

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

144

**BREAKING / CRACKING AND SEATING
CONCRETE PAVEMENTS**

TRANSPORTATION RESEARCH BOARD
National Research Council

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BREAKING / CRACKING AND SEATING CONCRETE PAVEMENTS

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C.

MARCH 1989

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

*By Staff
Transportation
Research Board*

This synthesis will be of interest to pavement designers, maintenance engineers, and others interested in reducing reflection cracking of asphalt overlays on portland cement concrete (PCC) pavement. Information is presented on the technique of breaking or cracking of the concrete pavement into small segments before overlaying with asphalt concrete.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Asphalt concrete overlays on existing PCC pavements are subject to reflection cracking induced by thermal movements of PCC pavement. This report of the Transportation Research Board discusses the technique of breaking/cracking and seating

of the existing PCC before an overlay as a means to reduce or eliminate reflection cracking.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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William G. Gunderman, Engineer of Materials and Construction, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

BREAKING/CRACKING AND SEATING CONCRETE PAVEMENTS

SUMMARY

Breaking/cracking and seating (B/C&S) of portland cement concrete (PCC) pavement is a technique being used before an overlay to create concrete pieces that are small enough that thermal stresses will not cause reflective cracking in the overlay. B/C&S techniques have been used on all types of facilities from city streets to Interstate highways and on plain and reinforced concrete. In all cases it is essential that the concrete be cracked completely through the slab to achieve the full potential of the B/C&S technique.

Most agencies require cracking in both transverse and longitudinal directions; a few require transverse only. Some states are reducing the concrete to rubble as a form of B/C&S treatment. Overlay thicknesses over B/C&S treatments are usually 3.5 in. or greater, with an average of more than 4 in.

The B/C&S treatment has a significant effect on the structural response and behavior of the PCC slab. Surface deflections and subgrade stresses increase, flexural stresses are reduced, and the behavior is more flexible in nature; slab structural models are no longer applicable. An equivalent modulus procedure can be used. Data obtained from nondestructive testing (falling-weight deflectometer, Benkelman beam, etc.) can be used for analysis and design of B/C&S pavements. Several states are using design procedures that rely on this type of data and a model has been developed at the University of Illinois. However, there is a considerable variation in the structural values assigned to a B/C&S slab. At this time there is no validated asphalt concrete (AC) overlay thickness design procedure for B/C&S pavements based on AC fatigue; however, in those projects in which overlay thickness was considered, thicker overlays provided better performance.

Construction of B/C&S pavements follows four major steps: (a) breaking/cracking the existing slab, (b) seating the cracked slab, (c) special treatments, and (d) AC overlay construction. A variety of equipment (pile drivers, guillotine drop hammers, impact hammers, resonant pavement breakers) is used to break the slab. The typical maximum specified size of slab segments ranges from 48 to 18 in., although a few agencies require that the slab be reduced to rubble (4 to 6 in. segments).

After breaking, the slab is seated by rolling to ensure that all segments are in contact with the supporting layer. There is no consensus among agencies as to the best practice for seating of slabs. A wide variety of roller equipment and passes has been used by various agencies. Weights currently being used vary from 35 to 50 tons and the number of passes required varies from two to five, depending on weight of roller and condition of base or subgrade. Rolling in excess of that needed to seat the slab may be harmful.

A performance survey by the Federal Highway Administration found that B/C&S as a rehabilitation alternative should be approached with caution. A significant reduction in reflective cracking after four to five years occurred on only 2 of 22 projects

reviewed. The University of Illinois surveyed 70 projects in 12 states and found that B/C&S treatment reduced reflection cracking in the early years of the overlay's life but that the effectiveness diminished with age. Kentucky surveyed and tested 451 lane-miles of B/C&S-treated pavement and found only one section that displayed unexpected reflection cracking; analysis of that section revealed that proper B/C&S had not been achieved.

There are many technology gaps related to breaking/cracking and seating. The system (AC overlay, PCC slab segments, base, subgrade) is complex compared with conventional pavement. Thus there is a need to develop improved techniques for quantifying the extent of breaking/cracking achieved, to quantify the effects of PCC slab segment geometry, to establish procedures for evaluating the structural effectiveness of the B/C&S slab, to monitor the performance of well-documented B/C&S sections, to develop a mechanistic AC overlay design procedure, and to establish criteria for determining the cost-effectiveness of the B/C&S procedure.

It is apparent that the B/C&S procedure is not a panacea. The gaps in technology make it difficult to establish the cost-effectiveness of the procedure. Effective use of B/C&S requires:

- Careful attention to engineering and economic analysis for each project,
- Selection of a cracking pattern that is adequate to eliminate thermally related reflection cracking,
 - Achievement of through-slab cracking,
 - Selection of a roller size and rolling pattern that will properly seat the PCC segments but not detrimentally affect the base or subgrade,
- Documentation of the construction process, and
- Monitoring the performance of well-documented B/C&S projects.

INTRODUCTION

Breaking/cracking and seating (B/C&S) of portland cement concrete (PCC) pavements before an asphalt concrete (AC) overlay has been extensively used in recent years. B/C&S has not been well defined. In some past projects only partial through-slab cracking was achieved. To achieve the full benefits of B/C&S, breaking (complete through-slab cracking) must be achieved to reduce the PCC slab to the desired PCC slab segment size.

A recent comprehensive National Asphalt Pavement Association (NAPA) survey (1) of B/C&S activities indicated widespread utilization. Eighteen state highway agencies used the technique in the 1985–1986 period. States that have constructed many lane-miles of B/C&S are Kentucky, Minnesota, Wisconsin, and California.

In the B/C&S process, an existing PCC slab that has been established as a suitable project for AC overlay rehabilitation is broken into reduced-size PCC segments. The PCC segment size and geometry normally vary from approximately 30 × 30 in. to rubble (6 to 8 in. maximum size) segments. In some instances only cracking transverse to centerline is required.

The Federal Highway Administration (FHWA) "Pavement Rehabilitation Manual" (2) indicates:

The intent of pavement cracking and seating is to create concrete pieces that are small enough to reduce horizontal slab movement to a point where thermal stresses which contribute to reflective cracking will be greatly reduced, yet still be large enough and still have some aggregate interlock between pieces so the majority of the original structural strength of PCC pavement is retained. Seating of the broken slabs after cracking is intended to reestablish support between the subbase and the slab where voids may have existed.

NCHRP Synthesis of Highway Practice 92 (3) considered the problem of reflection cracking and various techniques and procedures for alleviating or preventing this mode of distress. Stabilizing PCC slabs by breaking was discussed in Chapter Three as a method for treatment of existing pavements. However at the time Synthesis 92 was published (1982), cracking and seating of PCC slabs was not listed as a "demonstrated capability to retard reflective cracking of AC overlays on old PCC pavements." Since 1982, several reports (2, 4–8) have indicated that B/C&S of PCC slabs is an effective system for controlling reflective cracking in AC overlays. Cracking and seating is included in FHWA's "Pavement Rehabilitation Manual" (2) as a feasible technique.

B/C&S design and construction techniques vary considerably. The scope established by the topic panel for this synthesis indicated a need to (a) document the various techniques and their resulting performances and (b) identify areas of needed research.

B/C&S was not used extensively before the early 1980s. Thus, the technical and research literature is not voluminous. In addition to the references cited in the report, a listing of other publications is presented in the Selected Bibliography.

A NAPA-sponsored study (4) (published in 1982) was directed to summarizing the state of the art of the design and construction of asphalt overlays on cracked and seated PCC pavements. In the NAPA study (conducted during the fall of 1981 and the winter of 1982):

... personnel from over 40 federal, state, and municipal government agencies, contractors, and consultants from all sections of the United States were interviewed concerning their PCC pavement cracking and seating experience. In addition, several state asphalt pavement associations provided invaluable assistance and information. Site visits were made to PCC pavement cracking and seating projects in a half-dozen localities.

The NAPA report (4) indicated:

As is shown by the projects discussed in this report, PCC pavement cracking and seating has been used for over 20 years in various localities throughout the country. In all, over 60 projects in 12 states have been identified which have included cracking and seating to help reduce the amount and severity of reflection cracking. The technique has been used on all types of roads, from interstate highways to city streets with curb and gutter, and on reinforced and unreinforced concrete pavements.

Reducing the length of the concrete slabs definitely does reduce reflection cracking. The smaller the cracked pieces, the more the potential for reflective cracking is reduced, but also the more the structural strength of the concrete pavement is reduced. The optimum size of cracked pieces is yet to be established, but for pavements on reasonably firm subgrades or bases, cracked pavement sizes of two to three feet with 3- to 5-inch overlay thicknesses have performed the best to date. The actual overlay thickness will depend on the expected traffic and other usual design parameters. PCC breaking and seating prior to asphalt overlay is the most cost-effective treatment available for minimizing the damage caused by reflective cracking.

A recent NAPA publication (1) updated the initial NAPA report published in 1985. The report indicated that by using the B/C&S technique, "Reflection cracking can be reduced or at least delayed, thus saving pavement costs and extending service life." The 1987 FHWA Crack and Seat Performance Review Report (5) concluded that "overall, B/C&S appears to provide benefits under some conditions by *delaying*, not eliminating, reflective cracking."

Kentucky's experience (6) with B/C&S has demonstrated the technique is also effective in eliminating blowups in jointed PCC pavements. The FHWA Review Report (5) noted "isolated blow-up areas" in Indiana B/C&S sections on I-74.

Factors normally considered in establishing pavement serviceability are cracking, patching, rutting, and roughness. In most instances, the effectiveness of B/C&S procedures is primarily measured in terms of reflective cracking. Reflective cracking typically occurs early in the service life (perhaps as soon as one year or less) when an AC overlay is constructed over a PCC slab. If the B/C&S procedure is effective, reflective cracking will not develop and contribute to a loss in pavement serviceability. However, B/C&S pavements can develop AC layer fatigue cracking as traffic is applied. For larger PCC segment sizes, fatigue cracking will probably initiate over a crack. In the case of a PCC slab reduced to rubble, the AC fatigue cracking may develop in a manner similar to a conventional flexible pavement because the rubble is similar to a large-maximum-size aggregate base course.

AC layer rutting will not necessarily accumulate in the same manner when B/C&S procedures are employed. Stress states in an AC overlay are influenced by the stiffness and moduli of the supporting layers. The procedure used to create rubble generally produces PCC stiffness and modulus characteristics smaller than conventional B/C&S procedures.

The FHWA Pavement Rehabilitation Design and Techniques Study (the first component of the FHWA National Pavement Initiative, approved in May 1983) included a two-phase approach. Phase I "summarized state experiences with 60 rehabilitation techniques used on flexible and rigid pavements." Five of the more effective rehabilitation techniques (which included B/C&S) were identified.

Phase II of the FHWA study (which produced the "Pavement Rehabilitation Manual") focused "in much greater detail on the five techniques previously identified. Field reviews by personnel from the Offices of Engineering and Highway Operations accompanied by Region, Division, and State pavement specialists were conducted in 25 States for the purpose of gathering detailed information about design, construction, and performance of each technique. Information obtained from field reviews was verified and supplemented by an extensive literature search before each chapter was written."

Chapter 5 of the FHWA manual (2) is a comprehensive treatment of cracking and seating and includes several sections (Introduction, Concurrent Work, Design, Construction, Guide Specifications, and Key References).

Two major follow-up efforts were initiated by FHWA to further develop inputs concerning the long-term cost-effectiveness of concrete pavement restoration (CPR) and B/C&S procedures. An FHWA research project entitled "Determination of Rehabilitation Methods for Rigid Pavements" was conducted at the University of Illinois, and the FHWA Pavement Division conducted a "Performance Evaluation" for B/C&S rehabilitation techniques. The University of Illinois study (7) was completed in the summer of 1987, and the FHWA performance evaluation study is presented in Reference 5.

The FHWA "Pavement Rehabilitation Manual" indicates that California is the only state that has established formal criteria for B/C&S use. Caltrans uses the following guidelines:

1. Use in all lanes expected to carry an appreciable amount of truck traffic. On facilities with six or more lanes, this would generally include the outer two lanes. On four-lane facilities, it would often include all lanes, especially in urban areas.
2. Use on lanes expected to carry primarily auto traffic:
 - Where there is $\frac{1}{8}$ inch or more average faulting with or without slab breakage, cracking and seating is recommended.
 - Where there is less than $\frac{1}{8}$ inch average faulting and no slab breakage, cracking and seating is *not recommended*.

The state of the art and the state of the practice are very well documented in References 1 and 2. It appears that the major technological gaps are:

1. Determining *when* B/C&S procedures *should* be used;
2. Developing techniques and procedures for quantifying the extent of the cracking and breaking achieved in the PCC slab;
3. Optimizing PCC segment size and geometry (length \times width);
4. Developing improved guidelines and specifications for seating the PCC segments;
5. Evaluating the structural effectiveness of the B/C&S PCC slab;
6. Developing an adequate B/C&S performance data base; and
7. Establishing an AC overlay thickness design procedure methodology.

CHAPTER TWO

USE AND BEHAVIOR OF BROKEN/CRACKED AND SEATED PAVEMENTS

GENERAL

B/C&S pavement rehabilitation techniques have been used on all types of facilities from city streets to Interstate highways. Plain, reinforced, and wire mesh reinforced concrete pavements have been subjected to B/C&S rehabilitation with varying degrees of success. Crawford (1) indicates that "experience is limited with respect to continuously reinforced concrete pavement." Some agencies question the desirability of using B/C&S for continuously reinforced concrete pavement rehabilitation.

Through-slab cracking is essential to the success of B/C&S rehabilitation. The continuity of the PCC slab (and the ability to transmit horizontal slab movement) must be broken to achieve the full potential of the B/C&S rehabilitation technique. New York research (8) on reflection cracking in bituminous overlays on rigid pavements indicated that "crack initiation is due solely to horizontal movement."

Although most recommended B/C&S specifications require the removal of an existing AC overlay before cracking, B/C&S projects have been constructed *without* removing the existing AC overlay. Existing AC overlay thickness will influence the effectiveness and efficacy of the pavement breaking/cracking equipment. Cracking pattern and target PCC slab segment size varies considerably, as shown in Table 1 from the FHWA "Pavement Rehabilitation Manual" (2).

Cracking is normally achieved in both the transverse and longitudinal directions. However, some states (for example, Min-

nesota) require cracking in only a transverse pattern. In previous years, New York DOT achieved longitudinal cracking by moving transversely across the lane but does not currently use the longitudinal-cracking-only approach. Some states (New York, Minnesota, Michigan) have recently included reducing the PCC slab to rubble as a form of B/C&S rehabilitation. New York uses this procedure only when the existing PCC pavement is to be widened with a crushed stone subbase.

MECHANISTIC MODEL FOR AC REFLECTIVE CRACKING

Jayawickrama and Lytton (9) presented an excellent comprehensive mechanistic framework for considering reflective cracking in AC overlays placed over concrete pavements. They indicated:

The basic mechanisms generally assumed to lead to reflection cracking are the vertical and horizontal movements of the underlying pavement layers. These damaging movements may be caused by traffic loading, thermally induced contractions and expansions, or a combination of these mechanisms. [Figure 1]

TABLE 1
CRACK PATTERNS (2)

State	Cracked Pattern
California	4' x 6' and 4' x 4'
Illinois	1.5' x 2'
Iowa	6' x 6'
Kentucky *	1.5' x 2'
Michigan	1.5' x 2'
Minnesota	3-4' transverse
New York	3' x 3'
North Dakota	3' transverse
West Virginia	1.5' x 2'

* See Appendix B for Kentucky's most recent recommended practice.

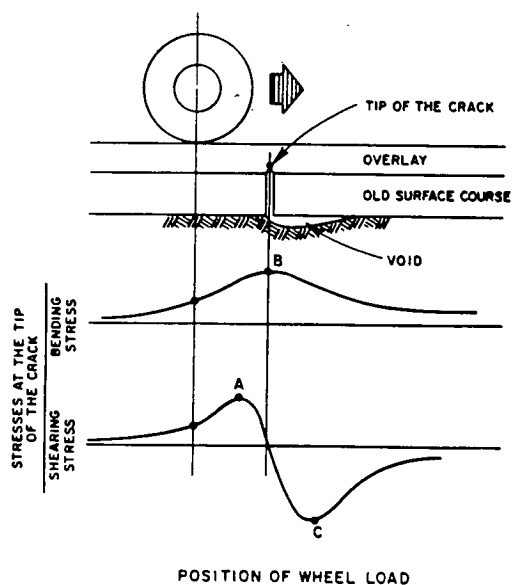


FIGURE 1 Stresses induced at the cracked section because of a moving wheel load (9).

shows the stresses induced within the overlay under the influence of a moving wheel load. It can be observed that three pulses of high stress concentrations occur at the tip of the crack as the wheel passes over it: one due to bending stresses and two due to shearing stresses. In addition to the influence of traffic loads, contraction and expansion of the pavement and the underlying layers with changes in temperature can also contribute towards the growth of reflection cracks.

The associated field verification study revealed that "the number of days to failure (reflective cracking) due to thermal movements were directly correlated to the observed pavement performance." They concluded that thermal movements were the major factor influencing reflective cracking but also indicated that "bending and shearing effects" are detrimental and will cause a reduction in the time until reflective cracking occurs. For given conditions (PCC coefficient of thermal expansion and temperature change), reducing the crack spacing in the PCC slab (which is the major thrust of B/C&S) effects a large reduction in K_T (the stress intensity factor due to temperature), which in turn increases the time required to experience reflective cracking. It is apparent based on the concepts presented and verified in the paper (9) that properly executed (proper PCC slab segment size, through-slab cracking) B/C&S construction will substantially reduce (perhaps eliminate) reflective cracking associated with temperature-induced length changes in the PCC layer. However, AC layer traffic-related cracking potentials associated with bending and shearing are still present and ultimately (assuming sufficient traffic loading is applied) will induce a cracking failure in the AC overlay.

TYPICAL PAVEMENT SECTIONS

There are many variations of B/C&S PCC pavements with AC overlays. PCC slab segment size varies considerably, as previously indicated. Most of the AC overlay thicknesses to date are 3 to 5 in. or greater, with an average of more than 4 in. (1). The AC overlays for Kentucky B/C&S Interstate projects are generally 6.5 in., but AC overlay thicknesses for some major Kentucky non-Interstate projects are 4 in.

STRUCTURAL RESPONSE/BEHAVIOR

The response of an *intact* PCC slab to wheel loading can be characterized using various structural models, such as the simple Westergaard equations, or more refined or realistic finite-element procedures such as ILLI-SLAB (10). For the intact-slab condition, PCC slab flexural stresses are significant, surface deflections are small, and subgrade stresses are quite low. The deflection basin is shallow and broad. AREAs (see Figure 2) for NDT (nondestructive testing) pavement testing are generally large (greater than 25 in.). The AREA for an "infinitely rigid slab" is 36 in. For a Boussinesq flexible system, AREA is about 13 in.

After the PCC slab has been cracked and seated, the slab size is typically reduced to 12-to-30-in. slab segments or, in the case of shattered slabs, the segment size may be only a few inches (approximating a large-maximum-size aggregate macadam base). At the PCC slab crack locations there is *no* moment-carrying capacity in the PCC slab but there are varying degrees of shear transfer among the various slab segments. As slab

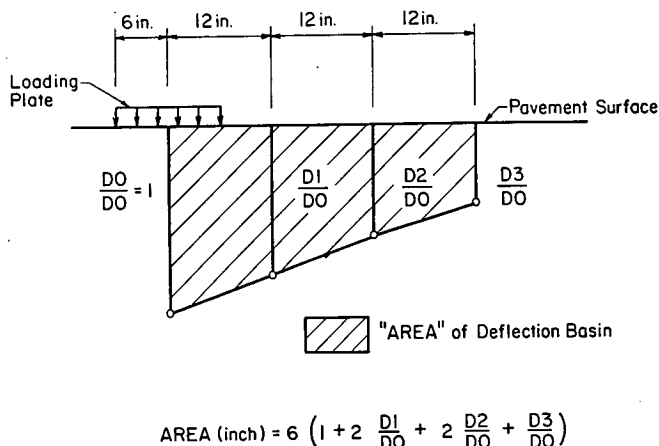


FIGURE 2 Deflection basin characterization parameters.

segment size decreases, the PCC flexural stress in the segment will decrease and the subgrade stresses will increase significantly. Because the deflection in a slab-on-grade system primarily accumulates in the support layers (base/subgrade) beneath the PCC slab segment, surface deflection will also increase considerably. Cohesive subgrades display a stress-softening effect (the resilient modulus decreases with increasing stress) (11). Thus, surface deflection may increase (relatively) *more* than the subgrade stress.

The deflection basin for a B/C&S pavement is deeper (larger maximum deflection) and not as broad. The NDT AREA term will be *less* than for the original intact PCC slab. Typical NDT data for a Minnesota job are shown in Table 2.

B/C&S does effect a significant change in the structural response and behavior of the PCC slab. Surface deflections and subgrade stresses will increase, maximum PCC slab segment flexural stresses are reduced, and NDT AREAs are reduced (behavior is more flexible in nature).

TABLE 2

TYPICAL NDT DATA (MINNESOTA)

Treatment	Deflection (mils)	AREA ^a (in.)	Effective Modulus ^b (ksi)
A - Crack/Seat	7.3	28.8	600
B - Rubble	11.3	22.4	130
C - 5 in. Crushed PCC Base	14.3	21.1	ND
D - 8 in. Full depth	7.9	26.3	1410

^a See Figure 2. Deflection and AREA values are for a 9-kip load. AC temperature was approximately 50°F.

^b Effective moduli were back-calculated using ILLI-PAVE structural model.

NOTES:

1. Original pavement was 8-in. PCC without steel and with 27-ft joint spacing.
2. Treatment C was a 5-in. crushed PCC aggregate.
3. Treatments A, B, and C were overlaid with a 4-in. asphalt concrete surface.

Heavy vehicle simulator (HVS) testing (12) of an AC surface with cement-treated base in South Africa indicated the importance of block size relative to structural behavior and performance under traffic. The behavior of a cracked cement-treated base layer is somewhat similar to a B/C&S PCC layer. South African criteria relating block size to structural behavior are:

1. Block sizes $> 5t$: Slab behavior
2. $5t > \text{block size} > t$: Behavior still predominantly controlled by the large blocks of material
3. Block sizes $< t$: The material is equivalent to a granular material.

Note: t = cemented base thickness.

For PCC slab thicknesses of 6 to 8 in., slab behavior would be significantly reduced for slab segment sizes less than 30 to 40 in.

After B/C&S construction, slab structural models (such as Westergaard or ILLI-SLAB) are not applicable. The B/C&S slab cannot accommodate moment transfer across a crack. Some shear transfer (of varying and unknown degrees) can be accomplished among the PCC slab segments.

The use of an equivalent modulus for characterizing the contribution of the B/C&S layer to the load-deflection response of the AC overlay on B/C&S PCC slab system is a procedure that

can be initially utilized for mechanistic modeling purposes. Frequently, the equivalent modulus of the B/C&S layer (based on NDT deflection data analyses) will be larger than the modulus of the AC overlay layer (particularly in hot weather conditions). NDT data for a general aviation airport (13) compared B/C&S PCC moduli with uncracked PCC moduli. The average moduli were 1900 ksi for B/C&S and the uncracked PCC moduli ranged from 3440 ksi to 4380 ksi.

If the equivalent modulus of the B/C&S PCC slab is larger than the AC modulus, the calculated radial strains beneath the center of the loaded area and at the bottom of the AC layer will be compressive. Obviously, this is not correct. Because the B/C&S PCC slab has through-slab cracks, there are radial tensile strains at the bottom of the AC layer over the cracks. Thus the calculated strains in the AC layer *cannot* be used to predict the fatigue life of the AC layer. This does not mean that such a structural modeling procedure cannot be used to establish reasonable estimates of the pavement surface deflection basin and perhaps subgrade stresses and strains.

Recent University of Illinois research (14) resulted in the development of preliminary concepts for a proposed ILLI-PAVE structural model for B/C&S analysis and design based on AC layer radius of curvature-AC radial tensile strain relations. The procedure (presented in Appendix A) facilitates the consideration of AC fatigue as a design criterion in establishing AC overlay thickness.

DESIGN TECHNIQUES

INTRODUCTION

Information presented in Chapter Two indicates the complex nature of B/C&S pavement behavior. It is important to acknowledge that the major goal of B/C&S is to eliminate, alleviate, or minimize AC reflection cracking problems. Thus, the first concern in B/C&S design is to select a B/C&S procedure that is effective in controlling (to a satisfactory degree) reflective cracking. After B/C&S operations are completed, the pavement section (B/C&S layer, underlying base layers, subgrade) must be characterized and evaluated to establish inputs for AC overlay thickness design. The structural response and behavior of the B/C&S PCC layer is dependent to some extent on the B/C&S construction procedure. This fact is quite evident from the Minnesota data (15) presented in Table 2. Because AC overlay thickness is established *before* construction, the structural effectiveness of the B/C&S layer must be estimated *a priori*. The estimating process should consider such factors as:

1. Condition of existing PCC pavement.
2. Presence of steel reinforcement.
3. Characteristics (thickness, nature, and quality of materials) of underlying base materials.
4. Subgrade soil properties. For stress-softening cohesive subgrades, the modulus will vary with subgrade stress. As indicated in Chapter Two, the subgrade stresses beneath an intact PCC slab are *less* than the stresses experienced after the PCC slab is subjected to B/C&S.
5. B/C&S procedure to be utilized.
6. PCC slab segment size specified.

NONDESTRUCTIVE TESTING (NDT) CHARACTERIZATION

Nondestructive testing with various devices (falling-weight deflectometer, vibratory devices, Benkelman beam) can be utilized in the evaluation process. A schematic illustrating the B/C&S PCC layer is shown in Figure 3. The relative placement of the NDT applied load and the deflection measuring points are difficult to quantify. The NDT deflection measurements will be influenced depending on the load application point (center of PCC segment, edge of PCC segment, etc.). Certain load application points will accentuate any PCC slab segment rocking tendency. The degree of shear transfer among the PCC slab segments is probably quite variable.

Accurate and reproducible deflection measurements are difficult to achieve if NDT is conducted on the surface of the B/

C&S PCC slab *before* the overlay is placed. The deflection sensors may be on or near a crack, not be properly seated on the irregular surface, jiggle or move during load application, etc. It is apparent that accurate, precise, and definitive NDT data are difficult to obtain if the unsurfaced B/C&S PCC slab is tested.

Many of the previously mentioned NDT difficulties can be alleviated if NDT is accomplished after the AC overlay is constructed. The AC layer provides a smooth and uniform surface for NDT load application and deflection sensor seating. Improved nondestructive test data accuracy and reliability can be achieved.

NDT evaluation of B/C&S PCC sections after placement of the AC overlay will provide load-deflection data representative of the composite section response of the complex structural system. Careful observation and evaluation of preconstruction PCC slab condition, B/C&S construction sequence and procedures, and NDT data for the B/C&S PCC section after AC overlay placement will aid in the difficult task of characterizing the structural effectiveness of the B/C&S PCC layer.

ASPHALT CONCRETE OVERLAY THICKNESS DETERMINATION

Several approaches have been proposed to establish the required AC overlay thickness. They are presented below.

In the 1986 AASHTO Guide procedure (16) a "structural layer coefficient (a)" is established for the B/C&S PCC layer. The overlay design is conducted using the normal structural number approach for flexible pavements. In the nominal crack spacing approach, the assigned "a" is 0.4 for a nominal slab segment size of 30 in. A note in Table 5.5 of the Guide indicates that "a" "actually varies from 0.35 for a nominal crack spacing

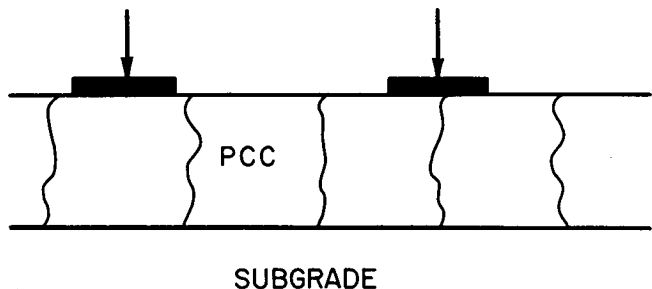


FIGURE 3 Variable nature of cracked PCC slab in nondestructive testing.

of approximately 2.0 ft to a value of 0.45 for a nominal crack spacing of 3.0 ft.”

The other AASHTO Guide-suggested procedure is based on NDT analysis of the PCC pavement following B/C&S operations. In NDT Method 1, the modulus of the B/C&S PCC layer is established and the “a”-modulus relation shown in Figure 4 is used to determine an “a” for the B/C&S PCC layer. Note that for “a” of 0.35 and 0.45, the corresponding PCC E-values are approximately 500 ksi and 1000 ksi, respectively (16).

In a study sponsored by NAPA, several B/C&S sections were analyzed using NDT procedures and the AASHTO “a-modulus relation.” A Model 2000 Road Rater and a Model 8000 Dynatest falling-weight deflectometer were utilized. The “a” values determined ranged from 0.21 to 0.53. Based on the study results, a recent NAPA publication (17) recommends the following structural layer coefficients for cracked and seated PCC pavements:

Crack Spacing	Structural Layer Coefficient
1 ft	0.25
2 ft	0.35
3 ft	0.45

A recent Kentucky report (18) summarized NDT deflection data (Road Rater) and back-calculated moduli for several B/C&S sections. Stiffness moduli for the B/C&S PCC layers varied from 25 ksi to 2000 ksi. The study indicated that “There appears to be a relationship between particle size, effective stiffness modulus, and ratio of deflections (after breaking/before breaking).” Increased PCC segment size and smaller ratios indicate increased stiffness moduli.

South African heavy vehicle simulator (HVS) testing (12) of an AC surface with cement-treated base produced various stages of cracking (a situation similar to B/C&S). Based on the HVS data, the following effective moduli were proposed:

- Large Blocks: $5t > \text{Block size} > t$: $E = 350 \text{ ksi to } 450 \text{ ksi}$
- Small Blocks: $\text{Block size} < t$: $E = 75 \text{ ksi to } 100 \text{ ksi}$
- Note: $t = \text{Base layer thickness}$.

In AASHTO Guide (16) NDT Method 2, the effective structural number of the entire pavement above the subgrade (B/C&S PCC layer plus other paving material layers) is established based on the subgrade modulus, maximum NDT deflection, and total thickness of all layers above the subgrade. The utilization of the NDT Method 2 procedure is described in Appendix PP-Volume 2 of the 1986 AASHTO Guide (16).

Pennsylvania used engineering judgment and assigned an “a” of 0.2 to a B/C&S PCC slab (2).

NAPA (1) indicates:

In the absence of deflection data or other specific design procedures, NAPA suggests that a structural layer coefficient of between 0.28 and 0.32 may be a reasonable range for properly Cracked and Seated pcc pavements. However, engineering judgment should be exercised if non-destructive testing is not performed. It is clear that age and condition of the pcc will influence the structural value (modulus) of the Cracked and Seated pavement.

Note that the NAPA values are considerably lower than those proposed in the AASHTO Guide.

The Asphalt Institute Overlay Manual (19) recommends an

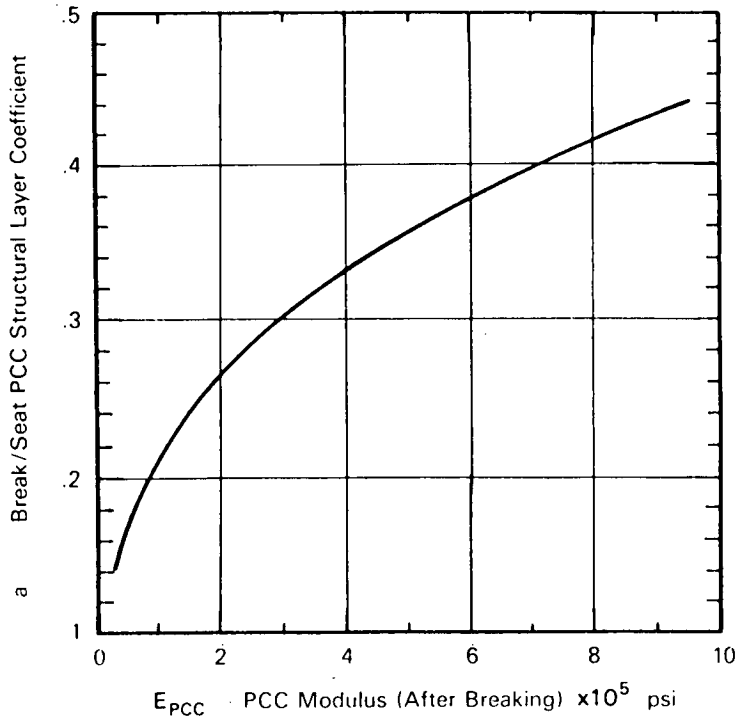


FIGURE 4 Structural layer coefficients for break/seat overlay analysis (16).

effective thickness procedure. In effect, the B/C&S PCC layer is converted to an equivalent thickness of asphalt concrete. The equivalent thickness is established by multiplying the B/C&S PCC slab thickness by a conversion factor. B/C&S PCC pavements are assigned a material classification of IV. The conversion factor range for Material Class IV is from 0.3 to 0.5. The Asphalt Institute description for Class IV is:

Portland cement concrete pavements, (including those under asphalt surfaces) that have been broken into small pieces 0.6 metre (2 ft) or less in maximum dimension, prior to overlay construction. Use upper part of range when subbase is present; lower part of range when slab is on subgrade.

The full-depth AC pavement thickness requirement is determined using the Asphalt Institute standard procedure presented in MS-1 (20).

Minnesota converts the B/C&S PCC slab to an equivalent AC thickness by using a conversion factor of 0.7 (2). If AC is assigned an "a" value of 0.4, the Minnesota "a" for the B/C&S PCC is 0.28 (0.7×0.4).

In Wisconsin the objective of the B/C&S process is to "produce a flexible base with fractured pieces of broken concrete that would be at least equivalent to a similar thickness of crushed stone or gravel" (21). Wisconsin DOT input to this synthesis indicated they now generally use an "a" coefficient of 0.20 to 0.25.

Kentucky assumes the B/C&S PCC slab is equivalent to crushed stone base (6, 22). They use their standard flexible pavement design approach to establish the required AC surface thickness. Kentucky frequently stages the AC overlay construction, and does not construct the entire design thickness overlay in the first phase. The remainder of the required AC overlay thickness is constructed at a later date.

Caltrans uses a standard design for B/C&S PCC (23). A 1.2-in. AC leveling course and a 3-in. AC surface course is normally

constructed. A paving fabric interlayer is placed on the surface of the 1.2-in. AC leveling course.

SUMMARY

There is considerable variation in the structural values assigned to a B/C&S PCC slab. Values of "a" range from 0.2 to 0.45 and Kentucky assumes the equivalent thickness of crushed stone base ($a = 0.13$ based on the original interpretation of the AASHTO Road Test data). The Caltrans practice of using a standard section (4.2-in. AC overlay) further demonstrates the lack of an accepted rational methodology for evaluating the structural effectiveness of the B/C&S PCC slab and establishing the required AC overlay thickness to accommodate varying traffic-loading levels.

At this time there is not a *validated* AC overlay thickness design procedure for B/C&S PCC pavements based on AC fatigue. Recently constructed projects have not (in many instances) experienced sufficient traffic to accommodate such validation studies. However, in those B/C&S projects in which direct AC overlay thickness effects were considered, thicker overlays provided better performance.

The effectiveness of B/C&S relative to controlling reflective cracking induced by temperature-related horizontal movements can be readily assessed during early life performance. For example, New York experience (8) indicates that reflection cracking (PCC slabs *without* B/C&S treatment) of most joints occurs by the end of the *first* winter. Similar reflection cracking trends have been widely observed by others. The cracking noted later in the pavement service life is probably primarily caused by traffic loading (i.e., AC fatigue) rather than thermal-related horizontal slab movement.

Kentucky has noted (6) infrequent PCC slab blowups in B/C&S sections. This distress obviously contributes to a pavement serviceability loss.

CHAPTER FOUR

CONSTRUCTION

The major steps in B/C&S construction are:

1. Breaking/cracking the existing PCC slab
2. Seating the cracked PCC slab
3. Special treatments
4. AC overlay construction

The recently published FHWA "Pavement Rehabilitation Manual" (2) and NAPA state of the art (1) provide considerable detail concerning construction operations. It is apparent from reviewing the recent literature that construction equipment, procedures, and techniques for cracking and seating PCC slabs have constantly been improved and are still evolving. There is still considerable art involved in B/C&S construction operations.

This synthesis is not directed at providing construction details to the extent presented in References 1 and 2.

PCC SLAB CRACKING

The objective of cracking is to reduce the extant PCC slab to a desired PCC segment size. Typical maximum dimensions

of segment sizes range from 48 in. to 18 in. In some states, only transverse cracking is required (typically 36-in. to 48-in. spacings). Slab shattering or reducing the PCC slab to rubble (4- to 6-in. maximum size segments, or even smaller) has recently emerged as a B/C&S option.

Good construction results in through-slab cracking to produce the desired PCC segment size. Specifications vary relative to the type and amount of surface or joint spalling permitted during the PCC slab breaking/cracking process. A variety of cracking equipment, including various types of pile drivers, guillotine drop hammers, impact hammers, and resonant pavement breakers, has been used with varying degrees of success. Figures 5 to 8 illustrate the various major types of pavement breakers. Equipment manufacturers and contractors have demonstrated ingenuity in adapting or modifying cracking equipment to achieve specification compliance. The equipment literature and construction articles indicate (for example):

- a. Various cracking heads can be mounted on the impact hammer;
- b. The breaking shoe size on a pile driver can be varied and the wear plates or bars can be modified to accommodate various breaking patterns;



FIGURE 5 A guillotine concrete-shattering machine.

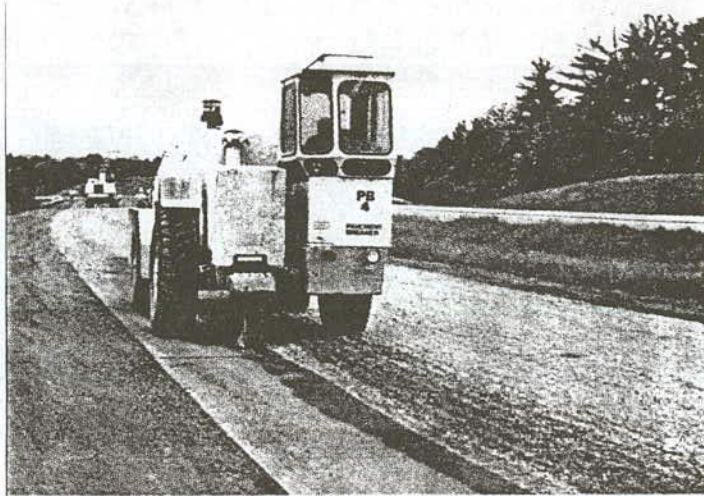


FIGURE 6 A resonant pavement breaker.

c. The guillotine edge can be modified on the drop-type guillotine pavement breaker; and

d. Such items as travel speed, energy/blow, etc. can be adjusted to accommodate a broad range of job conditions.

California B/C&S developmental activities (23) indicated that "All models of pavement equipment investigated were able to produce an acceptable cracking pattern." It should be noted that the normal Caltrans PCC section is a jointed pavement without any steel reinforcement or any load-transfer devices constructed over a stabilized base.

It is generally recommended that existing AC overlays be removed before cracking operations, although some agencies have achieved successful cracking without removal. In some situations, the removal of the AC overlay may reduce the structural capacity of the pavement section to the extent that cracking

and seating operations and AC overlay placement cannot be readily accomplished. This is a particularly significant consideration if the subgrade strength and stability is very low.

Factors that influence the cracking process effectiveness are concrete strength and quality, base and subgrade support conditions (strength and stability), presence and amount of reinforcing steel, and slab temperature.

To facilitate cracking of jointed PCC pavements with reinforcing steel, transverse slab sawing has been used. The transverse sawing operation reduces the slab size and separates the steel. Frequently a slab is sawed in half. Michigan has sawed on 20-ft spacings and West Virginia used 15-ft. New York DOT input to this synthesis indicated sawing at 20-ft intervals showed little benefit.

The increased difficulty in achieving cracking in PCC pavements with steel reinforcement undoubtedly is a major factor that contributes to the difficulty of achieving good performance (compared with no-steel B/C&S PCC sections). To eliminate or minimize the effect of the reinforcement, the concrete to steel bonding must be reduced or eliminated and the continuity of the steel broken between PCC slab segments.

It is important to note that Kentucky has successfully used B/C&S on Interstate pavements that contained steel mesh (60 lb for 50-ft joint spacing; 36 lb for 25-ft joint spacings) (6, 18). Kentucky DOT input to this synthesis indicated that they exert a strong and aggressive effort to break the concrete to steel bond and achieve through-slab cracking.

If the PCC slab temperature is high, the slab is expanded and may be in compression. The compressed state may hamper cracking operation effectiveness with some types of equipment. Careful monitoring is required to ensure that through-slab cracking and desired PCC slab segment size are being achieved. It may be necessary to limit cracking operations to time periods when PCC slab temperatures are below an acceptable level.

It is recommended practice to construct test sections to establish an acceptable cracking procedure operation. The achievement of through-slab cracking and acceptable PCC segment size without undue surface spalling is desired.

Procedures and techniques used to evaluate slab cracking include:

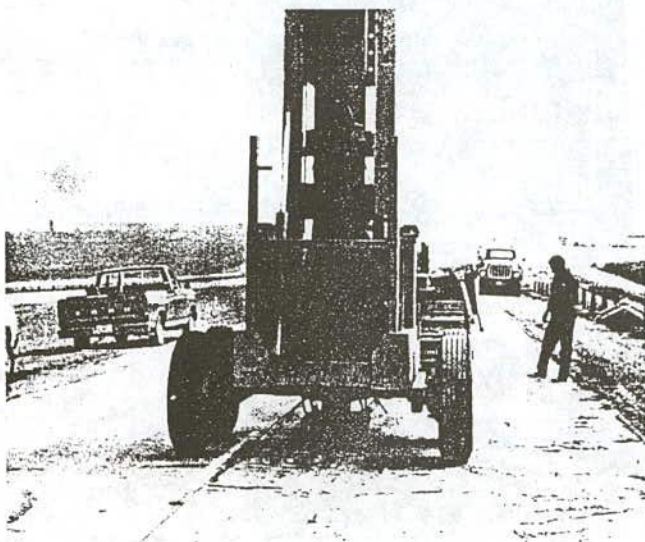


FIGURE 7 A diesel pile hammer pavement breaker.

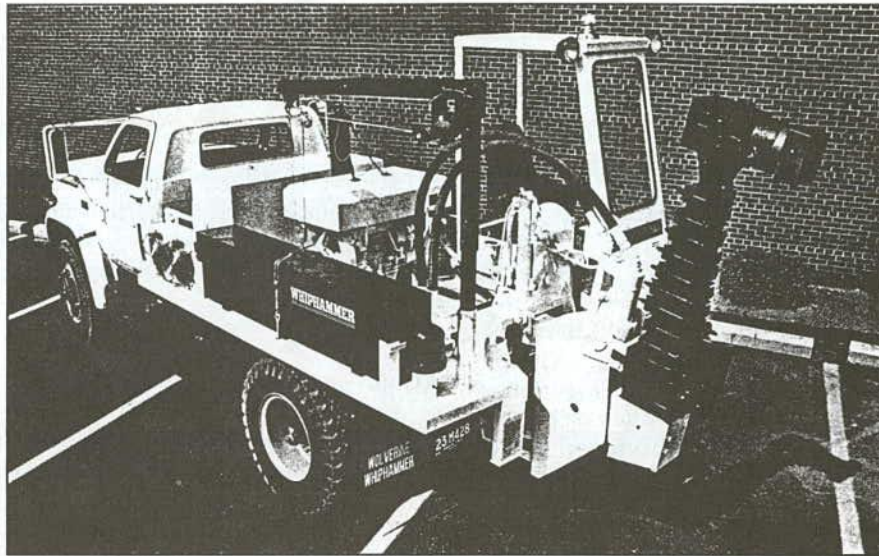


FIGURE 8 A whip hammer concrete pavement breaker.

- a. Visual examination of the dry slab;
- b. Visual examination of the wet slab;
- c. Visual examination of the slab with flour as a crack tracer;
- d. Coring;
- e. Picking up the slab for visual examination; and
- f. Use of nondestructive testing procedures.

The most recent Kentucky publication (18) on B/C&S incorporates several of the evaluation procedures:

It is recommended that construction specifications include a maximum particle size observable without the aid of a wetted pavement surface, but with a project-by-project correlation of maximum observable particle size for an unwetted slab relative to the maximum particle size observable for the same slab broken to an acceptable breaking pattern and viewed with the aid of a wetted surface. Such observations should be verified by deflection testing. Additionally, specifications should include acceptable ranges of deflection ratios of after breaking (but before overlaying) to before breaking.

SLAB SEATING

The cracked PCC slab is "seated" by rolling with various types of equipment. FHWA (2) and NAPA (1) indicate the objective of seating is to ensure the PCC slab segments are in contact with the supporting layer (base/subgrade). PCC slab segments may rock if adequate seating is not achieved, thus increasing reflective cracking potential.

A wide variety of roller equipment and passes has been used by various agencies. Pneumatic-tired/rollers (50-ton and 35-ton) are frequently used for seating operations. Crawford (1) indicates that "steel drum rollers and vibratory rollers tend to bridge over the cracked pieces, thus they are not generally satisfactory for seating purposes." The Caltrans specification (8/27/84 version) calls for either an "oscillating pneumatic-tired roller weighing not less than 15 tons or a vibratory sheepsfoot roller exerting a dynamic centrifugal force of at least 20,000 pounds." Current Wisconsin specifications also require a vibratory steel roller.

Once PCC slab segment seating is achieved, further roller passes are probably not beneficial and may be harmful. Kentucky (22) and Indiana (24) have evaluated roller pass effects. Kentucky's NDT (Road Rater) study (18) includes deflection data obtained before PCC slab breaking and at various intervals during rolling. Roller weight varied from 30 tons to 50 tons. The Kentucky report indicated the following general trends:

1. an increase in deflections on initial roller passes,
2. a reduction or stabilization of deflections with additional roller passes, and
3. an increase in deflections with a large number of roller passes.

The report indicated the desirability of adequate rolling to achieve seating, but cautioned against overrolling.

The Indiana study (which utilized the Dynaflect NDT device) indicated that for an increased number of 50-ton roller passes, "the concrete slab and subbase lost strength with each pass. . . ." A recommendation of the Indiana study was that a "50-ton roller should not be used since it unseated the slab instead of seating them." A close examination of the Indiana Dynaflect data suggests the roller pass effect is not pronounced. Statistical analyses were not used to evaluate the significance of the noted trends. The scatter and small magnitude of the Dynaflect data (all values are less than approximately 1 mil) may have obscured the roller pass deflection relations.

The reduced structural capacity of the cracked PCC slab is considered in Chapter Two. For some base and subgrade support conditions, the larger rollers and increased roller passes could be detrimental. For example:

1. Stabilized base layers (cement-treated aggregate, asphalt concrete, pozzolanic stabilized materials) could experience extensive cracking;
2. Granular base materials may decompact or severely distort;
3. Low-strength cohesive subgrades may soften, weaken, or

even rut under repeated loading. It may be impossible to achieve satisfactory construction in some instances.

Strand (21) has suggested that in those situations "where the existing pavement's base course or foundation is so weak that cracking and seating cannot be performed without excessive displacement of the old slab," it is possible to place lifts of crushed gravel or stone base over the B/C&S PCC layer before constructing the AC overlay.

A Caltrans investigation (25) into the effects of B/C&S on differential vertical movements at joints and cracks found that breaking decreased movement but subsequent seating increased movement (from the reduced amounts). The net result was still reduced differential vertical movements. A later investigation (26) recommended that breaking be used to reduce differential vertical movements at joints and cracks but that further studies were needed to determine whether seating (rollong) was justified.

It is apparent that there is no consensus among specifying agencies concerning seating. Crawford (1) concluded:

1. In general, the most effective seating is accomplished with a heavy pneumatic-tired roller. Two passes with a 50-ton pneumatic-tired roller has given good results. Success has also been obtained with a fully ballasted 35-ton multi-wheeled pneumatic-tired roller. Steel drum rollers and vibratory rollers tend to bridge over the cracked pieces, thus, they are not generally satisfactory for seating purposes.
2. However, practical experience seems to favor a few passes of a very heavy pneumatic-tired roller rather than a great number of passes with any kind of lighter roller.

Kentucky's comprehensive consideration (18) of roller factors on the effectiveness of seating the cracked PCC slab resulted in the following recommendations:

Considering experience in Kentucky and elsewhere and results of deflection measurements, it is recommended that the minimum size roller for seating be 35 tons. Multitired pneumatic rollers are recommended in lieu of two-tired rollers, when possible. At least five passes of a 35-ton pneumatic-tired roller are recommended, with a staggered (overlapping) pattern to assure adequate seating at the edges. Three passes of a 50-ton pneumatic-tired roller are also a permissible minimum. It should be emphasized that current data do not indicate the equivalency of the stated coverages for each roller size. Instead, the stated coverages are generally optimum on the basis of minimum number of passes (within the limits of practical construction procedures) for each roller size relative to magnitude of deflection after rolling.

SPECIAL TREATMENTS

Certain special treatments are sometimes required before AC overlay placement. They include:

1. Pavement sweeping or cleaning
2. Cleaning joints
3. Removal and replacement of failed areas, punch-throughs,

rocking slabs, soft spots, etc. and patching with full-depth hot mix AC.

The performance impact and cost-effectiveness of the various special-treatment operations have not been documented and evaluated.

Extensive special-treatment operations, particularly those requiring manual labor, will increase unit prices. Careful consideration should be directed to special treatments to ensure that a small detail does not jeopardize the success of the B/C&S project.

STRUCTURAL SECTION DRAINAGE

Many agencies incorporate edge drain construction into B/C&S rehabilitation procedures. Typical installations include fin-type drains and fabric-covered pipe with permeable back-fill materials. The University of Illinois study (7) indicated, "There are no data at present to indicate the effectiveness of drainage when added in conjunction with crack and seat. The database did not demonstrate a clear improvement in the performance of overlays when drainage was present."

In the breaking/cracking process, some fines are generated and new PCC surfaces are generated. Apparently the fines from cracking and other materials that may erode from the new surfaces are susceptible to being flushed out from the B/C&S PCC. There is not any information concerning the particle size distribution of the materials that are susceptible to flushing. However, limited field observations and data indicate the particles may tend to reduce the effectiveness of the edge drain installations.

AC OVERLAY CONSTRUCTION

Conventional construction procedures are used to place the hot-mix AC overlay. Careful consideration should be directed to sequencing the construction to avoid heavy trafficking of thin AC layers before the placement of the entire overlay thickness. Considerable fatigue life consumption may occur if a large number of heavy loads are applied to a thin AC layer. California practice (23) recommends, "The full overlay thickness should be placed promptly after seating to avoid 'incremental' cracking of partial overlays carrying traffic."

Some agencies have incorporated a paving fabric near the bottom of the overlay. For example, the standard Caltrans B/C&S AC overlay (1.2-in. AC + paving fabric interlayer + additional 3-in. AC layer) is providing good performance.

SPECIFICATIONS

Typical specifications for B/C&S construction are presented in Appendix B. Caution and concern should be exercised in adapting or modifying the specifications for local agency use.

CHAPTER FIVE

PERFORMANCE SURVEYS

The most recent NAPA summary (1) of B/C&S projects indicates many states have used B/C&S procedures. Individual states have monitored and evaluated completed projects.

The FHWA Review Report (5) and the University of Illinois Study (7) are the only available in-depth national studies documenting B/C&S pavement performance. Major findings of the FHWA study of 22 projects in eight states (5) were as follows:

Based on the findings of this review, the use of cracking, seating, and overlaying as a pavement rehabilitation alternate should be approached with caution. Since both positive and negative aspects of cracking and seating (B/C&S) were identified during the review, State agencies contemplating the use of B/C&S should do a thorough project analysis to determine if it is the most cost effective rehabilitation technique to employ.

Of the 22 projects reviewed, only four showed appreciably less reflective cracking in the B/C&S sections than in the control sections. Observations by the review team, coupled with previous State reports, indicate that there generally is a reduction in the amount of reflective cracks through the overlay during the first few years following construction of a B/C&S project. However, after 4 to 5 years the B/C&S sections exhibited approximately the same amount of reflective cracks as the control sections. A significant reduction in reflective cracks occurred on two of the projects reviewed. These projects are located on I-4 in Florida and on SR-99 in California. Both had the following similarities:

1. Constructed on a strong base;
2. Small changes in seasonal temperatures; and
3. Non-reinforced pavement.

The main concern with B/C&S is the reduction of the structural capacity of the pavement. To compensate for the reduction in structural capacity caused by cracking the pavement, more overlay thickness is required, thus increasing the cost. In addition, study is needed to determine if the delay in reflective cracking actually extends the life of the pavement as opposed to conventional overlays and if so, is it cost effective.

The University of Illinois study included 70 projects (108 sample units) in 12 states (7). Data concerning the original pavement design, AC overlay design, traffic, environmental conditions, and AC overlay performance were obtained. Project age varied from 1 to 25 years; equivalent single axle loads (ESALs) from 79×10^3 to 8.3×10^6 ; reflective cracking [(ft./1000 ft of low, medium, and high severity) and total (low + medium + high severity)] from 0 to 798, and rut depth from 0 to 0.42 inches. The large data base developed was extensively analyzed. The general study findings indicated:

Surveys have indicated that crack and seat overlays can reduce reflection cracking, particularly in the early years of the overlay's life. There is some evidence that after a specific number of years, the effectiveness of the crack and seat operation may diminish. The projects surveyed in this study exhibited good performance

in general with only one section exhibiting high severity reflection cracking and approximately one-third exhibiting medium severity reflection cracking of limited extent.

Note—The amount and severity of cracking are indicated in Figures 9 and 10 for pavements with and without reinforcement.

Overall conclusions and recommendations (as stated in the report) are presented below (7):

1. The presence of reinforcing steel has an influence on the effectiveness of the crack and seat operation. If the cracking operation does not rupture the steel the slab length will not be reduced. This means that the movement at the joints will not be reduced and reflection cracking will progress at the same rate as if the crack and seat operation had not been performed. If the steel is cracked, the performance of the overlay should be no different than that of an unreinforced pavement. The major difference is in the extra precautions which must be taken in the cracking operation on reinforced pavements. The database analysis did not show a difference in the performance with or without steel, due to other interactions.
2. Without deflection testing of the completed project, there is no way to evaluate the effectiveness of the cracking operation beyond a recognition of the size of the cracked pieces. At present there is no acceptable procedure for evaluating the cracking effectiveness on the concrete slab prior to overlay.
3. The crack and seat overlays will develop low severity reflection cracking relatively easily, and the development appears to be influenced more by the variables in the crack and seat operation and not the original pavement design or environment. The progression of low severity cracking to medium and high severity does not occur as easily as the development of low severity cracking, and is more a function of environment, age, original pavement design, and traffic; and less a function of the crack and seat construction variables.
4. The seating roller weight has a dual action on reflection cracking. Heavier rollers will cause more low severity cracking to develop initially, while reducing the rate at which the low severity cracks progress to medium and high severity cracking. The impact of heavier rollers is related to foundation quality, and heavy rollers should not be used on weak foundations. The use of a heavy roller does not guarantee improved performance.
5. Cracking pattern is more complicated than merely investigating the area of the cracked pieces. The area should be minimized to the range of 4 to 6 sq ft., and the ratio of length to width should also be controlled. [Note: Figure 11 illustrates the general effect of cracking pattern.] When the length of the cracked piece (length is measured along the longitudinal direction of the pavement, width is measured transversely across the pavement) is less than the width, more cracking will result than if the length and width are equal or the length is greater than the width. For construction it is recommended that the dimensions

REINFORCING STEEL

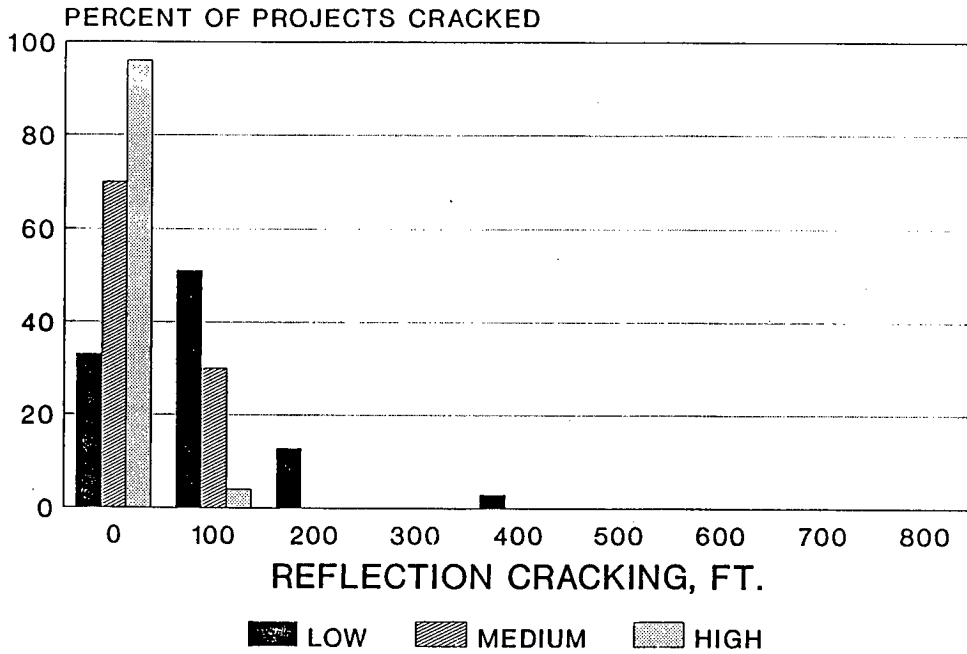


FIGURE 9 Amount and severity of reflection cracking present on crack and seat projects (7).

NO REINFORCING STEEL

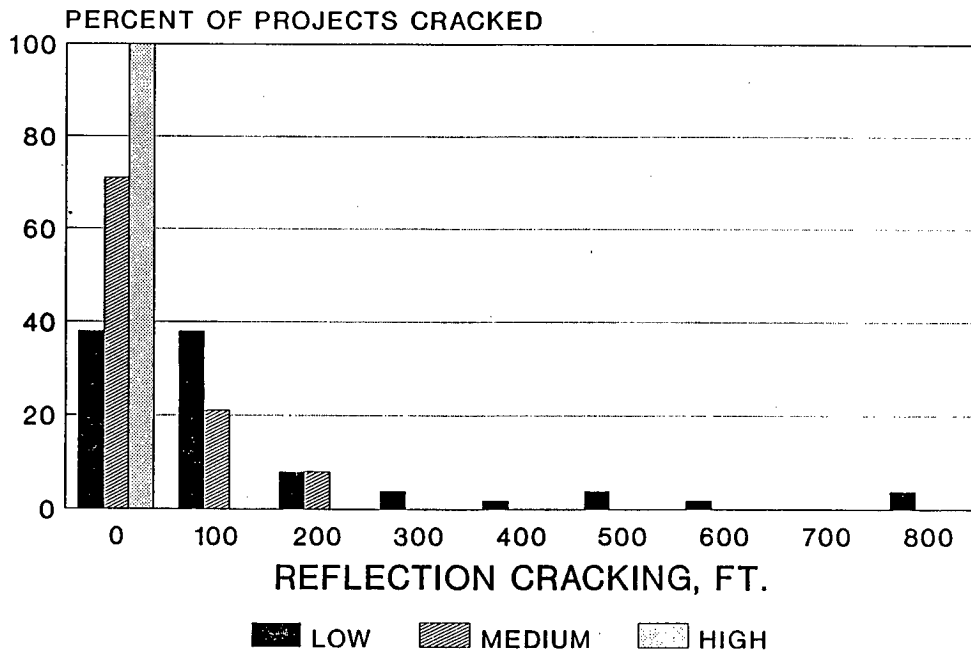
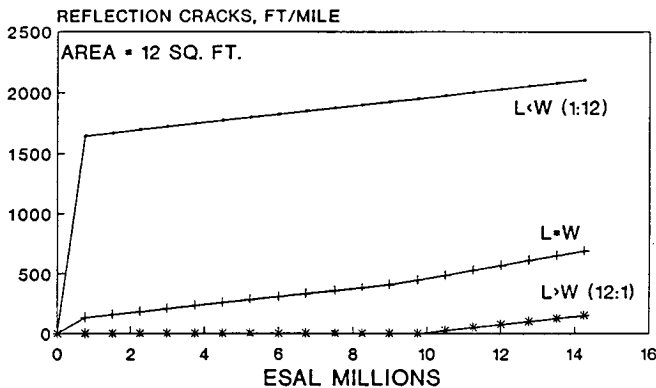


FIGURE 10 Amount and severity of reflection cracking present on crack and seat projects (7).

CRACKING PATTERN



CRACKING PATTERN

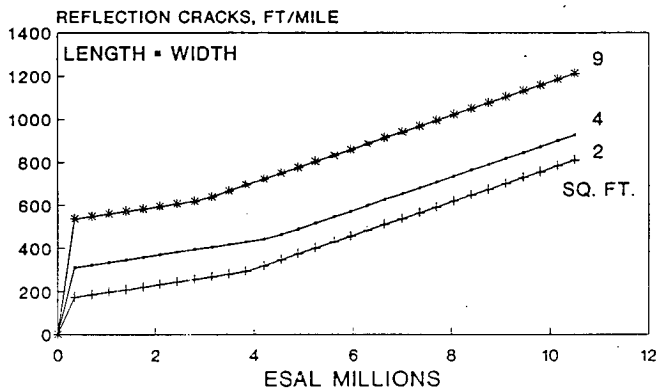


FIGURE 11 Influence of cracking pattern on reflection cracking (7).

be kept equal with the operation having the potential to err on the side of producing a pattern with a slightly greater length than width.

6. Overlay thickness did not show an influence on reflection cracking which may be due to an interaction effect with the reinforcing steel. The reinforced pavements generally had a thicker overlay, had been in place longer, and had higher traffic levels than the plain concrete sections. The performance of the reinforced and plain sections were so similar that the effect of steel and thickness did not enter the predictive relationships. In general thicker overlays will perform better for a longer period than thinner overlays placed over the same crack and seat sections.
7. The quality of the asphalt concrete mixture has a significant impact on the performance of an overlay in resisting reflection cracking. The data in the database contained no indication of the mix quality on the individual projects. The rutting performance of these sections was typical of conventional overlays which indicates the mix quality was not exceptionally bad and could be considered typical.

Any comparisons of the performance of individual sections should be made realizing that variability in mix quality can alter reflection cracking.

8. The environment showed an effect on the progression of cracking to the medium and high severity levels. In general, the milder climates showed the best performance. High monthly temperature extremes and low monthly average temperatures produce more medium and high severity cracking. This interaction is shown in the decreased cracking with lower freezing index, and the decreased cracking with higher precipitation. Higher precipitation generally occurs in areas with a more moderate climate without extreme swings in temperature.
9. Predictive models for low severity reflection cracking, medium and high severity reflection cracking, and rutting were developed using the database. These models can be used to estimate the development of distress and serve as preliminary checks on designs of crack and seat overlay projects. The ability to predict medium and high severity reflection cracking is essential to establishing rehabilitation needs. Rehabilitation of asphalt concrete overlays is typically indicated by an amount of medium and high severity cracks, not low severity. This is important in crack and seat performance as the two levels of cracking are related to very different variables.

Kentucky constructed more than 750 lane-miles of B/C&S between 1982 and 1986. In a report (18) documenting the performance (visual survey and deflection testing) of 451 lane-miles, only one section (approximately 8 lane-miles) displayed unexpected reflective cracking. Subsequent analysis of the section indicated proper B/C&S was not achieved on the project. The visual surveys further indicated that "none of the pavement sections have been subjected to an accumulation of fatigue [18-kip equivalent axleloads (EALs)] necessary for the manifestation of visual surface distresses." The extensive study prompted the Kentucky researchers to state, "Performance has been good; as a result the practice continues routinely."

It is interesting to note that California and Kentucky (two states with consistent and very good overall experience with B/C&S) rehabilitated PCC pavements *without* steel (California) and *with* steel mesh reinforcement (Kentucky).

An FAA report (13) indicated, "While the use of the crack and seat technique appears to be effective, reflective cracking is not eliminated." The general aviation facility was not subjected to heavy traffic. The very large (approximately 1900 ksi) equivalent modulus calculated for the B/C&S PCC layer indicates the slab was not cracked to the extent required to eliminate PCC thermal slab movement-induced reflective cracking. In fact, Rada and Witczak (13) indicated "a greater degree of cracking before placing the overlay would have been helpful."

A considerable range of performance has been achieved with the B/C&S procedure. It is apparent that a properly constructed B/C&S section can alleviate (perhaps eliminate in some cases) thermal-related reflective cracking in AC overlays. Thus, the procedure can be effective relative to achieving that objective.

The fact that AC cracking does ultimately occur in a B/C&S section is probably more related to AC fatigue. A thin AC overlay should *not* be expected to provide long-term crack-free performance under heavy traffic. The field performance studies indicate that the performance of an AC overlay placed on a B/C&S PCC slab is influenced by many factors. The University of Illinois report (7) provides some preliminary insights.

RESEARCH NEEDS AND RECOMMENDATIONS

RESEARCH NEEDS

There are many B/C&S technological gaps. The B/C&S system (AC overlay, PCC slab segments, base, and subgrade) is very complex compared with a conventional new pavement. It is apparent that the B/C&S treatment is beneficial with respect to thermally related AC reflective cracking. If through-slab cracking is achieved in producing appropriate-sized PCC slab segments (maximum size probably less than approximately 30 to 36 in.), AC overlay performance is primarily dependent on AC fatigue-related phenomenon.

The cost-effectiveness of B/C&S is obviously dependent on pavement performance. Even though thermal-related AC reflective cracking may be controlled, load-related AC fatigue cracking will contribute to pavement serviceability loss.

High priority B/C&S research and development needs are listed below.

1. Develop improved or new techniques, procedures, guides, manuals, etc. for quantifying the extent of the cracking/breaking achieved in the PCC slab during construction.
2. Consider, in a quantitative manner, the effects of PCC slab segment geometry (area, length, and width and maximum size and gradation of rubble, etc.).
3. Establish improved procedures and techniques for evaluating the structural effectiveness of the B/C&S PCC slab.
4. Continue to monitor the performance of well-documented B/C&S sections. NDT data should also be collected. The performance findings and trends and construction variable impacts identified in the FHWA (5), University of Illinois (7), and Kentucky (6, 18) studies need more in-depth validation.
5. Develop a comprehensive mechanistic-based AC overlay thickness design procedure.
6. Establish quantitative techniques, procedures, guidelines, and criteria for determining the cost-effectiveness of the B/C&S rehabilitation procedure.

An in-progress FHWA administrative research project (27) is considering some of these items.

RECOMMENDATIONS

B/C&S procedures are effective in alleviating or delaying (perhaps eliminating) AC overlay reflective cracking *attributed to PCC horizontal slab movement induced by cyclic temperature changes*. Load-related AC overlay cracking then becomes the

primary AC overlay thickness criterion. The reduced structural capacity of the B/C&S PCC layer may require a significant AC overlay thickness. The FHWA (5) has indicated, "The costs for additional overlay thickness, the cracking and seating, and other required work such as shoulder and guard rail raising, must be evaluated when determining the most cost effective rehabilitation strategy to employ."

It is apparent that the B/C&S procedure should not be considered a panacea. However, under appropriate circumstances it may be a cost effective PCC rehabilitation procedure.

The technological gaps identified in the previous section make it difficult to precisely establish the cost effectiveness of the B/C&S procedure. Continued research and development (as suggested above) are needed to enhance the existing technology.

Some general recommendations for effective use of B/C&S procedures are presented below:

A. Careful attention and adequate effort should be devoted to project engineering and economic analysis activities required to:

1. Assess the feasibility of using the B/C&S procedure (particularly important considerations are present PCC slab condition, presence of steel, base, and subgrade conditions);
2. Establish the appropriate AC overlay thickness; and
3. Ensure the use of definitive specifications, construction techniques, and procedures most suited to a particular B/C&S project.

B. Select a PCC slab cracking pattern that is adequate (small enough) to reduce (eliminate) thermally related AC overlay reflective cracking. Smaller PCC segments are preferred for controlling thermally related AC overlay cracking. However, smaller PCC segment sizes are associated with greater reductions in structural capacity. It appears that PCC segment sizes of approximate equal dimensions (length = width) provide good performance. Maximum PCC segment sizes from about 24 to 36 in. are reasonable. It should not be expected that the best PCC segment size will be the same for all conditions (PCC slab condition, climate, traffic, base and subgrade support, etc.).

C. Ensure that through-slab cracking is achieved. Test sections for establishing the effectiveness of the cracking construction sequence are essential. Factors influencing the cracking operation (particularly the presence of reinforcing steel and an existing AC overlay) are particularly important to consider. Project specifications should indicate *how* the degree and extent of through-slab cracking will be evaluated (quantified if possible). Inadequate breaking/cracking may result in the early appearance of AC overlay reflective cracking and perhaps PCC slab blowups.

D. Select a roller size and use a rolling pattern that is adequate for properly seating the PCC segments, but that will *not* detrimentally affect the underlying base and subgrade. The strength and stability of the subgrade must be considered when selecting roller weight. A broad range of roller types and weights have been used successfully.

E. Document the details of the construction process for sub-

sequent use in pavement structural response and performance studies.

F. Monitor the performance of well-documented B/C&S projects. Particular attention should be directed to identifying AC reflective cracking associated with thermal movements in the PCC slab segments versus load associated AC overlay fatigue cracking.

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APPENDIX A

CONCEPTS FOR THE ANALYSIS OF AC OVERLAYS ON BREAK/CRACK AND SEAT (B/C&S) PAVEMENTS

INTRODUCTION

When a PCC pavement is cracked (through-slab condition) the PCC slab is no longer an intact slab and will not behave and perform as a rigid pavement. A typical B/C&S pavement with an AC overlay is shown in Figure A-1. The major purpose of B/C&S is to alleviate or retard reflective crack development in the AC overlay. If that objective is achieved by B/C&S, then the goal of AC overlay thickness design is to consider fatigue in the AC layer.

The cracked slab section can *not* carry a bending moment at a crack; thus bending strains develop at the bottom of the AC layer. The AC bending strain is the criterion for AC overlay thickness design based on fatigue. Figure A-2 is a representative fatigue response for Illinois DOT Class I type AC mixtures (28).

NDT TESTING OF PCC SECTION

Falling-weight deflectometer (FWD) testing of the existing PCC pavement (preferably in the center of intact slab sections to facilitate back-calculating the subgrade modulus) can be used to estimate the in situ E_{Ri} (resilient subgrade modulus) of the subgrade.

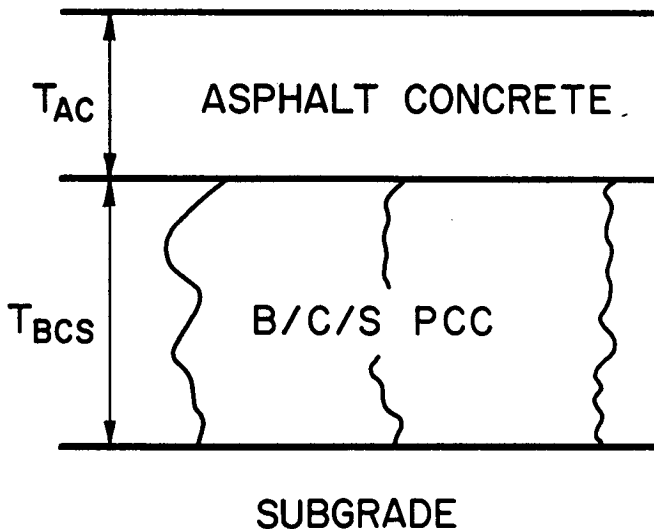


FIGURE A-1 Typical crack/seat pavement section.

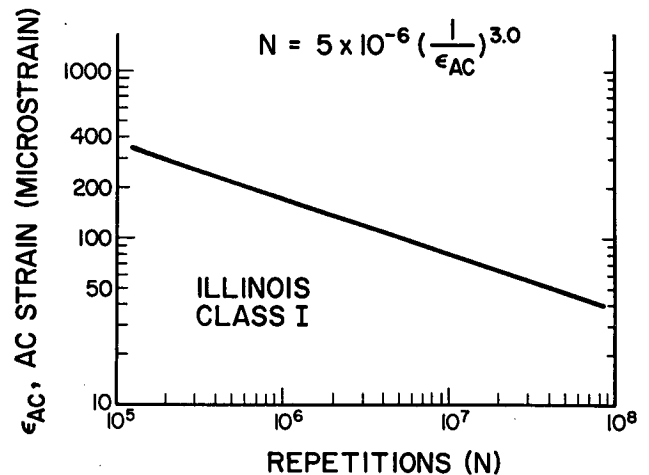


FIGURE A-2 Typical fatigue response for Illinois DOT Class I AC mixture.

AC OVERLAY DESIGN

The subgrade E_{Ri} (resilient modulus at approximately a 6 psi repeated deviator stress), AC modulus (E_{AC}), and the “equivalent modulus” of the B/C&S concrete layer (E_{CS}) are required inputs. Subgrade E_{Ri} is available from NDT (or can be established by other procedures); E_{AC} can be estimated from Figures A-3 and A-4 [based on the design time (28)], but an appropriate E_{CS} value must be assigned.

During the design phase, the PCC pavement is *not* in a B/C&S state. The E_{CS} must be assigned based on FWD data from similar PCC pavements that have been B/C&S and overlaid with AC. FWD testing on the surface of B/C&S PCC pavement before placing the AC overlay is of questionable value in estimating E_{CS} .

Several B/C&S sections have been subjected to FWD testing by the Illinois DOT. Table A-1 includes typical E_{CS} values back-calculated (using ILLI-PAVE) from the FWD data. For sections that have been properly cracked and seated (through-slab cracking achieved), the E_{CS} values are generally in the range of 300 ksi to 1000 ksi. The larger PCC slab segment sizes generally show the higher E_{CS} . A shattered slab (slab reduced to rubble) is broken down into very small segments (less than 4 to 6 in.). Typical E_{CS} for shattered PCC (based on Minnesota FWD data) is probably around 100 ksi. If through-slab cracking has not

been achieved, early life reflective cracking may occur (ILL 97, Willard in Table A-1) and very high E_{CS} values (as large as 4000 ksi) prevail.

ILLI-PAVE analyses (29) for the typical section (E_{AC} , E_{CS} , E_{Ri}) and various AC overlay thicknesses are conducted. Based on the calculated (9-kip axle loading, contact radius = 6 in.) *top of PCC slab deflections* at 0 and 12-in. offsets, the AC bending strain is estimated (see Table A-2). A calibration equation (based on full-depth AC pavements with good support) has been established to predict a "design" AC strain. The equation is given in Table A-2.

The fatigue relation (for typical Illinois DOT Class I AC mixtures) in Figure A-2 is used to estimate the number of load repetitions to cracking at the bottom of the AC layer. Stress concentrations will occur where the PCC slab is cracked; thus the calculated fatigue life is approximate (probably on the high side). However, the trends are considered to be quantitatively correct and meaningful.

Typical calculations for a recently constructed Illinois DOT project are shown in Table A-3. To attain increased levels of design reliability, the estimated fatigue life should be greater than the design traffic ESALs.

TABLE A-1

TYPICAL BACK-CALCULATED MODULI FOR C&S PAVEMENTS—ILLINOIS DATA

Pavement	Testing Period	E_{AC}^a (ksi)	T_{AC} (in.)	T_{CS}^b (in.)	E_{Ri}^c (ksi)	E_{CS}^d (ksi)
Rockton	Sp 85	500	3.0	9.0	3.1	300
Rockton	Sp 86	350	3.0	9.0	2.9	410
Rockton	S/F 86	325	3.0	9.0	3.3	535
IL 101	S/F 85	150	4.5	10.0	2.7	420
IL 101	Sp 86	300	4.5	10.0	3.5	600
IL 101	S/F 86	750	4.5	10.0	5.8	565
US6 3.5 in.	S/F 86	500	3.5	8.0	1.0	680
US6 4.0 in.	S/F 86	500	4.0	8.0	2.3	670
Lincoln	S/F 85	220	4.3	10.0	6.0	1080
Lincoln	Sp 86	350	4.3	10.0	5.0	770
Lincoln	S/F 86	750	4.3	10.0	6.7	1120
Willard	S/F 85	500	5.0	7.0	4.6	4100
Willard	Sp 86	1800	5.0	7.0	7.2	4000+
Willard	S/F 86	400	5.0	7.0	4.6	4000+
IL 97 3 in.	S/F 85	100	3.0	8.0	6.0	3250
IL 97 3 in.	Sp 86	600	3.0	8.0	5.3	1850
IL 97 4 in.	S/F 85	100	4.0	8.0	3.4	4000
IL 97 4 in.	Sp 86	600	4.0	8.0	4.5	2400

^aAssigned based on AC temperature.

^bThickness of C&S PCC slab or equivalent thickness of existing AC overlay and C&S PCC slab.

^cBack-calculated subgrade resilient modulus using ILLI-PAVE.

^dBack-calculated moduli (ILLI-PAVE) for C&S PCC slab.

TABLE A-2

AC STRAIN CALCULATIONS

Radius of Curvature

$$R = \frac{d^2}{(2)(d_0 - d_1)}$$

where

- R is the radius of curvature;
d is the horizontal distance between d_0 and d_1 (12 in.);
 d_0 is the deflection at the bottom of the AC overlay at the center of an applied circular, 9k, 80 psi load; and
 d_1 is the deflection at the bottom of the AC overlay at a radial offset of 12 in. from the center of an applied circular, 9k, 80 psi load.

All variables are in units of inches.

Design AC Strain (S_{AC})

$$\log(S_{AC}) = 5.0 - (0.038)(\log(R)) + (0.3968)(\log d_0) - (0.89)(\log(E_{AC})(T_{AC}))$$

$$R^2 = 0.932 \quad SEE = 0.0767$$

Variable Ranges: E_{Ri} : 7.68 - 25.00 ksi E_{AC} : 500-1000 ksi T_{AC} : 4-9 in.

where

- S_{AC} is the design tensile radial strain at the bottom of the AC overlay (microstrain),
R is the radius of curvature (inches),
 d_0 is the deflection at the bottom of the AC overlay at the center of an applied circular, 9k, 80 psi load (mils),
 E_{AC} is the dynamic modulus of the AC overlay (ksi), and
 T_{AC} is the thickness of the AC overlay (inches).

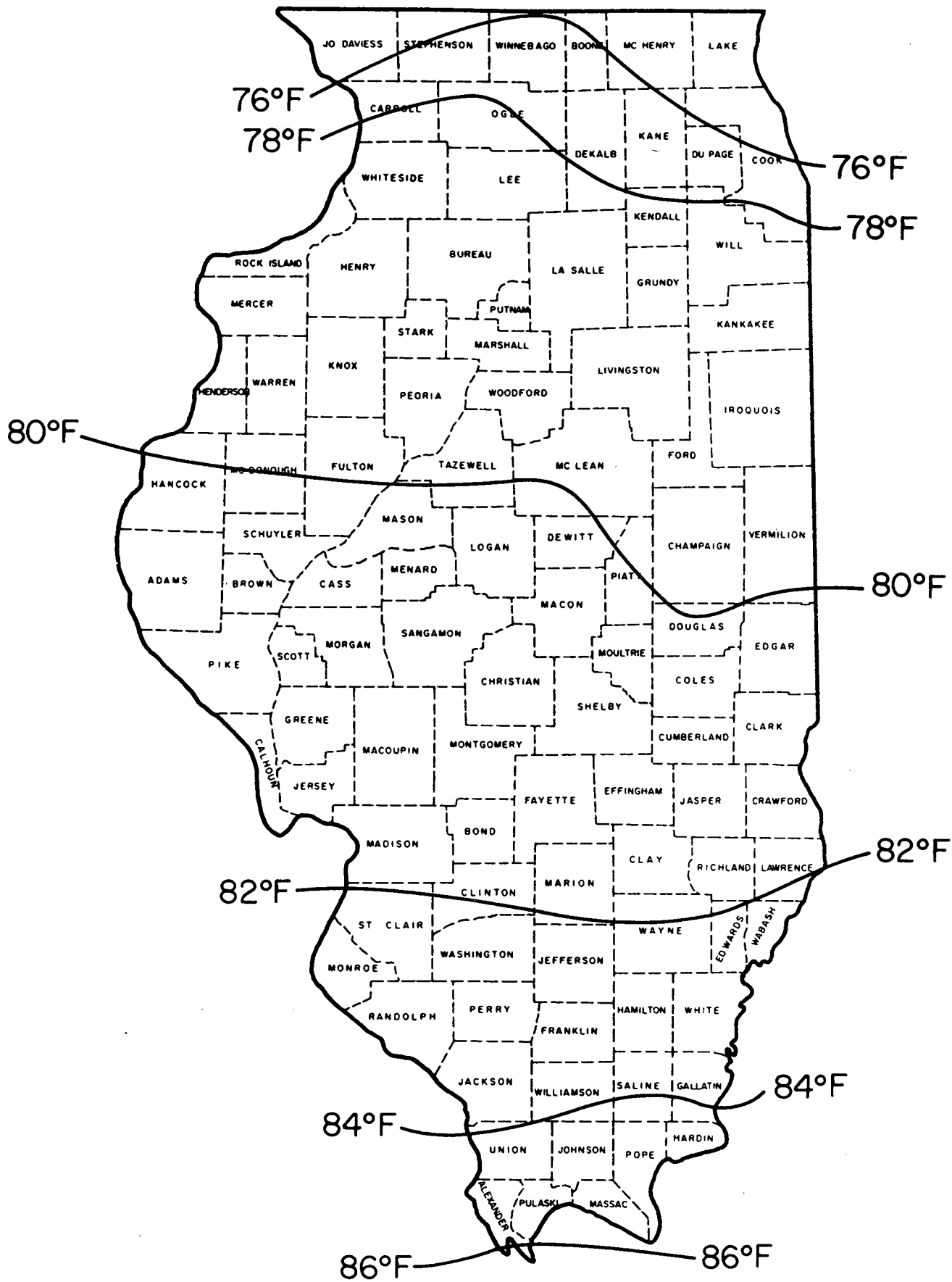


FIGURE A-3 Design pavement AC mixture temperature.

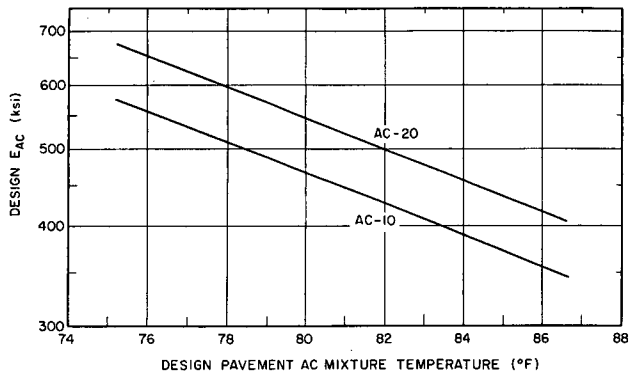


FIGURE A-4 Design pavement AC mixture modulus.

TABLE A-3
TYPICAL BREAK/CRACK AND SEAT DATA

AC Overlay (in.)	Subgrade E _{Ri} (ksi)	AC Design strain (micro-strain)	Estimated Life, ESAL (millions)
3	3	257	0.29
4	3	193	0.70
5	3	154	1.38
6	3	127	2.44
7	3	108	3.97
8	3	94	6.06

Notes: AC Modulus = 500 ksi
 B/C&S PCC Modulus = 500 ksi
 Thickness of B/C&S PCC section = 10 in.

APPENDIX B

TYPICAL SPECIFICATIONS

1. Kentucky Department of Highways
2. Wisconsin Department of Transportation
3. NAPA-National Asphalt Pavement Association
4. New York State Department of Transportation
5. Michigan Department of Transportation

KENTUCKY TRANSPORTATION CABINET
DEPARTMENT OF HIGHWAYS
SPECIAL PROVISION NO. 77B (85)

BREAKING AND SEATING EXISTING CONCRETE PAVEMENT

This Special Provision shall apply when indicated on the plans or in the proposal. Section references herein are to the Department's 1985 Standard Specifications for Road and Bridge Construction.

I. DESCRIPTION

This work shall consist of breaking and seating existing portland cement concrete (PCC) pavement for full depth and full panel width. All work shall comply with the applicable standard drawings and the 1985 Standard Specifications except as specifically superseded herein.

II. CONSTRUCTION REQUIREMENTS

A. General. Breaking and seating of the existing pavement, and placement of the bituminous concrete base course shall be accomplished one lane at a time.

The Contractor shall exercise care during breaking and seating to protect, and prevent damage to, underground utilities and drainage facilities.

B. Breaking of PCC Pavement.

(1) Size Requirements. The existing PCC pavement shall be broken such that the majority of the surface material shall be generally of 24 inch size or smaller, with no more than 20% of the material larger than 24 inches, and no individual fragments larger than 30 inches. The extent of the breakage will be based on cracks visible to unaided normal vision when the pavement surface is dry. The use of water to detect additional cracks will not be permitted.

The Contractor shall continuously monitor the breaking operation, and shall make adjustments in the striking pattern, striking energy, number of passes, or other factors as necessary to continually achieve acceptable breaking throughout the project.

(2) Equipment. Breaking shall be accomplished with an impact hammer. The hammer shall be capable of delivering such energy as may be necessary to satisfactorily break the pavement. The breaker shall be equipped with a plate-type shoe designed to prevent penetration into the existing surface. Other methods and equipment may be used when authorized by the Engineer in accordance with Section 108.06. A screen satisfactory to the Engineer shall be provided to protect vehicles in the adjacent lane from flying chips during the fracturing process when necessary.

(3) Test Section. Before breaking operations begin, the Engineer will designate a test section. The Contractor shall break the test section using varying energy and striking patterns and, if necessary, repeated passes of the equipment over the pavement until the test section is acceptably broken as specified in paragraph B(1). The extent of breakage of the test section shall be used as a guide for breaking the pavement on the remainder of the project. The Engineer may require additional test sections any time during the course of the work that the size requirements are not met.

C. Seating of Broken PCC Pavement.

(1) Roller Requirements. After breaking, the broken concrete shall be seated by rolling with a pneumatic-tire proof roller weighing 35 or 50 tons. The roller shall be one of the following types:

(a) The roller may be a pneumatic tire roller consisting of 4 rubber-tired wheels equally spaced across the full width and mounted in line on a rigid steel frame in such manner that all wheels carry equal loads, regardless of surface irregularities. Roller tires shall be capable of satisfactory operation at a minimum inflation pressure of 100 psi, and tires shall be inflated to the pressure necessary to obtain proper surface contact pressure to satisfactorily seat pavement slabs. At the Contractor's option, tires may contain liquid. The roller shall have a weight body suitable for ballasting to a gross load of either 35 or 50 tons, and ballast shall be such that gross roller weight can be readily determined and so controlled as to maintain the gross roller weight. The roller shall be towed with a rubber-tired prime mover.

(b) The roller may be a two-axle self-propelled pneumatic-tire roller, providing the roller is equipped with no more than 7 tires, and the requirements in (a) above concerning tire inflation pressure, surface contact pressure, and gross weight are met.

(2) Seating. At least 5 one-way passes of a 50-ton roller, or 7 one-way passes of a 35 ton roller, will be required. A rolling pattern shall be used that will ensure that the entire area of the broken pavement is well seated and is thoroughly and uniformly compacted.

D. Placement of Bituminous Concrete Base and Binder.

Placing of the bituminous concrete base shall follow the breaking and seating operation as closely as is practicable and, in no case, shall the broken pavement remain exposed more than 24 hours. If this 24-hour requirement is not met, breaking operations shall be suspended until all broken existing pavement has been covered by at least one course of bituminous concrete base.

If more than one course of bituminous base or binder is used each course shall cure for one night before the next course of bituminous concrete is applied, and a lane shall not be opened to public traffic until 2 courses of bituminous concrete (not including leveling courses) have been placed. The longitudinal joints in the bituminous concrete shall be offset 6 inches as required by Section 401.16. Then, traffic shall be turned onto the bituminous concrete and adjacent lanes closed and worked in the same manner.

On portions of the project designated to receive only one course of either bituminous concrete base or binder, leveling of the existing surface shall be performed in accordance with the Standard Specifications.

On portions of the project designated to receive 2 or more courses of bituminous concrete base or binder, normal leveling and wedging shall be performed on top of the first course of bituminous concrete, and not on the existing pavement. However, the Engineer may require grader patching to be performed directly on the broken and seated pavement at specific locations where a substantial amount of leveling is deemed necessary. Deviations in the surface of succeeding courses shall be corrected as specified in Section 401.18. Paving operations for bituminous courses following the first 2 courses of bituminous concrete shall conform to requirements specified elsewhere in the contract.

No bituminous concrete base shall be placed on the project when the natural light is insufficient, unless the Contractor provides artificial lighting satisfactory to the Engineer. Nighttime placing of bituminous concrete binder or surface will not be permitted unless otherwise specified elsewhere in the contract.

III. METHOD OF MEASUREMENT

The area of existing PCC pavement acceptably broken and seated will be measured in square yards. The width will be the actual width of the existing PCC pavement, and the length will be measured horizontally along the centerline of each roadway or ramp.

IV. BASIS OF PAYMENT

Payment for the measured area at the contract unit price shall be full compensation for furnishing all labor, equipment, materials, and incidentals necessary to acceptably break and seat the existing PCC pavement. Payment will be made under:

<u>Pay Item</u>	<u>Pay Unit</u>
Breaking and Seating Pavement	Square Yard

APPROVED *R. K. Capito*
R. K. CAPITO, P.E.
STATE HIGHWAY ENGINEER

11/30/87
DATE

Wisconsin DOT

Supplemental Specification #2/Sept, 1986

410.6.3 Cracking and Seating Concrete Pavement.

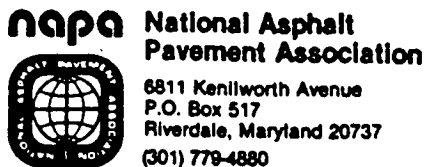
410.6.3.1 Description. Work under this item shall consist of cracking and seating the existing concrete pavement prior to the placement of the new bituminous pavement. The intent of the pavement cracking is to create portland cement concrete pavement pieces that are small enough to reduce joint movement to a point where reflection cracking will be greatly reduced, yet still be large enough and still have full aggregate interlock between pieces so that the majority of the original structural strength of the portland cement concrete pavement is retained. The intent of the seating operation is to set the individual pieces firmly on the subgrade and eliminate voids from under the pavement structure.

410.6.3.2 Equipment. The device used to crack the concrete pavement shall be capable of exerting a minimum of 12,000 foot pounds of energy. Cracking devices which cause undue displacement of the concrete or damage drainage facilities, utilities, or other property, or destabilize the subgrade shall not be used. A vibratory roller* conforming to the requirements of Subsection 405.4.4 shall be used to seat the cracked concrete.

410.6.3.3 Construction Methods. The concrete pavement after cracking shall have pieces which are on the order of four to six square feet in area. The greatest dimension of the piece shall be oriented transversely with the centerline of the pavement. The pieces shall be cracked and seated without undue displacement. The broken surface shall be rolled sufficiently to firmly seat and lay the cracked pieces to an even surface. After rolling and before use by traffic and again prior to the placement of the bituminous leveling course, the surface of the cracked and seated pavement shall be cleaned by removing therefrom dust, dirt, debris or other foreign or loose material.

* Vibratory Steel Roller

NATIONAL ASPHALT PAVEMENT ASSOCIATION
MODEL SPECIFICATION
FOR
CONCRETE PAVEMENT CRACKING AND SEATING



Description - This work shall consist of Cracking and Seating existing concrete pavement following removal of existing Hot Mix Asphalt overlays, if present, and prior to placement of a Hot Mix Asphalt overlay.

Equipment - The device to be used for cracking the concrete pavement shall be capable of producing the desired cracking pattern without displacing the concrete more than 1/4-inch vertically or without excessive spalling of the concrete. The equipment for seating the cracked concrete shall be a pneumatic tired roller with a suitable body for ballast loading with such capacity that the gross load may be varied from 30 to 50 tons.

Construction Methods - Following removal of any existing Hot Mix Asphalt overlays, the existing concrete pavement shall be cracked by such equipment and by such a method so as to produce full depth, generally transverse, hairline cracks at a nominal longitudinal spacing of 18" to 36". Care should be taken to prevent the formation of a continuous longitudinal crack.

Before cracking operations begin, the Engineer will designate test sections. The Contractor shall crack the test sections using varying energy and striking patterns until a satisfactory cracking pattern is established. This energy and striking pattern will then be required for the remainder of the project unless the Engineer determines conditions have changed such that a satisfactory cracking pattern is no longer being produced. Adjustments shall then be made to the energy and/or striking pattern as required to reestablish a satisfactory cracking pattern. When cracking the test sections, the Contractor shall furnish and apply water to dampen the pavement following cracking to enhance visual determination of the cracking pattern. The Contractor shall furnish and apply water to a check section once each day to verify that the specified crack pattern is being maintained.

Following cracking, the concrete shall be rolled until the concrete pieces are assured of being seated.

Prior to the placement of the Hot Mix Asphalt leveling course the pavement shall be cleaned by power sweeping and air blowing (including removing loose material from joints, cracks and bituminous patched areas) with 100 PSI nominal air pressure.

If the pavement is opened to traffic after the cracking operation but prior to placement of the first Hot Mix Asphalt course, the Contractor shall maintain the pavement for traffic by sweeping, patching, etc., as needed.

Measurement and Payment - The completed work as measured for CONCRETE PAVEMENT CRACKING AND SEATING will be paid for at the contract unit price for the following contract item (pay item).

<u>Pay Item</u>	<u>Pay Unit</u>
Concrete Pavement Cracking - - - - -	Square Yard

Payment for Concrete Pavement Cracking includes cracking the existing concrete pavement, assuring seating of the cracked pavement by use of a roller, and maintaining the cracked pavement in suitable condition for use by traffic if required.

**CRACKING & SEATING
PORTLAND CEMENT CONCRETE PAVEMENTS**

**Implementation Instructions
For**

Design and Construction Utilizing this Technique



**National Asphalt
Pavement Association**

6811 Kenilworth Avenue
P.O. Box 517
Riverdale, Maryland 20737
(301) 779-4880

The following information is furnished to assist in the implementation of the attached model specification for Cracking and Seating of portland cement concrete pavements:

Cracking Equipment - The model specification does not specify a particular type or model of equipment. This is done purposely so as not to limit the ingenuity of the contractor and the equipment manufacturer. What is desired, in addition to the cracking pattern detailed in the model specification, is the utilization of equipment that will provide the necessary transverse cracking, minimize the continuous longitudinal cracking, and provide a broad striking surface that does not punch holes, nor disintegrate otherwise sound pavement by the impact of the breaking head. What is desired is equipment whose foot pounds of energy transmitted to the pavement can be controlled to induce as near vertical cracks as possible with the minimum of conical cracking as would be developed by breaking for total removal.

"D" Cracking - Many old portland cement concrete pavements are extensively "D" cracked at transverse joints. One of the advantages of the Cracking and Seating technique is that it minimizes the cost expenditures on preparing the old pavement surface. No special provision should be made for joints that are heavily "D" cracked. The joint should be "blown out" as detailed under the model specification, and breaking operations should cease two feet plus or minus from the start of the "D" cracked pavement.

Rolling Pattern - By using the 30 to 50 ton pneumatic tired roller, as outlined in the model specification, it should only be necessary to roll the entire surface with one coverage of the pneumatic tires.

Proof of Cracking - Some states require that cores be taken to prove that the cracking is proceeding in accordance with the required pattern and to the extent desired by the specification. It would be the recommendation that this is not necessary and that the use of water on the cracked pavement should be sufficient to determine that the desired cracking is present.

Traffic Control - As noted in the model specification, there is no minimum time for the placement of the Hot Mix Asphalt overlay. This is a requirement that should be added on a job-to-job basis. Many pavements can remain open to traffic for a considerable period of time after cracking and seating with absolutely no problems due to the good condition of the top surface of the existing concrete pavement. Some concrete pavements, especially those that have had a Hot Mix Asphalt overlay which has been removed prior to cracking, may have severe spalling in the top inch to two inches of the existing pavement. In these cases where the condition can be determined by coring prior to award, then it is proper to call for either tight bladed asphalt mix (fine wearing course mixture placed with a grader) or a scratch coat of 90 to

Cracking & Seating Portland Cement Concrete Pavements

Traffic Control (continued)

100 pounds of fine wearing course mixture placed by a paver prior to the pavement for traffic. The only surface treatment necessary prior to either would be to remove the loose material prior to the placement of the Hot Mix Asphalt. If the pavement is sound, there is no need to incur additional project expense to cover with a partial overlay the cracked pavement prior to its use by traffic.

Sub-Base/Subgrade - The technique of Cracking and Seating portland cement concrete pavement should not be used on pavements that have very poor sub-base/subgrade foundations. If, in fact, the soil foundation condition is poor to the extent that the existing concrete pavement is providing some bridging action, then it is not wise to destroy that bridging action by cracking the concrete pavement into smaller sections. As design and testing methods become more sophisticated, it is possible that there would be a maximum deflection that could be determined as being acceptable for the utilization of this specification.

Sub-Base Drainage - As stated above, it is important that the sub-base be stable, and the sub-base condition in some cases may be improved by adding edge drains along the pavement. The benefits of adding a high-level edge drain to drain sand sub-bases should be investigated on each project.

Thickness of Overlay - There is at least one state which, at this time, is in the process of developing a method for determining coefficients of relative strength of Cracked and Seated portland cement concrete pavement. This would lead to a rational method for the design of Hot Mix Asphalt overlay thicknesses. At the present time, there is no prescribed method to predict overlay thicknesses. It is the opinion of the technical staff of the National Asphalt Pavement Association that, in the absence of the studies now being undertaken, a coefficient of relative strength of .28 to .32 can be utilized for properly Cracked and Seated concrete pavements.

Conclusion - It should be kept in mind that the utilization of the Cracking and Seating specification does not build a perfect pavement. It is, however, a technique that has satisfactorily, on many past projects, served to drastically reduce the percentage of reflective cracking that is encountered with Hot Mix Asphalt overlays on portland cement concrete pavements.

It is our opinion at this time that its use on continuously reinforced concrete pavement is not warranted, but that it performs equally well on plain and reinforced concrete pavements.

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

SPECIAL SPECIFICATIONITEM 18203.9902 CRACKING AND SEATING EXISTING CONCRETE PAVEMENT

Under this item, the Contractor shall crack and seat the existing concrete pavement within the payment lines shown on the plans or within revised payment lines established by the Engineer in writing prior to the placement of a bituminous overlay.

MATERIALS

None Specified.

CONSTRUCTION DETAILS

Before cracking and seating operations begin, the Engineer will designate a test section. The Contractor shall crack the pavement in the test section using varying impact energies until full depth cracking is established to the satisfaction of the Engineer. This impact energy, and the striking pattern later described, will then be used for the remainder of the project. Within the test section, coring will be required to verify that cracks are being established full depth. The Department of Transportation will obtain the necessary cores. The Contractor shall supply water to assist in locating cracks in the concrete pavement. The water shall be applied to the surface in a fine spray. Following cracking and after the surface dries, water remaining in the cracks will readily identify crack location.

The equipment for cracking the concrete pavement shall be approved by the Engineer and shall be capable of producing the desired cracking without excessive displacement or spalling of the concrete. Unguided free-falling weights such as "headache or wrecking balls" will not be permitted to crack the pavement. The Contractor shall crack the existing concrete pavement in conformance with one of the following patterns. Regardless of which pattern or pavement breaker is used, the pavement shall be cracked transversely such that adjacent cracks do not exceed 3 feet in the longitudinal direction.

If a drop hammer is used (approximately 1200 lb. weight with small diameter (5") breaking head), the following pattern shall apply. The spacing between hammer blows shall not exceed 6" moving transversely across the pavement lane or lanes. For each transverse pass of the breaking machine, the pattern shall begin one foot from the shoulder and proceed to the centerline of the pavement. The height of drop of the breaking head shall be adjusted to produce full depth cracking with a minimum of surface spalling.

The transverse cracking pattern is not required to be in a straight line across each lane. A drop hammer which creates a slightly arc-shaped pattern across each lane is acceptable. If such a pavement breaker is used, the following pattern shall apply. The radius of the arc shall be seven feet minimum. Cracking one full lane width using one or two arc-shaped patterns is acceptable, as long as the entire lane is cracked. The pattern shall begin one foot from the shoulder and progress transversely to the centerline, allowing not more than 6" between hammer blows.

If a pavement breaker is used incorporating a 12,000 lb. drop weight (six feet wide), one pass of the pavement breaker down the center of the lane is acceptable, provided cracking is produced across the entire lane width. Pavement cracks radiating from the ends of the drop weight to the pavement edge are acceptable. The height of drop shall be adjusted to produce full depth cracking with a minimum of surface spalling.

Cracking concrete pavement will not be permitted over drainage facilities, utilities, etc. Regardless of which type of equipment is used, provisions shall be made to protect passing traffic from flying debris during the cracking operation.

Following cracking but prior to asphalt patching and overlaying, the pavement shall be seated. The cracked pavement shall be seated by two passes of a roller conforming to the requirements of Section 203-3.13B and weighing fifty (50) tons gross weight. If the pavement is opened to traffic after the cracking and seating operations but prior to placement of the first bituminous course, the Contractor shall maintain the pavement by sweeping, asphalt patching, etc. to the satisfaction of the Engineer.

The sequence of the operations in conjunction with this item shall be performed in the following order: any sawcutting to cut steel mesh reinforcement, cracking, seating, patching with asphalt concrete, tack coat, overlaying. Work shall be sequenced so that the cracking and seating of the concrete pavement is completed prior to the construction of shoulders and the installation of underdrains. In conducting his operations, the Contractor shall avoid cracking over existing drainage structures and utilities.

The Contractor shall schedule his operations so that a minimum of 3 1/2" of asphalt concrete shall be placed over the cracked and seated pavement before paving ceases for the winter. Asphalt concrete shall be placed within two weeks of the completion of the cracking and seating operations. The Contractor can delay placement of the overlay (in the cracking and seating sections) beyond the two week limit if approved by the Engineer and he satisfactorily demonstrates he can maintain traffic safely over the cracked pavement by sweeping and/or patching.

METHOD OF MEASUREMENT

The quantity shall be the number of lane miles computed from the payment lines shown on the plans or from revised payment lines established by the Engineer in writing prior to performing the work.

BASIS OF PAYMENT

The unit price bid per lane mile shall include the cost of furnishing all labor, materials, and equipment necessary to complete the work.

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

ITEM 18502.75RUBBLEIZING EXISTING PORTLAND
CEMENT CONCRETE PAVEMENTDESCRIPTION

Under this item, the Contractor shall rubbleize and compact the existing Portland cement concrete pavement within the payment lines shown on the contract plans.

MATERIALS

None specified

CONSTRUCTION DETAILS

The existing pavement shall be rubbleized with a self contained, self propelled resonant frequency pavement breaking unit capable of producing low amplitude, 2000 foot-pound blows at a rate of 44 per second. The unit shall also be equipped with a water system to suppress dust generated by the rubbleizing operation. The operating speed of the unit shall be such that the existing pavement is rubbleized into particles ranging from sand sized to pieces not exceeding 6 inches in largest dimension, the majority being 1 to 2 inches in size.

Prior to placing the initial asphalt concrete overlay course, the rubbleized pavement shall be compacted with 8 passes of a smooth steel wheel roller having a nominal gross weight of not less than 10 tons and which exerts a minimum force of not less than 300 pounds-per-inch-of-width on the compression roll faces. The roller shall be operated at a speed not to exceed 6 feet per second. Any depressions, one inch or greater, that result from the compaction effort shall be filled with Type CA1 Coarse Aggregate, Type CA2 Coarse Aggregate or Type 2 Subbase Coarse. Filled depressions shall be compacted with the same roller and compactive effort previously described.

Welded wire mesh reinforcement in the rubbleized pavement shall be left in place. However, any mesh exposed at the surface as a result of rubbleizing and/or compaction operations shall be cut off and removed from the site.

Except at crossover and/or access points (intersecting streets, driveways, etc.), traffic will not be allowed on the rubbleized pavement before the initial asphalt overlay course is in place. In no instance shall more than 48 hours elapse between rubbleizing the existing pavement and placement of the initial asphalt concrete overlay course. However, in the event it rains between these operations, this time limitation may be waived to allow sufficient time for the rubbleized pavement to dry out to the satisfaction of the Engineer.

Crossover and/or access points shall be maintained in the same compacted state as non-accessible areas until the initial asphalt concrete overlay course is placed. Maintenance of crossover and/or access points shall be accomplished as ordered by the Engineer.

These preceding operations should be scheduled after widening and shoulder work has been progressed up to the elevation of the existing pavement grade. These areas can then be utilized to support the resonant frequency pavement breaking unit while the existing pavement is being rubbleized and can be completed in conjunction with the placement of asphalt concrete courses over the compacted rubbleized pavement.

METHOD OF MEASUREMENT

The quantity to be measured under this item shall be the actual number of square yards of existing Portland cement concrete pavement rubbleized.

BASIS OF PAYMENT

The unit price bid per square yard shall include the cost of furnishing all labor, materials and equipment necessary to rubbleize, suppress dust, fill depressions, remove exposed mesh, compact and maintain the compacted condition of the existing pavement before the initial asphalt concrete overlay course is placed.

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION
FOR
RUBBLIZING EXISTING PORTLAND
CEMENT CONCRETE PAVEMENT

CD:TAC

1 of 2

12-19-86

a. Description.-Under this item, the Contractor shall rubblize and compact the existing reinforced portland cement concrete pavement as shown on the plans or as directed by the Engineer.

b. Materials.-Filler Aggregate 6A, 6AA or 17A Coarse Aggregate shall meet the requirements specified in Section 8.02 of the 1984 Standard Specifications.

c. Construction Methods.-A joint shall be saw cut full depth or load transfer devices shall be severed at an existing joint on ramps or mainline where the rubblizing abuts concrete pavement which is to remain in place. The existing pavement shall be rubblized with a self contained, self propelled, resonant frequency pavement breaking unit capable of producing low amplitude, 2000 pound force blows at a rate of not less than 44 per second. The unit shall also be equipped with a water system to suppress dust generated by the operation.

The operating speed of the unit shall be such that the existing pavement is reduced into particles ranging from sand sized to pieces not exceeding 6 inches in largest dimension, the majority being a nominal 1 to 2 inches in size. The surface concrete to top of reinforcement shall be reduced to the 1 to 2-inch size to the extent possible. Continuous coverage with the breaking shoe shall be required. Additional passes of the resonator may be required if larger sizes remain above the reinforcement.

Prior to placing the initial bituminous course, the rubblized pavement shall be compacted with 2 passes of a vibratory steel wheel roller having a nominal gross weight of not less than 10 tons operated in the vibration mode. The roller shall be operated at a speed not to exceed 6 feet per second. Any depressions, one inch or greater in depth from that of the immediate surrounding area, resulting from the rubblizing or compaction effort shall be filled with Filler Aggregate 6A, 6AA, or 17A Coarse Aggregate and struck off level with the surrounding area. Filled depressions shall then be compacted with the same roller and compactive effort previously described.

Reinforcement in the rubblized pavement shall be left in place. However, any reinforcement exposed at the surface as a result of rubblizing and/or compaction operations shall be cut off below the surface and removed from the site.

Except at restricted crossover and ramp crossings, traffic will not be allowed on the rubblized pavement before the initial bituminous base and leveling courses are in place. In no instance shall more than 48 hours elapse between rubblizing the segments as shown on plans and placement of the initial bituminous course. However, in the event of rain, this time limitation may be waived to allow sufficient time for the rubblized pavement to dry to the satisfaction of the Engineer. Crossover and ramp crossings shall be maintained in the same compacted state as other areas until the initial bituminous course is placed.

2 of 2

These preceding operations should be scheduled after any widening and/or shoulder work has progressed up to the elevation of the existing pavement grade. These areas can then be utilized to support the resonant frequency pavement breaking unit while the existing pavement is being rubblized. Shoulders can then be completed in conjunction with the placement of bituminous pavement courses over the compacted rubblized pavement.

d. Method of Measurement.-The quantity measured under this item shall be the number of square yards of existing portland cement concrete pavement rubblized. The quantity of Filler Aggregate LM shall be the number of cubic yards of aggregate measured before placement and compacting.

e. Basis of Payment.-The unit price per square yard shall include the cost of furnishing all labor, materials and equipment necessary to rubblize, suppress dust, remove exposed reinforcement, compact and maintain the compacted condition of the existing pavement until the initial bituminous course is placed. The unit price per cubic yard LM of Filler Aggregate shall include the cost of furnishing, delivering to the job, placing, leveling, and compacting the aggregate to fill depressions in the rubblized pavement.

<u>Pay Item</u>	<u>Pay Unit</u>
Rubblizing Pavement	Square Yard
Filler Aggregate (LM)	Cubic Yard

TAC 12-19-86

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