Impacts of Wide-Base Tires on Pavement Performance

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Jaime Hernandez
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Agenda

- 2:00 – 2:05 Software Instructions: Lisa Marflak/Andrew Bevington
- 2:05 – 2:10 Introduction: Eric Weaver, FHWA
- 2:10 – 2:25 Introduction and Background on Wide-Base Tires: Imad Al-Qadi, UIUC
- 2:25 – 2:40 Tire-Pavement 3D Contact: Imad Al-Qadi, UIUC
- 2:40 – 3:00 Pavement Modeling and Impact of 3D Moving Tire Loading: Jaime Hernandez, UIUC
- 3:00 – 3:15 Failure Prediction Considering Contact Stress Variations: Hao Wang, Rutgers
- 3:15 – 3:25 Cost Impact of Using Wide-Base Tires: Hao Wang, Rutgers
- 3:25 – 3:35 Ongoing Work and Final Remarks: Imad Al-Qadi, UIUC
- 3:35 – 4:00 Question: Trenton Clark

Introduction

Eric Weaver

Introduction and Background on Wide-Base Tires

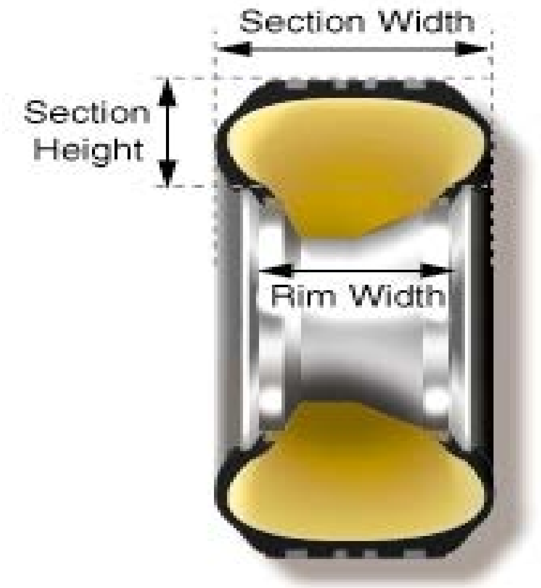
Imad Al-Qadi

Wide-Base Tire

WBT 445/50 R22.5

DTA 275/80 R22.5

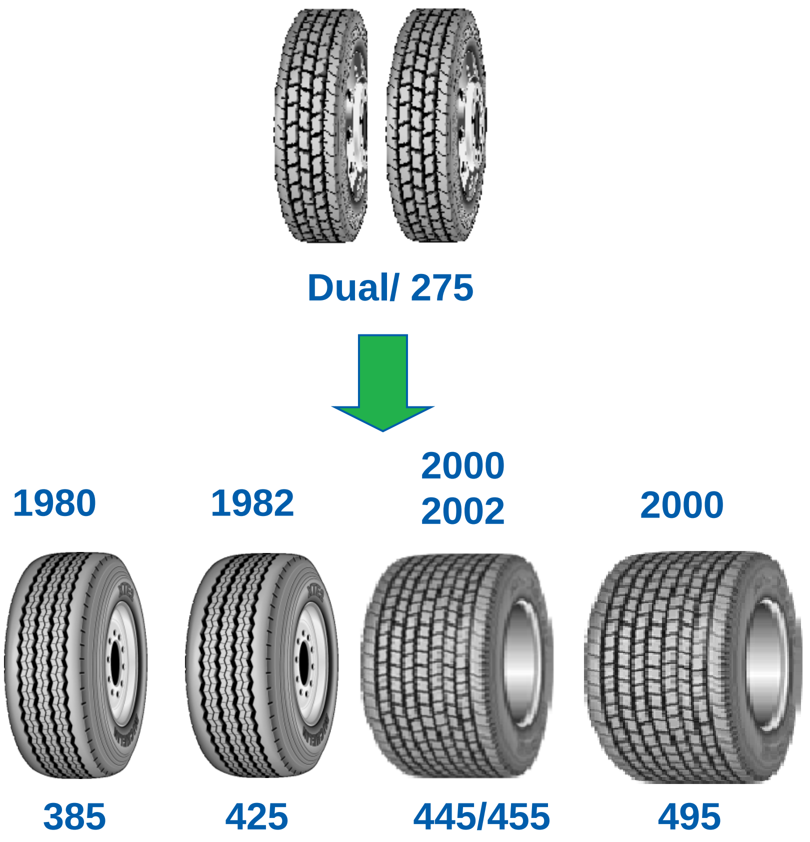
Wide-Base Tire



- **Wide-Base Tire**
  - Nominal tire width 400~460 mm
  - Low Profile
  - 385/65R22.5; 425/65R22.5; 455/55R22.5
- **Dual Tire**
  - Nominal tire width 250~305mm
  - High Profile
  - 12-22.5; 12R22.5; 275/80R22.5
- **Code**
  - Tire width (mm)/ tire aspect ratio (the ratio of section height to width)/ radial ply (R)/ rim diameter code (in)

Wide-Base Tire

- **Introduced to North America in 1982**
- **Low profile design**
- **Earlier design was for on- and off-road**
- **Relatively reduced empty weight**
- **Efficient fuel consumption**



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
- Earlier generation of wide-base tires were proven more detrimental to flexible pavement systems than regular dual tires

Impact of Wide-Base Tires on…

- **Road Infrastructure**
  - Accelerated pavement testing
  - Numerical modeling and analytical methods
- **Dynamic Tire Loading**
- **Trucking Operation**
  - Fuel economy; hauling capacity; tire cost and repair; safety; ride and comfort
- **Environment**
  - Gas emissions; tire recycling; noise

Impact on Road Infrastructure

- **First Generation WBT (FG-WBT)**
  - **Finland: FG-WBT caused 1.2 to 1.4 times the damage by DTA[1]**
  - **Virginia: FG-WBT produced 2 times greater permanent deformation and 25% less fatigue life[2]**
  - **Pennsylvania: FG-WBT resulted in 50-70% greater damage[3]**
  - **California: Overlay systems - Number of repetitions to failure was 50-70% lower[4]**

1. Huhtala, 1986; 1989
2. Bonaquist, 1992
3. Sebaaly and Tabatabaee, 1992
4. Harvey and Popescu, 2000

Impact on Road Infrastructure

- Europe[1]:
  - UK: WBT-495 caused 50-70% more rutting than WBT-385 for thin and medium-thick flexible pavements, respectively
  - Germany: WBT-495 produced 30% greater rutting than DTA (315/80R22.5) for thick pavements
  - France: No significant difference between tires when using very thick and stiff pavements
  - Finland: WBT-495 greater response when considering dynamic loading

1. COST 334, 2001

Impact on Road Infrastructure

- New Generation WBT
  - Virginia Smart Road[1]: Combined damage ratio showed NG-WBT and DTA had similar overall damage
  - Canada[2]: Comparison of damage depended on environmental conditions
  - Illinois[3]:
    - High-volume roads: WBT-425 more damaging than WBT-455
    - Low-volume roads: NG-WBT more damaging
  - Florida[4]: WBT-455 tire performed as good or better than DTA in rutting and cracking

1. Al-Qadi et al., 2001-2005
2. Pierre et al., 2003
3. Al-Qadi and Wang, 2009, 2009a
4. Greene et al, 2009

Impact on Dynamic Tire Loading

- WBT is **more flexible** than DTA (two walls instead of four)
- Transmissibility[1]:
  - WBT-425 has **less transmissibility** than DTA
  - Transmissibility is not affected by **load** and slightly affected by **tire-inflation pressure**
- WBT produced a **dynamic load coefficient between 10 and 12%** lower than that of DTA[2]

1. Tielking, 1994
2. Streit et al., 1998

Impact on Trucking Operation

- **Truck's fuel consumptions:**

aerodynamic drag

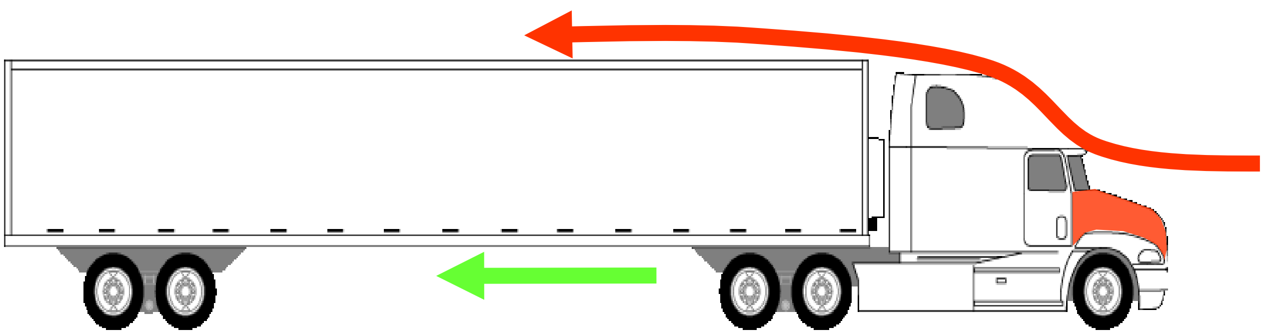
At 60 mph (100 kmh), aerodynamic drag consumes approximately 40% of the fuel

mechanical losses

Mechanical losses consume approximately 25% of the fuel

rolling resistance

Rolling resistance accounts for approximately 35% of the fuel consumed



Impact on Trucking Operation

- WBT reduces rolling resistance coefficient (10% greater fuel efficiency)[1]
- WBT combined with aerodynamic devices can improve fuel efficiency by 18%[2]
- Hauling companies reported savings between 3.5 and 12% in gas[3]
- Fuel consumption is reduced by 10% (instrumented trucks were used)[4]

1. Muster, 2000
2. Bachman et al., 2005
3. Genivar, 2005
4. Franzese, 2010

Impact on Trucking Operation

- **Hauling Capacity: WBT is lighter; hauling capacity is increased**[1]
- **Tire Cost and Repair: WBT is easier to inspect, repair, and maintain**[2]
- **Safety: WBT has similar or slightly better performance after sudden-air-loss test**[1]
- **Ride and Comfort: WBT reduces vibration; WBT and DTA require similar degree of handling**[1]

1. Markstaller, 2000
2. Genivar, 2005

Impact on Environment

- Gas Emissions:
  - Reduction in emissions due to less gas consumption[1,2]
  - Reduction in NOx emission (9-45%)[3]
- Tire Recycling: savings if WBT was disposed instead of DTA[1]
- Noise is slightly reduced when using WBT[4]

1. Genivar, 2005
2. Ang-Olson, 2002
3. Bachman, 2005
4. Markstaller, 2000

Summary

- WBT advantages over DTA include:
  - Fuel savings
  - Increase hauling capacity
  - Environment friendly
- FG-WBT were proven to be more damaging than DTA
- Damage between NG-WBT and DTA needs to be further studied

Tire-Pavement 3D Contact

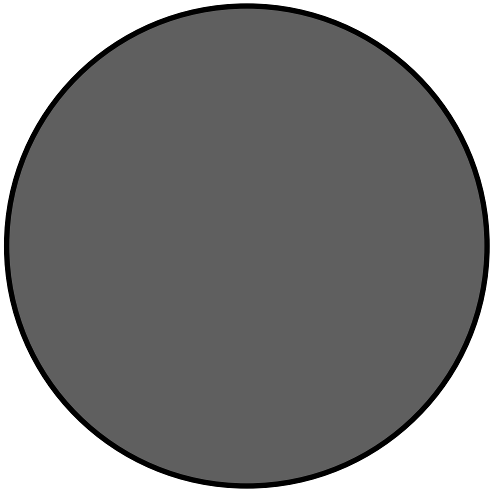
Imad Al-Qadi

Tire-Pavement 3D Contact

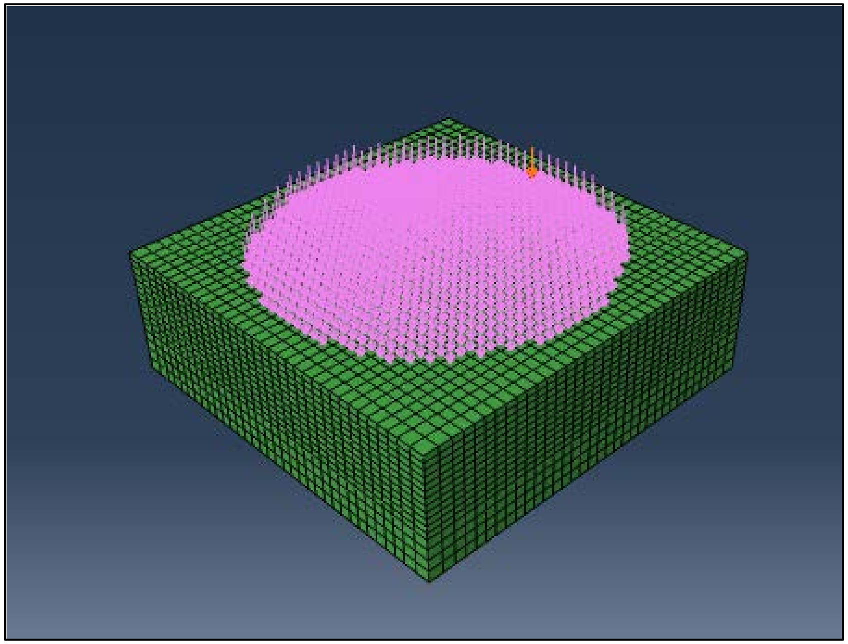
- Conventional pavement analysis assumptions includes:
  - Circular tire-pavement contact area
  - Contact stresses in the vertical direction only
  - Uniform contact stresses
  - Static loading
- Conventional analysis cannot compare WBT and DTA

Contact Area

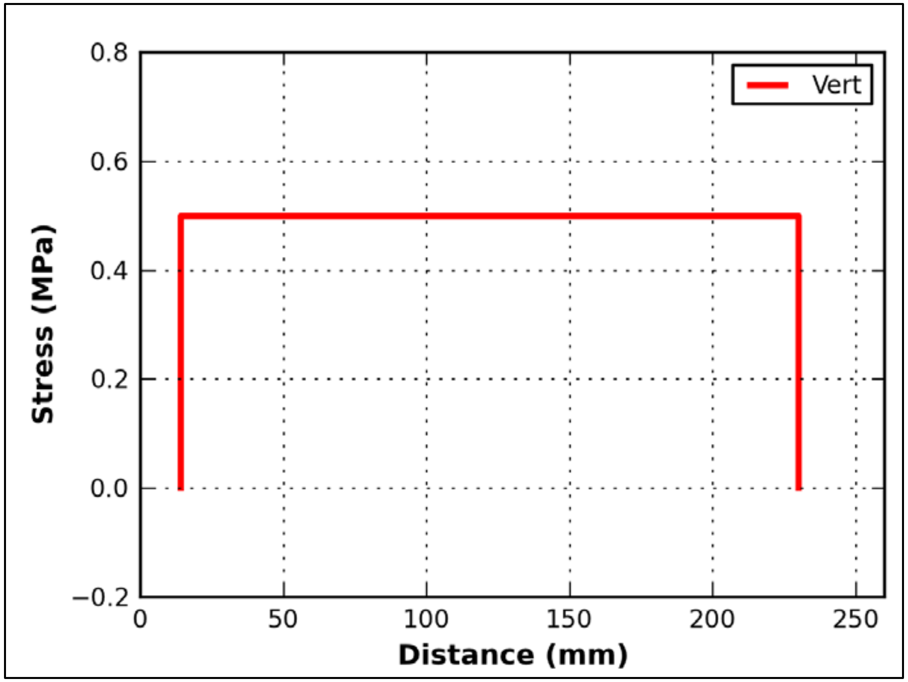
- Circular contact area does not accurately represent the actual geometry of the tire-pavement contact

Circular Contact Area	Actual Contact Area
	

Stress Distribution

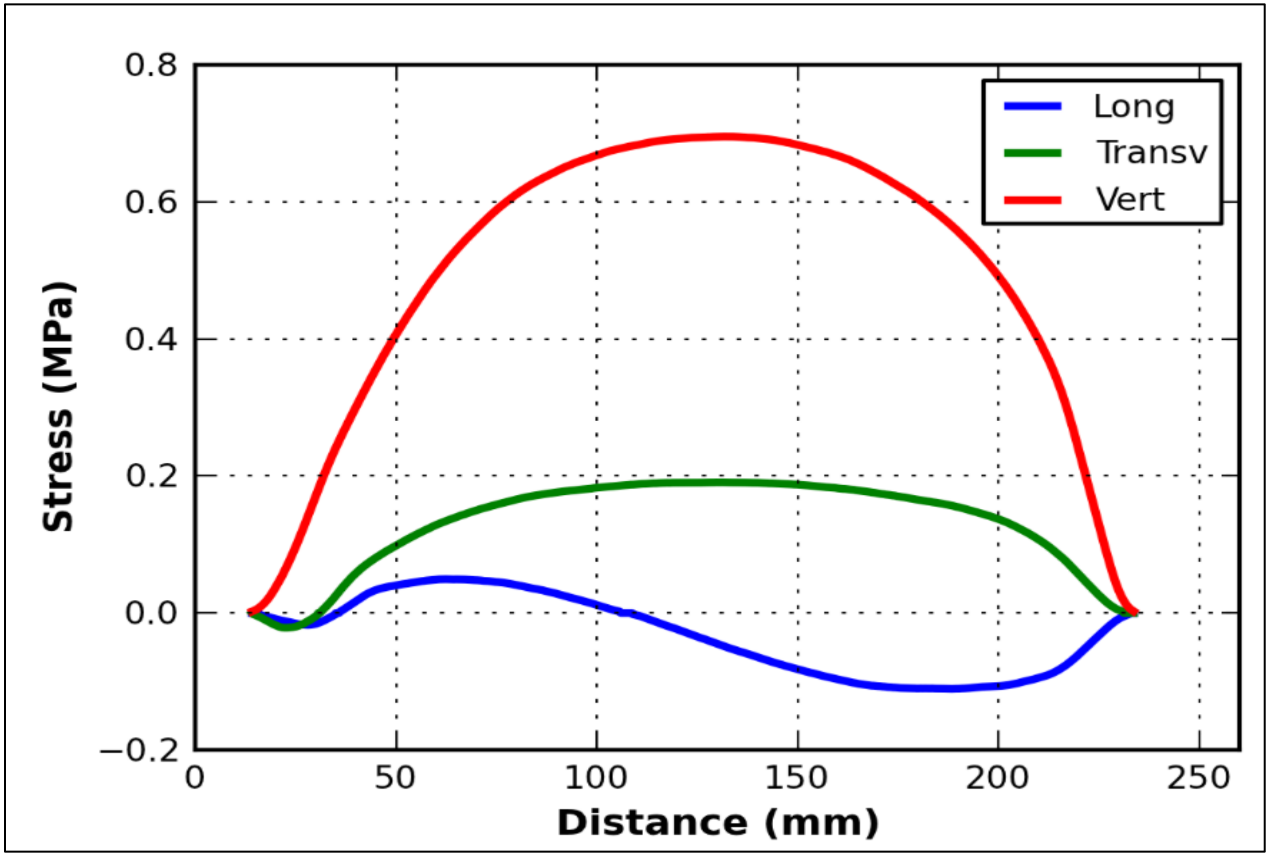


Conventional Assumption: Uniform magnitude and vertical direction only

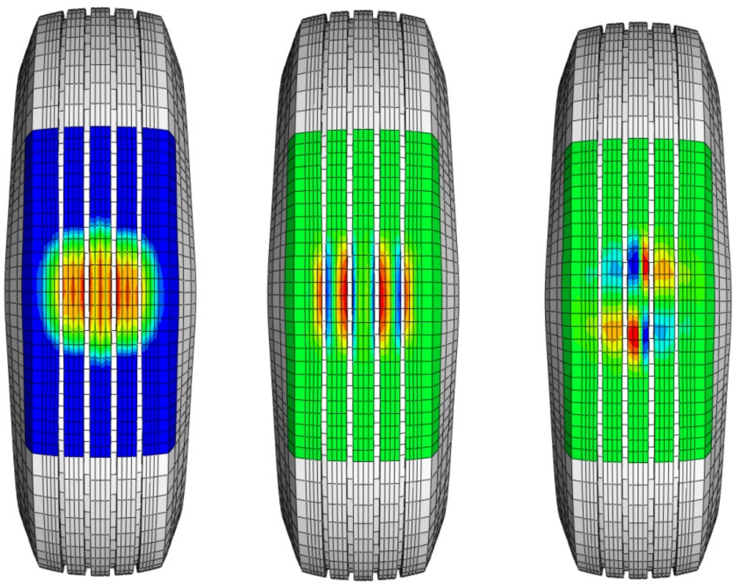


Stress Distribution

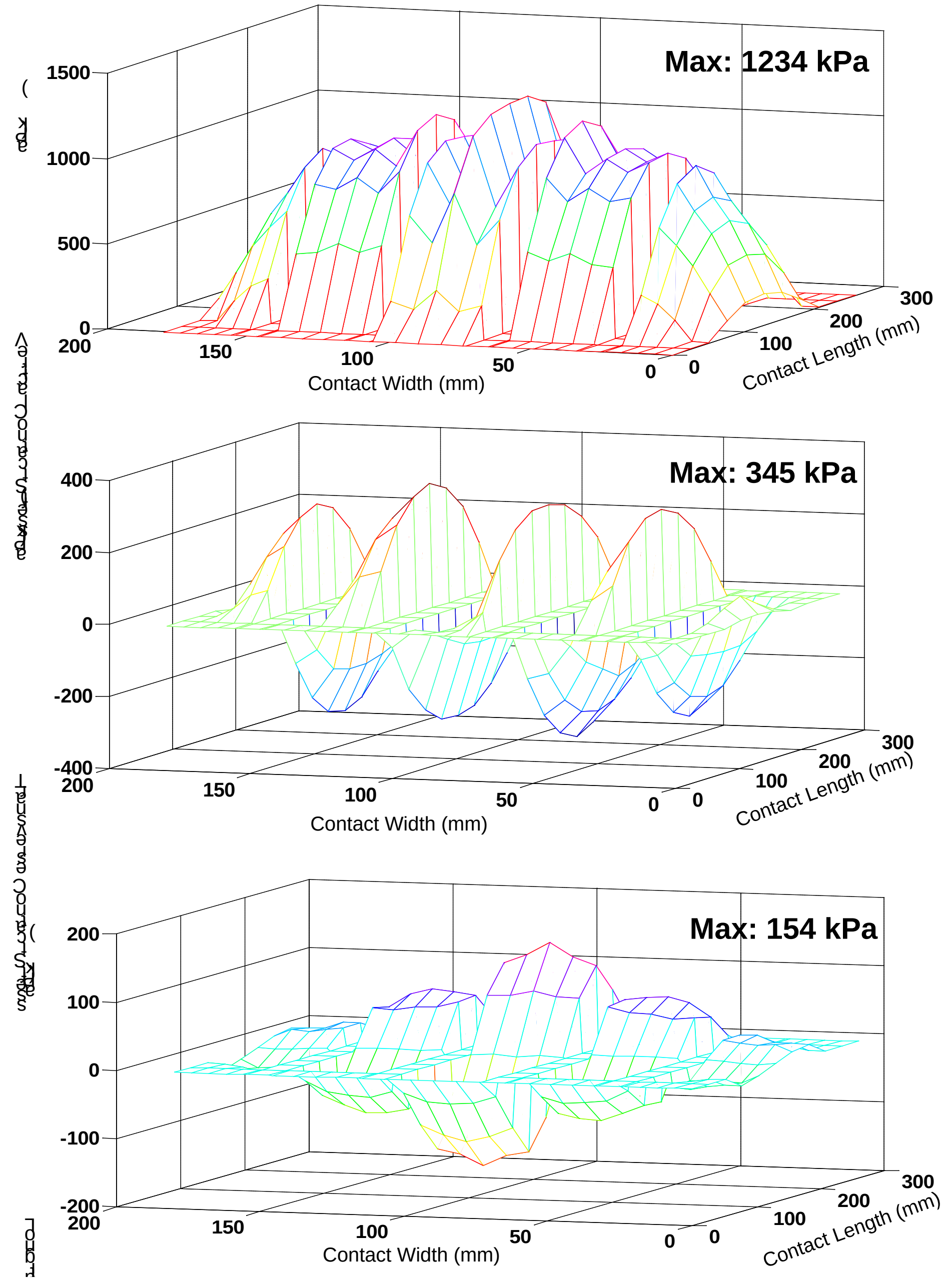
Actual Distribution: Nonuniform magnitude and three-dimensional



3-D Contact Stresses



Vertical Transverse Longitudinal

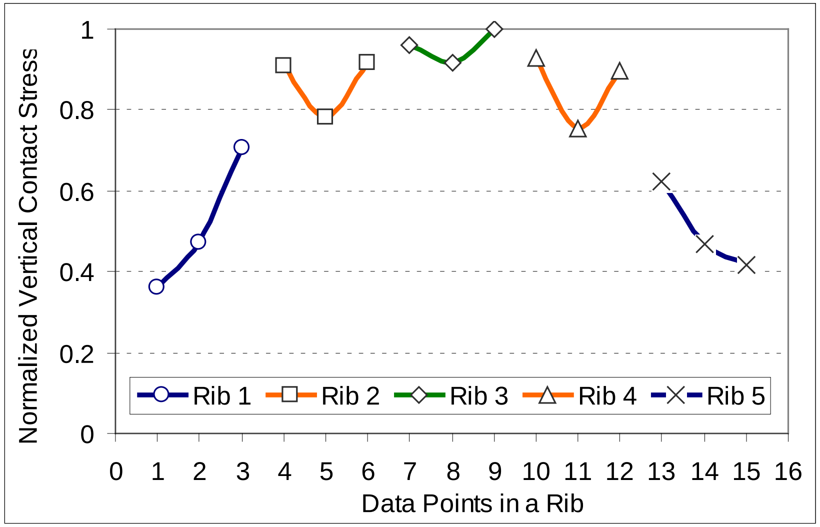


(17.8kN and 724kPa)

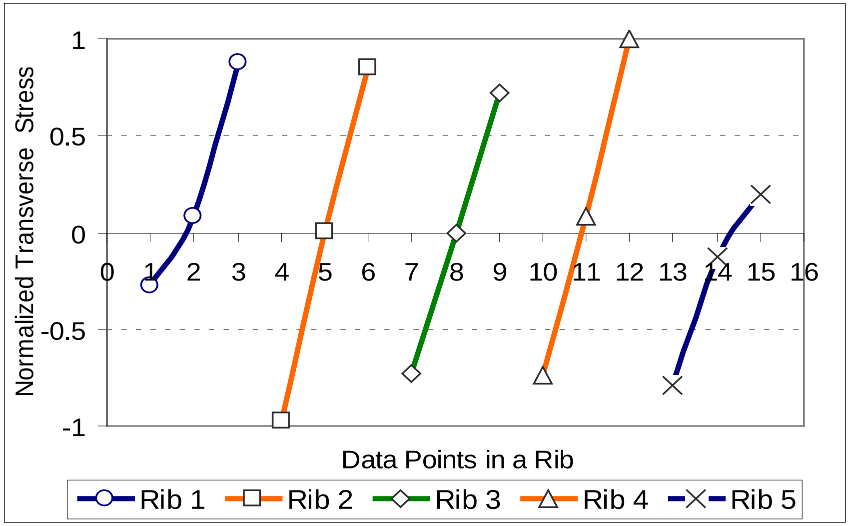
Stress Distribution

- Contact stresses across the tire

Vertical



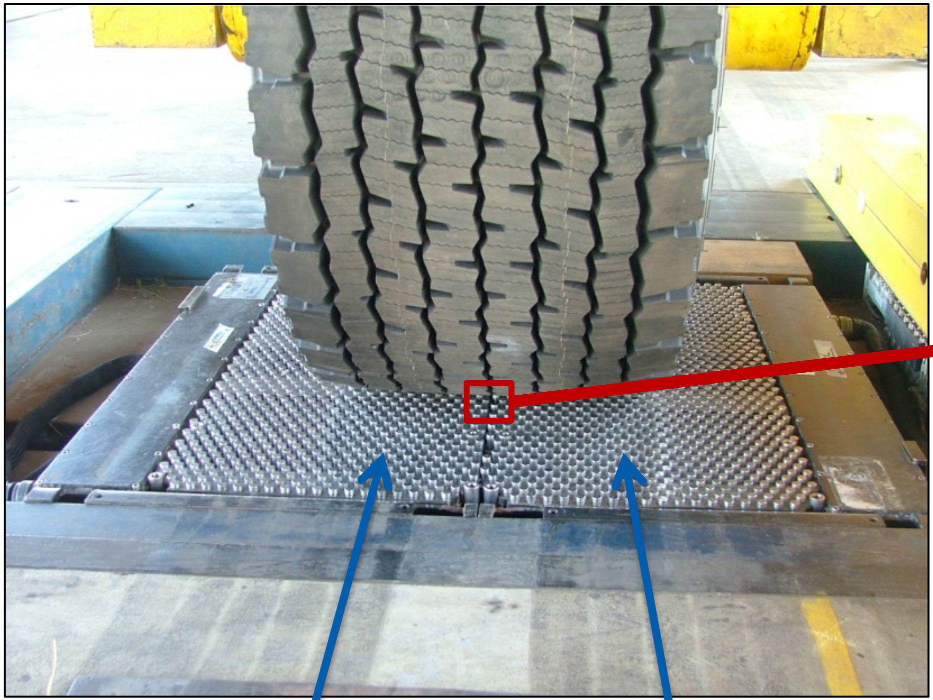
Transverse



3D Contact Stresses

- **3D contact stresses are crucial to compare effect of WBT and DTA on pavement and the resultant damage**
- **Two alternatives to determined 3D contact stresses:**
  - **Experimental Measurements**
  - **Modeling**

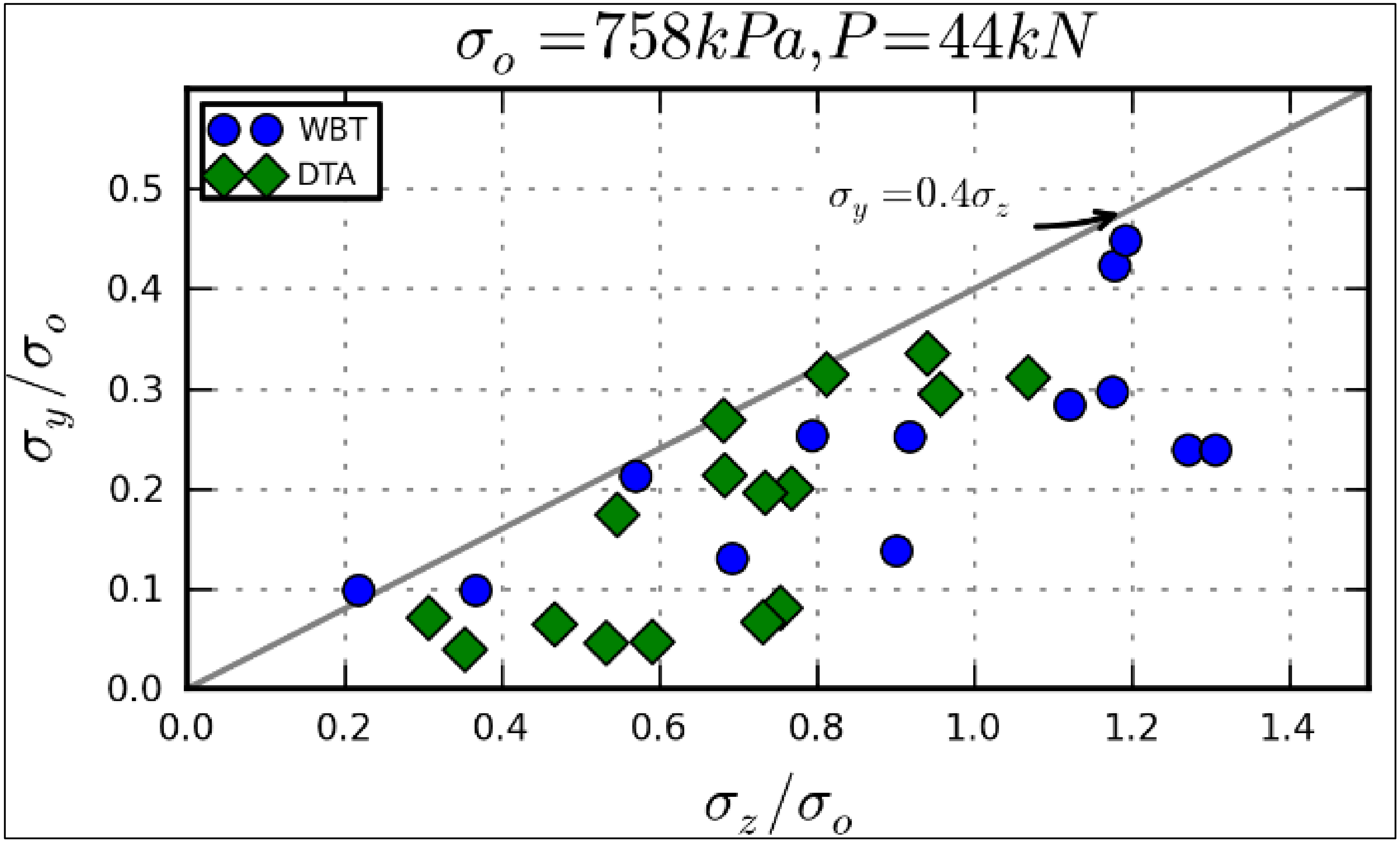
Measurement of 3D Contact Stresses



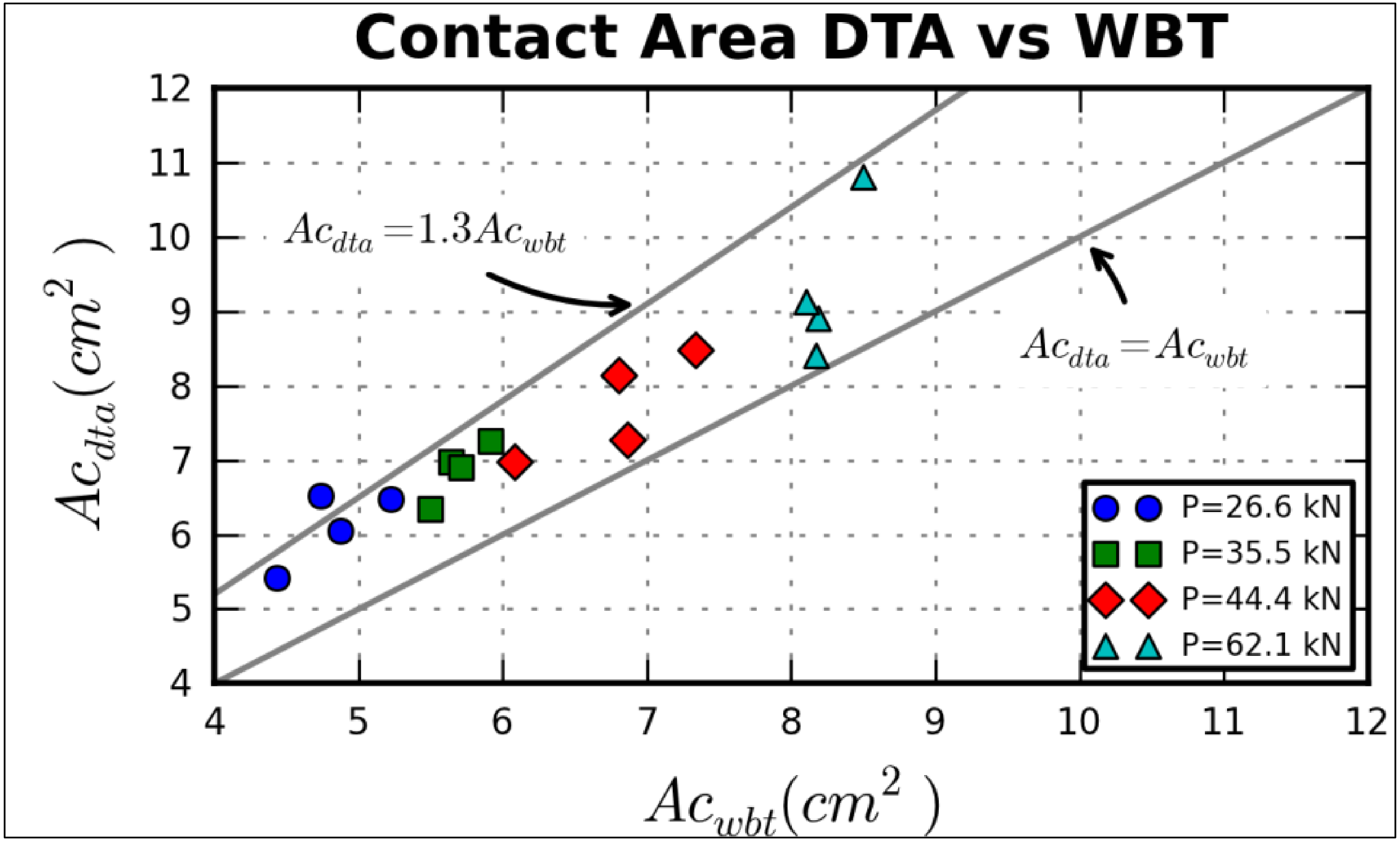
Pad Assemblies

Relevance of in-Plane Stresses

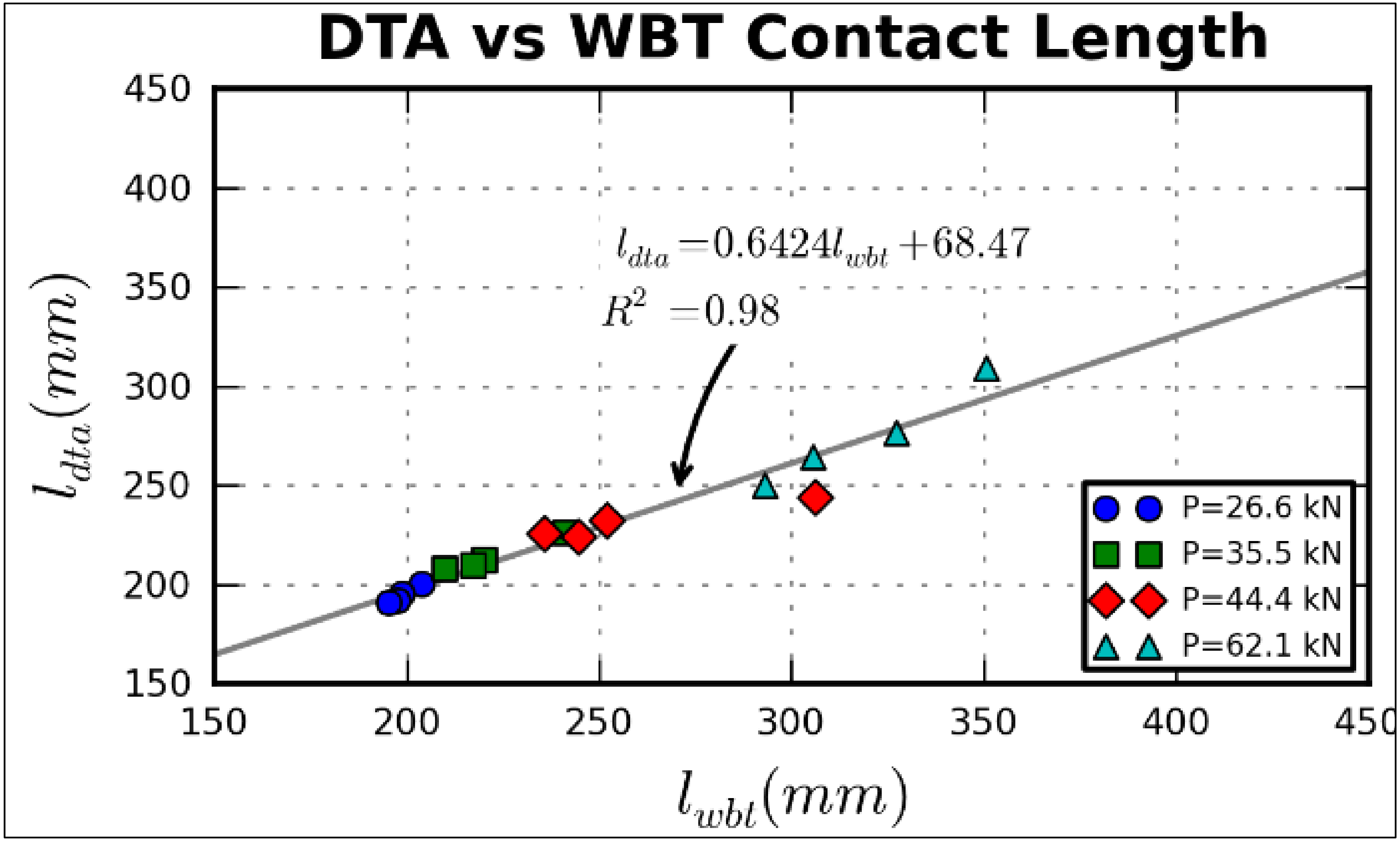
Transverse Contact Stresses



DTA vs WBT: Contact Area



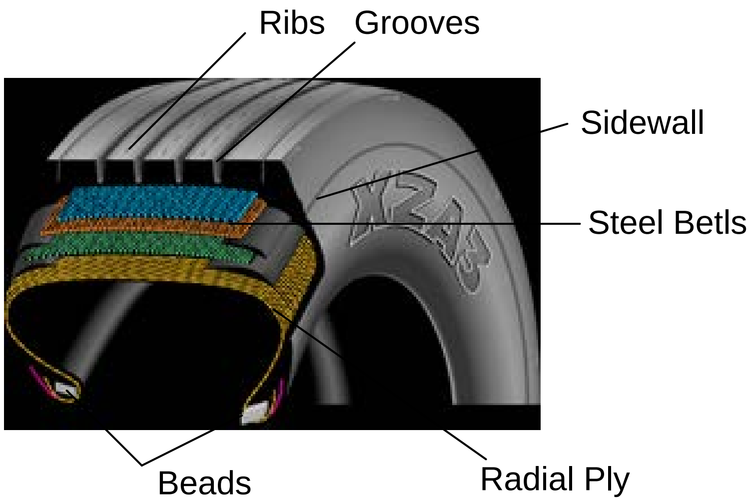
WBT vs DTA: Max. Contact Length

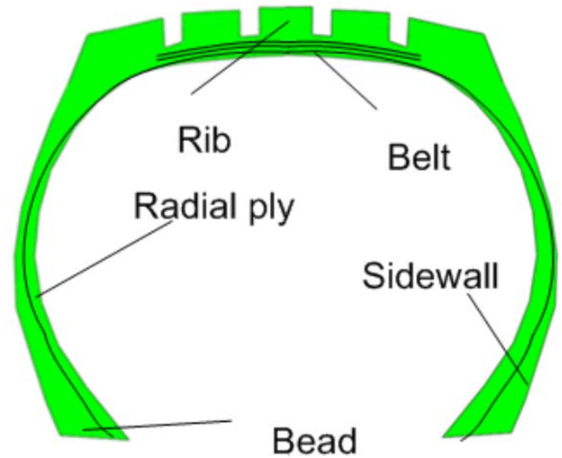


Tire Modeling

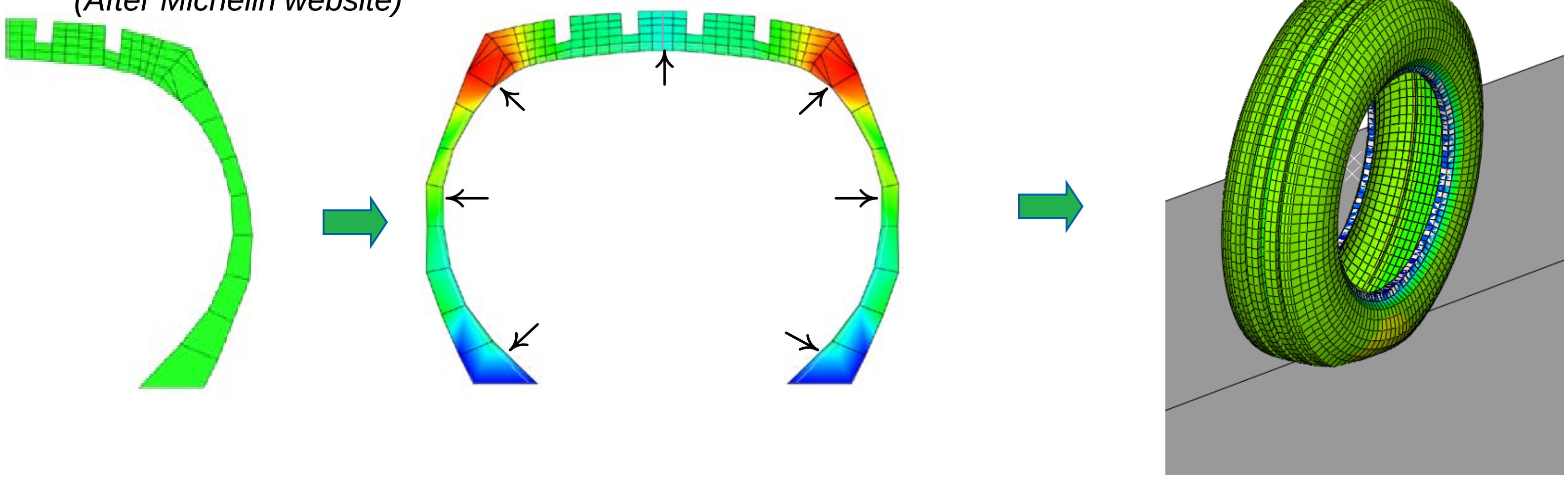
- Allows characterizing tire-pavement contact under various scenarios
  - Different loading cases
  - Rolling conditions: Braking, accelerating, cornering
- Utilize experimental measurements for validation

Simulation Process

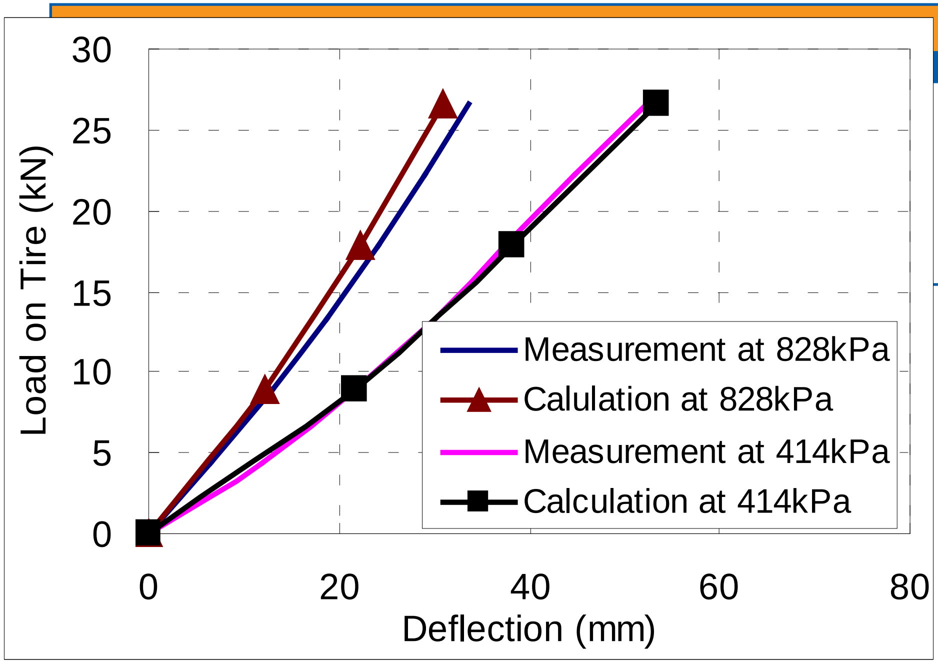


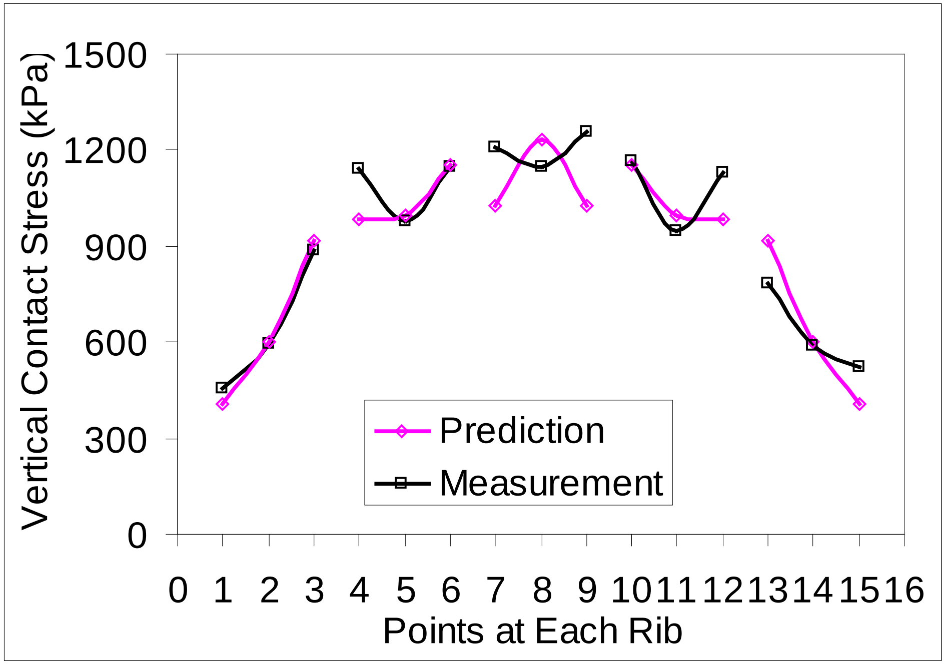


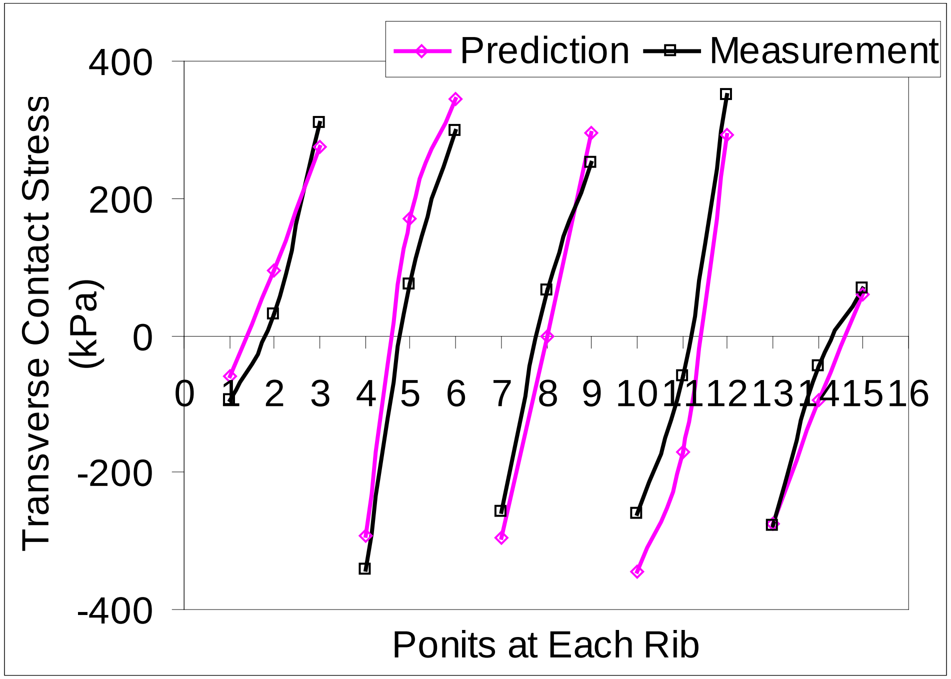
(After Michelin website)



Comparison between Prediction and Measurements







Summary

- Conventional pavement analysis does not properly consider **tire-pavement interaction**
- Tire-pavement **load-transfer** mechanism depends on **tire type**

Pavement Modeling and Impact of 3D Moving Tire Loading

Jaime Hernandez

Pavement Modeling

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

Pavement Modeling

	Conventional	3D FEM
AC Materials	Linear elastic	Viscoelastic
Granular Materials	Linear elastic	Nonlinear cross-anisotropic (stress- and direction-dependent)
Loading Area	Circular	Versatile
Loading	Static	Static/ dynamic and 3D
Layer Interaction	NO	YES

Dynamic Analysis

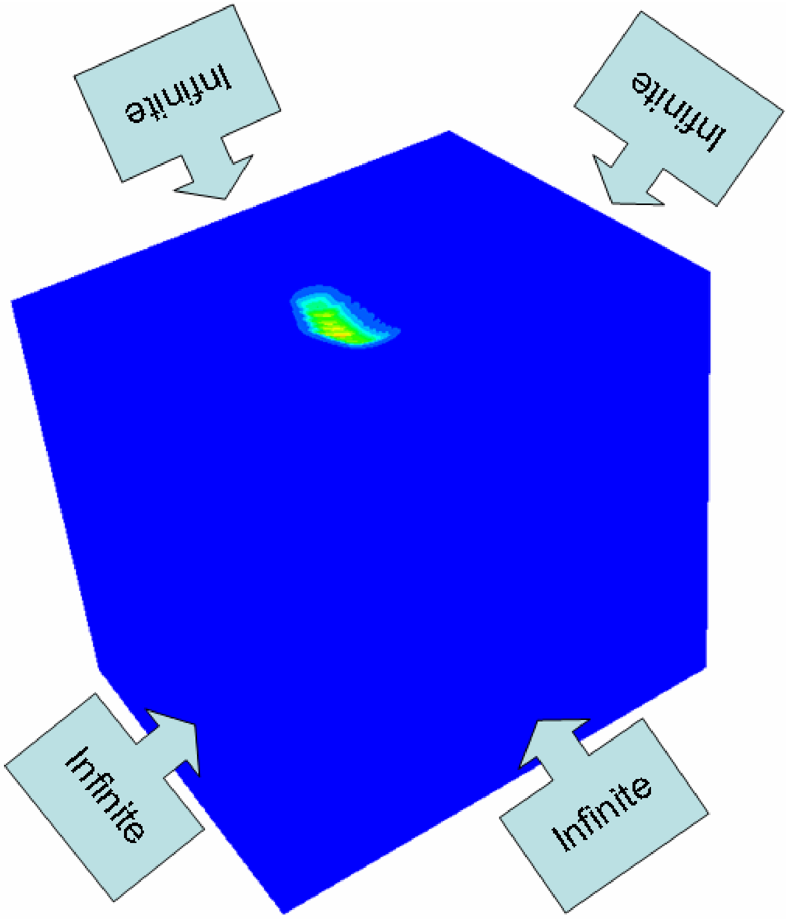
- Considers mass inertia and damping forces effect on pavement response
- Different contact areas of tire imprint can affect inertia force values
- Pavement response is affected by loading amplitude

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

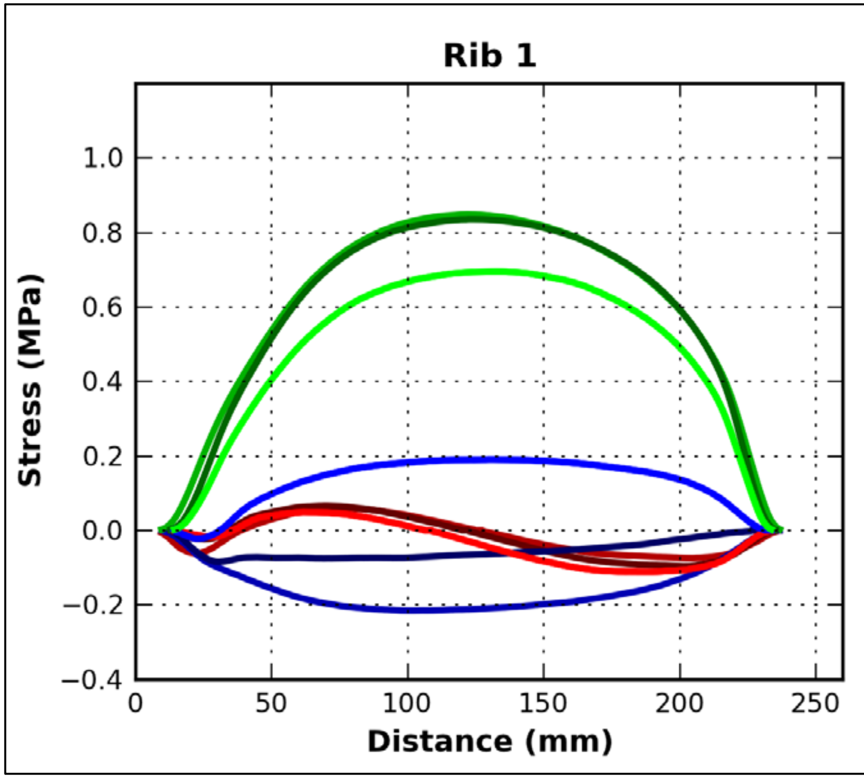
Boundary Conditions and Layer Interaction

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



3D Contact Stresses

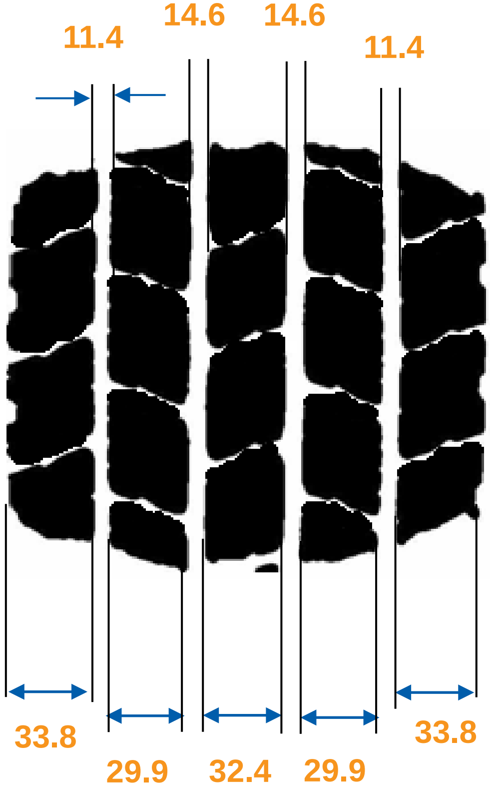
- Uniform constant stresses underestimate response close to surface
- 3D contact stresses may create greater compressive strain on top of subgrade and transverse tensile strain



3D Contact Stresses

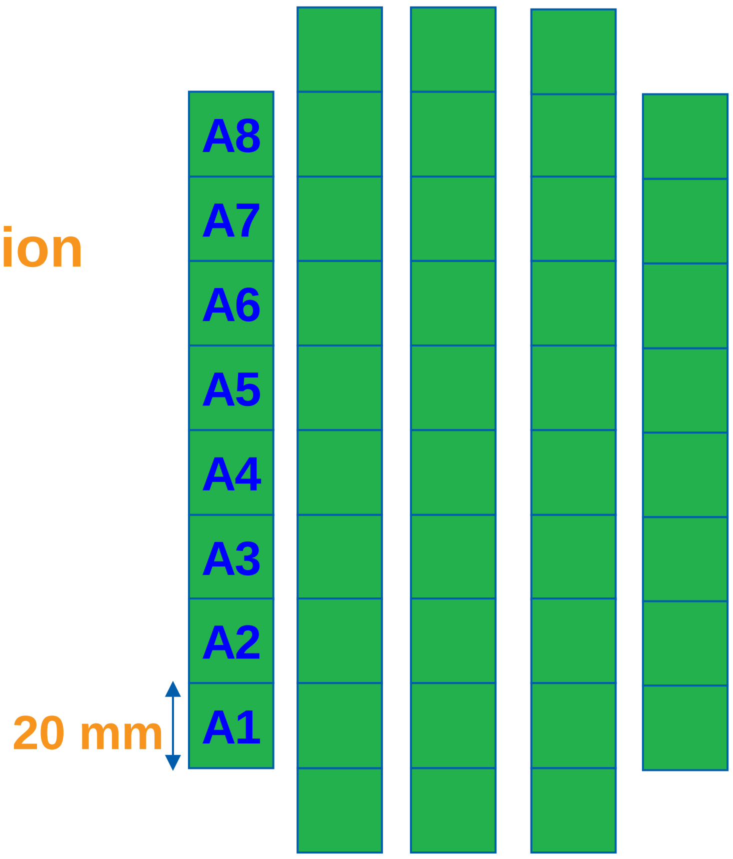
□ Discretization of tire footprint

Measured Imprint (mm)

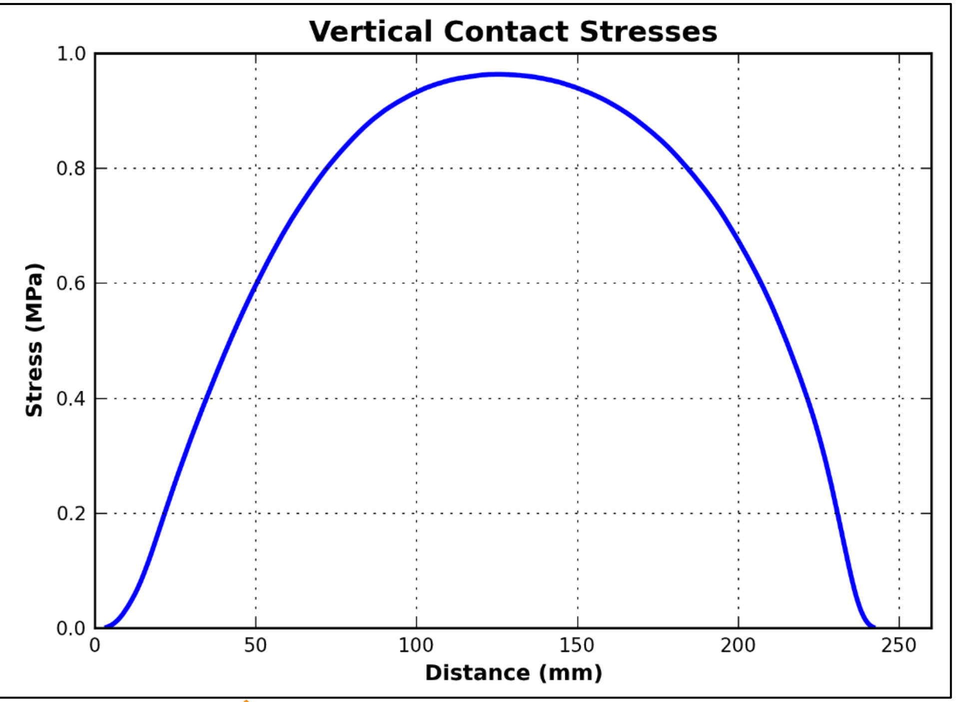


Discretization into FE

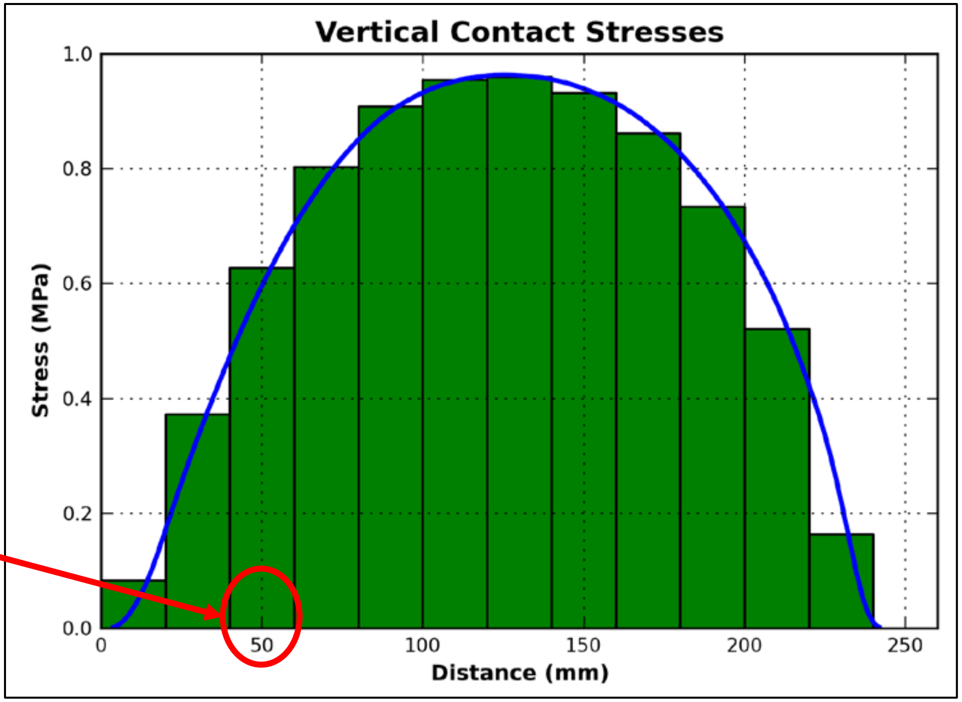
Discretized Imprint Finite Element



3D Contact Stresses



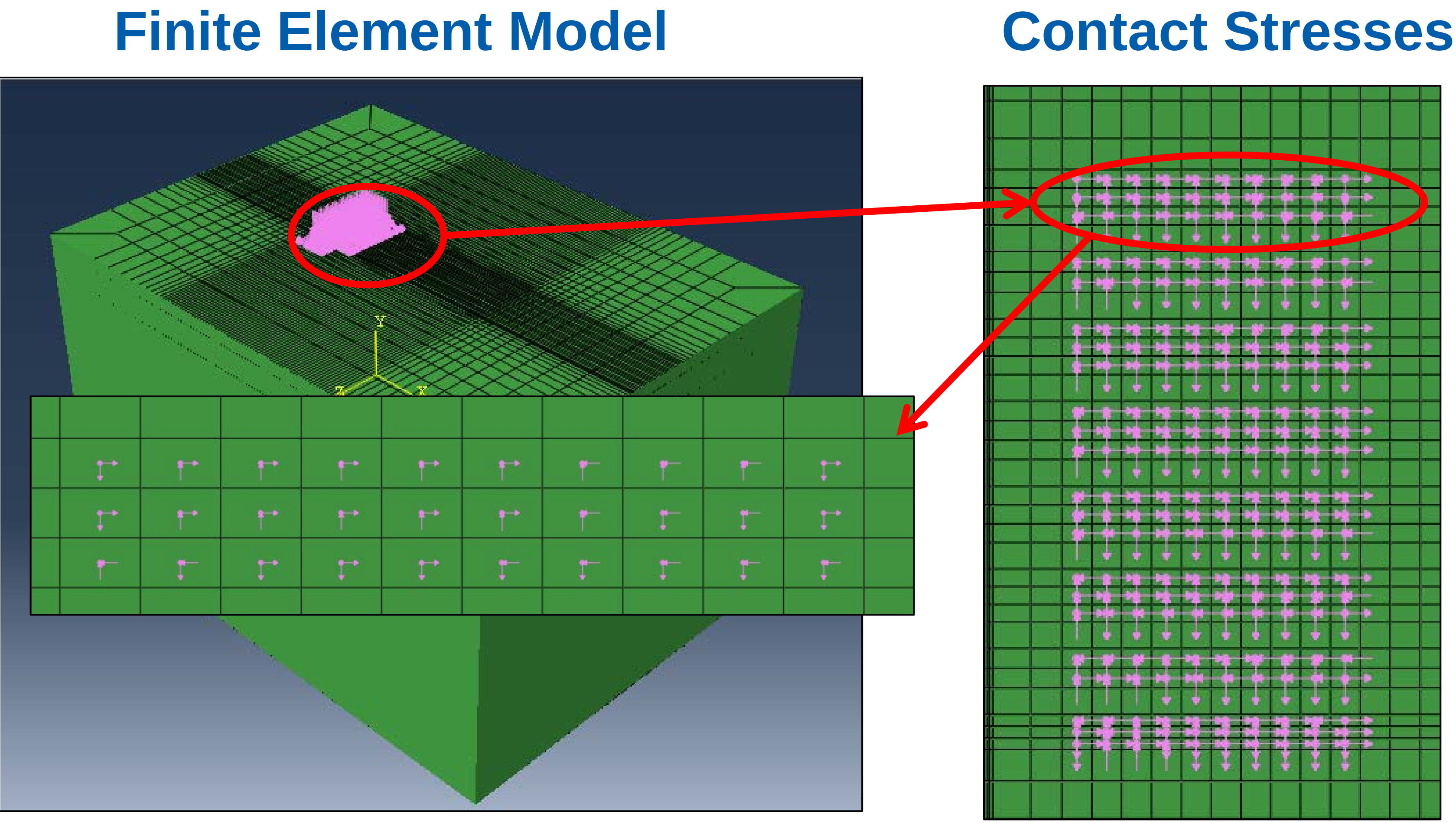
Measurements



Footprint's element size in plain view (20 mm)

FEM Input

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



Moving Loading

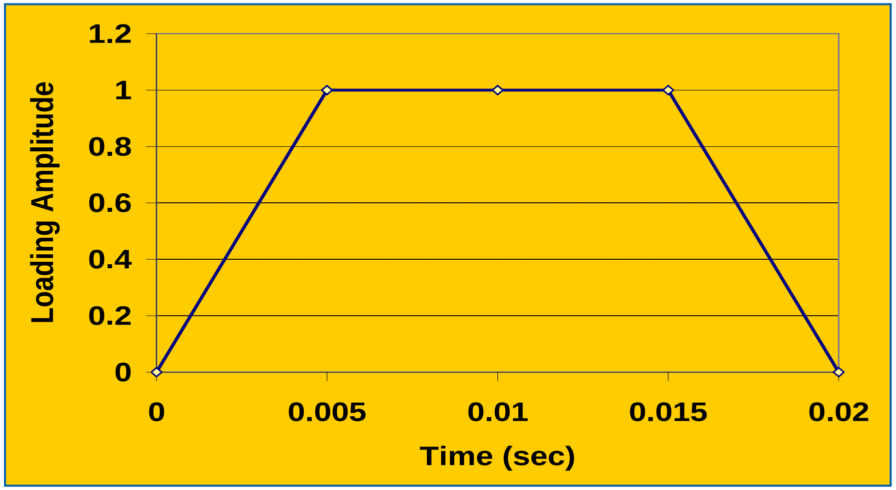
- Applied tire-loading is **moving**, not stationary
- Loading **amplitude** continuously changes
- Dynamic tire force is excited by **pavement irregularities** *(& vehicle suspensions)*
- **3D stress state** at tire-pavement interface

➡ **The nature of vehicle loading is critical to pavement response!**

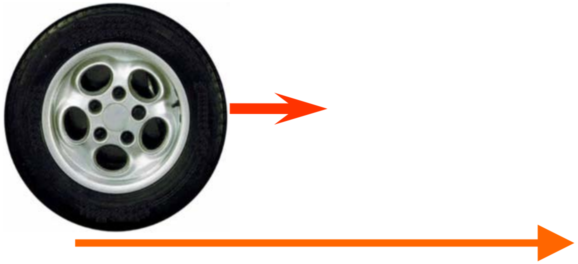
Moving Load

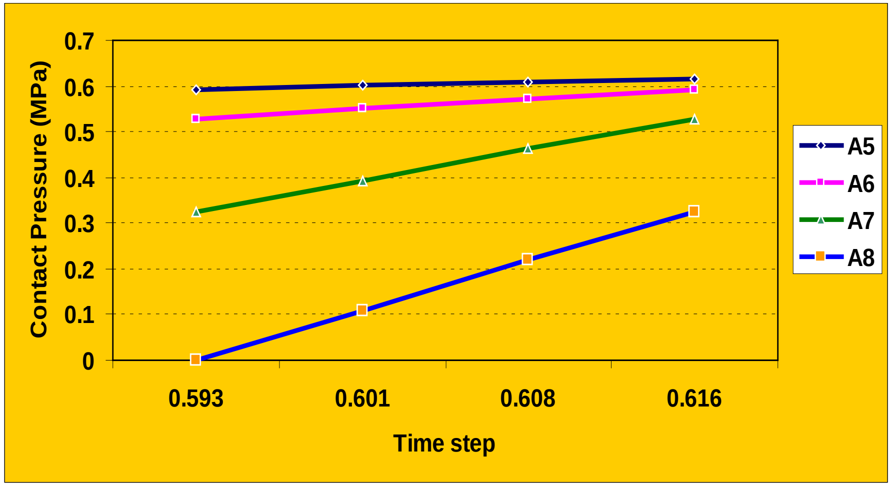
- Traditional method
  - Triangular, trapezoidal, rectangular amplitude in constant loading area
  - Pavement at different depths have same loading time
  - Impulsive loading (hammering)
- Continuous loading
  - Loading area changes as tire moves
  - Loading amplitudes are linearly varied with time for the entrance and exit parts of tire imprint

Continuous Moving Loading



Trapezoidal





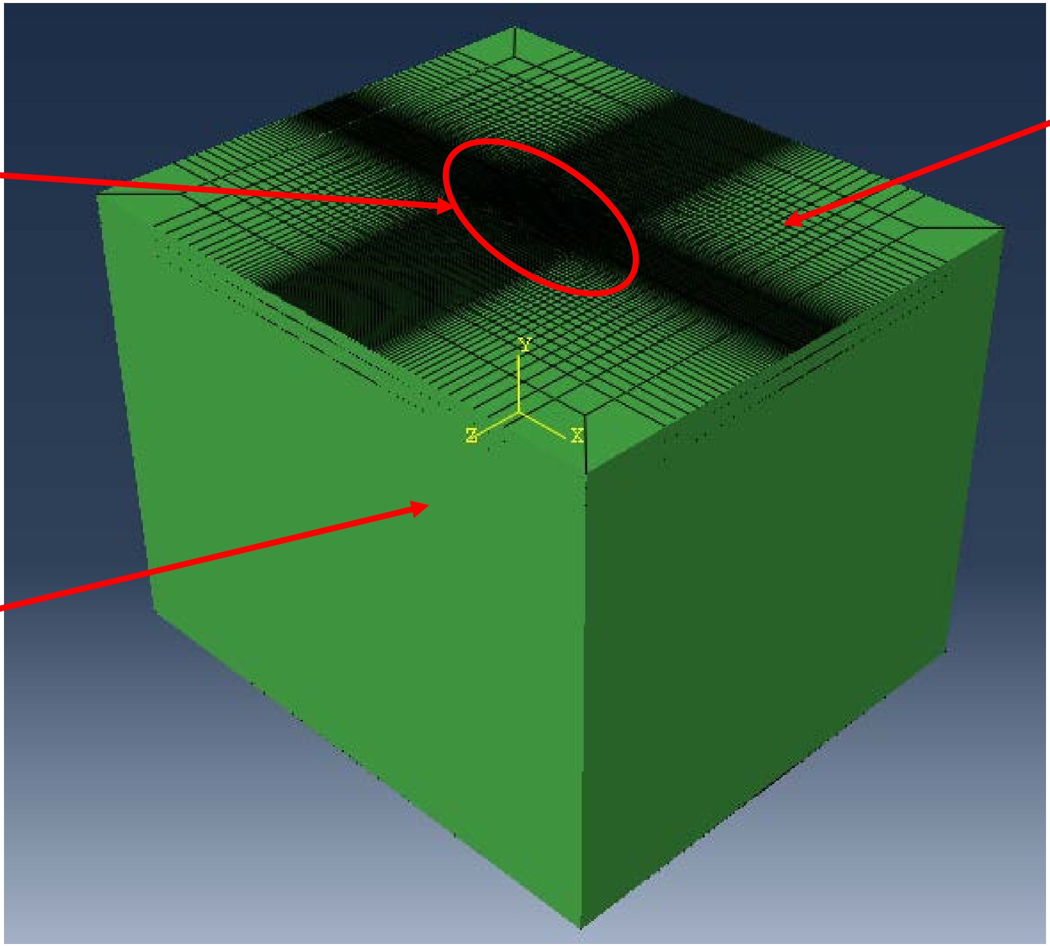
Continuous

Finite Element Model

- Mesh Configuration

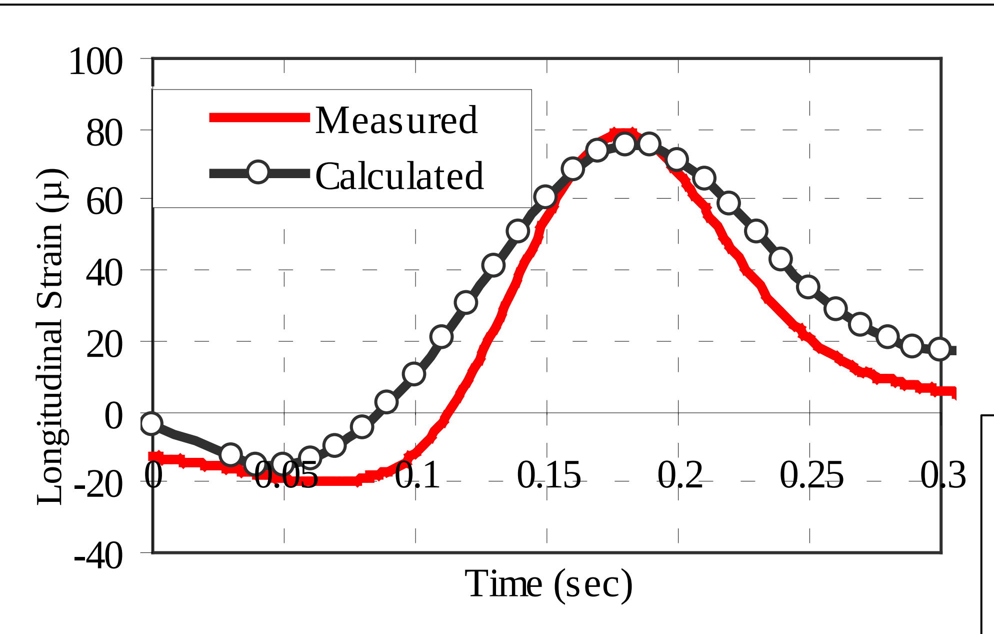
Wheel path

Transition zone



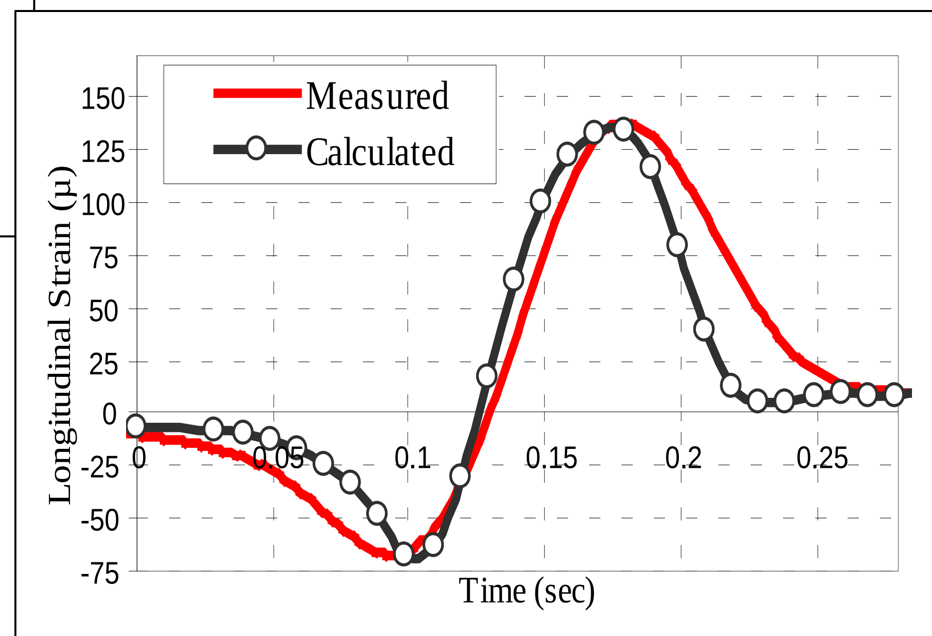
Infinite boundary elements

Validation – Smart Road

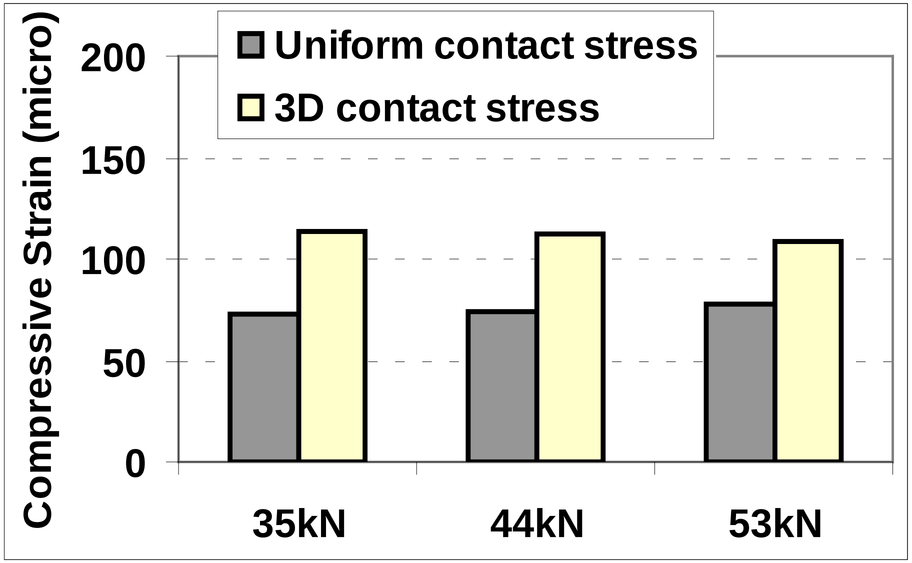


Dynamic FE Analysis: Bottom of HMA layers

Dynamic FE Analysis: Bottom of wearing surface



Effect of 3D Contact Stresses

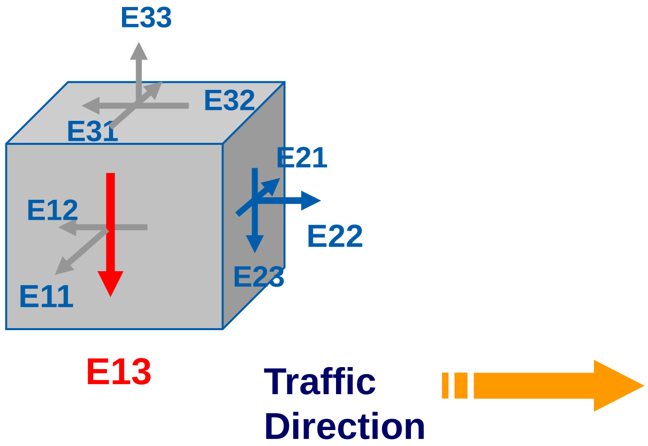


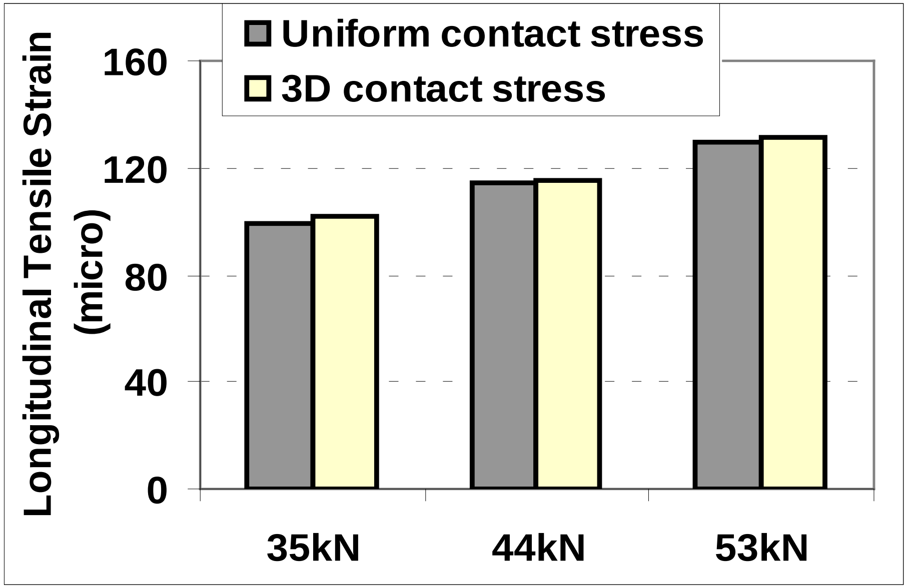
Pavement surface

➔ **Significant difference**

at 254mm HMA

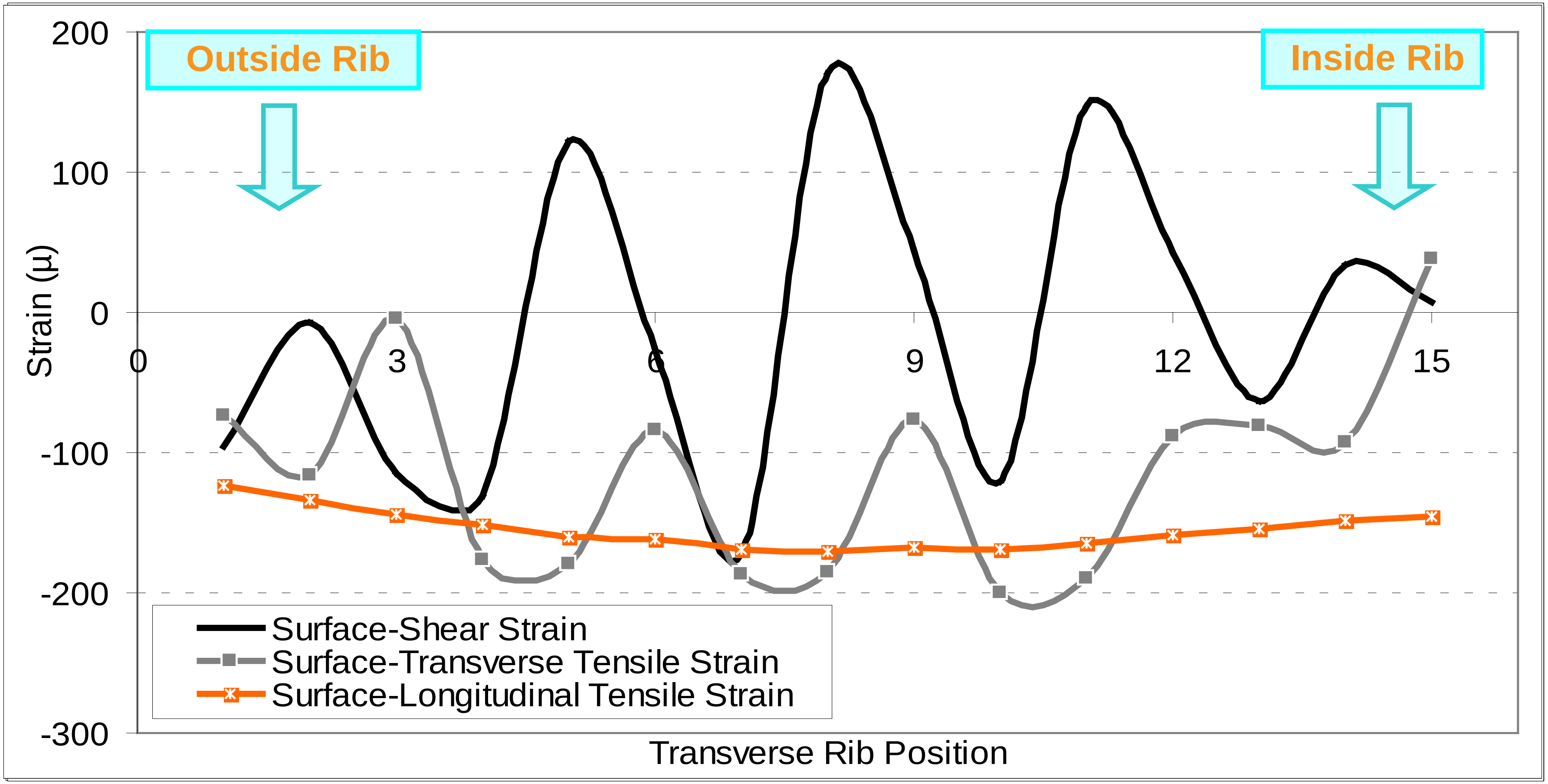
➔ **Slight difference**





Strain Distribution with Depth

- Critical strain within HMA
- Strain from the surface to bottom of 150mm HMA



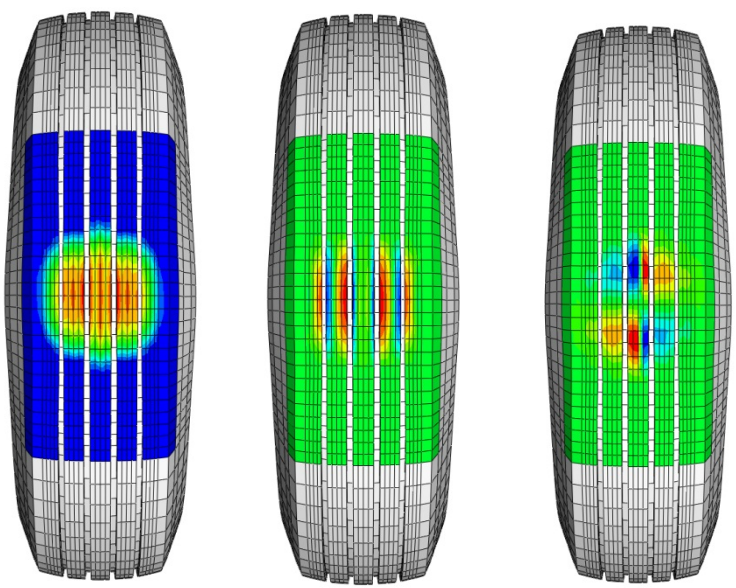
Summary

- Finite Element Modeling
  - Dynamic-implicit analysis
  - Material characterization
  - 3D contact stresses
  - Continuous moving loading
  - Infinite boundary elements
  - Layer interaction
- In-plane contact stresses are crucial for accurate near-surface pavement responses calculation

Failure Prediction Considering Contact Stress Variations

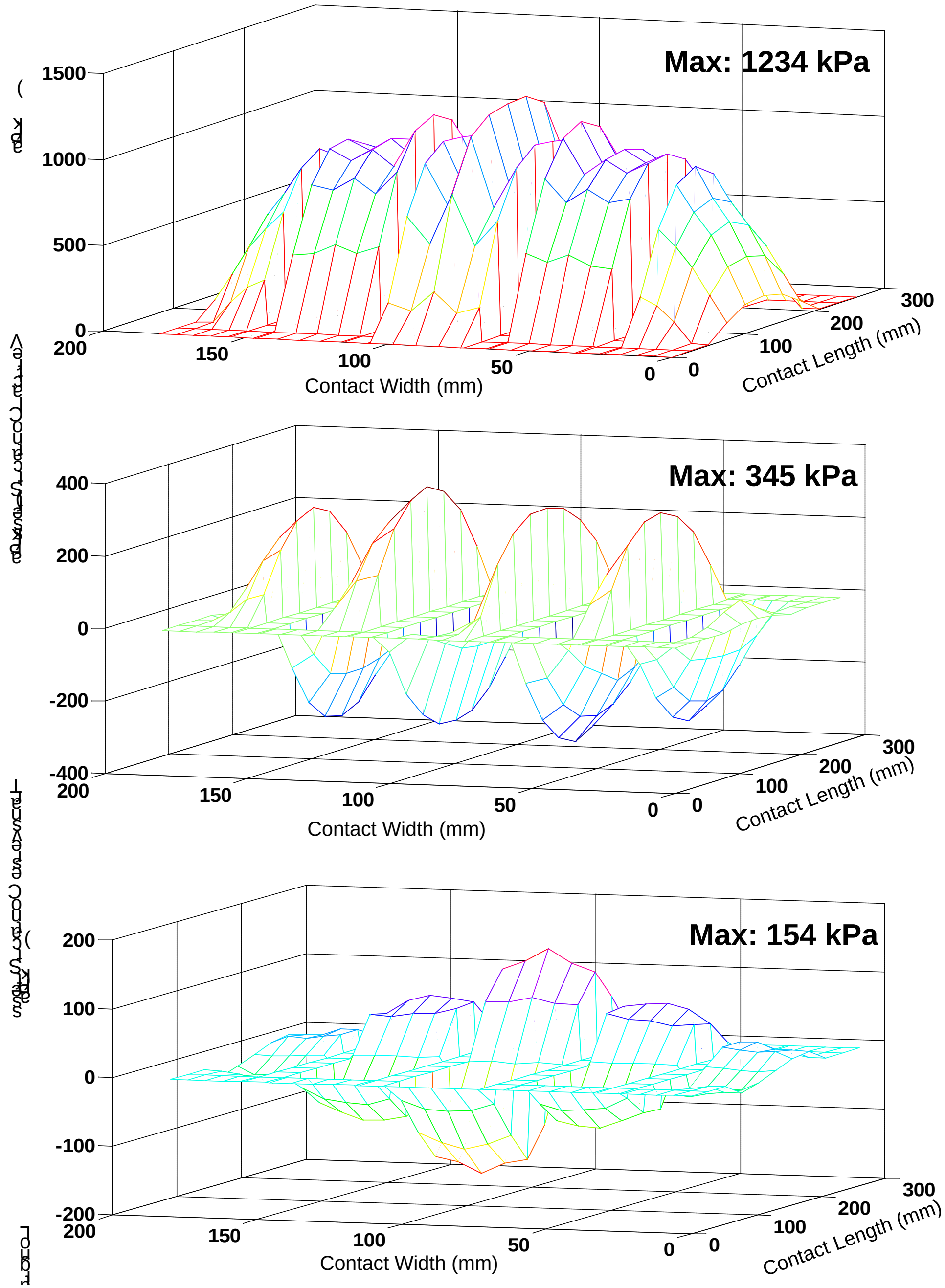
Hao Wang

3-D Contact Stresses



Vertical **Transverse** **Longitudinal**

(17.8kN and 724kPa)



Contact Stresses at Various Loading Conditions

Load, kN (kip)	Pressure, kPa (psi)	Maximum contact stress	Range, kPa	Avg.	Std.
17.8-40.2 (4-9)	414-966 (60-140)	Vertical	**854-1633**	**1220**	**264**
		Transverse	**194-490**	**339**	**100**
		Longitudinal	**103-306**	**214**	**50**
		Stress ratio	**1:0.23:0.07-1:0.31:0.30**	**1:0.28:0.17**	**/**

Contact Stresses at Various Rolling Conditions

Rolling conditions	Friction coefficient	Maximum contact stress, kPa			Ratio of maximum stress
		Vert.	Trans.	Long.	
Free rolling	**0.3**	**1056**	**223**	**65**	**1:0.21:0.06**
	0.8	**1067**	**391**	**81**	**1:0.37:0.08**
Full braking	**0.3**	**1053**	**14**	**316**	**1:0.02:0.30**
	0.8	**1144**	**73**	**915**	**1:0.06:0.80**
Cornering (slip angle=1°)	**0.3**	**1157**	**277**	**73**	**1:0.24:0.06**
	0.8	**1432**	**485**	**95**	**1:0.34:0.07**

Pavement Failure Mechanism

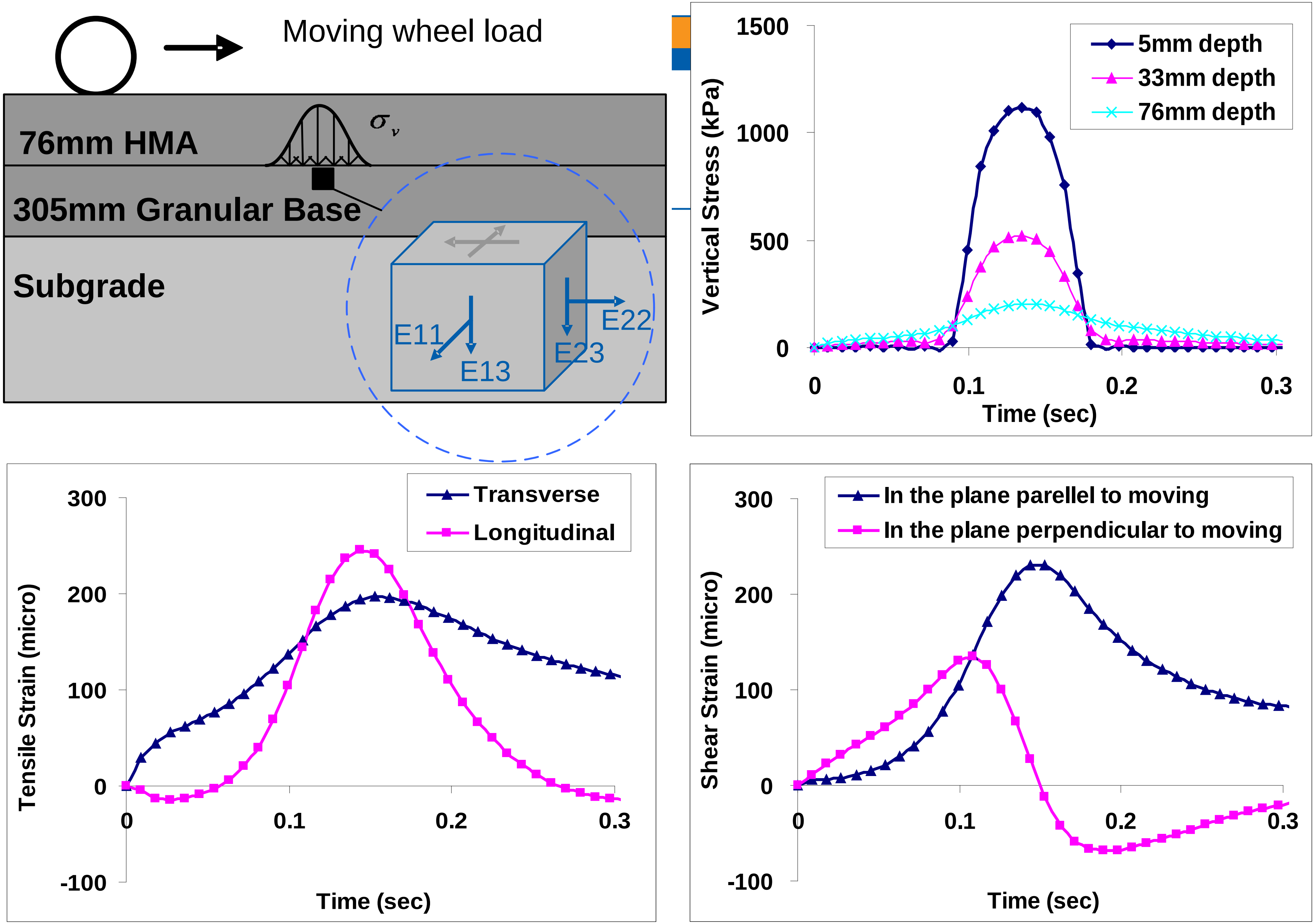
(After Al-Qadi et al. 2007)

(After Uhlmeyer et al. 2000)

(After Will and Timm 2007)

Analysis of Thin Pavement Responses

- A low-volume road pavement section built at ATREL: Geosynthetically stabilized pavements
- Conventional failures in thin asphalt pavements:
  - Bottom-up fatigue cracking
  - HMA rutting (distortional deformation)
  - Base permanent deformation (shear failure)
  - Subgrade rutting

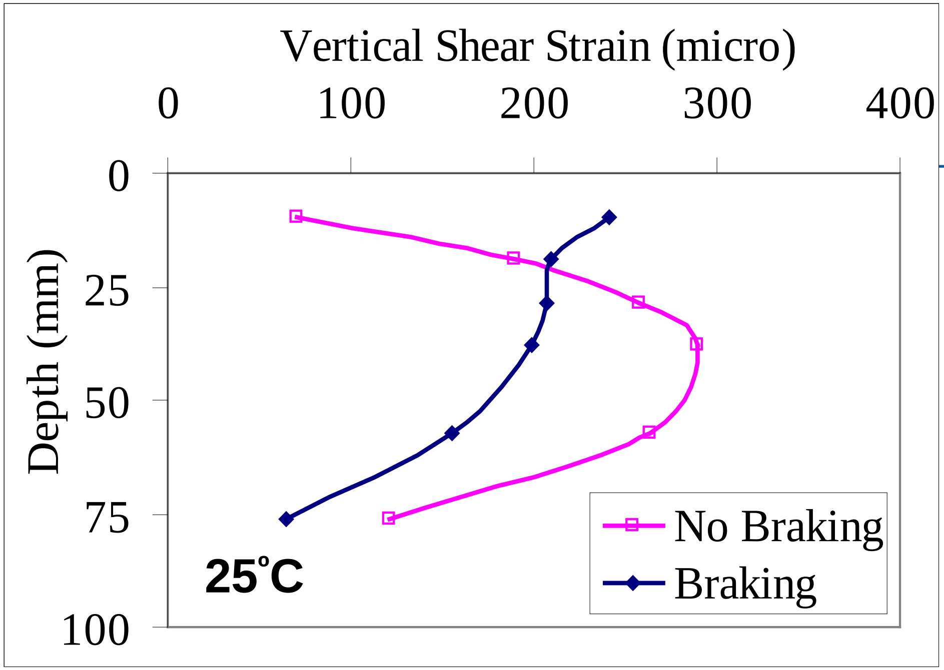


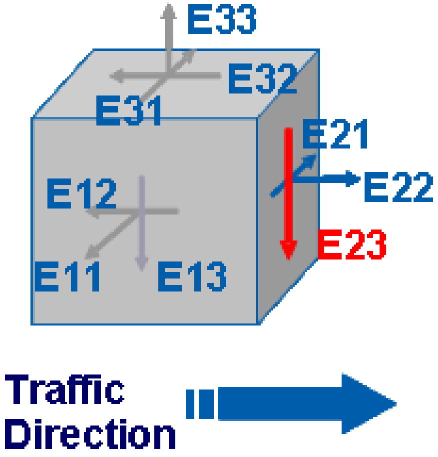
Moving wheel load
76mm HMA
σ_v
305mm Granular Base
Subgrade
E11
E13
E22
E23
Vertical Stress (kPa)
1500
1000
500
0
0
0.1
0.2
0.3
Time (sec)
5mm depth
33mm depth
76mm depth
Tensile Strain (micro)
300
200
100
0
-100
0
0.1
0.2
0.3
Time (sec)
Transverse
Longitudinal
Shear Strain (micro)
300
200
100
0
-100
0
0.1
0.2
0.3
Time (sec)
In the plane parellel to moving
In the plane perpendicular to moving

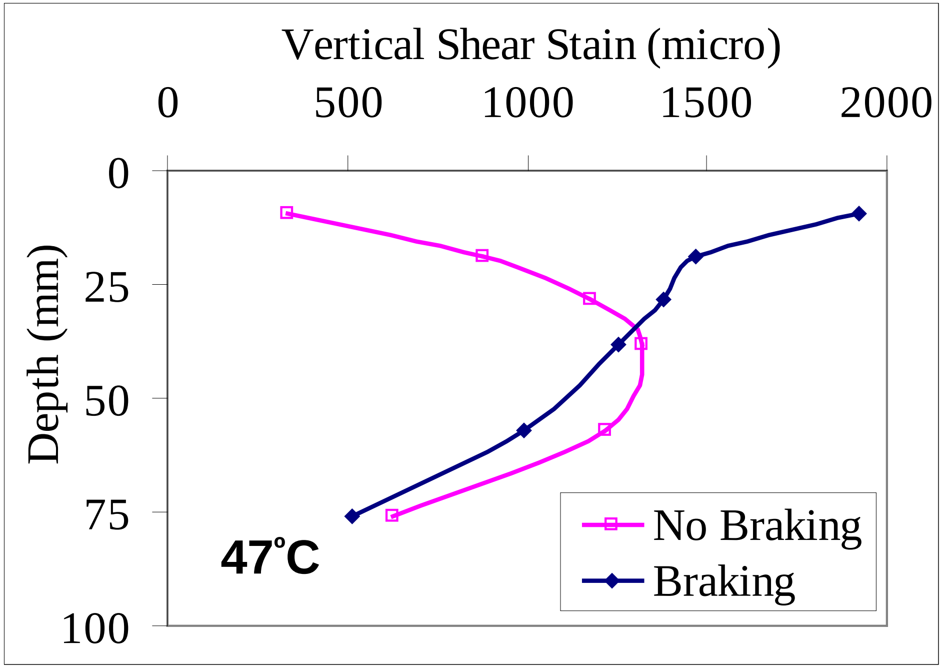
Effect of Contact Stresses on Pavement Responses

Locations	Responses	At 25°C		At 47°C	
		Uniform	3-D	Uniform	3-D
Bottom of asphalt layer	Long. tensile strain (micro)	**374**	**+0%**	**1057**	**+8%**
	Tran. tensile strain (micro)	**272**	**+6%**	**973**	**+19%**
Shallow depth of asphalt layer	Shear strain (micro)	**299**	**+4%**	**1499**	**+5%**
	Shear stress (kPa)	**401**	**+16%**	**243**	**+25%**
Top of subgrade	Deviatoric stress (kPa)	**54**	**-7%**	**81**	**-5%**
	Compressive strain (micro)	**1246**	**-9%**	**1781**	**-9%**

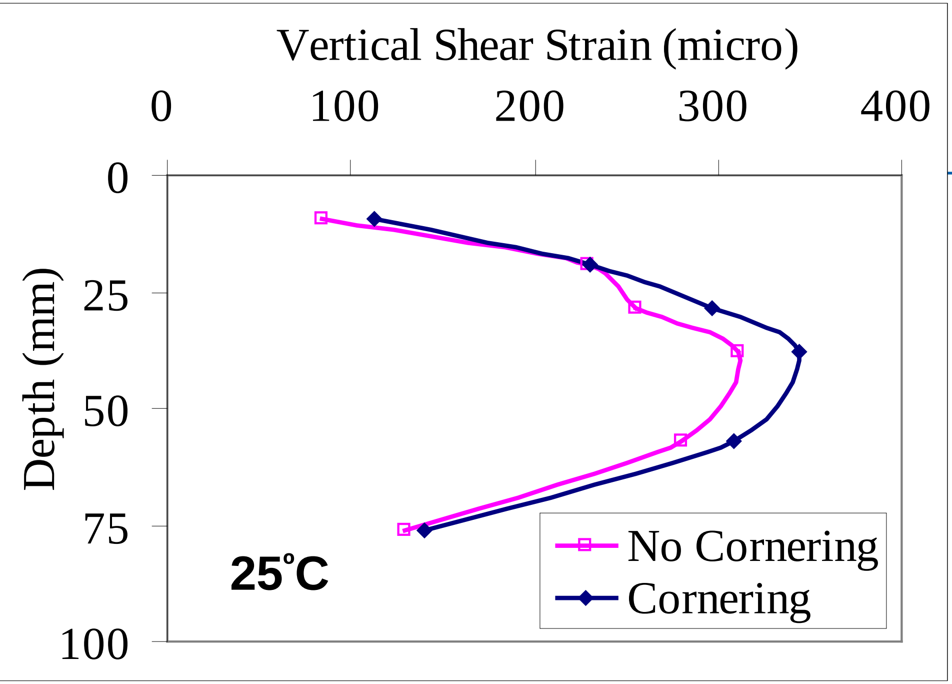
Effect of Tire Braking on Shear Strain

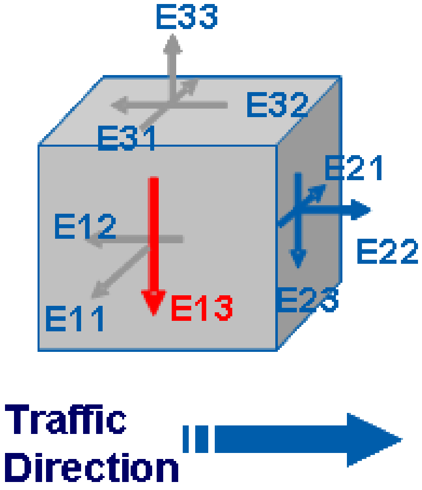


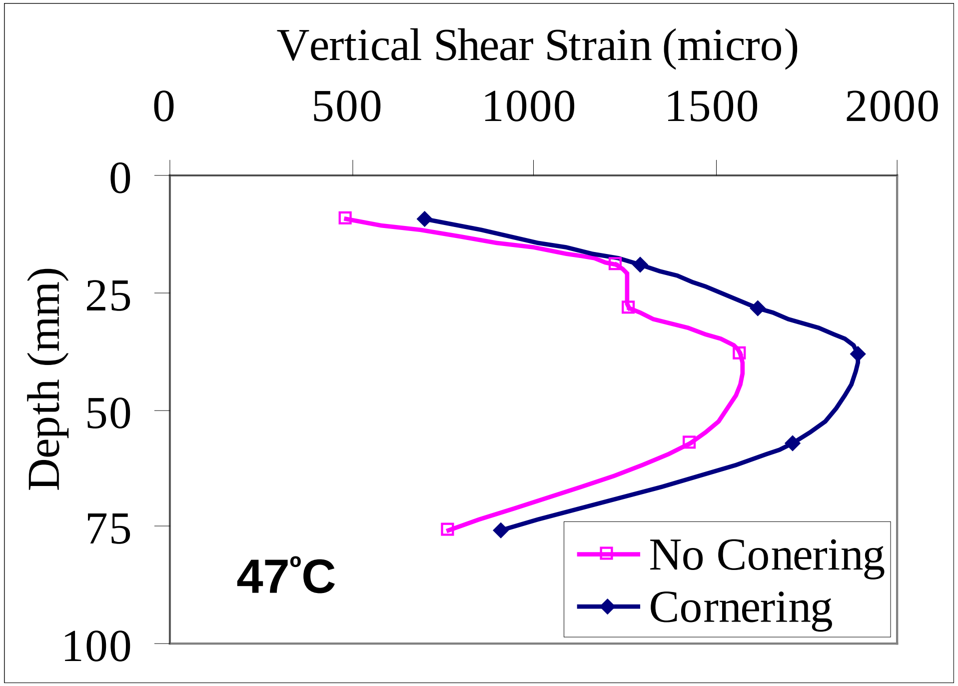




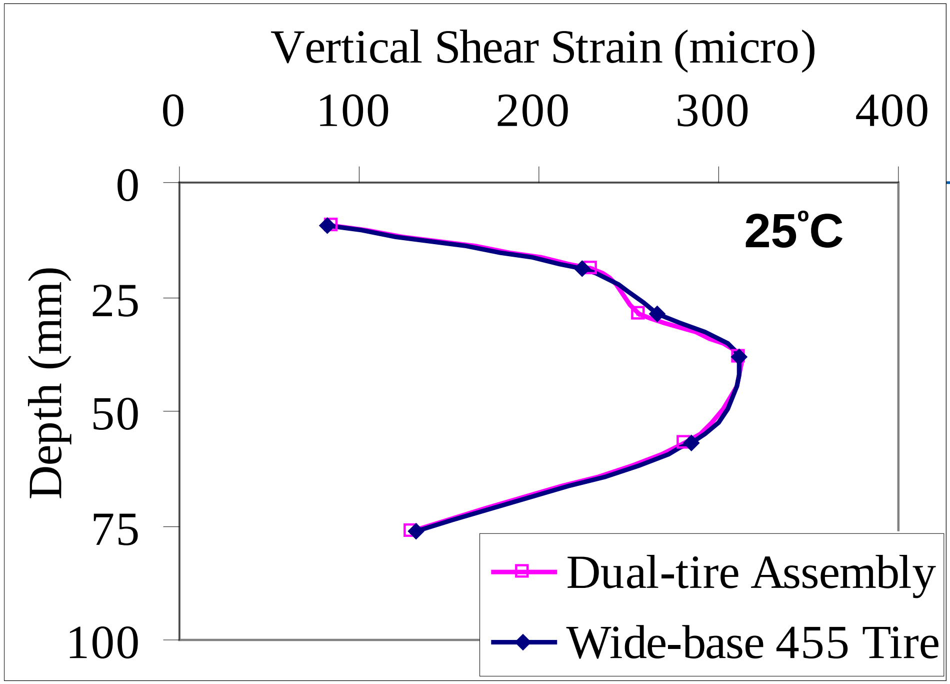
Effect of Tire Cornering on Shear Strain

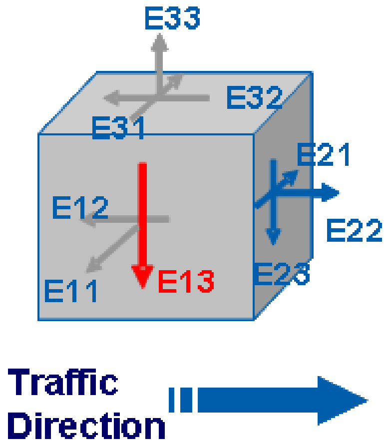


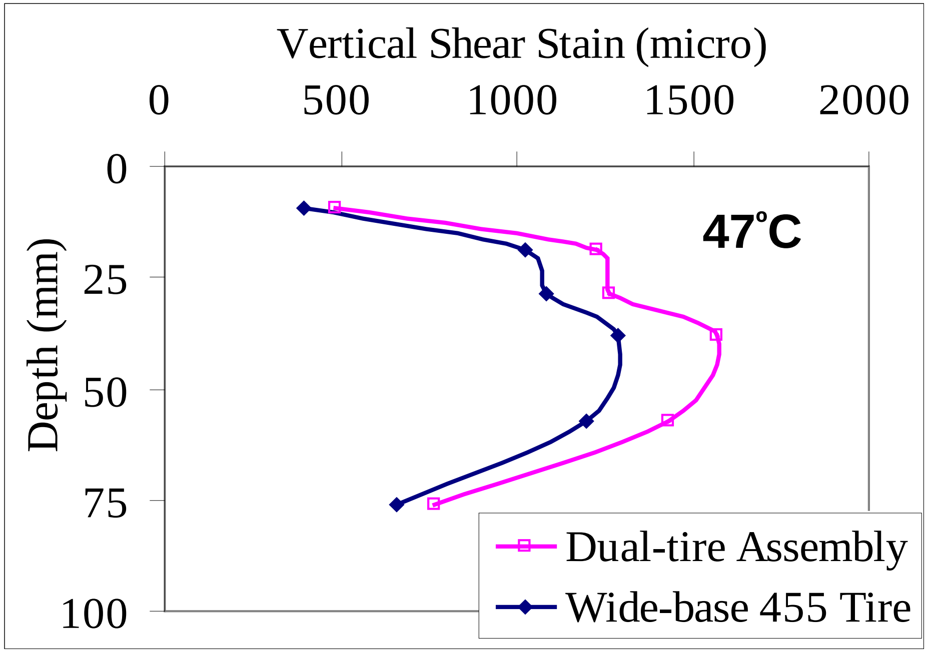




Effect of Wide-Base Tire on Shear Strain

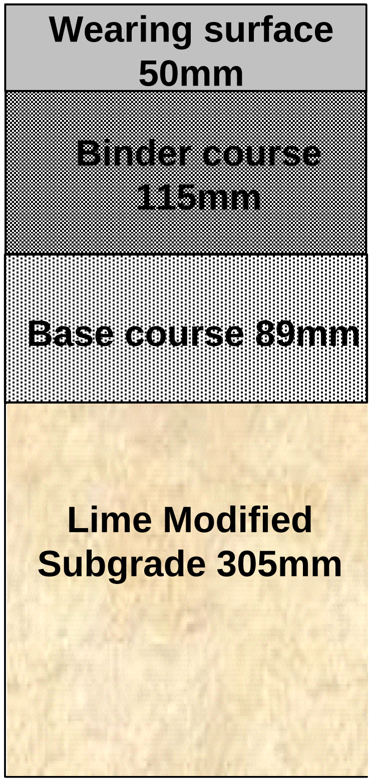




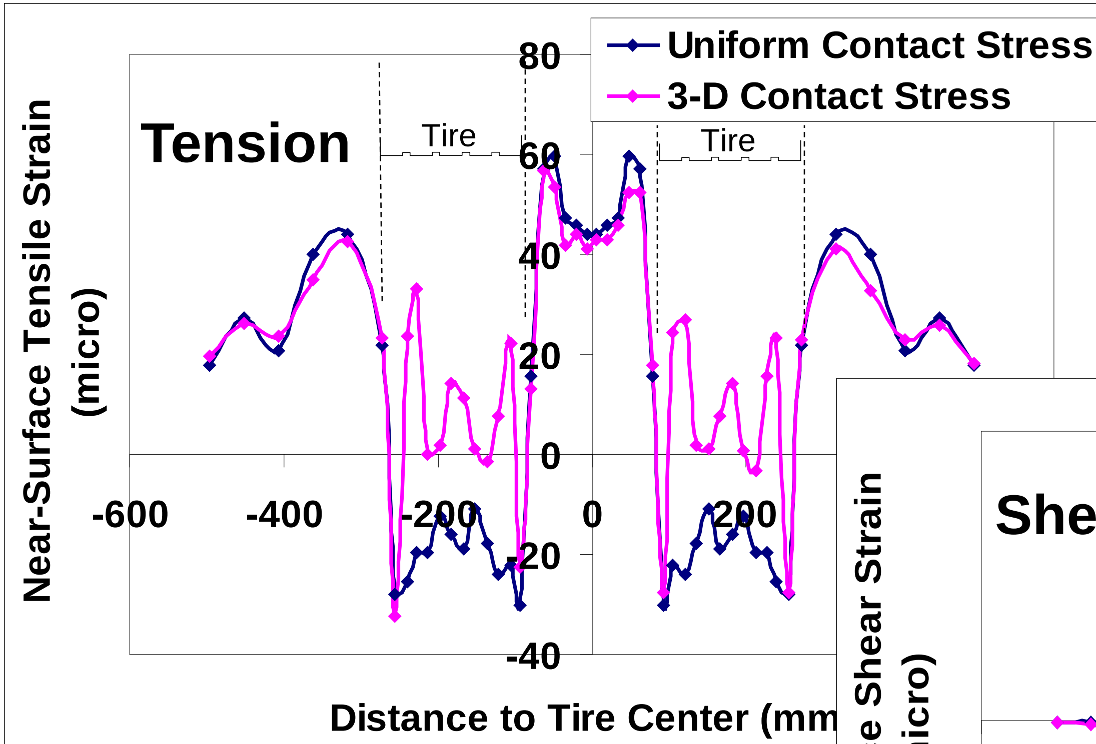


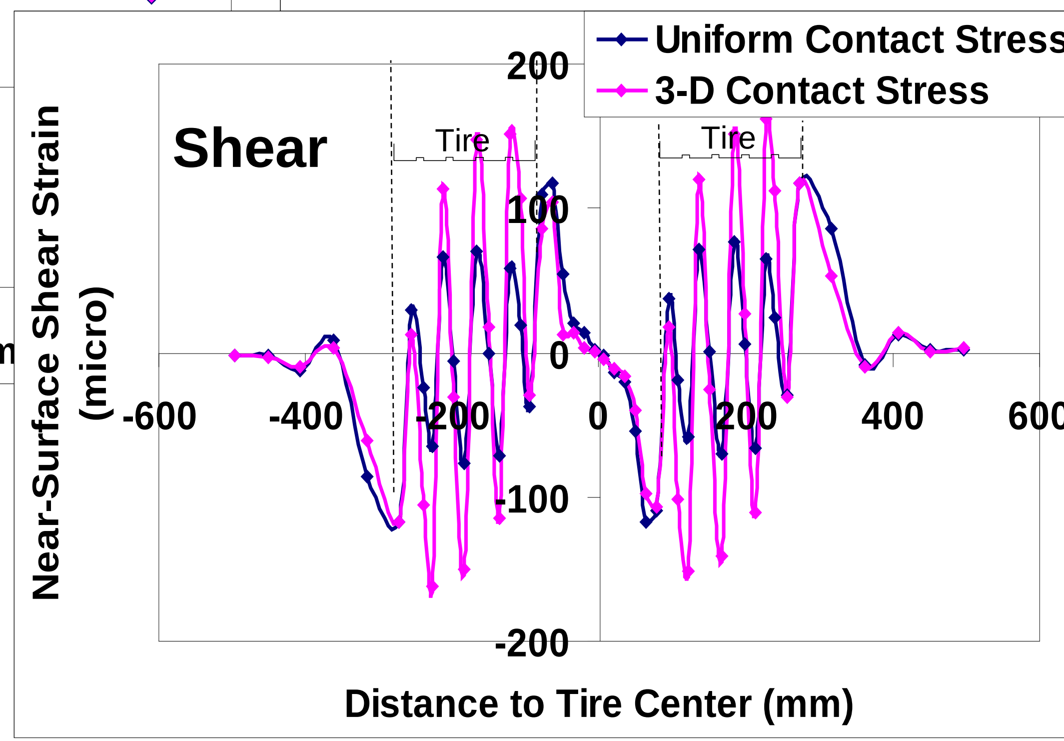
Near-Surface (Top-Down) Cracking

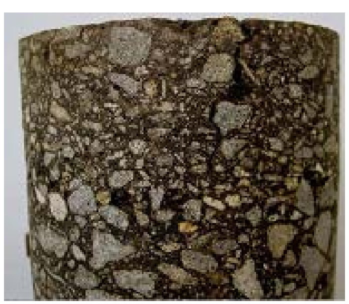
- A thick full-depth pavement section with 254-mm asphalt layer
- Near-surface (or top-down) cracking is more critical in thick asphalt pavements *(Baladi et al. 2002)*
  - Observed within 10 years after construction
  - Longitudinal or transverse cracking around wheel-path areas
  - Depth of cracking is generally contained in the wearing course



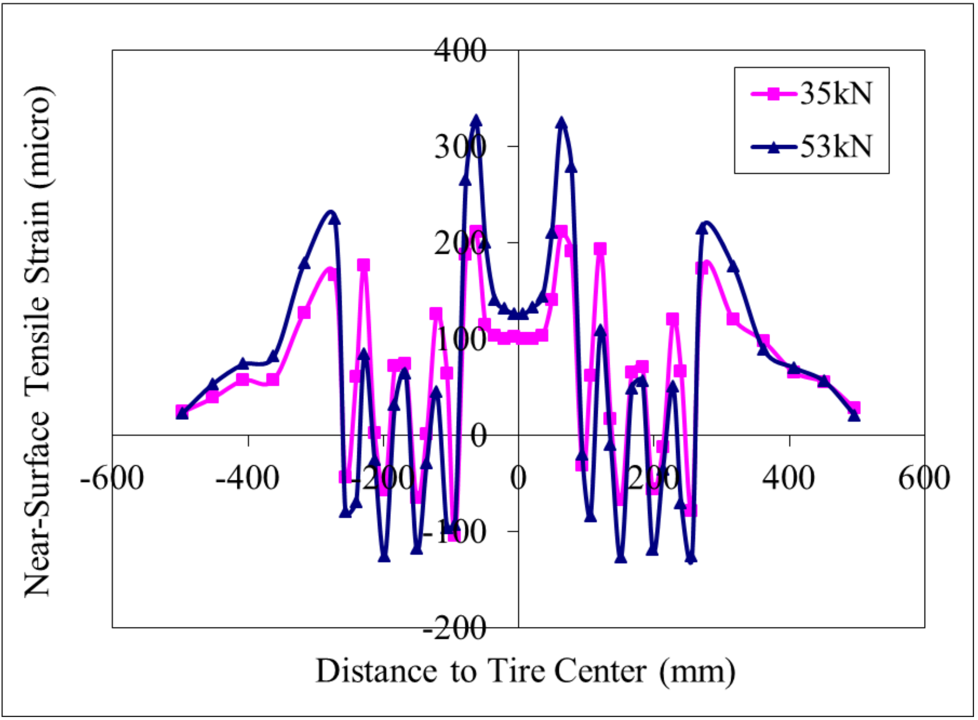
Strain Distribution at Near-Surface



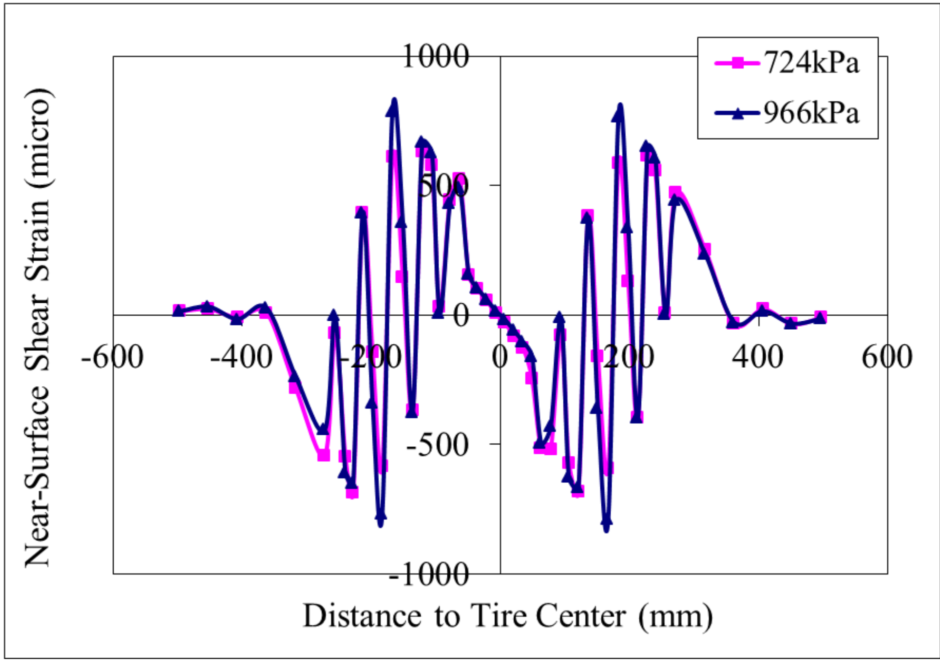




Effect of Load and Pressure on Near-Surface Strains

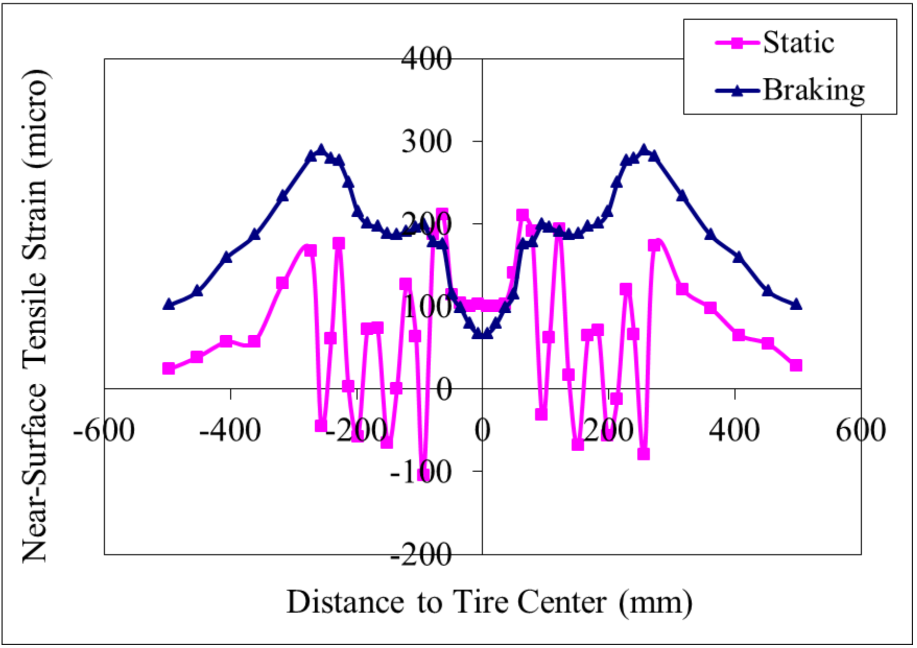


High Load

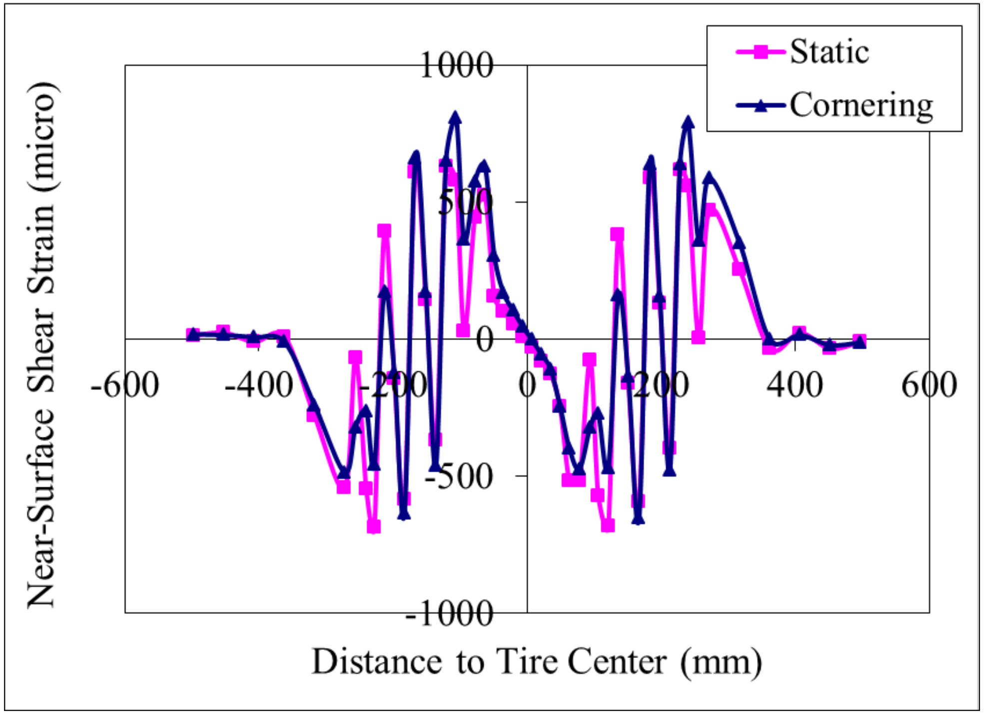


High Tire Pressure

Effect of Vehicle Maneuvering on Near-Surface Strains

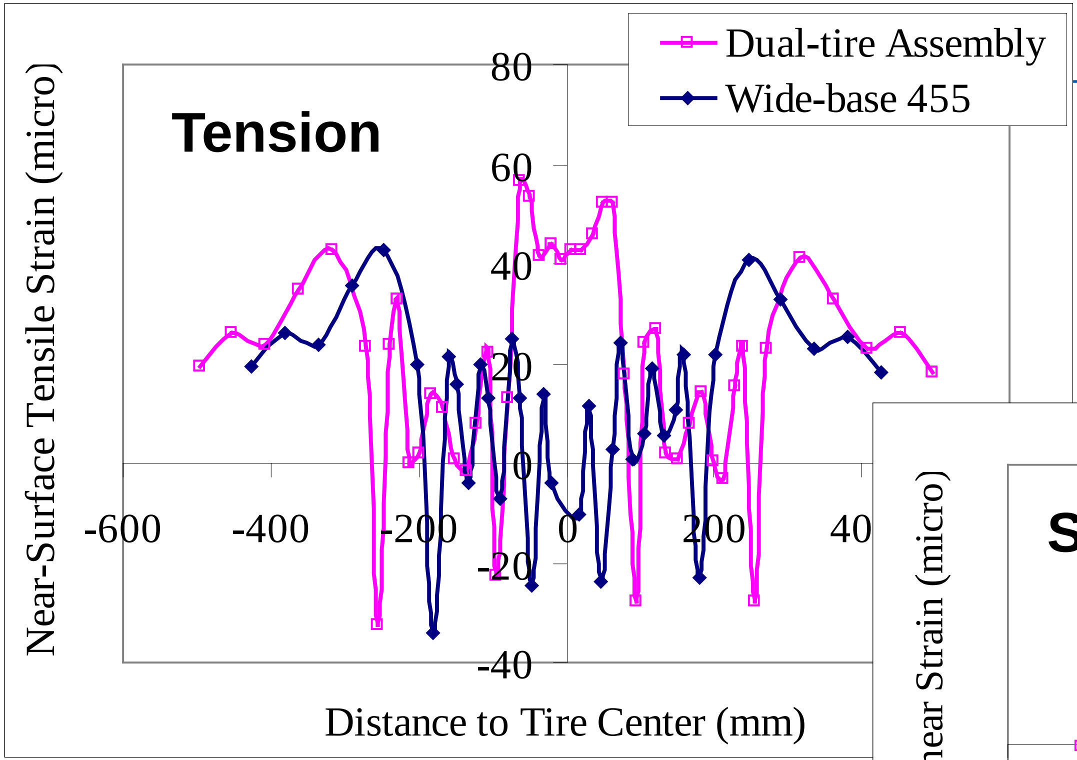


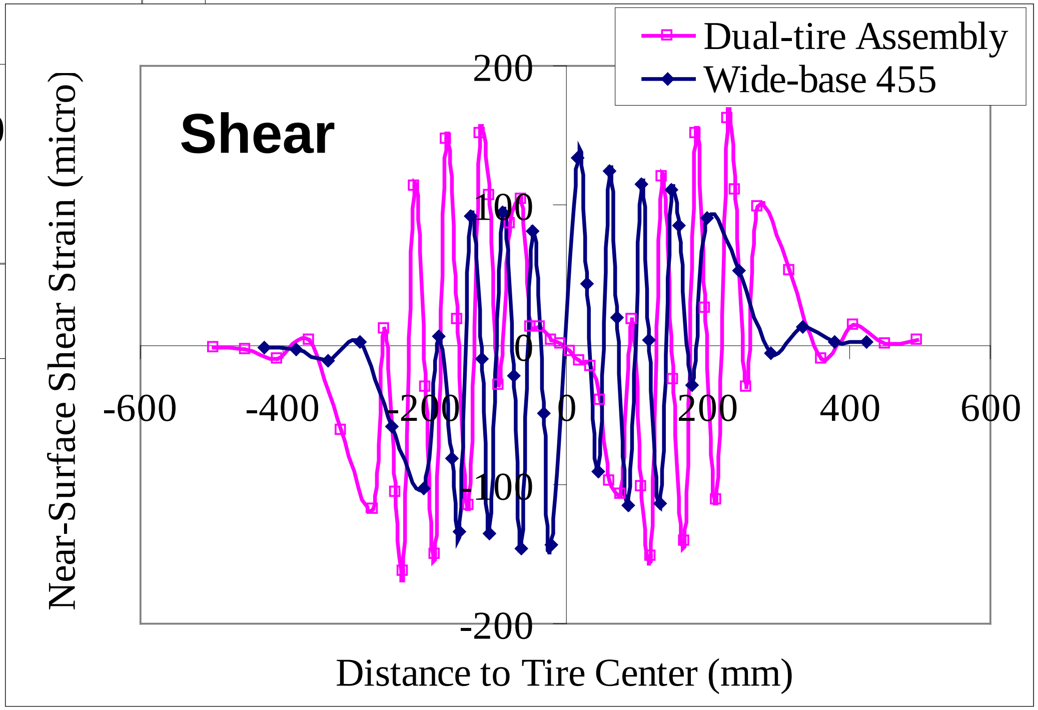
Tire Braking



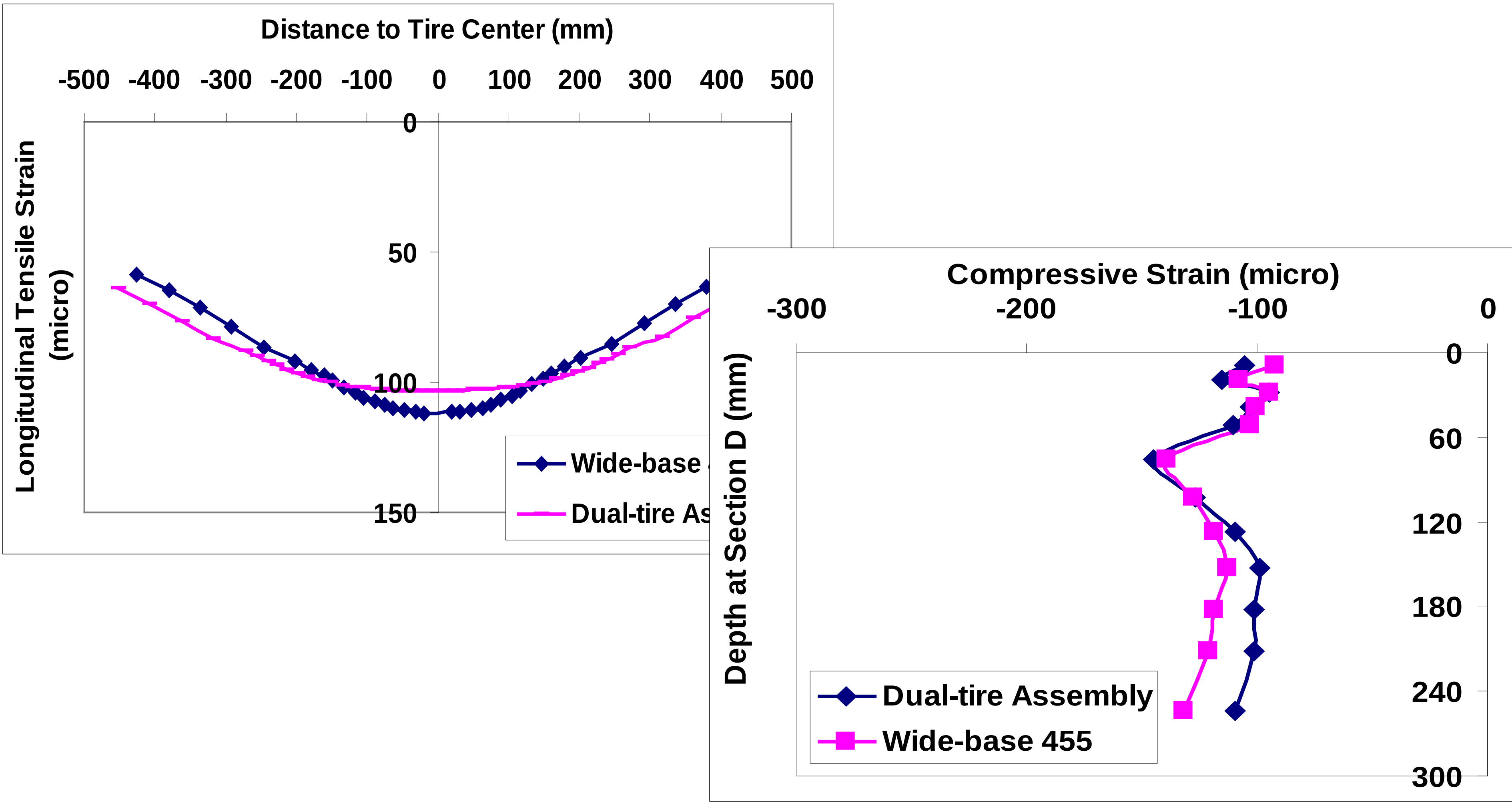
Tire Cornering

Effect of Wide-Base Tire on Near-Surface Strains





Effect of Wide-Base Tire on Tension and Compression Strains



Summary

- Effect of contact stresses on pavement responses depends on the following:
  - 3D contact stresses; applied load and tire pressure; and vehicle maneuvering
  - Pavement layer thickness
- Effect of wide-base tires on pavement responses
  - Different contact stress distributions
  - Depends on pavement failure type, asphalt layer thickness, and temperature

Cost Impact of Using Wide-Base Tires

Hao Wang

Case Study in South Dakota

- **2012-01 Research project sponsored by South Dakota DOT**
- **In South Dakota, wide-base tires may be generally substituted for standard duals; but the legally allowed weight on single axles is reduced**
  - **17.5kips for 445mm tires; 18kips for 455mm tires**
  - **20kips for dual-tire configuration**
- **Project goal: Assess potential impact of *allowing 20-kip load on single axle equipped with 445mm and 455mm wide-base tires* on state and local roads in South Dakota**

Web Survey and Interview

- Survey to SD state DOT on load regulation or permit fee of wide-base tires -- 22 responses
- Survey to state trucking associations on use percentage, trend, and benefits of wide-base tires -- 8 responses
- Interview local truck owners and operators -- 6
- Discussion with SDDOT staff to characterize road surface designs in SD

Damage Ratios

- **Damage Ratio:** ratio of damage caused by one pass of a single axle with wide-base tires with respect to damage caused by one pass of a single axle with dual tires when carrying the same load
  - Damage Ratio: $\mathbf{DR = \frac{1/N_{single}}{1/N_{dual}} = N_{dual}/N_{single}}$[1]
  - The allowable load repetitions (N) could be calculated directly from performance measurements or critical pavement responses (through transfer functions)
  - Performance models in new AASHTO MEPDG are mainly used

1. Al-Qadi, Elseifi, and Yoo, 2004

Individual Damage Ratios

Pavement Structure	Distress	Ratio of Critical Response	Damage Ratio	Source References
Full-Depth Pavement	Fatigue Cracking	1.03-1.25	1.13-2.41	ICT/IDOT Study
	Top-Down Cracking	0.89-0.91	0.64-0.70	
	Primary Rutting	0.86-0.91	0.77-0.85	
Thick Asphalt Pavement	Fatigue Cracking	0.96-1.06	0.86-1.26	Virginia Smart Road Study; Ontario Study; FLDOT Study
	Top-Down Cracking	0.63-0.90	0.16-0.67	
	Primary Rutting	1.06	1.05-1.27	
	Subgrade Rutting	N/A	N/A	
Thin Asphalt Pavement	Fatigue Cracking	1.14-1.30	1.68-2.82	Quebec Study; ICT/IDOT Study
	Primary Rutting	1.14-1.28	1.35-1.77	
	Subgrade Rutting	1.06-1.21	1.31-2.35	

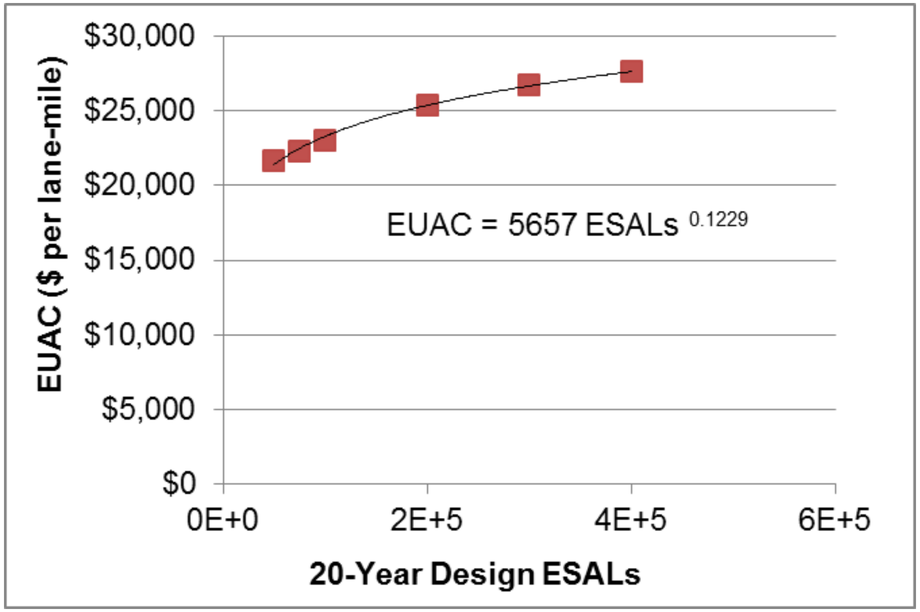
Combined Damage Ratios

Category	Pavement Type	% of Total Miles	Range of Damage Ratio	Ave. Damage Ratio
Interstate and Primary Road	Full Depth (> 10 in ACP w/no granular base)	3.4	0.85-1.32	1.085
	Thick (5 to 10 in ACP w/ granular base)	49.6	0.69-1.07	0.88
	ACP on PCCP (Asphalt overlay on top of PCCP)	12	1.0**	1.0**
	Rigid Pavements	35	1.0**	1.0**
Secondary Road	Thin on Strong Base (2 to 5 in ACP on > 8 in. granular base)	76	1.45-2.31	1.88
	Thin on Weak Base (2 to 5 in. ACP on < 8 in. granular base)	21.8	1.45-2.31	1.88
	Surface Treatment (Bituminous surface treatment or oil aggregate surface)	2.2	1.45-2.31*	1.88*

* Assume that BLOT has the same damage ratio as TonW and TonS.
** Assume that damage ratios on AonC and rigid pavements are equal to one.

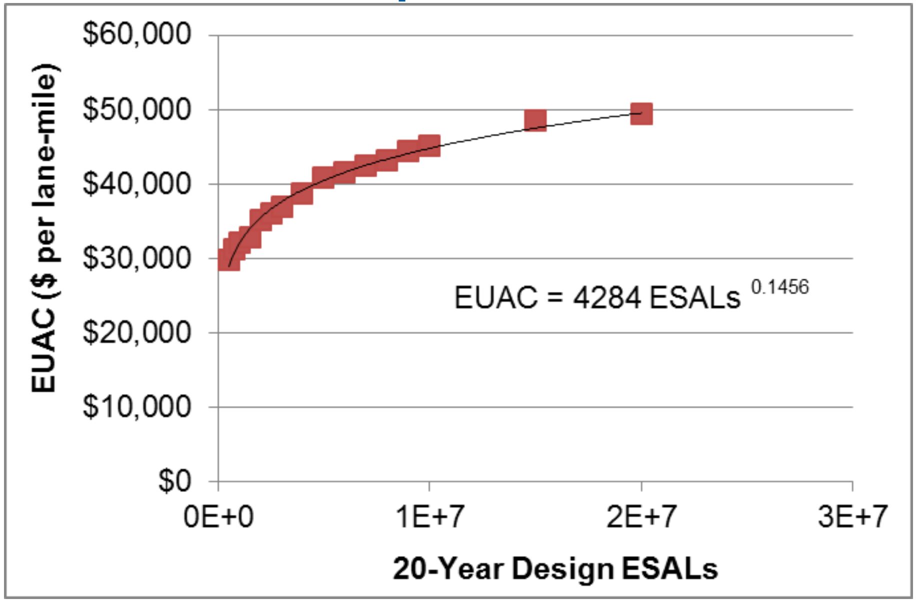
Impact on Pavement Damage Cost

- Step 1: Determine pavement cost functions



Thin Pavement on Weak Base

Thick Asphalt Pavement



Impact on Pavement Damage Cost

- Step 2: Estimate pavement cost when dual tires are used

Road Segment	Highway Number	Length (miles)	Pavement Type	Interstate	Millions of ESALs in 20 years	EUAC per lane-mile
1	010	9.08	TONS	No	0.26	$26,250
2	011	11.089	THK	No	0.16	$24,452
3	012	1.158	FD	No	0.43	$33,927
4	065	3.049	TONW	No	0.11	$23,548
5	090	2.374	FD	Yes	6.26	$46,567
6	090	8.005	THK	Yes	6.76	$42,284

TONS: Thin Asphalt Pavement on Strong Base; TONW: Thin Asphalt Pavement on Weak Base; THK: Thick Asphalt Pavement; FD: Full-Depth Pavement.

Impact on Pavement Damage Cost

- Step 3: Estimate the number of trucks with spread tandem axles and axle load spectrum

Category	% of Class 9 trucks in all trucks	%of trucks with spread tandem axles in all Class 9 tucks			% of spread tandem with full load	% of spread tandem with 40% full load
		8-9 ft axle spacing (max load allowed: 19 kips)	9-10 ft axle spacing (max load allowed: 19.5 kips)	>10 ft axle spacing (max load allowed: 20 kips)		
Interstate	51.7%	0.46%	8.12%	15.26%	78.97%	21.03%
Non-Interstate	35.2%	0.35%	8.29%	19.15%	65.12%	34.88%

Impact on Pavement Damage Cost

- Step 4: Estimate change of pavement cost when wide-base tires are used

Road Segment	Highway Number	Length (miles)	Pavement Type	Interstate	Millions of ESALs in 20 years	EUAC per lane-mile	Change of EUAC per lane
1	010	9.08	TONS	No	0.29	$26,693	+$4015
2	011	11.089	THK	No	0.16	$24,406	-$507
3	012	1.158	FD	No	0.44	$33,977	+$57
4	065	3.049	TONW	No	0.12	$23,827	+$851
5	090	2.374	FD	Yes	6.33	$46,631	+$152
6	090	8.005	THK	Yes	6.64	$42,176	-$859

Impact on Pavement Damage Cost

- Step 5: Calculate total change of pavement cost in state highway network

Change of EUAC ($ million)	Category	Percentage of spread tandem axles using wide-base tires replacing dual tires after policy change				
		10%	20%	30%	50%	100%
Using average damage ratios	Interstate	0.00	0.00	0.00	-0.01	-0.02
	Non-Interstate	0.36	0.71	1.06	1.73	3.28
	All state highways	0.36	0.71	1.06	1.72	3.26

Impact on Environmental Cost

- Recent studies proved that using wide-base tires can reduce tire rolling resistance by 12% and reduce fuel consumption by 5-12%
- Environmental damage and cost of neutralizing gas emission are estimated at $1.13/gal ($0.3/liter)

Cost Saving ($ million)	Percentage of spread tandem axles using wide-base tires replacing dual tires after policy change				
	10%	20%	30%	50%	100%
Fuel	0.17	0.35	0.52	0.86	1.73
Pollution	0.05	0.10	0.16	0.26	0.52
Total	0.22	0.45	0.67	1.12	2.25

Summary

- **Damage ratio provides a good approach to quantify impact of wide-base tires**
  - **Pavement failure mechanism**
  - **Mechanistic-empirical approach**
- **Impact of wide-base tires on life cycle assessment**
  - **Pavement damage cost**
  - **Cost of fuel consumption and emmision**

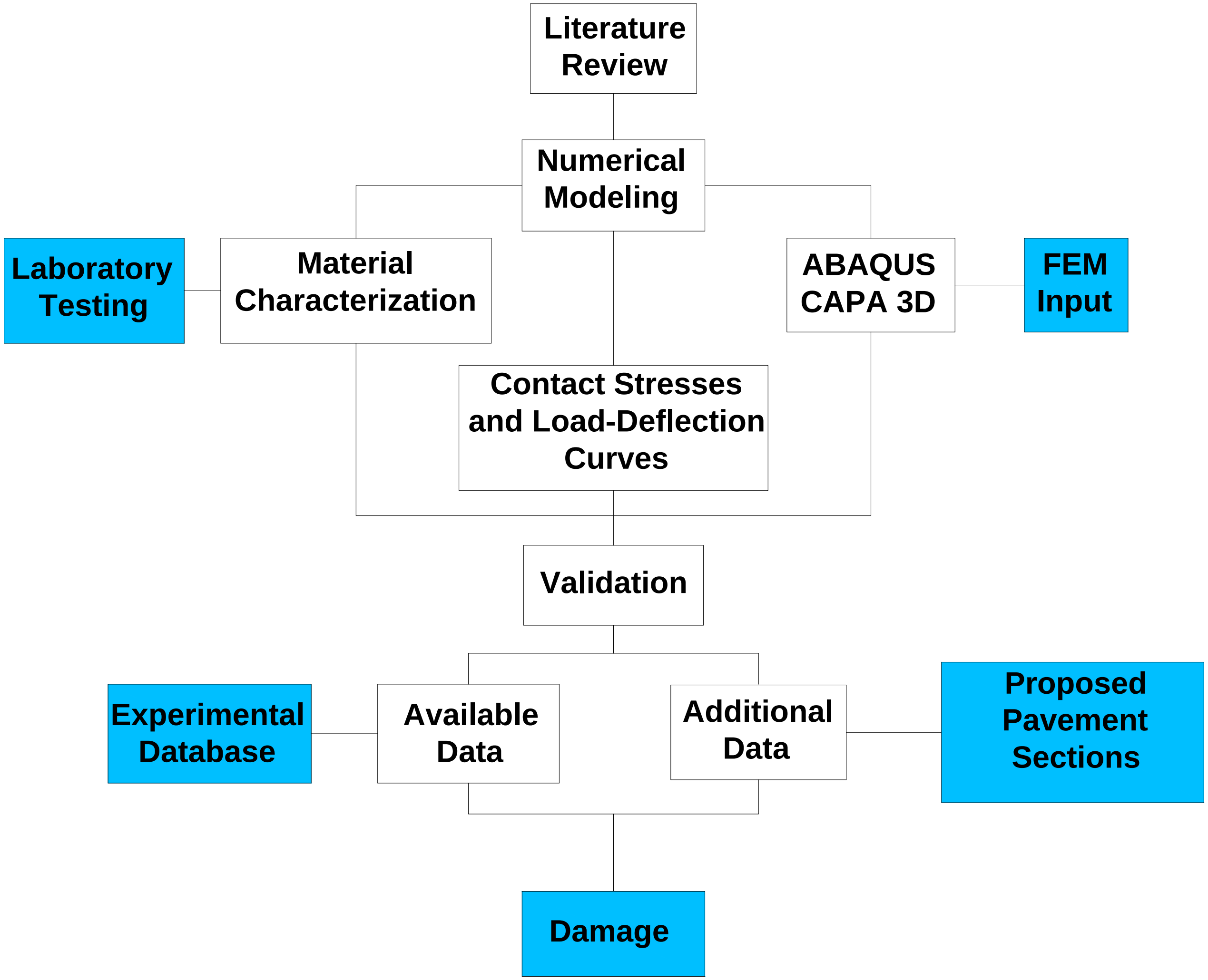
Ongoing Work and Final Remarks

Imad Al-Qadi

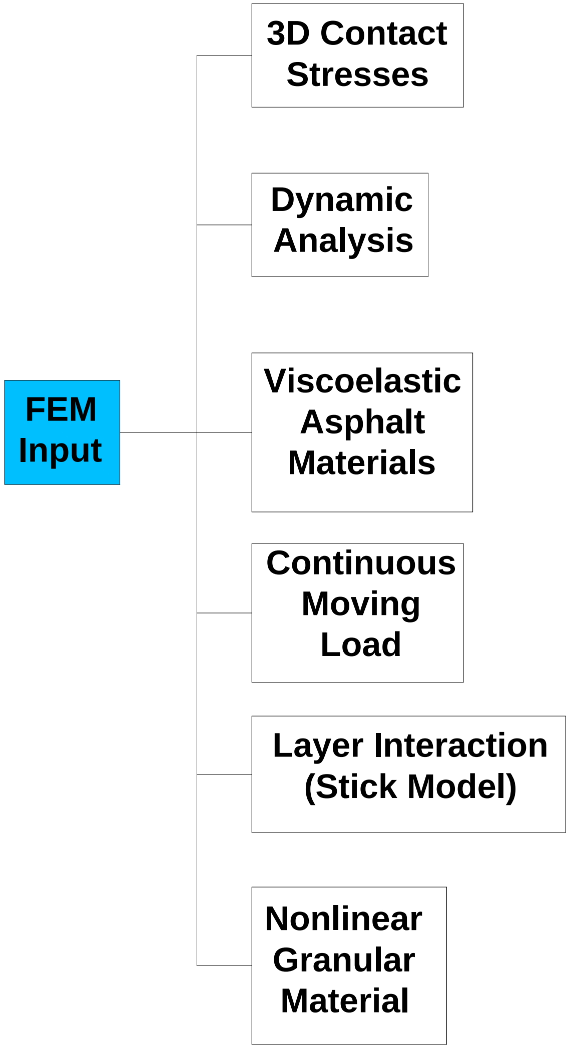
Project Overview

- 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

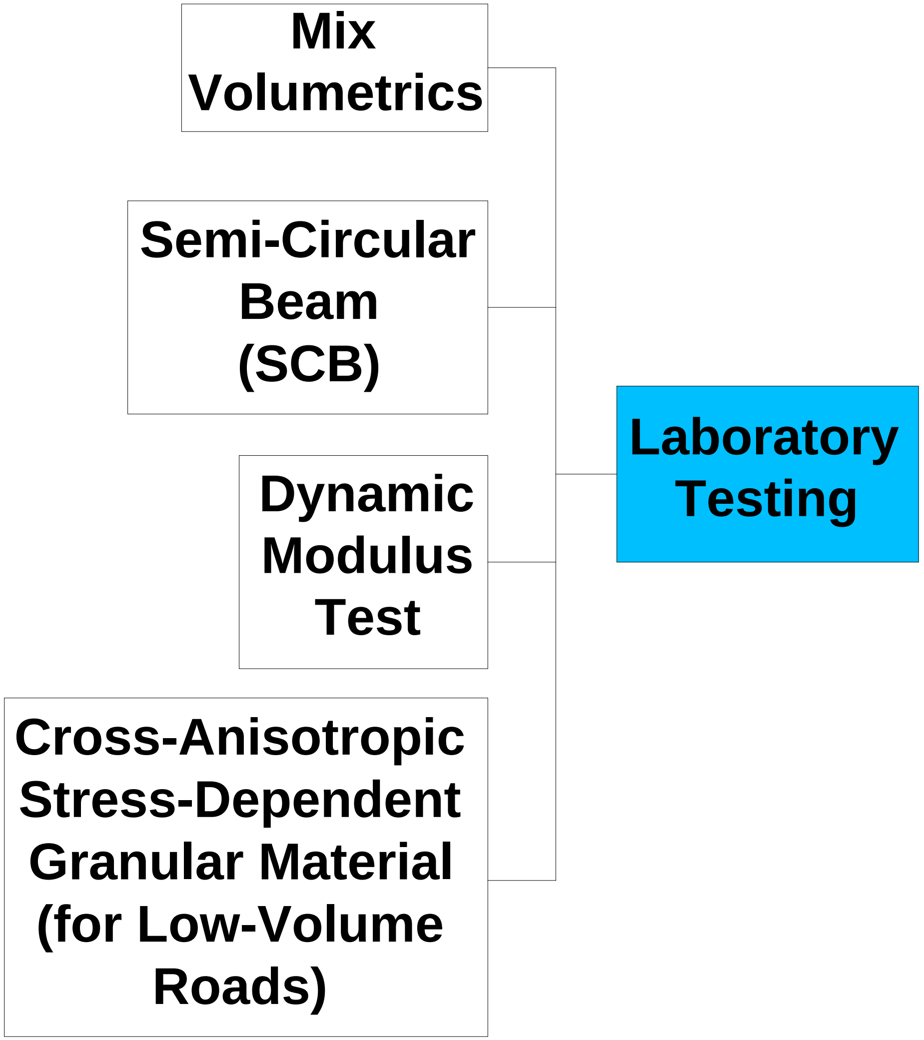
Project Overview



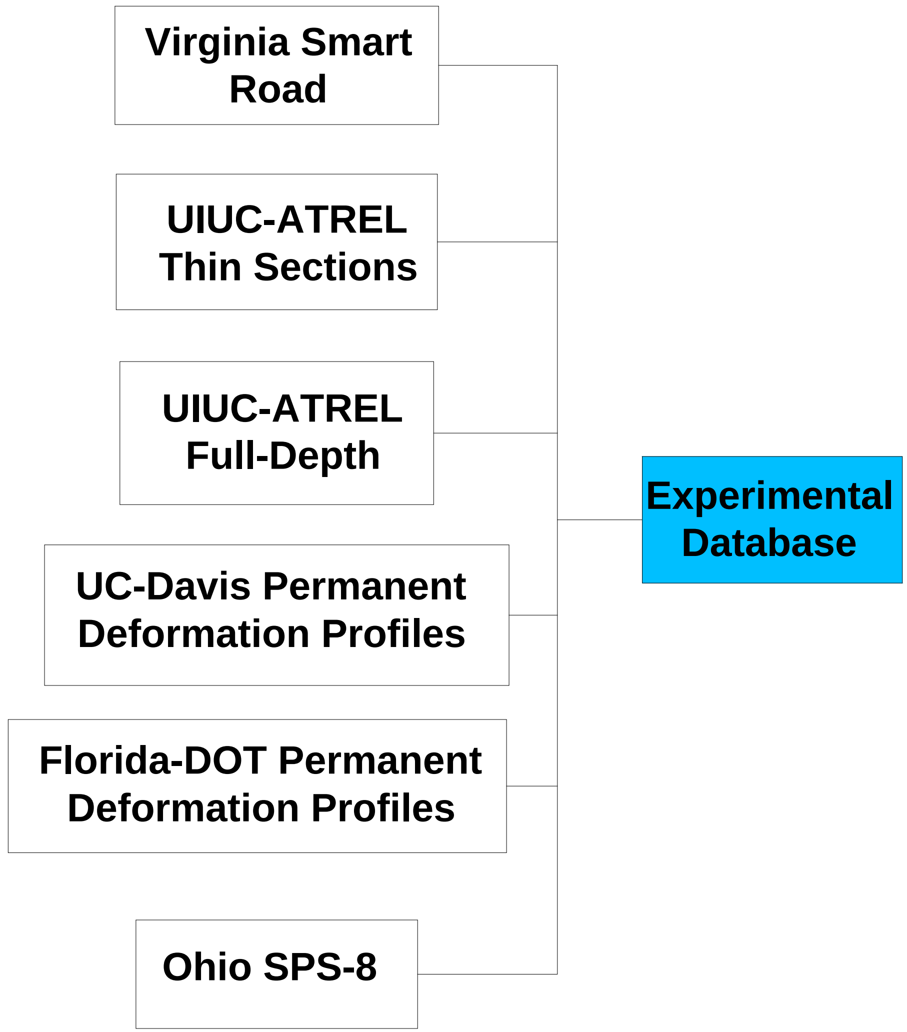
Project Overview



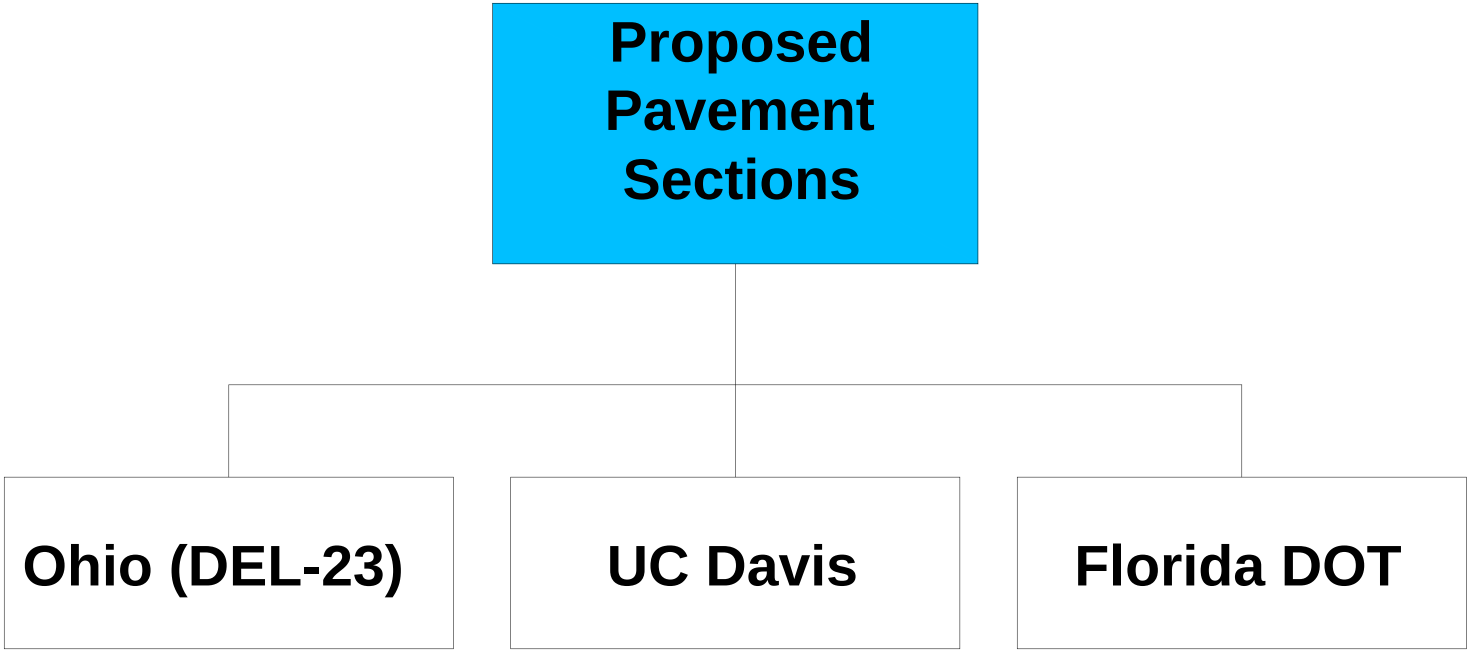
Project Overview



Project Overview



Project Overview



Project Overview

Loading Matrix

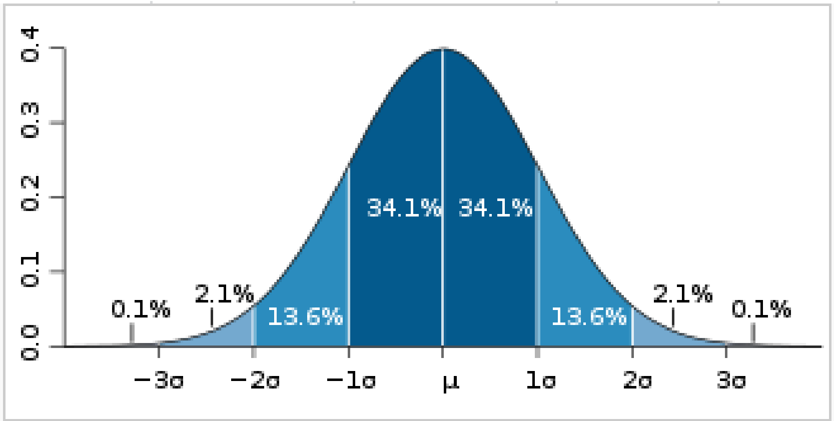
- Contact stress measurements and APT

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

FEM Input: AC Materials

- Based on more than **1000 data sets**



2σ ≈ 95.4%,

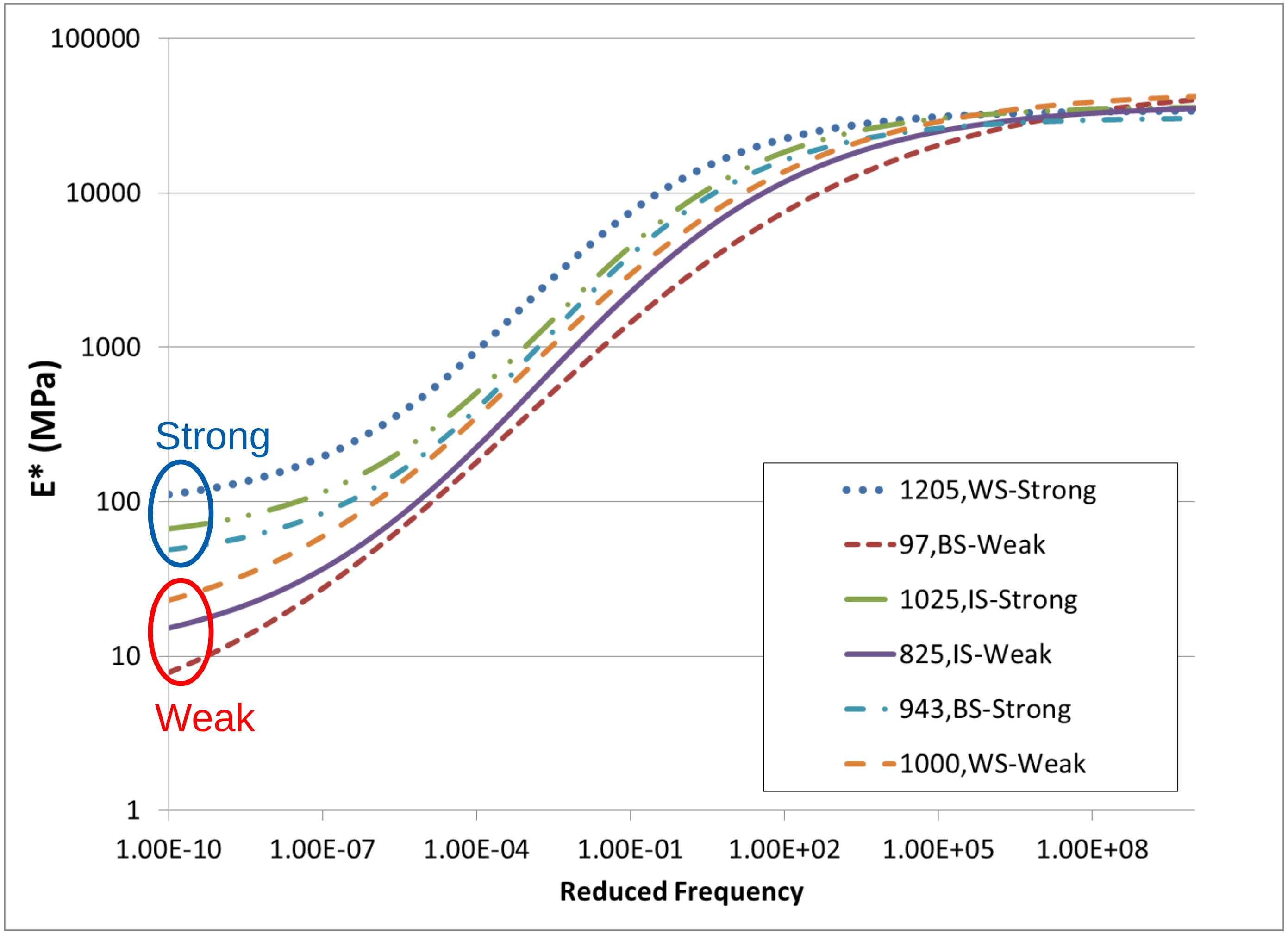
2.5σ ≈ 97.5%

and 3σ ≈ 99.8%

- Layers Considered:
  - 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.*

FEM Input: AC Materials



FEM Input: Granular Materials

- **Base materials (thin pavements)**
  - **Cross-anisotropic stress-dependent**
  - **Based on database of 114 materials (Tutumluer, 2008)**
  - **Materials in database tested using pulse load in vertical and radial directions**

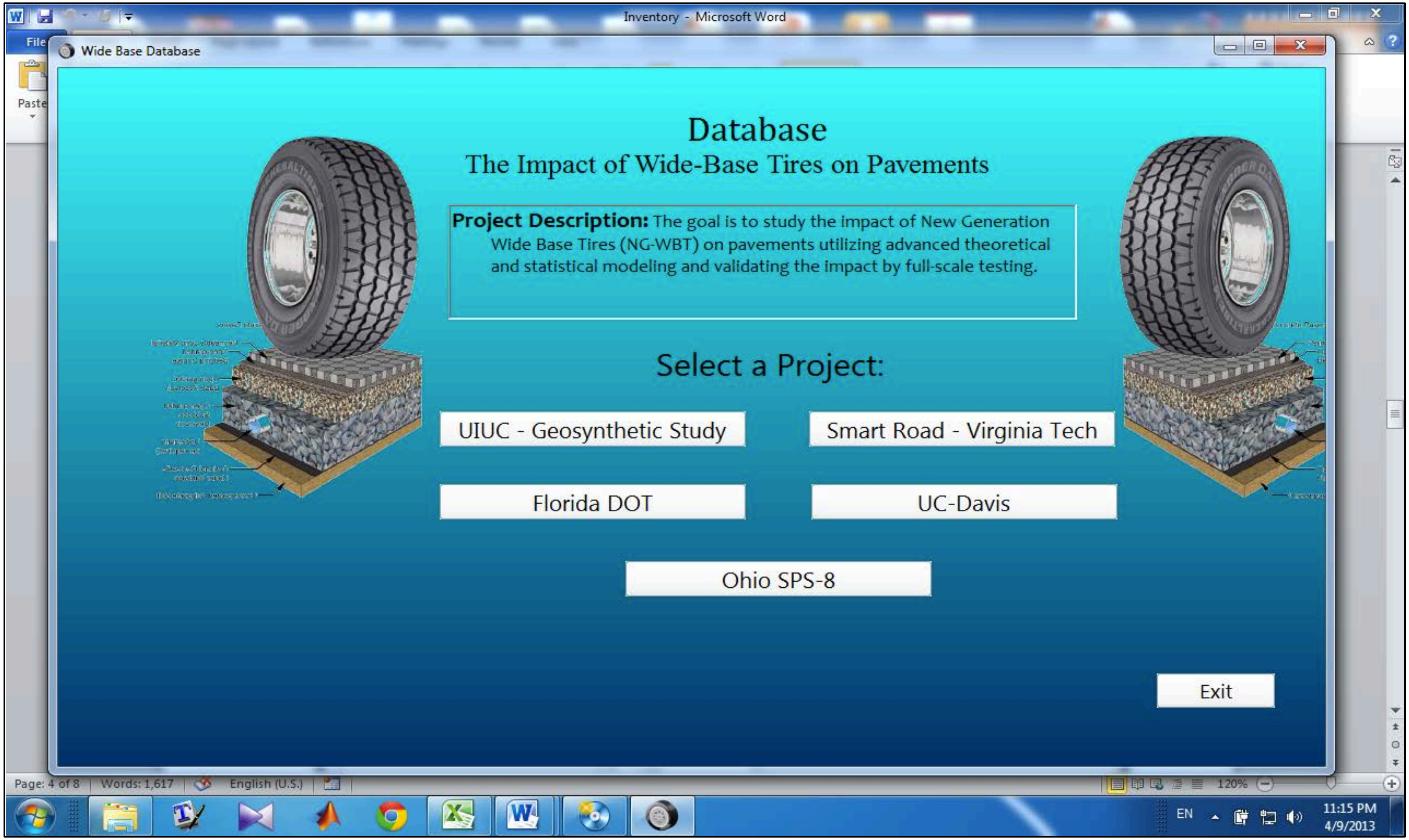
Laboratory Testing

Dynamic Modulus

SCB

IDT

Database of Measurements



Artificial Neural Network

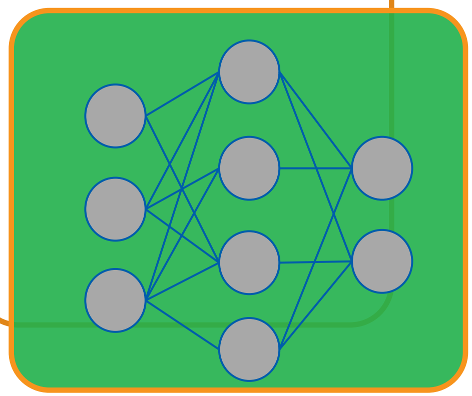
Experimental Measurement

- **Intermediate Cases**

Finite Element Model

- **Extreme Cases**

Artificial Neural Networks



Tool

- **Inputs:**
  - -Material Properties
  - -Tire Type
  - -Loading
  - -Pavement Structure
- **Outputs:**
  - -Stress and Strain
  - -Pavement Damage

Testing and Instrumentation

Accelerated Pavement Testing

Controlled Truck Load Testing

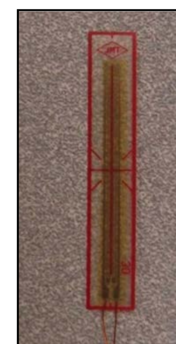
MDD

Strain Gauge

Thermocouple

Pressure Cell

Rosette



Foil Gauge

Life Cycle Cost Analysis (LCCA)

- **Guidelines to assess LCCA using RealCost:**
  - **Identify RealCost inputs**
  - **Calculate low-volume damage for current traffic (Control)**
  - **Calculate pavement damage caused by expected traffic (WBT)**
  - **Run RealCost for both scenarios (Control and WBT)**

Life Cycle Assessment (LCA)

- **Evaluation of environmental effects**
- **Focus on energy use and greenhouse gas emissions**
- **Sensitivity analysis including:**
  - **Range of smoothness, rolling resistance, and surface characteristics**
  - **Hauling distance**
  - **Traffic levels and congestion**
  - **Traffic closure during constructions**
  - **Fleet composition**

Project's Expected Outcome

- **Database** to access measured pavement responses
- **Validation** of pavement model using instrumented sections
- **Analysis tool** comparing pavement damage caused by WBT and DTA
- **LCA** and **LCCA**

Final Remarks

- **Proper characterization of tire-pavement interaction is crucial to accurately quantify pavement damage**
- **Robust analysis needs to be performed in order to determine the actual damage caused by WBT and DTA**
- **Tire-pavement load transfer mechanism depends on tire type, loading, and rolling conditions**

Acknowledgement

- TPF-5(197) Pool Fund Study Technical Panel:
  - FHWA, RMA, IL, MN, MT, NY, OK, VA, OH, and TX.
- ICT, Delft UT, FL DOT, UC Davis, Texas A&M, CSIR
- UIUC-NCSA, Ohio U., SD DOT
- B. Choubane, A. Coenen, M. De Beer, M. Elseifi, A. Gamez, J. Green, J. Harvey, I. Khoury, S. Lew, D. Little, H. Ozer, S. Sargand, T. Scarpas, R. Wu, P. J. Yoo, and M. Ziyadi.

QUESTIONS