ENHANCEMENTS TO THE MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE:

A MANUAL OF PRACTICE, JULY 2008 INTERIM EDITION

ADDENDUM NUMBER: **FY2016.01**

ADDENDUM TITLE: **SHORT JOINTED BONDED CONCRETE OVERLAY OF ASPHALT**

Addendum Date: **June 28, 2016**

Addendum #FY2016.01 overviews the design procedure for thin, short jointed, bonded concrete overlays of asphalt pavements developed by Li, Dufalla, and Vandenbossche at the University of Pittsburgh and included in Pavement ME Design software version 2.3, released in July 2016. Changes are reported by the respective Manual of Practice (MOP) chapters and sections related to the new flexible pavement rehabilitation design strategy type.

CHAPTER 3 - SIGNIFICANCE AND USE OF THE MEPDG

3.1 Performance Indicators Predicted by the MEPDG

- PCC-Surfaced Pavements and PCC Overlays
  - Short Jointed Plain Concrete Pavement (SJPCP) overlay bonded to existing asphalt pavement – Longitudinal Fatigue Cracking

3.4 New Rigid Pavement, PCC Overlay, and Restoration of Rigid Pavement Design Strategies Applicable for Use with the MEPDG

- Short Jointed Plain Concrete Pavement (SJPCP): This title is defined specifically as bonded concrete overlay placed over an existing asphalt pavement. These relatively thin (4 to 8 inch) concrete overlays are bonded to the existing asphalt pavement surface and have short joint spacing (5x5, 6x6, 7x7 and 8x8 ft). These overlays have also been referred to in the literature as Bonded Concrete Overlays of Asphalt pavements (BCOA).

3.5 Design Features and Factors Not Included Within the MEPDG Process

- **Ultra-Thin PCC overlays –**Ultra-thin PCC overlays (e.g., <4 inches or less than 5 ft joint spacing) cannot be designed with the MEPDG. The Short Jointed Plain Concrete (SJPCP) bonded overlays can be designed between 4 and 8 inches with joint spacings of 5 to 8 feet**.** The conventional full lane width JPCP overlays over existing asphalt or concrete pavement has a minimum thickness of 6 inches and joint spacing is also limited to a minimum of 10 feet. The minimum thickness of CRCP overlays is 7 inches.

CHAPTER 4 - TERMINOLOGY AND DEFINITION OF TERMS

4.6 Distress or Performance Indicators Terms – PCC-Surfaced Pavements

- **Bottom-up longitudinal cracking (SJPCP) –** When truck axles are near the transverse joint in the general area of the wheel paths, which generally lie between the longitudinal joints (typically 6x6 ft), a critical tensile bending stress occurs at the bottom of the slab under the wheel load. This stress increases when there is a high positive temperature gradient through the slab (the top of the slab is warmer than the bottom of the slab). Repeated loadings of heavy axles under those conditions result in fatigue damage along the bottom of the transverse joint of the slab, which eventually results in a longitudinal fatigue crack that propagates to the surface of the slab and along the slab length. Bottom-up longitudinal fatigue cracking is calculated as a percent of the total number of slabs which is the output parameter used for structural design.

CHAPTER 5 - PERFORMANCE INDICATOR PREDICTION METHODOLOGIES – AN OVERVIEW

5.3 Distress Prediction Equations for Short Jointed Bonded Concrete Overlays of Asphalt (SJPCP)

The damage and distress transfer functions for relatively thin bonded concrete overlays of asphalt pavements were globally calibrated in this study. The following summarizes the methodology and mathematical models used to predict longitudinal fatigue cracking.

5.3.6 Longitudinal Slab Cracking (Bottom-Up) – SJPCP

Bottom-up longitudinal fatigue cracking in the wheel paths is predicted as the primary structural distress. Critical bending stresses occur when the truck axle approaches the transverse joint of the slabs in both wheel paths. The wheel paths occur between the longitudinal joints (which are typically spaced from 5 to 8 ft depending on lane width) as illustrated in Figure 24a. Similar to conventional JPCP design, calculation of critical stresses was done using neural nets (for speed) that require the slab and lower layer to be combined into an “equivalent slab” thickness based on equivalent stresses (load and temperature/moisture gradients) and contact friction between slab and base. This is done monthly as these parameters change over time.

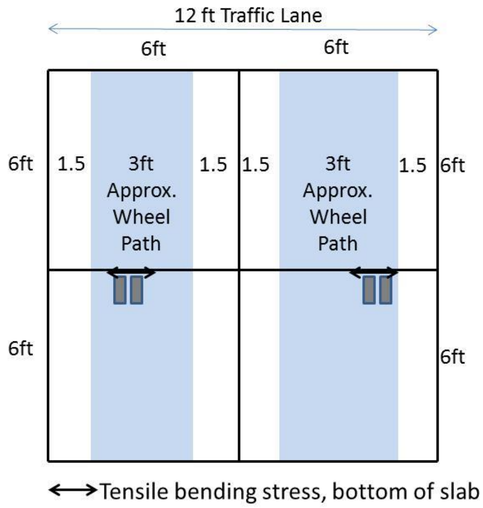

Figure 24a. Illustration of proper location of longitudinal joints to avoid overlap with truck wheel paths (to avoid corner cracking) and the resulting critical bending stresses at bottom of slab that are considered to limit longitudinal fatigue cracking.

A critical tensile bending stress occurs at the bottom of the slab under the wheel load which increases when there is a high positive temperature gradient through the slab (the top of the slab is warmer than the bottom of the slab). Repeated loadings of heavy axles under those conditions result in fatigue damage along the bottom transverse joint of the slab (the point of maximum fatigue damage is computed), which eventually results in a longitudinal crack that propagates to the surface of the slab and along the slab. Bottom-up longitudinal cracking is calculated as a percent of the total number of slabs in the wheel paths which is the output performance criteria used for structural design. This distress is predicted using the following globally calibrated equation (36a) for bottom-up longitudinal fatigue cracking:

$$LCRK = \frac{1}{1+0.41(DI_F)^{-2.33}} \tag{36a}$$

Where:

$LCRK$ = Predicted amount of bottom-up longitudinal fatigue cracking (percentage).
DI_F = Fatigue damage calculated using the procedure described in this section (fraction from 0 to > 1) at the most critical point along the transverse joint.

The fatigue damage calculation is a process of summing damage from each damage increment at several critical points across the bottom of the slab along the transverse joint. The general expression for fatigue damage accumulation considering all critical factors for SJPCP longitudinal cracking is equation 36b and referred to as Miner's hypothesis:

$$DI_F = \sum \frac{n_{i,j,k,l,m,n,o}}{N_{i,j,k,l,m,n,o}} \tag{36b}$$

Where:

DI_F = Total fatigue damage (bottom-up).

$n_{i,j,k,...}$ = Applied number of load applications at condition *i, j, k, l, m, n*.
$N_{i,j,k,...}$ = Allowable number of load applications at condition *i, j, k, l, m, n*.
i =Age (accounts for change in PCC modulus of rupture and elasticity, slab/AC contact friction.
j = Month (accounts for change in AC dynamic modulus and dynamic subgrade K-Value).
k = Axle type (single, tandem, and tridem for bottom-up cracking).
l = Load level (incremental load for each axle type).
m = Equivalent temperature difference between top and bottom PCC surfaces.
n = Traffic offset path (normal distribution).
o = Hourly truck traffic fraction.

The applied number of load applications ($n_{i,j,k,l,m,n}$) is the actual number of axle type *k* of load level *l* that passed through traffic path *n* under each condition (age, season, and temperature difference). The allowable number of load applications (to cracking $N_{i,j,k,l,m,n}$) is) is the number of load cycles at which fatigue cracking is expected on average and is a function of the applied stress and PCC strength. The allowable number of load applications ($N_{i,j,k,l,m,n}$) to cracking is determined using equation 36c PCC field fatigue equation 36c:

$$\log\left(N_{i,j,k,l,m,n}\right) = C_1 \cdot \left(\frac{MR_i}{\sigma_{i,j,k,l,m,n}}\right)^{C_2} + 0.4371 \qquad (36c)$$

Where:
$N_{i,j,k,...}$ = Allowable number of load applications at condition *i, j, k, l, m, n.*
M_{Ri} = PCC modulus of rupture at age *i*, psi.
$\sigma_{i,j,k,.}$ = Applied stress at condition *i, j, k, l, m, n.*
C_1 = Calibration constant, 2.0.
C_2 = Calibration constant, 1.22.

A plot of measured longitudinal cracking versus the computed fatigue damage at the bottom of the PCC slab is shown in Figure 24b. This plot follows the typical S-Shaped curve and is termed the transfer function between slab longitudinal fatigue cracking and cumulative fatigue damage at the bottom of the slab.

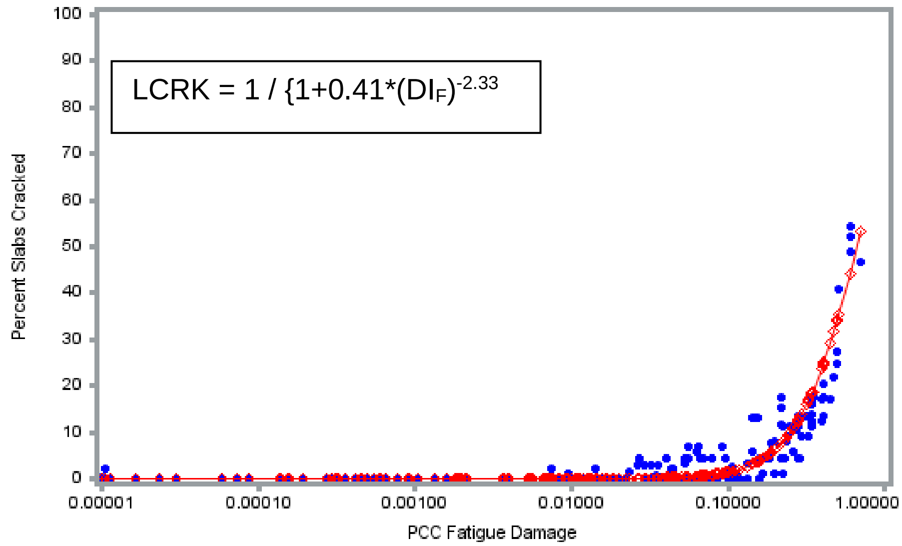

Figure 24b. Measured longitudinal fatigue cracking (LCRK) versus PCC fatigue damage (DI_F) bottom of PCC slab. [GRAPH TO BE REPLACED WITH BLACK CURVE]

A plot of measured versus predicted longitudinal cracking and the statistics resulting from the global calibration process is shown in Figure 24c. Statistical hypothesis testing at the 0.05 significance level for the slope of the line (equal to 1.0), intercept (equal to 0), and for prediction bias (either over or under prediction) were not significant.

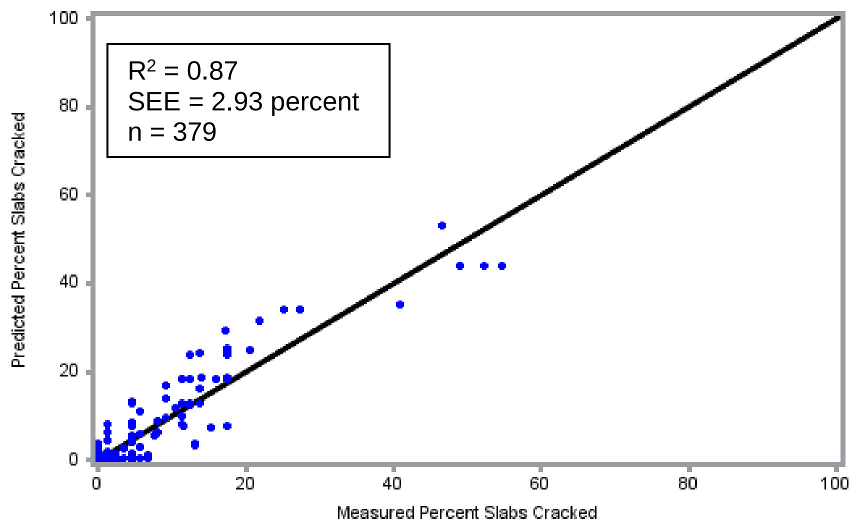

Figure 24c. Comparison of Measured and Predicted Percentage SJPCP Overlay Slabs Longitudinally Cracked Resulting from Global Calibration Process

The standard error (or standard deviation of the residual error) for the percentage of slabs longitudinally cracked prediction global equation is shown in equation 36d.

$$s_{e(LCRACK)} = 3.5522 * LCRACK^{0.4315} + 0.5000 \qquad (36d)$$

Where:

LCRACK = Predicted longitudinal fatigue cracking based on mean inputs (corresponding to 50% reliability), percentage of slabs.

$s_{e(CR)}$ = Standard error of the estimate of longitudinal fatigue cracking at the predicted level of mean longitudinal cracking.

CHAPTER 8 - SELECTING DESIGN CRITERIA AND RELIABILITY LEVEL

8.1 Recommended Design-Performance Criteria

Table 4 summarizes the default design or performance criterion recommended for use in designing a bonded concrete overlay with short joint spacing. Only one design criterion is provided at this time. An initial and terminal IRI value is not needed for this rehabilitation design strategy because insufficient data were available to develop an IRI prediction equation.

Table 4. Design Criteria or Threshold Values Recommended for Use in Judging the Acceptability of a Trial Design

Pavement Type	Performance Criteria	Maximum Value at End of Design Life
BCOA/SJPCP	Longitudinal fatigue cracking	Interstate: 10 percent slabs* Primary: 15 percent slabs* Secondary: 20 percent slabs*

*Performance criteria levels need review by agency for adequacy

CHAPTER 10 – PAVEMENT EVALUATION FOR REHABILITATION DESIGN

10.3 Analysis of Pavement Evaluation Data for Rehabilitation Design Considerations

10.3.6 SJPCP Bonded Overlay of Existing Asphalt Pavement Condition Input

- The condition of the existing flexible pavement is a preselected input level 2 at 65 percent fatigue cracking for this overlay design type. Calibration of the longitudinal cracking model indicated that a large proportion of the sections indicated some reduction in contact friction over service life between the PCC and AC layers. The use of 65 percent cracking was the approach selected to provide a reasonable input to the design that effectively reduced the equivalent slab thickness to calculate the appropriate bending stress in the bottom of the PCC slab. Levels 1 and 3 are not recommended for this input at this time.

CHAPTER 13 - REHABILITATION DESIGN STRATEGIES

13.3 Rehabilitation Design with PCC Overlays

13.3.4 JPCP Rehabilitation Design

- **SJPCP Short Jointed Bonded Concrete Overlay of Existing Asphalt Pavement –** Short jointed plain concrete pavement (thickness 4 to 8 in) over existing flexible pavements (SJPCP) can be considered in the MEPDG. When subjected to axle loads, the SJPCP overlaid flexible pavement behaves very different than a conventional JPCP over an AC base course and other underlying layers. The allowable longitudinal and transverse joint spacings are greatly reduced (5 to 8 ft), which dramatically reduces the curling stresses. For this design, the contact friction between the PCC slab and the existing AC surface is extremely important throughout the design life. A full contact friction and bonding is absolutely critical to good performance. Efforts during construction such as milling and cleaning the top surface will enhance the contact friction between the PCC and HMA surface over the service life.

Table 40 (Addition). Guidance on How to Select the Appropriate Design Features for Rehabilitated JPCP Design

Type of JPCP Rehabilitation	Specific Rehabilitation Treatments	Recommendation on Selecting Design Feature
Bonded Concrete Overlay of Asphalt (SJPCP)	**Short Jointed Bonded Concrete Overlay of Asphalt Pavement**	The longitudinal joint spacing is a very critical input. Joint spacing can vary from 5 to 8 ft depending on lane width. A critical design principle is to not locate a longitudinal joint in the truck wheel path. This design procedure does not consider heavy loads traveling down the longitudinal joint that create corner cracks. This design procedure considers truck wheel paths that travel between the longitudinal joints where tensile bending stresses are calculated at the bottom of the PCC slabs and used in the fatigue damage calculation for PCC thickness design. Transverse joint load transfer efficiency (LTE) can be varied from 25 to 95 percent and from season to season. An annual value of 80 percent is recommended as typical from FWD load transverse efficiency for this type of overlay. All sections were calibrated at 80 percent LTE. Condition of existing flexible pavement is a preselected level 2 input at 65 percent fatigue cracking. Calibration of the longitudinal cracking model indicated that a large proportion of the sections indicated some reduction in contact friction over service life between the PCC and AC layers. The use of 65 percent cracking was the approach selected to provide a reasonable input to the design that effectively reduced the equivalent slab thickness to calculate the appropriate bending stress in the bottom of the PCC slab.

Table 41. Recommendations for Modifying Trial Design to Reduce Distress/Smoothness for JPCP Rehabilitation Design

Distress Type	Recommended Modifications to Design
Longitudinal Fatigue Cracking	Increase slab thickness (8 inches maximum) Increase existing AC layer thickness Increase PCC strength (and concurrent change in PCC elastic modulus and CTE) Tied PCC shoulder

CHAPTER 14 - INTERPRETATION AND ANALYSIS OF THE TRIAL DESIGN

14.4 Predicted Performance Values

- Rigid pavements (JPCP).
  - Percent slabs longitudinally cracked (SJPCP): the mean predicted longitudinal cracks (in the heaviest trafficked lane) that form as a result of fatigue damage at the bottom of the slab. A critical value is reached when longitudinal cracking accelerates and begins to require significant repairs and lane closures.