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

7/31/2014

Agenda

- 9:00-9:15: Introduction and Meeting Purpose
- 9:15-10:15: Project Update
  - Finite Element Model
  - Laboratory Testing Results
  - Tire Contact Stresses/Loads
  - Thick and Thin Pavement Responses
  - Pavement Responses Database
  - Artificial Neural Network Model
- 10:15-11:00: Adjustment Factors for AASHTO-Ware
- 11:00-11:30: Example WBT vs DTA
- 11:30-12:00: Final Remarks
- 12:00: Adjourn

Introduction and Project Overview

9:00 – 9:15

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Project Overview

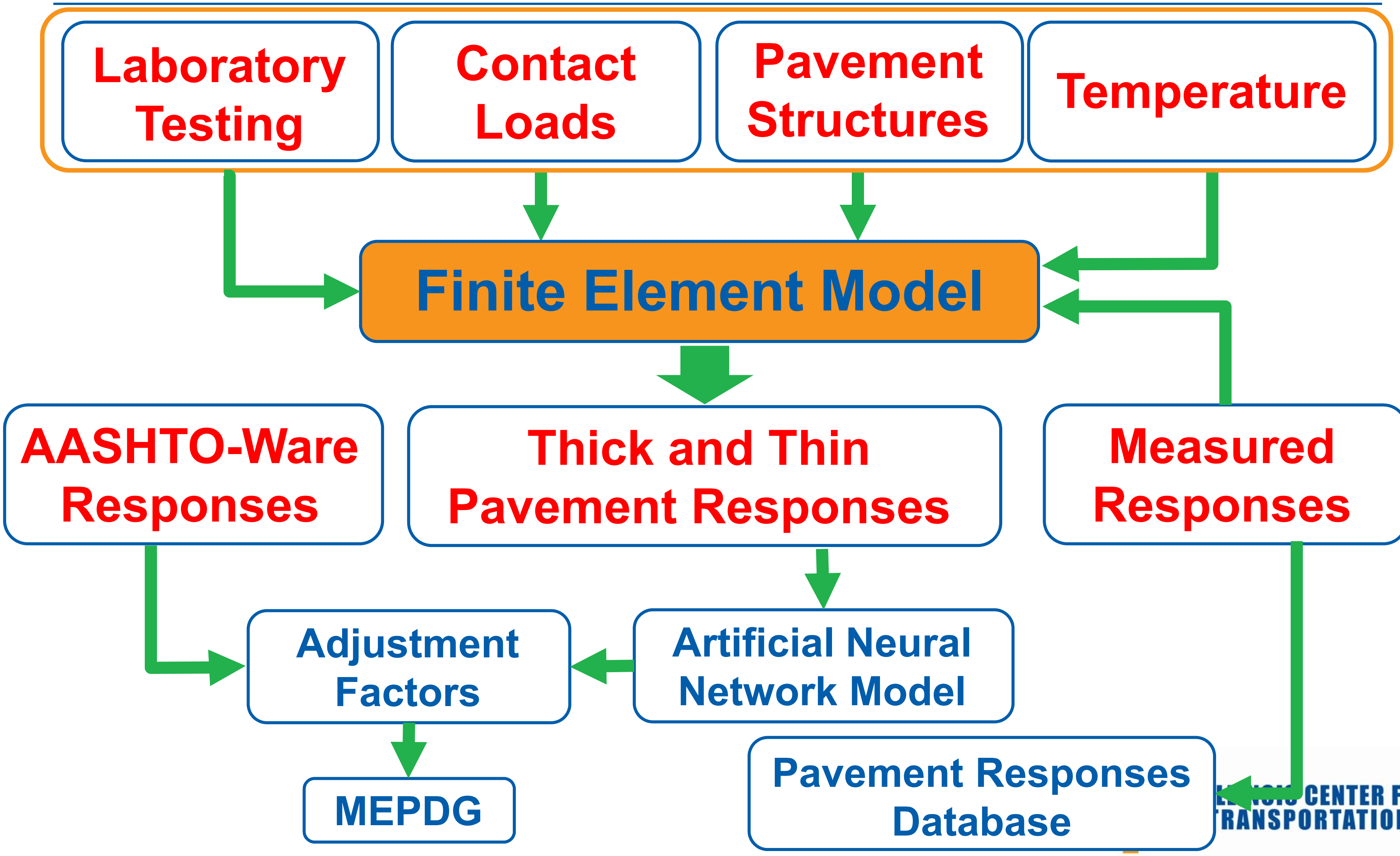
- Main Objective:
  - Quantify the impact of WBT on pavement damage utilizing advanced theoretical modeling and validate results using full-scale testing
- Scope:
  - Contact stress measurements of tires (WBT & DTA)
  - APT of pavement sections
  - FEM modeling of pavement loading
  - Adjustment factor for FEM vs AASHTO-Ware

Progress by Task

Phase	Task*	Progress (%)
Phase I	Comprehensive literature review and synthesis on past and current research	100
	Experimental plan and modeling framework	100
Phase II	Prepare experimental equipment, test structures, and instrumentation	100
	Conduct experiments, including material characterization and accelerated loading	85
	Perform modeling	95
	Development of analysis tool	70
	Delivery of draft Phase II report and analysis tool	40

*Not all tasks included

Project Flowchart



Project Update

9:15 – 10:15

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Outline

- Finite element model
- Laboratory testing results
- Tire contact load
- Thick and thin numerical pavement responses
- Experimental pavement responses database
- Artificial neural network (ANN) model

Finite Element Model

Finite Element Model

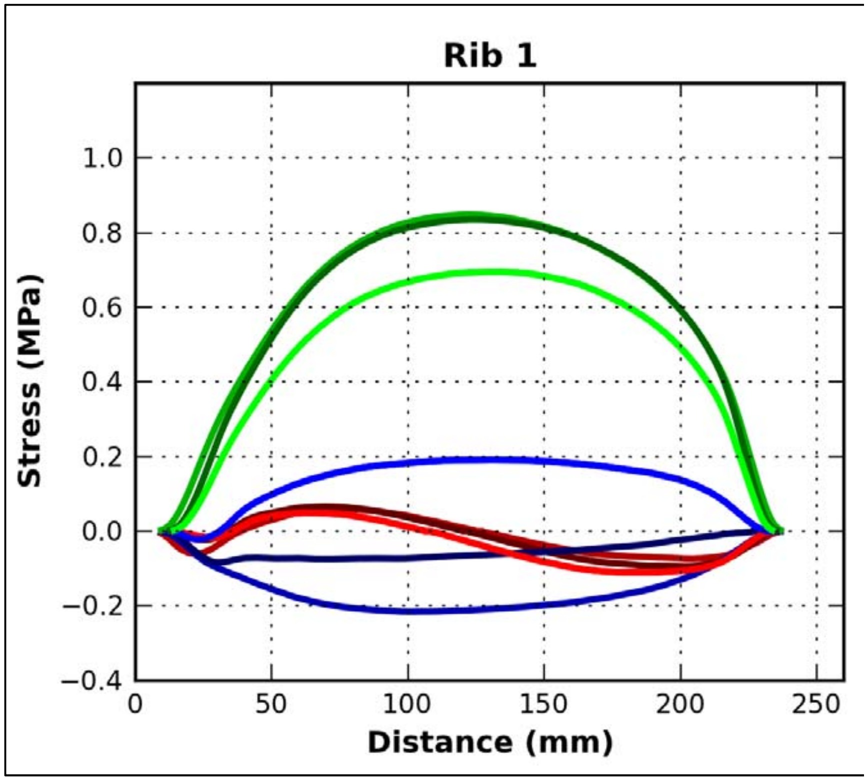
- Appropriate input: materials, loading, etc.
- Accurate representation of reality: moving load, layer interaction, etc.
- Validation using experimental measurements: pavement instrumentation

Material Characterization

- AC: Linear-viscoelastic:
  - Dynamic modulus test (E*)
  - Prony series expansion
- Granular materials:
  - Thin pavement: Nonlinear cross-anisotropic stress-dependent
  - Thick pavement: Linear Elastic

3D Contact Stresses/Forces

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



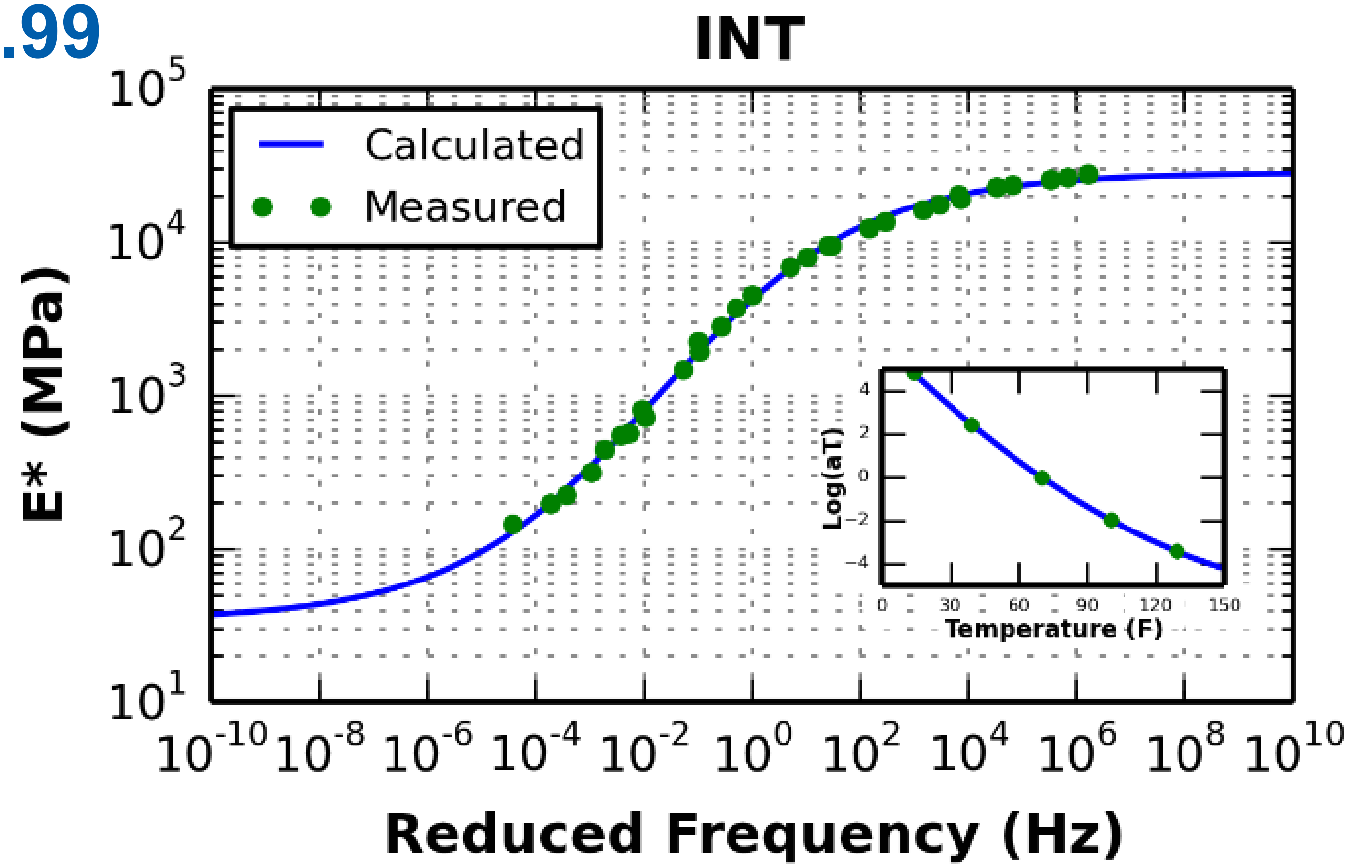
Laboratory Testing Results

Laboratory Testing Results

Test	Florida	UC-Davis	Ohio
E*	NA	NA	✓
IDT Creep	✓	✓	✓
SCB	✓	✓	✓
IDT Strength	✓	✓	✓
DCT	✓	✓	✓

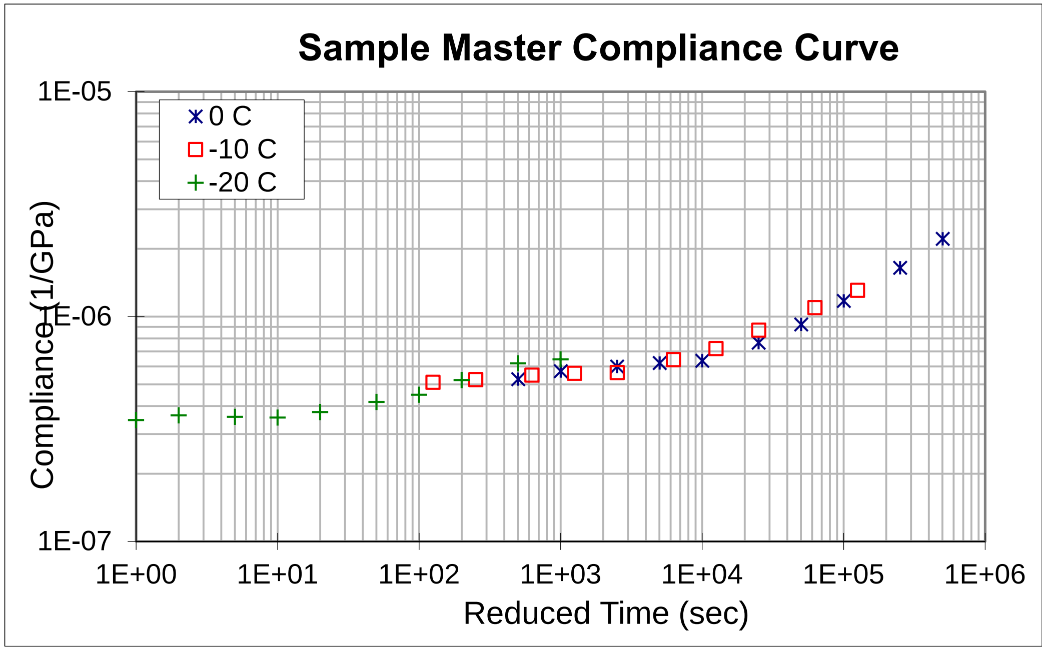
E* Sample Result

- Four samples per material
- Average COV for intermediate layer - Ohio: 10.99



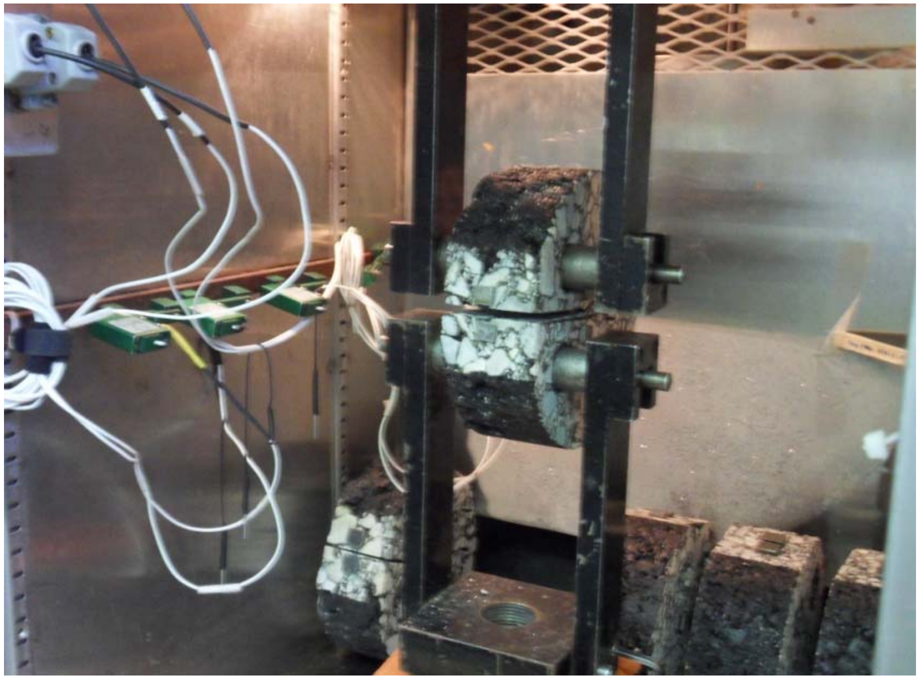
IDT

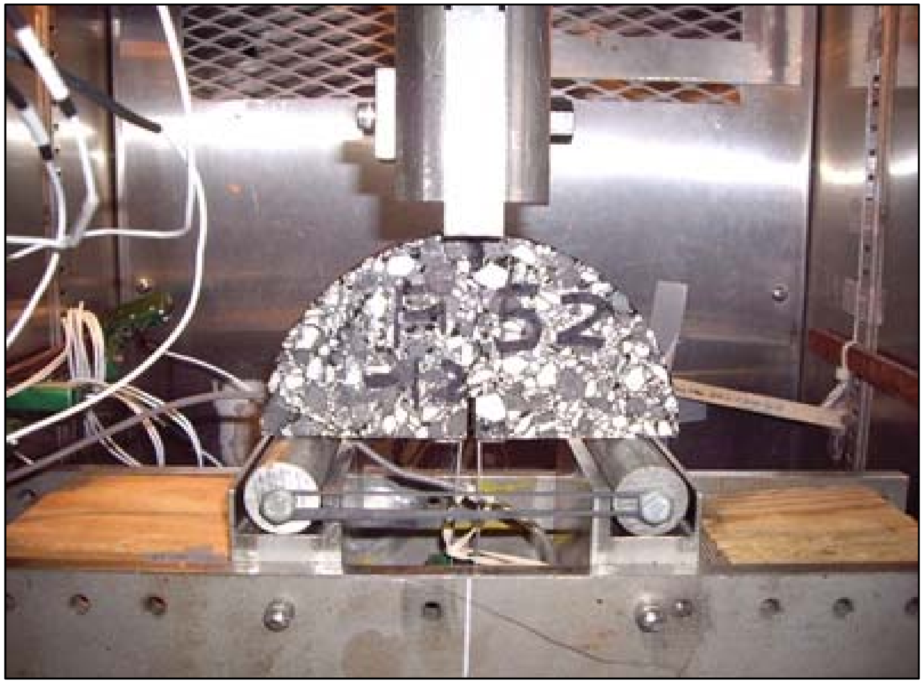
- Creep compliance can be used to obtained Prony series terms
- Appropriate alternative for viscoelastic characterization when loose mix is not available



SCB and DCT

- Used for low temperature characterization

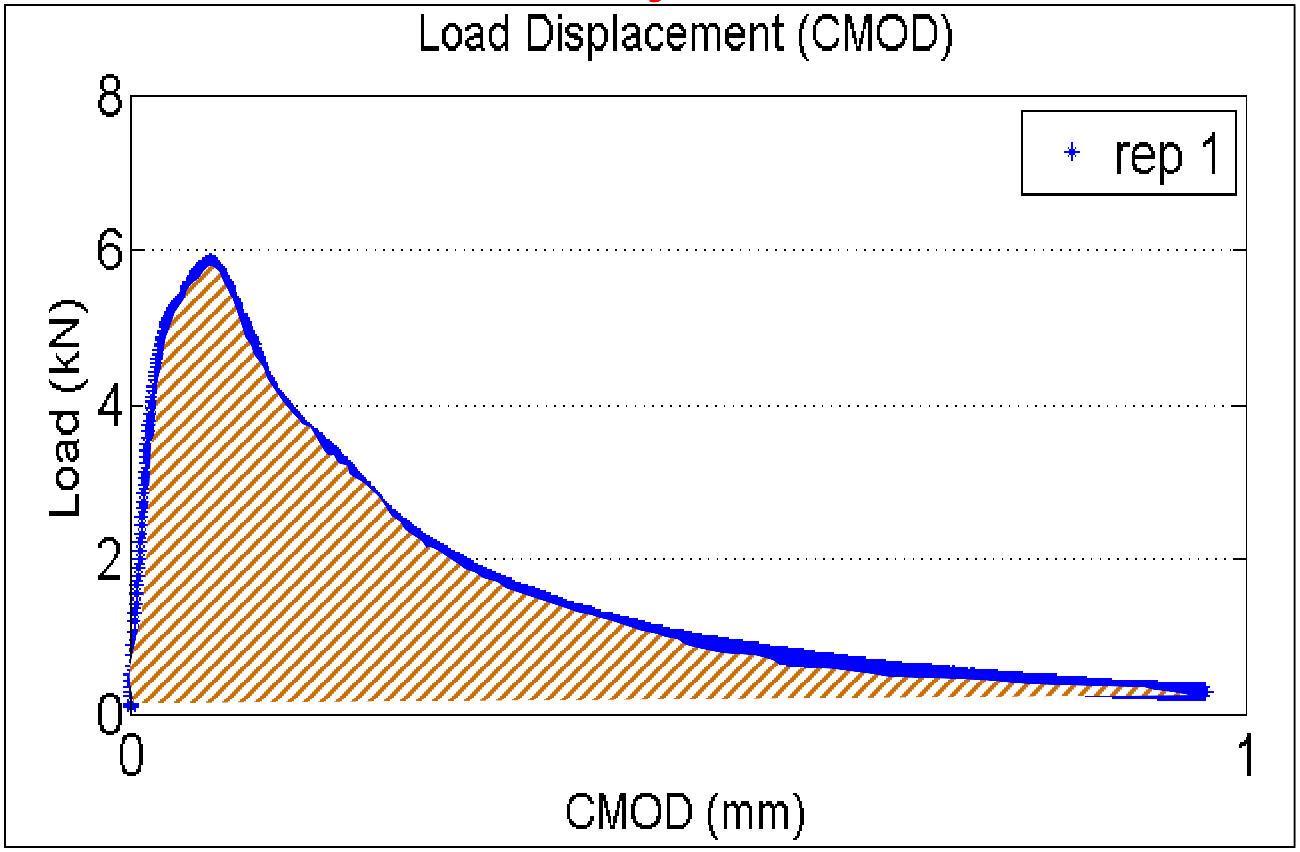




SCB Test

- Sample result

SCB Surface Layer Ohio



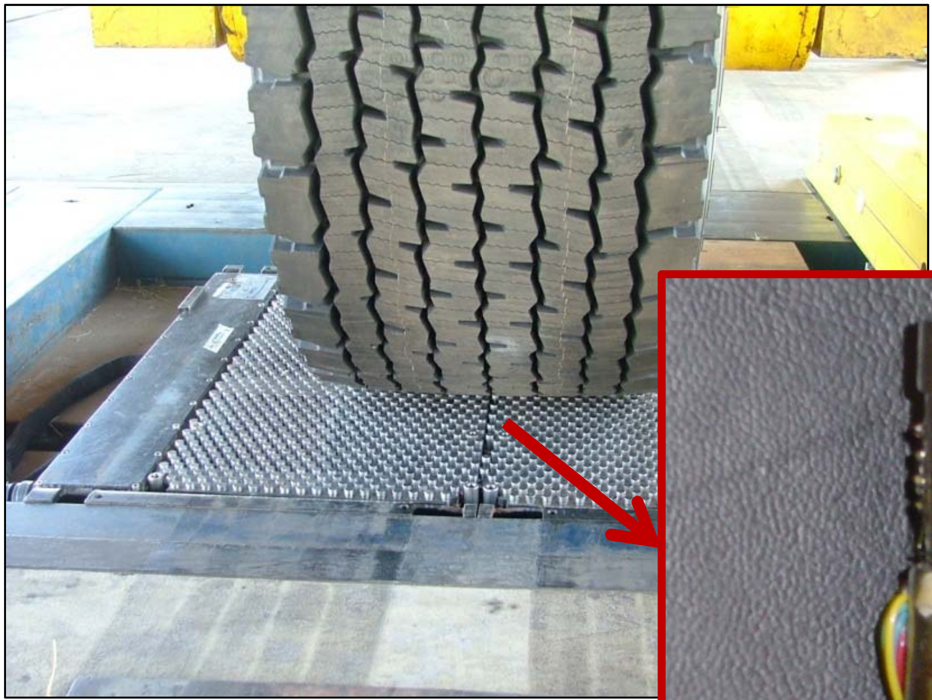
SCB Test Results

	Lift	Test Temp (C)	Thck (mm)	Fracture Energy (J/m^2)
Florida	Wearing	-12	27.4	**565.9**
	SP12.5	-12	34.9	**1104.6**
	SP12.5	-12	46.4	**804.0**
Davis	15% RAP	-6	51.1	**788.8**
Ohio	Surface	-12	51.3	**532.7**
	INT	-18	50.9	***Failed***
	ATB	-12	51.2	**256.4**
	FRL	-12	50.9	**317.6**

Tire Contact Stresses/ Loads

Experimental Program: Tested Tires

WBT 445/50 R22.5



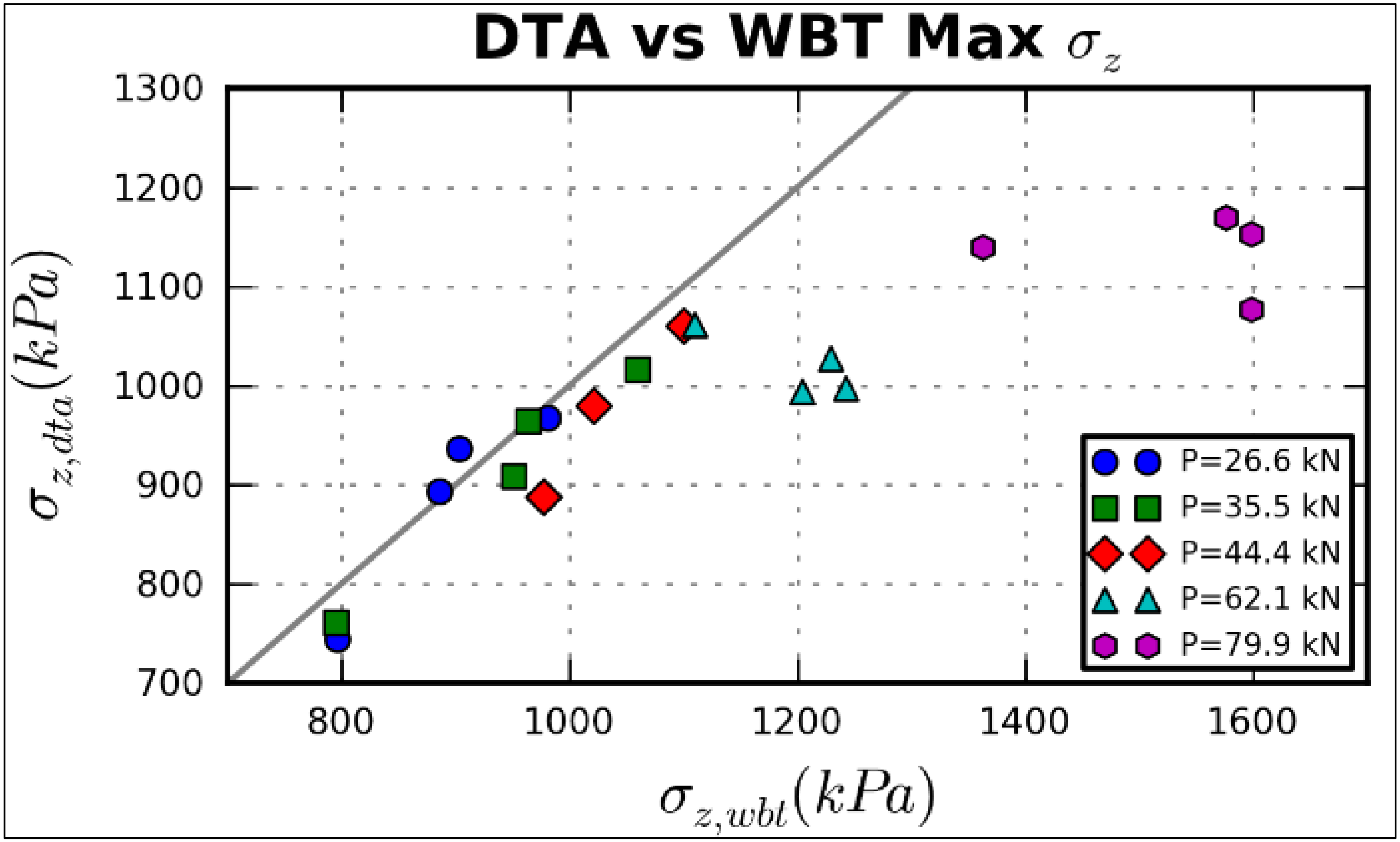
DTA 275/80 R22.5

Experimental Program

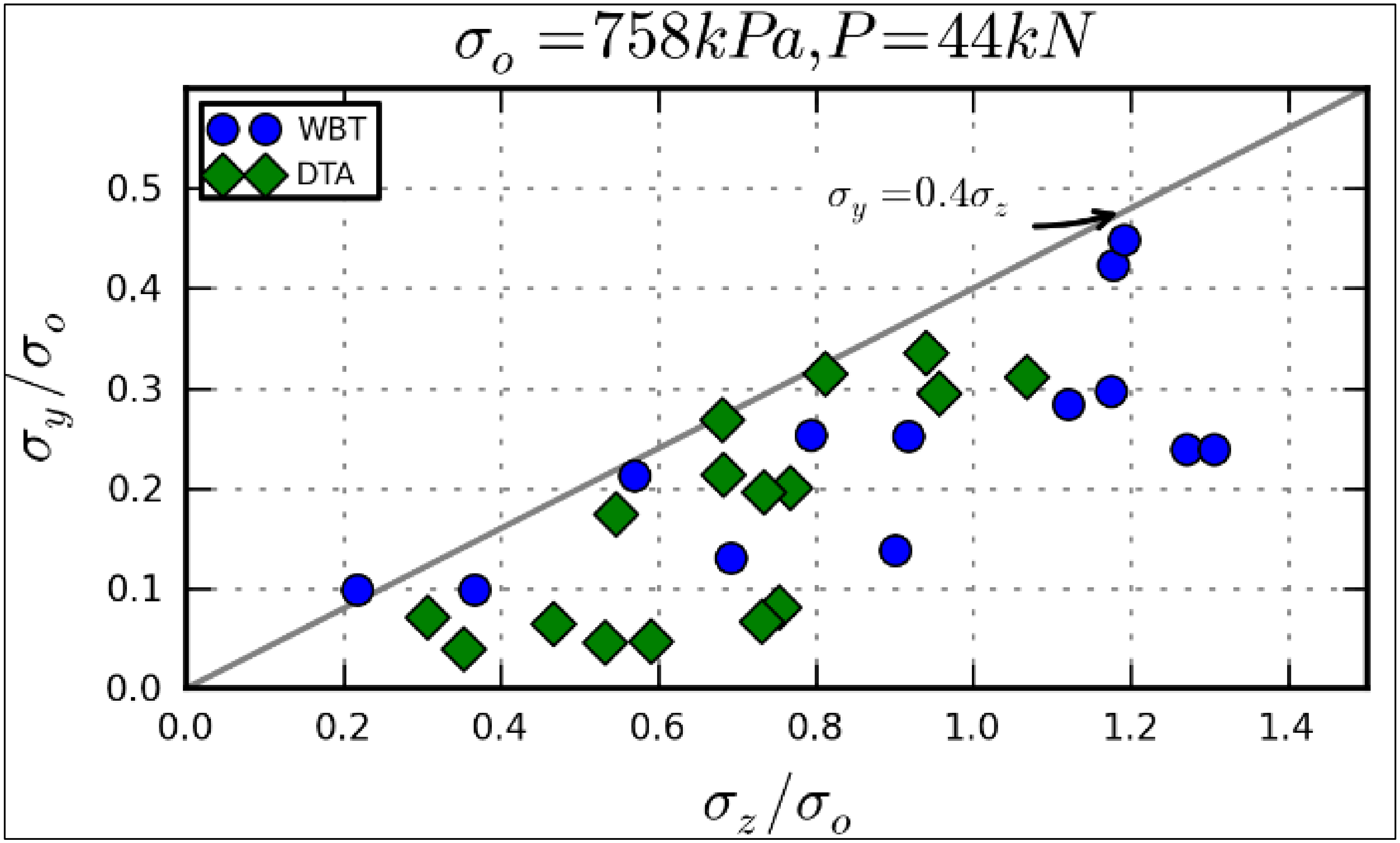
Tire Type	Inflation Pressure (kPa)	Tire Loading (kN)				
NGWB and Dual	552	26.6	35.5	44.4	62.2	79.9
NGWB and Dual	690					
NGWB and Dual	758					
NGWB and Dual	862					
Dual Only	414/758*					
Dual Only	552/758*					

*Differential Tire Inflation Pressure

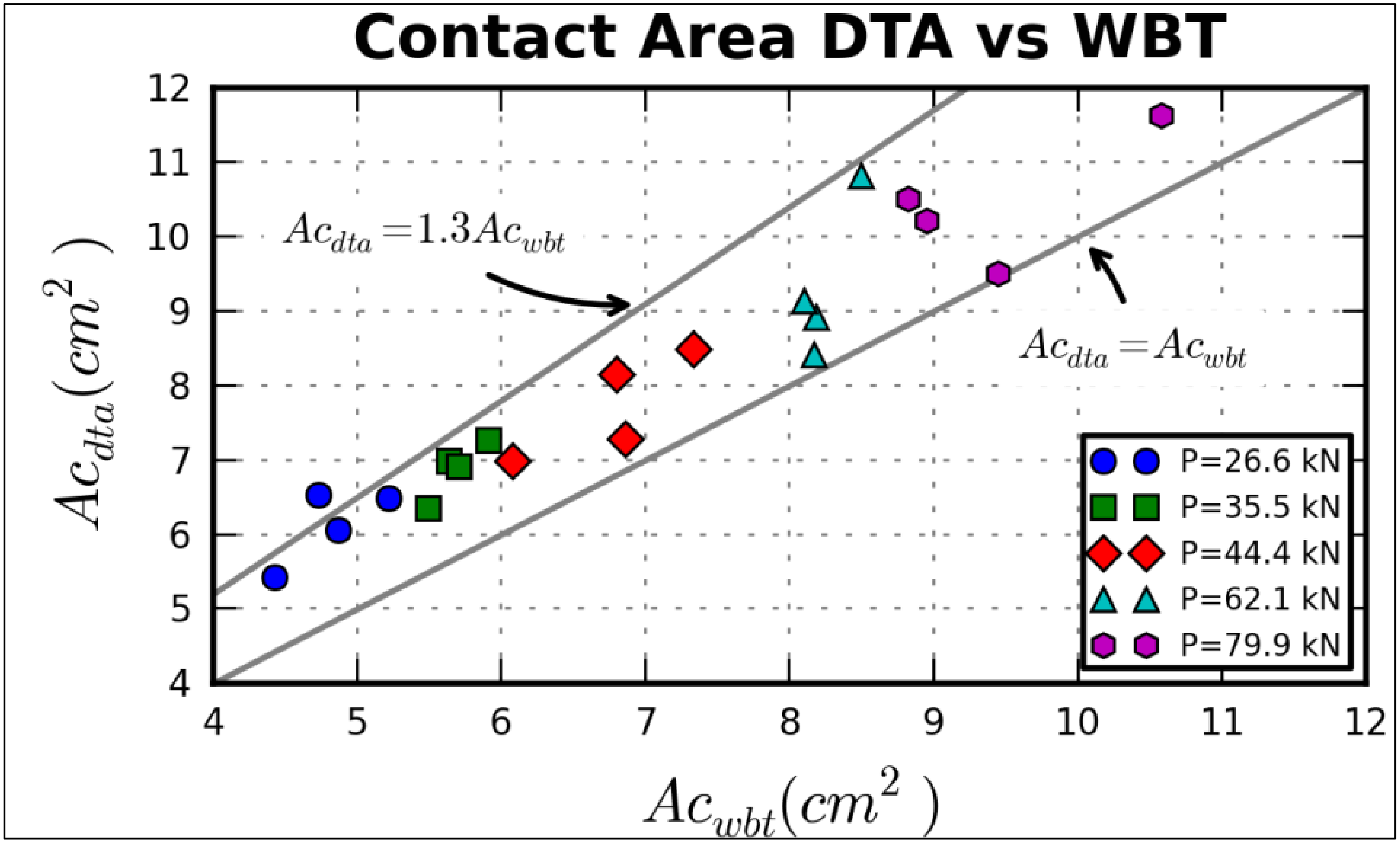
Vertical Contact Stresses



Relevance of in-Plane Stresses



Contact Area



Remarks

- Vertical contact stresses slightly higher for WBT
- 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

Thick and Thin Pavement Responses

FEM Simulation Matrix

- **Thin pavement structure**

Thin Pavement Structure		
	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
**Considered with nonlinear mat

FEM Simulation Matrix

- **Thick** pavement structure

Thick Pavement Structure		
	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

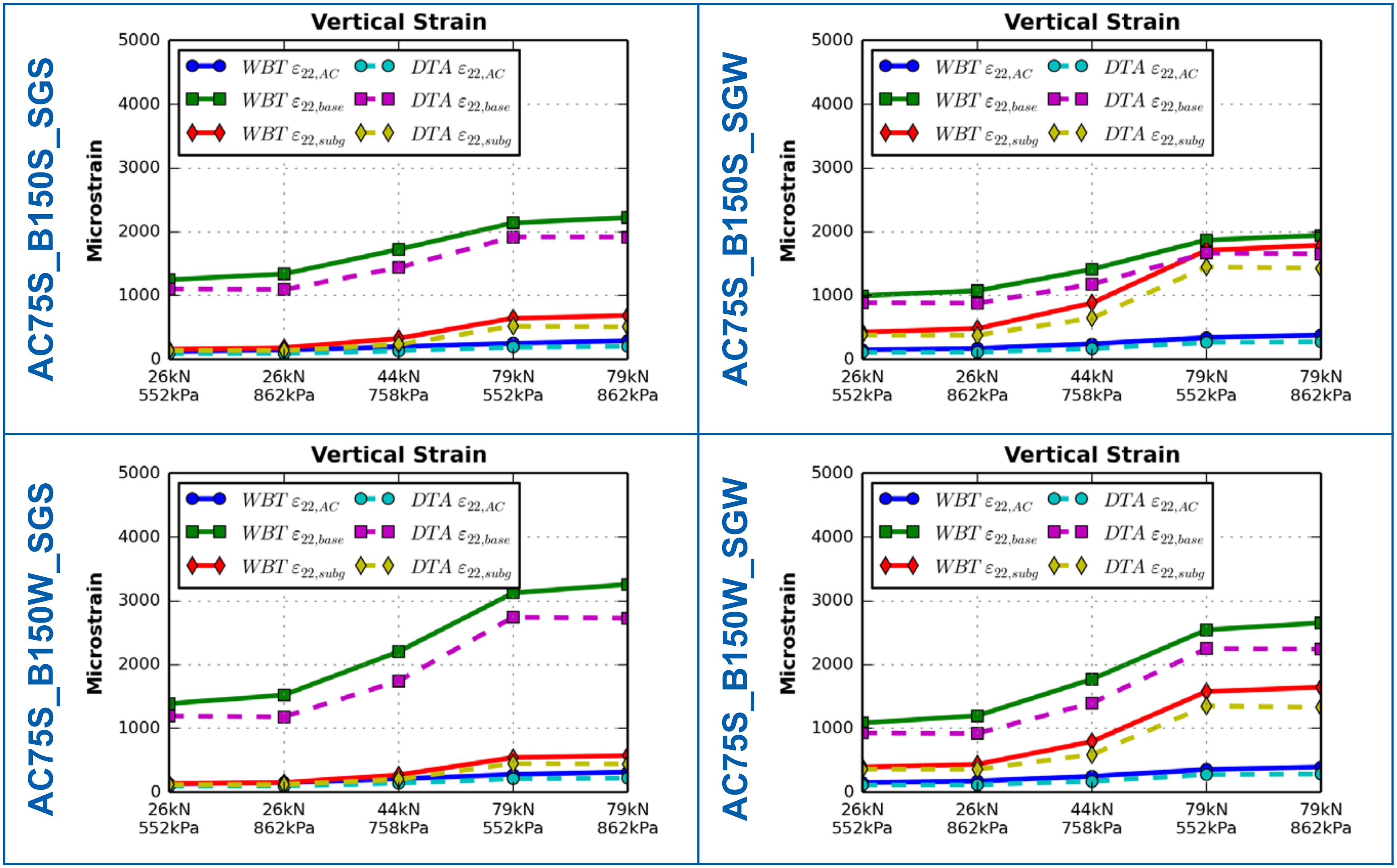
FEM Analysis Matrix

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	552/758
L8	DTA	79.9	552
L9	DTA	79.9	862
L10	DTA	79.9	552/758
L11	WBT	44.4	758
L12	DTA	44.4	758

Thin Pavement Response

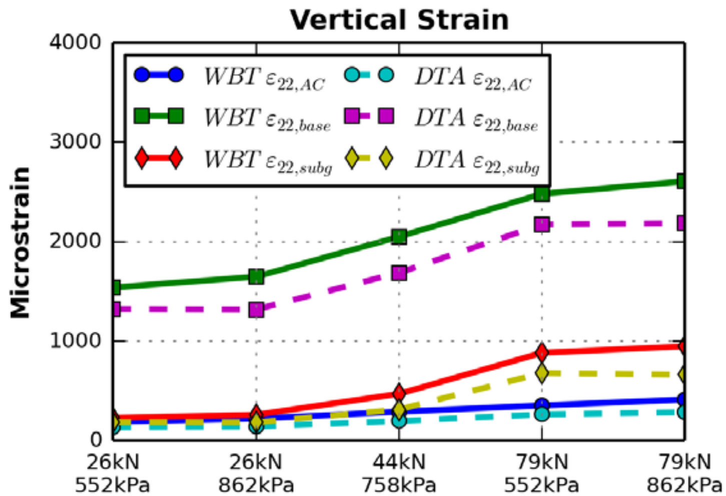
- Factors to be compared:
  - Load/tire pressure
  - Material property
  - Pavement structure
- Sample pavement responses
  - Vertical compressive strain
  - Horizontal tensile strain at bottom of AC

Effect of Load/Tire Pressure & Material

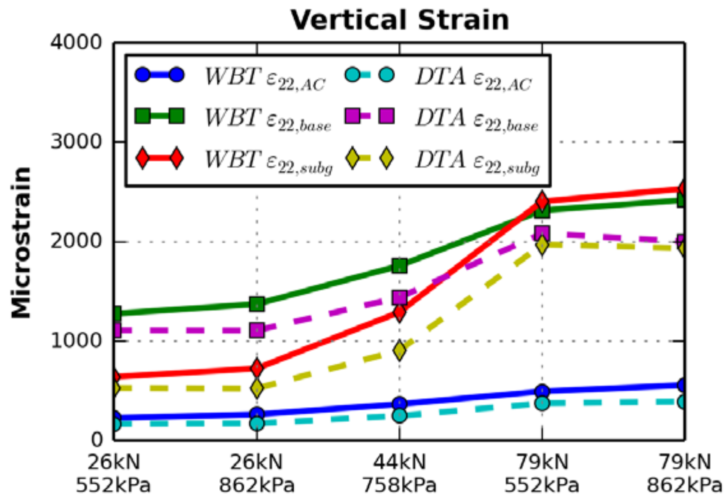


Effect of Material Property

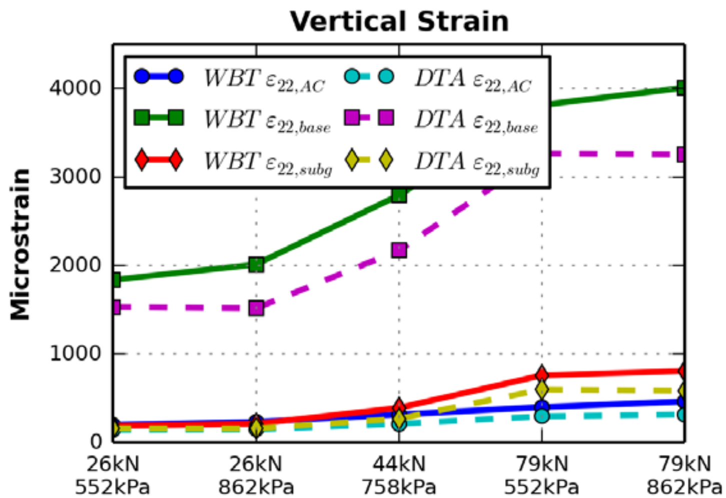
AC75W_B150S_SGS



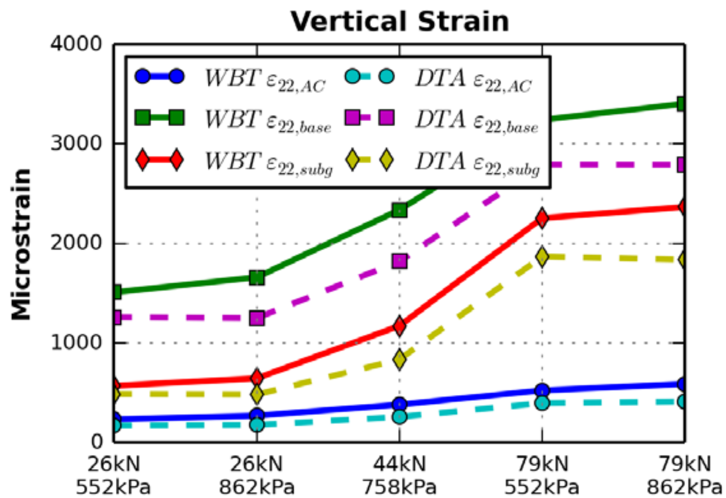
AC75W_B150S_SGW



AC75W_B150W_SGS



AC75W_B150W_SGW

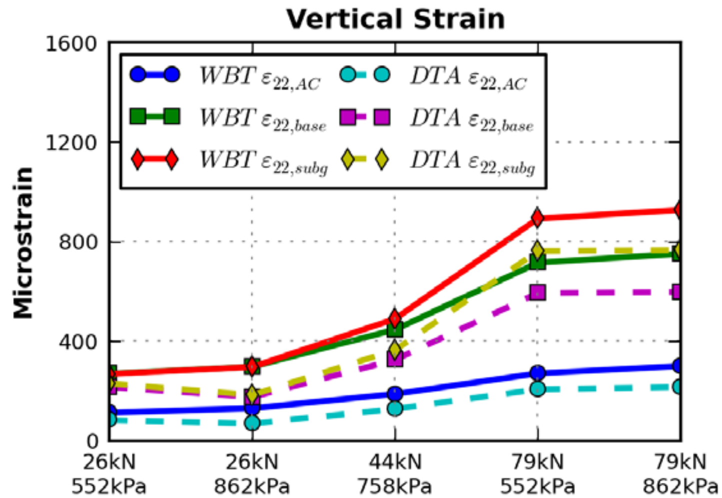


Remarks on Thin Pavements

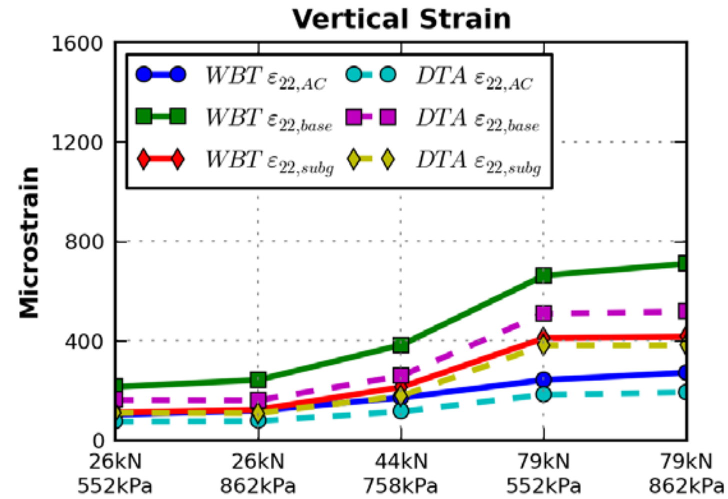
- Responses are more impacted by the **applied load** than tire inflation pressure
- Vertical compressive strain is **highest** in **granular base** layer
- Magnitude of the **base compressive strain** significantly **increased** when **subgrade** is “**strong**”
- Subgrade vertical compressive strain **increased** when **subgrade** is "**weak**"

Effect of Pavement Structure

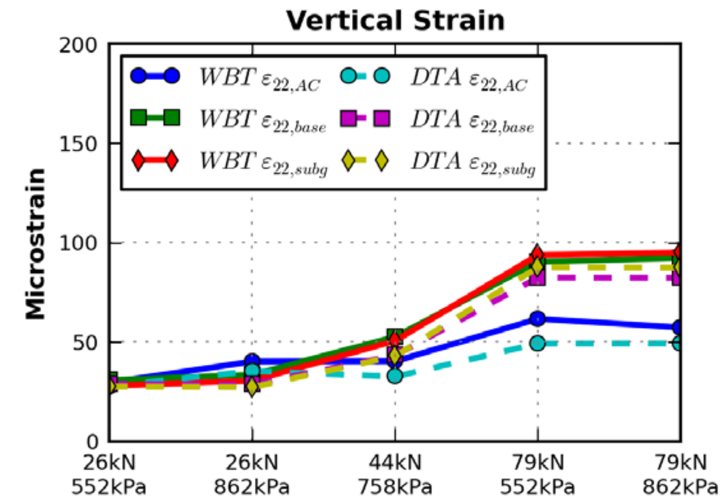
AC125W_B150W



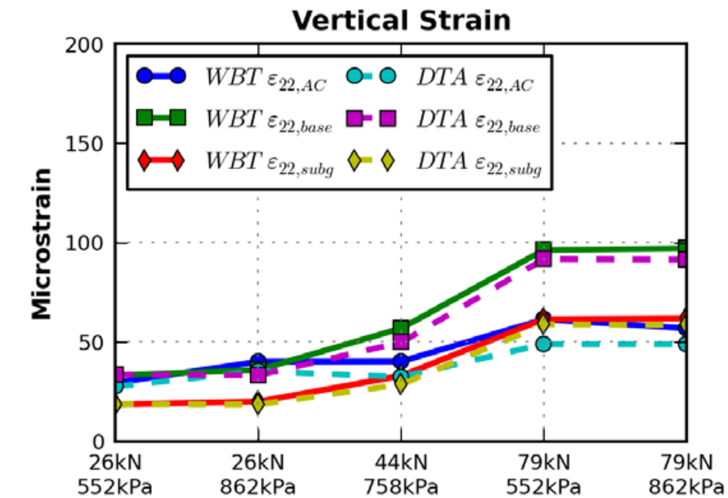
AC125W_B600W



AC412W_B150W



AC412W_B600W



Remarks for Thick Pavements

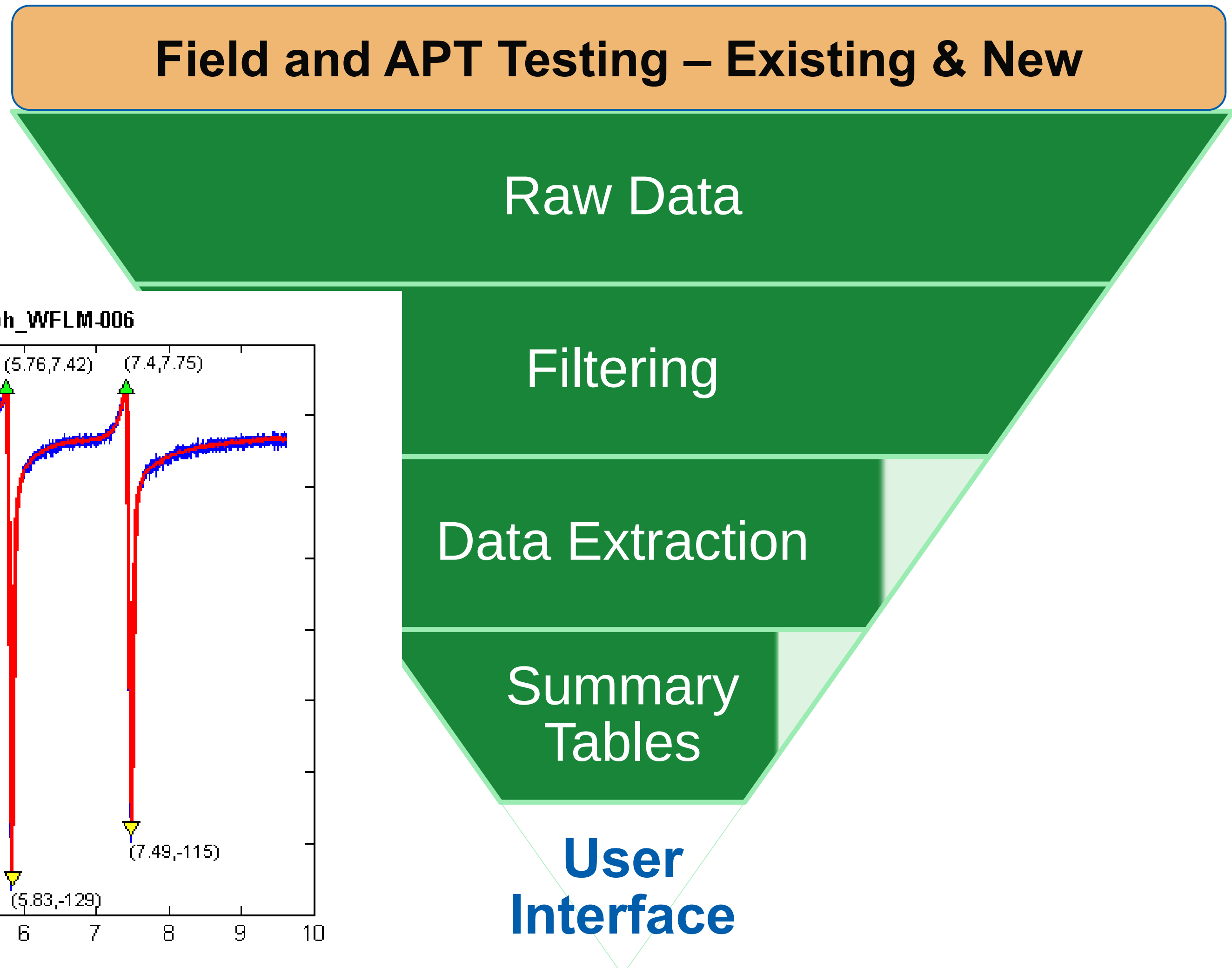
- Similar to thin cases, change in **load** has **greater impact** than that of tire inflation pressure
- **"Weak" AC affects surface strain** values greater than altering base material property
- Increase in **base** layer **thickness decreases subgrade** vertical compressive **strain** levels

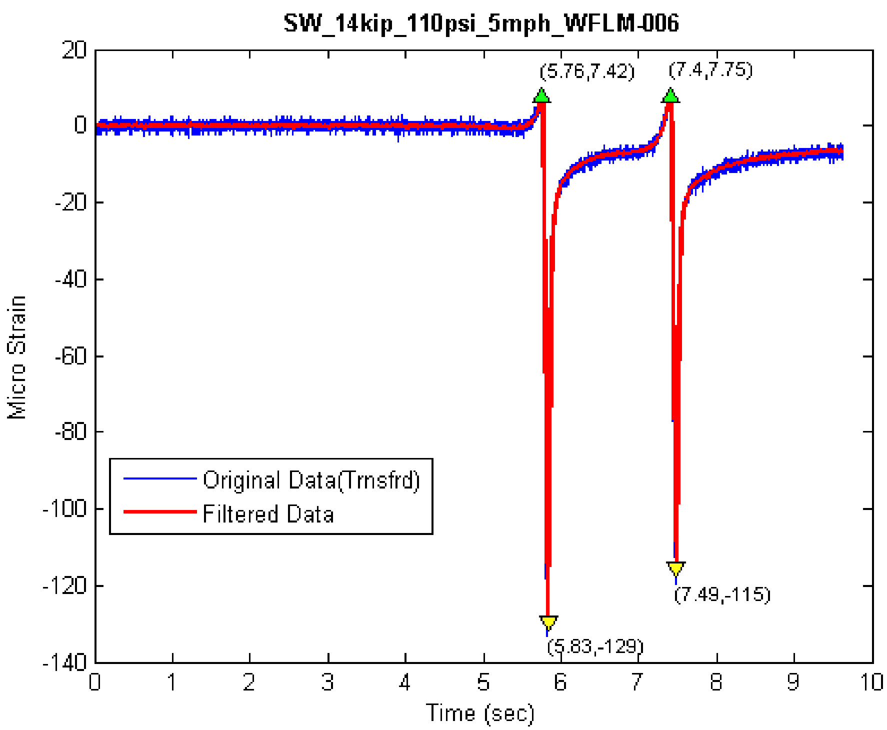
Remarks for Thick Pavements

- Relative difference between vertical strain responses between WBT and DTA decreases as AC layer thickness increases
- Increase in applied load produces a higher disparity between horizontal strains between WBT and DTA cases

Pavement Responses Database

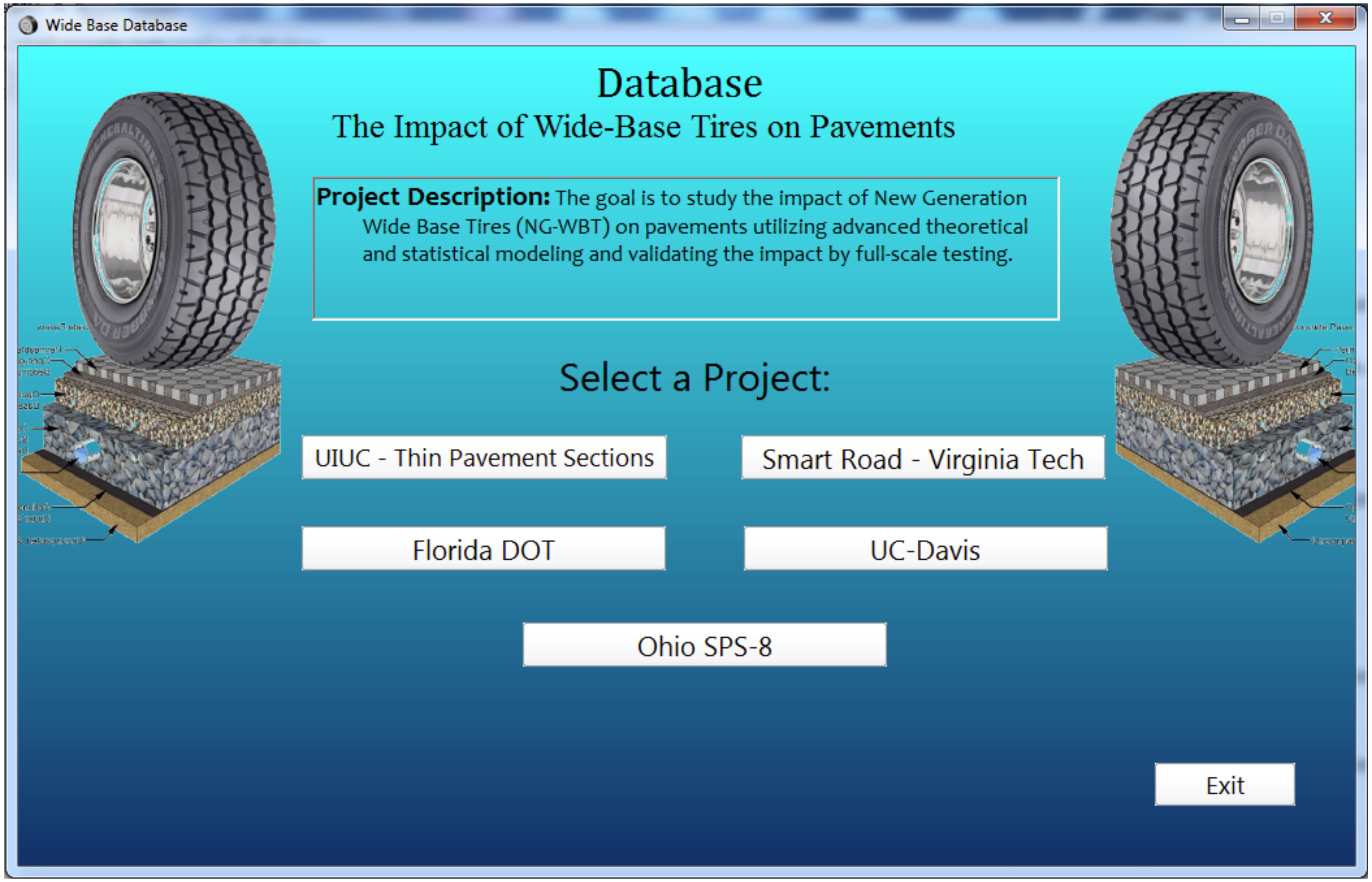
Database Management



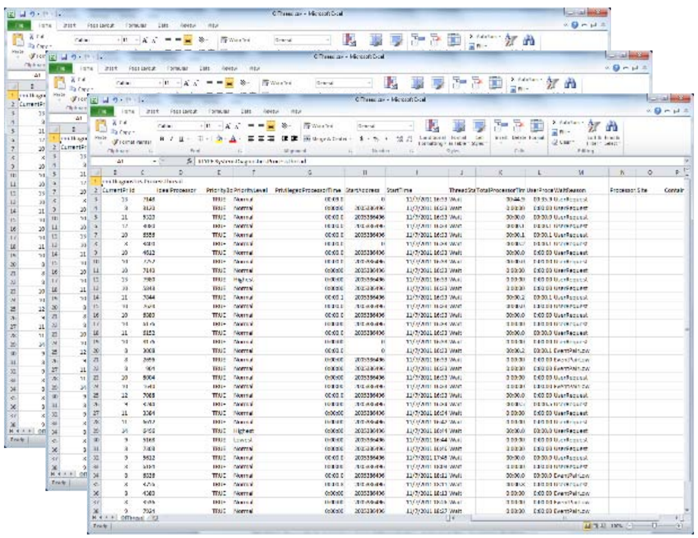


Database User Interface

- Started using "**Autoplay Studio**" and later changed to "**Online UI**":



Data Tier (Tier 1)

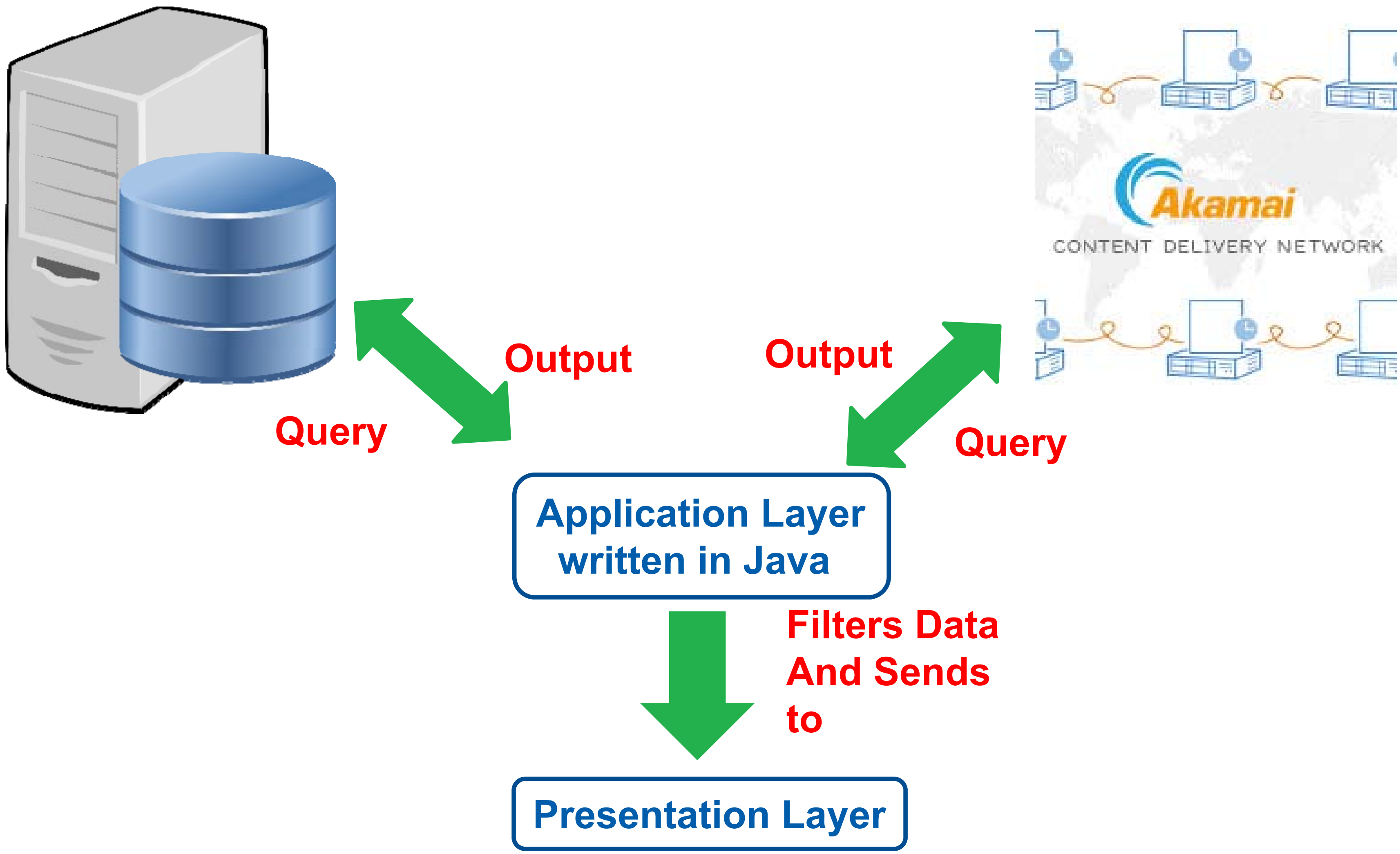


Data in form of CSV, txt PDF, JPG etc.

Dynamic Data Pre-processing, Parsing and Dumping

Static data like PDF, image

Querying Filtering (Tier-2)



Online User Interface

- **Demo**

http://128.174.2.148:8080

Artificial Neural Network Model

ANN

- 3D FEM model in Abaqus for broader number of cases is unfeasible
- ANN simplifies the procedure for users
- ANN is a nonlinear high-dimensional statistical method to learn from and infer about data
- ANN Steps include:
  - Training (~70% of data)
    - Number of layers and Neurons + Activation functions + Training Algorithm + Performance criteria
  - Validation (~10% of data)
  - Testing (~20% of data)

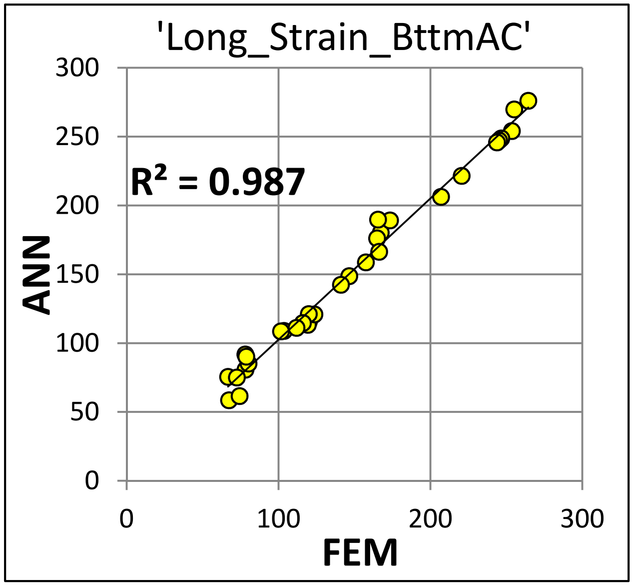
Artificial Neural Networks

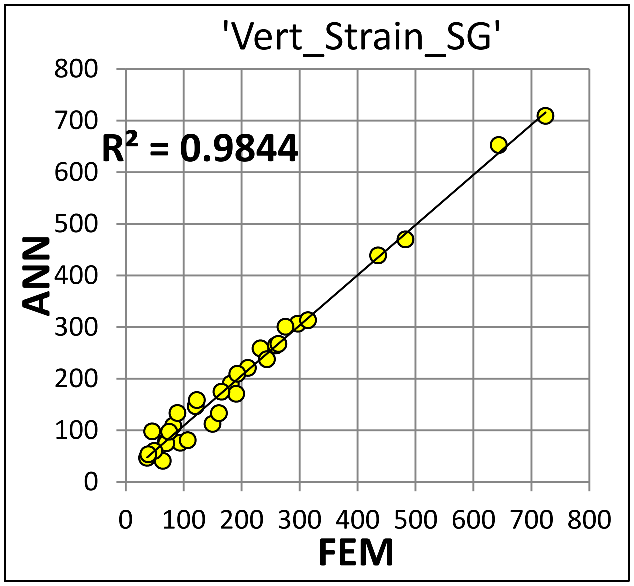
- **Objective**: Predict pavement responses for various loading conditions (WBT vs DTA)
- **Inputs**: Tire, loading, and pavement structure
- **Outputs**: Pavement critical responses including strains and stresses within pavement layers
- Develop a simplified **tool** for highway engineers and designer

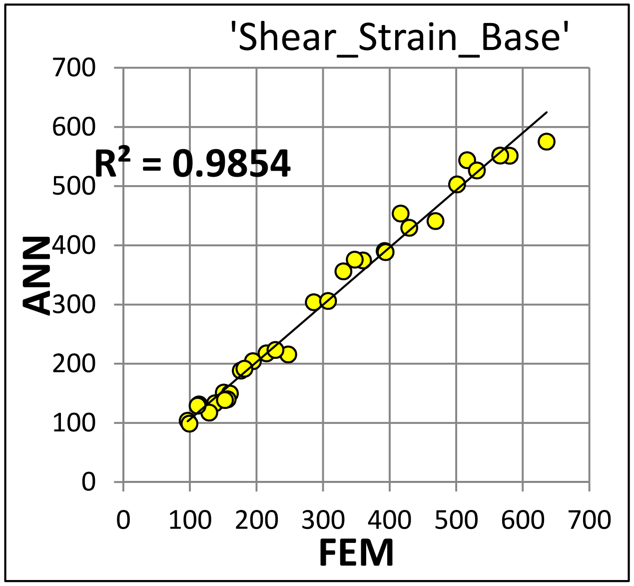
ANN Results

- **Test results for case L6 : 25.4 kN - 862 kPa**

(Thickness 75mm AC & 150mm Base, Weak and Strong combination of layers)

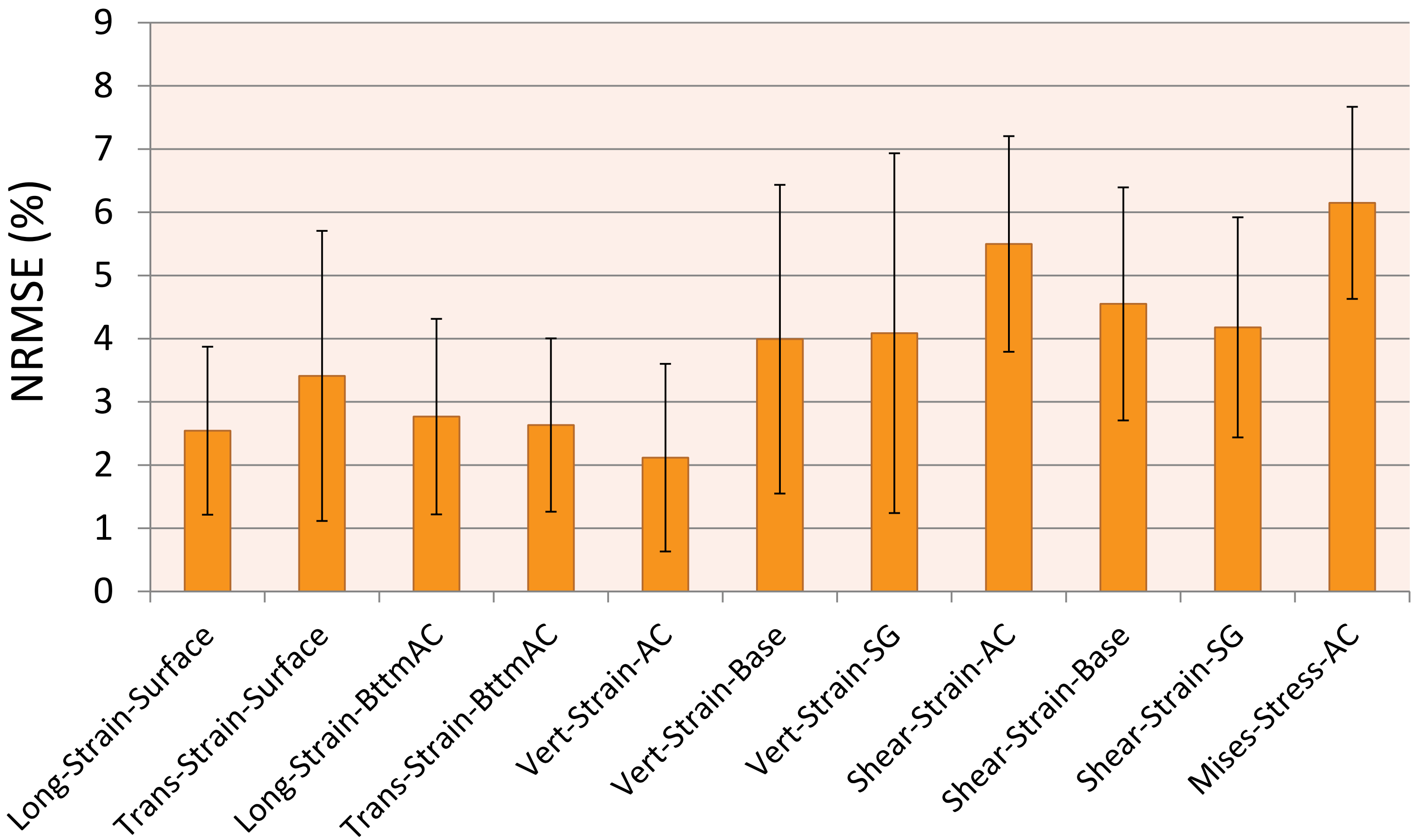






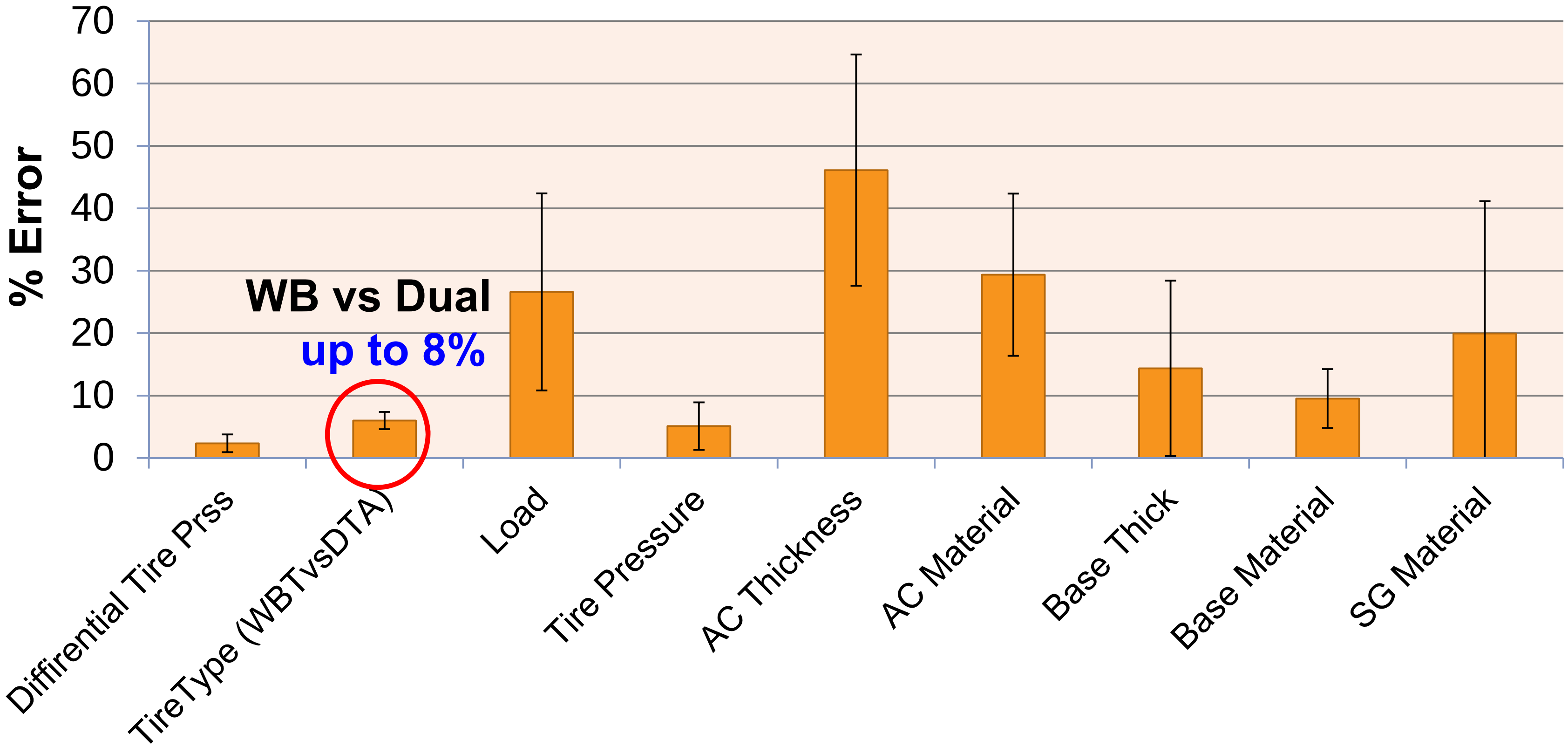
ANN Results

- **Model error with 1 STD for all 12 folds**



ANN - Sensitivity Analysis

- **Missing data problem**
  - Remove each variable at a time from model and calculate the error in response



ANN Tool

- Demo

Adjustment Factors for AASHTO-Ware

10:15 – 11:00

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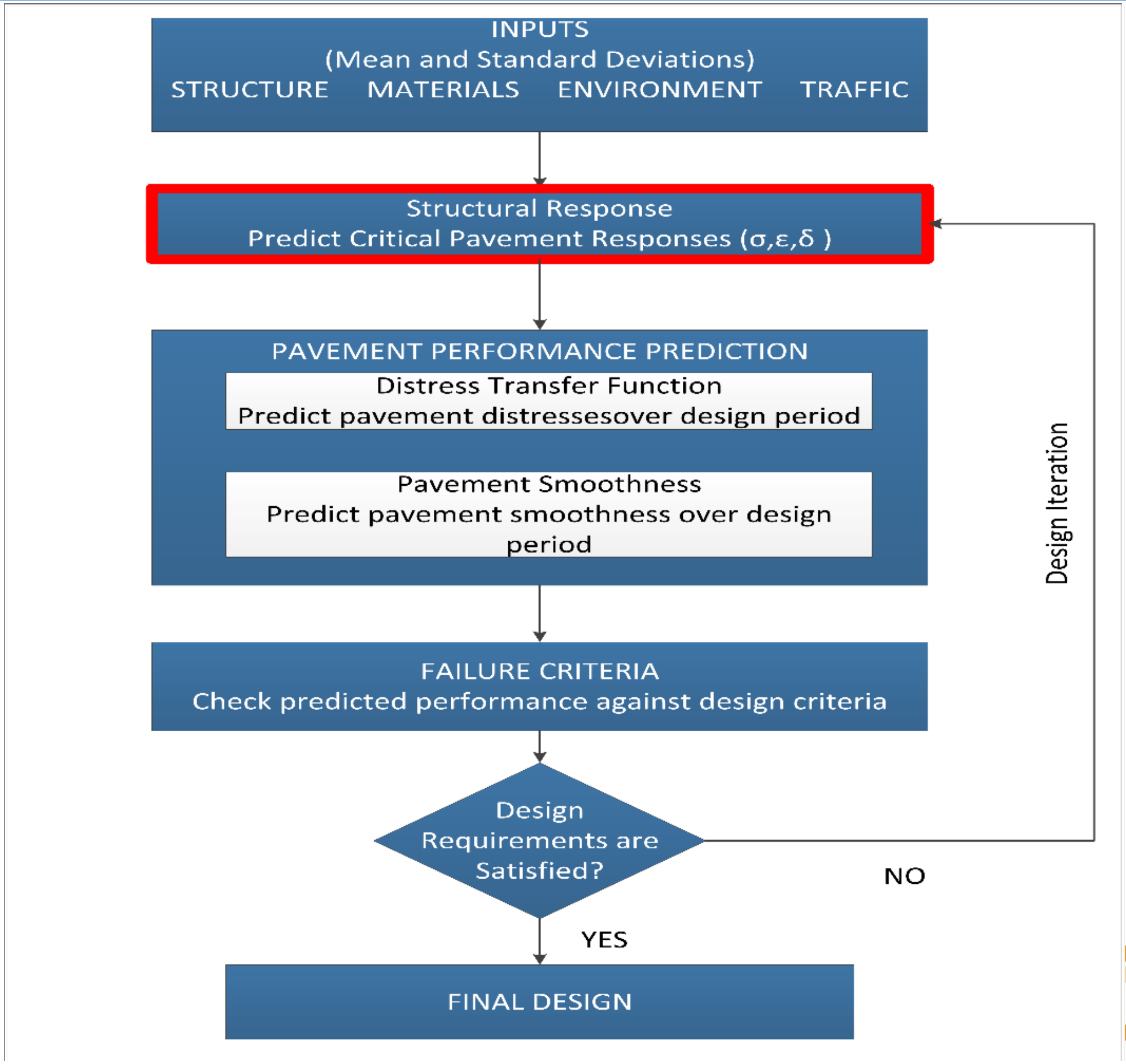
MEPDG Flowchart



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ME-PDG Pavement Response

Sub-Division

- Dividing pavement layers into sublayers to account for temperature and aging gradients

Modulus Calculation

- Calculation of modulus at the mid-depth of each sublayer considering velocity and temperature

JULEA

- Running JULEA (LET computer software) by also considering other inputs such as loads

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Objective and Proposed Approach

- **Objective:**
  - Develop **an adjustment factor** which **modifies** the pavement responses obtained from **MEPDG procedure** in accordance with the results **from FEA**
- **Approach:**
  - Limitation of MEPDG were divided into **two groups**: limitations due to assumptions regarding (i) **material characterization and loading condition** and (ii) incapability of **simulating WBT**

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Adjustment Factor Approach

WBT *Full FEA*

DTA *Full FEA*

DTA *MEPDG Procedure*

$$AF2 = \frac{WBT\ Full\ FEA}{DTA\ Full\ FEA}$$

$$AF1 = \frac{DTA\ Full\ FEA}{DTA\ ME\ Design}$$

$$WBT\ Full\ FEA = AF1 * AF2 * DTA\ ME\ Design$$

Fatigue cracking $N_f = f(E, \varepsilon_t'); \varepsilon_t' = AF1_t * AF2_t * \varepsilon_t'$

Permanent Deformation $N_f = f(T, \varepsilon_v'); \varepsilon_v' = AF1_v * AF2_v * \varepsilon_v$

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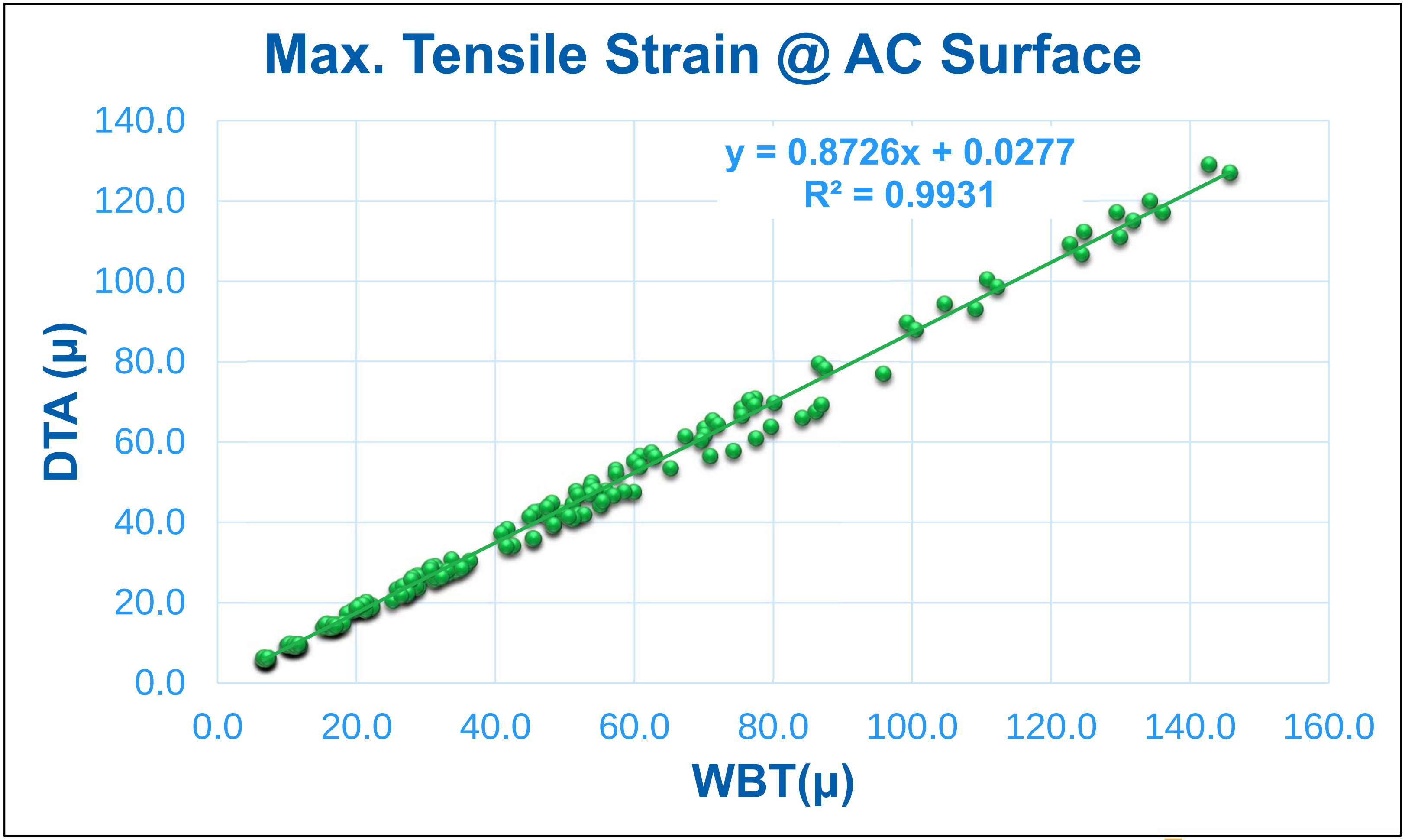
AF-1: WBT to DTA

- Total of 240 case for WBT and 240 cases for DTA have been run in ABAQUS considering same material properties and pavement structures
- The only differences are contact stresses and contact areas which were measured under the same axle load for WBT and DTA

AF-1: WBT to DTA



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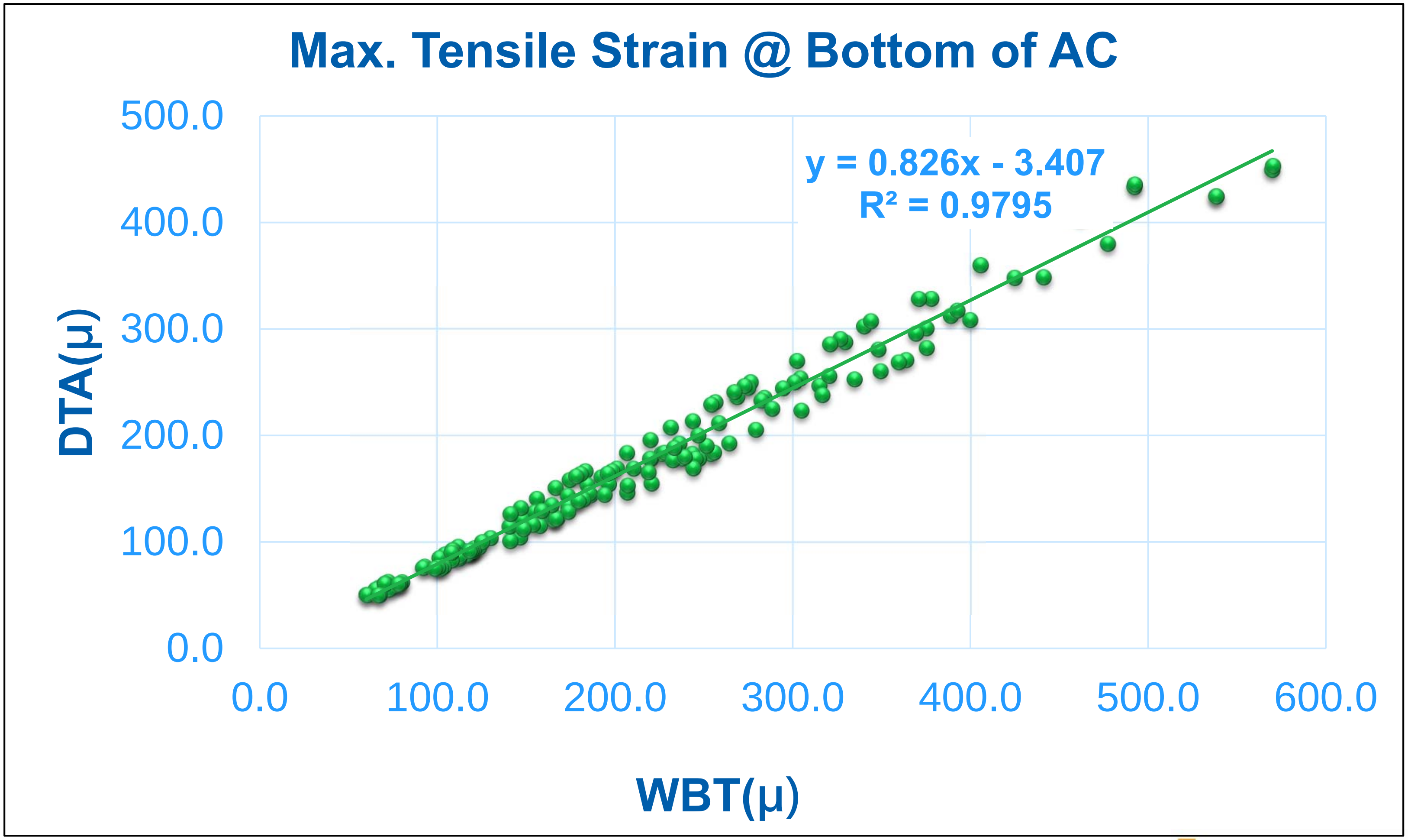
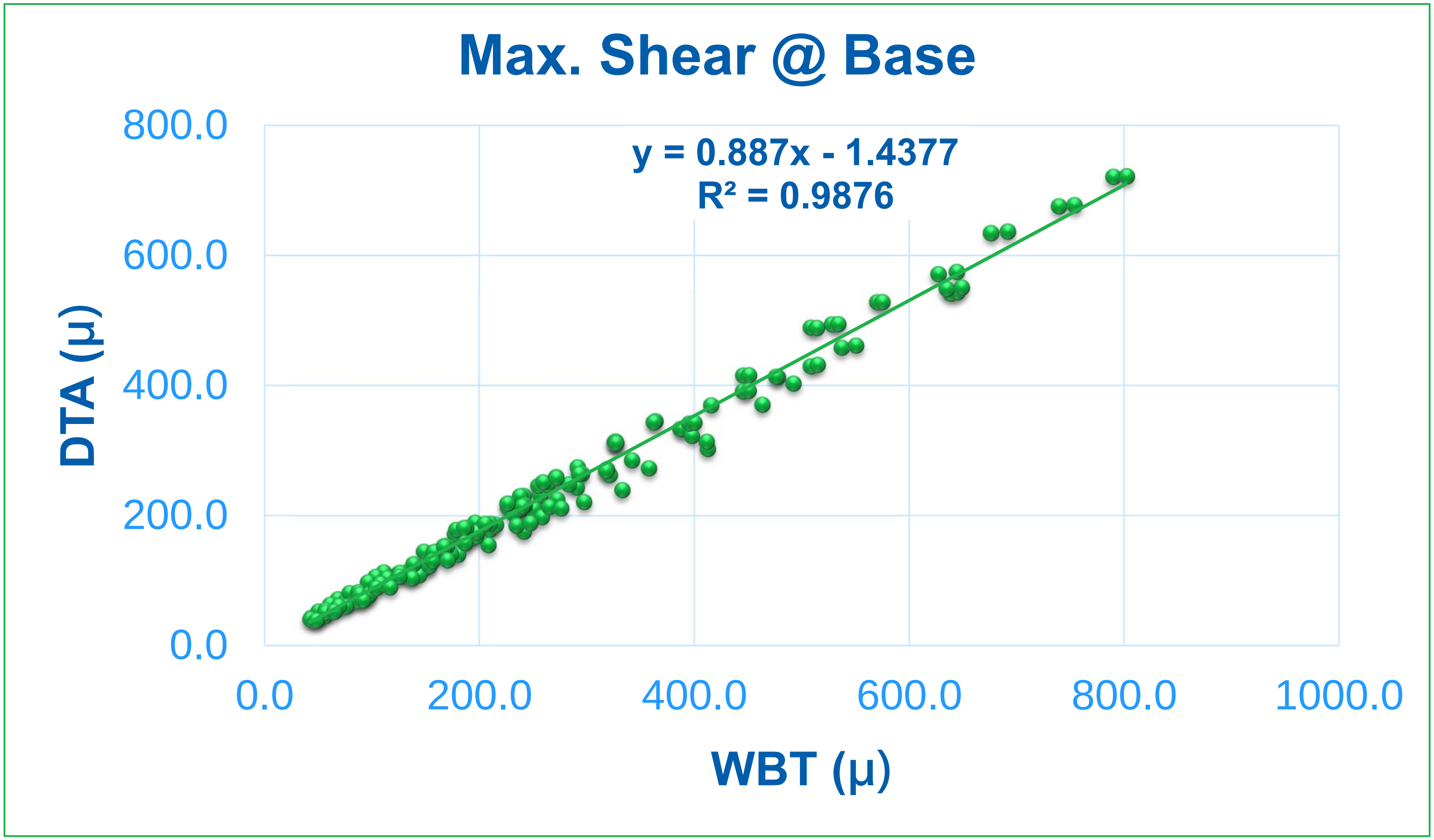
AF-1: WBT to DTA



AF-1: WBT to DTA



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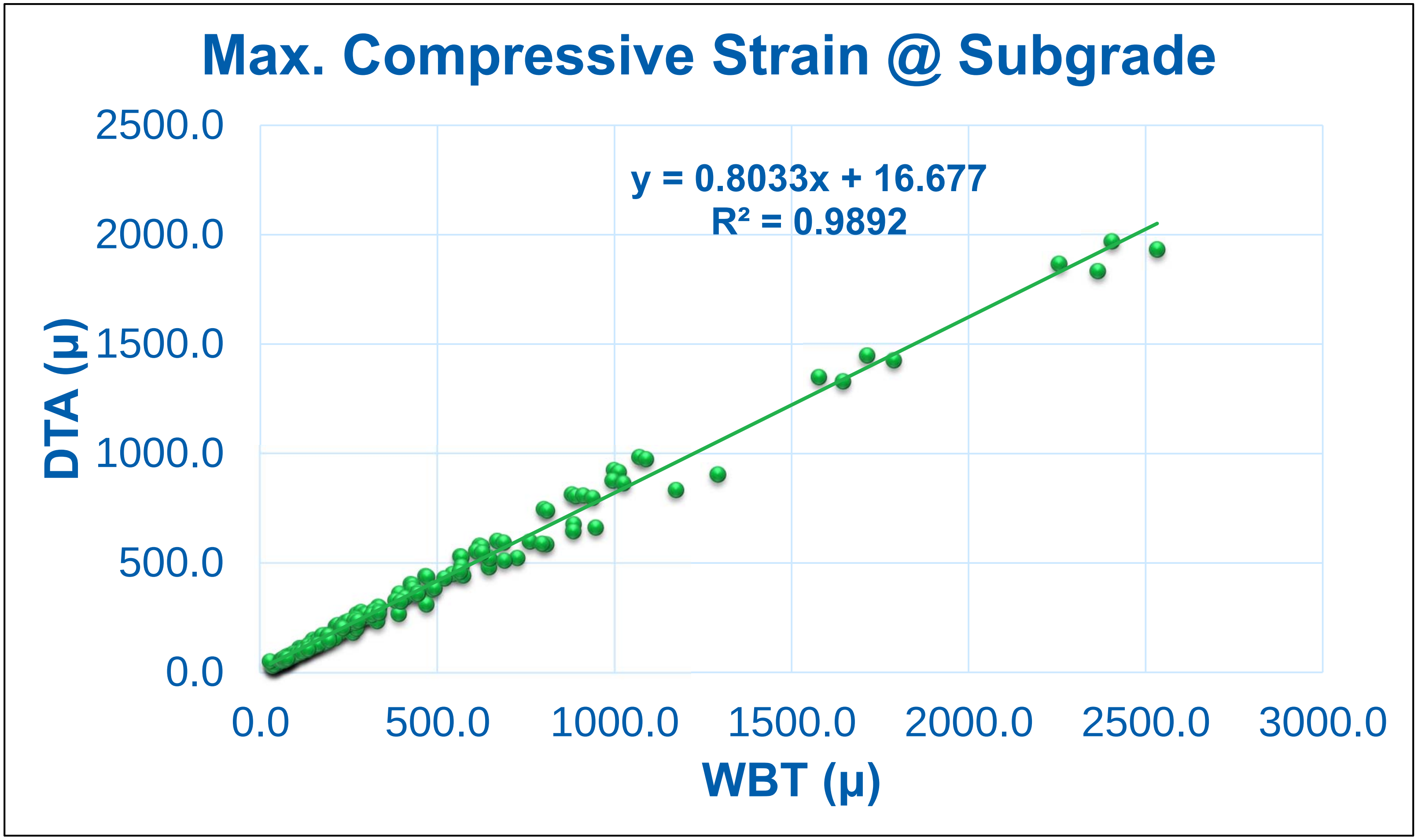
AF-1: WBT to DTA



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AF-2: MEPDG to FEA

- Since MEPDG can't simulate the WBT, only DTA cases are considered for AF-2
- A total of 336 cases have been run in FEA for DTA
- Same cases have been simulated in MEDPG

Running Same Simulations in MEPDG and FEA

	FEA (Reference)	MEPDG Procedure
Axle Load	From experiment	Same as in experiment
Contact Stress	Measured Non-uniform 3D stresses	Inflation tire pressure as in experiment
Contact Area	Measured contact area for each axle load	Circular calculated from pressure and load
Motion of Tire (Speed)	5 mi/h	Same as in E*
Temperature	Computed profile	Same as in E*

Running Same Simulations in MEPDG and FEA

	FEA (Reference)	MEPDG Procedure
Friction between Layers	Elastic Stick Model	Distributed Spring Model
AC Layer Material Properties	Prony coefficients fitted to master curve	E* obtained from master curve (MEPDG Procedure)
Base Layer	Thick = Linear Thin = nonlinear model	Linear Elastic
Subgrade	Linear Elastic	Linear Elastic

Implementation of MEPDG Procedure

- **MEPDG implemented procedure as standalone tool instead of running AASHTO-Ware because:**
  - **Running 576 cases in software is time consuming and not feasible**
  - **AASHTO-Ware only gives critical pavement responses used in the transfer functions.**

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Future Work

- Finalizing the developing of AF-1 for WBT to DTA
- Completing the cases in MEPDG Procedure
- Regression model after obtaining the responses from MEPDG procedure and developing AF-2

Example WBT vs DTA

11:00 – 11:30

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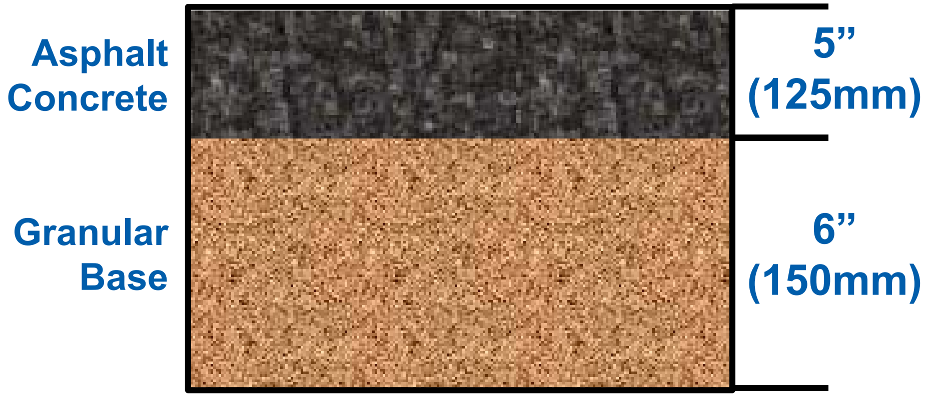
Simulation Inputs

- Thin Pavement
- Material Property
  - "Weak" AC
  - "Strong" Base
  - "Strong" Subgrade
- Loading Condition (measured)
  - Load: WBT=43.7 kN, DTA=39.3 kN
  - Tire Inflation Pressure = 758 kPa

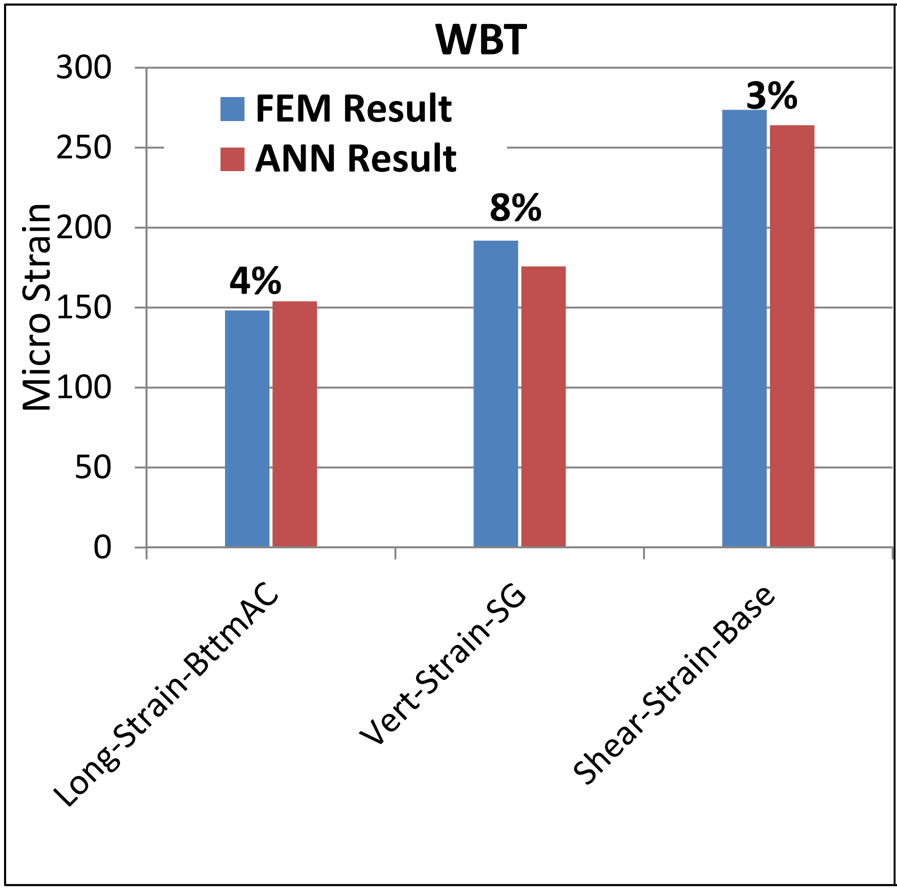


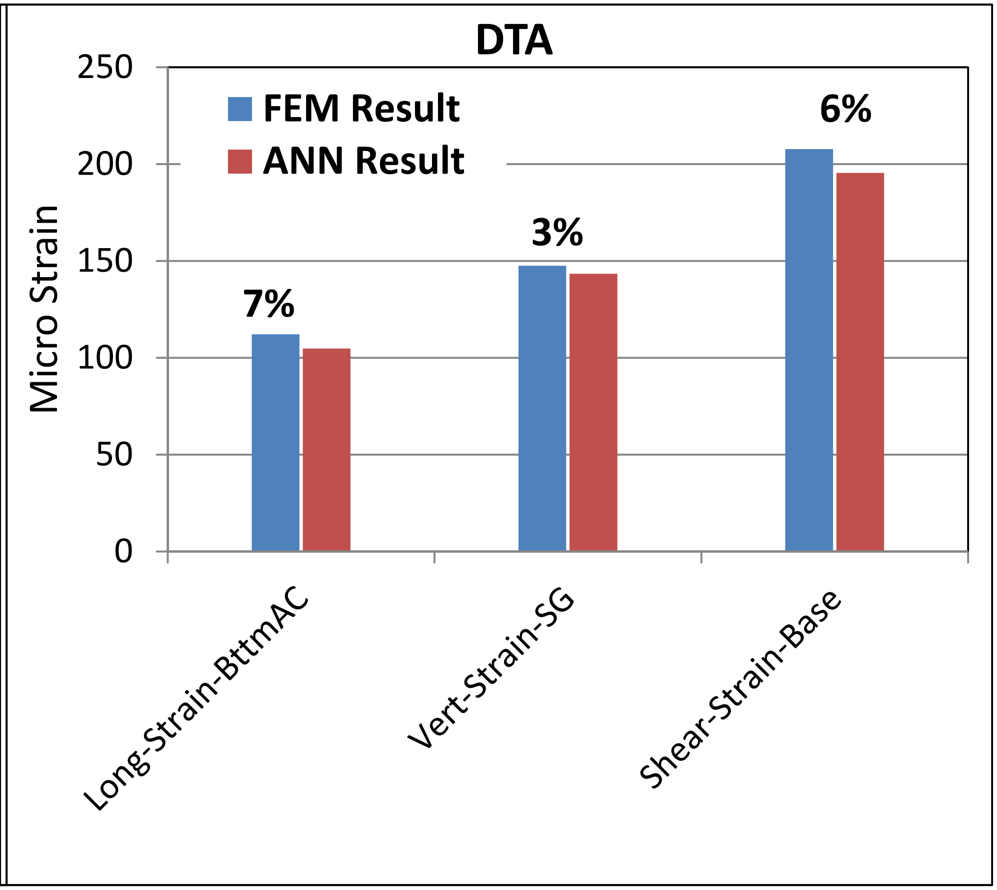
FEM Responses

Tire Type	$\epsilon_{11,botAC}$	$\epsilon_{22,subg}$	$\gamma_{23,base}$
WBT	148.2	191.9	273.6
DTA	112.1	147.5	207.8

- $\epsilon_{11,botAC}$ = longitudinal and transverse tensile strain at bottom of AC (fatigue cracking)
- $\epsilon_{22,subg}$ = maximum vertical strain on subgrade (rutting)
- $\gamma_{23,base}$ = shear strain in granular base layer

ANN Prediction





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ANN Interpolation

- **Typical Case:**
  - **Load = 8.5 kips - Tire Pressure = 690 kPa**
  - **Typical thin pavement structure**

Asphalt	125 mm	Weak
Base Granular	150 mm	Strong
Subgrade		Strong

- **Critical Responses:**
  - **Trans./Long. Strain Bottom of AC**
  - **Shear Strain at Base**
  - **Vertical Strain Top of SG**

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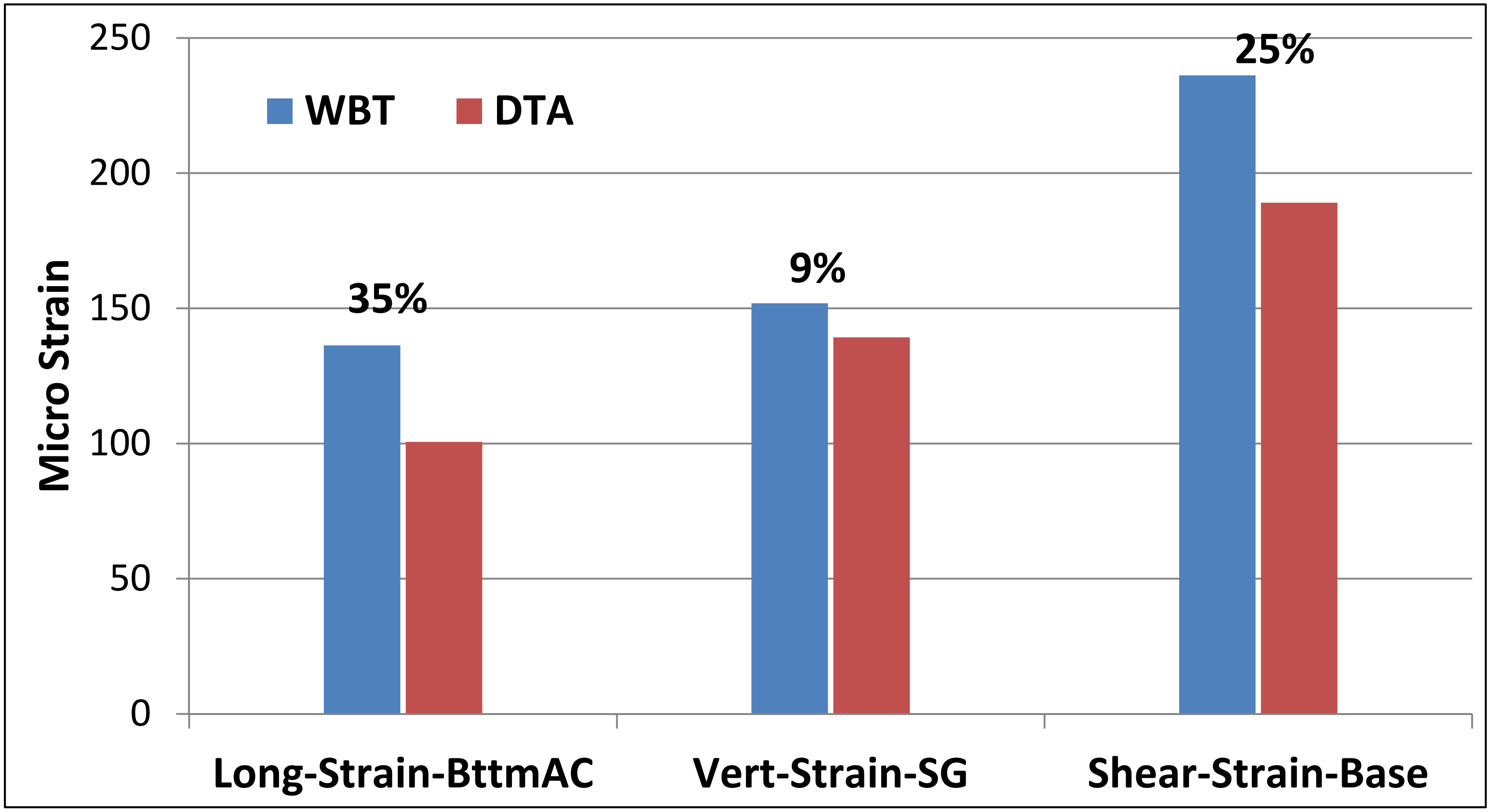
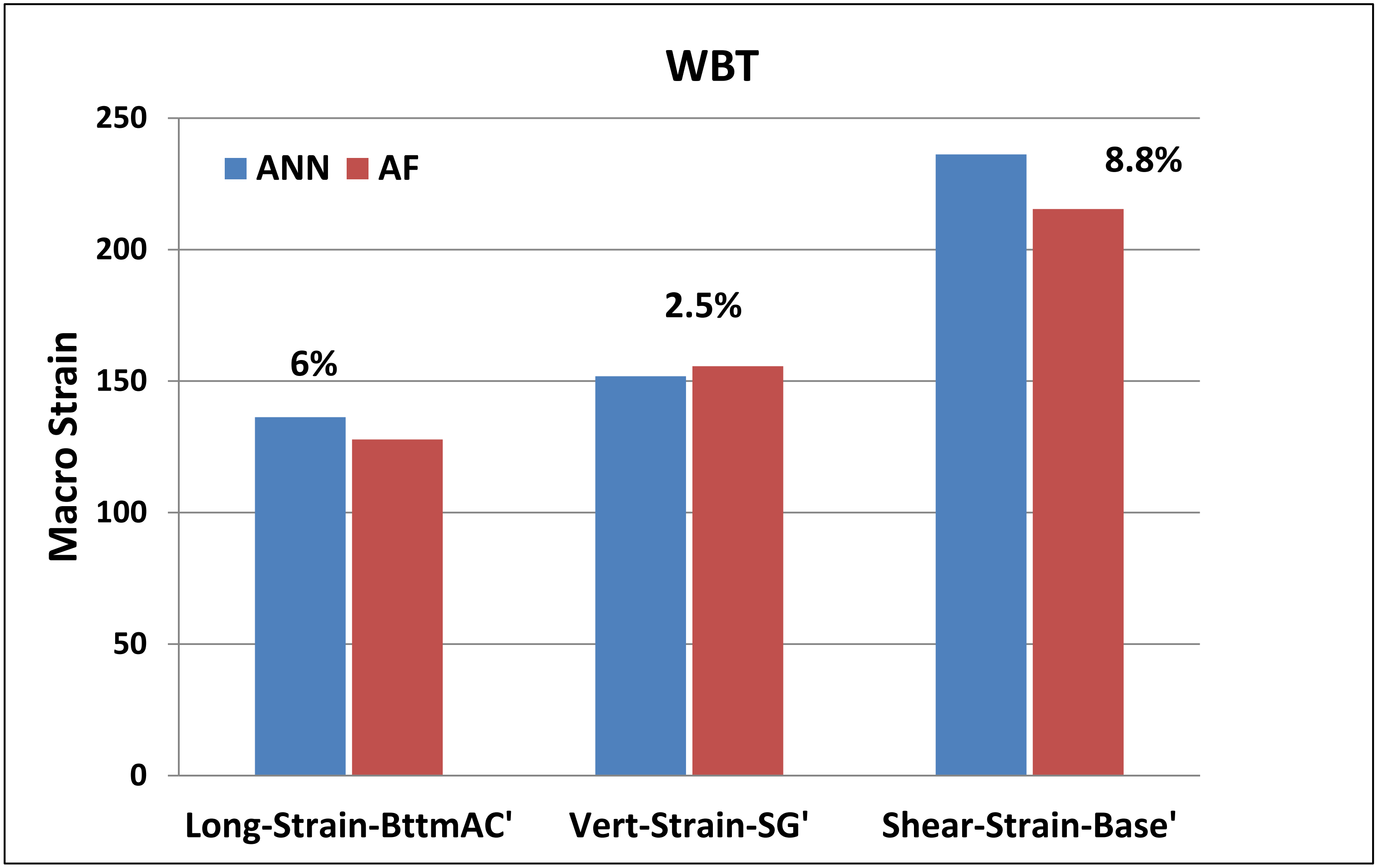
ANN Interpolation

- Prediction Results:

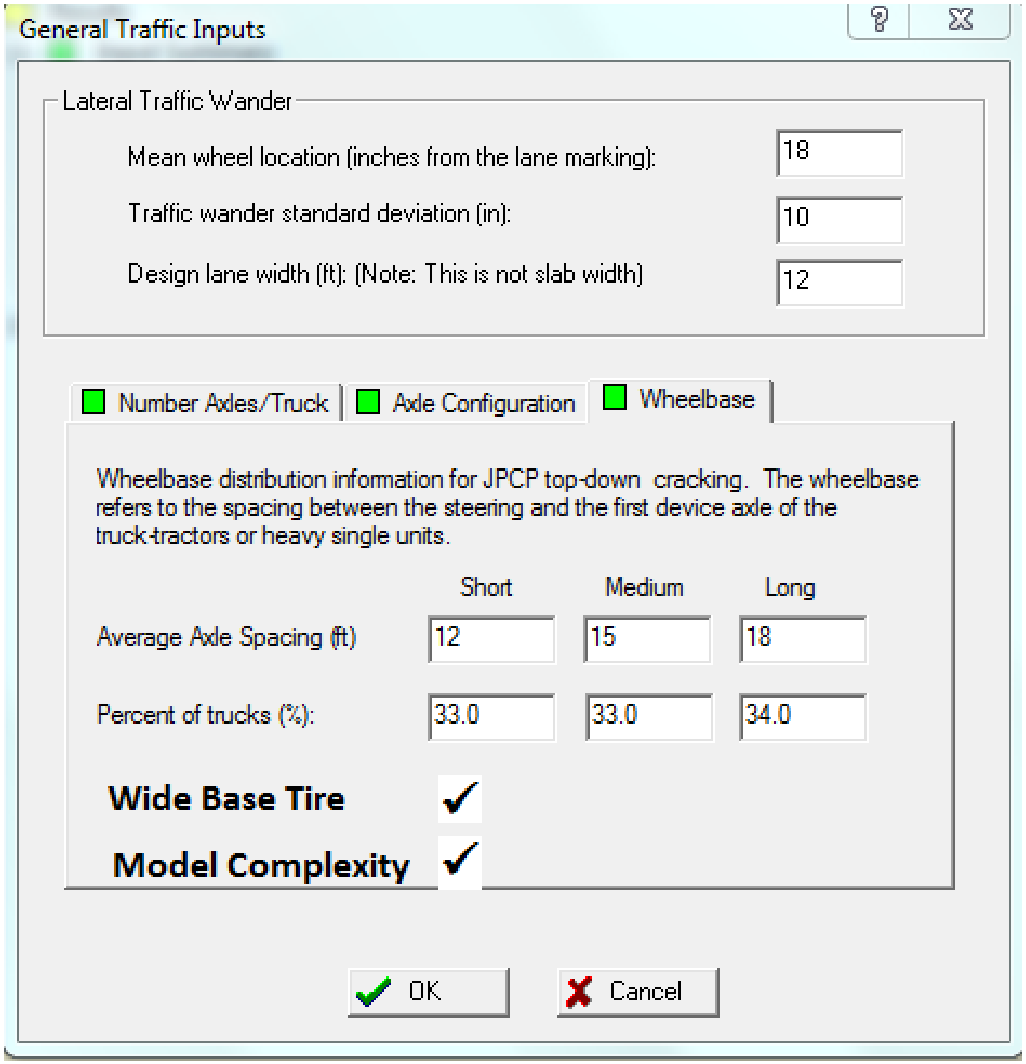


ANN & AF



ILLINOIS CENTER FOR TRANSPORTATION

Adjustment Factor Implementation



Final Remarks

11:30 – 12:00

ILLINOIS CENTER FOR TRANSPORTATION