest type of rehabilitation performed to the original pavement (PRJ-pressure relief joints, FDR-full-depth repairs, PDR-partial- depth repairs, JTS-joint resealing, ACOL-asphalt concrete overlay) and year performed.

Table 1. Rehabilitation Cost Analysis.

(1) PROJECT ID	(2) PAVEMENT AGE FROM NEW CONSTRUCTION TO FIRST REHABILITATION	(3) INITIAL REHABILITATION TECHNIQUE	(4) ADJUSTED INITIAL COST PER 2-LANE MI (1985 DOLLARS)	(5) SUBSEQUENT REHABILITATION TECHNIQUE	(6) ADJUSTED SUBSEQUENT COST PER 2-LANE MI (1985 DOLLARS)	(7) ANALYSIS PERIOD (YEARS)
OH071210	14	PRJ(73)	$385.02			12
IA030148	16	PRJ(80)	$1,491.30	JTS(84)	$11,951.51	14
IA035086	14	FDR(79)	$4,393.02	FDR(80)	$2,567.93	11
				FDR(83)	$13,065.60	
IL055098	20	FDR(83)	$44,807.35	FDR(84)	$3,493.82	2
IL055102	20	FDR(83)	$5,098.39			9
		PDR(83)	$10,267.26			9
IL080105	23	FDR(83)	$8,761.78	FDR(85)	$9,470.77	8
IL074-280	22	FDR(84)	$28,946.11			8
		PDR(84)	$2,853.53			8
		JTS(84)	$6,517.59			8
IL055252	21	PRJ&ACOL(75)	$92,231.06			15
VA095000	21	FDR(84)	$108,666.53			5
		JTS(84)	$23,414.41			5
VA064284	10	FDR(78)	$54,458.55	FDR(84)	$165,715.65	12
		JTS(78)	$19,719.14	PRJ(84)	$5,588.92	12
				JTS(84)	$26,748.78	
VA081148	11	PDR(76)	$4,606.53	FDR(85)	$19,992.27	15
		JTS(76)	$4,913.63	JTS(85)	$5,211.63	15
		PRJ(76)	$368.52			15
VA064202	10	PDR(76)	$10,249.53	FDR(84)	$94,415.59	12
		JTS(76)	$31,361.15	JTS(84)	$27,244.54	12
VA044000	9	PDR(76)	$4,143.83	FDR(84)	$10,348.49	15
		PRJ(76)	$967.58	PRJ(84)	$1,255.08	15
		JTS(76)	$5,908.72	JTS(84)	$2,829.23	15
				FDR(85)	$26,189.58	15
				PRJ(85)	$623.33	15
				JTS(85)	$5,247.22	15
VA064279	14	FDR(81)	$50,627.33			7
		PRJ(81)	$7,321.85			7
		JTS(81)	$12,922.71			7
IN069064	11	PRJ&ACOL(75)	$147,065.27			10
NE080189	16	FDR(81)	$32,574.12	FDR(85)	$56,938.00	12
		PRJ(81)	$1,957.28			12
NE080210	15	FDR(79)	$42,633.49	PRJ(80)	$1,175.77	8
NE080256	17	FDR(80)	$42,862.40			8
		PRJ(80)	$2,018.50			8
NE080279	19	FDR(82)	$47,354.79			7
		PDR(82)	$1,465.43			7
		PRJ(82)	$2,109.55			7
		JTS(82)	$3,619.98			7
NE080382	20	FDR(82)	$28,646.92			3
		PRJ(82)	$1,852.30			3
		JTS(82)	$13,648.89			3
NE080404	24	FDR(84)	$13,968.90			8
		PDR(84)	$6,701.59			8
		JTS(84)	$19,367.59			8

Table 1. (Continued).

(8) PROJECT ID	(9) TOTAL EQUIV. ANN. COST PER 2-LANE MI (1985 DOLLARS)	(10) LIFE IN TERMS OF ESALs FROM FIRST REHAB	(11) COST PER MIL ESAL * 2-LANE MI FROM FIRST REHAB (1985 DOLLARS)	(12) COMMENTS
OH071210	$45.92	3,000,000	$15.31	GOOD PERFORMANCE PRJ REHAB ONLY
IA030148	$1,178.92	700,000	$1,684.17	GOOD PERFORMANCE
IA035086	$2,377.76	3,000,000	$792.59	GOOD PERFORMANCE
IL055098	$26,237.37	2,600,000	$10,091.30	POOR FOR PERFORMANCE
IL055102	$2,259.09	2,000,000	$1,129.55	GOOD PERFORMANCE
IL080105	$2,768.33	2,200,000	$1,258.33	POOR FOR PERFORMANCE
IL074-280	$6,170.45	800,000	$7,713.06	GOOD PERFORMANCE
IL055252	$9,496.36	9,800,000	$969.02	GOOD PERFORMANCE-ACOL
VA095000	$31,355.54	500,000	$62,711.08	POOR FOR PERFORMANCE
VA064284	$25,501.13	4,400,000	$5,795.71	POOR FOR PERFORMANCE
VA081148	$2,554.18	5,300,000	$481.92	GOOD PERFORMANCE
VA064282	$16,457.47	2,900,000	$5,674.99	POOR PERFORMANCE
VA044000	$4,450.04	2,600,000	$1,711.55	GOOD PERFORMANCE
VA064279	$12,695.64	2,800,000	$4,534.16	POOR FOR PERFORMANCE
IN069064	$19,981.46	6,100,000	$3,275.65	FAIR PERFORMANCE-ACOL
NE080189	$9,498.22	4,400,000	$2,158.69	GOOD PERFORMANCE
NE080210	$7,044.15	7,100,000	$992.13	GOOD PERFORMANCE
NE080256	$7,227.44	6,700,000	$1,078.72	GOOD PERFORMANCE
NE080279	$9,771.77	6,400,000	$1,526.84	GOOD PERFORMANCE
NE080382	$16,516.24	1,600,000	$10,322.65	POOR FOR PERFORMANCE
NE080404	$6,447.57	1,300,000	$4,959.67	GOOD PERFORMANCE

4	Adjusted Initial Cost Per 2-Lane Mi (1985 dollars) - adjustment of initial rehabilitation costs ($/2-lane mi) to 1985 dollars using highway bid price index from Engineering News Record.
5	Subsequent Rehabilitation Technique - any subsequent rehabilitation performed after initial rehabilitation; year performed in parenthesis.
6	Adjusted Subsequent Cost Per 2-Lane Mi (1985 dollars) - adjustment of subsequent rehabilitation costs ($/2-lane mi) to 1985 dollars using highway bid price index from Engineering News Record.
7	Analysis Period - the time from the first rehabilitation to the time that the final rehabilitation is expected to last.
8	Project ID - same as column 1
9	Total Equiv. Ann. Cost Per 2-Lane Mi (1985 dollars) - addition of columns 4 and 6; total annual cost of rehabilitation over analysis period.
10	Life in Terms of ESALs From First Rehab - the number of ESALs sustained by the pavement over the analysis period, outer lane one direction.
11	Cost Per Mil ESAL * 2-Lane Mi From First Rehab - column 9 divided by column 10 (in millions); a unit cost per million ESALs.
12	Comments - applicable comments to explain cost values.

The individual cost items are broken down for the four rehabilitation techniques under consideration (pressure relief joints, full-depth repairs, partial-depth repairs, and joint resealing). Other techniques (such as diamond grinding, subsealing, etc.) and their costs were not included, although it should be noted that the length of the life estimates of the rehabilitation may have been partially due to these other techniques. The total cost given is the sum of all rehabilitation costs over the analysis period.

As an example calculation, consider the project IA030148. The pavement underwent the following rehabilitation:

Pressure relief joints (1980) - $1412.12/two-lane mile

Joint resealing (1984) - $10764.00/two-lane mile

These costs were adjusted to 1985 dollars:

PRJ:

$1412.40 \times (172.1/163) = 1491.30$

JTS:

$10764.00 \times (172.1/155) = 11951.51$

The ratios of (172.1/163) and (172.1/155) were the adjustment factors obtained from Engineering News Record.

The 1984 costs were brought back 4 years to the beginning of the analysis period (when the first rehabilitation was done) using the present worth factor:

$PW = 11951.51 \times [1/(1.06)^4] = 9466.72$

The interest rate was assumed to be 6% and there is four years difference between the rehabilitation techniques.

The Equivalent Uniform Annual Cost (EUAC) can now be computed:

$$EUAC = [1491.30 + 9466.72] \times [0.06/(1-(1.06)^{-14})] = 1178.92$$

The 14 represents the length of the analysis period.

To obtain the EUAC per million ESALs,

$$EUAC/mil\ ESAL = 1178.92/0.7 = 1684.17$$

Table 1 shows that the costs vary widely (columns 9 and 11 are the results), and it was noted from the summary reports that the performance of the rehabilitation techniques also varied widely. The following general conclusions are offered.

1. Projects which were largely considered as unsuccessful on an engineering basis from a performance standpoint (e.g., IL055098, NE080382, VA064284, etc.) have a much higher annual cost than those that were considered successful. No AC overlays were considered in either of these groupings. Mean costs for these projects both considering traffic ESALs and not are as follows:

		Costs per 2-lane mi per year	
Performance	No. Projects	Costs w/o ESALs	Costs/Million ESAL
Unsuccessful	7	$ 18,790	$ 14,341
Successful	11	5,362	2,202

The OH071210 project with the extremely low cost was not included in the successful performance projects.

2. One project with an AC overlay that showed 10 years life (e.g. IN069064) had much higher costs than one project with 15 years life (e.g., IL055252). The Illinois I-55 project also carried more traffic and utilized the heavy duty pressure relief joints. The cost of the AC overlay with a 10 year life was about the same as the other projects having an unsuccessful performance.

		Costs per 2-lane mi per year	
Project	Life of Overlay	Costs w/o ESALs	Costs/Million ESAL
IL055252	15	$ 9,469	$ 969
IN069064	10	19,981	3,275

This leads to the basic conclusion that if a rehabilitation is warranted and designed and constructed adequately, cost-effective performance is obtained. However, if a rehabilitation is not warranted or utilized poor design and construction practices, then the resulting life cycle costs will be several times greater.