

NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT

281

✓ **JOINT REPAIR METHODS FOR
PORTLAND CEMENT CONCRETE
PAVEMENTS**

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REPORT

281

JOINT REPAIR METHODS FOR PORTLAND CEMENT CONCRETE PAVEMENTS

M. I. DARTER, E. J. BARENBERG, and W. A. YRJANSON
University of Illinois
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WASHINGTON, D.C.

DECEMBER 1985

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

*By Staff
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Engineers faced with the maintenance and rehabilitation of portland cement concrete (PCC) pavements will find this study on the repair of joint- and crack-related distress of PCC pavements of great interest. Procedures for evaluating and selecting the appropriate repair and preventative techniques are presented. Detailed design and construction guidelines and guide specifications representing the latest state of practice were developed for seven different techniques: (1) full-depth repair of the pavement, (2) partial-depth patching, (3) subsealing pavement slabs, (4) restoration of load transfer across joints and cracks, (5) grinding of the pavement surface to provide smoothness, (6) resealing joints and cracks, and (7) improving support along the pavement slab edge. Documented field demonstrations and void detection procedures using nondestructive deflection testing to locate areas requiring subsealing are included in separate appendixes.

A significant portion of the nation's highway system consists of jointed portland cement concrete (PCC) pavements of numerous designs. These pavements have been in service for various lengths of time and have been exposed to different climatic conditions as well as different levels of traffic loading and varying standards of maintenance. Various forms of distress have occurred in some of these pavements that are costly to rehabilitate. Effective means to retard or arrest distress and to repair already damaged pavement are needed.

Recognizing that the study of all types of defects and deterioration in PCC pavements was beyond the resources available, a research team comprised of members from the University of Illinois at Urbana-Champaign and the American Concrete Pavement Association was assigned the objective to develop guidelines and criteria for making cost-effective decisions for correcting failures related to joints (or cracks acting as joints) of jointed PCC pavements. Many repair and preventative techniques were reviewed, seven of which were selected for further study. Based on a review of the literature, individual contacts, and assessments of actual field demonstrations, the researchers developed design and construction guidelines and guide specifications for the seven techniques noted earlier. The guidelines and guide specifications, representing a consensus of the actual state of practice, are included in this report.

Documentation of the field demonstrations and detailed procedures for the detection of voids beneath the pavement slab using nondestructive deflection testing are presented in separate appendixes. These appendixes are not included with this report. However, for a limited time, agency copies of Appendix B, "Field Demonstration Projects of Joint/Crack Repairs," and Appendix C, "Void Detection Procedures," will be available on a loan basis or for purchase (\$6.00 for Appendix B and \$6.00 for Appendix C) on request to the NCHRP, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

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JOINT REPAIR METHODS FOR PORTLAND CEMENT CONCRETE PAVEMENTS

SUMMARY

There exists a significant mileage of jointed concrete pavements in the United States that require preventative or repair types of rehabilitation. Therefore, a great need exists for the development of cost-effective and reliable rehabilitation techniques for the different types of deterioration.

The primary objective of NCHRP Project 1-21 was to develop effective guidelines and criteria for repairing and preventing deterioration of joints and cracks in portland cement concrete (PCC) pavements. The project was limited to the repair and prevention of deterioration of joints and cracks in both jointed plain concrete pavements and jointed reinforced concrete pavements.

Accomplishment of this objective involved identifying the most promising techniques needed to both repair and prevent the deterioration of joints and cracks. Only seven were chosen for further consideration in this project because of funding limitations.

Design and construction procedures were then developed using the current state-of-the-art methods, analytical analyses, and experience of numerous engineers from Federal and State governments and from industry (contractors and materials suppliers). This was followed by field testing of the techniques. The seven repair methods included in the demonstrations were:

1. Full-depth repair of joints, cracks, and shattered slabs.
2. Partial-depth repair of spalls.
3. Subsealing of voids (or slab stabilization).
4. Restoration of load transfer of joints and cracks.
5. Diamond grinding of faults at joints and cracks.
6. Resealing of joints and cracks.
7. Slab edge support improvement.

The research activities, the major findings, and the interpretation of those findings for each of the areas of investigation are discussed in Chapters One through Three. The design and construction guidelines and guide specifications are provided in Chapter Four, in conjunction with the individual repair techniques, as a self-contained document, for easy use. The guidelines cover, for each technique, the type of distress to be repaired or prevented, limitations, effectiveness, other rehabilitation work that should be performed concurrently, design concepts, construction materials, equipment, and procedures, and preparation of plans and specifications. The recommended guide specifications may be adopted in part or in their entirety, or used by an agency to update their current specifications. Each of the seven rehabilitation techniques has gone through several major reviews by numerous experienced Federal, State, and industry engineers and has been modified from the results of several field demonstration projects.

The conclusions and recommendations emanating from the research are detailed in Chapter Five. In summary, the study results suggest that the pavement evaluation phase cannot be neglected. Only when an adequate amount of information is available and analyzed properly to determine the *cause* and *extent* of the deterioration can the design engineer intelligently select and design cost-effective repair and preventative rehabilitation work. The general types of data collection recommended include: distress types, severities, and amounts; existing design, materials, and soils information; past and future traffic loadings; climatic data; and detailed testing data that are applicable to the rehabilitation techniques such as deflection testing at mid-slab, joints, cracks and corners, cores taken from selected joints and cracks, and surface profile measurements.

Once the causes and extent of the deterioration are determined, the design engineer can select one or more rehabilitation techniques that (in combination) both *repair* existing deterioration and *prevent* or minimize future similar deterioration. Several different alternatives should be investigated to determine the most cost-effective. The techniques recommended to repair and prevent major types of pavement deterioration include: full-depth repair (joint deterioration, blowups, shattered slabs, deteriorated cracks); partial-depth patch (joint spalls, crack spalls, localized surface distress); sub-sealing (fill voids beneath slab and/or subbase that results in loss of support); diamond grinding (removes faulting at joints and cracks and other roughness, also restores skid resistance); restore load transfer (improvement of deficient load transfer at joints and cracks); reseal joints/cracks (removal of incompressibles, sawing to provide a proper (designed) shape factor and resealing of joints and cracks to prevent (minimize) infiltration of incompressibles and moisture); edge support (provide increased edge support and reduce moisture infiltration along the slab edge through a tied PCC edge beam or PCC shoulder).

Supporting materials are contained in the appendixes. Appendix A identifies the different types of distress, severity levels, and amounts. Appendix B documents, in detail, the field demonstrations and testing of the seven rehabilitation techniques. Appendix C describes void detection procedures using nondestructive deflection testing data. Two procedures were developed for use by state or other agencies: (1) a detailed procedure that provides estimates of the horizontal size of the voids at joints and cracks, and (2) a procedure that can be applied rapidly in the field to indicate the presence of voids. Both procedures require a heavy load deflection device, such as the falling weight deflectometer, that can provide a series of different weights close to that of a loaded truck. The procedures were tested and field verified in the demonstration projects in six states.

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT AND RESEARCH OBJECTIVE

A significant portion of the Nation's highway system consists of jointed concrete pavements of various designs. Most of these pavements have been subjected to heavy truck traffic and damaging climatic conditions that have resulted in various types of pavement deterioration. A large majority of this deterioration has occurred at the joints and intermediate cracks.

The development of reliable technical guidelines and criteria for making cost-effective decisions for correcting distress in these pavements is an area of urgently needed research, and one with potentially large benefit-cost ratios. There have been many repair techniques and procedures used to repair portland cement concrete (PCC) pavements. Many of these repair methods have not been fully developed, and there is considerable lack of confidence in the procedures and uncertainty as to the best procedure to be used with each condition of distress. Associated with the solution of methods of repair is a need to identify different types of distress, and especially hidden distress such as voids, sub-surface joint deterioration, and the loss of load transfer across joints and cracks. Thus, there is a great need to make a comprehensive study of repair and preventative techniques.

SCOPE OF STUDY

In recognition of the fact that a study of all types of defects and deterioration in PCC pavements is beyond the realistic scope of this project, the objective of this research is to develop guidelines and criteria for making cost-effective decisions for correcting failures related to joints (or cracks acting as joints) of jointed PCC pavements. The types of failures to be considered include faulting, "D" cracking, joint spalling, corner cracking, blowups, pumping, loss of load transfer, and deteriorated cracks. The contributing causes are to be identified, and special consideration is to be given to techniques that retard or slow down joint deterioration. The techniques of overlay and recycling are not being considered as part of this research. However, the repair procedures required prior to the placement of an overlay will be covered. Procedures will be applicable to both contractors and state maintenance crews.

RESEARCH APPROACH

The research approach was divided into two major undertakings: first, an evaluation of current and new alternative methods of joint/crack repairs, and second, research and field trials to improve and verify promising methods and techniques. An outline of the effort is as follows:

- A literature review was conducted on published repair and preventative methods and specifications currently being used by agencies (10).
- An industry/agency workshop was held in October 1980 in Chicago, Illinois, that brought together some of the most knowledgeable state agency, contractor, equipment manufacturer, and other personnel in the concrete pavement area. All known preventative and repair methods were evaluated and brainstormed for ways to improve them. The results of this workshop were published in an interim report (10).
- Field visits were made by the project staff to observe first-hand pavement condition and repair techniques in Virginia, Georgia, Florida, California, Illinois, Michigan, Nebraska, and South Dakota (10).
- An overall evaluation of each repair preventative method was then conducted by the staff based on all of the information obtained (10).
- The top seven of the most promising repair and preventative methods were selected for field testing and further verification.
- A first draft of "Design and Construction Guidelines" and "Guide Specifications" was developed on previous information. These were reviewed by the Industry/Agency workshop participants and also by the NCHRP panel and subsequently revised.
- Several field tests were held as either part of regular state highway rehabilitation projects or as special demonstrations using the recommended guidelines from 1981 to 1984. Several of these projects are continuing to be evaluated by the agencies involved.
- The guidelines were revised based on feedback from the field tests, analytical analyses, reviews of the agency/industry panel, and other information obtained from the various states and on-going research projects. Subsequent field inspections were conducted on all field test sites (Appen. B).
- This process of verification of the guidelines was repeated over a period from 1981 to 1985 until the final version of the guidelines was developed and included as part of this final report.
- The foregoing research and development included the development of void detection procedures. These procedures use deflection measuring equipment and provide for the determination of locations of loss of support at joints and cracks (Appen. C).
- Procedures were also developed for adequate pavement evaluation to determine the cause and extent of deterioration. This information is essential to the selection of cost-effective rehabilitation procedures. Recommendations to select repair and preventative procedures were also developed.
- The expected pavement life extension for each of the rehabilitation techniques is provided. The expected overall life extension of the entire project after restoration is also provided for different traffic and climate conditions.

FINDINGS

The repair or prevention of joint and crack deterioration is a very complex problem which requires comprehensive engineering evaluation, adequate design and construction procedures, and effective inspection practices. Too often, pavement evaluations and rehabilitation designs have been inadequate, resulting in poor performance of the rehabilitated pavements.

Also, too often the specifications and inspections have been inadequate, resulting in poor performance of the rehabilitated pavement. This study has concentrated on the development of seven primary repair and/or preventative techniques for joints and cracks. The findings will be presented under the following major headings: evaluation of the pavement, selection of technique, and design and construction guidelines. Details of the design and construction of the techniques are given in Chapter Four of this report.

EVALUATION OF THE PAVEMENT

This section provides guidance to the design engineer in overall project evaluation of jointed concrete pavements so that cost-effective repair alternatives can be selected. The selection and design of the most cost-effective rehabilitation for a given project requires:

1. Collection of pavement design and condition data.
2. Evaluation of the causes and extent of deterioration.
3. Development of feasible alternatives that both repair existing distress and prevent its future development.
4. Selection of the most cost-effective feasible alternative.

Data Collection

To make correct decisions about the most cost-effective repair and preventative alternatives, the design engineer must have an adequate amount of information about the project under consideration. The general types of data that must be collected include:

1. Existing distress types, severities, and amounts.
2. Existing design and material types.
3. Past and future traffic loadings.
4. Climatic data.
5. More detailed information which the preliminary data collection suggests may be needed, such as: (a) deflection testing at joints, cracks and corners; (b) cores taken from selected joints and cracks, or (c) surface profile measurements.

A summary of the data which may be required is given in Table 1. The amount of information required will vary, depending on the type of repair work being contemplated. Another

factor will be the size of the project under consideration. For example, a project on a major highway will require the collection of far more information than a project on a low-volume road. When the needed information is available, the engineer can intelligently select and design cost-effective repair and preventative rehabilitation work.

Design, Materials, and Traffic

The engineer must first determine the design of the pavement and the materials that were used to construct it. As-built plans, soils and materials reports, specifications and special provisions, and other design and materials information must be obtained for the project under consideration. It is very important to also consult maintenance personnel to determine the extent of maintenance work that has been performed on the pavement since it was constructed. Some maintenance activities can have a very significant effect on the performance of a pavement. Perhaps the most critical factors in jointed concrete pavement performance are the original joint design and subsequent joint maintenance.

Information about the volume of traffic, particularly truck traffic, which has used the pavement in the past and which is expected to use the pavement in the future is essential to rehabilitation design. Future trends in traffic volumes and loadings must be examined to ensure that the repair work selected for the pavement is neither insufficient nor excessive.

Condition Survey

A condition survey of the existing pavement will normally provide much of the information needed for determining feasible repair alternatives. Condition surveys are also very useful in identifying what additional tests and evaluations need to be made. The most basic measure of pavement condition is the distress survey. Recording, locating, and evaluating the existing distress can help the engineer identify a pavement's rehabilitation needs. Each type of distress is the result of one or more causes which, when known, provide great insight into the type of rehabilitation work that is required.

Significant progress has been made in the identification and measurement of distress. The existing distress in a pavement can be properly quantified in terms of the following three parameters.

1. *Type*, which is based primarily on similar causation mechanisms and similar appearance.
2. *Severity*, which is a function both of the amount of time that the distress type has been allowed to develop and the susceptibility of the pavement to that particular distress type:

Table 1. Data required for determining feasibility and developing designs of several repair and preventative methods.

Data Required	Full Depth Patching	Partial Depth Patching	Overlay	Grinding	Recycling	Underseal	Slab Jacking	Underdrains	Reseal Jts.	Pressure Relief Jts.	Load Transfer Restoration
Pavement Design	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
Traffic Load & Volume	⊙		⊙	⊙	⊙	X		⊙	X	X	⊙
Distress	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
Skid			X	X	X						
Accidents			X	X	X						
Age	X	X	X	X	X			X	X	X	X
Materials Properties	X	X	⊙	⊙	⊙	X		⊙			
Subgrade			⊙		⊙	X	X	⊙	⊙		
Climate			⊙		X	⊙		⊙	⊙	X	
Vertical Clearance			⊙		⊙						
Geometrics			X		X						
NDT	X	X	⊙		X	⊙					⊙
Destructive Testing (coring)	⊙	⊙	⊙	X	⊙	X					X
Overall Roughness			X	X	X		X				
Profile of Surface				⊙			X				
Previous Maintenance	X		X	X	X	X		X	X	X	
Pushing of Bridges									X	⊙	
Utilities (underground)	X				X	X	X	X			
Original Construction Data	X		X	X	X			X			
Traffic Control Options	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
Drainage	X		⊙	X	⊙	X		⊙	X		

Key: ⊙ - Definitely needed. X - Desirable.

- **LOW**— generally does not require repair, but may need some preventative work.
- **MEDIUM**—typically requires some repair.
- **HIGH**— requires major repair.

3. *Amount/Location*, the quantity of a distress type of a particular severity at a particular location.

Adequate information for the design and comparison of feasible repair alternatives must include these three factors to be of any value.

Comprehensive distress identification manuals have been developed for highways (2, 15), city streets (3), and airfields (4). Definitions and descriptions of some of the more common distress types are included in the Appendix A of this report.

The distress data should be well documented so that a clear picture of the existing condition of the pavement is available. Aerial photography is one very useful way to assist in the recording of the condition of a pavement. Aerial photos at a scale of 1 in. = 20 to 50 ft can be used in preparing the plans to locate areas that need specific repairs.

Distress data are useful in many ways (1). First, distress types that are present at medium or high severity levels and that require repair work can be identified and quantified in the plans and estimates.

Second, an examination of all the distress data collected will indicate if pavement condition varies significantly over a given project. For example, the inner lanes of multiple-lane facilities usually manifest less distress and lower severity distress than the outer lanes. If this is the case on the project under consideration, substantially less repair work may be required in the inner lanes. Repair can then be varied with pavement condition to minimize costs.

Third, the results of the distress survey can indicate what further testing must be conducted to obtain sufficient data for design. For example, desposits of fine-grained soil at the pavement edge or other evidence that pumping has occurred may justify deflection testing at joints/cracks to determine the extent of void development.

Fourth, distress data are helpful in determining the causes and mechanisms of pavement deterioration. Pavement distresses can be categorized as being either load related or climate/materials related. Table 2 illustrates this distinction. Knowing whether a distress type is load related or climate/materials related helps the engineer to assign an appropriate repair. Load-related distress generally requires a structural restoration or improvement. Climate/materials-related distress requires repair that will either reduce or eliminate the damaging effect of climate on the materials in the pavement structure.

Nondestructive Deflection Testing (NDT)

Deflection testing has not been extensively used on concrete pavements. Recently, however, the use of heavy-load devices has clearly demonstrated the value of NDT. Available devices capable of producing heavy loads include the Falling Weight Deflectometer, heavy models of the Road Rater, and the Benkelman Beam used in conjunction with a load weight truck (1, 5, 6). The major uses of heavy-load NDT on jointed concrete pavements are as follows:

1. Measurement of the load transfer at joints and cracks. The load transfer is critical to the performance of a joint or crack. Poor load transfer leads to pumping, faulting, loss of support, and the development of voids. Poor load transfer also causes rapid deterioration of overlays.

2. Determination of the existence of voids beneath joints and cracks. Once loss of slab support occurs, rapid and serious slab breakup soon follows.

3. Back-calculation of the modulus of elasticity and the k-value of the foundation, for use in structural evaluation and overlay design.

Coring Pavement

Cores taken through selected joints can provide valuable information about the deterioration beneath the slab surface. Specifically, they show how much sound concrete remains. Cores should be taken from joints showing varying degrees of spalling and load transfer, so that an approximate correlation between the two can be established. Cores should also be taken at various distances from the joints (e.g., 12, 24, and 316 in.) to determine the extent of subsurface concrete deterioration and the minimum width of patches needed to remove unsound concrete which exhibits "D" cracking or which contains reactive aggregate.

Other Information

A variety of other information may be needed. One example is subdrainage-related test data that can be used to evaluate the adequacy of the pavement's drainage system. Another example is surface profile measurements to determine the average depth of faults or similar distresses requiring grinding. Refer to Table 1 for a complete summary of the types of data needed for determining feasible repair alternatives (1).

Table 2. General categorization of jointed concrete pavement distress (2).

Distress Type	Primarily Traffic Load Caused	Primarily Climate/Materials Caused
1. Blow Up		X
2. Corner Break	X	
3. Depression		X
4. Durability "D" Cracking		X
5. Faulting of Trans. Jts. and Cracks	X	
6. Jt. Load Transfer System Assoc. Det.	X	X
7. Jt. Seal Damage of Trans. Jts.		X
8. Lane/Shoulder Dropoff or Heave		X
9. Lane/Shoulder Jt. Separation		X
10. Longitudinal Cracks	X	X
11. Longitudnal Jt. Faulting	X	X
12. Patch Deterioration	X (M,H)	X (L)
13. Patch Adjacent Slab Det.	X	X
14. Popouts		X
15. Pumping and Water Bleeding	X (M,H)	X (L)
16. Reactive Agg. Dur. Dist.		X
17. Scaling, Map Cracking and Cracking		X
18. Spalling (Trans. and Long. Jts.)	X (M,H)	X (L,M,H)
19. Spalling (Corner)		X
20. Swell		X
21. Trans. and Diagonal Cracks	X (M,H)	X (L)

Detailed Pavement Evaluation

The previously collected data can be used to evaluate the existing condition of the pavement. *Pavement evaluation* is defined as determining the causes and the extent of the deterioration. Jointed concrete pavements have several major components: transverse joints, longitudinal joints (between lanes), concrete slab, base/subbase, subgrade, and shoulders. Each component can be evaluated, with respect to the following conditions:

1. *Transverse joints:*
 - Faulting, roughness severity.
 - Spalling, depth into the slab.
 - Corner breaks.
 - Load transfer ability.
 - Corrosion of dowels.
 - Previous maintenance applied.
 - Rate of deterioration (faulting, spalling, etc.).
 - Loss of support beneath joint.
 - Free moisture beneath the joint.
 - Pumping blowhole on shoulder at joint.
 - Variation of joint condition (along the project, across lanes).
 - PCC durability or reactive aggregate problem.
 - Joint lockup (question of whether transverse cracks are working joints).
 - Sealant condition and incompressibles in joints.
2. *Longitudinal joints:*
 - Separation.
 - Spalling.
 - Faulting.
 - Corrosion of tie bars.
 - Sealant condition.
3. *Concrete slab:*
 - Cracking (severity, type, amount).
 - PCC durability or reactive aggregate problem.
 - Surface scaling problem.
 - Thickness adequate for traffic load.
 - Loss of support at joints and cracks.
 - Rate of deterioration from cracking.
 - Skid problem.
 - Variation of slab condition (along project, across lanes).
4. *Base/subbase:*
 - Pumping.
 - Drainage (permeability).
 - Materials durability.
 - Variation of properties along project.
5. *Subgrade:*
 - Pumping.
 - Drainage (permeability).
 - Swells.
 - Depressions.
 - Variation along project.
6. *Shoulders:*
 - Pumping (blowholes at joints or cracks).
 - Subdrainage.
 - Cracking.
 - Settlement/heave.
 - Infiltration of moisture into lane/shoulder joint.
7. *Interaction of pavement components:* The different pave-

ment components may interact with each other to cause deterioration. For example, a joint lockup can result in intermediate slab crack opening and will cause these intermediate cracks to act as joints. Pumping of the base/subbase will cause a loss of support of the slab, resulting in corner breaks. Volume changes in the subgrade can result in slab cracking. These interactions must be taken into consideration.

8. *Constraints to design:*

- Available funding for project.
- Available lane closure situation.
- Minimum acceptable life of rehabilitation work (time between construction and future rehabilitation).
- Available contractors, equipment, and materials.

The answers to these questions provide the design engineer with the information needed to determine the *causes* and *extent* of deterioration of the pavement. With the problem thus well-defined, the engineer can then proceed on to the selection of feasible alternatives.

SELECTION OF FEASIBLE ALTERNATIVES

A *feasible alternative* is one that addresses the *cause* of the distress, and is effective in both repairing existing deterioration and preventing its reoccurrence, while satisfying the imposed constraints. A few projects exhibit only one or two different distress problems and can be rehabilitated using one or two methods. For example, a jointed reinforced concrete pavement (JRCP) exhibiting only joint deterioration caused by incompressibles in the joints can be repaired by full-depth repair at each joint, and joint deterioration in the future can be prevented (or reduced) by cleaning and resealing the joints.

Table 3 contains specific recommendations on the selection of candidate methods to repair the distress and to prevent or retard its reoccurrence. For each distress type, one or more

Table 3. Candidate repair and preventative methods for specific joint and crack distress.

Joint/Crack Distress	Repair Methods	Preventative Methods
Pumping	1. Subseal 2. Full-Depth Repair	1. Reseal Joints 2. Restore Load Transfer 3. Subdrainage* 4. Edge Support (PCC Shoulder/Edge Beam)
Faulting	1. Grind 2. Structural Overlay	1. Subseal 2. Reseal Joints 3. Restore Load Transfer 4. Subdrainage* 5. Edge Support
"D" Cracking	1. Full-Depth Repair 2. Partial-Depth Repair	1. Reseal Joints 2. Subdrains
Slab Cracking	1. Full-Depth Repair 2. Replace/Recycle Lane	1. Subseal loss of support 2. Restore Load Transfer 3. Structural Overlay
Joint Spalling	1. Full-Depth Repair 2. Partial-Depth Repair	1. Reseal Joints
Blowup	1. Full-Depth Repair	1. Pressure Relief Joint 2. Resealing Joints/Cracks

* Drainage analysis required for specific situation to determine need and benefit (1).

repair and/or preventative maintenance methods can be applied. For example, faulting can be repaired or removed by:

1. Diamond grinding.
2. Placement of a thick overlay.

Faulting of transverse joints can be prevented or retarded by:

1. Subsealing to fill voids and restore support.
2. Reestablishing load transfer across the joint with mechanical devices (this prevents further pumping by reducing deflection and differential deflection).
3. Resealing the transverse and longitudinal joints (this prevents further pumping).
4. Providing subdrainage, after conducting a drainage evaluation of the pavement and subgrade (this prevents further pumping).

If each of these two repair methods and each of the four preventative methods meet the pavements' needs (in other words, actually *repair* the faulting and *prevent its recurrence* at least to some degree) and satisfy the imposed constraints (such as available funding and minimum life extension), they qualify as feasible rehabilitation alternatives.

In order to make the most of the limited funds available, the engineer must choose the combination that is the most cost-effective for the particular project. As an example, the following table was developed to help select alternative methods for a pavement having both pumping (with loss of support) and faulting:

EXISTING DISTRESSES	CANDIDATE REPAIR	CANDIDATE PREVENTATIVE
Pumping (loss of support)	Subseal	Reseal joints Restore load transfer PCC shoulder Subdrainage
Faulting	Grind Thick OL	All above

One repair method and one or more preventative methods must be selected for each distress type. If only repair-type work is performed, such as grinding only, the mechanism that caused the pumping in the first place will immediately begin its destructive work when the pavement is opened to traffic. After each distress type has been treated with an appropriate repair, one or more preventative methods must be applied to provide a cost-effective design. For example, the following alternatives could be developed:

ALTERNATIVE	REPAIR METHOD	PREVENTATIVE METHOD
A	Subseal pumping Grind faults	Reseal joints Restore load transfer
B	Subseal pumping Grind faults	Subdrainage Reseal Joints Restore load transfer
C	Subseal pumping Grind faults	PCC shoulder Reseal joints

Other feasible alternatives may exist and could be developed.

Many projects such as the foregoing example exhibit several different types and severities of distress problems, and thus require a combination of several different repair and preventative rehabilitation methods. It is emphasized that very often a combination of different repair and preventative maintenance methods will be required to return a deteriorated pavement to serviceable condition and maintain it in that condition for a substantial period of time. Each of these alternatives is probably reasonably cost effective. The final selection of the most cost-effective alternative is then made as described in the next section.

The selection of the preventative methods is perhaps the most difficult because of the uncertainty of their effect for a given project. There are two different approaches to preventing the occurrence of moisture damage from pumping:

1. Minimizing the infiltration of as much moisture as possible.
2. Providing subdrains to drain out the moisture that enters the pavement structure.

Each of these approaches should be considered and analyses conducted to determine which is the most effective in a given area. The amount of available moisture and the permeability of the subgrade must be considered in this decision.

Selection Of Cost-Effective Alternatives

Once two or more feasible alternatives have been selected, a decision must be made as to which one is the most cost effective for the project under consideration.

Life-Cycle Cost Analysis

The overall life-cycle cost of each alternative is generally considered the "cost" factor that should ideally be used in determining cost effectiveness. The major life-cycle cost factors are:

1. Initial construction costs.
2. Future maintenance and rehabilitation costs.
3. Salvage value—what the pavement is worth when its service life has expired.
4. Extra user costs resulting from rougher pavements and lane closures:
 - a. Delays from traffic control during initial construction, maintenance, and rehabilitation.
 - b. Discomfort costs.
 - c. Extra vehicle operations costs.
 - d. Extra accident costs.

Life-cycle costs can be expressed in terms of "present worth," or in terms of an "equivalent uniform annual cost" (EUAC) (7, 8). The procedure for calculating both present worth and EUAC for a detailed life-cycle cost analysis is given in Figure 1.

It is important to realize that any given pavement has an associated cost that can be expressed on an average annual basis. This "equivalent uniform annual cost" for a pavement depends greatly on the maintenance and rehabilitation policies and designs. For example, a "failure"-type policy of letting a pavement

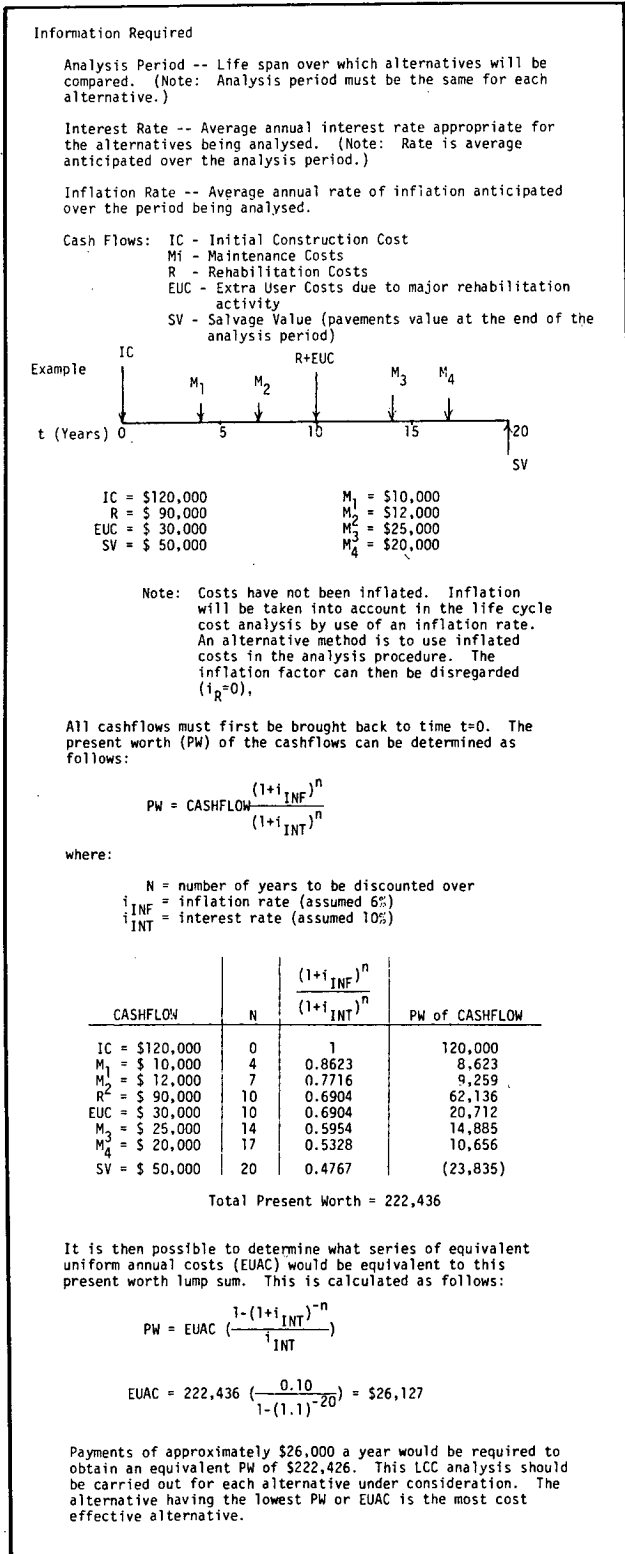


Figure 1. Life cycle cost analysis example.

deteriorate badly and then reconstructing it currently varies in annual cost from \$20,000 to \$40,000 per two-lane mile of Interstate-type roadway. The application of rehabilitation work such as described in this document at the appropriate times may result in average annual costs that are much less than those of the "failure" policy, and would thus be considered very cost effective.

The application of a detailed life-cycle cost analysis that considers all of the foregoing cost factors is normally beyond the capability of the design engineer. Also, the calculation of these user costs is quite approximate at the present time and subject to much controversy. Therefore, an approximate life-cycle cost procedure is recommended that can be performed by the design engineer that considers the most important factors:

1. The cost of initial construction of the rehabilitation.
2. The extension of service life of the pavement due to the application of the rehabilitation.

An approximate average annual cost can be computed with these data, by multiplying the initial construction cost by the capital recovery factor (Fig. 1) using the extension of service life of the pavement caused by the rehabilitation work.

Where unusually heavy traffic is involved, the impact of high user costs may need to be considered in more detail in making the final selection of rehabilitation method for joints and cracks.

Pavement Life Extension

The expected extension in service life of a pavement caused by the application of a repair or preventative technique must be estimated before the average annual cost can be computed. This extension is the increase in life beyond that obtained if no rehabilitation work is performed. An illustration of this life extension definition is shown in Figure 2. Defining life extension in this way is essential to ensure that the average annual cost computed is due solely to the effect of the rehabilitation technique.

It must be recognized that when a pavement is rehabilitated, there are two different "lives" that are of importance:

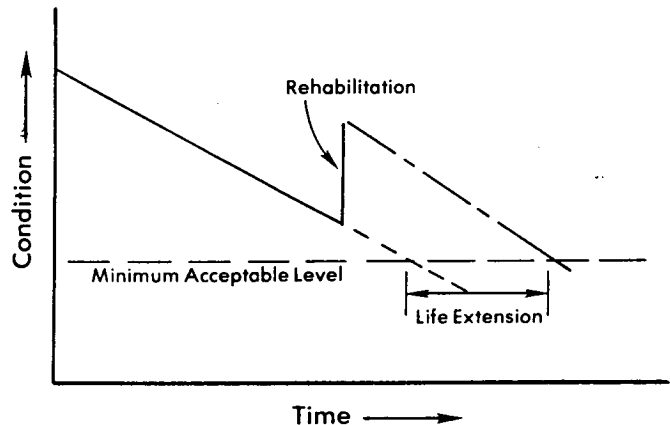


Figure 2. Definition of "life extension" resulting from rehabilitation work.

1. The life of the individual repair or preventative technique (e.g., full-depth repair or joint sealant).
2. The life of the pavement as a whole.

These two lives are interrelated. The future life of the overall pavement depends on the life of the individual repair or preventative techniques *and* on the deterioration of the rest of the pavement. Also, the lives of the individual repair or preventative techniques depend somewhat on the performance of the existing pavement. For example, a joint sealant may perform for 10 years, but if the joint spalls at 5 years it will fail at that time.

The life of an individual repair or preventative technique depends on the following major factors:

1. Type of technique.
2. Adequacy of construction.
3. Proper selection of the repair or preventative technique.
4. Concurrent rehabilitation work being performed.
5. Truck traffic level.
6. Climatic conditions (moisture, temperature, freeze-thaw).
7. Existing pavement design, materials, and subgrade.

A summary of the estimated range of lives of individual techniques is given in Table 4. These values were estimated by the research staff based on results from field demonstrations, experience on other projects, and information from other agencies.

The life of the overall pavement after rehabilitation depends on the following major factors:

1. Life of specific repair and preventative techniques placed.
2. Condition of the rest of the pavement that was not repaired (that is, how much of the existing deterioration was actually repaired).
3. Truck traffic level.
4. Climatic conditions.
5. Existing pavement design, materials, and subgrade.

It is extremely difficult to give estimates for overall project life because of the many interacting and complex factors involved. However, some general guidance is provided in Table 5 for some general conditions. The design engineer should not use any of these estimates without modification to the specific project under design. It must be remembered that these are only estimates and that local conditions and many other factors may change these estimates considerably. Thus, the final selection of the life extension of a repair or preventative method must be made by the design engineer for the specific project under design.

Step-by-Step Procedure—Example Number One

The following is a step-by-step procedure for selecting a cost-effective joint and crack rehabilitation technique:

Step 1. Collect important pavement data and conduct pavement evaluation. A brief summary of the important information for a hypothetical example pavement is as follows:

Design:
Age: 15 years

Table 4. Tentative estimated lives of individual repair and preventative techniques (see assumptions below).

Technique	Conditions	Expected Life (yrs.)*	Reliability*
Full-Depth Repair	Sound PCC slab Prevent pumping	10+	80%
Partial-Depth Patching	Sound PCC Slab	5 - 10	80
Subsealing	Prevent pumping	4 - 8	75
Restore Load Transfer	Prevent pumping	3 - 7	50 - 70
Edge Support (Beam or Shoulder)	Stabilize slab	10 - 20	80
Grinding	Stabilize slab Repair deterioration Prevent pumping	5 - 15	80
Reseal Joints	(a) Asphalt Rubber or Elastomer	4 - 6	80
	(b) Silicone or Compression Seal	8 - 15	80

* Based upon current technology. Improvements in future will increase both life and reliability.

Assumptions:

1. Traffic Load - for very heavy truck traffic (more than 1500 trucks per day in outer lane) reduce lives by 30 percent.
2. Adequate design and construction techniques are used as described in this document.
 - Prevent pumping - Subdrainage*, or reseal all joints, or tied edge support (PCC shoulder)
 - Stabilize slab - Subseal slabs and full-depth repairs
 - Repair deterioration - Full-depth and partial-depth repairs
 - Sound PCC - No "d" cracking or reactive aggregate

*Subject to drainage evaluation of subbase/subgrade.

Table 5. Tentative expected project life extension due to application of repair and preventative techniques (see assumptions below).

Truck Traffic Level	Climate	Expected Life Extension (yrs.)
Medium to High	Dry	15 - 20
Very High	Dry	10 - 15
Medium to High	Wet	10 - 15
Very High	Wet	5 - 10

Assumptions:

1. Truck Traffic - Medium to High is less than 1500 trucks per day in outer lane.
Very High is more than 1500 trucks per day in outer lane.
2. Climate - Wet regions have a Thornthwaite Index greater than zero, or average annual precipitation greater than 20 inches (9).

Jointed plain concrete pavement
 Joint spacing: 12 to 19 ft
 Slab thickness: 9 in.
 Four-lane divided highway
 Lanes 12 ft wide and AC shoulders 4 and 10 ft wide
 Subgrade: fine-grained soil (impermeable)

Evaluation:

Major distresses: Pumping fines, serious faulting (0.17 in., PSR = 3.2) and a few broken slabs all in outer truck lane. Outer AC shoulder needs repair also.

Major causes: Free water beneath slab and stabilized base caused by “bathtub” design (pavement section contained in non-drainable subgrade and shoulders) and poor load transfer at joints.

Extent of loss of support problem: Loss of support beneath approximately 50 percent of slabs confirmed by deflection testing.

Step 2. Select feasible alternatives to repair and prevent. Table 3 is used to develop the following summary of repair and preventative alternatives.

<u>Distress</u>	<u>Repair</u>	<u>Prevent</u>
Pumping (loss of support)	Subseal	Restore load transfer Reseal joints PCC shoulder Subdrains
Faulting	Grind Thick OL	Subseal Reseal joints PCC shoulder Subdrains
Cracking	Full-depth Repair	Subseal Prevent pumping (above)

One repair method and one or more preventative methods are selected for each distress to develop a specific rehabilitation alternative. Both the “seal out water” and the “drain out water” approaches were used to develop the following alternatives:

<u>Alternative</u>	<u>Repair Methods</u>	<u>Preventative Methods</u>
A	Subseal joints Full-depth repair Grind faults	Reseal all joints Add tied PCC shoulder
B	Subseal joints Full-depth repair Grind faults AC shoulder repair	Subdrains (outer edge)
C	Subseal joints Full-depth repair Grind faults AC shoulder repair	Reseal all joints Restore load transfer

Other alternatives could be developed.

Step 3. Conduct annual cost analysis. Estimate the construction costs and the expected life extension of each feasible alternative using Tables 4 and 5 and other experience and information

available to the design engineer. Then compute the approximate average annual cost of the life extension for each alternative.

<u>Feasible Alternative</u>	<u>Expected Life Extension (Yr.)</u>	<u>Present Expected Cost (\$)</u>	<u>Annual Cost* (\$)</u>
A. Subseal, grind, PCC shoulder full-depth repair, reseal joints	15	115,230	10,364
B. Subseal, subdrains, full-depth repair, grind, AC shoulder, shoulder repair	10	79,168	9,761
C. Subseal, full-depth repair, grind, restore load transfer, AC shoulder repair, reseal joints	10	102,230	12,604

*Note: A 4 percent interest rate was used to compute annual cost.

This example shows that alternatives A and B are the most cost effective. Their annual costs are very close and in light of the possible errors in cost and life extension estimation, they have essentially the same cost. The final choice of which to construct must then be based on some other criterion such as expected life extension, which would favor alternative A. However, if only, say, \$80,000 were available, alternative B would be selected.

Step-by-Step Procedure—Example Number Two

The following is a step-by-step procedure for selecting a cost-effective joint and crack rehabilitation technique:

Step 1. Collect important pavement data and conduct pavement evaluation. A brief summary of the important information for a hypothetical example pavement is as follows:

Design:

Age: 19 years
 Jointed reinforced concrete pavement
 Joint spacing: 50 ft
 Slab thickness: 10 in.
 Four-lane divided highway
 Lanes 12 ft wide and AC shoulders 4 and 10 ft wide
 Subgrade: fine-grained soil (impermeable)

Evaluation:

Major distresses: Extensive joint deterioration in both lanes, some pumping of fines and serious faulting (0.30 in.) in outer truck lane. Outer AC shoulder is in good condition.

Major causes: Incompressibles in transverse joints due to poor sealant, free water beneath slab caused by “bathtub” design.

Extent of loss of support problem: Loss of support beneath approximately 40 percent of transverse joints confirmed by deflection testing. Load transfer is adequate.

Step 2. Select feasible alternatives to repair and prevent. Table 3 is used to develop the following summary of repair and preventative alternatives.

<u>Distress</u>	<u>Repair</u>	<u>Prevent</u>
Joint Deterioration	Full-depth Repair	Reseal transverse joints
Pumping (loss of support)	Subseal	Subdrains Reseal all joints PCC shoulders
Faulting	Grind Thick OL	Subseal Reseal all joints PCC shoulder Subdrains

One repair method and one or more preventative methods are selected for each distress to develop a specific rehabilitation alternative. Both the "seal out water" and the "drain out water" approaches were used to develop the following alternatives:

<u>Alternative</u>	<u>Repair Methods</u>	<u>Preventative Methods</u>
A	Full-depth repair Subseal joints Grind faults	Reseal all joints
B	Full-depth repair Subseal joints Grind faults	Subdrains (outer edge) Reseal transverse joints

Other alternatives could be developed.

Step 3. Conduct annual cost analysis. Estimate the construction costs and the expected life extension of each feasible alternative using Tables 4 and 5 and other experience and information available to the design engineer. Then compute the approximate average annual cost of the life extension for each alternative.

<u>Feasible Alternative</u>	<u>Expected Life Extension (Yr.)</u>	<u>Present Expected Cost (\$)</u>	<u>Annual Cost* (\$)</u>
A. Full-depth repair, subseal joints, grind faults, reseal all joints	10	74,906	9,235
B. full-depth repair, subseal joints, grind faults, subdrains reseal transverse joints	13	89,199	8,933

*Note: A 4 percent interest rate was used to compute annual cost.

These results show that alternative B is the most cost effective. However, the annual costs of the two alternatives are fairly close.

Summary of Evaluation and Selection of Alternatives

The selection of the most cost-effective repair and/or preventative methods depends on both *engineering criteria* and on an *annual cost analysis*. Engineering criteria include the following major factors:

1. Obtaining a knowledge of the specific problems that exist in the pavement under consideration. This requires knowledge of the type, severity, and amount of distress and the causes and extent of the deterioration.

2. Identification of techniques that effectively repair existing distress. Four effective repair methods are described in detail in this document: full-depth repair, partial-depth repair, sub-sealing to fill voids, and grinding to remove faulting. Other techniques also exist, such as thick overlays to eliminate faulting.

3. Identification of techniques that effectively prevent (or minimize) the reoccurrence of the distress. Three effective preventative methods are described in detail in this document: restoration of load transfer, resealing of joints and cracks, and edge support through PCC beams or shoulders to minimize infiltration of moisture and to support the slab edge and corner. Other techniques exist such as placement of subdrainage. The two major approaches to minimize the damaging effects of free moisture in the pavement are recognized: (1) sealing out as much moisture as possible, and (2) draining out as much moisture as possible.

4. A feasible alternative is a combination of repair and preventative techniques that are chosen to repair and prevent each existing distress type. There may be several different feasible alternatives for any given jointed concrete pavement. The application of only repair techniques (without preventative techniques) will not stop the deterioration mechanisms, and thus will not prevent the premature failure of the pavement.

5. Each feasible alternative must be within the existing funding, minimum service life extension and other constraints.

The annual cost analysis requires the following for each feasible alternative:

1. An estimation of the construction cost per mile for each repair and each preventative technique that is selected.

2. An estimation of the extension in life of the pavement section that will result after the repair and preventative techniques are applied.

3. The annual cost for each feasible alternative is then calculated by dividing the total construction cost per mile by the life extension. *The feasible alternative having the lowest annual cost is the most cost effective for the particular pavement under consideration.* The cost analysis procedure presented here is, admittedly, an approximate one, but it is believed to be adequate for the intended purpose.

4. Different repair and preventative techniques may be very cost effective for one project and not for another project. No overall generalized conclusion can be made as to a given technique. *Each project must be analyzed individually to determine the most cost-effective repair and preventative techniques.*

DESIGN AND CONSTRUCTION GUIDELINES

Detailed design and construction guidelines as well as guide specifications were developed. These procedures were initially based on the best state-of-the-art methods in 1980 at the initiation of this project. They were then tested through field trials and demonstrations and improved over a 4-year period. Many improvements were also suggested by an industry / agency panel and by the NCHRP Project 1-21 panel.

The following represents the major findings related to each of the seven repair and preventative techniques included in this project.

Full-Depth Repair

1. Full-depth repairs must be designed to meet the project conditions. The pavement design, desired life extension, and traffic loadings will dictate the structural design of the repair. The lane closure time will impact on the design, particularly the mixture design and curing considerations.

2. Field layout is critical and the field engineer must have training in this aspect. All of the surface and underlying deterioration must be included within the repair boundaries. Many times the inadequate funds have been allocated to repair the existing pavement. This results in many areas needing repair being neglected. These areas then become the first failures in the rehabilitated pavement.

3. Adequate load transfer at the transverse joints is the most critical aspect of the design of the full-depth repair. This can best be achieved using dowels or tie bars having sufficient diameter and numbers placed in the wheel paths to prevent faulting and spalling. Guidelines are presented for achieving adequate load transfer for heavy traffic in Chapter Four (see also Figs. 3 and 4 in this Chapter). Additional research is needed in verifying the adequacy of this design approach. The actual process for installing load transfer devices needs substantial improvement.

4. A minimum size of patch of 6 ft long and 12 ft wide is recommended for heavy traffic.

5. Equipment exists to cut and lift out pieces of the deteriorated concrete slab. The lift-out method is highly recommended over the breakup-and-clean-out method.

6. Mixture designs including high cement factors, low water cement ratios, high early strength cement (Type III), and the use of insulation blankets over the repair can provide a repaired slab that can be opened rapidly to traffic. The use of insulation blankets has a dramatic effect on opening times, particularly at cooler temperatures, as illustrated in Table 6.

7. The so-called inverted "T" repairs caused differential frost heave in deep frost areas. Measured load transfer was also poor because of underconsolidation of the patch material in the undercut areas on a few projects.

8. The sawing/forming of a transverse joint sealant reservoir at the repair boundaries is recommended. A high quality sealant should be used.

9. The full depth repair of concrete pavements exhibiting "D" cracking requires the placement of the boundaries of the repair beyond the area of "D" cracking deterioration. During the evaluation, cores should be taken at different distances from typically deteriorated joints to determine the extent of deterioration. If there is considerable deterioration at the face of the slab after removal, the repair area should be extended to include the deterioration.

Partial Depth Patching

1. Partial depth patching is used to repair spalls and other partial depth distress. It is essential that the patch be isolated from the adjacent slab for proper performance. Compression failures are one of the biggest causes of partial depth patch failures.

2. The repair area must be properly prepared to develop good bond between the patch and the base concrete.

Table 6. Early opening guidelines for full-depth repairs.

Slab Thickness (inches)	Ambient Temperature At Placement (°F)	Full-Depth Repair Mixtures/Curing*					
		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 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 11).

3. When using a proprietary patching material it is essential that the manufacturer's recommendations are followed closely.

4. High strength portland cement concrete is one of the most often used materials for partial depth repairs.

5. When spalls extend deeper than one-half the slab thickness, full depth repairs should be considered.

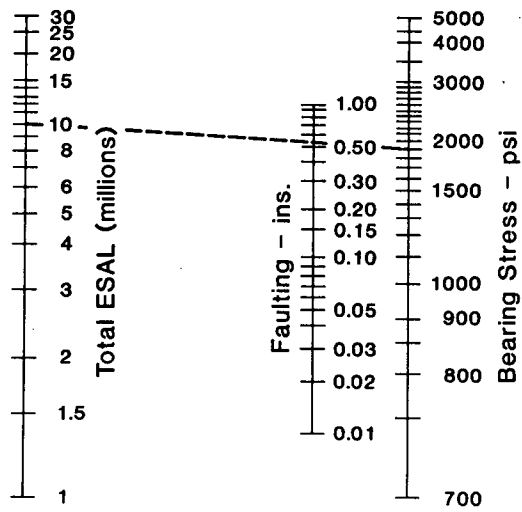
6. If "D" cracking exists in the slab, partial depth patching may not be effective because the deterioration is normally worse in the lower one-half of the slab. This should be investigated during the evaluation phase.

Subsealing

1. Pavement subsealing is used to fill small voids (e.g., 0.010 to 0.250 in. thick) beneath the slab and/or stabilized base that have been caused by pumping action. Subsealing could also be called slab stabilization. The loss of support results in up to a doubling of deflections, as shown in Figure 5 (for the leave corner), and stresses that cause faulting and slab breakup. When grout has sufficiently filled the voids, the corner deflection will be reduced to full support conditions, as illustrated in Figure 6.

2. The determination of joints/cracks that need subsealing has been a difficult and controversial question. The findings of this study conclusively show that only those joints/cracks that exhibit loss of support (voids) should be subsealed. However, it is a waste of effort and can even be detrimental to subseal joints/cracks with existing full support. The joints/cracks with loss of support can be identified using the deflection testing procedures described in Appendix C.

Solves: $\ln(F+1) = \ln(ESAL+1)[1.394 \cdot 10^{-4} \text{BSTRESS} - 0.0913]$



Example :
 Slab = 9 ins.
 3 Dowels Wheel Path
 1.25 ins. Diameter
 ESAL = $10 \cdot 10^6$
 BSTRESS = 1898 psi
 (Figure 3b)
 Fault = 0.52 ins.

Figure 3(a). Nomograph for determining dowel bar spacing and diameter (use with Fig. 3(b)).

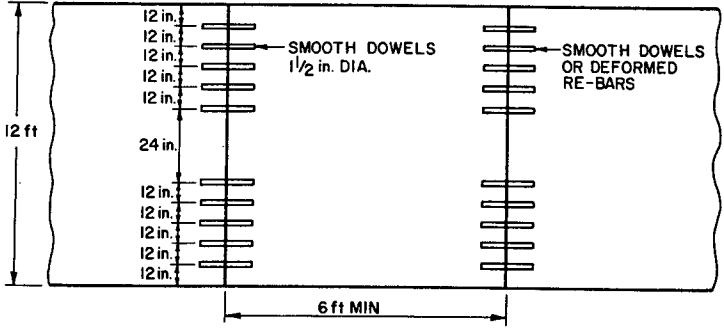
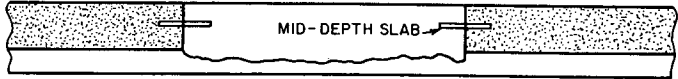


Figure 4. Recommended dowel bar spacing.

Slab Thickness (ins.)	Dowel Diameter (ins.)	Bearing Stress-psi*				
		2	3	4	5	6
8	1.00	3878	2889	2463	2279	2250
	1.25	2591	1930	1645	1522	1503
	1.375	2180	1624	1385	1281	1265
	1.500	1862	1387	1183	1094	1080
9	1.00	3857	2842	2388	2167	2089
	1.25	2576	1898	1595	1447	1395
	1.375	2168	1598	1342	1218	1174
	1.50	1852	1365	1147	1040	1002
10	1.00	3817	2786	2316	2077	1951
	1.25	2549	1861	1547	1387	1303
	1.375	2145	1566	1302	1167	1096
	1.50	1832	1338	1112	997	936

*Load = 9 Kips on outer dowel bar
 Dowel Spacing = 12 ins. (beginning 12 ins. from end)
 K-value = 150 pci $E_{pcc} = 5 \times 10^6$ psi
 (changing K has very little effect on stress) Poisson's ratio = 0.15
 $E_{dowel} = 1.5 \times 10^6$ psi
 Joint opening (Z) = 0.25 ins.

Figure 3(b). Dowel bearing stress computed using Friberg's procedure.

3. The estimation of grout quantities is extremely difficult, but can be accomplished using past experience, extent of visual distress such as faulting and pumping, and deflection testing for voids or loss of support. A procedure was developed, requiring deflection testing, which provides estimates of the horizontal size of voids at a given joint (detailed method) or an indication of the existence of a void (rapid method). Deflection testing can also be used, most importantly, to evaluate the effectiveness of the subsealing by retesting after subsealing.

4. The grout used in subsealing can have a significant influence on its effectiveness in stabilizing the slab. The use of pozzolanic (fly-ash) cement grouts is recommended because of their ability to flow into voids and their measured strength. Limestone dust-cement grouts have also been used effectively. The water content of the grout must be controlled through the flow cone test. When fly-ash grouts are used, a colloidal mixer must be used to achieve adequate mixing. The use of a sand-cement grout may result in infiltration into joints that may cause blow-ups in the pavement. This has not been observed for flyash— or lime dust-cement grouts.

5. The subsealing procedures must be carefully controlled in the field. Slab lift must be closely controlled with a beam device to avoid overgrouting, which may result in premature slab breakup. The down force exerted during the drilling of grout injection holes must be controlled so as not to cause deterioration or spalling at the bottom of the slab near the hole.

Pumping pressures must be limited to avoid damage to the pavement from excessive slab lift. Consideration should be given by agencies to pay for subsealing by the square yard instead of by the cubic foot of dry grout.

6. The long-term effectiveness of subsealing depends on preventing free moisture from accumulating in the pavement structure. All joints and cracks should be properly sealed using a shape factor designed for the sealant used and/or subdrains should be placed to get rid of moisture rapidly.

7. The unit costs of a subsealing project depend on unit materials cost, extent of voids, amount of lift allowed during subsealing, and the size of the project. The extension in service life due to subsealing depends on the success of sealing out moisture, the adequacy of the subseal work, truck traffic volume, and load transfer at joints.

Restoration of Load Transfer

1. The ability of a joint or crack to transfer load (shear) from one side to another is very important to the pavement's performance. Poor load transfer results in the following:

- High deflections causing increased pumping and subsequently faulting.
- Loss of support beneath the slab and/or base that results in slab breakup.

2. Load transfer restoration should be considered whenever it is less than 50 percent ((unloaded slab deflection/loaded slab deflection) × 100) during a cool temperature period (50°F to 80°F ambient). Load transfer can be measured using deflection equipment with at least two sensors, one placed on each side of the joint. This must be performed during cool weather.

3. Plain jointed PCC pavements without mechanical load transfer invariably have low load transfer during all but hot

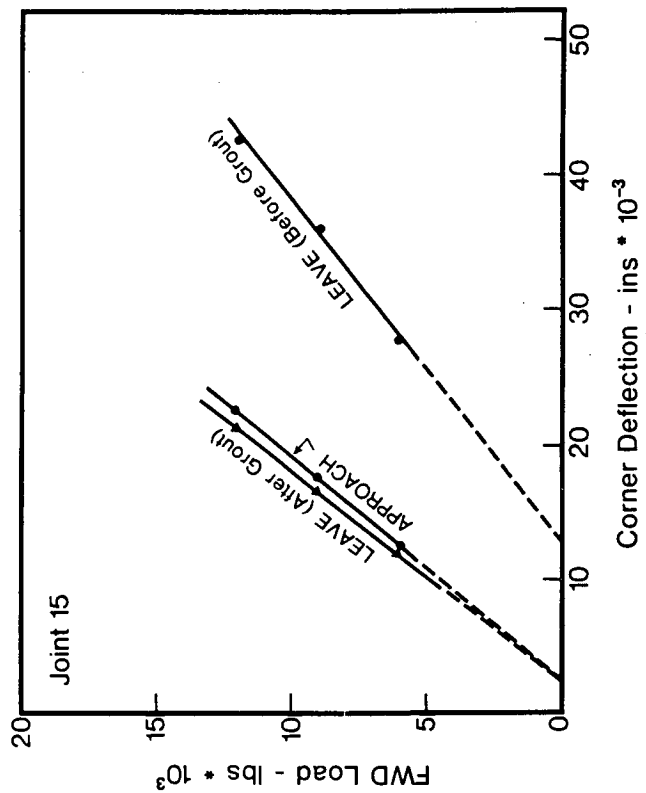


Figure 6. Void detection procedures—rapid field method.

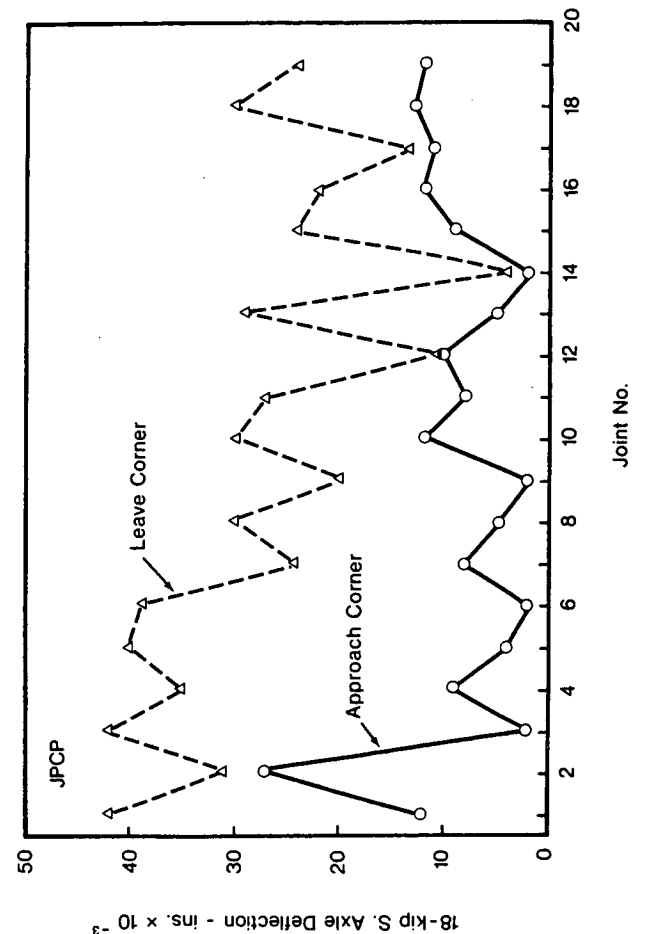


Figure 5. Corner deflection profile.

weather periods. These pavements tend to develop slab cracking near the joints much more easily than those pavements with dowels. Pavements with dowels or other mechanical load transfer devices can also lose good load transfer as a result of high bearing stresses wearing away the hole around the dowel.

4. Two types of retrofit mechanical load transfer devices are available: (1) dowel bars, and (2) shear devices.

Short term experience with load transfer restoration of a joint/crack indicates that both techniques can be used successfully. There have been several failures of the shear type of device on several projects because of lack of bonding between the patch material and the PCC slab. Research is continuing on improvements to this design. Dowel bars installed and grouted into slots cut into the surface of the pavement have performed well in the few projects where they have been installed.

5. The slab must be subsealed prior to the placement of any load transfer device if loss of support exists.

6. Placement recommendations for the load transfer devices are given in Chapter Four. These designs will ensure adequate load transfer across the joint as long as the devices remain in place.

Diamond Grinding

1. Diamond grinding is usually done to restore a smooth surface profile to a PCC pavement. Continuous diamond grinding over the entire project length is often required to restore a suitable ride to a pavement, particularly to remove faulting at joints and cracks.

2. The smoothness of a diamond ground pavement is equal to or better than a newly constructed surface.

3. Acceptance testing for smoothness is accomplished by different measuring devices (i.e., profilometers, Mays ride meter, etc.).

4. Initial skid resistance of diamond ground pavements is substantially improved over the existing worn surface.

5. Slab stabilization prior to grinding is essential to provide the smoothest ride with diamond grinding. Improvement of joint load transfer should also be considered.

6. All joints should be sealed to waterproof the pavement and to prevent reoccurrence of faulting of the pavement as a result of pumping action. A drainage analysis may indicate that subdrains should be installed to remove the infiltrated water.

7. Spacing of the diamond blades must be varied, depending on the hardness of the aggregates, to provide a durable surface texture.

8. Normally, diamond grinding is required only in the heavy traffic lane where roughness, due to faulting, is present. In some cases both lanes require grinding because of faulting or poor skid resistance.

9. The cost of diamond grinding is primarily dependent on the amount of roughness (faulting) to be removed, the hardness of the aggregate, and the job size.

Resealing Joints

1. Resealing joints is an essential part of effective preventative maintenance practice. An effective job of joint sealing will prolong the life of a PCC pavement.

2. The proper shape factor is essential for long-term per-

formance of sealants. The shape factor is a function of the particular sealant used. A backer rod is used to help establish a proper shape factor.

3. Joint walls must be clean and uniform for proper adhesion of sealant material.

4. Life cycle costs should be considered in the selection of sealant materials.

5. Resealing should be done before the existing sealant has failed (e.g., allowed water and incompressibles to infiltrate the joint), normally much sooner than the current practice in many areas of the United States.

6. Thorough inspection of all aspects of the resealing operation is essential to obtain good sealant performance. Detailed inspection procedures are given in Chapter Four.

7. For pavements exhibiting "D" cracking, the resealing of joints will reduce the infiltration of moisture and thus reduce the amount of time that the concrete is saturated near the joints.

8. If the reduction of free moisture in the pavement section is a major objective of resealing the transverse joints, all existing joints and cracks should also be resealed (longitudinal joints between lanes, longitudinal lane/shoulder joint, cracks).

Edge Support

1. Many concrete pavements exhibit distress resulting from loss of support beneath the slab edges and transverse joints. The major cause of this loss of support is heavily loaded, repeated truck loads, and the infiltration of water into the pavement system (particularly along the longitudinal joint) and the subsequent erosion of the base and/or subgrade material. This causes an increase in the corner and edge deflections and stresses that results in corner breaks, transverse and longitudinal cracking, and transverse joint faulting.

2. Increased edge support can be obtained from tying a relatively narrow PCC edge beam (e.g., 24 in.) or a wider standard PCC shoulder to the lane slab. The effectiveness of the edge support depends on the reduction in deflections and stresses in the traveled lane slab. This reduction depends on the adequacy of the tie system and the width and thickness of the PCC edge beam or shoulder. Design recommendations are provided in Chapter Four that will provide at least 70 percent load transfer between the traffic lane and the edge support.

Another benefit is the tight seal at the lane edge that greatly reduces water infiltration.

3. Only one test site of an edge beam was found in Minnesota (see Appen. B). There are, however, several projects throughout the United States where full width PCC shoulders were tied onto an existing jointed concrete traffic lane. No significant difficulties were encountered in construction of either the edge beam or the PCC shoulders.

The long-term effectiveness of the edge support has not been established through field performance. However, where shoulders were tied onto existing CRCP in Illinois, a substantial improvement in performance was noted after 10 years (12). This improvement did not occur in one experimental project in another state where either a deficient tie system was suspected or a significant loss of support already existed along the edge and was not stabilized before or after placing the PCC shoulder. However, it is believed that the two beneficial effects of edge support (reduced water infiltration and increased edge support) will add a substantial service life to a PCC pavement.

4. The cost effectiveness of improved edge support depends in part on the condition of the AC shoulder, the thickness of the slab, the amount of heavy truck traffic, and the amount of moisture available.

CHAPTER THREE

INTERPRETATION, APPRAISAL, APPLICATION

The major findings from the project are presented in Chapter Two. This chapter discusses the significance of those findings in a practical sense.

In general, the state-of-the-art procedures in 1980 were very much inadequate from a design and a construction standpoint. Considerably more engineering must go into the development of a concrete pavement rehabilitation project than is normally being done currently. Several states have taken the lead in this area and have developed comprehensive design and construction guidelines along with training courses for state and contractor personnel. This includes the performing of considerable research into improving their repair and preventative procedures for local conditions and the development of very reliable and cost-effective procedures (e.g., Georgia, Minnesota, Michigan).

In addition, there exists a great need for improved construction specifications and inspection practices. Training is essential for both the state personnel and the contractor crews in the highly specialized techniques involved in concrete pavement rehabilitation.

The purport of the findings is summarized in the following discussion for each of the seven techniques considered in this study. Each item corresponds to its respective item in Chapter Two.

FULL-DEPTH REPAIR

1. Rigid standards set up for an entire State (e.g., slab sizes and mix design) will not provide the flexibility needed for the field engineer to adequately lay out the repairs and to handle the traffic control conditions. The engineer must be allowed flexibility in the size of the repair, only adhering to the minimum size requirements for stability under load and minimum opening times to control damage.

2. More training and effort must be put into the layout of repairs in the field and in the provision of adequate funding to repair deteriorated areas. Many projects can be found where an inadequate amount of repair was accomplished. Analysis of these projects suggests serious deterioration has taken place within a few years because of these inadequacies.

3. Most agencies must consider the use of mechanical load transfer in their full-depth repairs placed on heavily trafficked routes. However, for jointed plain concrete pavements (short

joint spacing) with stabilized bases in drier climates, mechanical load transfer may not be needed. There are still questions as to the most efficient design of the load transfer devices. These concerns include the following:

- Installation of dowels and rebars have been inadequate. For example, epoxy has not set up properly and both epoxy and grout have not been inserted adequately to provide encapsulation of the rebar or dowel.
- One state is slightly overdrilling the diameter of the holes (1/16 in.) and inserting the bars without any bonding material.
- The number of dowels and their spacing are not fully resolved at this point. It appears that under heavy traffic and soft subgrades up to 5 dowels in each wheel path may be needed.

4. A minimum slab length is required to avoid rocking and pumping of the repair. The general experience indicates that 6 ft is a minimum when load transfer is provided. A minimum of 4 ft has worked satisfactorily, but there have also been significant problems under heavy traffic.

5. The lift-out method avoids disturbing the base/subgrade material which is a common problem with the break-up and clean-out method of slab removal. This is believed to be a very important factor in subsequent performance of the repair. The cost of either method appears to be approximately the same. It is extremely difficult to repair a disturbed base/subgrade.

6. Procedures are now available for rapid opening of full-depth repairs through the use of mix designs and curing techniques.

7. The inverted "T" type of repair is not recommended, except when coupled with dowels. It should definitely not be used in deep frost areas due to differential frost heave.

8. A sealed transverse joint (with the proper shape factor) at the repair boundaries reduces spalling and water infiltration into the pavement. It is strongly recommended.

PARTIAL DEPTH PATCHING

1. Partial depth patches must be separated from the adjacent slabs by some type of joint insert on material to prevent compression or shear failures as illustrated in Figure 7. Sawing the joint to the anticipated depth of the spall will also facilitate insertion

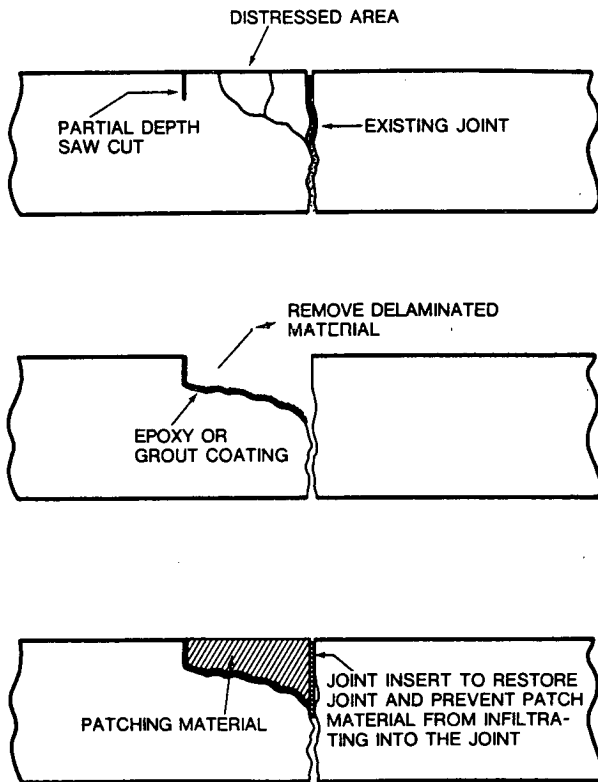


Figure 7. Partial-depth spall repair recommendations.

of an insert to isolate the patch. Various types of inserts have been used such as wallboard and foam plastic sheeting.

2. Proper bonding of patches is essential for good performance. The use of proper size removal equipment to prevent damage to the base pavement is essential. After removal, the patch area should be sandblasted to remove any loose material caused by removal operations. Bonding agents used in patching have been cement grouts, epoxies, and other proprietary materials. Where patches are protected from traffic for 24 to 72 hours, portland cement grout mixtures have provided adequate bonding when used with Type III portland cement mixtures. Epoxy bonding agents are generally used when patches are opened to traffic within 4 to 6 hours.

3. When using a proprietary patch material the handling, mixing, placement and consolidation, finishing, and curing of the patch material should be in accordance with the manufacturer's written instructions. The working tolerances of some of the proprietary patch materials are too tight for most repair projects.

4. Type III portland cement concrete, with and without admixtures, has been used for patch mixtures longer and more extensively than most other patch materials. It is low cost, easily available and simple to use. A high percentage of repair projects requires patches to be opened to traffic within 4 to 6 hours. Under hot weather conditions, a patch mixture using Type III cement with 2 percent CaCl_2 by weight of cement has been used successfully when an epoxy bonding agent is used.

5. Partial depth patches that extend below mid-depth of the pavement have exhibited variable performance, particularly with

doweled pavements. It is recommended that full depth patches be used where this condition exists.

SUBSEALING

1. The failure to restore support to a slab, whether or not an overlay is placed, will result in rapid deterioration of a pavement under heavy traffic. An adequate slab stabilization job can be performed if designed and constructed properly. Subsealing is still an "art," but there are procedures that can assist the engineer to obtain a successful job as documented in Chapter Four. Training of inspectors is urged.

2. The use of deflection measurements can aid the engineer in identifying the need for subsealing particular joints and/or cracks. The common practice of "blanket" subsealing (every joint and crack) may result in damaging slabs that already have full support by lifting them unevenly. Several agencies have used deflection measurements with success. Appendix C provides practical procedures for the identification of "voids" or loss of support which should be subsealed.

3. The difficult problem of grout quantity estimation, and particularly of evaluating the effectiveness of the subsealing work, can be assisted greatly through deflection testing and analysis using procedures outlined in Appendix C. This procedure is considered experimental.

4. The flowability of grout is crucial to a successful slab stabilization. Comparative studies have shown that fly-ash grouts provide excellent flowability and strength.

5. The lifting of slabs will result in even worse slab support and eventually in broken slabs. If the job is set up for payment by the cubic measure of dry grout, the contractor may attempt to pump as much grout as possible. This must be carefully controlled through effective inspection practices.

RESTORATION OF LOAD TRANSFER

1. While the load transfer of a joint or crack cannot usually be "observed" (it must be measured with highly sophisticated NDT equipment), the consequences of poor load transfer are readily evident. The measurement of load transfer should be a standard procedure for any PCC pavement evaluation.

2. There is excellent equipment available for measuring the deflection load transfer of a joint or crack. Two commercially available devices that can apply reasonably heavy loads include the Road Rater and the Falling Weight Deflectometer. Both of these devices can rapidly measure load transfer of joints and cracks.

3. JPCP designs without dowels usually have poor load transfer. Also, JPCP and JRCPC with dowels or other mechanical load transfer devices can lose their load transfer capabilities after being subjected to millions of load repetitions. The specific load transfer conditions at the time of rehabilitation must be measured.

4. This is a new rehabilitation technique that has not yet been fully developed. Improvements in the design and construction of shear devices and dowel installation are made on every project where they are used. The devices should be placed on an experimental basis before being incorporated into a major project so that successful procedures can be determined. An illustration of the typical design of load transfer restoration using dowels

is shown in Figure 8 (procedures for determining the required dowel diameter and number of dowels for a given level of traffic are given in Chapter Four).

5. The occurrence of voids beneath the slab near the joint could result in very high shear stresses on the devices causing them to debond with the PCC slab. The dowels may result in very high bearing stresses and spall out the patch material used to fill their slots.

6. The decrease in deflection and stress in the slab as a result of load transfer restoration will contribute to a substantial increase in the life of the joint/crack due to reduced pumping, faulting, and cracking.

Diamond Grinding

1. Intermittent grinding of faulted joints and cracks has been specified on a few projects and the resulting ride is usually not that much improved. There is a substantial difference in ride between a continuous ground and intermittent ground pavement. The noise and visual appearance of the pavement changes between the ground and unground sections resulting in perceived roughness that may not be present. Also, other roughness that may be present in the unground sections affects the quality of ride.

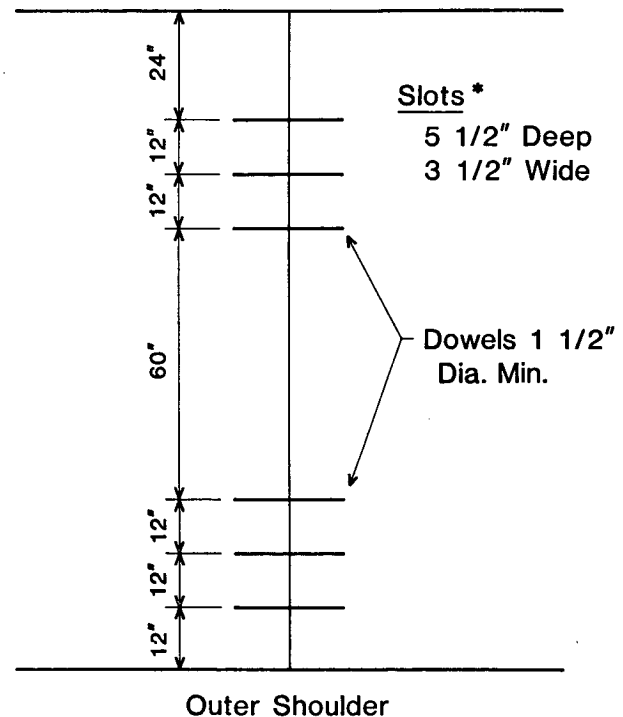
2. The grinding equipment available today is designed to act as a long wheel base plane. Faulted joints and other roughness are eliminated by diamond grinding without damage to joints. The smoothness specified is usually that for new pavement construction and in some cases a higher tolerance is specified.

3. The smoothness for diamond ground pavement is tested by such devices as the California profilograph, Rainhart profilograph, Mays ride meter, BPR roughometer and the Rolling straightedge. The use of the profilographs and the Mays ride meter have proved satisfactory for acceptance testing. The use of a 10-ft straightedge is not recommended except for ramps and bridges. Response type devices such as the Mays ride meter must be calibrated against a known standard frequently to assure that proper readings are being taken.

4. The initial skid resistance of a diamond ground pavement is often substantially improved because of the cleaning of the surface and the texture developed by grinding. The ridges are composed of rock and mortar which improve the surface macrotexture and provide an escape route for moisture under the tire. The use of the standard ribbed test tire (E501) may not provide an accurate evaluation of the skid resistance of this type of texture because this tire is not sensitive to macrotexture (6). The use of a blank (or smooth) tire (E524) shows definite improvement in the skid number after grinding (14). The Saab Friction Tester used on several of the demonstration projects appears to be a suitable device for measuring skid resistance of ground surfaces with a blank tire. The Saab Friction Tester has a constant slip ratio of 10 percent so "peak" friction is measured similar to what a vehicle measures under typical braking and accelerating conditions.

5. Slabs with excessive deflection should be stabilized prior to grinding to provide the smoothest ride. The weight of the new grinders will deflect unstable slabs making it difficult to grind the pavement smooth and to match adjacent cuts.

6. Sealing of all transverse, longitudinal, and shoulder-edge joints and cracks is essential for the long-term performance of



* Used On Exp. Projects

Figure 8. Example placement of dowels in driving lane.

diamond ground pavements to prevent refaulting of the joints. The pavement should be "waterproofed" insofar as possible through the proper installation of a quality sealant. Excessive water entry into the pavement system combined with heavy loads and high deflections can lead to reoccurrence of faulting by pumping of materials.

7. Blade spacing should be varied, depending on the hardness of the coarse aggregate. In general, the harder the coarse aggregate the closer the diamond blades must be spaced to result in breakoff of the coarse aggregate fins developed by grinding, particularly on the approach side of a faulted joint. If blades are spaced too wide, the fins will not break off when cutting through the coarse aggregate. It is recommended that the maximum spacing be used consistent with the aggregate hardness to improve the service life and friction factor of the texture.

8. An advantage of diamond grinding is that only the area where roughness is present needs treatment. Most grinding projects involve only the outside or heavy traffic lane. Where faulting has progressed across both lanes, grinding of both lanes is usually specified.

9. The cost of diamond grinding is primarily dependent on the amount of roughness (faulting) to be removed, the hardness of the aggregate, and the job size. In a diamond grinding operation, the planing action of the present day grinder blends the high areas with the low areas of a pavement surface to obtain a smooth ride. Therefore, the amount of material that must be removed to blend the approach and leave slab will depend on the depth of faulting. As more material is removed the cost of grinding increases.

The hardness of the aggregates has a great influence on grinding costs: on a typical project the cost of grinding of soft ag-

gregate is in the range of \$2.00 to \$3.00 per square yard; for medium hardness aggregate, \$3.00 to \$5.00 per square yard; and for hard aggregate, \$5.00 to \$8.00 per square yard.

The size of the project also influences grinding costs because of such considerations as mobilization or move in cost, equipment utilization, etc.

RESEALING OF JOINTS

1. The service life of a PCC pavement can be prolonged by a properly executed job of resealing the joints. During this operation the incompressibles in the joints are removed, a shape factor is established, and a seal is provided to reduce further infiltration. Distress caused by infiltration of incompressibles includes joint spalling and blowups. Jointed reinforced concrete pavements, in particular, show this type of distress because of the large joint movements associated with the longer joint spacing.

An effective seal will also reduce water infiltration into the joint. Free water beneath the slab or subbase can lead to pumping of fines that will lead to joint faulting, corner breaks, and slab breakup.

2. The proper shape factor for the sealant being used is essential for the long-term performance of joint sealants. Although the need for a proper shape factor has been recognized for several years, many resealing projects are not providing the proper shape factor for the existing pavement design and environment. The shape factor recommended by the manufacturer should be used. This will vary with the characteristics of the sealant used.

3. It is essential that joint faces are clean and dry for proper adhesion of joint sealant materials. All old sealant not compatible with the new sealant material must be removed by sawing or other means. Joints should be flushed out after sawing, sandblasted, and air blown (dry) prior to sealing. Again the joint seal manufacturer's recommendation should be followed.

4. Life cycle cost should be considered in the selection of a sealant material. When one considers the life of a sealant and

all the costs of joint preparation, traffic control, user delay, etc., the cost of a good sealant with an extended service life is a good investment. This is especially true for heavily trafficked routes.

5. Joints should be resealed at the proper time. Many pavements across the country have open joints and/or ineffective joint seals. The service life of these pavements can be prolonged with a proper job of joint resealing. This would delay such forms of distress as pumping, faulting, corner breaks, slab breakups, and slab blowups.

6. A thorough inspection is required on resealing projects to determine if the joints are satisfactorily cleaned, the backer rod is at the proper depth, and the sealant is properly placed to the specified depth below the surface.

EDGE SUPPORT

1. Pavement design procedures, such as the PCA(13) and the UI/FHWA Zero-Maintenance design (16), recognize the edge stress as the critical location for structural design. The impact of a securely tied shoulder is very significant on the thickness required and on the life of the pavement.

2. An important factor that must be considered is that the longitudinal joint must maintain good load transfer for many years. Tests from 10-year old retrofit PCC shoulders in Illinois show that where an adequate tie system was provided, over 70 percent load transfer was achieved. Where an inadequate tie system was used, load transfer was reduced to 50 percent or less because of pullouts and corrosion of the ties (12). Thus, it is possible to achieve a long-term load transfer if proper design and construction techniques are used, as described in Appendix A.

3. As with all other techniques, the performance of the edge support depends on adequate design and construction.

4. A deteriorated AC shoulder would need to be replaced anyway. The thinner the slab the more beneficial effect of the edge support. Heavy traffic and excess free water always cause problems in pavements.

CHAPTER FOUR

DESIGN AND CONSTRUCTION GUIDELINES AND GUIDE SPECIFICATIONS

I. FULL-DEPTH REPAIR OF JOINTED CONCRETE PAVEMENT

A. DESIGN AND CONSTRUCTION GUIDELINES

1.0 INTRODUCTION

These guidelines present important background information for engineers and technicians involved in designing and con-

structing 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 replacement under heavy 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 distress that occur at or near transverse cracks and joints which justify full-depth repair or slab replacement. The design engineer must conduct a preliminary condition survey of the project and identify the specific locations and approximate quantities that must be repaired (see Appen. A for distress identification). The engineer must first assess the causes of joint/crack deterioration. Some typical causes are as follows:

1. Heavy truck traffic can cause high bearing stresses between the dowels and concrete. The result of many repeated loadings is the enlargement of the dowel socket resulting in faulting of the joint.

2. Corrosion of the dowels or other load transfer devices can cause cracking at the joints. This is manifested by spalling over the top of the dowels and a transverse crack across the slab, parallel to the joint near the end of the dowels. This is termed joint load transfer distress in the concrete pavement distress identification manual (Refs. 1, 2). The complete lock up of joints from corrosion has also resulted in the opening of nearby transverse cracks causing steel rupture and eventual spalling and faulting of the crack. These cracks are now acting as a joint and will require full-depth repair.

3. Infiltration of incompressibles and large opening/closing of the joint can cause disintegration of concrete at the bottom of the joint. This occurs predominantly with long jointed reinforced concrete pavement (40 to 100 ft). This distress may not be visible at the surface, but will develop into a spalled joint. Coring of typical joints prior to full-depth repair will greatly assist in identifying this problem. This situation will often develop into a blowup from high compressive stresses.

4. The concrete may be deteriorated because of "D" cracking or reactive aggregate. Cores should be taken to determine the depth of deterioration and distance from the joint. Cores at the following intervals at several typical joints will provide information on the extent of deterioration: 0, 12, 24, 36, and 48 in. These results may also show that partial-depth patches may be acceptable in certain instances.

5. Certain types of joint inserts or load transfer devices cause spalling of the joint through entrapment of incompressibles, corrosion, or other means.

6. The infiltration of incompressibles into the joint results in much of the spalling at joints. This can be determined by observing a number of joints and digging into the joint with a knife to determine the amount of incompressibles, and by coring directly through the joint and opening up the core to examine the joint faces.

7. Slab breakup such as corner breaks or diagonal cracks near the joint is caused by a loss of support beneath the slab. 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 a small depression of the asphalt shoulder near the joint/crack as base materials are pumped out (e.g., blowholes).

8. The breakup of the slab in several pieces may be caused by heavy repeated 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 only occurring in the heaviest truck lane, fatigue damage is the likely cause, but if slab breakup occurs in all lanes, foundation problems are likely.

The severity of the deterioration of the joint or crack is the criterion by which the engineer decides if a repair is needed and 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). A summary of the text from the NCHRP Project 1-19 distress identification manual for joint/crack distress is given in Appendix A to this document. The low severity level does not require full-depth repair. The high severity level is a safety hazard and definitely requires repair. The medium severity may 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 a few 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 over one year will pass before construction will begin, much 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 to 20 percent to allow for the additional deterioration.

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 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.

2.0 CONCURRENT WORK

In addition to full-depth repair, other restoration may be required. The 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 the existing load transfer and the existence of void development. Subsealing of slabs where pumping has eroded the base is essential to reduce rapid slab cracking.

Where poor load transfer exists, consideration should be given to the reestablishment of good load transfer to reduce deflections and stresses. Methods to minimize free water beneath the slab by joint/crack sealing or the incorporation of underdrains is very important. If the joint deterioration has been caused by infiltration of water into the joint, a cleaning and resealing of the transverse joints is necessary.

When there has been a history of blowups in a JRCP, the

provision of pressure relief joints at 1,000- to 2,000- ft intervals should be considered. Expansion joints are also located at bridge ends where serious consequences can occur from pavement "growth." Finally, a smooth surface may be restored to the pavement by diamond grinding.

If an overlay is to be placed, almost 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 (Ref. 5).

3.0 DESIGN

3.1 General

Full-depth repairs should be designed to match the project conditions. The desired life of the repair and the level of traffic loading will dictate the design details of the repair. The longer the design life in years 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.

The lane closure time available for placement of the repairs must also be considered. The concrete mixture, curing and repair design must be selected to meet the available lane closure time.

3.2 Load Transfer

A high degree of load transfer across the transverse joints of the repair is very important whenever heavy truck traffic exists. Heavy truck traffic is defined as approximately 300 or more commercial trucks per day in a given lane. Poor load transfer results in pumping, spalling, rocking, and breakup. The exact conditions under which a high degree of load transfer is required is not fully known. If the base is stabilized and has not deteriorated, the potential for deterioration is reduced. Climate is also important in terms of the amount of free moisture available for pumping and the effects of frost heave on causing nonuniform heave between the existing slab and the repair. Another important aspect is the drainability of the subbase/subgrade/shoulder. Poor subdrainage greatly increases deterioration of the full-depth repair.

There are three different methods that have been used to provide load transfer: (1) aggregate interlock, (2) undercutting and filling with concrete, and (3) dowels and rebars. Aggregate interlock provides minimal load transfer and is not reliable. However, the following exceptions may exist where aggregate interlock is sufficient: low truck traffic, a nondeteriorated stabilized subbase, good subdrainage, or where "D" cracking or reactive aggregates cause expansion of the slab, causing the repair joints to be in compression most of the time. Undercutting should not be used in deep frost areas because the existing slab will heave up more than the repair, causing severe roughness. Its reliability in nonfrost areas has not been established but load transfer is generally poor. 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. 7, 8, 9, 10).

The recommended full-depth repair designs that will provide adequate horizontal movement and load transfer for the indi-

cated situations are shown in Figure I-1 (for jointed plain concrete pavement) and Figure I-2 (for jointed reinforced concrete pavement). A detailed layout of the dowels or rebars is shown in Figure I-3. The dowel design shown in Figure I-3 places the load transfer devices where they are needed the most, in the wheel paths (Ref. 11).

The number, spacing, and diameter of the dowels will determine the amount of future faulting of the transverse joints. An approximate design procedure is given in Figure I-4. These design charts were prepared using a relationship between joint faulting, equivalent single axle loads (ESAL) and dowel/concrete bearing stress developed using field data from over 100 in-service pavement sections in Illinois (13). The dowel diameters ranged from 1.00 to 1.625 in. and were all spaced at 12 in. across the joints. ESAL ranged up to 20 million. The bearing stress in the critical dowel outer corner was computed using Friberg's procedure (14). The required dowel design is determined by trial and error considering the following factors:

- Dowel diameter.
- Number of dowels in each wheelpath (spaced at 12 in.).
- Future ESAL in design lane.
- Allowable faulting of the repair transverse joint.

The bearing stress was computed for dowels spaced at 12 in., a joint opening of 0.25 in., and other assumptions given in Figure I-4. The major uncertainty with using this procedure is that the relationship was developed from in-service pavement joints, not full-depth repairs. Thus, it is essential that good grouting or epoxying of the dowels is achieved.

The use of 1½-in. diameter dowels is recommended in most cases because of the beneficial effect in reducing faulting for a small increase in cost of the dowel.

An example design is provided as follows.

Example—Very heavy traffic. An adequate load transfer system for full-depth repairs in a jointed concrete pavement must be designed. The pavement has the following design characteristics:

- Slab thickness is 9 in.
- Traffic over next 15 years is 10 million equivalent single axle loads in outer truck lane.

The maximum allowable load transverse joint faulting is set at 0.20 in. over the 15-year (10 million ESAL) design period. Another limiting faulting value could be used for design.

- *First trial:* Three dowels in wheel path spaced at 12 in.
First dowel placed 12 in. from edge.
Dowel diameter is 1.25 in.
Dowel/PCC bearing stress is 1,898 psi (Fig. I-4(a)).
Faulting is 0.52 in. (Fig. I-4(b)). *Unacceptable.*
- *Second trial:* Change dowel diameter to 1.50 in.
Bearing stress is 1,365 psi.
Faulting is 0.28 in. *Unacceptable.*
- *Third trial:* Use four dowels in wheel path.
Dowel diameter is 1.50 in.
Bearing stress is 1,147 psi.
Faulting is 0.19 in. *Acceptable.*

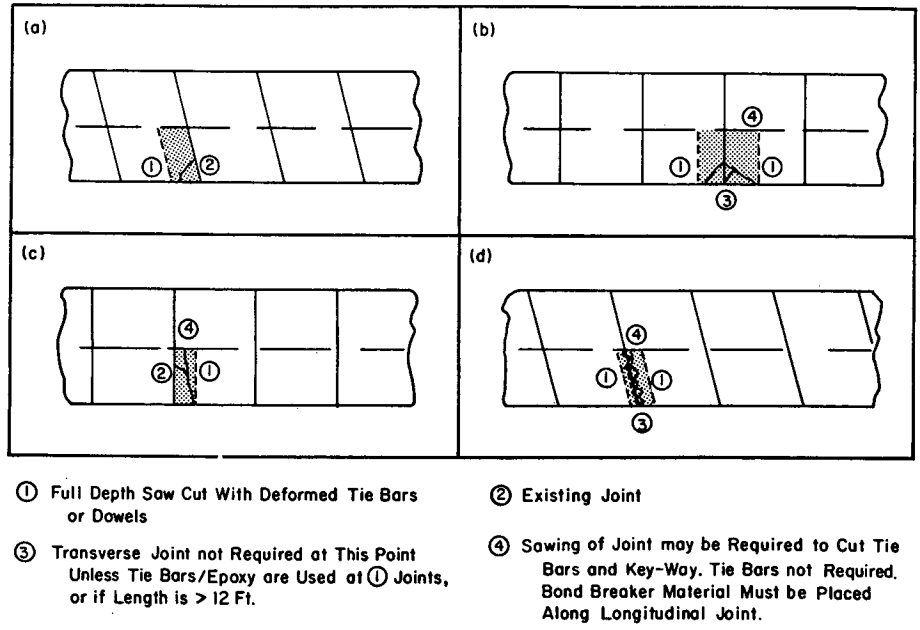


Figure I-1. Full-depth repair recommendations for plain jointed concrete pavements under heavy traffic.

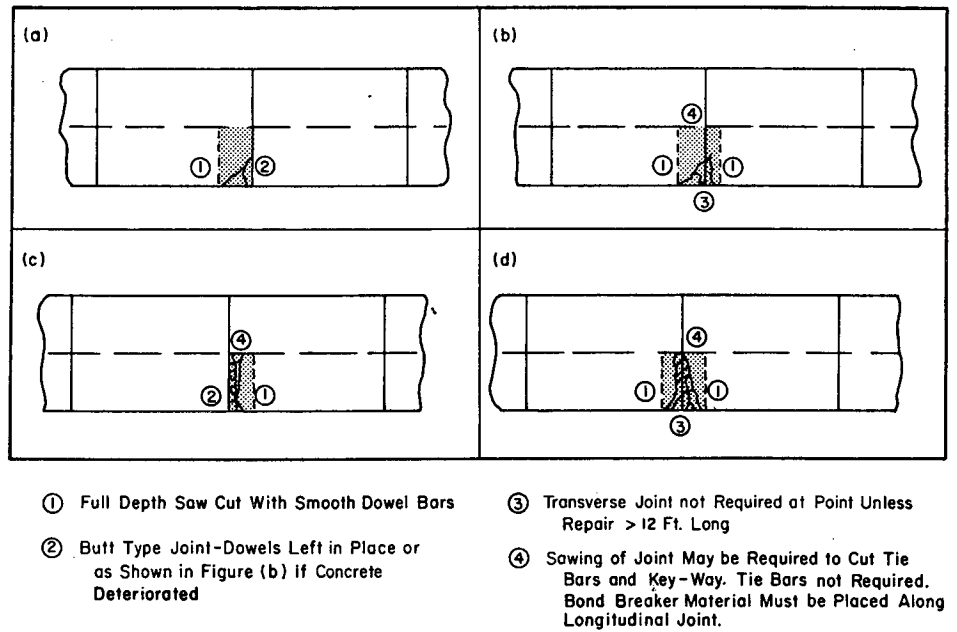


Figure I-2. Full-depth repair recommendations for reinforced jointed concrete pavements under heavy traffic.

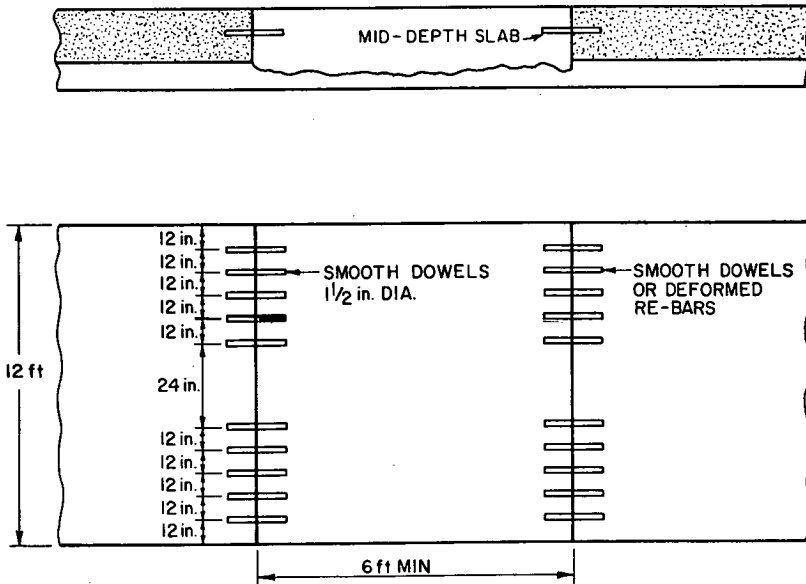
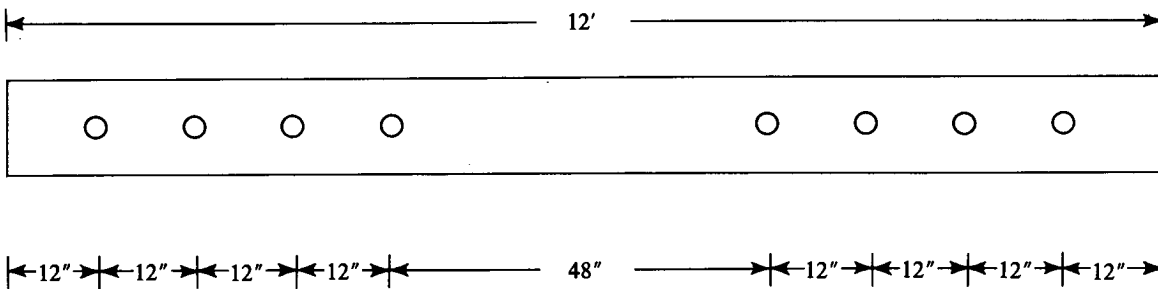


Figure I-3. Recommended dowel bar spacing.

- **Recommendations:** Provide the following transverse joint load transfer design:



Dowels = 1.50 in. in diameter and 18 in. long.

It is generally recommended to use smooth dowel bars for load transfer. This provides for a working joint (particularly for JRCPP). In some cases it may be desired to provide a nonworking joint with the use of heavy deformed rebar (No. 8 minimum).

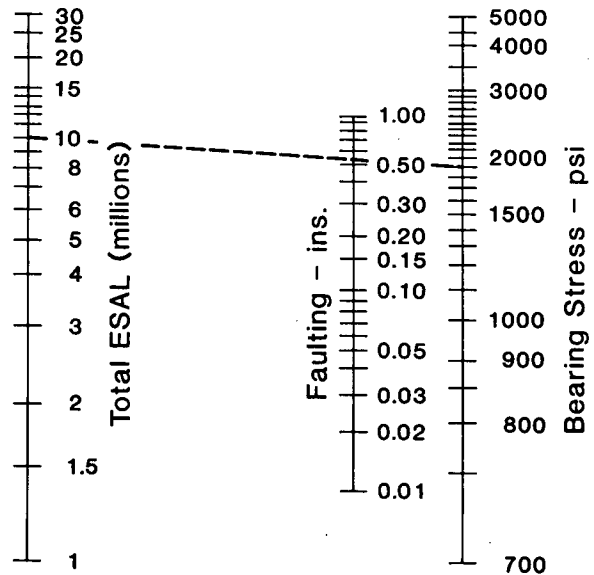
3.3 Selection of Boundaries

It is important that the boundaries be located so that all of the significant distress is removed. In general, the deterioration near joints and cracks is greater at the bottom of the slab than can be observed on the top of the slab. The repair boundaries are also controlled by the level of load transfer which is provided. The repairs must be of sufficient size to eliminate rocking, pumping, and breakup.

A minimum repair size 6 ft length by 12 ft width is recommended to provide stability under heavy traffic.

In the case of short plain jointed slabs with high-severity distress, it is recommended that normally the entire slab be replaced. Example repair layouts are shown in Figure I-5 for plain jointed concrete pavements (JPCP) and Figure I-6 for reinforced jointed concrete pavements (JRCP). Reinforcement is needed in JRCP where the repair is greater than about 12 ft in length, or where the existing mesh is extended into the repair. It may be more economical to place additional dowelled transverse joints at about 12-ft intervals, rather than to place reinforcement.

Solves: $\ln(F+1) = \ln(ESAL+1) [1.394 \cdot 10^{-4} \text{BSTRESS} - 0.0913]$



Example :
 Slab = 9 ins.
 3 Dowels Wheel Path
 1.25 ins. Diameter
 ESAL = $10 \cdot 10^6$
 BSTRESS = 1898 psi
 (Figure 4a)
 Fault = 0.52 ins.

Slab Thickness (ins.)	Dowel Diameter (ins.)	Bearing Stress-psi*				
		2	3	4	5	6
8	1.00	3878	2889	2463	2279	2250
	1.25	2591	1930	1645	1522	1503
	1.375	2180	1624	1385	1281	1265
	1.500	1862	1387	1183	1094	1080
9	1.00	3857	2842	2388	2167	2089
	1.25	2576	1898	1595	1447	1395
	1.375	2168	1598	1342	1218	1174
	1.50	1852	1365	1147	1040	1002
10	1.00	3817	2786	2316	2077	1951
	1.25	2549	1861	1547	1387	1303
	1.375	2145	1566	1302	1167	1096
	1.50	1832	1338	1112	997	936

*Load = 9 Kips on outer dowel bar
 Dowel Spacing = 12 ins. (beginning 12 ins. from end)
 K-value = 150 pci $E_{pc} = 5 \times 10^6$ psi
 (changing K has very little effect on stress) Poisson's ratio = 0.15
 $E_{dowel} = 1.5 \times 10^6$ psi
 Joint opening (Z) = 0.25 ins.

Figure I-4(a). Nomograph for determining dowel bar design (use with Fig. I-4(b)).

Figure I-4(b). Dowel bearing stress computed using Friberg's procedure (14).

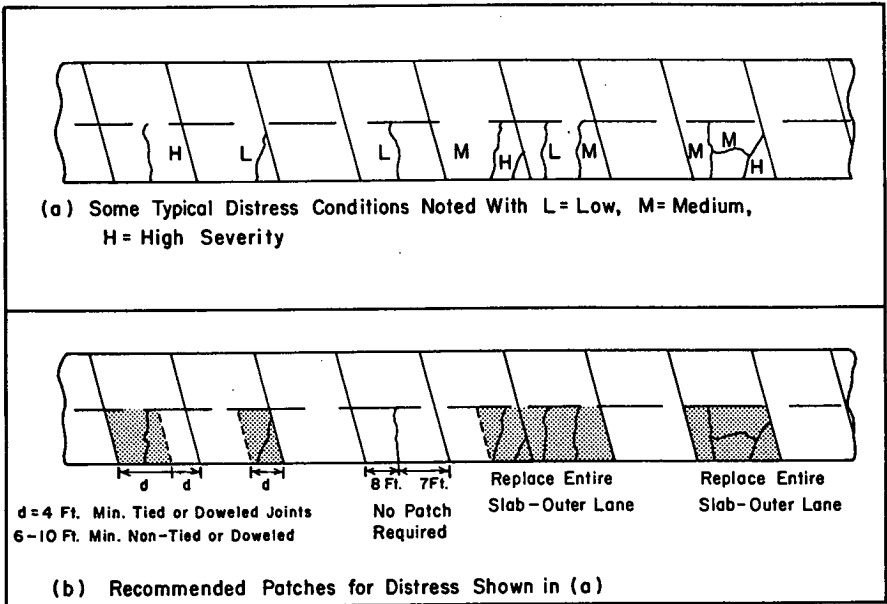


Figure I-5. Recommended designs for partial and full lane width patches for plain jointed concrete pavements (see Fig. I-3 for load transfer).

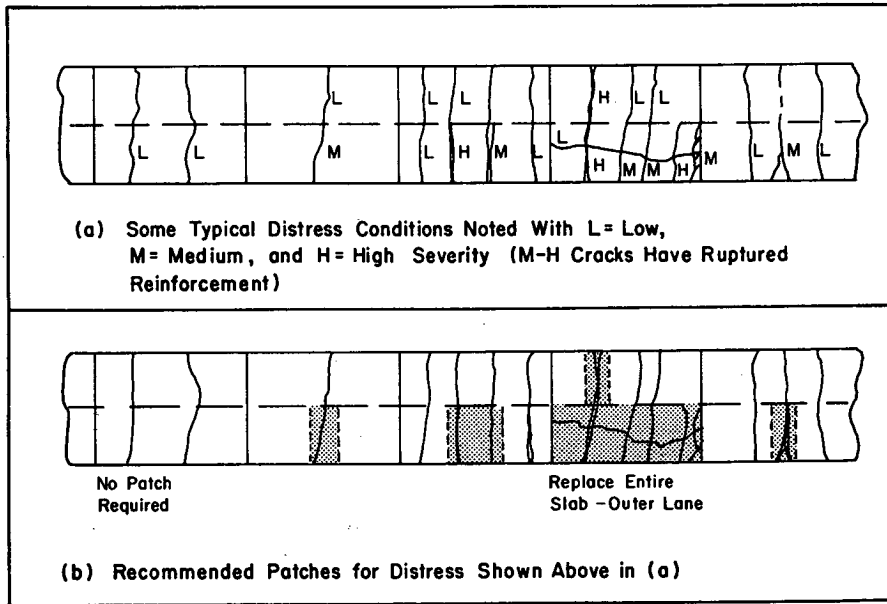


Figure I-6. Illustrations of patching recommendations for reinforced concrete pavements (see Fig. I-3 for load transfer).

4.0 CONSTRUCTION

4.1 Materials

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

1. A cement content of 658 to 845 lb per cubic yard of portland cement Types I, II, or III can be used, depending on opening time to traffic. A mix containing approximately 658 lb per cubic yard is normally sufficient for most repair work.
2. An approved air-entraining agent in amounts such that 6.5 ± 1.5 percent of air is entrained in the concrete.

Calcium chloride or another accelerating chemical admixture is recommended for use as an accelerator in the patching 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 because greater amounts can bring on a flash set. The maximum percentage is generally limited to 2 percent by weight of cement. It should be noted that on warm days, the initial set of the concrete can occur as soon as 30 min after the addition of calcium chloride.

The ready-mix truck must be mixed an additional 40 revolutions after the addition of the calcium chloride in solution at the site. Additional 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 to the concrete.

The superplasticizer should be added at the patching site because of its limited time of effectiveness. It should be added in accordance with the instructions supplied by the manufacturer to provide a 5 to 6-in. 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, the calcium chloride should be added at the site. If, after the addition of calcium chloride at the site, the concrete is too stiff, the ready-mix plant operator should be notified to increase the slump an appropriate amount provided that the maximum water/cement ratio is not exceeded. Concrete containing a chemical admixture, or combination of these, may have these added to the concrete at the batch plant, provided short haul to job site and cool temperatures exist.

4.2 Procedures

4.2.1 Sawing of Repair Boundaries

Repair transverse boundaries must be sawed *full depth* with diamond saw blades. The only exception to this is where a wheel saw (having carbide steel tips) is used to make wide cuts inside the full-depth saw cuts so that the center portion can be lifted out. If the wheel saw cut(s) are made first, diamond saw cuts must then be made at least 18 in. outside the wheel saw cuts.

The wheel saw cuts produce a highly ragged edge that promotes excessive spalling along the joint. The wheel saw must not penetrate more than $\frac{1}{2}$ in. into the subbase. The longitudinal joint between lanes should be sawed to a depth of 6 in. or to the bottom of the existing key-way, whichever is greater.

The full-depth sawing creates an open joint with no load transfer, and thus high deflections will occur. Therefore, 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.

4.2.2 Removing Existing Concrete

Procedures used for removal must not spall or crack adjacent concrete or disturb the base course. This requires that the following aspects be considered:

1. Heavy drop hammers should not be allowed on the job.
2. Hydrohammers (large automated jackhammers) must not be allowed near a sawed joint.
3. Joints can be placed to relieve pressure whenever the temperature is such that the sawed joint closes up, and spalling will result when the existing slab is broken up or lifted out. A relief cut that will eliminate spalling is shown in Figure I-7.

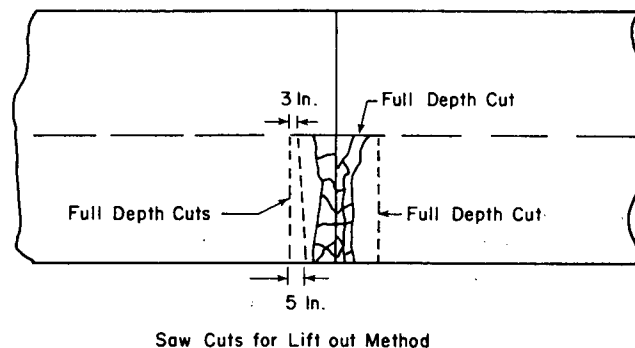


Figure I-7. Saw cut locations for lift out method of concrete removal (note: because of equipment limitations, it may be necessary to cut the slab into smaller pieces).

Procedures used for removal must not disturb the subbase or subgrade. The common practice of replacing the subbase does not work well because of the inability to adequately compact the material. If the contractor disturbs the subbase, he should be required to remove all disturbed material and then replace the material with concrete when the repair is placed.

There are two basic methods to remove the existing deteriorated concrete within the repair area. These include (1) the breakup and clean-out method and (2) the lift-out method. Advantages and disadvantages of each method are given in Figure I-8. The lift-out method will generally provide the best results and the highest production, for the same or lower cost along 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.

Method

1. Breakup and Cleanout
 - a. Advantages - Pavement breakers can efficiently breakup the concrete and the 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 generally does not disturb the subbase and does not damage the adjacent slab. It generally provides a more rapid removal than the breakup and clean out method.
 - b. Disadvantages - The disposal of the 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 say a front end loader.

Figure I-8. Advantages and disadvantages for removal of concrete in patch area.

After the existing concrete has been removed, the subbase/subgrade should be examined to determine its condition. All material that has been disturbed or that 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. The entire foundation should also be compacted before the concrete is placed to minimize the potential of slab settlement.

4.2.3 Dowel and Rebar Placement

Either smooth steel dowels or deformed rebar can be installed in the repair joints. For reinforced jointed pavement, it is recommended that dowels be used at both ends to allow movement. This is accomplished by drilling holes at specified locations into the exposed face of the slab. The holes can be drilled rapidly by placing the drill in a frame that holds them in a horizontal position at the correct height. Tractor-mounted equipment is available to drill multiple holes at the same time. Dowels must be carefully aligned with the direction of the pavement to provide easy movement.

The bars should be spaced 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. Figures I-3 and I-4 provide the recommended design spacing for bars. This will minimize the number of bars, but yet provide load transfer in the wheel paths. A quick-setting, nonshrinking mortar or a high-viscosity epoxy can be used to permanently attach the dowel or rebar in the hole. It is strongly recommended that even the smooth dowels be grouted or epoxied into the existing slab to provide a secure fit with minimum looseness. When using dowels, the end that extends into the repair area should be lightly greased to provide ease in movement. Care must be exercised in grouting or epoxying dowels/tie bars to ensure complete coverage of the device.

Load transfer across the longitudinal joint is not normally required.

4.2.4 Concrete Placement and Finishing

Critical aspects of concrete placement and finishing include

(1) adequate consolidation, (2) avoiding a mix that is either too stiff or has too high a slump, and (3) ensuring a level strike-off 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 in. at the repair site for best placement. However, this may vary depending on additives and construction conditions. A mix too stiff or too fluid could provide 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 because 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. The surface should then be textured similar to the existing slab surface.

4.2.5 Joint Sealing

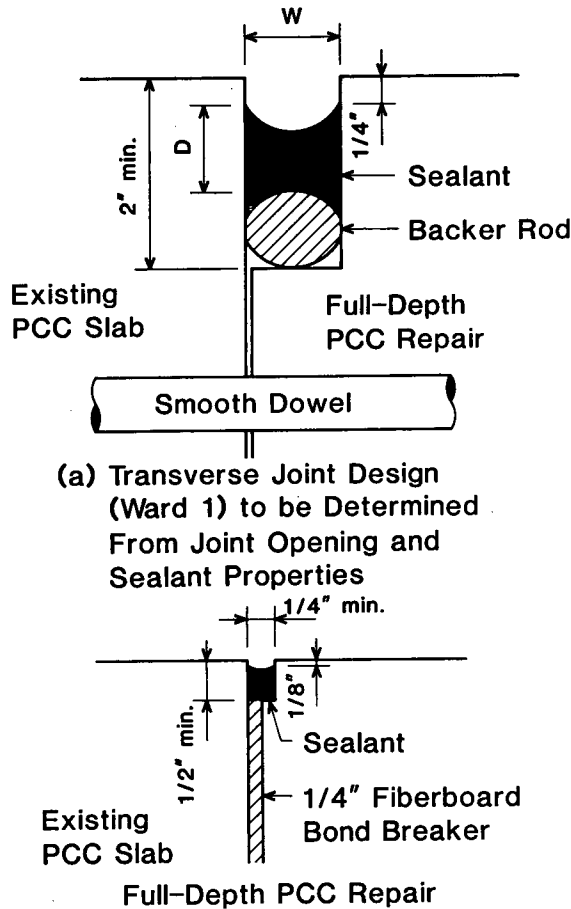
Experience has shown that the transverse joints must be formed and sealed. A reservoir should be formed or cut either in the new concrete (or both) that is at least 2 in. deep to avoid point-to-point contact at the top of the slab to reduce spalling potential. After cleaning, a backer rod and sealant are then 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 provide reduced spalling and water infiltration. Figure I-9 shows a typical diagram for transverse and longitudinal joints that could be placed in the project plans with appropriate dimensions.

4.2.6 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 difference ranges from 10 to 20°F at 4 hours after placement for noninsulated repairs. If an insulation blanket is placed over the repair, the temperature difference may be as high as 40 to 60°F. Thus, for rapid curing (particularly in cold weather) it is strongly recommended that insulation blankets be placed over the repair (Ref. 6). Polyethylene sheeting should be placed on the concrete surface before placing the insulation. The water/cement ratio and rapid setting additives also have a significant effect on rapid 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. Figure I-10 provides recommendations on early opening of full-depth concrete repairs.

5.0 PREPARATION OF PLANS AND SPECIFICATIONS

It is recommended that when there is a substantial amount of repair, aerial photography be used to clearly delineate the



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

(b) Longitudinal Joint Between Lanes

Figure I-9. Transverse and longitudinal joint reservoir designs.

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 Figs. I-3, I-7, and I-9).

Because of the difference in unit cost between small area repair and larger slab replacement, two or more pay items should be set up. For example, one agency has the following three sizes: Type I, less than 5 sq yd; Type II, 5 to 15 sq yd; and Type III, greater than 15 sq yd.

There are generally two different methods which 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 (e.g., 300 to 650 psi modulus of rupture). A modulus of rupture of 300 psi for center-point loading, or 250 psi for third-point loading, or 1,000 psi 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

Slab Thickness (inches)	Ambient Temperature At Placement (°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
8	90	40	30	13	13	9	3
	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
9	80	35	23	13	10	9	3
	90	29	22	11	9	8	3
	40	82	34	37	15	16	5
	50	51	25	23	12	13	3
	60	28	19	16	9	9	3
10	70	25	16	12	8	7	3
	80	20	14	10	6	6	3
	90	17	12	8	5	5	3
	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 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 11).

Figure I-10. Early opening guidelines for full-depth repairs.

the temperature in the slab will be higher from the heat of hydration.

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 in Figure I-10 are based on analytical and field tests (Refs. 4, 6). These recommendations should be carefully evaluated by an agency before adoption, and adjusted to local conditions where needed.

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

6.0 REFERENCES

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14. FRIBERG, B. F., "Design of Dowels in Transverse Joints of Concrete Pavements." *Transactions, ASCE*, Vol. 105 (1940).

B. GUIDE SPECIFICATIONS

1.0 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 applicable to the work on this

project are as published in the current edition of (Local, State, Special) "Standard Specifications."

2.0 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 845 lb) cubic yard of portland cement (Types I, II, or III) per cubic yard 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 T152 prior to addition of calcium chloride.
3. The material proportions shall be in accordance with the approved mixture design that gives a slump of 2 to 4 in.

b. *If calcium chloride is used as an additive, 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. When the temperature is below 70°F, 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 min.
2. At all times the percentage of calcium chloride by weight of cement is limited to a maximum of 2 percent.

c. *If a superplasticizer additive is used, the following conditions apply:*

1. The concrete mix shall be altered so as to produce a 1-in. 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 2.1(b) 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 7-in. slump concrete for easy placement. If the concrete begins to stiffen up by the time the second or third repairs are 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.

d. *If any chemical admixtures, ASTM C494, 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 in accordance with AASHTO M254. The dowels shall be 18 in. 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 M235.

2.8 Nonshrink Grout

(Used to attach the dowels in the existing slab and is pre-packaged.) Nonshrink grout shall be a flowable nonmetallic grout and nonshrink 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 3,000 psi at an age of 24 hours when tested using applicable portions of ASTM C109. 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 min when tested under CRD-C82, "Method of Test for Time of Setting of Grout Mixtures," Corps of Engineers.

3.0 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 clean-out method or the lift-out method. Equipment for breaking the concrete shall be limited to drop hammers, hydrohammers, and jackhammers. 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 $\frac{1}{8}$ in. in 12 in. 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 Forms, Metal, or Wood

See Standard Specifications

3.7 Chairs

See Standard Specifications

3.8 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 in. from the vibrator head.

3.9 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 ft 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 in. in width.

3.10 Pressure Hand Sprayer for Membrane Curing Compound

Manually operated spray equipment may be used to apply curing compound.

3.11 Insulating Blankets

When required, 2-in. 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.

4.0 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 2 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.

1. *Breakup and Clean-Out 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.

2. *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 of Dowels into Existing Slab

When specified, holes shall be drilled into the face of the existing slab at the specified diameter with a tolerance of $\frac{1}{8}$ in. in 12 in. They must be blown out with compressed air prior to placing the grout or epoxy material. They shall be spaced at middepth of the slab and located as indicated on the plans. The diameter of the holes shall be $\frac{1}{8}$ in. larger than the dowels or rebar.

For epoxy and nonshrink grouts, the material shall be injected to the rear of the hole and must be dispersed along its length to ensure that the bars are completely covered and no voids exist. The bars shall be inserted with a twisting motion and seated in place by tapping. 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 ft or less in length, the screed shall be placed parallel to the centerline of the roadway. For repairs over 12 ft 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 ft 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 $\frac{1}{8}$ in. 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 more than one lane full-depth repair is placed at one 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 sq ft/gal.

When the ambient temperature at the time of placement is below 90°F, insulation blankets having a minimum thickness of 2 in. 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 asphaltic concrete. The asphaltic concrete shall be compacted to the satisfaction of the engineer.

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 recommended) as determined from center-point loading beam tests, or ____ psi (250 psi recommended) for third-point loading, or ____ psi (1,000 psi recommended) compressive strength.
2. The time specified has elapsed (for a given ambient temperature at placement of the repair, concrete mixture, and curing condition).

5.0 WEATHER CONDITIONS

Portland cement concrete repairs shall not be placed when the air or pavement temperatures are below 40°F. Insulation may be used to improve the rate of curing.

6.0 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 Types I, II, or III as follows: Type I, less than 5 sq yd; Type II, 5 to 15 sq yd; and Type III, greater than 15 sq yd. The square yards of repair will be measured at the surface of the pavement.

II. PARTIAL DEPTH PATCHING OF JOINTED CONCRETE PAVEMENTS

A. DESIGN AND CONSTRUCTION GUIDELINES

1.0 INTRODUCTION

These guidelines cover permanent partial depth patching of jointed portland cement concrete (PCC) pavements. This type of patching involves the repair of spalls at joints and/or cracks and other distresses that can be repaired by partial depth patches.

1.1 Need for Partial Depth Patching

Partial depth patching can be used to repair spalls, potholes, and other partial depth distresses. One particular cause of spall-

ing is the metal insert (unitube) used in some states. These inserts have been generally used in areas where the hardness of the aggregate made sawing of joints very difficult and expensive.

Spalls are typically caused by the infiltration of incompressible materials into joints. This type of spalling is more evident on reinforced pavements with long joint spacing, where larger joint movements occur. The misalignment of dowel bars is another cause of joint spalling.

Partial depth patching has also been used to repair distress near joints associated with "D" cracking and alkali reactivity problems. If the distress is not too severe, this type of patching can provide some added life to the pavement. Other types of surfaces distress that can be repaired by partial depth patching include surface spalls over reinforcing steel, scaled pavement surfaces, etc. (see Append. A for distress identification).

1.2 Effectiveness

Partial depth repair will extend the life of a PCC pavement by restoring certain aspects of the ride quality of a pavement that has spalled or distressed joints/cracks. When properly placed with a durable patch material, the repair should last the remaining life of the pavement.

Spall repairs can be performed at any time needed. Many times spalls are filled with a bituminous material as a temporary repair technique until a sufficient quantity justifies a repair contract. If several spalls are present on one joint, it is usually more economical to full-depth repair the entire length of the joint than to patch individual spalls.

Spalls that extend deeper than one-half the slab thickness cannot effectively be partial-depth patched (e.g., pavement with "D" cracking that has deteriorated the bottom of the joints and cracks). A full-depth repair should be placed in these cases.

1.3 Limitations

The cost of partial depth patching is dependent on the size, number, and location of repair areas. In addition, the lane closure time and traffic volume all influence costs. Repairs done under single lane closure also affect production rate and costs.

The performance of partial depth patches has been excellent on many projects; however, the failure rate has been unsatisfactory on some projects. The failures are caused by lack of bond, compression failures (due to not reestablishing the joint for expansion), variability of patch material, improper use of patch material, insufficient consolidation, and differences in the coefficient of thermal expansion between the concrete slab and patch material. The working tolerances of some of the proprietary patch materials are too tight for most repair projects (i.e., exact measurements of quantities, exacting time of placement).

2.0 CONCURRENT WORK

If the spalling is caused by incompressibles in the joints, a joint cleaning should be accomplished to prevent further damage. On rehabilitation projects that involve diamond grinding, the spalls are repaired prior to grinding but after slab subsealing. After the repair of spalled joints, they should be resealed to prevent future infiltration damage.

3.0 DESIGN AND CONSTRUCTION

3.1 Materials

The type of patch material to use will depend on such factors as amount of time available before opening to traffic, ambient temperature, cost, size, and depth of patches.

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 patching material should be in accordance with the manufacturer's written instructions. The specifying agency should investigate the various patch materials available to determine their suitability for application and environment (Ref. 1). Other valuable information on patch material performance

can be obtained from agencies that have used the material (Ref. 1).

A high percentage of repair projects requires patches to be opened to traffic within 4 to 6 hours. To meet this challenge, a wide variety of rapid setting and/or high early strength patching materials are available (Ref. 1).

Under hot weather conditions, a patch mixture using Type III cement with 2 percent CaCl_2 by weight of cement accelerator can be used successfully when bonded with epoxy. Type III cement, with and without admixtures, has been used for patch mixtures longer and more widely than most other materials. It is low cost, readily available, and simple to use. Strength gain of rich mixtures (up to 752 lb per cubic yard) is rapid during warm weather. One disadvantage is that in cool or cold weather the rate of strength gain may be too slow to permit quick opening to traffic.

The use of a portland cement grout as a bonding agent for patches 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.

Where patches are protected from traffic for 24 to 72 hours a bonding agent of portland cement sand grout mixture has proved adequate when used with Type III cement mixtures. Excellent results have been obtained with 658-lb per cubic yard Type III mixture, using a cement-sand-grout bonding agent, with a cure period of 72 hours before opening to traffic.

Epoxy resin patching 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. Differences in the coefficient of thermal expansion can cause patch failures. Deep patches must be placed in several lifts to control heat development.

3.2 Procedures

3.2.1 Preparation of Patch Area

The success of partial depth patching depends on an adequate bond to the existing concrete so it is important that proper and adequate surface preparation be done. This involves sounding out the delaminated area with a steel rod, carpenter's hammer, chain or other device to determine the patch limits. Frequently all the surrounding delaminated concrete is not removed in an attempt to reduce patch size. The patch limits should be extended beyond the delaminated area about 2 to 6 in. to assure removal of all unsound concrete. If the concrete is spalled out and sounding indicates sound concrete at the spall limits, the saw cut could be made about 2 in. from the spall.

A 2-in. deep saw cut should be made around the perimeter of the patch area to provide a vertical face at the edge and sufficient depth for the patch. When extremely hard aggregate exists, a 1-in. depth saw cut is adequate. This requirement is made to avoid a feathered edge that may spall. The "run-out" of the saw cuts in the existing slab should be filled with the mortar phase of the patch material.

Concrete within the patch area should be broken out with pneumatic tools until sound and clean concrete is exposed. If the disintegration extends below the dowels in reinforced concrete pavements, strong consideration should be given to full-depth repair of the joint.

Where spalling has been caused by a metal insert such as unitube, the spalls usually start at the bottom fin of the insert about $2\frac{1}{2}$ in. 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. The joints can then be resealed. Small spall areas along joints generally do not need repair and the limits on the size of the spalls before repair, if required, can be set. For instance, areas less than 6 in. in length and $1\frac{1}{2}$ in. in width at the widest point would not be repaired but filled with a sealant (unless a preformed compression seal is to be used, then even small spalls must be repaired).

In removing the concrete within the patch area, it is important that proper size pneumatic hammers or other type equipment be used. The maximum size pneumatic hammer should be 30 lb to prevent fracturing the concrete below the patch. The use of heavy hammers can result in fracturing of concrete below the required depth. This increases the probability of compression failures by the patch bearing on the adjacent slab.

Concrete has also been removed by cold milling. It is intended that the edges of the partial depth patch area be reasonably straight and vertical. Some states have permitted near vertical edges resulting from using self-propelled milling machines. These have been used primarily on pavement with joint distress caused by "D" cracking or alkali reactivity.

After removal of the concrete, the surface of the patch area should be sandblasted free of loose particles, oil, dust, traces of asphaltic concrete and other contaminants immediately before placement of patch material.

Some states permit air blasting for cleaning the patch area after concrete removal. If the air blast will not sufficiently clean the repair area, sandblasting or waterblasting is required.

Compression failures are one of the biggest causes of partial depth patch failures. In order to eliminate this type of failure, the new patch must not be in contact with adjacent slab panels. This can be accomplished by installation of inserts that are placed in the joint to maintain space between the patch and the adjacent panel. Styrofoam has also been used for this purpose along with plastic sheeting to separate the patch from the adjacent slab. The joint must be resawed to provide a sealant reservoir.

During certain periods of the year when nights are cool and daytime temperatures are high, the expansion and contraction cycles become more critical in partial depth patches. Patches placed when the pavement slabs are contracted should have adequate space between the adjacent slab by use of inserts to prevent compression failure by point loading of the patch area.

Another cause of failure is contact of the bottom of the patch, near the joint, with the adjacent panel. This is caused by the crack below the sawed joint not breaking more or less vertically but breaking toward the spall area. In order to eliminate point loading, a foam plastic sheeting $\frac{1}{4}$ to $\frac{1}{2}$ in. thick can be used to provide space between the patch and the adjacent panel.

3.2.2 Placing Patch Materials

1. Portland cement concrete patch material. After the patch area is properly cleaned, a bonding agent should be applied. The type of bonding agent will depend on 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 patches 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 patch. The bonding grout should be composed of 1 part of sand, and 1 part cement (by volume), with sufficient water to produce a mortar with a thick, cream consistency. The grout is scrubbed evenly over the dry surface of the patch. Excess grout should not be permitted to collect in pockets. The concrete patch material should be placed before the bonding grout dries.

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

Portland cement concrete patches should not be placed when the air temperature or pavement temperature is below 40°F. At temperatures below 55°F, a longer cure period may be required and a tarp or insulation covering placed.

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

2. Rapid setting patch materials. These materials include rapid setting and/or high early strength patching materials that 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 patch materials. Bonding agents should be that recommended by the manufacturer for the placement conditions.

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

3.2.3 Curing

1. Concrete patches. Various curing methods have been specified for concrete patches that include 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 sq ft/gal max.) should be applied to the partial depth repair immediately after texturing to retain the moisture for adequate hydration of the cement.

The use of wet sand or burlap requires rewetting for proper cure. Traffic in the adjacent lane can also accelerate drying and make holding the burlap or polyethylene sheeting on the patch difficult.

2. Proprietary patch materials. The curing method for the proprietary patch materials should be as recommended by the manufacturer of the product.

3. Epoxy patch material. The patch should be protected from rain or traffic in accordance with the manufacturer's recommendations.

4.0 PREPARATION OF PLANS AND SPECIFICATIONS

It is recommended that when there is a substantial amount of partial depth patching (or a substantial amount of full-depth repair), aerial photography be used to clearly delineate the patching locations and estimated quantities. Diagrams of typical partial depth patches, removal procedures, and joint inserts illustrated in Figure II-1 may be helpful.

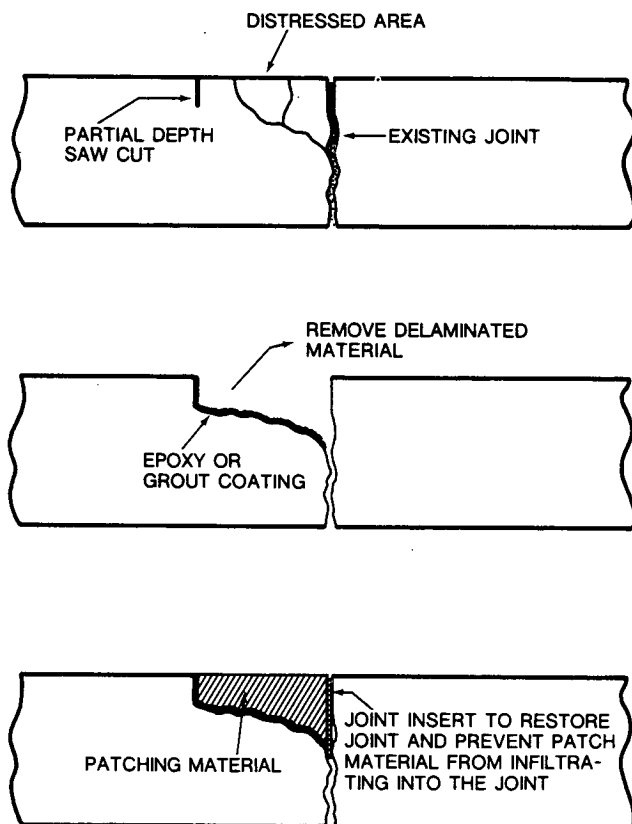


Figure II-1. Steps for partial depth patching.

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

5.0 REFERENCES

1. BAKER, W. M., and PRICE, R. G., "Concrete Patching Materials." *FHWA Report No. FHWA-RD-74-55*, Federal Highway Administration (1980).
2. TYNER, H. L., "Concrete Pavement Rehabilitation—Georgia Methodology." Preprint Volume For The National Seminar On Portland Cement Concrete Pavement Recycling And Rehabilitation, Transportation Research Board, St. Louis, Mo. (1981).

B. GUIDE SPECIFICATIONS

1.0 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 patching of spalls, potholes, scaling or other surface distress in portland cement concrete pavements. The patch area shall be prepared by removal of asphaltic concrete, or broken, damaged or disintegrated concrete from the area indicated. Patches shall be made with approved patching materials in accordance with this specification and in reasonably close conformity with the existing pavement cross section.

1.2 Location

The locations and approximate areas of the patches are shown on the plans. However, the final locations and boundaries of each patch 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."

2.0 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 Mfgr.
Coarse Aggregate	Size 89 AASHTO M-43

2.2 Patching Mixtures

2.2.1 Accelerated Strength Portland Cement Concrete Mixture

The accelerated strength shall be obtained by using Type I or Type III portland cement and a calcium chloride or other accelerator to obtain a minimum strength of 3,000 psi in 24 hours. The plastic concrete shall have an air content of 6.5 ± 1.5 percent. The slump shall be 1 to 3 in. at time of placing.

2.2.2 Portland Cement Concrete Mixture

Normal set portland cement concrete mixture shall have a minimum compressive strength of 3,000 psi in 3 days. The plastic concrete shall have an air content of 6.5 ± 1.5 percent and a slump level not to exceed 3 in. at time of placing unless a higher range water reducing system is used.

2.2.3 Rapid Setting Patching Materials

Rapid setting patching materials shall have a minimum compressive strength of 3,000 psi in 24 hours.

2.2.4 Epoxy Resin Patching Mortars

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

3.0 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 bottom of the patch.

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 patch 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 thick minimum insulation blankets shall be provided with a protective covering to avoid disintegration.

4.0 CONSTRUCTION METHODS

4.1 Determination of Patch Areas

Areas to be patched 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 in. in length and 1.5 in. 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 Preparations of Repair Area

A saw cut shall be made around the perimeter of the patch area to provide a vertical face at the edges and sufficient depth for the patch. The saw cut shall have a minimum depth of 2 in.

Concrete within the patch area shall be broken out to a minimum depth of 2 in. with pneumatic tools until sound and clean concrete is exposed. The maximum size pneumatic hammer shall be 30 lb. 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 asphaltic concrete, and other contaminants before patching. 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 Patch Material

4.3.1 Accelerated Portland Cement Concrete Patch Mixtures

Accelerated strength portland cement concrete (3,000 psi in 24 hours) patch mixtures can be used where early opening (4 to 6 hours) to traffic is required. An epoxy bonding agent is required when placing accelerated PCC patches 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 patches are returned 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, cream 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 patch material shall be placed before the bonding grout dries.

The patch mixture shall be placed and consolidated to eliminate essentially all voids at the interface of the patch and existing concrete. If a partial depth repair area abuts a working joint or crack that 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 patch and any adjacent slab that could cause compression or other types of failure in the patch must be prevented.

Accelerated PCC patches should not be placed when the air or pavement temperature is below 40°F. At air temperatures below 55°F, a longer cure period may be required. All patches shall be finished to the cross section of the existing pavement. The patch 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 sq ft/gal.

4.3.2 Normal Set Portland Cement Concrete Patch Materials

Normal set (3,000 psi in 3 days) portland cement concrete patch materials may be used where the patch is protected from traffic for 24 hours or more. The sand-cement grout discussed in section 4.3.1 may be used as a bonding agent. The patch mixture shall be placed and consolidated to eliminate essentially all voids at the interface between the patch and adjacent concrete. All patches shall be finished to the cross section of the existing pavement.

The patch 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 sq ft/gal.

4.3.3 Rapid Set Patch Materials

Rapid set patch 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 patch 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.

4.3.4 Epoxy Resin Patching 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. 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 homogeneous mass. Only that quantity of materials 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 areas 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 patch. 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.

4.3.5 Saw Cut "Run-Outs"

The saw cut "run-outs" in the exist slab shall be filled with the mortar phase of the patch material.

5.0 WEATHER CONDITIONS

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

6.0 MEASUREMENT AND PAYMENT

6.1 Measurement

The area measured for payment will be the number of square feet of surface area of patching 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 the asphaltic concrete patching material or the spalled, broken, or damaged portland cement concrete; cleaning the surface by sandblasting; furnishing, placing, finishing, and curing the concrete patch,

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 patching of Portland Cement Concrete Pavement _____ per sq. ft.

III. SUBSEALING OF JOINTED CONCRETE PAVEMENTS

A. DESIGN AND CONSTRUCTION GUIDELINES

1.0 INTRODUCTION

1.1 Need for Subsealing

Pavement subsealing is used to restore support to concrete slabs where pumping of fines has occurred creating small voids (e.g., 0.005 to 0.250 in. thick) beneath the slab and/or subbase. Most of the voids develop near transverse joints and cracks, particularly at corners. The loss of support causes large deflections and slab stresses. This leads to faulting of the joint, corner breaks/diagonal cracks, and finally complete breakup of the slab.

Subsealing is performed to stabilize slabs by filling voids beneath the slab and beneath the subbase with a suitable material. When the subsealing material has sufficiently filled the voids, the corner deflection will be reduced to full support conditions.

Subsealing should not be confused with the term "slabjacking," which refers to the lifting of the slab at a depression to its original uniform profile.

Subsealing should be performed as soon as any loss of support is detected at slab corners. This can be detected through deflection measurements (described in section 3.0), transverse joint faulting, or fines are observed near joints and cracks on the traffic lane or shoulder. Voids are definitely present when there are corner breaks or faulting, and generally develop first under the leave slab corner. Loss of support can also extend along the slab edges. These voids must be filled to prevent the rapid breakup of the slab.

Figure III-1 illustrates the progression of failure of jointed plain concrete pavements that do not contain dowels. For both plain and reinforced pavements, the initial pumping action is indicated by a small depression in the shoulder at the transverse joint (blowhole) where water under pressure has pumped out fines beneath the asphaltic concrete shoulder or the subbase surface. Reinforced jointed pavements generally develop serious faulting or spalling at the joints and deteriorated cracks, and may develop corner breaks at joints and at working transverse cracks where load transfer has been lost.

1.2 Limitations

Subsealing does not correct depressions, increase the design structural capacity, or eliminate faulting. The reduction of de-

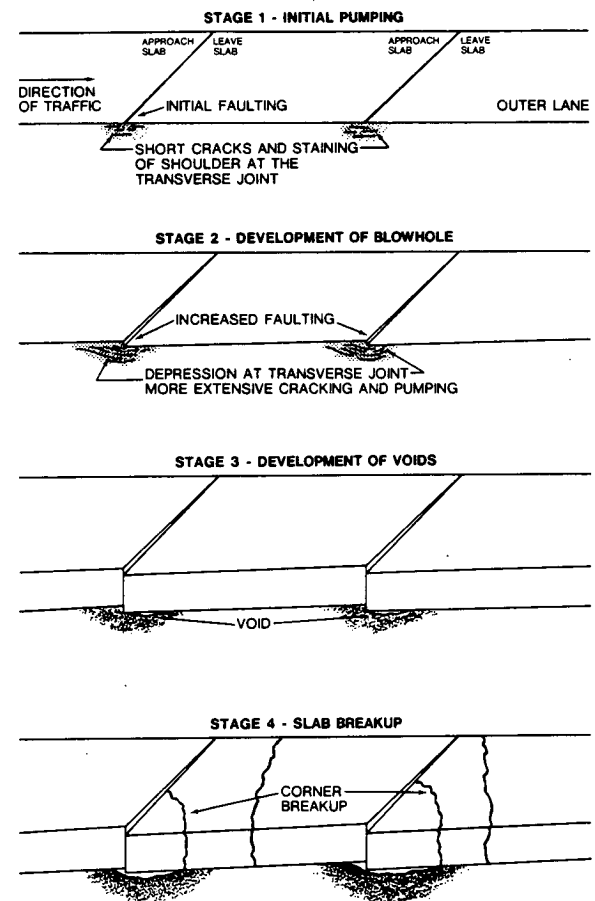


Figure III-1. Typical stages in the deterioration of a concrete pavement.

flections from the filling of voids restores the structural integrity of the slab, thereby reducing future pumping, faulting, and slab cracking. However, this benefit may diminish over time, in which case additional subsealing will be required.

Where serious pumping has occurred, it is essential to accomplish other rehabilitation work so that the beneficial effects of the subsealing in restoring slab support will not be lost rapidly. This includes work to:

- Reduce the amount of water entering the pavement.
- Reduce the time that free moisture remains within the pavement structure.
- Improve poor load transfer if it exists.

Where subdrains already exist along the pavement, great care must be used to avoid filling the drains with subseal material. One experimental site in Illinois showed that no grout flowed into existing edge drains. It may be necessary to restore load transfer to reduce deflections to prevent future pumping, (along with resealing) to reduce water inflow.

Research in NCHRP Project 1-21 has shown that *subsealing should only be performed at joints/cracks where loss of support exists*. If a joint/crack has low deflection and it is subsealed, either the deflection will remain the same or often it will increase, causing a loss of support (see Appen. C). The pumping of too much grout could easily result in an increase in broken slabs because of uneven support for slabs. Thus, the subsealing operation requires careful attention during construction.

2.0 CONCURRENT WORK

Subsealing will restore slab support of a pavement for a number of years when performed in conjunction with other rehabilitation work.

First, steps must be taken to reduce the amount of water flowing into the pavement section where substantial pumping has occurred. Joint and crack sealing will minimize water entry under the pavement. By limiting the entry of surface water into the pavement, the potential for pumping will be reduced.

Second, a subdrainage analysis should be conducted to determine the benefit of their installation. Pavement sections built in a "bathtub" could likely benefit from edge drains to rapidly remove free moisture in the structural section.

Third, load transfer restoration is also recommended wherever the existing load transfer is poor (less than 50 percent) to reduce differential slab deflections and thus pumping potential. A free corner deflection can be reduced by one-half with load transfer restoration (stresses are reduced by half as well).

Finally, full-depth slab replacement, spall repairs, grinding, and overlays could also be considered to restore riding quality to the pavement. Slabjacking should be used to restore a large depressed area to a smooth profile by pumping cement grout beneath the slab/subbase.

As with any other type of pavement repair, not only is it necessary to repair the existing distress (erosion of the pavement foundation), but actions must be taken to eliminate the causes of the distress as well. Effective repair requires that the proper measures be taken to prevent the reoccurrence of the distress.

3.0 DESIGN

The design of a subsealing project includes the selection of an acceptable subsealing material, testing of the pavements for voids, estimation of subseal quantities, and determination of an appropriate initial hole pattern.

3.1 Subsealing Materials

The subsealing material must be capable of penetrating very thin voids, yet have sufficient strength and durability to resist loading, moisture and temperature effects. Cement grouts and asphalt cements have been used for subsealing. Currently, cement grouts are used far more extensively than asphalt cements. This document describes only cement grouts for subsealing materials. Information on the use of asphalt cement is given in Ref. 2. Recommended cement grout materials for subsealing are described in section 4.1.

3.2 Determining Extent of Loss of Support and Grout Quantity Estimation

Experience has shown that grout quantities required to stabilize slabs are extremely difficult to estimate. The important concept to remember is that the grouting is being done to *restore support* to the slab. Deflection testing is the only known method to ensure that this is accomplished. Deflection testing is the best known aid in determining:

1. The extent of loss of support.
2. An estimate of required grout to restore support.
3. Whether or not the subsealing accomplished its purpose to restore support to the slab (determined through retesting).

Typical average quantities run from 1 to 3 cu ft of dry grout materials per joint. The higher quantities are for pavements with high severity pumping and more voids.

The following procedure is recommended to estimate grout quantities for a specific project:

Step 1—Visual Survey. Conduct a visual survey along portions of the project (such as one to two-tenths of a mile in each mile) and record the severity of pumping (low, medium, and high severity at each joint, as defined in Appen. A), faulting, and slab cracking. Plot profiles of pumping severity, faulting, and slab cracking vs. distance along the project. Use these illustrations to compute percent joints having low, medium, and high severity pumping and faulting. This gives an indication of the potential problem, but not conclusive proof unless significant pumping of fines exists as can be observed near the transverse joints or on the outside lane shoulder.

Step 2—Deflection Testing. Detailed void detection procedures using deflections are presented in Appendix C to this report. A brief summary of the procedure is given in this section. Select a representative section of approximately 500 ft in length in each mile of the project using the visual survey results, and conduct deflection testing. Since temperature gradients and joint closure in the slab greatly affect deflection, the tests must be conducted during early morning (e.g., between midnight and 10:00 AM). If the temperature is cool (e.g., less than 80°F) and the sky is overcast, the deflection may be taken throughout the day. Specific reference points should be identified to repeat a few of the tests every hour to see if the deflection has changed significantly.

The pattern of testing depends on the method of void detection used in Step 3. It is recommended that a heavy load deflection device having loads approaching that of a heavy truck be used. As a minimum, measure the maximum deflection under the loading plate at the corners of the outside traffic lane, and load

transfer across the joint. If the device can apply different magnitudes of load, apply at least 3 different levels of load and measure the deflections (e.g., 9, 15, 21 kips).

Step 3—Loss of Support (Void) Determination. This step involves the determination of how many joint/crack corners have voids, and the approximate size of those voids. The following methods are recommended:

- *Method A: Use of corner deflection profile.* This method requires the measurement of the corner deflections along a project under a constant load. Plot the approach and leave corner deflections on a profile and examine the results (see Figs. III-2 and III-3). Carefully observe the corners having the lowest deflections. The approach corner typically has either no void or a small void. Select a deflection

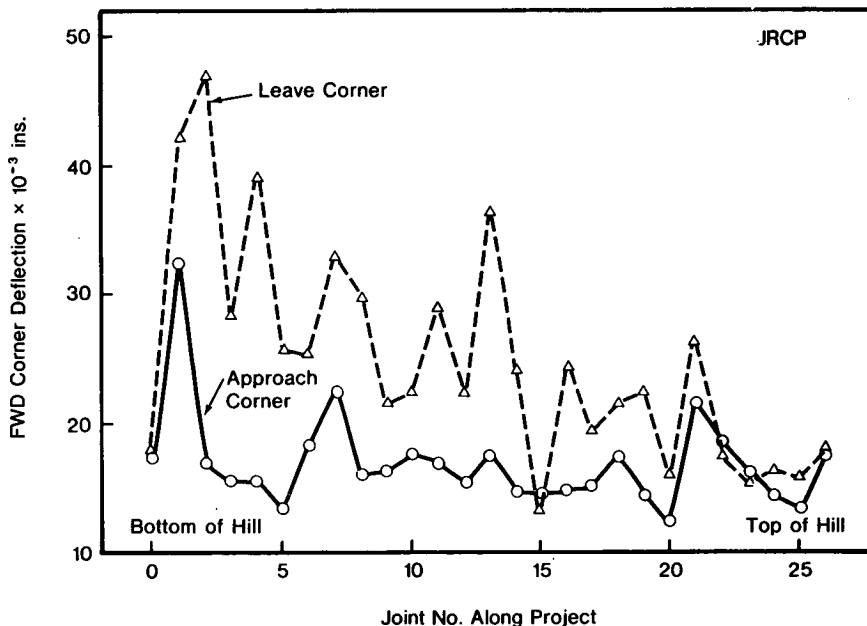


Figure III-2. Profile of corner deflection for JRCP (60-ft joint space).

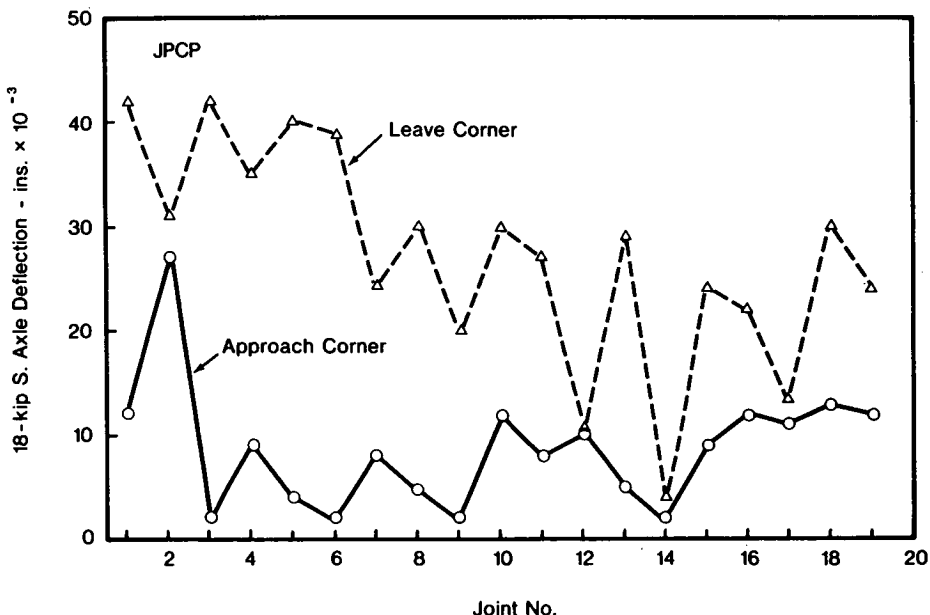


Figure III-3. 18-Kip single axle corner deflection profile of slab corners (nondoweled, 20-ft space).

level somewhat larger than what appears to be indicative of a full support condition. For example, the data from Figure III-2 using a Falling Weight Deflectometer for a doweled JRCP shows about 0.020 in. as a reasonable value. Figure III-3 data from an undoweled JPCP, using a weight truck, shows about 0.015 in. as a reasonable value. Do not select the lowest value because the contractor will be required to subseal every corner having a measured deflection greater than this selected value. The contractor will also be required to resubseal every corner that does not meet the deflection criteria after grouting.

This minimum deflection value should be reevaluated after the first few days of subsealing and modified if it appears to be unreasonable. Also, the same deflection measuring device must be used during construction as during the design engineering phase or different deflections will be obtained.

The proportion of slab corners having a greater deflection than the critical deflection can then be computed using the data. One problem with this method is that if load transfer varies widely from joint to joint, the deflections can be somewhat misleading.

- *Method B: Use of load versus deflection at corners.* This method uses the corner deflections measured at three load levels (e.g., 9, 15, 21 kips) to establish the load vs. deflection response for each test location (see Figs. III-4 and III-5). This rapid method can be used expeditiously in the field while deflection testing is in progress.

Typically, locations with no voids will cross the deflection axis very near the origin (or allowing for some random variation, less than or equal to 0.002 in.). Those locations where the load vs. deflection response crosses this axis at points further removed from the origin indicate that void is present as shown in Figure III-4. The one deflection plot on this graph that shows a 6-sq ft void has the flatter shape probably because the slab did not reach the bottom of the void before the maximum load was applied.

Because of the variations in joint load transfer, which affects the load vs. deflection response, this method cannot be used to establish the approximate size of the void. The effect of subsealing at the leave side of the joint where the void was suspected can be seen in Figure III-5).

Finally, the percentage of joints having voids can be computed. This value gives a good estimate of the proportion of joints and cracks that will need subsealing. This method was developed under NCHRP Project 1-21 and further details are given in Appendix C.

- *Method C: Comprehensive detection method to determine size of void.* Analytical procedures have been developed in NCHRP Project 1-21 to give an approximate void area for a given corner (Appen. C). The procedure requires a 9-kip plate load (or close to it), and a capability to measure deflections at the slab center (including the deflection basin), slab corners, and transverse joint load transfer.

Center slab testing results are used to establish (1) a representative modulus of elasticity for the slab section and (2) the bending tendencies of the pavement between the first sensor (in the center of the loading plate) and the second sensor (12 in. away). These results are then used to standardize the measured corner deflections (deflection from 9,000-lb plate load at $E = 4,000,000$ psi) and the measured load transfer.

All standardized corner deflections are then plotted on a void deflection plot (Fig. III-6) according to the adjusted load transfer. Joints for which no void exists are then determined. These joints are those whose deflections fall in the "zero voids band." Based on the location of this "zero voids band," deflection levels at all possible load transfer conditions are determined to indicate varying void sizes (4 to 72 sq ft of surface area). Deflection results from joints falling outside the "zero voids band" are then used to determine the approximate size and location of voids (square feet of surface area) at each joint.

Typical results from various demonstration projects indicate that voids can be located on one or both sides of the joint. Subsealing should be performed only at locations where voids exist with the hole pattern used for undersealing being adjusted according to the size of the void.

Again, the percentage of joints having voids can then be computed. This value gives an estimate of the number of joints that will need subsealing.

The percentage of joints having loss of support or voids has been found to vary from 10 to 90 percent on different projects. Those with the higher proportion had extensive visual pumping present. Those with a lower proportion had little visual pumping present.

Step 4—Estimate Grout Quantities. Compute the overall estimated dry grout quantities needed to fill the voids and stabilize the slabs. This is accomplished as follows:

$$\text{Grout} = \text{PJG} * \text{AGT} * \text{TNJ}$$

where:

Grout = total grout quantity for project (cu ft dry materials);

PJG = proportion of joints requiring grouting;

AGT = average grout take per joint grouted (1 to 3 cu ft typical); and

TNJ = total number of joints in project.

Also, include subsealing quantities for stabilizing slabs next to existing full-depth repairs.

4.0 CONSTRUCTION

4.1 Materials

4.1.1 Types of Grouts

Two different types of grouts are currently widely used: pozzolanic-cement grouts and limestone-cement grouts. Although both types of grouts have been used successfully, the pozzolanic materials are highly recommended for several reasons. They are generally available within reasonable distance of most projects, and are usually inexpensive. The particle size, gradation, and shape of pozzolanic materials are ideal for flow characteristics to fill very thin voids. When mixed with portland cement, pozzolanic materials produce a high strength durable mix which can adequately support slabs.

One comparative test site showed that the pozzolanic grout filled significantly more voids than did limestone dust grout (Illinois (I)).

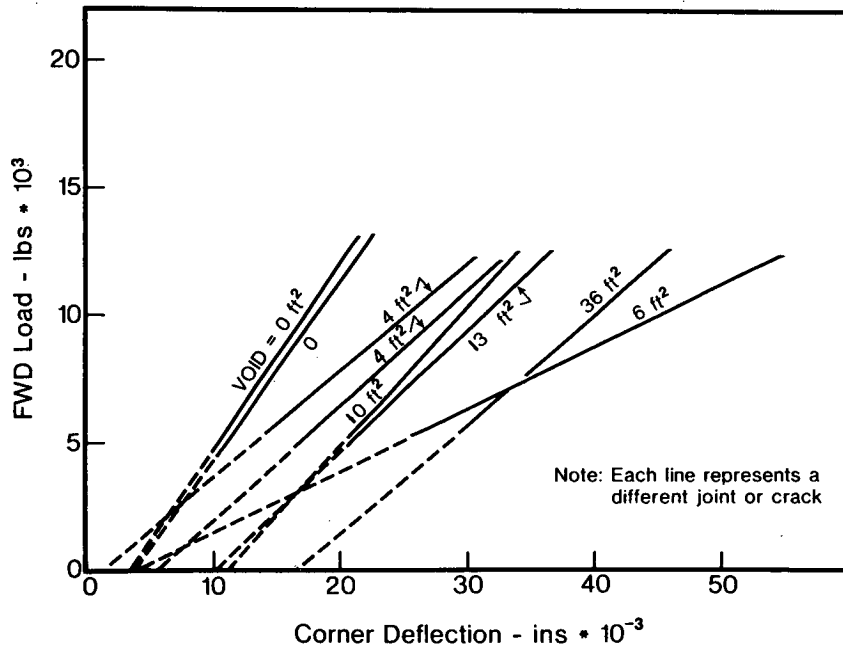


Figure III-4. Joint load deflection (leave side) with various sizes of suspected voids (Ohio I-77).

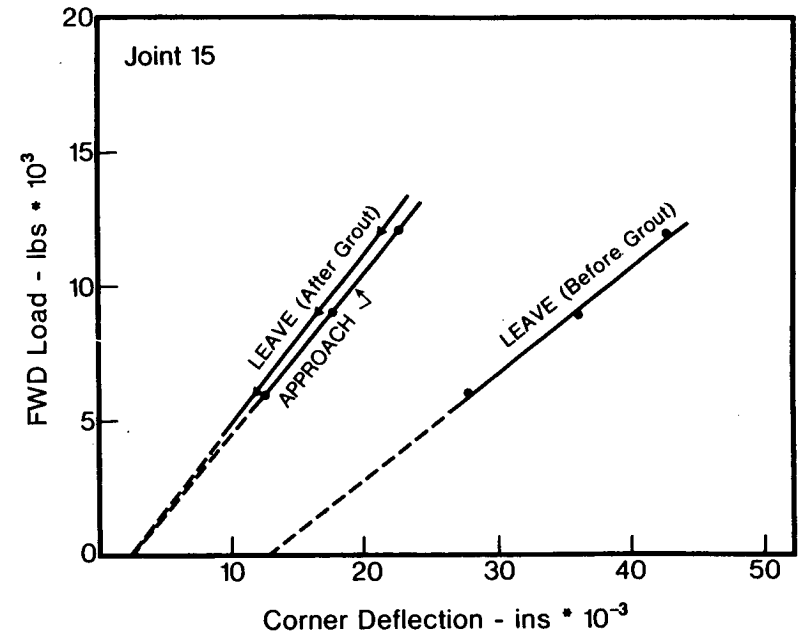


Figure III-5. Joint load deflection where large void under leave corner was suspected (Ohio I-77).

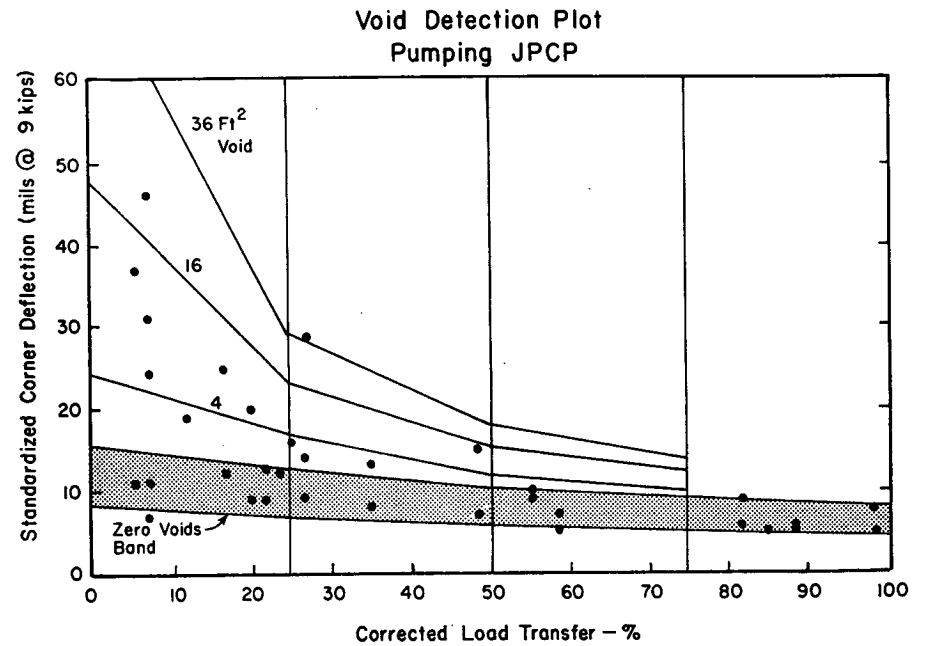


Figure III-6. Typical void detection plot for determining void size and location.

Sand-cement grouts are not recommended because (1) they infiltrate into joints during cold weather and may result in blowups (this occurred on one project recently), and (2) their flowability is much less than the fly-ash grouts.

4.1.2 Pozzolanic Grouts

Pozzolanic material includes natural pozzolans (volcanic ash and diatomaceous earth) and artificial pozzolans (fly ash) produced by the combustion of coal. The fineness of the pozzolan particle size and its *spherical shape* result in a ball-bearing effect which enhances the grout flow properties. The grout will remain in suspension longer, thus, reducing sedimentation. Although pozzolan particles are mainly silt size, they also contain a small but effective amount of clay-sized particles which provide sufficient grading to reduce segregation during pumping and injection, thereby resulting in increased durability when placed.

The pozzolanic characteristics of these materials in combination with lime produce a stable cementitious material. Because the hydration of cement produces lime, additional cementation results when pozzolans are mixed with cement. This cementitious reaction produces a more effective grout. Because of variations in pozzolans and limestone dusts from differing sources, the contractor should be required to show independent test results of chemical and physical properties as well as 1-day, 3-day, and 7-day compressive strength tests, flow cone times, time of initial set, and shrinkage/expansion results.

Portland cement Types I, II, and III may be used for grouts. The specific cement used must be tested with the fly ash to be used to ensure compatibility (5).

4.1.3 Limestone Dust Grouts

These grouts have been used successfully by several agencies. However, when specifying limestone dust, the crystalline structure should be specified. Flat platelet, rhombohedral, and other nonspherical grain structures are not recommended for subsealing.

4.1.4 Additives

Various additives may be specified to achieve required goals. Laboratory tests show widely differing reactions from the same additive when combined with pozzolans from different sources, or when various brands of additives are combined with the same pozzolan. Each must be tested and evaluated in the laboratory prior to final approval by the contracting agency. Additives may include water reducing agents, fluidifiers, expanding agents (powdered alumina) to offset the shrinkage sometimes found with volcanic ashes, calcium chloride to accelerate set, etc. The current trend is to use no additives whenever possible because of the unpredictable reaction results if additives are used. The contracting agency should allow the contractor to choose additives based on prior experience.

4.1.5 Mix Design

The mix design given in the subsealing specification is highly

recommended. Water content is determined by the use of the flow cone method (Corps of Engineers CRD-C-611). Grout slurries using fly ash give a time of efflux in the range of 10 to 16 sec for best flowability and strength. For limestone dust slurries, the time of efflux should be 16 to 22 sec. Some of the Western (Class C) ashes are sufficiently reactive that reduction in the cement component may be considered.

The quantity of water in the grout to achieve flowability exceeds that required to achieve hydration. The roundness of the fly ash particles and the uniform gradation combine to give the grout a high permeability for its average grain size (5). When the grout is being injected, the permeability permits excess water to be driven off with the application of relatively low pumping pressure. The grout immediately becomes more viscous. After injection is complete, additional excess water may drain from the grout, increasing in-place strength (5).

The determination of initial set time of the grout in laboratory tests is useful in comparing various mixes. Generally, the Gillmore Needle Test is used, and on some occasions the Corps of Engineers test method (CRD-C 82) is used. It should be noted that none of these current test methods consider that cement pozzolan grouts at normal temperatures lose their fluidity within 20 min (approximately) after injection. Because the grout is virtually always in total confinement under the slab, it is capable of supporting substantial loads before the set time of 1½ to 2 hours that would be indicated by the generally accepted testing methods. Opening the lane to traffic on the completion of subsealing has shown no known pumping or displacement of the in situ grout.

4.1.6 Strength

A minimum strength requirement is normally used to ensure the durability of the grout. A typical value is 600 psi at 7 days as measured by the standard mortar cube test, ASTM 109. The ultimate strength of the grout will be much higher (1,500 to 4,000 psi).

4.2 Equipment

4.2.1 Mixers

Pozzolan grouts require that a colloidal mixer be used to achieve a true colloidal mix that will stay in suspension and resist dilution by free water. Placement of the grout must be done by a positive displacement cement injection pump. The pump should be capable of pressures of up to 200 psi.

Ready mix trucks are not recommended because they are designed to mix aggregate mixes not cement grouts. A water tanker is also needed with a pressure pump and adequate capacity for the days production. Some grout plants contain a water tank of adequate size.

Paddle-type drum mixers may be used, but are not recommended because they require more water than high speed mixers to obtain grout with the same flowability. The grout should never be mixed with a mortar mixer or in a redi-mix truck because it will require higher water contents, and the solids will agglomerate (ball up) (5).

4.2.2 Hole Drilling

The downward pressure of rock drills whether by hand or mechanical means should be less than 200 lb to avoid spalling concrete adjacent to the injection hole at the bottom of the slab. This spalling will seriously weaken the slab and may result in premature cracking. The specifications contain a requirement for breakout at the bottom of the hole which should be strictly enforced.

4.2.3 Grout Packers

To provide quicker cutoff times for the grout when slab movement is detected, a return hose from the grout packer should be specified to minimize slab movement, overgrouting, and provide better control of injection pressure. The use of a grout return system helps to eliminate the problem of initial set in the injection hoses because the grout in the hose is recirculated back to the pump once the flow of grout is cut off. The use of metal nozzle injection hoses should not be allowed because they do not provide a tight fit, thus allowing grout to flow out of the injection hole. Expandable rubber nozzles should be specified to hold the hose tightly in place.

4.2.4 Slab Lift

The contracting agency should provide the slab lift detection device. One device is shown in Figure III-7. This device is only capable of detecting slab lift and must not be used for load-deflection readings. The device is not precise enough for load-deflection readings using a weight truck. Only a true Benkleman beam or other NDT device can be used to measure deflection under load. Gauges should be capable of detecting 0.001-in. uplift deflection.

4.3 Procedures

4.3.1 Identifying Joints and Cracks To Subseal

It is recommended that deflection testing at the corners of joints and working cracks be used to determine subsealing locations. Some agencies require the contractor to provide the deflection testing equipment and labor for testing every joint and working crack (2), and other agencies provide the deflection equipment and testing service. The reasons for this recommendation are as follows:

1. Subsealing joints that already have full support result in either no change in deflection or an increase in deflection and uneven support for the slab which may cause cracking in the future.
2. Subsealing joints that have loss of support as indicated by high deflections will normally reduce their deflections to a full support condition; thereby, limited funds for rehabilitation are spent where they are needed.
3. The retesting of deflections after subsealing will provide documentation of the benefit of the subsealing. If deflections are not reduced, further subsealing is required at that joint until they do reduce to full support conditions.

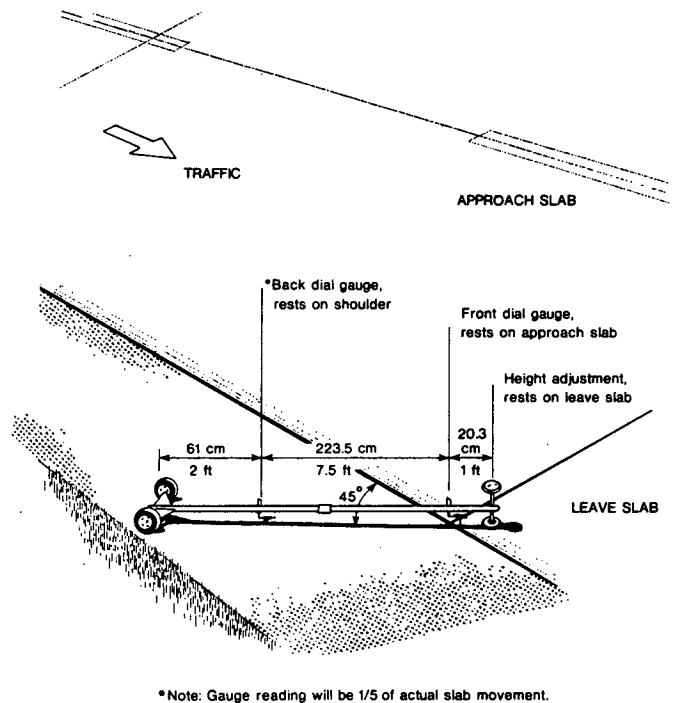


Figure III-7. Measurement device for determining lift of slab during undersealing operation.

4.3.2 Hole Pattern

A hole pattern must be established so that the areas where loss of support has occurred can be filled. These areas are usually thickest at the corners and become thinner as they progress inward toward the slab center. Ideally, the hole should be placed as far from the adjacent joints and cracks as possible, but yet still within the void area so that grout can flow from the injection hole toward the joint or crack. However, placing the injection hole too far away from the joint or crack will result in missing the void area and not being able to pump any grout.

The preliminary deflection testing provides some assistance in selecting an initial hole pattern—for example, the general location of voids on the leave side or the approach side of the joint, and their approximate size (see Appen. C). This hole pattern must be changeable to meet field conditions. The hole pattern used by the contractor should be subject to final approval by the contracting agency. It is necessary to experiment the first few days of subsealing to arrive at a hole pattern which optimizes subsealing.

The flowability of the grout can influence the optimum hole pattern as well as the general void configuration. Typically the holes should be placed close enough to achieve a flow of grout from one injection hole to another when a multiple hole pattern is used. If the flow is easily achieved, the hole-to-hole spacing may be increased, and likewise, if flow is not achieved before maximum back pressure is reached, the spacing should be reduced. All working cracks should be treated as joints, thus requiring the same type of optimum hole pattern.

Recommended hole patterns for different void conditions are shown in Figure III-8. The deflections on each corner can be used to identify if that corner has a loss of support. The larger the corner deflection (or the larger the shift of the load versus deflection line from the origin), the larger the area of loss of support, in general.

Although the pavement tends to curl up or down, depending on the pavement temperature differential, there have been no reported quantity differences whether the subsealing has been done at night or during the day. Initially, it was thought that subsealing performed when slabs are curled up would induce slab stresses or result in a faulted slab in the opposite direction as the curl dissipates. There is currently no evidence to this effect however.

In any case, locations that do not exhibit loss of support (based on deflection results) should *not* be subsealed. It has been found that significant quantities of grout can be pumped into areas that do not have loss of support and this grouting can result in increased corner deflections after grouting, which does not improve the situation.

It may become necessary to pump a small amount of water or air into a hole to create a small cavity to intercept the void structure.

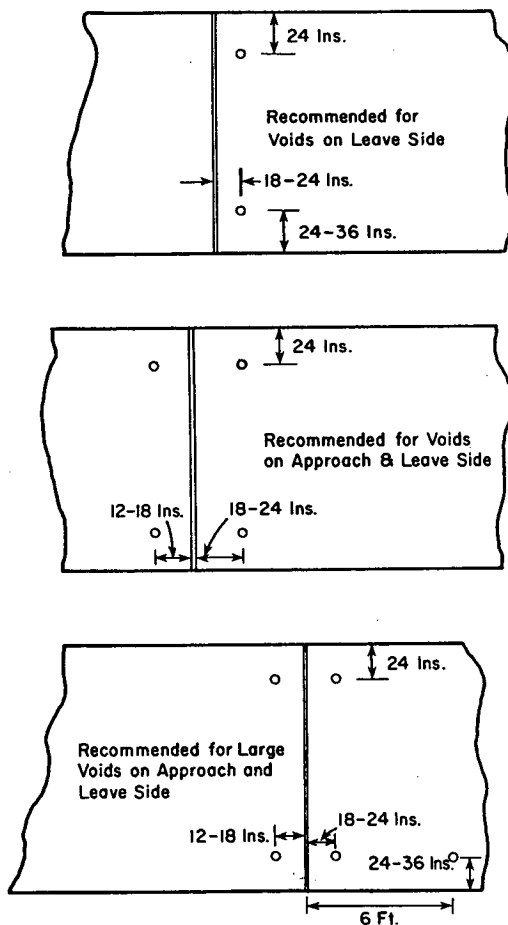


Figure III-8. Hole patterns previously used.

4.3.3 Depth of Holes

When a nonstabilized (or granular) base exists just beneath the PCC slab, holes should be drilled through the slab and just into the base. When a stabilized (e.g., asphalt, cement) base exists, it has been found that voids are often located at the bottom of the stabilized base. Thus, holes should be drilled through the stabilized base a maximum of 3 in. into the subgrade (Appen. C).

4.3.4 Grout Injection

Close inspection is required by the contracting agency during grout injection to prevent overgrouting and slab lifting which can create other voids beneath the slab or induce high slab stresses.

The grout injection should start with a low pumping rate and pressure. The grout should be pumped until:

1. The maximum allowable pressure of 100 psi (at the grout plant) is obtained (except that a short surge up to 200 psi can be allowed when starting to pump in order for the grout to penetrate the void structure if necessary).
2. The slab lift exceeds 0.125 in.
3. Grout is observed flowing from adjacent holes, cracks, or joints.
4. Grout is being pumped unnecessarily under the shoulder, as indicated by lifting.
5. A time period of about 1 min has elapsed (any longer than this indicates the grout is flowing into a cavity).

During initial injection the line pressure normally drops. As the void is nearly filled the pressure will exponentially increase. If slab lift exceeds the allowable 0.125 in., the contractor should not be paid for the excess grout.

After grouting has been completed at any one hole, the packer is removed from the hole and plugged immediately by tapered wooden plugs driven into the slab. When sufficient time has elapsed to permit the grout to set sufficiently so that back pressure will not force it through the hole, the plugs are removed and the hole is filled with an approved cement grout.

4.3.5 Retesting Slab Corners

The subsealing repair effectiveness is determined by remeasuring the deflection of the slab at the same points after subsealing. This testing should also include some joints that were not grouted for use as control joints. Using the same methods as previously described, if loss of support still exists after grouting, the slab should be regouted. In each regouting, new holes should be drilled. If after three attempts to stabilize the slab voids are still present, no further work is required of the contractor. Other methods of repair may then be considered for that slab such as full-depth repair.

4.3.6 Cold Weather Subsealing

Subsealing during cold weather with sand-cement grout has resulted in blowups in long jointed spacing (60 ft) pavement.

No known problems have occurred during cold weather grouting using fly-ash grouts.

4.3.7 Opening To Traffic

Deflections have been measured after subsealing and a reduction in deflections over a 1- to 3-hour time period typically occurs. This reduction of deflection is associated with the hardening of the grout over time and is depending on temperature and grout properties. This change in deflection could be measured for the given job site to aid in selecting a minimum opening time. As a minimum, all traffic should be kept off a grouted slab for at least 2 hours after grouting. In cold weather, accelerators should be used in the grout to speed up the initial set time.

5.0 PREPARATION OF PLANS AND SPECIFICATIONS

Presently, subsealing is an art rather than a science. The contracting agency should require the contractor to furnish references to show substantial subsealing experience satisfactorily completed. The consequences of having an inexperienced contractor are broken slabs and large overruns due to overgrouting.

To estimate grout quantities for subsealing, the only effective methods to date include: experience in the art of subsealing, previous job quantities in the general area with similar designs, and use of slab deflection measurements as described in section 3.0. Procedures using deflections have been developed to estimate location and size of voids in NCHRP Project 1-21. These procedures are discussed in detail in Ref. 1, Appendix C. A general estimate, using the grout procedures described later in this discussion, is 1 to 3 cu ft of grout per joint. Any individual location may greatly overrun or underrun this project average. Projects with extensive pumping may exceed this quantity.

There are two basic ways in which to handle pay quantities:

1. The most common by far is to pay for cement grout on the basis of cubic feet of dry bulk materials (cement, fly ash, limestone dust). This approach creates a tendency for the contractor to overgrout if the job is not carefully monitored. It is recommended that estimates for quantities be set up for number of holes drilled and cubic feet of dry grout.

2. The second approach is to pay for "slab stabilization" by the square yard. Although this procedure has not been used much, it certainly should be tested because "slab stabilization" is definitely the objective of subsealing, not just to pump as much grout as possible. With this approach, the contractor may bid higher because of the uncertainty in volume of grout required.

6.0 REFERENCES

1. CROVETTI, J. A., and DARTER, M. I. "Void Detection Procedures." Final Report: Appendix C, NCHRP Project 1-21, University of Illinois, (1985).
2. TYNER, H. L., "Concrete Pavement Rehabilitation—Georgia Methodology." Preprint Volume For The National Seminar On Portland Cement Concrete Pavement Recycling And

Rehabilitation, Transportation Research Board, St. Louis, Mo. (1981).

3. DARTER, M. I., CARPENTER, S. H., HERRIN, M., BARENBERG, E. J., DEMPSEY, B. J., THOMPSON, M. R., SMITH, R. E., and SNYDER, M. B., "Techniques For Pavement Rehabilitation, Participants Notebook." National Highway Institute/Federal Highway Administration (1984 Rev.).
4. DEL VAL, J., "Subsealing and Stabilization of Concrete Pavements." Del Val, Inc., Fort Worth, Texas.
5. "Pavement Undersealing—Principles & Techniques." Pamphlet Produced by ChemGrout, LaGrange Park, Illinois (1985).

B. GUIDE SPECIFICATIONS

1.0 GENERAL

1.1 Description of Work

The work performed under these specifications shall consist of testing the pavement for loss of support using deflection measurement equipment, drilling grout injection holes, injecting cement grout under pressure beneath the slab and/or base to fill voids without raising the slab, and filling the injection holes. A retest of each slab corner to ensure support is also required. Areas found to be deficient shall be regrouted.

1.2 Location

The general locations of the work are indicated on the plans. Actual subseal areas will be determined through deflection testing as described in section 5.0.

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."

2.0 Contractor Prequalification

In addition to financial prequalification, the bidder must be competent in pressure grouting and must show substantial work satisfactorily completed. Each bidder shall submit for evaluation with his bid a listing of major projects relating to pressure grouting and names, addresses, and telephone numbers of the engineer in charge to allow verification of satisfactory completion. Proposals will be rejected from any firm or individuals unable to show adequate competency and experience, as judged by the contracting agency.

3.0 MATERIALS

The mix design for subsealing is as follows:

1. 1 part (bulk volume basis) portland cement Types I, II, or III.
2. 3 parts (bulk volume basis) pozzolan (natural or artificial), or limestone dust.

3. Water to achieve required fluidity (see below).
4. If ambient temperatures are below 50°F, an accelerator may be used subject to approval of the contracting agency.
5. Additives (as required and approved): superplasticizers, water reducers, fluidifiers.

The physical properties of the grout materials used for sub-sealing are as follows:

1. Portland cement shall be Types I, II, or III meeting the requirements of AASHTO M85.
2. Pozzolans shall meet the requirements of ASTM C618, unless the contractor can show test data of other pozzolans meeting requirements of this section and previous use of the material for this purpose on other public work projects.
3. Limestone dust shall meet the requirements of AASHTO M17 for mineral fillers. Limestone dust must be spherical in shape. Dust containing mostly flat platelet grains or rhombohedral shaped grains will not be acceptable.
4. Fluidity of the grout slurry shall be measured by the Corps of Engineers flow cone method as per their specification CRD-C-611. Time of efflux for flyash grouts shall be within 10 to 16 sec. Time of efflux for limestone grouts shall be 16 to 22 sec. These measurements shall be made at least two times during each shift.

The contractor shall submit a proposal for materials and additives to be used in the mix design meeting the above requirements. This information must be submitted and approved before the material or additives may be used in the subseal operation. Submittals shall include mill certifications for the cement, physical and chemical analysis for the pozzolans, grain structure analysis for the limestone dust, and independent laboratory testing of the grout slurry. Test results of the slurry shall include 1-day, 3-day, and 7-day strengths, flow cone times, shrinkage and expansion observed, time of initial set, and water retentivity.

The 7-day strength shall not be less than 600 psi as measured using AASHTO Test Method T 106. Test specimens shall use the materials (including water and additives) that are to be used in the project.

Expansion shall be determined as per the Corps of Engineers CRD-C-613, "Method of Test for Expansion of Grout Mixtures." The time of initial set shall be determined as per ASTM C266, "Time of Setting of Hydraulic Cement by Gillmore Needles," or the Corps of Engineers CRD-C-614, "Method of Test for Time of Setting of Grout Mixtures." Water retentivity shall be tested as per the Corps of Engineers CRD-C-612, "Test Method for Water Retentivity of Grout Mixtures."

4.0 EQUIPMENT

The contractor shall furnish all equipment, tools, and other apparatus necessary for upkeep and maintenance necessary for the proper construction and acceptable completion of the work as follows.

4.1 Grout Plant

The grout plant shall consist of a positive displacement cement

injection pump capable of applying up to 250-psi pressure, a high-speed colloidal mixing machine, and a grout return system. The colloidal grout shall be produced by mixing in a colloidal mill connected to a cone-shaped bottom of a cylindrical drum. The colloidal mill shall operate at a minimum speed of 800 RPM, maximum speed of 2,000 RPM, creating a high shearing action and subsequent pressure release to make a homogeneous mixture.

If use of limestone dust grouts is approved, a paddle-type mixer may be substituted for the high-speed colloidal mixer.

The injection pump shall be capable of continuous pumping at rates as low as 1½ gal per minute or the system modified by adding recirculating hose and valve of the discharge of the pump.

The dry materials shall be accurately measured by weight or volume if delivered in bulk or shall be packaged in uniform volume sacks. The water shall be batched through a meter or scale with a totalizer for the day's consumption.

4.2 Water Tanker

If water tanks and pumps are not an integral part of the plant, a water truck equipped with a pump for delivery to the grout plant shall be supplied.

4.3 Drilling

An air compressor and rock drills or other device capable of drilling injection holes through the concrete slab and base material shall be supplied. The equipment shall be in good condition and operated in such a manner that the holes are vertical and not "out of round." Downward pressure shall not exceed 200-lb maximum downward pressure.

4.4 Flow Cone

A flow cone with all necessary components shall be supplied so that the consistency of the mixture can be determined. The flow cone shall conform to the dimensions and other measurements of the U.S. Army Corps of Engineers test method CRD-C-611.

4.5 Vertical Slab Movement Detection Equipment (Movement from Grouting Operation)

The contractor shall supply equipment to measure slab lift, which shall be capable of detecting simultaneously the movement of the pavement edge or of any two outside slab corners adjacent to a joint and the adjoining shoulder. The equipment shall have the capacity of making such measurements to 0.001 in. Measurement devices to detect slab movement with respect to a stable reference point shall be subject to final approval by the contracting agency.

4.6 Deflection Device

Alternative 1. The contractor shall furnish either a deflection measuring device that can apply at least 8,000 lb of force (either vibrating or falling weight) to the pavement, or a load vehicle

having a single axle that can be loaded to 18 kips evenly distributed between the two sides, with a vehicle driver and sufficient manpower to assist in the operation of the static measuring gauges.

Alternative 2. The contractor shall supply equipment to measure slab corner deflection under three different loadings above 8,000 lb (e.g., 9, 15, 21 kips). The equipment shall be either vibratory steady-state load type or impulse load type.

4.7 Miscellaneous

All necessary hoses, valving manifolds and positive cutoff and bypass provisions to control pressure and volume, pressure gauges with gauge protectors, expanding packers for positive seal grout injection, wood plugs, hole washing tools, drill steel and bits shall be provided by the contractor.

5.0 CONSTRUCTION METHODS

5.1 Determining locations to subseal

- *Method A: Agency determines locations.* The agency will designate the specific locations for subsealing, based on deflection or other means. The contractor shall subseal at these locations.

- *Method B: Contractor conducts deflection testing.* Preliminary testing shall be performed by the contractor on joints within the project limits using deflection devices or load vehicles, as approved by the contracting agency to obtain slab deflections.

All testing shall be performed between the hours of midnight and 10:00 AM, except that the engineer may stop testing earlier if there is evidence of slab lock-up due to thermal expansion of the slabs, and he may allow testing to continue after the hour specified if the slabs are not interlocked or under compression. These requirements need not be met if the engineer is satisfied that pavement slabs are not curled or interlocked under compression due to thermal expansion.

The following procedures shall be followed when using the load truck to obtain slab deflections. The vertical slab movement detection equipment shall have two deflection gauges that are capable of detecting slab movement under load. The gauge mount shall be positioned with one gauge referenced to the corner of each slab on both sides of the joint near the shoulder edge perpendicular to the pavement joint. The gauges will then be zeroed with no load on the slab on either side of the joint. The load truck will then be moved into position and stopped with the center of the 18-kip loaded axle about 1 ft behind the joint and the outside test wheel about 1 ft from the pavement edge. Both gauges will then be read. The load truck will then be moved across the joint to a similar position about 1 ft forward of the joint and stopped. Both gauges will again be read. This procedure will be repeated for each joint and crack to be tested.

The following procedures shall be followed when using a variable load deflection device. The loading plate shall be positioned as close as possible to the corner of the slab (within ± 3 in. of each side). Three different loads shall be applied in sequence starting at 9 kips, 15 kips, and 21 kips, approximately, and the corner deflection recorded for each load.

The contracting agency will be responsible for recording deflections and determining which slabs require stabilization.

For the devices capable of deflection measurement, the loading plate should be placed as close as possible to the slab corner. Load transfer shall be measured with sensors that are placed adjacent to the joint or crack on the loaded and unloaded side.

5.2 Drilling Holes for Grout Injection

Grout holes for injection will be drilled in a pattern determined by the contracting agency in consultation with the contractor. Holes will not be larger than 2 in. in diameter (5 cm), drilled vertically and round, and to a depth sufficient to penetrate through any stabilized base, but not more than 3 in. into the subgrade.

Subject to the engineer's approval, holes may be washed or air blown to create a small cavity to allow the initial spread of grout.

Holes shall be drilled in such a manner that breakout shall not exceed 1 in. at the bottom of the slab.

5.3 Grout Preparation

Minimum mixing time shall be 15 sec after all the cement and pozzolans or limestone dust has been placed in the drum with the required water. Any additives required will then be added, followed by another minimum mixing time of 15 sec. The grout will then be transferred to the agitator from which it can be pumped.

5.4 Subsealing

All locations with loss of support present, based on methods using measured deflections as previously described, will be subsealed. During the subsealing operation, a means of monitoring lift shall be implemented by the contracting agency. The upward movement of the pavement shall not exceed 0.125 in. An expanding rubber packer or hose connected to the discharge from the plant shall be lowered into the hole. The discharge end of the packer or hose shall not extend below the bottom of the concrete slab. Each hole shall be pumped until:

1. The maximum pressure is built up (see below).
2. The grout is observed flowing from hole to hole.
3. The grout is flowing out of transverse joints or edge joints.
4. The maximum slab lift is attained.
5. A reasonable time has elapsed (2 min).

Maximum continuous pressures to 100 psi will be permitted (or other values specified by the contracting agency) to minimize slab raising, except that a short surge up to 200 psi will be allowed when starting to pump the hole. The pressure shall be monitored by an accurate pressure gauge in the grout line that is protected from the grout slurry. Any water displaced from the void by the grout shall be allowed to flow freely. Excessive loss of the grout through cracks, joints, other grout holes, or from the insertion and removal of packers (backpressure in the hose) shall not be tolerated. Pay quantities will be reduced by the contracting agency accordingly.

Pavement which has been raised in excess of the 0.125 in. allowable and exceeds the contracting agency's roughness criteria tolerance shall be ground to the correct grade by the contractor. Cracks emanating radially from the grout injection holes will be presumed to have been caused by improper injection techniques by the contractor. For each 5 ft of such crack measured, the contractor's pay quantity shall be reduced by 1 cu ft of grout, or at the option of the contracting agency, the slab or portion of the slab may require removal and replacement at the contractor's cost. In the event that transverse cracks develop between adjacent grout injection holes, the contractor will be required to repair these cracks by an epoxy injection method to the satisfaction of the engineer, or at the discretion of the engineer he may require the removal and replacement of the entire slab or a portion of the slab at no cost to the contracting agency.

5.5 Sealing of Injection Holes

After grouting has been completed at any one hole, the packer shall be removed and the hole plugged immediately with a tapered wooden plug. The tapered plugs, however, are only temporary. When sufficient time has elapsed to permit the grout to set sufficiently so that back pressure will not force it through the hole, the temporary wooden plugs should be removed. Each hole must be permanently sealed flush with the pavement surface with a fast setting sand/cement or other patch material approved by the engineer.

6.0 WEATHER CONDITIONS

Subsealing shall not be performed when air temperatures are 35°F or below, or when the subgrade or subbase is frozen.

7.0 ACCEPTANCE

Prior to acceptance, each slab that is subsealed shall be retested according to testing requirements in section 5.0. Any joint or crack that still shows loss of support (or voids) shall be regouted using different holes from those that were initially used. Any slab which continues to show voids present after two properly performed groutings shall be acceptable, or the engineer may require a third subsealing attempt to stabilize the slab by extending the group holes into the subgrade. All loose concrete, joint filler, or grout accidentally or otherwise spilled on the surface or shoulder, and any other waste construction material shall be

removed and the surrounding areas shall be left in a neat orderly condition by the contractor prior to opening to traffic or final acceptance.

Excessive loss of grout through other injection holes, joints, and cracks shall not be tolerated. Pay quantities will be reduced by the contracting agency accordingly. Slab raising of more than 0.125 in. shall be corrected according to section 5.0. Penalties for radial or transverse cracking shall be assessed according to section 5.0. Grout held in the mixer or in the injection pump or hose for more than 1 hour after mixing may not be used for undersealing.

8.0 MEASUREMENT AND PAYMENT

8.1 Measurement

The quantities to be paid will be measured as follows:

1. Pay quantity per transverse joint and crack tested by deflection for void detection. Payment per joint and crack shall include both the initial testing and any subsequent testing (e.g., contractor will be paid only once for deflection testing no matter how many times retesting must be accomplished).

2. Pay quantity per hole drilled through the existing pavement. Payment includes drilling, plugging, and hole sealing after grouting is completed.

3. Unit price per cubic foot of dry material or unit price per square yard of slab stabilized. Includes water, additives, and all other materials necessary to obtain an acceptable grout mix.

4. Lump sum traffic control and mobilization costs.

8.2 Payment

The unit contract prices shall be full compensation to the contractor for furnishing all labor, materials, equipment, tools, traffic control, and all other costs necessary or incidental to accomplish subsealing at the designated locations in accordance with these specifications and the details on the plans.

<u>Pay Items</u>	<u>Pay Unit</u>
1. Deflection testing	Transverse joint or crack tested
2. Holes drilled	Hole
3. Grout—Dry materials or Slab Stabilization	Bulk cubic foot Square yard
4. Traffic control and mobilization	Lump sum

IV. RESTORATION OF JOINT LOAD TRANSFER IN JOINTED CONCRETE PAVEMENTS

A. DESIGN AND CONSTRUCTION GUIDELINES

1.0 INTRODUCTION

The ability of a joint or crack to transfer load is a major factor in its structural performance. Load transfer efficiency across a joint or crack is defined as the ratio of deflection of the unloaded side to the deflection of the loaded side. If perfect load transfer exists, the ratio will be 1.00 (or 100 percent), and if no load transfer exists (such as a free edge), the ratio will be 0.00 (or 0 percent). Joints that are doweled normally have very good load transfer (70 to 100 percent). However, repeated heavy loads can cause an elongation of the dowel sockets and looseness of the dowel. This leads to faulted and spalled joints with poor load transfer.

Many jointed plain concrete pavements have been constructed without dowels at transverse joints. The load transfer measured at these joints is typically low, except on warm afternoons when joints can close tightly. Transverse cracks in both jointed plain and reinforced concrete pavements (where steel has ruptured) can also have poor load transfer.

When load transfer is restored from 0 to 100 percent, deflection and stress in the slab are reduced by one-half. This effect greatly reduces the potential for pumping, faulting, and cracking and thus would extend the life of the pavement.

1.1 Need for Restoration of Load Transfer

Restoration of load transfer across a transverse joint or crack is used to retard further deterioration. Poor load transfer leads to joint or crack deterioration, including pumping, faulting, corner breaks, and spalling. Overlays placed over joints or cracks that have poor load transfer will soon develop reflective cracks that will spall and deteriorate into potholes.

Load transfer restoration is recommended on all transverse-faulted joints or cracks that exhibit poor deflection load transfer of approximately 0 to 50 percent when measured during early morning times or in cooler weather. Heavy load deflection devices should be used for the measurement so as to resemble regular traffic loads. These recommendations are for jointed concrete pavements with or without asphalt overlays (1).

1.2 Effectiveness and Limitations

Two methods of restoring load transfer of existing joints and cracks have been used: shear devices and dowels.

Short-term experience with load transfer restoration has indicated that dowels and shear devices can be effective in transferring loads across joints and cracks (Appen. B; 2, 4). Test results from the NCHRP Project 1-21 field demonstration projects and from the Georgia tests show an immediate increase in load transfer to 90 to 100 percent and a reduction in deflections ranging from 50 to 75 percent.

Long-term effectiveness has not yet been established, however, and a substantial number of failures of shear devices have oc-

curred by bond loss between the device and the core wall (2; Appen. B). Shear devices that have been effective in transferring load and have performed well under full-scale field load testing are the Double Vee device and the plate and stud connector (see Fig. IV-1). Both of these devices are proprietary. The plate and stud device has only been used in a few airport applications to date. Reference 7 provides details of its design and installation.

The Double Vee device has been tested in laboratory fatigue tests and in field installations. Fatigue tests at the University of Illinois have shown that load transfer failure occurred first with the device itself, failing in flexure only after several million repetitions. However, field tests have shown considerable failure of the bond between the polymer concrete and the core wall of the existing concrete. These failures were believed to be caused by loss of the liquid portion of the polymer concrete, which drained out through the bottom of the core hole because of improper sealing. Also, improvements have been made in the installation of the Double Vee devices by cutting grooves into the core walls and by precompressing the device in the core hole so that they will only be in compression. However, an improved bonding material is still greatly needed (see Appen. B).

The following conclusions are from Georgia short-term installations:

The results of the sections with Double Vee devices are variable and are largely influenced by the performance of the various patching materials used with these devices. The Double Vee devices are performing well where leaching of the polymer concrete did not take place, where portland cement concrete was used and with some of the rapid set materials. The Double Vee devices are performing marginal to poor where problems with leaching and material quality of the polymer concrete occurred during the 1981 construction season. (2)

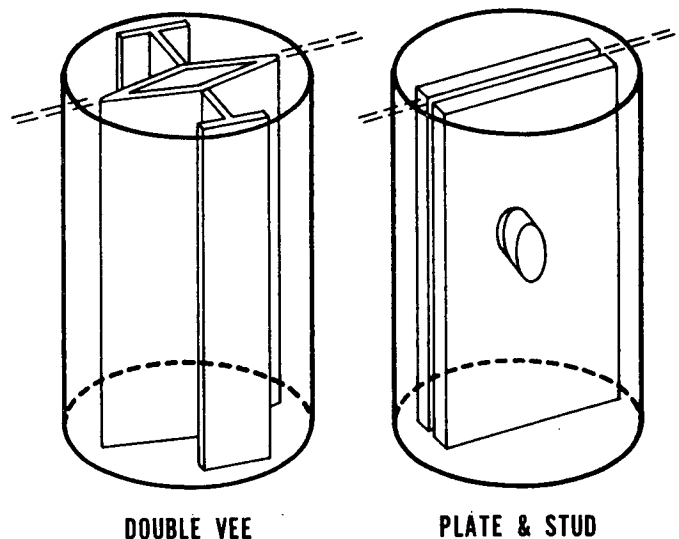


Figure IV-1. Illustration of Double Vee and plates and stud shear load transfer devices.

The only equipment needed for the installation of shear devices is a coring rig with a 6-in. diameter diamond bit, which is normally readily available to all pavement contractors.

Dowels cut in slots are believed to be an effective alternative to using shear devices to restore load transfer across joints or cracks. Dowel installation has been evaluated under an FHWA contract in Georgia (2, 4). Results show the dowels to have performed very well after 2 years of heavy traffic, although a few failures have occurred. The patching material was not as critical as for the shear type devices (2, 4). The equipment needed to install dowels is a diamond saw to cut the slots and air hammers. Equipment manufacturers are currently working on developing more efficient means of cutting the slot and removing the concrete.

Measurements show that the horizontal joint movement is not excessively restricted by either the Double Vee or dowel devices (2).

The successful installation of load transfer devices requires sound concrete adjacent to the joint or crack. If the concrete is deteriorated near joints or cracks, a full-depth repair should be placed rather than just load transfer restoration.

2.0 CONCURRENT WORK

Before any load transfer devices are installed it is necessary to determine the cause of the joint/crack distress. Attempts should be made to correct these deficiencies prior to load transfer restoration.

Heavily distressed slabs ("D" cracked, corner breaks, transverse, longitudinal, and diagonal cracking) may require portions, or all, of the slab to be replaced.

Additional work to be done prior to load transfer restoration may include subsealing to fill voids in the pavement foundation (this is essential if loss of support exists), full-depth repairs and spall repairs. Work that can be done after load transfer restoration includes grinding, joint and crack sealing, and installation of underdrains.

Joints or cracks having high deflections must be subsealed *before* load transfer devices are installed.

3.0 DESIGN

3.1 Identification of Joints/Cracks

Joints and cracks requiring improved load transfer must first be identified. Load transfer should be measured during cooler temperatures (e.g., ambient temperatures less than 80°F) and during early morning times. A heavy load device such as the Falling Weight Deflectometer, Road Rater, or a weight truck with two Benkleman Beams should be used.

The load transfer should be measured in the outer wheel path and is defined as follows:

$$\text{Load Transfer} = \frac{\text{Unloaded slab defl.}}{\text{Loaded slab defl.}} \times 100$$

Any joint or crack having a measured load transfer of less than 50 percent during cool temperatures should be considered for restoration. The deflection measurements should be taken as close as possible to the joint/crack, or if measured by a

sensor in the center of the load plate and 12 in. across the joint, they should be corrected for normal slab bending as measured in the center of the slab (see Appen. C for details).

It is recommended that transverse joints or cracks have devices installed when load transfer is less than 50 percent when measured at pavement surface temperatures less than 80°F.

3.2 Design Requirements

Gulden and Brown (4) conclude that the following factors must be met for a load transfer restoration system to provide long-term performance:

1. The patching material and device must have sufficient strength to carry the required load.
2. Sufficient bond must be achieved between the device and the patching material to carry the required load.
3. Sufficient bond must be achieved between the patching material and the existing concrete to carry the required load.
4. The device must be able to accommodate movement due to thermal movement of the concrete slabs.
5. The bond between the device and the patching material must be sufficient to withstand the forces due to thermal expansion of the concrete slabs.
6. The patching materials must have little or no shrinkage during curing. Shrinkage of the patching material can cause weakening or failure of the bond with the existing concrete.
7. The patching material must develop strength rapidly so that traffic can be allowed on the slabs in a reasonable length of time (3 to 4 hours).

Results from short-term tests in Georgia and in the field tests conducted in NCHRP Project 1-21 show that the Double Vee shear device and dowel bars can potentially meet the above requirements. These devices, when properly constructed, were found to greatly improve the existing load transfer (and reduce deflection) and to permit horizontal movement (or opening and closing) of the joints (Appen B; 4).

3.3 Shear Devices

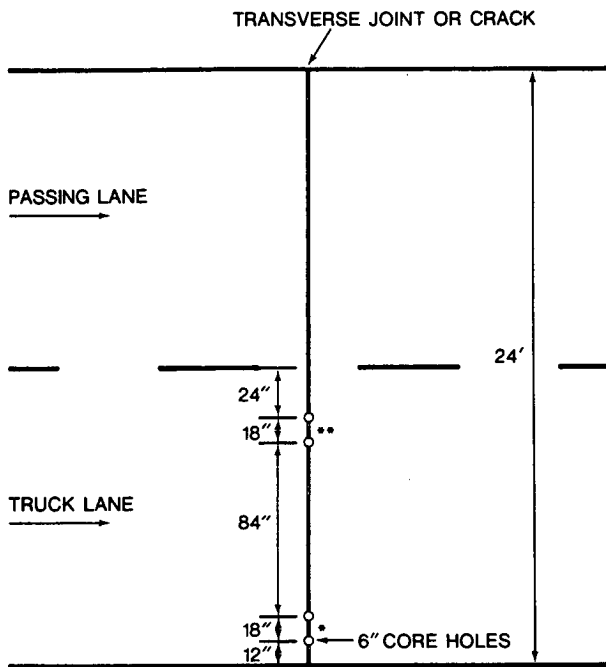
When heavily faulted slabs (both wheel paths) are observed, it is recommended that there be at least two shear devices per wheel path. Center-to-center spacing should be no more than 18 in. On joints or cracks with only one faulted wheel path, two shear devices in the faulted wheel path and only one in the other wheel path may be installed. Spacing, location, and number of devices per joint/crack should be indicated on the plans, as shown in Figure IV-2.

Grooves cut horizontally in the core wall are recommended to improve vertical shear capability and reduce dependency on bond strength. The devices must be installed in compression so that the devices will remain in compression during service to improve their bonding capability.

The Double Vee shear devices must be approximately 1 in. less in length than the slab thickness. The devices must be recessed about 1 in. to allow for joint sealing or grinding.

3.4 Dowel Devices

The number, diameter, and spacing of dowel devices must be determined. An analysis was conducted by Tayabji and Colley



NOTE: * SPACING MAY VARY SO THAT EXISTING DOWEL BARS ARE AVOIDED
 ** IF THE JOINT HAS GOOD LOAD TRANSFER IN THE INNER WHEEL PATH, ONLY ONE DEVICE IS REQUIRED

Figure IV-2. Recommended placement of shear load transfer devices.

that determined that stresses and deflections for six dowels spaced nonuniformly in a joint (in the wheel paths) were similar to stresses and deflections obtained for a joint with 12 uniformly spaced dowels (3). Thus, placing the dowels in the wheel paths will provide similar performance and be more cost effective.

The number, spacing, and diameter of the dowels will determine the amount of future faulting of the transverse joints. An approximate design procedure is given in Figure IV-3. These design charts were prepared using a relationship between joint faulting, equivalent single axle loads (ESAL) and dowel/concrete bearing stress developed using field data from over 100 in-service pavement sections in Illinois (5). The dowel diameters ranged from 1.00 to 1.625 in. and were all spaced at 12 in. across the joints. ESAL ranged up to 20 million. The bearing stress in the critical outer corner dowel was computed using Friberg's procedure (6). Thus, even though the dowels for load transfer restoration are only placed in the wheel paths, the critical bearing stress is calculated and used in determining the amount of faulting with traffic loadings.

The required dowel design is determined by trial and error considering the following factors:

- Dowel diameter.
- Number of dowels in each wheelpath (spaced at 12 in.).
- Future ESAL in design lane.
- Allowable faulting of the transverse joint.

The bearing stress was computed for dowels spaced at 12 in., a joint opening of 0.25 in., and other assumptions given in Figure IV-3. The major uncertainty with using this procedure is that the relationship was developed from in-service pavement joints, not dowels placed in slots in an existing pavement. Thus, it is essential that an adequate patching mix be placed around the dowels.

The use of 1/2-in. diameter dowels is recommended in most cases because of the beneficial effect in reducing faulting for a small increase in cost of the dowel. An example design is provided as follows.

Example—Heavy Traffic. An adequate load transfer system for a jointed plain concrete pavement that does not have any mechanical load transfer must be designed. The pavement has the following design characteristics:

- Slab thickness is 8 in.
- Traffic over next 15 years is 5 million equivalent single axle loads in outer truck lane.

The maximum allowable load transverse joint faulting is set at 0.20 in. over the 15-year (6 million ESAL) design period. Another limiting faulting value could be used for design.

- *First trial:* Three dowels in wheel path spaced at 12 in. First dowel placed 12 in. from edge. Dowel diameter is 1.25 in. Dowel/PCC bearing stress is 1,930 psi (Fig. IV-3(a)). Faulting is 0.40 in. (Fig. IV-3(b)). *Unacceptable.*
- *Second trial:* Change dowel diameter to 1.50 in. Bearing stress is 1,387 psi. Faulting is 0.20 in. *Acceptable.*
- *Recommendations:* Provide the following transverse joint load transfer design as shown in Figure IV-4.

This prediction model has not been field verified for load transfer restoration in existing pavements. Therefore, the resulting design must be carefully considered by the design engineer for adequacy.

4.0 CONSTRUCTION

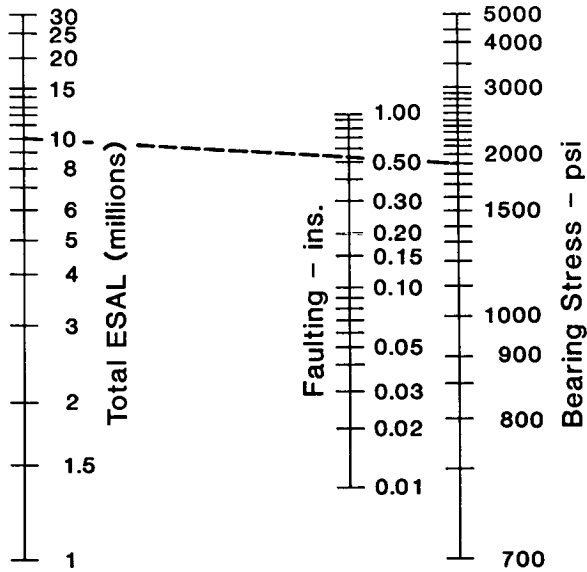
4.1 Materials

Plans should include details and sketches of the load transfer device itself. The Double Vee shear device should be made on stainless steel. Details of the Double Vee device are shown in Figure IV-5.

Details of the dowel device and supporting chair are shown in Figure IV-6.

The patch material used with load transfer devices is the most critical factor in performance, particularly with shear devices. Sufficient bond must be established between the device and patching material as well as between the existing concrete and the patching material to carry the applied loads and movement from thermal changes. Patching material must also develop

Solves: $\ln(F+1) = \ln(ESAL+1)[1.394 \cdot 10^{-4} \text{BSTRESS} - 0.0913]$



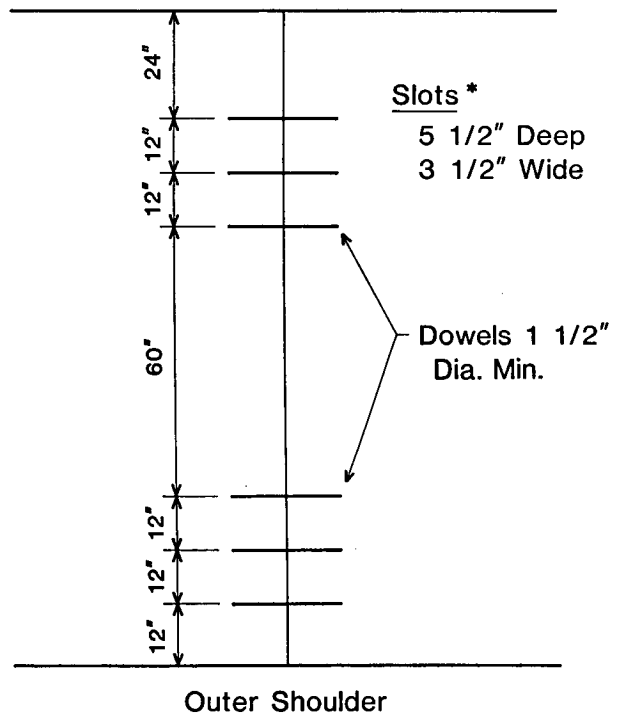
Example :
 Slab = 9 ins.
 3 Dowels Wheel Path
 1.25 ins. Diameter
 ESAL = $10 \cdot 10^6$
 BSTRESS = 1898 psi
 (Figure 4a)
 Fault = 0.52 ins.

Figure IV-3(a). Nomograph for design of dowel bars for local transfer restoration.

Slab Thickness (ins.)	Dowel Diameter (ins.)	Bearing Stress-psi*				
		2	3	4	5	6
8	1.00	3878	2889	2463	2279	2250
	1.25	2591	1930	1645	1522	1503
	1.375	2180	1624	1385	1281	1265
	1.500	1862	1387	1183	1094	1080
9	1.00	3857	2842	2388	2167	2089
	1.25	2576	1898	1595	1447	1395
	1.375	2168	1598	1342	1218	1174
	1.50	1852	1365	1147	1040	1002
10	1.00	3817	2786	2316	2077	1951
	1.25	2549	1861	1547	1387	1303
	1.375	2145	1566	1302	1167	1096
	1.50	1832	1338	1112	997	936

*Load = 9 Kips on outer dowel bar
 Dowel Spacing = 12 ins. (beginning 12 ins. from end)
 K-value = 150 pci $E_{pcc} = 5 \times 10^6$ psi
 (changing K has very little effect on stress) Poisson's ratio = 0.15
 $E_{dowel} = 29 \times 10^6$ psi
 $K_{dowel} = 1.5 \times 10^6$ psi
 Joint opening (Z) = 0.25 ins.

Figure IV-3(b). Dowel bearing stress computed using Friberg's procedure.



*Used On Exp. Projects

Figure IV-4. Recommended placement of dowels in driving lane.

strength rapidly to accommodate traffic and thermal stresses soon after placement.

A thorough laboratory evaluation must be made of any patching material to be used for the load transfer devices. Gulden and Brown (4) conclude that "working time, bond strength, rapid early strength gain and shrinkage are prime factors which must be evaluated prior to choosing a patching material."

Polymer concretes and high early strength portland cement concrete have been used in most installations to date. Polymer concrete material properties, fine aggregate gradation, and mix designs should be specified by the agency. A high early strength concrete mixture used in conjunction with an epoxy applied to the existing slab was used successfully in Georgia (2). Aggregate gradation should meet ASTM C33 "Standard Specification for Concrete Aggregates—Fine Aggregate" requirements. Because of the lack of space between the core wall and shear device only fine aggregate should be used in the polymer concrete. This allows the polymer concrete to easily fill this space. The mix design should allow the fine aggregate to be easily and completely coated.

The high early strength portland cement concrete mixture used successfully in Georgia is as follows (4):

- One bag cement—Type III.
- 125 lb sand.
- 220 lb stone— $\frac{3}{8}$ in. top sized pea gravel.
- 5 gal water.
- $1\frac{1}{2}$ lb calcium chloride.
- Expansion agent—4.5 oz.

The expansion agent was aluminum powder mixed with a filler in a ratio of one part powder to 50 parts of filler. Both inert fly ash and pumicite were used as a filler. Four-hour compressive strengths ranged from 1,250 to 1,650 psi.

4.2 Procedures

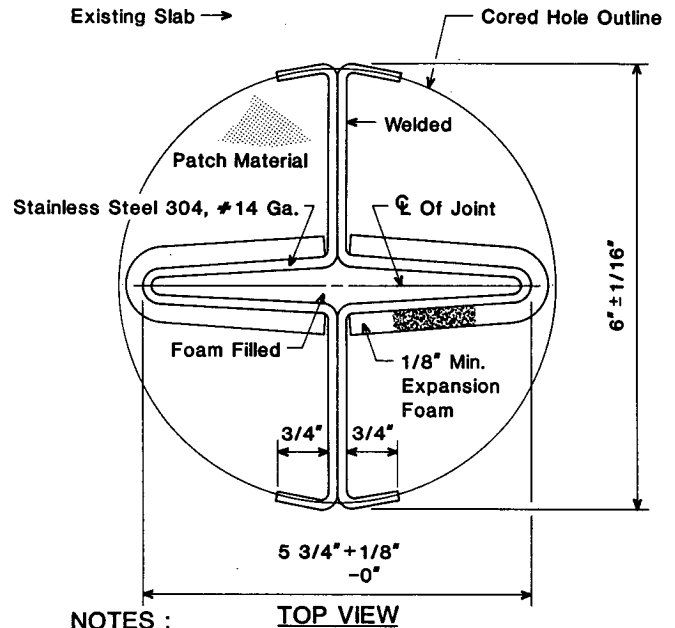
4.2.1 Dowels

When using dowels installed in slots, expansion caps should be specified unless it is certain that the pavement joint or crack is fully closed at the time of the repair. Coated dowels should be at least 18 in. long and of sufficient diameter to reduce faulting to an acceptable level as described under section 3.4.

Slots for dowels should be first cut with multiple blade saws. The "fins" have a life expectancy of about one week before they begin to break out and the open slot becomes a hazard to traffic (4).

Light weight pneumatic hammers are then used to remove the concrete with minimal damage to the surrounding concrete. Slots should be cut so that the dowels are allowed to rest horizontally and perpendicular to the joint or crack at middepth of the slab. Each dowel should be placed on a support chair to allow the patch material to surround the dowel.

Dowels must be provided with filler board or styrofoam material at midlength to prevent the intrusion of patch material into the existing joint/crack, and to form the joint in the kerf. To account for varying joint/crack widths over the project, multiple thin sheets of filler can be used. To keep joints/cracks free of material it is important to have a tight fitting filler. Details of the dowel placement are shown in Figure IV-6.



1. Devices to be Placed in 6" Dia. Hole With Compression Tool.
2. Edges to be Burr Free.
3. Center Portion Filled With Foam.
4. Expansive Foam—Furnished Loose and Field Applied With Adhesive Backing.

Figure IV-5. Detailed Double Vee device.

4.2.2 Shear Device

The placement of proprietary shear devices must be done in accordance with the manufacturer's recommendations. The following are general recommendations only. The Double Vee contains a compressible filler in its center to prevent the intrusion of patch material during installation. The Double Vee device also has to have some type of bond breaker along the outside of the "vee" portion (parallel to the joint) to allow slab movement as shown in Figure IV-5.

The latest recommendations from the manufacturer include the cutting of grooves in the core hole to assist in providing mechanical shear load transfer across the joint or crack. The devices are also precompressed in the hole so that they will not go into tension during cool weather. This is intended to improve the bonding reliability.

When using shear devices, the vertical face of the joints and cracks must be sealed to prevent polymer concrete from entering and leaching of the liquid component. Vertical cracks can be effectively sealed with caulking material from a tube.

The bottom of the core hole must also be completely sealed to prevent loss of the liquid portion of the polymer concrete. Loss of this liquid will leave the material unable to set up and has been a major reason for several failures. The liquid component is also highly reactive. Care must be taken to assure that the bottom sealer does not react with the liquid component. Plaster placed in the bottom of the holes will seal any cracks and base material (4).

The core holes should be brushed clean with a wire brush to enhance the polymer concrete bond with the existing slab. The

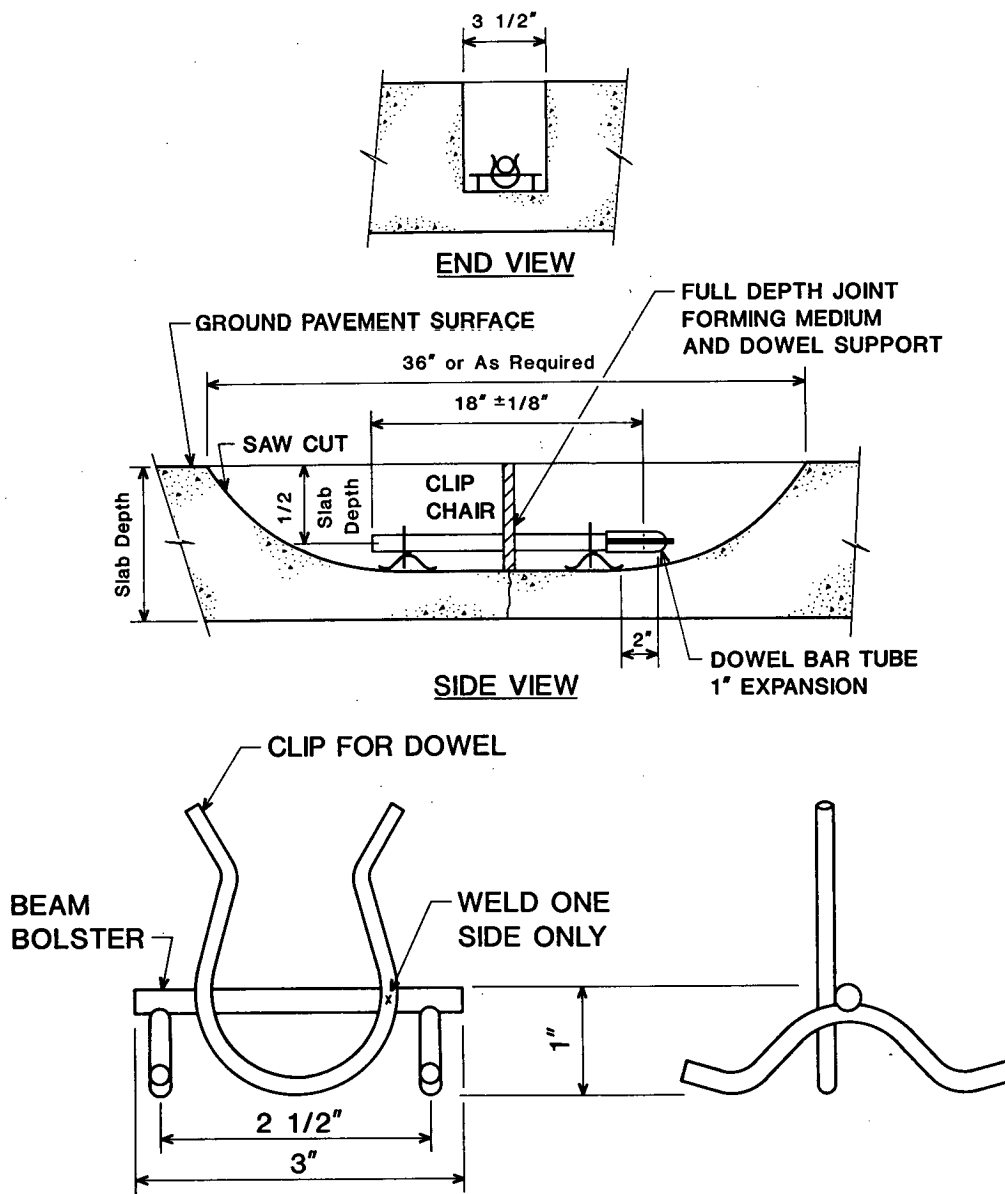


Figure IV-6. Details of dowel restoration design.

shear devices must be recessed 1 in. (minimum) from the pavement surface and a joint formed on top.

Once the core holes are cut, grooved, cleaned, and sealed the precompressed Double Vee load transfer devices are inserted and properly orientated with the joint/crack, 1 in. (minimum) below the surface. The patch material is then used to fill the core hole around the load transfer device and left to harden. A joint sealant reservoir must be provided at the top of the slab above the shear device.

The lane may be opened to traffic after several hours of hardening, depending on the agency's experience with patching material and slab temperature.

5.0 PREPARATION OF PLANS AND SPECIFICATIONS

The plans must indicate the locations where load transfer devices are to be placed. The agency should determine which joints/cracks need load transfer restoration by measurement of the deflection transfer as discussed in section 3.0.

A detailed engineering drawing of the device to be used must be provided, as shown in Figures IV-5 and IV-6.

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

6.0 REFERENCES

1. DARTER, M. I., BARENBERG, E. J., YRJANSON, W. A., ASHLEY, G. R., and OKAMOTO, P. A., "Evaluation of Joint Repair Methods for PCC Pavements." Evaluation Interim Report, NCHRP Project 1-21, University of Illinois (1981).
2. GULDEN, W., and BROWN, D., "Improving Load Transfer in Existing Jointed Concrete Pavements." Final Report, FHWA, Georgia DOT (Nov. 1983).
3. TAYABJI, S. D., and COLLEY, B. E., "Improved Rigid Pavement Joints." Construction Technology Laboratories—Presentation at Annual Meeting of Transportation Research Board (1983).
4. GULDEN, W., and BROWN, D., "Establishing Load Transfer In Existing Jointed Concrete Pavements." Paper presented at Annual Meeting of Transportation Research Board (Jan. 1985).
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6. FRIBERG, B. F., "Design of Dowels in Transverse Joints of Concrete Pavements." *Transactions, ASCE, Vol. 105* (1940).
7. BRANDLEY, R. W., "Concrete Pavement Joints, Measurement of Deflection and Slab Rocking, Development of Load Transfer Device." *Proce. World Congress on Joint Sealing and Bearing Systems for Concrete Structures, ACI, Niagara Falls, N.Y.* (1981).

B. GUIDE SPECIFICATIONS

1.0 GENERAL

1.1 Description of Work

Work performed under these specifications shall consist of removing portions of concrete at a joint or crack, installation of load transfer devices, and replacement of removed concrete with the specified patch material to provide load transfer across the joint or crack.

1.2 Location

The locations of the work areas are indicated on the plans. Joint/crack locations are specified by stationing. The number and spacing of load transfer devices are specified in the plans at each joint/crack.

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."

2.0 MATERIALS

2.1 Load Transfer Devices

Load transfer devices as detailed in the plans must meet the approval of the contracting agency. Samples of the load transfer

devices shall be submitted to the engineer for approval before being incorporated into the job.

2.2 Polymer Concrete (Alternate)

The contractor must submit material properties for the polymer concrete which include:

1. Compressive, flexural, tensile, impact strengths.
2. Hardness.
3. Shrinkage.
4. Surface and wear resistance.
5. Curing time.
6. Recommended temperature usage.
7. Storage characteristics.

The polymer concrete shall consist of a liquid resin, powder filler, and fine aggregate. The polymer concrete system must be "concrete" or equivalent. The mortar should attain 80 percent of its full strength in 45 min to 2 hours under field conditions at temperatures ranging from 40°F to 100°F. It shall be mixed in the field with selected aggregates capable of being troweled in place. Mixing instructions shall be printed on each container. The physical properties for the polymer concrete required after 3 hours are as follows:

1. Minimum compressive strength—8,200 psi (ASTM C109).
2. Minimum flexural strength—2,500 psi (ASTM C348).
3. Minimum tensile strength—1,000 psi (ASTM D638).
4. Minimum elongation at rupture—0.45% (ASTM D638).
5. Maximum shrinkage (linear)—0.01% (ASTM C157).

The polymer concrete shall not support combustion in the possible event of contact with an open flame 3 min after placement. This shall be determined by placing an open flame within ¼ in. of a sample polymer patch surface (approximately 1 ft sq) 3 min after placement. The pot life of the polymer concrete shall have a range of 8 to 15 min minimum and be consistent over a temperature range of 40°F to 100°F.

2.3 Portland Cement Concrete (Alternate)

The concrete patch mixture shall conform to the following:

1. 94 lb cement—Type III.
2. 125 lb sand.
3. 220 lb stone—¾ in. maximum sized.
4. 5 gal water (approximately).
5. 1½ lb calcium chloride.
6. Expansion agent—4.5 oz.

The expansion agent shall be aluminum powder mixed with a filler in a ratio of one part powder to 50 parts of filler. Either fly ash or pumicite can be used as a filler.

2.4 Epoxy Resin Adhesive

The epoxy resin adhesive shall meet the requirements of AASHTO M235.

2.5 Calcium Chloride

The calcium chloride shall meet the requirements of AASHTO M-144.

2.6 Aggregate

Aggregate gradation shall conform to ASTM C33 Standard Specifications for Concrete Aggregates—Fine Aggregate and be approved by the contracting agency. The mix design shall be approved by the contracting agency and give a high enough slump to allow the polymer concrete to flow freely around the load transfer device. The aggregate shall be stored in a manner that will keep it dry and prevent intrusion of foreign materials.

3.0 EQUIPMENT

The contractor shall furnish all equipment, tools, and other apparatus necessary for upkeep, maintenance, and proper construction and acceptable completion of the work as follows.

3.1 Concrete Saw

The concrete saw shall be equipped with diamond blades or approved equal. The saw shall be capable of sawing concrete to form slots in the pavement for the installation of dowels.

3.2 Light-Weight Pneumatic Chipping Hammers

Hammers used to chip slots into the pavement shall meet the engineer's approval and not spall or damage the adjoining concrete.

3.3 Drilling and Coring

Diamond coring devices or other equipment must be capable of cutting (for shear devices) to a diameter and depth sufficient to cut completely through the slab. The equipment shall be in good condition and operated in such a manner that the holes are vertical and not "out of round." Equipment shall be provided to cut grooves in the core wall as shown on the plans.

3.4 Cleaning Utensils

Wire brushes or other devices capable of cleaning the core holes and kerfs shall be provided by the contractor. These devices may not damage the existing pavement. The holes or kerfs must be sufficiently cleaned to provide adequate bond with the polymer concrete.

3.5 Miscellaneous

All necessary hoses, connectors, joint sealing equipment, gauges, steel drill bits, and saw blades shall be furnished by the contractor.

4.0 CONSTRUCTION METHODS

4.1 Double Vee Shear Devices

Core holes for shear devices shall be drilled at the nominal diameter shown on the plans and drilled vertically and round (centered over the joint or crack) through the entire depth of the slab. Grooves shall then be cut in the core wall, if specified. Core holes shall be brushed clean with a wire brush. Any specified primer or epoxy shall be applied to the core walls and device if specified. Joints and cracks shall be sealed inside the core hole with a suitable sealer such as caulking material to prevent intrusion of patch material. The core hole base must also be completely sealed off to prevent loss of the liquid portion of the patch material.

Devices shall be oriented inside the core hole in such a manner that will allow joint opening and closing as specified by the manufacturer. The devices shall be recessed 1 in. beneath the surface of the pavement. Spacing, number, and location of core holes shall be provided by the contracting agency, as specified. The devices shall be placed in compression in the core holes as recommended by the manufacturer.

The space surrounding the devices shall then be filled with the agency-approved patch material mix to the top of the slab surface. The joint inside the core hole area shall be formed with an approved filler. The polymer concrete shall be finished level and brushed. The surface shall be level with the slab, all adjacent spalls repaired, and finished rough. Any depressions after construction in the cores shall be filled with patch material at no cost to the agency.

4.2 Dowel Devices

Slots cut in pavements for installation of dowels shall be to the width, depth, and length as shown on the plans. As soon as possible after cutting, the slots shall be flushed with water to remove the cutting slurry. Prior to installation of dowels, the slots shall be blown by high pressure air jet to clean and dry the slot.

Each dowel must be fitted with a forming medium that is centered at the joint or crack to ensure that a joint will be formed through the patching material. The forming medium shall extend full depth from the top of the slab to the bottom of the slot as shown on the plans.

When using a portland cement concrete material, the slot walls and bottom shall be coated with the specified epoxy resin material before placement of patch material. A layer of patch material shall be placed in the bottom of the slot prior to placement of dowel bars. The dowel bars shall be provided with small chairs and both placed into the slots as shown on the plans. The dowel bars shall be installed parallel to the pavement surface and in line with longitudinal direction to a tolerance of $\frac{1}{4}$ in. in 18 in.

The remainder of the concrete patch material shall be placed and consolidated in the slot. The patch material shall be finished level with the pavement surface.

5.0 WEATHER CONDITIONS

Load transfer restoration shall be performed on a wet surface or when air temperatures are below 40°F or above 100°F.

6.0 ACCEPTANCE

Any load transfer device with inadequate corrosive coating shall be rejected at no cost to the agency. Polymer concrete may not be held in the mixer or pump for more than the manufacturer's suggested pot life after mixing. Any material held for longer times shall be rejected at no cost to the agency.

Prior to final acceptance, those load transfer devices that fail to exhibit bond (either concrete to patch material or device to patch material) shall be replaced at the contractors cost. Bond failures shall be detected by visual inspection 7 days after installation. All loose concrete, joint filler, other loose construction materials, and patch material accidentally or otherwise spilled on the surface shall be removed and the surrounding areas shall be left in a neat orderly condition by the contractor prior to opening to traffic or before final acceptance.

7.0 MEASUREMENT AND PAYMENT

7.1 Measurement

The quantities to be paid will be measured as follows:

1. Pay quantity per load transfer device installed.
2. Linear foot of joint resealing.
3. Linear foot of traffic markings repainted.
4. Lump sum traffic control and mobilization costs.

7.2 Payment

The unit contract prices shall be full compensation to the contractor for furnishing all labor, materials, equipment, tools, traffic control, and all other costs necessary or incidental to accomplish the restoration of load transfer at the designated locations in accordance with these specifications and the details on the plans.

V. DIAMOND GRINDING OF JOINTED CONCRETE PAVEMENTS

A. DESIGN AND CONSTRUCTION GUIDELINES

1.0 INTRODUCTION

These Guidelines cover the use of diamond impregnated blades for grinding and texturing of portland cement concrete (PCC) pavements. Diamond grinding is used to restore surface profile and retexture the pavement.

1.1 Need for Grinding

Diamond grinding is used to reprofile jointed concrete pavements that have developed a rough ride because of faulting or slab warping. Grinding is also used to eliminate wheel ruts and restore transverse drainage. Grinding is done to restore riding quality by removal of faults at joints in plain PCC pavements, or at joints and transverse cracks in reinforced PCC pavements (see Appen. A for distress identification).

Georgia has developed a faulting index to describe the degree of faulting on their pavements. Each $\frac{1}{32}$ in. of faulting is adjusted to a multiple of 5. As an example, a faulting index of 15 would represent an average fault of $\frac{3}{32}$ in. Every fourth joint is measured for faulting and an average fault per mile is determined. When pavements in Georgia reach a faulting index of 15 ($\frac{3}{32}$ in.), the pavement will usually have some faults approaching $\frac{1}{4}$ in.

Dowel-mesh (reinforced) pavements with long joint spacing (40+ ft) many times exhibit faulting at cracks within the panel. The mesh is broken and very little load transfer exists at these cracks due to openings caused by shrinkage due to temperature and moisture changes. In many cases, the doweled joints are not faulted at all, or only have minor faulting. The doweled joints in many cases exhibit very little movement due to dowel corrosion or other reasons. The expansion and contraction

movement is being accommodated by the intermediate cracks. Faulting at these cracks can be quite severe without slab breakup.

Faulting on multilane, divided highways is usually confined to the outside or heavy traffic lane. The inside or passing lanes in many cases have a satisfactory profile. In these cases, grinding is needed only in the outside lane. However, if the passing lane has low skid resistance it may be desirable to grind it also.

Rutted pavements from studded tires can also be reprofiled both transversely and longitudinally by diamond grinding. Transverse drainage is restored and ruts, which can be filled with water and result in hydroplaning, are eliminated.

1.2 Effectiveness

Diamond grinding should be performed before maximum faulting exceeds $\frac{1}{4}$ in. for plain PCC pavements. Grinding equipment can remove faults much greater than this; however, the cost of grinding and the incidence of cracked or broken slabs will accelerate during this stage making restoration much more costly. The specification of new pavement smoothness, or better, can be achieved. However, the tighter the specification the more the grinding work will cost. The life of a ground pavement depends largely on pumping activity. Lives ranging from 5 to 15+ years are typical. Increased life can be achieved through additional concurrent work to correct the problem which caused the problem as described in section 2.0.

2.0 CONCURRENT WORK

If roughness is caused by faulting of the joints or cracks, pumping has occurred beneath the slabs. In order to prolong the effective life of a ground pavement when pumping is evident,

certain other repair and/or preventative maintenance methods must be performed at the same time. If nothing is done to reduce pumping, faulting will develop again, and probably more rapidly.

Pumping must be reduced or eliminated by effectively sealing all joints including the longitudinal pavement centerline and edge joint. When pumping has proceeded to any appreciable degree there are usually voids near the joints that should be filled by subsealing to stabilize the slabs. Limited full-depth repair and spall repair may also be required for localized distress.

Drainage analysis may show that edge drains can also be used to reduce or eliminate pumping through rapid evacuation of water entering near the pavement edge. Recommendations of the installation of edge drains are contained in Ref. 1. The feasibility of installing edge drains should be carefully studied because under certain conditions the fines present under the pavement may be pumped out through the drainage system. The filter material that surrounds the pipe must be carefully designed to minimize the loss of fines.

Another method of reducing the potential for pumping is to limit the amount of deflection. This can be accomplished with the installation of load transfer devices in the joints, or by using edge beams or a tied concrete shoulder. Load and transfer restoration can reduce deflection by one-half and should be considered when pumping and faulting exist. When used in combination with resealing and subsealing, the pumping potential will be reduced considerably.

Another important distress relative to grinding is depressions. They should be leveled up by slab jacking or slab replacement prior to grinding. It is not cost effective to try and grind out major depressions in the pavement.

In a rehabilitation project involving grinding, the sequence of work is very important. Slab stabilization by subsealing, full-depth replacement, and spall repair should be completed before grinding. Resealing joints should follow the grinding operation to ensure proper sealant depth.

3.0 DESIGN

3.1 Condition Survey

A pavement condition survey should be conducted to determine the amount and type of distress present. The rehabilitation of the pavement can then be planned after an evaluation of the condition data. An important item to survey with regard to diamond grinding is the amount of faulting present. Periodic surveys will provide the information necessary to determine the degree of faulting and the increase in faulting with time in order to plan a timely preventative maintenance and rehabilitation program.

3.2 Cost of Grinding

The cost of grinding is primarily dependent on the amount of material to be removed and the hardness of the aggregate. On a typical project the cost of grinding for soft aggregate is in the range of \$2.00 to \$3.00/sq yd; for medium hardness aggregate, \$3.00 to \$5.00/sq yd; and for hard aggregate, \$5.00 to \$8.00/sq yd (1984). Costs are also affected by the size of the project, labor rates, traffic control procedures (roadway closed

or with traffic in adjacent lane), and the degree of smoothness specified.

3.3 Ride Quality

When designing a project involving diamond grinding the existing riding quality of the pavement should be determined. There are several methods used to measure the roughness of existing pavements. These include the California or Rainhart profilograph, the Mays ride meter, PCA or Wisconsin road meter, GM profilometer or the new noncontact high-speed profilometers, rolling straightedge and the BPR roughometer.

A profilograph makes a trace of the pavement surface. The trace is taken from about 3 ft from the pavement edge to about 3 ft from the centerline. This is performed in the outside lane (the heavy traffic lane). The trace indicates the amount of grinding necessary and the location of roughness. These charts can be used by contractors to estimate the amount of material to be removed. The profilographs should run at a maximum of 2½ mph.

The PCA or Wisconsin road meter has also been used to determine pavement roughness and acceptance testing of the ground surface. The meter should be used on the mainline pavement only with a test speed to 50 mph. These meters must be kept in calibration and recommended test procedures strictly followed in order to reduce the variability of this type device.

The Mays ride meter is also used to determine pavement roughness and the same precautions apply as for the Wisconsin road meter.

The rolling straightedge can be used to spot check smoothness of bridges and ramps. Where ruts are being eliminated by grinding, a stringline can be used to check the transverse profile.

The BPR roughometer should be used on mainline pavement only and run at 20 mph.

3.4 Skid Resistance

Specifications do not call for a specific level of skid resistance on any type of pavement surface for legal reasons. The corduroy type of texture developed by grinding would visually indicate a good friction factor. The ridges are composed of rock and mortar which improve the surface macrotexture and provide an escape route for moisture under a tire. The use of the ASTM ribbed test tire (E501) may not provide an accurate evaluation of the skid resistance of this type of texture because this ribbed tire is not sensitive to macrotexture (4). The use of a smooth (or blank) tire (E524) shows definite improvement in the after-grinding (4). Test data using a smooth (or blank) tire show definite improvement of the skid number on many projects.

4.0 CONSTRUCTION

4.1 Equipment

The degree of joint faulting or roughness that can and should be removed in a cost-effective manner is changing with current equipment and blade developments. Equipment is available or being developed that can make grinding a more viable option for pavement with a greater degree of roughness. These developments include larger and more powerful equipment (6-ft cut-

ting width), different types of segmental cutting heads, and blade development to increase the life of blades.

4.2 Procedures

Diamond grinding will result in retexturing the pavement surface that improves the friction factors. Blade spacing in the cutting head can be varied to improve the life and friction factor of the texture. When grinding aggregates susceptible to polishing, the spacing must be wider to provide more of a land area between blades. The grinding chip thickness (chip thickness of pavement broken off between blades), measured at its thickest point, should be 0.080 in. minimum and have an average thickness of 0.100 in. For the harder aggregates not subject to polishing, the minimum chip thickness should be 0.065 in. and an average of 0.080 in.

Water is used to cool the cutting head when diamond grinding. This slurry must be vacuumed from the surface and pumped into a tank with baffles or deposited into the grassed slopes. It is recommended that grinding slurry be deposited directly on grass shoulders from the grinding machine. This is the most economical solution and the slurry is not detrimental to vegetation. Where this is impossible in urban areas or for other reasons, a suitable disposal site should be provided.

Much of the grinding work on Interstate-type facilities has been done under single lane closure with traffic carried in the adjacent lane. This type of traffic control results in increased construction costs and increased risk to construction workmen. A reduced construction zone speed limit should be strictly enforced by Highway Patrol personnel. These services could be a bid item under the rehabilitation contract.

In urban areas it may be necessary to avoid interfering with traffic flow during rush hours to keep public inconvenience to a tolerable level. In this case, the work period may be confined to off-peak traffic hours (i.e. 8 PM to 6 AM). If at all possible it would be advantageous, from the standpoint of costs and work period required, to close sections of the entire roadway involved and route traffic over parallel service roads or an adjacent street. Tight completion schedules can be used to expedite work when roadway closures are specified. Closing a single lane with traffic on both sides should be avoided.

5.0 PREPARATION OF PLANS AND SPECIFICATIONS

Information which is of value to a grinding contractor and which should be included in the bid documents comprises:

1. Year pavement was constructed.
2. Source of both the coarse and fine aggregate used in the concrete slab.
3. Transverse joint spacing and sealant used.
4. Wheel rut depth if more than $\frac{1}{16}$ in.
5. Pavement design: plain, dowel-mesh, or CRCP. Evidence of any steel near the surface.
6. Type of traffic markers and replacement requirements. A pay item should be set up for temporary and/or permanent marking required.
7. Profile of existing pavement surface.

The working time should be stated in either working or cal-

endar days. The hours per day should also be stated if restrictions are imposed on the contractor's working time due to traffic volume considerations, etc.

Grinding limits on the plans should be clearly defined and should show transition or stop lines at bridges and ramps. Areas to be ground should be clearly marked.

Grinding production is typically 50 machine hours per lane mile, but this will vary considerably with aggregate hardness and the roughness of the pavement.

When specifying acceptance testing for smoothness, the test equipment should be listed along with the method or procedures to be followed in acceptance testing. Test methods commonly used for new pavement construction can be used for diamond grinding.

The maximum roughness per mile and the maximum average roughness for the project should be specified. The following values are recommended for pavements reprofiled by diamond grinding. These values are approximate only, and each agency must determine its own values based on the specific roughness measuring device and pavements. These values may be changed for different pavements to obtain a more cost-effective grinding job, e.g., low traffic volumes or very rough pavements. The "must grind" requirement for deviation in excess of 0.3 in. in 25 ft should not apply to grinding projects when using the California profilograph.

California Profilograph: $\frac{1}{10}$ -mile increments—profile index
15 maximum on mainline, 20 on ramps
1-mile increments—profile index
10 maximum on mainline, 7 average on mainline for job.

Note: One advantage of the profilograph type of device is that it determines the exact location of out-of-tolerance work. Another is that it is a constant measurement device.

Rainhart Profilograph: $\frac{1}{10}$ -mile increments—profile index
14 maximum on ramps
1-mile increments—profile index
7 maximum, 5 average for job.

PCA or Wisconsin Road Meter (50 mph) 1-mile increments,
300 maximum counts/mile, 250 counts average for job.

Mays Ride Meter (50 mph) 1-mile increments, 70 maximum,
50 average for job.

BPR Roughometer (20 mph) 1-mile increments, 95 maximum,
75 average for job.

Rolling Straightedge (Ramps and Bridges): $\frac{1}{8}$ -in. in 10 ft.

Transverse Slope: (by stringline for rut removal) + $\frac{1}{4}$ in. in 12 ft.

Note: Warning—All of these types must be calibrated on a regular basis using local pavement sections. Also, car meters may provide widely different values depending on the vehicle.

It is recommended that the acceptance testing for smoothness be based on 1-mile increments. Based on past history, this is the most cost-effective method of acceptance.

The specifications should also define who will run the acceptance tests and when these tests will be run.

Any noise limitations on equipment should be clearly defined. A level of 95 dBA at 50 ft is common and 86 dBA at 50 ft is

attainable. Project specifications have included incentive pay for a reduction in the noise level below a certain limit.

Specifications should also permit skipping a small portion of the surface or patching when steel is found near the surface.

When grinding a pavement, isolated low areas from original construction occasionally are present. Specifications recognize this and usually require 95 percent coverage in any 3 ft by 100 ft test area. Isolated low spots less than 2 sq ft in area should not require texture if lowering the cutting head is required. The maximum overlap between passes should be 2 in.

If other work in addition to grinding is to be accomplished, the sequence of operation should be specified (e.g., joint resealing after grinding, subsealing and patching before grinding).

The Guide Specifications accompanying these Design and Construction Guidelines are recommended for use after the appropriate revisions for local conditions have been made.

6.0 REFERENCES

1. DARTER, M. I., CARPENTER, S. H., HERRIN, M., BARENBERG, E. J., DEMPSEY, B. J., THOMPSON, M. R., SMITH, R. E., and SNYDER, M. B., "Techniques For Pavement Rehabilitation." Participants Notebook, National Highway Institute/Federal Highway Administration (1984 Rev.).
2. AMES, W. H., "Profile Correction and Surface Retexturing." Preprint Volume For The National Seminar On Portland Cement Concrete Pavement Recycling And Rehabilitation, Transportation Research Board, St. Louis, Mo. (1981).
3. TYNER, H. L., "Concrete Pavement Rehabilitation—Georgia Methodology." Preprint Volume For The National Seminar On Portland Cement Concrete Pavement Recycling And Rehabilitation, Transportation Research Board, St. Louis, Mo. (1981).
4. HENRY, J. J., and SATIO, K., "Skid-Resistance Measurements with Blank and Ribbed Test Tires and Their Relationship to Pavement Texture." *Transportation Research Record 946* (1983).

B. GUIDE SPECIFICATIONS

1.0 GENERAL

This specification is limited to the use of diamond blades to grind concrete pavements for profile improvement and texturing.

1.1 Description of Work

The work performed under this specification consists of diamond grinding of portland cement concrete pavement to eliminate joint faulting and other roughness, and restore proper drainage, riding quality, and tire friction to the pavement surface.

1.2 Location

The plans will designate the areas of pavement to be ground, or as directed by the engineer. Grinding of bridge decks and roadway shoulders to promote drainage will not be required unless indicated on the plans, or as directed 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."

2.0 EQUIPMENT

2.1 Power Driven, Self-Propelled Machines

Power-driven self-propelled machines with diamond blades that are specifically designed to grind and texture portland cement concrete pavement shall be used. The equipment shall be able to grind the surface of the pavement to the specified smoothness tolerances and leave a texture as specified. The equipment shall not cause spalls at joints or cracks, or fracture the aggregate at the surface.

3.0 CONSTRUCTION METHODS

3.1 Grinding

The pavement shall be ground in a longitudinal direction that begins and ends at lines normal to the pavement centerline. The grinding operation shall produce a uniform finished surface, eliminate joint or crack faults, and provide positive lateral surface drainage. A constant cross slope between grinding extremities in each lane shall be provided. Grind the auxiliary or ramp lanes to provide continuity with the positive drainage and riding surface of the mainline edge.

The pavement surfaces on both sides of the transverse joints or cracks shall be in essentially the same plane. The entire pavement surface shall be textured. However, extra depth grinding to eliminate minor depressions is not required.

The removal of slurry or residue resulting from the grinding operation shall be a continuous operation. Grinding slurry shall not be permitted to flow across lanes occupied by traffic or to flow into gutters or other drainage facilities, but may be allowed to drain into the adjacent ditch. When required, slurry shall be pumped from the pavement and discharged in an area designated by the contracting agency.

4.0 ACCEPTANCE

4.1 Final Surface Finish

The pavement surface shall be uniform in appearance with a longitudinal corduroy-type texture. The peaks of the ridges shall be approximately $\frac{1}{16}$ in. higher than the bottom of the grooves. The grooves shall be between 0.10 and 0.15 in. wide. The land area between the grooves shall be between 0.065 and 0.125 in. (depending on the hardness of the aggregate) as specified in the plans. There are typically 50 to 60 grooves per foot width, as specified by the engineer.

The ground pavement riding surface requirements that must be met are specified below.

(NOTE TO ENGINEER: The smoothness tolerances specified will be dependent on the type of testing equipment used. See Design and Construction Guidelines for suggested values.)

EXAMPLE (Georgia DOT):

Ground pavement surfaces shall meet a pavement roughness index value not to exceed 50 in./mile when tested with the Mays Meter in accordance with GHD-93. Any mile areas that do not meet the 50 roughness value shall be tested for Pavement Profile Index value, with the Rainhart Profilograph. Readings shall not exceed 7.0 in. per mile for each mile of pavement when tested in accordance with GHD-78. Any mile areas which exceed 7.0 in./mile shall be reground at no additional cost to the Department.

Transverse joints and random cracks shall be visually inspected to ensure that adjacent surfaces are in the same plane. Misalignment of the planes of the surfaces shall not exceed $\frac{1}{16}$ in. In any 3 ft by 100 ft test area at least 95 percent of the surface shall be textured.

The transverse slope of the pavement shall be uniform. No depressions or misalignment of slope greater than $\frac{1}{4}$ in. in 12 ft may exist when tested by stringline or straightedge placed perpendicular to the centerline. Grinding along the inside edge of existing pavement shall conform to straightedge requirements. Straightedge requirements do not apply across longitudinal joints or outside the ground areas.

5.0 MEASUREMENT AND PAYMENT**5.1 Measurement**

Grinding of the existing pavements will be measured by the square yard. The quantity of work completed is determined by multiplying the finished ground width by the total length of ground area.

5.2 Payment

The contract price per square yard for grinding concrete pavement is full compensation for furnishing all labor, materials, tools, equipment, and incidentals and for doing all work involved in grinding the existing surface, removing residue, and cleaning the pavement in accordance with these specifications and as shown on the plans.

Payment will be made under:

Item no. ____ Grind Concrete Pavement ____ per sq. yd.

VI. RESEALING JOINTS IN CONCRETE PAVEMENTS**A. DESIGN AND CONSTRUCTION GUIDELINES****1.0 INTRODUCTION**

These guidelines present important background information for engineers and technicians involved in designing and constructing projects where joints are to be resealed. These guidelines will also be useful to maintenance personnel in resealing joints as part of effective preventative 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 a seal to reduce further infiltration. Many jointed concrete pavements have been observed in all areas of the United States 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 sealant to keep out incompressibles.

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 that 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 the large compressive and tensile forces.

The determination of sealing needs should consider the amount of moisture or incompressible distress. If it is determined that moisture could or is causing a serious problem, the sealing of all joints and cracks should be considered (particularly the lane/shoulder joint) (see Appen. A for distress identification).

1.2 Limitations

The major purpose of resealing joints is to extend the life of the pavement. However, if resealing is performed under the following conditions, very little or no extended life will be obtained:

1. Badly deteriorated pavement with substantial slab breakup. Only with other extensive rehabilitation might this be effective.

2. Pavement with good subdrainage or located in areas with very little moisture. However, incompressibles may still cause serious problems; in which case resealing would be beneficial (particularly for JRCP).

3. Pavement with very little truck traffic. The incompressibles may still be a serious problem, however, and resealing would then be beneficial.

4. Poor quality sealant, or poor construction techniques, or if the joint reservoir is not properly designed.

1.3 Effectiveness

The proper resealing of joints will normally lead to an extension of pavement life until other major rehabilitation is necessary. The increase in life need only be a few years to pay for the joint reseat. A few agencies have recognized the cost effectiveness of preventative maintenance and have developed a regular resealing program on their concrete pavements. Results from NCHRP Project 1-19 showed that proper joint sealing reduced joint deterioration by 50 percent (5).

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

2.0 CONCURRENT WORK

There are several types of repair that should be considered along with joint resealing. The actual need depends on the specific existing design, distress, traffic, subgrade, and climate. However, the following work items should be considered:

1. Full-depth repair and spall repair of joints exhibiting deterioration.
2. The resealing of other joints (longitudinal, lane/shoulder) and cracks.
3. Subdrainage improvement.
4. Restoration of load transfer where poor load transfer exists.
5. Subsealing of voids beneath the joints.

If grinding of the surface is to be accomplished, it should be performed *before* the resealing operation so that the seal can be properly recessed beneath the top of the ground slab.

3.0 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 the repair of existing joints.

3.1 Purpose and Existing Conditions

The following factors should be studied when joint resealing is being considered:

1. What is the designated purpose of the sealant—to protect

against water infiltration or 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. Typical types of joint seal damage are given in the Appendix A for distress identification.

Pavements exhibiting a substantial amount of high severity sealants should be programmed for resealing as soon as possible. Low severity does not need replacement. Medium severity sealants should be replaced within the next few years, depending on what proportion of joints are near the high severity range.

3. What is the joint condition? 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 would not.

4. What is the existing joint shape factor? A small segment of the sealant should be removed from several joints and the joint sealant reservoir measured. The joint width and depth are 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—restoration of load transfer, subsealing?

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. The 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.
2. Elastomeric low modulus silicone.
3. Preformed compression seals.

These seals have given good performance for periods of time ranging from 5 to 15 years. 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 high quality to last at least 5 years and preferably longer.

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

3.3 Joint Reservoir Dimensions

The performance of field-molded sealants is heavily dependent on the shape and dimensions of the joint reservoir. The ratio

of depth, D , to width, W , is known as the sealant shape factor. Research studies have shown that, for elastomeric sealants, the closer D/W is to 1 the lower the stresses and strains and the better the subsequent performance of the sealant. For elastomeric low modulus silicones, the best seal performance shape factor is $1/2$. A sufficient depth of sealant is also required to ensure adequate adhesion between the joint face and the sealant. Therefore, most existing joints will require widening to provide for a better shape factor for field-molded sealants.

For hot poured elastomeric sealants, a depth of $1/2$ to 1 in. is normally recommended to provide adequate adhesion with the joint sidewalls (see Fig. VI-1). For elastomeric silicone sealants, a minimum depth of $1/4$ in. to a maximum $1/2$ in. is recommended (see Fig. VI-2). Example calculations are given in Ref. 2.

A backer rod is recommended with field-molded sealants to provide the desired shape factor and prevent three-sided adhesion. A maximum reservoir width of 1 in. is recommended to prevent direct traffic exposure. Most of the field-molded sealants can be tracked out of the joint with traffic, or are not very abrasion resistant. For this same reason, sealants must be recessed approximately $1/4$ in. below the surface (depending on the season of installation).

Preformed compression seals rely heavily on compressive forces from the joint to keep it in position. There is little or no bond between the seal and the joint face. If the joint opens wider than the seal, the seal will either fall into the joint or be pulled out by traffic. Therefore, it is critical that the correct size of preformed seal be selected and that the seal maintain its elastic properties. Generally accepted recommendations for width of sealant versus joint spacing are shown on Figures VI-1 and VI-2.

The sealing of longitudinal joints is different because of much less movement (usually tied). A minimum width of $1/4$ in. is recommended. It is considered to be very important to seal the longitudinal joints because much water infiltrates through these joints (including the lane/shoulder joint).

3.4 Repair of 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 $1\frac{1}{2}$ in. in width) must be repaired before sealing.

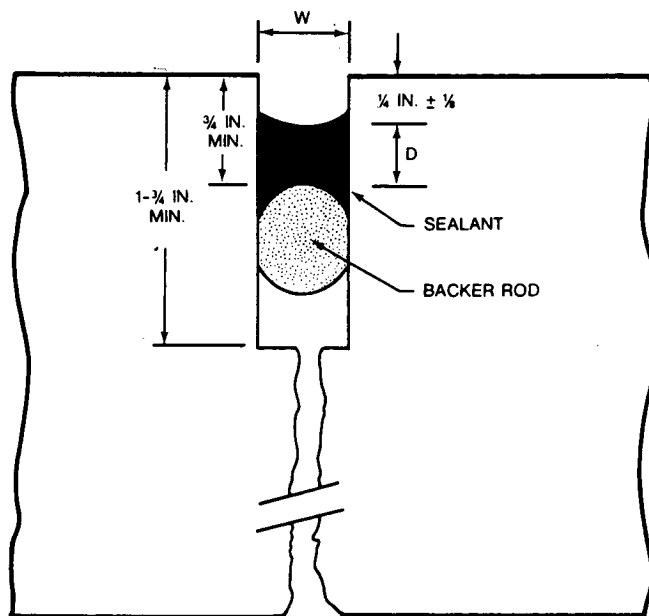
4.0 CONSTRUCTION

4.1 Materials

4.1.1 Sealants

Three basic sealant types are recommended in the Guide Specifications:

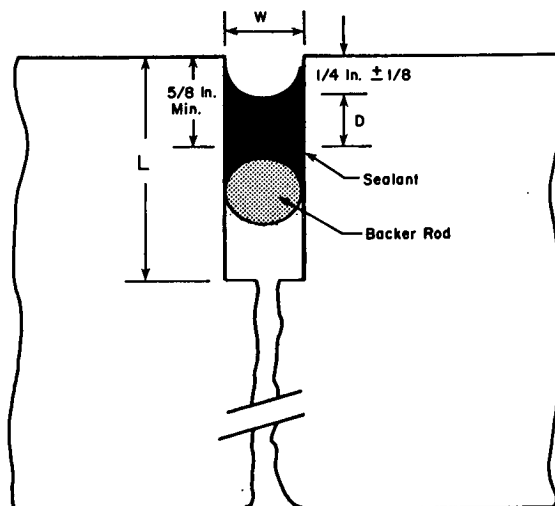
1. Hot poured, elastomeric-type that meet, ASTM D3406 or AASHTO M282. This specification requires that the material pass an artificial weathering test among other tests. This test



JT. SPACING (FT.)	D (INS.)	FREEZE AREA W (INS.)	NON-FREEZE AREA W (INS.)
≤ 20	1/2 - 1	1/2	3/4
21 - 40	1/2 - 1	3/4	1/2
41 - 60	1/2 - 1	1	3/4
61 - 100	.	.	.

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

Figure VI-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 VI-2. Silicone sealant recommendations.

provides an indication of the ability of the sealant to withstand environmental effects (ultraviolet light).

2. Low modulus silicone sealant that meets specifications similar to the Georgia Department of Transportation. This is a relatively newer 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.

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 high quality to last at least 5 years and preferably longer.

4.1.2 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, nonshrinking, nonreactive, and nonabsorptive material such as closed-cell polyethylene rod and foam rubber rod. Hard rubber rods, or any material that will absorb water and swell, must not be used. The backer rod should in no way limit the joint movement (mostly compression), and should preferably have minimal interaction with the seal so as not to restrict its movements. The backer rods should be at least 25 percent larger than the joint width so that it fits tightly in the joint and is not displaced.

4.1.3 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

4.2.1 Removal of Old Sealant

Any old sealant remaining in the joints must first be removed prior to resealing. This is normally done with a joint plow attachment; however, high pressure water blasting is also effective. V-shaped plow tools must not be allowed as these will spall the concrete and not completely remove all the sealant remains. The most effective removal tool is a rectangular steel section that fits loosely in the joint. The contractor should have different sizes available where joint widths vary.

4.2.2 Refacing the Joint Sidewalls

After the old sealant has been removed, joints should be refaced, using a concrete diamond saw. Refacing provides a clean surface for the sealant to bond to, 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 in. 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.

4.2.3 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 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 $\frac{1}{16}$ in. 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 control is difficult.
6. A guide or template should be used to ensure accurate alignment of the saw in the joint.

4.2.4 Reconstructing Defective Joints

Joints with widths in excess of $\frac{3}{4}$ in. or that are severely spalled should be considered for reconstruction. Unspalled, clean joint sidewalls are particularly important when preformed compression seals are being installed.

4.2.5 Cleaning

Once the old sealant has been removed and the joints have been refaced and rebuilt, all the joints are ready for cleaning. Sandblasting is *strongly recommended* for field-molded sealants to remove saw residue and any other material (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 field 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. Do not stretch or twist these materials 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 $\frac{1}{4}$ in. is obtained beneath the slab surface. Care in installation of the closed foam 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 are a continuous process. Do not leave the joints unsealed overnight. Preparation must not be done on more joints than can be sealed during the working day. This prevents unnecessary intrusion of moisture, incompressibles, and dust.

Prevent air entrapment by applying the sealant under pressure from the bottom up. Do not overfill the joint. A standard recess of $\frac{1}{4}$ in. is required. This will prevent damage to the sealant from traffic. In no instance will a joint or crack be overfilled intentionally.

4.4.1 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.

4.4.2 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 *must be tooled* to provide firm contact with the joint edges and to form the $\frac{1}{4}$ -in. recess below the slab surface. The depth of sealant over the crown of the backer rod should be $\frac{1}{4}$ to $\frac{1}{2}$ in.

Silicone skins over quickly at temperatures above 40°F and cures through to the recommended depth within 7 days at temperatures above 40°F. If sealant is applied in joints where no rocking or slab deflection is expected, traffic may be allowed over the sealed areas within 1 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 in all but extreme movement conditions or lower temperatures than 45°F.

4.4.3 Preformed Compression Seals

The preformed sealants are designed with the intent that the seal will always be in compression. A minimum of 20 percent compression from the normal uncompressed state is desired. The maximum compression is 50 percent. The preformed seal's performance relies heavily on its ability to maintain sufficient contact with the joint walls.

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 at the time of installation to assure proper adhesion. The seal should be inserted at a depth of $\frac{1}{4}$ in. plus $\frac{1}{8}$ in. or minus $\frac{1}{16}$ in. 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 present continually, problems can be corrected as they occur. If the inspector is not present continually, he will be telling the contractor to redo something that is complete but which may not be correct. Although this is the correct procedure, it can lead to animosity.

Continual observation of the operation to ensure the contractor is following his quality assurance plan will minimize the amount of testing and examining the inspector must perform. Because all operations will be occurring simultaneously, the inspector must be continuously moving 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:

- a. Joint face is clean and dry before sealant application.
- b. No backer material is floating in the sealant.
- c. Joints are not underfilled or overfilled.
- d. Joint sealant is not tacky.
- e. Sealant has adhered to the face of the joint.
- f. Spilled sealant has been removed.
- g. No debris is left on pavement surface.

2. For preformed sealants:

- a. Seal is properly compressed (i.e., seal is in contact with both joint faces).
- b. Seal is not overstretched.
- c. Seal is not twisted in joint.
- d. Seal is located at proper depth.

4.6 Common Sealant Defects and Preventative Measures

1. *Field-poured (hot and cold) sealants*: The defects result from excessive stress, and result in loss of bond between sealant and joint/crack face, internal rupture in the sealant, extrusion of sealant, and intrusion of debris into the sealant. These defects can be minimized or eliminated as follows:

- a. Reduce strains in sealants by using better shape factors.
- b. Use proper back-up materials to: (1) support the sealant and prevent sagging until sealant is cured, (2) provide a suitable shape factor, and (3) eliminate bond development along the bottom of the joint.
- c. Reduce movement at the joint with closer joint spacing.
- d. Make sure that joint/crack faces are clean before sealing.
- e. Select a sealant that resists intrusion of debris.
- f. Select a sealant that resists hardening or oxidizing.
- g. Remove debris from surface of pavement as much as possible.
- h. Avoid trapping air and moisture in the sealant during installation.

2. *Preformed-compression seals*: The defects include slip-down, twisting, extrusion and compression set of the seal. The defects can be minimized or eliminated as follows:

- a. Size the seal properly.
- b. Use seal with better properties to provide low temperature recovery and resistance to permanent set at high temperatures.
- c. Use care during installation of sealant. Select manufacturer's recommended installation equipment.

5.0 PREPARATION OF PLANS AND SPECIFICATIONS

The plans should clearly show the joints to be resealed. A diagram similar to Figures VI-1 and VI-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.

6.0 REFERENCES

1. TYNER, H. L., "Concrete Pavement Rehabilitation—Georgia Methodology." Preprint Volume For The National Seminar On Portland Cement Concrete Pavement Recycling And Rehabilitation, Transportation Research Board (1981).
2. DARTER, M. I., CARPENTER, S. H., HERRIN, M., BARENBERG, E. J., DEMPSEY, B. J., THOMPSON, M. R., SMITH, R. E., and SNYDER, M. B., "Techniques For Pavement Rehabilitation." Participants Training Course Notebook, by ERES Consultants, Inc. for National Highway Institute/Federal Highway Administration (1984 Rev.).
3. PETERSON, D. E., and MCBRIDE, J. C., "Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems Phases I and II, Final Report for NCHRP, Transportation Research Board (1978).

4. ZIMMER, T. R., CARPENTER, S. H., and DARTER, M. I., "Field Performance of a Low Modulus Silicone Highway Joint Sealant." Paper Presented at January 1984 Meeting of TRB.

5. DARTER, M. I., BECKER, J. M., SNYDER, M. B., "Portland Cement Concrete Pavement Evaluation System COPES." *NCHRP Report 277* (1985) 175 pp.

B. GUIDE SPECIFICATIONS

1.0 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 applicable to the work on this project are as published in the current edition of (Local, State, Special) "Standard Specifications."

1.4 Submittals

1.4.1 Materials

Sealant material and backer rod should be inspected, tested, and approved by the engineer before incorporation in the work. The contractor shall give sufficient advance notice 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 as unacceptable and unauthorized, and will not be paid for. Unless otherwise designated, tests in accordance with the most recent cited standard methods of ASSHTO 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.

1.4.2 Equipment

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 will be approved by the engineer prior to use on the project.

1.4.3 Manufacturer's Recommendations

Where installation procedures or any part thereof is 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.

2.0 MATERIALS

2.1 Joint Sealant

The sealant shall meet the requirements of one of the following specifications.

2.1.1 Hot Applied

1. AASHTO M282 or ASTM D3406 joint sealants, hot-poured, elastomeric-type, for portland cement concrete pavements.
2. ASTM D3408 testing joint sealants, hot-poured, elastomeric-type, for portland cement concrete pavements.

2.1.2 Cold Applied Silicone

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

2.1.3 Preformed

1. ASTM D2628 preformed polychloroprene elastomeric joint seals for concrete pavements.
2. 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, and 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. Use only the backer rod 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.

3.0 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 they shall be subject to approval by the engineer.

3.2 Joint Cleaning Equipment

3.2.1 Routing Tool

To remove old sealant from joints, select a routing tool that is adjustable 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 control.

3.2.2 Concrete Saw

A water-cooled, self-propelled power saw with diamond saw blades shall be used, which is designed for sawing hardened concrete, 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.

3.2.3 Sandblasting Equipment

Sandblasting equipment shall be capable of removing any residual sealer, 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. Attach an

adjustable guide to the nozzle or nozzles that will hold the nozzles aligned with the joint about 1 in. 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.

3.2.4 Air Compressor

A portable air compressor shall be used which is capable of operating the sandblasting equipment and is also 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 and a minimum volume of 150 cu ft of air per minute at the nozzles, and shall be free of oil and moisture.

3.2.5 Jet Waterblasting

A high-pressure water jet machine that shall include a compressor, pressure pumps, hose, water jets, and controls capable of discharging water up to 10,000 psi pressure at 22 gal per min may be used for cleaning purposes. Use adjustable nozzles to control nozzle pressure between 7,000 and 10,000 psi. Select high pressure hoses with burst pressures from 20,000 psi to 30,000 psi.

3.2.6 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.

3.2.7 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

3.3.1 Hot-Poured Field-Molded Sealant

Install hot-poured sealant materials with unit applicators that will heat and extrude the sealant in one operation. Equip the mobile units 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 sealer. 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. Insulate the applicator wand 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. Equip the nozzle tip with a metal cross-bar to assure that the top of the sealant fed into the joint

is level and within the indicated tolerance below the pavement surface.

3.3.2 Cold-Applied Silicone Sealant

The equipment shall be designed to install cold-applied silicone joint sealant materials. Equipment shall conform to the manufacturer's recommendations and shall also be subject to approval by the engineer.

3.3.3 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 5 percent during installation. Simple hand tools of the single-axle type should be permitted; this tool tends to cause excessive stretching and may cut or distort the seal.

1. Self-propelled gasoline engine-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 that 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.

4.0 CONSTRUCTION METHODS

4.1 Joint Preparation

4.1.1 General Joint Preparation

Unless otherwise indicated, remove existing material in joint and saw, and clean and reseal all joints. Do not proceed with final cleaning operations by more than one working day in advance of sealant. Cleaning procedures which damage joints or previously repaired patches by chipping or spalling will not be permitted.

4.1.2 Removal of Existing Material

Remove from the joint faces the major portion of the in-place sealants by using the specified routing tool. After cutting free the existing sealant from both joint faces, remove the sealant to the depth required to accommodate the bond breaking material and to maintain the specified depth for the new sealant to be installed. Remove in-place sealant to the depth (as shown, or

of the joint, which is ____ in., $\pm \frac{1}{8}$ in.). At the completion of routing operations clean the pavement surface with a vacuum sweeper and clean the joint opening by blowing with compressed air.

4.1.3 Refacing of Joints

Reface concrete joint walls 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. Remove all irregularities from sides of joint faces. Saw all joints in a straight line. 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. Protect adjacent joint spaces previously cleaned from receiving water and debris during the cleaning operation.

4.1.4 Final Cleaning of Joints

Final cleaning shall be conducted using sandblasting.

Using sandblasting methods clean the newly exposed concrete joint faces and pavement surfaces extending $\frac{1}{2}$ in. to 1 in. from the edges of the joint. 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 cu ft per min of air at a nozzle pressure of 90 lb per sq in. for final cleaning. After final cleaning and immediately prior to sealing, blow out the joints with compressed air using the specified air compressor to remove all sand and water to ensure that the joints are dry, dust free, and clean at the time of sealing.

4.1.5 Backer Rod

After the joints have received the final cleaning and are dry, install 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.

4.1.6 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 lineal footage of joint that can be resealed during the same workday.

4.1.7 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

4.2.1 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 remains in the applicator at the end of the day's operation shall be withdrawn and wasted. Heat the sealant in the specified equipment.

4.2.2 Cold-Applied Silicone Sealants and Preformed Seals

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

4.3 Installation of Sealant

4.3.1 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 5.0, commence sealing the joints. If the foregoing conditions cannot be met, or if rains interrupt sealing operations, reclean the open joints prior to installing the sealant.

4.3.2 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 $\frac{1}{4}$ in. below the top of the pavement within the tolerances as shown, 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 $\frac{1}{4}$ -in. 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 1 hour.

2. *Preformed Joint Sealant.* 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 5 percent. The joint seal shall be placed to a uniform depth within the tolerances specified. Joint seals in place which fail to meet specified requirements shall be removed and replaced in a satisfactory manner at no additional cost to the agency.

Unless otherwise directed, where joints have vertical sides, the joint seal shall be installed to a depth of $\frac{1}{4}$ in., $\pm \frac{1}{8}$ in. The seal shall be installed continuously across the transverse joints.

4.4 Trial Joint Installation

As a preliminary to 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, remove the material and again clean and prepare the joints for resealing. After approval of the trial joints, clean and seal all other joints in a similar manner and subject to approval.

5.0 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 and rising. The minimum placement temperature for silicone sealant is 40°F. Surfaces shall be dry and component materials shall be protected from free moisture.

6.0 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 on 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 nontacky and will not permit the adherence of dust, dirt, small stones, and similar contaminants.

7.0 MEASUREMENT AND 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 because of 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.

VII. EDGE SUPPORT FOR JOINTED CONCRETE PAVEMENTS

A. DESIGN AND CONSTRUCTION GUIDELINES

1.0 INTRODUCTION

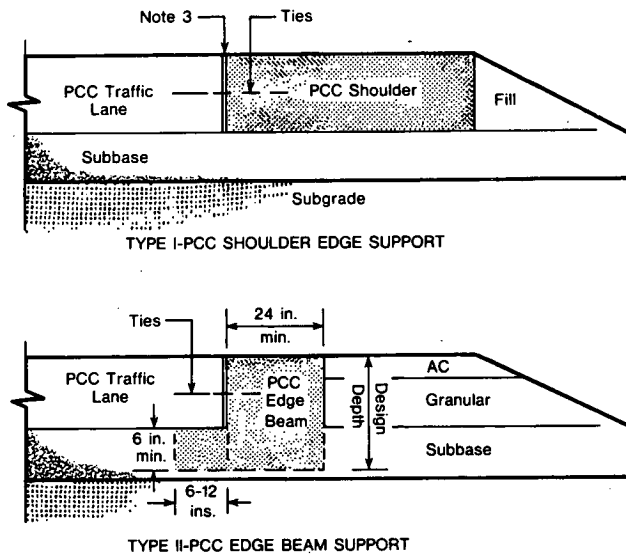
1.1 Need for Edge Support

Many concrete pavements exhibit distress resulting from loss of support beneath the slab edge and transverse joint. The major cause of this support loss is heavy repeated truck loads and the infiltration of water into the pavement system (particularly along the shoulder joint) and the subsequent erosion of the base and/or subgrade material. This causes an increase in the corner and edge deflections of the slab that results in faulting, corner breaks, transverse, and longitudinal cracking.

One approach to the reduction of these types of distresses

would be the construction of a rigid edge support. The major objective of providing increased edge support for an existing pavement is to reduce slab edge and corner deflections (as well as stresses) by providing either a slab edge beam or a tied shoulder (Refs. 1, 2). Another benefit is the reduction of moisture entering the pavement directly at the slab edge. Examples of different design concepts are shown in Figure VII-1. Type I represents a typical PCC shoulder, and Type II is a much narrower edge "beam" tied to the slab.

Experience with tied shoulders has shown that the service life of a concrete pavement may be significantly extended by decreasing critical edge stresses and deflections (Refs. 1, 2). Edge support improvement should be considered along the outer edge of the truck lane on heavily trafficked highways.



Notes:

- (1) Ties should be No. 5 deformed rebar or equivalent at middepth of slab.
- (2) Existing shoulder to be removed to the extent required.
- (3) Joint between traffic lane and shoulder should be either edged, or a reservoir that is formed or sawed and then sealed.

Figure VII-1. Diagram of different edge support designs.

1.2 Effectiveness

The effectiveness of increased edge support depends on the reduction in edge deflection and critical stresses. To investigate the effectiveness of the edge support techniques, the ILLISLAB finite element program developed at the University of Illinois was used (Ref. 3). This program was developed for the analysis of a variety of jointed concrete pavement systems. ILLISLAB is capable of analyzing the behavior of pavements using various types of load transfer systems such as dowel bars or tie systems, aggregate interlock, or a combination of both. The model is also capable of handling the effect of a stabilized base on the structural response of the pavement system. The model has been verified by comparison with the available theoretical solutions and results from field experimental studies.

Figure VII-2 shows the effect of edge support on edge deflection. A concrete shoulder with a strong tie that provides 100 percent deflection load transfer efficiency reduces the deflection by one-half as shown. Figure VII-3 shows the effect of both the joint load transfer efficiency and the width of the shoulder. Again, good load transfer reduces the stress by one-half. The width of the support beam/shoulder has a major effect from 1 to 3 ft.

To illustrate the effectiveness of the edge beam in decreasing the critical edge deflections and stresses of a pumping pavement, a void was placed beneath the slab at the joint under the corner of the leave slab. Initially, the corner deflection of the leave slab was computed using the finite element analysis to determine the response of the system before the edge beam was placed. Then

the corner deflection was calculated for varying shoulder widths and undercut lips of the edge beam. A slab thickness of 9 in. with a granular and stabilized subbase was used as an example.

Results from this analysis show that the edge support concept can substantially decrease critical edge and corner deflections and stresses in pavements even when voids are present (however, voids must always be filled). For example, Figure VII-4 shows that a 9-in. slab with a stabilized subbase and a void beneath the corner had a corner deflection of 0.047 in. under a 9-kip wheel load. The attachment of a 24-in. wide edge beam with a depth of 9 in. reduced the deflection to 0.023 in., or 50 percent. If the edge beam was thickened to 15 in. and undercut the slab 6 to 12 in., the corner deflection was reduced to 0.018 in., or 62 percent. Increasing the edge beam width to 48 in. decreases the deflection more, but at a decreasing rate. The effect of an edge beam on a 9-in. slab with a granular subbase is shown in Figure VII-5. The effect is similar to a stabilized subbase.

2.0 CONCURRENT WORK

The effectiveness of the edge support can be enhanced by the application of several other repair methods. One method that should be applied along with the installation of the edge support to decrease pavement deflections even further is restoration of support by subsealing of voids. This should be accomplished after the edge support has been placed. Slab replacement, spall repair, grinding, and joint resealing may also be accomplished at the same time depending on the overall pavement condition. The combination of these repair methods could serve to substantially increase the service life of a jointed concrete pavement.

The need for subdrainage must be considered. However, it is believed that the use of longitudinal pipes is normally not required, except where excessive free water exists beneath the slab. If placed, the longitudinal pipe should be placed along the outer edge at the bottom of the beam.

3.0 DESIGN OF EDGE SUPPORT

3.1 General

There are two different types of edge support designs shown in Figure VII-1: (1) a full-width concrete shoulder, and (2) a narrow "beam" attached to the edge of the slab.

The selection of one or the other is a matter of cost and condition of the existing shoulder. If the existing shoulder is deteriorated, a full-width PCC shoulder may be the most cost effective because extensive shoulder rehabilitation will be required anyway. If the shoulder is in good condition, the narrow edge beam may be the most cost effective (although this is not always the case because the quantities of materials and cost tradeoffs involved).

3.2 Shoulder Design (Full Width)

The design of the PCC concrete shoulder involves selecting its thickness, tapering (if any), transverse joint spacing and load transfer, and the lane/shoulder tie system. A detailed design procedure is provided in Ref. 1. A summary of design recommendations is as follows:

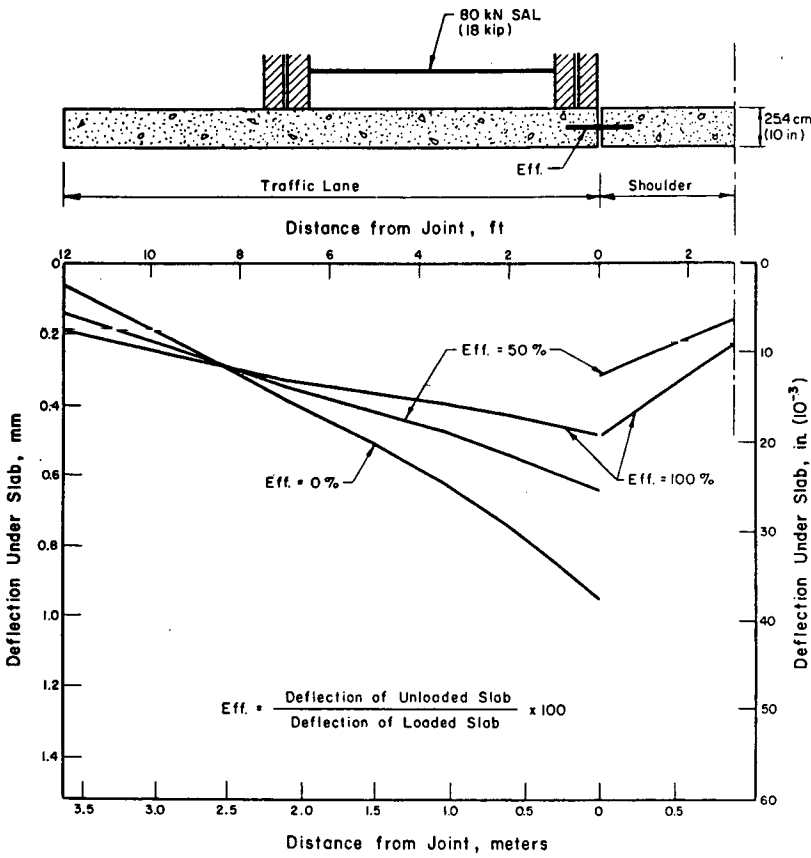


Figure VII-2. Effect of lane/shoulder tie on deflection of PCC traffic lane.

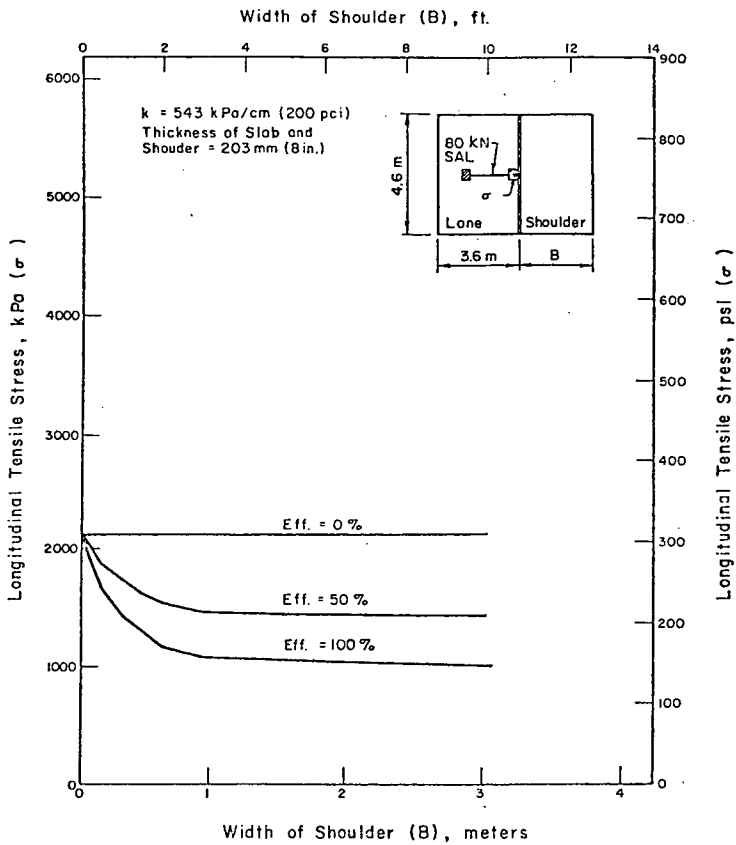


Figure VII-3. Effect of lane/shoulder tie and width of PCC shoulder on tensile stress of traffic lane.

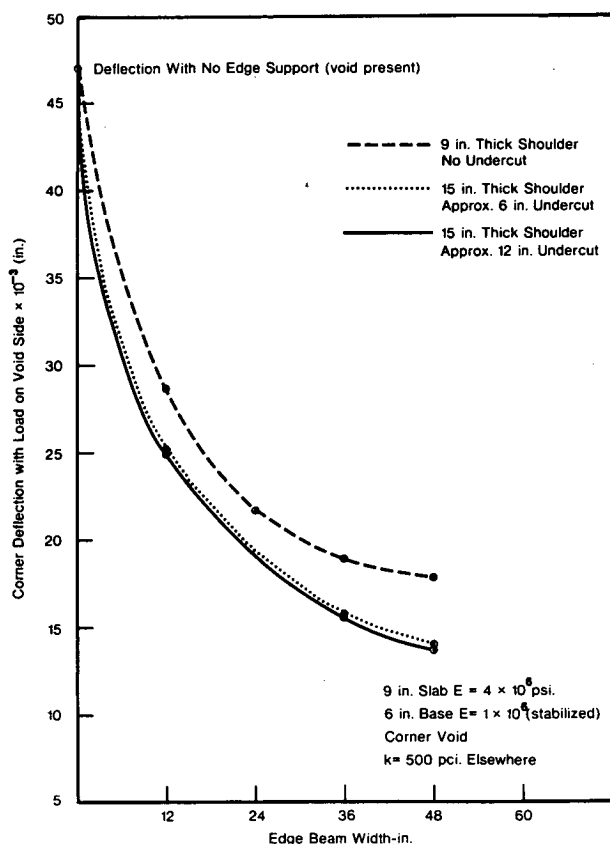


Figure VII-4. Effect of edge support on slab corner deflection with a stabilized subbase.

1. A jointed plain concrete pavement shoulder is recommended. The slab thickness of the shoulder can be designed for fatigue damage (Ref. 1) which generally shows that the outside edge is critical because of parking truck traffic. A slab thickness equal to that of the main line and tapering somewhat at the top may be the most cost effective design. The bottom of the shoulder slab would extend directly out as shown in Figure VII-1. The outer edge must be at least 6 in. thick and thicker if much heavy truck parking is expected. An abrupt change in shoulder thickness at the lane/shoulder may result in differential frost heave. The subbase must not be a frost susceptible material (in deep frost areas).

2. Transverse joints should be weakened plain type with no mechanical load transfer. Joint spacing should be a maximum of 20 ft and each joint type in the traffic lane must be matched with a similar joint in the shoulder (e.g., expansion joints must be extended into the shoulder). If the traffic lane slab was 30 ft long, the shoulder would require a 15-ft joint spacing, for example.

3. The lane/shoulder tie system is crucial to the success of the increased edge support. Good load transfer can be achieved through drilling holes for placement of deformed rebars. The bars must be installed in the holes with epoxy or a nonshrinkage cement grout. The embedment length of the bars into the existing and new shoulder slab should be adequate to develop full bar yield strength. This would be 8 in. minimum for a No. 4 bar and 10 in. minimum for a No. 5 bar according to the ACI Code

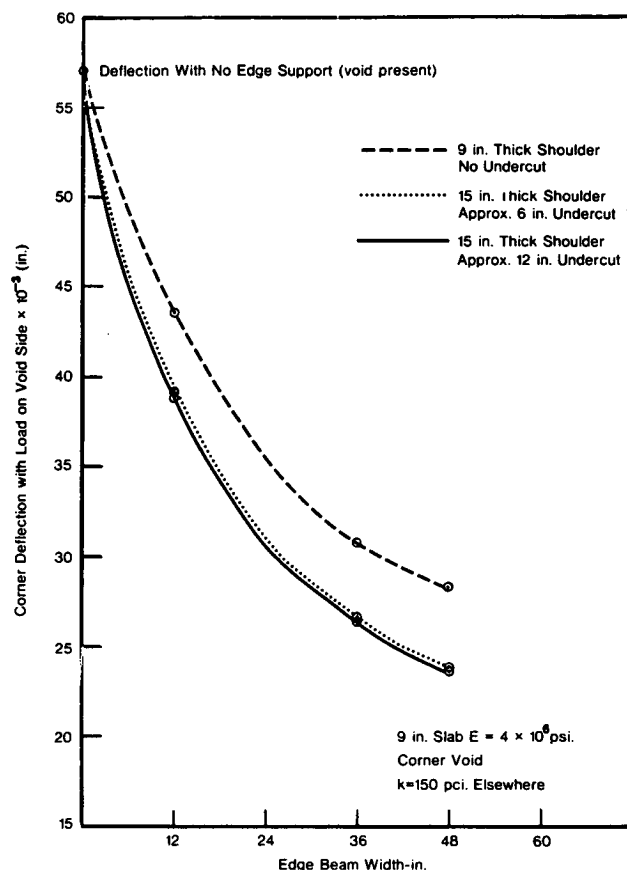


Figure VII-5. Effect of edge beam on slab corner deflection with a granular subbase.

($0.0004 \times \text{Bar Diameter} \times f_y$) for a Grade 40 bar. To ensure that an adequate strength is obtained, the Guide Specifications require minimum pull out strengths that are based on the yield strength of the reinforcement bars.

Malleable tie bars of small diameter (No. 4 or No. 5) and spaced 12 to 24 in. at midslab depth are preferable as shown in Figure VII-6. In areas where deicing salts are used, the bars should be coated with a corrosion resistant coating. Other means of tying the shoulder to the traffic lane (such as a $\frac{3}{8}$ -in. round tiebolt with a hook) should be fully tested to ensure that it will provide full bar yield strength development.

3.3 Edge Beam Design

The edge beam design is similar to the PCC shoulder design except that it is much narrower than the shoulder and can be thicker than the traffic lane slab. From the analysis performed with varying widths of the undercut lip, it was concluded that the corner deflection was not very sensitive to this parameter. Thus, because of this and obvious construction difficulties, the undercut is not recommended. This is not to say that the undercut is not important; it may be helpful in assuring long-term high load transfer efficiency across the shoulder joint. The two critical design parameters are the edge beam width and its thickness. Indications are that the edge beam width should be at least 24 in. to contribute significant structural benefit. The

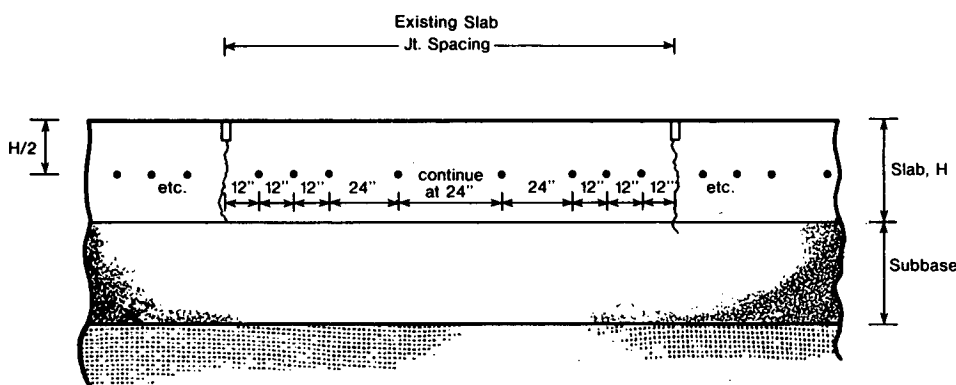


Figure VII-6. Recommended tie bar spacing.

depth of the beam should be at least the thickness of the slab, and possibly up to 6 in. thicker (e.g., for 9-in. PCC slabs the beam depth would be 15 in.). The edge beam should be jointed to match the existing pavement. Weakened-plane contraction joints, without dowels, should be formed as soon as possible after placement. Figure VII-6 illustrates the joints and tie bar design.

A critical part of the edge beam concept is the design and installation of the tie system. The purpose of the tie system is to provide the best possible joint load transfer across the lane/beam joint.

3.4 Sealing Longitudinal Joint

It is recommended that the joint between the existing slab and edge support be sawed $\frac{1}{4}$ in. wide by $\frac{1}{2}$ in. deep and sealed with a high quality sealant to keep out moisture. The transverse joints in the shoulder/edge beam should also be sealed.

4.0 CONSTRUCTION

4.1 Procedures

Because the edge beam is a new concept, there is no tested procedure for its installation, although the procedures used in constructing concrete shoulders to an existing traffic lane would be similar. The following should be considered in the construction of edge beams and PCC shoulders.

It is important that the base be in good condition. If the base material is disturbed during excavation, it should be adequately recompact. Settlement of the shoulder/beam can produce very high "pullout" stresses in the joint tie system. The magnitude of these stresses may be sufficient to exceed the strength of the tie bars and drastically decrease the edge support effectiveness.

Holes are drilled into the existing slab for the tie bars. Epoxy or grout can be used to secure the tie bars in these holes in the existing slab. The holes must be placed at slab middepth. Great care must be taken to ensure that the deformed tie bars are adequately attached into the existing slab. A minimum pull out strength that is equal to the yield strength of the bars used is

required (4) in the Guide Specifications. The grout must be a nonshrinking grout.

After the bars have been secured and the shoulder area is prepared, the fresh concrete should be placed. If an undercut is used, the concrete should be placed in two lifts. The first lift should be adequately vibrated beneath the slab to ensure that no voids exist. The second lift should be level with the pavement surface.

The texturing of the edge beam or shoulder should be different from the pavement. Drivers should be able to differentiate between the traffic lane and the shoulder. The edge beam should be textured perpendicular to the traffic lane (e.g., texturing). If the lane is textured longitudinally, the edge beam should be textured transversely, and vice versa.

5.0 PREPARATION OF PLANS AND SPECIFICATIONS

The plans should clearly show the areas where edge support is to be placed. A diagram showing the cross section with dimensions must be provided as well as specifics on transverse joints and the lane/shoulder longitudinal joint.

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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B. GUIDE SPECIFICATIONS

1.0 GENERAL

1.1 Description of Work

Work performed under these specifications shall consist of partial or complete removal of the shoulder, drilling and grouting or epoxying of tie bars into the edge of the existing slab, recompaction of disturbed base (if required), placement of a concrete edge beam or shoulder, and sawing and sealing the longitudinal joint (if required).

1.2 Location

The location of work areas is indicated on the plans. Edge beam or shoulder areas are specified by stationing.

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."

2.0 MATERIALS

2.1 Grout for Tie Bars

The grout, if used, shall meet the requirements of CRD-C 621 (Corps of Engineers Specification for nonshrink grout).

2.2 Epoxy for Tie Bars and for Face of Slab

The epoxy, if used, shall meet the requirements of AASHTO M235.

2.3 Tie Bars

Tie bars shall be No. 5 bars made of new billet steel grade 40 meeting ASTM A615(33) specifications. Bars shall be placed in accordance with these specifications and details shown on the plans.

2.4 Portland Cement Concrete

The portland cement concrete shall conform to the agency's normal paving standard specifications for paving concrete.

2.5 Joint Sealant

Joint material for the longitudinal and transverse joints shall conform to the applicable "Standard Specifications."

3.0 EQUIPMENT

The contractor shall furnish all equipment, tools, and other

apparatus necessary for upkeep and maintenance necessary for the proper construction and acceptable completion of the work as follows.

3.1 Grout Mixer (For Grouting Rebar)

The mixer shall be capable of continuous mechanical mixing to produce a grout, free of lumps and undispersed cement. Accessory equipment to provide for accurate solid and liquid measurement for batching all materials shall also be provided.

3.2 Drilling

An air compressor and rock drills or other devices shall be capable of drilling holes for tie bars parallel to the pavement surface at midslab. The equipment shall be maintained and operated so that the holes drilled are horizontal.

3.3 Other

Any and all miscellaneous tools, equipment, and supplies shall be furnished that may be required to satisfactorily complete the work.

4.0 CONSTRUCTION METHODS

4.1 Preparation

The edge beam or shoulder shall be constructed along the outside edge of the pavement designated in the plans. For an edge beam, the existing shoulder shall be sawed longitudinally at least 2 in. deep along a line outside of the edge beam and shall be excavated to the proper depth and dimensions according to the details on the plans. The material between the saw cut and the slab edge shall be removed and disposed of by the contractor. Care shall be taken not to damage the edge or the underside of the existing slab during excavation. The contractor may use any method desired in the removal of the material from the undercut portion as long as no damage is done to the slab or the adjacent shoulder that was not removed.

Holes for the tie bars shall be drilled according to the locations given on the plans. Tie bars shall be grouted or epoxied and allowed to set for at least 45 min.

The tie bars shall be capable of developing their full yield strength at 28 days as follows:

Grade	Bar Size	Minimum Pull-Out Strength (pounds)
40	#5	12,400
	#4	8,000
60	#5	18,600
	#4	12,000

Before work begins, the contractor shall furnish a proposed procedure along with testing results to verify that the procedure

will develop the minimum pull-out strength as specified above.

For a grout or epoxy system, the contractor shall furnish a 1-day strength that correlates to the 28-day strength. The approved 1-day strength will be used during construction to verify quality control of the grouting or epoxy system.

The contractor shall have jacking equipment available during construction to perform 1-day (24-hour) pull-out strength testing when requested by the engineer. All drilled holes in existing slabs shall be blown free of dust and loose particles by means of compressed air.

4.2 Edge Beam or Shoulder Installation

Concrete shall be conveyed to the work site by methods that will prevent segregation or loss of ingredients. The subgrade shall be moistened just before the concrete is placed. Concrete shall be placed in two lifts if the edge beam undercuts the traffic lane slab. The first lift shall be placed to just above the bottom edge of the existing slab. The concrete shall be adequately vibrated beneath the existing slab to ensure that no voids exist. The second layer shall be of such thickness that when compacted and finished the edge beam will match the adjacent slab in elevation and maintain the slope of the adjacent pavement as required by the plans. Transverse joints shall be placed in the edge beam as shown on the plans.

4.3 Finishing Requirements

The concrete surface shall be floated so that it does not vary more than 3/16 in. from the testing edge of a 10-ft straightedge. Irregularities exceeding the above shall be corrected to meet the tolerances at no added cost to the contracting agency.

After straight edging, the surface shall be textured. The texture shall be such to differentiate the edge beam from the traffic lanes. If the lane texture is transverse, the beam shall be longitudinal, and vice versa.

The outside edge of the edge beam shall be carefully finished with an edger having a radius of 1/4 in. Corners and edges that have crumbled and areas that lack sufficient mortar for proper finishing shall be cleaned and filled solidly with a properly proportioned mortar mixture and then finished.

A longitudinal joint between the slab and shoulder/beam shall be cleaned by sandblasting, and sealed with an approved sealer. Edge beams or shoulders shall be cured according to the

contracting agency's standard specifications for concrete pavements.

The portion of the shoulder between the edge beam and the longitudinal saw cut shall be replaced with asphaltic concrete and compacted to the satisfaction of the engineer. Where the asphalt shoulder is thick enough, the shoulder may be used as the form for the edge beam. Determination of adequate shoulder thickness will be made by the contracting agency. Any damage done to the existing shoulder shall be repaired by the contractor at his expense.

5.0 WEATHER CONDITIONS

Edge-beam construction shall not be performed at air temperatures below 35°F or above 100°F.

6.0 ACCEPTANCE

All loose concrete, joint filler, or grout accidentally or otherwise spilled on the surface or shoulder, and any other waste construction material shall be removed and the surrounding areas shall be left in a neat orderly condition by the contractor prior to opening to traffic or final acceptance.

7.0 MEASUREMENT AND PAYMENT

7.1 Measurement

The quantities to be paid will be measured as follows:

1. Linear foot of edge beam, or square yard of concrete shoulder.
2. Linear foot of traffic markings repainted.
3. Lump sum traffic control and mobilization costs.
4. Linear foot of longitudinal joint and transverse joint formed and sealed.

7.2 Payment

The unit contract prices shall be full compensation to the contractor for furnishing all labor, materials, equipment, tools, traffic control, and all other costs necessary or incidental to accomplish the installation of edge beams at the designated locations in accordance with these specifications and the details on the plans.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following general conclusions have been determined from this project.

1. The successful rehabilitation of PCC pavement joints is a complex problem that requires comprehensive evaluation, design, and construction procedures.

2. This project started with state-of-the-art techniques in 1980 and identified many different improvements during the succeeding 4 years. A substantial improvement in the state of the art for the seven selected repair and preventative techniques was achieved through interaction with numerous experienced engineers and contractors, results from various studies, and in the conduct of several field test projects.

3. There are *five* major steps in rehabilitating joints and cracks in PCC pavements.

- a. Pavement evaluation.
- b. Identification of feasible alternatives that both repair and prevent the deterioration.
- c. Selection of the most cost-effective alternative.
- d. Detailed design of the individual repair and preventative techniques
- e. Construction of the alternatives in accordance with plans and specifications

The procedures contained in Chapter Four and Appendix C provide the 1985 state-of-the-art procedures for the seven techniques studied. The results of short-term field testing performance is given in Appendix B. However, there are many aspects of each technique that need further research and development.

4. The timing of the construction of these seven techniques on many projects is deferred too long, typically until very serious deterioration has already occurred. This has often resulted in a decreased life of the rehabilitated project. The timely application of their repair and particularly preventative methods is of considerable importance.

SUGGESTED RESEARCH

There are several aspects of the evaluation, design, and construction of each of the techniques that need further research and development.

Full Depth Repair

1. Improved load transfer design and installation techniques.
2. Further study in the many aspects of early opening of full-depth repairs.
3. Additional studies into the consequences of the disturbance of base/subgrade of the repair.

4. Research into the different aspects of repair layout and selection of boundaries for varying JPCP and JRCP conditions.

Partial-Depth Patching

1. Rapid method for removal of deteriorated concrete.
2. Rapid method of detecting delaminated concrete.
3. Continuous testing of new and improved patch materials for early opening to traffic.

Subsealing

1. Further verification of the deflection-based void-detection procedures, and the establishment of correlations between needed grout quantities and void size and location.
2. Materials research into different grout types and mixture designs to improve flowability, strength, and durability (moisture and freeze-thaw).

Restoration of Load Transfer

1. Improvement of the bonding techniques between the grout material and the existing slab.
2. Field studies to demonstrate the benefits of load transfer restoration on performance.
3. Improved installation procedures for dowel bars.

Diamond Grinding

1. Diamond grinding initially produces a surface with excellent skid resistance characteristics. The long-term effects of diamond grinding on skid resistance are not well documented.

The skid resistance of ground surfaces should be measured using a smooth tire because studies indicate that treaded tires may not accurately measure the skid resistance experienced by an automobile (14). It is recommended that additional research should be conducted to investigate the measurement of skid resistance with smooth and treaded tires and other skid testing devices. Additional research to investigate the long-term skid resistance of ground pavements is also needed.

2. Diamond grinding develops a corduroy type texture with the texture cut through coarse aggregate and the mortar phase of the concrete. Blade spacing on the cutter head can be varied depending on the hardness of the rock. The harder the coarse aggregate the closer the blades must be spaced to result in breakoff of the coarse aggregate fines developed by grinding. It is proposed that a research project on optimum blade spacing for different aggregate hardness be conducted.

Some areas of the United States have limestone aggregates that polish under traffic. This results in a pavement with low wet water skid resistance. Generally, natural sands are used as

the fine aggregate and usually have a sufficient amount of silica to develop good skid resistance. Blade spacing for this type of coarse aggregate can be widened and still get breakoff of the coarse aggregate fines. With the wider spacing, a more durable texture could be developed. The ridges would be composed of limestone and mortar. The mortar in these ridges could provide the skid resistance even if the limestone in the ridges polished.

Another method of providing longer term skid resistance would be to cut transverse grooves in the diamond ground texture. This has been done in Iowa on an experimental project on I-80 where a limestone aggregate was used in the concrete.

The purpose of this research would be to arrive at an optimum spacing of blades for a variety of aggregates considering the texture life. Blades could perhaps be spaced wider than the current practice. This would result in a higher ridge in some areas of the pavement such as the approach side of a faulted joint. What effect this may have on the long-term skid resistance and smoothness of the pavement is not known.

3. Various smoothness measuring devices are in current use

for acceptance testing of grinding projects. Research should be conducted to determine the proper type of equipment to be used for acceptance testing.

Resealing of Joints

1. Continue to test and field evaluate new and improved joint sealants.
2. Additional research is needed into the effective sealing of the lane/shoulder joint.

Edge Support

1. Improved and proven techniques to achieve a permanent tie between the PCC edge beam or PCC shoulder and the traffic lane.
2. Field testing of different designs to provide performance information.

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APPENDIX A

DISTRESS IDENTIFICATION*

FAULTING OF TRANSVERSE JOINTS AND CRACKS

Description

Faulting is the difference of elevation across a joint or crack. Faulting is caused in part by a buildup of loose materials under the approach slab near the joint or crack as well as depression of the leave slab. The buildup of eroded or infiltrated materials is caused by pumping from under the leave slab and shoulder (free moisture under pressure) due to heavy loadings. The warp and/or curl upward of the slab near the joint or crack due to moisture and/or temperature gradient contributes to the pumping condition. Lack of load transfer contributes greatly to faulting.

Severity Levels

Severity is determined by the average faulting over the joints within the sample unit.

How to Measure

Faulting is determined by measuring the difference in elevation of slabs at transverse joints for the slabs in the sample unit. Faulting of cracks is measured as a guide to determine the distress level of the crack. Faulting is measured 1 ft in from the outside (right) slab edge on all lanes except the innermost passing lane. Faulting is measured 1 ft in from the inside (left) slab edge on the inner passing lane. If temporary patching prevents measurement, proceed on to the next joint. Sign convention: + when approach slab is higher than departure slab, - when the opposite occurs.

CORNER BREAKS

Description

A corner break is a crack that intersects the joints at a distance less than 6 ft (1.8 m) on each side measured from the corner of the slab. A corner break extends vertically through the entire slab thickness. It should not be confused with a corner spall that intersects the joint at an angle through the slab and is typically within 1 ft (0.3 m) from the slab corner. Corner breaks are the result of loss of support from pumping and heavy repeated loads. Poor load transfer across the joint also contributes to corner breaks.

Severity Levels

- L—The crack is tight (hairline). Well-sealed cracks are considered tight. No faulting or break-up of broken corner exists. Crack is not spalled.
- M—Crack is working and spalled at medium severity, but break-up of broken corner has not occurred. Faulting of crack or joint is less than ½ in. (13 mm). Temporary patching may have been placed because of corner break.
- H—Crack is spalled at high severity, the corner piece has broken into two or more pieces, or faulting of crack or joint is more than ½ in. (13 mm).

How to Measure

Corner breaks are measured by counting the number that exists in the sample unit. Different levels of severity should be counted and recorded separately. Corner breaks adjacent to a patch will not be recorded.

TRANSVERSE AND DIAGONAL CRACKS

Description

Linear cracks are caused by one or a combination of the following: heavy load repetition, thermal and moisture gradient stresses, and drying shrinkage stresses. Medium or high severity cracks are working cracks and are considered major structural distresses. (Note: hairline cracks that are less than 6 ft (1.8 m) long are not rated.)

Severity Levels

- L—Hairline (tight) crack with no spalling or faulting, a well-sealed crack with no visible faulting or spalling.
- M—Working crack with low to medium severity level of spalling, and/or faulting less than 1/2 in. (13 mm). Temporary patching may be present.
- H—A crack with width of greater than 1 in. (25 mm); a crack with a high severity level of spalling; or, a crack faulted ½ in. (13 mm) or more.

How to Measure

Cracks are measured in linear feet (or meters) for each level of distress. The length and average severity of each crack should

* Extracted from: M. I. Darter, J. M. Becker, M. B. Snyder, and R. E. Smith, "Portland Cement Concrete Pavement Evaluation System—COPES." *NCHRP Report 277* (1985).

be identified and recorded. Cracks in patches are recorded under patch deterioration.

JOINT SEAL DAMAGE OF TRANSVERSE JOINTS

Description

Joint seal damage exists when incompressible materials and/or water can infiltrate into the joints. This infiltration can result in pumping, spalling, and blow-ups. A joint sealant bonded to the edges of the slabs protects the joints from accumulation of incompressible materials, and also reduces the amount of water seeping into the pavement structure. Typical types of joint seal damage are:

1. Stripping of joint sealant.
2. Extrusion of joint sealant.
3. Weed growth.
4. Hardening of the filler (oxidation).
5. Loss of bond to the slab edges
6. Lack or absence of sealant in the joint.

Severity Levels

- L—Joint sealant is in good condition throughout the section with only a minor amount of any of the above types of damage present. Little water and no incompressibles can infiltrate through the joint.
- M—Joint sealant is in fair condition over the entire surveyed section, with one or more of the above types of damage occurring to a moderate degree. Water can infiltrate the joint fairly easily; some incompressibles can infiltrate the joint. Sealant needs replacement within 1 to 3 years.
- H—Joint sealant is in poor condition over most of the sample unit, with one or more of the above types of damage occurring to a severe degree. Water and incompressibles can freely infiltrate the joint. Sealant needs immediate replacement.

How to Measure

Joint sealant damage of transverse joints is rated based on the overall condition of the sealant over the entire unit.

SPALLING (TRANSVERSE AND LONGITUDINAL JOINT/CRACK)

Description

Spalling of cracks and joints is the cracking, breaking, or chipping (or fraying) of the slab edges within 2 ft (0.6 m) of the joint/crack. A spall usually does not extend vertically through the whole slab thickness, but extends to intersect the joint at an angle. Spalling usually results from:

1. Excessive stresses at the joint or crack caused by infiltration of incompressible materials and subsequent expansion.
2. Disintegration of the concrete from freeze-thaw action of "D" cracking.

3. Weak concrete at the joint (caused by honeycombing).
4. Poorly designed or constructed load transfer device (misalignment, corrosion).
5. Heavy repeated traffic loads.

Severity Levels

- L—The spall or fray does not extend more than 3 in. (8 cm) on either side of the joint or crack. No temporary patching has been placed to repair the spall.
- M—The spall or fray extends more than 3 in. (8 cm) on either side of the joint or crack. Some pieces may be loose and/or missing, but the spalled area does not present a tire damage or safety hazard. Temporary patching may have been placed because of spalling.
- H—The joint is severely spalled or frayed to the extent that a tire damage or safety hazard exists.

How to Measure

Spalling is measured by counting and recording separately the number of joints with each severity level. If more than one level of severity exists along a joint, it will be recorded as containing the highest severity level present. Although the definition and severity levels are the same, spalling of cracks should not be recorded. The spalling of cracks is included in rating severity levels of cracks. Spalling of transverse and longitudinal joints will be recorded separately. Spalling of the slab edge adjacent to a permanent patch will be recorded as patch adjacent slab deterioration. If spalling is caused by "D" cracking, it is counted as both spalling and "D" cracking at appropriate severity levels.

PUMPING AND WATER BLEEDING

Description

Pumping is the movement of material by water pressure beneath the slab when it is deflected under a heavy moving wheel load. Sometimes the pumped material moves around beneath the slab, but often it is ejected through joints and/or cracks (particularly along the longitudinal lane/shoulder joint with an asphalt shoulder). Beneath the slab there is typically particle movement counter to the direction of traffic across a joint or crack that results in a buildup of loose materials under the approach slab near the joint or crack. Many times some fine materials (silt, clay, sand) are pumped out leaving a thin layer of relatively loose clean sand and gravel beneath the slab, along with voids causing loss of support. Pumping occurs even in pavement sections containing stabilized subbases. The erosion of the top of the stabilized subbase often occurs, and also a pumping of the foundation material from beneath the stabilized subbase is common.

Water bleeding occurs when water seeps out of joints and/or cracks. It many times drains out over the shoulder in low areas.

Severity Levels

- L—No fines can be seen on the surface of the traffic lanes or shoulder. However, there is evidence that water is forced out of a joint or crack when trucks pass over the joints or cracks. One evidence of water pumping is the existence of small “blowholes” in the asphalt shoulder adjacent to a transverse joint. The asphalt surface may have settled some indicating a loss of material beneath the surface. Another evidence of low severity pumping is the bleeding of water from the longitudinal lane/shoulder joint.
- M—A small amount of pumped material can be observed near some of the joints or cracks on the surface of the traffic lane or shoulder. Blowholes may exist.
- H—A significant amount of pumped materials exist on the pavement surface of the traffic lane or shoulder along the joints or cracks.

How to Measure

Pumping or water bleeding is recorded at the highest severity level that occurs within the given sample unit, as defined above.

APPENDIXES B AND C

Appendix B, “Field Demonstration Projects of Joint/Crack Repairs,” (which gives detail coverage of the field demonstration projects conducted to test the recommended guidelines to verify their suitability and effectiveness under actual field conditions) and Appendix C, “Void Detection Procedures,” (which gives step-by-step procedural outline for void detection using non-

destructive deflection testing data) are not published herewith but are contained under separate binding, as submitted by the research agency to the sponsors, and are available on a loan basis, or for purchase at the cost of reproduction, from the Transportation Research Board Publications Office, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

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