Impact of Wide-Base Tires on Pavements

Shongtao Dai

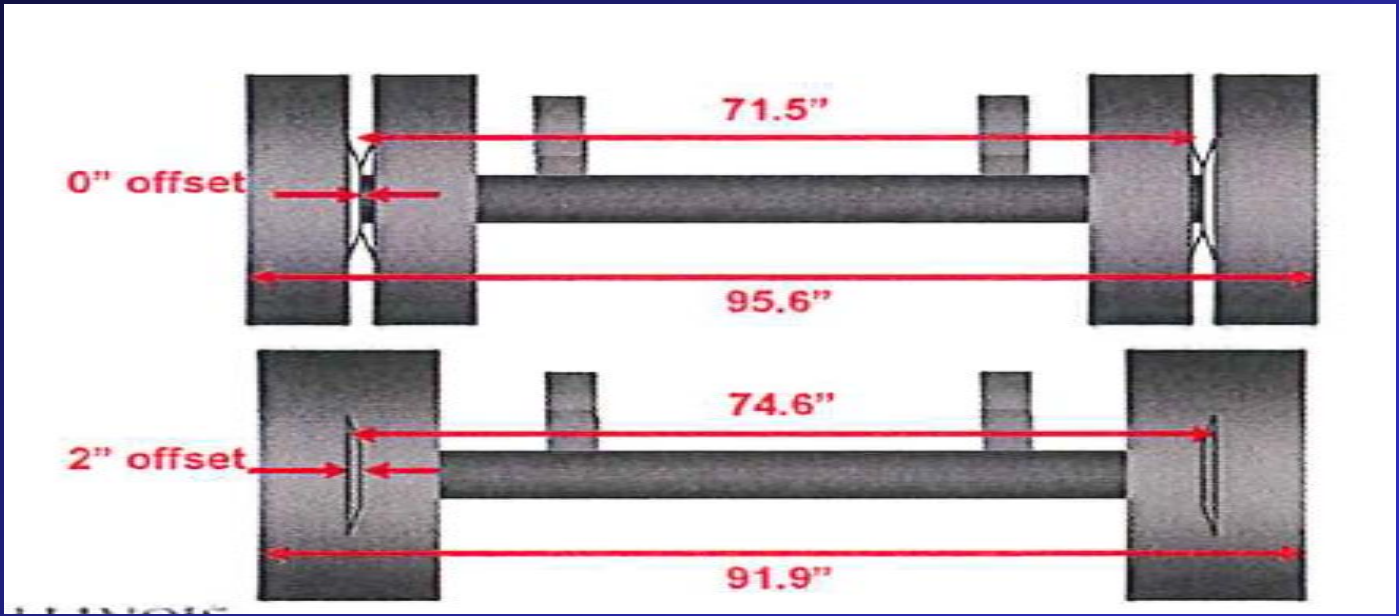
Office of Materials and Road Research

Minnesota Department of Transportation

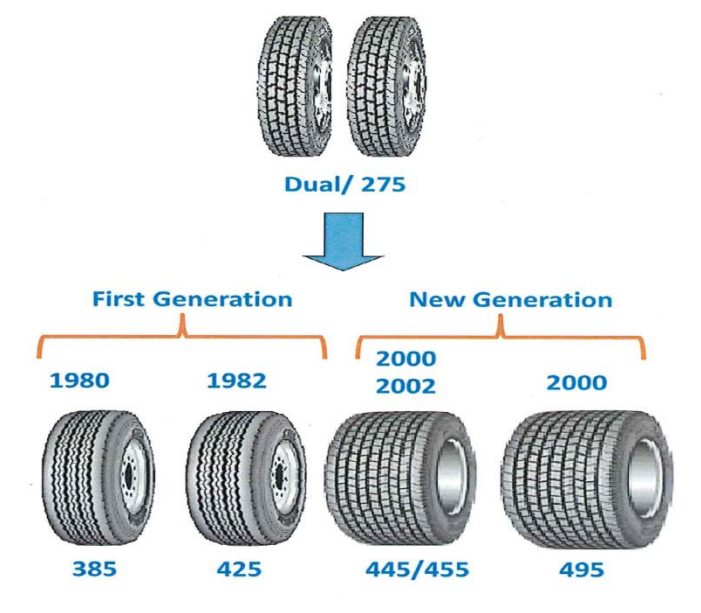
Mn/DOT

Office of Materials and Road Research

- **A pooled fund study**
- **Participating Agencies:**
  - FHWA, IL , MN , MT , NY , OK , TX , VA, Michelin, Rubber Manufacture Association
- **PI: University of Illinois, Dr. Imad Al-Qadi**


71.5"
0" offset
95.6"
74.6"
2" offset
91.9"

- First (Early) Generation Wide-Base Tires (1980s to 2000)
  - 385/65R22.5, 425/65R22.5 and 445/65R22.5
    - Cause signification damage to pavement compared to dual tire due to required high inflation pressure



- New Generation Wide-Base Tires (after 2000)
  - 445/50R22.5 and 455/55R22.5
    - 16 to 18% wider than the early generation WBT
    - Reduced tire inflation pressure
    - Designed for more uniform contact pressure distribution

- Benefits of WBT to Truck Industry:
  - Reduced tire weight: 800-1000lbs for a typical 5-axle truck
  - Increase hauling capacity (payload)
  - Fuel saving: 2 – 5%
    - Due to less rolling resistance
  - Reduced emission
  - More comfortable ride

New-Generation Wide-Base Tire

- Wide-base tires have been used in Europe since early 1980s
- In some countries more than 80% of trailers use wide-base tires
- FG-WBT was proven more detrimental to flexible pavements than dual tires; NG-WBT is less damaging than FG-WBT
- Damage between NG-WBT and DTA needs to be further studied

NGWBS Tires

All Zones – Field Count

All Zones NGWBS Study

% vs. Duals

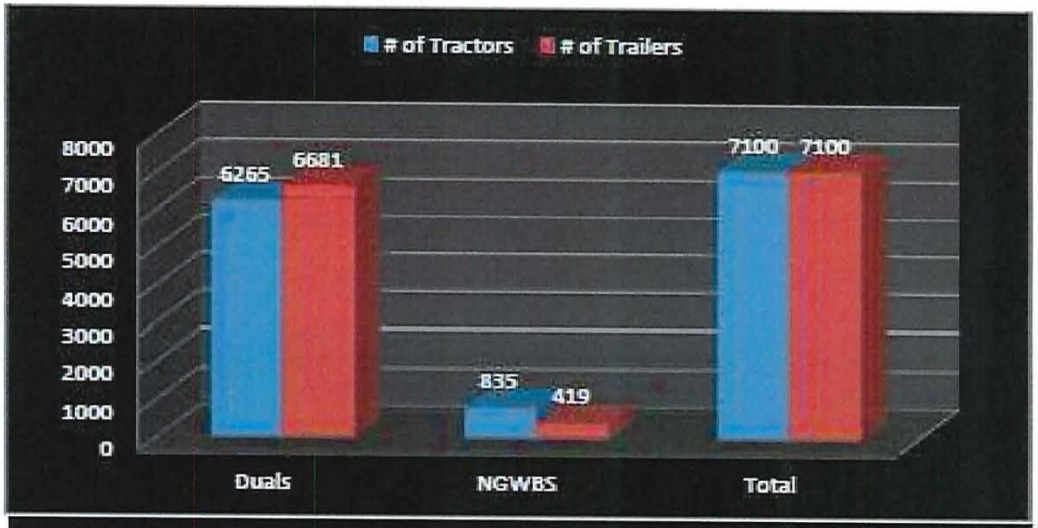
All Zones Roll-Up, April 2014

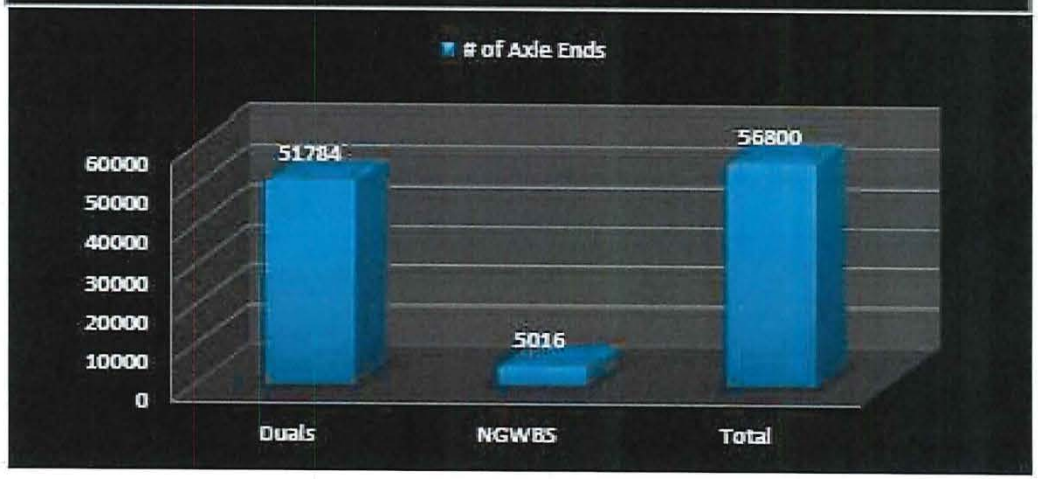
TOTALS				
DUALS - DRIVE & TRAILER	NGWBS - DRIVE & TRAILER	NGWBS - DRIVE ONLY	NGWBS - TRAILER ONLY	Total Trucks
6151	305	530	114	7100

# of Tractors		
Duals	6265	88.2%
NGWBS	835	11.8%
Total	7100	

# of Trailers		
Duals	6681	94.1%
NGWBS	419	5.9%
Total	7100	

# of Axle Ends		
Duals	51784	91.2%
NGWBS	5016	8.8%
Total	56800	





NGWBS Tires

Minneapolis, MN – Field Count

Minneapolis NGWBS Study

% vs. Duals

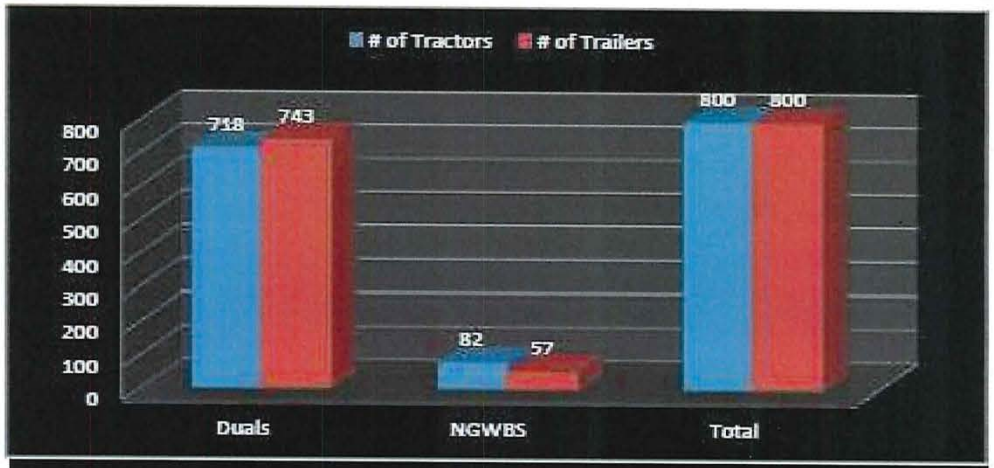
Conducted in Minneapolis, MN - April 1, 2014

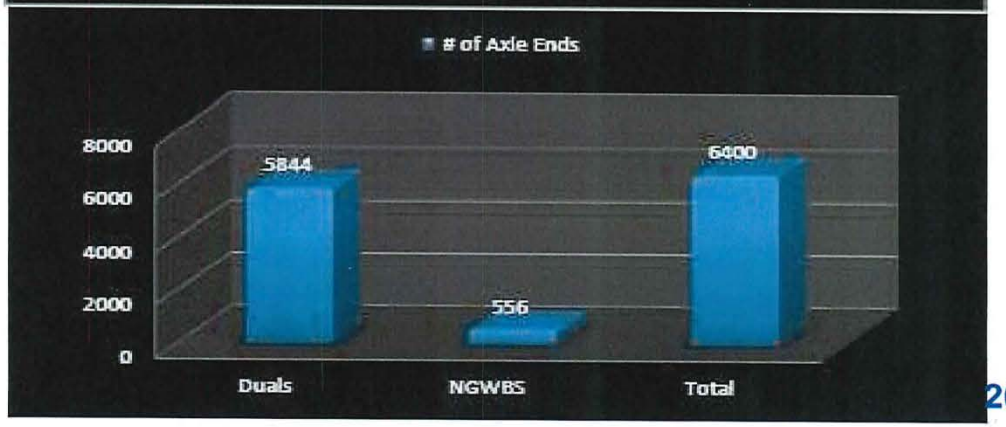
TOTALS				
DUALS - DRIVE & TRAILER	NGWBS - DRIVE & TRAILER	NGWBS - DRIVE ONLY	NGWBS - TRAILER ONLY	Total Trucks
694	33	49	24	800

# of Tractors		
Duals	718	89.8%
NGWBS	82	10.3%
Total	800	

# of Trailers		
Duals	743	92.9%
NGWBS	57	7.1%
Total	800	

# of Axle Ends		
Duals	5844	91.3%
NGWBS	556	8.7%
Total	6400	





This Study:

WBT 445/50R22.5

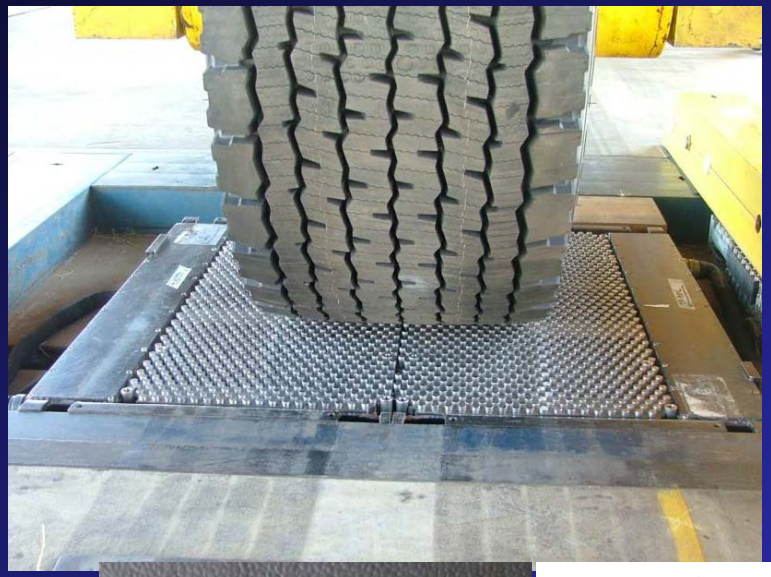
New-Generation Wide-Base Tire

DTA 275/80R22.5

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)
  - FEM modeling of pavement loading
  - Field validation on pavement test sections
  - Adjustment factor from FEM vs AASHTO-Ware

- **Contact stress measurements (South Africa):**
  - Tested Tires: WBT 445/50R22.5; DTA 275/80R22.5



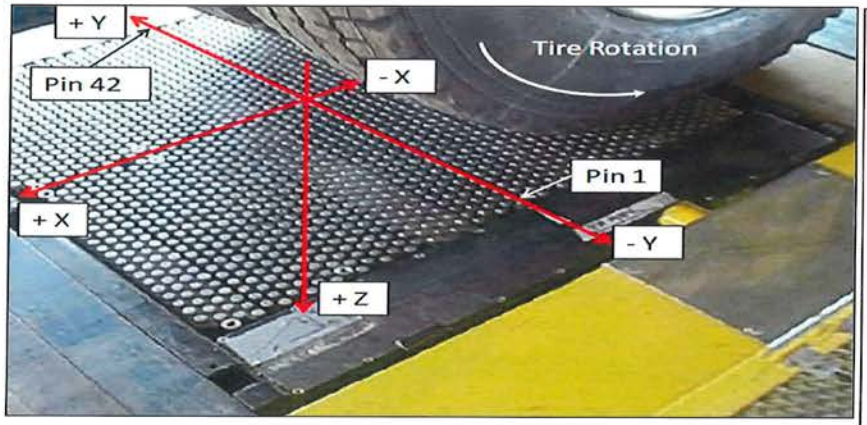
Experimental Program

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

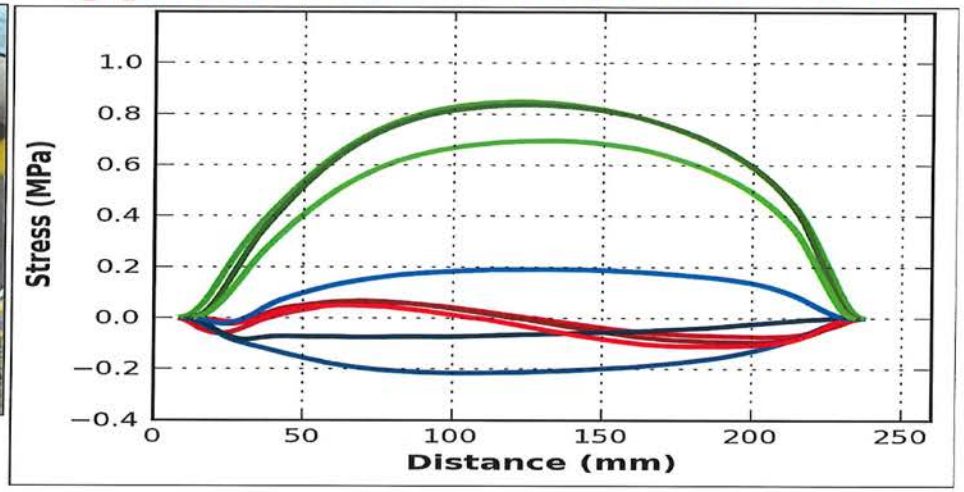
*Differential Tire Inflation Pressure

1 kN = 225 lbs; 1 kPa = 0.145 psi

Contact Stress Distributions

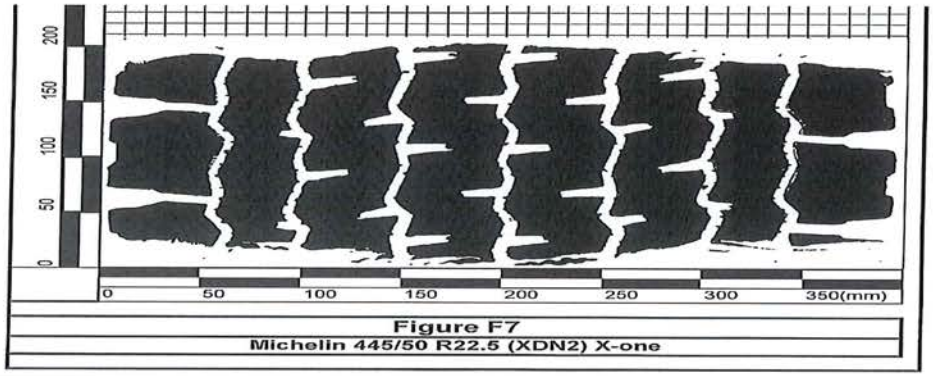


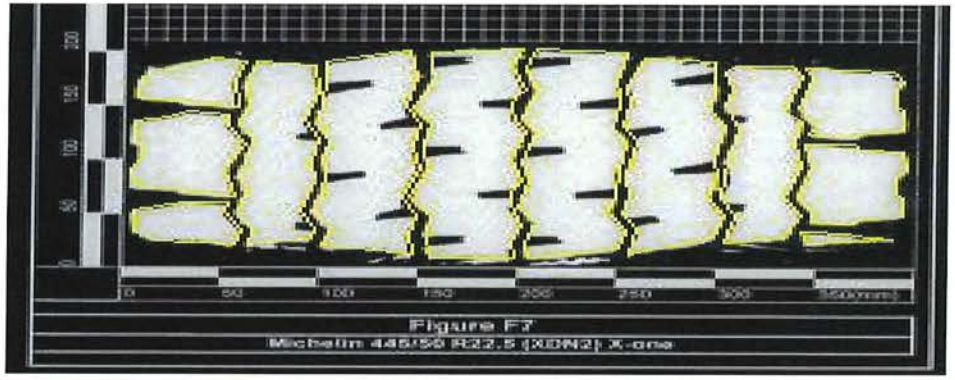
Typical Stress Distribution



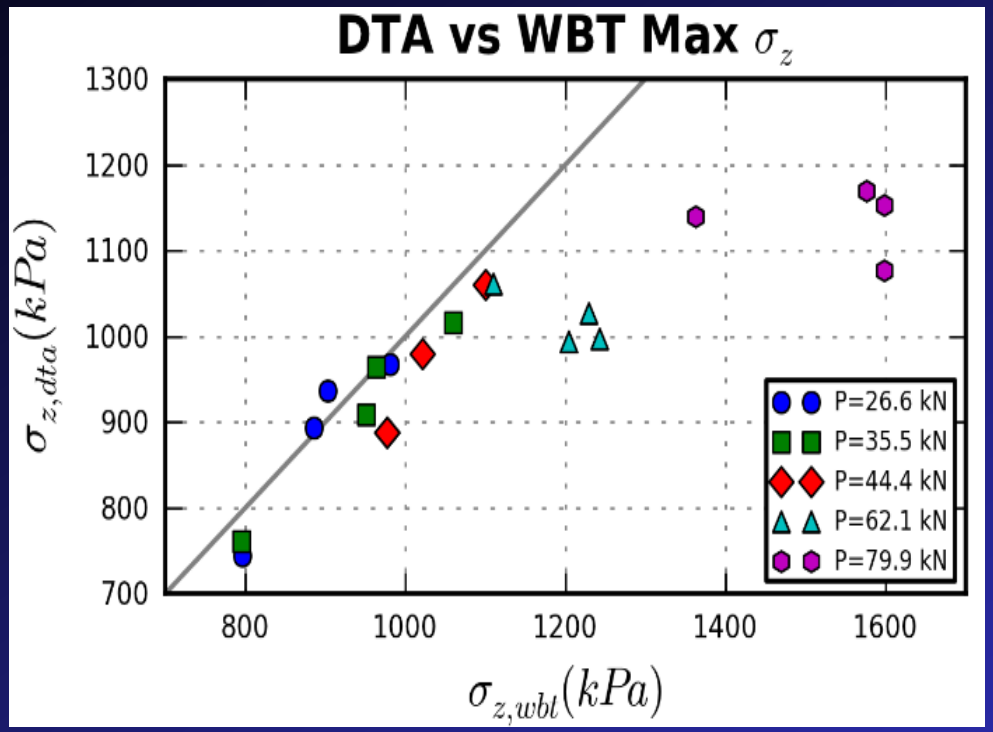
Data Processing: Contact Area

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

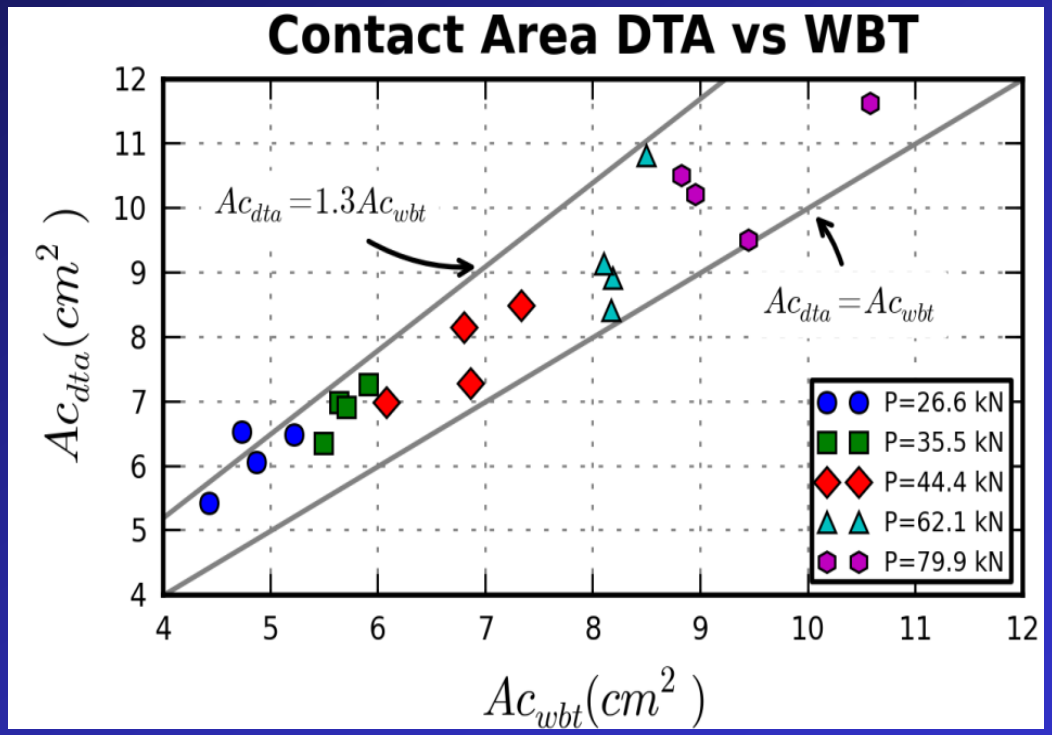




Vertical Contact Stresses



Contact Area



Vertical contact stresses higher for WBT

Remarks

- Complex 3D contact stresses are important to determine pavement response
- Contact area may be up to 30% greater for DTA than WBT
- Contact length may be up to 65% shorter for DTA than WBT

Vertical contact stresses higher for WBT than DTA

FEM Results:

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

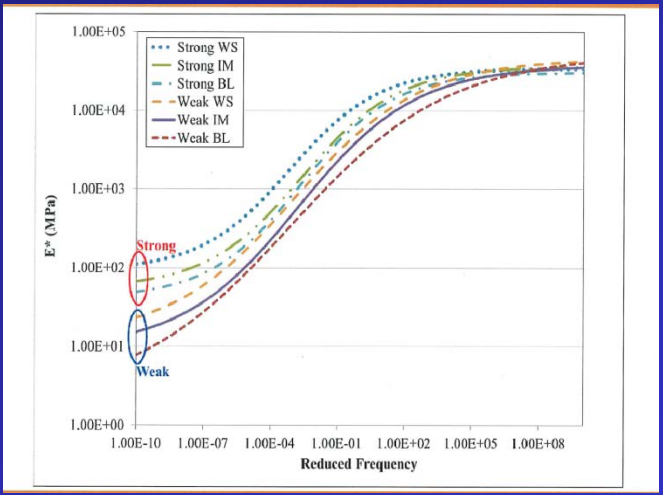
FEM Simulation Matrix

- 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

AC: 3” & 5”
Base: 6” & 24”



AC: 5” & 16.5”
Base: 6” & 24”

MINNESOTA DEPARTMENT OF TRANSPORTATION

Material Characterization

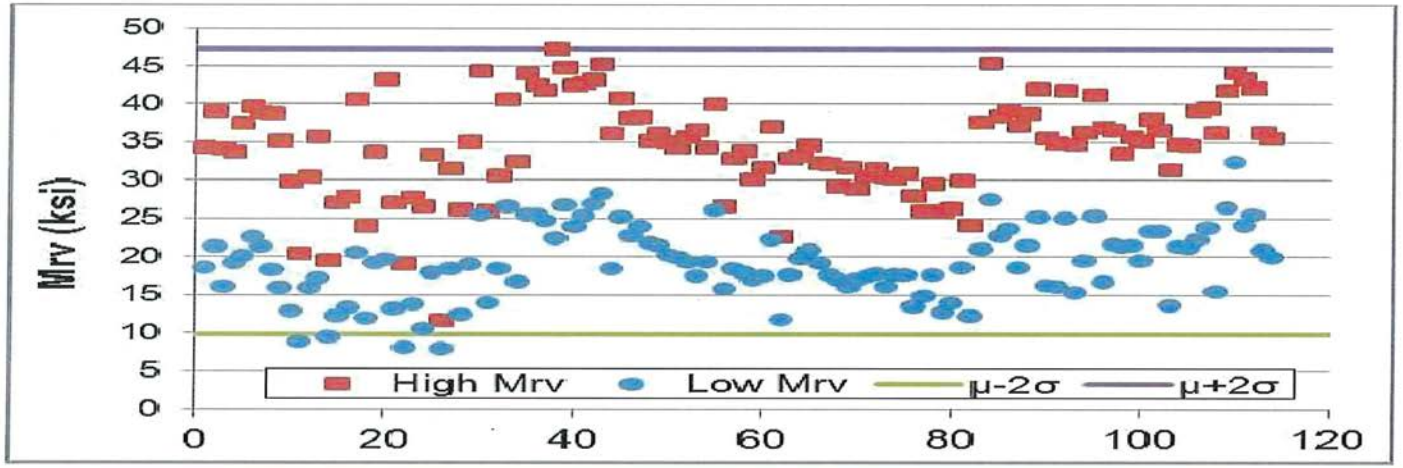
- AC: Linear-viscoelastic:
  - Dynamic modulus test (E*)
  - Prony series expansion
- Granular materials:
  - Thin pavement: Nonlinear cross-anisotropic stress-dependent
  - Thick pavement: Linear Elastic

Nonlinear Granular Materials

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

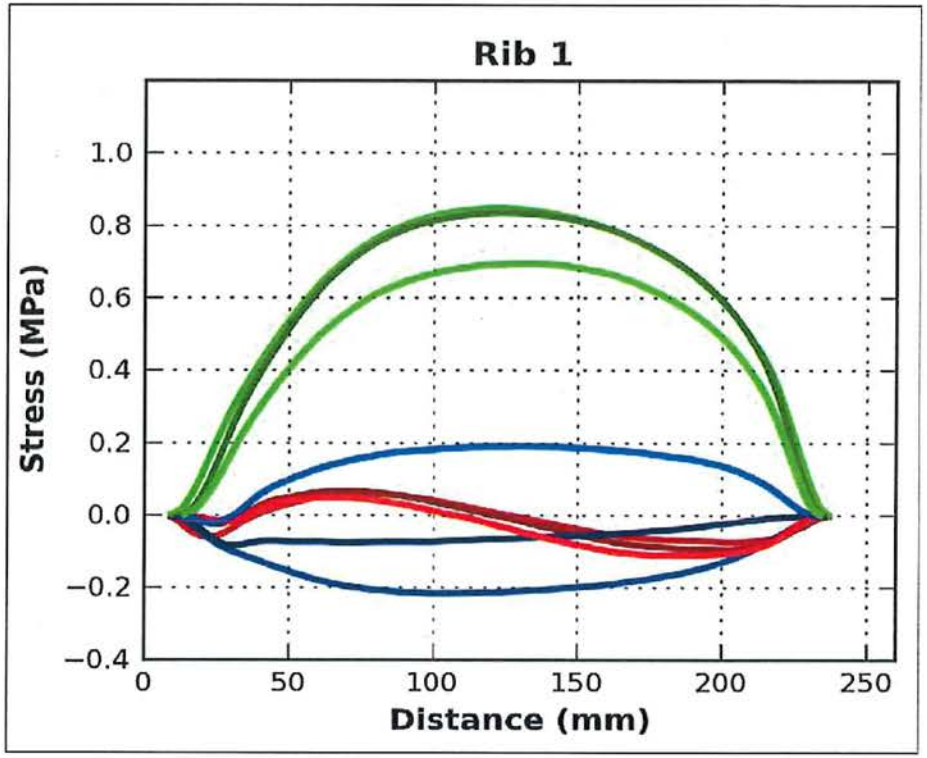


Remarks

- Asphalt concrete was assumed as linear viscoelastic with properties from LTPP database
- Base materials for thin pavements were assumed nonlinear (stress-dependent) cross-anisotropic

3-D Contact Stresses

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



Field Validation

- Instrumented sections: Smart Road; FL DOT; UC Davis and ICT

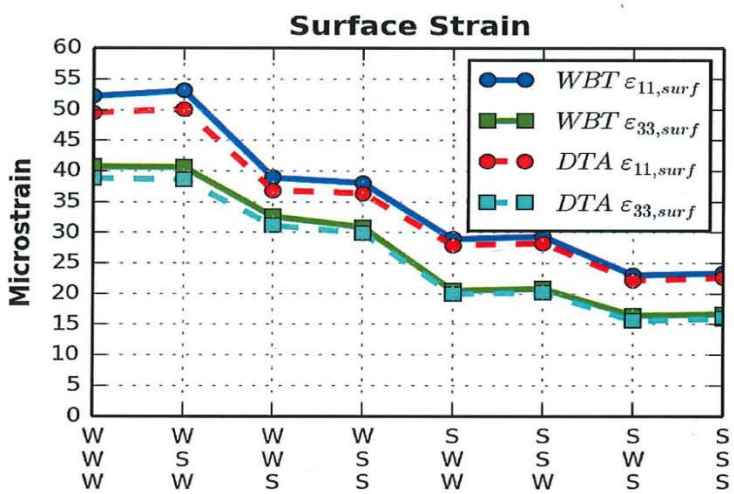
Model Validation

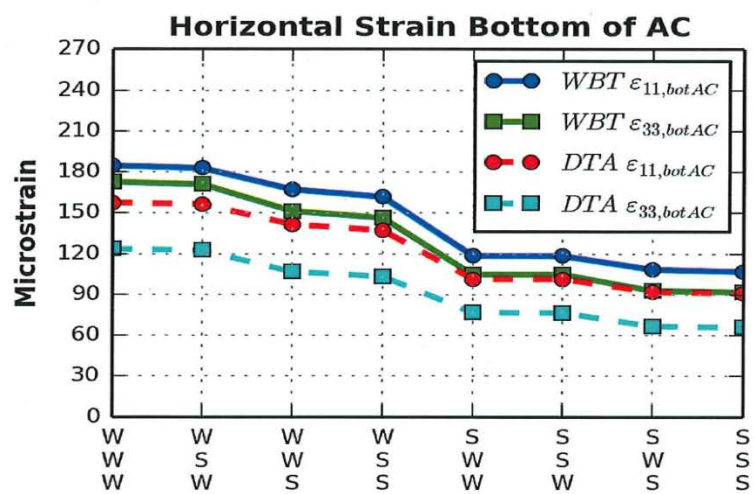
- Modeling approach validated using measurements of low-volume roads and interstate highways
- Differences in vertical pressure on top of subgrade ranged from 2.4% to 17.7%
- Horizontal strains at the bottom of AC ranged from 2.1% to 28.7%

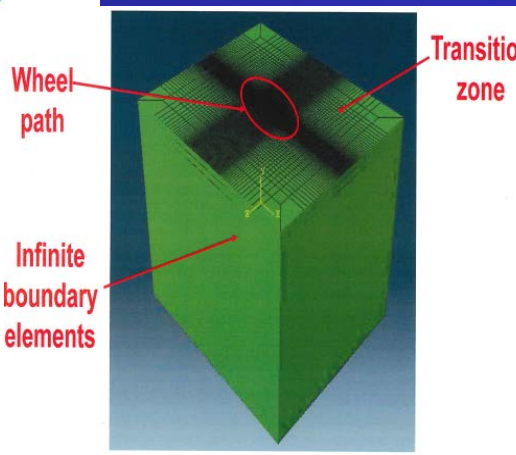
Modeling Thin Pavements

Tensile Strain Surface and bottom of AC

- $\varepsilon_{11,AC}$ and $\varepsilon_{33,AC}$ was higher for NG-WBT than DTA
- The $\varepsilon_{33,AC}$ for NG-WBT was also higher than $\varepsilon_{11,AC}$ and $\varepsilon_{33,AC}$ for DTA

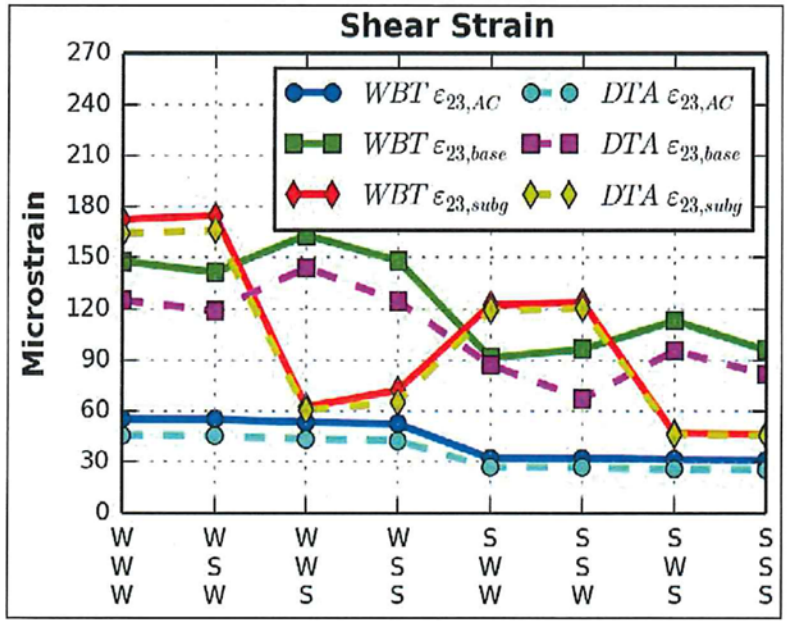


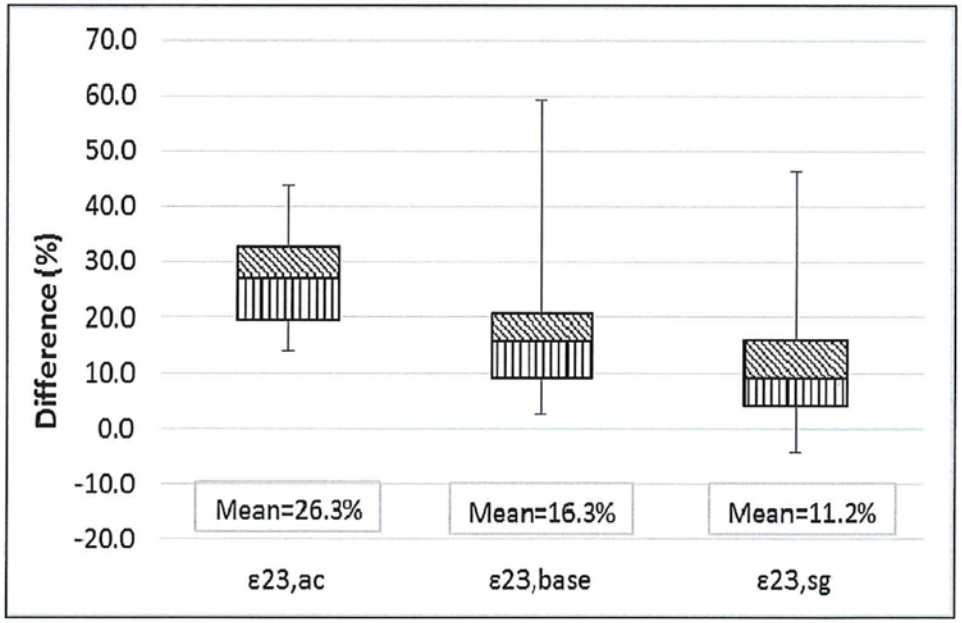




Shear Strain

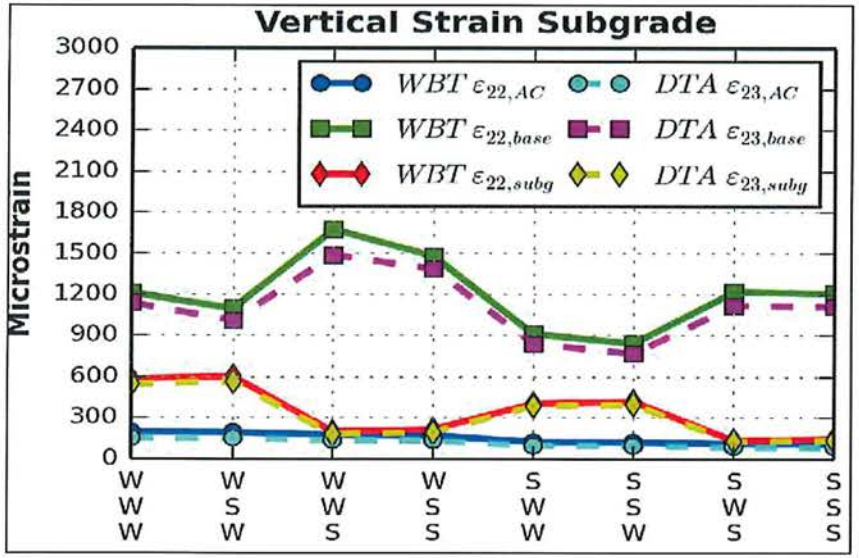
- Mean difference decreased with depth from 26.3% in AC to 11.2% in subgrade
- In some cases, shear strain in subgrade was smaller for NG-WBT than for DTA (negative difference)

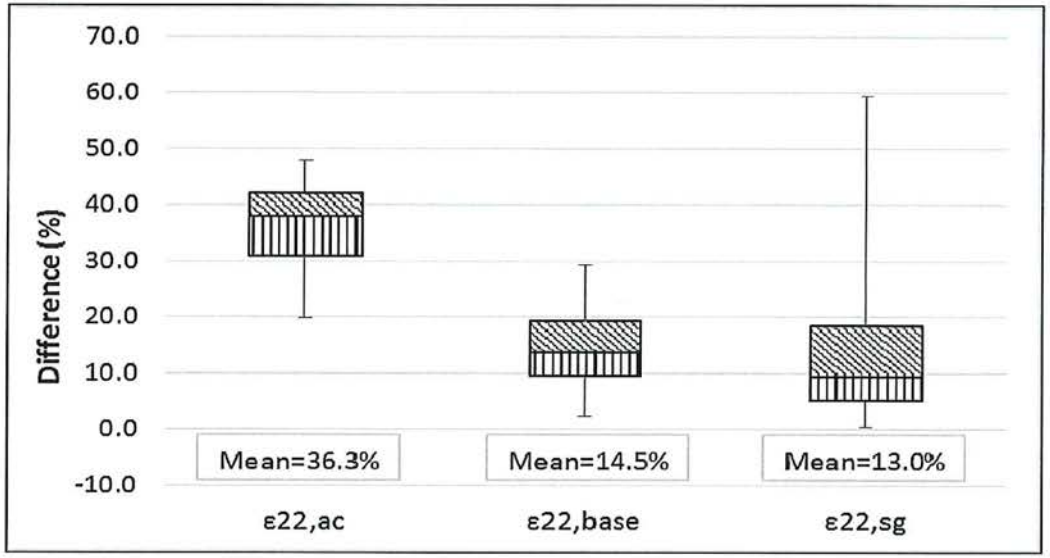




Vertical Strain

- Highest average difference was 36.3% (in AC)
- Average difference decreased with depth, reaching 14.5% in base and 13.0% in subgrade

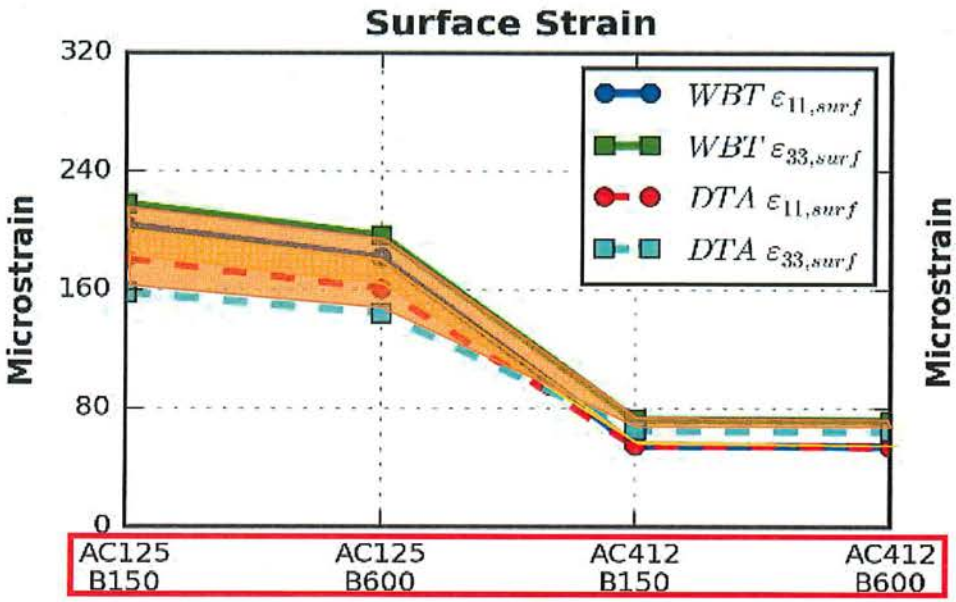


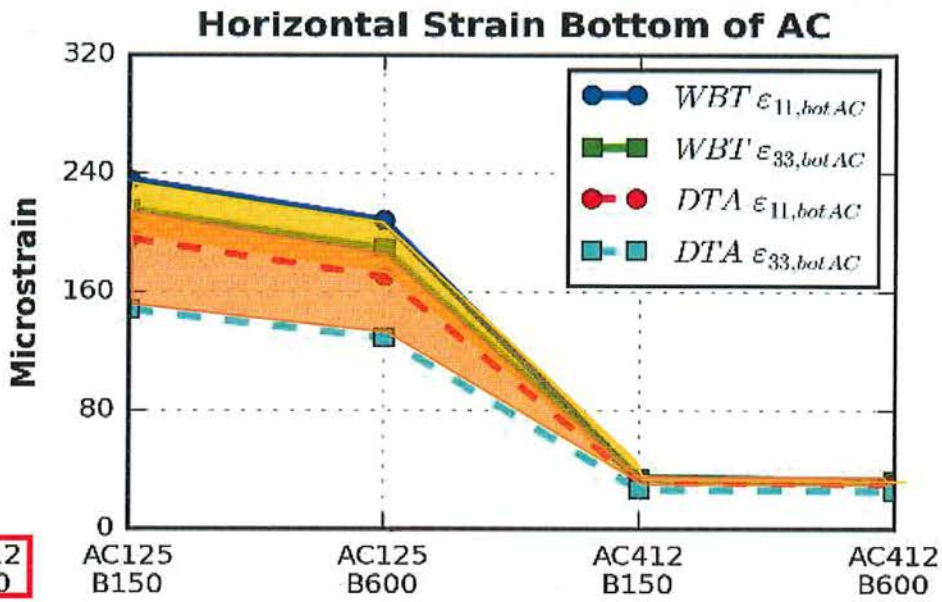


Modeling Thick Pavements

Effect of Structure

Tire type	WBT and DTA
Inflation pressure	44 kN
Load	758 kPa
AC Material	Weak
Base Material	Weak

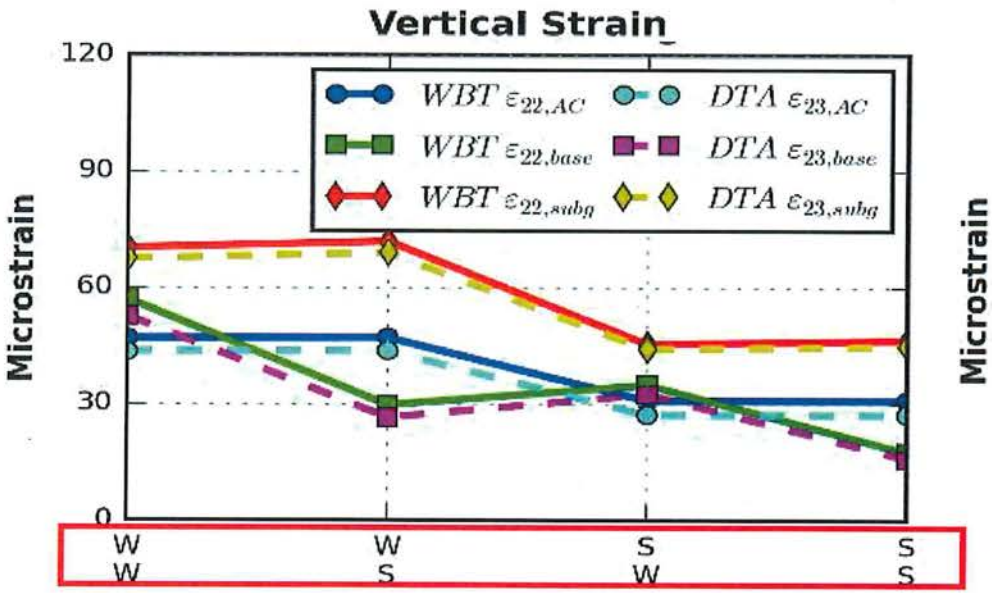


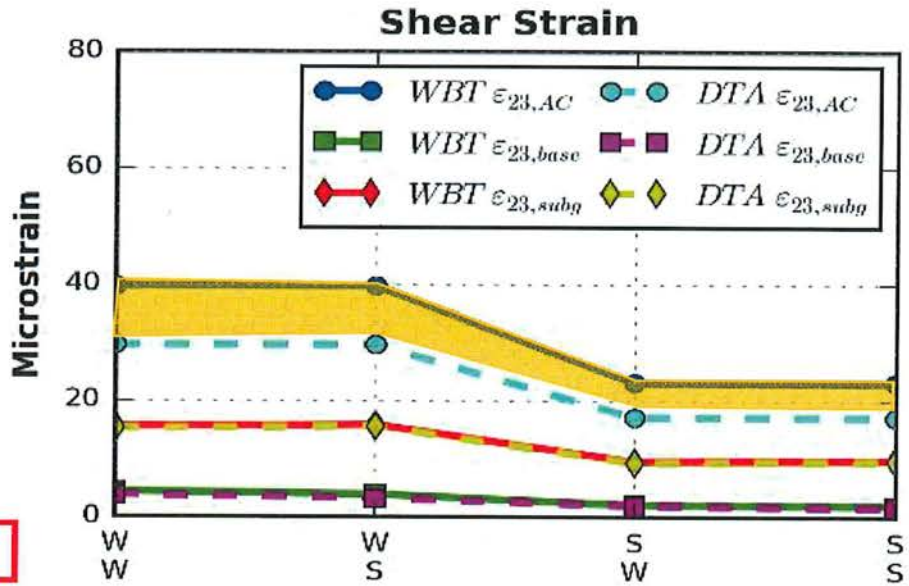


- Vary AC and base layer thicknesses
  - AC: 5 & 16 in (125 & 412.5 mm)
  - Base: 6 & 24 in (150 & 600 mm)
- Constant *weak* AC and base materials
- NG-WBT > DTA wherein disparity greater at *thinner* structure

Effect of Material

Tire type	WBT and DTA
Inflation pressure	44 kN
Load	758 kPa
AC thickness	412 mm
Base Thickness	150 mm

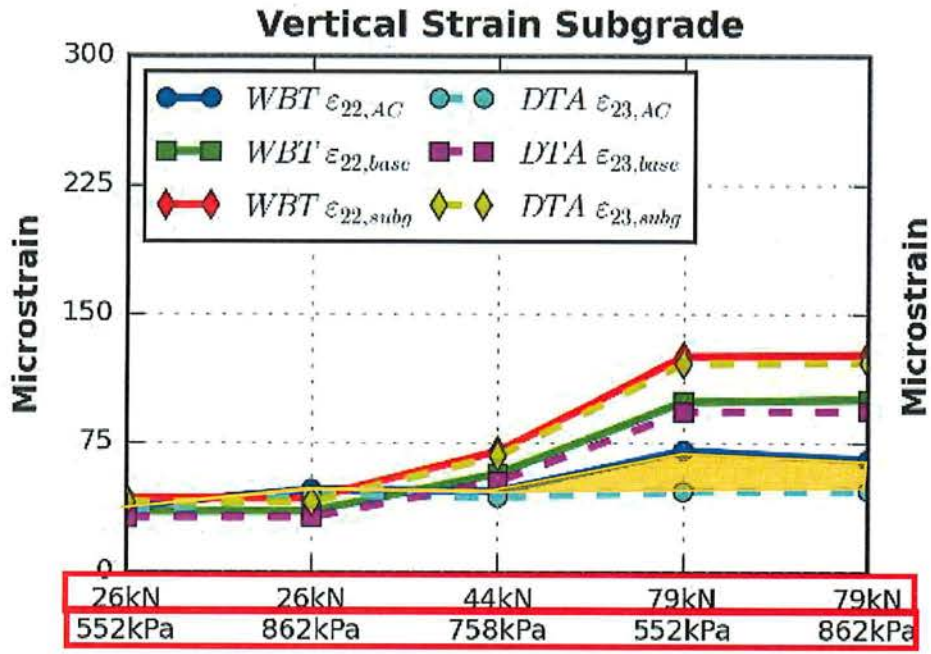


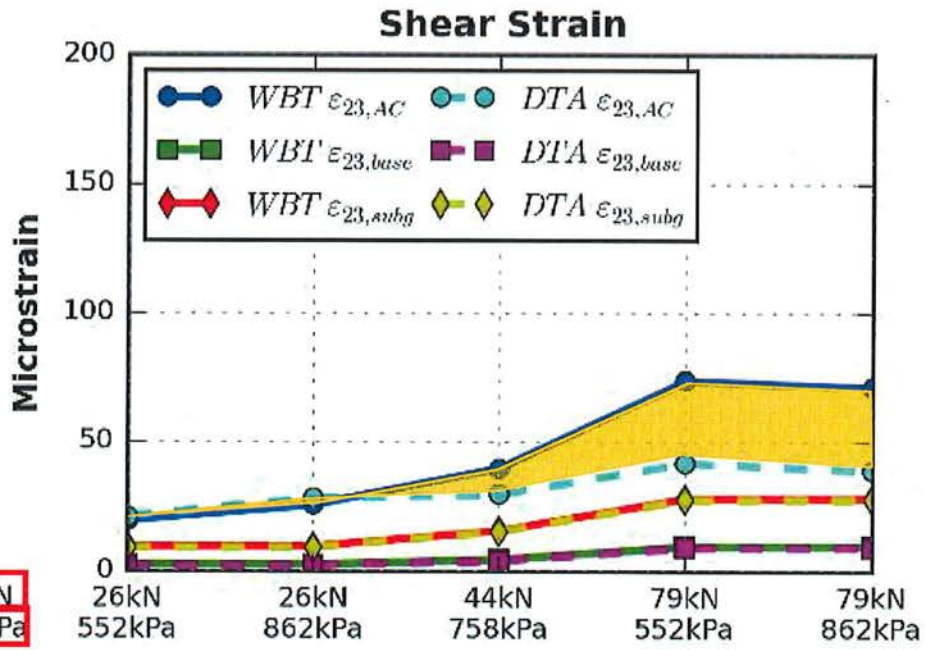


- Tire type did not show difference in vertical strains
- Vertical strain values were highest within subgrade and highly affected by base material
- Shear strain values within AC were highest, which affect near surface crack development

Effect of Load

AC thickness	412 mm
Base Thickness	150 mm
AC Material	Weak
Base Material	Weak





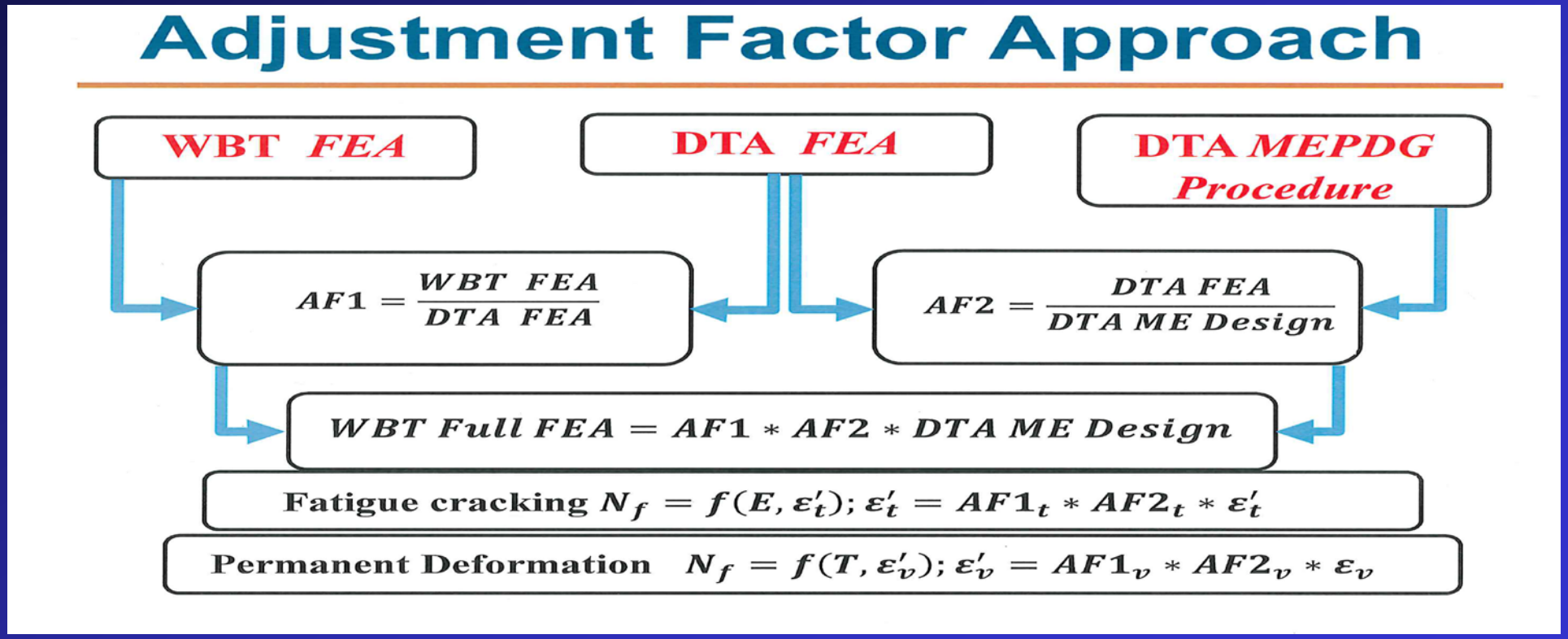
- Increasing load results in greater impact than increasing inflation pressure
- Greater effect on AC layer's vertical and shear strains than other responses within base layer

Remarks on Pavement Responses

- NG-WBT loading results in greater pavement responses than DTA loading
- Response difference between NG-WBT and DTA is reduced with depth
- Thin pavement:
  - The highest difference between NG-WBT and DTA was observed for $\varepsilon_{33,ac}$
  - $\varepsilon_{23,sg}$ provided the smallest discrepancy between both tires (in some case; it was higher for DTA)
- Thick pavement:
  - Greatest response difference in least structural capacity
  - Effect at near-surface is evident as indicated by $\varepsilon_{23,ac}$ and $\varepsilon_{22,ac}$

Proposed Damage Calculation under WBT

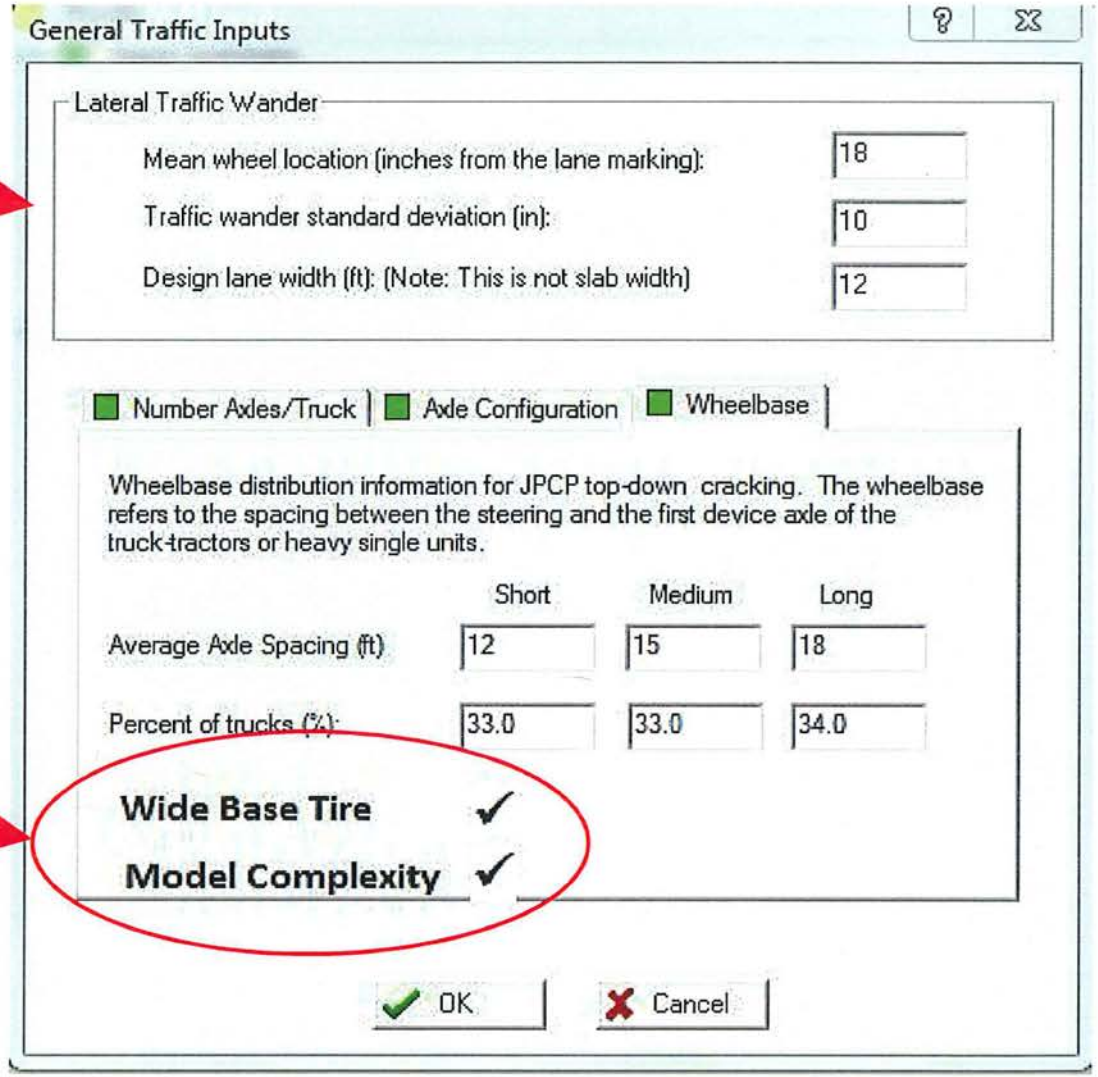
- MEPDG is selected for fatigue and rutting damage calculation
- MEPDG can not handle WBT and assumes loading over a circular area.



Adjustment Factor Implementation

Current MEPDG Window

Proposed addition



UIWide Software

- Compared Dual Tire Axle (DTA) & Wide-Base Tire (WBT)
- Axle load: 20,000 lbs
- Tire Pressure: 105 psi

UIWide Software

- **HMA**
  - Thickness: 4”
- **Aggregate Base (Class 5)**
  - Thickness: 17”
  - Modulus: 35,640 psi
- **Subgrade (CL)**
  - Modulus: 14,000 psi

UIWide Software

- **Level 1**
  - Uses a variable modulus default value
- **Level 2**
  - Uses one modulus default value
- **Used weak default settings**

UIWide Software

Level 1, Weak Default										
	Surface Strain		AC Strain, Bttm		Vert. Strain			Shear Strain		
Tire	Long.	Trans.	Long.	Trans.	AC	Base	SG	AC	Base	SG
WBT	76	62	242	214	246	1,576	297	126	520	204
DTA	55	42	194	165	208	1,414	57	90	406	188
	39%	48%	25%	30%	18%	12%	417%	40%	28%	9%

UIWide Software

Level 2, Weak Default										
	Surface Strain		AC Strain, Bttm		Vert. Strain			Shear Strain		
Tire	Long.	Trans	Long.	Trans.	AC	Base	SG	AC	Base	SG
WBT	116	132	471	551	776	1,293	411	155	593	328
DTA	107	132	496	497	701	1,197	367	115	464	247
	9%	0%	-5%	11%	11%	8%	12%	35%	28%	33%

UIWide Software

Comparing Leve 1 & 2 using Weak Default Values										
	Surface Strain		AC Strain, Bttm		Vert. Strain			Shear Strain		
Level	Long.	Trans	Long.	Trans.	AC	Base	SG	AC	Base	SG
1	39%	48%	25%	30%	18%	12%	417%	40%	28%	9%
2	9%	0%	-5%	11%	11%	8%	12%	35%	28%	33%

Thank you!