NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 415

Evaluation of Unbonded Portland Cement Concrete Overlays

Transportation Research Board
National Research Council

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Evaluation of Unbonded Portland Cement Concrete Overlays

ERES CONSULTANTS, INC.
Champaign, IL

Subject Areas

Pavement Design, Management, and Performance
Materials and Construction

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report contains the findings of a study that was performed to evaluate existing methods for rehabilitating portland cement concrete pavements with unbonded concrete overlays and to develop guidelines for their use. The report provides a comprehensive description of the research and includes detailed guidelines for the design and construction of unbonded portland cement concrete overlays. The contents of this report will be of immediate interest to pavement design and construction engineers and others involved in the design, construction, and rehabilitation of concrete pavements.

Portland cement concrete pavements constitute a large portion of pavements that are designed to carry a high volume of heavy traffic. An unbonded portland cement concrete overlay is an effective resurfacing method for rehabilitating these pavements, because it improves the structural capacity of the old pavement and enhances rideability by providing a new surface.

Under NCHRP Project 10-41, "Evaluation of Unbonded Portland Cement Concrete Overlays," ERES Consultants, Inc. of Champaign, Illinois was assigned the task of developing guidelines for use of unbonded concrete overlays. To accomplish this objective, the researchers reviewed relevant domestic and foreign literature, surveyed U.S. departments of transportation, analyzed field performance data, and evaluated the design criteria and performance aspects of existing methods for rehabilitating portland cement concrete pavements with unbonded concrete overlays, and then recommended guidelines for the design and construction of unbonded concrete overlays. The report documents the work performed under this project.

The recommended guidelines for the design and construction of unbonded concrete overlays, included in this report, provide guidance on the overlay thickness needed to ensure sufficient structural capacity over the design life and on the design features that must be included to provide a long-lasting pavement structure. This information will be particularly useful to highway agencies and is recommended for consideration and adoption by AASHTO as recommended practice.

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AUTHOR ACKNOWLEDGMENTS

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EVALUATION OF UNBONDED PORTLAND CEMENT CONCRETE OVERLAYS

SUMMARY

An unbonded portland cement concrete (PCC) overlay is an effective method for rehabilitating concrete pavements. With the increasing demand on our highways (high volumes and increasing weights of heavy truck traffic), it is likely that this type of overlay will continue to be a useful and economical method for rehabilitation of PCC pavements.

This study provides comprehensive and improved guidelines for the design and construction of unbonded concrete overlays for use by state highway agencies. The guidelines are based on field studies of the performance of unbonded overlays (UBOLs) obtained during this study and from the Long-Term Pavement Performance (LTPP) database, analytical studies of critical design features, a review of previous publications on UBOLs, and reviews of existing design procedures.

A literature review was conducted to obtain information on the influence of site conditions and design features on overlay performance. Substantial data were obtained from a survey of state highway agency practices and from the LTPP database. These data obtained indicate that there have been many outstanding successes with unbonded concrete overlays, such as a 152-mm (6-in.) jointed reinforced concrete pavement (JRCP) built over an existing pavement of the same type that lasted 38 years with little maintenance or rehabilitation. There have also been some early failures, such as faulting and cracking, that appear to be caused by design deficiencies.

In spite of the documented successes, fewer than 27 states have constructed unbonded concrete overlays since 1970, and only 11 of those states constructed more than 5 UBOL projects during that period. Iowa, Pennsylvania, Texas, Colorado, Minnesota, Ohio, and Wisconsin each constructed over 10 UBOL projects in the same period. One reason for this disparity is believed to be a lack of mutually accepted and reliable guidelines for states to use. Consequently, the states that use UBOLs are generally those that have developed their own guidelines for design features and construction details.

Several site conditions and design features are identified that affect the long-term performance of UBOLs. These are summarized as follows:

- Traffic loadings—UBOLs can be designed to handle any level of traffic loadings. Some UBOLs carry 3 million equivalent single-axle loads (ESALs) per year, and others carry 100,000 ESALs per year.

- Climate—Temperature and moisture distributions through the overlay slab affect joint spacing [especially for jointed plain concrete pavements (JPCP)].
- Roadbed soil support—The appropriate subgrade modulus (*k*-value) to use in design is that of the subgrade, not the "top of the existing slab" *k*-value, which will lead to an unconservative design.
- Structural integrity of the existing pavement—Working cracks and joints with poor load transfer (nonuniform support) are most critical to reflection cracking in the overlay. Continuously reinforced concrete pavement (CRCP) overlays are most affected by this common occurrence in the existing pavement. The existing pavement contributes to the "flexural stiffness" of the total pavement system (overlay/existing pavement), not to the subgrade support.
- Preoverlay repair—The type and amount required depend on the overlay type, the interlayer chosen, the traffic level, and the condition of the existing pavement. Fracturing of a badly deteriorated existing pavement is an alternative that produces more uniform support and may be cost-effective. CRCP is the most critical UBOL with respect to the nonuniform condition of the existing pavement.
- Interlayer properties—The main purposes of an interlayer are to (1) separate the deteriorated existing pavement from the newly constructed overlay to prevent any reflection cracks or failures, (2) maintain a sufficient amount of bonding and friction between the existing slab and the new PCC overlay so that joints can form in JPCP and JRCP overlays and the proper amount of cracks will form in a JRCP or CRCP overlay, (3) provide a level-up layer, and (4) be a cost-effective component of the UBOL system. The most successful interlayer by far has been hot-mix asphalt concrete (AC) placed at least 25 mm (1 in.) thick.
- Overlay thickness—Commonly used UBOL thickness design procedures for highways are often unconservative and have resulted in several major early failures. Clearly, improved procedures are needed.
- Overlay type and material properties—JPCP is the most successful and popular UBOL in use today. Both CRCP and JRCP can be designed to perform very well as an UBOL; however, attention to critical design problems (to reduce reflection cracking) is required, including reinforcement content, interlayer type and thickness, and preoverlay repair of localized discontinuities.
- Overlay joint spacing—Joint spacing for JPCP UBOL should be approximately the same as that for a PCC pavement on a stiff lean concrete base course. A maximum L/l ratio of 4.5 to 5.5 is recommended, depending on climate and other factors.
- Overlay joint load transfer design (JPCP/JRCP)—When to use dowel bars is an issue. Dowels eliminate faulting and corner breaks in an UBOL, but they may not be required when traffic is low and a nonerodible interlayer is used (either dense AC or permeable AC). Research showed that UBOLs with dowels had virtually no faulting, and those without dowels had less faulting than comparable new designs.
- Mismatching of joints—Mismatching reduces corner deflections and stresses in an UBOL, which would extend its life; however, doing so may increase construction costs by requiring widely varying joint spacing. This effect should be examined on a project-by-project basis.
- Subdrainage—Two drainage methods have been shown to improve performance. First, a permeable AC interlayer with edge drains will remove water that seeps between the two slabs, thereby reducing erosion. However, the permeable AC material must be fully designed, tested, and constructed to resist and prevent stripping, which occurred on one UBOL tested. The second way to handle drainage is through placement of a dense AC interlayer with edge drains.
- Shoulder type—All types of shoulders have been used successfully with UBOLs.

- Reinforcement content for JRCP and CRCP—Increased reinforcement content for JRCP and CRCP should be considered to prevent the deterioration of transverse cracks located over significant discontinuities in the existing pavement when heavy traffic exists.
- Overlay widening—Intentional widening of the traffic lane overlay slab to move traffic away from the free edge may be very beneficial to the performance of an UBOL. Widening the UBOLs over a narrower existing slab can be successful if adequate support is provided.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT AND RESEARCH OBJECTIVES

Portland cement concrete (PCC) pavements constitute a large portion of those pavements that are designed to carry a high volume of heavy traffic, including those on the Interstate highway system. Many of these pavements have already been overlaid with asphalt concrete (AC) several times, others are now approaching the end of their design life, and others have reached their terminal serviceability level. The numbers of heavy-axle loads have increased greatly over the past three decades [equivalent single-axle loads (ESALs) virtually doubled every decade], and there appears to be no end in sight. In several instances, the serviceability of these PCC pavements (or AC/PCC pavements) has deteriorated well beyond the stage where typical rehabilitation measures will be sufficient to restore their condition to acceptable performance levels.

These conditions have precipitated a need to find ways to rehabilitate these pavements in a manner that will meet increasing demands in the future. One specific method of rehabilitating PCC pavements that are in an advanced stage of distress is to resurface them with an unbonded PCC overlay, which involves using an interlayer to separate the action of the PCC overlay from the existing pavement. This is often a cost-effective way to increase the structural strength of the existing pavement as well as to provide a new surface that will improve the riding quality of the pavement. Another advantage of unbonded concrete overlays is that they often do not require extensive repairs to the existing pavement. They may also be constructed without costly subgrade corrections.

The interlayer helps to minimize the occurrence of reflection cracking from discontinuities in the existing pavement. Field observations have shown that reflection cracking is minimal on deteriorated PCC pavements overlaid with jointed unbonded concrete overlays (*1,2*). The interlayer can also serve as a leveling course that limits the chances of the resurfacing material from overrunning during construction, and it has been used successfully as a drainable layer in some states (*3*).

Because unbonded overlays (UBOLs) are relatively thick, typically ranging from 152 to 305 mm (6 to 12 in.) for highway pavements, no special techniques are necessary during construction, and the overlays can usually be built with conventional paving methods and equipment. The thicker overlay also permits future application of conventional concrete pavement maintenance and rehabilitation techniques to improve the performance of the pavement.

As a result of these advantages, and given that more and more PCC and AC/PCC pavements require major rehabilitation, unbonded concrete overlays are likely to become increasingly common. However, although unbonded concrete overlays have been used successfully since 1916, there is still a lack of guidance, or shared knowledge of success and failure, about the design and construction features that can make it a more cost-effective and reliable rehabilitation measure (*2*). Consequently, a number of highway agencies do not even consider rehabilitation with unbonded concrete overlay and are unfamiliar with its design and construction.

SCOPE OF STUDY

This research study was instituted to investigate current design and construction practices and performance of unbonded concrete overlays to develop practical guidelines for their future design and construction. To obtain these results, the specific research objectives of the study were as follows:

- Evaluate the criteria for, and performance of, existing techniques for rehabilitating PCC pavement with unbonded concrete overlays.
- Assess the expected long-term performance of these techniques.
- Develop guidelines for the design and construction of long-lasting unbonded concrete overlays.

Three types of conventional unbonded PCC overlays have been used: jointed plain concrete pavements (JPCP), jointed reinforced concrete pavements (JRCP), and continuously reinforced concrete pavements (CRCP). In some instances, unbonded prestressed concrete overlays and fibrous concrete overlays have been used for pavement rehabilitation, but these options are relatively uncommon in the United States (*1,2*).

Unbonded concrete overlays have also been used to resurface badly deteriorated composite AC/PCC pavements (*2*).

This is an important potential use for unbonded PCC overlays, because AC/PCC pavements cannot be overlaid indefinitely with AC.

The main focus of this study was investigation of JPCP, JRCP, and CRCP unbonded concrete overlays on existing JPCP, JRCP, and CRCP. Unbonded concrete overlays of resurfaced PCC or AC/PCC pavements and of fractured PCC pavements were also considered. "Guidelines for Design and Construction of Unbonded Portland Cement Concrete Overlays" was developed to improve the performance of UBOLs. The guidelines, contained in this report, include information on the various design parameters and site condition factors that affect the performance of UBOLs and address anticipated maintenance and rehabilitation needs of unbonded concrete overlays.

RESEARCH APPROACH

The approach taken to meet the goals of the project consisted of work in two phases. Phase I of the study comprised three tasks. Task 1 involved identification of the site conditions and other design parameters that are necessary to characterize the performance of unbonded concrete overlays. In Task 2, the research team reviewed the design, construction, and performance data available on unbonded concrete overlays and compiled the information into a summary of current practices. In Task 3, the information obtained was used to develop a work plan for analytical and field verification studies for estimating the long-term performance of unbonded concrete overlays.

The work plan was executed in Phase II of the research study. Based on the results of the investigations and the information obtained on current practice, guidelines for the design and construction of unbonded concrete overlays were developed. A final report that documents the results of the research effort in both phases of the project was then prepared. Extensive details of the study are included in the appendixes to this report.

Although research has been conducted in the past on several aspects of resurfacing concrete pavements with unbonded concrete overlays, the failure to fully address the critical issues and details, as well as a lack of implementable results, has hindered the use of unbonded concrete overlays. Therefore, in this research effort, particular attention has been paid to developing practical guidelines that can be used by state highway agencies to improve the performance of unbonded concrete overlays.

CHAPTER 2

FINDINGS

INTRODUCTION

This study produced several important findings that address various concerns about the design and construction of unbonded concrete overlays. These findings, summarized in this chapter, were used to develop the guidelines. Appendixes A, B, C, and D, not published herein, contain many details of the analyses conducted under this project.

SITE CONDITIONS

Traffic Loadings

UBOLs are typically constructed on heavily trafficked highways and must be properly designed to carry this traffic loading; the sites studied in this project have shown that this is, indeed, possible. Total ESALs carried on some sections ranged up to 30 million. Annual ESALs ranged from as few as 100,000 to as many as 3 million. Faulting models for UBOLs show that ESALs are a major factor in fault development. Fatigue cracking of the concrete overlay is also caused by repeated heavy traffic loadings.

Climate

Climate manifests itself mainly as temperature gradients and moisture gradients through the UBOL slab. JPCP curling and warping must be directly considered in design or transverse cracks will develop. Joint spacing, for example, must be limited for JPCP based on thickness and climatic conditions.

Another way climate affects performance of unbonded concrete overlays is through pumping and erosion of the interlayer material. Therefore, material and structural design features must be considered. For example, dowels could be used at joints to reduce deflections, erosion, and corner cracking. Mismatching of joints also minimizes deflections at corners.

Subgrade

One advantage of unbonded concrete overlays is that they are built on top of the existing pavement, separated from the subgrade. However, an appropriate subgrade modulus (*k*-value) must be selected for design. Recent studies (*4*) have clearly shown that the appropriate modulus is that of the subgrade and not that "on top of the existing pavement." "Bumping" the *k*-value to somehow represent that on top of the existing pavement is not an appropriate concept and should not be used in designing an UBOL. The existing pavement is part of the overall pavement structure (overlay, interlayer, existing pavement).

Existing Pavement

UBOLs are traditionally constructed on top of very badly deteriorated pavements. The underlying pavement can have a beneficial or a detrimental effect on the performance of the overlay. Working cracks or joints in the existing pavement can contribute to reflection cracking in the UBOL, depending on the type of overlay (JPCP, JRCP, CRCP), the adequacy of the interlayer, and certain design features. Thus, to ensure that the total pavement system will function as desired, the following factors must be considered simultaneously in design:

- Structural condition of the existing pavement;
- The interlayer type, thickness, and stripping potential;
- Amount of preoverlay repair; and
- The UBOL type.

The structural characteristics affecting the performance of UBOLs include the following:

- Load transfer across transverse joints;
- Number of working cracks;
- Disintegration of the concrete at joints;
- Any localized areas with high deflections from rocking slabs or pieces of slabs;
- Erosion of the existing base, causing loss of support at the corners and high deflections; and
- Continuing concrete disintegration from D-cracking, alkali-silica reactivity, and sulfate attack.

Results from this study clearly show that the existing pavement contributes to the flexural stiffness of the total pavement system and not to subgrade support.

DESIGN FEATURES

Preoverlay Repair

The condition of the existing pavement, the type and thickness of the interlayer, the traffic level, and the type of UBOL will control the amount of preoverlay repairs needed. JPCP overlay requires less preoverlay repair than a CRCP overlay to prevent reflection cracking because, with a proper interlayer, the JPCP slab will bridge most discontinuities in the existing pavement. Pieces of slabs that rock or deflect visibly under a moving heavy wheel load should be removed and replaced properly.

If an existing AC/PCC pavement is considered for an UBOL, the existing AC surface may be used as the interlayer or as a portion of the interlayer. (If the existing interlayer is badly deteriorated, it may be better to remove all or part of it and place a new layer of AC.) The existing AC surface can be milled to level it up so that the UBOL can be constructed on a smooth surface. It is not necessary for the existing AC layer to be of uniform thickness; it can vary somewhat along a project as long as a minimum thickness of approximately 25 mm (1 in.) remains after milling.

An alternative, sometimes more economical, approach is to let the changes in longitudinal profile and transverse profile be adjusted in the thickness of the concrete slab. If this alternative is selected, two aspects must be fully considered and adjusted for during construction:

- For JPCP or JRCP, the depth of joint sawing is critical (should be $\frac{1}{3}t$). If the UBOL varies in thickness, the depth of joint saw also must be adjusted. The depth of sawing may need to be increased throughout the project to ensure adequate depth in the thicker-than-design sections.
- For CRCP, the percent of reinforcement is critical. If the thickness varies too much, it will affect the crack spacing and opening. Increased reinforcement may be needed to ensure that the thicker-than-design portions will contain the minimum percent reinforcement. The depth of reinforcement should not vary along the pavement (must be above mid-depth).

A list of distresses that require repair for each type of overlay is provided in the guidelines. These are not independent from interlayer thickness/type and other design features.

Fracturing the Existing Pavement

Several agencies have cracked and seated (or broken and seated) the existing pavement before placement of the interlayer and UBOL. This is often done in lieu of extensive preoverlay repair. Some agencies have rubblized the existing pavement, which totally changes its condition. After slab fracturing, the slab typically has the following moduli:

- Cracking/break and seat: $E = 1$ to 4 million psi (6.9 to 27.6 kPa), and
- Rubblizing: $E = 40{,}000$ to 100,000 psi (276 to 690 Pa).

These results show that it is still appropriate to design an UBOL when the existing pavement is cracked/broken and seated. However, if rubblization is used, the overlay should be designed as a new pavement with a high-quality granular base course and not as an UBOL.

Thickness of Overlay

There are some examples of thin unbonded JPCP and CRCP overlays in the database that failed under heavy traffic. Results show that a 152-mm (6-in.) overlay is not adequate for heavy Interstate highway traffic, especially if the underlying pavement is badly deteriorated. There are many good examples of 178-mm (7-in.) and greater overlays; however, thickness is a very critical design feature and must be fully analyzed for a given site.

There are many examples of unbonded concrete overlays that were too thin for the specific site conditions; although designed according to current design procedures. This cause-and-effect relationship is especially obvious when the existing slab is very thick and the calculated design thickness of the UBOL is only a few centimeters. Use of a high *k*-value (i.e., top of existing slab *k*-value) is another common design error. The critical stresses and deformations in the UBOL caused by load and climate must be considered fully in the design (*5*). Ideally, the thickness of an unbonded concrete overlay should depend on the factors shown in Table 1.

Overlay Type

JPCP can be used as an UBOL for any type and condition of existing PCC pavement, traffic level, subgrade, and climate. JPCP is the most common and most reliable type of UBOL. Its performance has been excellent as long as the slab thickness, joint spacing, joint load transfer, and interlayer are adequate for the given site conditions.

JRCP can be used as an UBOL for any type and most conditions of existing PCC pavement, traffic level, subgrade, and climate. The major problems with JRCP UBOLs are the same as those for conventional JRCP: joint deterioration and transverse crack deterioration. These can now largely be addressed with improved design features (improved joint sealants, shorter joint spacing, and increased reinforcement). Because of past problems, few agencies are currently building JRCP for any type of application, new or overlay.

Many CRCP UBOLs exist in the United States and Europe. In general, they have performed very well when their design features were adequate. CRCP can be used as an UBOL for almost any type and condition of existing PCC

TABLE 1 Factors affecting the thickness design of unbonded concrete overlays

Site Condition/ Design Feature	JPCP Overlay	JRCP Overlay	CRCP Overlay
Traffic	Yes	Yes	Yes
Climate	Yes (gradients)	Yes (steel stress)	Yes (steel stress)
Subgrade modulus	Yes	Yes	Yes
Existing pavement	Yes	Yes	Yes (critical)
Fractured slab	Yes	Yes	Yes
Interlayer	Yes	Yes	Yes (critical)
Joint spacing	Yes (critical)	Yes (joint opening)	NA
Joint load transfer	Yes	Always use dowels	NA
Widened slab	Yes	Yes	Yes
Overlay type	Yes	Yes	Yes

pavement, traffic level, subgrade, and climate. However, the structural condition of the existing PCC pavement is very critical, as is the interlayer. Transverse joints and cracks with poor load transfer (and high differential deflections) will cause reflection cracks and failures in the CRCP overlay if they are not repaired before the overlay or if other design features are not adjusted to minimize the cracking (extra thick AC interlayer, increased reinforcement, increased thickness of CRCP).

Overlay Materials

PCC used for UBOLs has the same requirements for durability and strength as PCC used for new or reconstructed pavements.

Interlayer

The interlayer is critical to the success of an unbonded PCC overlay. Its main purposes include the following:

- Separate the deteriorated existing pavement from the newly constructed overlay to prevent any reflection cracks or failures.
- Maintain a sufficient amount of bonding and friction between the existing slab and the new PCC overlay so joints can form in JPCP and JRCP, and the proper amount of cracks will form in JRCP or CRCP.
- Provide a level-up layer for uniform overlay thickness construction.
- Be a cost-effective component of the UBOL system.

The most successful interlayer has been hot-mixed AC approximately 25 mm (1 in.) thick or more.

At least two states (Minnesota and Pennsylvania) use a permeable hot-mixed AC interlayer approximately 25 mm (1 in.) thick. Success has been good thus far; however, cores from one section in Minnesota showed stripping of this layer. Permeable asphalt-treated bases placed beneath conventional PCC pavements have also shown considerable stripping in some states. Thus, tests must be conducted to ensure that this layer will not strip, whether it is permeable or dense graded.

Chip seals, slurry seals, and emulsion with sand cover seals are the next most common interlayers used. Although some UBOLs with these types of interlayer have performed well, they are not generally recommended for several reasons. These materials easily erode near the joint, cannot provide much level-up of the old pavement, and do not separate very deteriorated pavements from the UBOLs (especially CRCP overlays) sufficiently to prevent reflection cracks.

Various other interlayers, such as polyethylene sheeting, roofing paper, and curing compound, have not performed well. Many working cracks in the underlying PCC pavement have reflected through the overlay, resulting in premature failure.

Overlay Joint Design

In general, those factors that affect the performance of conventional JPCP and JRCP joints also affect the performance of an UBOL. The main difference is the stiffness of the underlying interlayer/slab/subgrade system.

Joint Spacing of JPCP

The spacing of joints for JPCP may need to be somewhat shorter than for conventional design, except where the conventional design has a lean concrete base course. Conventional design of JPCP over a granular base recommends a maximum ratio of joint spacing to radius of relative stiffness (L/l) of 6.0. Conventional design of JPCP over a stiff treated base recommends a ratio of 5.5 (*6,7*). A maximum L/l ratio of 4.5 to 5.5 is recommended for JPCP UBOLs where the k-value in l is that of the subgrade, not the top of the existing pavement. This is the same recommendation when JPCP is placed on a lean concrete base course. However, each agency should conduct a study of the appropriate value. A lower value may be appropriate in dry and warm climates because of increased curling and warping.

Joint Spacing of JRCP

The spacing of joints for JRCP should be no different than that specified for conventional JRCP over a lean concrete base. Uniform spacing is recommended over repeated variable spacing.

Joint Orientation

When dowel bars are used in transverse joints of JPCP or JRCP, they control faulting very well, and there is no need to skew the transverse joints.

When no dowel bars are used in transverse joints of JPCP, skewed joints have been shown to reduce faulting by about 50 percent in two limited head-to-head tests with perpendicular joints for conventional JPCP (*7*). There is no evidence that skewed joints have any adverse effects on the performance of UBOLs. Many of the projects included in the database have skewed joints and have performed very well.

Overlay Joint Load Transfer

Joint load transfer of nondoweled UBOL (JPCP) was significantly better than a newly constructed doweled JPCP over an aggregate base course and soft subgrade for a project near Montreal, Quebec. Comparisons have shown that nondoweled joints of an UBOL do not fault as much as they normally do in conventional JPCP. Design criteria for when dowels should be used in design of JPCP UBOLs can be obtained from sensitivity analyses with two models developed for faulting of UBOLs. Both of these faulting models show that nondoweled UBOLs with a good AC interlayer or permeable AC interlayer can handle up to about 10 million ESALs. If a lower quality interlayer is used (surface treatment or sand asphalt), then dowels must be specified at lower traffic levels.

However, there are two major reasons that dowels should be considered for JPCP overlays under heavy traffic loadings (1 million or more ESALs per year). The first is that dowels definitely eliminate faulting on UBOLs, even under very heavy traffic. The second reason is that dowels virtually eliminate the development of corner breaks in JPCP UBOLs, as well as in conventional JPCP.

Mismatching of Joints

Transverse joints in unbonded concrete overlays are often deliberately mismatched with those in the underlying pavement. A minimum offset distance of 1 m (3.3 ft) between the joints in the overlay and the existing slab is commonly specified. Analysis showed that joint mismatching leads to better protection of the overlay, underlying pavement, and subgrade from traffic and climatic loading by reducing corner deflections and some critical stresses. However, the additional cost of construction should also be considered. If the joints in the overlay are doweled, then the effect of mismatching would be minimized. If the existing pavement has skewed joints, a thick AC interlayer [25 to 50 mm (1 to 2 in.)] should be used to negate any potential detrimental effects on overlay performance. The overlay does not need to match the skewed joints in the existing pavement as long as a thick AC underlayer is placed.

Subdrainage

There are two ways to improve subdrainage in UBOLs: (1) place a permeable AC interlayer between slabs to promote free drainage of infiltrated water from the pavement section, and (2) install edge drains along the side of the existing slab.

Surface treatments used as interlayers such as asphalt emulsion and sand spread on top have demonstrated problems with erosion, washing away near the transverse joints after a few years, which creates a loss of support that contributes to joint faulting. Thus, no type of surface treatment is recommended as an interlayer for unbonded pavements that are subjected to repeated heavy axle loads.

The erosion of dense-graded AC interlayers has not been reported as a problem. However, the stripping of an existing permeable AC interlayer indicates that this layer can still fail. Therefore, for both dense and permeable AC interlayers, a strong program of testing for stripping of the AC must be carried out, because this layer will be subjected to millions of deflections and, thus, water pressure spikes. If an asphalt-treated permeable layer is to be used, 100 percent crushed aggregate is recommended.

There is no evidence that the effect of edge drains on UBOLs is any more beneficial than it is on conventional new/reconstruction design. However, if placed, edge drains should be designed to carry any water that may seep out of the interlayer. If the interlayer is permeable, then underdrains are required to carry this water out of the pavement structure.

Shoulders

All types of shoulders have been used on UBOLs, and there is no reason to expect that they would have any different effect on UBOLs than on conventional pavements. Making maximum use of the existing shoulders, of course, is a desirable design and construction objective. Recent evidence indicates that unless a tied PCC shoulder is monolithically placed and tied to the mainline pavements, the measured load transfer across the joint may not be high enough to reduce deflections or stresses significantly (*7*).

Pavement Widening

Two types of widening are discussed in this study: *intentional widening* of the traffic lane slab to move traffic away from the free edge and *required widening* of the UBOL over a narrower existing slab.

Intentional Widening for Structural Purposes

Previous research has shown that widening the slab in the outer lane, but maintaining the standard-width paint strip, may significantly improve concrete pavement performance, especially protecting it against faulting and cracking. Conceptually, moving traffic away from the pavement edge will lead to a near interior loading condition and significantly reduce the maximum stresses and deflections that the pavement experiences at the edge. Also, because there is no discontinuity in a widened lane, it provides more reliable performance than a tied concrete shoulder. It also makes longitudinal edge joint sealing less critical.

Widening Due to Narrow Underlying Slab

A number of the early thin-slab unbonded concrete pavements involved placing wider slabs to increase lane widths. The UBOLs often developed longitudinal cracks. However, agencies like Minnesota have been building widened unbonded concrete overlays and have reported success with such widening on the portions of the existing pavement that have been extended with an AC or PCC layer before overlay. Thicker UBOLs [>250 mm (10 in.)] have not developed longitudinal cracks as long as an adequate interlayer is placed.

A study was conducted to determine the difference in use of AC or PCC (both tied and untied) for the extension along the edge of the existing slab. The differences identified were not considered significant, and either material can be used except where the edge widening rests on a soft subgrade and tends to settle, resulting in a loss of support along the edge of the UBOL. Tying the extension to the slab may be beneficial in this situation.

Reinforcement in JRCP and CRCP

Substantial evidence shows that increasing the reinforcement content in conventional JRCP or CRCP reduces the amount of deteriorated transverse cracks and punchouts. One site in Illinois demonstrates this phenomenon in an unbonded CRCP. Friction between the UBOL and the interlayer needs to be considered. Also, working cracks in the existing underlying pavement may create a need for additional reinforcement to hold the cracks tightly together. Deformed welded wire fabric, not smooth welded wire fabric, should be used.

DESIGN PROCEDURES FOR UBOLs

A summary of a comparison of the main design procedures is shown in Table 2. The results of this study tend to confirm the findings of Hall et al. (*5*) that the traditional method used to design unbonded concrete overlays is unreliable and unresponsive to the performance characteristics of jointed and continuously reinforced UBOLs. The results of this study for highway pavements show that the design procedures appear to be unconservative, resulting in overlays that are too thin to accommodate the design traffic loads.

A clear example of the serious flaws in the traditional square root unbonded design equation is provided when the existing pavement has a thick slab and, regardless of the traffic or condition of the existing slab, the calculated overlay thickness is very thin. This simple equation was not derived for design of highway pavements with the very large numbers of traffic loadings that are now commonplace. The database includes several examples of poor performance of UBOLs that were designed too thin and resulted in early failure under heavy traffic.

Appendixes A, B, C, and D, not published herein, contain discussions and analyses of many key pavement design features and site conditions that should be considered in the design of JPCP, JRCP, and CRCP UBOLs.

SIGNIFICANT FINDINGS FROM IN-SERVICE SECTIONS

The database developed under this project and the Long-Term Pavement Performance (LTPP) GPS-9 sections have provided a wealth of information. However, with such a diverse database, it is difficult to extract real consensus findings. This section summarizes some of the most significant findings from specific sections that performed well or poorly. A simplified table of information was prepared to show these effects (Table 3). Each section that had a critical amount of data available was included. Note that some of the traffic loadings were estimated from very limited data and should be considered only very approximate estimates.

An approximate performance rating was assigned to each UBOL section by using the following general guidelines:

Poor: Overlay < 10 years old, exhibiting significant distress;

Fair: Overlay between Poor and Good (significant distress between 10 and 20 years); and

Good: Overlay > 20 years old, or overlay at any age with no significant distress.

Following are some illustrative examples of unbonded concrete overlays that are performing well and poorly.

Poor CRCP

Arkansas-1

A 152-mm (6-in.) CRCP overlay over JRCP under heavy traffic (2 million ESALs per year) developed punchouts rapidly within a few years. Inadequate CRCP thickness for given traffic levels appears to be the main reason.

Illinois-3

CRCP overlays of 152 mm (6 in.) with 0.7 and 1.0 percent reinforcement over a thick AC interlayer over an old JRCP under heavy traffic (17 million ESALs over 19 years) developed punchouts and required extensive repairs (4.9 to 7.3 percent repair). Thicker slabs at the same location required much less repair [178 mm (7 in.) required 0.6 to 2.3 percent repair, and 203 mm (8 in.) required no repair].

TABLE 2 Design factors considered by unbonded overlay design methods

Design Factors	AASHTO *(8)*	Corps of Engineers *(9)*	Rollings *(10)*
Analytical model	Empirical equation, ($h^n=h^n-h_e^n$)	Empirical equation, ($h^n=h^n-h_e^n$)	Layered elastic theory
Failure criteria	Deterioration in terms of serviceability loss	Cracking in 50%	Deterioration in terms of a structural condition index
Interface condition	Considers overlay to be fully unbonded, n=2	Power in design equation is adjusted to account for level of bonding	Varies between full bonding and completely unbonded
Material properties	Modulus of elasticity and flexural strength for overlay concrete, k-value for subgrade	Equivalent required thickness, "h," as input to empirical equation	Modulus of elasticity and Poisson's ratio for all materials, and flexural strength of overlay concrete
Difference in strength/modulus of overlay and base pavement concrete	Not considered	Thickness of base pavement is adjusted	Included directly in calculation of stresses and design factors
Cracking in base pavement before overlay	Effective thickness of base pavement is reduced	Effective thickness of base pavement is reduced	Modulus of elasticity of base pavement is reduced
Fatigue effects of traffic on uncracked base pavement	Effective thickness of base pavement is reduced	Effective thickness of base pavement is reduced	Included in terms of equivalent traffic
Cracking of base after overlay	Not directly considered	Not directly considered	Modulus of elasticity of base is reduced to compensate for cracking under traffic
Temperature curling or moisture warping	Assumes AASHO Road Test conditions	Not considered	Not considered
Joint spacing	Maximum joint spacing $1.75*h_{OL}$ (JPCP)	No recommendation provided	No recommendation provided
Joint load transfer	Thickness increased if not doweled	Dowels assumed	Not considered
Drainage	Included in thickness design by empirical coefficient	Not considered	Requires retrofit of drainage system (if necessary)
Interlayer	Recommends 1-in. min. thick AC interlayer or permeable open-graded interlayer	No recommendation provided	No recommendation provided

(continued on next page)

TABLE 2 Design factors considered by unbonded overlay design methods (*continued*)

Design Factors	PCA	Belgium	Minnesota
Analytical model	Plate theory/Finite element model	Empirical equation	Corp of Engineers/PCA
Failure criteria	Depends on failure criterion for full depth concrete design procedure	Fatigue failure; subgrade failure	Not applicable
Interface condition	Unbonded	Power in design equation is adjusted to account for level of bonding	Power in design equation is adjusted to account for level of bonding
Material properties	Modulus of elasticity and modulus of rupture for overlay concrete, k-value for subgrade	Modulus of elasticity for all layers	Modulus of elasticity and modulus of rupture for overlay concrete, k-value, k-value for concrete
Difference in strength/ modulus of overlay and base pavement concrete	Included directly in calculation of stresses and design factors	Not considered	Not considered
Cracking in base pavement before overlay	Included directly in calculation of stresses using soft elements	Thickness of base pavement is reduced	Thickness of base pavement is reduced
Fatigue effects of traffic on uncracked base pavement	Not considered	Not considered	Not considered
Cracking of base after overlay	Not considered	Not considered	Not considered
Temperature curling and moisture warping	Does not affect thickness selection	Not considered	Not considered
Joint spacing	Maximum joint spacing in feet is 1.75*h_{OL}(in) (JPCP)	Maximum joint spacing 18 ft	15 ft if 7 in < h_{OL} < 10.5 in; 20 ft if h_{OL} > 10.5 in
Joint load transfer	Not specified for overlay but considered in evaluation of base pavement	Can be doweled or undoweled	Dowels assumed
Drainage	Edge drains are recommended where pumping and erosion has occurred in the existing slab	Not available	Edge drains and permeable interlayer for all pavements, interceptor drains when overlay is wider than the base pavement
Interlayer	Thin interlayer (<0.5 in) if extensive repair work performed, Thick (>0.5 in) otherwise	Not available	>1 in. >2 in. if base pavement is badly faulted and/or has a rough profile

Georgia-1, -3, and -5

Georgia constructed a series of CRCP overlays in the 1970s that were 76, 114, and 152 mm (3, 4.5, and 6 in.) thick. No interlayer was used, and the CRCP overlays were placed directly on old JPCP. Traffic during the first 10 years was 0.7 million ESALs per year. The 76- and 114-mm (3- and 4.5-in.) CRCP developed deteriorated cracks and punchouts directly over the joints in the JPCP and required repairs in 1 to 5 years. The 152-mm (6-in.) CRCP performed much better but still had deteriorated cracks and punchouts over the joints after 8 years.

Wisconsin-1

A 203-mm (8-in.) CRCP overlay with surface treatment interlayer over JRCP deteriorated rapidly, with punchouts occurring under heavy traffic (1 million ESALs per year).

Summary

CRCP that perform poorly tend to be 76 to 203 mm (3 to 8 in.) thick, placed over an old JRCP with a surface treatment interlayer or no interlayer, and subjected to heavy traffic (>1 million ESALs per year). It also appears that CRCP

TABLE 3 Summary of the synoptic table for unbonded concrete overlays

ID	Highway	OLType	OLThk	ConsYr	InspYr	AGE	MESAL	Rating	ExistPVT	ID	Repair	Interlayer	InterThick	JTSpacing	Dowel
GA-4	I-75	CRCP	7 & 8	1972	1993	21	30	Good	JPCP	GA-4	None	None			
IL-1	I-55	CRCP	9	1974	1986	12	9	Good	JRCP	IL-1	Limited patching	AT	4 (min.)		
IL-2	I-55	CRCP	8	1970	1986	16	9	Good	JRCP '	IL-2	Limited patching	AT	4 (min).		
IL-3	I-70	CRCP	8	1967	1986	19	17	Good	JRCP	IL-3	Limited patching	AC	4 in		
GA-1	I-85 (SR-403)	CRCP	6	1975	1993	18	16	Fair	JPCP	GA-1	CPR as needed	None			
IL-3	I-70	CRCP	7	1967	1986	19	17	Fair	JRCP	IL-3	Limited patching	AC	4		
ND-1	I-29	CRCP	8	1974	1993	19	2	Fair	JPCP	ND-1		AC	2		
ND-2	I-29	CRCP	6	1972	1993	21	3	Fair	JPCP	ND-2		AC	2		
AR-1	I-30	CRCP	6	1992	1995	3	6	Poor	JRCP	AR-1	Limited patching	AC	1		
GA-3	I-85 (SR-403)	CRCP	3	1975	1985	10	7	Poor	JPCP	GA-3	CPR where req	None			
GA-5	I-85	CRCP	4.5	1975	1985	10	7	Poor	JPCP	GA-5	CPR where req	None			
IL-3	I-70	CRCP	6	1967	1986	19	17	Poor	JRCP	IL-3	Limited patching	AC	4		
MD-1	I-70	CRCP	6	1974	1985	11	8	Poor	JRCP	MD-1		AC	1		
PA-5	I-90	CRCP	7	1976	1993	17	20	Poor	JRCP	PA-5	5% Patching	SA	1		
WI-1	IH 94	CRCP	8	1980	1993	13	12	Poor	JRCP	WI-1	Patching	ST	1.75		
CA-1	I-80	JPCP	10.2	1993	1994	1	2	Good	JPCP	CA-1	Shattered slab replacement	AC	1	12,15,13,14	None
CA-2	I-80	JPCP	10.2	1992	1994	2	3	Good	JPCP	CA-2	Shattered slab replacement	AC	1	12,15,13,14	None
CA-5	I-80	JPCP	10.2	1991	1992	1	1	Good	JPCP	CA-5	Shattered slab replacement	AC	1	12,15,13,14	None
CA-6	I-8	JPCP	6	1970	1991	21	6	Good	JPCP	CA-6		AC	0.5	13,19,18,12	
CO-10	I-76	JPCP	8	1990	1996	6	2	Good	JPCP	CO-10	Some slab remov/replace	AC	1		None
CO-3	I-25	JPCP	8	1987	1996	9	12	Good	JPCP	CO-3	Some slab remov/replace	ST		-	N
CO-5	I-25	JPCP	8	1985	1996	11	14	Good	JPCP	CO-5	Some slab remov/replace	ST			N
CO-6	I-25	JPCP	7.75	1984	1996	12	20	Good	JPCP	CO-6	Some slab remov/replace	ST			N
CO-7	I-76	JPCP	8.5	1992	1996	4	1	Good	JPCP	CO-7	Some slab remov/replace	AC	0.75		N
DE-1	I-495	JPCP	12	1992	1996	4	4	Good	CRCP	DE-1	Spall repair	AC	2	20	
IA-7	Sec. Rd. W47	JPCP	7	1990	1992	2	1	Good	JPCP	IA-7		AC	1	15	
MN-10	I-90	JPCP	8	1992	1994	2	1	Good	CRCP	MN-10		AC	1	15 - random	1
MN-2	TH 212	JPCP	7	1985	1993	8	10	Good	JPCP	MN-2		SA	1.5	15 - random	1
MN-4	I-35	JPCP	8	1987	1994	7	10	Good	JRCP	MN-4		AC	1	15 - random	1
MN-5	I-90	JPCP	9	1988	1993	5	6	Good	JRCP	MN-5		AC	1	15 - random	1.25
MN-6	I-90	JPCP	8	1990	1994	4	3	Good	JRCP	MN-6		AC	1	15 - random	1
MN-7	I-90	JPCP	8	1991	1994	3	2	Good	CRCP	MN-7		AC	1	15-random	1
MN-8	USTH 52	JPCP	9.5	1992	1994	2	1	Good	JPCP	MN-8		AC	2	15 - random	1.25
MN-9	I-35	JPCP	7.5	1992	1994	2	1	Good	JRCP	MN-9		AC	1	15 - random	1
NB-1	US-281	JPCP	7	1988	1993	5	2	Good	JRCP	NB-1	Full depth joint, panel repair	CS	0.5	16.5	None
OH-1	US-33	JPCP	7	1982	1986	4	3	Good	JRCP	OH-1	Pothole patching	AC	0.75	12-15-13-14	None
OH-3	US-33	JPCP	8	1985	1994	9	3	Good	CRCP	OH-3	Level slags with AC	AC	0.75	13-16-14-15	None
PA-15	I-78	JPCP	12	1985	1994	9	5	Good	CRCP	PA-15	Concrete patching	SA	1	20	1.5
PA-16	I-78	JPCP	12 & 13	1991	1995	4	8	Good	JRCP	PA-16	Bituminous patching	PAC	4	20	1.5
PA-17	I-80	JPCP	13	1993	1994	1	4	Good	JRCP	PA-17	Bituminous patching	PAC	2.5	20	1.5
PA-18	I-1	JPCP	10	1988	1995	7	10	Good	JRCP	PA-18		AC	1		
TX-6	I-45	JPCP	10	1968	1990	22	5	Good	CRCP	TX-6		AC	3.9		
GA-2	I-85 (SR-403)	JPCP	6	1975	1993	18	16	Fair	JPCP	GA-2	Underseal, slab repl., spall repair	None		15	1.125
IA-10	*	JPCP	7	1987	1992	5	1	Fair	JPCP	IA-10		SS	0.25	15	None
IA-8	Sec. Rd. G52	JPCP	7	1987	1992	5	1	Fair	JPCP	IA-8		AC	1	15	None
IA-9	Sec. Rd. G38	JPCP	7	1991	1992	1	0	Fair	JPCP	IA-9		AC	1	15	None
CA-4	I-80	JPCP	8	1989	1992	3	8	Poor	JPCP	CA-4	Shattered slab replacement	AC		12,15,12,14	None
IL-4	I-88	JPCP	8	1981	1989	8	10	Poor	JRCP	IL-4		SA	0.5	14.5 (random)	None
KS-1	US-24	JPCP	6	1978	1988	10	4	Poor	JRCP	KS-1		AC	1	15	None
MN-1	TH 71	JPCP	5.5	1977	1995	18	1	Poor	JPCP	MN-1		SA	1	13-16-14-19	0.75
MI-2	I-96	JRCP	7	1984	1993	9	5	Good	CRCP	MI-2	Bituminous patching	AC	0.8	41 AVG	1.25
MI-3	US-23	JRCP	7	1984	1993	9	6	Good	JRCP	MI-3	Bituminous patching	AC	0.8	41 AVG	1.25
MN-3	I-90	JRCP	8.5	1986	1994	8	10	Good	CRCP	MN-3		AC	1	27	0.75
MO-1	I-70	JRCP	11	1992	1995	3	5	Good	JRCP	MO-1		AC	varied	61.5	1.5
MS-2	I-20	JRCP	10	1990	1993	3	5	Good	JRCP	MS-2		AC	3	21	1.25
MS-3	I-20	JRCP	10	1990	1993	3	5	Good	JRCP	MS-3		AC	3	21	1.25
MS-4	I-20	JRCP	10	1990	1993	3	4	Good	JRCP	MS-4		AC	3	21	1.25
OH-2	Rte. 70	JRCP	10	1984	1986	2	4	Good	JRCP	OH-2	Full depth jt repair, underseal	AC	1	60	1.375
PA-14	I-80	JRCP	10	1988	1994	6	5	Good	JRCP	PA-14	slab stab., joint and crack repair, base drain	AC	1-4	20	1.5
MS-5	I-20	JRCP	10	1987	1993	6	7	Fair	JRCP	MS-5		NA	NA	21	1
AR-3	I-40	JRCP	10	1985	1995	10	15	Poor	JRCP	AR-3		AC	1		1.25
MS-1	I-59	JRCP	6	1982	1993	11	10	Poor	JRCP	MS-1		AC	1.5	20	1

AC = Asphalt concrete, SA = Sand asphalt, ST = Surface treatment, CS = Chip seal, SS = Slurry seal, PAC = Permeable asphalt concrete
AT = Asphalt treated, Poor = M-H distress, <10 years, Fair = 10 - 20 years with M-H distress, Good = >20 years old
CPR = concrete pavement restoration, N = none

150 mm (6 in.) or thinner perform poorly under heavy traffic regardless of interlayer.

Good CRCP

Illinois-3

A 203-mm (8-in.) CRCP overlay with a 102-mm (4-in.) asphalt-treated base interlayer over JRCP with 0.6 percent reinforcement carried over 17 million ESALs over 19 years with no repairs required.

Georgia-4

CRCP overlays 178 and 203 mm (7 and 8 in.) thick with no interlayer placed over JPCP carried over 30 million ESALs over a 21-year period with low-severity punchouts.

North Dakota-1 and -2

CRCP overlays 152 and 203 mm (6 and 8 in.) thick placed over a 51-mm (2-in.) AC interlayer over JPCP carried 2 to 3 million ESALs over 19 to 21 years with some deterioration.

Summary

CRCP overlays that perform well tend to be 178 mm (7 in.) or thicker and placed on a thick AC interlayer over old JPCP or CRCP.

Poor JRCP

Arkansas-3

A 254-mm (10-in.) JRCP overlay over a 25-mm (1-in.) AC interlayer over an old JRCP under heavy traffic (1.5 million ESALs per year) developed many deteriorated transverse cracks over 10 years. Reinforcement content may be low in the JRCP overlay.

Mississippi-1

A 152-mm (6-in.) JRCP overlay over AC interlayer placed over old JRCP under heavy traffic (1 million ESALs per year) developed many deteriorated transverse cracks. Reinforcement content may be low in the JRCP.

Summary

JRCP that perform poorly develop deteriorated transverse cracks, perhaps from a low reinforcement content and heavy traffic. These deteriorated crack failures may be due to inadequate reinforcement content more than to reflection from the underlying pavement.

Good JRCP

Missouri-1

A 279-mm (11-in.) JRCP overlay under heavy traffic (1.7 million ESALs per year) has performed well after 2 years of traffic.

Michigan-3

A 178-mm (7-in.) JRCP overlay over an AC interlayer over old JRCP carried 6 million ESALs over 9 years with no deterioration.

Minnesota-3

A 216-mm (8.5-in.) JRCP overlay over an AC interlayer over old CRCP carried 10 million ESALs over an 8-year period with no deterioration.

Summary

JRCP that perform well have a widely varying range of design features.

Poor JPCP

Illinois-4

A 203-mm (8-in.) JPCP overlay (nondoweled) over a surface treatment interlayer placed over an old JRCP carried 10 million ESALs over 8 years but faulted badly because of the eroded interlayer. It also showed some transverse cracking and corner cracking. The JPCP was diamond ground after 8 years, which lasted another 8 years.

California-4

A 203-mm (8-in.) JPCP overlay (nondoweled) over an AC interlayer over an old JPCP carried extremely heavy traffic of 8 million ESALs over 3 years. It has developed some medium-severity corner breaks and low-severity transverse cracking.

Minnesota-1

A 140-mm (5.5-in.) JPCP overlay [19-mm (0.75-in.) dowels] over a sand-asphalt interlayer placed over an old JPCP carried very heavy traffic of 1 million rigid ESALs over 18 years. This section showed significant slab cracking over its lifetime.

Kansas-1

A 152-mm (6-in.) JPCP (nondoweled) overlay over an AC interlayer placed over an old JRCP carried 4 million ESALs over 10 years and developed slab cracking (transverse cracks, longitudinal cracking, and corner breaks).

Georgia-2

JPCP overlays of 152 mm (6 in.) (with dowels) with no interlayer and with joints matching the 9-m (30-ft) existing slab joints rapidly developed transverse cracks at midslab. One section also had sawed joints at 4.5 m (15 ft), and these did not develop transverse cracks. This section has carried approximately 16 million ESALs over a 20-year period.

Summary

JPCP that perform poorly tend to be thin slabs [152 to 203 mm (6 to 8 in.)], nondoweled, with long joint spacing, and with an erodible interlayer or no interlayer.

Good JPCP

Colorado-5

A 203-mm (8-in.) JPCP (nondoweled) overlay over a surface treatment interlayer placed over an old JPCP has performed well under 14 million ESALs over 11 years.

Delaware-1

A 304-mm (12-in.) JPCP (doweled) overlay over an AC interlayer placed over an old CRCP is carrying over 1 million ESALs per year and has shown good performance over the first 4 years.

Texas-6

A 254-mm (10-in.) JPCP (nondoweled) over a thick AC interlayer over an old CRCP has carried 5 million ESALs over 22 years with no significant distresses.

Pennsylvania-15

A 305-mm (12-in.) JPCP (doweled) overlay over a sand asphalt interlayer over an old CRCP has carried 5 million ESALs over 9 years with no significant distress.

Ohio-3

A 203-mm (8-in.) JPCP (doweled) overlay over an AC interlayer over an old CRCP has carried 3 million ESALs over a 9-year period with no significant distress.

Minnesota-4

A 203-mm (8-in.) JPCP (doweled) overlay over an AC interlayer over an old JRCP has carried 10 million ESALs over a 7-year period and has not shown significant distress.

Summary

JPCP that perform well tend to have thick slabs [≥180 mm (7 in.)], an AC interlayer [≥25 mm (1 in.)], and doweled joints.

CHAPTER 3

INTERPRETATION, APPRAISAL, APPLICATION

INTRODUCTION

The significant findings discussed in Chapter 2 were used to develop guidelines for practicing engineers in state, county, and city highway agencies. The guidelines contain the following main topics:

- Characterizing site conditions
  –Traffic loading, climate, subgrade support, and existing pavement;
- Design guidelines
  –Standardized assessment of condition of existing pavement, preoverlay repair, thickness design, overlay pavement type, overlay materials, interlayer design, joint design, subdrainage, edge support, reinforcement, and design checks;
- Construction guidelines
  –Construction constraints, subsurface drainage, preoverlay repair, interlayer, overlay paving operations, and joints;
- Maintenance and rehabilitation guidelines;
- Case studies; and
- References.

The guidelines and the appendixes to this report should be of immediate use to administrators and design engineers who are interested in the design of unbonded concrete overlays. All three types of conventional UBOLs are considered, including the following:

- JPCP (doweled and nondoweled);
- JRCP; and
- CRCP.

Each of these pavement types requires somewhat different design, construction, and maintenance considerations.

The findings of this research study add the following information to the current understanding of rehabilitation with unbonded concrete overlays:

- Answers for why some UBOLs have not performed as well as they should have;
- Verification that UBOLs are an effective rehabilitation technique if designed and constructed properly;
- Examples of UBOLs that have performed extremely well; and
- Reasons for premature failures of UBOLs.

EFFECT OF FINDINGS

- Practical guidelines, verified with case studies, are available for use by states.
- Many PCC and AC/PCC pavements under heavy traffic are at, or will soon reach, the end of their design lives. Rehabilitation with UBOLs will continue to be extremely important.
- Guidelines (as illustrated with case studies) can be used to build long-lasting UBOLs that will result in substantial savings.

LIMITATIONS OF FINDINGS AND GUIDELINES

- Thickness design procedures for unbonded concrete overlays for highways that are based on the square root equation are often inadequate.
- A critical need exists for improved mechanistic-based thickness design procedures.
- More detailed performance information is needed to develop performance prediction models applicable to unbonded concrete overlays. LTPP GPS-9 data will provide this opportunity in the future.

CHAPTER 4

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

The following conclusions are made based on the findings of this project:

- Unbonded concrete overlays provide an effective alternative for rehabilitating concrete pavements that are badly deteriorated. Properly designed and constructed unbonded concrete overlays restore the structural capacity and ride quality of the pavement to handle any level of future design traffic. Some UBOLs are carrying 3 million ESALs per year, and others are carrying 100,000 ESALs per year. Ample proof that unbonded concrete overlays are effective can be found from UBOL sections of all types in the database included in Appendixes C and D.
- Designers must consider four major site conditions: traffic loadings, subgrade support, temperature and moisture effects, and the structural integrity of the existing pavement. Each of these site conditions was found to be significant in the design and performance of unbonded concrete overlays.
- Several critical design features must be fully considered in the design process. These design features include preoverlay repair, interlayer properties and thickness, overlay thickness, overlay type and material properties, joint spacing for JPCP and JRCP, transverse joint load transfer, mismatching of joints, subdrainage, shoulders, reinforcement for JRCP and CRCP, and pavement widening. Findings on the effects of each of these design features are provided in this report, and guidelines are provided for considering each feature in the design and construction process.
- Commonly used UBOL thickness design procedures for highways are often unconservative, and they have resulted in several major early failures because of insufficient thickness. Improved procedures that consider all the listed site conditions and design features are clearly needed.
- The most comprehensive database of UBOLs ever compiled was used to identify the findings summarized in Chapter 2. This database includes projects surveyed in this study as well as those from the LTPP GPS-9 experiment. The database is included in Appendixes C and D.
- Construction of an unbonded concrete overlay can utilize conventional equipment and materials and, aside from traffic control, should pose no unusual risk or difficulty to the contractor. Even traffic control can be planned to eliminate any unusual risk to the contractor.
- Maintenance and rehabilitation of an UBOL should be very similar to those for a conventional pavement.

Details on design, construction, and maintenance are provided under "Guidelines for Design and Construction of Unbonded Portland Cement Concrete Overlays."

SUGGESTED RESEARCH AND IMPLEMENTATION

The goal of this study was to develop reliable guidelines for design and construction of unbonded PCC overlays. The guidelines included in this report are adequate for immediate consideration and possible implementation by highway agencies. Each agency should review these recommendations and make its own modifications based on its unique climate, existing pavement types, and design of JPCP, JRCP, or CRCP overlays.

Although the guidelines are adequate for implementation, there are many areas where additional research is needed. This study documents the identification of those factors that influence the performance of unbonded concrete overlays and that are necessary to characterize its performance, including the site-condition factors of traffic loading, climate, roadbed soil or subgrade support, and the structural condition of the existing pavement. These are factors over which the designer has little or no control, but they should be considered nonetheless. Factors over which the designer has some control include the design features of the overlay—that is, preoverlay repair, overlay thickness, type of overlay, overlay materials, interlayer layer type and design, joint spacing and design, subdrainage, shoulders, reinforcement content, and pavement widening.

As indicated in this report, the effect of some of these factors on unbonded concrete overlay performance is not different from their influence on performance of conventional concrete pavement. For example, information is available on the effects of traffic loading and subgrade on conventional concrete pavements. On the other hand, the influence of certain climatic variables and the condition of the existing pavement on the performance of unbonded concrete overlay may affect the design of an UBOL somewhat.

Similarly, the influences of overlay pavement type, overlay materials, and shoulders on unbonded concrete overlay performance are not very different from their influences on conventional concrete pavements. However, design features such as preoverlay repair, overlay thickness, interlayer type and design, joint spacing and design, subdrainage, and pavement widening warrant further investigation because they may have a different effect on unbonded concrete overlays than on a conventional pavement design.

The greatest deficiency in current overlay design procedures is the thickness design procedure. Current methods are unreliable and grossly oversimplify the complex structure of an UBOL. Mechanistic design procedures using finite element analysis are greatly needed to improve the current procedures. This is critical because of the many UBOLs that develop early failures because they are designed too thin for the existing site conditions. Further research is needed to determine the cost-effectiveness of joint sealing for UBOLs, optimization of steel design for JRCP and CRCP, improved guidelines for considering nonuniformity of support, and improved guidelines for interlayer thickness and permeability.

In many ways, the construction of unbonded concrete overlays is similar to that of conventional concrete pavements. However, some additional issues must be considered. For example, preoverlay repairs may be required. Likewise, placement of the interlayer must ensure adequate separation of the concrete pavements and uniform support. The use of accelerated paving techniques may be required to reduce lane closures and traffic delays, thus allowing unbonded concrete overlays to remain competitive with other rehabilitation options. Such factors can have a significant impact on the performance of unbonded concrete overlays.

To obtain the information required to develop guidelines for the design and construction of unbonded concrete overlays, definitive information about the influence of all the key factors on the performance of UBOLs clearly must be obtained. Therefore, further investigation into the effects of these factors on UBOL performance is necessary.

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APPENDIXES A THROUGH D

UNPUBLISHED MATERIAL

Appendixes A through D contained in the research agency's final report are not published herein. For a limited time, copies of that report, entitled "Evaluation of Unbonded Portland Cement Concrete Overlays—Appendixes," will be available on a loan basis or for purchase ($26.00) on request to NCHRP, Transportation Research Board, Box 289, Washington, D.C., 20055. The available appendixes are titled as follows:

APPENDIX A: Factors That Affect the Performance of Unbonded Concrete Overlays
APPENDIX B: Overview of Design Procedures for Unbonded Concrete Overlays
APPENDIX C: Current Highway Agency Experience
APPENDIX D: LTPP Unbonded Concrete Overlay Sections—Description and Analysis

Guidelines for Design and Construction of Unbonded Portland Cement Concrete Overlays

GUIDELINES CONTENTS

CHAPTER 1

INTRODUCTION

OVERVIEW

Detailed guidelines have been developed for the design, construction, maintenance, and rehabilitation of unbonded concrete overlays. Information and recommendations included in these guidelines were obtained from (1) a survey of current state practices for the design and construction of unbonded portland cement concrete (PCC) overlays, (2) a review of past practices of states, (3) several field surveys, (4) previously published information on unbonded PCC overlay design and construction from both the United States and foreign sources, and (5) the Long-Term Pavement Performance (LTPP) database.

Guidelines are provided for the thickness design of an unbonded PCC overlay to ensure sufficient structural capacity over the design life. The guidelines include information for assessing the structural integrity of the existing PCC, including the use of information from nondestructive testing (NDT) to measure the structural capability of the existing pavement and subgrade. Guidance is also provided on the design features that must be included and the recommended construction practices that will provide long-lasting pavements.

Although the guidelines are applicable to all classes of PCC pavements, emphasis is placed on pavements that carry traffic loads similar to those experienced on Interstate, primary, and major arterial highways and some collector roads in urban areas. The guidelines cover the following six major areas:

1. General considerations, including applicability, feasibility, limitations, and uses of unbonded PCC overlays;
2. Guidelines for characterizing traffic loading, climate, and support provided by the existing pavement and subgrade;
3. Selection of design features for unbonded PCC overlays;
4. Construction of unbonded PCC overlays;
5. Maintenance and rehabilitation of unbonded PCC overlays; and
6. Case studies that demonstrate the application and validity of the guidelines.

Figure 1 shows the framework for application of the guidelines. The framework is used for case studies to show the applicability of the guidelines in Chapter 6.

Appendixes A through D (not published herein) include important background information that was used to develop the guidelines. In addition, finite element analyses and back-calculation show the true effects of the interlayer, existing pavements, and subgrade.

DESCRIPTION

Figure 2 illustrates an unbonded concrete overlay. The rehabilitation of concrete pavements with an unbonded concrete overlay involves construction of a concrete overlay on an interlayer that is placed on the existing PCC pavement. The interlayer provides a uniform, flat foundation for the overlay as well as a separation layer to prevent reflection cracking. However, the term "unbonded" does not mean that there is no friction between the new overlay, the interlayer, and the old pavement. A certain amount of friction is very critical to successful performance of the unbonded overlay (UBOL).

The three main types of UBOLs are jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP); JPCP UBOLs are the most common. The existing pavement can be JPCP, JRCP, CRCP, or any of these pavement types that has been previously overlaid with an asphalt concrete (AC) layer. UBOLs can also be constructed on fractured PCC pavements with an AC interlayer placed over the fractured pavement.

APPLICATION OF UNBONDED CONCRETE OVERLAYS

Unbonded concrete overlays can remedy functional or structural deficiencies of existing pavements. Functional deficiencies result from conditions that adversely affect the highway user (e.g., poor surface friction, hydroplaning, and excess surface distortion). Structural deficiencies arise from any conditions that adversely affect the load-carrying capability of the pavement structure (e.g., inadequate thickness, cracking, deterioration, and disintegration). There are also other types of distress (e.g., durability distress) that are not initially caused by traffic loads but that can become more severe under traffic loading.

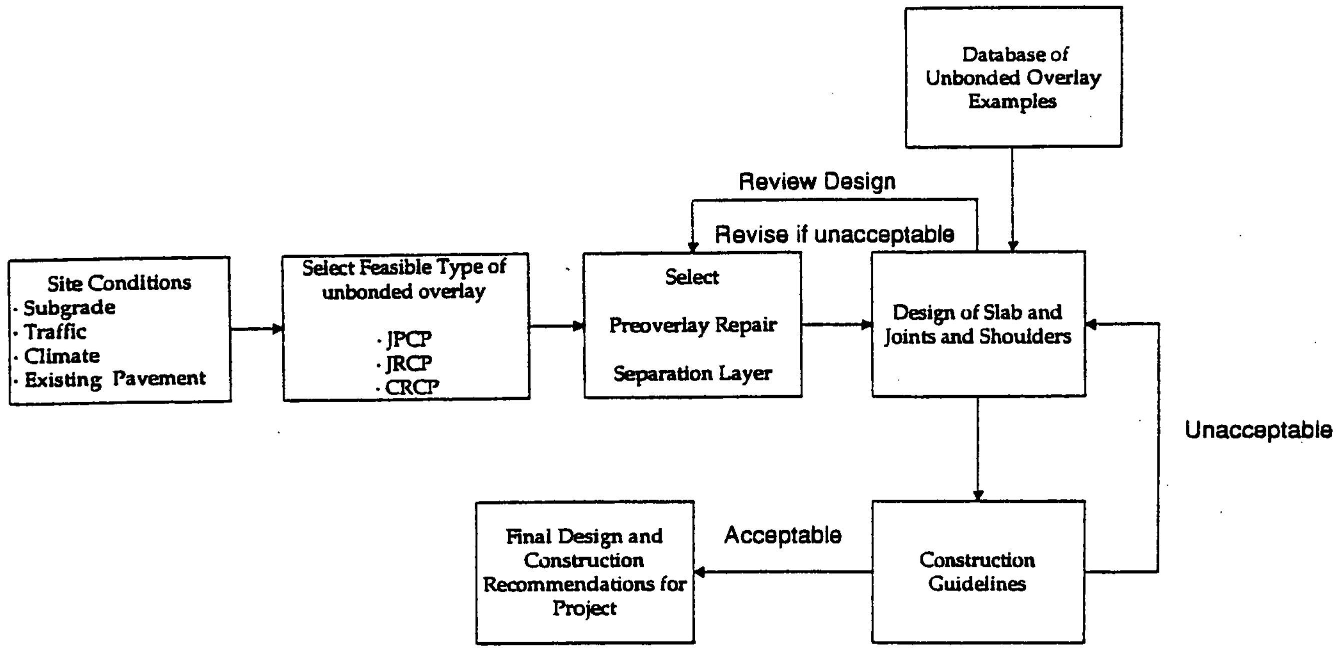


Figure 1. Framework for application of guidelines for a single alternative unbonded concrete overlay.

To select the appropriate overlay type and develop a suitable design, the designer should consider the type of deterioration present and determine whether the pavement has a functional or structural deficiency. A pavement that is functionally deficient may still be structurally adequate; however, if a pavement is both functionally and structurally deficient, a structural rehabilitation such as an UBOL can correct both problems.

An UBOL should be considered only if a structural overlay is required. Therefore, certain indicators that signify whether a pavement is structurally or functionally adequate need to be evaluated. A visual survey to identify key distress types is the easiest way to judge the structural and functional performance of a pavement. Other means for evaluating the structural and functional performance of the pavement include profile measurements, laboratory testing, and NDT.

Although an unbonded concrete overlay is typically constructed to improve the structural capacity or load-bearing capacity of the existing pavement, the new surface generally improves the functional condition and provides a smooth riding surface as well. The thickness and other overlay design features required depend on the structural requirements of the future projected traffic, the climate, and the structural integrity provided by the existing pavement and underlying subgrade. Thicknesses of unbonded concrete overlays range from 152 mm (6 in.) for low-volume roads to as high as 305 mm (12 in.) for Interstate and primary highway pavements.

General construction procedures involve the repair and improvement of badly deteriorated areas of the existing pavement (or fracturing of slabs to provide uniformity of support) and, where necessary, improvement of subsurface drainage. Where widening or additional lanes are required, the underlying portions are constructed before an interlayer is placed over the entire width; the concrete overlay is then placed over the interlayer. If designed and constructed properly, the unbonded concrete overlay will last as long as or longer than a reconstructed concrete pavement. UBOLs also provide an opportunity to raise the grade to improve both surface and subsurface drainage.

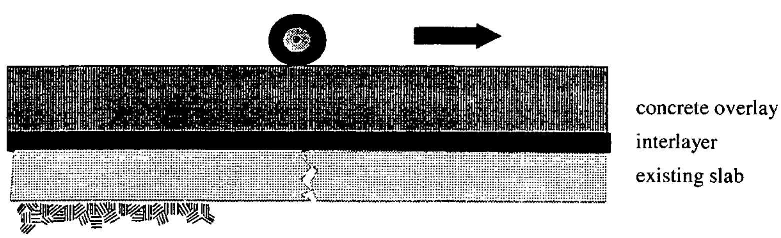


Figure 2. Illustration of an unbonded concrete overlay.

FEASIBILITY AND LIMITATIONS

An unbonded PCC overlay is a feasible alternative for structural rehabilitation of PCC pavements in practically all cases; however, because of the reduced need for preoverlay repair compared with other overlays, it is more cost-effective when the existing pavement is badly deteriorated. In addition, if the subgrade is particularly wet and soft, reconstruction of a new pavement may cause significant problems during construction as well as large cost overruns. Because of the support provided by the existing PCC pavement, UBOLs are less susceptible to weakening of the subgrade. Therefore, an UBOL is particularly effective in those areas where effects of spring thaw are significant. In addition, UBOLs can be constructed relatively easily and rapidly with fewer major risks than are involved with reconstruction over soft subgrades.

All types of UBOLs have been constructed, but JPCP overlays are the predominant type built in the United States. Also, although unbonded concrete overlays have been constructed on all types of highways, they may be most cost-effective for pavements that carry large volumes of heavy truck traffic. On these pavements an UBOL can strengthen the existing PCC pavement and provide the structural capacity to carry a large number of heavy truck traffic applications.

Another key benefit of an UBOL is that it requires low maintenance and provides a new smooth riding surface.

Conditions under which a PCC UBOL are not feasible include the following:

- The amount of deteriorated slab cracks, joint spalling, or pavement disintegration is not large, and other repair alternatives would be more economical.
- Geometric constraints exist, such as vertical clearance at bridges that are inadequate for the required overlay thickness. Thicker UBOLs may also necessitate raising signs, guardrails, or curbs as well as increasing side slopes and extending culverts. Sufficient right-of-way must be present or obtainable to permit these activities.
- The existing pavement is an urban design where it is impossible or cost-prohibitive to raise the grade.
- The existing pavement has experienced or is susceptible to large heaves or settlements that the UBOL cannot counteract.
- Traffic cannot be detoured sufficiently for construction of the UBOL. This situation can generally be overcome, but on occasion it may pose a problem.

Where possible, guidance is presented on how these limitations can be addressed. For example, if duration of construction is critical, high early strength PCC mixes can be used for unbonded concrete overlay construction. The use of such mixtures and fast-track paving techniques has allowed PCC overlays to be opened within 6 to 24 hours after placement (*1*).

CHAPTER 2

CHARACTERIZING SITE CONDITIONS

INTRODUCTION

Evaluation of the site conditions is of first priority in unbonded PCC overlay design and construction. The objectives are to assess the requirements for design so that, under the prevailing climatic conditions and the support provided by the existing pavement and subgrade, the overlay will be able to support the traffic loading expected throughout the design life of the pavement.

TRAFFIC LOADING

To begin the overlay design process, the designer must estimate the cumulative traffic loading expected on the pavement during its design life. For a particular project, the combination of different types of vehicles with different gross weights, axle types, and axle weight distributions must be converted into a standard measure for use in design. Because the 80-kN (18-kip) equivalent single-axle load (ESAL) is the standard traffic loading designation currently used in most design procedures (*2*), it was selected for use in these guidelines. Specific procedures for estimating future ESALs over the design life of a pavement are provided in the 1993 *AASHTO Guide for the Design of Pavement Structures* (*3*).

For major overlay projects, efforts should be made to obtain project-specific traffic classification and weigh-in-motion loading data. Historical traffic data should be examined to determine past loading patterns. Using the data obtained, the following key issues need to be considered in determining the traffic loading inputs used in design.

Design Period

A minimum design period of 20 years is recommended for unbonded concrete overlays; however, design periods of up to 50 years may be considered for high-type pavements. A longer design period provides some insurance in the near term against increases in traffic that are not anticipated and that can shorten service life. A limited increase in cost resulting from the inclusion of a few features (such as dowels, nonerodible interlayers, higher steel content for reinforced pavements, widened lanes, and positive subdrainage) will increase pavement life substantially. Shorter design periods will mean more frequent lane closures for major rehabilitation and reconstruction that may, in the end, lead to large increases in user costs.

Truck Traffic

The type, frequency, and weight of truck traffic are important inputs for design of unbonded concrete overlays. Depending on the axle configuration, two different trucks with the same gross weight can cause greatly different amounts of damage to the pavement (*4*). Therefore, axle type and weight are far more critical to unbonded concrete overlay pavement performance than vehicle gross weight. Consequently, specific knowledge on axle type, frequency, and weights from weigh-in-motion scales should be obtained and used to determine the appropriate design features to reduce the damaging effect of the expected truck traffic.

The key parameters required to obtain accurate information on traffic loading include the average daily truck traffic or the percent of trucks in the traffic stream, vehicle type classification, growth rates, the current mean vehicle type rigid pavement equivalency factors, and the truck equivalency factor growth rate. On-site traffic count and weight data are by far the best source of information for project design. Historical traffic data are useful for estimating the growth rate of trucks.

Table 1 shows an example of information on the percent of truck traffic. Table 2 also provides information on the growth rates for multiaxle trucks, which shows that, although the overall growth rate for all vehicles is typically between 3 and 5 percent, the growth rate for some truck classes can be much higher.

Another key parameter that has a large influence on traffic loading is the truck equivalency factor, which is defined as the mean number of ESAL applications per truck or vehicle class on a given facility. It provides a way to express the mean amount of damage that is inflicted by the "average" truck in a vehicle class or across classes. Because of this direct implication of damage to the roadway, it is very important to use accurate vehicle class (truck) equivalency factors to calculate the cumulative ESALs. This information can best be obtained from an on-site weigh-in-motion scale.

TABLE 1 Percentages of trucks on various highway systems *(5)*

Highway System	Rural Average Daily Traffic			Urban Average Daily Traffic		
	2-Axle, 4-Tire SU	Trucks (ADTT)	Total of Both	2-Axle, 4-Tire SU	Trucks (ADTT)	Total of Both
Interstate	14	21	35	8	16	24
Other Federal-Aid Primary	16	13	29	17	9	26
Federal-Aid Secondary	10	15	25	14	8	22

Table 3 shows mean rigid pavement truck equivalency factors across all vehicle classes for the various highway designations. This information was obtained from weigh-in-motion scales from seven states in the Midwest from 1994 to 1996. The procedure for calculating the truck equivalency factor for a given vehicle class is illustrated in Figure 3. There is very strong evidence that these truck factors have been increasing steadily over the years; therefore, a reasonable growth rate should be considered.

Table 4 shows rigid pavement truck factors calculated for test pavement sections in selected midwestern states that are being studied under the LTPP program. The rigid pavement truck factors were obtained from actual weigh-in-motion data collected from the LTPP sections.

Simplified ESAL Calculation Procedure

The most appropriate ESAL estimation procedure is to obtain the mean truck equivalency factors for each truck vehicle class. The total number of ESALs is computed by multiplying these mean truck equivalency factors by the number of trucks in each class and then adding the products. If a mean truck factor is not available in each truck equivalency class, the following equation can be used. Because this procedure uses an average truck equivalency factor for all truck vehicle classes instead of separate values for the different truck classes, it provides only a very approximate ESAL value.

$$ESAL = ADT \times PTRKS \times GF \times DD \times LD \times TF \times 365 \qquad (1)$$

where

$ESAL$ = number of 80-kN (18-kip) ESAL applications over design period;
ADT = initial two-way average daily traffic (vehicles per day);
$PTRKS$ = percent heavy trucks (FHWA class 5 or greater) (decimal);

TABLE 2 Growth rates for different classes of trucks *(6)*

LOCATION	ANNUAL GROWTH RATES (PERCENT)			
	All Vehicles	All Trucks	Trucks, 5 Axle or Greater	18-kip ESALs
MT - I-94, Wilbaux to ND	3.4	5.4	6.3	10.3
MT - I-90, Billings to Laurel	4.0	8.1	13.1	18.9
MT - I-90, Butte	2.6	4.2	9.9	N/A
MT - I-90, Superior West	3.9	9.5	10.4	10.4
WA - I-90, Cle Elum, WA	2.1	N/A	5.6	8.5
WA - I-5, Vancouver to Olympia, WA	3.6	N/A	10.1	13.2
OR - I-5, Ashland, OR	4.1	8.8	11.7	12.6
OR - I-84, Oregon-Idaho Border	4.4	8.0	10.4	11.1
AVERAGE	3.5	7.33	9.69	12.1

TABLE 3 Typical rigid pavement truck equivalency factors as a function of highway designation*

Highway Designation	Mean and Range Truck factors (ESALs per truck)
State highways	0.75 (0.20 - 1.38)
U.S. highways	1.00 (0.43 - 1.80)
Interstate highways	1.33 (0.50 - 2.35)

* Weigh-in-motion data from seven Midwest states.

GF = composite growth factor to account for growth in truck volume and truck factor over the design period [obtained from Table 5 by entering a composite growth rate (g)];

$g = [(1 + g_{tv}) \times (1 + g_{tf})] - 1$;

g_{tv} = growth rate of traffic volume;

g_{tf} = growth rate of truck factor;

DD = directional distribution of truck traffic (decimal, not percent);

LD = lane distribution of trucks in design lane (decimal, not percent); and

TF = average current truck rigid pavement equivalency factor for all trucks (ESALs per truck).

Typical LD factors for multiple highways are provided in Table 6 (*7*).

Rigorous ESAL Calculation

A more rigorous ESAL calculation is described in detail in the AASHTO design guide (*3*). The approach requires classification of the traffic by axle type, weight, and number from classification counts and weigh-in-motion stations. It takes into account the actual axle load distributions of all single, tandem, and tridem axles and greatly increases the accuracy of the estimated design ESALs. It involves conversion of the axles in individual axle-load groups to ESALs by using specific equivalency factors for each group for the current year.

Axle Load, lb	Axle Load Equivalency Factor	Number of Axles	Accumulated ESALs
Single Axles	$P_t = 2.5$ D = 10 in		
Under 3,000	0.0002	0	0.000
3,000—6,999	0.0002	1	0.002
7,000—7,999	0.0060	6	0.036
8,000—11,999	0.0810	144	11.664
12,000—15,999	0.3380	16	5.408
26,000—29,999	6.6100	1	6.610
Tandem Axles			
Under 6,000	0.0020	0	0.000
6,000—11,999	0.0063	14	0.088
12,000—17,999	0.0510	21	1.071
18,000—23,999	0.2126	44	9.354
24,000—29,999	0.6360	42	26.712
30,000—32,000	1.2325	44	54.230
32,001—32,500	1.5662	21	32.890
32,501—33,999	1.7350	101	175.235
34,000—35,999	2.0975	43	90.192
80-kN (18-kip) ESALs for all trucks weighed			**413.492**

$$\textit{Truck Factor} = \frac{\textit{ESALs for all trucks weighed}}{\textit{Number of trucks weighed}} = \frac{413.492}{165} = 2.506$$

Figure 3. Computation of the truck equivalency factor for five-axle or greater trucks on a rigid pavement (3).

TABLE 4 Typical 1994 mean truck rigid pavement equivalency factors (across all truck vehicle classes) for LTPP sections in the Midwest

State	Roadway Type	Minimum	Maximum	Average Truck Factor/ Number of sections
IN	State highways	0.054	0.724	0.451/5
	Major arterial	0.273	0.952	0.672/5
	Interstate highways	0.827	2.692	1.690/4
MI	State highways	N/A	N/A	N/A
	Major arterial	0.886	1.819	1.162/5
	Interstate highways	0.518	1.599	0.923/4
MN	State highways	0.933	0.933	0.933/1
	Major arterial	0.150	1.064	0.520/4
	Interstate highways	0.462	1.358	1.034/10
OH	State highways	1.131	2.474	1.803/2
	Major arterial	N/A	N/A	N/A
	Interstate highways	1.273	1.556	1.397/4

TABLE 5 Traffic growth factors *(3)*

Analysis Period, Years (n)	Annual Growth Rate, Percent (g)							
	No Growth	2	4	5	6	7	8	10
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.02	2.04	2.05	2.06	2.07	2.08	2.10
3	3.0	3.06	3.12	3.15	3.18	3.21	3.25	3.31
4	4.0	4.12	4.25	4.31	4.37	4.44	4.51	4.64
5	5.0	5.20	5.42	5.53	5.64	5.75	5.87	6.11
6	6.0	6.31	6.63	6.80	6.98	7.15	7.34	7.72
7	7.0	7.43	7.90	8.14	8.39	8.65	8.92	9.49
8	8.0	8.58	9.21	9.55	9.90	10.26	10.64	11.44
9	9.0	9.75	10.58	11.03	11.49	11.98	12.49	13.58
10	10.0	10.95	12.01	12.58	13.18	13.82	14.49	15.94
11	11.0	12.17	13.49	14.21	14.97	15.78	16.65	18.53
12	12.0	13.41	15.03	15.92	16.87	17.89	18.98	21.38
13	13.0	14.68	16.63	17.71	18.88	20.14	21.50	24.52
14	14.0	15.97	18.29	19.16	21.01	22.55	24.21	27.97
15	15.0	17.29	20.02	21.58	23.28	25.13	27.15	31.77
16	16.0	18.64	21.82	23.66	25.67	27.89	30.32	35.95
17	17.0	20.01	23.70	25.84	28.21	30.84	33.75	40.55
18	18.0	21.41	25.65	28.13	30.91	34.00	37.45	45.60
19	19.0	22.84	27.67	30.54	33.76	37.38	41.45	51.16
20	20.0	24.30	29.78	33.06	36.79	41.00	45.76	57.28
25	25.0	32.03	41.65	47.73	54.86	63.25	73.11	98.35
30	30.0	40.57	56.08	66.44	79.06	94.46	113.28	164.49
35	35.0	49.99	73.65	90.32	111.43	138.24	172.32	271.02

Factor = $[(1+g)^n-1]/g$, where g = rate/100 and is not zero. If annual growth rate is zero, the growth factor is equal to the analysis period.

TABLE 6 Lane distribution factors for multiple-lane highways *(7)*

One-Way ADT	2 Lanes (One Direction) Inner	2 Lanes (One Direction) Outer	3+ Lanes (One Direction) Inner*	3+ Lanes (One Direction) Center	3+ Lanes (One Direction) Outer
2,000	6**	94	6	12	82
4,000	12	88	6	18	76
6,000	15	85	7	21	72
8,000	18	82	7	23	70
10,000	19	81	7	25	68
15,000	23	77	7	28	65
20,000	25	75	7	30	63
25,000	27	73	7	32	61
30,000	28	72	8	33	59
35,000	30	70	8	34	58
40,000	31	69	8	35	57
50,000	33	67	8	37	55
60,000	34	66	8	39	53
70,000	—	—	8	40	52
80,000	—	—	8	41	51
100,000	—	—	9	42	49

* *Combined inner one or more lanes*
** *Percent of all trucks in one direction*

Current Typical Traffic Loading on Unbonded Concrete Overlays

Based on the information in the database assembled for this study, unbonded concrete overlays in service carry a wide range of traffic loads. An evaluation of the information obtained provided the approximate rates of loadings on unbonded concrete overlays from 1985 to 1995, as shown in Table 7.

CLIMATE

The effects of climate that are of particular concern are thermal curling, permanent construction curling, and moisture warping. Thermal curling occurs when temperature gradients exist in the pavement *(8–10)*. Similarly, moisture gradients in the slab typically cause upward warping of the slab. Permanent construction curling has been observed on pavements that set and harden when there is a high positive temperature differential in the slab *(9,10)*. Because the slab was flat when it began to harden with this high positive temperature differential, it will always be permanently curled upward at subsequent lower temperature differentials when the top gets cooler and contracts.

For unbonded PCC overlays, the critical stresses from thermal gradients, moisture gradients, and permanent construction curling are those that result in upward curl of the slab. Corner loading of such slabs that do not have dowels may lead to corner breaks, diagonal cracks, and transverse cracks close to the joint. This is the typical climate-related mode of failure that has been observed for thin UBOLs [203 mm (8 in.) or less], which often do not have doweled joints. For thicker UBOLs that have doweled joints, however, an effective positive temperature differential that causes a downward curling may be critical. Midslab loading of such slabs leads to transverse cracks that form from the bottom edge and migrate toward the center *(11,12)*.

Loss of Support from Curling/Warping

The loss of support that results from curling and warping of the slab is exacerbated in UBOLs because of the high stiffness of the underlying pavement. The loss of support at the corner when the slab is curled upward, as shown in Figure 4,

TABLE 7 Typical traffic loading (rigid pavement ESALs) on unbonded concrete overlays in database (1985–1995)

Highway Type	Mean ESALs/Year, millions	Range, millions/yr
Interstate	1.43	0.5 - 4.0
State	0.70	0.4 - 1.25
County	0.25	0.1 - 0.5

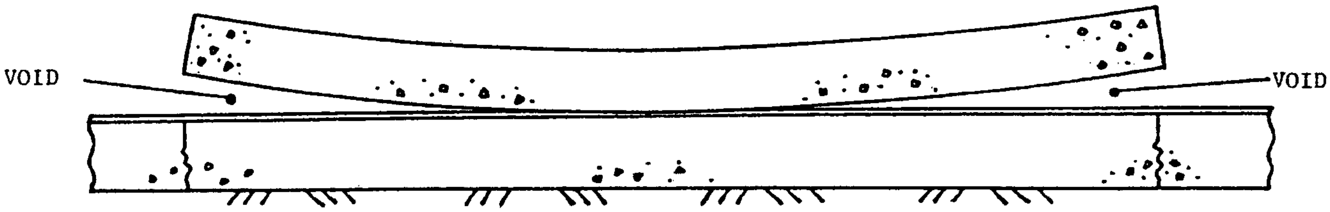


Figure 4. Upward thermal curling of UBOL due to nighttime temperature gradient, construction gradient, or moisture shrinkage of the slab surface (13).

leads to excessive tensile stresses at the slab surface and high deflections when loads are applied at the corner (*8,12–14*). This is what leads to the corner breaks, diagonal cracks, and transverse cracks that form about 0.6 to 1.2 m (2 to 4 ft) from the joint for nondoweled slabs. Therefore, the stresses due to upward curling and warping of the slab should be taken into account during design for the corner load condition when dowels are not used.

Similarly, downward curling, as illustrated in Figure 5, may lead to loss of support at the middle of the longitudinal edge of the slab. The results after repeated loadings at the midslab location are excessive stresses at the bottom of the slab and increased deflections at the longitudinal edge that cause midslab transverse cracking. Therefore, the stresses due to downward curling of the slab also need to be taken into account during design for the midslab load condition.

Curling and Warping Stresses

The key item that needs to be evaluated is whether thermal and moisture gradients will be considered and, if so, how the stresses that result can be quantified. A procedure (*12*) is available for calculating the total equivalent negative or positive temperature differential that will generate stresses in PCC pavements equivalent to the combined stresses from thermal gradients, moisture gradients, and permanent construction curling. The stresses that result for the total equivalent negative temperature differential can be used to check the design for the corner loading condition, and those from the total equivalent positive temperature differential can be used to check the design for the midslab loading condition. Equations for calculating these stresses are available for PCC pavements on treated and granular bases, but such equations are not available for unbonded concrete overlays. Further research is recommended to develop equations or charts for use in unbonded concrete overlay design. It should be noted that the thicker the slab, the smaller the effects of curling and warping stresses.

EVALUATING EXISTING PAVEMENT AND SUBGRADE

Support for an UBOL is provided by the subgrade, the interlayer, and the existing pavement. The common parameter for characterizing subgrade support is the *k*-value of the subgrade. The existing pavement, unless it is fractured, results in an increase in structural stiffness of the UBOL pavement; it does not contribute to the *k*-value of the subgrade. Therefore, an evaluation of the support conditions for UBOL design involves a structural evaluation of both the subgrade and the existing pavement. Data are also needed for assessing the extent of preoverlay repairs that may be needed and for the design of the specific type of interlayer and overlay.

A structural evaluation, including evaluation of joints and working cracks, is best accomplished by using deflection

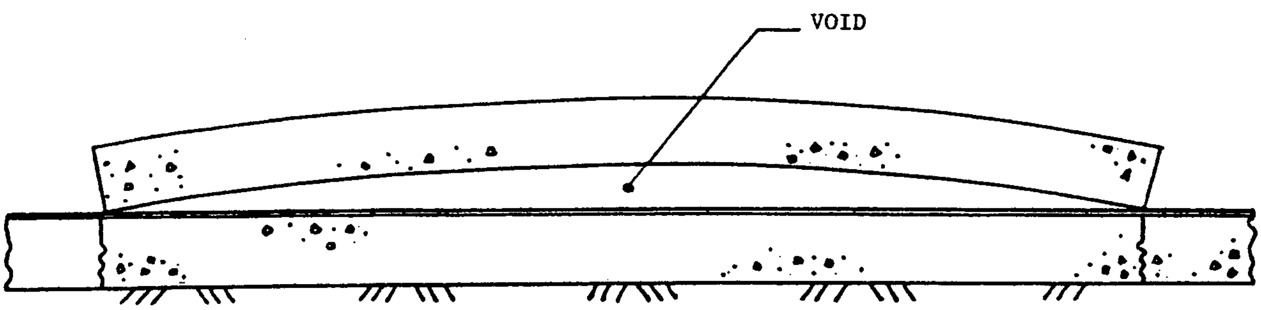


Figure 5. Downward thermal curling of UBOL due to daytime temperature gradient (13).

measurements obtained with NDT equipment such as the falling weight deflectometer (FWD) or the Road Rater. A visual condition survey to rate the condition of the pavement, including joints and cracks, is also required.

Because a single overlay thickness is often provided for uniform sections of the pavement, examination of the uniformity of support is more important than the magnitude of the support provided by the existing pavement. An adequate overlay thickness can always be placed to remedy an overall low magnitude of support provided by the existing pavement. Therefore, the results from the structural evaluation should include the necessary information for selection of the preoverlay repair, thickness of interlayer, and the thickness and length of PCC slab for adequate long-term performance.

Structural Evaluation

As mentioned previously, structural evaluation of the existing pavement with deflection testing equipment (e.g., FWD) is recommended with a load magnitude of 40 kN (9,000 lbf). Hall et al. (*15*) recommend deflection measurements with sensors located 0, 203, 305, 457, 610, 915, and 1524 mm (0, 8, 12, 18, 24, 36, and 60 in.) from the center of the load.

For UBOL design for an existing PCC or composite (AC/PCC) pavement, deflections should be measured for back-calculation of the effective static elastic k-value of the subgrade, the load-transfer efficiency of joints and working cracks, and overall assessment of the condition of the existing pavement. Slab deflection basins should be measured in the outer wheel path along the project at an interval that is sufficient to assess conditions. Intervals of 30 to 300 m (100 to 1,000 ft) are typical.

For jointed concrete pavements, slabs that deflect excessively and rock should be noted. Rocking can be detected visually by observing slab corners as heavy trucks roll over the pavement.

Back-Calculation of Effective k-Value

Extensive guidelines for back-calculating the effective static elastic k-value by the AREA method are provided (*12,15*) and include the following steps:

- Step 1. Compute the appropriate AREA of each deflection basin;
- Step 2. Estimate the radius of relative stiffness, l, assuming an infinite slab size;
- Step 3. Estimate the subgrade k-value assuming an infinite slab size;
- Step 4. Compute adjustment factors for the maximum deflection d_0 and the initially estimated l to account for the finite slab size;
- Step 5. Adjust the initially estimated k-value to account for the finite slab size;
- Step 6. Compute the mean back-calculated subgrade k-value for all the deflection basins considered; and
- Step 7. Compute the estimated mean static k-value for use in design.

These steps are described in more detail below, and the relevant equations for bare concrete and composite pavements are provided for each step.

Step 1–Compute AREA

For a bare concrete pavement, compute $AREA_7$ of each deflection basin by the following equation:

$$AREA_7 = 4 + 6\left(\frac{d_8}{d_0}\right) + 5\left(\frac{d_{12}}{d_0}\right) + 6\left(\frac{d_{18}}{d_0}\right) + 9\left(\frac{d_{24}}{d_0}\right) + 18\left(\frac{d_{36}}{d_0}\right) + 12\left(\frac{d_{60}}{d_0}\right) \quad (2)$$

where

d_0 = deflection in center of loading plate (in.); and
d_i = deflections at 0, 203, 305, 457, 610, 915, and 1524 mm (0, 8, 12, 18, 24, 36, and 60 in.) from plate center (in.).

For a composite pavement, compute $AREA_5$ of each deflection basin by the following equation:

$$AREA_5 = 3 + 6\left(\frac{d_{18}}{d_{12}}\right) + 9\left(\frac{d_{24}}{d_{12}}\right) + 18\frac{d_{36}}{d_{12}} + 12\left(\frac{d_{60}}{d_{12}}\right) \quad (3)$$

Step 2–Estimate l Assuming an Infinite Slab Size

The radius of relative stiffness for a bare concrete pavement (assuming an infinite slab) may be estimated by the following equation:

$$l_{est} = \left[\frac{\ln\left(\frac{60 - AERA_7}{289.708}\right)}{-0.698}\right]^{2.566} \quad (4)$$

The radius of relative stiffness for a composite pavement (assuming an infinite slab) may be estimated by the following equation:

$$l_{est} = \left[\frac{\ln\left(\frac{48 - AERA_5}{158.40}\right)}{-0.476}\right]^{2.220} \quad (5)$$

Step 3–Estimate k Assuming an Infinite Slab Size

For a bare concrete pavement, compute an initial estimate of the k-value by the following equation:

$$k_{est} = \frac{Pd_0^*}{d_0(l_{est})^2} \quad (6)$$

where

k = back-calculated dynamic k-value (psi/in.);
P = load (lb);
d_0 = deflection measured at center of load plate (in.);
l_{est} = estimated radius of relative stiffness from previous step (in.); and
d_0^* = nondimensional coefficient of deflection at center of load plate.

$$d_0^* = 0.1245e^{[-0.14707e^{(-0.07565 l_{est})}]} \tag{7}$$

For a composite pavement, compute an initial estimate of the k-value by the following equation:

$$k_{est} = \frac{Pd_{12}^*}{d_{12}(l_{est})^2} \tag{8}$$

where

d_{12} = deflection measured 305 mm (12 in.) from center of load plate (in.);
l_{est} = estimated radius of relative stiffness from previous step (in.); and
d_{12}^* = nondimensional coefficient of deflection 305 mm (12 in.) from center of load plate.

$$d_{12}^* = 0.12188e^{[-0.79432e^{(-0.07074 l_{est})}]} \tag{9}$$

Step 4–Compute Adjustment Factors for d_0 and l for Finite Slab Size

For both bare concrete and composite pavements, the initial estimate of l is used to compute the following adjustment factors to d_0 and l to account for the finite size of the slabs tested:

$$AF_{d_0} = 1 - 1.15085e^{-0.71878(L/l_{est})^{0.80151}} \tag{10}$$

$$AF_l = 1 - 0.89434e^{-0.61662(L/l_{est})^{1.04831}} \tag{11}$$

where, if the slab length is less than or equal to twice the slab width, L is the square root of the product of the slab length and width, both in inches; if the slab length is greater than twice the width, L is the product of the square root of 2 and the slab length in inches.

$$\begin{aligned} &\text{if } L_l \le 2 \times L_w, \quad L = \sqrt{L_l L_w} \\ &\text{if } L_l > 2 \times L_w, \quad L = \sqrt{2} \times L_l \end{aligned} \tag{12}$$

Step 5–Adjust dynamic k for Finite Slab Size

For both bare concrete and composite pavements, adjust the initially estimated k-value by the following equation:

$$k = \frac{k_{est}}{AF_l^2 AF_{d_0}} \tag{13}$$

Step 6–Compute Mean Dynamic k-Value

Exclude from the calculation of the mean dynamic k-value any unrealistic values [i.e., less than 14 kPa/mm (50 psi/in.) or greater than 407 kPa/mm (1,500 psi/in.)] as well as any individual values that appear to be significantly out of line with the rest of the values.

Step 7–Compute the Estimated Mean Static k-Value for Design

Divide the mean dynamic k-value by 2.0 to estimate the mean static k-value for design. This value is the modulus of reaction of the subgrade and not of the existing pavement, and it is the value used in the design of unbonded concrete overlays. It is important to note that the concept of a k-value on top of the existing pavement is erroneous and it is not the appropriate k-value to use in pavement design.

Table 8 is a worksheet for computation of k-value from deflection data that includes example computations of k-value from deflection basins measured on two pavements, one bare concrete and the other composite.

Seasonal Variation in Back-Calculated k-Values

The design k-value determined from back-calculation represents the k-value for the season in which the deflection testing was conducted. A procedure for combining the seasonal k-values into a single static k-value for use in design is described (*12,15*). However, for UBOL design, a substantial change in the static k-value due to seasonal correction will not result in a significant change in thickness. Therefore, this adjustment is not necessary for UBOL design.

Condition Survey

A condition survey is required to determine the type, quantity, and severity of distresses in the existing pavement. This information is necessary to determine the extent and type of repair that may be required on the existing pavement before placement of the unbonded concrete overlay. For unbonded concrete overlays, the objective of the condition survey is to determine the distresses on the existing PCC pavement that will affect the performance of the UBOL if not repaired. If a thick interlayer is used, minor distress can be left unrepaired without any detrimental effect on the UBOL. In general, the critical distress types are those that create areas of localized weakness (high deflections) and do not provide uniform support to the overlay (such as wide working cracks).

A good source for information on the description of types and severities of PCC pavement distresses is the *Distress Identification Manual for the Long-Term Pavement Performance Project* (*16*). This manual is recommended if a locally developed distress identification manual is not available. For pavements scheduled for overlay with an unbonded PCC

TABLE 8 Determination of design subgrade *k*-value from deflections *(15)*

BARE CONCRETE PAVEMENT

Step	Equation	Calculated Value	Example
d_0 d_8 d_{12} d_{18} d_{24} d_{36} d_{60}		________ ________ ________ ________ ________ ________ ________	0.00418 0.00398 0.00384 0.00361 0.00336 0.00288 0.00205
$AREA_7$	(2)		45.0
Initial estimate of ℓ	(4)		40.79
Nondimensional d_0* and initial estimate of k	(7) (6)		0.1237 160
AF_{d_0} AF_ℓ	(10) (11)		0.867 0.934
Adjusted k*	(13)		212
Mean dynamic k**			212
Mean static k for design			106

COMPOSITE PAVEMENT

Step	Equation	Calculated Value	Example
d_{12} d_{18} d_{24} d_{36} d_{60}		________ ________ ________ ________ ________	0.00349 0.00332 0.00313 0.00273 0.00202
$AREA_5$	(3)		37.8
Initial estimate of ℓ	(5)		48.83
Nondimensional d_{12}* and initial estimate of k	(9) (8)		0.1189 128
AF_{d_0} AF_ℓ	(10) (11)		0.823 0.896
Adjusted k*	(13)		195
Mean dynamic k**			195
Mean static k for design			97

*Adjustment for slab sized one for one slab at a time.
**Mean value for all slabs; assumed the same as above for illustration purposes.

pavement, medium- and high-severity distresses are of concern. The condition survey should determine the amount of medium- and high-severity distresses along the length of the project that require repair. Measurements should be taken for the project divided into some unit section; unit sections 1.6 km (1 mi) long are typical. *Figure 6* provides a form that can be used to record the distress types and severities observed along the roadway. The *Distress Identification Manual* also contains forms for distress surveys. Following are the key distress types that should be measured for each PCC pavement type.

Jointed Concrete Pavements

Table 9 provides information on the conditions that are of concern for existing jointed concrete pavements. For jointed concrete pavements scheduled for unbonded concrete overlay, the distress types and conditions that are critical are those associated with the joints and cracks. Pavements with extremely deteriorated joints create localized areas of weakness that cannot be effectively bridged by the interlayer and unbonded concrete overlay. Joints with poor load transfer and that have deteriorated badly will continue to deteriorate and can cause distress in the UBOL if adequate remedial measures are not taken. Therefore, for existing JPCP and JRCP, the condition survey should be conducted to determine whether the following distresses are present in the existing pavement:

- Working transverse joints and cracks [severely spalled or faulted, exhibiting poor deflection load transfer (less than 50 percent)];

To Be Sketched	Note on Sketch	
All Cracking	LF	L M H
Longitudinal Joint Spalling		L M H
Longitudinal Faulting	in	
Crack Faulting	in	
Scaling/Map Cracking	Area	L M H
Patches/Replaced Slabs	Dimensions	
Improper Joint Construction Cracks	LF	
Missawed Joints (Bonded OL)	LF	
Blowups	BU	
D-Cracking	D	L M H
Reactive Aggregate	RA	

Field Survey: *Data Collection Form*

Date of Survey (mm/dd/yy): ___/___/___

Surveyors' Initials: _____/_____/_____

Project ID: ________________

Page No: ______ of _____

Transverse Joint Type Code
1. Contraction Joint
2. Construction Joint
3. Patch Approach Joint
4. Pressure Relief Joint

	OUTER LANE						INNER LANE					
STATION												
Trans Joint Type (Code)												
Transverse Joint Spalling	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H
Transverse Joint Seal Damage	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H
Longitudinal Joint Seal Damage	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H
D-Cracking	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H
Pumping	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H
Patch/Slab Replacement Deterioration	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H
Slab Deterioration Adjacent to Patch	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H	N L M H
Lane to Shoulder Dropoff (in)												
Lane to Shoulder Separation (in)												
Faulting (in)												
Joint Width — Outer Lane Only (in)												
Joint Depth (in)												

Figure 6. Condition survey form.

TABLE 9 Conditions of concern for existing jointed concrete pavements

Factor	Possible Condition
Transverse joints	Poor deflection load transfer (< 50 percent), spalling/disintegration, pumping, faulting
Longitudinal joints	Wide joint opening, corrosion of tie bar, poor deflection load transfer, pumping, spalled/deteriorated
PCC slab-cracking	Working transverse cracks[1], working longitudinal cracks, corner breaks, shattered slabs, movement or rocking of slabs when loaded
PCC slab durability	Severe D-cracking, ASR, sulfate attack
Drainage	Pumping and other evidence of poor subsurface drainage
Uniformity of support	Relatively excessive deflections at certain locations
Surface profile	Settlements, heaves
Overlay lane width	Same as overlay, or narrower than overlay, and is widening required

[1] Working cracks are spalled or faulted cracks that exhibit poor load transfer (<50 percent deflection transfer: unloaded deflection/ loaded deflection).

- Corner breaks;
- Expansion joints;
- Severe durability problems;
- Excessive joint faulting (indicative of poor load transfer and high deflections); and
- Badly shattered slabs (four or more pieces that rock under load);

Distress measurements should be taken to obtain information on the following (*3*):

- Number of deteriorated transverse and longitudinal joints per 1.6 km (1 mi);
- Number of deteriorated (working) transverse and longitudinal cracks per 1.6 km (1 mi);
- Number of existing expansion joints, exceptionally wide joints [greater than 25 mm (1 in.)], or full-depth and full-lane-width asphalt concrete patches per mile;
- Presence and general severity of PCC durability problems (high-severity D-cracking and reactive aggregate cracking);
- Evidence of faulting, pumping of fines or water at joints, cracks, and pavement edge; and
- Evidence of improper drainage.

Continuously Reinforced Concrete Pavements

The conditions of existing CRCP that are critical to the performance of UBOLs include deteriorated and working transverse cracks, steel rupture, punchouts, pumping, expansion joints, durability problems, and the amount of previous repairs. Because of the closely spaced cracks in CRCP, it is relatively flexible; therefore, adequate foundation support is critical, and the condition survey should examine any localized conditions that indicate the lack of support. Table 10 summarizes the key distress types that are of concern for CRCP to be overlaid with an unbonded concrete overlay.

A condition survey for an existing CRCP should include measurement of the following distress types, as a minimum (*3*):

- Number of deteriorated transverse cracks per 1.6 km (1 mi);
- Number of punchouts per 1.6 km (1 mi);
- Number of existing expansion joints, exceptionally wide joints [greater than 25 mm (1 in.)] or full-depth, full-lane-width AC patches per 1.6 km (1 mi);
- Number of existing and new repairs before overlay per 1.6 km (1 mi);
- Presence and general severity of PCC durability problems [high-severity D-cracking, alkali-silica reactivity (ASR), sulfate attack]—surface spalling of tight cracks where the underlying CRCP is sound should not be considered a durability problem; and
- Evidence of pumping of fines or water.

Composite (AC/PCC) Pavements

A condition survey must also be conducted for PCC pavements with AC overlays that are scheduled for unbonded PCC overlay. The condition survey should include an evaluation of the distresses that have reflected through the AC overlay and the integrity of the existing AC layer that will serve as an interlayer. Following are the typical distress measurements that should be done on jointed concrete pavements overlaid with AC:

TABLE 10 Conditions of concern for existing CRCP

Factor	Possible Condition
Transverse cracks	Wide working cracks, steel rupture, poor crack load transfer, spalling/disintegration, pumping, faulting
Longitudinal joints	Wide joint opening, corrosion of tie bar, poor load transfer, spalled/deteriorated
Punchouts and punchout potential	Wide working closely spaced transverse cracks, steel rupture, poor foundation support, and existing punchouts
PCC slab durability	Severe D-cracking, ASR, sulfate attacks
Drainage	Pumping and other evidence of poor subsurface drainage
Uniformity of support	Relatively excessive deflections at certain locations
Surface profile	Settlements, heaves
Overlay lane width	Same as overlay, or narrower than overlay, and is widening required

- Number of deteriorated transverse reflection cracks per 1.6 km (1 mi);
- Number of full-depth AC patches and expansion joints per 1.6 km (1 mi);
- Evidence of pumping of fines and water through reflection cracks and at the pavement edge;
- Average rut depth;
- Condition of AC material (e.g., stripping, raveling, bleeding); and
- Debonding of layer from existing pavement.

The condition survey on CRCP overlaid with AC should include measurement of the following:

- Number of unrepaired punchouts per 1.6 km (1 mi);
- Number of unrepaired deteriorated transverse reflection cracks per 1.6 km (1 mi);
- Number of unrepaired deteriorated repairs and full-depth AC repairs per 1.6 km (1 mi);
- Evidence of pumping of fines and water through reflection cracks and at the pavement edge;
- Average rut depth;
- Number of localized failures (punchouts); and
- Evidence of stripping at the AC/PCC interface.

Drainage Survey

Positive drainage will remove excess water from the pavement and prevent any reduction in support provided by the foundation. It will also decrease the occurrence and progression of moisture-related distresses such as, pumping and stripping of the AC interlayer. Therefore, a drainage survey is an important part of the condition survey. The objectives of the drainage survey should be to determine the adequacy of the drainage provided to the existing pavement and to gather information for provision of positive drainage if it is determined that the pavement is not adequately drained.

The survey should consist of evaluating the condition of specific drainage items present in the pavement as well as identifying signs of poor drainage. This requires examination of the following drainage-related items during the condition survey and identification of any unsatisfactory conditions on the condition survey form shown in Figure 6:

1. Do the drainage ditches have adequate depth and slope?
2. Are the ditches clear of standing water?
3. Are the ditches and pavement edge free of weed growth?
4. After rainfall, does water stand in the joints and cracks in the existing pavement? Does water stand at the outer edge of the shoulder, or is there evidence of water ponding on the shoulder?
5. If a subsurface drainage system is present, can the outlets be located and are they clear of debris and with adequate inverts? Can a video camera inspection of the pipes be conducted? Is there any evidence of materials pumping?
6. Are storm drain inlets clear and set at proper elevations for both the existing pavement and the expected unbonded PCC overlay?
7. Is there evidence of a high or perched water table?

CHAPTER 3

DESIGN OF UNBONDED CONCRETE OVERLAY

INTRODUCTION

This chapter provides guidance on the design of unbonded concrete overlays with information obtained from evaluation of site conditions. The requirements for good design include the following:

- Application of the appropriate preoverlay repairs for the specific overlay type. This includes the option of slab fracture and drainage design to provide positive drainage, if necessary.
- Design of an interlayer that will provide uniform support, adequate friction, and level-up and will prevent reflection cracking and other distresses in the overlay.
- Design of the PCC overlay that includes selection of design features such as slab thickness, quality concrete, widened lanes, joint spacing (JPCP and JRCP), reinforcement (JRCP and CRCP), and others that will provide a long-lasting overlay.

PREOVERLAY REPAIR

In these guidelines, *preoverlay repair* refers to minor repairs or fracturing of the existing concrete slab (or milling of an existing AC overlay). Because an unbonded concrete overlay consists of the placement of a relatively thick PCC slab on an interlayer that is placed over a deteriorated existing pavement, not much preoverlay repair is required for most JPCP and JRCP overlays. (More is usually necessary for CRCP overlays.) The preoverlay repair may be required to address areas with major deterioration to meet the following objectives:

- Provide a reasonably uniform support;
- Eliminate excessive localized deflections, especially at joints, cracks, and punchouts without effective load transfer;
- Eliminate further progression of durability-related and other distresses in the existing pavement that will cause premature failure of the overlay (also including ASR and sulfate attack); and
- Provide a level-up over the existing pavement if necessary.

General

The results from testing the existing pavement by the procedures outlined in Chapter 2 in the section "Evaluating Existing Pavement and Subgrade" are necessary to identify the type and level of necessary preoverlay repairs. The type and amount of preoverlay repair selected are a function of the following:

- Type and thickness of interlayer;
- Projected future traffic loading on the overlay;
- Type of UBOL (JPCP, JRCP, or CRCP); and
- Subdrainage requirements and conditions.

Based on these factors, concrete pavement repairs may be required when the repairs will restore uniformity of support or minimize the potential for further deterioration of the existing pavement after overlay. The distresses that require particular attention fall into the following three categories:

- Joint-related distresses in jointed concrete pavement;
- Non-joint-related distresses that significantly reduce the structural capacity of the existing pavement, including loss of support and punchouts; and
- Durability-related distresses (D-cracking, ASR, and sulfate attack) with the propensity to get worse.

When repair is necessary, it is extremely important to identify the specific distresses and locations that need repair, the exact boundaries for repair, and the type of repair that will be most suitable relative to its influence on performance of the overlay. Depending on the type and thickness of interlayer that is used, only minor repairs of the existing pavement may be necessary. For a cost-effective design, it is important that only those areas that absolutely require repairs receive them.

The repair alternatives that have been used include AC partial-depth patching, full-depth PCC joint and crack repair, full-depth repair of blowups, load transfer restoration at working cracks or joints with poor load transfer, and slab replacement. Fracturing the existing pavement is a potential preoverlay treatment if the existing pavement is very badly deteriorated.

Existing Jointed Concrete Pavements

Most of the serious deterioration in existing JPCP and JRCP that requires preoverlay repair occurs at joints. Because improperly repaired joints in the existing pavement will continue to deteriorate and reflect through the interlayer and, possibly, into the PCC overlay, the objective of repair is to restore the structural integrity, load transfer, and continuity.

Spalling

High-severity spalling is a key distress type that exists at badly deteriorated joints and cracks and may require repair. Any loose material resulting from spalling should be removed and the hole should be filled with AC material.

Faulting

The implications for design of unbonded concrete overlays is that, if faulting is severe, the joints and cracks may cause reflection cracking in the overlay if the interlayer or overlay thickness is not adequate. Additionally, for thin interlayers, the faulted joints and cracks may restrict expansion and contraction of the overlay and could lead to distress early in the life of the unbonded concrete overlay. In most instances, a thick [>25 mm (1 in.)] AC interlayer will be adequate for design, and no repair of the joints or cracks for faulting will be necessary. This will work if the average faulting is less than 5 mm (0.2 in.). It will also work in most instances if the UBOL is either a JPCP or a JRCP.

For existing JPCP and JRCP with excessive faulting [average > 5 mm (0.2 in.)], however, localized diamond grinding may be appropriate for selected joints and cracks in rare cases. This may include when a CRCP overlay is used over a badly faulted JPCP or JRCP. However, the cost-effectiveness of grinding should be compared with the use of an even thicker AC interlayer and perhaps increased reinforcement in the CRCP.

For all types of UBOL, if the measured deflection joint load transfer at the faulted joints of the existing JPCP or JRCP is less than 50 percent, an interlayer thickness greater than 38 mm (1.5 in.) is recommended. Reinforcement in JRCP and CRCP should also be increased. Another option is to fracture the existing pavement to obtain more uniform support.

Additionally, for all types of overlay, it is important to recognize that four elements must be present for faulting: free water in the pavement, an erodible underlying or supporting material, heavy truck traffic, and inadequate load transfer. Therefore, if there is excessive faulting of the existing pavement, these underlying causes must also be addressed. The options that are available include provision of positive drainage to reduce the amount of free water that will be available to the overlay. Without excess moisture, there can be no faulting. The drainage measures that can be implemented include use of a permeable interlayer and retrofitting with edge drains. Restoration of load transfer across working cracks is an effective alternative. Also, design features can be included in the overlay that will reduce the occurrence of faulting (JPCP and JRCP) and the effect of faulting on the overlay. Adequate slab thickness and high-quality concrete and stiffness of the overlay will reduce the effect of faulting of the existing pavement. For JPCP and JRCP overlays, excessive faulting of the existing pavement is indicative of heavy truck traffic, and the joints should be doweled.

PCC Durability

Durability distress in the existing pavement should be investigated to determine the best repair method to apply. A thick AC interlayer [>25-mm (1-in.)] will be adequate in most instances. Several pavements in the research database that had D-cracking and ASR problems are performing well even though the only preoverlay treatment was an interlayer. Removal of loose pieces of concrete from D-cracking and filling with AC material before placement of the interlayer is necessary.

Continued progression of D-cracking in the existing pavement may lead to a reduction in performance of thinner unbonded concrete overlays. D-cracking of the existing pavement can lead to loss of support near the joints in the existing pavements and subsequently to cracking of the unbonded concrete overlay. Several examples of this were observed on unbonded concrete overlays in Iowa that were evaluated in this study.

Because water is a primary ingredient for durability distress, any measures taken to provide positive drainage will reduce the propensity of the existing pavement to deteriorate. This was observed on the Iowa sections; the overlays with drainage systems that were constructed on D-cracked pavements performed far better than those without drainage provisions. Fracturing of the D-cracked pavements to obtain a quality aggregate base is another viable alternative.

Loss of Support

Loss of support under the existing pavement can result from pumping and rocking slabs, curling and warping of the pavement slabs, and shattered slabs. Following are the recommended repair methods for such existing pavements:

- Rocking or unstable slabs with large deflections or pumping problems should be replaced full depth with concrete or should be stabilized (corner breaks may exist along project).
- Badly shattered slabs with working cracks should be replaced full depth.
- Settlements should be leveled-up with asphalt concrete.

Fracturing of the pavement into a good-quality aggregate base is also a viable option for repairing existing pavements with a significant number of badly shattered slabs. It is necessary to do spot repairs of the subbase/subgrade during full-depth slab replacement if there are soft spots or if excessive loss of support exists.

Existing Continuously Reinforced Concrete Pavements

The most serious distresses in CRCP that require repair are punchouts and ruptured steel. Punchouts occur when there is loss of aggregate interlock load transfer at one or two closely spaced cracks that then fault and spall. Heavy truck traffic along the edge of the pavement over the piece of slab between the two transverse cracks will cause it to act as a cantilever beam. With repeated load applications, a short longitudinal crack will form at the top of the slab and about 1 m (3.3 ft) from the outside longitudinal joint. Continued traffic load applications over the piece of pavement will cause it to break up and punch into the subbase or subgrade.

Punchouts

Preoverlay repair of CRCP should include full-depth removal and replacement of all punchouts. Because punchouts are likely to occur as a result of a lack of support provided by the subbase or subgrade, repair of the foundation is very important. Excavation and recompaction of the subbase or subgrade 0.5 to 1 m (1.6 to 3.3 ft) beyond the distress boundaries is recommended (*17*). The repair area should extend at least 0.5 m (1.6 ft) beyond the area of distress so that the patch will be adjacent to sound material. The patch boundary should be a minimum of 203 mm (8 in.) from cracks in the CRCP. Similar repairs should be applied to areas with blowups and high-severity D-cracking.

Deteriorated Transverse Cracks or Construction Joints

Deteriorated or working transverse cracks with ruptured steel should also be repaired with full-depth repairs. Similarly, construction joints with high-severity spalls should be repaired with full-depth patches. Except for minor distresses that extend a few inches into the slab from the surface, removal and replacement of distresses that extend to the bottom of the existing slab with bituminous mixtures is not recommended.

Fracturing of Existing Pavement

Fracturing of the existing pavement before overlay is a viable preoverlay treatment for unbonded concrete overlays in some cases. For severely deteriorated concrete pavements with major structural deficiencies and other durability-related problems that can cause future problems in the overlay, fracturing the existing pavement may be the best alternative for achieving uniform support.

The three common slab fracturing techniques that are currently used include cracking and seating, breaking and seating, and rubblizing. These techniques have the following unique characteristics (*18,19*):

- Cracking and seating is performed on existing JPCP to reduce the effective slab length and reduce slab movement.
- Breaking and seating is conducted on JRCP to shorten the slab lengths and reduce slab movement by rupturing the steel in the slab or breaking the bond between the steel and concrete.
- Rubblizing is the fracturing of a pavement slab into small pieces and is generally performed on badly deteriorated JRCP or CRCP.

Cracking and Seating

This technique creates pieces that are small enough to reduce the movement caused by temperature changes, yet are still large enough to maintain some structural stability (*19*). Cracking and seating has the advantage of not disturbing a preexisting drainage system. The construction practices for cracking and seating of existing JPCP pavements are described in Chapter 4.

The severity of deterioration is the criterion by which an engineer should determine the applicability of cracking and seating. A crack-and-seat operation reduces the structural integrity of a PCC pavement, which requires thicker overlays and limits future rehabilitation options. To determine the cost-effectiveness of cracking and seating, the designer should compare the increased overlay cost and the cost of cracking and seating with the potential savings in preoverlay repairs. The following types of distresses, when they exist in substantial quantities at a high severity, may justify cracking and seating of a PCC slab (*18,20*):

- Seriously faulted transverse joints and transverse cracks;
- Presence of many working transverse cracks;
- A large quantity of rocking of slabs because of the presence of voids;
- Presence of many working longitudinal cracks;
- Lane separation (separation of longitudinal joints);
- Extensive joint deterioration due to D-cracking;
- Extensive slab deterioration due to reactive aggregates or sulfate attack;
- Uneven slab settlement; and
- Extensive corner breaks.

Unbonded concrete overlays with cracked and seated existing pavements have had both successes and failures. Several of the unbonded concrete overlays evaluated in this study were built on crack and seated JPCP and are performing well. However, Stoffels and Morian (*21*) report significant amounts of cracking of unbonded concrete overlays on crack and seated pavements (1 to 4 years old) in the northwestern Pennsylvania area.

Breaking and Seating

For existing JRCP, breaking and seating and rubblizing are viable alternatives. To be effective, breaking and seating must reduce horizontal movements by rupturing the reinforcing steel or by debonding the PCC from the steel. This effort generally requires that the existing PCC be broken into smaller pieces than are required for cracking and seating, thus reducing the structural capacity of the break-and-seat section (*19*).

When a breaking and seating operation does not adequately disrupt the reinforcement in a JRCP, full-depth cracking does not always occur and the reinforcing steel will continue to hold the broken pieces together. As a result, the slab continues to function as a unit, which leads to larger horizontal movements at the joints and increased reflection cracking (*13*). If the steel is ruptured, the performance of a break-and-seat section should not differ from a crack-and-seat section.

Rubblization

Rubblization is a fracturing technique that has been used for unbonded concrete overlays (*21*). Rubblization is usually appropriate for all PCC pavement types, but it is particularly effective for JRCP and CRCP. Reduction of the PCC to aggregate-sized particles [smaller at the surface and up to 22 cm (9 in.) at slab bottom] dramatically reduces the structural capacity of the pavement; the resilient modulus has been estimated at 275 MPa (initially) to 690 MPa (after 1 to 2 years) (40,000 to 100,000 psi). Therefore, the concrete overlay must be designed as a new pavement over a high-quality base and not as an unbonded concrete overlay. This will result in thicker overlays, but no preoverlay repair is needed except, perhaps, a level-up with AC if the pavement profile is too rough for paving a uniform slab thickness. Rubblization offers several advantages over traditional break-and-seat methods:

- The PCC completely debonds from the reinforcing steel during the rubblization process. Therefore, rubblization is effective on JRCP and CRCP, with only the need to remove steel exposed on the surface before overlaying.
- The impact load applied is relatively small, so disturbance to the support material, underground drainage structures, and utilities is minimized.

Some difficulties of rubblization have occurred when the slab is rested directly on a soft subgrade, as described in Chapter 4. Adequate performance of unbonded concrete overlays over rubblized pavement sections has been reported (*21*). Several of the UBOLs evaluated in this study are built on rubblized pavements and are performing well.

Benefits and Limitations

The fracture techniques provide a viable preoverlay treatment for excessively deteriorated pavements. Fracturing the existing pavement creates a uniform base that eliminates reflection cracking. According to observations in Pennsylvania, the rubblized pavements may also provide some positive drainage. If done properly, fracturing will not be detrimental to the subgrade; crack and seat will not damage the existing drainage system.

Drawbacks include a reduction in the structural capacity of the existing pavement, but that can be remedied by providing additional overlay thickness, provided there is adequate vertical clearance. Other possible problems include washing out of the calcium from the fractured concrete and the noise that is created during fracturing. Rubblization may be difficult or impossible if the slab is resting directly on a fine-grained soft soil; the foot of the equipment used may sink into the rubblized material and subgrade.

Recommendations

Rubblizing and crack and seat of the existing pavement have been used successfully as preoverlay treatments for unbonded concrete overlays. Rubblizing is recommended for reinforced pavements that have a lot of durability problems or that require extensive repairs over more than 50 to 70 percent of the surface area of the existing pavement. The implications of fracturing on thickness are discussed in the section on thickness design. An interlayer is still required on fractured existing slabs.

SUBDRAINAGE

The need for a subsurface drainage system for an unbonded concrete overlay will be evident from observation of the types of distress on the existing pavement. Poor drainage will lead to distresses such as pumping and faulting. The presence of large amounts of these distresses indicates the need for positive drainage and installation of a subsurface drainage system.

Several options are available. One option that has been used by the Iowa Department of Transportation with some success consists of drying out the existing pavement by using deep trenches [810 mm (32 in.) deep] for edge drains 1 year before rehabilitation so that moisture in the subgrade will be reduced. Some states, including Minnesota and Pennsylvania, also use asphalt-treated permeable interlayers as a means for providing drainage. The permeable layer intercepts the water that infiltrates the unbonded concrete overlay and channels it to an edge drain. Evidence uncovered in this study indicates that stripping of the AC can cause the permeable interlayer to be reduced to gravel. Cores taken from an unbonded concrete overlay showed that the AC of the permeable interlayer had stripped.

Retrofitting of the unbonded concrete overlay with an edge drain is another option that has been used. There is some general evidence that retrofit edge drains for PCC pavements may not provide substantial long-term performance benefits (*22*). On the other hand, a number of sections evaluated in this study showed that even the most rudimentary edge drain could significantly improve performance. An unbonded concrete overlay in Iowa, with farm tiles used as an edge drain, outperformed an adjacent section without drainage.

INTERLAYER DESIGN

After preoverlay treatment of the existing pavement, the next step in UBOL design is the design of the interlayer. The main purposes of the interlayer are as follows:

- Isolate the overlay from the underlying deteriorated pavement and prevent reflection cracking or other reflective failures.
- Contribute to the uniform support provided to the overlay.
- Maintain a sufficient amount of bonding and friction between the existing slab and the new PCC overlay so that weakened joints can form in JPCP and JRCP, and the proper amount of cracks at the appropriate spacing will form in JRCP and CRCP overlays.
- Provide a level-up layer when necessary.
- Provide a cost-effective component in the UBOL system.

To serve these purposes, the interlayer should not disintegrate or erode over time so that it will maintain its beneficial separation qualities over the design life of the overlay. The type, quality, and thickness of the material selected as an interlayer will ensure that these objectives are met. Also, the uniform support provided allows stresses within the overlay to be distributed evenly. Numerous materials have been used as interlayers. These include hot-mix AC, bituminous surface treatment, lean concrete, cement-treated aggregate, polyethylene sheeting, heavy roofing paper, and curing compound (*13,17,23,24*). The thicknesses of the layers range from 0.15 mm (6 mils) for polyethylene sheeting to 25 to 100 mm (1 to 4 in.) for an AC leveling course. Some of these materials have additional beneficial qualities, such as being permeable enough to serve as a drainage layer (*21,25*).

The best results by far have been obtained with a relatively thick [25 mm (1 in.) or more] layer of hot-mix AC. According to Pfeifer (*26*), an asphalt interlayer provides an improved, soft support condition for the overlay that prevents construction of a stiff rigid layer on top of another rigid layer, which would lead to cracking and faulting for nondoweled pavements. Projects in Iowa that were evaluated for this study also show that the unbonded concrete overlays that perform best are those constructed with uniform support provided by both the subgrade and the interlayer (*27*). Therefore, for most designs, an AC layer is recommended as the interlayer. A layer of AC at least 25 mm (1 in.) thick can effectively isolate the overlay from the existing pavement slabs; it can also serve as a leveling course and smooth surface for the paving operation. However, if the measured deflection load transfer at transverse joints and cracks is less than 50 percent, an interlayer thickness greater than 38 mm (1.5 in.) is recommended.

Thin-layer materials such as polyethylene sheeting, roofing paper, and curing compound have not performed well as interlayer materials and are not recommended (*24*). The poor performance of these materials is believed to be due to the inadequacy of the thin interlayer to effectively isolate the two layers.

Minnesota and Pennsylvania have started to experiment with using thick permeable AC interlayers that drain into an edge drain as the combination separation-drainage layer. This design is relatively new, so no long-term performance data are available. Stripping of the permeable base was observed from some cores taken during this study; however, the remaining granular material appeared to be acting effectively as a permeable layer. More performance data are necessary before permeable AC interlayers can be recommended for widespread use. Clearly, tests should be conducted on the AC interlayer for stripping susceptibility (i.e., modified Lottman test), and crushed aggregate should be used to minimize the detrimental effect if stripping occurs. If an asphalt-treated permeable layer is to be used, 100 percent crushed aggregate is recommended. Other bituminous surface treatment materials are available that can be used as interlayer materials but only on low-volume roads. These include slurry seals and cutbacks or emulsified asphalt with a sand cover. They are thin-layer materials that can be used when surface roughness is not present in the existing pavement or has been removed during preoverlay repair (*17*). These materials tend to erode quickly and are not durable.

Lean concrete is one of the standard materials used as an interlayer in Germany (*28*). This layer is used as a leveling course and to adjust the cross-slope; the standard thickness used is 100 mm (4 in.). Although this material has been used successfully in Germany, it is important to reiterate that the standard practice in Germany is to fracture the existing pavement before overlaying and to put a thick overlay on the lean concrete interlayer (with sawed joints that match the overlay joints) placed on the fractured pavement.

Table 11 provides recommendations for selecting an interlayer for unbonded concrete overlays. These recommendations are based on information that was provided by the American Concrete Pavement Association (*17*) and were revised based on the information gathered during this study. See Appendix A for further information.

If an existing AC overlay is present, this layer may be used as all or part of the interlayer. If badly deteriorated, it should be removed and replaced with AC. Otherwise, it should be milled to provide a smooth surface on which to build the overlay.

THICKNESS DESIGN

All currently available design procedures for unbonded concrete overlays for highway applications have significant limitations. However, two procedures are suggested for thickness design of unbonded concrete overlays. The approach recommended in these guidelines for thickness design is to use these two approaches and any other locally available approach to develop multiple designs. The final design should be selected based on a comparison of the designs, an evaluation of additional factors, and specific design checks.

The first approach is based on the structural deficiency concept, which requires the unbonded concrete overlay to satisfy a structural deficiency between the required thickness for a new slab resting on the same foundation, if one were to be built, and the thickness of the existing pavement. The second approach requires that the maximum structural responses in the overlay pavement should be equal to the maximum structural responses of a new pavement that would have to be built on the subgrade to meet the same requirements. Following is a description of how each approach can be used to obtain a design.

TABLE 11 Recommendations for selecting interlayer materials (*17*)

General Pavement Condition	Repair Work Performed?	Minimum Recommended Interlayer*	Other Factors To Consider
ALL CONCRETE PAVEMENTS:			
Badly Shattered Slabs	Yes - Replaced Full-Depth	Thin	Subgrade Repair, Drainage
High Deflections/Pumping	Yes - Replaced Full-Depth Yes - Seated	Thin Thick	Subgrade Repair, Drainage Drainage/Dowels in Overlay**
Unstable Slabs	Yes - Undersealed Yes - Seated	Thin Thick	Drainage/Faulting/Dowels in Overlay** Drainage/Dowels in Overlay**
Faulting < 0.25 in.	None	Thin	Repair Voids? - Drainage
Faulting > 0.25 in.	Yes - Cold Milled None	Thin Thick	Repair Voids? - Drainage Repair Voids? - Drainage
Surface Spalled/Extensive "D"-cracking	Yes - Filled with Cold-Patch None	Thin Thick	Mismatch Joints/Dowels in Overlay** Mismatch Joints/Dowels in Overlay**
Reactive Aggregate	None	Thin	Drainage
JOINTED CONCRETE PAVEMENTS:			
Spalled & Deteriorated Joints	Yes - Filled with Cold-Patch None	Thin Thick	Mismatch Joints Mismatch Joints
CONTINUOUS REINFORCED PAVEMENTS:			
Punchouts	Yes - Replaced Full-Depth	Thick	Subgrade Repair, Drainage
COMPOSITE PAVEMENTS:			
Rutting < 2-in.	None	Thin/None	Joint Sawing Depth
Rutting > 2-in.	Yes - Cold Milled	Thin	Drainage
Medium to High Severity Reflective Cracking	Yes - Repair Exist. PCC None	Thin Thin	Mismatch Joints from Refl. Cracks Mismatch Joints from Refl. Cracks
Remove Asphalt Surface	Yes - Repair Exist. PCC	Thin	Drainage

* Thick Interlayer>0.5 in, Thin Interlayer < 0.5 in.

** Particularly for heavy traffic routes.

Note: if poor load transfer exists (<50 percent deflection load transfer), a minimum AC interlayer thickness of 38 mm (1.5 in) is recommended.

Structural Deficiency Approach

The *AASHTO Guide for Design of Pavement Structures* (*3*) provides a design procedure for unbonded concrete overlays that is based on the structural deficiency concepts developed by the Corps of Engineers (*29,30*). Using this approach to determine overlay thickness involves the following three steps:

1. Evaluate the condition of the existing pavement.
2. Determine a thickness of the new pavement, required to sustain the future traffic loading if the existing pavement is ignored.
3. Find the UBOL thickness by using the following empirical square root equation:

$$D_{OL} = \sqrt{D_f^2 - D_{eff}^2} \quad (14)$$

where

D_{OL} = concrete overlay thickness;
D_f = required thickness for a new concrete pavement under the same design conditions; and
D_{eff} = effective thickness of the existing concrete pavement [maximum of 254 mm (10 in.) allowed].

The required thickness for new pavement can be obtained with the AASHTO design monographs or the computer program DARWin. This is also the thickness of the overlay if the existing pavement is rubblized. Two methods are available in the AASHTO Guide for determining D_{eff}: the condition survey method and the structural equivalency approach. The method recommended to determine D_{eff} for unbonded concrete overlay design is the condition survey method.

Using the condition survey method provided in the AASHTO Guide, the effective slab thickness can be determined from the following equation (*3*):

$$D_{eff} = F_{jcu} \times D \quad (15)$$

where

D = existing PCC slab thickness (in.) [limited to a maximum of 250 mm (10 in)]; and
F_{jcu} = joints and cracks adjustment factor for unbonded concrete overlays.

The maximum D that is recommended for unbonded concrete overlay design is 250 mm (10 in.). Therefore, even if D is greater than 250 mm (10 in.), a value of 250 mm (10 in.) should be used. If there is an existing AC overlay, it should be neglected when D_{eff} of the existing pavement is being determined.

F_{jcu} is determined based on the condition survey results. The following information is required to determine F_{jcu}:

- Number of unrepaired deteriorated joints per 1.6 km (1 mi);
- Number of unrepaired deteriorated cracks per 1.6 km (1 mi); and
- Number of expansion joints, exceptionally wide joints [greater than 25 mm (1 in.)], or full-depth, full-lane-width AC patches per 1.6 km (1 mi).

Based on the total number of unrepaired deteriorated joints, cracks, and other discontinuities per 1.6 km (1 mi), F_{jcu} is determined from Figure 7. If extensive full-depth repair is conducted on the existing pavement before placement of the

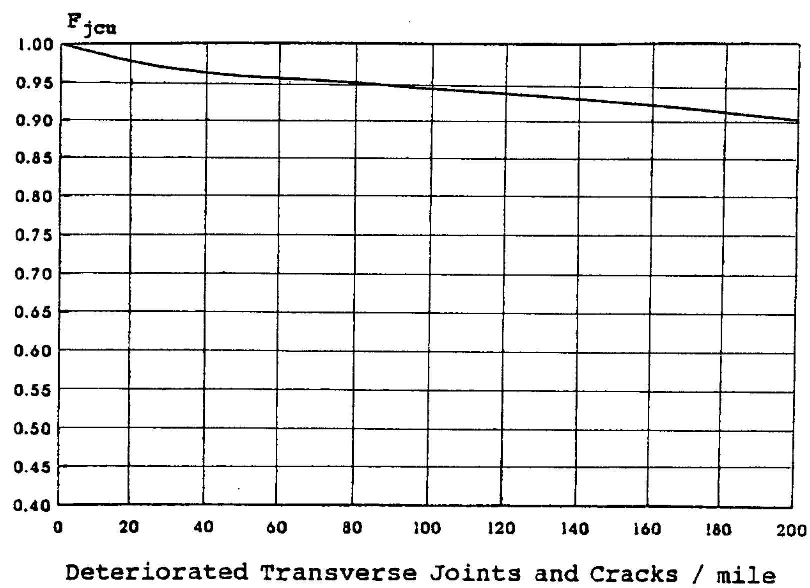


Figure 7. F_{jcu} factor (3).

unbonded concrete overlay, a thinner AC interlayer should be used and an F_{jcu} value equal to 1.00 is used. Hall et al. (*31*) report that this approach has some limitations and must be used with caution; obtaining other designs with alternative procedures for comparison is strongly recommended. The most serious and obvious limitation occurs if the existing pavement is fairly thick, and the UBOL may be too thin. This problem has occurred on several UBOLs.

Structural Equivalency Approach

The structural equivalency concept requires that the structural responses in the unbonded concrete overlay pavement be equal to the corresponding structural response in an equivalent new pavement. This design approach was used by the Portland Cement Association (PCA) to develop a design procedure based on the equality of the maximum bending stresses in the overlay and the equivalent pavement (*32*). The computer program J-SLAB was used in development of the PCA overlay design method. This program is capable of analyzing a two-layered plate, but it assumes that the layers exhibit the same deflection profile. The cracks in the existing slab were modeled with soft elements. Curling caused by thermal gradients was not considered in development of the PCA design method, which is a major limitation.

Because the condition of the existing pavement can significantly affect the stresses in the overlay, three design charts are available for thickness design for the different conditions often encountered (*32*):

- Case 1: Existing pavement exhibits a large amount of midslab and corner cracking, and poor load transfer exists at joints and cracks.
- Case 2: Existing pavement exhibits a small amount of midslab and corner cracking. It exhibits reasonably good load transfer at the joints and cracks. Localized repairs are performed to correct distressed slabs.
- Case 3: Existing pavement exhibits a small amount of midslab cracking and good load transfer at the cracks and joints. The loss of support is corrected by subsealing.

The PCA design charts for design of unbonded PCC overlays are shown in Figures 8, 9, and 10 for Cases 1, 2, and 3, respectively. The full-depth pavement thickness determined by the PCA procedure for new design is used with the overlay design charts to determine the required overlay thickness.

As shown in the design charts, the minimum thickness required for unbonded PCC overlays is 150 mm (6 in.). When a tied shoulder is used, the overlay thickness may be reduced by 25 mm (1 in.), provided the minimum thickness

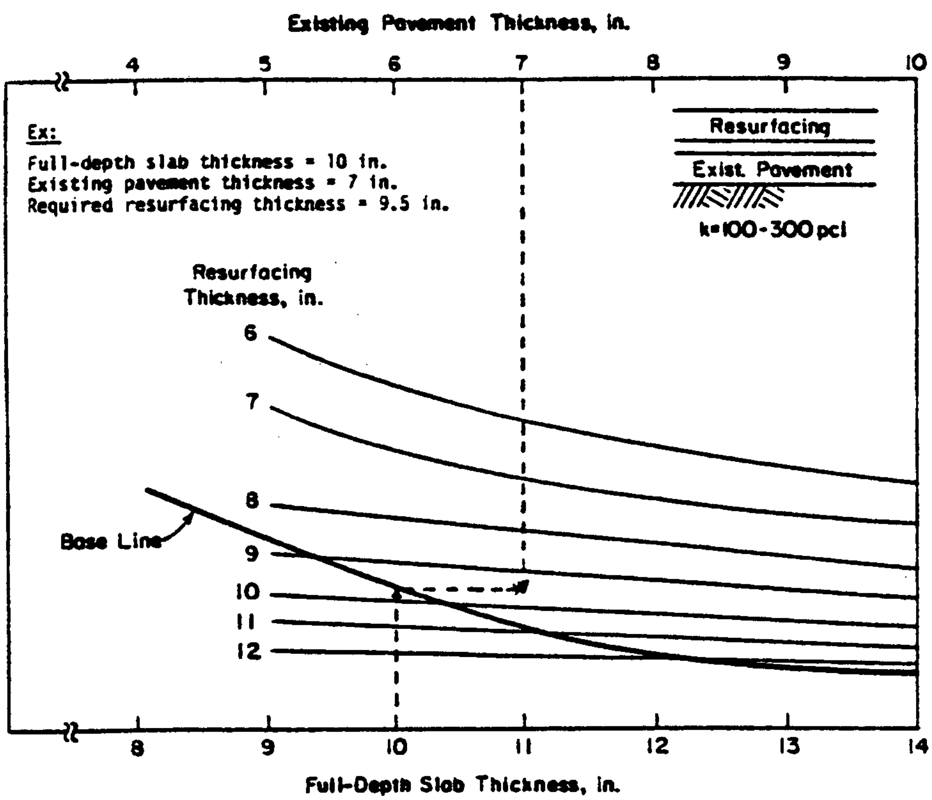


Figure 8. UBOL design chart for Case 1 (32).

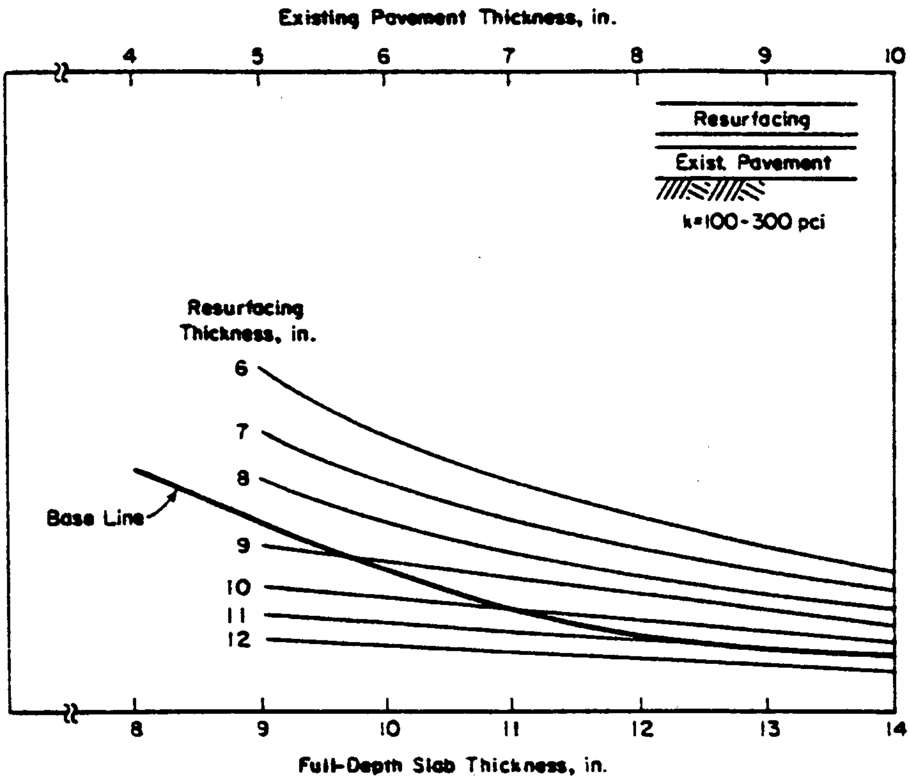


Figure 9. UBOL design chart for Case 2 (32).

criterion is met. This provision is based on the results of a field evaluation of pavement sections with tied shoulders that was performed in Minnesota (*14*). Note that the tied shoulder should be placed monolithically to provide significant load transfer so that slab thickness can be reduced.

Preliminary Thickness Designs

In addition to the thicknesses determined for the given site conditions by the two procedures, an UBOL design should also be developed by a local procedure, if available, to obtain another thickness design. The minimum recommended thickness for an unbonded concrete overlay using any design procedure based on the results from this study is 178 mm (7 in.) for heavy traffic conditions. Thinner overlays have often failed rapidly under heavy traffic; this is especially true for CRCP. Exceptions include thinner [140 to 165 mm (5.5 to 6.5 in.)] unbonded concrete overlays for low-volume roads such as those used successfully by Iowa on county routes. Consequently, if any design thickness is less than 178 mm (7 in.) thick, the thickness should be adjusted to 178 mm for traffic greater than 0.25 million ESALs per year.

The initial thickness estimate is used to determine the other design features that require thickness as an input, such as reinforcement and joint spacing. The selected designs are then used in design checks to establish whether they will meet minimum performance criteria. These include the following:

- Faulting for JPCP;
- Transverse crack deterioration of JRCP; and
- Localized failure (punchouts) for CRCP.

Guidelines for conducting such checks of the preliminary designs are described in detail in the section "Design Checks." If models are available, checks should also be made for corner breaks of JPCP and faulting of JRCP. See Appendix A for further information.

OVERLAY PAVEMENT TYPE

All types of conventional PCC pavements (JPCP, JRCP, and CRCP) can be used as UBOLs, provided the best practices are followed. Following are recommendations on the conditions under which the different pavement types can be used.

JPCP

JPCP is recommended for most conditions. It can be used as an overlay for all types of existing pavements and all traffic, climate, and support conditions. When used on an exist-

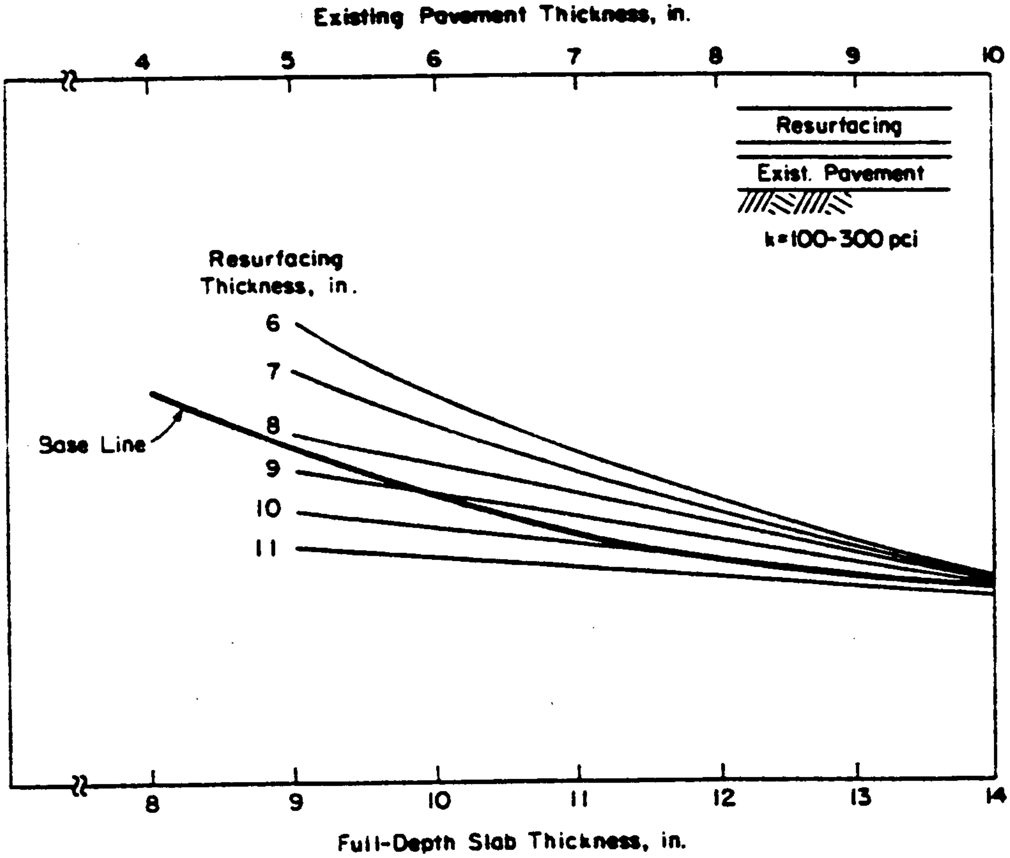


Figure 10. UBOL design chart for Case 3 (32).

ing JPCP, it is recommended that the joints be mismatched or at least not intentionally matched. The performance of JPCP overlays has been excellent as long as the slab thickness, joint spacing, joint load transfer, and interlayer are adequate for the given conditions.

JRCP

JRCP can be used for most types of existing pavements and for most site conditions. However, similar to conventional JRCP, UBOLs of JRCP tend to have problems with joint deterioration and transverse crack deterioration. These problems can be addressed through improved design features, including the use of sealants, shorter joint spacing, and increased reinforcement. However, few agencies are building JRCP because of the problems that have been associated with them in the past.

CRCP

There has been some concern about the use of CRCP unbonded concrete overlays because of widely publicized premature failures of a few projects. This includes the early punchouts of a 175-mm (7-in.)-thick unbonded CRCP overlay over a JRCP with high deflections on I-90 in Pennsylvania (*33*). Another 150-mm (6-in.)-thick CRCP overlay over JRCP in Arkansas also developed punchouts a few months after it was opened to traffic (*34*). However, successes in Illinois, Texas, and Europe, for example, indicate that reasons other than pavement type (probably very poor load transfer at joints and cracks in the underlying JRCP) were responsible for these early failures.

Based on the results of this study, CRCP UBOLs can be used for any type and condition of existing pavement, traffic level, and climate. However, the structural condition of the existing pavement is very critical to the performance. The type of interlayer used and the thickness of the CRCP overlay are also critical to long-term performance. The interlayer used must allow development of sufficient friction so that transverse cracks can form uniformly in the overlay and prevent the development of wide cracks and, therefore, poor load transfer and high deflections in the overlay later in life.

Because of the large number of cracks in existing CRCP, care must be taken to ensure that all wide and deteriorated cracks are repaired before overlay or other design features (such as an extra thick AC interlayer, increased reinforcement, and increased overlay slab thickness) are used to prevent reflection cracking and failures of an unbonded CRCP overlay. Under no circumstance should the thickness of a CRCP overlay be below 175 mm (7 in.).

OVERLAY MATERIALS

Good-quality conventional concrete mixes that will provide high-quality concrete with the desired strength and that will be durable under the expected load and environmental conditions are adequate for unbonded concrete overlays. Fast-track mixes that allow high early strength gain and make it possible for the pavement to be opened to traffic within 6 to 24 hours may also be used for unbonded concrete overlays. Specialty concretes such as fiber-reinforced concrete can also be used (*1,23,35,36*).

The characteristics of conventional mixes that influence new and reconstructed PCC pavement performance will also influence the performance of unbonded concrete overlay. A low water-cement ratio, high-quality aggregates, adequate cement content, and appropriate air entrainment are all important attributes of good-quality concrete. Concrete that is placed, consolidated, finished, textured, and cured by the proper construction techniques will provide concrete with adequate strength, durability, and performance. A 28-day compressive strength of 30 MPa (4,000 psi)/4.5 MPa (650 psi) flexural strength for unbonded concrete overlays is typical. Table 12 provides recommendations for entrained air in finished slabs that will provide weather-resistant concrete; these are recommended even in locations where freeze-thaw conditions do not exist (*37*), but they must be adjusted to fit local materials and climate. These amounts of entrained air will also improve the concrete while it is still in the plastic stage by doing the following (*37*):

- Prevent segregation;
- Increase workability;
- Reduce bleeding; and
- Reduce the water required for satisfactory workability.

Other materials used in construction of unbonded concrete overlays include interlayer materials, curing materials, and, where required, joint sealant materials. The influence of interlayer materials on the performance of unbonded concrete overlays is discussed elsewhere. The effects of curing and joint sealant materials are not particularly different for unbonded concrete overlays compared with conventional pavements.

TABLE 12 Recommended air entrainment in finished slab (*37*)

Maximum-size Aggregate, mm (in)	Entrained Air, percent
37.5 (1½)	5±1½
25.0 (1)	6±1½
19.0 (¾)	6±1½
12.5 (½)	7±1½
9.5 (⅜)	7±1½

Note: The air contents are for the finished slab. Most air tests are conducted on plastic concrete taken in front of the paver. The vibrating of the concrete in the paver will reduce the final air content.

REINFORCEMENT

Reinforcement design for JRCP and CRCP unbonded concrete overlays is not different than that for conventional pavements. There is substantial evidence that increasing the reinforcement content for conventional JRCP or CRCP will reduce the amount of deteriorated transverse cracks in both pavements and punchouts in CRCP (*38–42*). Factors that need to be considered include (1) the friction between the UBOL and the interlayer and (2) the influence of the working cracks in the existing pavement that may create a need for additional reinforcement to hold the cracks in the overlay tightly together.

Reinforcement for JRCP Overlays

For JRCP unbonded concrete overlays, steel is required to hold tight the transverse cracks that will form and that could deteriorate over time from a combination of load, temperature gradient, moisture gradient stresses, and concrete volume changes due to temperature and moisture variations in the PCC. Previous reinforcement design guidelines for conventional JRCP have been shown to be inadequate (*40,41*) because of the traditional basis used to calculate the amount of steel reinforcement, i.e., the concept of pulling the slab over the layer beneath by the reinforcement without yielding it.

Table 13 provides recommendations, based on recent research (*43*), for adequate reinforcement to limit the number of deteriorated transverse cracks in the overlay to 15 per kilometer (25 per mile). A minimum steel content of 0.15 percent is recommended to limit crack deterioration potential. Deformed steel wire or deformed reinforcement bars are strongly recommended for use in JRCP (*40,41*). Transverse steel may be used to aid placement of the longitudinal steel. The reinforcement should be located above mid-depth but with at least 76 mm (3 in.) of concrete cover on top. The resulting cracks will be tighter the closer the reinforcement is to the top of the slab.

Reinforcement for CRCP Overlays

The transverse cracks that form in CRCP will deteriorate over time if adequate steel is not provided to hold tight the cracks so that there is enough aggregate interlock to withstand the shear forces from heavy axle loads. Holding the cracks tight also limits the infiltration of deicing chemicals into the crack that will corrode the steel. There is consider-

TABLE 13 Recommended minimum percent deformed reinforcement content for JRCP

Slab Thickness, mm (in.)	Minimum Percent Reinforcement[1]
125 - 165 (5 - 6.5)[2]	0.15
165 - 190 (6.5 - 7.5)[2]	0.16
190 - 216 (7.5 - 8.5)	0.17
216 - 241 (8.5 - 9.5)	0.18
241 - 267 (9.5 - 10.5)	0.19
267 - 292 (10.5 - 11.5)	0.20
292 318 (11.5 - 12.5)	0.21

[1] Required deformed reinforcement to limit the number of deteriorated transverse cracks to 15/km or less.
[2] Thicknesses and reinforcement for low-volume unbonded concrete overlays if required. JPCP is recommended instead.

able evidence that crack spacing less than the 0.9 to 2.4 m (3 to 8 ft) cited in the literature will not be detrimental to performance. Several CRCPs that have transverse crack spacing less than 0.9 m (3 ft) but adequate steel content (higher than conventional) are performing very well (*38,39,42*). Crack width appears to be the more critical parameter for minimizing punchouts and ruptured steel (*44–47*).

Table 14 provides recommendations for the percent steel reinforcement in CRCP overlays based on the cross-sectional area of the slab. The recommendations were developed based on results from the AASHTO design guide procedure and from a model developed from field data collected on CRCP in Illinois (*3,42*). The criteria used to develop these recommendations include a crack width of 0.51 mm (0.02 in.) and temperature drops of 15.5°C (60°F) and 37.8°C (100°F) for nonfreeze and freeze areas, respectively. This crack width protects the cracks against the potential for loss of aggregate interlock over time. Also, according to this model, the percent steel range of 0.60 to 0.75 obtained for CRCP will protect against development of more than approximately three punchouts per kilometer (five punchouts per mile).

Several CRCPs in Illinois, Belgium, France, and Spain with steel contents between 0.7 and 0.85 percent have very tight cracks (*38,48*). Over 100 km (62 mi) of CRCP in Belgium with 0.85 percent steel and cracks spaced at approximately 0.49 m (1.6 ft) are known to have carried estimated traffic of more than 35 million ESALs over 20 years without any punchouts. The standard Illinois CRCP reinforcement content is 0.70 percent, which has produced closely spaced tight cracks and excellent performance (*48*).

Deformed steel bars that meet AASHTO specifications (AASHTO Designation M31, M42, or M53) and conform to ASTM Grade 60 tensile strength requirements are recommended for longitudinal steel. The steel must be placed above mid-depth, close to the top of the slab, but with a minimum of 76 mm (3 in.) of concrete cover. Placing the steel close to the top will keep the cracks tighter. Transverse steel is not required in CRCP because the longitudinal joints will minimize random longitudinal cracking. However, if used for construction expediency, transverse reinforcement should be No. 4, 5, or 6 Grade 60 deformed bars that meet requirements similar to those for longitudinal steel. It is emphasized that friction is very important to uniformity of crack spacing in CRCP; therefore, it is necessary to ensure that friction exists between the interlayer and the CRCP overlay slab.

TABLE 14 Recommended reinforcement content for CRCP overlays to minimize localized failures (punchouts)

Slab Thickness, mm (in.)	Minimum Percent Reinforcement		Punchouts/ km (mi) freeze
	Non-freeze	Freeze	
184 - 222 (7.25 - 8.75)	0.60	0.70	<2.5 (4.0)
222 - 260 (8.75 - 10.25)	0.65	0.70	<2.8 (4.5)
260 - 330 (10.25 - 13.0)	0.65	0.75	< 3 (5.0)

JOINT DESIGN

For jointed concrete overlays, proper joint design is extremely important to long-term performance. The key aspects of joint design are described in the following sections.

Joint Spacing

Unbonded JPC overlays are subject to greater curling stresses because of the very stiff support provided by the existing pavement. Therefore, JPC overlays generally require shorter joint spacing than conventional jointed concrete pavements on an aggregate base course. To prevent cracking due to curling stresses, either shorter joint spacing or reinforcement must be provided. Results from this study and others have shown that, for adequate performance and to keep curling stresses low, the *L/l* ratio should be less than 5.5 (perhaps as low as 4.5 in drier climates), which is identical to the recommendation for JPCP over a very stiff base (*49*). The L/*l* ratio is calculated by the following equation:

$$L/l = \frac{L}{\left[Eh^3/\left\{12(1-\mu^2)k\right\}\right]^{1/4}} \quad (16)$$

where

- l = radius of relative stiffness (in.);
- L = slab length (joint spacing) (in.);
- E = concrete modulus of elasticity (psi);
- h = slab thickness (in.);
- μ = Poisson ratio; and
- k = modulus of subgrade reaction (for the subgrade, not the top of the existing pavement) (psi/in.).

A maximum *L/l* of 5.5 results in joint spacing in feet of approximately 1.7 to 2.0 times the slab thickness in inches. As a rule of thumb, joint spacing in feet less than 1.75 times the slab thickness in inches is recommended for JPCP up to a maximum joint spacing of 6 m (20 ft). However, this rule does not properly consider the subgrade stiffness, which is very important in affecting curling stress. Table 15 provides recommendations for unbonded JPCP overlay joint spacing that does consider the subgrade stiffness. Pfeifer (*26*) recommends a thick interlayer to provide an improved, softer bedding condition for the overlay to reduce the curling stresses that can develop.

Although a maximum *L/l* ratio of 5.5 is recommended, each agency should conduct an evaluation into an appropriate value for local conditions. A lower value may be appropriate in dry and warm climates because of increased curling and warping. Joint spacing recommendations for unbonded jointed reinforced concrete overlay are similar to those for conventional JRCP design.

Joint Mismatching

The transverse joints in unbonded concrete overlays are often deliberately mismatched with those in the underlying pavement (Figure 11). A minimum offset distance of 1 m (3 ft) between the joints in the overlay and the underlying joints or cracks is usually recommended (*17*). By placing the joint in the overlay before the joint in the underlying pavement, as illustrated in Figure 12, a sleeper slab effect is provided that should further improve load transfer across the joints.

TABLE 15 Recommended maximum transverse joint spacing for unbonded jointed plain concrete overlays[1]

Slab Thickness, mm (in)	Subgrade k-value, KPa/mm (psi/in.)	Maximum Joint Spacing, m (ft)
152 (6)	28 (100)	3.96 (13)
	55 (200)	3.66 (12)[2]
	110 (400)	3.66 (12)[2]
203 (8)	28 (100)	4.88 (16)
	55 (200)	4.27 (14)
	110 (400)	3.96 (12)[2]
254 (10)	28 (100)	5.79 (19)
	55 (200)	4.88 (16)
	110 (400)	4.27 (14)
305 (12)	28 (100)	6.10 (20)[3]
	55 (200)	5.79 (19)
	110 (400)	4.88 (16)

[1]Maximum $L/\ell = 5.5$; E = 27,586 MPa (4,000,000 psi); μ=0.15. Each agency should evaluate this recommendation and perhaps use a lower value, such as 4.5 or 5.0, for specific climatic conditions. [2]Minimum recommended. [3]Maximum recommended. See references 12 and 15 for improved recommendations on joint spacing with climate.

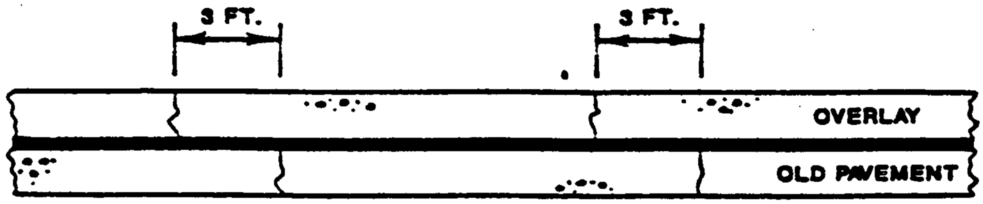


Figure 11. Joint mismatching of unbonded concrete overlays (17).

No documented data or results from analytical examinations were available to support this recommendation before this study. Work carried out to investigate the effect of joint mismatching shows that in a few cases joint mismatching significantly reduces bending stresses in the overlay pavement. However, this was not true in most cases. In general, similar stresses are obtained for pavements with matched and mismatched joints. However, the results indicate that the maximum corner deflections in pavements with mismatched joints are significantly lower than those in corresponding pavements with matched joints.

This reduction in deflections obviously will improve performance and lead to better protection of the overlay, interlayer, underlying pavement, and subgrade from traffic loading. Based on these results, mismatching of joints (including at major cracks) by an offset of at least 1 m (3 ft) is recommended. However, mismatching of joints needs to be balanced against the additional construction work that can lead to a significant increase in cost.

Load Transfer Design

The support of the underlying pavement is a means of providing load transfer across the joints of unbonded concrete

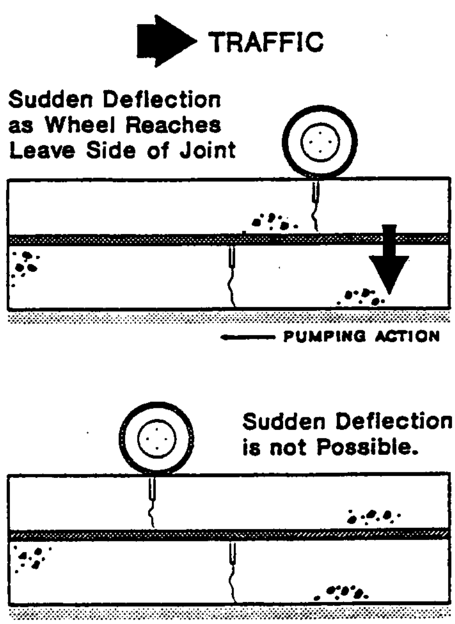


Figure 12. Sleeper slab providing support to UBOL (17).

overlays. Consequently, joint performance in terms of load transfer efficiency is significantly better in unbonded concrete overlays than in new or reconstructed pavements. As discussed previously, the transverse joints in unbonded concrete overlays are often deliberately mismatched from those in the underlying pavement; this provides additional load transfer. Because of the support provided at the joint from these different sources, faulting tends to be less of a problem for unbonded concrete overlays.

However, it may still be necessary to include dowels at the joint to improve load transfer if heavy truck traffic is expected. Dowels will promote good load transfer, minimize joint faulting, prevent corner breaks, and ensure good long-term performance overall (*43,50–52*). Two models (one developed in a previous study and another developed in this study with LTPP data) show that dowel presence and size significantly influence the occurrence and progression of faulting of unbonded concrete overlays. These models are presented later for use as design checks.

For pavements with heavy truck traffic (i.e., 1 million or more ESALs per year), dowels are recommended. Table 16 provides recommendations for dowel sizes for the typical ranges of design traffic for JPCP and JRCP. Solid Grade 40 or higher steel dowels placed at 305-mm (12-in.) centers are recommended, although variable spacing (wider spacing used outside the wheel paths) is also allowed. To decrease the susceptibility of the dowels to corrosion, epoxy-coated, stainless steel-coated, or metallic-sleeved dowels are recommended. In Germany, plastic-coated 25-mm (1-in.) dowels are used spaced at 254-mm (10-in.) centers in the wheel paths with high-quality concrete (7,000 psi), a strong base (30- to 36-in. total pavement structure), and good subgrade support that is checked with the German plate load test (*39*).

Dowels should also be considered in areas where snowplowing is common to prevent negative faulting where the edge of the joints are damaged by snowplows, even though total faulting may not be excessive.

Joint Orientation

Joint orientation refers to whether the joints are skewed or normal or to whether uniform or repeated variable joint spacing is used. Comparison of two conventional pavements showed that when no dowels are used in transverse joints of JPCP, skewed joints reduce faulting by as much as 50 percent over perpendicular joints (*43*). No such evidence is

TABLE 16 Recommended dowel diameter for different loading conditions[1] *(53)*

Design Traffic (million ESALs)	Recommended Dowel Diameter, mm (in)
<30	32 mm (1¼ in)
30 - 90	38 mm (1½ in)
>90 - 150	41 mm (1⅝ in)

[1] Dowel spacing of 305 mm (12 in) assumed.

available for unbonded concrete overlays, but there is also no evidence that joint orientation by itself has a negative influence on long-term performance of unbonded concrete overlays. Several of the unbonded concrete overlay pavements evaluated in this study have skewed joints and have not performed any differently than conventional pavements with skewed joints or unbonded concrete overlays with normal joints.

An evaluation of a 180-mm (7-in.)-thick JPCP unbonded concrete overlay in Canada, 4 years after construction, showed no negative effects due to the skewed joints at random spacings between 3.7 and 5.8 m (12 and 19 ft) *(54)*. Also, California had been using randomly spaced [4.0, 5.8, 5.5, and 3.7 m (13, 19, 18, and 12 ft)] skewed joints in unbonded concrete overlays for years with no detrimental effects except for transverse cracking in the longer slabs *(24,55)*. To reduce cracking, this design was later reduced to 3.6, 4.5, 4.0, and 4.2 m (12, 15, 13, and 14 ft). However, California also has over 144 km (90 mi) of nondoweled JPCP with untied center longitudinal joint and (3.6-, 4.0-, 5.8-, and 5.5-m) (12-, 13-, 19-, and 18-ft) skewed joints over a cement-treated base that have experienced interior corner break cracking of the acute angle between the transverse and longitudinal joints. In view of this actual in-service performance, CALTRANS has discontinued the use of skewed joints *(56)*.

Similar observations have been made in Florida, where the performance of skewed joints for pavements with rigid bases has been poor. Significant corner cracks were observed on a 229-mm (9-in.) unbonded concrete overlay with skewed joints placed on a 152-mm (6-in.) econocrete base on I-75 south of Tampa *(57)*. Based on these observations, there is no justification for using either skewed joints or random joint spacing if the joints are adequately doweled and the slabs are sufficiently short. Also, when skewed joints are used for non-doweled JPCP, there is evidence that skews in excess of 1 in 10 will lead to occasional corner breaks *(58)*.

Joint Sealant

The two main purposes of joint sealant are to prevent or minimize the infiltration of surface water into the pavement and to keep incompressibles from getting into the joints. High-quality sealant will provide good performance over a considerable time if the manufacturer's recommendations for installation are followed. Joint sealant recommendations are the same for unbonded concrete overlays as for conventional pavements. Important considerations include design of the reservoir, joint width, and sealant type. Recommendations for reservoir dimensions for hot pour, silicone, and preformed sealants are illustrated in Figures 13 to 15. Manufac-

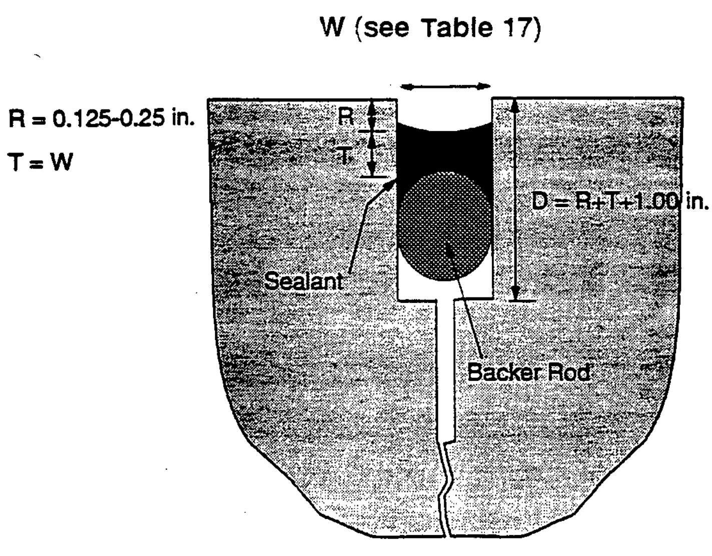


Figure 13. Recommendations for rubberized asphalt and low-modulus rubberized asphalt (53).

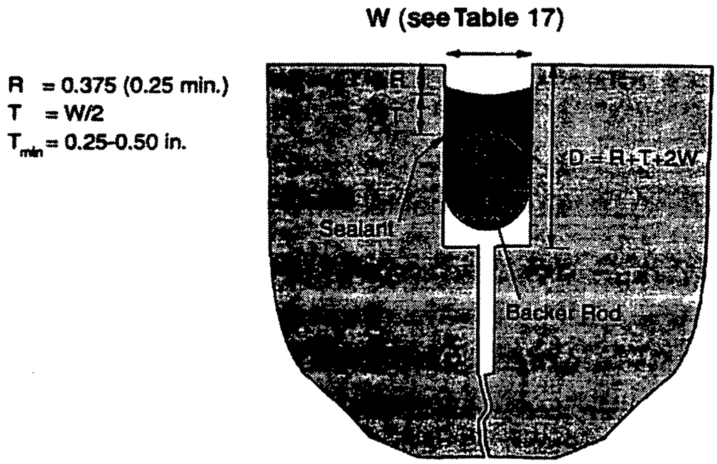


Figure 14. Recommendations for silicone sealant (53).

turers' recommended shape factors and percent extension were used to develop these recommendations. Table 17 provides recommendations for the design widths for the joint sealants. Information on joint sealants is also provided (*59*).

EDGE SUPPORT

Increased edge support will improve the performance of unbonded concrete overlays tremendously. This is especially true for pavements that carry large numbers of heavy trucks. Edge support can be provided either by widening the traveled lane slab or with a tied and monolithically placed PCC shoulder.

Widening

Two types of widening were observed for the unbonded concrete overlays evaluated in this study: intentional widening for structural purposes and widening over a narrower underlying pavement.

Intentional Widening

There is strong evidence to show that intentionally widened slabs significantly improve concrete pavement performance by reducing the critical stresses at the edge of the pavement (*57*). Conceptually, moving traffic away from the pavement edge will lead to a more interior loading condition and will significantly reduce the maximum stresses and deflections that the pavement would otherwise experience at the edge. One study found that a 0.6-m (2-ft) widened slab is equivalent to about 25 mm (1 in.) of slab thickness in terms of the structural benefit provided (*60*). Because there is no discontinuity in a widened slab, it provides more reliable long-term support than a tied concrete shoulder.

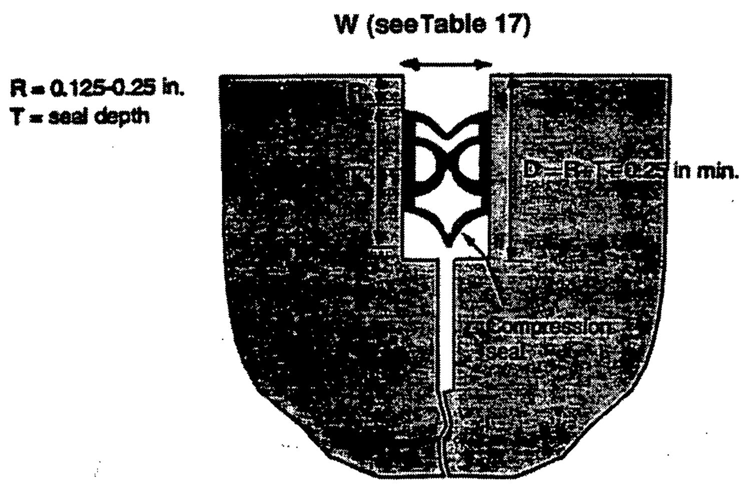


Figure 15. Recommendations for preformed neoprene compression seal (53).

TABLE 17 **Recommended design width for transverse joint sealants** *(53)*

Sealant Type	Joint Spacing	Minimum Joint Width (W), Non-freeze Region	Minimum Joint Width (W), Freeze Region
Rubberized Asphalt	< 15 ft	0.375 in.	0.375 in.
(20% extension maximum)	16 to 25 ft	0.50 in.	N/A
	26 to 40 ft	0.50 in.	N/A
Low-Modulus Asphalt	< 15 ft	0.375 in.	0.375 in.
(50% extension maximum)	16 to 25 ft	0.375 in.	0.50 in.
	26 to 40 ft	0.50 in.	0.50 in.
Silicone	< 15 ft	0.375 in.	0.375 in.
(50% ext. max)	16 to 25 ft	0.375 in.	0.375 in.
	26 to 40 ft	0.375 in.	0.50 in.
Preformed Compression	< 15 ft	0.375 in.	0.375 in.
(20 to 50% compression)	16 to 25 ft	0.375 in.	0.437 in.
	26 to 40 ft	0.50 in.	0.50 in.

1 in = 25.4 mm, °C= (°F-32)/1.8

Computations and assumptions:
Minimum joint width = 0.375 in for improved performance of asphalt and silicone seals
Maximum joint opening = Mmax = C*L(A*T+E)
C = 0.80 aggregate base (used to compute joint widths), 0.65 treated base
L = joint spacing, in
A = thermal coefficient of expansion of concrete (5.5*10^-6/F)
T = change in temperature (installation temperature - minimum temperature)
Installation temperature = 80 °F
Minimum temperature non-freeze region = 20 °F
Minimum temperature freeze region = - 15 °F
E = shrinkage coefficient of concrete (200*10^-6)
Width of the uncompressed seal = S >= Mmax / (Cmax - Cmin)
Cmax = 0.8; Cmin = 0.2
Width of joint saw cut = W = { 1 - PC } * S
PC = percent compression of seal at installation, expressed as a decimal
S = width of uncompressed seal, in

Widening over Narrower Underlying Slab

For expediency, a number of early unbonded concrete pavements involved the placement of wider slabs to increase lane widths to 3.7 m (12 ft) (*24,55,61*). The UBOLs often developed longitudinal cracks. For example, longitudinal cracks observed in the widened I-70 CRCP overlay in Illinois required substantial patching later in the pavement's service life (*61,62*). One design that has been used in widening of narrow concrete pavements is to make the widening portion thicker on each edge. However, this may also lead to longitudinal cracking and is not recommended.

No such distresses have been observed on similar designs constructed in Minnesota. The state continues to build widened unbonded concrete overlays and has reported success with widened slabs built over existing pavements that have been extended along the edge with a bituminous or concrete layer before overlay (*25*). Analytical evidence from this study shows that both AC and PCC (tied and untied) extensions can be used with no significant differences in performance. The main concern is to ensure that adequate support is provided to the edge extension so that it does not settle and lead to a loss of support along the edge. Tying the edge extension may be beneficial in such situations.

Shoulders

Similar to widening, shoulders can influence unbonded concrete overlay performance. An AC shoulder does not improve load transfer at the longitudinal lane/shoulder joint. Like conventional pavements, unbonded concrete overlays that have a tied concrete shoulder monolithically constructed with the traffic lanes will have significantly less bending stresses and deflections at the midslab edge locations. Consequently, the PCA design procedure(s) allows for a decrease in overlay thickness by 25 mm (1 in.) if a tied concrete shoulder is used. However, studies indicate that these reductions in bending stresses and deflections may not be significant at longitudinal joints for retrofitted PCC shoulders (*12,60*). Therefore, the thickness reductions are not recommended unless there is substantial tying of the shoulder to the overlay near the joint to provide long-term load transfer. Other studies have also found the addition of a tied concrete shoulder to be structurally equivalent to 25 mm (1 in.) of slab thickness, although the deflection load transfer efficiency must remain high (greater than 80 percent) to achieve long-term benefits (*53*).

DESIGN CHECKS

After application of the design guidelines to obtain a preliminary unbonded concrete overlay design for particular site conditions, a number of checks can be used to determine whether the design will meet certain performance criteria. A design check can be made by using available performance prediction models. Mechanistic-empirical models that more realistically consider the stresses related to load and temperature differentials that occur in PCC slabs are recommended (*43,50–52*). Because of the limited performance data that are available, not many performance prediction models exist for unbonded concrete overlays. In fact, the only model that has been developed specifically for unbonded concrete overlays is a JPCP joint faulting model developed in this study. [A similar model was also developed in a previous research study (*13*).]

This section presents models that are recommended for use in design checks until improved models become available for predicting distress of unbonded concrete overlays. The critical checks recommended for unbonded concrete overlays include the following:

- Faulting for JPCP;
- Transverse crack deterioration of JRCP; and
- Localized failure (punchouts) for CRCP.

Each of the models should be used to predict distress for the UBOL design and the results should be checked against performance criteria selected by the agency.

Faulting of JPCP

Faulting is the critical distress that must be checked in JPCP designs. The following model was developed under this project by multiple regression with performance data available from the unbonded concrete overlays in the LTPP database:

$$FAULT = 0.5106\frac{KESAL^{0.4}}{H_{ol}^{3}}(1 - 0.51DOWEL) \tag{17}$$

where

$FAULT$ = transverse joint mean faulting (in.);
H_{ol} = concrete overlay thickness (in.);
$KESAL$ = cumulative traffic (thousand ESALs); and
$DOWEL$ = transverse joint dowel diameter (in.).

Statistics: $R^2 = 0.53$, $SEE = 0.020$ in., and $N = 20$.

Transverse Crack Deterioration of JRCP

Low-severity transverse cracks are a normal occurrence in JRCP. These cracks will develop as the slab responds to drying shrinkage, thermal curling, and thermal contractions. Reinforcement is placed in JRCP to hold the cracks tight and prevent deterioration. However, repeated heavy-load applications, environmental effects, and inadequate steel design can result in breakdown and deterioration of the cracks. Medium- and high-severity transverse cracks in JRCP cause localized failures, increased roughness, and user discomfort, and they trigger the need for rehabilitation. The following model is recommended for design checking (*43*):

$$\begin{aligned} CRACKJR = AGE^{2.5} \times [&6.88 \times 10^{-5} \\ &\times FI/THICK + (0.116 - 0.073BASE) \\ &\times CESAL \times (1 - e^{-0.032a}) \\ &\times e^{(7.55188 - Epcc - 66.5PERSTEEL + 5PERSTEEL \times Epcc)}] \end{aligned} \tag{18}$$

where

$CRACKJR$ = number of transverse cracks (medium- and high-severity) (per mi);
AGE = time since construction (years);
$CESAL$ = cumulative 80-kN (18-kip) ESALs in traffic lane (millions);
$PERSTEEL$ = percentage of steel (longitudinal reinforcement);
a = Thornwaite moisture index (MI) if MI is greater than 1; 1 if MI is less than 1.
$Epcc$ = mean back-calculated modulus of elasticity of concrete (million psi);
$THICK$ = PCC slab thickness (in.);
$BASE$ = 0 (if nonstabilized base exists), = 1 (if stabilized base exists); and
FI = freezing index (degree days below freezing).

Statistics: $R^2 = 0.67$, $SEE = 32$ cracks/mi, and $N = 111$.

Localized Failure (Punchouts) of CRCP

A large number of CRCP sections (408) were used for development of a CRCP localized failure model under Project IHR-529 of the Illinois Cooperative Highway Research

Program. The model recommended for design checking is as follows (*42*):

$$\log_e(FAIL) = 6.8004 - 0.0334 \times PAVTHK^2 - 6.5858 \times PSTEEL + 1.2875 \times \log_e(CESAL) - 1.1408 \times BAM - 0.9367 \times CAM - 0.8908 \times GRAN - 0.1258 \times CHAIRS \quad (19)$$

where

FAIL = total number of failures in the outer lane (per mi);
PAVTHK = CRCP slab thickness (in.);
PSTEEL = longitudinal reinforcement (percent);
CESAL = cumulative ESALs (millions);
BAM = 1 (if subbase material is bituminous-aggregate mixture), = 0 (otherwise);
CAM = 1 (if subbase material is cement-aggregate mixture), = 0 (otherwise);
GRAN = 1 (if subbase material is granular), = 0 (otherwise); and
CHAIRS = 1 (if chairs used for reinforcement placement), = 0 (if tubes used).

Statistics: $R^2 = 0.44$, $SEE = 1.06$, and $N = 408$.

Quite a few CRCP sections had either exceptionally good or exceptionally poor performance, which makes it difficult to predict over a wide range of designs, materials, construction, and maintenance.

CHAPTER 4

CONSTRUCTION OF UNBONDED PCC OVERLAYS

INTRODUCTION

Several factors that influence the long-term performance of unbonded concrete overlays need to be considered during construction. These construction practices can be loosely divided into two groups. The first group includes construction practices required to prepare the existing pavement to an acceptable condition ready for placement of the overlay. Following that, and in addition to the usual practices that must be followed during construction of conventional PCC pavement (e.g., paving operations, joints, and smoothness considerations), the second group includes special geometric, traffic control, and other construction constraints that place unusual demands on the construction of unbonded concrete overlays. Both phases of construction practices play a critical role in the overall performance of unbonded concrete overlays.

CONSTRUCTION CONSTRAINTS

Because overlays are constructed on existing pavements, several constraints are encountered during the construction of unbonded PCC overlays that require special attention, including traffic control constraints, geometric constraints, and constraints associated with transition areas.

Traffic Control

Traffic control during construction of overlays is a very important consideration. Because the overlay is constructed on an existing pavement, it not only involves control of construction traffic and equipment but also the traffic that uses the highway. Moreover, unbonded concrete overlays are typically used to rehabilitate pavements that have experienced a lot of distress and probably carry a lot of traffic. Poor traffic control on such facilities can lead to substantial problems. Consequently, it is necessary to have a comprehensive plan for diverting traffic from the planned construction site while also minimizing traffic disruption.

The type of facility and the amount of traffic it carries will determine the right type of traffic control. Complete detours are not uncommon for rural secondary and urban highways. Of course, the detour facility must have adequate structural capacity to carry the traffic that is diverted to it during construction. Failure of such detours before the pavement being overlaid is ready to be opened to traffic can cause severe and costly problems.

The number of lanes on Interstate and primary highways will determine the appropriate type of traffic-control arrangement. Construction on roadways with more than three lanes and shoulders in each direction can be accomplished by keeping traffic in one lane and an adjacent shoulder while construction proceeds on the remaining lanes and shoulder. Portable concrete barriers should be used whenever possible to separate traffic from the work zone, but tubular guideposts embedded in the roadway or plastic cones may also be used.

For four-lane divided highways, the usual method of traffic control is to close the lanes in one direction for repair and divert traffic to the opposing lanes (*23*). This requires crossovers that are placed at each end of the construction zone with enough room for staging the construction. All necessary measures should be taken to ensure safe operation of the two-way traffic on the remaining two lanes. Concrete barriers should be used for separation of traffic in the crossover areas; tubular guideposts are an economical and safe option for separating the two-way traffic in the two lanes.

Accelerated rigid paving techniques or fast-track paving is another means for limiting the time the highway is closed to traffic. Fast-track paving techniques can provide concrete that meets opening strength criteria in less than 12 hours (*1,63*).

Geometric Constraints

Because unbonded concrete overlays are placed over the existing pavement with an interlayer, there can be a considerable increase in the elevation of the overall pavement structure. With interlayers as thick as 100 mm (4 in.) and UBOL thicknesses that can be as high as 305 mm (12 in.), the total structure placed on the existing pavement can result in a decrease of 405 mm (16 in.) in the available clearance. Although most highway agencies use clearances that take future resurfacing into account, unbonded concrete overlays may pose construction problems under some bridges without adequate clearance. Solutions that have been used include bridge jacking and removal and reconstruction of the pavement under the bridge (requires special drainage considerations to handle excess moisture). Bridges can be jacked up by raising the bridge with spacers (cast concrete or steel) that are placed above piers and abutments (*17*).

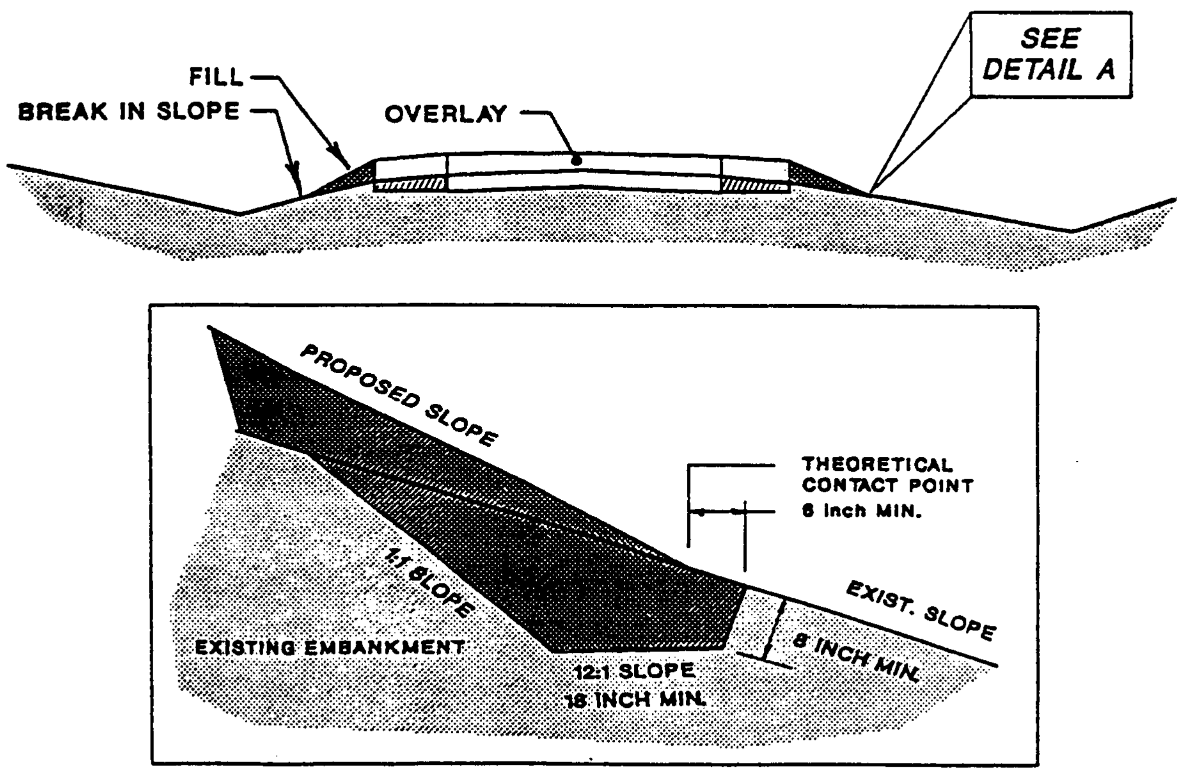
Typically, construction of unbonded concrete overlays will require reconstruction of shoulders and curb and gutters because of the increase in elevation caused by the additional thickness. Likewise, if the UBOL includes widening, there must be extension of side slopes and culverts. The extension of side slopes will require fills. A practical solution for reducing the volume of fill required, suggested by the American Concrete Pavement Association, is to allow a break in the side slope (see Figure 16). This will require less construction time and material and is less costly than complete regrading of the side slopes (*17*).

Transition Areas

Certain circumstances will necessitate reconstruction of the existing pavement at particular locations. For example, the difference in elevation between an unbonded concrete overlay and a bridge deck requires reconstruction of the pavement adjacent to the bridge. Similarly, another option for solving clearance problems under overpasses (aside from bridge jacking) is reconstruction of the pavement under the overpass. In both cases, taper sections are required in the transition areas between the unbonded concrete overlay and the reconstructed section. Such tapers must be designed carefully to make sure they do not interfere with construction or pose safety or ride problems.

Figure 17 illustrates two typical methods for achieving a continuous transition during paving (*17*). A transition and taper length between 90 and 150 m (300 and 500 ft) will be adequate under most circumstances. For tapers at bridge ends, the actual length of removal of the existing pavement will depend on the difference in elevation between the overlay and the bridge deck. For a smooth transition, 12 m (40 ft) of removal for every 25-mm (1-in.) difference in elevation has been suggested (*64*).

Where an expansion joint is designed to separate sections of unequal thickness, the recommendation is to pave in a continuous transition (as illustrated in Figure 17) and later replace part of the transition section with the expansion joint. Similarly, expansion joints at bridge approaches must be reestablished in the transition section or added if none are present (*17*). Bridge approach slabs do not always have to be replaced; they can be kept in place and the transition can be made to the approach slabs.



DETAIL A

Figure 16. Breaking the grade by filling side slopes can significantly reduce the volume of fill and work required (17).

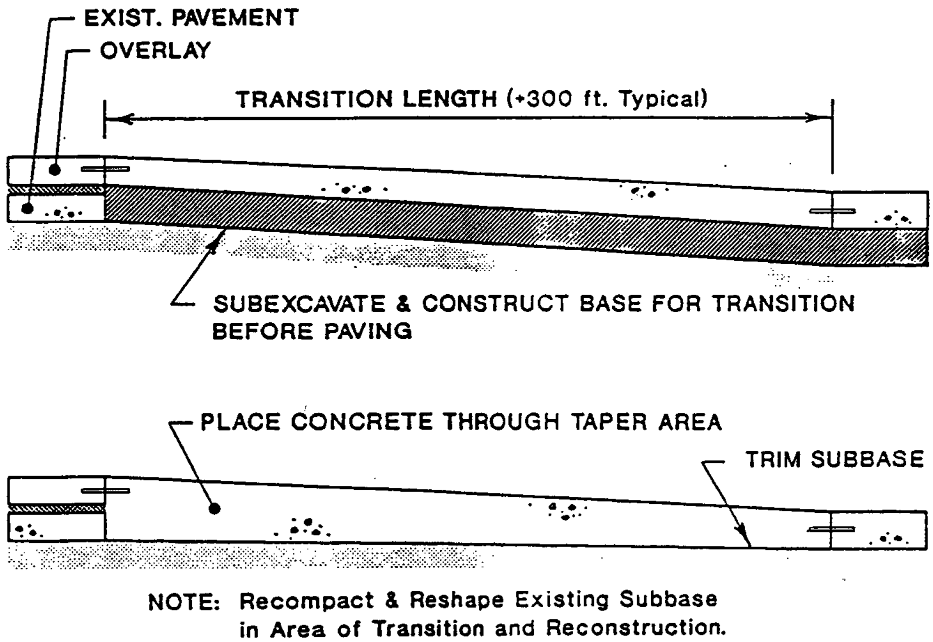


Figure 17. Typical transition tapers for bridge approach slabs and to maintain clearance under overpasses (17).

PREOVERLAY REPAIR

Not much preoverlay repair is necessary for an unbonded concrete overlay unless the existing pavement is seriously deteriorated and does not provide uniform support. If proper and adequate design features are incorporated in the overlay and a sufficiently thick interlayer is used, JPCP and JRCP overlays will bridge over all but the most deteriorated areas in the existing pavement. However, as a result of the closely spaced transverse cracks, CRCP is a relatively flexible pavement; therefore, uniform foundation support is extremely important (*65*). Consequently, considerably more preoverlay repairs may be necessary for CRCP. The main preoverlay treatments can be classified into three categories: slab replacement and full-depth patching, fracturing of the existing pavement, and other repairs.

Slab Replacement and Full-Depth Patching

The construction techniques used for repairing the existing pavement are similar to those used for conventional concrete pavements. These techniques, summarized here, have been described extensively in another publication (*66*). Repair of most of the seriously deteriorated areas involves their removal and replacement. The boundaries of the repair area must be carefully selected to make sure all the deteriorated pavement and underlying material are removed.

Removal of Deteriorated Concrete

Deteriorated or shattered slabs of JPCP and JRCP can be removed entirely. Deteriorated concrete on sections of JPCP, JRCP, and CRCP are repaired by sawing the repair boundaries with a diamond saw blade. The preferred method is to saw the pavement full depth, which will result in a smooth face without aggregate interlock. Another alternative is to saw up to 30 percent of the slab depth and use a jackhammer to break up the deteriorated concrete within the boundaries for removal. The rough face obtained provides some aggregate interlock but is susceptible to spalling.

For both types of saw cuts, a common method of removing the deteriorated concrete is to break it up with a jackhammer, drop hammer, or hydraulic ram and remove it with a backhoe and hand tools. Care should be taken not to disturb the surrounding concrete and underlying material when this method is used.

The preferred method is to saw cut full depth and remove the concrete within the boundaries by lifting it up in as few pieces as possible (one piece is ideal). This will disturb less of the underlying pavement and will provide more uniformity of support.

Preparation of Repair Area

Careful preparation of the repair area should include cleaning out the removal area and repairing the foundation.

In the past, some states have included reinforcement and load transfer devices with full-depth repairs for unbonded concrete overlays, so the preparation would include placing reinforcement and installing load transfer devices (*67*). Based on the information obtained in this study, there is no justification for including reinforcement or load transfer devices in full-depth patches of the existing pavement for unbonded concrete overlays. A plain concrete patch is adequate for repair of the existing pavement. However, for CRCP overlays, the following additional provisions are recommended:

- Use a minimum of 25-mm (1-in.)-thick AC interlayer.
- Use minimum reinforcement of 0.7 percent steel in the CRCP overlay.

Patches should be sawed if necessary to keep the maximum dimension of the patch less than 4.6 m (15 ft).

Concrete Placement, Finishing, and Curing

The critical aspects of concrete placement and finishing for a full-depth patch are obtaining adequate consolidation and a finish that is level with the surrounding concrete (*68,69*). Typical state practices are adequate; information on procedures is provided elsewhere (*20,68,70,71*). The key concerns are to ensure that the concrete is well vibrated around the edges of the repair and is not overfinished. Curing as soon as possible after texturing by standard methods is adequate. The specific details for placing, finishing, and curing the concrete patch are similar to the procedures applied to the overlay (described later in this chapter).

Fracturing the Existing Pavement

The three fracturing techniques for existing pavements are cracking and seating, breaking and seating, and rubblizing. The equipment available for fracturing existing PCC pavements includes the following (*19,72*):

- Crane with wrecking ball,
- Whiphammer,
- Pavement breakers (e.g., drop hammers, guillotine, and hydraulic/pneumatic hammers),
- Pile-driving hammer, and
- Resonant pavement breaker.

Table 18 provides information on the characteristics and productivity of this equipment (*19*). A guillotine (*19*), shown in Figure 18, is effective for crack and seat and break and seat; a resonant pavement breaker, illustrated in Figure 19, is ideal for rubblizing. Following are guidelines on the approaches for fracturing the existing pavement for unbonded concrete overlay construction.

Cracking and Seating

The slabs should be cracked to full depth and typically broken into pieces 0.3 to 1.0 m (1 to 3 ft) in size. Several European countries use this approach and fracture the existing pavement into pieces less than 0.5 m (1.6 ft) (*38*). After the PCC pavement is cracked, the pieces should be seated firmly into the supporting layer to prevent them from rocking under the influence of traffic.

Seating can be accomplished with a pneumatic roller. To ensure adequate performance of crack and seating, it is necessary to confirm that the subgrade will provide adequate support to the fractured slab. It is not uncommon to find that an adequate subgrade for an existing PCC pavement may not be adequate to support the fractured pavement and the traffic. If inadequately supported, fractured pieces may sink into a saturated, weak subgrade and become embedded in the subgrade layer, which can lead to poor performance.

Break and Seat

Break and seat is similar to crack and seat except that a greater impact force is required to rupture the reinforcing steel or debond the PCC from the steel in JRCP. This requires that the existing PCC be broken into pieces smaller than required for crack and seating. It is important to confirm that a breaking and seating operation adequately disrupts the reinforcement in a JRCP, because if full-depth cracking does not occur, the reinforcing steel will continue to hold the broken pieces together and the PCC slabs continue to function as a unit and lead to larger horizontal movements at the joints of the existing slab (*13*). This technique is not recommended.

Rubblization

Rubblization is accomplished with a resonant pavement breaker capable of reducing an existing slab into small pieces varying from sand-sized particles to pieces 150 mm (6 in.) across at the bottom of the slab. A resonant pavement breaker applies a 9-kN (2,000-lbf) impact force at a frequency of 44 impacts per second to the pavement surface through a shoe that is attached to a massive steel beam. In essence, this beam acts as a giant tuning fork, shattering the pavement into pieces with an average size of 20 to 50 mm (0.75 to 2 in.) at the top of the slab and 150 mm (6 in.) at the bottom. Finally, the pavement is compacted with at least two passes of a vibratory roller weighing at least 90 kN (10 tons). The sealing must be effective. Large rollers, not self-propelled, may be necessary. Seating rubblized pavement into a poor subgrade is important for establishing a sound support layer for the new overlay.

Other Repairs

Areas with low- to medium-severity distresses can be repaired by removing the deteriorated concrete and replacing

TABLE 18 Summary of equipment types, characteristics, and productivity *(19)*

Equipment Type	Applications	Energy Range (ft. lbs.)	Production Rate (lane-miles/day)	Advantages	Limitations
Crane and wrecking ball	small areas where specialized equipment not justified		.25 to .75	Equipment generally available	Requires skilled crane operator
Whip hammer	JPCP		1.00	High productivity covers full lane width	Not effective on JRCP
Pavement breakers					
Drophammer	JPCP and wire mesh reinforced JRCP	4,800 - 15,000	.15 to .75	Effective with JPCP	Developed unusual crack pattern with mesh reinforced JRCP Several passes required
Guillotine	JPCP and JRCP	12,000 - 120,000	.75 to 4.0	Versatile - effective with JPCP and JRCP; preferred by several states; high productivity; covers full lane width	
Impact hammer		2,000			Rubblized portions of concrete below cracks
Pile-driving	JRCP	8,000 - 115,000	.27	covers full lane width	Low productivity
Resonant pavement breaker	JPCP, JRCP, CRCP	<2000	.50	Excellent for rubblizing	Not effective for making transverse cracks

it with AC or other patching materials. These areas can also be leveled up with interlayer material during construction. Unstable slabs can be stabilized by injecting grout underneath to fill up voids. A cement-pozzolan grout material that is pumped through holes drilled in the slab is adequate (*13*). For joints that have faulted in excess of 5 mm (0.2 in.), a thicker interlayer consisting of a minimum of 25-mm (1-in.) AC is recommended. Alternatively, localized diamond grinding of the joints by standard practices can be used if, for some reason, a thinner interlayer is inevitable. It is essential to consider the economy of grinding the faulted joints versus a thicker interlayer.

SUBSURFACE DRAINAGE

Construction of a subsurface drainage system for an UBOL is not very different from conventional pavements. The options available include using a permeable interlayer or retrofitting with edge drains. Some state highway agencies, including Iowa, have dried out the subgrade with trenches dug at the side of the roadway to reduce moisture in the subgrade.

Figure 18. Guillotine (19).

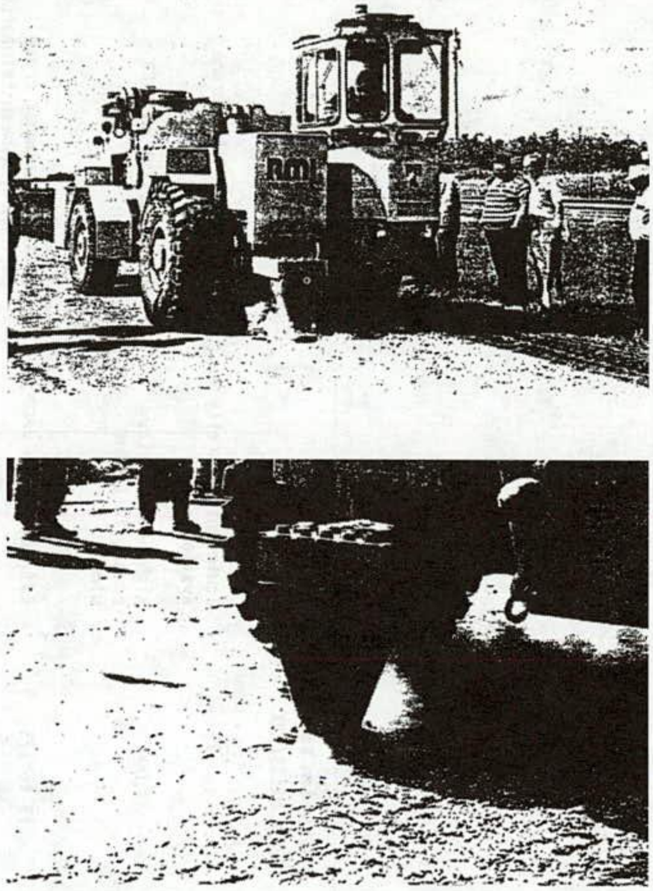


Figure 19. Resonant pavement breaker (73).

Permeable interlayer construction is not different from construction of any other interlayer. Important considerations include proper connection of the permeable interlayer to an edge drain system or a properly designed permeable shoulder so that it can discharge the infiltrated water. Figure 20 provides an example of a permeable interlayer that is connected to a pipe edge drain. This design was recently adopted by Pennsylvania (*74*).

If used, a pipe edge drain in an aggregate trench that is partially wrapped with a geotextile, as illustrated in Figure 21, is recommended. The construction procedure for retrofitting the pavement with edge drains is similar to that for conventional pavement. Installation of the edge drain includes the following steps (*22*):

1. Trenching,
2. Placing of geotextile, and
3. Placing drainage and outlet pipes and backfilling.

The trench should be cut deep enough to place the top of the drainage pipe a minimum of 50 mm (2 in.) below the bottom of the permeable interlayer (i.e., top of the existing pavement). A minimum 50-mm (2-in.) layer of bedding material

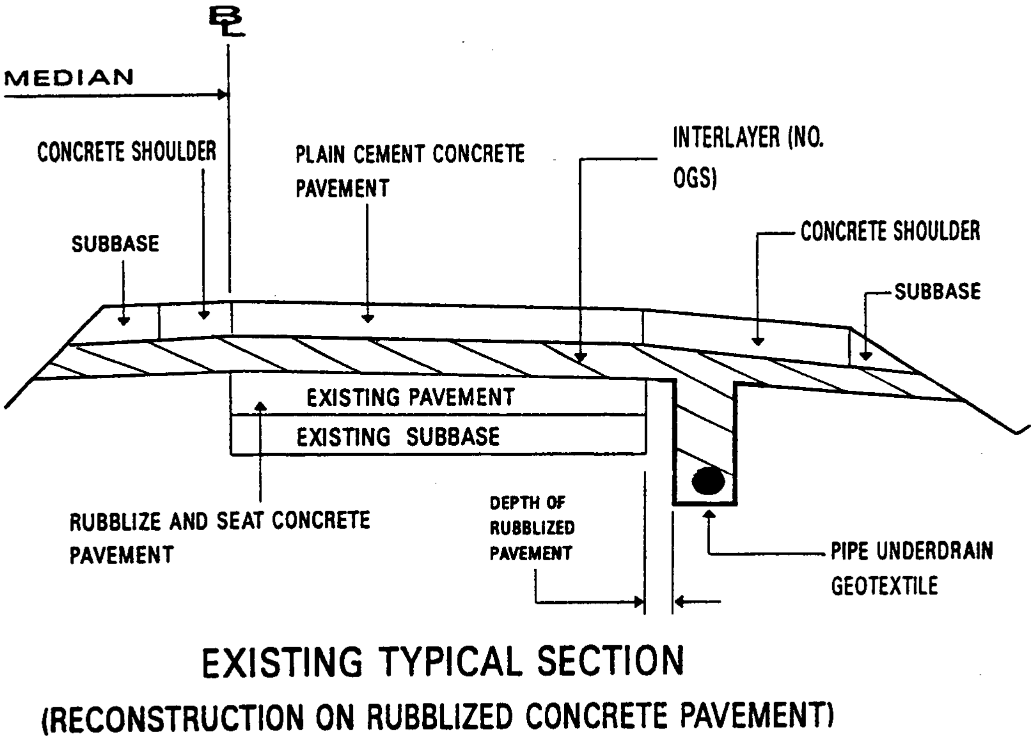


Figure 20. Typical example of Pennsylvania's design of permeable interlayer connected to a pipe edge drain (74).

is also recommended beneath the drainage pipe. The trench must be lined with the geotextile to prevent migration of fines from the surrounding soil into the drainage trench; however, the top of the trench adjacent to the interlayer should be left open to allow a direct path for water into the drainage pipe.

To provide uniform support to the pipe, a layer of bedding material should be placed at the bottom of the trench. A groove or haunch in the bedding material at the trench bottom is recommended as a means for holding the pipe in place during installation. It is important for the size of the groove to match that of the pipe being used; an oversized bedding groove can do more harm than good (*22*).

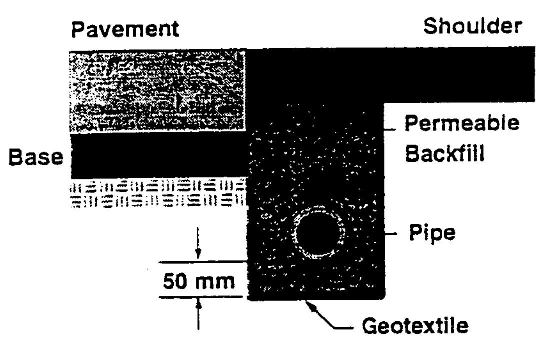


Figure 21. Details of recommended partially wrapped pipe edge drain (22).

After placement of the pipe in the groove, backfill material should be placed by using chutes (or other means that will prevent damage to the pipe) and then compacted. Additional details for construction of edge drains and outlets that discharge the water from them are described elsewhere (*22*).

INTERLAYER CONSTRUCTION

There is no specific procedure for constructing the interlayer, as it depends on the type of material used. The standard procedures and specifications for placing those materials on roadways are adequate. However, the major objective is to make sure the material is placed in a manner that provides a uniform, stable, nonerodible, and nonstripping supporting layer for the unbonded concrete overlay. An AC interlayer is recommended whenever possible. For composite AC/PCC pavement, the AC overlay can be milled to obtain a suitable uniform interlayer for the unbonded concrete overlay. The texture of the milled surface may influence joint crack spacing and performance of slabs.

The best approach for constructing an AC interlayer is to use a control strip so that the combination of materials and construction practices can be tested and, if necessary, adjusted. Cleaning any loose material or debris from the existing pavement surface by using a mechanical sweeper or air-blowing equipment is adequate before placement of the interlayer (*17*). Care should be taken to ensure that there is no segregation of material during placement. The interlayer should be placed so that it extends past the edge of the concrete slab on each side by 0.6 to 1 m (2 to 3 ft) or enough to support the paver tracks.

When the temperature of the asphalt concrete material used as an interlayer is expected to be uncomfortable to touch with the open palm, the interlayer should be cooled down before concrete placement by water fogging or spraying with water (*17,37*). This is especially necessary for a recently placed AC interlayer, as it will absorb more heat because of its dark color. Older AC overlays on a composite pavement scheduled for unbonded concrete overlay do not generally store as much heat because of discoloration with time.

Another alternative that has been used in the past is application of whitewash consisting of either white-pigmented curing compound or lime slurry. Studies have shown that whitewash reduces surface temperature by −7 to −4°C (20 to 25°F) (*17*). Also, whitewash prevents excessive heat buildup of the separation material, which can cause shrinkage cracking in the concrete overlay. However, there is evidence that the whitewash may break the bonding between the asphalt concrete interlayer and the concrete overlay. In fact, application of whitewash is often accompanied by warnings not to apply it excessively to the paver trackline so that loss of traction and drifting can be prevented (*37*). Because a significant amount of bonding or friction is absolutely necessary for the formation of weakened joints in JPCP and JRCP and the proper amount of cracks in JRCP and CRCP soon after placement, application of whitewash in unbonded concrete overlay construction is not recommended.

PAVING OPERATIONS

The paving operations for unbonded concrete overlays are similar to those for conventional PCC pavements. Important considerations include placing and finishing the concrete, texturing, curing, and joint construction. Information on paving operations is provided elsewhere (*3,75*), and this information is summarized in the following sections.

Placing and Finishing

Standard practices and specifications for placing, consolidating, and finishing concrete for conventional PCC pavements are applicable to unbonded concrete overlays. The concrete can be placed with a slip-form paver or fixed forms. Slip-form paving is preferred for most applications because it results in higher quality and smoother PCC pavements. Fixed-form paving can also be used to place concrete and is particularly suitable for short segments with variable width and complicated sections as well as for streets and local roads. Regardless of the method of paving, the concrete should be placed at least to the minimum thickness shown on the plans. For unbonded concrete overlays, it is typical to use a uniform interlayer thickness and adjust for deviations in profile and cross section with concrete. When practical, any significant expected temperature variations should be considered in planning times to pave.

Slip-Form Paving

With string lines preset for line and grade, a slip-form paver is used to spread, consolidate, screed, and float finish the concrete in one pass. Dual construction string lines provide excellent grade control and smooth pavements. Concrete from either a ready-mix plant or a batch plant can be used. Some of the critical factors of slip-form paving that ensure good quality and smooth pavement include the following:

- Monitoring of uniformity in mix consistency, rate of delivery, placement, and finishing of concrete;
- Consistent workability;
- Maintenance of string-line (preferably dual) accuracy;
- Adequate vibration and consolidation to achieve proper density;
- Clean and well-maintained paver and proper management of paving operation; and
- Proper timing and application of texturing.

The advantages of slip-form paving include its use of low-slump concrete, high productivity, and ability to produce a very smooth riding surface (*3,75*).

Fixed-Form Paving

Fixed-form paving uses paving forms to hold the concrete in place at the proper grade and alignment to provide a smooth-riding pavement surface. The forms may be used as tracks for the paving equipment. Typical forms are steel sections that are equal in height to the PCC slab edge thickness and have a wide base for stability. A conventional fixed-form riding train of equipment includes a spreader with a gang of interval vibrators embedded in the struck-off concrete and finishing machines. Automatic machines that use a heavy-duty paving carriage to vibrate; strike off; and longitudinally smooth, seal, and texture the concrete are also being used (*75*). Important considerations in fixed-form paving include the following:

- Forms set accurately to line and grade, anchored firmly and uniformly to the foundation, and oiled before placing concrete;
- Careful setting of headers at the beginning and end of the section being placed;
- Maintenance of string-line accuracy;
- Uniformity in mix consistency, rate of delivery, placement, and finishing of concrete;

- Consistent workability;
- Adequate vibration and consolidation to achieve proper density;
- Clean and well-maintained paving equipment and proper management of paving operation;
- Proper timing and application of texturing; and
- Proper timing and removal and cleaning of forms.

Dowels and Reinforcement Steel

For nondoweled JPCP, the concrete can be placed on the interlayer by either of the placing methods without any other requirements. When specified, dowels in JPCP and JRCP can be set up in steel baskets that are staked firmly to the interlayer/existing pavement. Anchoring of dowel baskets into relatively thin AC has been a serious construction problem. It can be dealt with successfully once the agency and contractor are aware of the problem. Lubricated dowels (very thin layer to prevent looseness) are recommended to allow free movement at the joint. Dowel bar inserters that mechanically insert the dowels into the fresh concrete will eliminate the need for baskets. All locations of dowels should be marked clearly for joint sawing. Checks should be made to ensure that the dowels are at the proper location.

Reinforcement for JRCP in slip-form paving can be placed by the two-lift construction method. Approximately two-thirds of the pavement thickness is first placed. The mesh is then set on the first lift and the second lift is placed over it to achieve the total thickness with final consolidation, strike off, and finishing. Vibration of reinforced pavement must not float reinforcement upward toward the surface. Alternatively, the full slab thickness can be placed and a mesh depressor used to depress the reinforcement mat into the plastic concrete ahead of the paver but behind the lay-down machine or concrete pump/delivery system. This can also be used to place reinforcement during fixed-form paving.

Longitudinal deformed bars placed on continuous runner chairs or placed by tube feeders are used for CRCP reinforcement in slip-form paving. The depth of reinforcement must be uniform in CRCP. The reinforcement must be placed above mid-depth of the slab. The closer the reinforcement to the surface, the tighter the resulting transverse cracks; however, a minimum of 75 mm (3 in.) must be maintained above the reinforcement (*48*).

Curing

Curing will prevent rapid water loss from the concrete, allow proper strength gain, and prevent plastic shrinkage cracking. A curing compound should be applied to the surface immediately after texturing. Typical materials used include the following (*17,37,75*):

- Liquid, white-pigmented membrane curing compound;
- Waterproof paper or plastic covers (e.g., polyethylene sheets); and
- Wet cotton mats or burlap.

A liquid, white-pigmented membrane curing compound is recommended. Waterproof covers are susceptible to tears that leave holes for loss of curing moisture, and wet cotton mats and burlap need to be kept moist throughout the curing process. It is important to keep all exposed surfaces of the pavement moist until the curing material is applied. Curing should be applied to all those surfaces. During hot and cold weather, certain precautions must be taken to keep the concrete within proper temperature range for adequate curing.

Joint Sawing and Sealing

Timely sawing is critical to formation of the proper pavement joints at the desired locations. A narrow saw cut to a depth of at least one-third the thickness of the PCC slab is recommended for unbonded concrete overlays on an AC interlayer. The joints should be sawed as soon as the concrete gains adequate strength to carry sawing equipment and to avoid saw raveling. The minimum depth of saw cut for green sawing is 25 mm (1 in.). Recommendations are provided elsewhere (*76*).

The joints can be skewed but, as indicated previously, if the joints are doweled there is no justification for skew joints. Random spacing of the joints has also been used to minimize resonant vehicle responses when faulting develops. If the pavement is adequately designed to withstand faulting, randomized joints will not be necessary. The joints can be left unsealed or sealed, but sealed joints are recommended at this time.

CHAPTER 5

MAINTENANCE AND REHABILITATION

INTRODUCTION

Guidelines are provided in this chapter for maintenance and rehabilitation of unbonded concrete overlays. The maintenance and rehabilitation needs and techniques for unbonded concrete overlays are very similar to those of equivalent newly constructed PCC pavements. However, special considerations may be required in relation to design features such as the interlayer, expansion joints connecting UBOLs with new reconstruction beneath bridges, and rehabilitation strategies.

KEY DISTRESSES THAT REQUIRE MAINTENANCE AND REHABILITATION

UBOLs develop the same types of deterioration associated with conventional pavements. However, certain types of distresses may occur more often in UBOLs (e.g., corner breaks, longitudinal cracking, punchouts over underlying joints) and some occur less often (e.g., joint faulting). The following are the main distresses associated with each type of UBOL that lead to maintenance and rehabilitation needs.

- **JPCP overlay**—Transverse cracking, longitudinal cracking, corner breaks, joint faulting, joint seal damage, and spalling at joints;
- **JRCP overlay**—Deteriorated transverse cracks, deteriorated longitudinal cracks, joint seal damage, joint faulting, and spalling at joints;
- **CRCP overlay**—Localized failures (classical punchouts, steel rupture, or deteriorated transverse cracks), settlements, and spalling and localized failures; and
- **Others**—Expansion joints that connect the UBOL with new pavement reconstruction beneath bridges may require maintenance.

MAINTENANCE NEEDS

Maintenance of JPC, JRC, and CRC overlays includes a variety of activities to keep the pavement in good functional condition. Many agencies have renewed their commitment to pavement maintenance in recent years based on performance data that show that extending the life of a pavement with regular maintenance is often very cost-effective. The following summarizes the main types of maintenance activities and provides key references on state-of-the-art maintenance practices (*17,59,77,78*).

Transverse Joint Resealing

Guidelines on the best materials, cross-section configuration, equipment, and procedures are provided in the SHRP *Concrete Pavement Repair Manuals of Practice.* Joint resealing guidelines are given in *Materials and Procedures for the Repair of Joint Seals in Concrete Pavements* (*59*). Other good sources of information include the manual entitled *Techniques for Pavement Rehabilitation* from NHI/FHWA (*66*) and the *FHWA Pavement Rehabilitation Manual* (*20*). These references have been used by many state highway agency personnel for years and are readily available from FHWA.

Longitudinal Lane/Lane or Lane/Shoulder Joint Sealing

Sealing longitudinal joints will minimize the amount of water that flows into the interlayer and causes erosion or stripping. Guidelines for sealing longitudinal joints are provided elsewhere (*59,66*).

This lane/AC shoulder joint is a major source of water infiltration into the pavement (perhaps as much as 60 percent of runoff can enter the pavement through this joint). Guidelines on resealing this joint are provided elsewhere (*66*).

Crack Sealing

Cracks should be sealed only if there are a lot of longitudinal cracks that allow substantial water to enter the interlayer; guidelines are provided elsewhere (*66*).

Partial-Depth Patching

Repairing a spalled joint or crack will remove a source of roughness, thereby benefiting the traveling public. Guidelines on the best materials, cross-section design, equipment, and procedures are provided in the *SHRP Concrete Pavement Repair Manuals of Practice—Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete*

Pavements (*77*). Another good source of information is the manual entitled *Techniques for Pavement Rehabilitation* from NHI/FHWA (*66*).

Full-Depth Repairs at Joints, Cracks, and Punchouts

The specific type and design of full-depth repair varies by overlay type. Complete guidelines and details have been published (*62,66*). The following additional comments are relative to full-depth repair of UBOLs.

JPCP Overlay

High-severity transverse or longitudinal slab cracking or shattered slabs require full slab replacement. Partial slab replacement is not recommended unless the pieces are longer than 4.6 m (15 ft) and doweled. As much as possible, the interlayer should not be disturbed; therefore, the lift-out method should be used. If disintegrated, replace with hot-mixed AC or some bond-breaker material to avoid causing a potential for a blowup from the new slab bonding to the underlying slab.

JRCP Overlay

Full-depth repair is most often performed to replace individual deteriorated joints and transverse cracks. The interlayer is not to be disturbed, if possible. If disintegrated, replace with hot-mixed AC or some bond-breaker material to avoid causing a potential for a blowup from the new slab bonding to the underlying slab. See also published guidelines (*66*).

CRCP Overlay

Localized failures, usually punchouts or steel ruptures across transverse cracks, require full-depth repair with continuous reinforcement. Plain PCC repairs should not be used in CRCP because they create a discontinuity that will cause roughness and can lead to a blowup. The interlayer is not to be disturbed, if possible. If disintegrated, replace with hot-mixed AC or some bond-breaker material to avoid creating a potential for blowup by the new CRCP slab bonding to the underlying slab.

Slab Replacement

Removal and replacement is recommended for an entire slab or several contiguous slabs containing multiple cracks and excessive roughness. The specific type and design of full-depth repair varies by overlay type. Complete guidelines and details are provided elsewhere (*66*). The following additional comments are provided relative to slab replacement of UBOLs.

JPCP Overlay

High-severity transverse or longitudinal slab cracking or shattered slabs require full slab replacement. See published guidelines (*66*). The interlayer is not to be disturbed, if possible. If disintegrated, replace with hot-mixed AC or some bond-breaker material to avoid causing a potential for a blowup from the new slab bonding to the underlying slab. All slab replacements should include anchoring of dowel bars into the slabs on either side to provide adequate load transfer for pavements carrying over 1 million ESALs per year. When repairs are being made adjacent to existing lanes and shoulders, the joints in the repair should match the joints in the existing pavement to prevent cracking.

JRCP Overlays

Full slab replacement is performed to replace slabs containing several deteriorated joints and transverse cracks. The interlayer is not to be disturbed, if possible. If disintegrated, replace with hot-mixed AC or some bond-breaker material to avoid causing a potential for a blowup from the new slab bonding to the underlying slab. See published guidelines (*66*). All slab replacements should include anchoring dowel bars into the slabs on either side to provide adequate load transfer for pavements carrying over 1 million ESALs per year.

CRCP Overlays

Several localized failures, usually punchouts or steel ruptures across transverse cracks along a long stretch, require the section replacement with continuous reinforcement. The interlayer is not to be disturbed, if possible. If disintegrated, replace with hot-mixed AC or some bond-breaker material to avoid causing a potential for a blowup from the new CRCP slab bonding to the underlying slab. See published guidelines (*66*).

Subdrainage Outlets and Pipe Flushing

If edge drains are installed they will require continuous maintenance to keep them free flowing and carrying water away from the pavement structure. Besides the obvious cleaning of the outlets, the use of high-pressure water to clean out the pipes may be required every 5 years or so. If the interlayer is permeable, then maintaining free-flowing pipes and outlets is even more critical (*79*).

Expansion Joint Problems

When bridge clearance is a problem, the pavement under the bridge is often reconstructed. This requires an expansion joint at each end of the reconstructed pavement. This expansion joint can deteriorate over time. The expansion joints should be checked regularly and any loss of expansive material that would allow incompressibles into the joint should be repaired.

REHABILITATION OPTIONS

UBOLs last a long time; however, eventually distress from heavy traffic loads or climatic factors will develop to such a degree that pavement rehabilitation is necessary. Three main types of concrete overlay rehabilitation are possible, and each includes a variety of alternative techniques. Many excellent documents are available that provide detailed information about each of these techniques (*66,78*). Again, each technique must be tailored to the specific UBOL type.

Restoration Without Overlays

This is a group of specific treatments that address a specific distress.

For unbonded JPC overlays, restoration involves diamond grinding to remove faulting, slab replacement or partial slab replacement for cracked slabs, edge drains where appropriate, partial depth patching for spalls, load transfer restoration for JPCP with no dowels and significant past faulting, cross-stitching for longitudinal cracks, and resealing of transverse joints.

For unbonded JRC overlays, restoration involves diamond grinding to remove faulting, full-depth repair of deteriorated joints and working cracks, slab replacement or partial slab replacement of badly cracked areas, edge drains where appropriate, partial-depth patching for spalls, load transfer restoration for working transverse cracks, cross-stitching for longitudinal cracks, and resealing of joints.

For unbonded CRC overlays, restoration involves full-depth reinforced repair of localized failure areas and deteriorated working transverse cracks, edge drains where appropriate, and cross-stitching for longitudinal cracks.

Restoration with Overlays

Additional overlays on top of the UBOL is not feasible in most cases because of geometric constraints (although there are projects where a second UBOL was placed on top of the first and is performing well). The most likely overlay will be an AC overlay; the design and construction of such an overlay is no different than when it is placed on a conventional concrete pavement (*62*).

Reconstruction

Reconstruction of an UBOL would not be a difficult operation if only the overlay and interlayer were to be removed. The old underlying pavement would serve as a good working platform after removal of the UBOL. Experience has shown that a pavement breaker can break (or rubblize) the concrete overlay without breaking the underlying slab as long as there is an adequately thick AC interlayer. The existing interlayer would likely need to be removed and replaced before reconstruction of any other overlay.

CHAPTER 6

CASE STUDIES

INTRODUCTION

This chapter includes two parts. First, a case study is presented to demonstrate the use and validity of the guidelines presented for the design of unbonded concrete overlays. Second, information is provided on selected projects that performed particularly well or particularly poorly. Design features that contribute to well and poorly performing UBOLs are identified. A summary synoptic table (spreadsheet) extracted from the database for selected unbonded concrete overlay projects is included. Key design and construction data for each overlay are provided in the synoptic table; designers can use the information provided on sections with similar site conditions as a comparison to their own new designs.

CASE STUDY

An unbonded PCC overlay is to be designed for a six-lane expressway (three lanes in each direction). The overlay is to be constructed on approximately 3.6 km (2.2 mi) of the highway, and a reconstructed JPCP is to be provided on the remaining 1.9 km (1.2 mi) in areas where grade constraints prevent placement of an overlay. The following demonstrates application of the unbonded concrete overlay design guidelines.

Site Conditions

The first step in application of the guidelines for design of an unbonded concrete overlay is an evaluation of the site conditions.

Traffic

The current one-way average daily traffic was estimated to be 32,000 vehicles, which includes 16 percent trucks (includes vehicles with six tires and up but excludes pickups and panel trucks). The mean truck equivalency factor was estimated to be 3.1 (very heavily loaded axles are allowed on this route), and the annual traffic volume growth was estimated at 4 percent (compounded). The lane distribution of the trucks was estimated by using Table 6. The lane distribution was partially verified from on-site counts and is as follows:

Traffic lane	Lane distribution
Inner lane	8 percent
Center lane	33 percent
Outer lane	59 percent
Total	100 percent

The results of the traffic analysis to estimate the ESALs in the outer, center, and inner lanes are summarized in Tables 19, 20, and 21. The forecasted total ESALs for this freeway are extremely high. The 20-year projections for each lane are as follows:

Traffic lane	20-year ESALs/lane
Outer	90,000,000
Center	50,000,000
Inner	12,000,000

The ESALs in the outer lane over the next 20 years will average about 4.5 million per year, which is very high. The high truck volume, the high mean truck equivalency factor, and the compounded growth rate are the primary causes of these high ESAL projections. Truck factors in Canada, European countries, and South American countries, which all have high legal axle loads, can be 3.1 and higher.

Climate

This rehabilitation project is located in a wet-freeze climate. The annual rainfall is approximately 90 cm (35 in.) per year, and the mean freezing index is 556 degree-days °C (1,000 degree-days °F).

Existing Subgrade Support Conditions

The subgrade is a fine-grained soil (silts and clays) with a moisture content higher than the optimum. The in situ subgrade support was determined with FWD data taken on the existing pavement and the closed-form back-calculation methods specified in Chapter 3. The resulting k-values were

TABLE 19 Summary of traffic (ESAL) calculations (inside lane)

Year	Year	One-way ADT	% trucks	One-way ADTT	Estimated truck factor	Trucks in inner lane	Total ESALs for year (inner lane)	Cumulative ESALs (inner lane)
0	1995	32,000	0.160	5,120	3.1	0.08	380,928	380,928
1	1996	33,280	0.160	5,325	3.1	0.08	396,165	777,093
2	1997	34,611	0.160	5,538	3.1	0.08	412,012	1,189,105
3	1998	35,996	0.160	5,759	3.1	0.08	428,492	1,617,597
4	1999	37,435	0.160	5,990	3.1	0.08	445,632	2,063,229
5	2000	38,933	0.160	6,229	3.1	0.08	463,457	2,526,686
6	2001	40,490	0.160	6,478	3.1	0.08	481,995	3,008,682
7	2002	42,110	0.160	6,738	3.1	0.08	501,275	3,509,957
8	2003	43,794	0.160	7,007	3.1	0.08	521,326	4,031,283
9	2004	45,546	0.160	7,287	3.1	0.08	542,179	4,573,462
10	2005	47,368	0.160	7,579	3.1	0.08	563,866	5,137,329
11	2006	49,263	0.160	7,882	3.1	0.08	586,421	5,723,750
12	2007	51,233	0.160	8,197	3.1	0.08	609,878	6,333,628
13	2008	53,282	0.160	8,525	3.1	0.08	634,273	6,967,901
14	2009	55,414	0.160	8,866	3.1	0.08	659,644	7,627,545
15	2010	57,630	0.160	9,221	3.1	0.08	686,030	8,313,575
16	2011	59,935	0.160	9,590	3.1	0.08	713,471	9,027,046
17	2012	62,333	0.160	9,973	3.1	0.08	742,010	9,769,056
18	2013	64,826	0.160	10,372	3.1	0.08	771,690	10,540,746
19	2014	67,419	0.160	10,787	3.1	0.08	802,558	11,343,304
20	2015	70,116	0.160	11,219	3.1	0.08	834,660	12,177,964

highly variable along the project because of widely different support conditions. The results show that the subgrade has a mean static k-value of approximately 27 KPa/mm (100 psi/in.), which indicates a very soft subgrade. A sample calculation of the k-value is provided in Table 22 for one deflection point measured at the center of the slab.

Existing Pavement

The existing pavement is a 200-mm (8-in.) JRCP that was built 35 years ago. The joint spacing in the existing JRCP pavement is 24 m (80 ft). Currently, the existing pavement is very deteriorated, with widespread medium- and high-severity cracking and joint deterioration. There are approximately four transverse cracks per panel, two of which are working deteriorated cracks with ruptured steel. A few slabs are broken into several pieces and rock under load. Most of the joints are deteriorated (spalled), and a few have been replaced with full-depth repairs. The joints and deteriorated transverse cracks have poor load transfer as measured by a FWD (<50 percent on cool days).

Design Features

Type of Overlay

Only JPCP is considered in this case study. According to Chapter 3, JPCP is a feasible UBOL type for these site conditions.

Preoverlay Repair of Existing JRCP

Two alternatives for preoverlay treatment are considered: repair or rubblization of the existing pavement.

- **Alternative 1—repair existing JRCP.** Based on visual surveys of the existing JRCP and applying the guidelines from Chapter 3, it is anticipated that about 0.5 percent of the existing JRCP will require replacement with PCC before placement of the interlayer and construction of the unbonded JPCP overlay. These PCC repairs include replacement of badly shattered, rocking slabs and portions of slabs and full-depth repair of a few badly deteriorated joints. There are many regular working transverse cracks and deteriorated transverse joints that do not need to be repaired for the JPCP overlay. The working cracks could be repaired by load transfer restoration with smooth dowels.
- **Alternative 2—fracture existing JRCP.** Break and seat is not recommended. It has not been very effective for JRCP in the past because of its failure to adequately rupture steel in JRCP. The existing JRCP could be rubblized to provide more uniform support; however, the feasibility of rubblizing must first be determined. The existing slab rests on an aggregate base and a very soft, wet subgrade. This may cause problems during rubblization, because the heavy vibrating head could sink into the rubblized PCC material and prevent completion of the process. Given the low k-value of 27 KPa/mm (100 psi/in.), it is doubtful that rubblizing is feasible in this instance. However, if

TABLE 20 Summary of traffic (ESAL) calculations (center lane)

Year	Year	One-way ADT	% trucks	One-way ADTT	Estimated truck factor	Trucks in center lane	Total ESALs for year (center lane)	Cumulative ESALs (center lane)
0	1995	32,000	0.160	5,120	3.1	0.33	1,571,328	1,571,328
1	1996	33,280	0.160	5,325	3.1	0.33	1,634,181	3,205,509
2	1997	34,611	0.160	5,538	3.1	0.33	1,699,548	4,905,057
3	1998	35,996	0.160	5,759	3.1	0.33	1,767,530	6,672,588
4	1999	37,435	0.160	5,990	3.1	0.33	1,838,232	8,510,819
5	2000	38,933	0.160	6,229	3.1	0.33	1,911,761	10,422,580
6	2001	40,490	0.160	6,478	3.1	0.33	1,988,231	12,410,811
7	2002	42,110	0.160	6,738	3.1	0.33	2,067,760	14,478.572
8	2003	43,794	0.160	7,007	3.1	0.33	2,150,471	16,629,043
9	2004	45,546	0.160	7,287	3.1	0.33	2,236,490	18,865,532
10	2005	47,368	0.160	7,579	3.1	0.33	2,325,949	21,191,482
11	2006	49,263	0.160	7,882	3.1	0.33	2,418,987	23,610,469
12	2007	51,233	0.160	8,197	3.1	0.33	2,515,747	26,126,216
13	2008	53,282	0.160	8,525	3.1	0.33	2,616,377	28,742,592
14	2009	55,414	0.160	8,866	3.1	0.33	2,721,032	31,463,624
15	2010	57,630	0.160	9,221	3.1	0.33	2,829,873	34,293,497
16	2011	59,935	0.160	9,590	3.1	0.33	2,943,068	37,236,565
17	2012	62,333	0.160	9,973	3.1	0.33	3,060,791	40,297,355
18	2013	64,826	0.160	10,372	3.1	0.33	3,183,222	43,480,578
19	2014	67,419	0.160	10,787	3.1	0.33	3,310,551	46,791,129
20	2015	70.116	0.160	11,219	3.1	0.33	3,442,973	50,234,102

feasible, very little or no repair will be required before rubblization. A thick AC interlayer would be required on top of the rubblized JRCP for level-up and construction purposes. The overlay would be designed as a new pavement over a high-quality base/subbase.

Interlayer Material and Thickness

Because of extensive deterioration of the existing JRCP, the number of working cracks and joints with poor load transfer, the heavy traffic loading, and the need to level-up several sags in the grade, a thick AC interlayer is selected for the JPCP overlay. A 25-mm (1.0-in.) dense-graded, hot-mix AC layer is selected as the interlayer for the JPCP overlay with repair alternative 1. A maximum coarse aggregate size of 9.5 mm (0.375 in.) is recommended for the AC mix.

For the rubblizing alternative, based on the deteriorated condition of the existing JRCP, the use of a minimum 50-mm (2.0-in.) AC interlayer thickness is recommended to provide a working platform for construction of the JPCP overlay. Another option for the interlayer is a permeable asphalt-treated layer. This has proven to be a good option in two states; however, the permeable AC material would need to be tested for stripping before use as an interlayer.

Thickness of Overlay

The traffic analysis has shown that the level of loading varies greatly across all three lanes. One option is to use the same thickness that is required for the most heavily loaded lane (usually the outer lane) for all three lanes; however, this would result in an overdesign of lesser trafficked lanes. Another option would be to vary the thickness across all three lanes to achieve the required thickness for every traffic lane but optimize the use of materials.

Another option is to construct a widened slab in the outer lane, where the unbonded JPCP overlay would overhang about 0.5 m (1.6 ft). A strip of either AC or PCC must be constructed along the edge of the old JRCP slab to provide support to this overhanging JPCP overlay. This design would lead to a reduction in overlay thickness of approximately 25 mm (1 in.). Design procedures used include the PCA and the AASHTO design guide procedure recommended in Chapter 3.

- **PCA procedure:** Single- and tandem-axle load distributions were obtained for this heavily trafficked highway. The maximum single-axle load was 176 kN (40 kips), and the maximum tandem-axle load was 320 kN (72 kips). Using the PCA procedure, a new JPCP thickness for each lane was calculated. The results are based on a subgrade *k*-value of 27 KPa/mm (100 psi/in.) and are presented in Table 23. The required unbonded PCC overlay thickness was calculated with the following equation that was originally developed by the PCA but is not part of the current published design procedures:

$$D_{OL} = (D_{NEW}^2 - 0.35D_{EXIST}^2)^{0.5}$$

where

TABLE 21 Summary of traffic (ESAL) calculations (outside lane)

Year	Year	One-way ADT	% trucks	One-way ADTT	Estimated truck factor	Trucks in outside lane	Total ESALs for year (outside lane)	Cumulative ESALs (outside lane)
0	1995	32,000	0.160	5,120	3.1	0.59	2,809,344	2,809,344
1	1996	33,280	0.160	5,325	3.1	0.59	2,921,718	5,731,062
2	1997	34,611	0.160	5,538	3.1	0.59	3,038,586	8,769,648
3	1998	35,996	0.160	5,759	3.1	0.59	3,160,130	11,929,778
4	1999	37,435	0.160	5,990	3.1	0.59	3,286,535	15,216,313
5	2000	38,933	0.160	6,229	3.1	0.59	3,417,997	18,634,310
6	2001	40,490	0.160	6,478	3.1	0.59	3,554,716	22,189,026
7	2002	42,110	0.160	6,738	3.1	0.59	3,696,905	25,885,931
8	2003	43,794	0.160	7,007	3.1	0.59	3,844,781	29,730,713
9	2004	45,546	0.160	7,287	3.1	0.59	3,998,573	33,729,285
10	2005	47,368	0.160	7,579	3.1	0.59	4,158,515	37,887,800
11	2006	49,263	0.160	7,882	3.1	0.59	4,324,856	42,212,656
12	2007	51,233	0.160	8,197	3.1	0.59	4,497,850	46,710,507
13	2008	53,282	0.160	8,525	3.1	0.59	4,677,764	51,388,271
14	2009	55,414	0.160	8,866	3.1	0.59	4,864,875	56,253,146
15	2010	57,630	0.160	9,221	3.1	0.59	5,059,470	61,312,616
16	2011	59,935	0.160	9,590	3.1	0.59	5,261,849	66,574,464
17	2012	62,333	0.160	9,973	3.1	0.59	5,472,323	72,046,787
18	2013	64,826	0.160	10,372	3.1	0.59	5,691,215	77,738,002
19	2014	67,419	0.160	10,787	3.1	0.59	5,918,864	83,656,866
20	2015	70,116	0.160	11,219	3.1	0.59	6,155,619	89,812,485

D_{OL} = required UBOL thickness (in.) (not widened slab),
D_{NEW} = required new PCC pavement thickness (in.), and
D_{EXIST} = existing PCC thickness (in.),

The load safety factor was varied from 1.0 to 1.3, and the required overlay thicknesses are presented in Table 23.

- **AASHTO procedure:** New JPCP and unbonded PCC overlay designs were also evaluated with the 1993 AASHTO guide. These results are presented in Table 23 and are based on a subgrade *k*-value of 27 KPa/mm (100 psi/in.) for different design reliability values. For expressway-type pavements, reliability levels of 90 percent (or more) are generally recommended. A comparison of the thicknesses in millimeters (inches) for each

TABLE 22 Example calculation of the design subgrade *k*-value from FWD deflection measures taken on top of the existing concrete pavement

Step	Equation	Example
d_0		0.00418
d_8		0.00398
d_{12}		0.00384
d_{18}		0.00361
d_{24}		0.00336
d_{36}		0.00288
d_{60}		0.00205
$AREA_7$	(4)	45.0
Initial estimate of ℓ	(6)	40.79
Nondimensional d_0^* and initial estimate of k	(9) (8)	0.1237 160
AF_{d_0} AF_ℓ	(12) (13)	0.867 0.934
Adjusted k	(15)	212
Mean dynamic k		212
Mean static k for design		106 psi/in

TABLE 23 Summary of new JPCP and unbonded JPCP overlay designs

PCA JPCP Unbonded Overlay Design Procedures

Lane	New JPCP Thickness, in.	Unbonded JPCP Overlay Thickness, in.
Load Safety Factor = 1.0		
Right	11.0	10.00
Center	10.5	9.50
Left	10.0	9.00
Load Safety Factor = 1.1		
Right	12.0	11.00
Center	11.0	10.00
Left	10.5	9.50
Load Safety Factor = 1.2		
Right	13.0	12.25
Center	12.0	11.00
Left	11.0	10.00
Load Safety Factor = 1.3		
Right	13.5	12.75
Center	13.0	12.25
Left	11.5	10.50

Note: Modulus of subgrade reaction = 100 psi/in in both the new JPCP and JPCP overlay designs.

1993 AASHTO Pavement Design Procedures

	New JPCP Thickness, in.			Unbonded JPCP Overlay Thickness, in.		
Lane	95% Reliability	90% Reliability	80% Reliability	95% Reliability	90% Reliability	80% Reliability
Right	13.75	13.25	12.50	11.75	11.00	10.00
Center	11.75	11.25	10.75	9.25	8.50	7.75
Left	10.25	9.75	9.25	7.5 (min)	7.50 (min)	7.50 (min)

Note: Modulus of subgrade reaction = 100 psi/in in both the new JPCP and JPCP overlay designs.

NCHRP 1-30 Pavement Design Check/Analysis

Lane	New JPCP Thickness, in. (k =100 psi.in)	Unbonded JPCP Overlay Thickness, in.
Right	11.50	10.00
Center	10.75	9.25
Left	9.00	7.50

lane is shown as follows for specific reliability/safety factor conditions and for a slab of conventional width:

Traffic lane	PCA (load safety factor = 1.1)	AASHTO (*R* = 90 percent)
Outer	280 (11.00)	280 (11.00)
Center	250 (10.00)	215 (8.50)
Inner	240 (9.50)	190 (7.50)

The change in thickness across lanes is much more significant for the AASHTO procedure than for the PCA procedure.

Another interesting comparison is between the new/reconstructed thickness and the UBOL thickness. The new JPCP slab is about 25 to 50 mm (1 to 2 in.) thicker than the UBOL. This difference represents the benefit of the underlying existing pavement based on these design procedures. The required overlay thickness for a widened slab was computed to be approximately 25 mm (1 in.) thinner by the AASHTO procedure.

Transverse Joint Spacing

The joint spacing in the existing JRCP pavement is 24 m (80 ft). Joint spacing for the UBOL will be selected from Table 15 based on the slab thickness of 250 mm (10 in.) for a widened slab design across all traffic lanes, a subgrade k-value of 27 KPa/mm (100 psi/in.), and a wet-freeze climatic zone. This results in a maximum joint spacing of 5.4 m (18 ft). A check of the $L/l \leq 5.5$ criterion was made, as recommended in Chapter 3. It was computed to be 5.0 ($L/l = 18 \times 12/43.2 = 5.0$, with $E = 4{,}000{,}000$ psi, $k = 100$ psi/in., $D = 10$ in., $u = 0.20$), which is adequate. As another general check, the joint spacing of the new JPCP (in feet) should not exceed 1.75 times the thickness of the JPCP (in inches). Therefore, $1.75 \times 10 = 17.5$ ft, which is very close. The standard for the agency is 4.5 m (15 ft), which is certainly within the maximum transverse joint spacing for the 250-mm (10-in.) JPCP overlay thickness.

The joints will be perpendicular and of uniform spacing, as recommended under "Joint Design" in Chapter 3, because dowel bars will be specified in all lanes. This section of the guidelines also recommends that the transverse joints be mismatched with the underlying pavement joints and working cracks. However, there are so many random working cracks and joints in the JRCP, that would require a substantial effort to ensure that they were all mismatched from each other. This highway has such high traffic that dowel bars and a thick interlayer will be provided to ensure adequate load transfer even when the joints match up.

Load Transfer in the Unbonded JPCP Overlay

This overlay will be subjected to a very large number of heavy-axle loadings. The recommendations in the section "Load Transfer Design" in Chapter 3 make it clear that dowel bars are required to control joint faulting and slab corner cracking. The diameter of the dowels selected, based on the recommendation in Table 16 for 90 million ESALs, is 38 mm (1.50 in.) for the outer lane. Because of the extremely high truck traffic that is expected in all lanes, the omission of the transverse joint dowels would result in high amounts of transverse joint faulting, poor pavement rideability, and eventually corner cracking of the JPCP overlay.

Shoulders

Alternative shoulder designs include an AC shoulder, a tied PCC shoulder, or a widened slab with either a PCC or an AC shoulder. The shoulder thickness must be equal to that of the new UBOL. A widened slab with a tied PCC or hot-mix AC shoulder is recommended, as discussed in Chapter 3.

Design Check

A design check was made on the recommended unbonded JPCP overlay by using several recently developed performance prediction models. These are mechanistic-empirical models that more realistically consider the stresses related to load and temperature differentials that occur in PCC slabs. The results are presented in Table 24 for a joint spacing of 4.5 m (15 ft). New JPCP and unbonded PCC overlay performance predictions were made with slab cracking and joint faulting models contained in the ILLICON pavement analysis program (*80*) and the Present Serviceability Rating (PSR) or roughness model (*38*). Performance predictions were made for a 20-year pavement life and are based on the traffic levels presented in Tables 19, 20, and 21.

The predictions, made for a wide range of pavement thicknesses, allow the designer to determine the performance level that can be expected for a given pavement thickness. Note that these predictions should be considered approximate, as they are based on performance models developed with data from only the United States and southern portions of Canada.

Based on the results obtained, the tentative recommended unbonded JPCP overlay design is as follows:

Unbonded concrete overlay = 250-mm (10-in.) JPCP with 25-mm (1-in.) hot-mix AC interlayer, with a widened traffic lane slab [0.6 m (1.6 ft)];

Joint spacing = 4.5 m (15 ft); and

Dowel bar = 38 mm (1.50 in.)

The estimated future distress predictions are as follows:

Distress/ESAL	Inner	Center	Outer
ESAL (million)	12	50	90
Joint faulting (in.)	0.03	0.06	0.08
Slab cracking (%)	0.4	1.2	2.1
Serviceability (PSR)	4.15	3.1	<2

All these distresses are within acceptable limits except the serviceability level in the outer traffic lane, where faulting and cracking combine to produce a fairly rough pavement according to these predictions. If this much traffic actually develops, the outer lane will require a considerable amount of maintenance over the last 10 years of the life of the JPCP. One option is to thicken the outer lane by about 25 mm (1 in.) through a trapezoidal cross section.

Final Recommendations

The final selection of the design thickness should consider the results from these computations and the practical implications (including cost) of building an overlay with varying

TABLE 24 Summary of 20-year pavement performance predictions

ILLICON YEAR 20 PERFORMANCE PREDICTION RESULTS

PCC Thickness, in	Left Lane (12,000,000 ESALs) Percent Slabs cracked	Left Lane Doweled Joint Faulting, in	Left Lane Present Serviceability Rating	Center Lane (50,000,000 ESALs) Percent Slabs cracked	Center Lane Doweled Joint Faulting, in	Center Lane Present Serviceability Rating	Right Lane (90,000,000 ESALs) Percent Slabs cracked	Right Lane Doweled Joint Faulting, in	Right Lane Present Serviceability Rating
New JPCP Pavement (k = 100 pci, Syracuse temperature gradient, 15 ft joint spacing, 38 mm (1.5 in) dowels, PCC MR = 800 psi, Ec = 5,000,000 psi, granular base)									
8	11.60	0.07	< 2.00	31.20	0.13	< 2.00	43.00	0.18	< 2.00
9	0.80	0.06	2.65	2.80	0.13	< 2.00	4.60	0.17	< 2.00
10	0.00	0.06	3.70	0.10	0.13	< 2.00	0.20	0.17	< 2.00
11	0.00	0.06	4.15	0.00	0.13	2.90	0.00	0.16	< 2.00
12	0.00	0.06	4.30	0.00	0.13	3.70	0.00	0.16	3.10
13	0.00	0.06	4.35	0.00	0.13	4.10	0.00	0.16	3.75
Unbonded JPCP Overlay (k = 300 pci, Syracuse temperature gradient, 15 ft joint spacing, 38 mm (1.5 in) dowels, PCC MR = 800 psi, Ec = 5,000,000 psi)									
7.5	27.30	0.04	2.65	56.50	0.07	< 2.00	68.40	0.10	< 2.00
8	12.90	0.04	3.25	33.90	0.07	< 2.00	46.10	0.09	< 2.00
9	2.30	0.03	3.75	7.50	0.06	< 2.00	11.90	0.09	< 2.00
10	0.40	0.03	4.15	1.20	0.06	3.10	2.10	0.08	< 2.00
11	0.00	0.03	4.35	0.10	0.05	3.85	0.20	0.07	3.30
12	0.00	0.03	4.40	0.00	0.05	4.15	0.00	0.07	3.90

thickness. Based on an evaluation of the results, the following design appears adequate:

JPCP overlay: 250-mm (10-in.) uniform thickness across traffic lanes;
Widened lane: 0.6 m (1.6 ft) and place AC or PCC along edge of slab as support;
Joint spacing: 4.5 m (15 ft);
Dowel bars: 38-mm (1.50-in.) diameter spaced at 305 mm (12 in.);
Shoulder: Either AC or tied PCC same thickness as JPCP;
Interlayer: 25-mm (1-in.) hot-mixed AC (dense graded);
Subdrainage: Add longitudinal edge drains; and
Old JRCP: Repair approximately 0.5 percent with PCC.

An alternative to this design is to rubblize the existing JRCP and place a 25-mm (1-in.) or greater AC interlayer on it and then place a JPCP slab that has been designed as a new pavement on top of the interlayer. This alternative will provide a JPCP thickness of at least 280 mm (11 in.). Thus, the costs that would have to be compared are those of an extra inch of JPCP and the cost of rubblizing versus the cost of pre-overlay repairs. In this situation, the rubblizing alternative may not be cost-effective; however, in another situation it may be the preferred option.

DATABASE AND SUMMARY OF GOOD AND POORLY PERFORMING UNBONDED CONCRETE OVERLAYS

The database developed under this project and the LTPP GPS-9 sections have provided a wealth of information. However, with such a diverse database, it is difficult to extract real consensus findings. This section summarizes some of the most significant findings from specific sections that performed well or poorly. A simplified table of information was prepared to show these effects (Table 25). Each section that had a critical amount of data available was included. Note that some of the traffic loadings were estimated from very limited data and should be considered very approximate estimates only.

An approximate performance rating was assigned to each UBOL section according to the following general guidelines:

Poor: Overlay < 10 years old, exhibiting significant distress;
Fair: Overlay between Poor and Good (significant distress between 10 and 20 years); and
Good: Overlay > 20 years old, distress not considered, or overlay at any age with no significant distress.

Following are some illustrative examples of unbonded concrete overlays that are performing well and poorly.

TABLE 25 Summary of the synoptic table for unbonded concrete overlays

ID	Highway	OLType	OLThk	ConsYr	InspYr	AGE	MESAL	Rating	ExistPVT	ID	Repair	Interlayer	InterThick	JT Spacing	Dowel
GA-4	I-75	CRCP	7 & 8	1972	1993	21	30	Good	JPCP	GA-4	None	None			
IL-1	I-55	CRCP	9	1974	1986	12	9	Good	JRCP	IL-1	Limited patching	AT	4 (min.)		
IL-2	I-55	CRCP	8	1970	1986	16	9	Good	JRCP	IL-2	Limited patching	AT	4 (min).		
IL-3	I-70	CRCP	8	1967	1986	19	17	Good	JRCP	IL-3	Limited patching	AC	4 in		
GA-1	I-85 (SR-403)	CRCP	6	1975	1993	18	16	Fair	JPCP	GA-1	CPR as needed	None			
IL-3	I-70	CRCP	7	1967	1986	19	17	Fair	JRCP	IL-3	Limited patching	AC	4		
ND-1	I-29	CRCP	8	1974	1993	19	2	Fair	JPCP	ND-1		AC	2		
ND-2	I-29	CRCP	6	1972	1993	21	3	Fair	JPCP	ND-2		AC	2		
AR-1	I-30	CRCP	6	1992	1995	3	6	Poor	JRCP	AR-1	Limited patching	AC	1		
GA-3	I-85 (SR-403)	CRCP	3	1975	1985	10	7	Poor	JPCP	GA-3	CPR where reqired	None			
GA-5	I-85	CRCP	4.5	1975	1985	10	7	Poor	JPCP	GA-5	CPR where reqired	None			
IL-3	I-70	CRCP	6	1967	1986	19	17	Poor	JRCP	IL-3	Limited patching	AC	4		
MD-1	I-70	CRCP	6	1974	1985	11	8	Poor	JRCP	MD-1		AC	1		
PA-5	I-90	CRCP	7	1976	1993	17	20	Poor	JRCP	PA-5	5% Patching	SA	1		
WI-1	IH 94	CRCP	8	1980	1993	13	12	Poor	JRCP	WI-1	Patching	ST	1.75		
CA-1	I-80	JPCP	10.2	1993	1994	1	2	Good	JPCP	CA-1	Shattered slab replacement	AC	1	12,15,13,14	None
CA-2	I-80	JPCP	10.2	1992	1994	2	3	Good	JPCP	CA-2	Shattered slab replacement	AC	1	12,15,13,14	None
CA-5	I-80	JPCP	10.2	1991	1992	1	1	Good	JPCP	CA-5	Shattered slab replacement	AC	1	12,15,13,14	None
CA-6	I-8	JPCP	6	1970	1991	21	6	Good	JPCP	CA-6		AC	0.5	13,19,18,12	
CO-10	I-76	JPCP	8	1990	1996	6	2	Good	JPCP	CO-10	Some slab remov/replace	AC	1		None
CO-3	I-25	JPCP	8	1987	1996	9	12	Good	JPCP	CO-3	Some slab remov/replace	ST			N
CO-5	I-25	JPCP	8	1985	1996	11	14	Good	JPCP	CO-5	Some slab remov/replace	ST			N
CO-6	I-25	JPCP	7.75	1984	1996	12	20	Good	JPCP	CO-6	Some slab remov/replace	ST			N
CO-7	I-76	JPCP	8.5	1992	1996	4	1	Good	JPCP	CO-7	Some slab remov/replace	AC	0.75		N
DE-1	I-495	JPCP	12	1992	1996	4	4	Good	CRCP	DE-1	Spall repair	AC	2	20	
IA-7	Sec. Rd. W47	JPCP	7	1990	1992	2	1	Good	JPCP	IA-7		AC	1	15	
MN-10	I-90	JPCP	8	1992	1994	2	1	Good	CRCP	MN-10		AC	1	15 - random	1
MN-2	TH 212	JPCP	7	1985	1993	8	10	Good	JPCP	MN-2		SA	1.5	15 - random	1
MN-4	I-35	JPCP	8	1987	1994	7	10	Good	JRCP	MN-4		AC	1	15 - random	1
MN-5	I-90	JPCP	9	1988	1993	5	6	Good	JRCP	MN-5		AC	1	15 - random	1.25
MN-6	I-90	JPCP	8	1990	1994	4	3	Good	JRCP	MN-6		AC	1	15 - random	1
MN-7	I-90	JPCP	8	1991	1994	3	2	Good	CRCP	MN-7		AC	1	15-random	1
MN-8	USTH 52	JPCP	9.5	1992	1994	2	1	Good	JPCP	MN-8		AC	2	15 - random	1.25
MN-9	I-35	JPCP	7.5	1992	1994	2	1	Good	JRCP	MN-9		AC	1	15 - random	1
NB-1	US-281	JPCP	7	1988	1993	5	2	Good	JRCP	NB-1	Full depth joint, panel repair	CS	0.5	16.5	None
OH-1	US-33	JPCP	7	1982	1986	4	3	Good	JRCP	OH-1	Pothole patching	AC	0.75	12-15-13-14	None
OH-3	US-33	JPCP	8	1985	1994	9	3	Good	CRCP	OH-3	Level slags with AC	AC	0.75	13-16-14-15	None
PA-15	I-78	JPCP	12	1985	1994	9	5	Good	CRCP	PA-15	Concrete patching	SA	1	20	1.5
PA-16	I-78	JPCP	12 & 13	1991	1995	4	8	Good	JRCP	PA-16	Bituminous patching	PAC	4	20	1.5
PA-17	I-80	JPCP	13	1993	1994	1	4	Good	JRCP	PA-17	Bituminous patching	PAC	2.5	20	1.5
PA-18	I-1	JPCP	10	1988	1995	7	10	Good	JRCP	PA-18		AC	1		
TX-6	I-45	JPCP	10	1968	1990	22	5	Good	CRCP	TX-6		AC	3.9		
GA-2	I-85 (SR-403)	JPCP	6	1975	1993	18	16	Fair	JPCP	GA-2	Underseal, slab repl., spall repair	None		15	1.125
IA-10	•	JPCP	7	1987	1992	5	1	Fair	JPCP	IA-10		SS	0.25	15	None
IA-8	Sec. Rd. G52	JPCP	7	1987	1992	5	1	Fair	JPCP	IA-8		AC	1	15	None
IA-9	Sec. Rd. G38	JPCP	7	1991	1992	1	0	Fair	JPCP	IA-9		AC	1	15	None
CA-4	I-80	JPCP	8	1989	1992	3	8	Poor	JPCP	CA-4	Shattered slab replacement	AC		12,15,12,14	None
IL-4	I-88	JPCP	8	1981	1989	8	10	Poor	JRCP	IL-4		SA	0.5	14.5 (random)	None
KS-1	US-24	JPCP	6	1978	1988	10	4	Poor	JRCP	KS-1		AC	1	15	None
MN-1	TH 71	JPCP	5.5	1977	1995	18	1	Poor	JPCP	MN-1		SA	1	13-16-14-19	0.75
MI-2	I-96	JRCP	7	1984	1993	9	5	Good	CRCP	MI-2	Bituminous patching	AC	0.8	41 AVG	1.25
MI-3	US-23	JRCP	7	1984	1993	9	6	Good	JRCP	MI-3	Bituminous patching	AC	0.8	41 AVG	1.25
MN-3	I-90	JRCP	8.5	1986	1994	8	10	Good	CRCP	MN-3		AC	1	27	0.75
MO-1	I-70	JRCP	11	1992	1995	3	5	Good	JRCP	MO-1		AC	varied	61.5	1.5
MS-2	I-20	JRCP	10	1990	1993	3	5	Good	JRCP	MS-2		AC	3	21	1.25
MS-3	I-20	JRCP	10	1990	1993	3	5	Good	JRCP	MS-3		AC	3	21	1.25
MS-4	I-20	JRCP	10	1990	1993	3	4	Good	JRCP	MS-4		AC	3	21	1.25
OH-2	Rte. 70	JRCP	10	1984	1986	2	4	Good	JRCP	OH-2	Full depth jt repair, underseal	AC	1	60	1.375
PA-14	I-80	JRCP	10	1988	1994	6	5	Good	JRCP	PA-14	slab stab., joint and crack repair, base drain	AC	1-4	20	1.5
MS-5	I-20	JRCP	10	1987	1993	6	7	Fair	JRCP	MS-5		NA	NA	21	1
AR-3	I-40	JRCP	10	1985	1995	10	15	Poor	JRCP	AR-3		AC	1		1.25
MS-1	I-59	JRCP	6	1982	1993	11	10	Poor	JRCP	MS-1		AC	1.5	20	1

AC = Asphalt concrete, SA = Sand asphalt, ST = Surface treatment, CS = Chip seal, SS = Slurry seal, PAC = Permeable asphalt concrete
AT = Asphalt treated, Poor = M-H distress, <10 years, Fair = 10 - 20 years with M-H distress, Good = >20 years old

Poor CRCP

Arkansas-1

A 152-mm (6-in.) CRCP overlay (with AC interlayer) over JRCP under heavy traffic (2 million ESALs/year) developed punchouts rapidly within a few years. Inadequate CRCP thickness for given traffic levels appears to be the main reason.

Illinois-3

CRCP overlays of 152 mm (6 in.) with 0.7 and 1.0 percent reinforcement over a thick AC interlayer over an old JRCP under heavy traffic (17 million ESALs over 19 years) developed punchouts and required extensive repairs (4.9 to 7.3 percent repair). Thicker slabs at the same location required much less repair [178 mm (7 in.) required 0.6 to 2.3 percent repair, and 203 mm (8 in.) required no repair].

Georgia-1, -3, and -5

Georgia constructed a series of CRCP overlays in the 1970s that were 76, 114, and 152 mm (3, 4.5, and 6 in.) thick. The CRCP overlays were placed directly on old JPCP; no interlayer was used (except curing compound). Traffic during the first 10 years was 0.7 million ESALs per year. The 76- and 114-mm (3- and 4.5-in.) CRCP developed deteriorated cracks and punchouts directly over the joints in the JPCP and required repairs in 1 to 5 years. The 152-mm (6-in.) CRCP performed much better but still had deteriorated cracks and punchouts over the joints after 8 years.

Wisconsin-1

A 203-mm (8-in.) CRCP overlay with surface treatment interlayer over JRCP deteriorated rapidly, with punchouts occurring under heavy traffic (1 million ESALs/year).

Summary

CRCP that perform poorly tend to be 76 to 203 mm (3 to 8 in.) thick, placed over an old JRCP with a surface treatment interlayer or no interlayer, and subjected to heavy traffic (>1 million ESALs/year). It also appears that CRCP 150 mm (6 in.) or thinner performs poorly under heavy traffic regardless of interlayer.

Good CRCP

Illinois-3

A 203-mm (8-in.) CRCP overlay with a 102-mm (4-in.) asphalt-treated base interlayer over JRCP with 0.6 percent reinforcement carried more than 17 million ESALs over 19 years with no repairs required.

Georgia-4

CRCP overlays 178 and 203 mm (7 and 8 in.) thick with no interlayer placed over JPCP carried more than 30 million ESALs over a 21-year period with low-severity punchouts.

North Dakota-1 and -2

CRCP overlays 152 and 203 mm (6 and 8 in.) thick placed over a 51-mm (2-in.) AC interlayer over JPCP carried 2 to 3 million ESALs over 19 to 21 years with some deterioration.

Summary

CRCP overlays that perform well tend to be 178 mm (7 in.) or thicker and placed on a thick AC interlayer over old JPCP or CRCP.

Poor JRCP

Arkansas-3

A 254-mm (10-in.) JRCP overlay over a 25-mm (1-in.) AC interlayer over an old JRCP under heavy traffic (1.5 million ESALs/year) developed many deteriorated transverse cracks over 10 years. Reinforcement content may be low in the JRCP overlay.

Mississippi-1

A 152-mm (6-in.) JRCP overlay over an AC interlayer placed over old JRCP under heavy traffic (1 million ESALs /year) developed many deteriorated transverse cracks. Reinforcement content may be low in the JRCP.

Summary

JRCP that perform poorly develop deteriorated transverse cracks, perhaps from a low reinforcement content and heavy traffic. These deteriorated crack failures may be due to inadequate reinforcement content more than to reflection from the underlying pavement.

Good JRCP

Missouri-1

A 279-mm (11-in.) JRCP overlay under heavy traffic (1.7 million ESALs/year) has performed well after 2 years of traffic.

Michigan-3

A 178-mm (7-in.) JRCP overlay over an AC interlayer over old JRCP carried 6 million ESALs over 9 years with no deterioration.

Minnesota-3

A 216-mm (8.5-in.) JRCP overlay over an AC interlayer over old CRCP carried 10 million ESALs over an 8-year period with no deterioration.

Summary

JRCP that perform well have a widely varying range of design features.

Poor JPCP

Illinois-4

A 203-mm (8-in.) nondoweled JPCP overlay with 4.4-m (14.5-ft) joint spacing over a surface treatment interlayer placed over an old JRCP carried 10 million ESALs over 8 years but faulted badly because of the eroded interlayer. It also showed some transverse cracking and corner cracking. The JPCP was diamond ground after 8 years, which lasted another 8 years.

California-4

A 203-mm (8-in.) nondoweled JPCP overlay with 3.6- to 4.6-m (12- to 15-ft) joint spacing over an AC interlayer over an old JPCP carried extremely heavy traffic of 8 million ESALs over 3 years. It has developed some medium-severity corner breaks and low-severity transverse cracking.

Minnesota-1

A 140-mm (5.5-in.) JPCP overlay [19-mm (0.75-in.) dowels] over a sand-asphalt interlayer placed over an old JPCP carried very heavy traffic of 1 million rigid ESALs over 18 years. This section showed significant slab cracking over its lifetime.

Kansas-1

A 152-mm (6-in.) JPCP (nondoweled) overlay over an AC interlayer placed over an old JRCP carried 4 million ESALs over 10 years and developed slab cracking (transverse cracks, longitudinal cracking, and corner breaks).

Georgia-2

JPCP overlays of 152 mm (6 in.) (with dowels) with no interlayer and with joints matching the 9-m (30-ft) existing slab joints rapidly developed transverse cracks at midslab. One section also had sawed joints at 4.5 m (15 ft), and these did not develop transverse cracks. This section has carried approximately 16 million ESALs over a 20-year period.

Summary

JPCP that perform poorly tend to be thinner slabs [152 to 203 mm (6 to 8 in.)], nondoweled, with longer joint spacing, and with an erodible interlayer or no interlayer.

Good JPCP

Colorado-5

A 203-mm (8-in.) JPCP (nondoweled) overlay over a surface treatment interlayer placed over an old JPCP has performed well under 14 million ESALs over 11 years.

Delaware-1

A 304-mm (12-in.) JPCP (doweled) overlay over an AC interlayer placed over an old CRCP is carrying over 1 million ESALs per year and has shown good performance over the first 4 years.

Texas-6

A 254-mm (10-in.) JPCP (nondoweled) over a thick AC interlayer over an old CRCP has carried 5 million ESALs over 22 years with no significant distresses.

Pennsylvania-15

A 305-mm (12-in.) JPCP (doweled) overlay over a sand asphalt interlayer over an old CRCP has carried 5 million ESALs over 9 years with no significant distress.

Ohio-3

A 203-mm (8-in.) JPCP (doweled) overlay over an AC interlayer over an old CRCP has carried 3 million ESALs over a 9-year period with no significant distress.

Minnesota-4

A 203-mm (8-in.) JPCP (doweled) overlay over an AC interlayer over an old JRCP has carried 10 million ESALs over a 7-year period and has not shown significant distress.

Summary

JPCP that perform well tend to have thicker slabs [≥180 mm (7 in.)], an AC interlayer [≥25 mm (1 in.)], and doweled joints.

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AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

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