

Design of Concrete Overlays Using Existing Methodologies

Authors

Helga Torres

Project Manager, The Transtec Group, Inc.
512-451-6233
helga@thetranstecgroup.com

Robert Otto Rasmussen

Vice President, The Transtec Group, Inc.

Dale Harrington

Senior Engineer, Snyder and Associates

Sponsor

Federal Highway Administration



U.S. Department of Transportation
Federal Highway Administration

National Concrete Pavement Technology Center

2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
www.cptechcenter.org

Director

Tom Cackler
515-294-5798
tcackler@iastate.edu

Managing Editor

Sabrina Shields-Cook
515-294-7124
shieldsc@iastate.edu

National Concrete Pavement Technology Center



IOWA STATE UNIVERSITY
Institute for Transportation

Introduction

Over the years, concrete overlay design procedures have been developed by a number of agencies, including the American Association of State Highway and Transportation Officials (AASHTO), the National Cooperative Highway Research Program (NCHRP), the Portland Cement Association (PCA), the American Concrete Pavement Association (ACPA), and various state departments of transportation (DOTs). Each method addresses different types of concrete overlays and involves different inputs, software, strengths, and deficiencies.

This technical summary provides an overview of the concrete overlay design process and identifies some of the more sensitive variables inherent with three different procedures: (1) the 1993 AASHTO Guide for Design of Pavement Structures (1993 AASHTO Guide), (2) the Mechanistic-Empirical Pavement Design Guide (MEPDG), and (3) the ACPA method for bonded concrete overlays on asphalt (BCOA) pavements. The first method, the 1993 AASHTO Guide, is the procedure most commonly used today for concrete overlay thickness design. The MEPDG is currently being implemented and evaluated by numerous state DOTs and is therefore included here. Finally, the ACPA BCOA method is presented to address the unique behavior of thinner BCOA, which is not captured by the first two methods.

This technical summary documents the early tasks in developing the *Design of Concrete Overlays Using Existing*

Methodologies, a guide that will provide straightforward and simple guidance for concrete overlay design. Under this effort, five different methods are being reviewed. An overview of the first three methods is presented here. The remaining two design procedures are for BCOA and include (4) a procedure developed by the Colorado Department of Transportation (CDOT) and (5) work resulting from the Transportation Pooled Fund Study TPF-5(165), which is led by the Minnesota Department of Transportation (Mn/DOT). For brevity, these two additional methods are not included in this technical summary but will be discussed in the final *Design of Concrete Overlays Using Existing Methodologies*, which will be available in late 2011.

The information presented in this technical summary is specific to concrete overlay design and focuses on thickness design in particular. Designers who desire detailed information and guidance on the various concrete overlay types and selection process, pre-overlay repair requirements, materials, construction techniques, and maintenance expectations should consult the *Guide to Concrete Overlays* (Harrington et al. 2008).

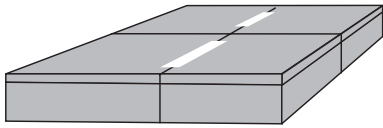
Concrete overlays can be used to rehabilitate all existing pavement types exhibiting various levels of deterioration. The *Guide to Concrete Overlays* categorizes all concrete overlays into two main types: bonded and unbonded (Figure 1).

Bonded Overlay Systems (Resurfacing/Minor Rehabilitation)

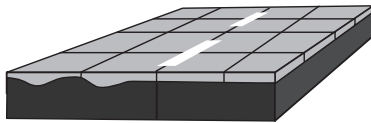
In general, bonded overlays are used to add structural capacity and/or eliminate surface distress when the existing pavement is in good structural condition.

Bonding is essential, so thorough surface preparation is necessary before resurfacing.

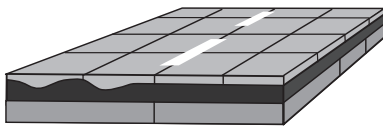
Bonded Concrete Overlays of Concrete Pavements —previously called bonded overlays—



Bonded Concrete Overlays of Asphalt Pavements —previously called ultra-thin whitetopping—



Bonded Concrete Overlays of Composite Pavements

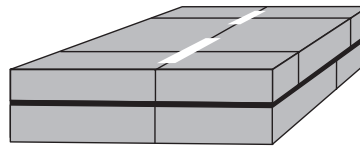


Unbonded Overlay Systems (Minor/Major Rehabilitation)

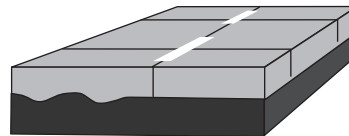
In general, unbonded overlays are used to rehabilitate pavements with some structural deterioration.

They are basically new pavements constructed on an existing, stable platform (the existing pavement).

Unbonded Concrete Overlays of Concrete Pavements —previously called unbonded overlays—



Unbonded Concrete Overlays of Asphalt Pavements —previously called conventional whitetopping—



Unbonded Concrete Overlays of Composite Pavements

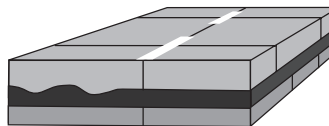


Figure 1. Bonded and unbonded concrete overlay systems (Harrington et al. 2008)

Overview of Bonded Concrete Overlays

Bonded concrete overlays over existing concrete, asphalt, and composite pavements are used to restore the structural capacity and/or to correct surface defects of existing pavements that are in fair to good condition. These overlays commonly range between 2 and 6 in. in thickness (Figure 2) and rely on the assumption of a long-term physical bond between the overlay and the existing surface to create a monolithic pavement layer. Special attention to surface preparation activities is essential to ensure a clean pre-overlay surface and

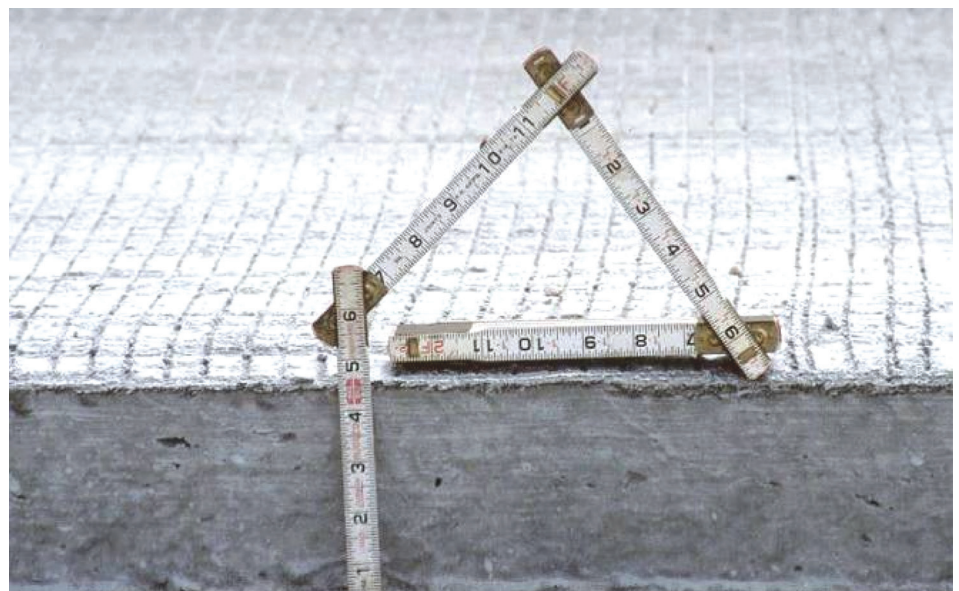


Figure 2. Bonded concrete overlay, 4.5 in. thick

to provide an appropriate macrotexture level for bonding. Furthermore, to minimize the potential for reflective cracking, pre-overlay repairs may be required to address severe cracking, spalling, patches, punchouts, pumping/faulting, and/or settlement/heaving in the existing pavement. Bonded overlays are not feasible if the existing pavement requires significant removal and replacement, if durability problems are present, or if vertical clearance limitations exist.

Overview of Unbonded Concrete Overlays

Unbonded concrete overlays over existing concrete, asphalt, and composite pavements are commonly used to address moderately to severely distressed pavements. In this case, the existing pavement provides a foundation for the unbonded overlay that in turn serves as a new pavement with increased structural capacity.

Unbonded overlays over existing concrete pavements require a separation layer to prevent reflective cracking by providing a shear plane for differential movements and to prevent bonding between the concrete layers.

Figure 3 shows the application of an asphalt separation layer to an existing concrete pavement exhibiting faulting and longitudinal displacement/slab slippage. Unbonded overlays over existing asphalt or composite pavements require little or no surface preparation and typically do not require an additional separation layer. These unbonded overlays typically range between 4 and 11 in. in thickness and are most cost effective when the pre-overlay repairs can be minimized by placing a separation layer of a certain thickness or type.



Figure 3. Application of asphalt separation layer to existing concrete pavement for unbonded concrete overlay

Background of Design Methodologies

Designing either bonded or unbonded concrete overlays is a process that begins with characterizing the existing pavement, defining critical design variables, and then proceeding with calculations to determine the required overlay thickness. This section presents a general overview of the three design methodologies discussed in this technical summary: (1) the 1993 AASHTO Guide, (2) the MEPDG, and (3) the ACPA BCOA method.

1993 AASHTO Guide

The method found in the 1993 AASHTO Guide is based on mathematical models derived from empirical data collected during the AASHTO Road Test carried out in the late 1950s. Even though there were no overlay test sections during the AASHTO Road Test, experience has shown that, when used properly, this procedure provides suitable bonded and unbonded concrete overlay designs.

The AASHTO computer software for implementing the 1993 AASHTO Guide is called DARWin. In addition, a number of agencies and state DOTs

have developed custom software and spreadsheets to apply this procedure. ACPA has also developed the WinPAS software, which implements the procedure.

The 1993 AASHTO Guide uses the concepts of structural deficiency and effective structural capacity for evaluating and characterizing the existing pavement to be overlaid. The structural capacity (SC) of a pavement section will decrease with traffic and time. In this procedure, SC is expressed in terms of effective structural number for existing asphalt pavements (SN_{eff}) or the effective slab thickness for concrete pavements (D_{eff}). Figure 4 is an adaptation of Figure 5.1 in Part III of the 1993 AASHTO Guide that is used to illustrate this concept. This figure illustrates how the structural capacity of an overlay ($SC_{overlay}$) will restore the structural capacity of the existing pavement ($SC_{effective}$) to meet the requirements to carry the predicted future traffic ($SC_{future\ traffic}$).

The 1993 AASHTO Guide presents three evaluation methods for determining the effective structural capacity of existing pavements (SC_{eff}) when designing concrete overlays. The designer should select the most feasible method based

on the available resources but should recognize that each method will yield different estimates. Table 1 presents a summary of the three AASHTO evaluation methods as they apply to concrete overlays.

Even though the Remaining Life method presented in Table 1 is often used, it is important to note that the 1993 AASHTO Guide cites major deficiencies associated with this method and explains that the method is mostly applicable when the existing pavement exhibits very little deterioration. The 1993 AASHTO Guide explains that the Remaining Life procedure is based on the AASHTO Road Test equations and that estimating past traffic (in equivalent single axle loads [ESALs]) may be subjective and/or uncertain. In addition, this method does not account for pre-overlay repairs. For these reasons, the designer should use the Condition Survey method or Nondestructive Deflection Testing when the structural capacity estimates made with the Remaining Life method are inconsistent with the observed existing pavement condition.

MEPDG

The MEPDG combines a mechanistic-based approach with field performance data so that the engineer can confidently predict the performance of pavement systems not considered in the original calibration. This method adopts an integrated pavement design approach that allows the designer to determine the overlay thickness based on the interaction between the pavement geometry (slab size, shoulder type, load transfer, steel reinforcement) and support conditions, local climatic factors, and concrete material and support layer properties. At this time, the MEPDG documentation and accompanying computer software are available online at www.trb.org/mepdg. An AASHTOWare version called DARWin-ME is currently

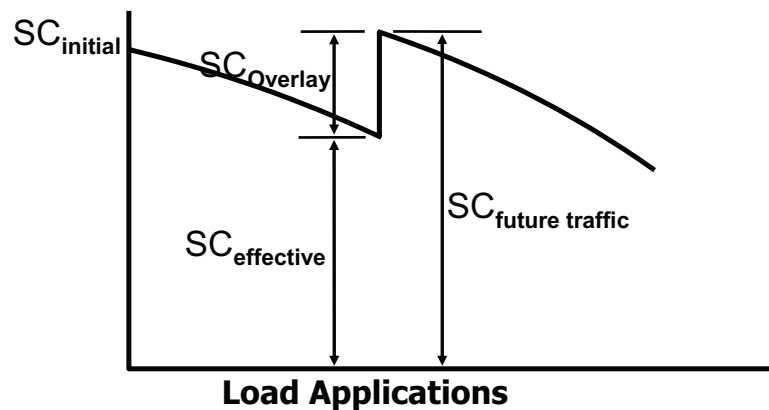


Figure 4. Illustration of structural capacity loss over time and with traffic

Table 1. Summary of AASHTO guide methods to evaluate effective structural capacity of existing pavements to receive a concrete overlay

Method	Description
Visual Survey and Materials Testing (Condition Survey)	Condition assessment based on historical records, distress and drainage surveys, and coring and material testing. The pavement layer thicknesses and conditions are determined through coring or ground penetrating radar. Typical laboratory testing of the portland cement concrete (PCC) cores involves strength tests. Correlations with compressive strength are typically used to estimate the existing slab elastic modulus and modulus of rupture. If a bonded overlay will be used, areas that will require repairs or full-depth repairs are identified to ensure a sound and uniform section before the bonded overlay is applied.
Nondestructive Deflection Testing (NDT)	Direct evaluation of in situ subgrade and pavement stiffness along a project. NDT also allows for evaluating the pavement layer load transfer efficiency, effective modulus of subgrade reaction, and elastic modulus. The majority of state highway agencies and private engineering companies have the required equipment and personnel available.
Fatigue Damage from Traffic (Remaining Life)	Estimate of a pavement's remaining fatigue life based on past traffic. This method requires estimating traffic in terms of ESALs, both the ESALs accumulated to date and the total expected ESALs that the pavement will carry. Note that the Remaining Life method is only applicable to pavements with very little deterioration. In addition, this method applies only to bonded and unbonded overlays of existing concrete pavements and does not apply to unbonded overlays of composite and asphalt pavements.

being developed and is anticipated to be available in 2011.

Chapter 7 of Part 3 of the MEPDG ("PCC Rehabilitation Design of Existing Pavements") covers the design of bonded and unbonded concrete overlays. The MEPDG is an iterative design process that involves analyzing a trial overlay design not only in terms of thickness but also accounting for other relevant design features, such as joint dimensions and load transfer, steel reinforcement (if applicable), and concrete material

properties. The following list summarizes the MEPDG inputs (NCHRP 2004):

- Rehabilitation Type
- Design Life
- Pavement Failure Criteria (cracking, faulting, International Roughness Index [IRI])
- Reliability
- Traffic
- Local Climate
- Pavement Cross Section and Layer Properties

- Pavement Design Features
 - Slab Geometry
 - Joint and Shoulder Type
 - Concrete Properties (strength, mixture proportions, coefficient of thermal expansion, etc.)
 - Drainage and Surface Properties

There are three input levels available for the pavement design depending on the quality of the input data acquired. Level 1 inputs are used if project-specific traffic data are available and if certain pavement layer material properties have been measured. Level 2 inputs are used if correlations with standard tests are necessary to complete the design. Level 3 inputs assume national default values in the design process. This technical summary emphasizes Level 2 and 3 inputs as a recommended starting point when using the MEPDG.

The MEPDG method predicts performance indicators, such as IRI, transverse cracking, and mean joint faulting over the design life for jointed plain concrete overlays. For continuously reinforced concrete overlays, the MEPDG predicts the mean crack spacing as well as the crack width, IRI, and number of punchouts over the design life. For all of the distress predictions, the MEPDG calculates incremental damage by employing transfer functions for the specific distresses that are linked with the corresponding maximum pavement response (deflection or tensile stress).

ACPA

ACPA (1998) developed a mechanistic procedure to design thinner (2 to 4 in.) bonded concrete overlays of asphalt pavements, which are not captured by the first two methods. This method consists of an iterative design process where the designer evaluates the proposed overlay thickness and joint spacing along with traffic, the concrete

strength (modulus of rupture), the existing asphalt concrete thickness, and the composite subgrade/subbase stiffness (k-value). The procedure determines the allowable trucks for the trial design.

The ACPA procedure is based on calculating the fatigue damage in the slab for a corner loading condition, as well as limiting the fatigue damage at the bottom of the existing asphalt pavement at the transverse joint location (ACPA 1998). Temperature curling stresses are also considered in the critical pavement response. One limitation of this method is that it is based on the PCA beam fatigue model, which is very conservative. As a result, Riley developed a Modified ACPA Method, which incorporated a new probabilistic concrete fatigue algorithm (Riley et al. 2005). This modified method allows for inputting the existing asphalt pavement properties, accounts for structural fibers, and checks for a potential bond plane failure.

In January 2011, ACPA released a BCOA thickness design web application that incorporates work by Riley (2006) and Roesler et al. (2008). This tool is available at <http://apps.acpa.org/apps/bcoa.aspx>. The inputs for the ACPA BCOA thickness design tool include

- ESALs.
- Percentage of Allowable Cracked Slabs.
- Reliability.
- Effective Temperature Gradient and Corresponding Percentage Time.
- Existing Hot Mix Asphalt (HMA) Pavement:
 - Remaining Asphalt Thickness and Modulus.
- Composite Subgrade/Subbase k-value.
- Concrete Overlay:
 - Strength, Modulus, Fiber Type, and Coefficient of Thermal Expansion (CTE).

- Proposed Slab Size and Pre-Overlay Surface Preparation

It should be noted that while the current ACPA method is suitable for designing bonded concrete overlays over asphalt pavements, revisions to the software are ongoing. Future updates will enhance some of the models and provide default inputs that will streamline the design process for locations throughout the U.S. Specifically, it is important to note that this method requires project-specific temperature gradient inputs and that this information may not be readily available to pavement designers. Roesler et al. (2008) developed the current default values in the ACPA web application for the effective temperature gradient and percentage time at the effective temperature gradient based on field data for the State of Illinois. Current efforts to define this information for different locations throughout the U.S. and to improve this method's fiber reinforcement characterization are ongoing; the BCOA web tool will be updated accordingly.

Design Methodology Applicability

The preceding subsections provided a general overview of the three concrete overlay design methodologies discussed in this technical summary. Table 2 summarizes more specific design assumptions, deficiencies, and strengths inherent to each method. Two of the most important aspects in concrete overlay design are (1) how each method handles the bond between the existing pavement and the concrete overlay and (2) if the method assumes the existing pavement will provide significant structural capacity or, alternatively, contribute to the quality of the pavement foundation. With this type of information, pavement designers are able to make an informed decision about

Table 2. Summary of design methodology relevant assumptions and items to note (Harrington et al. 2008)

Overlay Type	Design Method	Design Assumptions, Deficiencies/Strengths, and/or Items to Note
Bonded Overlays of Concrete Pavements	1993 AASHTO Guide	<ul style="list-style-type: none"> Assumes complete bond for entire overlay life. Existing pavement effective structural capacity is based on the Condition Survey or the Remaining Life methods. These two methods have different limitations and may yield inconsistent or unreasonable results. Pavement designers are familiar with this design process and variables. It has been around for nearly 20 years.
	MEPDG	<ul style="list-style-type: none"> Integrates slab geometry, climatic factors, and concrete material and layer properties into thickness design compared to the 1993 AASHTO Guide. Assumes complete bond for entire overlay life. This method is still under evaluation, calibration, and implementation by state highway agencies.
Bonded Overlays of Asphalt Pavements	1993 AASHTO Guide	<ul style="list-style-type: none"> Not applicable to bonded overlays of asphalt pavements. <ul style="list-style-type: none"> Does not account for the bond between the concrete and the asphalt or shorter slab sizes. Composite k-value is used to account for the existing asphalt, base, and subbase materials. and therefore the existing asphalt contributes to the support layer stiffness and not to the structural slab layer stiffness.
	MEPDG	<ul style="list-style-type: none"> The user inputs the number of months after which the bond between the concrete and asphalt changes from bonded to unbonded. Similar to the 1993 AASHTO Guide, the MEPDG treats the existing asphalt as a base material that contributes to the concrete layer stiffness. Not applicable to thinner (2 to 6 in.) bonded overlays of asphalt pavements. The analysis is limited to slab sizes greater than or equal to 10 ft, and this type of concrete overlay typically has shorter slab sizes. The MEPDG currently refers to the ACPA method for thinner (2 to 4 in.) bonded overlays of asphalt pavements.
	ACPA BCOA	<ul style="list-style-type: none"> Evaluates smaller slab sizes, the use of structural fibers in the overlay concrete, and bond plane failure. Data used for this method's calibration are currently limited to 15 years of overlay performance, and designers need to be careful when extrapolating for longer design life periods. The current default values in the ACPA web application for the temperature gradient information are representative of the climate conditions in the state of Illinois. Current efforts to define this information for different locations throughout the U.S. are ongoing and are to be included in the web application when available.
Bonded Overlays of Composite Pavements	1993 AASHTO Guide	<ul style="list-style-type: none"> Not applicable to bonded overlays of composite pavements. <ul style="list-style-type: none"> Does not account for bond and shorter joint spacing, uses a composite k-value, and consequently yields conservative overlay thickness designs.
	MEPDG	<ul style="list-style-type: none"> Not originally developed for overlays of composite pavements but can be used correctly by selecting a concrete overlay of asphalt and then inserting a chemically stabilized layer (existing jointed plain concrete pavement [JPCP] or continuously reinforced concrete pavement [CRCP]) under the asphalt layer. Allows for loss of bond over time, implying that the bond is short term. Not applicable to thinner (2 to 6 in.) bonded overlays because the analysis is limited to slab sizes greater than or equal to 10 ft and this type of concrete overlay typically involves shorter slab sizes.
	ACPA BCOA	<ul style="list-style-type: none"> Addresses bond plane failure, shorter joint spacing, and the use of structural fibers in the overlay concrete. Not originally developed for overlays of composite pavements but can be used correctly if the equivalent stiffness of the supporting structural layers is input properly.
Unbonded Overlays (All Types)	1993 AASHTO Guide	<ul style="list-style-type: none"> This procedure assumes no friction between the concrete overlay and the existing asphalt pavement or interlayer, uses a composite k-value, and consequently yields conservative thickness designs. The effective structural capacity of existing concrete and composite pavements is based on the Condition Survey or the Remaining Life methods. These two methods have different limitations and may yield inconsistent or unreasonable results.
	MEPDG	<ul style="list-style-type: none"> Integrates slab geometry, climatic factors, and concrete material and support layer properties compared to the 1993 AASHTO Guide. The asphalt and concrete are treated as unbonded structural layers without any frictional consideration with the concrete overlay. This method is still under evaluation, calibration, and implementation by state highway agencies.

which method to apply when designing a certain type of concrete overlay.

Based on the background information discussed for each method and the details presented in Table 2, the following sections of this technical summary discuss the 1993 AASHTO Guide and the MEPDG design methodologies in greater detail for

- Bonded Overlays of Concrete Pavements
- Unbonded Overlays of Concrete Pavements and Composite Pavements
- Unbonded Overlays of Asphalt Pavements

In addition, the ACPA overlay design methodology is discussed for Bonded Overlays of Asphalt and Composite Pavements.

Bonded Concrete Overlay Design

In this section, bonded concrete overlay designs procedures are summarized.

Bonded Overlays of Concrete Pavements, 1993 AASHTO Guide

Section 5.8 of the 1993 AASHTO Guide addresses the thickness design of bonded overlays over existing concrete pavements. The design process is based on the following equation:

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

where D_{ol} = required concrete overlay thickness (in.), D_f = slab thickness required to carry the future traffic (in.), and D_{eff} = effective thickness of the existing concrete slab (in.).

The first part of the design process involves determining the required thickness for a new pavement to carry the predicted future traffic (D_f). For this, the rigid pavement design equation or nomograph in Figure 3.7 in Part II of the 1993 AASHTO Guide is used. It should be noted that a number of inputs

used when determining D_f for a bonded overlay correspond to the existing pavement materials and conditions and not to the proposed overlay. Specifically, the elastic modulus, modulus of rupture, load transfer coefficient, and drainage coefficient are representative of the existing pavement. Table 3 lists the inputs required to determine D_f and the corresponding typical ranges.

The effective slab thickness of the existing pavement (D_{eff}) must then be determined with either the Condition Survey or the Remaining Life method that were described in the Background of Design Methodologies section. Table 4 summarizes the Condition Survey procedure to estimate D_{eff} when designing a bonded concrete overlay over an existing concrete pavement.

Table 3. AASHTO inputs to determine D_f for bonded overlays

Existing Pavement Inputs	Typical Ranges
Elastic Modulus, E (psi)	3 to 6 million
Modulus of Rupture, S'_c (psi)	600 to 800
Load Transfer Coefficient, J	2.2 to 4.4
Drainage Coefficient, C_d	0.8 to 1.2
General Inputs	Typical Ranges
Effective k-value (psi/in.)	50 to 500
Terminal Serviceability, p_t	1.5 to 2.5
Design Serviceability Loss, Δp	1.5 to 2.5
Design Reliability, R (%)	95
Standard Deviation, s_0	0.39
Future Traffic, W_{18} (ESALs)	1 to 100 million

Table 4. Summary of 1993 AASHTO Guide condition survey method and adjustment factors

$D_{eff} = F_{jc} * F_{dur} * F_{fat} * D$, where D = existing slab thickness (in.).	Joint and cracks adjustment factor, F_{jc}: Typically 1.0 if all deteriorated cracks and joints are repaired before the overlay. If repairs are not performed, the total number of unrepaired joints and cracks per mile is estimated and Figure 5.12 in Part III of the 1993 AASHTO Guide is used to determine F_{jc} .
	Durability adjustment factor, F_{dur}: 1.0: no signs of durability problems, such as "D" cracking or reactive aggregate distress. 0.96–0.99: durability cracking exists but no spalling. 0.80–0.95: cracking and spalling exists (bonded overlay not ideal solution).
	Fatigue damage adjustment factor, F_{fat}: 0.97–1.00: few transverse cracks/punchouts <ul style="list-style-type: none"> • JPCP: <5% cracked slabs • CRCP: <4 punchouts per mile 0.94–0.96: significant number of transverse cracks/punchouts <ul style="list-style-type: none"> • JPCP: 5%–15% cracked slabs • CRCP: 4–12 punchouts per mile 0.90–0.93: large number of transverse cracks/punchouts <ul style="list-style-type: none"> • JPCP: >15% cracked slabs • CRCP: >12 punchouts per mile

Bonded overlays should be placed over existing pavements that are in fair to good condition; therefore, only a limited number of pre-overlay repairs are typically necessary to address any localized distresses. Furthermore, bonded overlays are not recommended when durability problems are present. Therefore, Table 4 below indicates that the adjustment factors F_{jc} and F_{dur} for the Condition Survey equation are typically 1.0 or close to 1.0.

Table 5 summarizes the Remaining Life procedure to estimate D_{eff} . As previously mentioned, bonded overlays are placed over existing pavements that are in relatively fair to good condition, and some recommend using a condition factor (CF) equal to one for this method (Smith et al. 2002). As previously discussed in the Background of Design Methodologies section, the Remaining Life approach does not account for pre-overlay repairs and, thus, in some cases it may underestimate D_{eff} .

Note that for bonded overlays, D_{eff} with both procedures described in Tables 4 and 5 will likely be close to the original existing slab thickness because the adjustment and condition factors are close to one. D_f and the corresponding inputs for its calculation will likely have the most impact on the overlay thickness design.

Critical Design Variables

Input variables that have a moderate to high impact on the bonded concrete overlay thickness design include the traffic (W_{18}), load transfer (J), drainage (C_d), and the modulus of rupture (S'_c). The most sensitive input is the expected ESALs, which must be carefully assessed in order to meet the performance expectations for the bonded overlay. The load transfer and drainage coefficients are dependent on the existing pavement design and condition. Pre-overlay repairs are typically conducted to address major

Table 5. Summary of AASHTO remaining life method and adjustment factors

$D_{eff} = CF \cdot D$, where D = existing slab thickness (in.).	Remaining Life, RL (%): $RL = 100[1 - (N_p / N_{1.5})]$ where N_p = total traffic to date (ESALs) and $N_{1.5}$ = total traffic to failure (ESALs). Use Figure 5.2 in Part III of the 1993 AASHTO Guide to determine the CF based on RL.
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load transfer and/or drainage deficiencies before a bonded overlay is placed to prevent overdesigning the concrete overlay thickness.

Bonded Overlays of Concrete Pavements, MEPDG

In order to provide an overview of the MEPDG iterative design process, screen captures for the MEPDG software inputs are provided. Recommended modifications to the trial designs by addressing the most sensitive design variables when performance criteria are not met.

To begin a design for a bonded overlay of concrete pavement, the General Information menu is used to select the PCC overlay type and indicate if it is a bonded PCC overlay over an existing JPCP or CRCP. Additional general information includes the design life (years), the estimated construction dates of the existing pavement and for the proposed overlay, and when the overlay is expected to be opened to traffic.

Traffic

Traffic inputs for the MEPDG are based on traffic load spectra, which describe the traffic distribution in terms of the number, weight, and geometries of the associated axle loads. It further characterizes the traffic distribution by the season and time of the day. Traffic input Levels 1 and 2 are based on automated vehicle classification (AVC) and weigh-in-motion (WIM) measurements, which can be either segment-specific or regional average values; Level 3 inputs are based on nationally developed default

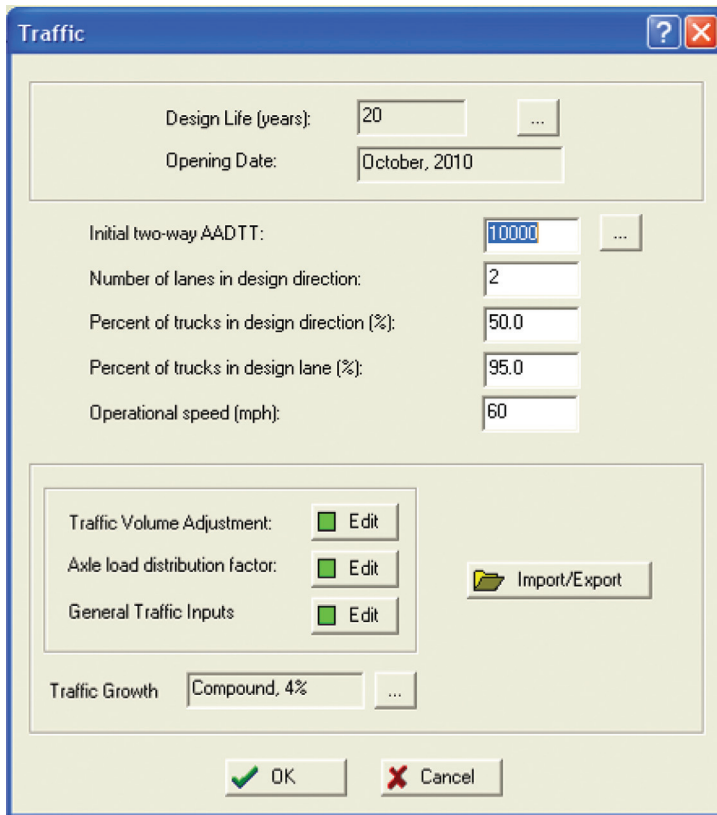
distributions from the Long-Term Pavement Performance (LTPP) database.

The main Traffic screen (see Figure 5) requires the annual average daily truck traffic (AADTT), the directional distribution factor, and the lane distribution factor. The next submenu, Traffic Volume Adjustment Factors, includes monthly adjustment, vehicle class distribution, and hourly truck distribution factors.

If project-specific information is not available, default values can be used, assuming an equal monthly vehicle distribution, the default vehicle class distribution (road functional classification and Truck Traffic Classification [TTC] group need to be checked under the Level 3 tab), and hourly truck distributions. The last input in this submenu, Traffic Growth Factors, is where the designer enters the growth rate and growth function (linear or compound).

The Axle Load Distribution Factor is the next submenu. This information is obtained from WIM data, and the MEPDG has been preloaded with default values based on LTPP data. This submenu is very important because it defines the percentage of axles at each axle weight.

The last submenu for traffic is General Traffic Inputs, and it covers items particularly relevant to analyzing concrete pavements and overlays, such as mean wheel location, traffic wander standard deviation, and the axle and wheel geometry. It is important for the designer to review this submenu even if default values are used.



Traffic

Design Life (years): 20 ...

Opening Date: October, 2010

Initial two-way AADTT: 10000 ...

Number of lanes in design direction: 2

Percent of trucks in design direction (%): 50.0

Percent of trucks in design lane (%): 95.0

Operational speed (mph): 60

Traffic Volume Adjustment: ☐ Edit

Axle load distribution factor: ☐ Edit

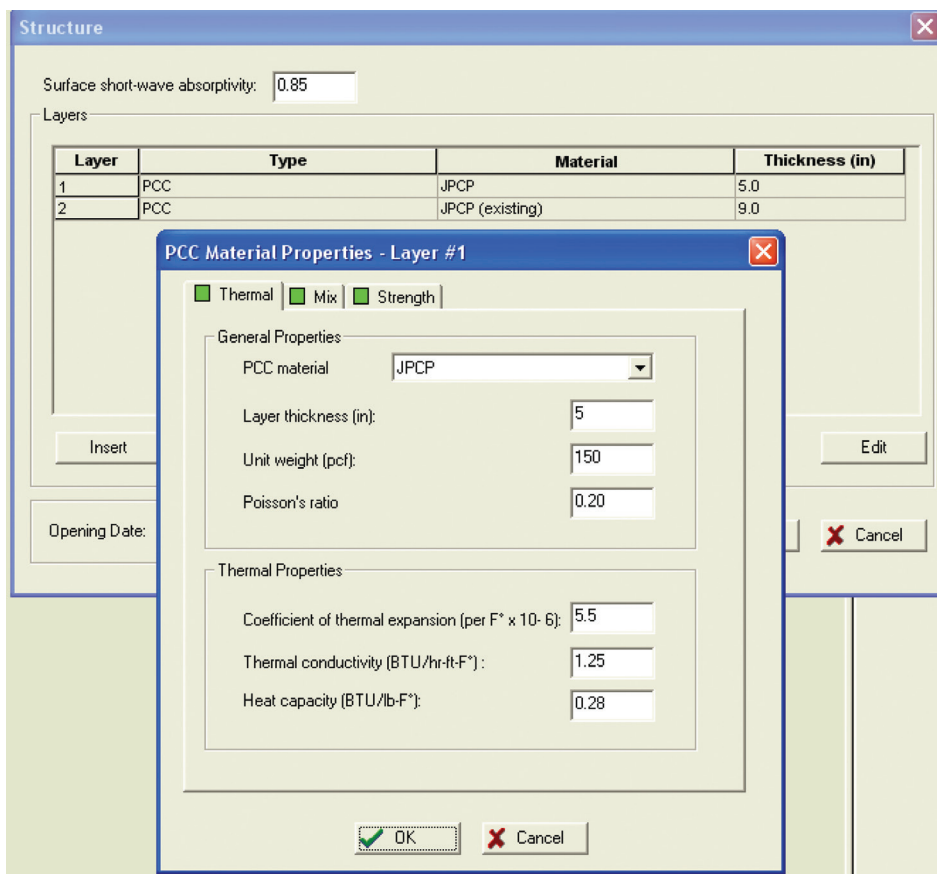
General Traffic Inputs: ☐ Edit

Import/Export

Traffic Growth: Compound, 4% ...

OK Cancel

Figure 5. MEPDG software traffic menu



Structure

Surface short-wave absorptivity: 0.85

Layers

Layer	Type	Material	Thickness (in)
1	PCC	JPCP	5.0
2	PCC	JPCP (existing)	9.0

Insert

Opening Date:

PCC Material Properties - Layer #1

☒ Thermal ☐ Mix ☐ Strength

General Properties

PCC material: JPCP

Layer thickness (in): 5

Unit weight (pcf): 150

Poisson's ratio: 0.20

Thermal Properties

Coefficient of thermal expansion (per F° x 10⁻⁶): 5.5

Thermal conductivity (BTU/hr-ft-F°): 1.25

Heat capacity (BTU/lb-F°): 0.28

OK Cancel

Figure 6. MEPDG software structure/layers menu

Climate

The MEPDG software allows users to load climatic information (air temperature, solar radiation, wind, humidity) from an extensive database of cities across the US, and it also allows data to be interpolated from weather stations near a specific project. The designer enters the seasonal or constant water table depth for the project location. Climatic factors in the MEPDG have been shown to have a significant impact on concrete pavement and overlay performance.

Structure

The Structure menu is subdivided into design features and layer definition and material properties. Only the proposed concrete overlay and significant structural layers will be discussed. In the Layers submenu (see Figure 6), the overlay and existing concrete pavement layer are both defined in terms of general, thermal, mix, shrinkage, and strength properties. General properties for these two layers include the thickness, unit weight, and Poisson's ratio.

Thermal properties include the CTE, thermal conductivity, heat capacity, and surface shortwave absorptivity. The default values in the MEPDG software are recommended for all of these properties except for the CTE. The MEPDG considers the CTE a critical design variable for bonded overlays of existing concrete pavements. Determining this value in the laboratory for both the overlay and the existing concrete pavement is recommended. The CTE may also be determined using the CTE weighted average of the concrete mixture components (typical values are presented in Table 6).

AASHTO TP 60, Standard Test Method for the Coefficient of Thermal Expansion of Hydraulic Cement Concrete, has been used for a number of years to determine CTE. The CTE values

Table 6. Typical CTE ranges

Material Type		CTE, α ($10^{-6}/^{\circ}\text{F}$)
Aggregate	Granite	4-5
	Basalt	3.3-4.4
	Limestone	3.3
	Dolomite	4-5.5
	Sandstone	6.1-6.7
	Quartzite	6.1-7.2
	Marble	2.2-4
Cement paste		10-11
Concrete		4.1-7.3 (typical value 5.5)

presented in Table 6 are representative of this standard, and the current MEPDG software is calibrated using CTE values obtained through this method. However, issues with the equipment calibration procedure in AASHTO TP 60 were recently identified and a new procedure, AASHTO T 336, was developed to rectify those problems (Tanesi et al. 2010). Note that the CTE values obtained with these two procedures may vary significantly, and it is expected that the models in future versions of the MEPDG software (i.e., DARWin-ME) will be recalibrated to account for this difference.

The Mix submenu represents mix properties, which are project specific and should be obtained from mix designs and specifications. These properties include cement type and content, water/cement ratio, and aggregate type.

The third tab, Strength, is for properties that are critical design variables in the MEPDG. These properties include modulus of elasticity and modulus of rupture for JPCP and CRCP overlay design. Similar to the AASHTO method, the compressive strength can be used to estimate the strength properties of the existing concrete pavement and of the new concrete overlay if the modulus of rupture is not directly measured. In addition, deflection testing may be used

to estimate the elastic modulus of the existing pavement. Note that sampling and deflection testing of existing concrete pavements is typically conducted on areas that are not severely deteriorated; therefore, the estimated modulus of elasticity needs to be adjusted to represent the overall condition of the section that is under evaluation. Titus-Glover and Stanley (2008) present guidance on how to select an appropriate modulus of elasticity for existing JPCP.

In the Design Features submenu for bonded overlays of existing concrete pavements, the joint spacing and dowel inputs should correspond to the existing pavement. As for the existing PCC-base interface, “full friction contact” is selected for the existing slab-base interface condition. The base erodibility index can be estimated based on the base material description. For CRCP overlays, steel reinforcement for the proposed overlay is inputted instead of joint information.

Critical Design Variables

Chapter 7 of Part 3 of the MEPDG (PCC Rehabilitation Design of Existing Pavements) describes the critical design variables that affect each type of concrete

overlay. This chapter also presents strategies to modify trial designs that do not meet the established performance criteria, such as cracking and faulting (and consequently IRI). For example, for bonded overlays of concrete pavements, the designer should consider increasing the overlay thickness and/or adding a concrete shoulder.

Recommendations for bonded overlays of CRCP designs not meeting the performance criteria include increasing the overlay thickness, changing the steel content, and/or adding a tied concrete shoulder. With the MEPDG procedure, minimum combined thicknesses for the existing concrete pavement and concrete overlay of 6 and 7 in. are used for JPCP and CRCP analysis, respectively.

Bonded Overlays of Asphalt and Composite Pavements, ACPA Method

Bonded overlays of asphalt pavements, previously referred to as ultra-thin whitetopping (UTW), are traditionally between 2 and 4 in. thick but could include slabs up to 6 in. thick. Smaller slab sizes are used for this type of overlay—typically between 4 and 6 ft long and cut both longitudinally



Figure 7. Bonded concrete overlay of asphalt pavement

and transversely, as shown in Figure 7. In addition to the *Guide to Concrete Overlays* (2008), NCHRP Synthesis 338 documents the state of the practice for designing and applying these overlays. The ACPA design procedure (ACPA 1998) and its latest improvements (Riley 2006 and Roesler et al. 2008) for these types of overlays were described in the Background of Design Methodologies section.

As previously mentioned, the latest improvements that Riley (2006) and Roesler et al. (2008) made to the ACPA design methodology were incorporated into the BCOA thickness design web application (see Figure 8), which is available at <http://apps.acpa.org/apps/bcoa.aspx>. The current design process calculates the proposed overlay thickness and allows for evaluating the appropriateness of the assumed slab size and of the fiber content.

As shown in Figure 8, the ACPA BCOA web tool begins with the General Design Details, specifically traffic, which includes the design lane ESALs that may be directly inputted or estimated with an embedded ESAL calculator. Riley (2006) notes that the data used for this method's calibration are currently limited to 15 years of overlay performance; thus, designers need to use caution when designing for longer periods.

Next, the failure criteria are entered in terms of maximum percentage for cracked slabs and reliability. In the General Design Details, the effective temperature gradient and the percentage time at the effective temperature gradient are entered. As noted in the Background of Design Methodologies section, the current default values for the temperature gradient information were developed for the state of Illinois; however, typical values for other locations in the U.S. will be incorporated into the BCOA web application at a future date.

The next section in the BCOA application is the Existing Pavement Structure Details, which includes the thickness of the existing asphalt layer after surface preparation and the corresponding elastic modulus. Another input is the composite modulus of subgrade reaction (k-value) for the existing subgrade combined with the existing base (described as the k-value at the bottom of the asphalt layer).

The Concrete Material Details are inputted to describe the proposed overlay. If no project-specific information is available, designers may base their inputs on the typical values that the local agency uses for the average 28-day third-point flexural strength, elastic modulus, and CTE. Note that the flexural strength input for this method is the average value and not the minimum. In addition, the use of structural fibers is indicated in this section.

The last section is the Concrete Overlay Details, which include the proposed joint spacing for the overlay and the type of surface preparation that will be performed. Shorter joint spacings are typically used for bonded overlays over asphalt pavements, such as 4 or 6 ft for a 12-ft wide lane. At this point, the BCOA calculates a thickness based on the inputs provided, and the designer should modify the design details accordingly until a satisfactory design is achieved. Advanced outputs are available to assist in the trial design selection.

Critical Design Variables

Riley (2006b) and Roesler et al. (2008) list several critical variables, such as the existing asphalt thickness and stiffness, concrete overlay elastic modulus and flexural strength, slab size, effective temperature gradient, and use of structural fibers. Furthermore, care is required for selecting the concrete

mixture design to avoid excessive concrete drying shrinkage. While proper curing can help mitigate shrinkage, the concrete mixture will still significantly affect this property. Adequate surface preparation is also important. Excess shrinkage and/or improper surface preparation can lead to debonding at the concrete-asphalt interface.

Unbonded Concrete Overlay Design

In this section, the procedures found in the design methodologies with respect to unbonded concrete overlays are described.

Unbonded Overlays of Concrete and Composite Pavements, 1993 AASHTO Guide


Section 5.9 of the 1993 AASHTO Guide covers the design of unbonded overlays of existing concrete and composite pavements. The design process is based on the following equation:

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

where D_{ol} = required concrete overlay thickness (in.), D_f = slab thickness required to carry the future traffic (in.), and D_{eff} = effective thickness of the existing concrete slab (in.).

The design of unbonded overlays is similar to that of bonded overlays with determining D_f . The rigid pavement design equation or nomograph in Figure 3.7 in Part II of the 1993 AASHTO Guide is used, but the values for the slab elastic modulus, modulus of rupture, load transfer, and drainage coefficients are for the concrete overlay and not for the existing concrete pavement. The inputs and typical ranges shown in Table 2 also apply to calculating D_f for unbonded overlays.

D_{eff} is determined using the Condition Survey or Remaining Life procedures.



Description


This bonded concrete overlay on asphalt (BCOA) thickness design web application is based primarily on the results of FHWA-IDT-08-016, "[Design and Concrete Material Requirements for Ultra-Thin White Topping](#)", a research project conducted in cooperation with the Illinois Center for Transportation at the University of Illinois, the Illinois Department of Transportation, and the Federal Highway Administration. Designers should understand the assumptions/limitations of the research on which this tool is based and also be knowledgeable about the various types of concrete overlay offerings and design/construction details of each type. For more details on the design and construction of concrete overlays, see the National Concrete Pavement Technology Center's (NCPTC) "Guide to Concrete Overlays," available in [PDF format here](#) or [printed format here](#), or the [National Concrete Overlay Explorer](#).

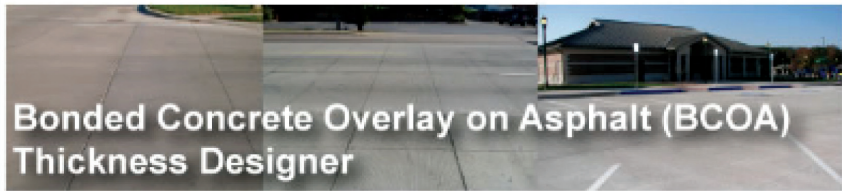
Status of This Design Method

While this thickness designer is based on the latest in bonded concrete overlay on asphalt (BCOA) design methodologies, research into this topic is still ongoing. For example, research into typical effective temperature gradients and time at the effective temperature gradient for different locations in the United States currently is being conducted and will be incorporated into this web app upon its release. Research to better define the impact of fibers on thin concrete overlays also is ongoing; the results of such research will be included in future updates of this tool. Thus, this tool should be treated as a state-of-the-art interim design procedure for BCOA.

Acknowledgements

National Concrete Pavement Technology Center





Bonded Concrete Overlay on Asphalt (BCOA) Thickness Designer

General Design Details

Design Lane ESALs:	Estimate ESALs	<input type="text" value="0"/>	Help
Slabs Cracked at End of Design Life (%):		<input type="text" value="20 %"/>	Help
Reliability (%):		<input type="text" value="85 %"/>	Help
Effective Temperature Gradient (°F/in.):		<input type="text" value="-1.4"/>	Help
Time at Effective Temperature Gradient (%):		<input type="text" value="58 %"/>	Help

Existing Pavement Structure Details

Remaining Asphalt Thickness (in.):	<input type="text" value="4"/>	Help
Asphalt Modulus of Elasticity (psi):	<input type="text" value="700,000"/>	Help
Modulus of Subgrade Reaction (pci):	<input type="text" value="150"/>	Help

[Calculate k-value](#)

Concrete Material Details

28-Day Flexural Strength (psi):	<input type="text" value="750"/>	Help
Fibers Used In Concrete:	<input type="text" value="No Fibers"/>	
Concrete Modulus of Elasticity (psi):	<input type="text" value="3,600,000"/>	Help
Coefficient of Thermal Expansion (10 ⁻⁶ /°F):	<input type="text" value="5.5"/>	Help

Concrete Overlay Details

Joint Spacing (in.):	<input type="text" value="72"/>	Help
Preoverlay Surface Preparation:	<input type="text" value="Old Asphalt, Cleaned"/>	Help

Calculate Design

Figure 8. ACPA BCOA thickness design web-based application

Table 7 summarizes the Condition Survey method for unbonded overlays. The Remaining Life method follows the same steps for bonded overlays that are summarized in Table 5 with two exceptions: 1) D cannot exceed 10 in. (even if the existing pavement is thicker) and 2) the Remaining Life method is not applicable to composite pavements.

Smith et al. (2002) and ACI Committee 325 (2006) discuss the following major limitations on unbonded overlay designs that apply to the 1993 AASHTO Guide:

- Lack of consideration of the structural contribution of the separation layer and its interaction in terms of friction or bonding with the overlay and existing pavement.
- Overestimation of the existing pavement effective thickness when the existing slab is relatively thick.
- Lack of consideration of curling, warping, and joint spacing in the concrete overlay.

Critical Design Variables

Critical design variables that have a moderate to high impact on the thickness design of unbonded overlays over concrete and composite pavements include the traffic (W_{18}), load transfer (J), drainage coefficient (C_d), modulus of rupture (S'_c), effective k-value, and the change in serviceability (ΔPSI).

In the 1993 AASHTO Guide, the unbonded overlay is designed with the same structural design procedure as a new pavement. For the 1993 AASHTO design, dowel bars at the joints significantly affect the overlay thickness by changing the load transfer coefficient (J) from 4.4 to 3.2.

Drainage improvements and an accurate knowledge of the mean concrete strength will also have an impact on the drainage coefficient and the modulus of rupture, respectively. Traffic and support conditions are sensitive design inputs but are not inputs that will vary for a given project.

Unbonded Overlays of Concrete and Composite Pavements, MEPDG

The design process for unbonded overlays of concrete or composite pavements follows the same general steps using the MEPDG software described for bonded overlays. Under the General Information menu, the type of unbonded overlay is selected, such as JPCP over JPCP, JPCP over CRCP, CRCP over JPCP, or CRCP over CRCP. The Traffic and Climate inputs are the same as the design of bonded overlays. The Pavement Structure inputs represent the main differences.

Structure

The Design Features submenu includes joint design information for JPCP. The joint spacing for unbonded overlays is typically recommended to be shorter than the spacing for new pavements, and the joints in the new overlay do not need to match the existing pavement joints/cracks. The MEPDG (see table on page 3.7.17 of the MEPDG) recommends offsetting the overlay joints a minimum of 3 ft from the existing pavement joints to improve load transfer, as shown in Figure 9. However, many states do not intentionally match or mismatch joints for unbonded overlays and have not experienced any adverse effects (Harrington et al. 2008). Dowels may not be required; but, if they are needed to address faulting, the spacing and diameter are determined following the same guidelines as for new JPCP.

For CRCP, the Design Features menu includes the steel reinforcement information instead of joint design information, which includes the percent of steel, the bar diameter, and the steel depth. Longitudinal steel reinforcement for unbonded CRCP overlays is designed following the same guidelines as for new CRCP. The MEPDG cites typical values of 0.6 percent to 0.75 percent of steel,

Table 7. Summary of 1993 AASHTO Guide condition survey method for unbonded overlays

$D_{eff} = F_{jcu} * D$ where D = existing slab thickness (in.). For composite pavements, neglect the asphalt thickness.	F_{jcu} is the joints and cracks adjustment factor for unbonded overlays and is used to account for the deteriorated cracks and joints that are not repaired before the unbonded overlay. Figure 5.13 in Part III of the 1993 AASHTO Guide is used to determine F_{jcu} , which ranges from 0.9 to 1 and is based on the total number of unrepaired deteriorated joints/cracks and other discontinuities per mile. When a thick asphalt separation layer is applied (greater than 1 in.), it is likely to eliminate reflection cracking problems and an $F_{jcu} = 1$ is used.
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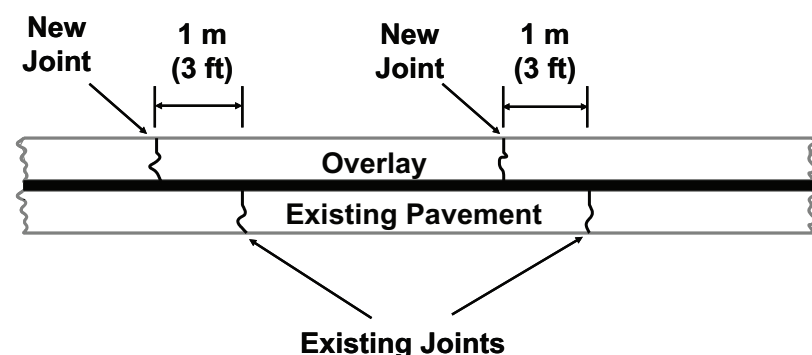


Figure 9. Unbonded overlays—mismatching joints (ACPA 1990)

a bar diameter of 0.625 to 0.75 in., and 3.5 in. to mid-depth steel position.

In the same Design Features submenu, the base properties information includes the erodibility index. For both JPCP and CRCP unbonded overlays, the asphalt separation layer (shown in Figure 10) represents the base and, if the asphalt interlayer is of good quality, an erodibility index of 1 (extremely resistant) is recommended. For JPCP unbonded overlays, the PCC slab-base interface is automatically set as “zero friction”/no bond. For CRCP unbonded overlays, a base-slab friction coefficient of 7.5 is recommended when an asphalt separation layer is used, but this value may be changed if necessary.

For the Layers submenu, the new unbonded overlay general, thermal, mix, and strength properties are estimated similar to bonded overlays. A minimum thickness of 7 in. must be entered in the MEPDG for unbonded overlays. Also in this submenu, the asphalt separation layer typically used for unbonded overlays is treated as a chemically stabilized base requiring material property inputs.

Critical Design Variables

To address trial designs for JPCP unbonded overlays that do not meet the performance criteria for faulting and cracking (and consequently smoothness), the designer should consider increasing the overlay thickness, decreasing the joint spacing, using dowel bars (or increasing the diameter), using a widened lane, or adding tied PCC shoulders. Recommendations for unbonded CRCP overlay designs not meeting the performance criteria include increasing the overlay thickness, increasing the percent of longitudinal steel reinforcement, and adding a concrete shoulder.



Figure 10. Asphalt separation layer

Unbonded Concrete Overlays of Asphalt Pavements, 1993 AASHTO Guide

Section 5.10 of the 1993 AASHTO Guide covers the design of unbonded overlays of existing asphalt pavements. This alternative is most cost effective when the existing flexible pavement is severely deteriorated. For thickness design purposes, the existing asphalt pavement is treated as the base and the concrete overlay is designed as a new concrete pavement based on the future traffic to be carried. The design process is based on the following equation:

$$D_{ol} = D_f$$

where D_{ol} = required concrete overlay thickness (in.) and D_f = slab thickness required to carry the future traffic (in.).

The design process to determine the overlay thickness (D_o) involves the same steps and inputs described for unbonded overlays of concrete and composite pavements.

Critical Design Variables

Critical design variables that have a moderate to high impact on the

thickness design of unbonded overlays over asphalt pavements include the traffic (W_{18}), load transfer (J), drainage coefficient (C_d), modulus of rupture (S'_c), and composite k-value. These sensitivities are similar to unbonded overlays of concrete pavements.

Unbonded Concrete Overlays of Asphalt Pavements, MEPDG

The MEPDG design process for unbonded overlays of asphalt pavements also follows similar guidelines as those for designing a new concrete pavement, where the existing pavement is treated as the base. A key input for this procedure, under the Structure/Design Features menu, is the “PCC-stabilized base interface” for JPCP and the “Base/slab friction coefficient” for CRCP. An unbonded condition between the overlay and the existing pavement is typically assumed; therefore, the “PCC-stabilized base interface” is set to “zero friction contact” for JPCP overlays, and the “Base/slab friction coefficient” is set to 7.5 as the default/mean for CRCP. The selection of this concrete-asphalt interface condition can have a significant impact on the overlay thickness design.

Critical Design Variables

To address trial designs for JPCP unbonded overlays of asphalt pavements that do not meet the performance criteria for faulting and cracking (and consequently IRI), the designer should consider decreasing the joint spacing, using dowel bars (or increasing the diameter), and using a widened slab or tied concrete shoulder. Recommendations for CRCP unbonded overlay of asphalt pavement designs not meeting the performance criteria include increasing the overlay thickness, increasing the percent of longitudinal steel reinforcement, or adding tied concrete shoulders.

Conclusions

This technical summary provided brief overview of the 1993 AASHTO Guide and MEPDG procedures and their more sensitive variables for

- Bonded Overlays of Concrete Pavements.
- Unbonded Overlays of Concrete Pavements and Composite Pavements.
- Unbonded Overlays of Asphalt Pavements.

In addition, an overview of the ACPA overlay design methodology was presented for Bonded Overlays of Asphalt and Composite Pavements.

There are a number of additional design procedures available for the different types of concrete overlays that were not discussed in this technical summary. It is important for the pavement designer to recognize the requirements, the most relevant design variables, and the strengths and weaknesses of any design procedure.

The intent of this technical summary, and ultimately the *Design of Concrete Overlays using Existing Methodologies*, is

to assist in that task. To facilitate this, the future *Design of Concrete Overlays using Existing Methodologies* will provide additional information about these design methodologies and will include step-by-step examples to design both bonded and unbonded concrete overlays.

Finally, it should be recognized that there is a significant amount of ongoing research and development in the area of concrete overlay design. Ongoing efforts to develop typical effective temperature gradients and time at the effective temperature gradient for different locations in the U.S. and to improve fiber reinforcement characterization were cited, and the results will be incorporated into the ACPA BCOA web tool in the near future.

Another project of importance is the ongoing Pooled Fund Study TPF-5(165) to develop a new design guide and software for bonded concrete overlays of existing asphalt pavements. In addition, as previously mentioned, several state highway agencies are currently evaluating, calibrating, and working to implement the MEPDG.

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