G 加鋪厚度設計

G.1 REHABILITATION METHODS WITH OVERLAYS (AASHTO, 1993 年版, CHAPTER 5)

資料來源：

AASHTO, “AASHTO Guide for Design of Pavement Structures,” Volume I, 1993.

G.2 1993 年 AASHTO 加鋪設計法 (張記恩期末報告)

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CHAPTER 5
REHABILITATION METHODS WITH OVERLAYS

Overlays are used to remedy functional or structural deficiencies of existing pavements. It is important that the designer consider the type of deterioration present in determining whether the pavement has a functional or structural deficiency, so that an appropriate overlay type and design can be developed.

Functional deficiency arises from any conditions that adversely affect the highway user. These include poor surface friction and texture, hydroplaning and splash from wheel path rutting, and excess surface distortion (e.g., potholes, corrugation, faulting, blowups, settlements, heaves). The overlay design procedures in this chapter address structural deficiencies. If a pavement has only a functional deficiency, procedures in Part III, Chapter 4 and Section 5.3.2 should be used.

Structural deficiency arises from any conditions that adversely affect the load-carrying capability of the pavement structure. These include inadequate thickness as well as cracking, distortion, and disintegration. It should be noted that several types of distress (e.g., distresses caused by poor construction techniques, low-temperature cracking) are not initially caused by traffic loads but do become more severe under traffic to the point that they also detract from the load-carrying capability of the pavement. Part III, Section 4.1.2 provides descriptions of various structural conditions.

Maintenance overlays and surface treatments are sometimes placed as preventive measures to slow the rate of deterioration of pavements. This type of treatment includes thin AC overlays and various surface treatments which help keep out moisture.

The following abbreviations for pavement and overlay types are used in this chapter:

AC:	Asphalt concrete
PCC:	Portland cement concrete
JPCP:	Jointed plain concrete pavement
JRCP:	Jointed reinforced concrete pavement
CRCP:	Continuously reinforced concrete pavement
AC/PCC:	AC-overlaid Portland cement concrete (JPCP, JRCP, or CRCP)

The procedures described in this chapter address the following types of overlays and existing pavements:

Section	Overlay	Existing Pavement
5.4	AC	AC
5.5	AC	Break/crack and seat and rubblized PCC
5.6	AC	JPCP, JRCP, and CRCP
5.7	AC	AC/JPCP, AC/JRCP, and AC/CRCP
5.8	Bonded PCC	JPCP, JRCP, and CRCP
5.9	Unbonded PCC	JPCP, JRCP, and CRCP
5.10	PCC	AC

5.1 OVERLAY TYPE FEASIBILITY

The feasibility of any type of overlay depends on the following major considerations.

(1) Availability of adequate funds for construction of the overlay. This is basically a constraint, as illustrated in Part III, Figure 2.1.

(2) Construction feasibility of the overlay. This includes several aspects.
   (a) Traffic control
   (b) Materials and equipment availability
   (c) Climatic conditions
   (d) Construction problems such as noise, pollution, subsurface utilities, overhead bridge clearance, shoulder thickness and side slope extensions in the case of limited right-of-way, etc.
   (e) Traffic disruptions and user delay costs

(3) Required future design life of the overlay. Many factors will affect the life of an overlay, such as the following.
   (a) Existing pavement deterioration (specific distress types, severities, and quantities)

(b) Existing pavement design, condition of pavement materials (especially durability problems), and subgrade soil
(c) Future traffic loadings
(d) Local climate
(e) Existing subdrainage situation

All of these factors and others specific to the site need to be considered to determine the suitability of an overlay.

5.2 IMPORTANT CONSIDERATIONS IN OVERLAY DESIGN

Overlay design requires consideration of many different items, including: preoverlay repair, reflection crack control, traffic loadings, subdrainage, milling an existing AC surface, recycling portions of an existing pavement, structural versus functional overlay needs, overlay materials, shoulders, rutting in an existing AC pavement and overlay, durability of PCC slabs, design of joints, reinforcement, and bonding/separation layers for PCC overlays, overlay design reliability level and overall standard deviation, and pavement widening.

These considerations must not be overlooked by the designer. Each of these is briefly described in this section, especially those that are common for all overlay types. They are described in more detail in the sections for each overlay type.

5.2.1 Pre-overlay Repair

Deterioration in the existing pavement includes visible distress as well as damage which is not visible at the surface but which may be detected by other means. How much of this distress should be repaired before an overlay is placed? The amount of pre-overlay repair needed is related to the type of overlay selected. If distress in the existing pavement is likely to affect the performance of the overlay within a few years, it should be repaired prior to placement of the overlay. Much of the deterioration that occurs in overlays results from deterioration that was not repaired in the existing pavements. The designer should also consider the cost tradeoffs of preoverlay repair and overlay type. If the existing pavement is severely deteriorated, selecting an overlay type which is less sensitive to existing pavement condition may be more cost-effective than doing extensive preoverlay repair. Excellent guidelines are available on preoverlay repair techniques (*1, 2, 3, 4*).

5.2.2 Reflection Crack Control

Reflection cracks are a frequent cause of overlay deterioration. The thickness design procedures in this chapter do not consider reflection cracking. Additional steps must be taken to reduce the occurrence and severity of reflection cracking. Some overlays are less susceptible to reflection cracking than others because of their materials and design. Similarly, some reflection crack control measures are more effective with some pavement and overlay types than with others. Reflection crack control is discussed in more detail in the sections for each overlay type.

5.2.3 Traffic Loadings

The overlay design procedures require the 18-kip equivalent single-axle loads (ESALs) expected over the design life of the overlay in the design lane. The estimated ESALs must be calculated using the appropriate flexible pavement or rigid pavement equivalency factors from Part II of this Guide. The appropriate type of equivalency factors for each overlay type and existing pavement type are given in the following table.

Existing Pavement	Overlay Type	Equivalency Factors to Use
Flexible	AC	Flexible
Rubblized PCC	AC	Flexible
Break/Crack/Seat JRCP, JRCP	AC	Flexible
Jointed PCC	AC or PCC	Rigid
CRCP	AC or PCC	Rigid
Flexible	PCC	Rigid
Composite (AC/PCC)	AC or PCC	Rigid

An approximate correlation exists between ESALs computed using flexible pavement and rigid pavement equivalency factors. Converting from rigid pavement ESALs to flexible pavement ESALs requires multiplying the rigid pavement ESALs by 0.67. For example, 15 million rigid pavement ESALs equal 10 million flexible pavement ESALs. Five million flexible pavement ESALs equal 7.5 million rigid pavement ESALs. Failure to utilize the correct type of ESALs will result in significant errors in the overlay designs. Conversions must be made, for example, when designing an AC overlay of a flexible pavement (flexible ESALs required) and when designing an alternative PCC overlay of the same flexible pavement (rigid ESALs required). Throughout this chapter, ESALs are designated as rigid ESALs or flexible ESALs as appropriate.

The type of ESALs used in the overlay design depends on the pavement performance model (flexible or rigid) being used. In the overlay design procedures presented in this chapter, the flexible pavement model is used in designing AC overlays of AC pavements and fractured slab PCC pavements. The rigid pavement model is used in designing AC and PCC overlays of PCC and ACC/PCC pavements and PCC overlays of AC pavements.

5.2.4 Subdrainage

The subdrainage condition of an existing pavement usually has a great influence on how well the overlay performs. A subdrainage evaluation of the existing pavement should be conducted as described in Part III, Section 3.3. Further guidance is provided in Reference 5. Improving poor subdrainage conditions will have a beneficial effect on the performance of an overlay. Removal of excess water from the pavement cross-section will reduce erosion and increase the strength of the base and subgrade, which in turn will reduce deflections. In addition, stripping in AC pavement and "D" cracking in PCC pavement may be slowed by improved subdrainage.

5.2.5 Rutting in AC Pavements

The cause of rutting in an existing AC pavement must be determined before an AC overlay is designed. An overlay may not be appropriate if severe rutting is occurring due to instability in any of the existing pavement layers. Milling can be used to remove the rutted surface and any underlying rutted asphalt layers.

5.2.6 Milling AC Surface

The removal of a portion of an existing AC surface frequently improves the performance of an AC overlay due to the removal of cracked and hardened AC material. Significant rutting or other major distortion of any layer should be removed by milling before another overlay is placed; otherwise, it may contribute significantly to rutting of the overlay.

5.2.7 Recycling the Existing Pavement

Recycling a portion of an existing AC layer may be considered as an option in the design of an overlay. This has become a very common practice. Complete recycling of the AC layer may also be done (sometimes in conjunction with the removal of a deteriorated base course).

5.2.8 Structural versus Functional Overlays

The overlay design procedures in this chapter provide an overlay thickness to correct a structural deficiency. If no structural deficiency exists, an overlay thickness less than or equal to zero will be obtained. This does not mean, however, that the pavement does not need an overlay to correct a functional deficiency. If the deficiency is primarily functional, then the overlay thickness should be only that which is needed to remedy the functional problem (*6*). If the pavement has a structural deficiency as well, a structural overlay thickness which is adequate to carry future traffic over the design period is needed.

5.2.9 Overlay Materials

The overlay materials must be selected and designed to function within the specific loading, climatic conditions, and underlying pavement deficiencies present.

5.2.10 Shoulders

Overlaying traffic lanes generally requires that the shoulders be overlaid to match the grade line of the traffic lanes. In selecting an overlay material and thickness for the shoulder, the designer should consider the extent to which the existing shoulder is deteriorated and the amount of traffic that will use the shoulder. For example, if trucks tend to park on the shoulder at certain locations, this should be considered in the shoulder overlay design.

If an existing shoulder is in good condition, any deteriorated areas should be patched. An overlay may then be placed to match the shoulder grade to that of the traffic lanes. If an existing shoulder is in such poor condition that it cannot be patched economically, it should be removed and replaced.

5.2.11 Existing PCC Slab Durability

The durability of an existing PCC slab greatly influences the performance of AC and bonded PCC overlays. If "D" cracking or reactive aggregate exists, the deterioration of the existing slab can be expected to continue after overlay. The overlay must be designed with this progressive deterioration of the underlying slab in mind (*7*).

5.2.12 PCC Overlay Joints

Bonded or unbonded jointed concrete overlays require special joint design that considers the characteristics (e.g., stiffness) of the underlying pavement. Factors to be considered include joint spacing, depth of saw cut, sealant reservoir shape, and load transfer requirements.

5.2.13 PCC Overlay Reinforcement

Jointed reinforced and continuously reinforced concrete overlays require an adequate amount of reinforcement to hold cracks together. Friction between the overlay slab and the base slab should be considered in the reinforcement design.

5.2.14 PCC Overlay Bonding/Separation Layers

The bonding or separation of concrete overlays must be fully considered. Bonded overlays must be constructed to insure that the overlay remains bonded to the existing slab. Unbonded overlays must be constructed to insure that the separation layer prevents any reflection cracks in the overlay.

5.2.15 Overlay Design Reliability Level and Overall Standard Deviation

An overlay may be designed for different levels of reliability using the procedures described in Part I, Chapter 4 for new pavements. This is accomplished through determination of the structural capacity (SN_f or D_f) required to carry traffic over the design period at the desired level of reliability.

Reliability level has a large effect on overlay thickness. Varying the reliability level used to determine SN_f or D_f between 50 and 99 percent may produce overlay thicknesses varying by 6 inches or more (*8*). Based on field testing, it appears that a design reliability level of approximately 95 percent gives overlay thicknesses consistent with those recommended for most projects by State highway agencies, when the overall standard deviations recommended in Part I and II are used (*8*). There are, of course, many situations for which it is desirable to design at a higher or lower level of reliability, depending on the consequences of failure of the overlay. The level of reliability to be used for different types of overlays may vary, and should be evaluated by each agency for different highway functional classifications (or traffic volumes).

The designer should be aware that some sources of uncertainty are different for overlay design than for new pavement design. Therefore, the overall standard deviations recommended for new pavement design may not be appropriate for overlay design. The appropriate value for overall standard deviation may vary by overlay type as well. An additional source of variation is the uncertainty associated with establishing the effective existing structural capacity (SN_{eff} or D_{eff}). However, some sources of variation may be smaller for overlay design than for new pavement design (e.g., estimation of future traffic). Additional research is needed to better establish the standard deviations for overlay design. At the present time it is recommended to use 0.39 for any type of concrete overlay and 0.49 for any type of AC overlay, which is consistent with Part I, Section 4.3.

5.2.16 Pavement Widening

Many AC overlays are placed over PCC pavements in conjunction with pavement widening (either adding lanes or adding width to a narrow lane). If multiple lane widening is to be designed, refer to Part II for guidance. Widening requires coordination between the design of the widened pavement section and the overlay, not only so that the surface will be functionally adequate, but also so that both the existing and widening sections will be structurally adequate. Many lane widening projects have developed serious deterioration along the longitudinal joint due to improper design. The key design recommendations are as follows:

(1) The design "lives" of both the overlay and the new widening construction should be the same to avoid the need for future rehabilitation at significantly different ages.

(2) The widened cross section should generally closely match the existing pavement or cross section in material type, thickness, reinforcement, and joint spacing. However, a shorter joint spacing may be used.

(3) A widened PCC slab section must be tied with deformed bars to the existing PCC slab face. The tie bars should be securely anchored and consistent with ties used in new pavement construction (e.g., No. 5 bars, 30 inches long, grouted and spaced no more than 30 inches apart).

(4) A reflection crack relief fabric may be placed along the longitudinal widening joint.

(5) The overlay should generally be the same thickness over the widening section as over the rest of the traffic lane.

(6) Longitudinal subdrainage should be placed if needed.

5.2.17 Potential Errors and Possible Adjustments to Thickness Design Procedure

The overlay thicknesses obtained using these procedures should be reasonable when the pavement has a structural deficiency. If the overlay thickness appears to be unreasonable, one or more of the following causes may be responsible.

(1) The pavement deterioration may be caused primarily by nonload-associated factors. A computed overlay thickness less than zero or close to zero suggests that the pavement does not need a structural improvement. If a functional deficiency exists, a minimum constructible overlay thickness that addresses the problem could be placed.

(2) Modifications may be needed in the overlay design inputs to customize the procedures to the agency's specific conditions. Each agency should test the overlay design procedures on actual projects to investigate the need for modifications. Reference 8 contains many example overlay designs that illustrate typical inputs and outputs.

  (a) Overlay reliability design level, R. The recommended design reliability levels should be reviewed for overlay designs by each agency, since the recommendations given in Part I are intended for new pavement designs. See Section 5.2.15 for discussion of overlay design reliability.

  (b) Overall standard deviation, S_o. The values recommended for new pavement design may be either too low or too high for overlay design. See Section 5.2.15 for discussion of overall standard deviation.

  (c) Effective slab thickness and structural number adjustment factors. There are many aspects to these that may need agency adjustment.

  (d) Design subgrade resilient modulus and effective k-value. Specifically, a resilient modulus which is consistent with that incorporated into the flexible pavement design equation in Part II, Section 5.4.5 must be used.

  (e) Other design inputs may be in error. Ranges of typical values for inputs are given in the worksheets for overlay design.

5.2.18 Example Designs and Documentation

Reference 8 provides many examples of overlay designs for pavements in different regions of the United States. These may provide the designer with valuable insight into results obtained for actual projects. Reference 9 contains documentation for the concepts involved in the overlay design procedures.

5.3 PAVEMENT EVALUATION FOR OVERLAY DESIGN

It is important that an evaluation of the existing pavement be conducted to identify any functional and structural deficiencies, and to select appropriate preoverlay repair, reflection crack treatments and overlay designs to correct these deficiencies. This section provides guidance in pavement evaluation for overlay design.

The following sections of Part III of this Guide provide information on pavement evaluation for rehabilitation:

Section 2.3: Selection of Alternative
Rehabilitation Methods

Chapter 3: Guides for Field Data Collection
Chapter 4: Rehabilitation Methods Other
  Than Overlay (portions of this chapter are
  applicable to preoverlay pavement
  evaluation and preoverlay repair)

The guidelines and procedures in these chapters are not repeated in this section, but are referenced as needed. This section provides guidelines for pavement evaluation specifically for overlay design purposes. Further details are provided in the sections for design of each overlay type.

5.3.1 Design of Overlay Along Project

Pavement rehabilitation projects involve lengths of pavement that range from a few hundred feet to several miles. There are two approaches to designing an overlay thickness for a project, and both have advantages and disadvantages. The design engineer should select the approach that best fits the specific design situation.

(1) *Uniform Section Approach.* The project is divided into sections of relatively uniform design and condition. Each uniform section is considered independently and overlay design inputs are obtained from each section that represents its average condition (e.g., mean thicknesses, mean number of transverse cracks per mile, mean resilient modulus). Identification of uniform sections is described in Part III, Section 3.2.2. The mean inputs for the section are used to obtain a single overlay thickness for the entire length of the section. The mean inputs must be used in the AASHTO design procedure because design reliability is applied later to give the appropriate safety factor.

(2) *Point-By-Point Approach.* Overlay thicknesses are determined for specific points along the uniform design section (e.g., every 300 feet). All required inputs are determined for each point so that the overlay thickness can be designed. Factors that may change from point to point include deflection, thickness, and condition; other inputs are usually fairly constant along the project. This approach may appear to require much more work; however, in reality it does not require much additional field work, only more runs through the design procedure. This can be done efficiently using a computer.

The point-by-point approach produces a required overlay design thickness for each analysis point along the entire project for a given reliability level. In selecting one thickness for the uniform section, be aware that each overlay thickness has already been increased to account for the design reliability level. Selection of a thickness that is greater than the mean of these values would be designing for a higher level of reliability. The point by point overlay thicknesses can be used to divide the project into different overlay design thickness sections if systematic variation exists along the project, or one design thickness can be selected for the entire project. Areas having unusually high thickness requirements may be targeted for additional field investigation, and may warrant extensive repair or reconstruction.

5.3.2 Functional Evaluation of Existing Pavement

Functional deterioration is defined as any condition that adversely affects the highway user. Some recommended overlay solutions to functional problems are provided (also see table on next page).

(1) Surface Friction and Hydroplaning

All pavement types. Poor wet-weather friction due to polishing of the surface (inadequate macrotexture and/or microtexture). A thin overlay that is adequate for the traffic level may be used to remedy this problem. Guidelines for use of asphalt concrete friction courses are provided in Reference 10.

AC-surfaced pavement. Poor friction due to bleeding of the surface. Milling the AC surface may be required to remove the material that is bleeding to prevent further bleeding through the overlay, and to prevent rutting due to instability. After milling, an open-graded friction course or an overlay thickness adequate for the traffic level may be used to remedy this problem.

AC-surfaced pavement. Hydroplaning and splashing due to wheel path rutting. Determining which layer or layers are rutting and taking appropriate corrective action are important.

(2) Surface Roughness

All pavement types. Long wavelength surface distortion, including heaves and swells. A

Cause of Rutting	Layer(s) Causing Rut	Solution
Total pavement thickness inadequate	Subgrade	Thick overlay
Unstable granular layer due to saturation	Base or subbase	Remove unstable layer or thick overlay
Unstable layer due to low shear strength	Base	Remove unstable layer or thick overlay
Unstable AC mix (including stripping)	Surface	Remove unstable layer
Compaction by traffic	Surface, base, subbase	Surface milling and/or leveling overlay
Studded tire wear	Surface	Surface milling and/or leveling overlay

level-up overlay with varying thickness (adequate thickness on crests) usually corrects these problems.

AC-surfaced pavement. Roughness from deteriorated transverse cracks, longitudinal cracks, and potholes. A conventional overlay will correct the roughness only temporarily, until the cracks reflect through the overlay. Full-depth repair of deteriorated areas and a thicker AC overlay incorporating a reflection crack control treatment may remedy this problem.

AC-surfaced pavement. Roughness from ravelling of surface. A thin AC overlay could be used to remedy this problem. Milling the existing surface may be required to remove deteriorated material to prevent debonding. If the ravelling is due to stripping, the entire layer should be removed because the stripping will continue and may accelerate under an overlay.

PCC-surfaced pavement. Roughness from spalling (including potholes) and faulting of transverse and longitudinal joints and cracks. Spalling can be repaired by full- or partial-depth repairs consisting of rigid materials. Faulting can be alleviated by an overlay of adequate thickness; however, faulting indicates poor load transfer and poor subdrainage. Poor load transfer will lead to spalling of reflected cracks in an AC overlay. Subdrainage improvement may be needed.

Some agencies apply what are called "preventive overlays" that are intended to slow the rate of deterioration. This type of overlay includes thin AC and various surface treatments. These may be applied to pavements which do not present any immediate functional or structural deficiency, but whose condition is expected to deteriorate rapidly in the future.

Overlay designs (including thickness, preoverlay repairs and reflection crack treatments) must address the causes of functional problems and prevent their recurrence. This can only be done through sound engineering, and requires experience in solving the specific problems involved. The overlay design required to correct functional problems should be coordinated with that required to correct any structural deficiencies.

5.3.3 Structural Evaluation of Existing Pavement

Structural deterioration is defined as any condition that reduces the load-carrying capacity of the pavement. The overlay design procedures presented here are based on the concept that time and traffic loadings reduce a pavement's ability to carry loads and an overlay can be designed to increase the pavement's ability to carry loads over a future design period.

Figure 5.1 illustrates the general concepts of structural deficiency and effective structural capacity. The structural capacity of a pavement when new is denoted as SC_o. For flexible pavements, structural capacity is the structural number, SN. For rigid pavements, structural capacity is the slab thickness, D. For existing composite pavements (AC/PCC) the structural capacity is expressed as an equivalent slab thickness.

The structural capacity of the pavement declines with time and traffic, and by the time an evaluation for overlay design is conducted, the structural capacity has decreased to SC_{eff}. The effective structural capacity for each pavement type is expressed as follows:

Flexible pavements: SN_{eff}
Rigid and composite pavements: D_{eff}

If a structural capacity of SC_f is required for the future traffic expected during the overlay design period, an overlay having a structural capacity of SC_{ol} (i.e., $SC_f - SC_{eff}$) must be added to the existing structure. This approach to overlay design is commonly called the structural deficiency approach. Obviously, the required overlay structural capacity can be correct only if the evaluation of existing structural capacity is correct. The primary objective of the structural evalua-

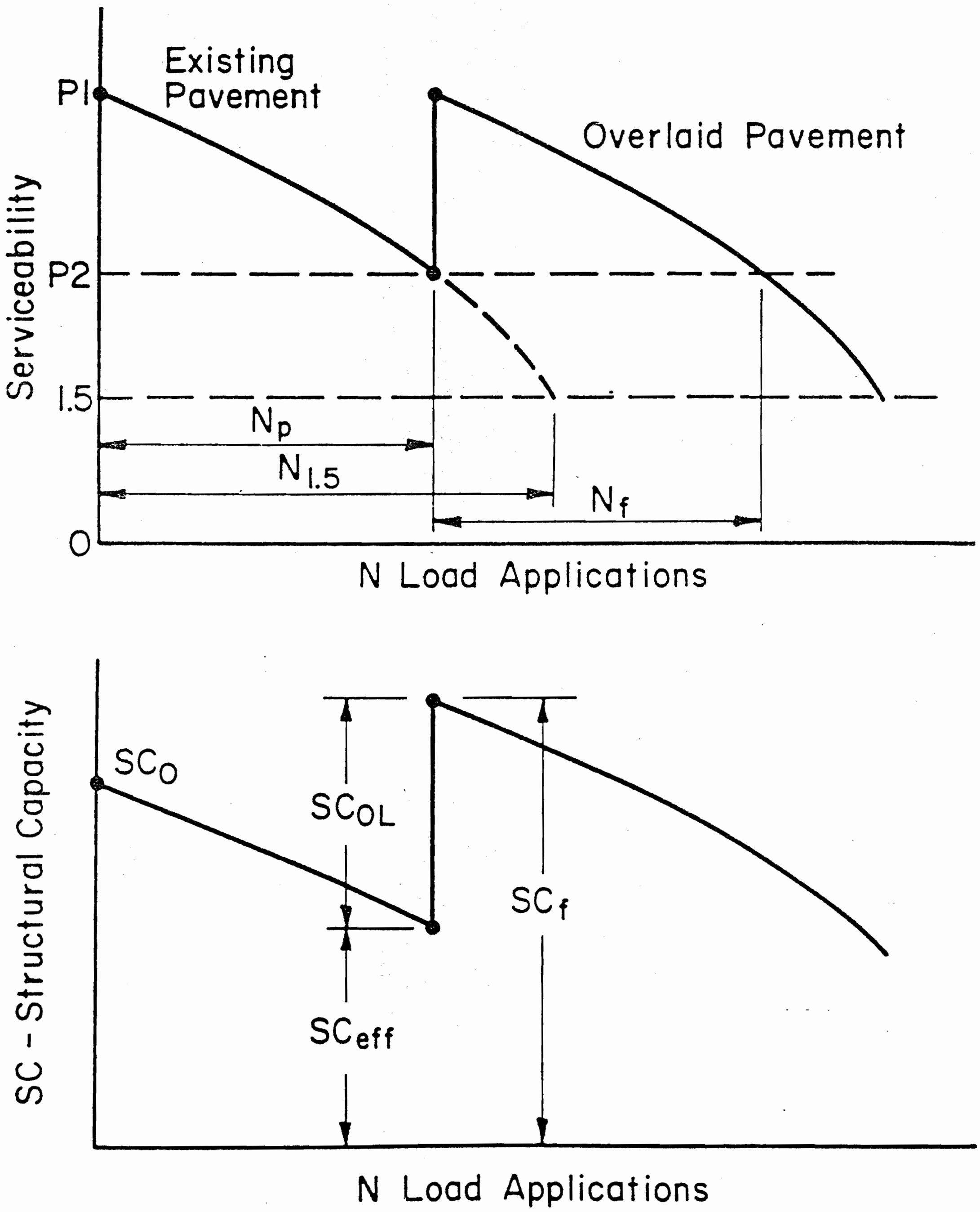


Figure 5.1. Illustration of Structural Capacity Loss Over Time and with Traffic

tion is to determine the effective structural capacity of the existing pavement.

If the declining relationship depicted in Figure 5.1 were well defined, the evaluation of effective structural capacity would be quite easy. This, however, is not the case. No single, specific method exists for evaluating structural capacity. The evaluation of effective structural capacity must consider the current condition of the existing pavement materials, and also consider how those materials will behave in the future. Three alternative evaluation methods are recommended to determine effective structural capacity.

(1) *Structural capacity based on visual survey and materials testing.* This involves the assessment of current conditions based on distress and drainage surveys, and usually some coring and testing of materials.

(2) *Structural capacity based on nondestructive deflection testing (NDT).* This is a direct evaluation of in situ subgrade and pavement stiffness along the project.

(3) *Structural capacity based on fatigue damage from traffic.* Knowledge of past traffic is used to assess the existing fatigue damage in the pavement. The pavement's future remaining fatigue life can then be estimated. The remaining life procedure is most applicable to pavements which have very little visible deterioration.

Because of the uncertainties associated with the determination of effective structural capacity, the three methods cannot be expected to provide equivalent estimates. The designer should use all three methods whenever possible and select the "best" estimate based on his or her judgement. There is no substitute for solid experience and judgment in this selection.

(1) Structural Capacity Based on Visual Survey and Materials Testing

Visual Survey. A key component in the determination of effective structural capacity is the observation of existing pavement conditions. The observation should begin with a review of all information available regarding the design, construction, and maintenance history of the pavement. This should be followed by a detailed survey to identify the type, amount, severity, and location of surface distresses.

Some of the key distress types that are indicators of structural deficiencies are listed below. Some of these are not initially caused by loading, but their severity is increased by loading and thus load-carrying capacity is reduced.

(a) **AC-surfaced pavements**

Fatigue or alligator cracking in the wheel paths. Patching and a structural overlay are required to prevent this distress from recurring.

Rutting in the wheel paths.

Transverse or longitudinal cracks that develop into potholes.

Localized failing areas where the underlying layers are disintegrating and causing a collapse of the AC surface (e.g., underlying PCC slab with severe "D" cracking, CRCP punchouts, major shear failure of base course/subgrade, stripping of AC base course). This is a very difficult problem to repair and an investigation should be carried out to determine its extent. If it is not extensive, full-depth PCC repair (when a PCC slab exists), and a structural overlay should remedy the problem. If the problem is too extensive for full-depth repair, reconstruction or a structural overlay designed for the weakest area is required.

(b) **PCC-surfaced pavements**

Deteriorating (spalling or faulting) transverse or longitudinal cracks. These cracks usually must be full-depth repaired, or they will reflect through the overlay. This does not apply to unbonded JPCP or JRCP overlays.

Corner breaks at transverse joints or cracks. Must be full-depth repaired with a full-lane-width repair (this is not required for unbonded JPCP or JRCP overlays).

Localized failing areas where the PCC slab is disintegrating and causing spalls and potholes (e.g., caused by severe "D" cracking, reactive aggregate, or other durability problems). Overlay thickness and preoverlay repair requirements may be prohibitive for some types of overlays.

Localized punchouts, primarily in CRCP. Full-depth repair of existing punchouts and placement of a structural overlay will greatly reduce the likelihood of future punchouts.

Subdrainage Survey. A drainage survey should be coupled with the distress survey. The objective of the drainage survey is to identify moisture-related pavement problems and locations where drainage improvements might be effective in improve the existing structure or reducing the influence of moisture on the performance of the pavement following the overlay.

Coring and Materials Testing Program. In addition to a survey of the surface distress, a coring and testing program is recommended to verify or identify the cause of the observed surface distress. The locations for coring should be selected following the distress survey to assure that all significant pavement conditions are represented. If NDT is used, the data from that testing should also be used to help select the appropriate sites for coring.

The objective of the coring is to determine material thicknesses and conditions. A great deal of information will be gained simply by a visual inspection of the cored material. However, it should be kept in mind that the coring operation causes a disturbance of the material especially along the cut face of AC material.

For example, in some cases coring has been known to disguise the presence of stripping. Consequently, at least some of the asphalt cores should be split apart to check for stripping.

The testing program should be directed toward determining how the existing materials compare with similar materials that would be used in a new pavement, how the materials may have changed since the pavement was constructed, and whether or not the materials are functioning as expected. The types of tests to be performed will depend on the material types and the types of distress observed. A typical testing program might include strength tests for AC and PCC cores, gradation tests to look for evidence of degradation and/or contamination of granular materials, and extraction tests to determine binder contents and gradations of AC mixes. PCC cores exhibiting durability problems may be examined by a petrographer to identify the cause of the problem.

Specific recommendations on estimating the effective structural capacity from the distress survey information are given in the sections for each overlay type.

(2) Structural Capacity Based on Nondestructive Deflection Testing

Nondestructive deflection testing is an extremely valuable and rapidly developing technology. When properly applied, NDT can provide a vast amount of information and analysis at a very reasonable expenditure of time, money, and effort. The analyses, however, can be quite sensitive to unknown conditions and must be performed by knowledgeable, experienced personnel.

Within the scope of these overlay design procedures, NDT structural evaluation differs depending on the type of pavement. For rigid pavement evaluation, NDT serves three analysis functions: (1) to examine load transfer efficiency at joints and cracks, (2) to estimate the effective modulus of subgrade reaction (effective k-value), and (3) to estimate the modulus of elasticity of the concrete (which provides an estimate of strength). For flexible pavement evaluation, NDT serves two functions: (1) to estimate the roadbed soil resilient modulus, and (2) to provide a direct estimate of SN_{eff} of the pavement structure. Some agencies use NDT to backcalculate the moduli of the individual layers of a flexible pavement, and then use these moduli to estimate SN_{eff}. This approach is not recommended for use with these overlay design procedures because it implies and requires a level of sophistication that does not exist with the structural number approach to design.

In addition to structural evaluation, NDT can provide other data useful to the design process. Deflection data can be used to quantify variability along the project and to subdivide the project into segments of similar structural strength. The NDT data may also be used in a backcalculation scheme to estimate resilient modulus values for the various pavement layers. Although this procedure does not include the use of these values as a part of the structural condition determination, backcalculation of an unusually low value for any layer should be viewed as a strong indication that a detailed study of the condition of that layer is needed.

The specific methods for estimating effective structural capacity by NDT analysis are discussed within the sections pertaining to the specific overlay types.

(3) Structural Capacity Based on Remaining Life

The remaining life approach to structural evaluation relies directly on the concepts illustrated in Figure 5.1. This follows a fatigue damage concept that repeated loads gradually damage the pavement and reduce the number of additional loads the pavement can carry to failure. At any given time, there may be no directly observable indication of damage, but there is a reduction in structural capacity in terms of the future load-carrying capacity (the number of future loads that the pavement can carry).

To determine the remaining life, the designer must determine the actual amount of traffic the pavement has carried to date and the total amount of traffic the pavement could be expected to carry to "failure" (when serviceability equals 1.5, to be consistent with the AASHO Road Test equations). Both traffic amounts must be expressed in 18-kip ESAL. The difference between these values, expressed as a percentage of the total traffic to "failure," is defined as the remaining life:

$$RL = 100\left[1 - \left(\frac{N_p}{N_{1.5}}\right)\right]$$

where

RL = remaining life, percent
N_p = total traffic to date, 18-kip ESAL
$N_{1.5}$ = total traffic to pavement "failure" ($P2 = 1.5$), 18-kip ESAL

With RL determined, the designer may obtain a condition factor (CF) from Figure 5.2. CF is defined by the equation:

$$CF = \frac{SC_n}{SC_o}$$

where

SC_n = pavement structural capacity after N_p ESAL
SC_o = original pavement structural capacity

The existing structural capacity may be estimated by multiplying the original structural capacity of the pavement by CF. For example, the original structural number (SN_o) of a flexible pavement may be calculated from material thicknesses and the structural coefficients for those materials in a new pavement. SN_{eff} of the pavement based on a remaining life analysis would be:

$$SN_{eff} = CF * SN_o$$

The structural capacity determined by this relationship does not account for any preoverlay repair. The calculated structural capacity should be viewed as a lower limit value and may require adjustment to reflect the benefits of preoverlay repair.

For the remaining life determination, $N_{1.5}$ can be roughly estimated using the new pavement design equations or nomographs, or other equations based on local agency information. To be consistent with the AASHO Road Test and the development of these equations, a failure PSI equal to 1.5 and a reliability of 50 percent is recommended.

When using this approach, the designer need not be alarmed if the traffic to date (N_p) is found to exceed the expected traffic to failure ($N_{1.5}$) resulting in a calculated negative remaining life. When this happens, the designer could use the minimum value for CF (0.50), or not use the remaining life approach.

The remaining life approach to determine SN_{eff} or D_{eff} has some serious deficiencies associated with it. There are four major sources of error:

(1) The predictive capability of the AASHO Road Test equations,
(2) The large variation in performance typically observed even among pavements of seemingly identical designs,
(3) Estimation of past 18-kip ESALs, and
(4) Inability to account for the amount of preoverlay repair to the pavement. For pavements with considerable deterioration, the SN_{eff} or D_{eff} value obtained from the remaining life method may be much lower than values obtained from other methods that adjust for preoverlay repairs. Thus, the remaining life procedure is most applicable to pavements which have very little visible deterioration.

As a result, this method of determining the remaining life of the pavement can in some cases produce very erroneous results. The following two extreme errors may occur with this approach:

(1) The remaining life estimate may be extremely low even though very little load-associated distress is present. While some fatigue damage

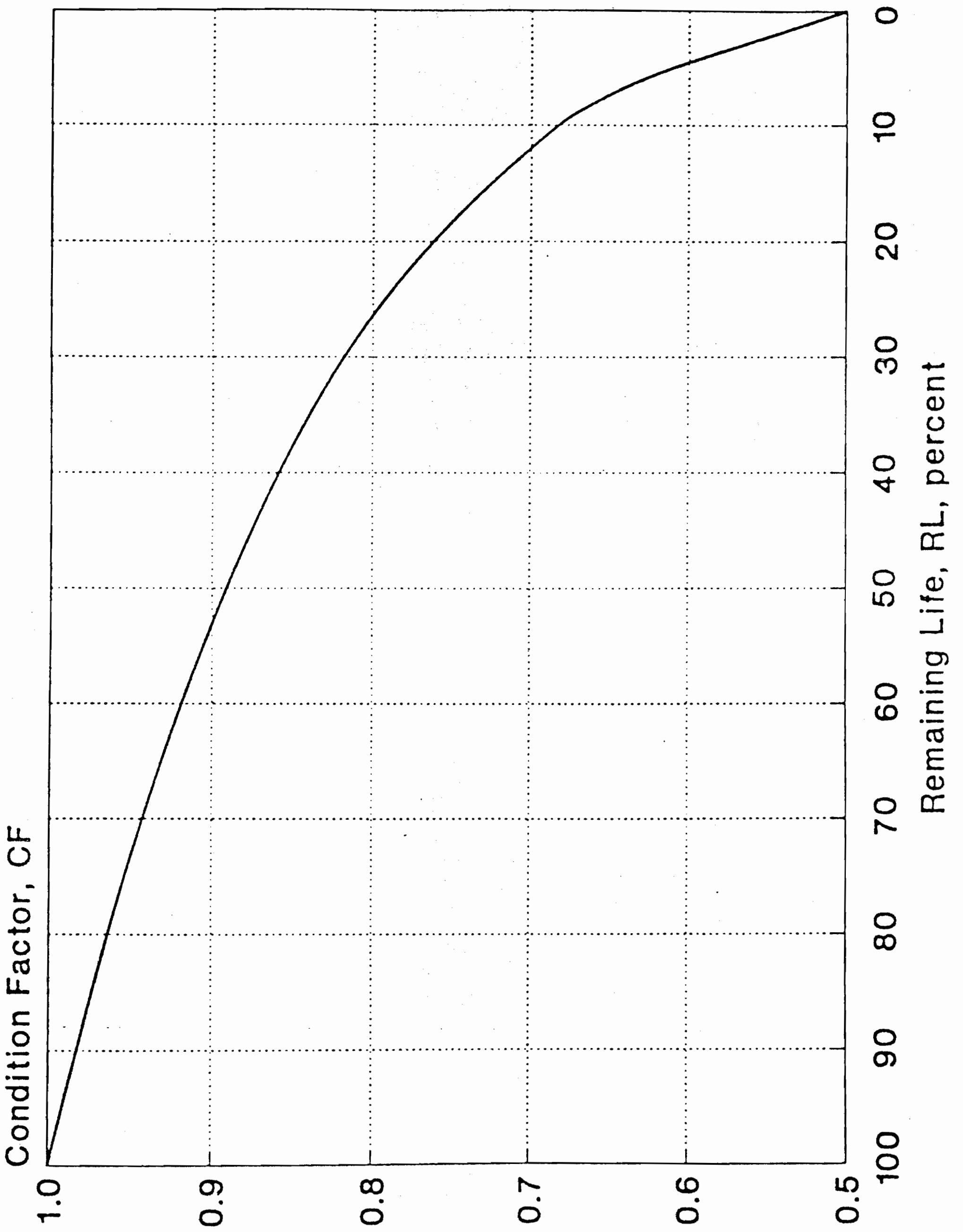


Figure 5.2. Relationship Between Condition Factor and Remaining Life

can exist in a pavement structure before a significant amount of cracking appears, it cannot be a large amount of damage, or it would certainly be evidenced by a significant amount of cracking. If load-related cracking is present in very small amounts and at a low severity level, the pavement has considerable remaining life, regardless of what the traffic-based remaining life calculation suggests.

(2) The remaining life estimate may be extremely high even though a substantial amount of medium- and high-severity load-related cracking is present. In this case, the pavement really has little remaining life.

At any point between these two extremes, the remaining life computed from past traffic may not reflect the amount of fatigue damage in the pavement, but discerning this from observed distress may be more difficult. If the computed remaining life appears to be clearly at odds with the amount and severity of load-associated distress present, do not use the remaining life method to compute the structural capacity of the existing pavement.

The remaining life approach to determining structural capacity is not directly applicable, without modification, to pavements which have already received one or more overlays.

5.3.4 Determination of Design M_R

The design subgrade M_R may be determined by: (1) laboratory testing, (2) NDT backcalculation, (3) estimation from resilient modulus correlation studies, or (4) original design and construction data. Regardless of the method used, the design M_R value must be consistent with the value used in the design performance equation for the AASHO Road Test subgrade. This is especially important when M_R is determined by NDT backcalculation. The backcalculated value is typically too high to be consistent and must be adjusted. If M_R is not adjusted, the SN_f value will be unconservative and poor overlay performance can be expected.

A subgrade M_R may be backcalculated from NDT data using the following equation:

$$M_R = \frac{0.24P}{d_r r}$$

where

M_R = backcalculated subgrade resilient modulus, psi

P = applied load, pounds

d_r = measured deflection at radial distance r, inches

r = radial distance at which the deflection is measured, inches

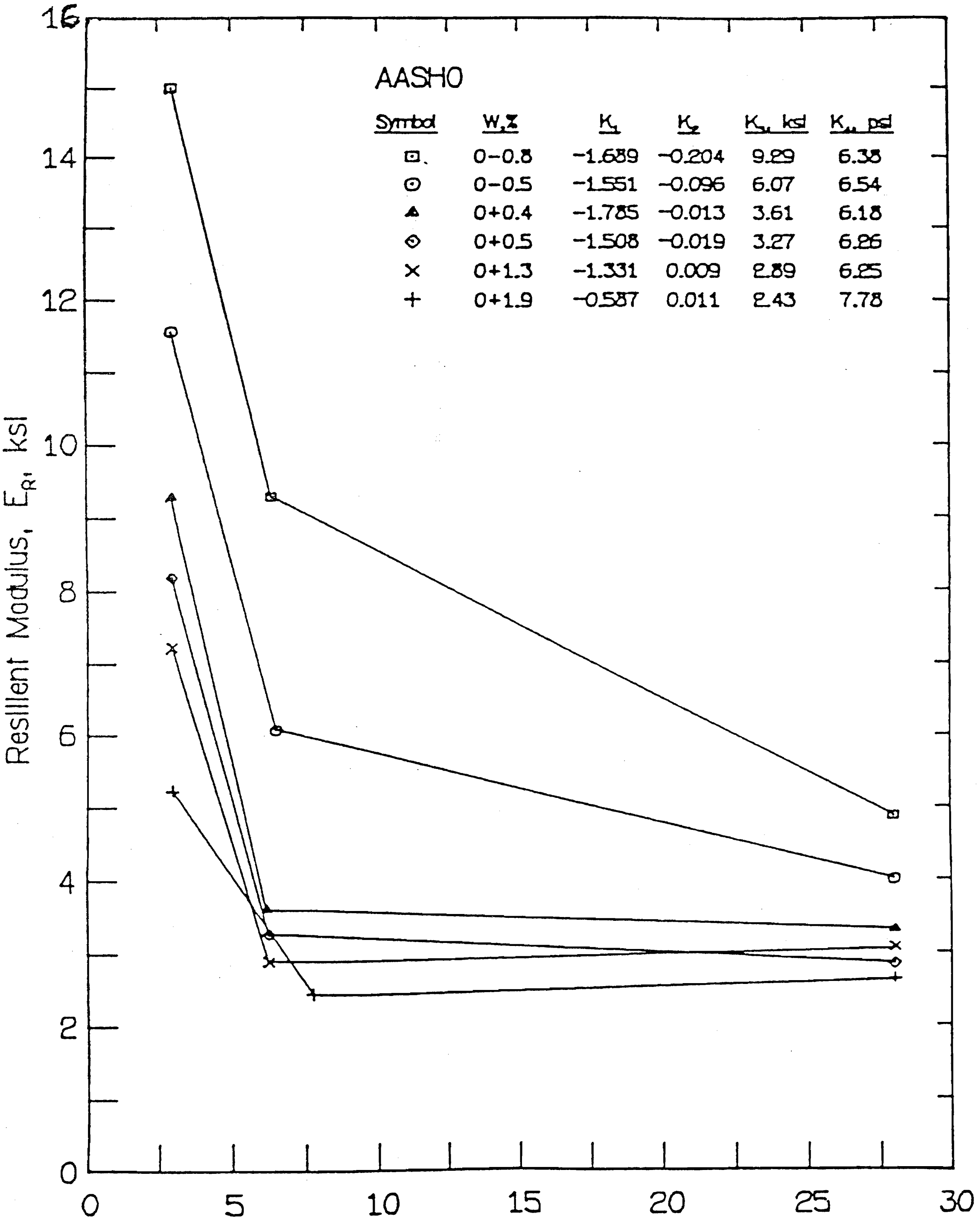
This equation for backcalculating M_R is based on the fact that, at points sufficiently distant from the center of loading, the measured surface deflection is almost entirely due to deformation in the subgrade, and is also independent of the load radius. For practical purposes, the deflection used should be as close as possible to the loading plate, but must also be sufficiently far from the loading plate to satisfy the assumptions inherent in the above equation. Guidance is provided later in this chapter for selecting the minimum radial distance for determination of M_R.

The recommended method for determination of the design M_R from NDT backcalculation requires an adjustment factor (C) to make the value calculated consistent with the value used to represent the AASHO subgrade. A value for C of no more than 0.33 is recommended for adjustment of backcalculated M_R values to design M_R values. The resulting equation is:

$$\text{Design } M_R = C\left(\frac{0.24P}{d_r r}\right)$$

A subgrade M_R value of 3,000 psi was used for the AASHO Road Test soil in the development of the flexible pavement performance model. This value is consistent with some laboratory tests of soil samples from the AASHO Road Test site, as Figure 5.3 illustrates (*11*). However, these data also show that the resilient modulus of the AASHO Road Test soil is quite stress-dependent, increasing rapidly for deviator stresses less than 6 psi. The subgrade deviator stress at a radial distance appropriate for use in the equation given above for backcalculated M_R will almost always be far less than 6 psi. Thus, the subgrade modulus determined by backcalculation can be expected to be too high to be consistent with the 3,000 psi assumed for the AASHO subgrade.

This was confirmed by two methods. In the first analysis, M_R values backcalculated from deflection data were compared with M_R values obtained from laboratory tests, for the AASHO Road Test and other sites (*12, 13*). The results, which are shown in Figure 5.4, indicate that backcalculated M_R values exceed laboratory M_R values by a factor of three or more. In



AASHO

Symbol	W,%	K_1	K_2	K_3, ksi	K_4, psi
⊡	0−0.8	−1.689	−0.204	9.29	6.38
⊙	0−0.5	−1.551	−0.096	6.07	6.54
▲	0+0.4	−1.785	−0.013	3.61	6.18
◈	0+0.5	−1.508	−0.019	3.27	6.26
×	0+1.3	−1.331	0.009	2.89	6.25
+	0+1.9	−0.587	0.011	2.43	7.78

Figure 5.3. AASHO Road Test Subgrade Resilient Modulus Test Results (*11*)

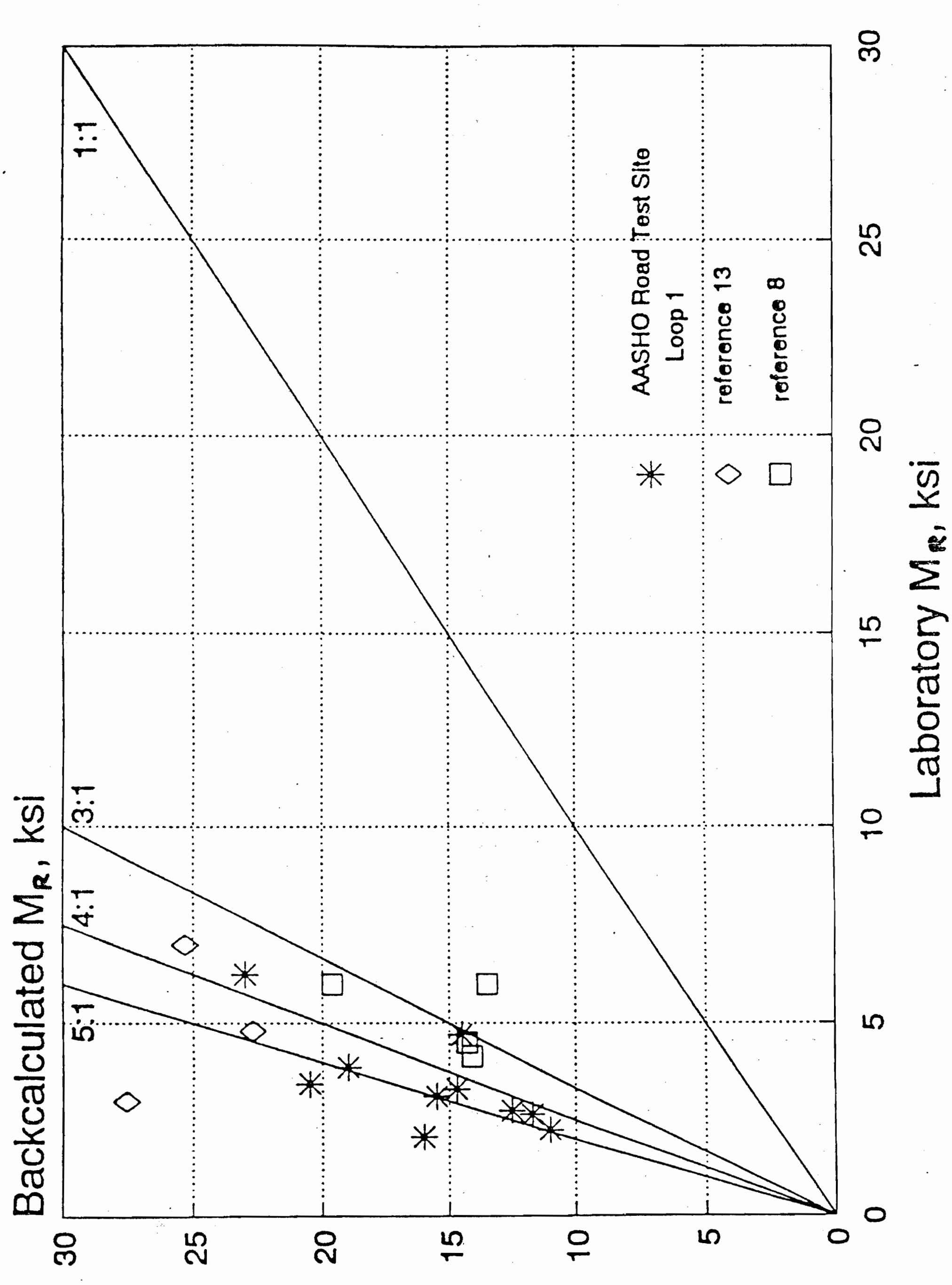


Figure 5.4. Backcalculated Resilient Modulus Versus Laboratory Results on Shelby Tube Samples from the AASHO Road Test Site Plus Data from Two Additional States

the second analysis, the ILLI-PAVE finite element program (*14, 15*) was used to compute M_R values for a variety of pavement structures and subgrade characteristics representative of the AASHO Road Test soil. At radial distances appropriate for backcalculation of M_R, the computed M_R values also exceeded the value of 3,000 psi assumed in development of the AASHO flexible pavement model by a factor of at least three. Similarly, pavement surface deflections computed by ILLI-PAVE produced backcalculated M_R values three or more times greater than 3,000 psi.

All of these analyses suggest that for the soils examined, backcalculated M_R values should be multiplied by an adjustment factor C of no more than 0.33 in order to obtain M_R values appropriate for use in design with the AASHTO flexible pavement model.

The analyses described here pertain to the fine-grained, stress-sensitive soil at the AASHO Road Test site plus fine-grained soil from seven other projects. No attempt has been made in this study to investigate the relationship between backcalculated and laboratory M_R values for granular subgrades. It may be that backcalculated M_R values for granular subgrades would not require a correction factor as large as is required for cohesive subgrades. However, this subject requires further research.

Users are cautioned that the resilient modulus value selected has a very significant effect on the resulting structural number determined. Therefore, users should be very cautious about using high resilient modulus values, or their overlay thickness values will be too thin.

5.4 AC OVERLAY OF AC PAVEMENT

This section covers the design of AC overlays of AC pavements. The following construction tasks are involved in the placement of an AC overlay on an existing AC pavement:

(1) Repairing deteriorated areas and making subdrainage improvements (if needed).
(2) Correcting surface rutting by milling or placing a leveling course.
(3) Constructing widening (if needed).
(4) Applying a tack coat.
(5) Placing the AC overlay (including a reflective crack control treatment if needed).

5.4.1 Feasibility

An AC overlay is a feasible rehabilitation alternative for an AC pavement except when the condition of the existing pavement dictates substantial removal and replacement. Conditions under which an AC overlay would not be feasible include the following.

(1) The amount of high-severity alligator cracking is so great that complete removal and replacement of the existing surface is dictated.
(2) Excessive surface rutting indicates that the existing materials lack sufficient stability to prevent recurrence of severe rutting.
(3) An existing stabilized base shows signs of serious deterioration and would require an inordinate amount of repair to provide uniform support for the overlay.
(4) An existing granular base must be removed and replaced due to infiltration of and contamination by a soft subgrade.
(5) Stripping in the existing AC surface dictates that it should be removed and replaced.

5.4.2 Pre-overlay Repair

The following types of distress should be repaired prior to overlay of AC pavements. If they are not repaired, the service life of the overlay will be greatly reduced.

Distress Type	Required Repair
Alligator Cracking	All areas of high-severity alligator cracking must be repaired. Localized areas of medium-severity alligator cracking should be repaired unless a paving fabric or other means of reflective crack control is used. The repair must include removal of any soft subsurface material.
Linear Cracks	High-severity linear cracks should be patched. Linear cracks that are open greater than 0.25 inch should be filled with a sand-asphalt mixture or other suitable crack filler. Some method of reflective crack control is recommended for transverse cracks that experience significant opening and closing.

Rutting	Remove ruts by milling or placement of a leveling course. If rutting is severe, an investigation into which layer is causing the rutting should be conducted to determine whether or not an overlay is feasible.
Surface Irregularities	Depressions, humps, and corrugations require investigation and treatment of their cause. In most cases, removal and replacement will be required.

5.4.3 Reflection Crack Control

The basic mechanism of reflection cracking is strain concentration in the overlay due to movement in the vicinity of cracks in the existing surface. This movement may be bending or shear induced by loads, or may be horizontal contraction induced by temperature changes. Load-induced movements are influenced by the thickness of the overlay and the thickness and stiffness of the existing pavement. Temperature-induced movements are influenced by daily and seasonal temperature variations, the coefficient of thermal expansion of the existing pavement, and the spacing of cracks.

Pre-overlay repair (patching and crack filling) may help delay the occurrence and deterioration of reflection cracks. Additional reflection crack control measures which have been beneficial in some cases include the following:

(1) Synthetic fabrics and stress-absorbing interlayers (SAMIs) have been effective in controlling reflection of low- and medium-severity alligator cracking. They may also be useful for controlling reflection of temperature cracks, particularly when used in combination with crack filling. They generally do little, however, to retard reflection of cracks subject to significant horizontal or vertical movements.

(2) Crack relief layers greater than 3 inches thick have been effective in controlling reflection of cracks subject to larger movements. These crack relief layers are composed of open-graded coarse aggregate and a small percentage of asphalt cement.

(3) Sawing and sealing joints in the AC overlay at locations coinciding with straight cracks in the underlying AC may be effective in controlling the deterioration of reflection cracks. This technique has been very effective when applied to AC overlays of jointed PCC pavements when the sawcut matches the joint or straight crack within an inch.

(4) Increased AC overlay thickness reduces bending and vertical shear under loads and also reduces temperature variation in the existing pavement. Thus, thicker AC overlays are more effective in delaying the occurrence and deterioration of reflection cracks than are thinner overlays. However, increasing the AC overlay thickness is a costly approach to reflection crack control.

Reflection cracking can have a considerable (often controlling) influence on the life of an AC overlay. Deteriorated reflection cracks detract from a pavement's serviceability and also require frequent maintenance, such as sealing and patching. Reflection cracks also permit water to enter the pavement structure, which may result in loss of bond between the AC overlay and existing AC surface, stripping in either layer, and softening of the granular layers and subgrade. For this reason, reflection cracks should be sealed as soon as they appear and resealed periodically throughout the life of the overlay. Sealing low-severity reflection cracks may also be effective in retarding their progression to medium and high severity levels.

5.4.4 Subdrainage

See Section 5.2.4 for guidelines.

5.4.5 Thickness Design

If the overlay is being placed for the purpose of structural improvement, the required thickness of the overlay is a function of the structural capacity required to meet future traffic demands and the structural capacity of the existing pavement. The required thickness to increase structural capacity to carry future traffic is determined by the following equation.

$$SN_{ol} = a_{ol} * D_{ol} = SN_f - SN_{eff}$$

where

SN_{ol} = Required overlay structural number
a_{ol} = Structural coefficient for the AC overlay
D_{ol} = Required overlay thickness, inches

SN_f = Structural number required to carry future traffic
SN_{eff} = Effective structural number of the existing pavement

The required overlay thickness may be determined through the following design steps. These steps provide a comprehensive design approach that recommends testing the pavement to obtain valid design inputs. If it is not possible to conduct testing (e.g., for a low-volume road), an approximate overlay design may be developed based upon visible distress observation, by skipping Steps 4 and 5 and by estimating other inputs.

Step 1: Existing pavement design and construction.

1. Thickness and material type of each pavement layer.
2. Available subgrade soil information (from construction records, soil surveys, county agricultural soils reports, etc.)

Step 2: Traffic analysis.

1. Past cumulative 18-kip ESALs in the design lane (N_p), for use in the remaining life method of SN_{eff} determination only.
2. Predicted future 18-kip ESALs in the design lane over the design period (N_f).

Step 3: Condition survey.

Distress types and severities are defined in reference 11. The following distresses are measured during the condition survey and are used in the determination of the structural coefficients. Sampling along the project in the heaviest trafficked lane can be used to estimate these quantities.

1. Percent of surface area with alligator cracking (class 1, 2, and 3 corresponding to low, medium, and high severities).
2. Number of transverse cracks per mile (low, medium, and high severities).
3. Mean rut depth.
4. Evidence of pumping at cracks and at pavement edges.

Step 4:* *Deflection testing (strongly recommended).

Measure deflections in the outer wheel path at an interval sufficient to adequately assess conditions. Intervals of 100 to 1,000 feet are typical. Areas that are deteriorated and will be repaired should not be tested. A heavy-load deflection device (e.g., Falling Weight Deflectometer) and a load magnitude of approximately 9,000 pounds are recommended. ASTM D 4694 and D 4695 provide additional guidance on deflection testing. Deflections should be measured at the center of the load and at least one other distance from the load, as described below.

(1) Subgrade resilient modulus (M_R). At sufficiently large distances from the load, deflections measured at the pavement surface are due to subgrade deformation only, and are also independent of the size of the load plate. This permits the backcalculation of the subgrade resilient modulus from a single deflection measurement and the load magnitude, using the following equation:

$$M_R = \frac{0.24P}{d_r r}$$

where

M_R = backcalculated subgrade resilient modulus, psi
P = applied load, pounds
d_r = deflection at a distance r from the center of the load, inches
r = distance from center of load, inches

It should be noted that no temperature adjustment is needed in determining M_R since the deflection used is due only to subgrade deformation.

The deflection used to backcalculate the subgrade modulus must be measured far enough away that it provides a good estimate of the subgrade modulus, independent of the effects of any layers above, but also close enough that it is not too small to measure accurately. The minimum distance may be determined from the following relationship:

$$r \geq 0.7a_e$$

where

$$a_e = \sqrt{\left[a^2 + \left(D\sqrt[3]{\frac{E_p}{M_R}}\right)^2\right]}$$

a_e = radius of the stress bulb at the subgrade-pavement interface, inches
a = NDT load plate radius, inches
D = total thickness of pavement layers above the subgrade, inches
E_p = effective modulus of all pavement layers above the subgrade, psi (described below)

Before the backcalculated M_R value is used in design, it must be adjusted to make it consistent with the value used in the AASHTO flexible pavement design equation. An adjustment may also be needed to account for seasonal effects. These adjustments are described in Step 6.

(2) Temperature of AC mix. The temperature of the AC mix during deflection testing must be determined. The AC mix temperature may be measured directly, or may be estimated from surface or air temperatures.

(3) Effective modulus of the pavement (E_p). If the subgrade resilient modulus and total thickness of all layers above the subgrade are known or assumed, the effective modulus of the entire pavement structure (all pavement layers above the subgrade) may be determined from the deflection measured at the center of the load plate using the following equation:

$$d_0 = 1.5pa\left\{\frac{1}{M_R\sqrt{1 + \left(\frac{D}{a}\sqrt[3]{\frac{E_p}{M_R}}\right)^2}} + \frac{\left[1 - \frac{1}{\sqrt{1 + \left(\frac{D}{a}\right)^2}}\right]}{E_p}\right\}$$

where

d_0 = deflection measured at the center of the load plate (and adjusted to a standard temperature of 68°F), inches
p = NDT load plate pressure, psi
a = NDT load plate radius, inches
D = total thickness of pavement layers above the subgrade, inches
M_R = subgrade resilient modulus, psi
E_p = effective modulus of all pavement layers above the subgrade, psi

For a load plate radius of 5.9 inches, Figure 5.5 may be used to determine the ratio E_p/M_R, and E_p may then be determined for a known or assumed value of M_R.

For purposes of comparison of E_p along the length of a project, the d_0 values used to determine E_p should be adjusted to a single reference temperature. Furthermore, if the effective structural number of the existing pavement is to be determined in Step 7 using the values of E_p backcalculated from deflection data, the reference temperature for adjustment of d_0 should be 68°F, to be consistent with the procedure for new AC pavement design described in Part II. Figure 5.6 may be used to adjust d_0 for AC pavements with granular and asphalt-stabilized bases. Figure 5.7 may be used to adjust d_0 for AC pavements with cement- and pozzolanic-stabilized bases.

Step 5: Coring and materials testing (strongly recommended).

(1) *Resilient modulus of subgrade.* If deflection testing is not performed, laboratory testing of samples of the subgrade may be conducted to determine its resilient modulus using AASHTO T 292-91 I with a deviator stress of 6 psi to match the deviator stress used in establishing the 3,000 psi for the AASHO Road Test soil that is incorporated into the flexible design equation. Alternatively, other tests such as R value, CBR or soil classification tests could be conducted and approximate correlations used to estimate resilient modulus. Use of the estimating equation $M_R = 1500 * \text{CBR}$ may produce a value that is too large for use in this design procedure. The relationships found in Appendix FF, Figure FF-6 may be more reasonable.

(2) *Samples of AC layers and stabilized base* should be visually examined to assess asphalt stripping, degradation, and erosion.

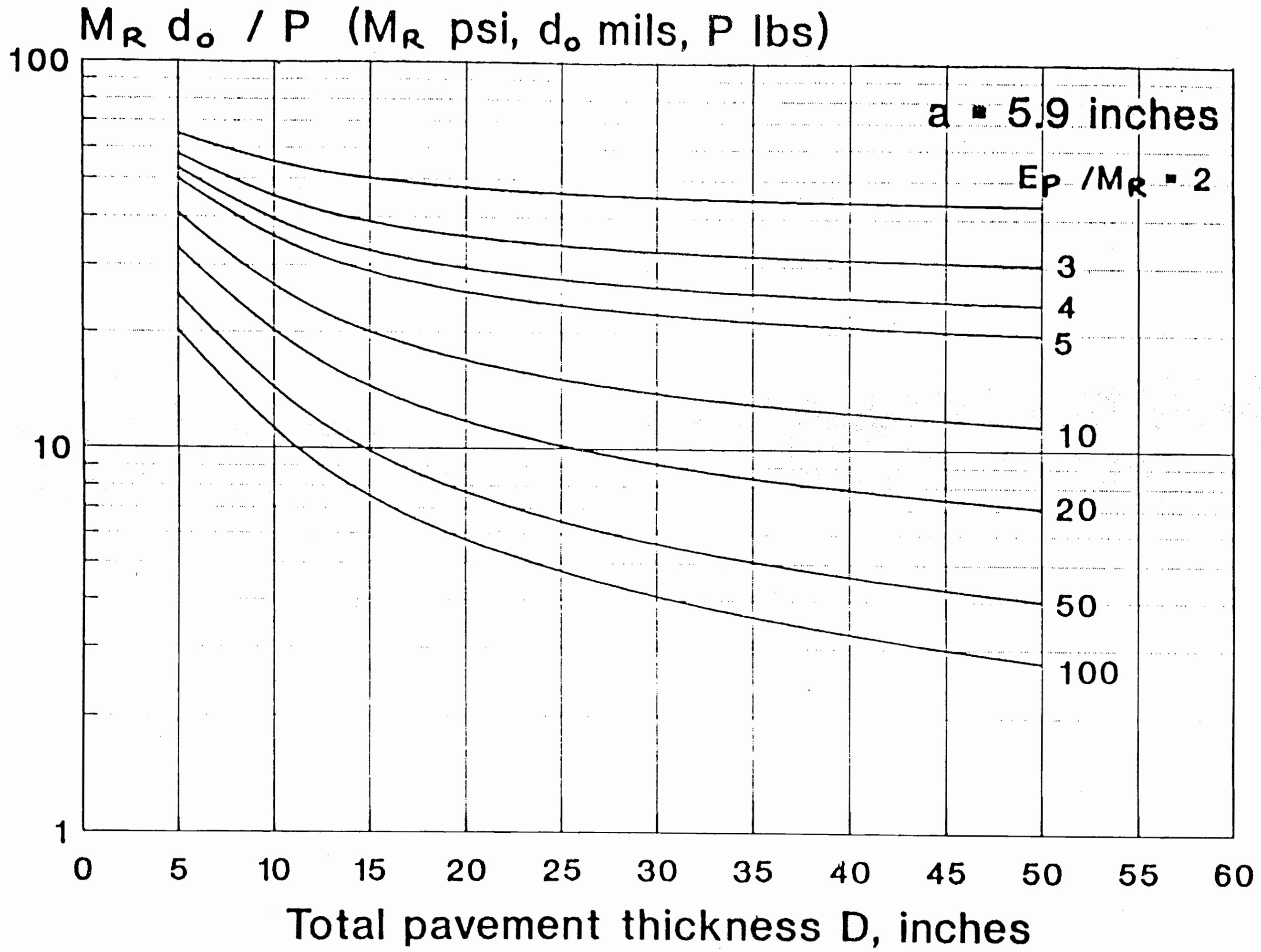


Figure 5.5. Determination of E_p/M_R

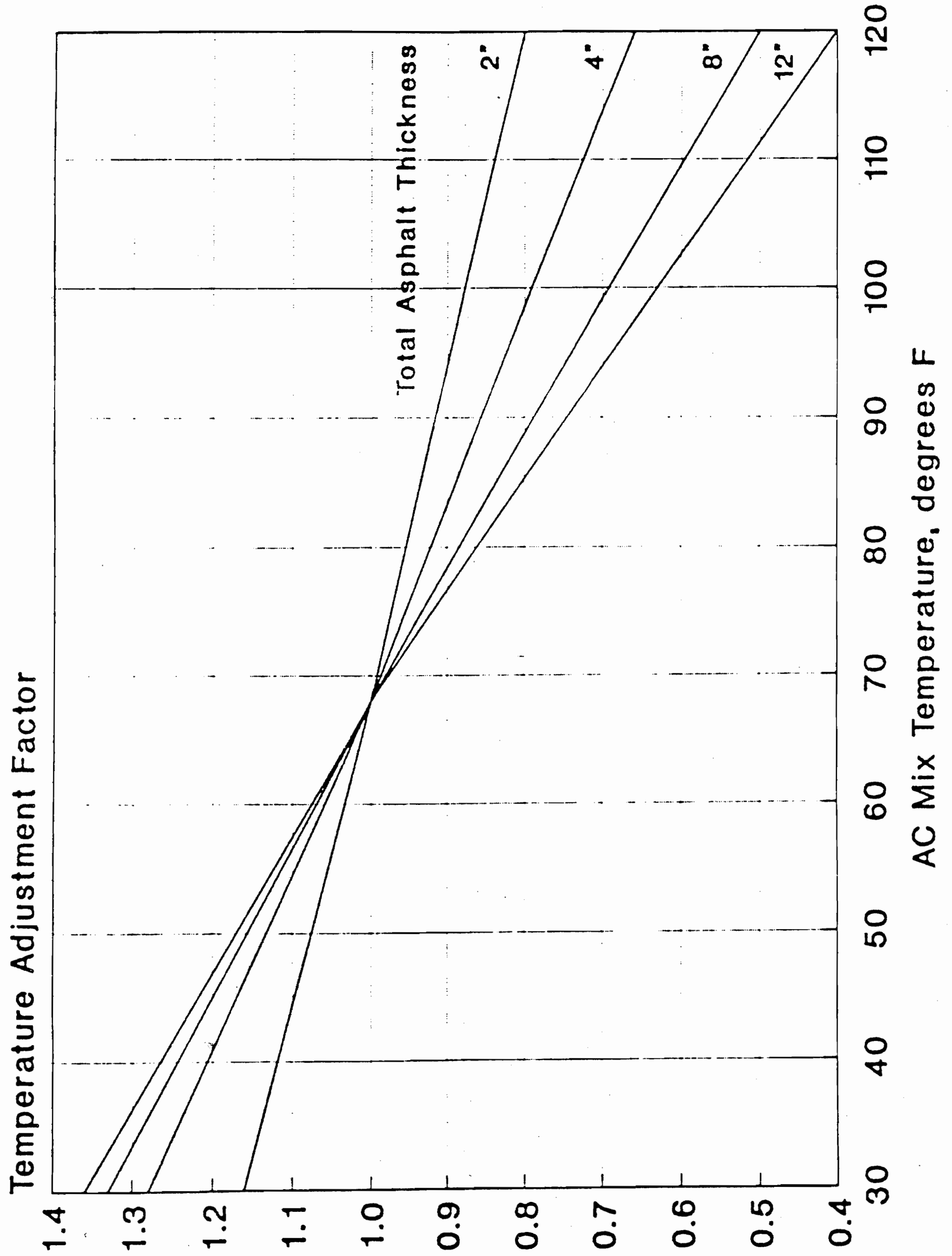


Figure 5.6. Adjustment to d_0 for AC Mix Temperature for Pavement with Granular or Asphalt-Treated Base

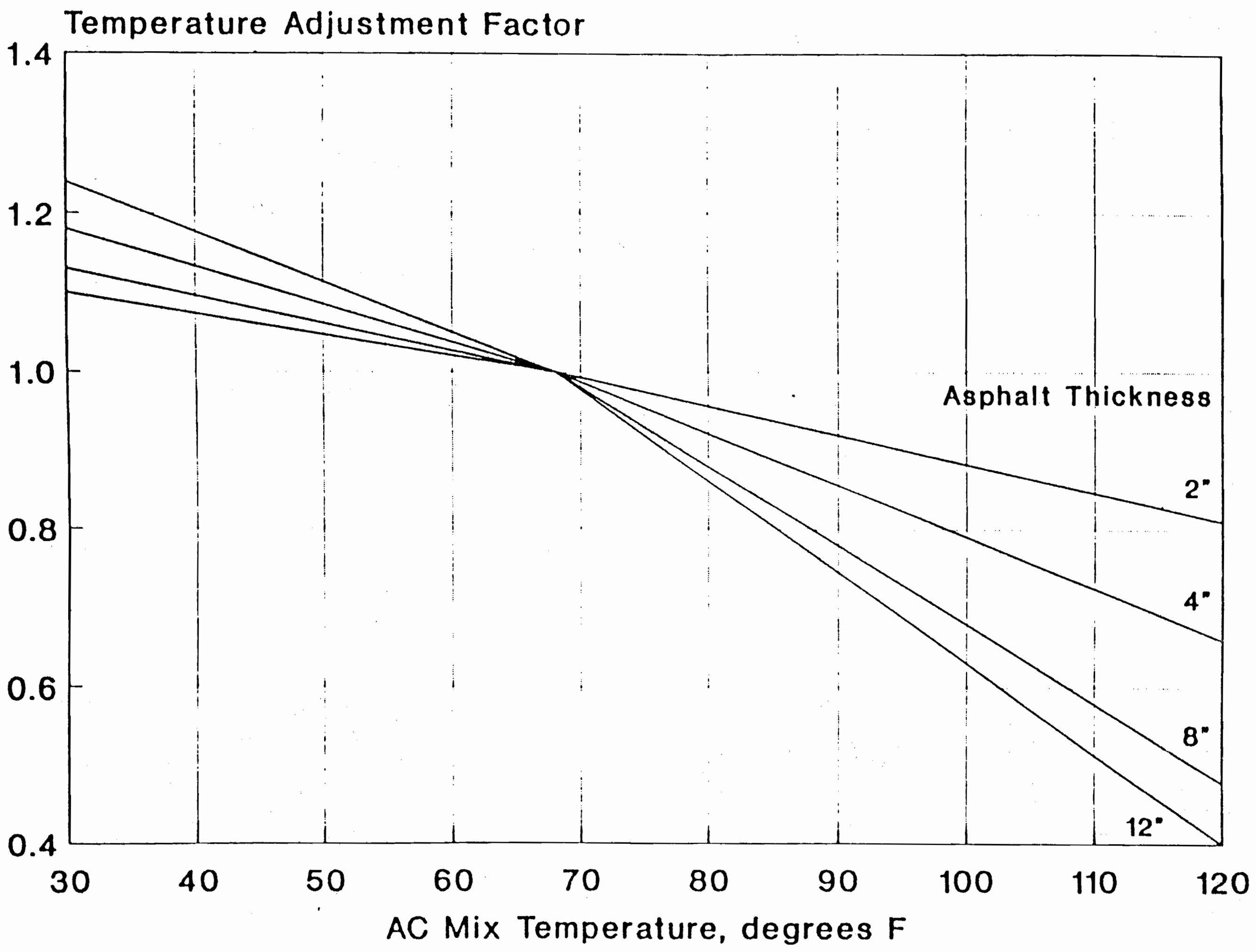


Figure 5.7. Adjustment to d_0 for AC mix Temperature for Pavement with Cement- or Pozzolanic-Treated Base

(3) *Samples of granular base and subbase* should be visually examined and a gradation run to assess degradation and contamination by fines.

(4) *The thickness of all layers* should be measured.

Step 6: Determination of required structural number for future traffic (SN_f).

(1) *Effective design subgrade resilient modulus.* Determine by one of the following methods:
   - (a) Laboratory testing described in Step 5.
   - (b) Backcalculation from deflection data. (NOTE: this value must be adjusted to be consistent with the value used in the AASHTO flexible pavement design equation as described below.)
   - (c) A very approximate estimate can be made using available soil information and relationships developed from resilient modulus studies. However, if as-constructed soil data are used, the resilient modulus may have changed since construction due to changes in moisture content or other factors.

Regardless of the method used, the effective design subgrade resilient modulus must be (1) representative of the effects of seasonal variation and (2) consistent with the resilient modulus value used to represent the AASHO Road Test soil. A seasonal adjustment, when needed, may be made in accordance with the procedures described in Part II, Section 2.3.1. M_R values backcalculated from deflections must be adjusted to be consistent with the laboratory-measured value used for the AASHO Road Test soil in the development of the flexible pavement design equation. It is recommended that backcalculated M_R values be multiplied by a correction factor C = 0.33 for use in determination of SN_f for design purposes when an FWD load of approximately 9,000 pounds is used (*9*). This value should be evaluated and adjusted if needed by user agencies for their soil and deflection measurement equipment. Therefore, the following design M_R should be used to determine SN_f:

$$\text{Design } M_R = C\left(\frac{0.24P}{d_r r}\right)$$

where recommended C = 0.33

Note also that the presence of a very stiff layer (e.g., bedrock) within about 15 feet of the top of the subgrade may cause the backcalculated M_R to be high. When such a condition exists, a value less than 0.33 for C may be warranted (*9*).

The designer is cautioned against using a value of M_R that is too large. The value of M_R selected for design is extremely critical to the overlay thickness. The use of a value greater than 3,000 psi is an indication that the soil is stiffer than the silty-clay A-6 soil at the Road Test site, and consequently will provide increased support and extended pavement life.

(2) *Design PSI loss.* PSI immediately after overlay (P1) minus PSI at time of next rehabilitation (P2).

(3) *Overlay design reliability R (percent).* See Part I, Section 4.2, Part II, Table 2.2, and Part III, Section 5.2.15.

(4) *Overall standard deviation S_o for flexible pavement.* See Part I, Section 4.3.

Compute SN_f for the above design inputs using the flexible pavement design equation or nomograph in Part II, Figure 3.1. When designing an overlay thickness for a uniform pavement section, mean input values must be used. When designing an overlay thickness for specific points along the project, the data for that point must be used. A worksheet for determining SN_f is provided in Table 5.1.

Step 7: Determination of effective structural number (SN_{eff}) of the existing pavement.

Three methods are presented for determining the effective structural number of a conventional AC pavement: an NDT method, a condition survey method, and a remaining fatigue life method. It is suggested that the designer use all three of these to evaluate the pavement, and then select a value for SN_{eff} based on the results, using engineering judgment and the past experience of the agency.

SN_{eff} from NDT for AC Pavements

The NDT method of SN_{eff} determination follows an assumption that the structural capacity of the pavement is a function of its total thickness and overall stiffness. The relationship between SN_{eff}, thickness, and stiffness is:

Table 5.1. Worksheet for Determination of SN_f for AC Pavements

---

TRAFFIC:

Future 18-kip ESALs in design lane over
design period, N_f = ____________________

EFFECTIVE ROAD-BED SOIL RESILIENT MODULUS:

Design resilient modulus, M_R = ____________________ psi

(Adjusted for consistency with flexible pavement model and for seasonal variations. Typical design M_R is 2,000 to 10,000 psi for fine-grained soils, 10,000 to 20,000 for coarse-grained soils. The AASHO Road Test soil value used in the flexible pavement design equation was 3,000 psi.)

SERVICEABILITY LOSS:

Design PSI loss (P1 − P2) (1.2 to 2.5) = ____________________

DESIGN RELIABILITY:

Overlay design reliability, R (80 to 99 percent) = ____________________ percent

Overall standard deviation, S_o (typically 0.49) = ____________________

FUTURE STRUCTURAL CAPACITY:

Required structural number for future traffic is determined from flexible pavement design equation or nomograph in Part II, Figure 3.1.

SN_f = ____________________

$$SN_{eff} = 0.0045 D \sqrt[3]{E_p}$$

where

D = total thickness of all pavement layers above the subgrade, inches
E_p = effective modulus of pavement layers above the subgrade, psi

E_p may be backcalculated from deflection data as described in Step 4. Figure 5.8 may be used to determine SN_{eff} according to the above equation.

SN_{eff} from Condition Survey for AC Pavements

The condition survey method of SN_{eff} determination involves a component analysis using the structural number equation:

$$SN_{eff} = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

where

D_1, D_2, D_3 = thicknesses of existing pavement surface, base, and subbase layers
a_1, a_2, a_3 = corresponding structural layer coefficients
m_2, m_3 = drainage coefficients for granular base and subbase

See Part II, Table 2.4, for guidance in determining the drainage coefficients. In selecting values for m_2 and m_3, note that the poor drainage situation for the base and subbase at the AASHO Road Test would be given drainage coefficient values of 1.0.

Depending on the types and amounts of deterioration present, the layer coefficient values assigned to materials in in-service pavement should in most cases be less than the values that would be assigned to the same materials for new construction. An exception to

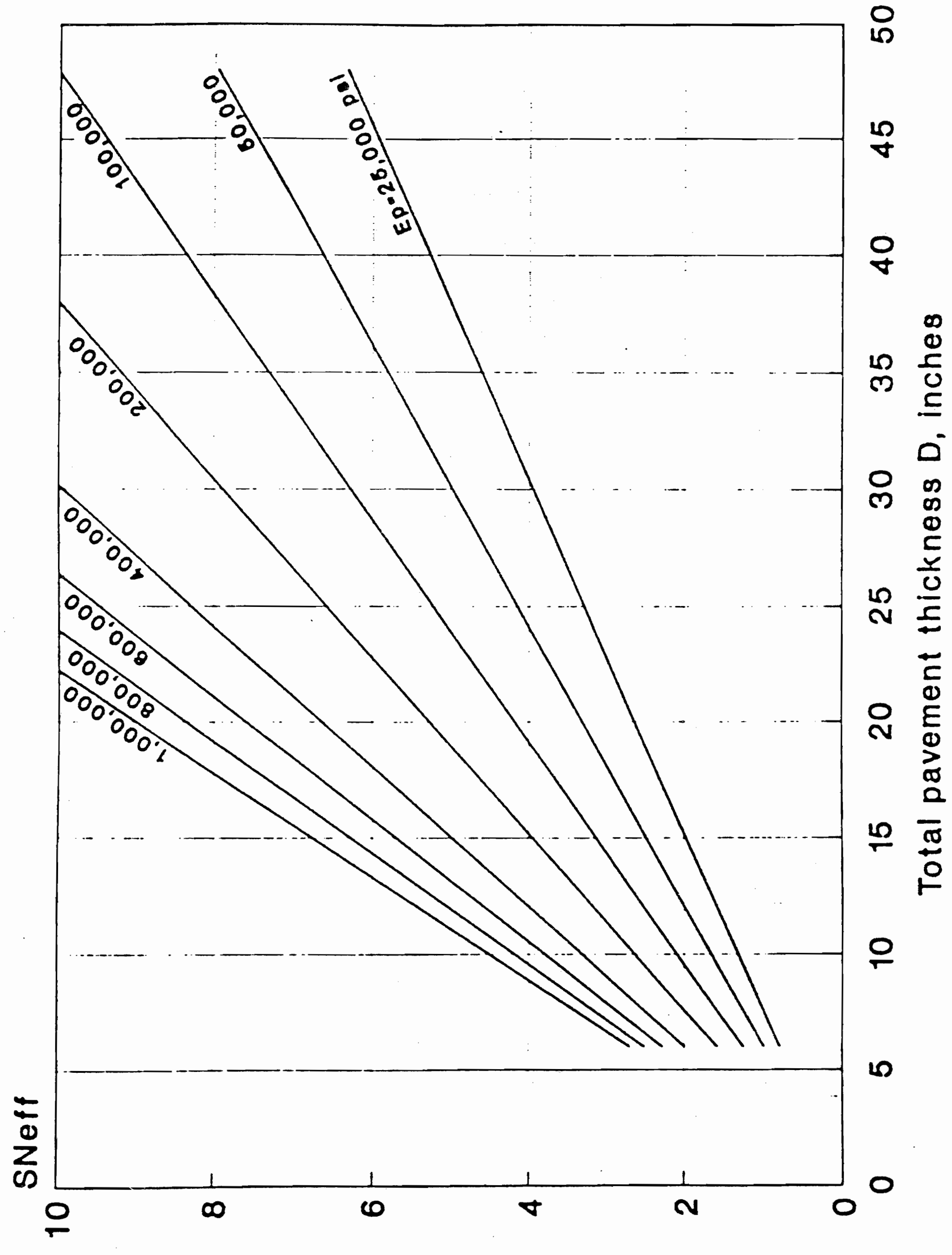


Figure 5.8. SN_{eff} from NDT Method

this general rule might be for unbound granular materials that show no sign of degradation or contamination.

For example, one State uses 0.44 for its new high-quality AC surface, but for overlay design purposes uses a reduced coefficient for the same material in an existing pavement. A value of 0.34 is assigned if the AC layer is in good condition, 0.25 if its condition is fair, and 0.15 if its condition is poor. The condition ratings are made on the basis of the amount of cracking present.

Limited guidance is presently available for the selection of layer coefficients for in-service pavement materials. Each agency must adopt its own set of values. Some suggested layer coefficients for existing materials are provided in Table 5.2.

The following notes apply to Table 5.2:

(1) All of the distress is as observed at the pavement surface.

(2) Patching all high-severity alligator cracking is recommended. The AC surface and stabilized base layer coefficients selected should reflect the amount of high-severity cracking remaining after patching.

(3) In addition to evidence of pumping noted during condition survey, samples of base material should be obtained and examined for evidence of erosion, degradation and contamination by fines, as well as evaluated for drainability, and layer coefficients reduced accordingly.

(4) The percentage of transverse cracking is determined as (linear feet of cracking/square feet of pavement) * 100.

(5) Coring and testing are recommended for evaluation of all materials and are strongly recommended for evaluation of stabilized layers.

(6) There may be other types of distress that, in the opinion of the engineer, would detract from the performance of an overlay. These should be considered through an appropriate decrease of the structural coefficient of the layer exhibiting the distress (e.g., surface raveling of the AC, stripping of an AC layer, freeze-thaw damage to a cement-treated base).

SN_{eff} from Remaining Life for AC Pavements

The remaining life of the pavement is given by the following equation:

$$RL = 100\left[1 - \left(\frac{N_p}{N_{1.5}}\right)\right]$$

where

RL = remaining life, percent
N_p = total traffic to date, ESALs
$N_{1.5}$ = total traffic to pavement "failure," ESALs

$N_{1.5}$ may be estimated using the new pavement design equations or nomographs in Part II. To be consistent with the AASHO Road Test and the development of these equations, a "failure" PSI equal to 1.5 and a reliability of 50 percent is recommended.

SN_{eff} is determined from the following equation:

$$SN_{eff} = CF * SN_o$$

where

CF = condition factor determined from Figure 5.2
SN_o = structural number of the pavement if it were newly constructed

The designer should recognize that SN_{eff} determined by this method does not reflect any benefit for pre-overlay repair. The estimate of SN_{eff} obtained should thus be considered a lower limit value. The SN_{eff} of the pavement will be higher if pre-overlay repair of load-associated distress (alligator cracking) is done. This method for determining SN_{eff} is not applicable, without modification, to AC pavements which have already received one or more AC overlays.

A worksheet for determination of SN_{eff} is provided in Table 5.3.

Step 8: Determination of overlay thickness.

The thickness of AC overlay is computed as follows:

$$D_{ol} = \frac{SN_{ol}}{a_{ol}} = \frac{(SN_f - SN_{eff})}{a_{ol}}$$

where

SN_{ol} = Required overlay structural number
a_{ol} = Structural coefficient for the AC overlay
D_{ol} = Required overlay thickness, inches
SN_f = Structural number determined in Step 6

Table 5.2. Suggested Layer Coefficients for Existing AC Pavement Layer Materials

MATERIAL	SURFACE CONDITION	COEFFICIENT
AC Surface	Little or no alligator cracking and/or only low-severity transverse cracking	0.35 to 0.40
	< 10 percent low-severity alligator cracking and/or < 5 percent medium- and high-severity transverse cracking	0.25 to 0.35
	> 10 percent low-severity alligator cracking and/or < 10 percent medium-severity alligator cracking and/or > 5-10 percent medium- and high-severity transverse cracking	0.20 to 0.30
	> 10 percent medium-severity alligator cracking and/or < 10 percent high-severity alligator cracking and/or > 10 percent medium- and high-severity transverse cracking	0.14 to 0.20
	> 10 percent high-severity alligator cracking and/or > 10 percent high-severity transverse cracking	0.08 to 0.15
Stabilized Base	Little or no alligator cracking and/or only low-severity transverse cracking	0.20 to 0.35
	< 10 percent low-severity alligator cracking and/or < 5 percent medium- and high-severity transverse cracking	0.15 to 0.25
	> 10 percent low-severity alligator cracking and/or < 10 percent medium-severity alligator cracking and/or > 5-10 percent medium- and high-severity transverse cracking	0.15 to 0.20
	> 10 percent medium-severity alligator cracking and/or < 10 percent high-severity alligator cracking and/or > 10 percent medium- and high-severity transverse cracking	0.10 to 0.20
	> 10 percent high-severity alligator cracking and/or > 10 percent high-severity transverse cracking	0.08 to 0.15
Granular Base or Subbase	No evidence of pumping, degradation, or contamination by fines	0.10 to 0.14
	Some evidence of pumping, degradation, or contamination by fines	0.00 to 0.10

SN_{eff} = Effective structural number of the existing pavement, from Step 7

The thickness of overlay determined from the above relationship should be reasonable when the overlay is required to correct a structural deficiency. See Section 5.2.17 for discussion of factors which may result in unreasonable overlay thicknesses.

5.4.6 Surface Milling

If the AC pavement is to be milled prior to overlay, the depth of milling must be reflected in the SN_{eff} analyses. No adjustment need be made to SN_{eff} values determined by NDT if the depth of milling does not exceed the minimum necessary to remove surface ruts. If a greater depth is milled, the NDT-determined SN_{eff} may be reduced by an amount equal to the depth milled times a structural coefficient for the AC surface based on the condition survey.

5.4.7 Shoulders

See Section 5.2.10 for guidelines.

Table 5.3. Worksheet for Determination of SN_{eff} for AC Pavement

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(1) **NDT Method For SN_{eff} For AC Pavement:**

Total thickness of all pavement layers above subgrade, D = ______________ inches

Backcalculated subgrade resilient modulus, M_R = ______________ psi

Backcalculated effective pavement modulus, E_p = ______________ psi

$$SN_{eff} = 0.0045D\sqrt[3]{E_p} = \underline{\qquad\qquad\qquad}$$

(2) **Condition Survey Method For SN_{eff} For AC Pavement:**

Thickness of AC surface, D_1 = ______________ inches

Structural coefficient of AC surface, a_1, based on condition survey and coring data = ______________

Thickness of base, D_2 = ______________ inches

Structural coefficient of base, a_2, based on condition survey, material inspection, and testing = ______________

Drainage coefficient of base, m_2 = ______________

Thickness of subbase, D_3, if present = ______________ inches

Structural coefficient of subbase, a_3, based on condition survey, material inspection, and testing = ______________

Drainage coefficient of subbase, m_3 = ______________

$$SN_{eff} = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 = \underline{\qquad\qquad\qquad}$$

5.4.8 Widening

See Section 5.2.16 for guidelines.

5.5 AC OVERLAY OF FRACTURED PCC SLAB PAVEMENT

This section covers the design of AC overlays placed on PCC pavements after they have been fractured by any of the following techniques: break/seat, crack/seat or rubblize/compact.

Break/seat consists of breaking a JRCP into pieces larger than about one foot, rupturing the reinforcement or breaking its bond with the concrete, and seating the pieces firmly into the foundation.

Crack/seat consists of cracking a JPCP into pieces typically one to three feet in size and seating the pieces firmly into the foundation.

Seating typically consists of several passes of a 35- to 50-ton rubber-tired roller over a cracked or broken slab.

Rubblize/compact consists of completely fracturing any type of PCC slab (JRCP, JPCP, or CRCP) into pieces smaller than one foot and then compacting the layer, typically with two or more passes of a 10-ton vibratory roller.

The following construction tasks are involved in the placement of an AC overlay on a fractured PCC slab pavement:

(1) Removing and replacing areas that will result in uneven support after fracturing
(2) Making subdrainage improvements if needed

Table 5.3. Worksheet for Determination of SN_{eff} for AC Pavement (continued)

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(3) **Remaining Life Method For SN_{eff} for AC Pavement:**

Past 18-kip ESALs in design lane since construction, N_p = ____________________

18-kip ESALs to failure of existing design, $N_{1.5}$ = ____________________

$$RL = 100\left[1 - \left(\frac{N_p}{N_{1.5}}\right)\right] = \underline{\hspace{6cm}}$$

Condition factor, CF (Figure 5.2) = ____________________

Thickness of AC surface, D_1 = ____________________ inches

Structural coefficient of AC surface, a_1, if newly constructed = ____________________

Thickness of base, D_2 = ____________________ inches

Structural coefficient of base, a_2, if newly constructed = ____________________

Thickness of subbase, D_3, if present = ____________________ inches

Structural coefficient of subbase, a_3, if newly constructed = ____________________

$$SN_o = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 = \underline{\hspace{6cm}}$$

$$SN_{eff} = CF * SN_o = \underline{\hspace{6cm}}$$

---

(3) Breaking and seating, crack and seating or rubblizing the PCC slab and rolling to seat or compact
(4) Constructing widening if needed
(5) Applying a tack or prime coat
(6) Placing the AC overlay (including a reflection crack control treatment if needed)

5.5.1 Feasibility

Break/seat, crack/seat and rubblizing techniques are used to reduce the size of PCC pieces to minimize the differential movements at existing cracks and joints, thereby minimizing the occurrence and severity of reflection cracks. The feasibility of each technique is described below.

Rubblizing can be used on all types of PCC pavements in any condition. It is particularly recommended for reinforced pavements. Fracturing the slab into pieces less than 12 inches reduces the slab to a high-strength granular base. Recent field testing of several rubblized projects showed a wide range in backcalculated modulus values among different projects, from less than 100,000 psi to several hundred thousand psi (*16, 17, 18*), and within-project coefficients of variation of as much as 40 percent (*16, 18*).

Crack and seat is used only with JPCP and involves cracking the slab into pieces typically one to three feet in size. Recent field testing of several cracked and seated JPCP projects showed a wide range in backcalculated modulus values among different projects, from a few hundred thousand psi to a few million psi (*16, 19, 20, 21, 22*), and within-project coefficients of variation of 40 percent or more (*16*). Reference 16 recommends that to avoid reflection cracking no more than 5 percent of the fractured slab have a modulus greater than 1 million psi. Effective slab cracking techniques are necessary in order to satisfy this criterion for crack/seat of JPCP.

Break/seat is used only with JRCP and includes the requirement to rupture the reinforcement steel across each crack, or break its bond with the concrete. If the reinforcement is not ruptured and its bond with the concrete is not broken, the differential movements at working joints and cracks will not be reduced and reflection cracks will occur. Recent field testing of several break/seat projects showed a wide range in backcalculated modulus values ranging from a few hundred thousand psi to several million psi (*16, 18, 19, 22*), and within-project coefficients of variation of 40 percent or more (*16, 18*). The wide range in backcalculated moduli reported for break and seat projects suggests a lack of consistency in the technique as performed with past construction equipment. Even though cracks are observed, the JRCP frequently retains a substantial degree of slab action because of failure to either rupture the reinforcing steel or break its bond with the concrete. This may also be responsible for the inconsistency of this technique in reducing reflection cracking. More effective breaking equipment may overcome this problem. This design procedure assumes that the steel will be ruptured or that its bond to the concrete will be broken through an aggressive break/seat process, and that this will be verified in the field through deflection testing before the overlay is placed. The use of rubblization is recommended for JRCP due to its ability to break slab continuity.

These slab fracturing techniques are generally more cost-effective on more deteriorated concrete pavements than on less deteriorated concrete pavements. This is due to the trade-off between the reduction in the amount of pre-overlay repair required for working cracks and deteriorated joints, and the cost of slab fracturing and increased overlay thickness required (*1, 22*).

5.5.2 Pre-overlay Repair

The amount of preoverlay repair needed for break/seat, crack/seat and rubblized projects is not clear. Most projects done prior to 1991 have not included a significant amount of repair. However, the recommended approach is to repair any condition that may provide nonuniform support after the fracturing process so that it will not rapidly reflect through the AC overlay. Also, some AC leveling may be needed for settled areas before the overlay is placed.

5.5.3 Reflection Crack Control

Slab fracturing techniques were developed as methods of reflection crack control. When properly constructed, the crack/seat and rubblizing methods are reasonably effective and should require no additional crack control treatment. However, care must be exercised to assure uniform cracking or rubblizing across the slab width and to firmly seat the cracked slab or compact the rubble. At least one agency that has used crack/seat of JPCP successfully for several years specifies that a fabric be placed in the overlay to aid in controlling reflection cracking. For break/seat of JRCP, reflective cracks will develop if the steel reinforcement is not ruptured and its bond to the concrete is not broken, and if this cannot be guaranteed, it is recommended that JRCP be rubblized.

5.5.4 Subdrainage

See Section 5.2.4 for guidelines. Rubblizing PCC pavement produces fines which may clog the filter materials placed in edge drains. This should be considered in the design of the filter materials. If longitudinal subdrains are to be installed, this should be done prior to fracturing the slab.

5.5.5 Thickness Design

The required thickness of the overlay is a function of the structural capacity required to meet future traffic demands and the structural capacity of the existing slab after fracturing. The required thickness is determined by the following equation:

$$SN_{ol} = a_{ol} * D_{ol} = SN_f - SN_{eff}$$

where

SN_{ol} = Required overlay structural number
a_{ol} = Structural coefficient for the AC overlay
D_{ol} = Required overlay thickness, inches
SN_f = Structural number required to carry future traffic
SN_{eff} = Effective structural number of the existing pavement after fracturing

The required overlay thickness is determined through the following design steps.

Step 1: Existing pavement design and construction.

(1) Thickness and material type of each pavement layer
(2) Available subgrade soil information (from construction records, soil surveys, county agricultural soils reports, etc.)

Step 2: Traffic analysis.

(1) Predicted future 18-kip ESALs in the design lane over the design period (N_f)

Use flexible pavement equivalency factors. If available future traffic estimates are in terms of rigid pavement ESALs, they must be converted to flexible pavement ESALs by dividing by 1.5 (e.g., 15 million rigid pavement ESALs approximately equal 10 million flexible pavement ESALs).

Step 3: Condition survey.

Condition survey data are not used in the determination of overlay thickness. However, condition survey data should be used to determine whether or not fracturing is cost-effective compared to other types of rehabilitation.

Step 4: Deflection testing (recommended).

Deflection measurements are used only for the determination of the design subgrade resilient modulus. Deflections should be measured on the bare PCC slab surface (prior to fracturing) at midslab locations that are not cracked. A heavy-load deflection device (e.g., Falling Weight Deflectometer) and a load magnitude of approximately 9,000 pounds are recommended. ASTM D 4694 and D 4695 provide additional guidance on deflection testing. A deflection measurement at a distance of approximately 4 feet from the center of load is needed.

(1) Subgrade resilient modulus (M_R). At sufficiently large distances from the load, deflections measured at the pavement surface are due to subgrade deformation only, and are also independent of the size of the load plate. This permits the backcalculation of the subgrade resilient modulus from a single deflection measurement and load magnitude, using the following equation.

$$M_R = \frac{0.24P}{d_r r}$$

where

M_R = backcalculated subgrade resilient modulus, psi
P = applied load, pounds
d_r = deflection at a distance r from the center of the load, inches
r = distance from center of load, inches

The deflection used to backcalculate the subgrade modulus must be measured far enough away that it provides a good estimate of the subgrade modulus, independent of the effects of any layers above, but also close enough that it is not too small to measure accurately. The minimum distance may be determined from the following relationship:

$$r \geq 0.7a_e$$

where

$$a_e = \sqrt{\left[a^2 + \left(D\sqrt[3]{\frac{E_p}{M_R}}\right)^2\right]}$$

a_e = radius of the stress bulb at the subgrade-pavement interface, inches
a = NDT load plate radius, inches
D = total thickness of pavement layers above the subgrade, inches
E_p = effective modulus of all pavement layers above the subgrade, psi (described below)

Before the backcalculated M_R value is used in design, it must be adjusted to make it consistent with the value used in the AASHTO flexible pavement design equation. An adjustment may also be needed to account for seasonal effects. These adjustments are described in Step 6.

(2) Effective modulus of the pavement (E_p). If the subgrade resilient modulus and total thickness of all layers above the subgrade are known or assumed, the effective modulus of the entire pavement structure (all pavement layers above the subgrade) may be determined from the deflection measured at the center of the load plate using the following equation:

$$d_0 = 1.5pa\left\{\frac{1}{M_R\sqrt{1 + \left(\frac{D}{a}\sqrt[3]{\frac{E_p}{M_R}}\right)^2}} + \frac{\left[1 - \frac{1}{\sqrt{1 + \left(\frac{D}{a}\right)^2}}\right]}{E_p}\right\}$$

where

d_0 = deflection measured at the center of the load plate, inches
p = NDT load plate pressure, psi
a = NDT load plate radius, inches
D = total thickness of pavement layers above the subgrade, inches
M_R = subgrade resilient modulus, psi
E_p = effective modulus of all pavement layers above the subgrade, psi

For a load plate radius of 5.9 inches, Figure 5.5 may be used to determine the ratio E_p/M_R, and E_p may then be determined for a known or assumed value of M_R.

Deflection measurements are also useful after the break/seat or crack/seat operations to insure that the slab has been sufficiently fractured (*16*).

Step 5: Coring and material testing.

(1) *Resilient modulus of subgrade.* If deflection testing is not performed, laboratory testing of samples of the subgrade may be conducted to determine its resilient modulus using AASHTO T 292-91 I with a deviator stress of 6 psi to match the deviator stress used in establishing the 3,000 psi for the AASHO Road Test soil that is incorporated into the flexible design equation. Alternatively, other tests such as R value, CBR or soil classification tests could be conducted and approximate correlations used to estimate resilient modulus. Use of the estimating equation $M_R = 1500 * \text{CBR}$ may produce a value that is too large for use in this design procedure. The relationships found in Appendix FF, Figure FF-6 may be more reasonable.

(2) *Samples of base layers* should be examined to assess degradation and contamination by fines.

Step 6: Determination of required structural number for future traffic (SN_f).

(1) Effective design subgrade resilient modulus. Determine by one of the following methods:

(a) Laboratory testing as described in Step 5.

(b) Backcalculation from deflection data. (NOTE: this value must be adjusted to be consistent with the value used in the AASHTO flexible pavement design equation as described below.)

(c) A very approximate estimate can be made using available soil information and relationships developed from resilient modulus studies. However, if as-built records are used, it should be noted that the resilient modulus may have changed since construction due to changes in moisture content or other factors.

Regardless of the method used, the effective design subgrade resilient modulus must be (1) representative of the effects of seasonal variation and (2) consistent with the resilient modulus value used to represent the AASHO Road Test soil. A seasonal adjustment, when needed, may be made in accordance with the procedures described in Part II, Section 2.3.1. M_R values backcalculated from deflections must be adjusted to make the values consistent with the laboratory-measured value used for the AASHO Road Test soil in the development of the flexible pavement design equation. For conventional AC pavements, it was recommended that backcalculated M_R values be multiplied by a correction factor C = 0.33 for use in determination of SN_f for design purposes when a FWD load of approximately 9,000 pounds is used (*9*). However, because subgrade stresses are much lower under a PCC slab than under a flexible pavement, it is recommended that a smaller correction factor, C = 0.25, be used to provide a better estimate of the subgrade M_R. This value should be evaluated and adjusted if needed by user agencies for their soil and deflection measurement equipment. The following design M_R is recommended for use in determining the SN_f for fractured slabs when deflection testing is done on top of the PCC slab:

$$\text{Design } M_R = C\left(\frac{0.24P}{d_r r}\right)$$

where recommended C = 0.25.

NOTE also that the presence of a very stiff layer (e.g., bedrock) within about 15 feet of the top of the subgrade may cause the back-calculated M_R to be high. When such a condition exists, a value less than 0.25 for C may be warranted (*8, 9*).

The designer is cautioned against using a value of M_R that is too large. The value of M_R selected for design is extremely critical to the overlay thickness. The use of a value greater than 3,000 psi is an indication that the soil is stiffer than the silty-clay A-6 soil at the Road Test site, and consequently will provide increased support and extended pavement life.

(2) *Design PSI loss.* PSI immediately after overlay (P1) minus PSI at time of next rehabilitation (P2).

(3) *Overlay design reliability R (percent).* See Part I, Section 4.2, Part II, Table 2.2, and Part III, Section 5.2.15.

(4) *Overall standard deviation S_o for flexible pavement.* See Part I, Section 4.3.

Compute SN_f for the above design inputs using the flexible pavement design equation or nomograph in Part II, Figure 3.1. When designing an overlay thickness for a uniform pavement section, mean input values must be used. When designing an overlay thickness for specific points along the project, the data for that point must be used. A worksheet for determining SN_f is provided in Table 5.4.

Step 7: Determination of effective structural number (SN_{eff}) of the existing fractured slab pavement.

SN_{eff} is determined by component analysis using the structural number equation:

$$SN_{eff} = a_2 D_2 m_2 + a_3 D_3 m_3$$

where

D_2, D_3 = thicknesses of fractured slab and base layers
a_2, a_3 = corresponding structural layer coefficients
m_2, m_3 = drainage coefficients for fractured PCC and granular subbase

See Part II, Table 2.4, for guidance in determining the drainage coefficients. Due to lack of information on drainage characteristics of fractured PCC, a default value of 1.0 for m_2 is recommended. In selecting values for m_3, note that the poor drainage situation for the base and subbase at the AASHO Road Test would be given drainage coefficient values of 1.0.

Suggested layer coefficients for fractured slab pavements are provided in Table 5.5. Each agency should adopt its own set of layer coefficient values for fractured slabs keyed to its construction results on its pavements.

Since the layer coefficient represents the overall performance contribution of that layer, it is likely that it is not related solely to the modulus of that layer, but to other properties as well, such as the load transfer capability of the pieces. The large variability of layer moduli within a project is also of concern. This extra variability should ideally be expressed in an increased overall standard deviation in designing for a given reliability level.

A worksheet for determination of SN_{eff} is provided in Table 5.6.

Step 8: Determination of overlay thickness.

The thickness of AC overlay is computed as follows:

$$D_{ol} = \frac{SN_{ol}}{a_{ol}} = \frac{(SN_f - SN_{eff})}{a_{ol}}$$

where

SN_{ol} = Required overlay structural number
a_{ol} = Structural coefficient for the AC overlay
D_{ol} = Required AC overlay thickness, inches
SN_f = Structural number determined in Step 6
SN_{eff} = Effective structural number of the existing pavement, from Step 7

The thickness of overlay determined from the above relationship should be reasonable when the overlay is required to correct a structural deficiency. See Section 5.2.17 for discussion of factors which may result in unreasonable overlay thicknesses.

5.5.6 Shoulders

See Section 5.2.10 for guidelines.

5.5.7 Widening

See Section 5.2.16 for guidelines.

Table 5.4. Worksheet for Determination of SN_f for Fractured Slab Pavements

TRAFFIC:

Future 18-kip ESALs in design lane over design period, N_f = ____________________

EFFECTIVE ROADBED SOIL RESILIENT MODULUS:

Design resilient modulus, M_R = ____________________ psi

(Adjusted for consistency with flexible pavement model and for seasonal variations. Typical design M_R is 2,000 to 10,000 psi for fine-grained soils, 10,000 to 20,000 for coarse-grained soils. The AASHO Road Test soil value used in the flexible pavement design equation was 3,000 psi.)

SERVICEABILITY LOSS:

Design PSI loss (P1 − P2) (1.2 to 2.5) = ____________________

DESIGN RELIABILITY:

Overlay design reliability, R (80 to 99 percent) = ____________________ percent

Overall standard deviation, S_o (typically 0.49) = ____________________

FUTURE STRUCTURAL CAPACITY:

Required structural number for future traffic is determined from flexible pavement design equation or nomograph in Part II, Figure 3.1.

SN_f = ____________________

Table 5.5. Suggested Layer Coefficients for Fractured Slab Pavements

MATERIAL	SLAB CONDITION	COEFFICIENT
Break/Seat JRCP	Pieces greater than one foot with ruptured reinforcement or steel/concrete bond broken	0.20 to 0.35
Crack/Seat JPCP	Pieces one to three feet	0.20 to 0.35
Rubblized PCC (any pavement type)	Completely fractured slab with pieces less than one foot	0.14 to 0.30
Base/subbase granular and stabilized	No evidence of degradation or intrusion of fines Some evidence of degradation or intrusion of fines	0.10 to 0.14 0.00 to 0.10

Table 5.6. Worksheet for Determination of SN_{eff} for Break/Seat, Crack/Seat and Rubblized Pavements

Thickness of break/crack or rubblized PCC, D_2 = ______________ inches

Structural coefficient of break/crack/seat or rubblized PCC, a_2 = ______________

Drainage coefficient of fractured slab, m_2 (1.0 recommended) = ______________

Thickness of subbase, D_3, if present = ______________ inches

Structural coefficient of subbase, a_3 = ______________

Drainage coefficient of subbase, m_3 = ______________

$SN_{eff} = a_2D_2m_2 + a_3D_3m_3$ = ______________

5.6 AC OVERLAY OF JPCP, JRCP, AND CRCP

This section covers the design of AC overlays of existing JPCP, JRCP, or CRCP. This section may also be used to design an AC overlay if a previous AC overlay is completely removed.

Construction of an AC overlay over JPCP, JRCP, or CRCP consists of the following major activities:

1. Repairing deteriorated areas and making subdrainage improvements (if needed).
2. Constructing widening (if needed).
3. Applying a tack coat.
4. Placing the AC overlay, including a reflection crack control treatment (if needed).

5.6.1 Feasibility

An AC overlay is a feasible rehabilitation alternative for PCC pavements except when the condition of the existing pavement dictates substantial removal and replacement. Conditions under which an AC overlay would not be feasible include:

1. The amount of deteriorated slab cracking and joint spalling is so great that complete removal and replacement of the existing surface is dictated.
2. Significant deterioration of the PCC slab has occurred due to severe durability problems (e.g., "D" cracking or reactive aggregates).
3. Vertical clearance at bridges is inadequate for required overlay thickness. This may be addressed by reducing the overlay thickness under the bridges (although this may result in early failure at these locations), by raising the bridges, or by reconstructing the pavement under the bridges. Thicker AC overlays may also necessitate raising signs and guardrails, as well as increasing side slopes and extending culverts. Sufficient right-of-way must be available or obtainable to permit these activities.

5.6.2 Preoverlay Repair

The following types of distress in JPCP, JRCP, and CRCP should be repaired prior to placement of an AC overlay.

Distress Type	Repair Type
Working cracks	Full-depth repair or slab replacement
Punchouts	Full-depth PCC repair
Spalled joints	Full-depth or partial-depth repair
Deteriorated repairs	Full-depth repair
Pumping/faulting	Edge drains
Settlements/heaves	AC level-up, slab jacking, or localized reconstruction

Full-depth repairs and slab replacements in JPCP and JRCP should be PCC, dowelled or tied to provide load transfer across repair joints. Some agencies have placed full-depth AC repairs in JPCP and JRCP prior to an AC overlay. However, this has often resulted in rough spots in the overlay, opening of nearby joints and cracks, and rapid deterioration of reflection cracks at AC patch boundaries. (See Part III, Section 4.3.1 and References 1 and 3.)

Full-depth repairs in CRCP should be PCC and should be continuously reinforced with steel which is tied or welded to reinforcing steel in the existing slab to provide load transfer across joints and slab continuity. Full-depth AC repairs should not be used in CRCP prior to placement of an AC overlay, and any existing AC patches in CRCP should be removed and replaced with continuously reinforced PCC. Guidelines on repairs are provided in References 1 and 3.

Installation of edge drains, maintenance of existing edge drains, or other subdrainage improvement should be done prior to placement of the overlay if a subdrainage evaluation indicates a need for such an improvement.

Pressure relief joints should be placed only at fixed structures, and not at regular intervals along the pavement. The only exception to this is where reactive aggregate has caused expansion of the slab. On heavily trafficked routes, pressure relief joints should be of heavy-duty design with dowels (*3*). If joints contain significant incompressibles, they should be cleaned and resealed prior to placement of the overlay.

5.6.3 Reflection Crack Control

The basic mechanism of reflection cracking is strain concentration in the overlay due to movement in the vicinity of joints and cracks in the existing pavement. This movement may be bending or shear induced by loads, or may be horizontal contraction induced by temperature changes. Load-induced movements are influenced by the thickness of the overlay and the thickness and stiffness of the existing pavement. Temperature-induced movements are influenced by daily and seasonal temperature variations, the coefficient of thermal expansion of the existing pavement, and the spacing of joints and cracks.

In an AC overlay of JPCP or JRCP, reflection cracks typically develop relatively soon after the overlay is placed (often in less than a year). The rate at which they deteriorate depends on the factors listed above as well as the traffic level. Thorough repair of deteriorated joints and working cracks with full-depth dowelled or tied PCC repairs reduces the rate of reflection crack occurrence and deterioration, so long as good load transfer is obtained at the full-depth repair joints. Other preoverlay repair efforts which will discourage reflection crack occurrence and subsequent deterioration include subdrainage improvement, subsealing slabs which have lost support, and restoring load transfer at joints and cracks with dowels grouted in slots.

A variety of reflection crack control measures have been used in attempts to control the rates of reflection crack occurrence and deterioration. Any one of the following treatments may be employed in an effort to control reflection cracking in an AC overlay of JPCP or JRCP:

(1) *Sawing and sealing joints in the AC overlay* at locations coinciding with joints in the underlying JPCP or JRCP. This technique has been very successful when applied to AC overlays of jointed PCC pavements when the sawcut matches the joint or straight crack within an inch.

(2) *Increasing AC overlay thickness.* Reflection cracks will take more time to propagate through a thicker overlay and deteriorate more slowly.

(3) *Placing a bituminous-stabilized granular interlayer (large-sized large stone), prior to or in combination with placement of the AC overlay* has been effective.

(4) *Placing a synthetic fabric or a stress-absorbing interlayer prior to or within the AC overlay.* The effectiveness of this technique is questionable.

(5) *Rubblizing and compacting JPCP, JRCP, or CRCP* prior to placement of the AC overlay. This technique reduces the size of PCC pieces to a maximum of about 12 inches and essentially reduces the slab to a high-strength granular base course. See Section 5.5 for the design procedure for AC overlays of rubblized PCC pavement.

(6) *Cracking and seating JPCP or breaking and seating JRCP* prior to placement of the AC overlay. This technique reduces the size of PCC pieces and seats them in the underlying base, which reduces horizontal (and possibly vertical) movements at cracks. See Section 5.5 for the design procedure for AC overlays of crack/seat JPCP and break/seat JRCP.

Reflection cracking can have a considerable (often controlling) influence on the life of an AC overlay of JPCP or JRCP. Deteriorated reflection cracks detract from a pavement's serviceability and also require frequent maintenance, such as sealing, milling, and patching. Reflection cracks also permit water to enter the pavement structure, which may result in loss of bond between the AC and PCC, stripping in the AC, progression of "D" cracking or reactive aggregate distress in PCC slabs with these durability problems, and softening of the base and subgrade. For this reason, reflection cracks should be sealed as soon as they appear and resealed periodically throughout the life of the overlay. Sealing low-severity reflection cracks may also be effective in retarding their progression to medium and high severity levels.

With an AC overlay of CRCP, permanent repair of punchouts and working cracks with tied or welded reinforced PCC full-depth repairs will delay the occurrence and deterioration of reflection cracks. Improving subdrainage conditions and subsealing in areas where the slab has lost support will also discourage reflection crack occurrence and deterioration. Reflection crack control treatments are not necessary for AC overlays of CRCP, except for longitudinal joints, as long as continuously reinforced PCC repairs are used to repair deteriorated areas and cracks.

5.6.4 Subdrainage

See Section 5.2.4 for guidelines.

5.6.5 Thickness Design

If the overlay is being placed for some functional purpose such as roughness or friction, a minimum thickness overlay that solves the functional problem should be placed. If the overlay is being placed for the purpose of structural improvement, the required thickness of the overlay is a function of the structural capacity required to meet future traffic demands and the structural capacity of the existing pavement. The required overlay thickness to increase structural capacity to carry future traffic is determined by the following equation.

$$D_{ol} = A(D_f - D_{eff})$$

where

D_{ol} = Required thickness of AC overlay, inches
A = Factor to convert PCC thickness deficiency to AC overlay thickness
D_f = Slab thickness to carry future traffic, inches
D_{eff} = Effective thickness of existing slab, inches

The A factor, which is a function of the PCC thickness deficiency, is given by the following equation, and is illustrated in Figure 5.9.

$$A = 2.2233 + 0.0099(D_f - D_{eff})^2 - 0.1534(D_f - D_{eff})$$

AC overlays of conventional JPCP, JRCP, and CRCP have been constructed as thin as 2 inches and as thick as 10 inches. The most typical thicknesses that have been constructed for highways are 3 to 6 inches.

The required overlay thickness may be determined through the following design steps. These design steps provide a comprehensive design approach that recommends testing the pavement to obtain valid design inputs. If it is not possible to conduct this testing (e.g., for a low-volume road), an approximate overlay design may be developed based upon visible distress observations by skipping Steps 4 and 5, and by estimating other inputs.

The overlay design can be done for a uniform section or on a point-by-point basis as described in Section 5.3.1.

Step 1: Existing pavement design.

(1) Existing slab thickness
(2) Type of load transfer (mechanical devices, aggregate interlock, CRCP)
(3) Type of shoulder (tied PCC, other)

Step 2: Traffic analysis.

(1) Past cumulative 18-kip ESALs in the design lane (N_p), for use in the remaining life method of D_{eff} determination only
(2) Predicted future 18-kip ESALs in the design lane over the design period (N_f)
Use ESALs computed from rigid pavement load equivalency factors

Step 3: Condition survey.

The following distresses are measured during the condition survey for JPCP, JRCP, and CRCP. Sampling along the most heavily trafficked lane of the project may be used to estimate these quantities. Distress types and severities are defined in Reference 23. Deteriorated means medium or higher severity.

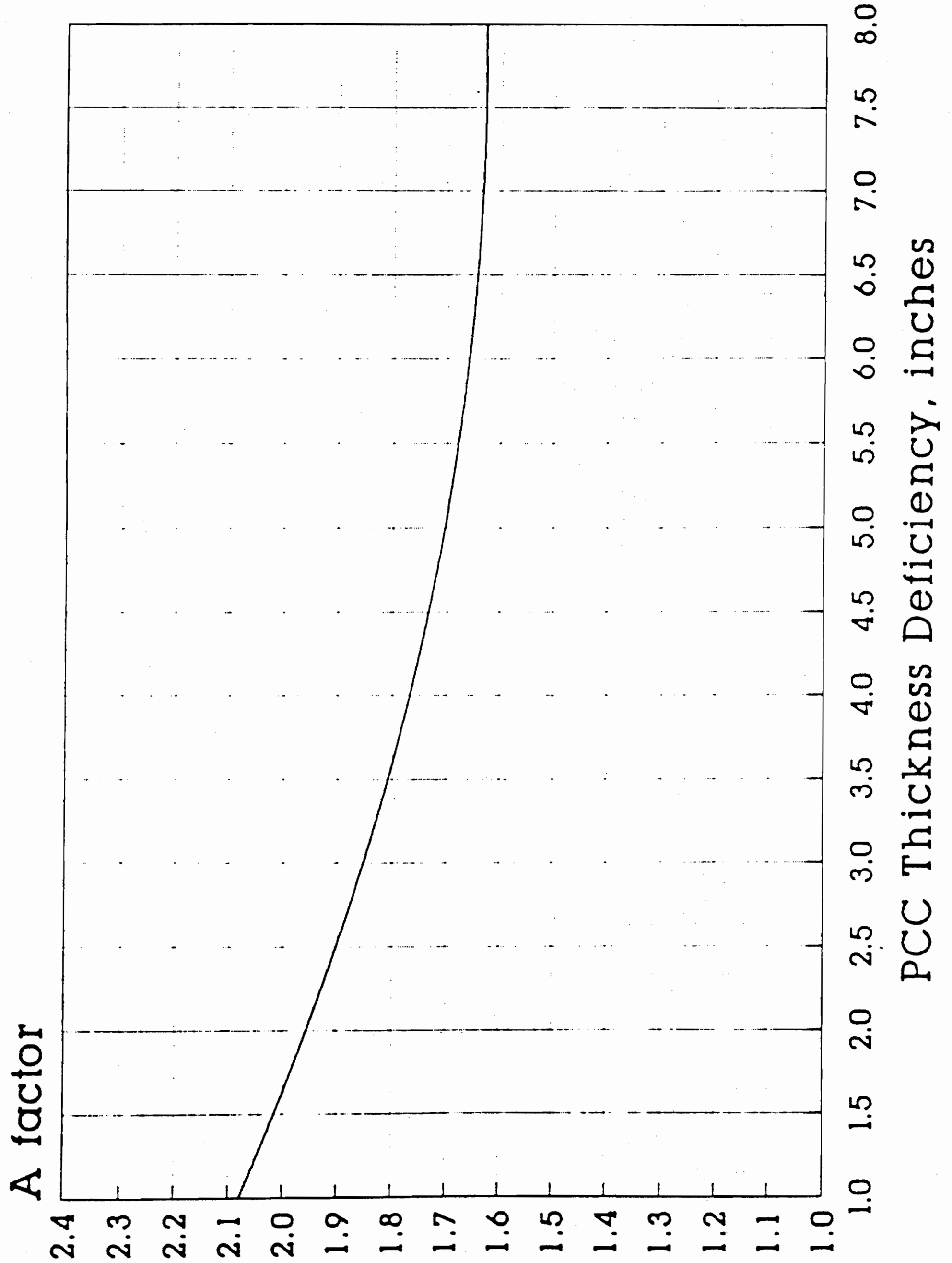

Figure 5.9. A Factor for Conversion of PCC Thickness Deficiency to AC Overlay Thickness

JPCP/JRCP:

- (1) Number of deteriorated transverse joints per mile
- (2) Number of deteriorated transverse cracks per mile
- (3) Number of full-depth AC patches, exceptionally wide joints (greater than 1 inch), and expansion joints per mile (except at bridges)
- (4) Presence and overall severity of PCC durability problems
  - (a) "D" cracking: low severity (cracks only), medium severity (some spalling), high severity (severe spalling)
  - (b) Reactive aggregate cracking: low, medium, high severity
- (5) Evidence of faulting, or pumping of fines or water at joints, cracks, and pavement edge

CRCP:

- (1) Number of punchouts per mile
- (2) Number of deteriorated transverse cracks per mile
- (3) Number of full-depth AC patches, exceptionally wide joints (greater than 1 inch) and expansion joints per mile (except at bridges)
- (4) Number of existing and new repairs prior to overlay per mile
- (5) Presence and general severity of PCC durability problems (NOTE: surface spalling of tight cracks where the underlying CRCP is sound should not be considered a durability problem.)
  - (a) "D" cracking: low severity (cracks only), medium severity (some spalling), high severity (severe spalling)
  - (b) Reactive aggregate cracking: low, medium, high severity
- (6) Evidence of pumping of fines or water

Step 4: Deflection testing (strongly recommended).

Measure slab deflection basins along the project at an interval sufficient to adequately assess conditions. Intervals of 100 to 1,000 feet are typical. Measure deflections with sensors located at 0, 12, 24, and 36 inches from the center of load. Measure deflections in the outer wheel path. A heavy-load deflection device (e.g., Falling Weight Deflectometer) and a load magnitude of 9,000 pounds are recommended. ASTM D 4694 and D 4695 provide additional guidance on deflection testing. For each slab tested, backcalculate the effective k-value and the slab's elastic modulus using Figures 5.10 and 5.11 or a backcalculation program.

The AREA of each deflection basin is computed by the following equation. AREA will typically range from 29 to 32 for sound concrete.

$$\text{AREA} = 6 * \left[1 + 2\left(\frac{d_{12}}{d_0}\right) + 2\left(\frac{d_{24}}{d_0}\right) + \left(\frac{d_{36}}{d_0}\right)\right]$$

where

d_0 = deflection in center of loading plate, inches
d_i = deflections at 12, 24, and 36 inches from plate center, inches

(1) *Effective dynamic k-value.* Enter Figure 5.10 with d_0 and AREA to determine the effective dynamic k-value beneath each slab for a circular load radius of 5.9 inches and magnitude of 9,000 pounds. For loads within 2,000 pounds more or less, deflections may be scaled linearly to 9,000-pound deflections.

If a single overlay thickness is being designed for a uniform section, compute the mean effective dynamic k-value of the slabs tested in the uniform section.

(2) *Effective static k-value.*

Effective static k-value
= Effective dynamic k-value/2

The effective static k-value may need to be adjusted for seasonal effects using the approach presented in Part II, Section 3.2.1. However, the k-value can change substantially and have only a small effect on overlay thickness.

(3) *Elastic modulus of PCC slab (E).* Enter Figure 5.11 with AREA, proceed to the effective dynamic k-value curves, and determine a value for ED^3, where D is the slab thickness. Solve for E knowing the slab thickness, D. Typical slab E values range from 3 to 8 million psi. If a slab E value is obtained that is out of this range, an error may exist in the assumed slab thickness, the deflection basin may have been measured over a crack, or the PCC may be significantly deteriorated.

If a single overlay thickness is being designed for a uniform section, compute the mean E value of the slabs tested in the uniform section.

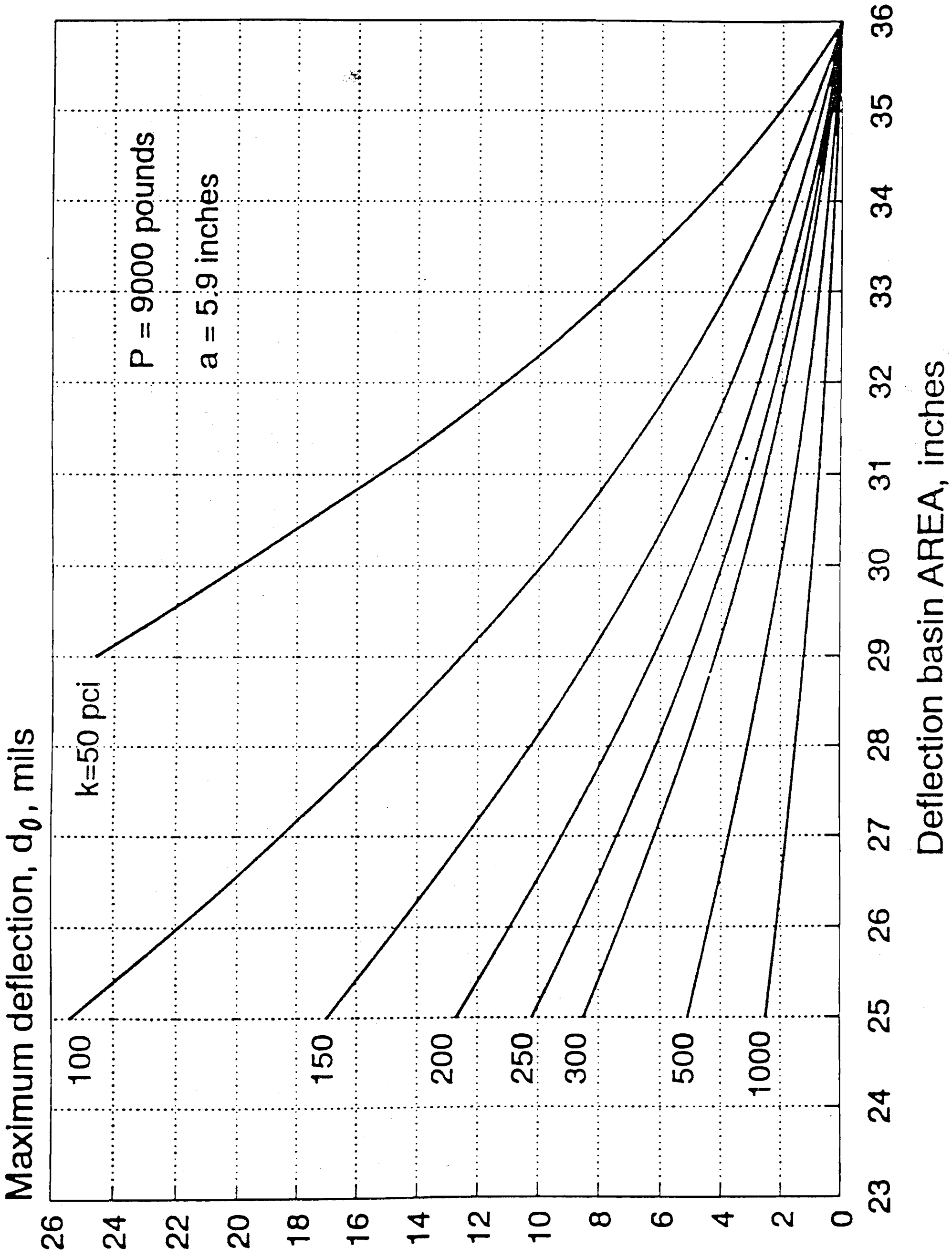

Figure 5.10. Effective Dynamic k-Value Determination from d_0 and AREA

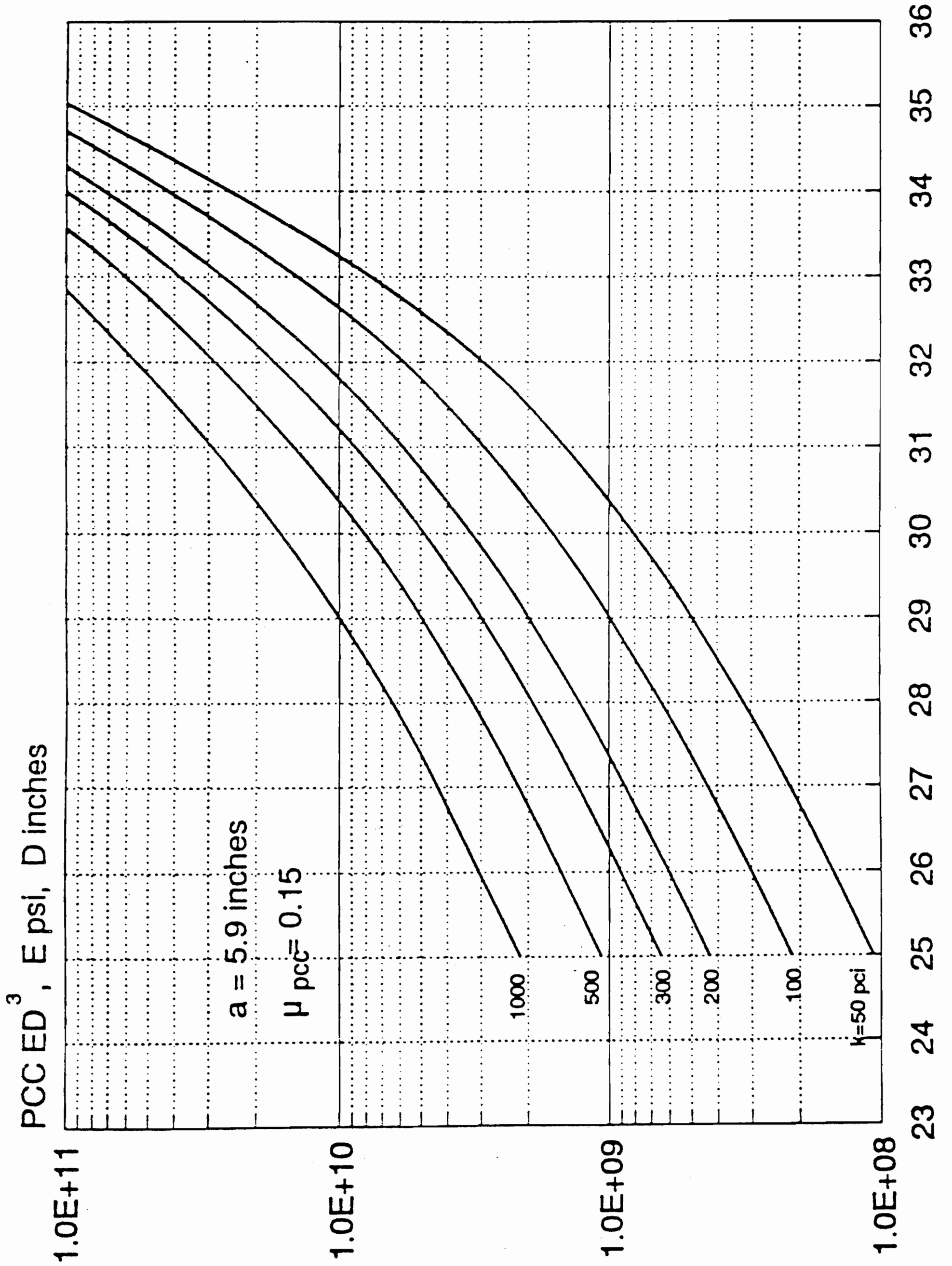

Figure 5.11. PCC Elastic Modulus Determination from k-Value, AREA, and Slab Thickness

Do not use any k-values or E values that appear to be significantly out of line with the rest of the data.

(4) *Joint load transfer.* For JPCP and JRCP, measure joint load transfer in the outer wheelpath at representative transverse joints. Do not measure load transfer when the ambient temperature is greater than 80°F. Place the load plate on one side of the joint with the edge of the plate touching the joint. Measure the deflection at the center of the load plate and at 12 inches from the center. Compute the deflection load transfer from the following equation.

$$\Delta LT = 100 * \left(\frac{\Delta_{ul}}{\Delta_l}\right) * B$$

where

ΔLT = deflection load transfer, percent
Δ_{ul} = unloaded side deflection, inches
Δ_l = loaded side deflection, inches
B = slab bending correction factor

The slab bending correction factor, B, is necessary because the deflections d_0 and d_{12}, measured 12 inches apart, would not be equal even if measured in the interior of a slab. An appropriate value for the correction factor may be determined from the ratio of d_0 to d_{12} for typical center slab deflection basin measurements, as shown in the equation below. Typical values for B are between 1.05 and 1.15.

$$B = \frac{d_{0\ \text{center}}}{d_{12\ \text{center}}}$$

If a single overlay thickness is being designed for a uniform section, compute the mean deflection load transfer value of the joints tested in the uniform section.

For JPCP and JRCP, determine the J load transfer coefficient using the following guidelines:

Percent Load Transfer	**J**
>70	3.2
50–70	3.5
<50	4.0

If the rehabilitation will include the addition of a tied concrete shoulder, a lower J factor may be appropriate. See Part II, Table 2.6.

For CRCP, use J = 2.2 to 2.6 for overlay design, assuming that working cracks are repaired with continuously reinforced PCC.

Step 5: Coring and materials testing (strongly recommended).

(1) *PCC modulus of rupture (S'_c).* Cut several 6-inch-diameter cores at midslab and test in indirect tension (ASTM C 496). Compute the indirect tensile strength (psi) of the cores. Estimate the modulus of rupture with the following equation.

$$S'_c = 210 + 1.02IT$$

where

S'_c = modulus of rupture, psi
IT = indirect tensile strength of 6-inch-diameter cores, psi

Step 6: Determination of required slab thickness for future traffic (D_f).

The inputs to determine D_f for AC overlays of PCC pavements are representative of the existing slab and foundation properties. This is emphasized because it is the properties of the existing slab (i.e., elastic modulus, modulus of rupture, and load transfer) which will control the performance of the AC overlay.

(1) *Effective static k-value beneath existing PCC slab.* Determine from one of the following methods.
   (a) Backcalculate the effective dynamic k-value from deflection basins. Divide the effective dynamic k-value by 2 to obtain the effective static k-value. The effective static k-value may need to be adjusted for seasonal effects using the approach presented in Part II, Section 3.2.1.
   (b) Conduct plate load tests (ASTM D 1196) after slab removal at a few sites. This alternative is very costly and time-consuming and not often used. The static k-value obtained may need to be adjusted for seasonal effects (see Part II, Section 3.2.1).
   (c) Estimate from soils data and base type and thickness, using Figure 3.3 in Part

II, Section 3.2. This alternative is simple, but the static k-value obtained must be recognized as a rough estimate. The static k-value may need to be adjusted for seasonal effects (see Part II, Section 3.2.1).

(2) *Design PSI loss.* PSI immediately after overlay (P1) minus PSI at time of next rehabilitation (P2).

(3) *J, load transfer factor of existing PCC slab.* See Step 4.

(4) *PCC modulus of rupture of existing slab* determined by one of the following methods:
   (a) Estimated from indirect tensile strength measured from 6-inch-diameter cores as described in Step 5.
   (b) Estimated from the backcalculated E of slab using the following equation.

$$S'_c = 43.5 \left(\frac{E}{10^6}\right) + 488.5$$

where

S'_c = modulus of rupture, psi
E = backcalculated elastic modulus of PCC slab, psi

For CRCP, S'_c may be determined from the backcalculated E values only at points which have no cracks within the deflection basins.

(5) *Elastic modulus of existing PCC slab,* determined by one of the following methods:
   (a) Backcalculated from deflection measurements as described in Step 4.
   (b) Estimated from indirect tensile strength.

(6) *Loss of support of existing slab.* Joint corners that have loss of support may be identified using FWD deflection testing as described in Reference 2. CRCP loss of support may be determined by plotting a slab edge or wheelpath deflection profile and identifying locations with significantly high deflections. Existing loss of support can be corrected with slab stabilization. For overlay thickness design assume a fully supported slab, LS = 0.

(7) *Overlay design reliability, R (percent).* See Part I, Section 4.2, Part II, Table 2.2, and Part III, Section 5.2.15.

(8) *Overall standard deviation (S_o) for rigid pavement.* See Part I, Section 4.3.

(9) *Subdrainage capability of existing slab,* after subdrainage improvements, if any. See Part II, Table 2.5, as well as reference 5, for guidance in determining C_d. Pumping or faulting at joints and cracks determined in Step 3 is evidence that a subdrainage problem exists. In selecting this value, note that the poor subdrainage situation at the AASHO Road Test would be given a C_d of 1.0.

Compute D_f for the above design inputs using the rigid pavement design equation or nomograph in Part II, Figure 3.7. When designing an overlay thickness for a uniform pavement section, mean input values must be used. When designing an overlay thickness for specific points along the project, the data for that point must be used. A worksheet for determining D_f is provided in Table 5.7. Typical values of inputs are provided for guidance. Values outside these ranges should be used with caution.

Step 7: ***Determination of effective slab thickness (D_{eff}) of existing pavement.***

Condition survey and remaining life procedures are presented.

D_{eff} From Condition Survey For PCC Pavements

The effective thickness of the existing slab (D_{eff}) is computed from the following equation:

$$D_{eff} = F_{jc} * F_{dur} * F_{fat} * D$$

where

D = existing PCC slab thickness, inches

(1) *Joints and cracks adjustment factor (F_{jc}).* This factor adjusts for the extra loss in PSI caused by deteriorated reflection cracks in the overlay that will result from any unrepaired deteriorated joints, cracks, and other discontinuities in the existing slab prior to overlay. A deteriorated joint or crack in the existing slab will rapidly reflect through an AC overlay and contribute to loss of serviceability. Therefore, it is recommended that all deteriorated joints and cracks (for non-"D" cracked or reactive aggregate related distressed pavements) and any other major discontinuities in the existing slab be full-depth repaired with dowelled or tied PCC repairs prior to overlay, so that F_{jc} = 1.00.

Table 5.7. Worksheet for Determination of D_f for JPCP, JRCP, and CRCP

SLAB:

Existing PCC slab thickness = ____________________ inches

Type of load transfer system: mechanical device, aggregate interlock, CRCP

Type of shoulder = tied PCC, other

PCC modulus of rupture (typically 600 to 800 psi) = ____________________ psi

PCC E modulus (3 to 8 million psi for sound PCC, <3 million for unsound PCC) = ____________________ psi

J load transfer factor (3.2 to 4.0 for JPCP, JRCP 2.2 to 2.6 for CRCP) = ____________________

TRAFFIC:

Future 18-kip ESALs in design lane over the design period (N_f) = ____________________

SUPPORT AND DRAINAGE:

Effective dynamic k-value = ____________________ psi/inch

Effective static k-value = Effective dynamic k-value/2 (typically 50 to 500 psi/inch) = ____________________ psi/inch

Subdrainage coefficient, C_d (typically 1.0 for poor subdrainage conditions) = ____________________

SERVICEABILITY LOSS:

Design PSI loss (P1 − P2) = ____________________

RELIABILITY:

Design reliability, R (80 to 99 percent) = ____________________ percent

Overall standard deviation, S_o (typically 0.39) = ____________________

FUTURE STRUCTURAL CAPACITY:

Required slab thickness for future traffic is determined from rigid pavement design equation or nomograph in Part II, Figure 3.7.

D_f = ____________________ inches

If it is not possible to repair all deteriorated areas, the following information is needed to determine F_{jc}, to increase the overlay thickness to account for the extra loss in PSI from deteriorated reflection cracks in the design lane:

Pavements with no "D" cracking or reactive aggregate distress:

Number of unrepaired deteriorated joints/mile

Number of unrepaired deteriorated cracks/mile

Number of unrepaired punchouts/mile

Number of expansion joints, exceptionally wide joints (greater than 1 inch), and full-depth, full-lane-width AC patches/mile

Note that tight cracks held together by reinforcement in JRCP or CRCP are not included. However, if a crack in JRCP or CRCP is spalled and faulted the steel has probably ruptured, and the crack should be considered as working. Surface spalling of CRCP cracks is not an indication that the crack is working.

The total number of unrepaired deteriorated joints, cracks, punchouts, and other discontinuities per mile in the design lane is used to determine the F_{jc} from Figure 5.12.

Pavements with "D" cracking or reactive aggregate deterioration:

These types of pavements often have deterioration at the joints and cracks from durability problems. The F_{dur} factor is used to adjust the overlay thickness for this problem. Therefore, when this is the case, the F_{jc} should be determined from Figure 5.12 only using those unrepaired deteriorated joints and cracks that are not caused by durability problems. If all of the deteriorated joints and cracks are spalling due to "D" cracking or reactive aggregate, then F_{jc} = 1.0. This will avoid adjusting twice with F_{jc} and F_{dur} factors.

(2) *Durability adjustment factor (F_{dur}).* This factor adjusts for an extra loss in PSI of the overlay when the existing slab has durability problems such as "D" cracking or reactive aggregate distress. Using condition survey data from Step 3, F_{dur} is determined as follows.

1.00: No sign of PCC durability problems
0.96–0.99: Durability cracking exists, but no spalling
0.88–0.95: Substantial cracking and some spalling exists
0.80–0.88: Extensive cracking and severe spalling exists

(3) *Fatigue damage adjustment factor (F_{fat}).* This factor adjusts for past fatigue damage that may exist in the slab. It is determined by observing the extent of transverse cracking (JPCP, JRCP) or punchouts (CRCP) that may be caused primarily by repeated loading. Use condition survey data from Step 3 and the following guidelines to estimate F_{fat} in the design lane.

0.97–1.00: Few transverse cracks/punchouts exist (none caused by "D" cracking or reactive aggregate distress)
JPCP: <5 percent slabs are cracked
JRCP: <25 working cracks per mile
CRCP: <4 punchouts per mile

0.94–0.96: A significant number of transverse cracks/punchouts exist (none caused by "D" cracking or reactive aggregate distress)
JPCP: 5–15 percent slabs are cracked
JRCP: 25–75 working cracks per mile
CRCP: 4–12 punchouts per mile

0.90–0.93: A large number of transverse cracks/punchouts exist (none caused by "D" cracking or reactive aggregate distress)
JPCP: >15 percent slabs are cracked
JRCP: >75 working cracks per mile
CRCP: >12 punchouts per mile

D_{eff} From Remaining Life For PCC Pavements

The remaining life of the pavement is given by the following equation:

$$RL = 100\left[1 - \left(\frac{N_p}{N_{1.5}}\right)\right]$$

where

RL = remaining life, percent
N_p = total traffic to date, ESALs
$N_{1.5}$ = total traffic to pavement "failure," ESALs

$N_{1.5}$ may be estimated using the new pavement design equations or nomographs in Part II. To be consistent with the AASHO Road Test and the development of these equations, a "failure" PSI equal to 1.5 and a reliability of 50 percent are recommended.

D_{eff} is determined from the following equation:

$$D_{eff} = CF * D$$

where

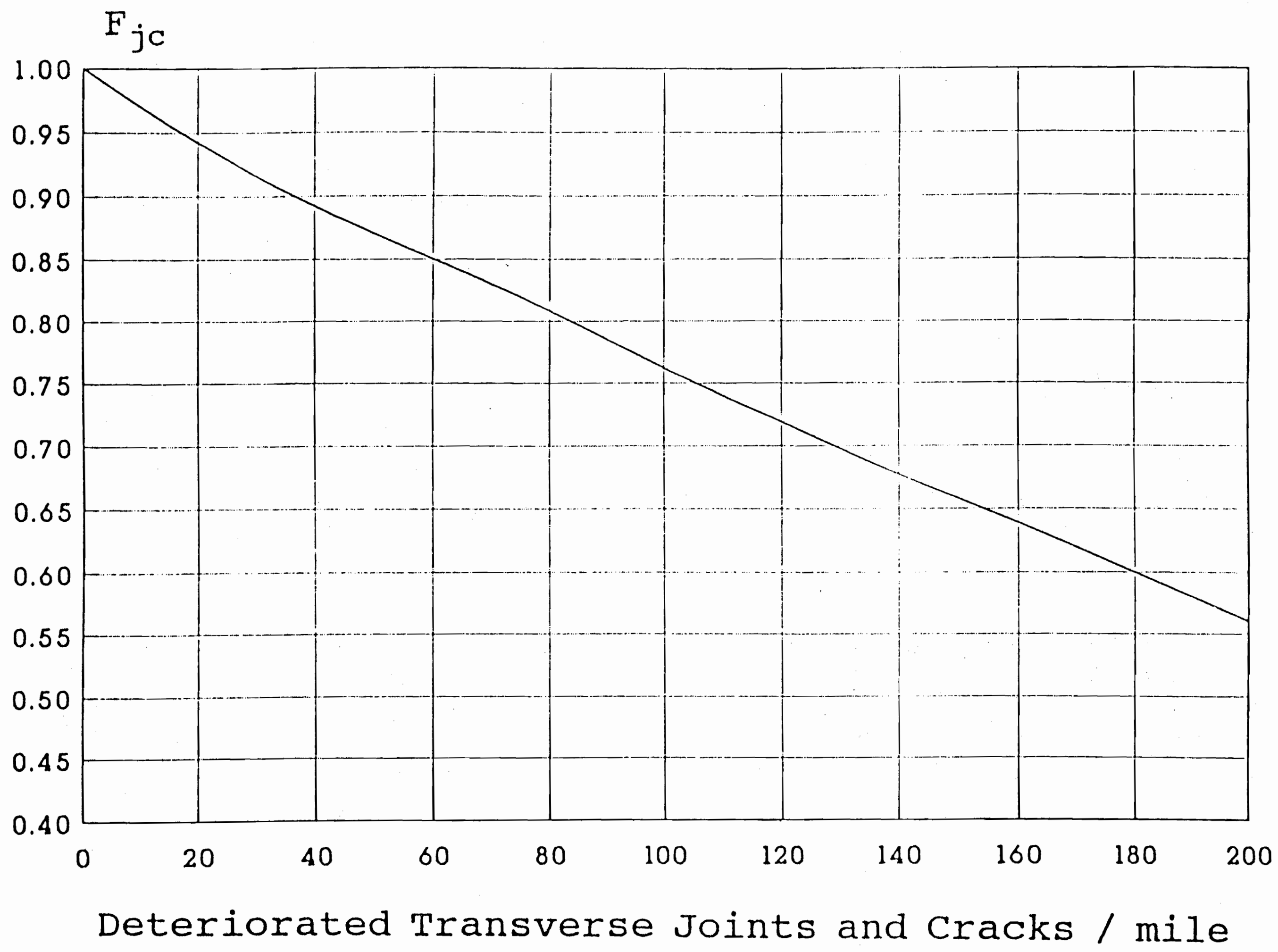

Figure 5.12. F_{jc} Adjustment Factor

CF = condition factor determined from Figure 5.2
D = thickness of the existing slab

The designer should recognize that D_{eff} determined by this method does not reflect any benefit for preoverlay repair. The estimate of D_{eff} obtained should thus be considered a lower limit value. The D_{eff} of the pavement will be higher if preoverlay repair of load-associated distress is done. This method for determining D_{eff} is not applicable without modification to pavements which have already received one or more overlays, even if the overlay has been or will be completely milled off.

A worksheet for determination of D_{eff} for JPCP, JRCP, and CRCP is provided in Table 5.8.

Step 8: Determination of Overlay Thickness.

The thickness of AC overlay is computed as follows:

$$D_{ol} = A(D_f - D_{eff})$$

where

D_{ol} = Required thickness of AC overlay, inches
A = Factor to convert PCC thickness deficiency to AC overlay thickness
D_f = Slab thickness determined in Step 6, inches
D_{eff} = Effective thickness of existing slab determined in Step 7, inches

The A factor, which is a function of the PCC thickness deficiency, is given by the following equation and is illustrated in Figure 5.9.

$$A = 2.2233 + 0.0099(D_f - D_{eff})^2 - 0.1534(D_f - D_{eff})$$

The thickness of overlay determined from the above relationship should be reasonable when the overlay is required to correct a structural deficiency. See Section 5.2.17 for discussion of factors which may result in unreasonable overlay thicknesses.

5.6.6 Shoulders

See Section 5.2.10 for guidelines.

5.6.7 Widening

See Section 5.2.16 for guidelines.

5.7 AC OVERLAY OF AC/JPCP, AC/JRCP, AND AC/CRCP

This section covers the design of AC overlays of existing AC/JPCP, AC/JRCP, or AC/CRCP. Although some pavements are newly constructed as AC/PCC, the vast majority of existing AC/PCC pavements are PCC pavements which have been overlaid with AC at least once.

Construction of an AC overlay of AC/JPCP, AC/JRCP, or AC/CRCP consists of the following major activities:

(1) Repairing deteriorated areas and making subdrainage improvements (if needed)
(2) Milling a portion of the existing AC surface
(3) Constructing widening (if needed)
(4) Applying a tack coat
(5) Placing the AC overlay, including a reflection crack control treatment (if needed)

5.7.1 Feasibility

An AC overlay is a feasible rehabilitation alternative for an AC/PCC pavement except when the condition of the existing pavement dictates substantial removal and replacement. Conditions under which another AC overlay would not be feasible include the following.

(1) The amount of deteriorated slab cracking and joint spalling is so great that complete removal and replacement of the existing surface is dictated.
(2) Significant deterioration of the PCC slab has occurred due to severe durability problems (e.g., "D" cracking or reactive aggregates).
(3) Vertical clearance at bridges is inadequate for required overlay thickness. This may be addressed by reducing the overlay thickness under the bridges (although this may result in early failure at these locations), by raising the bridges, or by reconstructing the pavement under the bridges. Thicker AC overlays may also necessitate raising signs and guardrails, as well as increasing side slopes and extending culverts. Sufficient right-of-way must be available or obtainable to permit these activities.

Table 5.8. Calculation of D_{eff} for AC Overlay of JPCP, JRCP, and CRCP in the Design Lane

Condition Survey Method:

F_{jc} Number of unrepaired deteriorated joints/mile = ____________________

Number of unrepaired deteriorated cracks/mile = ____________________

Number of unrepaired punchouts/mile = ____________________

Number of expansion joints, exceptionally wide joints (>1 inch) or AC full-depth patches/mile = ____________________

Total/mile = ____________________

F_{jc} = ____________________ (Figure 5.12)

(Recommended value 1.0, repair all deteriorated areas)

F_{dur} 1.00: No sign of PCC durability problems

0.96–0.99: Some durability cracking exists, but no spalling exists

0.88–0.95: Substantial cracking and some spalling exists

0.80–0.88: Extensive cracking and severe spalling exists

F_{dur} = ____________________

F_{fat} 0.97–1.00: Very few transverse cracks/punchouts exist

0.94–0.96: A significant number of transverse cracks/punchouts exist

0.90–0.93: A large number of transverse cracks/punchouts exist

F_{fat} = ____________________

$$D_{eff} = F_{jc} * F_{dur} * F_{fat} * D = \rule{4cm}{0.4pt}$$

Remaining Life Method:

N_p = Past design lane ESALs = ____________________

$N_{1.5}$ = Design lane ESALs to P2 of 1.5 = ____________________

$$RL = 100\left[1 - \left(\frac{N_p}{N_{1.5}}\right)\right] = \rule{4cm}{0.4pt}$$

CF = ____________________ (Figure 5.2)

$$D_{eff} = CF * D = \rule{4cm}{0.4pt}$$

When another AC overlay of an existing AC/JPCP, AC/JRCP, or AC/CRCP is being considered, the causes of the deterioration in the existing pavement should be carefully investigated. If the PCC slab is sound and in good condition but the existing AC layer is badly rutted or otherwise deteriorated, the AC should be thoroughly repaired or milled off. If, however, distress visible at the AC surface is predominantly a reflection of deterioration in the underlying PCC, the pavement must be repaired through the full depth of the AC and PCC. Otherwise, the distress will reflect rapidly through the new AC overlay. It is strongly recommended that coring and deflection testing be conducted to thoroughly investigate the causes and extent of deterioration in the existing pavement.

5.7.2 Pre-overlay Repair

The following types of distress in AC/JPCP, AC/JRCP, and AC/CRCP should be repaired prior to placement of an AC overlay.

Distress Type	Repair Type
Rutting	Milling
Deteriorated reflection cracks	Full-depth repair or slab replacement
Deteriorated repairs	Full-depth repair
Punchouts	Full-depth repair
Localized distress in AC only	AC patching
Localized distress in PCC	Full-depth repair
Pumping	Edge drains
Settlements/heaves	AC level-up, slab jacking, or localized reconstruction

In AC/JPCP and AC/JRCP, medium- and high-severity reflection cracks in the AC surface are evidence of working cracks, deteriorated joints, or failed repairs in the PCC slab, all of which should be full-depth repaired. Low-severity reflection cracks may exist at regular joints and full-depth repair joints. If these cracks are sealed and do not appear to be deteriorating at a significant rate, they might not warrant pre-overlay repair other than sealing.

In AC/CRCP, reflection cracks of all severities suggest the presence of working cracks, deteriorated construction joints, or failed repairs in the PCC slab, all of which should be repaired. Coring through selected reflection cracks should be conducted to assess the condition of the underlying pavement.

Coring should be conducted at areas of localized distress to determine whether they are caused by a problem in the AC mix or deterioration in the PCC (e.g., "D" cracking). In the latter case, the PCC may be deteriorated to a much greater extent than is evident at the AC surface. Additional coring or removal of portions of the AC may be necessary to select appropriate repair boundaries.

Full-depth repairs to AC/PCC pavements should match the existing cross-section, i.e., the PCC slab should be full-depth repaired with the same thickness of PCC, and then capped with AC to the same thickness as the existing AC. Full-depth repairs and slab replacements in AC/JPCP or AC/JRCP should be AC/PCC, dowelled or tied to provide load transfer across repair joints. Some agencies have placed full-depth AC repairs in AC/JPCP and AC/JRCP prior to an AC overlay. However, this has often resulted in rough spots in the new overlay, opening of nearby joints and cracks, and rapid deterioration of reflection cracks at AC patch boundaries.

AC/CRCP full-depth repairs should be AC/PCC and should be continuously reinforced with steel which is tied or welded to reinforcing steel in the existing slab, to provide load transfer across joints and slab continuity. Full-depth AC repairs should not be used in AC/CRCP prior to placement of an AC overlay, and any existing AC patches in AC/CRCP should be removed and replaced with AC over continuously reinforced PCC. Guidelines on repair are provided in References 1 and 3.

Installation of edge drains, maintenance of existing edge drains, or other subdrainage improvement should be done prior to placement of the overlay if a subdrainage evaluation indicates a need for such an improvement.

Pressure relief joints should be placed only at fixed structures, and not at regular intervals along the pavement. The only exception to this is where reactive aggregate has caused expansion of the slab. On heavily trafficked routes, pressure relief joints should be of heavy-duty design with dowels (*3*).

5.7.3 Reflection Crack Control

Reflection cracking in an AC overlay of AC/JPCP, AC/JRCP, or AC/CRCP occurs over reflection cracks in the first AC overlay, and may also occur over new repairs. The basic mechanism of reflection cracking is strain concentration in the overlay due to movement in the vicinity of joints and cracks in the existing pavement. This movement may be bending or shear induced by loads, or may be horizontal contraction induced by temperature changes. Load-induced movements are influenced by the thickness and stiffness of the AC layers, the thickness of the PCC, the degree of load transfer at the joints and cracks, and the extent of loss of support under the PCC slab. Temperature-induced movements are influenced by daily and seasonal temperature variations, the coefficients of thermal expansion of the existing pavement layers, and the spacing of joints and cracks.

Pre-overlay repair, including full-depth repair, subdrainage improvement, and subsealing, is the most effective means of controlling reflection crack occurrence and deterioration in a second AC overlay of an AC/JPCP or AC/JRCP pavement. Additional reflection crack control treatments may be used as well, including:

(1) *Placing a synthetic fabric, stress-absorbing interlayer, or bituminous-stabilized granular layer prior to or in combination with the AC overlay.*

(2) *Sawing and sealing joints in the AC overlay* at locations coinciding with reflection cracks and repair boundaries in the AC/JPCP or AC/JRCP. This technique has been very successful when applied to AC overlays of jointed PCC pavements when the sawcut matches the joint or straight crack within an inch.

(3) *Increasing the AC overlay thickness.* Reflection cracks will take more time to propagate through a thicker overlay and may deteriorate more slowly.

Reflection cracking can have a considerable (often controlling) influence on the life of an AC overlay of AC/JPCP or AC/JRCP. Deteriorated reflection cracks detract from a pavement's serviceability and also require frequent maintenance, such as sealing, milling, and patching. Reflection cracks also permit water to enter the pavement structure, which may result in loss of bond between the AC and PCC, stripping in the AC layers, progression of "D" cracking or reactive aggregate distress in PCC slabs with these durability problems, and softening of the base and subgrade. For this reason, reflection cracks should be sealed as soon as they appear and resealed periodically throughout the life of the overlay. Sealing low-severity reflection cracks may also be effective in retarding their progression to medium and high severity levels.

Repairing reflection cracks in existing AC/CRCP prior to placement of an AC overlay will delay the occurrence and deterioration of new reflection cracks. Improving subdrainage conditions and subsealing in areas where the slab has lost support will also discourage reflection crack occurrence and deterioration. Reflection crack control treatments are not necessary for AC overlays of AC/CRCP, except for longitudinal joints, as long as continuously reinforced AC/PCC repairs are used to repair deteriorated areas and cracks.

5.7.4 Subdrainage

See Section 5.2.4 for guidelines.

5.7.5 Thickness Design

If the overlay is being placed for some functional purpose such as roughness or friction, a minimum thickness overlay that solves the functional problem should be placed. If the overlay is being placed for the purpose of structural improvement, the required thickness of the overlay is a function of the structural capacity required to meet future traffic demands and the structural capacity of the existing pavement. The required overlay thickness to increase structural capacity to carry future traffic is determined by the following equation.

$$D_{ol} = A(D_f - D_{eff})$$

where

D_{ol} = Required thickness of AC overlay, inches
A = Factor to convert PCC thickness deficiency to AC overlay thickness
D_f = Slab thickness to carry future traffic, inches
D_{eff} = Effective equivalent PCC slab thickness of existing AC/PCC, inches

The A factor, which is a function of the PCC thickness deficiency, is given by the following equation and is illustrated in Figure 5.9.

$$A = 2.2233 + 0.0099(D_f - D_{eff})^2 - 0.1534(D_f - D_{eff})$$

The required overlay thickness may be determined through the following design steps. These design steps provide a comprehensive design approach that recommends testing the pavement to obtain valid design inputs. If it is not possible to conduct this testing (e.g., for a low-volume road), an approximate overlay design may be developed based upon visible distress observations by skipping Steps 4 and 5, and by estimating other inputs.

The overlay design can be done for a uniform section or on a point-by-point basis as described in Section 5.3.1.

Step 1: ***Existing pavement design.***

(1) Existing AC surface thickness
(2) Existing PCC slab thickness
(3) Type of load transfer (mechanical devices, aggregate interlock, CRCP)
(4) Type of shoulder (tied PCC, other)

Step 2: ***Traffic analysis.***

(1) Predicted future 18-kip ESALs in the design lane over the design period (N_f)
Use ESALs computed from rigid pavement load equivalency factors

Step 3: ***Condition survey.***

The following distresses are measured during the condition survey. Sampling along the most heavily trafficked lane of the project may be used to estimate these quantities. Distress types and severities are defined in Reference 23. Deteriorated means medium or higher severity.

AC/JPCP OR AC/JRCP:

(1) Number of deteriorated reflection cracks per mile
(2) Number of full-depth AC patches and expansion joints per mile (except at bridges)
(3) Evidence of pumping of fines or water at cracks and pavement edge
(4) Mean rut depth
(5) Number of localized failures

The following distresses are measured during the condition survey for AC/CRCP. Sampling may be used to estimate these quantities.

AC/CRCP:

(1) Number of unrepaired punchouts per mile
(2) Number of unrepaired reflection cracks per mile
(3) Number of unrepaired existing deteriorated repairs and full-depth AC repairs per mile
(4) Evidence of pumping of fines or water
(5) Mean rut depth

Step 4: ***Deflection testing***
(strongly recommended).

Measure slab deflection basins along the project at an interval sufficient to adequately assess conditions. Intervals of 100 to 1,000 feet are typical. Measure deflections with sensors located at 0, 12, 24, and 36 inches from the center of the load. Measure deflections in the outer wheel path, unless rutting of the AC surface interferes with proper seating of the load plate, in which case deflections should be measured between the wheelpaths. A heavy-load deflection device (e.g., Falling Weight Deflectometer) and a load magnitude of 9,000 pounds are recommended. ASTM D 4694 and D 4695 provide additional guidance on deflection testing.

(1) *Temperature of AC mix.* The temperature of the AC mix during deflection testing must be determined. This may be measured directly by drilling a hole into the AC surface, inserting a liquid and a temperature probe, and reading the AC mix temperature when it has stabilized. This should be done at least three times during each day's testing, so that a curve of AC mix temperature versus time may be developed and used to assign a mix temperature to each basin.

If measured AC mix temperatures are not available, they may be approximated from correlations with pavement surface and air temperatures (*24, 25, 26, 27*). Pavement surface temperature may be monitored during deflection testing using a hand-held infrared sensing device which is aimed at the pavement. The mean air temperature for the five days prior to deflection testing, which is an input to some of the referenced methods for estimating mix temperature, may be obtained from a local weather station or other local sources.

(2) *Elastic modulus of AC.* The modulus of the AC layer should be determined for each deflection basin. Two methods are available for determining the AC modulus, E_{ac}.

(a) *Estimate E_{ac} from AC mix temperature.* The elastic modulus of the AC layer may be estimated from AC mix properties and the AC mix temperature assigned to a deflection basin using the following equation (*26*):

$$\log E_{ac} = 5.553833 + 0.028829\left(\frac{P_{200}}{F^{0.17033}}\right) - 0.03476V_v + 0.070377\eta_{70°F,10^6} + 0.000005t_p^{(1.3+0.49825\log F)}P_{ac}^{0.5} - \frac{0.00189}{F^{1.1}}t_p^{(1.3+0.49825\log F)}P_{ac}^{0.5} + 0.931757\left(\frac{1}{F^{0.02774}}\right)$$

where

E_{ac} = elastic modulus of AC, psi
P_{200} = percent aggregate passing the No. 200 sieve
F = loading frequency, Hz
V_v = air voids, percent
$\eta_{70°F,10^6}$ = absolute viscosity at 70°F, 10^6 poise (e.g., 1 for AC-10, 2 for AC-20)
P_{ac} = asphalt content, percent by weight of mix
t_p = AC mix temperature, °F

This may be reduced to a relationship between AC modulus and AC mix temperature for a particular loading frequency (i.e., approximately 18 Hz for the FWD load duration of 25 to 30 milliseconds) by assuming typical values for the AC mix parameters P_{ac}, V_v, P_{200}, and η. For example, the AC mix design used by one State has the following typical values:

P_{200} = 4 percent
V_v = 5 percent
$\eta_{70°F,10^6}$ = 2 for AC-20
P_{ac} = 5 percent

For these values and an FWD loading frequency of 18 Hz, the following equation for AC elastic modulus versus AC mix temperature is obtained:

$$\log E_{ac} = 6.451235 - 0.000164671t_p^{1.92544}$$

Each agency should establish its own relationship for AC modulus versus temperature which is representative of the properties of its AC mixes.

It should be noted that the equation for AC modulus as a function of mix parameters and temperature applies to new mixes. AC which has been in service for some years may have either a higher modulus (due to hardening of the asphalt) or lower modulus (due to deterioration of the AC, from stripping or other causes) at any given temperature.

(b) Diametral resilient modulus testing of AC cores taken from the in-service AC/PCC pavement, as described in Step 5, may be used to establish a relationship between AC modulus and temperature. This relationship may be used to determine the AC modulus of each deflection basin at the time and temperature at which it was measured.

(3) *Effective dynamic k-value beneath PCC slab.* Compute the compression which occurs in the AC overlay beneath the load plate using the following equations.

AC, PCC LAYERS BONDED:

$$d_{0\,compress} = -0.0000328 + 121.5006 * \left(\frac{D_{ac}}{E_{ac}}\right)^{1.0798}$$

AC, PCC LAYERS UNBONDED:

$$d_{0\,compress} = -0.00002133 + 38.6872 * \left(\frac{D_{ac}}{E_{ac}}\right)^{0.94551}$$

where

$d_{0\,compress}$ = AC compression at center of load, inches
D_{ac} = AC thickness, inches
E_{ac} = AC elastic modulus, psi

The interface condition is a significant unknown in backcalculation. The AC/PCC interface is fully bonded when the AC layer is first placed, but how well that bond is retained is not known. Examination of cores taken at a later time may show that bond has been reduced or completely lost. This is particularly likely if stripping occurs at the AC/PCC interface. If the current interface bonding condition is not determined by coring, the bonding condition which is considered more representative of the project may be assumed.

Using the above equations, the d_0 of the PCC slab in the AC/PCC pavement may be determined by subtracting the compression which occurs in the AC surface from the d_0 measured at the AC surface.

Compute the AREA of the PCC slab for each deflection basin from the following equation.

$$AREA_{pcc} = 6 * \left[1 + 2\left(\frac{d_{12}}{d_{0\,pcc}}\right) + 2\left(\frac{d_{24}}{d_{0\,pcc}}\right) + \left(\frac{d_{36}}{d_{0\,pcc}}\right) \right]$$

where

$d_{0\,pcc}$ = PCC deflection in center of loading plate, inches (surface deflection d_0 minus AC compression $d_{0_{compress}}$)
d_i = deflections at 12, 24, and 36 inches from plate center, inches

Enter Figure 5.10 with the $d_{0\,pcc}$ and $AREA_{pcc}$ of the PCC slab to determine the effective dynamic k-value beneath the slab for a circular load radius of 5.9 inches and magnitude of 9,000 pounds. Note that for loads within 2,000 pounds more or less, deflections may be scaled linearly to 9,000-pound deflections.

If a single overlay thickness is being designed for a uniform section, compute the mean effective dynamic k-value of the slabs tested in the uniform section.

(4) *Effective static k-value.*

Effective static k-value
= Effective dynamic k-value/2

The effective static k-value may need to be adjusted for seasonal effects using the approach presented in Part II, Section 3.2.1. However, the k-value can change substantially and have only a small effect on overlay thickness.

(5) *Elastic modulus of PCC slab (E).* Enter Figure 5.11 with the $AREA_{pcc}$ of the top of the PCC slab, proceed to the effective dynamic k-value curves, and determine a value for ED^3, where D is the PCC slab thickness. Solve for E knowing the slab thickness, D. Typical slab E values range from 3 to 8 million psi. If a slab E value is obtained out of this range, an error may exist in the assumed slab thickness, the deflection basin may have been measured over a crack, or the PCC may be significantly deteriorated.

If a single overlay thickness is being designed for a uniform section, compute the mean E value of the slabs tested in the uniform section.

Do not use any k-values or E values that appear to be significantly out of line with the rest of the data.

(6) *Joint load transfer.* For AC/JPCP and AC/JRCP, measure joint load transfer in the outer wheelpath (or between the wheelpaths if the AC is badly rutted) at representative reflection cracks above transverse joints in the PCC slab. Do not measure load transfer when the ambient temperature is greater than 80°F. Place the load plate on one side of the reflection crack with the edge of the plate touching the joint. Measure the deflection at the center of the load plate and at 12 inches from the center. Compute the deflection load transfer from the following equation.

$$\Delta LT = 100 * \left(\frac{\Delta_{ul}}{\Delta_l}\right) * B$$

where

ΔLT = deflection load transfer, percent
Δ_{ul} = unloaded side deflection, inches
Δ_l = loaded side deflection, inches
B = slab bending and AC compression correction factor

The slab bending and AC compression correction factor, B, is necessary because the deflections d_0 and d_{12}, measured 12 inches apart, would not be equal even if measured in the interior of a slab. An appropriate value for the correction factor may be determined from the ratio of d_0 to d_{12} for typical center slab deflection basin measurements, as shown in the equation below.

$$B = \frac{d_{0\,center}}{d_{12\,center}}$$

If a single overlay thickness is being designed for a uniform section, compute the mean deflection load transfer value of the joints tested in the uniform section.

For AC/JPCP and AC/JRCP, determine the J load transfer coefficient using the following guidelines:

Percent Load Transfer	J
>70	3.2
50–70	3.5
<50	4.0

If the rehabilitation will include the addition of a tied concrete shoulder, a lower J factor may be appropriate. See Part II, Table 2.6.

For AC/CRCP, use J = 2.2 to 2.6 for overlay design, assuming that working cracks are repaired with continuously reinforced PCC overlaid with AC.

Step 5: Coring and materials testing (strongly recommended).

(1) *Modulus of AC surface.* Laboratory testing of cores taken from the AC surface in uncracked areas may be used to determine the elastic modulus of the AC surface. This may be done using a repeated-load indirect tension test (ASTM D 4123). The tests should be run at two or more temperatures (e.g., 40, 70, and 90°F) to establish points for a curve of log E_{ac} versus temperature. AC modulus values at any temperature may be interpolated from the laboratory values obtained at any two temperatures. For example, E_{ac} values at 70° and 90°F may be used in the following equation to interpolate E_{ac} at any temperature t°F:

$$\log E_{ac\,t^\circ F} = \left(\frac{\log E_{ac\,70^\circ F} - \log E_{ac\,90^\circ F}}{70 - 90}\right) * (t^\circ F - 70^\circ F) + \log E_{ac\,70^\circ F}$$

For purposes of interpreting NDT data, AC modulus values obtained from laboratory testing of cores must be adjusted to account for the difference between the loading frequency of the test apparatus (typically 1 to 2 Hz) and the loading frequency of the deflection testing device (18 Hz for the FWD). This adjustment is made by multiplying the laboratory-determined E_{ac} by a constant value which may be determined for each laboratory testing temperature using the equation given in Step 4 for AC modulus as a function of mix parameters and temperature. Field-frequency E_{ac} values will typically be 2 to 2.5 times higher than lab-frequency values.

Agencies may also wish to establish correlations between resilient modulus and indirect tensile strength for specific AC mixes.

(2) *PCC modulus of rupture (S'_c).* Cut several 6-inch-diameter cores at midslab and test in indirect tension (ASTM C 496). Compute the indirect tensile strength (psi) of the cores. Estimate the modulus of rupture with the following equation.

$$S'_c = 210 + 1.02IT$$

where

S'_c = modulus of rupture, psi

IT = indirect tensile strength of 6-inch-diameter cores, psi

Step 6: Determination of required slab thickness for future traffic (D_f).

The inputs to determine D_f for AC overlays of AC/PCC pavements are representative of the existing slab and foundation properties. This is emphasized because it is the properties of the existing slab (i.e., elastic modulus, modulus of rupture, and load transfer) which will control the performance of the AC overlay.

(1) *Effective static k-value beneath existing PCC slab.* Determine from one of the following methods.

(a) Backcalculate effective dynamic k-value from deflection basins as described in Step 4. Divide the effective dynamic k-value by 2 to obtain the effective static k-value. The effective static k-value may need to be adjusted for seasonal effects using the approach presented in Part II, Section 3.2.1.

   (b) Conduct plate load tests (ASTM D 1196) after slab removal at a few sites. This alternative is very costly and time-consuming and not often used. The static k-value obtained may need to be adjusted for seasonal effects (see Part II, Section 3.2.1).

   (c) Estimate from soils data and base type and thickness, using Figure 3.3 in Part II, Section 3.2. This alternative is simple, but the static k-value obtained must be recognized as a rough estimate. The static k-value obtained may need to be adjusted for seasonal effects (see Part II, Section 3.2.1).

(2) *Design PSI loss.* PSI immediately after overlay (P1) minus PSI at time of next rehabilitation (P2).

(3) *J, load transfer of existing PCC slab.* See Step 4.

(4) *PCC modulus of rupture,* determined by one of the following methods:

   (a) Estimate from indirect tensile strength measured from 6-inch-diameter cores, as described in Step 5.

   (b) For AC/JPCP and AC/JRCP, estimate from the E of the slab, backcalculated as described in Step 4. Use the following equation:

$$S'_c = 43.5 \left(\frac{E}{10^6}\right) + 488.5$$

where

S'_c = modulus of rupture, psi
E = backcalculated elastic modulus of PCC slab, psi

For AC/CRCP, estimating S'_c from backcalculated E values is not recommended since cracks which are not reflected in the existing AC overlay may exist in the CRCP within the deflection basins.

(5) *Elastic modulus of existing PCC slab,* determined by one of the following methods:

   (a) Backcalculated from deflection measurements, as described in Step 4.

   (b) Estimated from indirect tensile strength.

(6) *Loss of support of existing slab* that might exis after rehabilitation. Procedures for use of deflection testing to investigate loss of suppor beneath AC/PCC pavements have not yet bee established. For overlay thickness design assume the slab is fully supported, LS = 0.

(7) *Overlay design reliability, R (percent).* Se Part I, Section 4.2, Part II, Table 2.2, and Par III, Section 5.2.15.

(8) *Overall standard deviation, S_o, for PCC pavement.* See Part I, Section 4.3.

(9) *Subdrainage capability of existing slab, afte subdrainage improvements, if any.* See Part II Table 2.5, as well as reference 5, for guidanc in determining C_d. Pumping or faulting at re flection cracks is evidence that a subdrainag problem exists. In selecting this value, no that the poor drainage situation at the AASH Road Test would be given a C_d of 1.0.

Compute D_f for the above design inputs using th rigid pavement design equation or nomograph in Pa II, Figure 3.7. When designing an overlay thicknes for a uniform pavement section, mean input valu must be used. When designing an overlay thicknes for specific points along the project, the data for th point must be used. A worksheet for determining D_f provided in Table 5.9. Typical values of inputs a provided for guidance. Values outside these range should be used with caution.

Step 7: Determination of effective slab thicknes (D_{eff}) of existing pavement.

A condition survey method for determination D_{eff} is presented for AC/PCC pavements. The effe tive thickness of the existing slab (D_{eff}) is comput from the following equation:

$$D_{eff} = (D_{pcc} * F_{jc} * F_{dur}) + \left[\left(\frac{D_{ac}}{2.0}\right) * F_{ac}\right]$$

where

D_{pcc} = thickness of existing PCC slab, inches
D_{ac} = thickness of existing AC surface, inches

(1) *Joints and cracks adjustment factor (F_{jc}).* T factor adjusts for the extra loss in PSI caus by deteriorated reflection cracks that will c cur in a second overlay due to unrepair deteriorated reflection cracks and other d

Table 5.9. Worksheet for Determination of D_f for AC/JPCP, AC/JRCP, and AC/CRCP

SLAB:

Existing AC surface thickness = ____________________ inches

Existing PCC slab thickness = ____________________ inches

Type of load transfer system: mechanical device, aggregate interlock, CRCP

Type of shoulder = tied PCC, other

PCC modulus of rupture (typically 600 to 800 psi) = ____________________ psi

PCC E modulus (3 to 8 million psi for sound PCC, <3 million for unsound PCC) = ____________________ psi

J load transfer factor (3.2 to 4.0 for AC/JPCP, AC/JRCP 2.2 to 2.6 for AC/CRCP) = ____________________

TRAFFIC:

Future 18-kip ESALs in design lane over the design period (N_f) = ____________________

SUPPORT AND DRAINAGE:

Effective dynamic k-value = ____________________ psi/inch

Effective static k-value = Effective dynamic k-value/2 (typically 50 to 500 psi/inch) = ____________________ psi/inch

Subdrainage coefficient, C_d (typically 1.0 for poor subdrainage conditions) = ____________________

SERVICEABILITY LOSS:

Design PSI loss (P1 − P2) = ____________________

RELIABILITY:

Design reliability, R (80 to 99 percent) = ____________________ percent

Overall standard deviation, S_o (typically 0.39) = ____________________

FUTURE STRUCTURAL CAPACITY:

Required slab thickness for future traffic is determined from rigid pavement design equation or nomograph in Part II, Figure 3.7.

D_f = ____________________ inches

continuities in the existing AC/PCC pavement prior to overlay. A deteriorated reflection crack in the existing AC/PCC pavement will rapidly reflect through a second overlay and contribute to loss of serviceability. Therefore, it is recommended that all deteriorated reflection cracks and any other major discontinuities in the existing pavement be full-depth repaired with dowelled or tied PCC repairs prior to overlay, so that F_{jc} = 1.00.

If it is not possible to repair all deteriorated areas, the following information is needed to determine F_{jc}, to increase the overlay thickness to account for the extra loss in PSI from deteriorated reflection cracks:

Number of unrepaired deteriorated reflection cracks/mile
Number of unrepaired punchouts/mile
Number of expansion joints, exceptionally wide joints (greater than 1 inch), and full-depth, full-lane-width AC patches/mile

The total number of unrepaired deteriorated reflection cracks, punchouts, and other discontinuities per mile is used to determine the F_{jc} from Figure 5.12.

(2) *Durability adjustment factor (F_{dur}).* This factor adjusts for an extra loss in PSI of the overlay when the existing slab has durability problems such as "D" cracking or reactive aggregate distress. Using historical records and condition survey data from Step 3, F_{dur} is determined as follows.

1.00: No evidence or history of PCC durability problems
0.96–0.99: Pavement is known to have PCC durability problems, but no localized failures or related distresses are visible
0.88–0.95: Some durability distress (localized failures, etc.) is visible at pavement surface
0.80–0.88: Extensive durability distress (localized failures, etc.) is visible at pavement surface

(3) AC quality adjustment factor (F_{ac}). This factor adjusts the existing AC layer's contribution to D_{eff} based on the quality of the AC material. The value selected should depend only on distresses related to the AC layer (i.e., not reflection cracking) which are not eliminated by surface milling: rutting, stripping, shoving, and also weathering and ravelling if the surface is not milled. Consideration should be given to complete removal of a poor-quality AC layer.

1.00: No AC material distress
0.96–0.99: Minor AC material distress (weathering, ravelling) not corrected by surface milling
0.88–0.95: Significant AC material distress (rutting, stripping, shoving)
0.80–0.88: Severe AC material distress (rutting, stripping, shoving)

A worksheet for calculation of D_{eff} is provided in Table 5.10.

Step 8: ***Determination of Overlay Thickness.***

The thickness of AC overlay is computed as follows:

$$D_{ol} = A(D_f - D_{eff})$$

where

D_{ol} = Required thickness of AC overlay, inches
A = Factor to convert PCC thickness deficiency to AC overlay thickness
D_f = Slab thickness determined in Step 6, inches
D_{eff} = Effective thickness of existing slab determined in Step 7, inches

The A factor, which is a function of the PCC thickness deficiency, is given by the following equation and is illustrated in Figure 5.9.

$$A = 2.2233 + 0.0099(D_f - D_{eff})^2 - 0.1534(D_f - D_{eff})$$

The thickness of overlay determined from the above relationship should be reasonable when the overlay is required to correct a structural deficiency. See Section 5.2 for discussion of factors which may result in unreasonable overlay thicknesses.

5.7.6 Surface Milling

If the AC surface is to be milled prior to overlay, the depth of milling should be considered in the determination of D_{eff}. No adjustment need be made to D_{eff} values if the depth of milling does not exceed the minimum necessary to remove surface ruts. If a greater depth is milled, the AC thickness remaining after milling should be used in determining D_{eff}.

5.7.7 Shoulders

See Section 5.2.10 for guidelines.

Table 5.10. Calculation of D_{eff} for AC Overlay of AC/JPCP, AC/JRCP, and AC/CRCP

Condition Survey Method:

F_{jc}

Number of unrepaired deteriorated reflection cracks/mile = ____________________

Number of punchouts/mile = ____________________

Number of expansion joints, exceptionally wide joints (> 1 inch) or full-depth patches/mile = ____________________

Total/mile = ____________________

F_{jc} = ____________________ (Figure 5.12)

(Recommended value 1.0, repair all deteriorated areas)

F_{dur}

1.00: No sign or knowledge of PCC durability problems

0.96–0.99: Pavement is known to have PCC durability problems, but no localized failures or related distresses

0.88–0.95: Some durability distress (localized failures, etc.) is visible at pavement surface

0.80–0.88: Extensive durability distress (localized failures, etc.)

F_{dur} = ____________________

F_{ac}

1.00: No AC material distress

0.96–0.99: Minor AC material distress (weathering, ravelling) not corrected by surface milling

0.88–0.95: Significant AC material distress (rutting, stripping, shoving)

0.80–0.88: Severe AC material distress (rutting, stripping, shoving)

F_{ac} = ____________________

$$D_{eff} = (D_{pcc} * F_{jc} * F_{dur}) + \left[\left(\frac{D_{ac}}{2.0}\right) * F_{ac}\right] = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

5.7.8 Widening

See Section 5.2.16 for guidelines.

5.8 BONDED CONCRETE OVERLAY OF JPCP, JRCP, AND CRCP

Bonded concrete overlays have been placed on jointed plain, jointed reinforced and continuously reinforced concrete pavements to improve both structural capacity and functional condition. A bonded concrete overlay consists of the following construction tasks:

(1) Repairing deteriorated areas and making subdrainage improvements (if needed)
(2) Constructing widening (if needed)
(3) Preparing the existing surface to ensure a reliable bond
(4) Placing the concrete overlay
(5) Sawing and sealing the joints

5.8.1 Feasibility

A bonded overlay of JPCP, JRCP, or CRCP is a feasible rehabilitation alternative for PCC pavements except when the conditions of the existing pavement dictate substantial removal and replacement or when durability problems exist (*28*). Conditions under which a PCC bonded overlay would not be feasible include:

(1) The amount of deteriorated slab cracking and joint spalling is so great that a substantial amount of removal and replacement of the existing surface is dictated.
(2) Significant deterioration of the PCC slab has occurred due to durability problems (e.g., "D" cracking or reactive aggregates). This will affect performance of the overlay.
(3) Vertical clearance at bridges is inadequate for required overlay thickness. This is not usually a problem because bonded overlays are usually fairly thin.

If construction duration is critical, PCC overlays may utilize high-early-strength PCC mixes. PCC overlays have been opened within 6 to 24 hours after placement using these mixtures.

5.8.2 Pre-overlay Repair

The following types of distress should be repaired prior to placement of the bonded PCC overlay.

Distress Type	Repair Type
Working cracks	Full-depth repair or slab replacement
Punchouts	Full-depth repair
Spalled joints	Full- or partial-depth repair
Deteriorated patches	Full-depth repair
Pumping/faulting	Edge drains
Settlements/heaves	Slab jack or reconstruct area

Full-depth repairs and slab replacements in JPCP and JRCP should be PCC, dowelled or tied to provide load transfer across repair joints. Full-depth repairs in CRCP should be PCC and should be continuously reinforced with steel which is tied or welded to reinforcing steel in the existing slab, to provide load transfer across joints and slab continuity. Full-depth AC repairs should not be used prior to placement of a bonded PCC overlay, and any existing AC patches should be removed and replaced with PCC. Guidelines on repairs are provided in References 1 and 3.

Installation of edge drains, maintenance of existing edge drains, or other subdrainage improvement should be done prior to placement of the overlay if a subdrainage evaluation indicates a need for such an improvement.

Pressure relief joints should be done only at fixed structures, and not at regular intervals along the pavement. The only exception to this is where a reactive aggregate has caused expansion of the slab. On heavily trafficked routes, expansion joints should be of the heavy-duty type with dowels (*3*). If joints contain significant incompressibles, they should be cleaned and resealed prior to overlay placement.

5.8.3 Reflection Crack Control

Any working (spalled) cracks in the existing JPCP, JRCP, or CRCP slab may reflect through the bonded concrete overlay within one year. Reflection cracks can be controlled in bonded overlays by full-depth repair of working cracks in the existing pavement, and for JPCP or JRCP, sawing and sealing joints through the overlay directly over the repair joints. Tight nonworking cracks do not need to be repaired because not all will reflect through the overlay and those that do will usually remain tight. Tight cracks in CRCP will take several years to reflect through, and even then will remain tight.

5.8.4 Subdrainage

See Section 5.2.4 for guidelines.

5.8.5 Thickness Design

If the overlay is being placed for some functional purpose such as roughness or friction, a minimum thickness overlay that solves the functional problem should be placed.

If the overlay is being placed for the purpose of structural improvement, the required thickness of the overlay is a function of the structural capacity required to meet future traffic demands and the structural capacity of the existing pavement. The required overlay thickness to increase structural capacity to carry future traffic is determined by the following equation.

$$D_{ol} = D_f - D_{eff}$$

where

D_{ol} = Required thickness of bonded PCC overlay, inches
D_f = Slab thickness to carry future traffic, inches
D_{eff} = Effective thickness of existing slab, inches

Bonded concrete overlays have been successfully constructed as thin as 2 inches and as thick as 6 inches or more. Three to 4 inches has been typical for most highway pavement overlays (*28*). If the bonded overlay is being placed only for a functional purpose such as roughness or friction, a thickness of 3 inches should be adequate.

The required overlay thickness may be determined through the following design steps. These design steps provide a comprehensive design approach that recommends testing the pavement to obtain valid design inputs. If it is not possible to conduct this testing, an approximate overlay design may be developed based upon visible distress observations by skipping Steps 4 and 5, and by estimating other inputs.

The overlay design can be done for a uniform section or on a point-by-point basis as described in Section 5.3.1.

Step 1: Existing pavement design.

(1) Existing slab thickness
(2) Type of load transfer (mechanical devices, aggregate interlock, CRCP)
(3) Type of shoulder (tied, PCC, other)

Step 2: Traffic analysis.

(1) Past cumulative 18-kip ESALs in the design lane (N_p), for use in the remaining life method of D_{eff} determination only
(2) Predicted future 18-kip ESALs in the design lane over the design period (N_f)

Step 3: Condition survey.

The following distresses are measured during the condition survey for JPCP, JRCP, and CRCP. Sampling along the project may be used to estimate these quantities in the most heavily trafficked lane. Distress types and severities are defined in Reference 23. Deteriorated means medium or higher severity.

JPCP/JRCP:

(1) Number of deteriorated transverse joints per mile
(2) Number of deteriorated transverse cracks per mile
(3) Number of existing expansion joints, exceptionally wide joints (>1 inch) or AC full-depth patches
(4) Presence and general severity of PCC durability problems
    (a) "D" cracking: low severity (cracks only), medium severity (some spalling), high severity (severe spalling)
    (b) Reactive aggregate cracking: low, medium, high severity
(5) Evidence of faulting, pumping of fines or water at joints, cracks and pavement edge

CRCP:

(1) Number of punchouts per mile
(2) Number of deteriorated transverse cracks per mile
(3) Number of existing expansion joints, exceptionally wide joints (>1 inch) or AC full-depth patches
(4) Number of existing and new repairs prior to overlay per mile
(5) Presence and general severity of PCC durability problems (NOTE: surface spalling of tight cracks where the underlying CRCP is sound should not be considered a durability problem)
    (a) "D" cracking: low severity (cracks only), medium severity (some spalling), high severity (severe spalling)
    (b) Reactive aggregate cracking: low, medium, high severity
(6) Evidence of pumping of fines or water

Step 4: Deflection testing (strongly recommended).

Measure slab deflection basins in the outer wheel path along the project at an interval sufficient to adequately assess conditions. Intervals of 100 to 1,000 feet are typical. Measure deflections with sensors located at 0, 12, 24, and 36 inches from the center of load. A heavy-load deflection device (e.g., Falling Weight Deflectometer) and a load magnitude of 9,000 pounds are recommended. ASTM D 4694 and D 4695 provide additional guidance on deflection testing.

For each slab tested, backcalculate the effective k-value and the slab's elastic modulus using Figures 5.10 and 5.11 or a backcalculation procedure. The AREA of each deflection basin is computed as follows:

$$AREA = 6 * \left[1 + 2\left(\frac{d_{12}}{d_0}\right) + 2\left(\frac{d_{24}}{d_0}\right) + \left(\frac{d_{36}}{d_0}\right)\right]$$

where

d_0 = deflection in center of loading plate, inches
d_i = deflections at 12, 24, and 36 inches from plate center, inches

AREA will typically range from 29 to 32 for sound concrete.

(1) *Effective dynamic k-value.* Enter Figure 5.10 with d_0 and AREA to determine the effective dynamic k-value beneath each slab for a circular load radius of 5.9 inches and magnitude of 9,000 pounds. Note that for loads within 2,000 pounds more or less, deflections may be scaled linearly to 9,000-pound deflections.

If a single overlay thickness is being designed for a uniform section, compute the mean effective dynamic k-value of the slabs tested in the uniform section.

(2) *Effective static k-value.*

Effective static k-value
= Effective dynamic k-value/2

The effective k-value may need to be adjusted for seasonal effects using the approach presented in Part II, Section 3.2.1. However, the k-value can change substantially and have only a small effect on overlay thickness.

(3) *Elastic modulus of PCC slab (E).* Enter Figure 5.11 with AREA, proceed to the effective dynamic k-value curves, and determine a value for ED^3, where D is the slab thickness. Solve for E knowing the slab thickness, D. Typical slab E values range from 3 to 8 million psi. If a slab E value is obtained that is out of this range, an error may exist in the assumed slab thickness, the deflection basin may have been measured over a crack, or the PCC may be significantly deteriorated.

If a single overlay thickness is being designed for a uniform section, compute the mean E value of the slabs tested in the uniform section.

Do not use any k-values or E values that appear to be significantly out of line with the rest of the data.

(4) *Joint load transfer.* For JPCP and JRCP, measure joint load transfer in the outer wheelpath at representative transverse joints. Do not measure load transfer when the ambient temperature is greater than 80°F. Place the load plate on one side of the joint with the edge of the plate touching the joint. Measure the deflection at the center of the load plate and at 12 inches from the center. Compute the deflection load transfer from the following equation.

$$\Delta LT = 100 * \left(\frac{\Delta_{ul}}{\Delta_l}\right) * B$$

where

ΔLT = deflection load transfer, percent
Δ_{ul} = unloaded side deflection, inches
Δ_l = loaded side deflection, inches
B = slab bending correction factor

The slab bending correction factor, B, is necessary because the deflections d_0 and d_{12}, measured 12 inches apart, would not be equal even if measured in the interior of a slab. An appropriate value for the correction factor may be determined from the ratio of d_0 to d_{12} for typical center slab deflection basin measurements, as shown in the equation below. Typical values for B are between 1.05 and 1.15.

$$B = \frac{d_{0\,center}}{d_{12\,center}}$$

If a single overlay thickness is being designed for a uniform section, compute the mean deflection load transfer value of the joints tested in the uniform section.

For JPCP and JRCP, determine the J load transfer coefficient using the following guidelines:

Percent Load Transfer	J
>70	3.2
50–70	3.5
<50	4.0

If the rehabilitation will include the addition of a tied concrete shoulder, a lower J factor may be appropriate. See Part II, Table 2.6.

For CRCP, use J = 2.2 to 2.6 for overlay design, assuming that working cracks and punchouts are repaired with continuously reinforced PCC.

Step 5: Coring and materials testing (strongly recommended).

(1) *PCC modulus of rupture (S'_c).* Cut several 6-inch-diameter cores at mid-slab and test in indirect tension (ASTM C 496). Compute the indirect tensile strength (psi) of the cores. Estimate the modulus of rupture with the following equation:

$$S'_c = 210 + 1.02IT$$

where

S'_c = modulus of rupture, psi
IT = indirect tensile strength of 6-inch diameter cores, psi

Step 6: Determination of required slab thickness for future traffic (D_f).

The inputs to determine D_f for bonded PCC overlays of PCC pavements are representative of the existing slab and foundation properties. This is emphasized because it is the properties of the existing slab (i.e., elastic modulus, modulus of rupture, and load transfer) which will control the performance of the bonded overlay.

(1) *Effective static k-value.* Determine from one of the following methods.
  (a) Backcalculate the effective dynamic k-value from deflection basins as described in Step 4. Divide the effective dynamic k-value by 2 to obtain the effective static k-value.
  (b) Conduct plate load tests (ASTM D 1196) after slab removal at a few sites. This alternative is very costly and time-consuming and not often used. The static k-value obtained may need to be adjusted for seasonal effects using the approach presented in Part II, Section 3.2.1.
  (c) Estimate from soils data and base type and thickness, using Figure 3.3 in Part II, Section 3.2. This alternative is simple, but the static k-value obtained must be recognized as a rough estimate. The static k-value obtained may need to be adjusted for seasonal effects using the approach presented in Part II, Section 3.2.1.

(2) *Design PSI loss.* PSI immediately after overlay (P1) minus PSI at time of next rehabilitation (P2).

(3) *J, load transfer factor.* See Step 4.

(4) *PCC modulus of rupture* determined by one of the following methods:
  (a) Estimated from indirect tensile strength measured from 6-inch diameter cores as described in Step 5.
  (b) Estimated from the backcalculated E of slab using the following equation:

$$S'_c = 43.5\left(\frac{E}{10^6}\right) + 488.5$$

where

S'_c = modulus of rupture, psi
E = backcalculated elastic modulus of PCC slab, psi

For CRCP, S'_c may be determined from the backcalculated E values only at points which have no cracks within the deflection basins.

(5) *Elastic modulus of existing PCC slab,* determined by one of the following methods:
  (a) Backcalculate from deflection measurements as described in Step 4.
  (b) Estimate from indirect tensile strength.

(6) *Loss of support of existing slab.* Joint corners that have loss of support may be identified using FWD deflection testing as described in Reference 2. CRCP loss of support can be determined by plotting a slab edge or wheel path deflection profile and identifying locations with significantly high deflections. Existing loss of support can be improved with slab stabilization. For thickness design, assume a fully supported slab, LS = 0.

(7) *Overlay design reliability, R (percent).* See Part I, Section 4.2, Part II, Table 2.2, and Part III, Section 5.2.15.

(8) *Overall standard deviation (S_o) for rigid pavement.* See Part I, Section 4.3.

(9) *Subdrainage capability of existing slab, after subdrainage improvements, if any.* See Part II,

Table 2.5, as well as Reference 5, for guidance in determining C_d. Pumping or faulting at joints and cracks determined in Step 3 is evidence that a subdrainage problem exists. In selecting this value, note that the poor subdrainage situation at the AASHO Road Test would be given a C_d of 1.0.

Compute D_f for the above design inputs using the rigid pavement design equation or nomograph in Part II, Figure 3.7. When designing an overlay thickness for a uniform pavement section, mean input values must be used. When designing an overlay thickness for specific points along the project, the data for that point must be used. A worksheet for determining D_f is provided in Table 5.11. Typical values of inputs are provided for guidance. Values outside these ranges should be used with caution.

Step 7: Determination of effective slab thickness (D_{eff}) of existing pavement.

The condition survey and remaining life procedures are presented.

D_{eff} From Condition Survey For PCC Pavements

The effective thickness of the existing slab (D_{eff}) is computed from the following equation:

$$D_{eff} = F_{jc} * F_{dur} * F_{fat} * D$$

where

D = existing PCC slab thickness, inches

(1) *Joints and cracks adjustment factor (F_{jc}).* This factor adjusts for the extra loss in PSI caused by deteriorated reflection cracks in the overlay that will result from any unrepaired deteriorated joints, cracks, and other discontinuities in the existing slab prior to overlay. A deteriorated joint or crack in the existing slab will rapidly reflect through an AC overlay and contribute to loss of serviceability. Therefore, it is recommended that all deteriorated joints and cracks (for non-"D" cracked or reactive aggregate related distressed pavements) and any other major discontinuities in the existing slab be full-depth repaired with dowelled or tied PCC repairs prior to overlay, so that F_{jc} = 1.00.

If it is not possible to repair all deteriorated areas, the following information is needed to determine F_{jc}, to increase the overlay thickness to account for the extra loss in PSI from deteriorated reflection cracks (per design lane):

Pavements with no "D" cracking or reactive aggregate distress:

Number of unrepaired deteriorated joints/mile
Number of unrepaired deteriorated cracks/mile
Number of unrepaired punchouts/mile
Number of expansion joints, exceptionally wide joints (greater than 1 inch), and full-depth, full-lane-width AC patches/mile

NOTE that tight cracks held together by reinforcement in JRCP or CRCP are not included. However, if a crack in JRCP or CRCP is spalled and faulted the steel has probably ruptured, and the crack should be considered as working. Surface spalling of CRCP cracks is not an indication that the crack is working.

The total number of unrepaired deteriorated joints, cracks, punchouts, and other discontinuities per mile is used to determine the F_{jc} from Figure 5.12.

Pavements with "D" cracking or reactive aggregate deterioration:

These types of pavements often have deterioration at the joints and cracks from durability problems. The F_{dur} factor is used to adjust the overlay thickness for this problem. Therefore, when this is the case, the F_{jc} should be determined from Figure 5.12 only using those unrepaired deteriorated joints and cracks that are not caused by durability problems. If all of the deteriorated joints and cracks are spalling due to "D" cracking or reactive aggregate, then F_{jc} = 1.0. This will avoid adjusting twice with the F_{jc} and F_{dur} factors.

(2) *Durability adjustment factor (F_{dur}).* This factor adjusts for an extra loss in PSI of the overlay when the existing slab has durability problems such as "D" cracking or reactive aggregate distress. Using condition survey data from Step 3, F_{dur} is determined as follows.

1.00:	No sign of PCC durability problems
0.96–0.99:	Durability cracking exists, but no spalling

Table 5.11. Worksheet for Determination of D_f for JPCP, JRCP, and CRCP

SLAB:

Existing PCC slab thickness = ____________ inches

Type of load transfer system: mechanical device, aggregate interlock, CRCP

Type of shoulder = tied PCC, other

PCC modulus of rupture (typically 600 to 800 psi) = ____________ psi

PCC E modulus (3 to 8 million psi for sound PCC, <3 million for unsound PCC) = ____________ psi

J load transfer factor (3.2 to 4.0 for JPCP, JRCP 2.2 to 2.6 for CRCP) = ____________

TRAFFIC:

Future 18-kip ESALs in design lane over the design period (N_f) = ____________

SUPPORT AND DRAINAGE:

Effective dynamic k-value = ____________ psi/inch

Effective static k-value = effective dynamic k-value/2 (typically 50 to 500 psi/inch) = ____________ psi/inch

Subdrainage coefficient, C_d (typically 1.0 for poor subdrainage conditions) = ____________

SERVICEABILITY LOSS:

Design PSI loss (P1 − P2) = ____________

RELIABILITY:

Design reliability, R (80 to 99 percent) = ____________ percent

Overall standard deviation, S_o (typically 0.39) = ____________

FUTURE STRUCTURAL CAPACITY:

Required slab thickness for future traffic is determined from rigid pavement design equation or nomograph in Part II, Figure 3.7.

D_f = ____________ inches

0.80–0.95: Cracking and spalling exist (normally a bonded PCC overlay is not recommended under these conditions)

(3) *Fatigue damage adjustment factor (F_{fat}).* This factor adjusts for past fatigue damage that may exist in the slab. It is determined by observing the extent of transverse cracking (JPCP, JRCP) or punchouts (CRCP) that may be caused primarily by repeated loading. Use condition survey data from Step 3 and the following guidelines to estimate F_{fat} for the design lane.

0.97–1.00: Few transverse cracks/punchouts exist (none caused by "D" cracking or reactive aggregate distress)

JPCP: <5 percent slabs are cracked
JRCP: <25 working crack per mile
CRCP: <4 punchouts per mile

0.94–0.96: A significant number of transverse cracks/punchouts exist (none caused by "D" cracking or reactive aggregate distress)
JPCP: 5–15 percent slabs are cracked
JRCP: 25–75 working cracks per mile
CRCP: 4–12 punchouts per mile

0.90–0.93: A large number of transverse cracks/punchouts exist (none caused by "D" cracking or reactive aggregate distress)
JPCP: >15 percent slabs are cracked
JRCP: >75 working cracks per mile
CRCP: >2 punchouts per mile

D_{eff} From Remaining Life For PCC Pavements

The remaining life of the pavement is given by the following equation:

$$RL = 100\left[1 - \left(\frac{N_p}{N_{1.5}}\right)\right]$$

where

RL = remaining life, percent
N_p = total traffic to date, ESALs
$N_{1.5}$ = total traffic to pavement "failure," ESALs

$N_{1.5}$ may be estimated using the new pavement design equations or nomographs in Part II. To be consistent with the AASHO Road Test and the development of these equations, a "failure" PSI equal to 1.5 and a reliability of 50 percent is recommended.

D_{eff} is determined from the following equation:

$$D_{eff} = CF * D$$

where

CF = condition factor determined from Figure 5.2
D = thickness of the existing slab, inches

The designer should recognize that D_{eff} determined by this method does not reflect any benefit for pre-overlay repair. The estimate of D_{eff} obtained should thus be considered a lower limit value. The D_{eff} of the pavement will be higher if pre-overlay repair of load-associated distress is done.

A worksheet for determination of D_{eff} for JPCP, JRCP, and CRCP is provided in Table 5.12.

Step 8: Determination of Overlay Thickness.

The thickness of bonded PCC overlay is computed as follows:

$$D_{ol} = D_f - D_{eff}$$

where

D_{ol} = Required thickness of bonded PCC overlay, inches
D_f = Slab thickness determined in Step 6, inches
D_{eff} = Effective thickness of existing slab determined in Step 7, inches

The thickness of overlay determined from the above relationship should be reasonable when the overlay is required to correct a structural deficiency. See Section 5.2.17 for discussion of factors which may result in unreasonable overlay thicknesses.

5.8.6 Shoulders

See Section 5.2.10 for guidelines.

5.8.7 Joints

Existing JPCP and JRCP. Transverse and longitudinal joints should be saw cut completely through the overlay thickness (plus 0.5-inch depth) as soon as curing allows after overlay placement. Failure to saw joints soon after placement may result in debonding and cracking at the joints. No dowels or reinforcing steel should be placed in these joints. An appropriate sealant reservoir should be sawed and sealant should be placed as soon as possible.

Existing CRCP. Transverse joints must not be cut in the bonded overlay, as they are not needed. Transverse joints are also not needed for the end joints for full-

Table 5.12. Calculation of D_{eff} for Bonded PCC Overlay of JPCP, JRCP, and CRCP

Condition Survey Method:

F_{jc} Number of unrepaired deteriorated joints/mile = ____________________

Number of unrepaired deteriorated cracks/mile = ____________________

Number of unrepaired punchouts/mile = ____________________

Number of expansion joints, exceptionally wide joints (> 1 inch) or AC full-depth patches/mile = ____________________

Total/mile = ____________________

F_{jc} = ____________________ (Figure 5.12)

(Recommended value 1.0, repair all deteriorated areas)

F_{dur} 1.00: No sign of PCC durability problems

0.96–0.99: Some durability cracking exists, but no spalling exists

0.88–0.95: Cracking and spalling exist

F_{dur} = ____________________

F_{fat} 0.97–1.00: Very few transverse cracks/punchouts exist

0.94–0.96: A significant number of transverse cracking/punchouts exist

0.90–0.93: A large amount of transverse cracking/punchouts exist

F_{fat} = ____________________

$D_{eff} = F_{jc} * F_{dur} * F_{fat} * D$ = ____________________

Remaining Life Method:

N_p = Past design lane ESALs = ____________________

$N_{1.5}$ = Design lane ESALs to P2 of 1.5 = ____________________

$RL = 100\left[1 - \left(\frac{N_p}{N_{1.5}}\right)\right]$ = ____________________

CF = ____________________ (Figure 5.2)

$D_{eff} = CF * D$ = ____________________

depth reinforced tied concrete patches. Longitudinal joints should be sawed in the same manner as for JPCP and JRCP.

5.8.8 Bonding Procedures and Material

The successful performance of the bonded overlay depends on a reliable bond with the existing surface *(28)*. The following guidelines are provided:

(1) The existing surface must be cleaned and roughened, through a mechanical process that removes a thin layer of concrete, but does not damage (crack) the surface. Shot blasting is the most used system. Cold milling has been used, but may cause damage to the surface and thus requires sand blasting afterward to remove any loose particles.
(2) A bonding agent is recommended to help achieve a more reliable bond. Water, cement, and sand mortar; water and cement slurry; and low-viscosity epoxy have been used for this purpose. Bonded overlays constructed without a bonding agent have performed well in some instances.

5.8.9 Widening

See Section 5.2.16 for guidelines.

5.9 UNBONDED JPCP, JRCP, AND CRCP OVERLAY OF JPCP, JRCP,CRCP, AND AC/PCC

An unbonded JPCP, JRCP, or CRCP overlay of an existing JPCP, JRCP, CRCP, or composite (AC/PCC) pavement can be placed to improve both structural capacity and functional condition. An unbonded concrete overlay consists of the following construction tasks:

(1) Repairing only badly deteriorated areas and making subdrainage improvements (if needed)
(2) Constructing widening (if needed)
(3) Placing a separation layer (this layer may also serve as a leveling course)
(4) Placing the concrete overlay
(5) Sawing and sealing the joints

5.9.1 Feasibility

An unbonded overlay is a feasible rehabilitation alternative for PCC pavements for practically all conditions. They are most cost-effective when the existing pavement is badly deteriorated because of reduced need for pre-overlay repair. Conditions under which a PCC unbonded overlay would not be feasible include:

(1) The amount of deteriorated slab cracking and joint spalling is not large and other alternatives would be much more economical.
(2) Vertical clearance at bridges is inadequate for required overlay thickness. This may be addressed by reconstructing the pavement under the overhead bridges or by raising the bridges. Thicker unbonded overlays may also necessitate raising signs and guardrails, as well as increasing side slopes and extending culverts. Sufficient right-of-way must be available or obtainable to permit these activities.
(3) The existing pavement is susceptible to large heaves or settlements.

If construction duration is critical, PCC overlays may utilize high-early-strength PCC mixes. PCC overlays have been opened within 6 to 24 hours after placement using these mixtures.

5.9.2 Pre-overlay Repair

One major advantage of an unbonded overlay is that the amount of repairs to the existing pavement are greatly reduced. However, unbonded overlays are not intended to bridge localized areas of nonuniform support. The following types of distress (on the next page) should be repaired prior to placement of the overlay to prevent reflection cracks that may reduce its service life.

Guidelines on repairs are provided in References 1 and 3. Other forms of pre-overlay treatment for badly deteriorated pavements include slab fracturing (break/seat, crack/seat, or rubblizing) the existing PCC slab prior to placement of the separation layer. Fracturing and seating the existing slab may provide more uniform support for the overlay.

5.9.3 Reflection Crack Control

When an AC separation layer of 1 to 2 inches is used, there should be no problem with reflection of cracks through unbonded overlays. However, this sep-

Distress Type	Overlay Type	Repair
Working crack	JPCP or JRCP	No repair needed
	CRCP	Full-depth dowelled repair if differential deflection is significant
Punchout	JPCP, JRCP, CRCP	Full-depth repair
Spalled joint	JPCP or JRCP	No repair needed
	CRCP	Full-depth repair of severely deteriorated joints
Pumping	JPCP, JRCP, CRCP	Edge drains (if needed)
Settlement	JPCP, JRCP, CRCP	Level-up with AC
Poor joint/crack load transfer	JPCP, JRCP, CRCP	No repair needed; if pavement has many joints or cracks with poor load transfer, consider a thicker AC separation layer

aration layer thickness may not be adequate for an unbonded overlay when the existing pavement has poor load transfer and high differential deflections across transverse cracks or joints.

5.9.4 Subdrainage

See Section 5.2.4 for guidelines.

5.9.5 Thickness Design

The required thickness of the unbonded overlay is a function of the structural capacity required to meet future traffic demands and the structural capacity of the existing pavement. The required overlay thickness to increase structural capacity to carry future traffic is determined by the following equation.

$$D_{ol} = \sqrt{D_f^2 - D_{eff}^2}$$

where

D_{ol} = Required thickness of unbonded PCC overlay, inches
D_f = Slab thickness to carry future traffic, inches
D_{eff} = Effective thickness of existing slab, inches

Unbonded concrete overlays have been successfully constructed as thin as 5 inches and as thick as 12 inches or more. Thicknesses of seven to 10 inches have been typical for most highway pavement unbonded overlays.

The required overlay thickness may be determined through the following design steps. These design steps provide a comprehensive design approach that recommends testing the pavement to obtain valid design inputs. If it is not possible to conduct this testing, an approximate overlay design may be developed based upon visible distress observations by skipping Steps 4 and 5, and by estimating other inputs.

The overlay design can be done for a uniform section or on a point-by-point basis as described in Section 5.3.1.

Step 1: Existing pavement design.

(1) Existing slab thickness
(2) Type of load transfer (mechanical devices, aggregate interlock, CRCP)
(3) Type of shoulder (tied, PCC, other)

Step 2: Traffic analysis.

(1) Past cumulative 18-kip ESALs in the design lane (N_p), for use in the remaining life method of D_{eff} determination only
(2) Predicted future 18-kip ESALs in the design lane over the design period (N_f)

Step 3: Condition survey.

The following distresses are measured during the condition survey for JPCP, JRCP, and CRCP. Sampling along the project may be used to estimate these quantities in the most heavily trafficked lane. Distress types and severities are defined in Reference 23. Deteriorated means medium or higher severity.

JPCP/JRCP:

(1) Number of deteriorated transverse joints per mile

(2) Number of deteriorated transverse cracks per mile

(3) Number of existing expansion joints, exceptionally wide joints (more than 1 inch) or full-depth, full-lane-width AC patches

(4) Presence and general severity of PCC durability problems

  (a) "D" cracking: low severity (cracks only), medium severity (some spalling), high severity (severe spalling)

  (b) Reactive aggregate cracking: low, medium, high severity

(5) Evidence of faulting, pumping of fines or water at joints, cracks and pavement edge

CRCP:

(1) Number of punchouts per mile

(2) Number of deteriorated transverse cracks per mile

(3) Number of existing expansion joints, exceptionally wide joints (> 1 inch) or full-depth, full-lane-width AC patches

(4) Number of existing and new repairs prior to overlay per mile

(5) Presence and general severity of PCC durability problems (NOTE: surface spalling of tight cracks where the underlying CRCP is sound should not be considered a durability problem)

  (a) "D" cracking: low severity (cracks only), medium severity (some spalling), high severity (severe spalling)

  (b) Reactive aggregate cracking: low, medium, high severity

(6) Evidence of pumping of fines or water

Step 4: Deflection testing (strongly recommended).

When designing an unbonded overlay for existing JPCP, JRCP, or CRCP, follow the guidelines given below for deflection testing and determination of the effective static k-value. When designing an unbonded overlay for existing AC/PCC, follow the guidelines given in Section 5.7, Step 4, for deflection testing and determination of the effective static k-value.

Measure slab deflection basins in the outer wheel path along the project at an interval sufficient to adequately assess conditions. Intervals of 100 to 1,000 feet are typical. Measure deflections with sensors located at 0, 12, 24, and 36 inches from the center of load. A heavy-load deflection device (e.g., Falling Weight Deflectometer) and a load magnitude of 9,000 pounds are recommended. ASTM D 4694 and D 4695 provide additional guidance on deflection testing.

For each slab tested, backcalculate the effective k-value using Figure 5.10 or a backcalculation procedure. The AREA of each deflection basin is computed from the following equation.

$$\text{AREA} = 6 * \left[1 + 2\left(\frac{d_{12}}{d_0}\right) + 2\left(\frac{d_{24}}{d_0}\right) + \left(\frac{d_{36}}{d_0}\right)\right]$$

where

d_0 = deflection in center of loading plate, inches
d_i = deflections at 12, 24, and 36 inches from plate center, inches

AREA will typically range from 29 to 32 for sound concrete.

(1) *Effective dynamic k-value.* Enter Figure 5.10 with d_0 and AREA to determine the effective dynamic k-value beneath each slab for a circular load radius of 5.9 inches and magnitude of 9,000 pounds. NOTE that for loads within 2,000 pounds more or less, deflections may be scaled linearly to 9,000-pound deflections.

If a single overlay thickness is being designed for a uniform section, compute the mean effective dynamic k-value of the slabs tested in the uniform section.

(2) *Effective static k-value.*

Effective static k-value
= Effective dynamic k-value/2

The effective static k-value may need to be adjusted for seasonal effects using the approach presented in Part II, Section 3.2.1. However, the k-value can change substantially and have only a small effect on overlay thickness.

Step 5: Coring and materials testing.

When designing an unbonded overlay for existing JPCP, JRCP, or CRCP, coring and materials testing of the existing PCC slab are not needed for overlay thickness design. When designing an unbonded overlay for existing AC/PCC, follow the guidelines given in Section 5.7, Step 5, for determination of the AC modulus by coring and materials testing.

Step 6: Determination of required slab thickness for future traffic (D_f).

The elastic modulus, modulus of rupture, and load transfer inputs to determine D_f for unbonded PCC overlays of PCC and AC/PCC pavements are representative of the new PCC overlay to be placed rather than of the existing slab. This is emphasized because it is the properties of the overlay slab (i.e., elastic modulus, modulus of rupture, and load transfer), which will control the performance of the unbonded overlay.

(1) *Effective static k-value beneath the existing pavement.* Determine from one of the following methods.
   (a) Backcalculate the effective dynamic k-value from deflection basins as described in Step 4. Divide the effective dynamic k-value by 2 to obtain the effective static k-value. The static k-value obtained may need to be adjusted for seasonal effects (see Part II, Section 3.2.1).
   (b) Conduct plate load tests (ASTM D 1196) after slab removal at a few sites. This alternative is very costly and time-consuming and not often used. The static k-value obtained may need to be adjusted for seasonal effects (see Part II, Section 3.2.1).
   (c) Estimate from soils data and base type and thickness, using Figure 3.3 in Part II, Section 3.2. This alternative is simple, but the static k-value obtained must be recognized as a rough estimate. The static k-value obtained may need to be adjusted for seasonal effects (see Part II, Section 3.2.1).

(2) *Design PSI loss.* PSI immediately after overlay (P1) minus PSI at time of next rehabilitation (P2).

(3) *J, load transfer factor for joint design of the unbonded PCC overlay.* See Part II, Section 2.4.2, Table 2.6.

(4) *PCC modulus of rupture of unbonded PCC overlay.*

(5) *Elastic modulus of unbonded PCC overlay.*

(6) *Loss of support.* Use LS = 0 for unbonded PCC overlay.

(7) *Overlay design reliability, R (percent).* See Part I, Section 4.2, Part II, Table 2.2, and Part III, Section 5.2.15.

(8) *Overall standard deviation (S_o) for rigid pavement.* See Part I, Section 4.3.

(9) *Subdrainage capability of existing slab,* after subdrainage improvements, if any. See Part II, Table 2.5, as well as Reference 5, for guidance in determining C_d. Pumping or faulting at joints and cracks determined in Step 3 is evidence that a subdrainage problem exists. In selecting this value, note that the poor drainage situation at the AASHO Road Test would be given a C_d of 1.0.

Compute D_f for the above design inputs using the rigid pavement design equation or nomograph in Part II, Figure 3.7. A worksheet for determining D_f is provided in Table 5.13.

Step 7: Determination of effective slab thickness (D_{eff}) of existing pavement.

The condition survey and remaining life procedures are presented.

D_{eff} From Condition Survey

The effective thickness (D_{eff}) of an existing PCC or AC/PCC pavement is computed from the following equation:

$$D_{eff} = F_{jcu} * D$$

where

D = existing PCC slab thickness, inches (NOTE: maximum D for use in unbonded concrete overlay design is 10 inches even if the existing D is greater than 10 inches)

F_{jcu} = joints and cracks adjustment factor for unbonded concrete overlays

NOTE that the existing AC surface is neglected in determining the effective slab thickness of an existing AC/PCC pavement.

Field surveys of unbonded jointed concrete overlays have shown very little evidence of reflection cracking or other problems caused by the existing slab. Therefore, the F_{dur} and F_{fat} are not used for unbonded concrete overlays. The F_{jcu} factor is modified to show a reduced effect of deteriorated cracks and joints in the existing slab, and is given in Figure 5.13.

(1) *Joints and cracks adjustment factor (F_{jcu}).* This factor adjusts for the extra loss in PSI caused by deteriorated reflection cracks or punchouts in the overlay that result from any unrepaired

Table 5.13. Worksheet for Determination of D_f for Unbonded PCC Overlay

SLAB:

Type of load transfer system: mechanical device, aggregate interlock, CRCP

Type of shoulder = tied PCC, other

PCC modulus of rupture of unbonded overlay (typically 600 to 800 psi) = ____________________ psi

PCC E modulus of unbonded overlay (3 to 5 million psi) = ____________________ psi

J load transfer factor of unbonded overlay (2.5 to 4.4 for jointed PCC, 2.3 to 3.2 for CRCP) = ____________________

TRAFFIC:

Future 18-kip ESALs in design lane over the design period (N_f) = ____________________

SUPPORT AND DRAINAGE:

Effective dynamic k-value = ____________________ psi/inch

Effective static k-value = Effective dynamic k-value/2 (typically 50 to 500 psi/inch) = ____________________ psi/inch

Subdrainage coefficient, C_d (typically 1.0 for poor subdrainage conditions) = ____________________

SERVICEABILITY LOSS:

Design PSI loss (P1 − P2) = ____________________

RELIABILITY:

Design reliability, R (80 to 99 percent) = ____________________ percent

Overall standard deviation, S_o (typically 0.39) = ____________________

FUTURE STRUCTURAL CAPACITY:

Required slab thickness for future traffic is determined from rigid pavement design equation or nomograph in Part II, Figure 3.7.

D_f = ____________________ inches

deteriorated joints, cracks and other discontinuities in the existing slab prior to overlay. Very little such loss in PSI has been observed for JPCP or JRCP unbonded overlays.

The following information is needed to determine F_{jcu} to adjust overlay thickness for the extra loss in PSI from deteriorated reflection cracks that are not repaired:

Number of unrepaired deteriorated joints/mile

Number of unrepaired deteriorated cracks/mile

Number of expansion joints, exceptionally wide joints (greater than 1 inch) or full-depth, full-lane-width AC patches/mile

The total number of unrepaired deteriorated joints/cracks and other discontinuities per mile

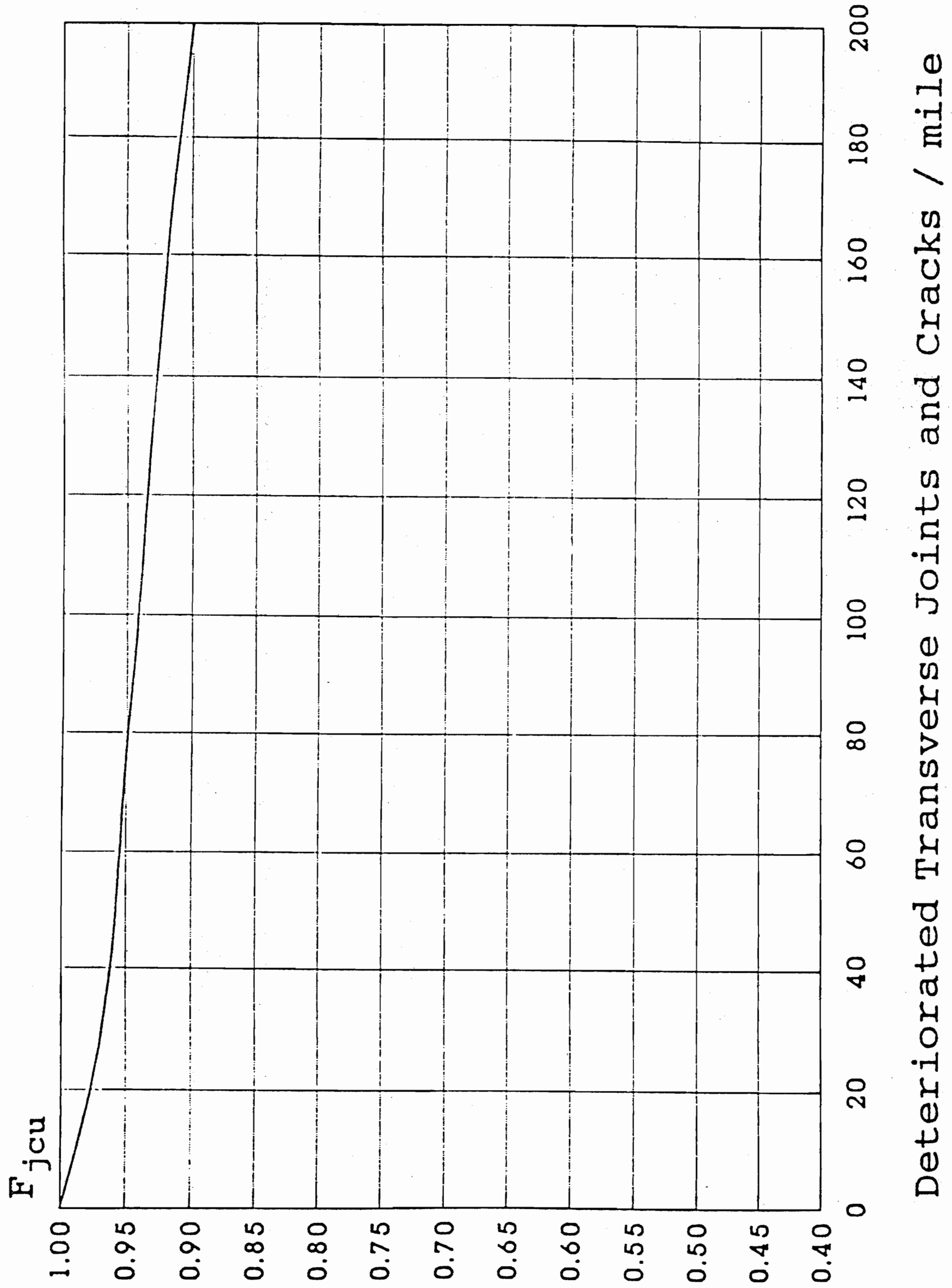

Figure 5.13. F_{jcu} Adjustment Factor for Unbonded JPCP, JRCP, and CRCP Overlays

prior to overlay is used to determine the F_{jcu} from Figure 5.13 for the appropriate type of PCC overlay. As an alternative to extensive full-depth repair for an unbonded overlay to be placed on a badly deteriorated pavement, a thicker AC interlayer should eliminate any reflection cracking problem, so that $F_{jcu} = 1.0$.

D_{eff} From Remaining Life For PCC Pavements

The remaining life of the pavement is given by the following equation:

$$RL = 100 \left[1 - \left(\frac{N_p}{N_{1.5}} \right) \right]$$

where

RL = remaining life, percent
N_p = total traffic to date, ESALs
$N_{1.5}$ = total traffic to pavement "failure," ESALs

$N_{1.5}$ may be estimated using the new pavement design equations or nomographs in Part II. To be consistent with the AASHO Road Test and the development of these equations, a "failure" PSI equal to 1.5 and a reliability of 50 percent are recommended.

D_{eff} is determined from the following equation:

$$D_{eff} = CF * D$$

where

CF = condition factor determined from Figure 5.2
D = thickness of the existing slab, inches (NOTE: maximum D for use in unbonded concrete overlay design is 10 inches even if the existing D is greater than 10 inches)

The designer should recognize that D_{eff} determined by this method does not reflect any benefit for preoverlay repair. The estimate of D_{eff} obtained should thus be considered a lower limit value. The D_{eff} of the pavement will be higher if preoverlay repair of load-associated distress is done. It is also emphasized that this method of determining D_{eff} is not applicable to AC/PCC pavements.

A worksheet for determination of D_{eff} is provided in Table 5.14.

Step 8: Determination of Overlay Thickness.

The thickness of unbonded PCC overlay is computed as follows:

$$D_{ol} = \sqrt{D_f^2 - D_{eff}^2}$$

where

D_{ol} = Required thickness of unbonded PCC overlay, inches
D_f = Slab thickness determined in Step 6, inches
D_{eff} = Effective thickness of existing slab determined in Step 7, inches

The thickness of overlay determined from the above relationship should be reasonable when the overlay is required to correct a structural deficiency. See Section 5.2.17 for discussion of factors which may result in unreasonable overlay thicknesses.

5.9.6 Shoulders

See Section 5.2.10 for guidelines.

5.9.7 Joints

Transverse and longitudinal joints must be provided in the same manner as for new pavement construction, except for the following joint spacing guidelines for JPCP overlays. Due to the unusually stiff support beneath the slab, it is advisable to limit joint spacing to the following to control thermal gradient curling stress:

Maximum joint spacing (feet)
= 1.75 * Slab thickness (inches)

Example: slab thickness = 8 inches
joint spacing = 8 * 1.75 = 14 feet

Table 5.14. Calculation of D_{eff} for Unbonded PCC Overlay of JPCP, JRCP, CRCP, and AC/PCC

Condition Survey Method:

JPCP, JRCP, or CRCP Overlay:

F_{jcu} Number of unrepaired deteriorated joints/mile = ____________

Number of unrepaired deteriorated cracks/mile = ____________

Number of unrepaired deteriorated punchouts/mile = ____________

Number of expansion joints, exceptionally wide joints (>1 inch) or full-depth, full-lane-width AC patches/mile = ____________

Total/mile = ____________

F_{jcu} = ____________ (Figure 5.13)

Effective Slab Thickness:

$$D_{eff} = F_{jcu} * D = \_\_\_\_\_\_\_\_\_\_$$

NOTES: Maximum D allowed is 10 inches for use in calculating D_{eff} for unbonded overlays. Existing AC surface is neglected in calculating D_{eff} for existing AC/PCC pavement when designing an unbonded PCC overlay.

Remaining Life Method:

N_p = Past design lane ESALs = ____________

$N_{1.5}$ = Design lane ESALs to P2 of 1.5 = ____________

$$RL = 100\left[1 - \left(\frac{N_p}{N_{1.5}}\right)\right] = \_\_\_\_\_\_\_\_\_\_$$

CF = ____________

$$D_{eff} = CF * D = \_\_\_\_\_\_\_\_\_\_$$

NOTE: Maximum D allowed is 10 inches for use in calculating D_{eff} for unbonded overlays.

5.9.8 Reinforcement

Unbonded JRCP and CRCP overlays must contain reinforcement to hold cracks tightly together. The design of the reinforcement would follow the guidelines given for new pavement construction, except that the friction factor would be high (e.g., 2 to 4) due to bonding between the AC separation layer and the new PCC overlay (see Part II, Section 3.4).

5.9.9 Separation Interlayer

A separation interlayer is needed between the unbonded PCC overlay and the existing slab to isolate the overlay from the cracks and other deterioration in the existing slab. The most common and successfully used separation interlayer material is an AC mixture placed one inch thick. If a level-up is needed the AC interlayer may also be used for that purpose (*29, 30*).

Some thin materials that have been used as bondbreakers have not performed well. Other thin layers have been used successfully, including surface treatments, slurry seals, and asphalt with sand cover for existing pavements without a large amount of faulting or slab breakup. For heavily trafficked highways, the potential problem of erosion of the interlayer must be considered. A thin surface treatment may erode faster than an AC material. There is no reason that a permeable open-graded interlayer cannot be used, provided a drainage system is designed to collect the water from this layer. This type of interlayer would provide excellent reflective crack control as well as preventing pumping and erosion of the interlayer.

5.9.10 Widening

See Section 5.2.16 for guidelines.

5.10 JPCP, JRCP, AND CRCP OVERLAY OF AC PAVEMENT

JPCP, JRCP, and CRCP overlays of AC pavement can be placed to improve both structural capacity and functional conditions. This type of overlay consists of the following major construction tasks:

(1) Repairing deteriorated areas and making subdrainage improvements (if needed)
(2) Constructing widening (if needed)
(3) Milling the existing surface if major distortion or inadequate cross-slope exists
(4) Placing an AC leveling course (if needed)
(5) Placing the concrete overlay
(6) Sawing and sealing the joints

5.10.1 Feasibility

A PCC overlay is a feasible rehabilitation alternative for AC pavements for practically all conditions. They are most cost-effective when the existing pavement is badly deteriorated. Conditions under which a PCC overlay would not be feasible include:

(1) The amount of deterioration is not large and other alternatives would be much more economical.
(2) Vertical clearance at bridges is inadequate for required overlay thickness. This may be addressed by reconstructing the pavement under the overhead bridges or by raising the bridges. Thicker PCC overlays may also necessitate raising signs and guardrails, as well as increasing side slopes and extending culverts. Sufficient right-of-way must be available or obtainable to permit these activities.
(3) The existing pavement is susceptible to large heaves or settlements.

If construction duration is critical, PCC overlays may utilize high-early-strength PCC mixes. PCC overlays have been opened within 6 to 24 hours after placement using these mixtures.

5.10.2 Pre-overlay Repair

One major advantage of a JPCP, JRCP, or CRCP overlay over AC pavement is that the amount of repair required for the existing pavement is greatly reduced. However, the following types of distress (on the next page) should be repaired prior to placement of the overlay to prevent reflection cracks that may reduce its service life. Guidelines on repairs are provided in References 1 and 3.

5.10.3 Reflection Crack Control

Reflection cracking is generally not a problem for JPCP, JRCP, or CRCP overlays of AC pavement. However, if the existing AC pavement has severe transverse thermal cracks, it may be desirable to place some type of separation layer over the transverse cracks to reduce the potential for reflection cracking.

Distress Type	Overlay Type	Repair Type
Alligator cracking	JPCP or JRCP	No repair needed
	CRCP	Patch areas with high deflections
Transverse cracks	JPCP, JRCP, CRCP	No repair needed
Pumping, stripping	JPCP, JRCP, CRCP	Edge drains (if needed) Remove stripping layer if severe
Settlement/heave	JPCP, JRCP, CRCP	Level-up with AC

5.10.4 Subdrainage

See Section 5.2.4 for guidelines.

5.10.5 Thickness Design

The required thickness of the PCC overlay is a function of the structural capacity required to meet future traffic demands and the support provided by the underlying AC pavement. The required overlay thickness to increase structural capacity to carry future traffic is determined by the following equation.

$$D_{oi} = D_f$$

where

D_{ol} = Required thickness of PCC overlay, inches
D_f = Slab thickness to carry future traffic, inches

PCC overlays of AC pavement have been successfully constructed as thin as 5 inches and as thick as 12 inches or more. Seven to 10 inches has been typical for most highway pavement overlays.

The required overlay thickness may be determined through the following design steps. These design steps provide a comprehensive design approach that recommends testing the pavement to obtain valid design inputs. If it is not possible to conduct this testing, an approximate overlay design may be developed based upon visible distress observations by skipping Steps 4 and 5, and by estimating other inputs.

The overlay design can be done for a uniform section or on a point-by-point basis as described in Section 5.3.1.

Step 1: Existing pavement design.

(1) Existing material types and layer thicknesses.

Step 2: Traffic analysis.

(1) Predicted future 18-kip ESALs in the design lane over the design period (N_f).

Step 3: Condition survey.

A detailed survey of distress conditions is not required. Only a general survey that identifies any of the following distresses that may affect the performance of a PCC overlay is needed:

(1) Heaves and swells.
(2) Signs of stripping of the AC. This could become even more serious under a PCC overlay.
(3) Large transverse cracks that, without a new separation layer, may reflect through the PCC overlay.

Step 4: Deflection testing (strongly recommended).

Measure deflection basins in the outer wheel path along the project at an interval sufficient to adequately assess conditions. Intervals of 100 to 1,000 feet are typical. A heavy-load deflection device (e.g., Falling Weight Deflectometer) and a load magnitude of 9,000 pounds are recommended. ASTM D 4694 and D 4695 provide additional guidance on deflection testing. Deflections should be measured at the center of the load and at least one other distance from the load, as described in Section 5.4.5, Step 4.

For each point tested, backcalculate the subgrade modulus (M_R) and the effective pavement modulus (E_p) according to the procedures described in Section 5.4 for AC pavements.

(1) *Effective dynamic k-value.* Estimate the effective dynamic k-value from Figure 3.3 in Part II, Section 3.2, using the backcalculated subgrade resilient modulus (M_R), the effective modulus of the pavement layers above the subgrade (E_p), and the total thickness of the pavement layers above the subgrade (D). It is emphasized that the backcalculated subgrade

resilient modulus value used to estimate the effective dynamic k-value should *not* be adjusted by the C factor (e.g., 0.33) which pertains to establishing the design M_R for AC overlays of AC pavements.

If a single overlay thickness is being designed for a uniform section, compute the mean effective dynamic k-value of the uniform section.

Step 5: Coring and materials testing.

Unless some unusual distress condition exists, coring and materials testing are not required.

Step 6: Determination of required slab thickness for future traffic (D_f).

(1) *Effective static k-value (at bottom of PCC overlay over an existing AC pavement).* Determine from one of the following methods.
   (a) Determine the effective dynamic k-value from the backcalculated subgrade modulus M_R, pavement modulus E_p, and pavement thickness D as described in Step 4. Divide the effective dynamic k-value by 2 to obtain the static k-value. The static k-value may need to be adjusted for seasonal effects (see Part II, Section 3.2.1).
   (b) Estimate from soils data and pavement layer types and thicknesses, using Figure 3.3 in Part II, Section 3.2. The static k-value obtained may need to be adjusted for seasonal effects (see Part II, Section 3.2.1).

(2) *Design PSI loss.* PSI immediately after overlay (P1) minus PSI at time of next rehabilitation (P2).

(3) *J, load transfer factor for joint design of the PCC overlay.* See Part II, Section 2.4.2, Table 2.6.

(4) *Modulus of rupture of PCC overlay.* Use mean 28-day, third-point-loading modulus of rupture of the overlay PCC.

(5) *Elastic modulus of PCC overlay.* Use mean 28-day modulus of elasticity of overlay PCC.

(6) *Loss of support.* See Part II.

(7) *Overlay design reliability, R (percent).* See Part I, Section 4.2, Part II, Table 2.2, and Part III, Section 5.2.15.

(8) *Overall standard deviation (S_o) for rigid pavement.* See Part I, Section 4.3.

(9) *Subdrainage capability of existing AC pavement,* after subdrainage improvements, if any. See Part II, Table 2.5, as well as Reference 5, for guidance in determining C_d. In selecting this value, note that the poor drainage situation at the AASHO Road Test would be given a C_d of 1.0.

Compute D_f for the above design inputs using the rigid pavement design equation or nomograph in Part II, Figure 3.7. When designing an overlay thickness for a uniform pavement section, mean input values must be used. When designing an overlay thickness for specific points along the project, the data for that point must be used. A worksheet for determining D_f is provided in Table 5.15.

Step 7: Determination of Overlay Thickness.

The PCC overlay thickness is computed as follows:

$$D_{ol} = D_f$$

The thickness of overlay determined from the above relationship should be reasonable when the overlay is required to correct a structural deficiency. See Section 5.2.17 for discussion of factors which may result in unreasonable overlay thicknesses.

5.10.6 Shoulders

See Section 5.2.10 for guidelines.

5.10.7 Joints

See Section 5.8.7 for guidelines.

5.10.8 Reinforcement

See Section 5.8.8 for guidelines.

5.10.10 Widening

See Section 5.2.16 for guidelines.

Table 5.15. Worksheet for Determination of D_f for PCC Overlay of AC Pavement

SLAB:

Type of load transfer system: mechanical device, aggregate interlock, CRCP

Type of shoulder = tied PCC, other

PCC modulus of rupture of unbonded overlay (typically 600 to 800 psi) = ____________________ psi

PCC E modulus of unbonded overlay (3 to 5 million psi) = ____________________ psi

J load transfer factor of unbonded overlay (2.5 to 4.4 for jointed PCC, 2.3 to 3.2 for CRCP) = ____________________

TRAFFIC:

Future 18-kip ESALs in design lane over the design period (N_f) = ____________________

SUPPORT AND DRAINAGE:

Effective dynamic k-value = ____________________ psi/inch

Effective static k-value = Effective dynamic k-value/2 (typically 50 to 500 psi/inch) = ____________________ psi/inch

Subdrainage coefficient, C_d (typically 1.0 for poor subdrainage conditions) = ____________________

SERVICEABILITY LOSS:

Design PSI loss (P1 − P2) = ____________________

RELIABILITY:

Design reliability, R (80 to 99 percent) = ____________________ percent

Overall standard deviation, S_o (typically 0.39) = ____________________

FUTURE STRUCTURAL CAPACITY:

Required slab thickness for future traffic is determined from rigid pavement design equation or nomograph in Part II, Figure 3.7.

D_f = ____________________ inches

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