Unbonded Concrete Overlays of Existing Concrete Pavements (UBOLs): Task 3 Structural Model Development

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Task 2: Consolidation

Permanent deformation in HMA

- MI open graded
- MI dense graded
- MN dense graded
- MN open graded

Increasing permanent deformation

Fabric not influenced

Longitudinal outer wheel path crack in LTPP section
Task 2: Fatigue

Fatigue in interlayer

- MN open graded
- None exhibited in other interlayers
Task 2: Friction

Frictional restraint

- MI open graded
- MI dense graded
- MN dense graded
- MN open graded
- 10 oz fabric glued
- 10 oz fabric pinned
- 15 oz fabric glued
- 15 oz fabric pinned

Decreasing frictional restraint
Task 2: Friction

Too much vs too little

- All joints not working (large effective panel size)
- Result: Jt deterioration and/or fatigue cracking

Not deployed (Approx. 0.25-in wide)  
Deployed (Approx. 0.5-in wide)
Task 2: Reflective cracking

- Reflective cracking not generated when fully supported
- Fabric tends to increase resistance to reflective cracking when compared to HMA
- MI open graded appears to perform better than other HMA interlayers
  - Greater resistance to reflective cracking and less permanent deformation
Task 2: Direct tension

- Examine curling warping stresses
- Measure vertical deformations within interlayer and interface strength

Decreasing resistance to vertical uplift

MI dense graded
MN dense graded
MI open graded
MN open graded
10 oz fabric
15 oz fabric
Joint performance

• Erosion
• Consolidation
• Fatigue
• Faulting
Interlayer erosion

Contributing Factors

- Moisture
- Traffic
- Asphalt susceptibility
- Drainage

Photo courtesy of Andy Bennett

US-23 in MI
Interlayer erosion

- Erodibility factor
  - Interlayer drainability
  - Binder content
  - Film thickness
  - Permeability
  - Binder and aggregate type

- Predicted erosion depth
  - Critical response from FEM rapid solution
  - Erodibility factor
Consolidation

- Void created in interlayer
- Observed in lab testing
- Contributing factors
  - Traffic
  - Asphalt compressive strength
  - Vertical interlayer strain
  - LTE and Mag. of deflection
Interlayer fatigue

- Observed in lab testing
- Contributing factors
  - Traffic
  - Asphalt compressive strength
  - Vertical interlayer strain
  - LTE and mag. of deflection
Faulting

- Occurs in HMA interlayer (not fabric)
- Affected by
  - Fatigue
  - Erosion
  - Consolidation
Faulting prediction framework

1. **Faulting**
   - Sum of basin deflection near joint on loaded and unloaded sides

2. **Interlayer Fatigue**
   - Strain at top and bottom of interlayer in wheelpath

3. **Interlayer Erosion**
   - Peak deflection directly under overlay slab in wheelpath

4. **Interlayer Consolidation**
   - Vertical strain at interlayer nodes

5. **Erodibility Factor**
   - Predicted void between interlayer and overlay

6. **Predicted Interlayer Erosion Depth**

7. **Predicted Interlayer Damage**

8. **Predicted Faulting**

9. **Longitudinal Cracking in Wheelpath**

UBOL
Neural Network development

- FEM results to develop rapid solutions
- NN trained to predict critical responses
Joint faulting response

- 3D ABAQUS Model
- Model:
  - 3 overlay slabs
  - Shoulder
  - Asphalt Interlayer (no fabric)
  - Existing PCC
Slab sizes

- 3 overlay slabs
- 12 ft lane (jt. spacing = 10, 15, 20 ft)

- 6 ft x 6 ft slabs
Modeling properties

- $E_{OL}, h_{OL}$
- $E_{IL}, h_{IL}$
- $E_{EX}, h_{EX}$
- $k$

- Shear springs
- Spring elements
- Frictionless interface

Overlay PCC

Interlayer

Existing PCC
PCC and asphalt layers

- Elastic solids
  - $E$
  - $\mu_{\text{pcc}} = 0.18$, $\mu_{\text{hma}} = 0.35$

- Isotropic linear expansion
  - $\alpha_{\text{pcc}}$, $\alpha_{\text{hma}}$

- 20 node brick elements
  (C3D20 quadratic element)
Foundation support

- Winkler foundation
Transverse joints

• Joint through overlay and asphalt

• Load transfer in PCC only
  • Shear springs at overlay nodes
  • No load transfer through interlayer
  • Only dof in vertical direction
  • Simulate aggregate interlock and doweled joints

• Hard contact between joint surfaces
  - simulate compression effects
Transverse joints

- 3 spring stiffnesses
  - Corner nodes - K
  - Edge nodes - 2K
  - Interior nodes - 4K
Longitudinal joints

- Lane-shoulder joint
  - Asphalt shoulder – LTE = 0%
  - Tied PCC shoulder – LTE ~ 90%

- 6 ft x 6 ft longitudinal joint
  - Longitudinal LTE = Transverse LTE (undoweled jt)
  - Longitudinal LTE < Transverse LTE (doweled jt)
Interface bond: existing-interlayer

- Interaction between top of existing and interlayer:
  - Treated as frictionless
  - Full slip between two surfaces

Interface tied with spring elements

Frictionless interface
Interaction between overlay and interlayer:

- Treated as fully bonded
- Achieved with stiff springs connecting nodes of parts
- Response can be modified to achieve debonding and to introduce gap between overlay and interlayer
Thermal loads

• Uniform distributed temperature loads
  • Predefined field on top/bottom PCC surfaces
  • 3 temperature differences considered
    • -12, 0, 24 °F

• Equivalent strain will be used to convert nonlinear temperature differences

\[ T = 0 \, ^\circ\text{F} \quad \Delta T = -12 \, ^\circ\text{F} \]

\[ T = 12 \, ^\circ\text{F} \]
Axle configuration

- Tire footprint of 6 in x 8 in
- Single, tandem, and tridem
- Wheel wander
Axle type and wheel wander

- \( s \) = wheel wander
  - 0, 2, 6, 12, 36 in

- \( d_1 \) = tandem axle spacing
  - 0, 40 in

- \( d_2 \) = tridem axle spacing
  - 0, 40 in
Load magnitude

- Single axles
  - 0 – 45,000 lbs (15,000 lb increment)

- Tandem axles
  - 0 – 90,000 lbs (30,000 lb increment)

- Tridem axles
  - 0 – 120,000 lbs (40,000 lb increment)

- Gravity load
  - Uniform pressure on surface
  - Equal to weight of structure
Reduction of parameters

• Overlay represented w/ flexural stiffness, $D$

\[ D = \frac{E_{OL}h_{OL}^3}{12(1 - \mu^2)} \]

• Existing PCC & foundation represented w/ radius of relative stiffness, $\ell$

\[ \ell = \frac{4}{\sqrt{12(1 - \mu^2)k}} \]
Reduction of parameters

- PCC $E$ and $k$-value kept constant
- Change $h$ of PCC layers to change $D_{OL}$ and $\ell$
## Range of parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing slab and foundation, L (in)</td>
<td>20 35 50 65 80</td>
</tr>
<tr>
<td>PCC Poisson’s ratio</td>
<td>0.18</td>
</tr>
<tr>
<td>Overlay Flexural Stiffness, D (#-in)</td>
<td>2.00E+07 2.40E+08 4.60E+08 6.80E+07 9.00E+08</td>
</tr>
<tr>
<td>Overlay PCC joint spacing (ft)</td>
<td>6 10 15 20</td>
</tr>
<tr>
<td>Overlay PCC CTE (in/in/°F)</td>
<td>3.80E-06 5.50E-06</td>
</tr>
<tr>
<td>Overlay Temp Difference (°F)</td>
<td>-12 0 24</td>
</tr>
<tr>
<td>Interlayer Thickness (in)</td>
<td>2</td>
</tr>
<tr>
<td>Interlayer Stiffness (psi)</td>
<td>100000 400000 700000 1000000</td>
</tr>
<tr>
<td>Interlayer Poisson’s ratio</td>
<td>0.35</td>
</tr>
<tr>
<td>Interlayer CTE (in/in/°F)</td>
<td>6E-06</td>
</tr>
<tr>
<td>Lane shoulder LTE (%)</td>
<td>Tied PCC</td>
</tr>
<tr>
<td>Wheel wander (in)</td>
<td>0 2 6 12 36</td>
</tr>
<tr>
<td>Single axle (lb)</td>
<td>0-45,000 (15 kip increment)</td>
</tr>
<tr>
<td>Tandem axle (lb)</td>
<td>0-90,000 (30 kip increment)</td>
</tr>
<tr>
<td>Tridem axle (lb)</td>
<td>0-120,000 (40 kip increment)</td>
</tr>
</tbody>
</table>
Range of parameters

- $E_{OL} = 4 \times 10^6$ psi
- $E_{EX} = 4.5 \times 10^6$ psi
- $k = 100 \text{psi/in}$

- $D = \frac{E_{OL}h_{OL}^3}{12(1 - \mu^2)}$
- $E_{IL}, h_{IL}$
- $\ell = 4 \sqrt{\frac{E_{EX}h_{EX}^3}{12(1 - \mu^2)k}}$

- $D$ and $\ell$ ranges result in wide range of slab thicknesses considered:
  - $h_{OL} = 3.9 - 13.8$ in
  - $h_{EX} = 3.5 - 22$ in
Thank You

Any Questions?
Keying in overlay

- How much faulting can be in existing pavement before nonwoven fabric no longer prevents keying?
  - Function of fabric thickness

Reflective Cracking

Interlayer

SMOOTHER SLIP PLANE

OLD PAVEMENT

OVERLAY

"KEY"

No reflective Cracking

Photos courtesy of John Donahue of MoDOT
Reflectex fabric thickness

- ASTM D5199 – relate pressure to overlay thickness

\[ y = 215.77e^{-0.037x} \]

\[ R^2 = 0.99 \]

<table>
<thead>
<tr>
<th>Overlay Thickness (in)</th>
<th>Thickness (mils)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.28</td>
<td>177</td>
</tr>
<tr>
<td>2.8</td>
<td>122</td>
</tr>
<tr>
<td>28</td>
<td>52.4</td>
</tr>
</tbody>
</table>

- Thickness due to self-weight of 6 in overlay ~ 96 mils