TPF(5)-169, Development of an Improved Design Procedure for Unbonded Concrete Overlays

Task 3, Structural Modeling

Prof. Lev Khazanovich
**Project Tasks**

- Task 1: Literature review and database assembly
- Task 2: Laboratory and field testing
- **Task 3: Structural model development**
- Task 4: UBOL procedure development
- Task 5: Procedure user guide development
- Task 6: Evaluate guidelines on suitability of UBOL
- Task 7: Draft final report
- Task 8: Final report
Task 1 & 2 highlights

• Field observations
• Drainage review
• Lab study observations
Field observations

• Transverse mid-slab cracking is not very common
• Transverse new joint cracking
• Longitudinal cracking
• Corner cracking
Field observations

Longitudinal cracks on US 10 near Coleman
(cracks digitally enhanced)
Field observations

Longitudinal cracks on US 10 near Coleman
(cracks digitally enhanced)
Field observations

Corner breaks
Task 1 & 2 highlights

- Field observations
- Drainage review – Dr. Snyder
- Lab study observations
Task 1 & 2 highlights

• Lab Study Observations
  – No reflective cracking was replicated in lab study
  – Significant deterioration of the interlayer may lead to cracking in the overlay
  – Permanent deformation, consolidation, and erosion observed under joint loading
Task 3, Overview of modeling (1)

- Model accounts for
  - overlay
  - interlayer
  - existing slab
  - subgrade support

- Joints in the overlay do not necessarily match with joints in the existing pavements

- Unlike AASHTO M-E, the structural model does not convert the existing and overlay into a single-layer system
Using UBOL system model:

- Gain insight on effects of damage in existing PCC slab and effects of deterioration near joints
- Can estimate single-layer structural equivalents for different UBOL systems (given a “worst case”)

Model modified/extended to:

- Simulate lab beams to estimate interlayer properties
- Investigate systems with 6-ft panels
Totsky approach for interlayer modeling

- Totsky approach models “cushioning” property of the interlayer using springs

- Advantages of Totsky approach:
  - Computationally efficient (big concern for FEM)
  - Already incorporated into ISLAB2005 specifically for UBOL
  - Can be adopted for more sophisticated models (e.g. 3D joint faulting) without issue

- Requires estimate of interlayer spring coefficient
Modeling Task 2 reflective cracking beam behavior and interlayer response

• 2D finite element simulation of Task 2 reflective cracking beams using ISLAB2005
• Factorial of simulations created for exact beam dimensions and support conditions
  – Interlayer coefficient varied from 10 to 50,000
Simulating beam interlayer response to 1 kip line load in laboratory

ISLAB model of Refl Cr Beams from Task 2 Lab,
Response normalized to 1 kip load,
No support for middle third under span,
Avg layer properties from lab details

$y = 4997.7x^{-1.068}$
$R^2 = 0.9975$
Estimating HMA and fabric interlayer coefficients with Task 2 lab data

• Use exponential regression from simulations to estimate interlayer coefficients given lab data
  – Select subset of well-behaved beams (i.e. no strange behavior or outliers)
  – 4 fabric beams, 12 HMA beams

• HMA average of 5478
  – No correlation with thickness, no significant difference between dense-graded and open-graded

• Fabric average of 532
Estimating HMA and fabric interlayer coefficients with Task 2 lab data

Graph 1: Relationship between Totsky Coefficient and Avg. HMA Thickness
- Avg 5478.0

Graph 2: Comparison of Totsky Coefficient for different Fabric Types
- Avg 531.9

UBOL, Task 3, 22 Feb 2016
Equivalence to single-layer structures

- 139 simulations for single-layer and UBOL systems of variable thicknesses
  - Subjected to +15F thermal gradient and 18-kip single-axle load
  - UBOL assume both fabric and HMA interlayer coefficients

- Comparing structural response of single-layer systems to UBOL using average critical stress
  - “Influence charts”
  - Create regression to calculate and compare with AASHTO 1993 equivalence
Critical response: $\sigma_{\text{avg}}$ vs. $\sigma_{\text{max}}$

- Most designs use maximum stress, $\sigma_{\text{max}}$, at a critical location
  - Use of $\sigma_{\text{max}}$ may underestimate the structural equivalence of UBOL to single-layer systems
- As alternative, this analysis averages stress across a 36-inch wide region centered on load to develop average stress, $\sigma_{\text{avg}}$
  - $\sigma_{\text{avg}}$ adoption prevents overly thick overlay design
  - Critical region can be widened or narrowed for design procedure given additional analysis
Equating critical stresses in systems (1)

\[ \sigma_{\text{avg}} \text{ (psi)} \]

HMA Interlayer

\[ h_{\text{PCC}} \text{ (in)} \]

- 1L
- 5 h OL, HMA
- 6 h OL, HMA
- 7 h OL, HMA
- 8 h OL, HMA
- 9 h OL, HMA
- 10 h OL, HMA
- 11 h OL, HMA
- 12 h OL, HMA

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Equating critical stresses in systems (2)

\[ \sigma_{\text{avg}} \text{ (psi)} \]

Fabric Interlayer

\[ h_{\text{PCC}} \text{ (in)} \]

- 1L
- 5 h_OL, Fab
- 6 h_OL, Fab
- 7 h_OL, Fab
- 8 h_OL, Fab
- 9 h_OL, Fab
- 10 h_OL, Fab
- 11 h_OL, Fab
- 12 h_OL, Fab

+15°F ΔT

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Civil, Environmental, and Geo-Engineering
# Comparing with AASHTO 1993 UBOL

$$h_{eff} = \sqrt{h_{OL}^2 + C_{ex}h_{PCC}^2}$$

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<th>$h_{OL}$</th>
<th>$E_{OL}$</th>
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<th>$h_{PCC}$</th>
<th>$E_{PCC}$</th>
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<td>165</td>
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Modeling longitudinal cracking

- If an adjacent slab is cracked longitudinally, there is an increase in the stress in the loaded slab.
- Benefits of load transfer between adjacent slabs are nullified or can begin to add stress to the uncracked loaded slab as the slab curls downward.
Existing crack location relative to load

- Simulations of 6-on-9 inch UBOL single slab with existing crack
- Move crack relative to load at mid-slab
- Critical location is within 2 feet of existing crack, outside of that area stresses within 5% of response with no crack
Effect of deterioration at existing crack

- Simulations of 6-on-9 inch UBOL single slab with existing crack
- Vary width of deterioration over crack
- Stress response varies given deterioration area
  - 6-inch area amplifies critical stress by 2.5%, 18-inch by 12%, 36-inch by 52%
Effect of deterioration at joint

- Two-slab, jointed, 6-on-9 inch UBOL system
  - Vary LTE and deterioration area under joint
  - 18-kip SA load with +/- 15F gradient
- Critical stress location depends on slab curl (due to thermal gradient) and LTE
Response of 6-ft panels to loading

- Vary system properties in 8-panel, jointed, 6-on-9 inch UBOL 6-ft panel simulations
  - 18-kip SA load with +/- 15F gradient
  - Case studies include existing cracks and joint deterioration
- 6-ft panels respond similarly to jointed 12-by-15-ft slabs
• Why create 3D structural model?
  – Need to model erodibility and the development of a void under a joint
  – Void development result will inform other models
• 3D model developed using ABAQUS, a commercial FEM software package
**3D structural model for joint faulting (2)**

- Model parameters currently under development to create final factorial for database of rapid solutions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
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<tbody>
<tr>
<td>Existing slab and foundation, l (in)</td>
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<tr>
<td>PCC Poisson’s ratio</td>
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<tr>
<td>Overlay Flexural Stiffness, D (#-in)</td>
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<tr>
<td>Overlay PCC jt spacing (ft)</td>
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<tr>
<td>Overlay PCC CTE (in/in/°F)</td>
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<td>Overlay Temp Difference (°F)</td>
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<td>Interlayer Stiffness (psi)</td>
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<td>Interlayer Poisson’s ratio</td>
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<td>Interlayer CTE (in/in/°F)</td>
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<td>Lane shoulder LTE (%)</td>
<td>Tied PCC  Asphalt</td>
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<td>Wheel wander (in)</td>
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<td>Tridem axle (lb)</td>
<td>0-120,000 (40 kip increment)</td>
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</table>
Implications of modeling on UBOL design procedure: Transverse cracking

- Transverse bottom-up cracking model directly accounted for cracking in the existing pavement
  - AASHTO M-E approach of reducing the existing pavement stiffness can be improved or replaced
  - The design approach can also be combined either with a linear temperature gradient spectrum or an equivalent thermal approach developed in TPF(5)-165

- Erosion of the interlayer can significantly affect top-down transverse cracking
  - Transverse top-down cracking model should be tied with the 3D structural model for joint faulting and the permanent deformation of the interlayer
Implications of modeling on UBOL design: Longitudinal cracking

• Longitudinal cracking better understood through task structural modeling
  – Longitudinal cracking in a slab/panel increases stresses in the adjacent slab, which accelerates longitudinal cracking development
  – Cannot quantify longitudinal cracking directly given propagation issue

• A damage limit will be established for performance prediction based on UBOL design parameters
Concerns about reflective cracking have been directly addressed by:

- Task 3 structural modeling
- Task 2 laboratory work
- Previous MinneALF study
- TPF(5)-165

No need to develop a separate model exclusive to reflective cracking

- Limiting damage for the benefit of controlling other distresses will impose sufficient limitations to prevent reflective cracking
Joint faulting model utilizes slab faulting response solutions from a three-dimensional finite element structural model.

The 3D structural model for joint faulting will also provide data to other models on deterioration under joints.

Parameters for structural model currently being established to build a rapid-solution database of responses (e.g. deflection near joint, joint deterioration development).
Project Tasks

- Task 4: UBOL procedure development – May 31, 2016
- Task 7: Draft final report – November 30, 2016
- Task 8: Final report – March 31, 2017