Impact of Wide-Base Tires on Pavements – A National Study

5/30/2013

DRAFT/CONFIDENTIAL

OHIO UNIVERSITY · TUDelft Delft University of Technology · UCDAVIS UNIVERSITY OF CALIFORNIA · ILLINOIS CENTER FOR TRANSPORTATION

Agenda

- 08:00-08:30 Introduction/Project Overview
- 08:30-09:15 Tire Contact Stress
- 09:15-10:00 Pavement Modeling (Delft/UIUC)
- 10:00-10:15 Break
- 10:15-11:00 Pavement Modeling (Thin & Thick)
- 11:00-12:00 Data Management
- 12:00-13:00 Lunch
- 13:00-13:45 Laboratory Testing
- 13:45-15:15 Instrumentation and Field Testing
- 15:15-15:30 Break
- 15:30-15:45 Future Plans Discussion
- 15:45-16:15 Technical Committee Discussion
- 16:15-16:45 Final Remarks
- 16:45 Adjourn

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Project Overview
8:10-8:30am

5/30/2013

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Project Overview

- Quantify the impact of WBT on pavement damage utilizing advanced theoretical modeling and validate results using full-scale testing
- Scope:
  - Contact stress measurements of tires (WBT & DTA)
  - APT of pavement sections
  - FEM modeling of pavement loading
  - Calculation of pavement damage

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Project Overview

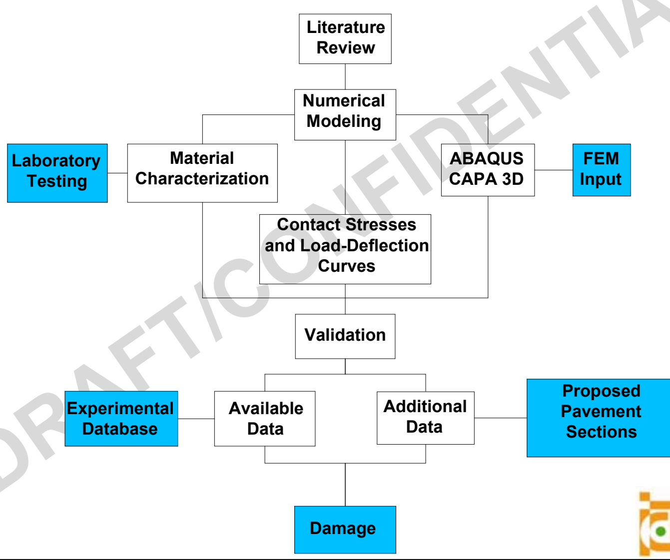
DRAFT/CONFIDENTIAL

- **Phase I Tasks**
  - 1.1. Comprehensive literature review and synthesis on past and current research
  - 1.2. Experimental plan and modeling framework
  - 1.3. Implementation and marketing plan
  - 1.4. Phase I report
  - 1.5. Conference call with panel
  - 1.6. Presentations to relevant conferences and symposiums
- **Phase II Tasks**
  - 2.1. Prepare experimental equipment, test structures, and instrumentation
  - 2.2. Conduct experiments (material characterization and APT)
  - 2.3. Conduct modeling
  - 2.4. Develop of analysis tool
  - 2.5. Delivery of draft Phase II report and analysis tool
  - 2.6. Present to relevant conferences and symposiums
  - 2.7. Prepare article and technical papers

ILLINOIS CENTER FOR TRANSPORTATION

Project Overview

DRAFT/CONFIDENTIAL



ILLINOIS CENTER FOR TRANSPORTATION

Project Overview

DRAFT/CONFIDENTIAL

FEM Input

- 3D Contact Stresses
- Dynamic Analysis
- Viscoelastic Asphalt Materials
- Continuous Moving Load
- Layer Interaction (Stick Model)
- Nonlinear Granular Material

ILLINOIS CENTER FOR TRANSPORTATION

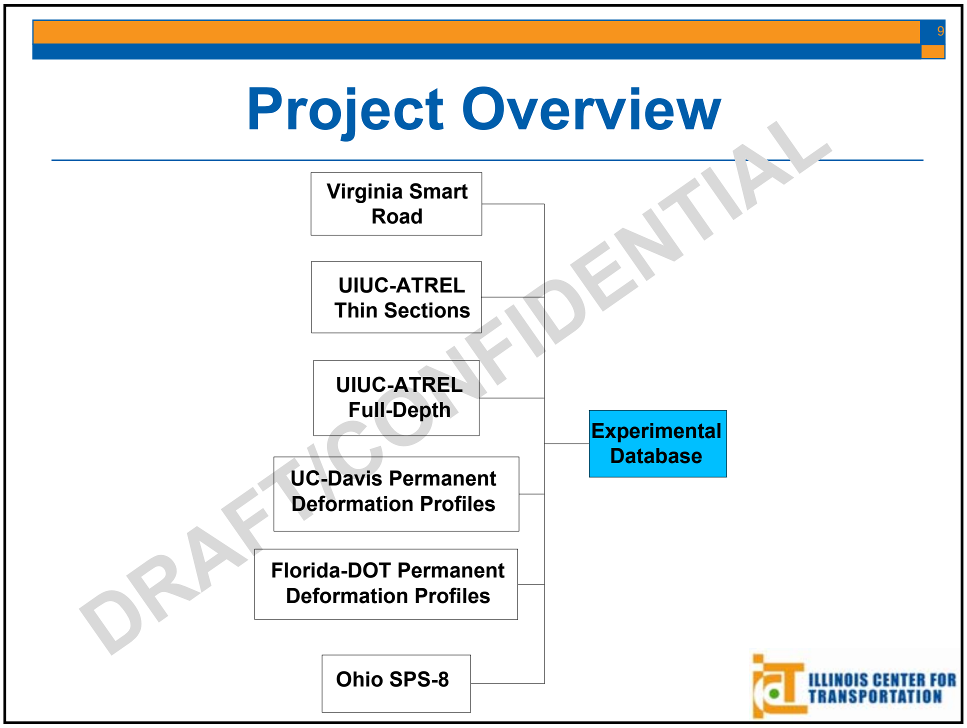
Project Overview

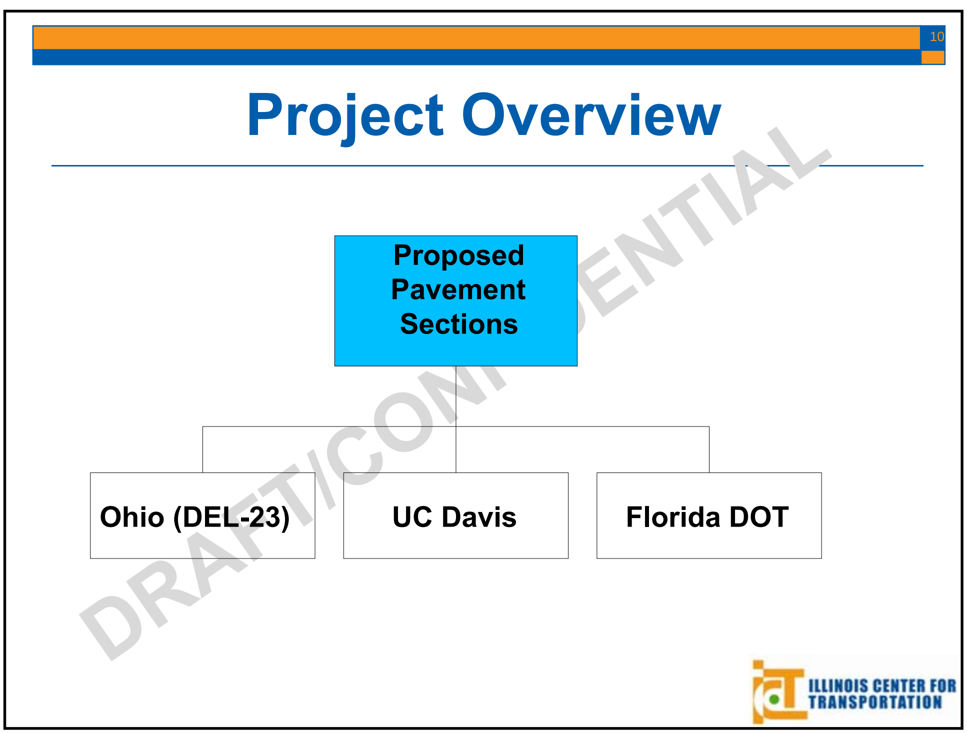
DRAFT/CONFIDENTIAL

Laboratory Testing

- Mix Volumetrics
- Semi-Circular Beam (SCB)
- Dynamic Modulus Test
- Cross-Anisotropic Stress-Dependent Granular Material (for Low-Volume Roads)

ILLINOIS CENTER FOR TRANSPORTATION


9
Project Overview
Virginia Smart Road
UIUC-ATREL Thin Sections
UIUC-ATREL Full-Depth
UC-Davis Permanent Deformation Profiles
Florida-DOT Permanent Deformation Profiles
Ohio SPS-8
Experimental Database
DRAFT/CONFIDENTIAL
ILLINOIS CENTER FOR TRANSPORTATION


10
Project Overview
Proposed Pavement Sections
Ohio (DEL-23)
UC Davis
Florida DOT
DRAFT/CONFIDENTIAL
ILLINOIS CENTER FOR TRANSPORTATION

Project Overview

DRAFT/CONFIDENTIAL

Damage

↓

ANN-Based Prediction Models

↓

Life-Cycle Cost Analysis (LCCA) Guidelines Using RealCost

↓

Life-Cycle Assesment of Environmental Impacts (LCA)

↓

Implementation

ILLINOIS CENTER FOR TRANSPORTATION

COMMENTS!

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Tire Contact Stress
8:30-9:15am

5/30/2013

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Outline

- Experimental Program
- Data Processing
- Contact Stress Distributions
- 3D Contact Stresses
- Tire Contact Area
- Maximum Rib Contact Length
- Summary

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

15

Experimental Program

<table>
<tr><th>Tire Type</th><th>Inflation Pressure (kPa)</th><th colspan="5">Tire Loading (kN)</th></tr>
<tr><td>NGWB and Dual</td><td>552</td><td rowspan="6">26.6</td><td rowspan="6">35.5</td><td rowspan="6">44.4</td><td rowspan="6">62.2</td><td rowspan="6">79.9</td></tr>
<tr><td>NGWB and Dual</td><td>690</td></tr>
<tr><td>NGWB and Dual</td><td>758</td></tr>
<tr><td>NGWB and Dual</td><td>862</td></tr>
<tr><td>Dual Only</td><td>414/758*</td></tr>
<tr><td>Dual Only</td><td>552/758*</td></tr>
</table>

*Differential Tire Inflation Pressure

ILLINOIS CENTER FOR TRANSPORTATION

16

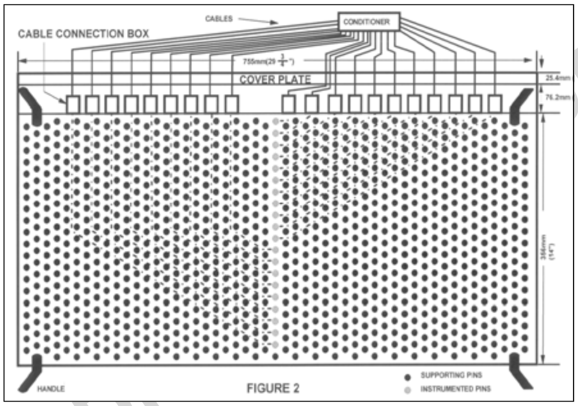
Experimental Program: Tested Tires

WBT 445/50 R22.5

DTA 275/80 R22.5

ILLINOIS CENTER FOR TRANSPORTATION

Experimental Program: Measuring System

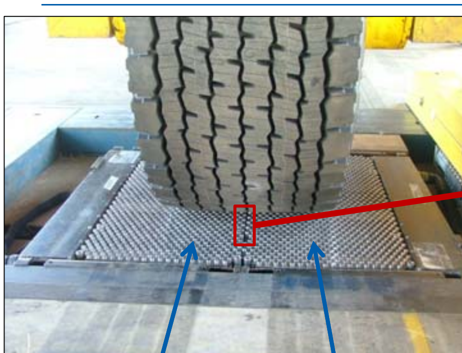


Single Pad Assembly
(SIM is composed by two Pads)

- Nominal Area: 840x417 mm
- 1020 Supporting Pins
  - 21 Instrumented Steel Pins

ILLINOIS CENTER FOR TRANSPORTATION

Experimental Program



Pad Assemblies

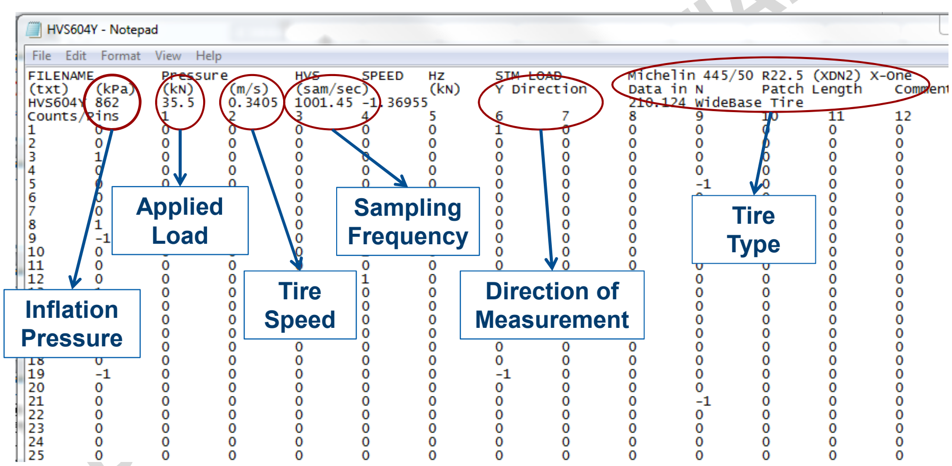
Experimental Program

- Lateral position of tires was fixed
- Pin measured applied force
- Average speed: 0.331m/s (1.19km/h)
- Sampling frequency: 1001hz
- Static imprints of tires obtained
- Load deflection curves were measured
- Each load combinations were repeated 10 times; optimum three repetitions were used

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Pin Measurements in txt Format

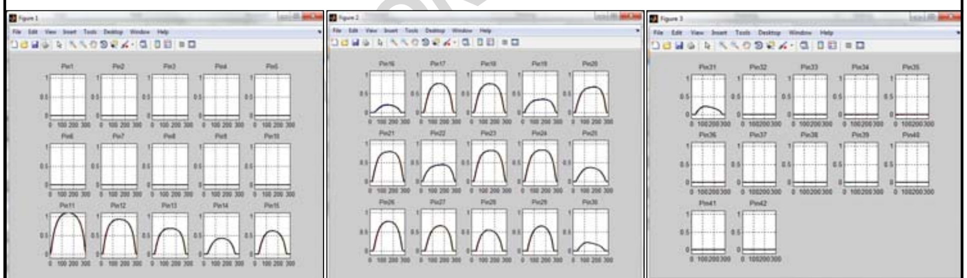


ILLINOIS CENTER FOR TRANSPORTATION

Data Processing

CONFIDENTIAL

- Script written in Matlab:
  - Data filtered using moving average (window size = 20 measurements)
  - Simultaneous observation of three repetitions and filtered data

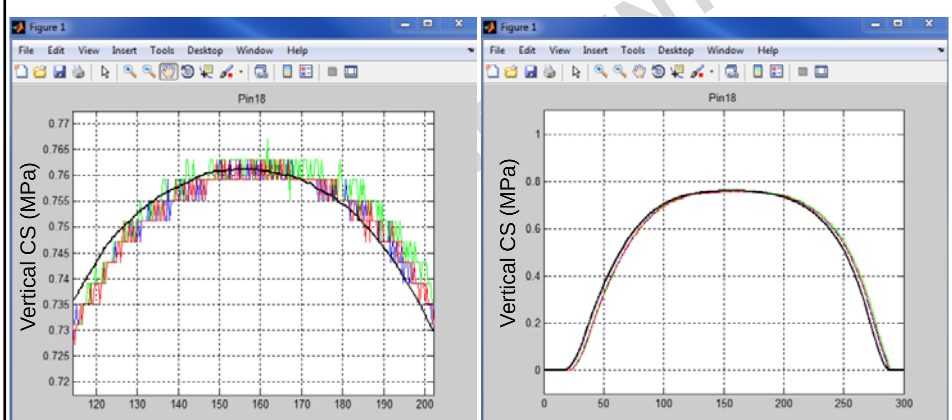


ILLINOIS CENTER FOR TRANSPORTATION

Data Processing

CONFIDENTIAL

- Filtering data using moving average



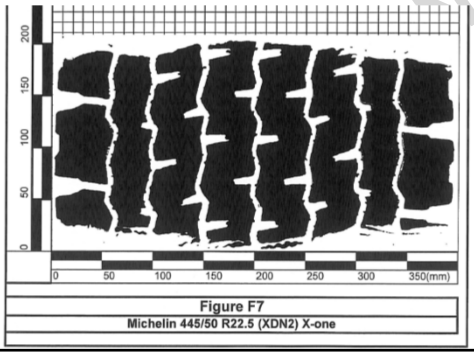
Distance (mm)

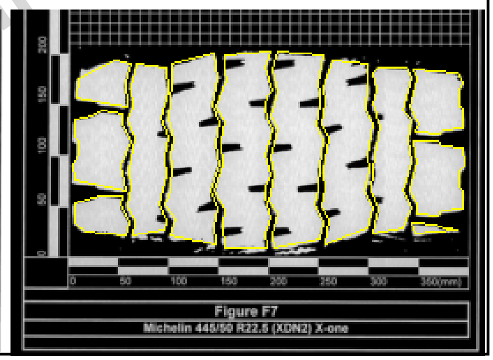
Distance (mm)

ILLINOIS CENTER FOR TRANSPORTATION

Data Processing: Contact Area

- Contact area from footprint (processed in AutoCAD)
- Contact length from pin measurements

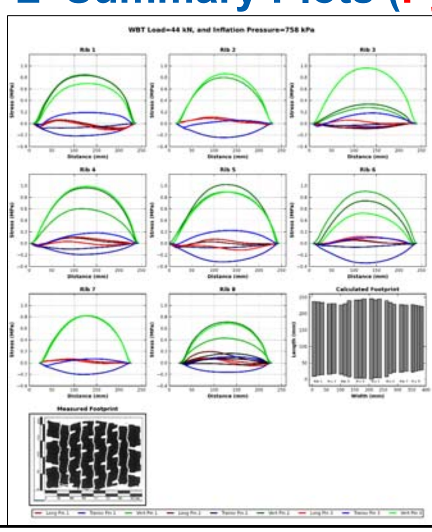


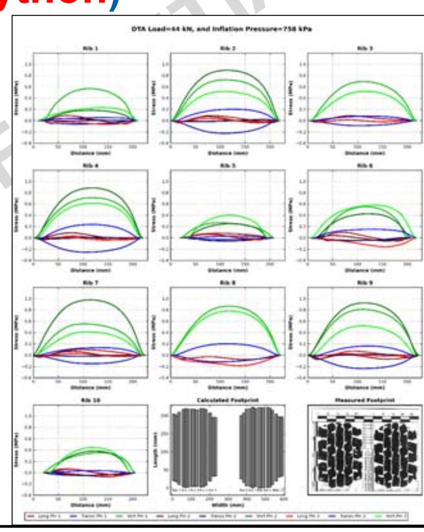


CONFIDENTIAL

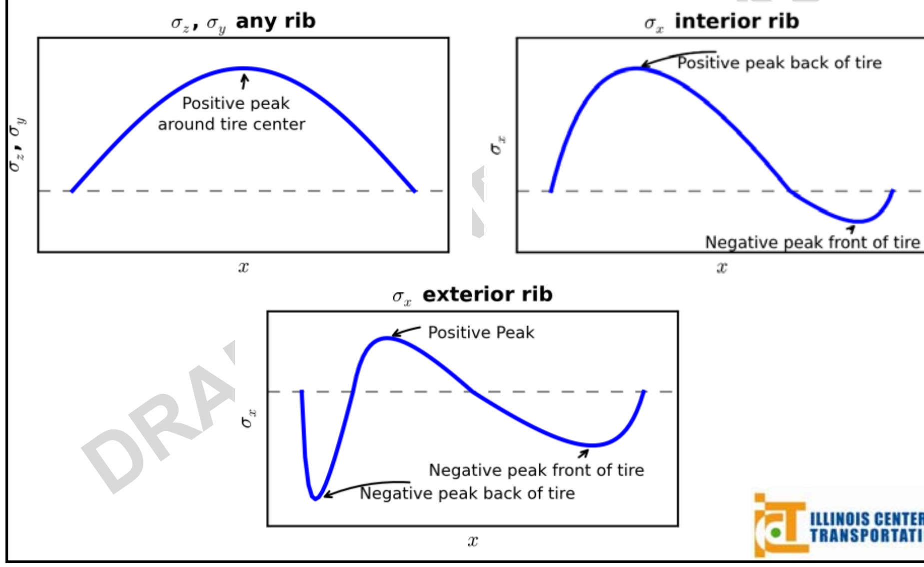
Data Processing

- Summary Plots (Python)



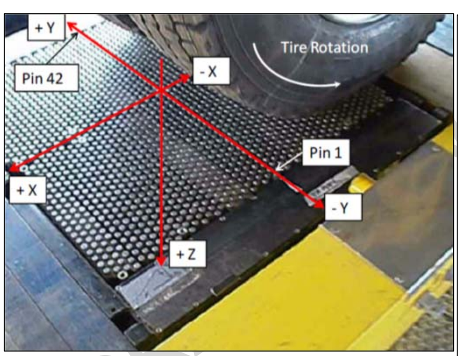


Contact Stress Distributions

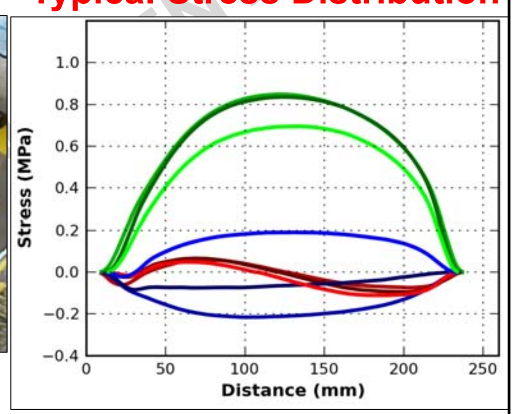


ILLINOIS CENTER FOR TRANSPORTATION

Contact Stress Distributions



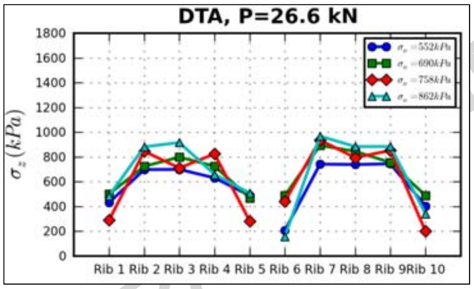
Typical Stress Distribution

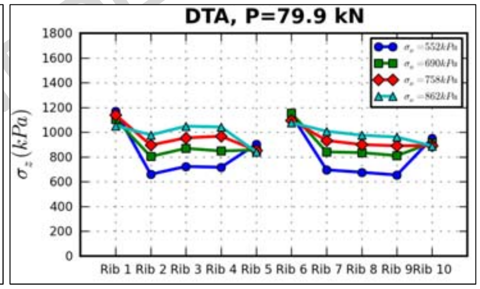


ILLINOIS CENTER FOR TRANSPORTATION

Vertical Contact Stresses

- "n" and "m" Shape Patterns: DTA



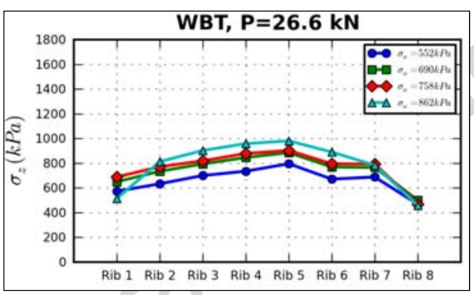


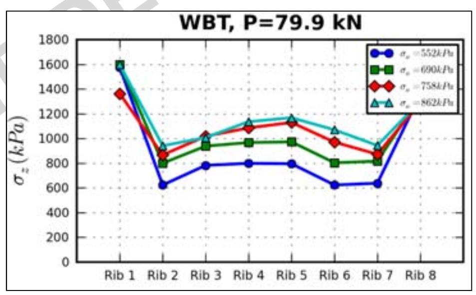
ILLINOIS CENTER FOR TRANSPORTATION

DRAFT CONFIDENTIAL

Vertical Contact Stresses

- "n" and "m" Shape Patterns: WBT





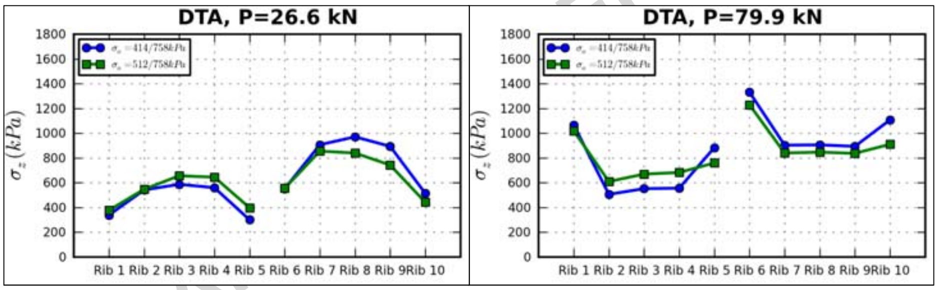
ILLINOIS CENTER FOR TRANSPORTATION

DRAFT CONFIDENTIAL

29

Vertical Contact Stresses

- Effect of σ_o on σ_z for DTA with differential σ_o

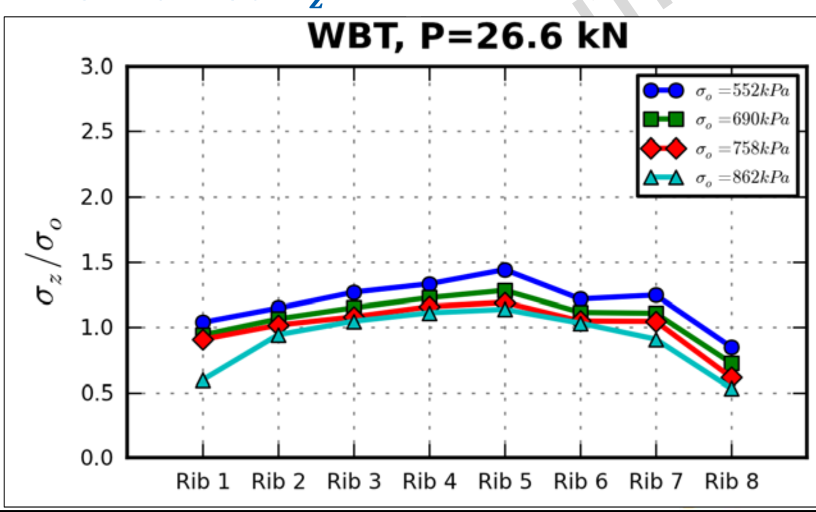


ILLINOIS CENTER FOR TRANSPORTATION

30

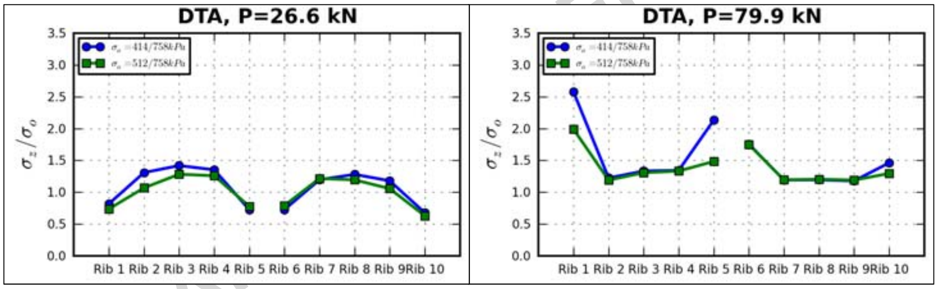
Vertical Contact Stresses

- Normalized σ_z



Vertical Contact Stresses

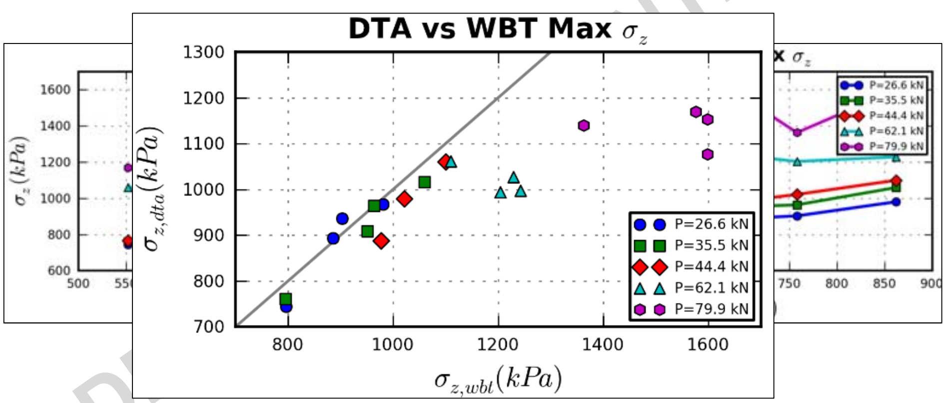
- Normalized σ_z for DTA with differential σ_o



ILLINOIS CENTER FOR TRANSPORTATION

Vertical Contact Stresses

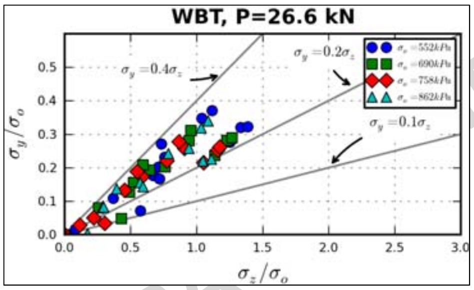
- Maximum σ_z

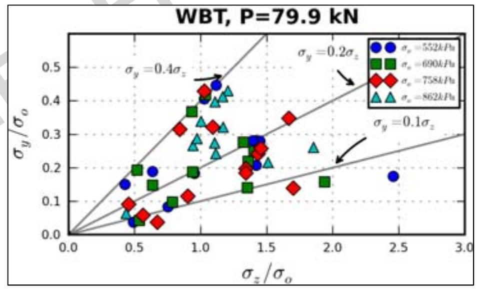


ILLINOIS CENTER FOR TRANSPORTATION

Transverse Contact Stresses

- Maximum σ_y for WBT



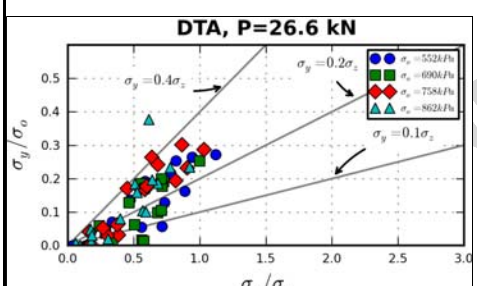


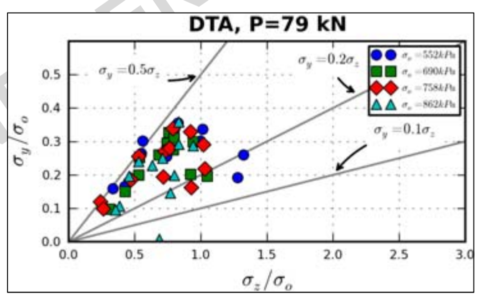
DRAFT CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Transverse Contact Stresses

- Maximum σ_y for DTA



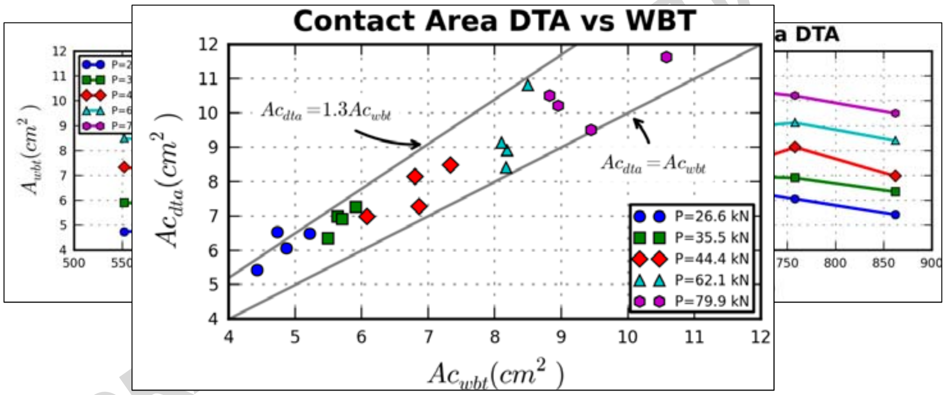


DRAFT CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

35

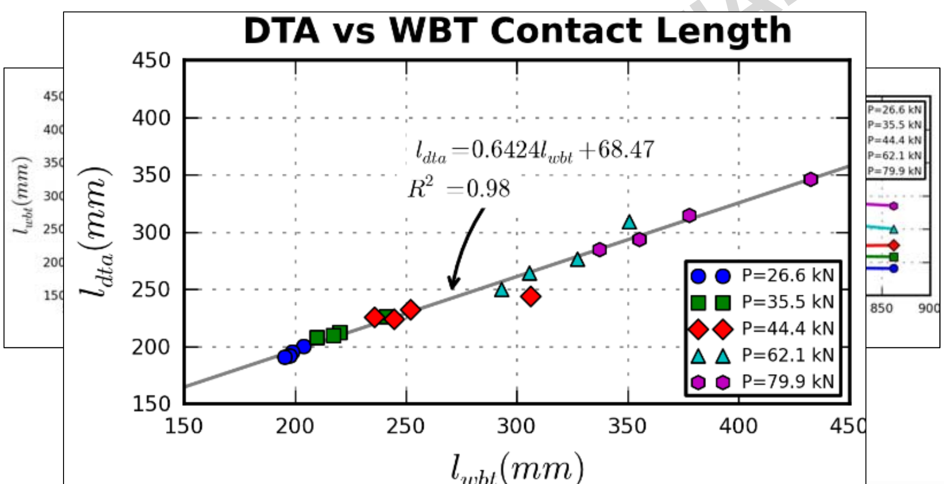
Contact Area



ILLINOIS CENTER FOR TRANSPORTATION

36

Maximum Contact Length



ILLINOIS CENTER FOR TRANSPORTATION

Remarks

- Mechanisms of load transfer vary for various tires:
  - Contact area may be up to 30% greater for DTA than WBT
  - Contact length may be up to 65% shorter for DTA than WBT
- Complex 3D contact stresses are important to determine pavement response
- Robust analysis needs to be performed in order to determine the actual damage caused by the two tires

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Future Plans

- Finalize detailed analysis of DTA and WBT magnitude and distribution of contact stresses
- Finalize prediction of contact stresses using FEM

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

COMMENTS!

DRAFT/CONFIDENTIAL

Pavement Modeling (Delft/UIUC)

9:15-10:00am

5/30/2013

DRAFT/CONFIDENTIAL

TU Delft Update

TU Delft Delft University of Technology

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

ILLINOIS CENTER FOR TRANSPORTATION

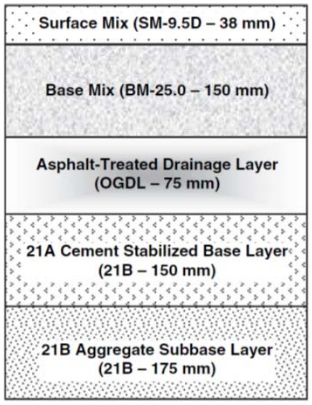
Outline

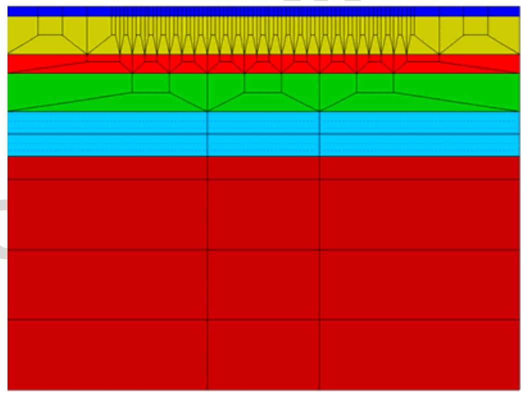
- Pavement Structure
- Mesh Configuration
- Loading Function
- Dual and Wide-Base Tires
- Material Characteristics
- Analysis Output
- Completed Tasks
- Future Works

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

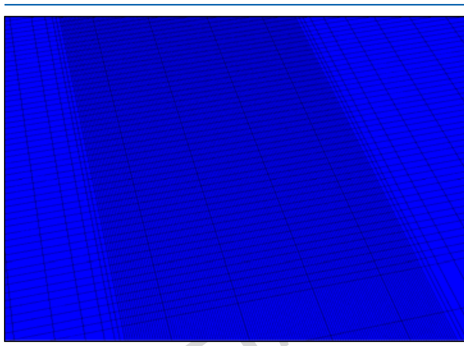
Thick Pavement Structure

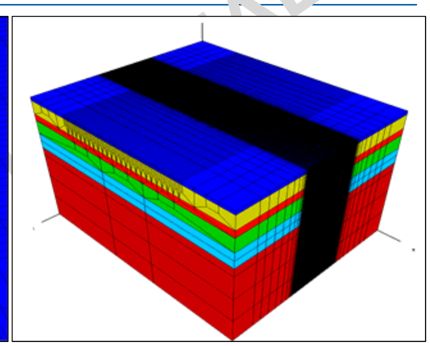




ILLINOIS CENTER FOR TRANSPORTATION

Mesh of Thick Pavement

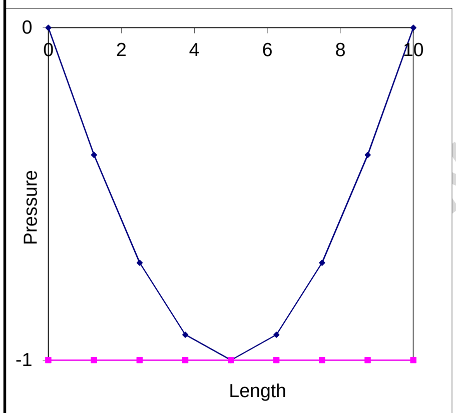




- Mesh size reduction in the depth direction provides a balance of accuracy directly under the loading area and reduced computational time
- Fine mesh in the transverse direction based on previous research from UIUC

ILLINOIS CENTER FOR TRANSPORTATION

Sinusoidal Loading Function in CAPA-3D



Total force calculated from the closed form solution of the integration of a sine load:

$$F = (p\ell)\,w = \left(-\int_0^{10} \sin\left(\frac{2\pi}{20}x\right)dx\right)\cdot 10 = \left(\frac{10}{\pi}\cos\left(\frac{\pi}{10}x\right)\Bigg|_{x=0}^{x=10}\right)\cdot 10 =$$

$$= \left(\frac{10}{\pi}\left(\cos(\pi) - \cos(0)\right)\right)\cdot 10 = \frac{10}{\pi}(-1-1)\cdot 10 = \frac{200}{\pi} = -63.662$$

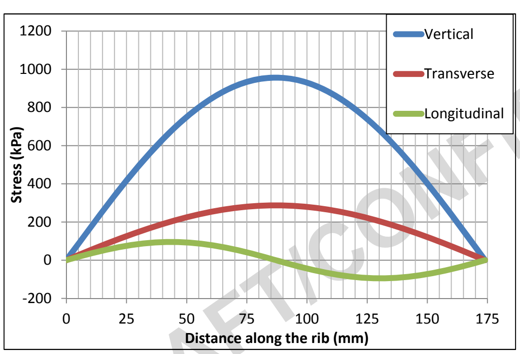
Sum of reaction forces in CAPA-3D for the same loading as the closed form solution = 63.671

Error of less than 0.01%

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

General Form of Loading Used



Contact stress distribution in 3D is assumed as follows:

$$\sigma_{ver} = \sigma_{max,ver}\sin\left(\frac{\pi x}{L}\right)$$

$$\sigma_{trans} = 0.3\sigma_{max,ver}\sin\left(\frac{\pi x}{L}\right)$$

$$\sigma_{long} = 0.1\sigma_{max,ver}\sin\left(\frac{2\pi x}{L}\right)$$

where,

$\sigma_{max,ver}$ = maximum vertical contact stress in the rib

L = length of the rib

x = distance along the rib

ILLINOIS CENTER FOR TRANSPORTATION

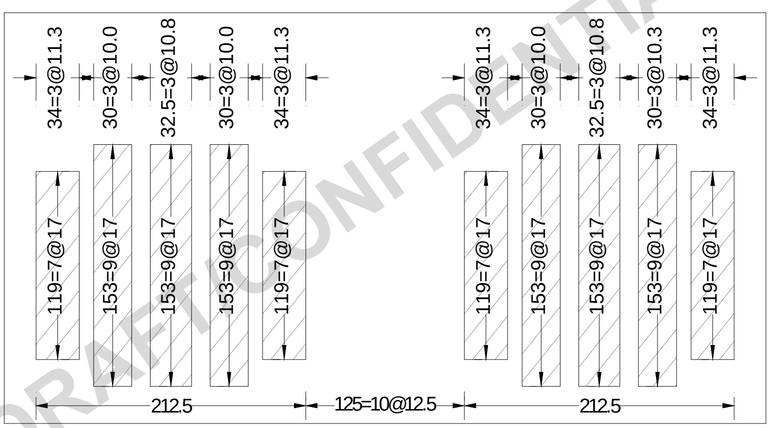
DRAFT/CONFIDENTIAL

Maximum Vertical Pressure & Footprint Dimensions

		Rib 1	Groove 1	Rib 2	Groove 2	Rib 3	Groove 3	Rib 4	Groove 4	Rib 5
DTA	Vertical pressure (kPa)	641	11.4	872	14.6	988	14.6	858	11.4	644
	Length (mm)	119		153		153		153		119
	Width (mm)	34		30		32.5		30		34
WBT	Vertical pressure (kPa)	502	9.6	832	9.6	886	10.3	936	11.4	956
	Length (mm)	136		153		153		170		170
	Width (mm)	38		31		31		31		35

ILLINOIS CENTER FOR TRANSPORTATION

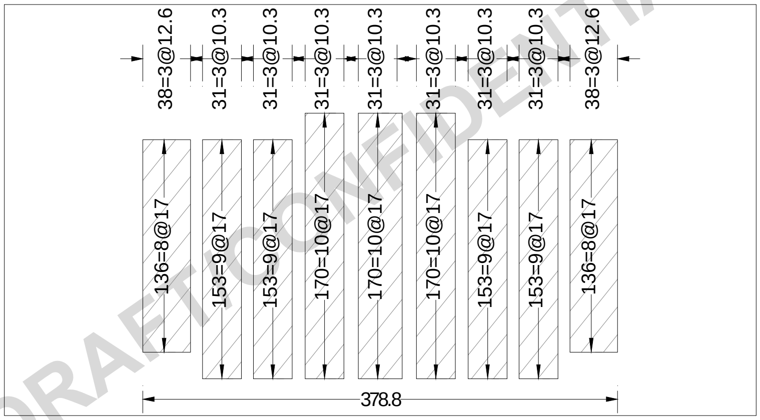
DTA Loading Footprint



ILLINOIS CENTER FOR TRANSPORTATION

DRAFT CONFIDENTIAL

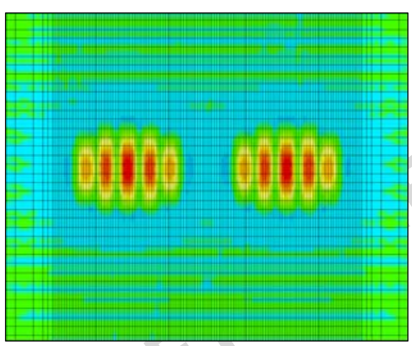
WBT Loading Footprint



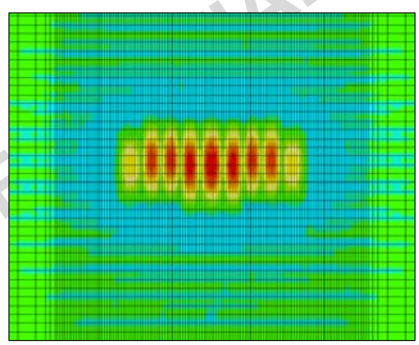
DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

3D Loading on Thick Pavement Mesh



DTA

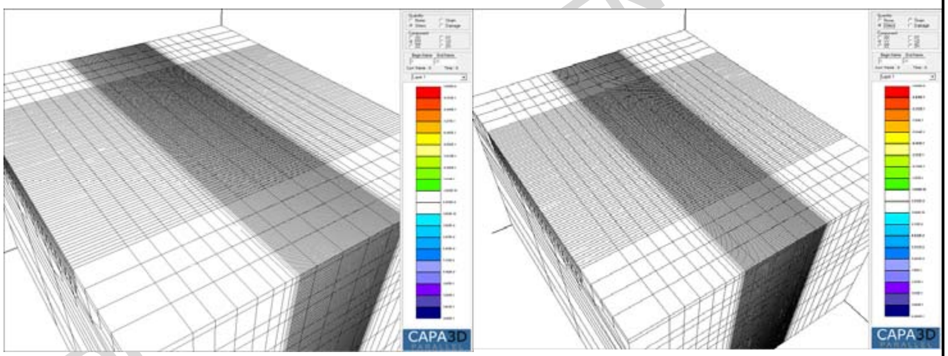


WBT

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Moving DTA and WBT Loading



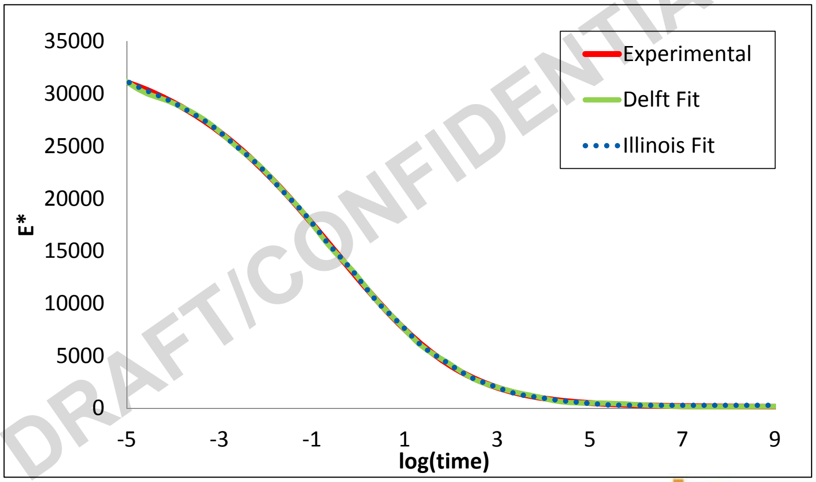
ILLINOIS CENTER FOR TRANSPORTATION

Material Characteristics

Layer	Modulus (MPa)	Poisson's Ratio
Surface Mix (SM-9.5D)	4230.0	0.33
Base Mix (BM-25.0)	4750.0	0.30
Asphalt-Treated Drainage Layer (OGDL)	2415.0	0.30
21A Cement Treated Base Layer (21B)	10342.0	0.20
21B Aggregate Subbase Layer (21B)	310.0	0.35
Subgrade	262.0	0.35

ILLINOIS CENTER FOR TRANSPORTATION

Surface Layer Viscoelastic Characterization



DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

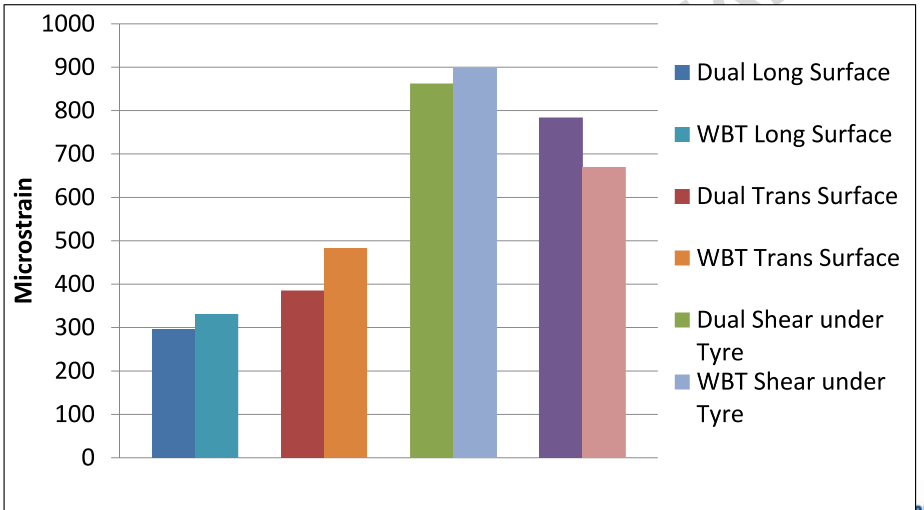
Positions Where Outputs Are Required

- Maximum tensile strain on transverse and longitudinal directions of asphalt concrete surface.
- Maximum tensile strain on transverse and longitudinal directions at of bottom of the asphalt concrete layers.
- Maximum vertical compressive strain at top of subgrade.
- Maximum shearing strain in asphalt concrete layers: under the tire and beside the tire.

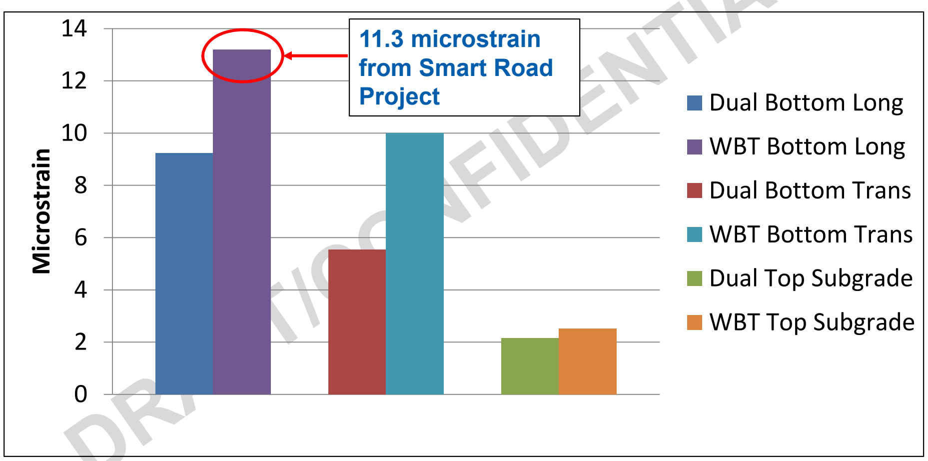
DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Output from Dual and WBT Loadings



Output from Dual and WBT Loadings



ILLINOIS CENTER FOR TRANSPORTATION

Loading Positions for DTA Relative to Center

Strain Label (Dual)	Depth from Surface location	Distance from Loading Center in Traveling Direction	Distance from Center of Loading in Transverse Direction
Long Surface	Surface	-78mm	-0.3mm
Trans Surface	Surface	-10mm	15mm (between rib 3-4)
Shear under tire	34mm	+41mm	0.3mm
Shear beside tire	34mm	+24mm	111mm (5mm from the tire edge)
Bottom Long	Bottom of Asphalt	-37mm	-50mm
Bottom Trans	Bottom of Asphalt	-37mm	-7mm
Top Subgrade	Top of Subgrade	+42mm	173mm (center of DTA)

Note: Minus indicates a position beyond the center

ILLINOIS CENTER FOR TRANSPORTATION

Loading Positions for WBT Relative to Center

Strain Label (WBT)	Depth Location from Surface location	Distance from Loading Center in Traveling Direction	Distance from Center of Loading in Transverse Direction
Long Surface	Surface	-87mm	0.6mm
Trans Surface	Surface	-19mm	29mm (between rib 5-6)
Shear under tire	34mm	-32mm	-0.6mm
Shear beside tire	34mm	-19mm	192mm (2mm from the tire edge)
Bottom Long	Bottom of Asphalt	-45mm	-0.6mm
Bottom Trans	Bottom of Asphalt	-45mm	-0.6mm
Top Subgrade	Top of Subgrade	+34mm	-0.6mm

Note: Minus indicates a position beyond the center

ILLINOIS CENTER FOR TRANSPORTATION

Remarks

- An efficient and accurate mesh has been developed for CAPA-3D per the specifications outlined by TU Delft
- Discretization of the non-uniform contact stress measurements supplied for the DTA and the WBT into a moving 3D non-uniform contact stress pulse.
- Viscoelastic model parameter determination for the surfacing layer using LTTP 26.0 data provided by UIUC. The CAPA-3D model matched the experimental and the Illinois results
- Determination of mesh locations for output of maximum strains at pre-agreed key locations

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Future Plans

- TU Delft will continue analysis using the contact stress matrix for DTA and WBT upon complete verification of the model
- TU Delft will proceed to produce the cloud of data needed for the Artificial Neural Networks tool

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

COMMENTS!

DRAFT/CONFIDENTIAL

TU Delft Delft University of Technology

ILLINOIS CENTER FOR TRANSPORTATION

Pavement Modeling (UIUC)

DRAFT/CONFIDENTIAL

5/30/2013

ILLINOIS CENTER FOR TRANSPORTATION

Outline

- Finite element modeling (FEM)
  - Dynamic-implicit analysis
  - Material characterization
  - 3D contact stresses
  - Continuous moving loading
  - Infinite boundary elements
  - Layer interaction
- Mesh sensitivity analysis
- FEM analysis matrix
  - Pavement structures
  - Load cases

DRAFT/CONFIDENTIAL

Outline

- Python Development Environment
- FEM input
  - Load
  - Materials
  - Temperature
- Sample results
- Response of thin pavements
- Response of thick pavements

DRAFT/CONFIDENTIAL

Finite Element Modeling

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Dynamic-Implicit Analysis

- Considers mass inertia and damping forces effect on pavement response
- Different contact areas of tire imprint can affect inertia force values
- Pavement response is affected by loading amplitude

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Materials Characterization

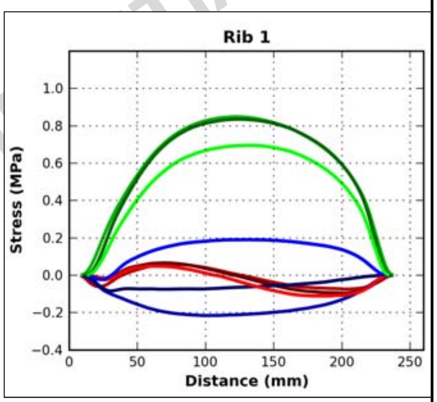
- AC: Linear-Viscoelastic:
  - E* test
  - Prony Series Expansion
- Granular Materials:
  - Thin Pavement: Nonlinear stress-dependent
  - Thick Pavement: Linear Elastic

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

3D Contact Stresses

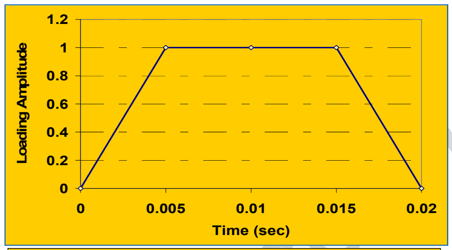
- Uniform constant stresses underestimate response close to the surface
- 3D contact stresses may create greater compressive strain on top of subgrade and transverse tensile strain

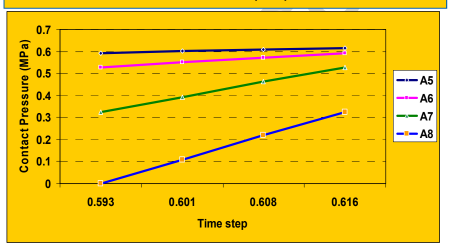


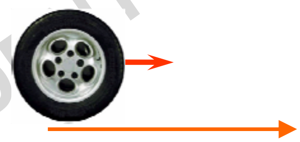
DRAFT/CONFIDENTIAL

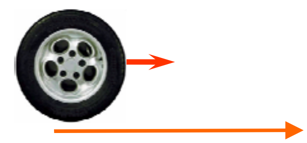
ILLINOIS CENTER FOR TRANSPORTATION

Continuous Moving Loading







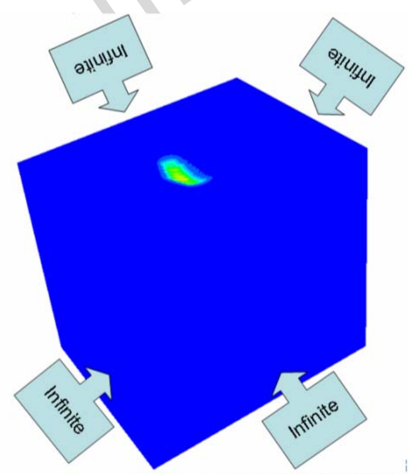


ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Finite Element Model

- Infinite Boundary Elements
  - Simulates far-field region
- Layer Interaction:
  - Fully-bonded
  - Simple Friction
  - Elastic Slip



TRANSPORTATION

DRAFT/CONFIDENTIAL

Mesh Sensitivity Analysis

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

72

Mesh Sensitivity Analysis

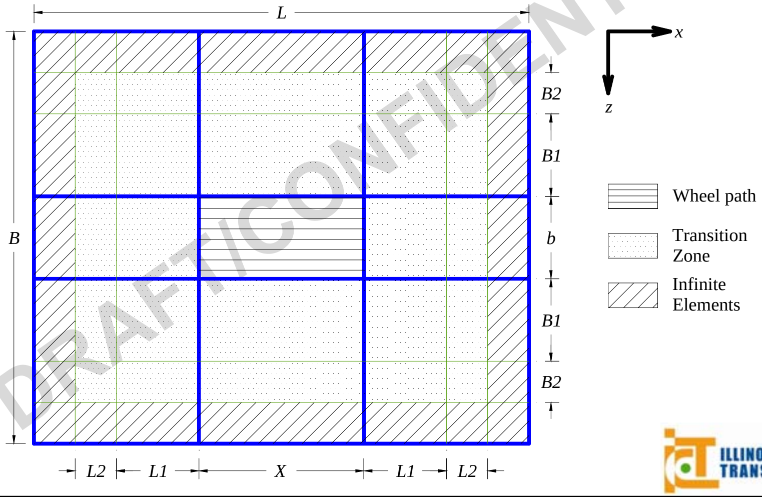
- Optimum (computational- and accuracy-wise) distribution and location of finite elements
- Parametric study in Abaqus using BISAR as reference
- Responses compared: tensile strains at bottom of AC; shear strain in each layer; and vertical strain on top of subgrade
- 5% difference used as criteria for optimum mesh
- Mesh in plan view defined by tire's footprint and transition to model's boundary

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Mesh Sensitivity Analysis

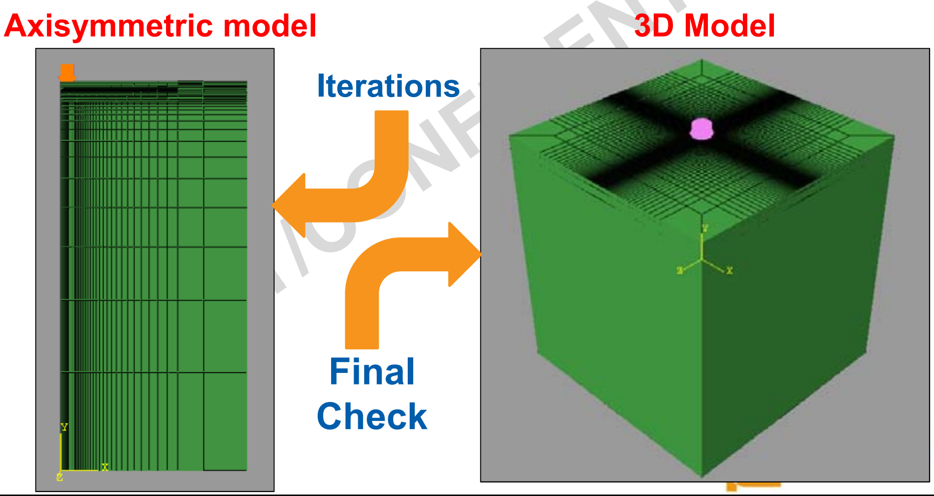
- Model parameters in plan view



DRAFT/CONFIDENTIAL

Mesh Sensitivity Analysis

- Two-step approach



DRAFT/CONFIDENTIAL

Mesh Sensitivity Analysis

- Abaqus (3D) vs. BISAR: thin pavements

	AC=75 mm, Base=150 mm			AC=75 mm, B=600 mm.			AC=125 mm, Base=150 mm			AC=125 mm, Base=600 mm		
	Abaq.	BIS.	Dif.*	Abaq.	BIS.	Dif.*	Abaq.	BIS.	Dif.*	Abaq.	BIS.	Dif.*
$\varepsilon_{11,ac}$	126.5	133.8	5.5	105.4	111.3	5.3	63.9	67.2	4.9	56.6	59.5	4.9
$\varepsilon_{22,subg}$	817.9	836.8	2.3	354.6	364.4	2.7	341.0	348.9	2.3	206.5	212.6	2.9
$\varepsilon_{23,ac}$	27.0	27.4	1.4	25.5	26.1	2.3	17.0	17.0	0.2	16.4	16.5	0.7
$\varepsilon_{23,base}$	193.0	190.4	1.4	179.1	170.7	4.9	68.4	67.9	0.8	75.2	73.0	3.0
$\varepsilon_{23,subg}$	269.9	276.6	2.4	128.7	135.1	4.8	101.6	103.9	2.2	70.6	75.8	6.9

*Difference in %

DRAFT CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Mesh Sensitivity Analysis

- Abaqus (3D) vs. BISAR: thick pavements

	AC=125 mm, Base=150 mm			AC=412 mm, Base=600 mm			AC=125 mm, B=150 mm			AC=412 mm, Base=600 mm		
	Abaq.	BIS.	Dif.*	Abaq.	BIS.	Dif.*	Abaq.	BIS.	Dif.*	Abaq.	BIS.	Dif.*
$\varepsilon_{11,ac}$	65.6	68.1	3.7	61.1	63.8	4.2	9.9	9.4	5.2	9.1	9.7	6.3
$\varepsilon_{22,subg}$	300.0	295.5	1.5	157.4	159.7	1.4	36.0	36.1	0.3	27.9	27.8	0.3
$\varepsilon_{23,ac}$	19.4	19.2	1.0	19.8	19.4	1.8	7.3	7.6	4.0	7.6	7.3	4.2
$\varepsilon_{23,base}$	73.3	70.0	4.7	74.9	74.7	0.3	6.8	6.6	3.3	7.9	8.0	1.3
$\varepsilon_{23,subg}$	83.2	88.2	5.7	53.7	56.6	5.1	8.5	8.1	5.0	7.8	8.2	4.8

*Difference in %

DRAFT CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Mesh Sensitivity Analysis

- Final configuration thin pavement:

Thin Pavements		Model			
		AC=75 mm, Base=150 mm	AC=75 mm, Base=600 mm	AC=125 mm, Base=150 mm	AC=125 mm, Base=600 mm
Dimensions (mm)	L	4300	5800	4800	5300
	B	4300	5800	4800	5300
	D	4500	4500	4500	4500
	$L1 = B1$	1200	1950	1450	1700
	$L2 = B2$	300	300	300	300
AC	No. Elem.	12	12	15	15
	Bias	1.0	1.0	1.2	1.2
Base	No. Elem.	12	25	12	25
	Bias	1.7	1.3	1.7	1.0
Subgrade	No. Elem.	15	15	15	15
	Bias	70.0	30.0	50.0	30.0
$L1 = B1$	No. Elem.	25	30	30	25
	Bias	10.0	20.0	10.0	15.0
$L2 = B2$	No. Elem.	1	1	1	1
	Bias	1.0	1.0	1.0	1.0

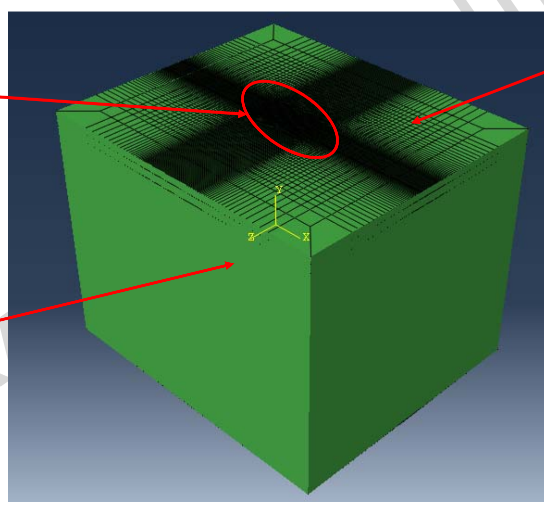
Mesh Sensitivity Analysis

- Final Model

Wheel path

Transition zone

Infinite boundary elements



FEM Analysis Matrix

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

FEM Analysis Matrix

- Structures considered: Thin pavement

Thin Pavement Structure		
	Different Materials	Thicknesses
AC Layer	W, S*	75 and 125 mm
Base	W, S*	150 and 600 mm
Subgrade	35 and 140 MPa	--
Possible combination	32	
With load cases (12)	384	

*W = Weak; S = Strong

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

FEM Analysis Matrix

- Structures considered: Thick pavement

Thick Pavement Structure		
	Different Materials	Thicknesses
Wearing Surface	W1, S1*	25 and 62.5 mm
Intermediate Layer	W2, S2*	37.5 and 100 mm
Binder Layer	W3, S3*	62.5 and 250 mm
Base and Subbase	140 and 415 MPa	150 and 600 mm
Subgrade	70 MPa	--
Possible Combination	16	
With Load cases (12)	192	

*W = Weak; S = Strong

ILLINOIS CENTER FOR TRANSPORTATION

FEM Analysis Matrix

- Loading Cases

Load Case	Tire Type	Applied Load (kN)	Tire Inflation Pressure (kPa)
L1	WBT	26.6	552
L2	WBT	26.6	862
L3	WBT	79.9	552
L4	WBT	79.9	862
L5	DTA	26.6	552
L6	DTA	26.6	862
L7	DTA	26.6	562/758
L8	DTA	79.9	562
L9	DTA	79.9	862
L10	DTA	79.9	562/758
L11	WBT	44.4	758
L12	DTA	44.4	758

ILLINOIS CENTER FOR TRANSPORTATION

Pavement Modeling (Thin & Thick)

10:15-11:00am

5/30/2013

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Abaqus Python Development Environment (PDE)

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Abaqus PDE

- Abaqus PDE*
  - Automate repetitive tasks
  - Perform parametric studies
  - Create and modify models
  - Access data in an output database

DRAFT/CONFIDENTIAL

*Abaqus 6.11 Documentation

Generation of Input Files (Abaqus PDE)

- Geometry and materials: Model dimensions, layer thicknesses, material definition, and layer interaction
- Mesh: element type and size in each layer, mesh configuration in tire's footprint, and transition to model boundary
- Load: 3D contact stresses in footprint, continuous moving load, temperature

DRAFT/CONFIDENTIAL

Abaqus PDE

- Extract information from output database (post-processing):
  - Extreme responses in each layer
  - Locations of responses
  - Variation of responses along paths (e.g. depth)

DRAFT/CONFIDENTIAL

FEM Input

DRAFT/CONFIDENTIAL

FEM Input

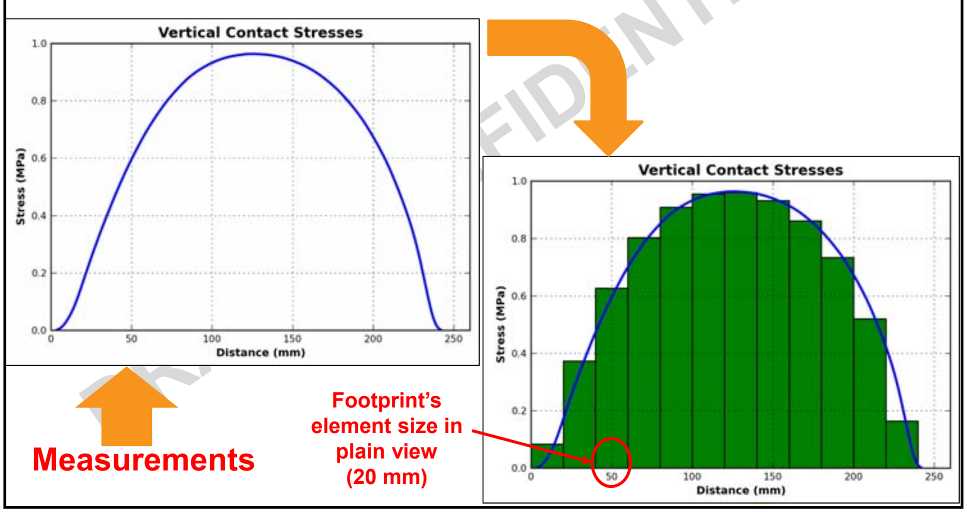
- **Load: Contact stress measurements**
- **AC materials: LTPP Database**
- **Granular materials: Nonlinear cross-anisotropic laboratory characterization**
- **Temperature profile: Analytical temperature distribution model**

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

FEM Input

- **Load**

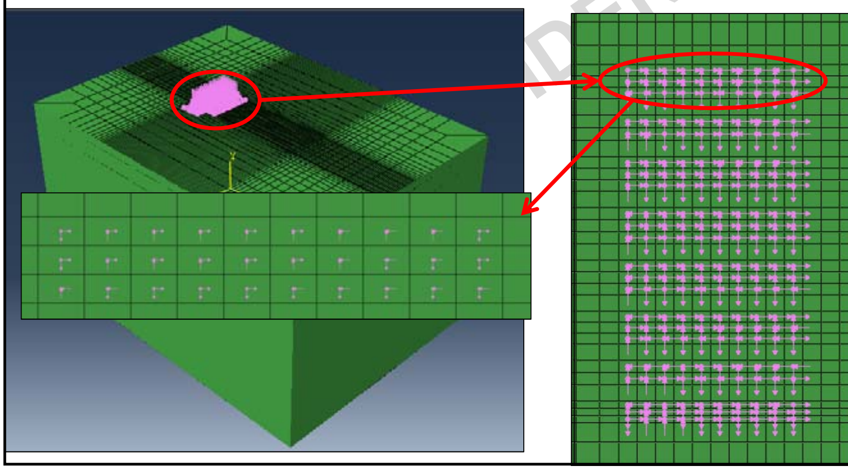


DRAFT/CONFIDENTIAL

FEM Input

- From **measurements** to **FEM**

Finite Element Model — Contact Stresses



IS CENTER FOR
SPORTATION

DRAFT/CONFIDENTIAL

FEM Input

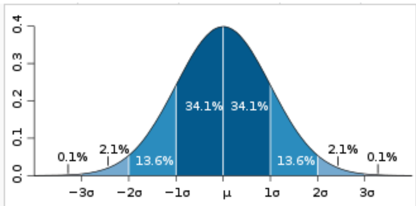
- AC Materials
  - Long-Term Pavement Performance (LTPP) Data Release #26
    - Two sets representing the extreme limits → (a) weak and (b) strong
  - Methodology
    - Statistical Analysis
    - NMAS Criterion (typical values per layer)

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

FEM Input

- Based on more than 1000 data sets



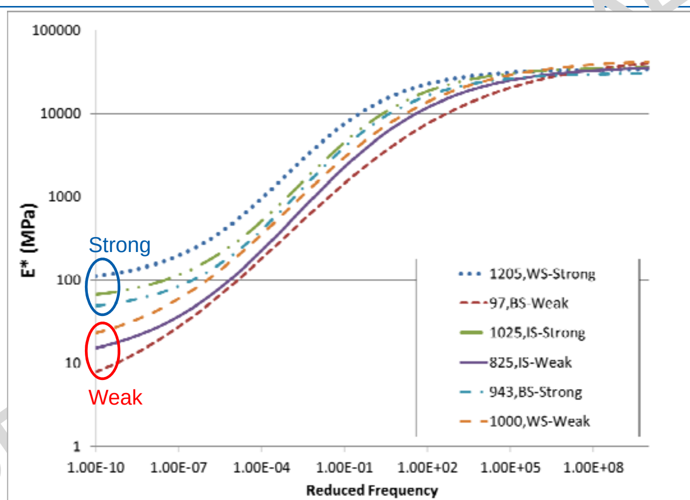
2σ ≈ 95.4%,
2.5σ ≈ 97.5%
and 3σ ≈ 99.8%

- Layer Properties: NMAS
  - Wearing Surface (WS) 9.5 or 12.5mm
  - Intermediate Layer (IS) 25 or 19.5mm
  - Base Layer (BS) 25 or 37.5mm

From *http://en.wikipedia.org/wiki/Normal_distribution.*

ILLINOIS CENTER FOR TRANSPORTATION

FEM Input: AC Materials



ILLINOIS CENTER FOR TRANSPORTATION

95

FEM Input

- Base materials (thin pavements)
  - Cross-anisotropic stress-dependent

$$M_r = k_1 p_a \left(\frac{\theta}{p_a}\right)^{k_2} \left(\frac{\tau_{oct}}{p_a} + 1\right)^{k_3}$$

  - Based on database of 114 materials (Tutumluer, 2008)
  - Materials in database tested using pulse load in vertical and radial directions

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

96

FEM Input

- Two stress levels defined to select weak and strong material (Xiao et al., 2011)

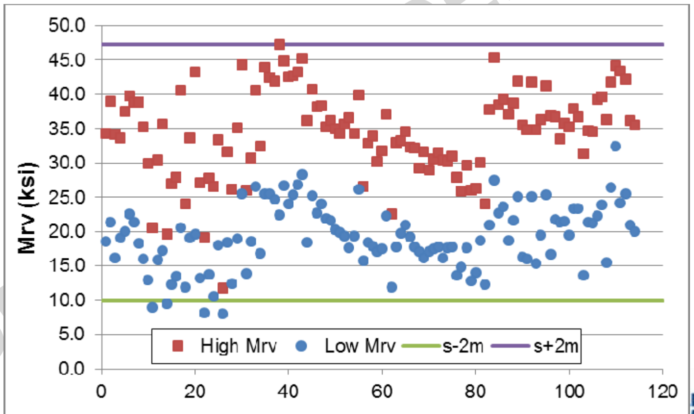
	Low stress level	High stress level
	kPa	kPa
σ_3	34.9	104.8
σ_d	104.8	209.5
σ_1	139.7	314.3
σ_2	34.9	104.8
θ	209.5	523.9

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

FEM Input

- Vertical resilient modulus of each material at **both stress levels**



CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

FEM Input

- Vertical and horizontal shear modulus from **laboratory tests**
- Shear resilient modulus from **simplified procedure** (Tutumluer and Thompson, 1998)

Direction	Weak			Strong		
Vertical	k_1=453.3	k_2=0.8858	k_3=-0.5713	k_1=869.6	k_2=0.9785	k_3=-0.5673
Horizontal	k_4=282.4	k_5=0.6701	k_6=-1.1341	k_4=596.6	k_5=1.1419	k_6=-1.3464
Shear	k_7=310.3	k_8=1.0297	k_9=-1.1036	k_7=389.1	k_8=0.9083	k_9=-0.2409

CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

FEM Input

- **Temperature distribution in AC (Wang, 2013)**
  - Two layer system: AC layers and granular
  - Bound temperature distribution
  - Initial temperature distribution function of depth z only
  - Continuous heat flow at the interface between layers

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Temperature Distribution

- Governing Equations
  - Temperature distribution in each layer:

$$\frac{\partial T_1}{\partial t}(z,t) = \alpha_1 \frac{\partial^2 T_1}{\partial z^2}(z,t) \qquad 0 < z < H$$

$$\frac{\partial T_2}{\partial t}(z,t) = \alpha_2 \frac{\partial^2 T_2}{\partial z^2}(z,t) \qquad z > H$$

  - Initial temperature in each layer:

$$T_1(z,0) = G_1(z) \qquad 0 < z < H$$

$$T_2(z,0) = G_2(z) \qquad z > H$$

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Temperature Distribution

- Continuous temperature and heat flow at interface:

$$T_1(H,t) = T_2(H,t)$$

$$\lambda_1 \frac{\partial T_1}{\partial z}(H,t) = \lambda_2 \frac{\partial T_2}{\partial z}(H,t)$$

- Energy Balance at pavement surface:

$$\lambda_1 \frac{\partial T_1}{\partial z}(0,t) = B[T(t) - T_1(0,t)]$$

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Temperature Distribution

- Solution for AC layer:

$$\hat{U}_1(z,s) = \frac{B\hat{f}(s)\left[e^{\sqrt{\frac{s}{\alpha_1}}z} - Le^{(2H-z)\sqrt{\frac{s}{\alpha_1}}}\right]}{B-\lambda_1\sqrt{\frac{s}{\alpha_1}} - e^{2H\sqrt{\frac{s}{\alpha_1}}}L\left(B+\lambda_1\sqrt{\frac{s}{\alpha_1}}\right)};$$

$$\text{with } L = \frac{1+\frac{\lambda_1 r_1}{\lambda_2 r_2}}{1-\frac{\lambda_1 r_1}{\lambda_2 r_2}}$$

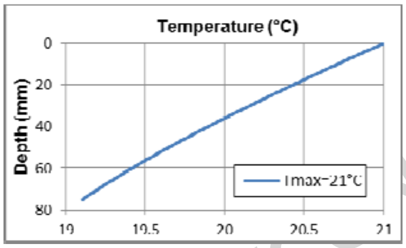
DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

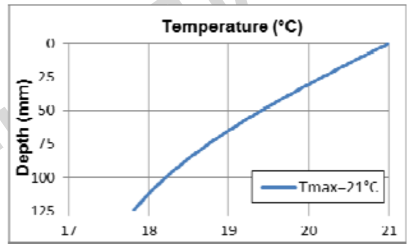
103

Temperature Distribution

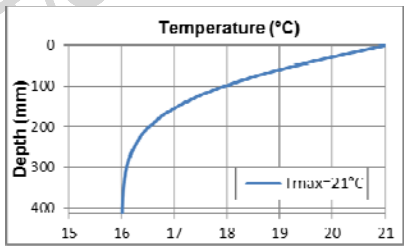
H=75 mm



H=125 mm



H=412 mm



ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Sample of Results

ILLINOIS CENTER FOR TRANSPORTATION

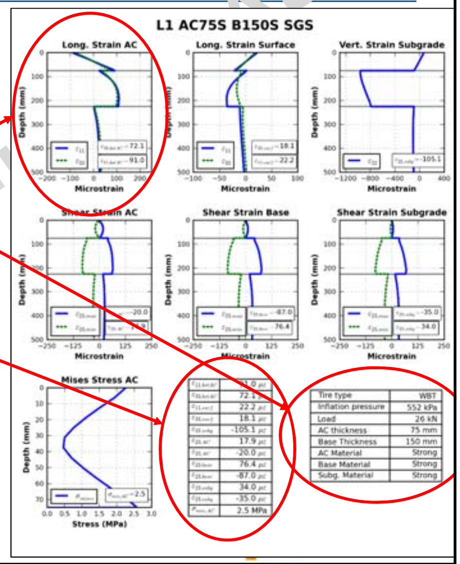
DRAFT/CONFIDENTIAL

Sample of Results

- For each one of the **576 cases**

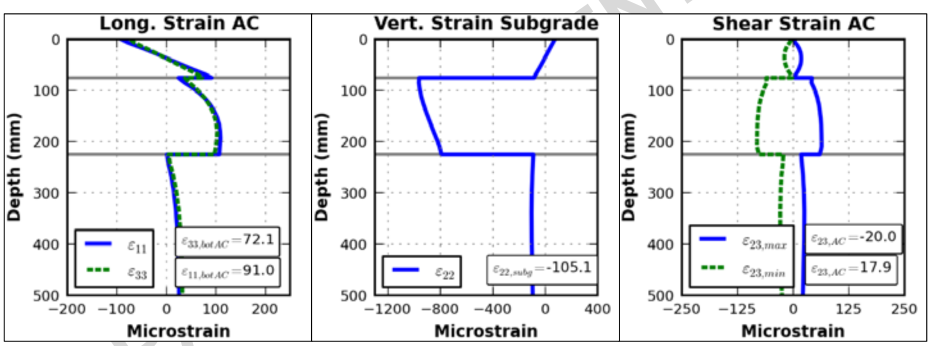
$\varepsilon_{11,botAC}$	91.0 $\mu\varepsilon$
$\varepsilon_{33,botAC}$	72.1 $\mu\varepsilon$
$\varepsilon_{11,surf}$	22.2 $\mu\varepsilon$
$\varepsilon_{33,surf}$	18.1 $\mu\varepsilon$
$\varepsilon_{22,subg}$	-105.1 $\mu\varepsilon$
$\varepsilon_{23,AC}$	17.9 $\mu\varepsilon$
$\varepsilon_{23,AC}$	-20.0 $\mu\varepsilon$
$\varepsilon_{23,base}$	76.4 $\mu\varepsilon$
$\varepsilon_{23,base}$	-87.0 $\mu\varepsilon$
$\varepsilon_{23,subg}$	34.0 $\mu\varepsilon$
$\varepsilon_{23,subg}$	-35.0 $\mu\varepsilon$
$\sigma_{mis,AC}$	2.5 MPa

Tire t	WBT
Inflat	552 kPa
Load	26 kN
AC th	75 mm
Base	150 mm
AC M	Strong
Base	Strong
Subg	Strong



Sample of Results

L1 AC75S B150S SGS



ILLINOIS CENTER FOR TRANSPORTATION

Responses of Thin Pavements

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Responses of Thin Pavements

- **Thinnest pavement (AC=75 mm and Base=150 mm) all material combinations:**
  - **WBT vs. DTA at low load and tire-inflation pressure (P=26.6 kN, σ=552 kPa)**
  - **WBT vs. DTA at high load and tire-inflation pressure (P=79.9 kN, σ=862 kPa)**
- **All load combinations for the same pavement structure**

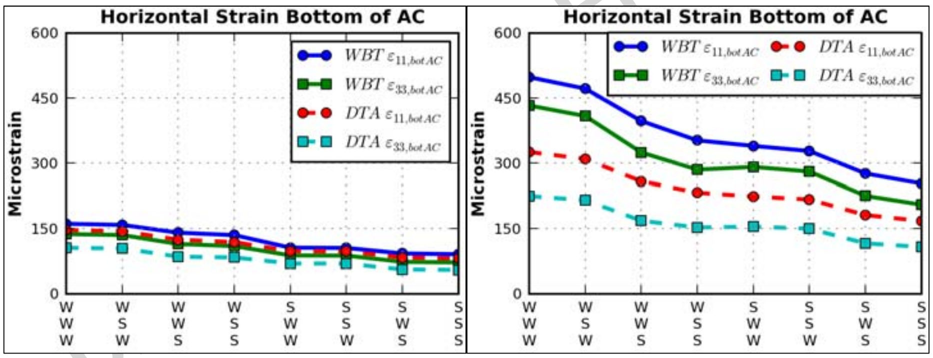
DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Strain at the bottom of AC

AC75 B150

P=26.6 kN, σ=552 kPa | **P=79.9 kN, σ=862 kPa**

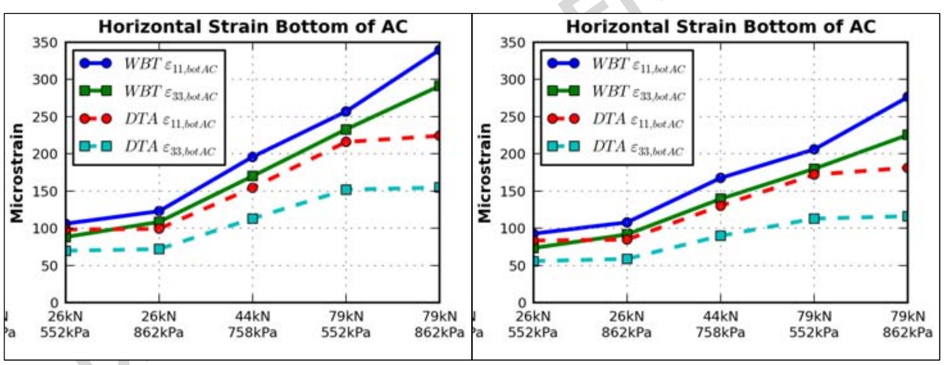


ILLINOIS CENTER FOR TRANSPORTATION

Effect of Loading Cases

- Tensile strain at bottom of AC

AC75S B150W SGW | **AC75S B150W SGS**



Weak Subgrade | **Strong Subgrade**

ILLINOIS CENTER FOR TRANSPORTATION

Responses of Thick Pavement

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Responses of Thick Pavements

- **Thinnest** pavement (AC=125 mm and Base=150 mm) **all material combinations**:
  - WBT vs. DTA at **low** load and tire-inflation pressure (P=26.6 kN, σ=552 kPa)
  - WBT vs. DTA at **high** load and tire-inflation pressure (P=79.9 kN, σ=862 kPa)
- **All load combinations** for the same pavement structure (AC=412 mm and Base=150 mm)

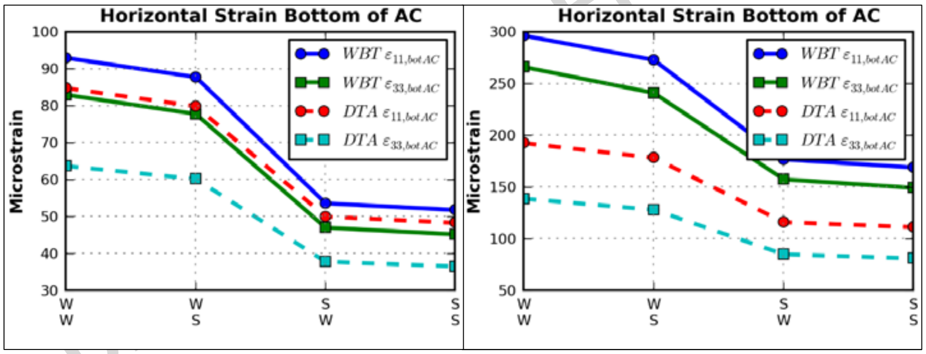
DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Effect of Material Properties

AC125 B150

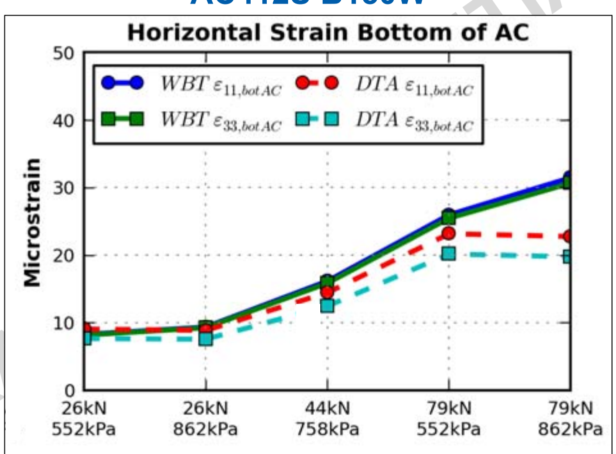
P=26 kN, σ=552 kPa | **P=79 kN, σ=862 kPa**



ILLINOIS CENTER FOR TRANSPORTATION

Effect of Loading Cases

AC412S B150W



ILLINOIS CENTER FOR TRANSPORTATION

115

Remarks

- Small difference between horizontal strains in the longitudinal and lateral directions (top and bottom of AC)
- Difference between WBT and DTA become more pronounced with higher load and higher tire pressure

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

116

Future Plans

- Complete thin and thick pavement cases with various combinations of axle loads and tire inflation pressures
- Provide comprehensive analysis with regards to the effect of:
  - Tire type
  - Material property
  - Loading case
  - Pavement structure

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

COMMENTS!

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Data Management
11:00-12:00am

5/30/2013

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Outline

- Introduction and Objectives
- Existing data
- New data
- Filtering process
- Interface design
- Future Plans: Artificial Neural Network

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

The Need for Field and APT Data

- Represent real conditions
- Realistic responses from field
- Model validation
- Utilize as training or for the testing phase of Artificial Neural Networks

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

121

Objectives of Data Management

- Data **filtering** as needed and process **automation**
- Data management and organization
- Allow easy access to data by designing an **interface**
- Provide a platform for future data **updates**

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

122

Data Sources

- Five main data sources:
  - UIUC-Thin Pavement Sections
  - Florida DOT
  - UC-Davis
  - Ohio SPS-8
  - Virginia Tech - Smart Road
- Huge amount of data/information
- **Update** w/ new data as it becomes available

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

123

UIUC-Thin Pavement Sections

- Nine low-volume AC sections
- Three tire types: Dual, WBT-425, and WBT-455
- Various loads, speeds, and tire inflation pressures
- Instrumentation: Strain gauges, LVDT, pressure cells, and thermocouples

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

124

UIUC-Thin Pavement Sections-Data

- Strain at the bottom of surface layer
- Vertical deflection on top of subgrade
- Longitudinal and transverse base deformations
- Surface rutting

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Florida DOT

- Six test lanes
- Open- and dense-graded AC layers
- Tires: Dual, WBT-445, WBT-455
- Instrumentation: Surface strain gauges (longitudinal and transverse)
- Rutting data

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

UC-Davis

- Rutting of two overlay systems: dense-graded AC (DGAC) and asphalt-rubber hot mix gap-graded (ARHM-GG)
- Tire types: Dual radial, dual bias-ply, WBT-425, and aircraft tires
- Profile data
- 3D contact stresses

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Ohio SPS-8

- Two sections of 4- and 8-in-thick AC on the U.S. Route 23 Test Road
- Single-unit two axle truck with two tires: Two dual and two wide-base (WBT425, WBT495)
- Strain gage rosettes in different directions at AC layer
- Tire pressure patterns
- FWD

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Virginia Tech Smart Road

- 1999-2002 database
- Instrumentation: Strain gauges (AC, base, sub-base); Pressure cells (two types); Time-domain reflectometry (TDR), thermocouples, …
- Dynamic data response
- Static environmental data response
- GPR, friction, roughness, and FWD

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

129

New Data Sources

- Florida DOT
- UC-Davis
- Ohio

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

130

Florida DOT

- Test Pit and Test Track data
- Dual and NGWB tires
- Instrumentation: Embedded and surface strain gauges
- Pressure cells (bottom of AC and base)

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Florida DOT – Test Matrix

Tire Type	Inflation Pressure (kPa)	Tire Loading (kN)				
NGWB and Dual	552	26.6	35.5	44.4	62.2	79.9
NGWB and Dual	690					
NGWB and Dual	758					
NGWB and Dual	862					
Dual Only	414/758*					
Dual Only	552/758*					

*Differential Tire Inflation Pressure

ILLINOIS CENTER FOR TRANSPORTATION

UC-Davis

- 5-in high RAP surface layer and 2-in AC wearing surface layer
- Strain gauges in both directions under the AC layer lifts
- Instrumentation: Longitudinal and transverse strain gauges (bottom of AC and RAP base layers)
- Pressure cells at bottom of aggregate base layer
- Multi-Depth Deflectometer (MDD)

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Ohio

- Total of three sections (mainline and ramp)
- Test matrix includes:
  - Two tire type (dual and wide)
  - Two axles (single and tandem)
  - Various loads, speeds and tire inflation pressures
- Instrumentation: Two types of strain gauges, Rosettes, two types pressure cells, and LVDTs
- Collected data to date: 3 sections out of 4 at highest load case (6 out of 48 cases - 10% completed)

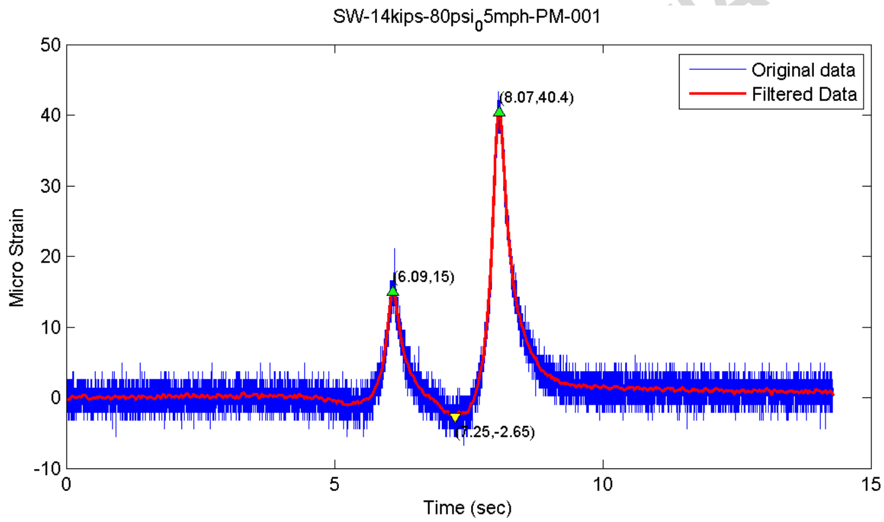
DRAFT/CONFIDENTIAL

Data Filtering Process

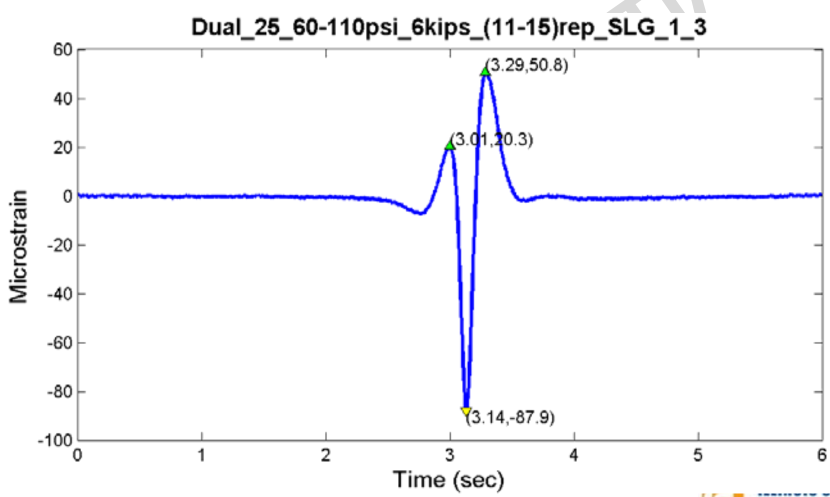
- Florida and Ohio data filtering is in progress
- Three-step filtering process:
  - Transferring data to origin
  - Smoothing/filtering using Robust Local Regression Method
  - Extracting local extrema
- All processes are done in Matlab

DRAFT/CONFIDENTIAL

Typical Strain Data - Ohio



Typical Strain Data - Florida



TRANSPORTATION

Interface Design

- Data organization for easy access
- AutoPlay Media Studio 8 software

Run Demo

DRAFT/CONFIDENTIAL

Future Plans: Artificial Neural Network

- All useful collected **data** will be utilized
- To **predict pavement damage** caused by various **loading** and **tire configurations**
- Robust, nonlinear, and strong modeling technique
- **Accurate** if trained properly
- **Easier to use** compared to FEM
- Less computational time

DRAFT/CONFIDENTIAL

Artificial Neural Networks Input

- Pavement structure characteristics: number of layers, thicknesses, binder, elastic modulus, agg. properties, etc.
- Loading, tire configuration, and speed
- Data include: FEM, field, and APT data
  - FEM modeling data will be used for training
  - Field and APT data for validation purposes

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Artificial Neural Networks Output

- Responses related to fatigue, rutting and thermal cracking;
  - Transverse strain at bottom of AC
  - Vertical strain (deformation) on top of subgrade
- Damage Ratio

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

COMMENTS!

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Laboratory Testing

1:00-1:45pm

5/30/2013

DRAFT/CONFIDENTIAL

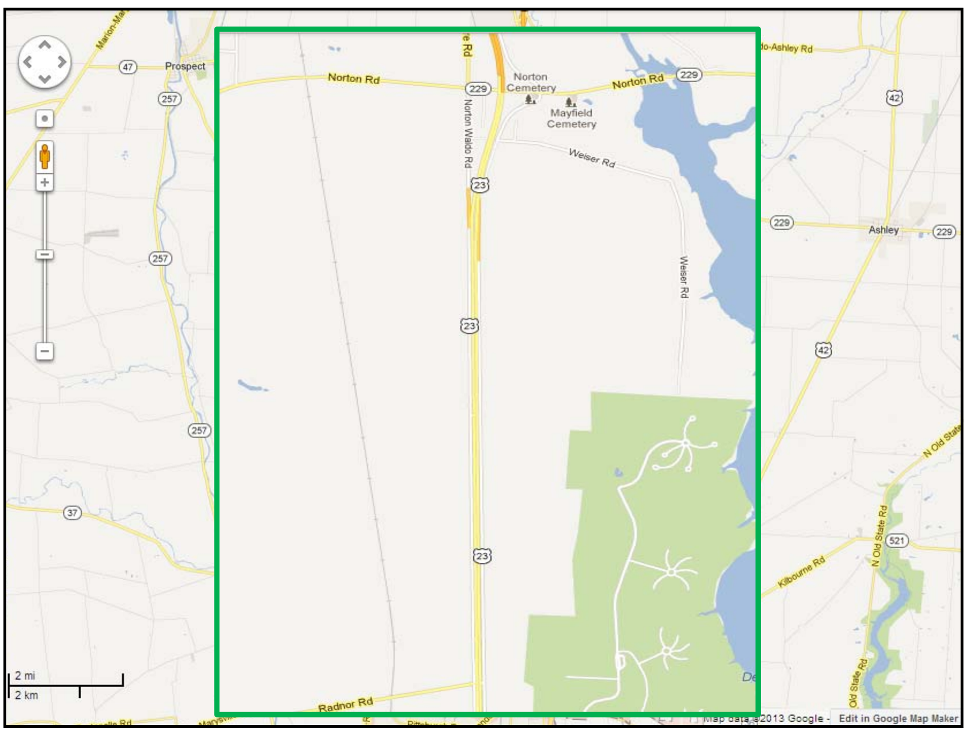
ILLINOIS CENTER FOR TRANSPORTATION

Laboratory Testing

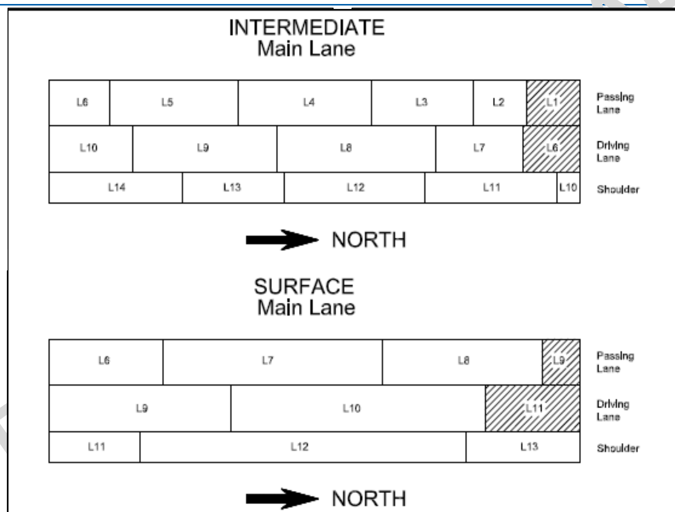
- Sampling Overview
  - Sampling
  - Splitting
  - Compacting
  - Loose Mix, MRL, etc
  - Tracking of trucks
- Cutting & Coring
- Testing

“Mobilized” Lab

ILLINOIS CENTER FOR TRANSPORTATION



Paving Sequence



DRAFT INITIAL

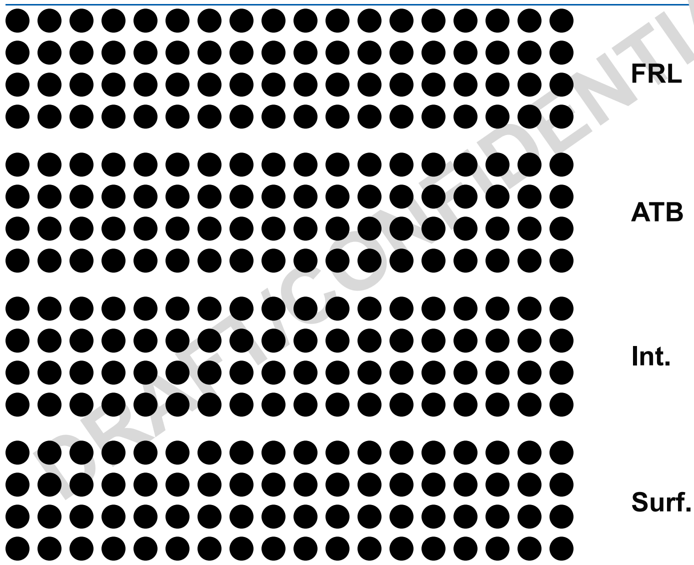
ILLINOIS CENTER FOR TRANSPORTATION

Target Density

DRAFT INITIAL

ILLINOIS CENTER FOR TRANSPORTATION

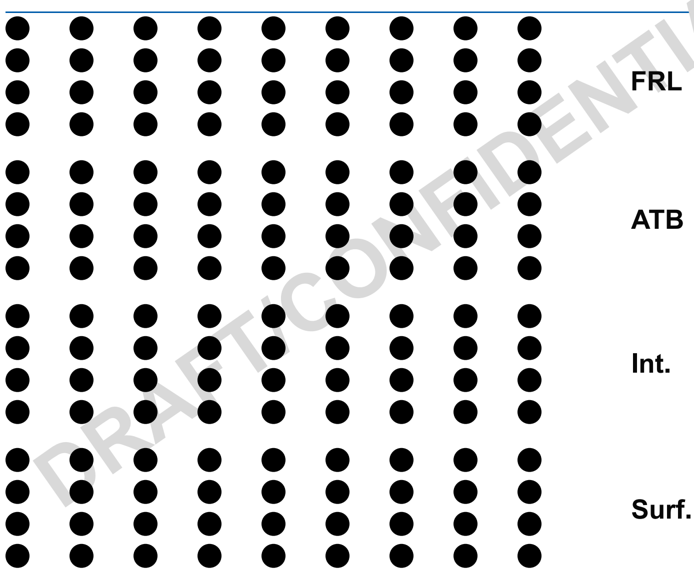
Specimen Allocation



DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Specimen Allocation



DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Specimen Allocation

Per Material

FRL

ATB

Int.

Surf.

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

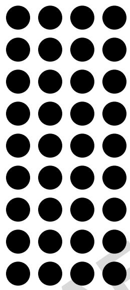
Specimen Allocation

Per Material

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Specimen Allocation



E*

SCB

IDT

DCT

Push-Pull

Spares-TBD

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

E* Fabrication

150mm→100mm

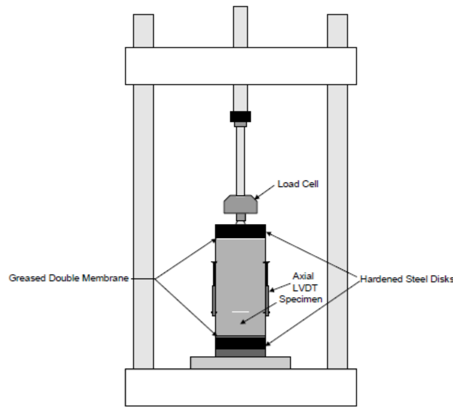
Top/Bottom cuts

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

E* Specification

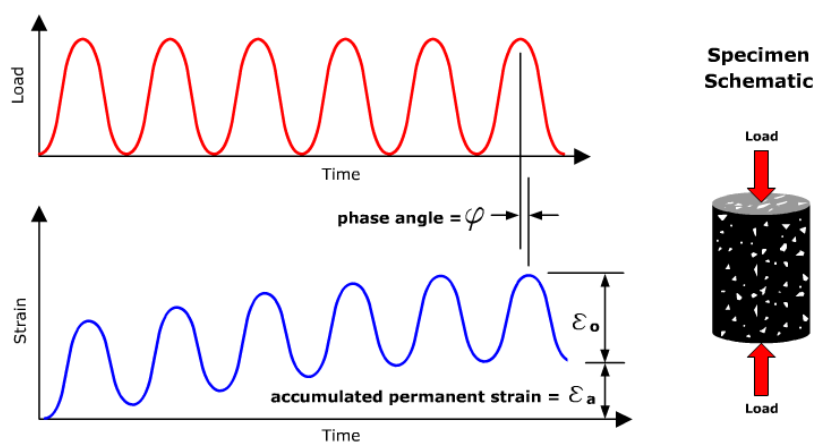
- AASHTO T 342-11 (formerly TP 62-07)
  - NMAS ≤ 37.5 mm
    - Dense- or gap-graded
  - Conditions:
    - 5 temperatures
      - -10, 4.4, 21, 38, 54 °C
      - (14, 40, 70, 100, 130 °F)
    - 6 frequencies
      - 25, 10, 5, 1, 0.5, 0.1 Hz
  - Stress-controlled test
  - Haversine axial compressive load



DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

E* Testing



Courtesy of pavementinteractive.org

ILLINOIS CENTER FOR TRANSPORTATION

E* Testing Images

DRAFT CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

IDT Fabrication

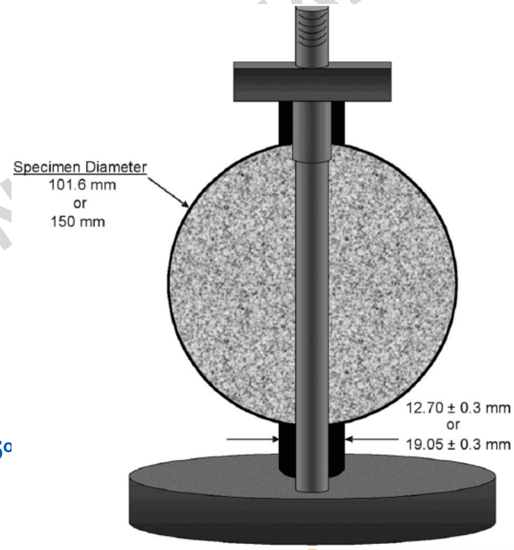
50mm Slice

DRAFT CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

IDT Specification

- ASTM D 6931-12
  - Tensile strength
  - Constant vertical deformation
  - 25 ± 1°C
- AASHTO T 322-07
  - Tensile creep
    - Static Load
      - Limited by strain
    - -20, -10, and 0 ± 0.5°
    - 3 ± 1 hrs



DRAFT/CONFIDENTIAL

IDT Testing Images

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

SCB Fabrication

DRAFT/CONFIDENTIAL

25-50mm Slice

Top/Bottom cuts

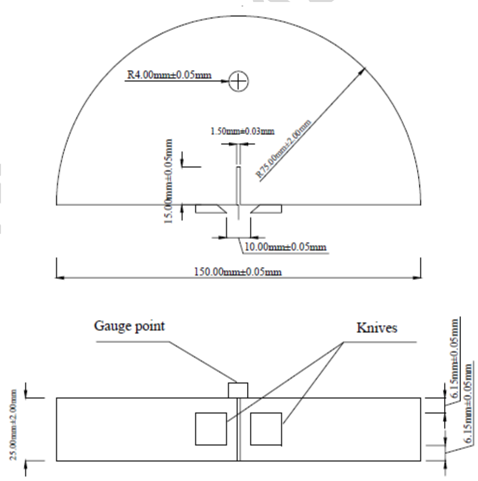
Notch

ILLINOIS CENTER FOR TRANSPORTATION

SCB Specification

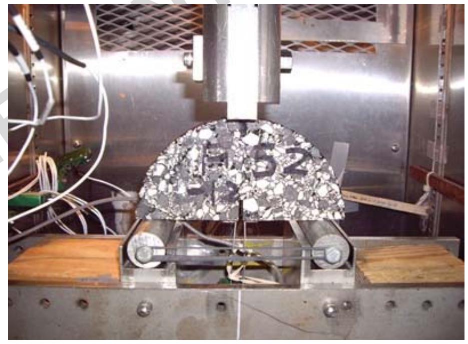
DRAFT/CONFIDENTIAL

- AASHTO Draft
  - Displacement control
    - CMOD
      - 0.0005 mm/s
      - 0.03 mm/min
  - Low PG + 10°C
  - Conditioning time = 2 ± 0.2 hrs
    - Temp. = ± 1°C



165

SCB Testing Images



ILLINOIS CENTER FOR TRANSPORTATION

DRAFT CONFIDENTIAL

166

DC(T) Fabrication

50mm Slice

Front Face Cut

Core Drilled Holes

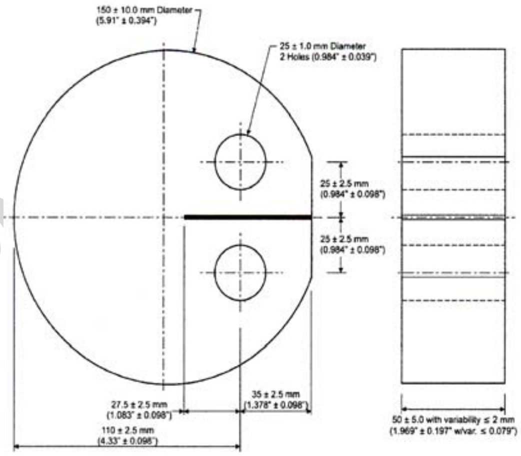
Notch

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT CONFIDENTIAL

DC(T) Specification

- ASTM D 7313
  - Test developed in 2005
  - Advantages
    - Provides larger ligament length than SCB
    - Easier geometry than SEB to fabricate from field cores
  - Displacement controlled test
    - 1.0mm/min
  - Required equipment
    - Load cell with capable resolution
    - Crack mouth opening displacement (CMOD) gauge
  - Low PG + 10°C



DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

DC(T) Testing Images

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Push-Pull Fabrication

150mm→100mm

Top/Bottom cuts

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Push-Pull Specification

- Draft
  - Fatigue test
  - Continuum damage characteristics
  - Simple Uniaxial test
  - 15 & 20 $\pm$ 0.5^{o}C

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

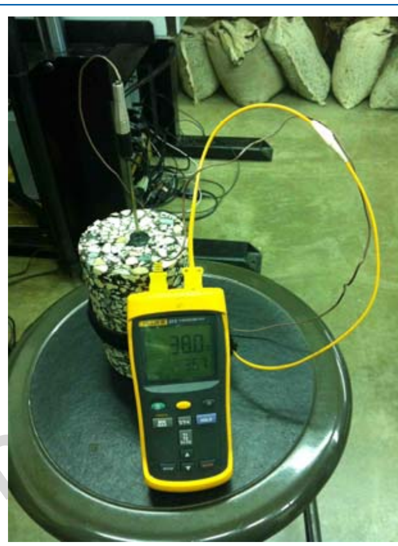
171

Push-Pull Testing Images

ILLINOIS CENTER FOR TRANSPORTATION

172

Equilibration Time



ILLINOIS CENTER FOR TRANSPORTATION

This is Characterization…

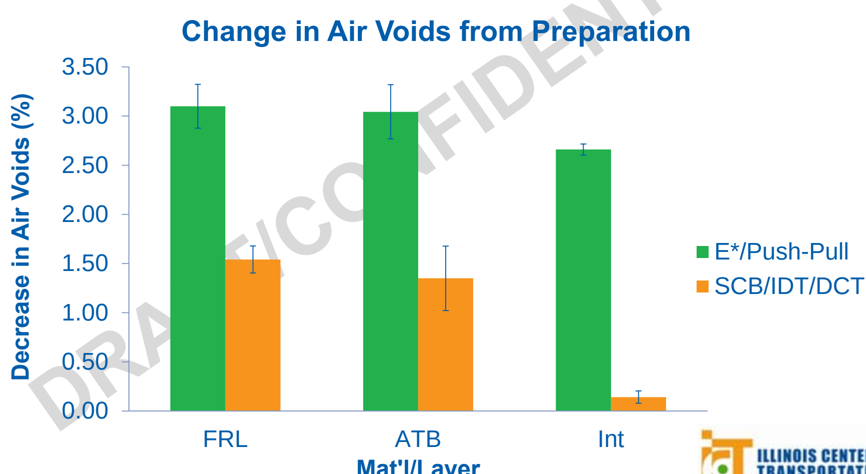
- Constant target **density**, regardless of field data
- Allows for cataloging to a **vast database** with other materials that have undergone general characterization
- Monitors **consistency** of production truck-by-truck

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Density Results

- Useful to carry into validation phase



DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Validation

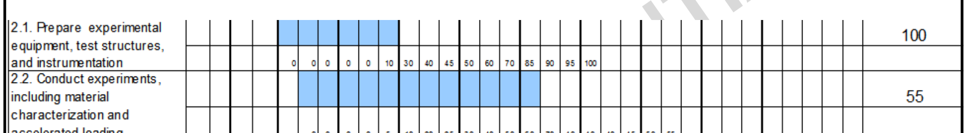
- Loose mix collected during production will be compacted to match the nuclear density data from the field at time of placement (no longer 7.0 ± 0.5%)
- Allows for direct comparison, validation of models

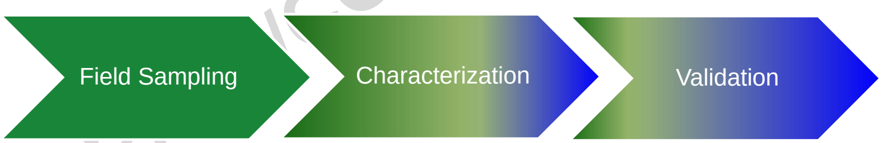
(%AV: FRL=4.5, ATB=4.6, INT=4.5, SURF=4.7)

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Laboratory Testing Progress

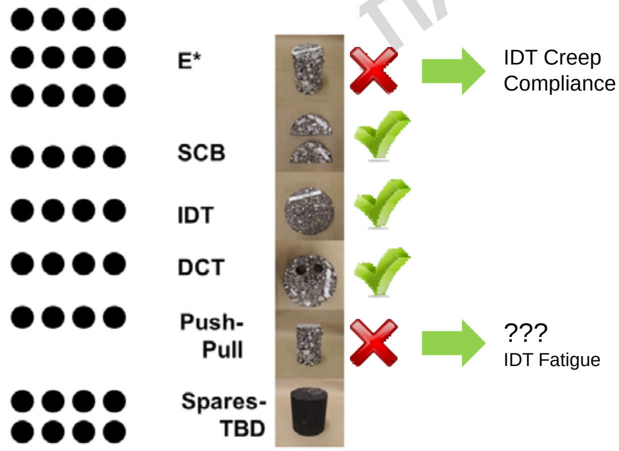




DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Adjustments for Field Cores



***Note: Both FL & UC-Davis will be performing E* testing on SGC specimens

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Future Plans

- Compact **SGC** specimens that **simulate** the **field**-compacted samples (air void validation)
- Finish **laboratory test matrix** for materials in all testing sites

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

COMMENTS!

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Instrumentation and Testing: Ohio, Florida, and Davis

1:45-3:15pm

5/30/2013

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Instrumentation and Testing: Florida

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Topics

- FDOT's APT Facility
- Test Section Design
- Instrumentation
- Construction
- Material Sampling
- HVS Testing

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

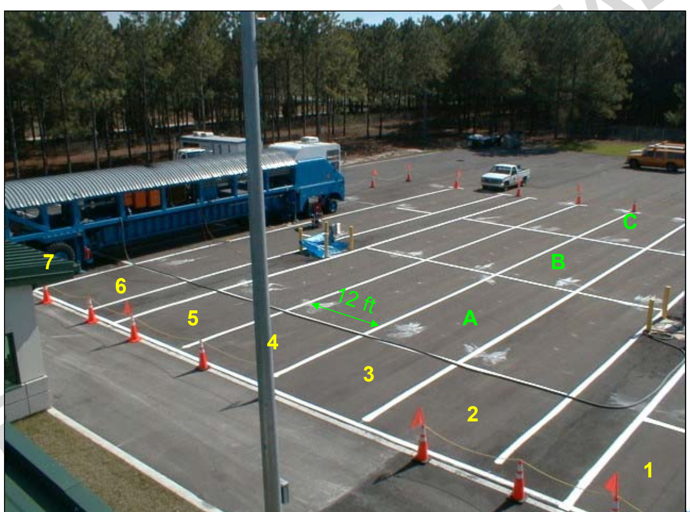
FDOT's APT Facility

- State Materials Research Park, Gainesville
- Test sections
  - Eight test tracks
  - Two test pits
- Heavy Vehicle Simulator (HVS)

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Test Tracks

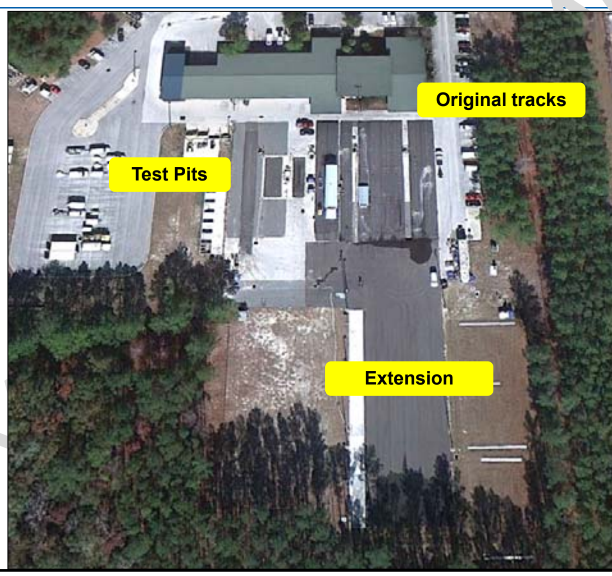


ILLINOIS CENTER FOR TRANSPORTATION

Test Pits

ILLINOIS CENTER FOR TRANSPORTATION

Test Track Aerial View



ILLINOIS CENTER FOR TRANSPORTATION

Heavy Vehicle Simulator

- Heavy Vehicle Simulator, Mark IV
  - Wheel speed: 7 mph
  - Loading: 7 to 45 kips
  - Dual or single tires

Dual Tire

Wide-Base Tire

ILLINOIS CENTER FOR TRANSPORTATION

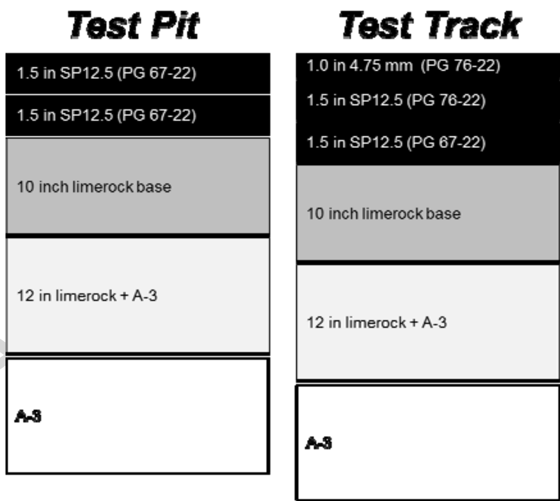
CONFIDENTIAL

Heating System

- Six 9 ft. long elements attached to HVS test beam
- Independently controlled to provide six heating zones
- Thermocouples monitor asphalt temperature to a depth of 2 in
- Styrofoam filled panels insulate the test area

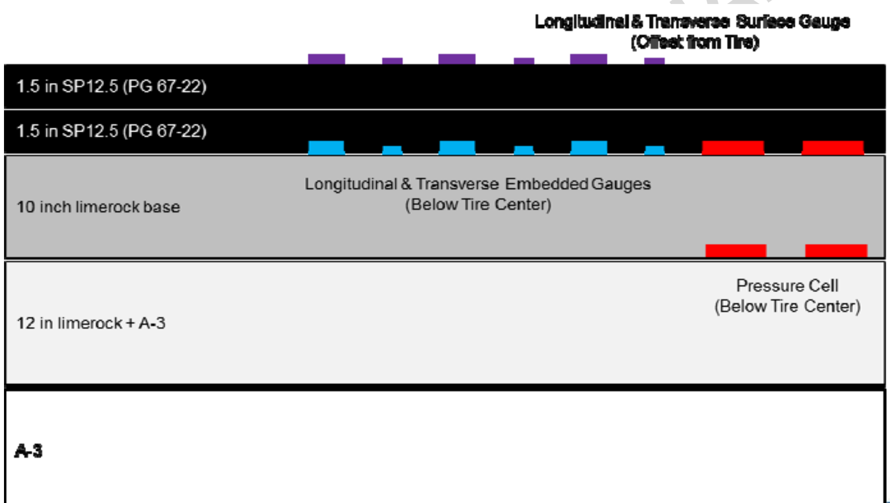
DRAFT/CONFIDENTIAL

Test Section Design



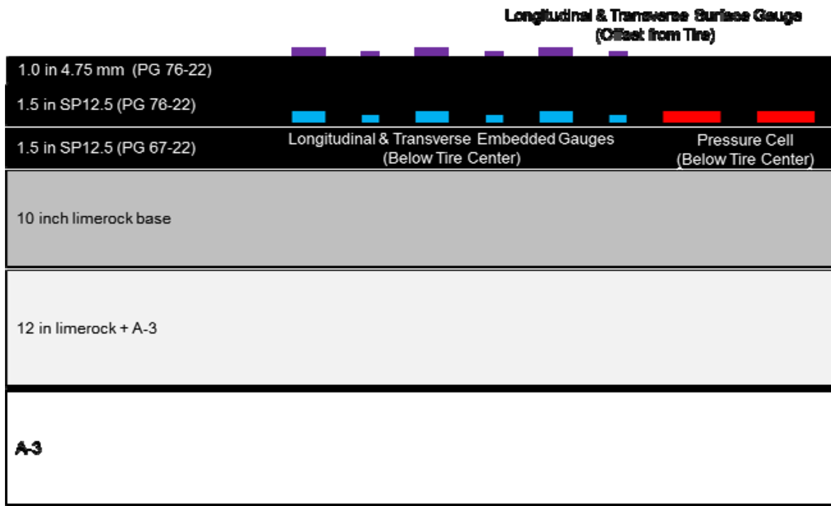
ILLINOIS CENTER FOR TRANSPORTATION

Test Pit Instrumentation

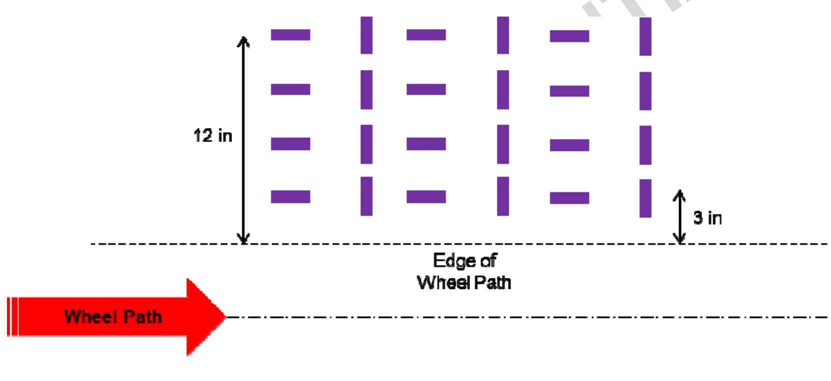


TRANSPORTATION

Test Track Instrumentation



Surface Strain Gauges



ILLINOIS CENTER FOR TRANSPORTATION

Instrumentation Summary

Sensor Type	Number of Sensors per Test Section	Model	Vertical Location	Offset from Wheel Path
Surface strain gauge	24	Tokyo Sokki PFL-30-11-5L	HMA surface	Transverse and longitudinal orientations at various offsets from wheel path edge
Asphalt strain gauge	6	Tokyo Sokki KM-100HAS	Bottom of new HMA	Transverse and longitudinal orientations below tire center
Pressure cell	2	RST Instruments LPTPC09-S	Bottom of new HMA	Below tire center
Pressure cell (Test Pit only)	2	Geokon 3500	Bottom of base	Below tire center

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Pressure Cells

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

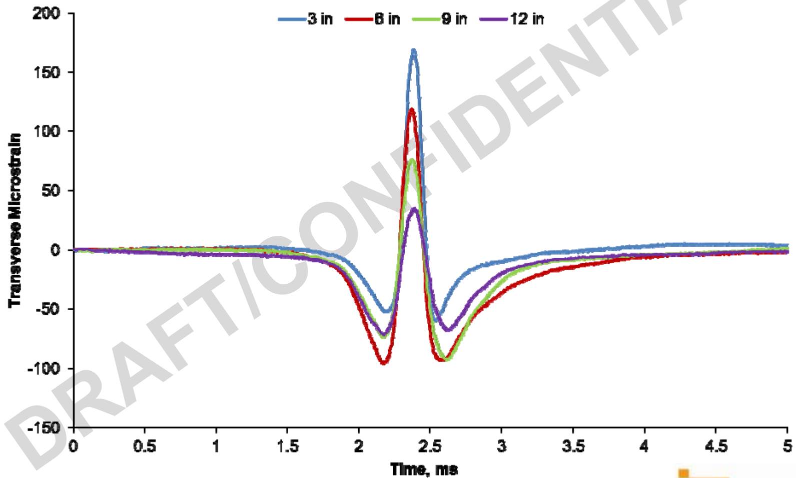
Asphalt Strain Gauges (H-Gauges)

ILLINOIS CENTER FOR TRANSPORTATION

196

Asphalt Surface Strain Gauges (Foil)

Surface Strain – Dual Tire at 55^{o}C



DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Test Pit Construction

ILLINOIS CENTER FOR TRANSPORTATION

Test Pit Paving

DRAFT CONFIDENTIAL

Test Track Paving

DRAFT CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Material Sampling

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Laboratory Testing

- Granular Materials
  - Resilient modulus
  - Moisture-density relationship
- HMA
  - Cores
    - Verification of density
    - Cores to University of Illinois
  - Loose mixture
    - Volumetric data
    - IDT
    - AMPT

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

203

HVS Test Matrix

Tire Type	Inflation Pressure (psi)	Tire Loading (kips)				
NGWB and Dual	80	6	8	10	14	18
NGWB and Dual	100	6	8	10	14	18
NGWB and Dual	110	6	8	10	14	18
NGWB and Dual	125	6	8	10	14	18
Dual Only	60/110	6	8	10	14	18
Dual Only	80/110	6	8	10	14	18
Tests at 25^{0}C, 40^{0}C, and 55^{0}C						

ILLINOIS CENTER FOR TRANSPORTATION

204

Completed Tasks

- The construction, instrumentation, and testing at Florida has been completed

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

COMMENTS!

DRAFT/CONFIDENTIAL

Instrumentation and Testing: California

UCDAVIS
UNIVERSITY OF CALIFORNIA

DRAFT/CONFIDENTIAL

Completed Tasks

- HVS response testing on two flexible pavements
  - Status: Completed
- Prelimi… CA) for energy … n house gas) em…
  - Status…

208

Pavement Structure

Instrumentation

- Strain Gauges
- Pressure Cells
- Multi-Depth Deflectometers
- Thermocouples

ILLINOIS CENTER FOR TRANSPORTATION

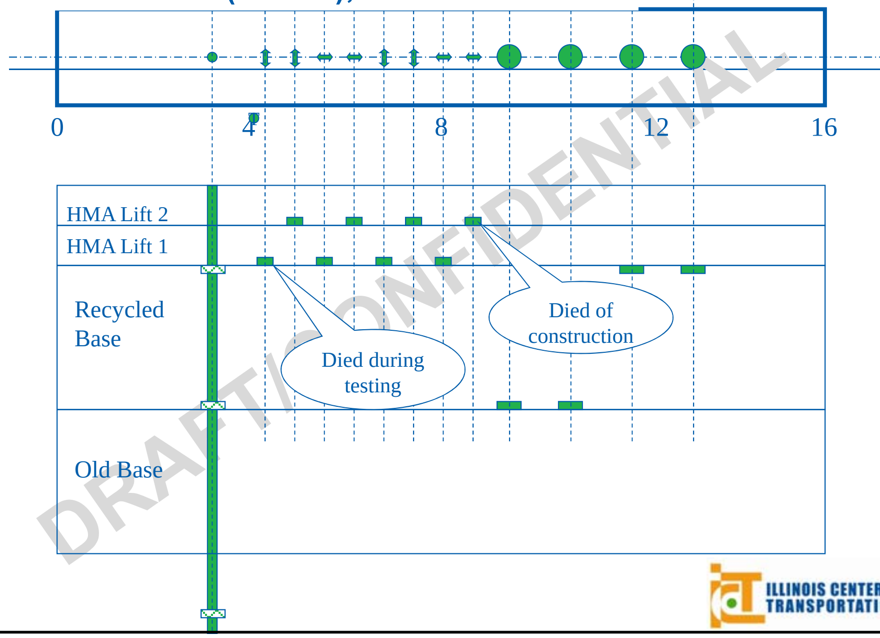
Instrumentation

- **Thick Section**
  - 8 Strain Gauges (two malfunctioned, 1 const, 1 testing)
  - 4 Pressure Cells
  - 1 MDD hole with three depths
  - 12 Thermocouples
- **Thin Section**
  - 6 Strain Gauges (two malfunctioned in testing)
  - 1 Pressure Cell
  - 1 MDD hole with four depths
  - 12 Thermocouples

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Thick Sections (671HC), Two Lifts of HMA



ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

212

Thick Section
On Top of the Recycled Aggregate Base

ILLINOIS CENTER FOR TRANSPORTATION

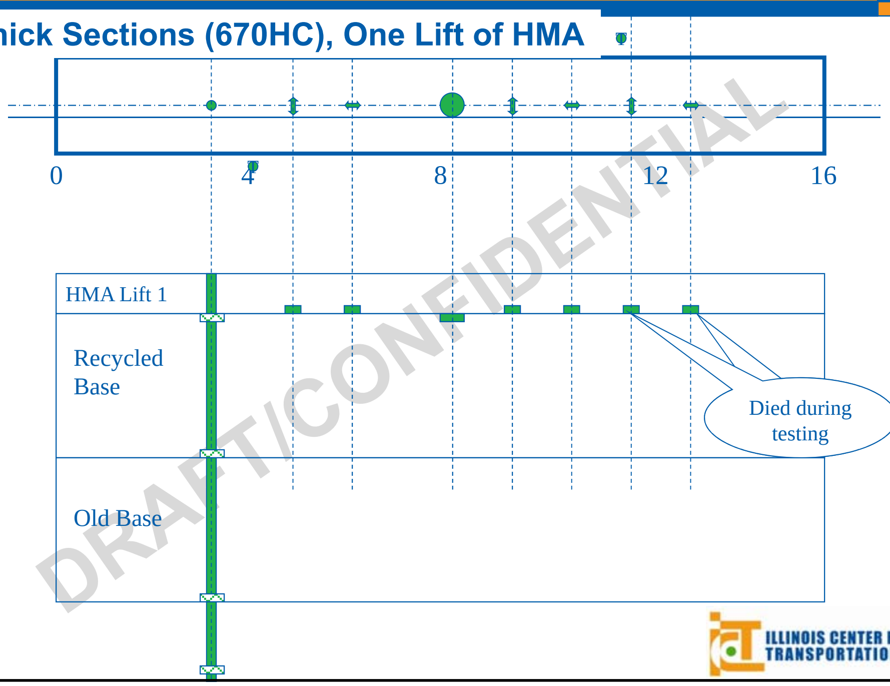
DRAFT/CONFIDENTIAL

Thick Section
Between the Two Lifts of HMA

DRAFT/CONFIDENTIAL

CENTER FOR TRANSPORTATION

Thick Sections (670HC), One Lift of HMA



DRAFT/CONFIDENTIAL

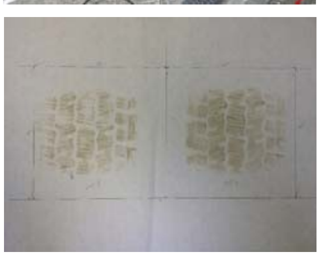
ILLINOIS CENTER FOR TRANSPORTATION

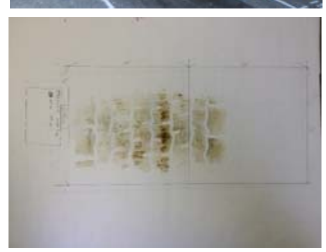
215

Thin Section
On Top of the Recycled Aggregate Base

ILLINOIS CENTER FOR TRANSPORTATION

DTA and WBT Imprints





ILLINOIS CENTER FOR TRANSPORTATION

HVS Testing Program – 1/3

- Full Factorial
  - HMA Thickness (2.4 and 4.7 in)
  - Pavement Temperature (69, 95, 122F)
  - Tire Pressure (80,100,110,125 psi for both, 60/110, 80/110 psi for dual)
  - Half Axle Load (6, 8, 10, 14, 18 kips)
- Partial Factorial
  - Lateral Offset (0, 7, 12 in)
- Spot Check (by repetition) in the end

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

HVS Testing Program – 2/3

- Testing Sequence
  - Perform permutations for half axle loads less than 18 kips
    - Wheel type (WBT, DTA)
    - Temperature
    - Tire pressure
    - Load
  - Then repeat with half axle load at 18 kips
    - To prevent excessive damage at 18 kips
  - Spot check (repeat selected combinations)
    - Wheel type
    - Temperature
    - Tire pressure

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

HVS Testing Program 3/3

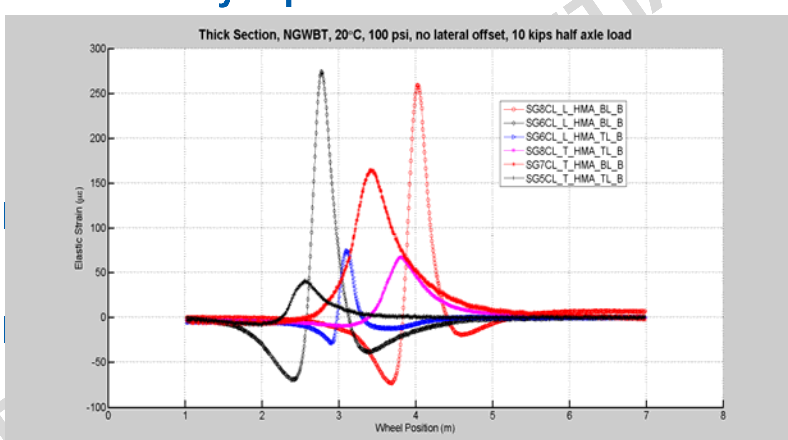
- **174 combinations in total**
- **Each combination:**
  - **100 repetitions**
  - **Constant speed of 8 km/h**
  - **Channelized (no wander)**
- **Thick Section**
  - **3/6/2013~4/15/2013**
  - **22,100 repetitions total**
- **Thin Section**
  - **4/26/2013~5/20/2013**
  - **20,300 repetitions total**

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Data Collection

- **Record every repetition:**



ILLINOIS CENTER FOR TRANSPORTATION

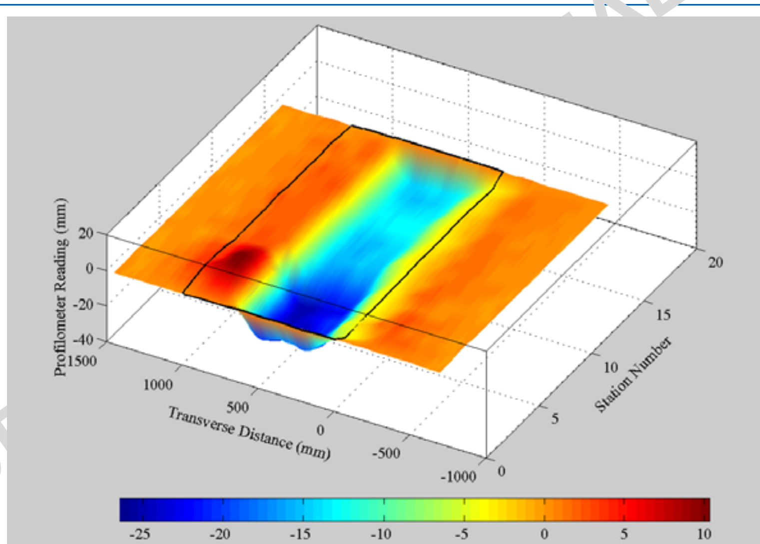
DRAFT/CONFIDENTIAL

221

After HVS Testing – Thin Section

222

Surface Rut Contour – Thin Section

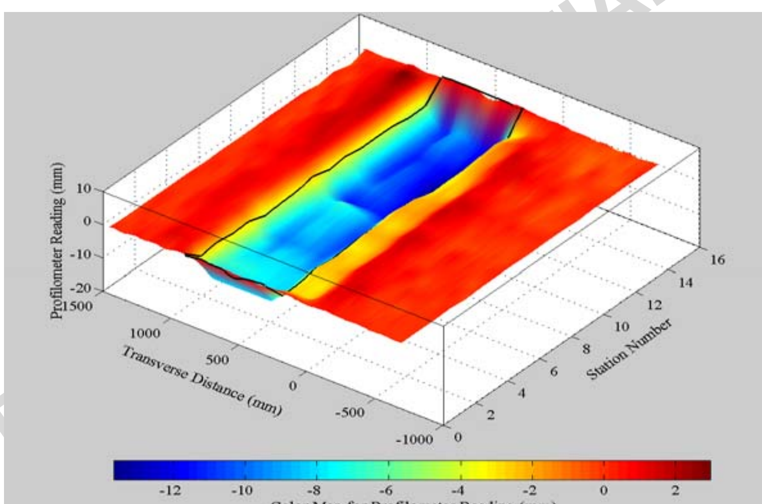


223

After HVS Testing – Thick Section

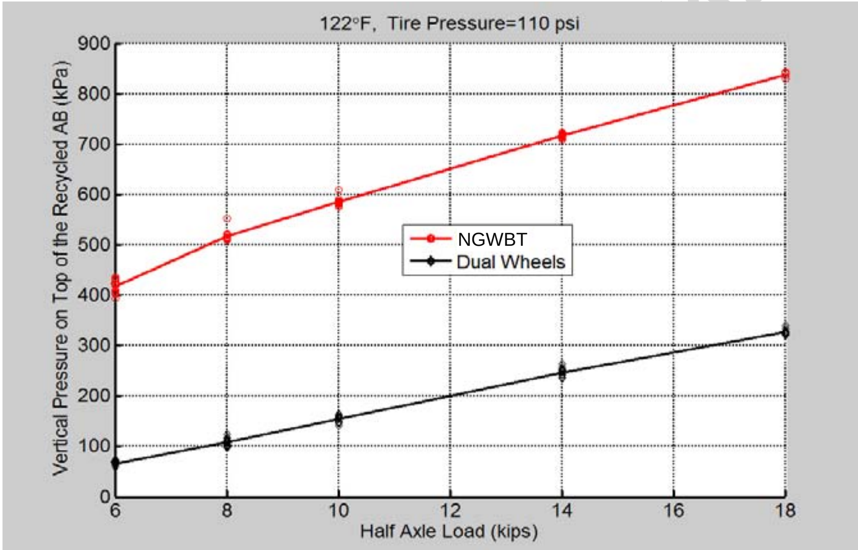
224

Surface Rut Contour – Thick Section

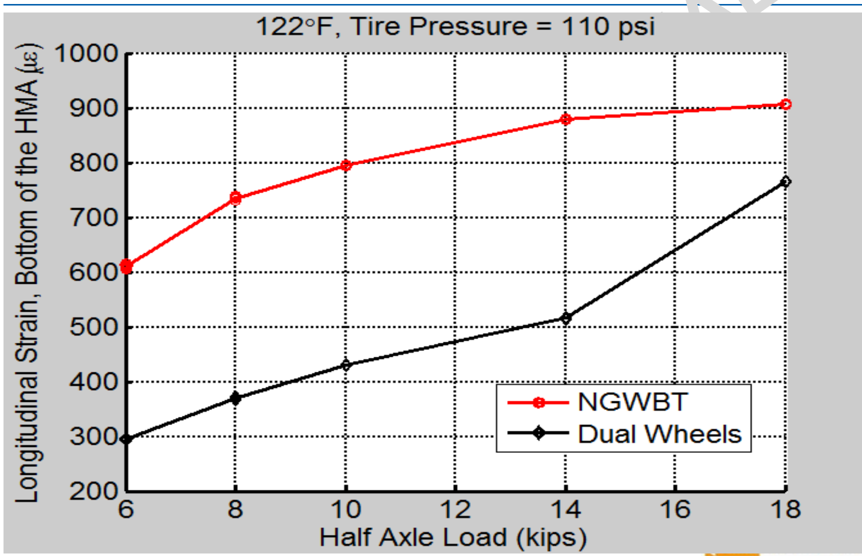


ILLINOIS CENTER FOR TRANSPORTATION

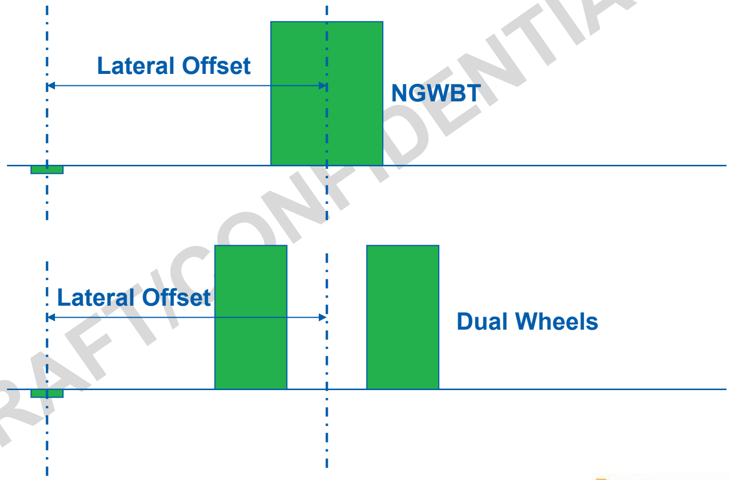
Example of Preliminary Results – Thin Section, Vertical Pressure at Bottom of the HMA



Example of Preliminary Results – Thin Section, Longitudinal Strain at Bottom of HMA (First Lift)



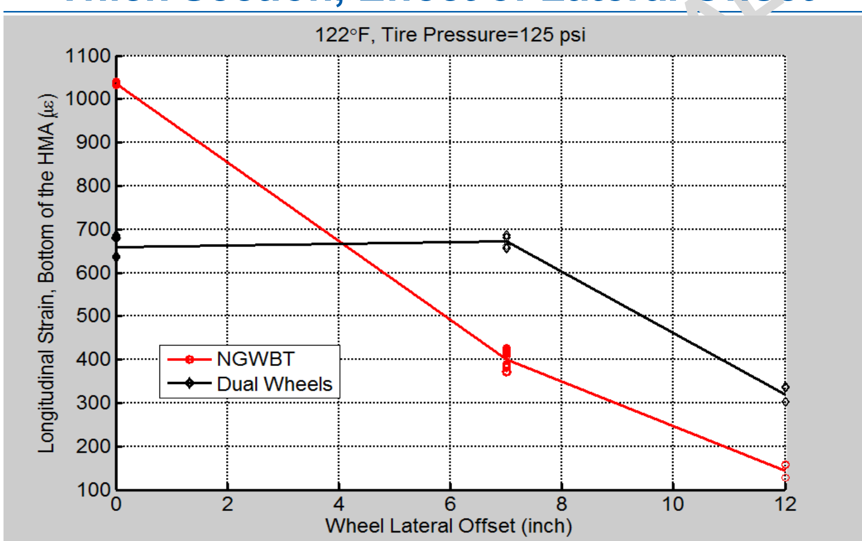
Definition of Lateral Offset



DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Preliminary Results – Strain in Thick Section, Effect of Lateral Offset



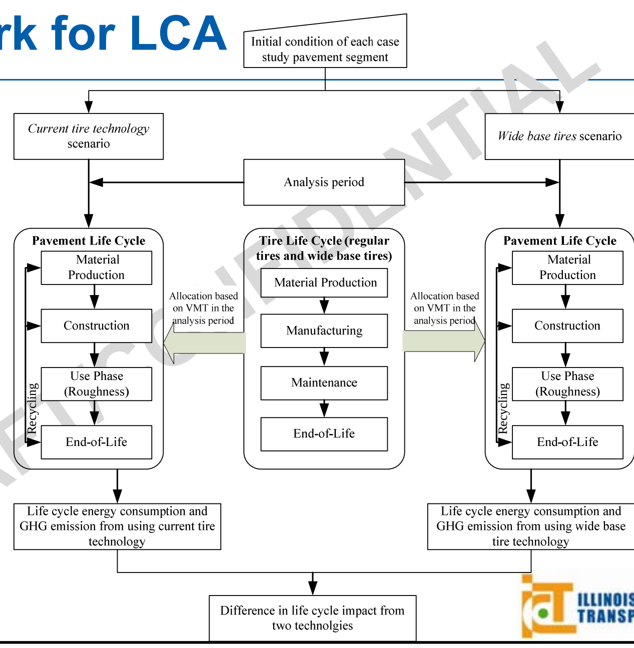
LCA - Basic Approach

- Select scenarios for pavement network based on:
  - Traffic level
  - Pavement Structure
- For each scenario perform LCA
  - Using existing inventories
- Additional sensitivity analyses on:
  - Market penetration rates, types, traffic levels, congestion levels, etc.
- Deliverables:
  - Framework for LCA
  - Provide guidance for decision makers on impact of NGWBT
  - Suggest particular scenarios where impact is greater

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

Framework for LCA



ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

231

Remarks

- Significant **difference** in pavement **responses** between **Dual** and **NGWBT** were observed.
- Testing caused **rutting** in the pavement, which did not affect the relative comparison.
- Effect of wheel **lateral offset** needs to be considered when making comparisons.
- **LCA framework** established, will need some inputs to the model.

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

232

Future Plans

- Complete APT test matrix
- Data collection for life-cycle inventory
- LCA case studies

ILLINOIS CENTER FOR TRANSPORTATION

DRAFT/CONFIDENTIAL

COMMENTS!

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Instrumentation and Testing: Ohio

OHIO UNIVERSITY

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

235

Outline

- Project description
- Typical section
- Instrumentation
- Material sampling
- Controlled loading test

DRAFT/CONFIDENTIAL

OHIO UNIVERSITY

ILLINOIS CENTER FOR TRANSPORTATION

236

Project Description

- Located in Delaware, OH (US-23)
- Optimization of AC thickness in perpetual pavements
- Three heavily instrumented pavement sections (AC thickness: 13 and 15 in)
- Truck load test: WBT and DTA; single and tandem axle

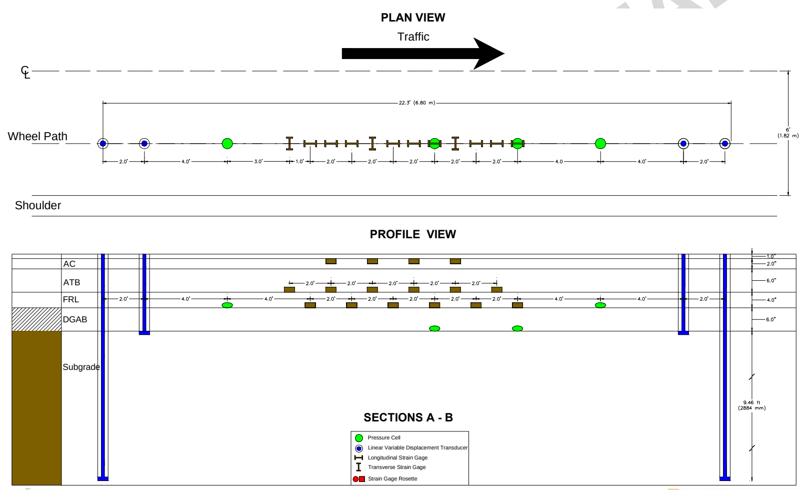
DRAFT/CONFIDENTIAL

OHIO UNIVERSITY

ILLINOIS CENTER FOR TRANSPORTATION

237

Typical Section



OHIO UNIVERSITY

ILLINOIS CENTER FOR TRANSPORTATION

238

Instrumentation

- Deep and shallow LVDTs
- Pressure cells at the bottom of AC and base
- Thermocouples
- Strain gauges in longitudinal and transverse directions at various depths
- Rosettes strain gauges

DRAFT/CONFIDENTIAL

OHIO UNIVERSITY

ILLINOIS CENTER FOR TRANSPORTATION

Pressure Cells

Pressure cells on top of subgrade	Pressure cells on top of DGAB
	

Strain Gauges

Strain Gauges Rosettes

Material sampling

Loose mix from each material (layer)

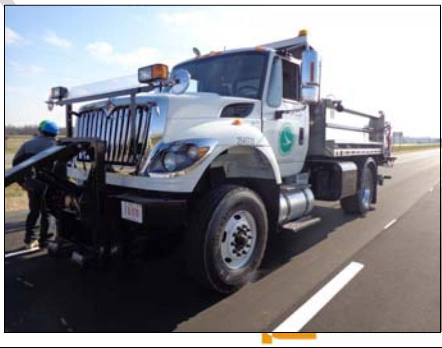
Material sampling

Compacted samples from each material (layer)

OHIO UNIVERSITY
ILLINOIS CENTER FOR TRANSPORTATION

Controlled Truck Loading Test

Tire load (kip)	Speed (mph)	Tire pressure (psi)	Tire configuration	Axle Configuration
10, 14	5, 30, and 55	80, 110, 125	WBT-445 & DTA-275	Single & Tandem



Controlled Truck Loading Test

Controlled Truck Loading Test

COMMENTS!

DRAFT/CONFIDENTIAL

Future Plans Discussion
3:30-3:45pm

DRAFT/CONFIDENTIAL

5/30/2013

Future Plans

- Contact stresses
  - Complete detailed contact stress analysis of DTA and WBT magnitude and distribution
  - Prediction of contact stresses using FEM
- Modeling
  - Complete thin and thick pavement cases with various combinations of axle loads and tire inflation pressures
  - Provide a analysis considering the effect of tire type; material property; loading characteristics; and pavement structure

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Future Plans

- Laboratory testing:
  - Compact SGC specimens that simulate field-compacted samples (air void validation)
  - Complete laboratory test matrix for materials in all testing sites
- Complete APT and field-instrumented data collection and analysis
- Finalize the instrumentation response database
- Preliminary LCA scenarios
- Marketing and publications

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

COMMENTS!

DRAFT/CONFIDENTIAL

Technical Committee Discussion

3:45-4:15pm

5/30/2013

DRAFT/CONFIDENTIAL

COMMENTS!

DRAFT/CONFIDENTIAL

ILLINOIS CENTER FOR TRANSPORTATION

Final Remarks
4:15-4:45pm

DRAFT/CONFIDENTIAL

5/30/2013

ILLINOIS CENTER FOR TRANSPORTATION