Department of Civil, Environmental, and Geo- Engineering

COLLEGE OF Science & Engineering

UNIVERSITY OF MINNESOTA

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

Task 3, Structural Modeling

Prof. Lev Khazanovich

Project Tasks

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- 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

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

Field observations

Corner breaks

Task 1 & 2 highlights

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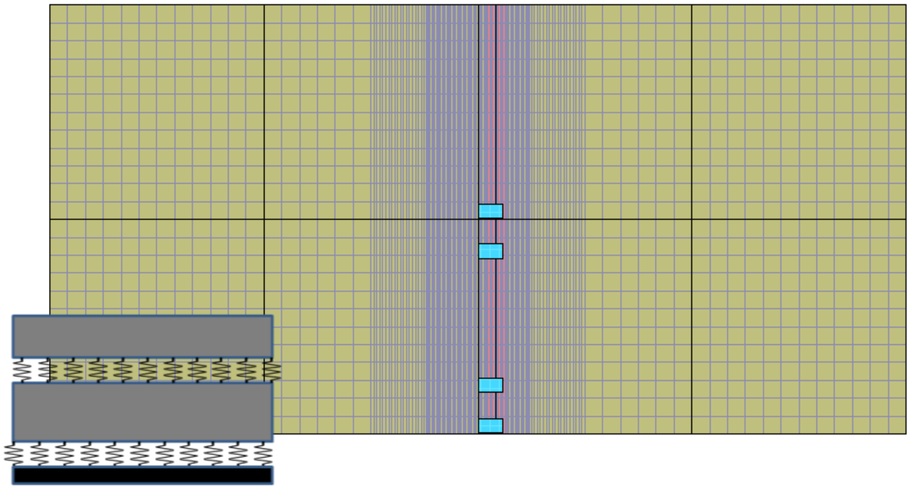
- Field observations
- **Drainage review – Dr. Snyder**
- Lab study observations

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

Task 3, Overview of modeling (2)

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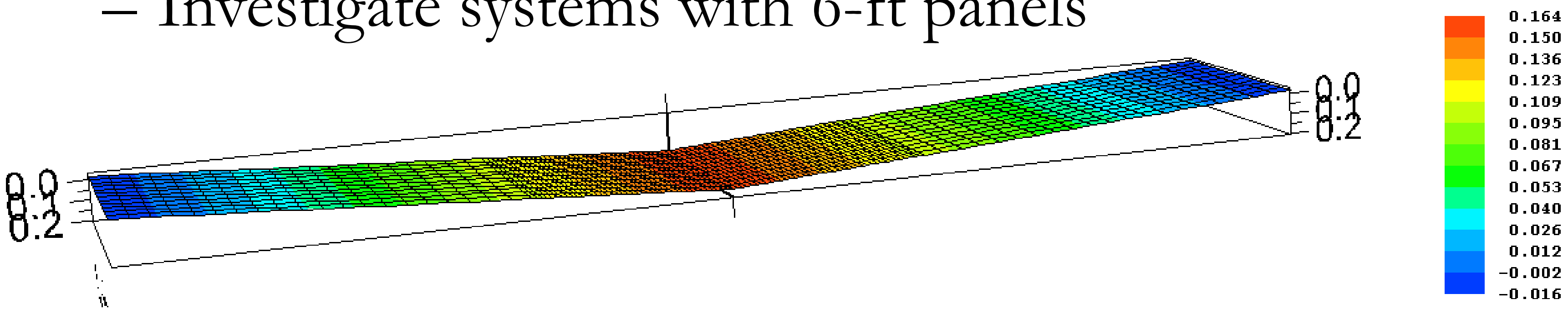
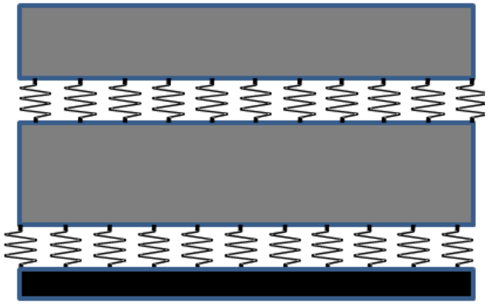
- Using UBOL system model:
  - Gain insight on effects of damage in existing PCC slab and effects of deterioration near joints
  - Can estimate single-layer structural equivalents for different UBOL systems (given a "worst case")
- Model modified/extended to
  - Simulate lab beams to estimate interlayer 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

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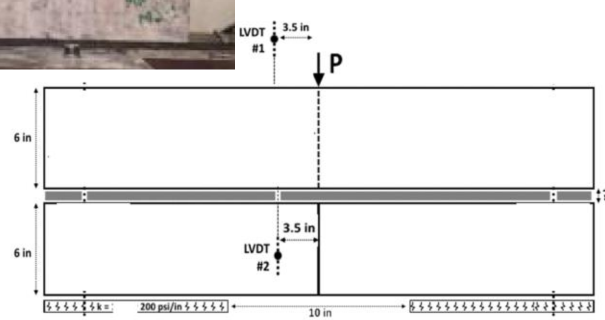
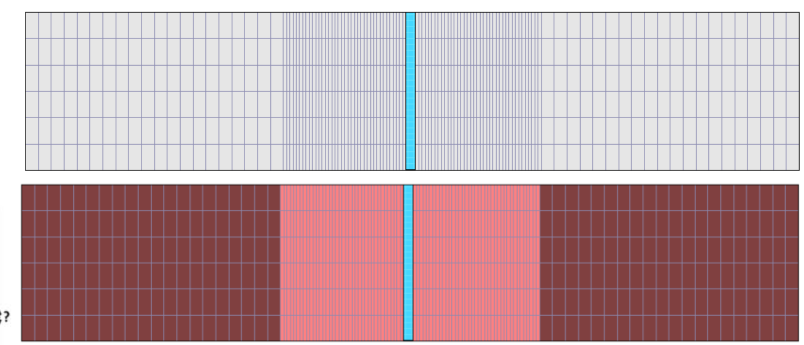
- 2D finite element simulation of Task 2 reflective cracking beams using ISLAB2005
- Factorial of simulations created for exact beam dimensions and support conditions
  - Interlayer coefficient varied from 10 to 50,000





Simulating beam interlayer response to 1 kip line load in laboratory

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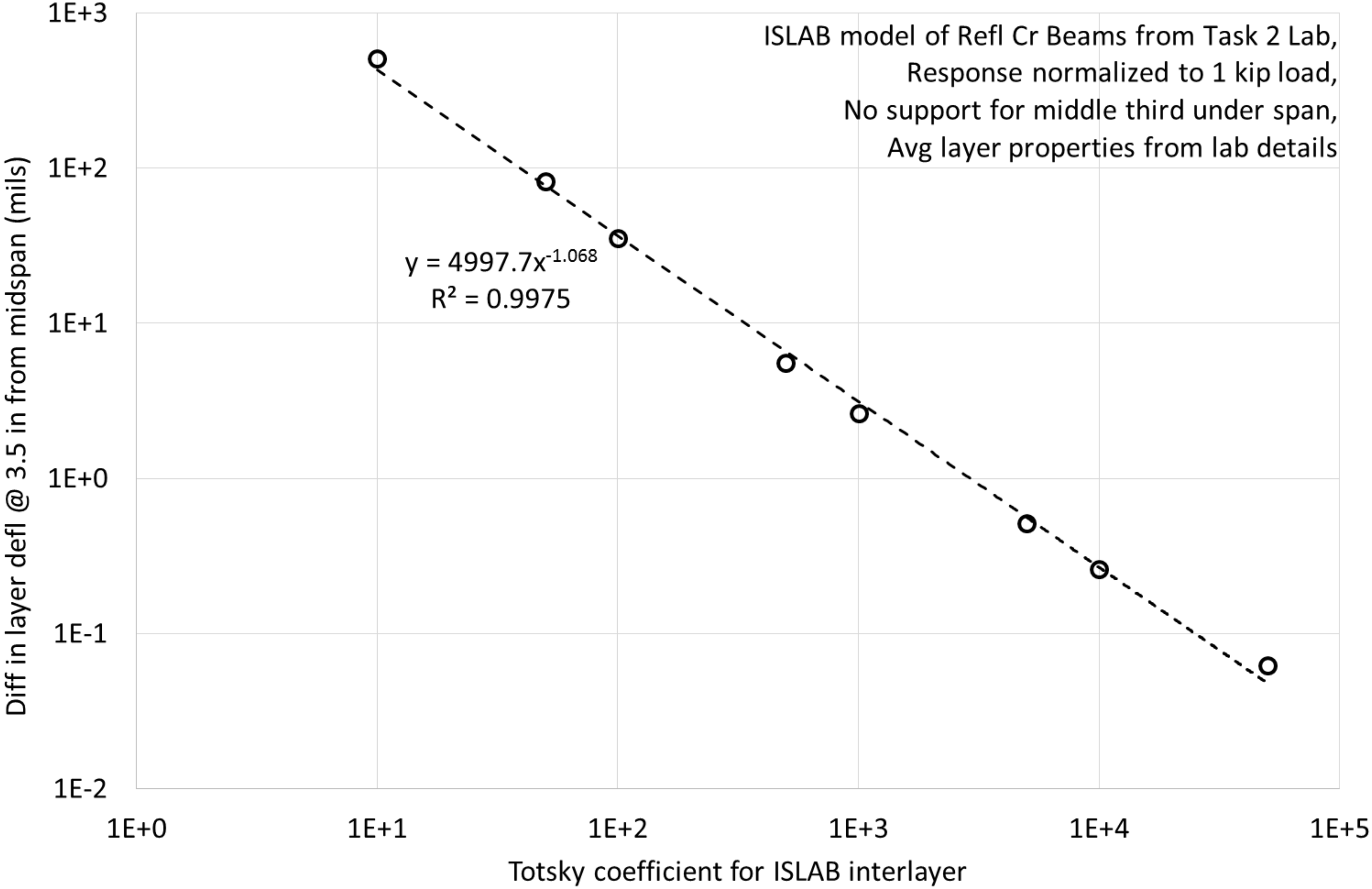

Estimating HMA and fabric interlayer coefficients with Task 2 lab data

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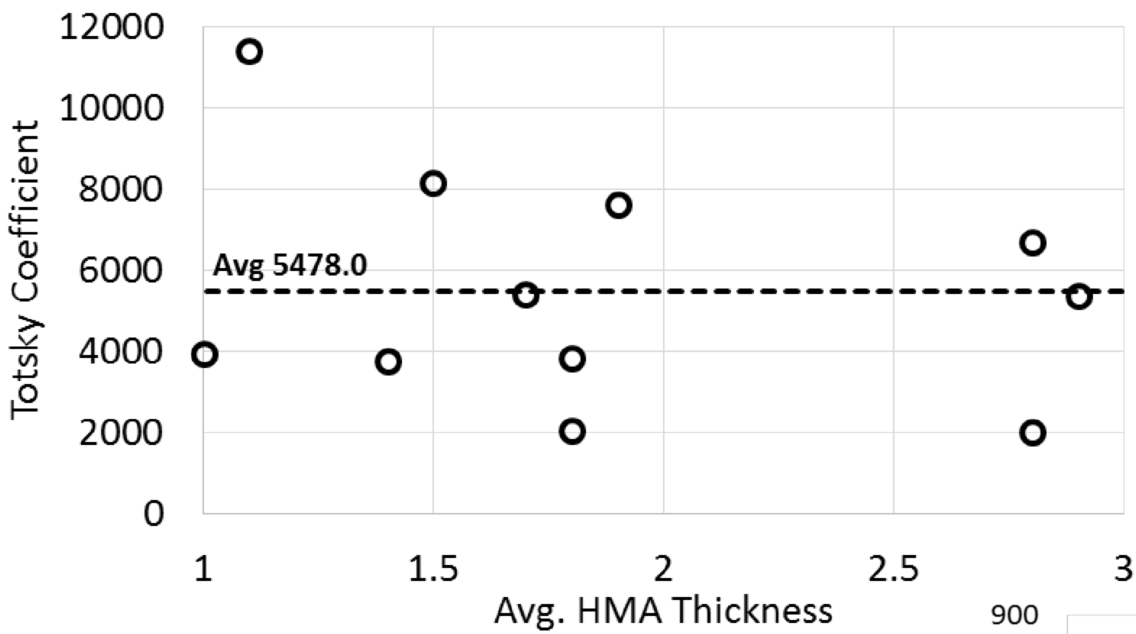
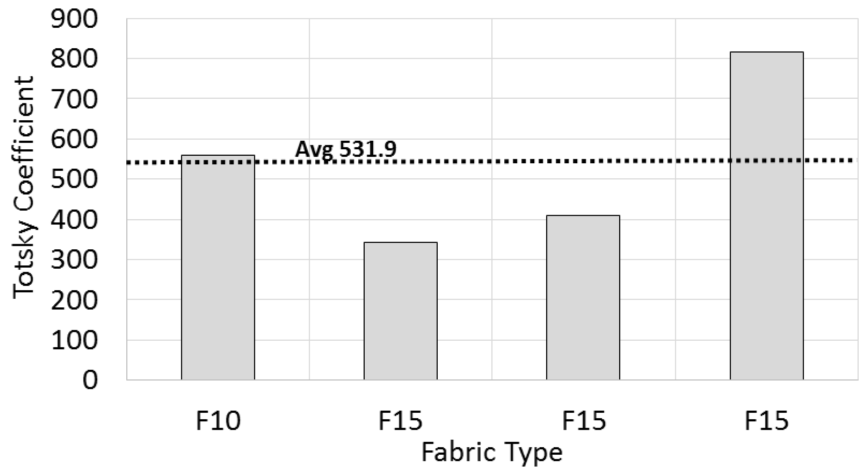
- Use exponential regression from simulations to estimate interlayer coefficients given lab data
  - Select subset of well-behaved beams (i.e. no strange behavior or outliers)
  - 4 fabric beams, 12 HMA beams
- HMA average of 5478
  - No correlation with thickness, no significant difference between dense-graded and open-graded
- Fabric average of 532

Estimating HMA and fabric interlayer coefficients with Task 2 lab data





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: σ_{avg} vs. σ_{max}

- Most designs use maximum stress, σ_{max}, at a critical location
  - Use of σ_{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, σ_{avg}
  - σ_{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)

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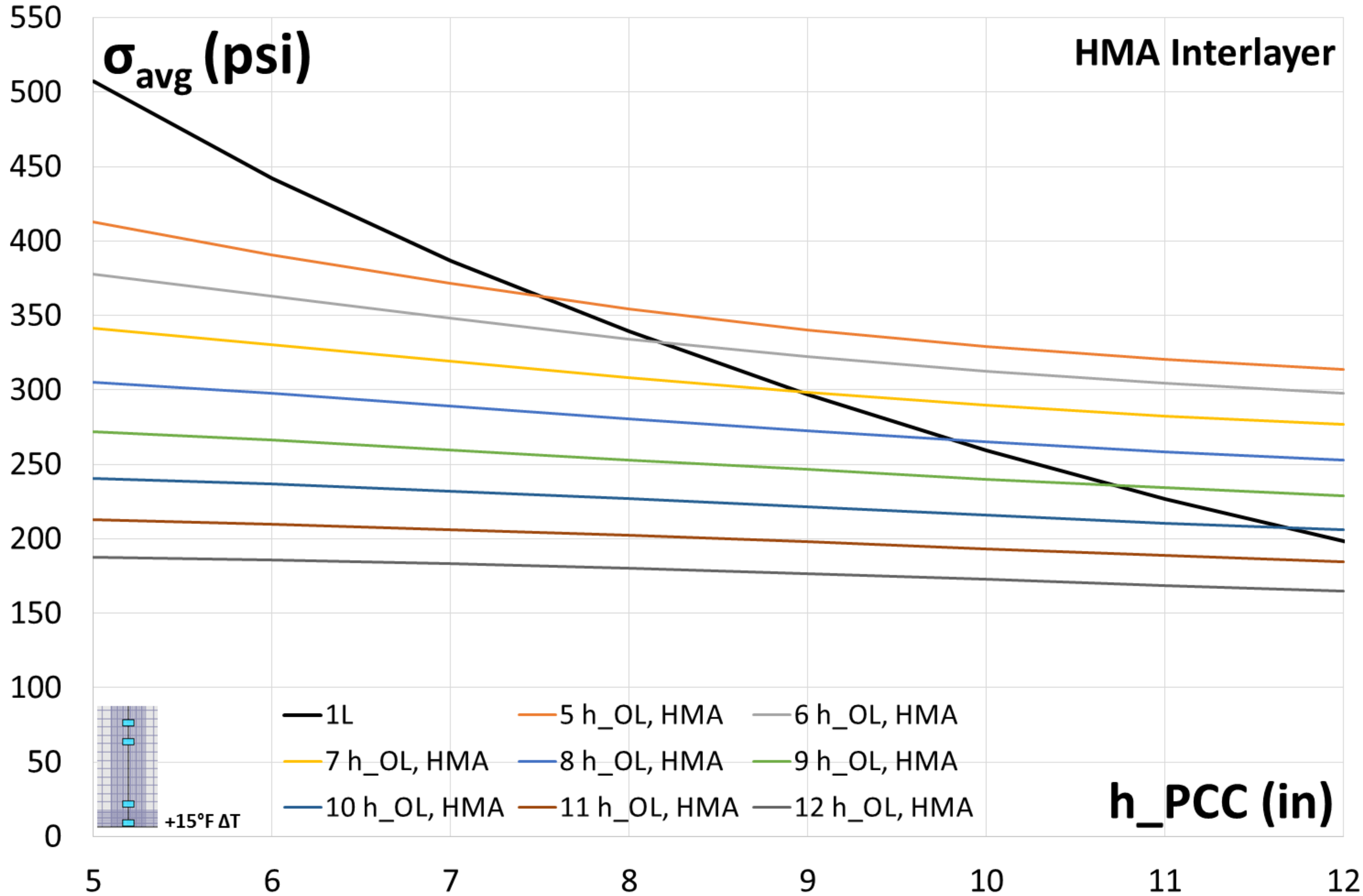
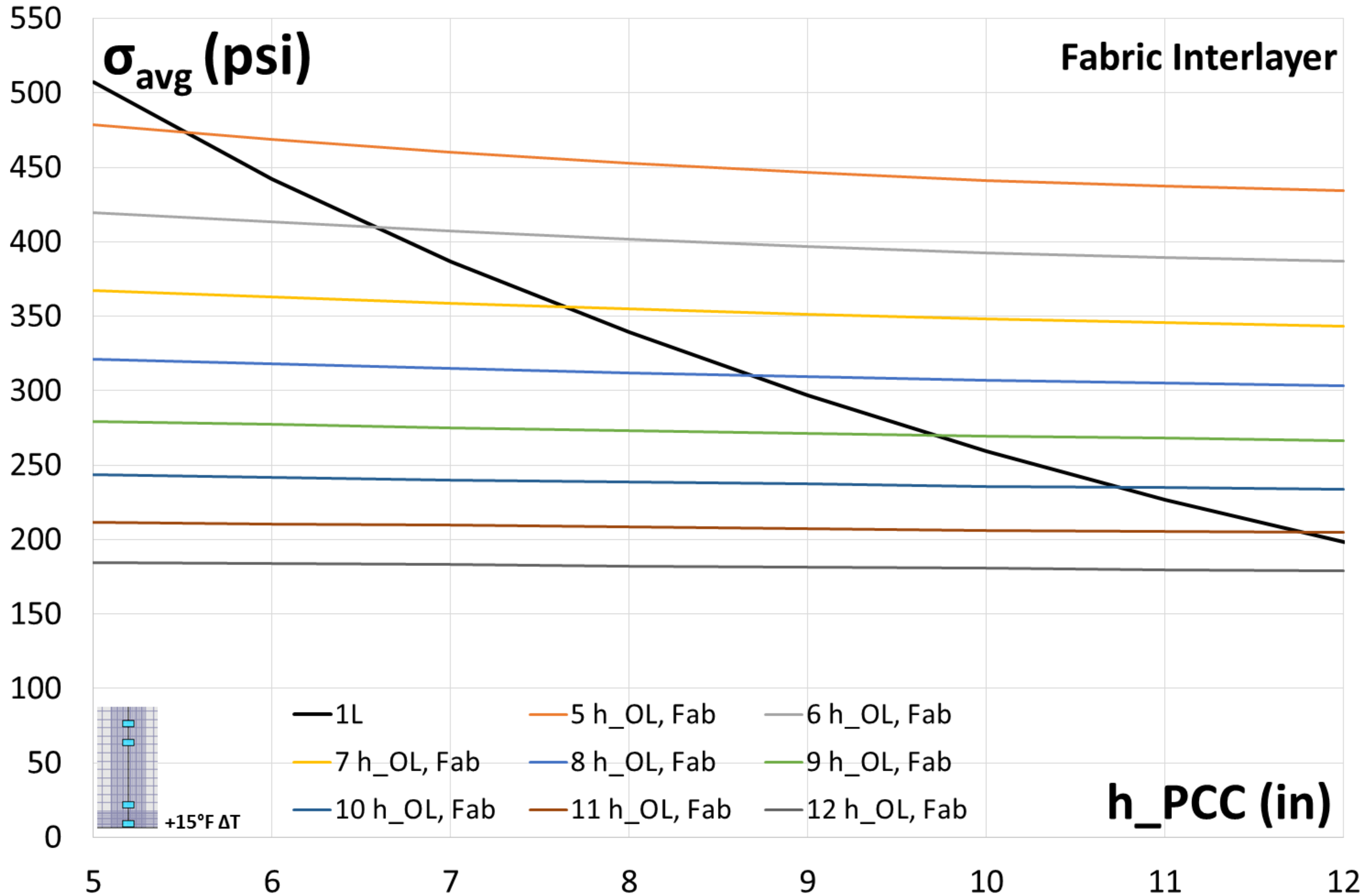


Equating critical stresses in systems (2)



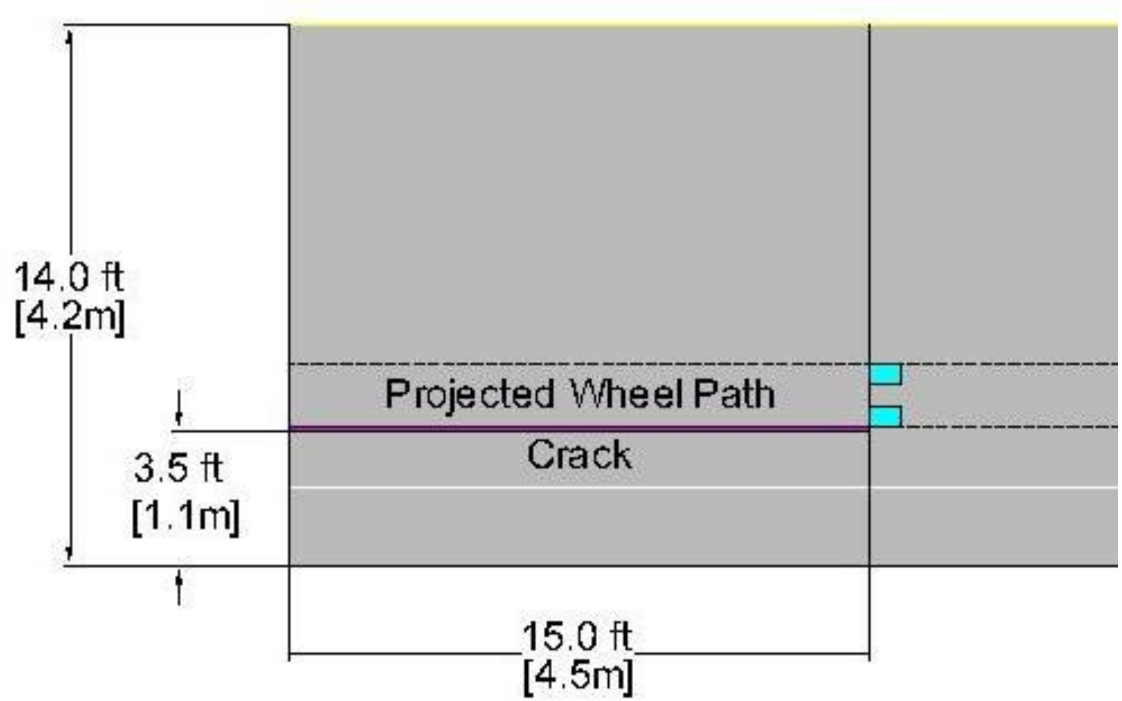
Comparing with AASHTO 1993 UBOL

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

HMA Project	h_{OL}	E_{OL}	k_{totsky}	h_{PCC}	E_{PCC}	σ_{max}	σ_{avg}	h_{eff} AASHTO 1993	h_{eff} ISLAB/ TPF(5)-269
H_06_06	6	4.26E+6	5.48E+3	6	4.79E+6	584	363	7.0	7.5
H_06_12	6	4.26E+6	5.48E+3	12	4.79E+6	498	298	9.3	9.0
H_07_06	7	4.26E+6	5.48E+3	6	4.79E+6	496	331	7.8	8.2
H_07_12	7	4.26E+6	5.48E+3	12	4.79E+6	427	277	10.0	9.5
H_08_06	8	4.26E+6	5.48E+3	6	4.79E+6	426	298	8.8	9.0
H_08_12	8	4.26E+6	5.48E+3	12	4.79E+6	369	253	10.7	10.2
H_09_06	9	4.26E+6	5.48E+3	6	4.79E+6	368	266	9.7	9.8
H_09_12	9	4.26E+6	5.48E+3	12	4.79E+6	321	229	11.5	10.9
H_10_06	10	4.26E+6	5.48E+3	6	4.79E+6	319	237	10.6	10.7
H_10_12	10	4.26E+6	5.48E+3	12	4.79E+6	280	206	12.3	11.7
H_11_06	11	4.26E+6	5.48E+3	6	4.79E+6	278	210	11.6	11.6
H_11_12	11	4.26E+6	5.48E+3	12	4.79E+6	245	184	13.1	12.6
H_12_06	12	4.26E+6	5.48E+3	6	4.79E+6	243	186	12.5	12.5
H_12_12	12	4.26E+6	5.48E+3	12	4.79E+6	216	165	13.9	13.4

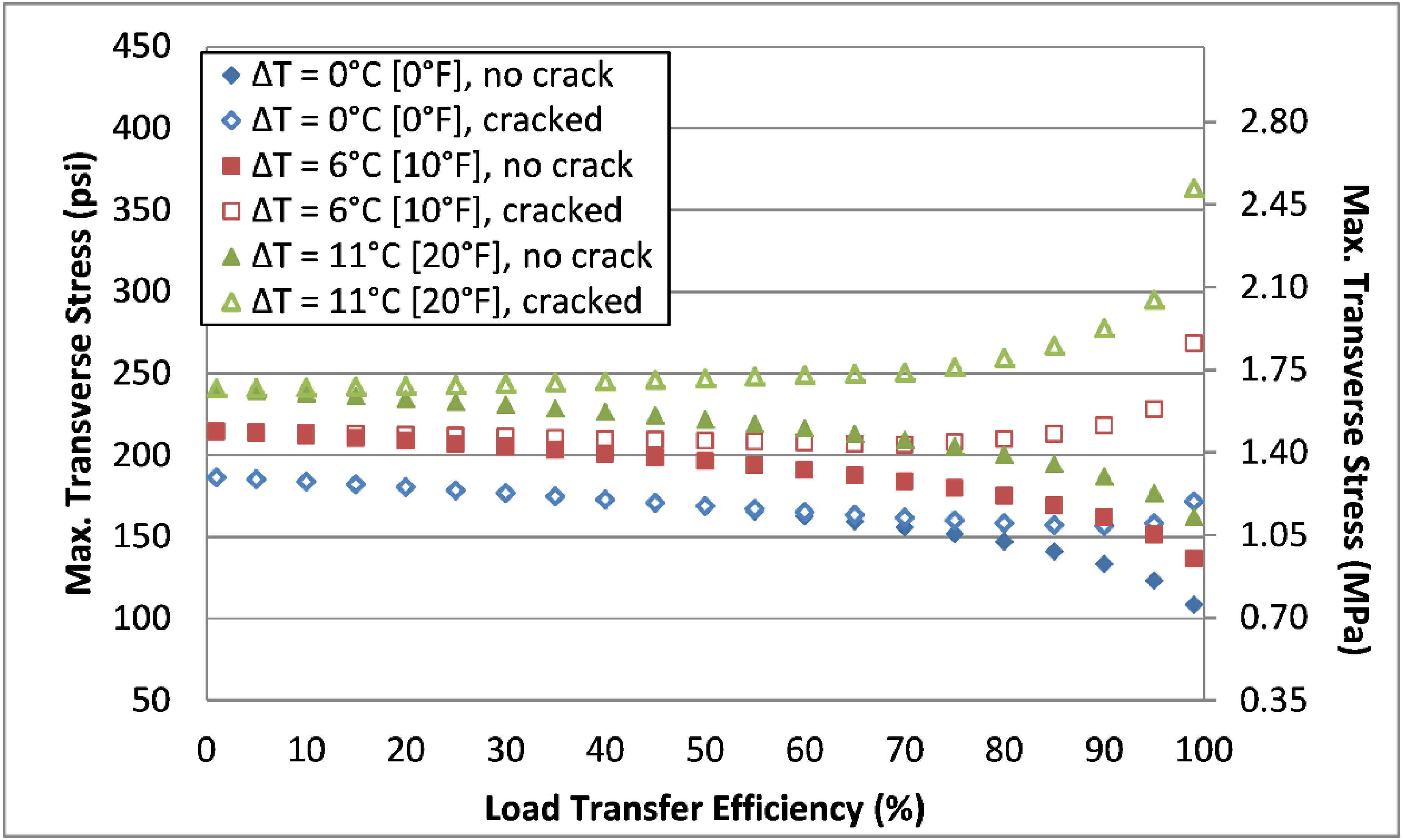
Modeling longitudinal cracking

- If an adjacent slab is cracked longitudinally, there is an increase in the stress in the loaded slab



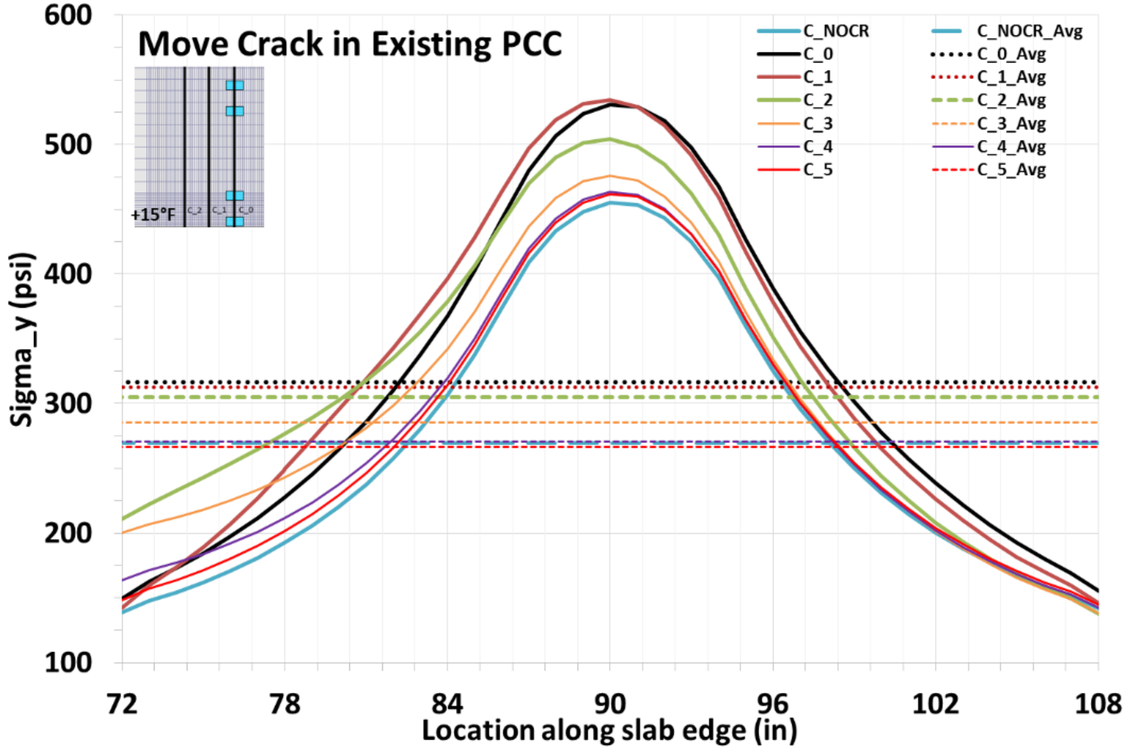
- Benefits of load transfer between adjacent slabs are nullified or can begin to add stress to the uncracked loaded slab as the slab curls downward

Modeling longitudinal cracking



Existing crack location relative to load

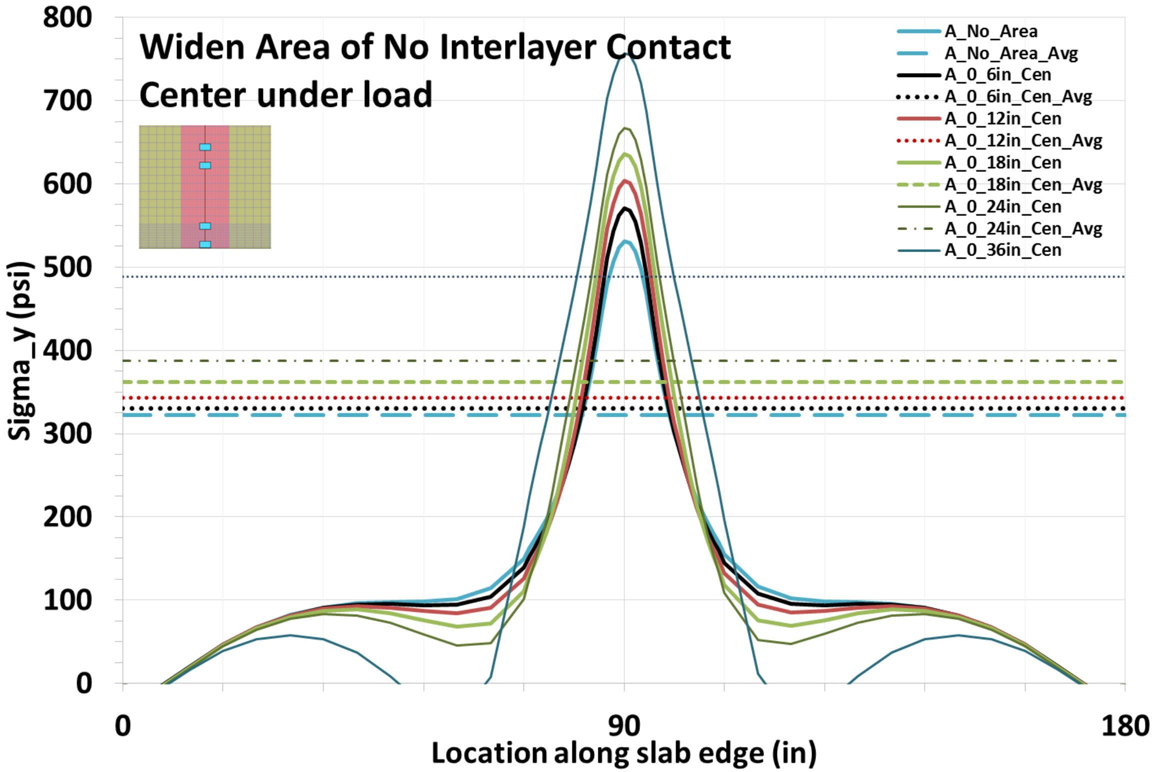
- Simulations of 6-on-9 inch UBOL single slab with existing crack
- Move crack relative to load at mid-slab



- Critical location is within 2 feet of existing crack, outside of that area stresses within 5% of response with no crack

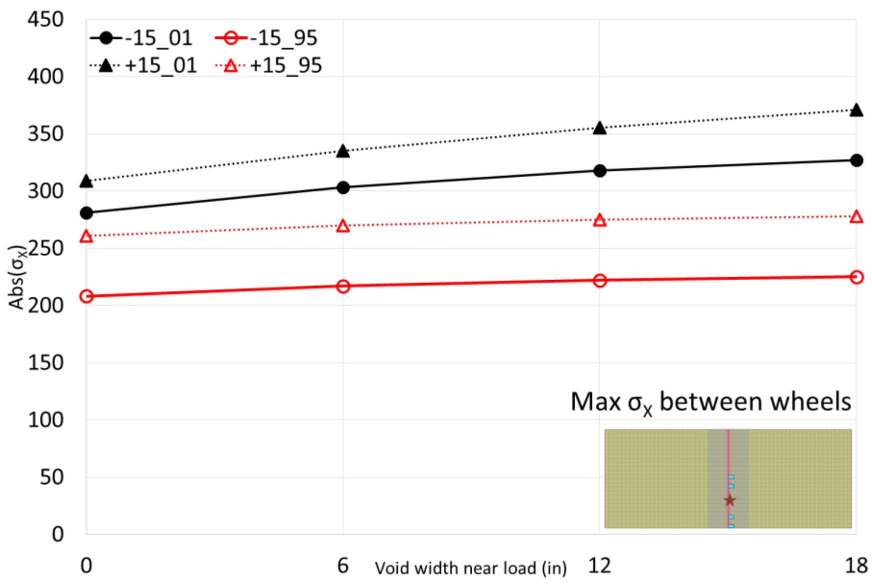
Effect of deterioration at existing crack

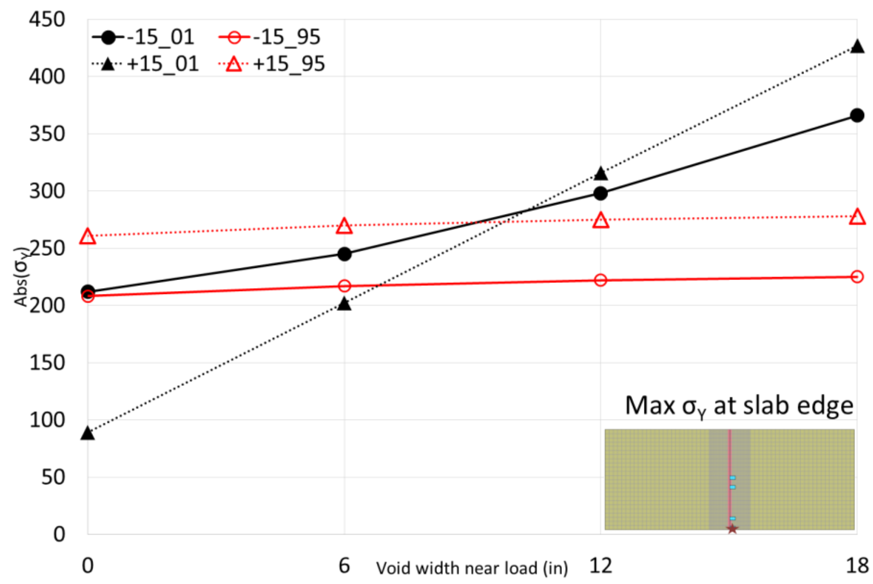
- Simulations of 6-on-9 inch UBOL single slab with existing crack
- Vary width of deterioration over crack



- 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

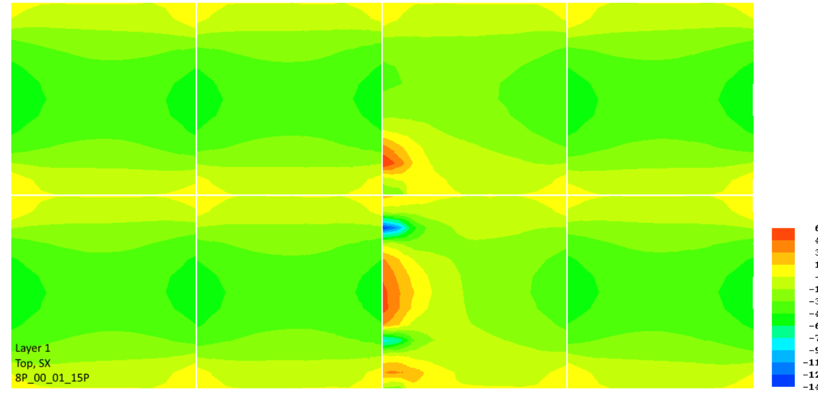


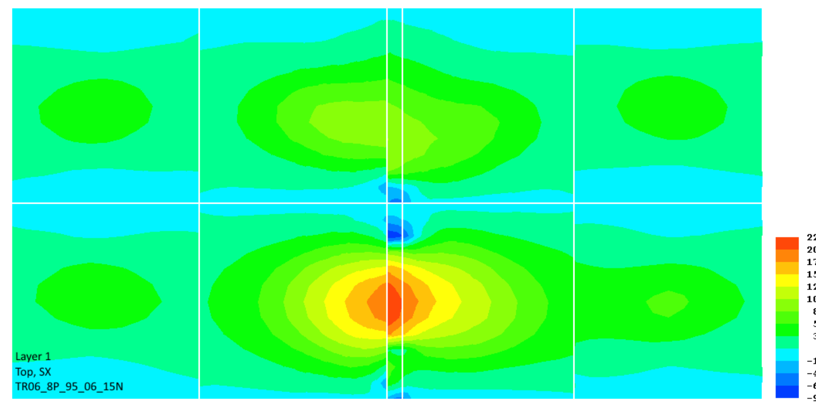


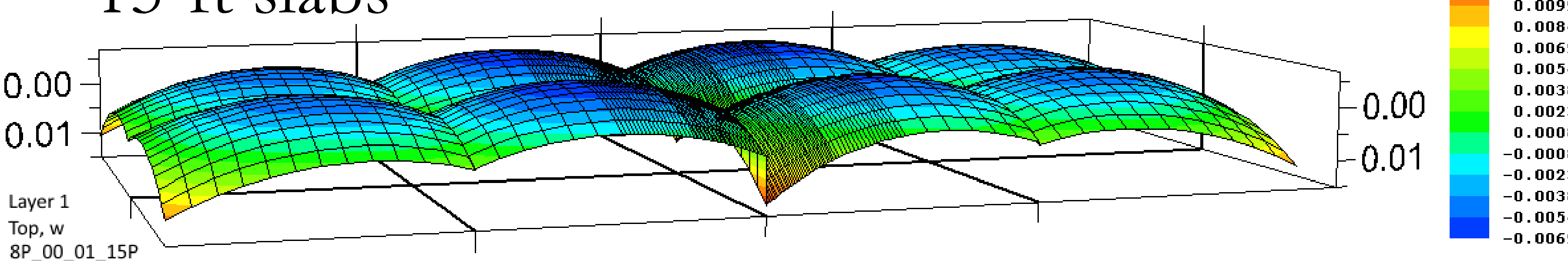
- Two-slab, jointed, 6-on-9 inch UBOL system
  - Vary LTE and deterioration area under joint
  - 18-kip SA load with +/- 15F gradient
- Critical stress location depends on slab curl (due to thermal gradient) and LTE

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







3D structural model for joint faulting (1)

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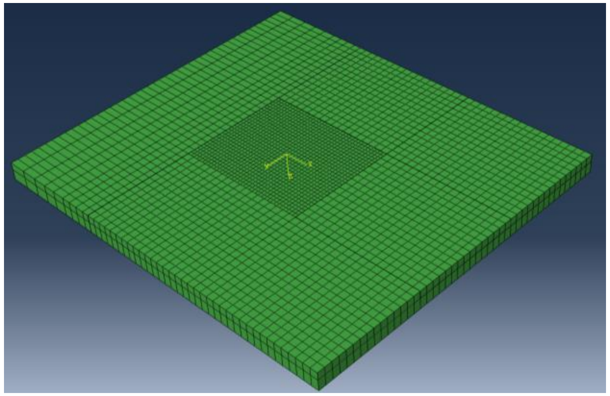
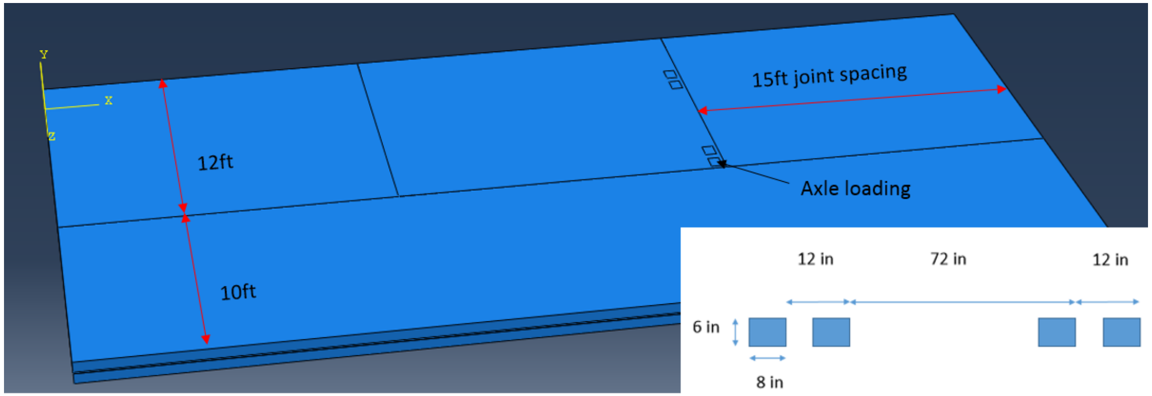
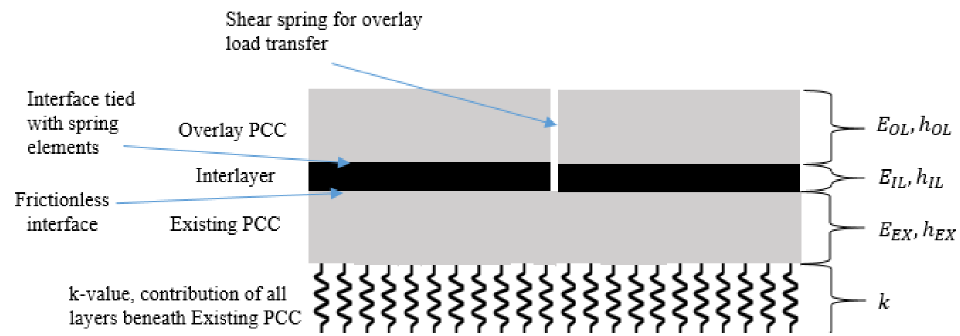
- Why create 3D structural model?
  - Need to model erodibility and the development of a void under a joint
  - Void development result will inform other models
- 3D model developed using ABAQUS, a commercial FEM software package





3D structural model for joint faulting (2)

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



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

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

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- 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

Implications of modeling on UBOL design: Reflective cracking

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- 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

Implications of modeling on UBOL design: Joint faulting

- 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 5: Procedure user guide development – June 30, 2016
- Task 6: Evaluate guidelines on suitability of UBOL – September 30, 2016
- Task 7: Draft final report – November 30, 2016
- Task 8: Final report – March 31, 2017