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Investigation of Applicability and Use of a Pavement Response Model with High Speed Deflection Devices (HSDDs)

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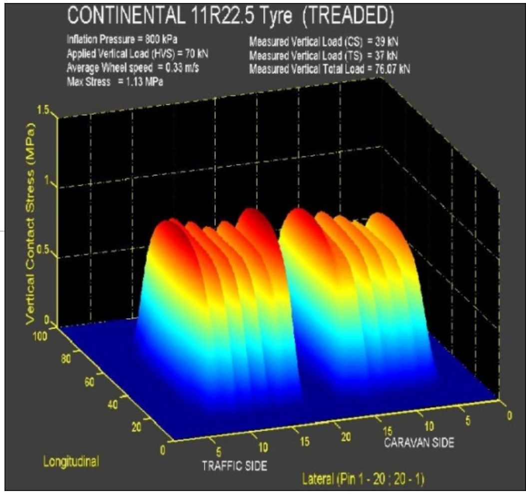
Outline



Introduction: High Speed Deflection Devices (HSDDs)

- Dynamic Surface Disp. of Response of Layered Systems

Issues: 3D- Viscoelastic Continuum (Vehicle Velocity?)
Moving Surface Load (Non-stationary)
3D Loading – Normal and Shear (Breaking?)

Analytical Modeling: 3D-Move

Formulation of a Generalized Analytical Model
Material Characterization

Calibration of Analytical Model
- Existing Classical Solutions
- Model Tests _ Lab Calibration
- Field Calibration

Use of 3D-Move to FHWA Network Level Project DTFH61-12-C-00031

- **Calibration with Field Measurement (Surface Disp.)**
- **Calibration with MnROAD Measurements (Stress & Strains)**
- **Future Work in Sensitivity Studies**

Existing Methods: - ELSYM5/WinLEA/JULEA

Static/Stationary/Circular/Uniform, q/ Linear Elastic/Multi-Layer/
"Work Horse" ; Developed in 1970s;
AASHTO Pavement Design1986 and 2002, 2012 (MEPDG & Pavement ME)

- Finite Element – **(Recent "Large" Studies)**

Wide-Base Tire (Pool-funded study) - 2011

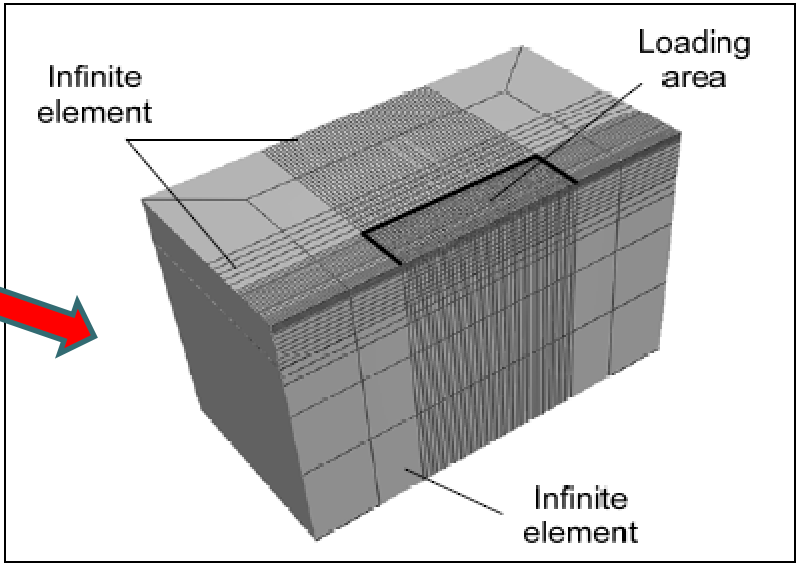
PANDA Software (Texas A&M) - 2010

ABAQUS (Version 6.7)

3D – Brick Elements

NOTE: " Problems" – Stationary Load

Loaded area & and layers are of same size



"Computer Intensive"

3D-Move Formulation Finite Layer Approach

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Solution for Single Harmonic Pressure

- It can be shown that U_{nm} is given by: (6th order differential equation)

$$D_1 \frac{d^6 U_{nm}}{dz^6} + D_2 \frac{d^4 U_{nm}}{dz^4} + D_3 \frac{d^2 U_{nm}}{dz^2} + D_4 U_{nm} = 0$$

  - D_1, D_2, D_3, & D_4 = constants that depends on
    - layer material properties,
    - velocity of wave propagation,
    - λ_n and μ_m.

Summary: Elements of 3D-Move

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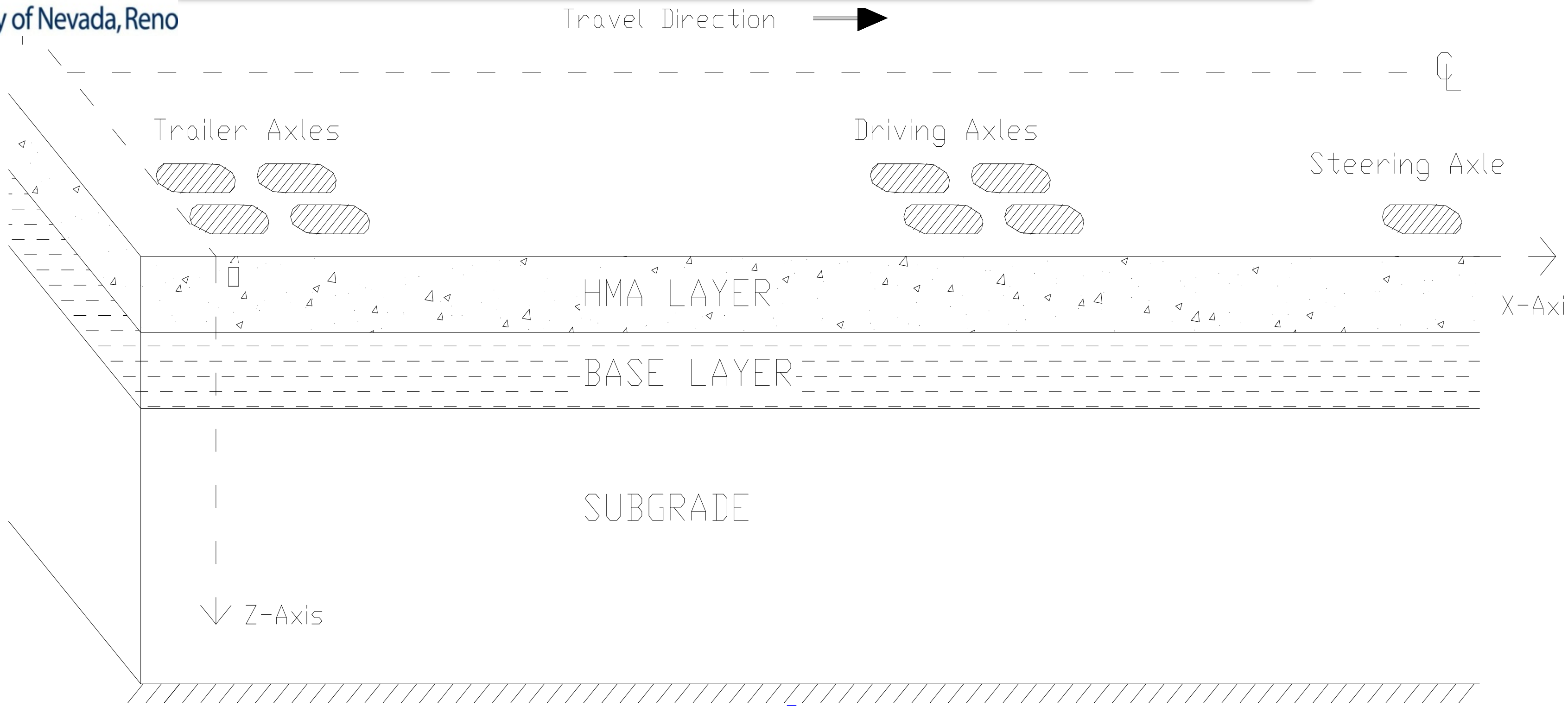
(1) Uses Finite-Layer Continuum Approach – Takes Advantage of Horizontally-Layered Pavement Layers; No Discretization; No Lateral Boundary Effects. – **Computer Efficient**

(2) Models Moving 3D-Surface Stresses (Dynamic; Normal & Shear Contact Stresses) – Handles Vehicle Speed

(3) Direct Use of Frequency-Sweep Data (Viscoelastic Modeling)

(4) Ideally-Suited when Responses are Needed at a Selected Few Locations - Computer Efficient

Material Characterization: Pavement Layers



Pavement Layer Properties

Horizontally-Layered; HMA can be Viscoelastic

- Unbound Materials (?) - Elastic

Experimental Testing, |E*|

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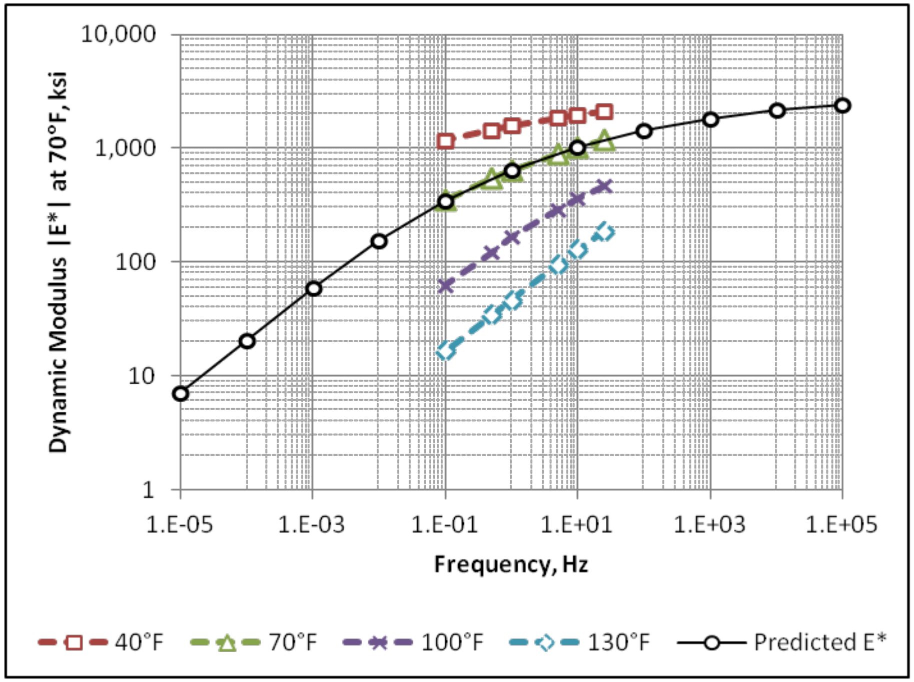
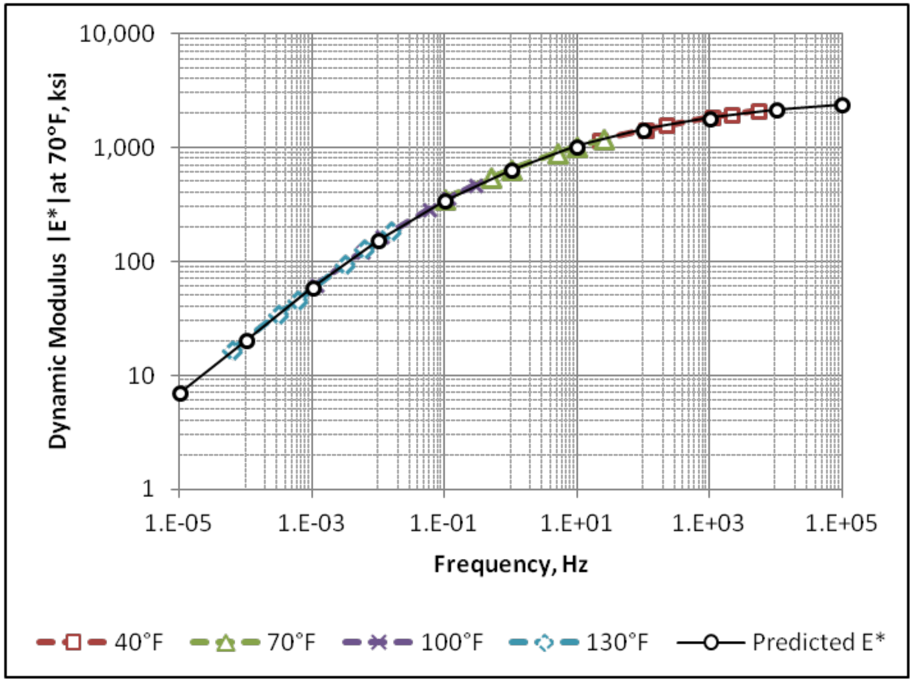
Dynamic Modulus, |E*|

Master Curve





Comparison Between 3D-Move and ViscoRoute (2.0)

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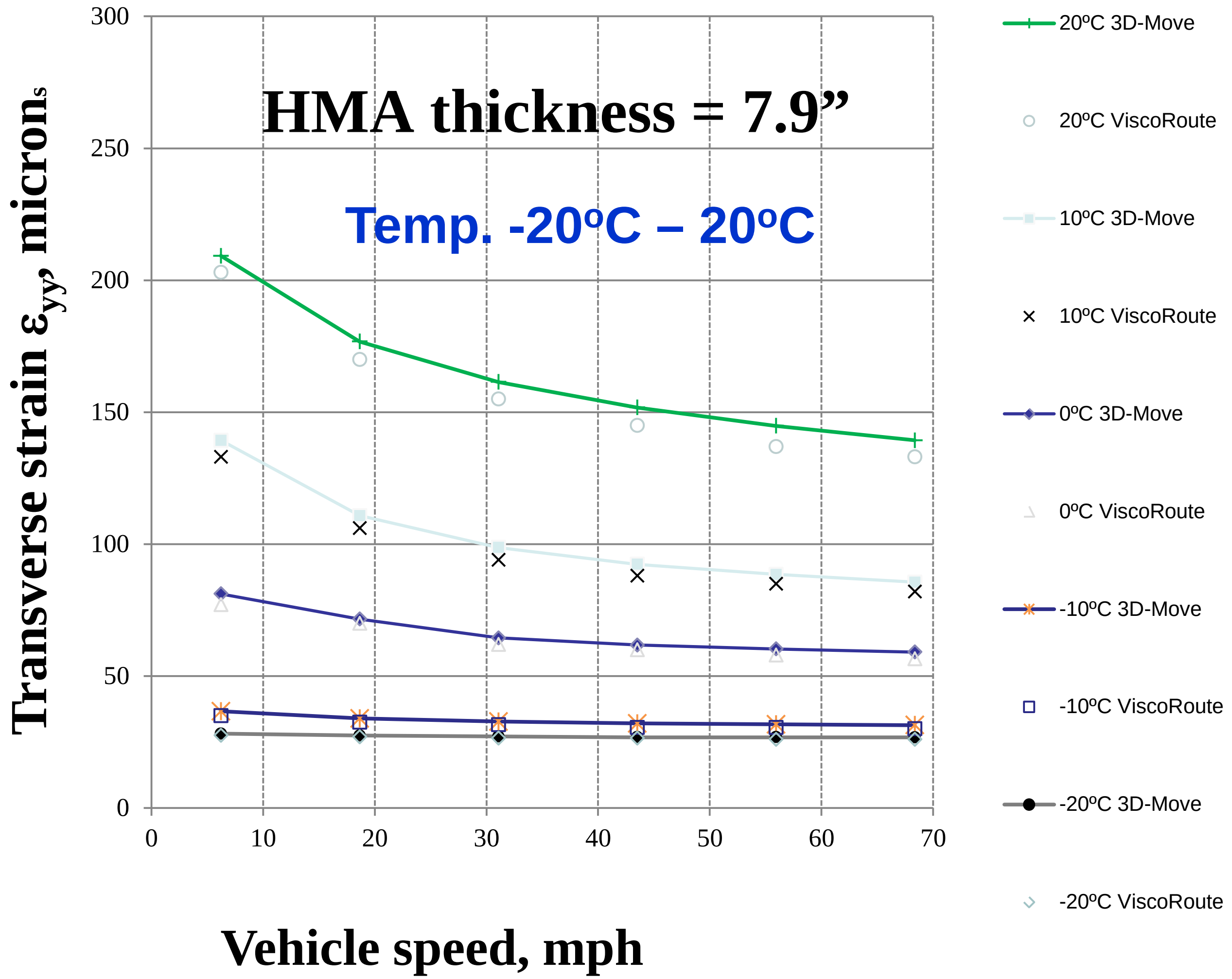

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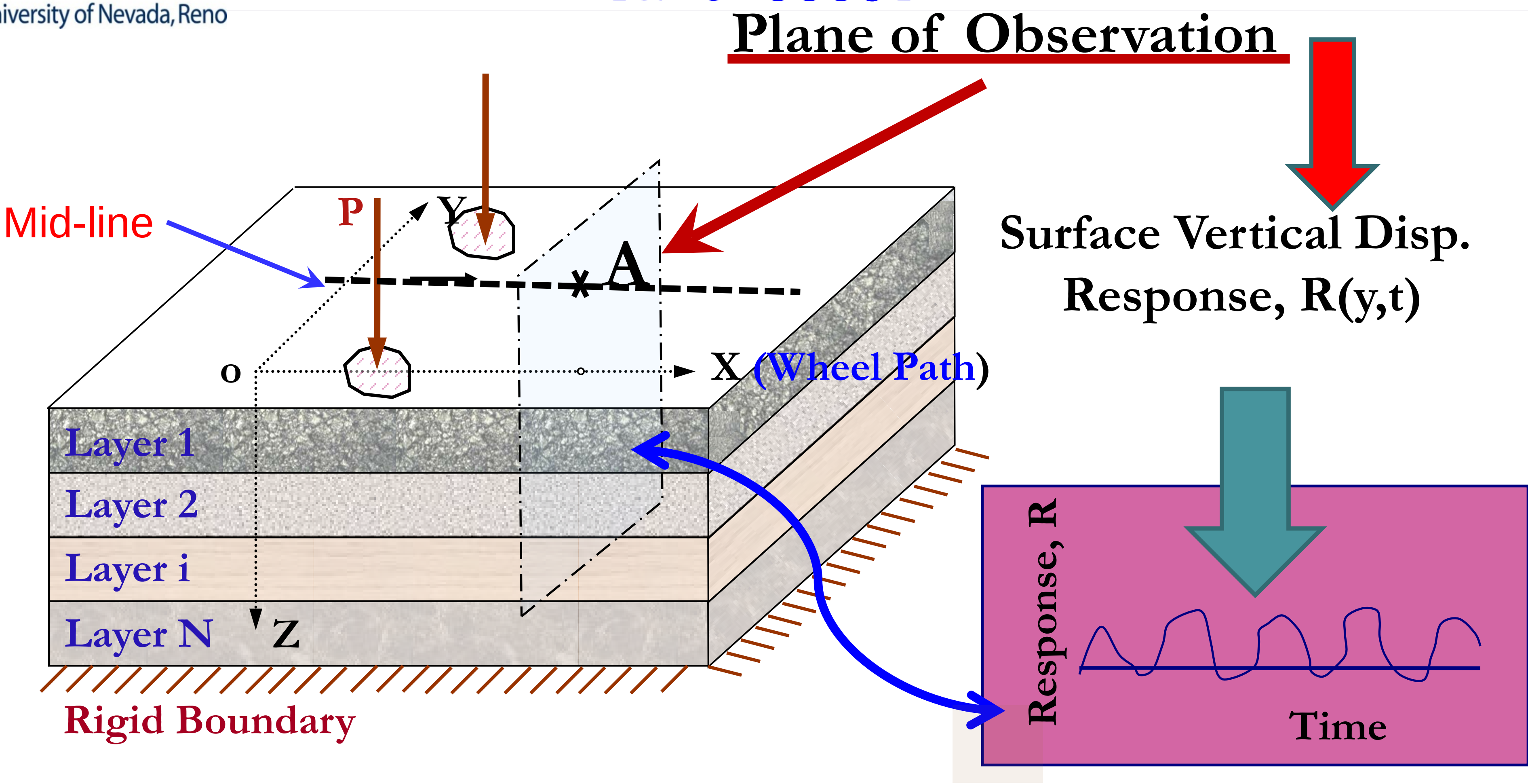
Both Models are: Dynamic and Viscoelastic.

Important Attributes of Pavement Modeling: Load-Related			
Factor	Layered Elastic Analysis (LEA) e.g.: ELSYM5, WESLEA, JULEA	Finite Element Method (FEM)	3D-Move Model
Non-Circular Loaded Shape	NO	YES	YES
Non-Uniform Vertical Contact Stress	NO	YES	YES
Contact Shear Stresses (Braking & Sloping Pavements)	NO	YES	YES
Moving Load (Non-Stationary) and Inertia Included (i.e. Dynamic)	NO	NO/YES	YES
Important Attributes of Pavement Modeling: Material Properties			
Viscoelastic Properties (Modulus and Phase Shift)	NO	YES	YES
Vehicle Speed	NO	YES	YES
Direct use of Freq. Sweep Data	NO	NO	YES

Use of 3D-Move to FHWA Network Level Project- DTFH61-12-C-00031



Pavement Responses from 3D-Move

Responses: Vertical Disp., HMA strain, Earth Pressure

Use of 3D-Move in FHWA Network Level Project- DTFH61-12-C-00031

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Focus: High Speed Deflection Devices (HSDDs)

HSDDs: TSD & RWD

Main Goals:

Phase 1: Calibration of 3D-Move using Surface Disp. (UTEP) and with MnROAD Measurements (Stresses & Strains)

Three HMA Cells (3, 19 & 34)

Phase 2: Sensitivity Studies: Robust Indicators for Pavement Deterioration

MnROAD Cells under Investigation

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Cell 3

HMA FWD Modulus = 554 ksi σ = 34 ksi	3 in
Base E = 68.8 ksi σ = 8.5 ksi	43 in
Subgrade E = 17.7 ksi σ = 2.9 ksi	122.4 in

Cell 19

HMA FWD Modulus = 301 ksi σ = 65 ksi	5 in
Base E = 32 ksi σ = 5.8 ksi	31 in
Subgrade E = 6.1 ksi σ = 0.6 ksi	18.1 in

Cell 34

HMA FWD Modulus = 299 ksi σ = 67 ksi	4 in
Base E = 15.7 ksi σ = 3.1 ksi	12 in
Subgrade E = 8.5 ksi σ = 0.9 ksi	46.3 in

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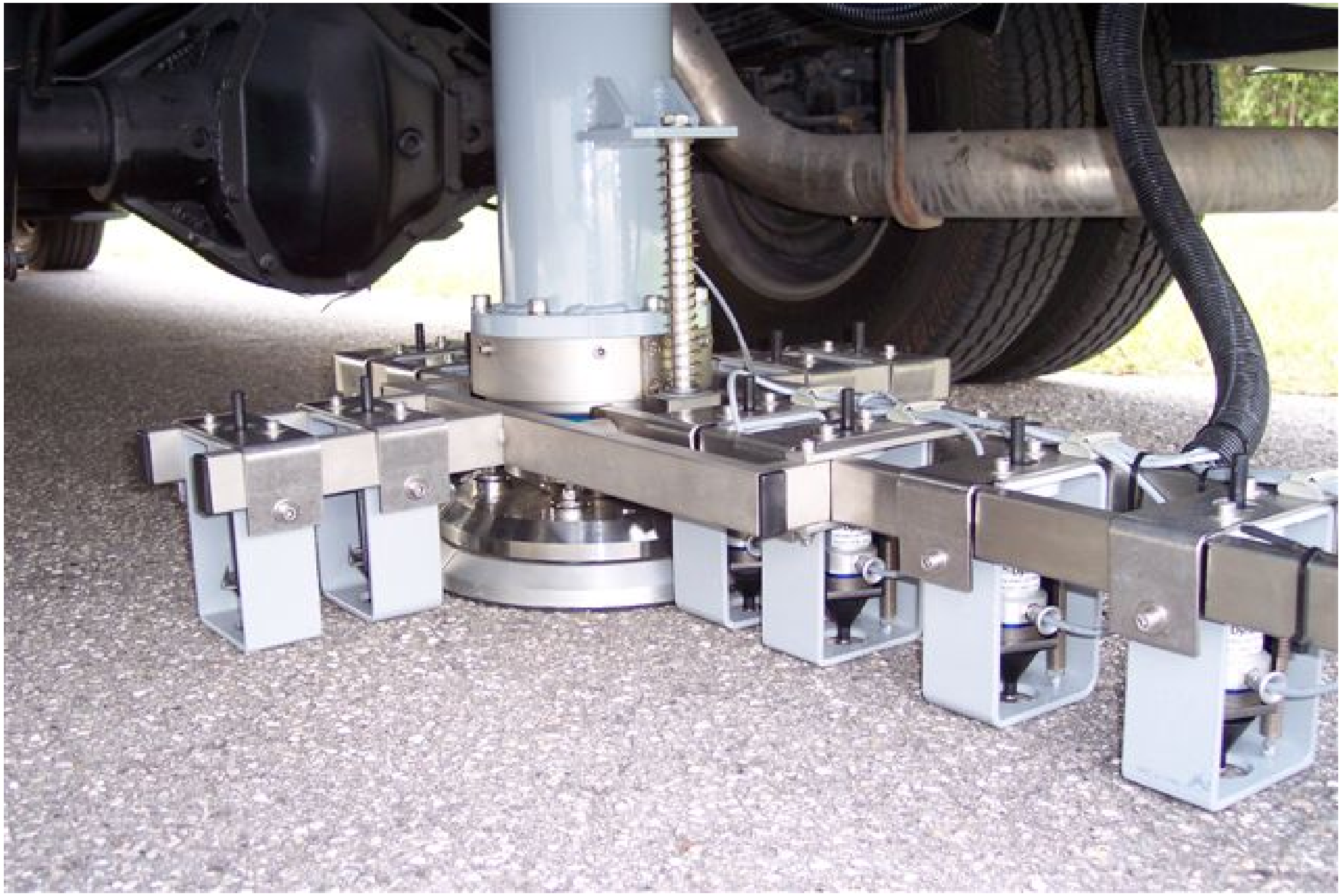
Material Characterization: FWD Field Measurements

amec



Backcalculated Stiffnesses of Pavement Layers for Accuracy Cells

Cell	Material	Thickness, in. (cm)	Average Modulus, ksi, (MPa)	Standard Deviation, ksi, (MPa)	Coefficient of Variation (%)
3	HMA	3 (7.6)	554 (3820)	34 (234)	14
	Base	43 (109.2)	68.8 (474)	13.6 (94)	19.8
	Subgrade	122.4 (310.9)	17.7 (122)	2.2 (15)	12.3
19	HMA	5 (12.7)	301 (2075)	65 (448)	22
	Base	31 (78.7)	32 (221)	5.8 (40)	18
	Subgrade	18.1 (46)	6.1 (42)	0.6 (4)	10.2
34	HMA	4 (10.2)	299 (2062)	67 (462)	22
	Base	12 (30.5)	15.7 (108)	3.1 (21)	19.9
	Subgrade	46.3 (117.6)	8.5 (59)	0.9 (6)	10.2

Pavement Temperature

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- HMA Modulus is sensitive to temp.

- Require Ave. HMA temp. @ time of testing (FWD & HSDDs)

All FWD and HSDDs Trials “within” 3 Weeks

- Use thermocouple measurements made within HMA (Incomplete data for Cells 19 & 34)

- Use BELLS equation to find appropriate temperature for missing data

Average temperatures within HMA layer

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CELL	Temperature at time of FWD, °F (°C)	Temperature at time of TSD, °F (°C)	Temperature at time of RWD, °F (°C)
3	99 (37)	91 (33)	99 (37)
19	81 (27)	68 (20)	63 (17)
34	108 (42)	91 (33)	90 (32)

Procedure:

- Backcalculate "Existing" Layer Moduli

  - Use FWD Data (HMA, Base & Subgrade)

  All FWD and HSDDs Trials "within" 3 Weeks

- Use Wictzack Equn. to find Master Curve for HMA Modulus (Temp. & Freq.)

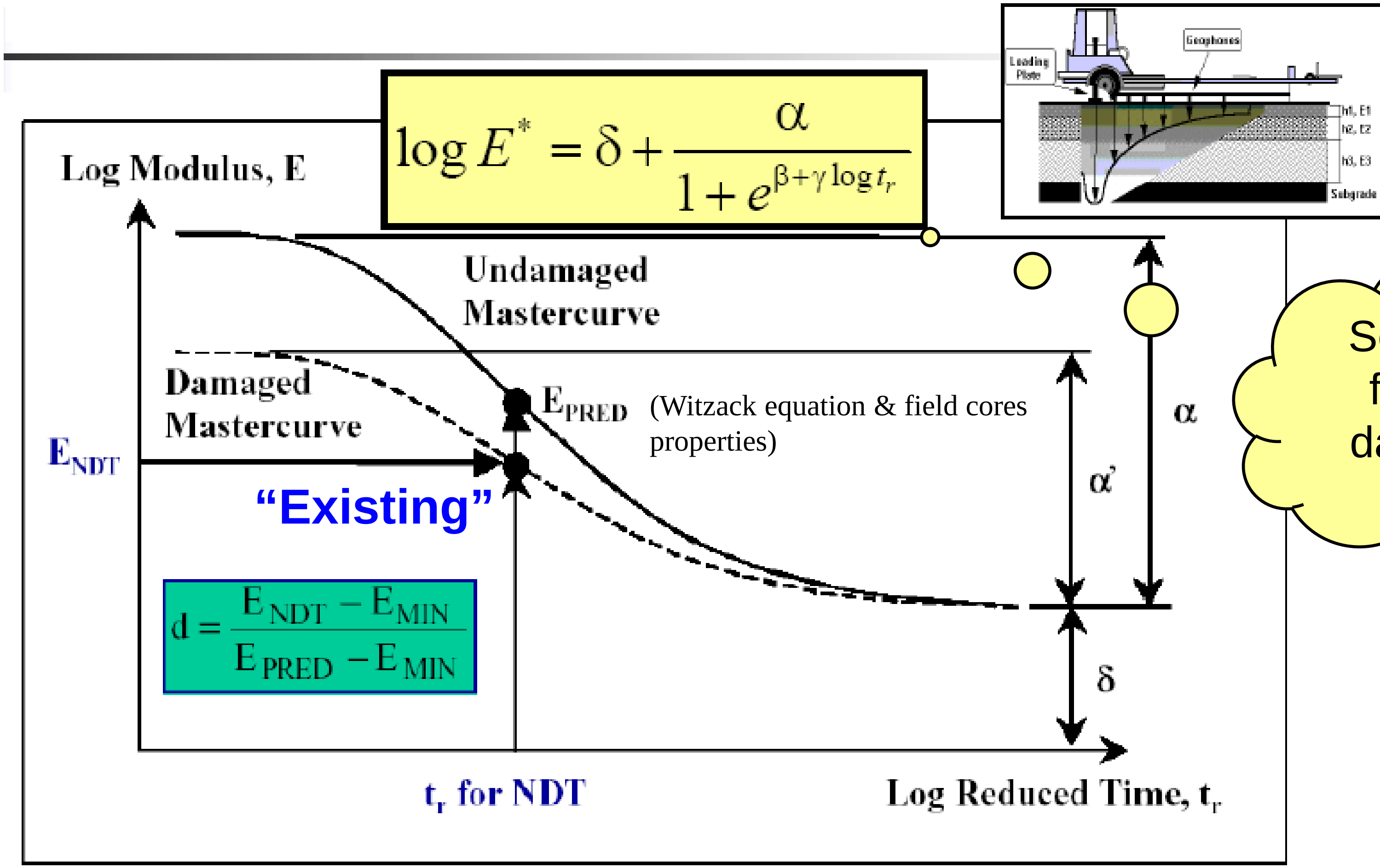
  - Note: f_{FWD} = 30Hz; Use FWD Test Temp.

Parameters needed for the dynamic modulus predictive equation are:

- Air void content.
- Asphalt content.
- Gradation.
- A & VTS for the recovered binder.

Undamaged Master Curve

Obtaining Damaged/Existing Modulus: Witczak Equn.



Solve for fatigue damage, d_{AC}

$$E^*_{dam} = 10^{\delta} + \frac{E^* - 10^{\delta}}{1 + e^{-0.3 + 5 \times \log(d_{AC})}}$$

HMA Modulus at HSDDs Trial Temps

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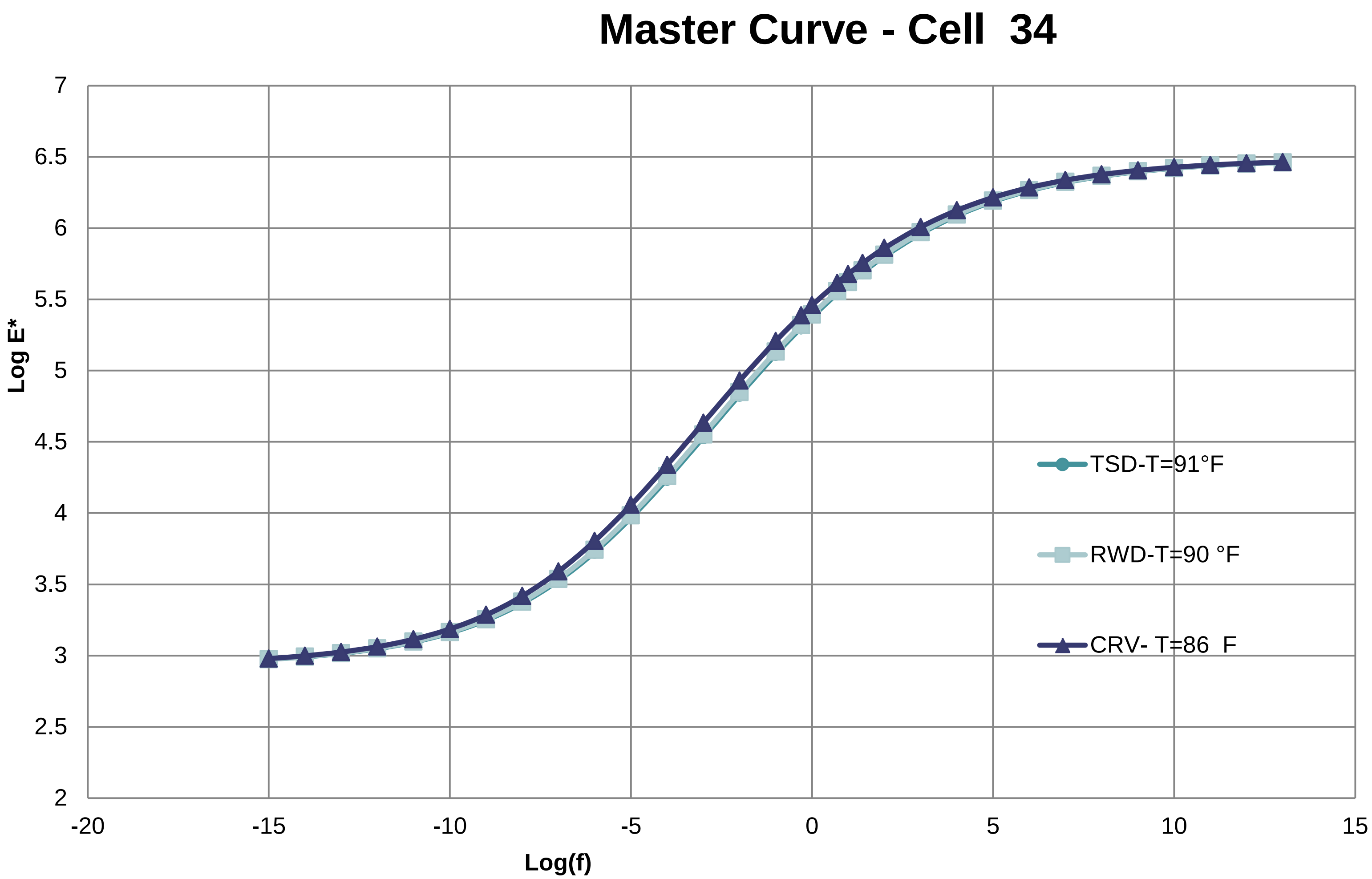

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HSDDs Trials at MnROAD

Cell	HSDD	Passes	Velocity
Cell 3	TSD	3 Passes	48, 72 km/h
	RWD	3 Passes	48, 72, & 97 km/h
	CRV	3 Passes	17.6 km/h
Cell 19	TSD	3 Passes	48, 72, & 97 km/h
	RWD	3 Passes	48, 72, & 97 km/h
	CRV	3 Passes	17.6 km/h
Cell 34	TSD	3 Passes	48 & 72 km/h
	RWD	3 Passes	48 & 72 km/h
	CRV	3 Passes	17.6 km/h

Total: 15 Cases (TSD & RWD) + 3 Cases (CRV)

TSD Loading and UTEP Instruments

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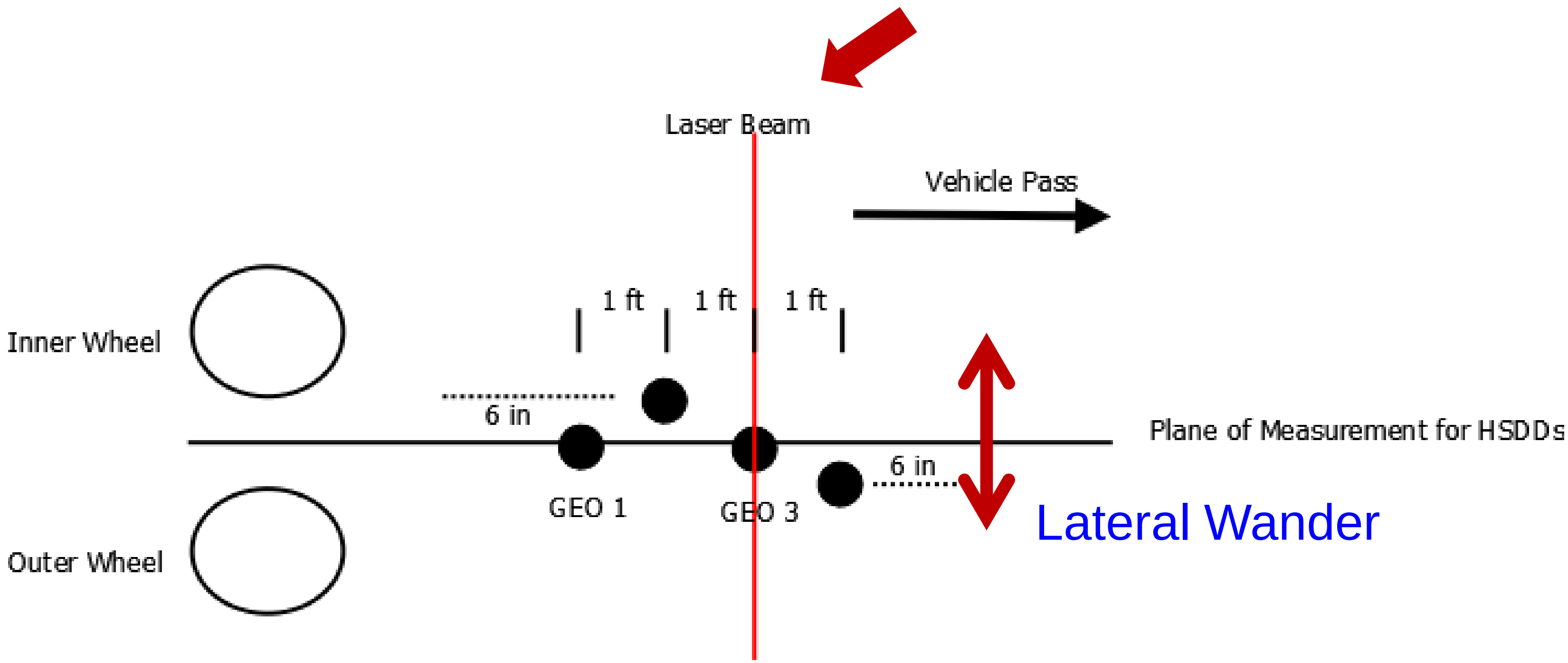

Typical UTEP Measurements

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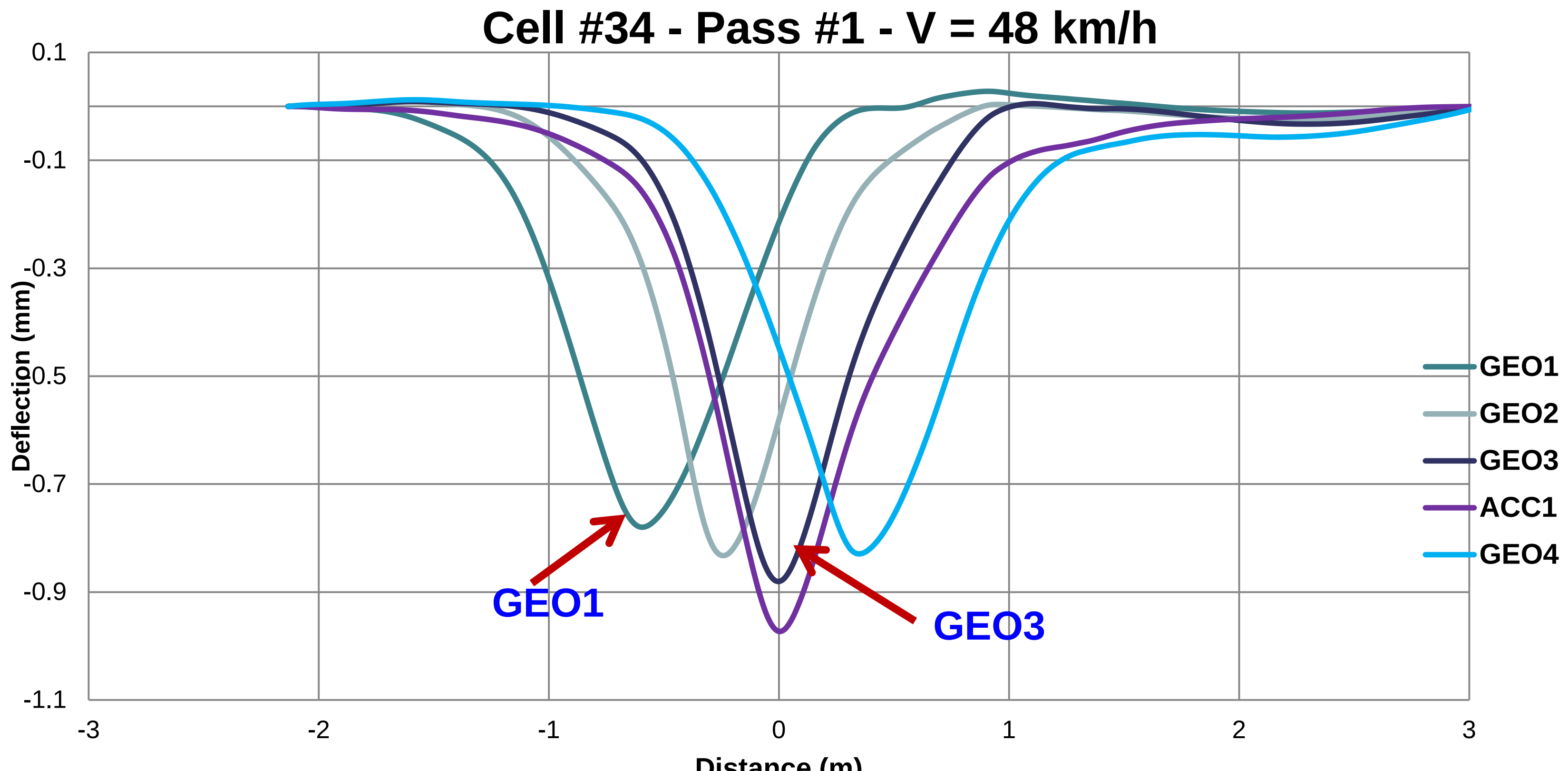
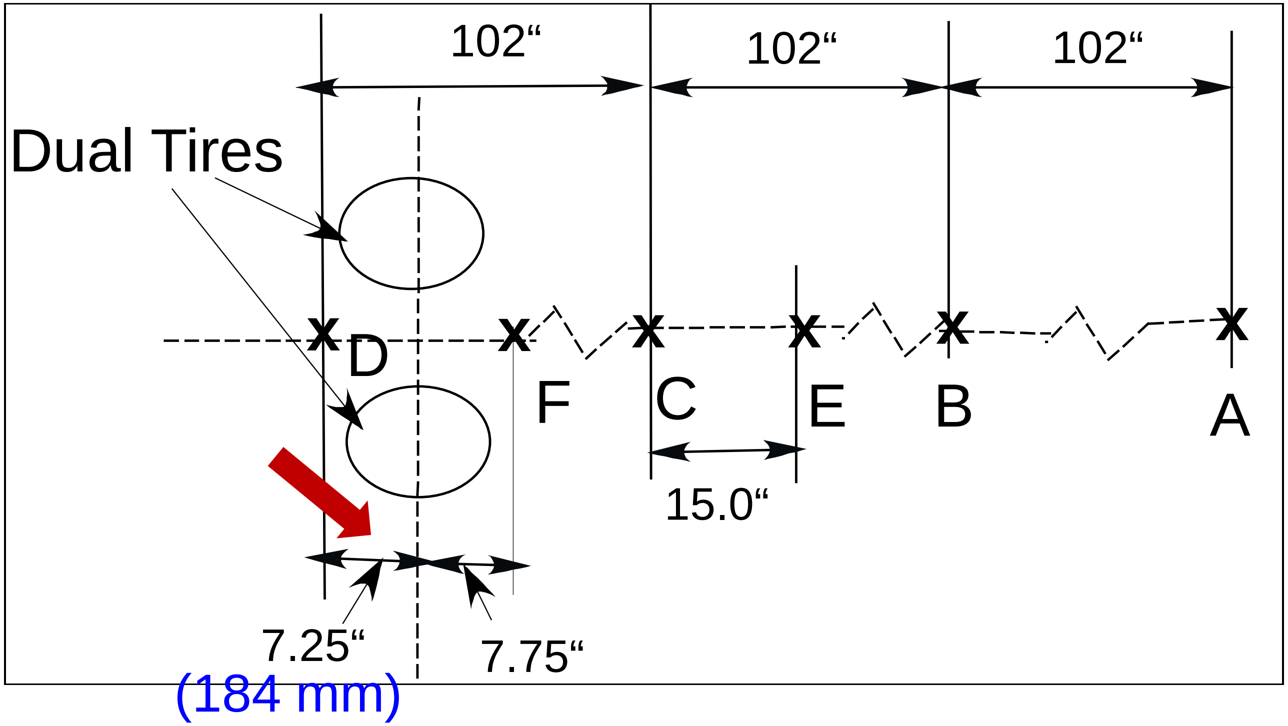


NOTE: Ideally GEO1 & GEO3 should yield same results (Indication of variability)

For 3D-Move Calibration use Highest UTEP Geophone Disp. Sensor Measurements (i.e., GEO3)

RWD Sensor Locations for Disp. Measurements



Locate sensor behind wheel, when looking for w_{max}

Looking for Maximum Displacement (Transverse Plane)

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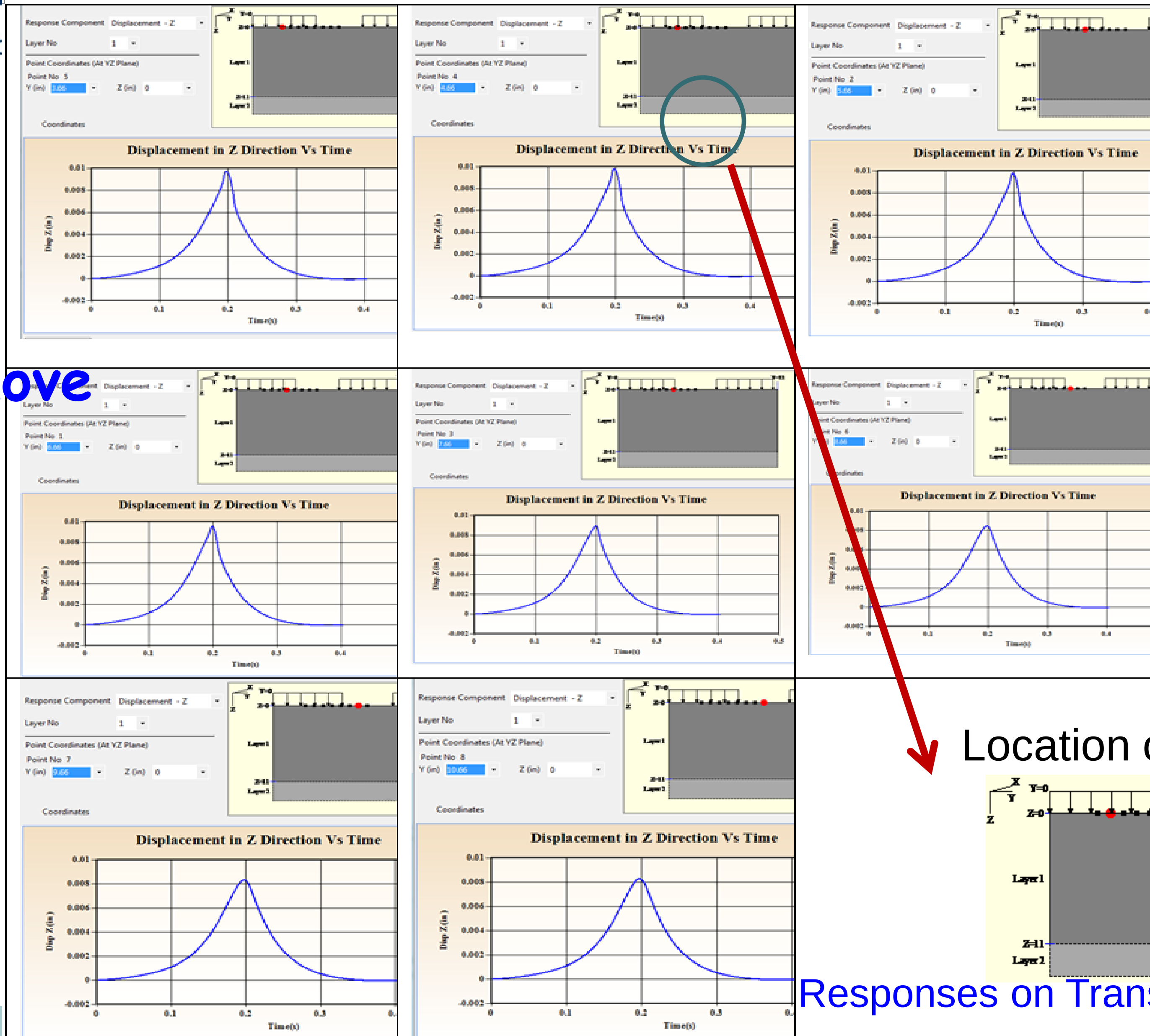
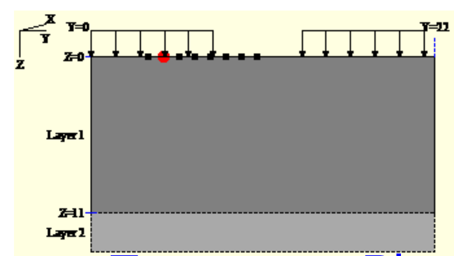
3D-Move Runs



Vehicle Path

Location of Max Disp



Responses on Transverse Plane

Location of Max. Disp. (3D-Move)

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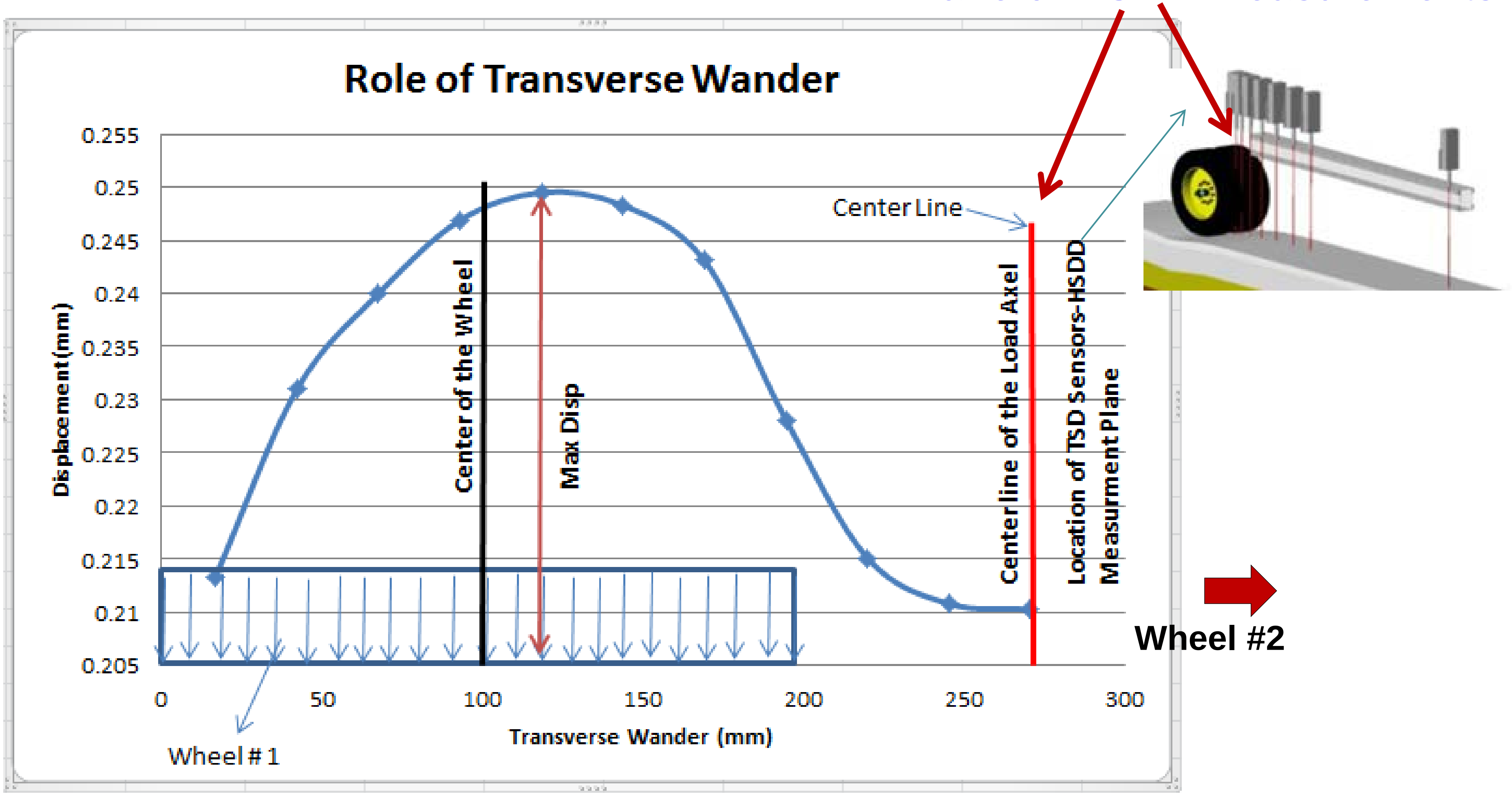
Plane of HSDD Measurements



Role of Variation in Tire Load in TSD

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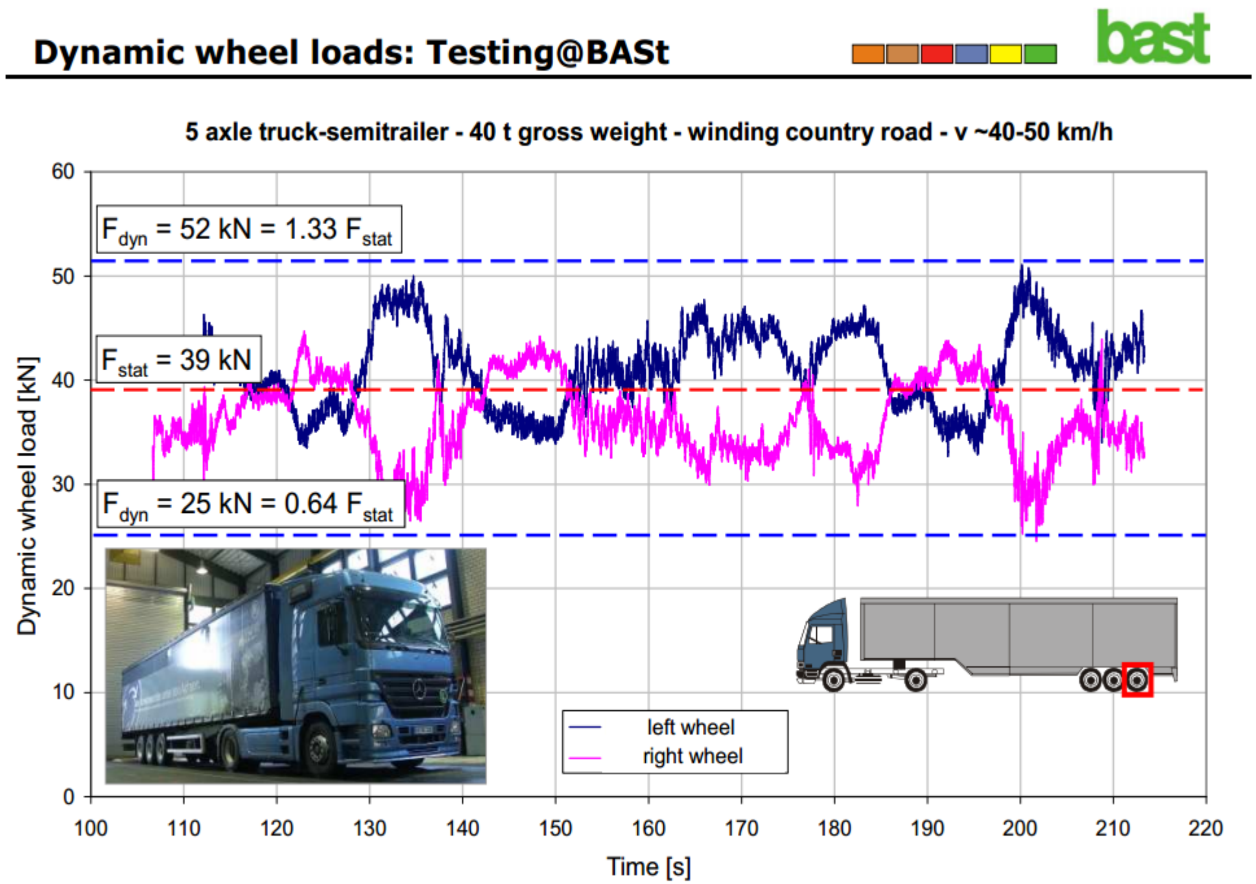
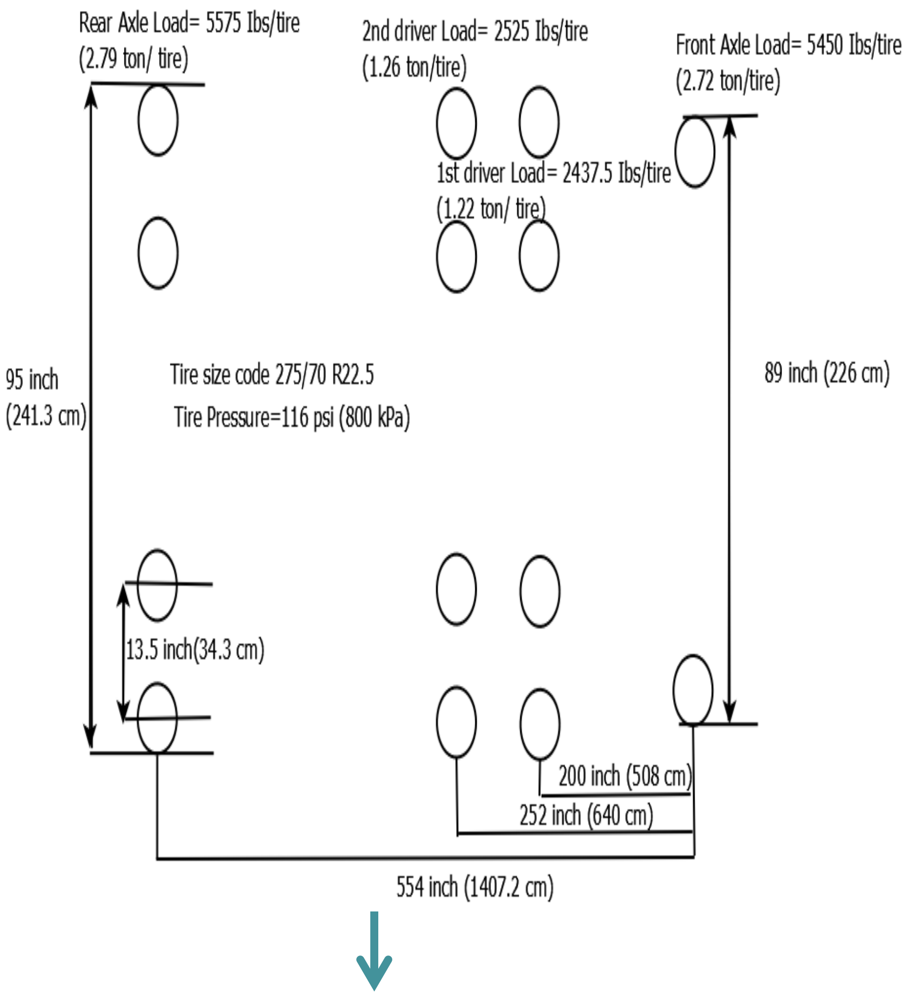
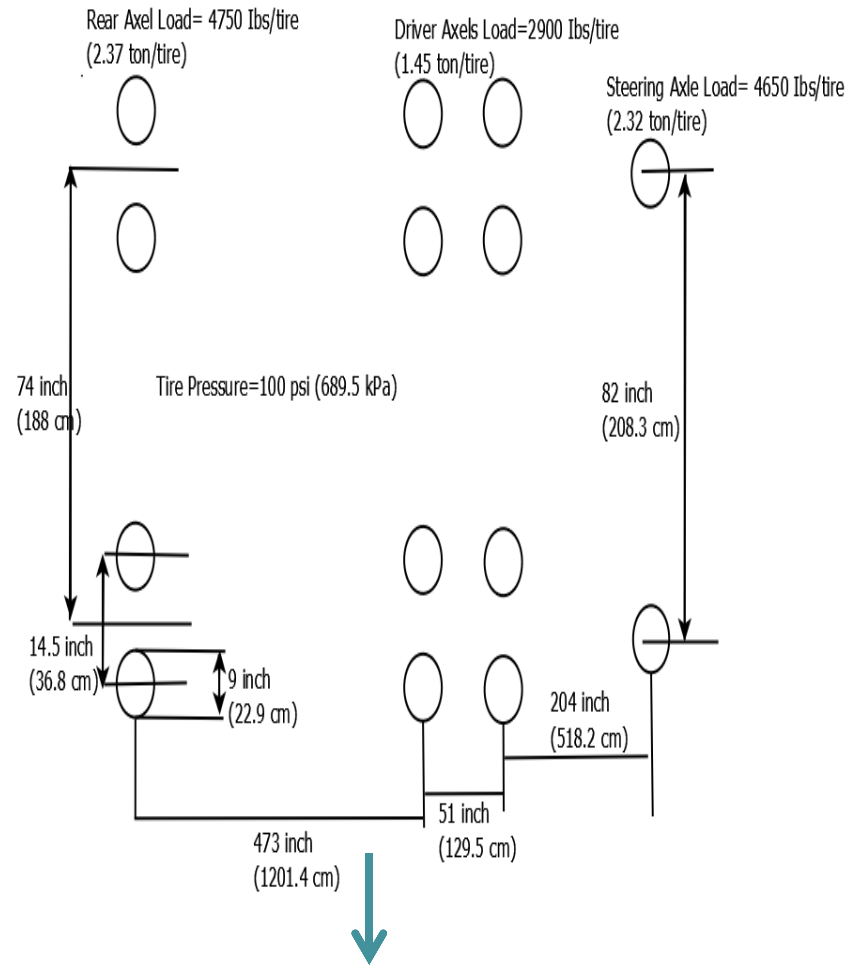


NOTE: Uneven Load Distribution within Axle



TSD Axle Configuration and Load



RWD Axel Configurationand Load

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3D-Move Case Scenarios

Case 1: Three layer pavement structure with same thicknesses as used in the FWD backcalculation and corresponding mean layer moduli derived from the FWD backcalculation results;

Case X: Three layer pavement with: (a) thicknesses used in the FWD backcalculation except decreasing the HMA layer thickness by 1 in, (b) (mean – σ) of FWD backcalculated layer moduli for HMA and base layers, (c) (mean + σ) of FWD backcalculated layer moduli for subgrade, and (d) +25% of nominal tire load;

Case X1: Same as Case X, but with no reduction in HMA layer thickness.

3D-Move Results in TSD Trials

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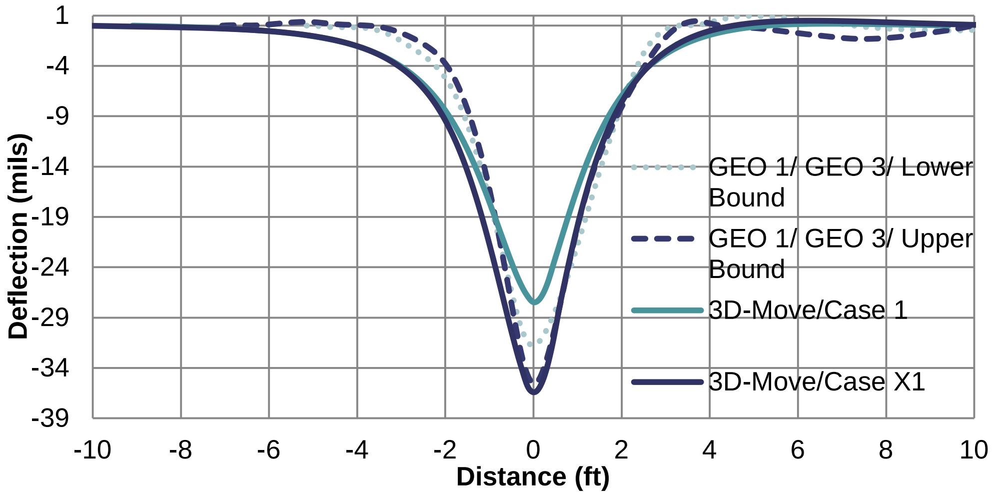

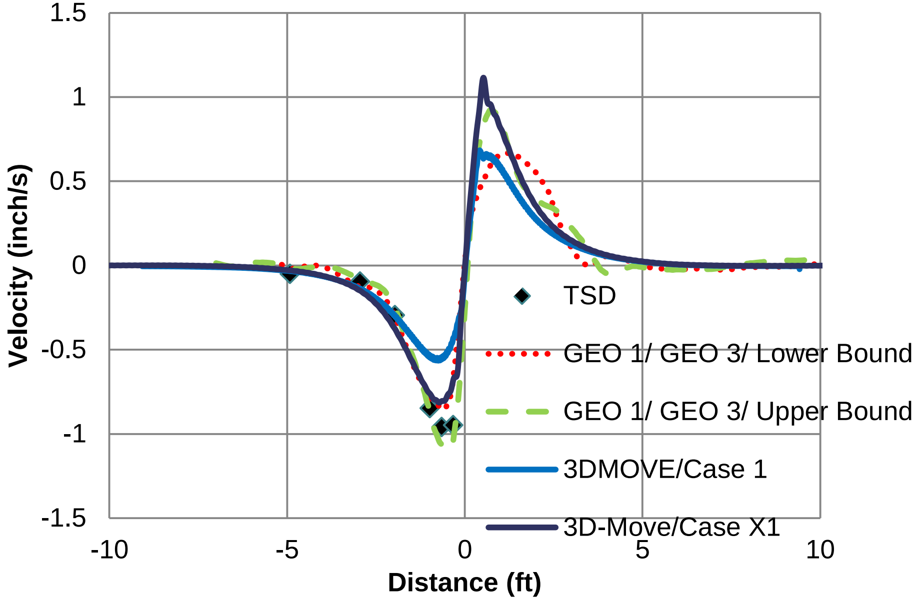

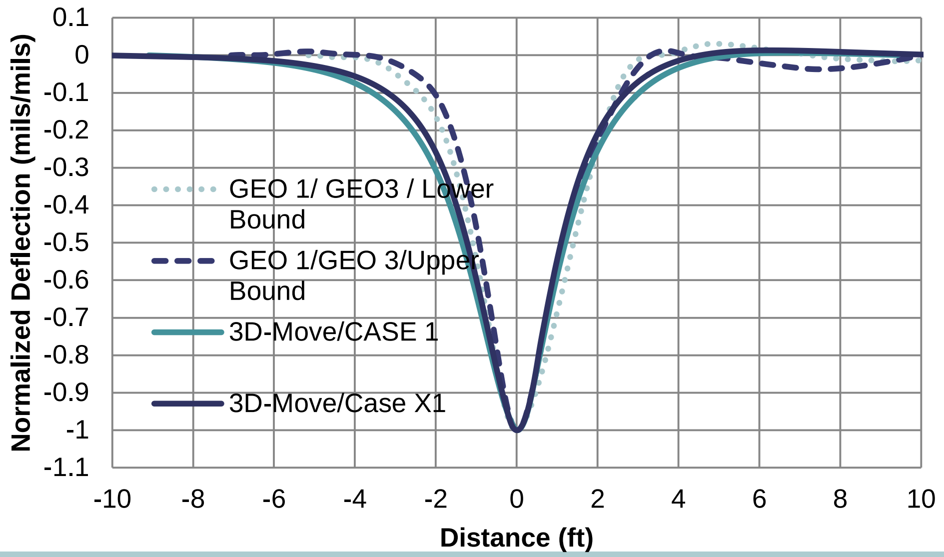

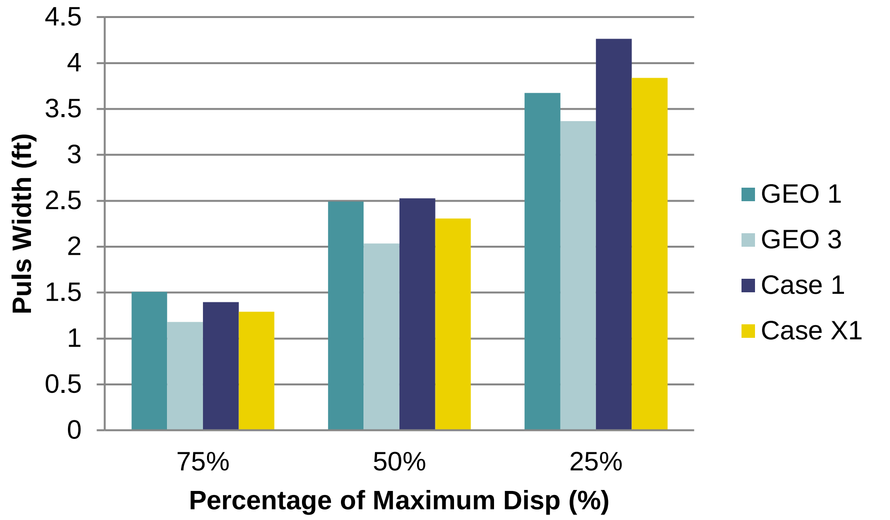

3D-Move Results in RWD Trials

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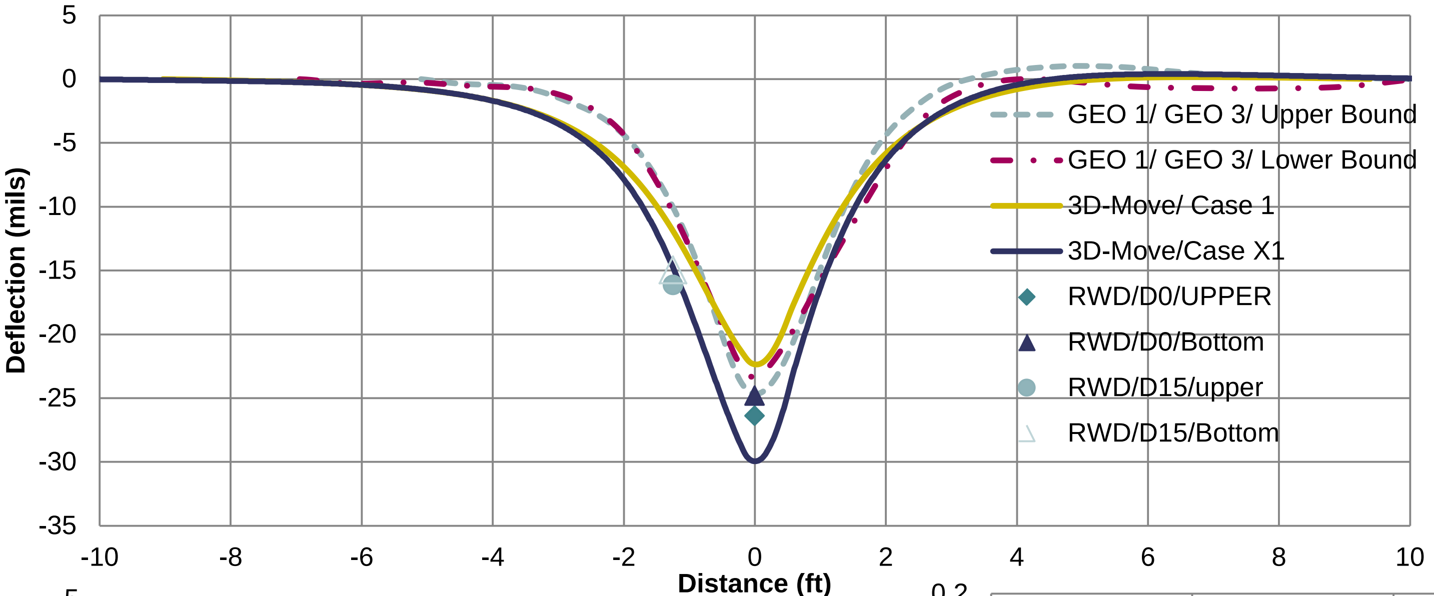

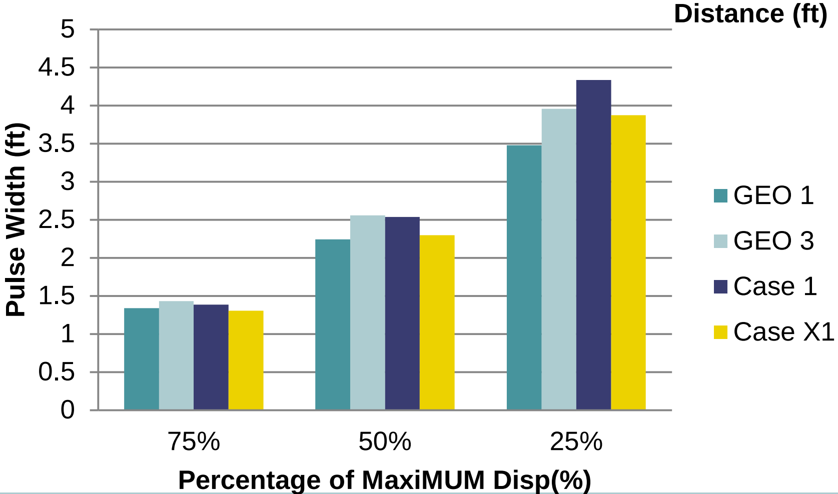

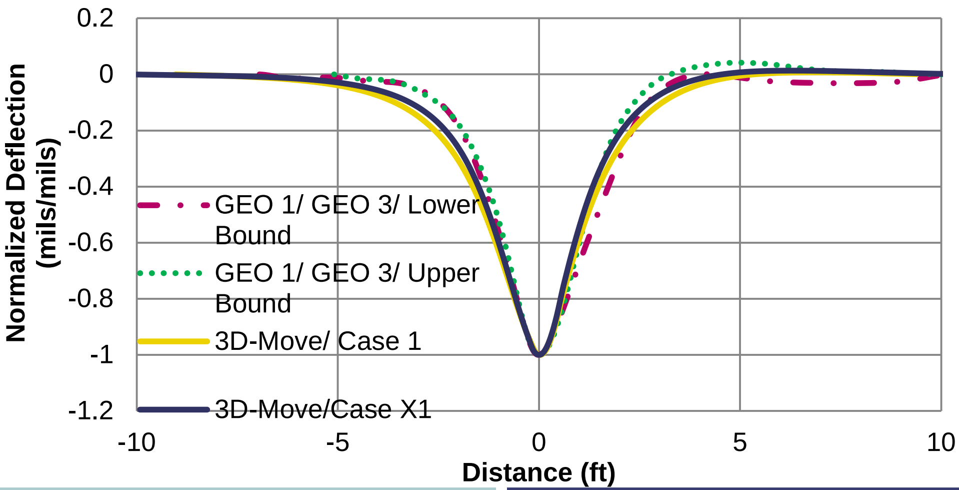

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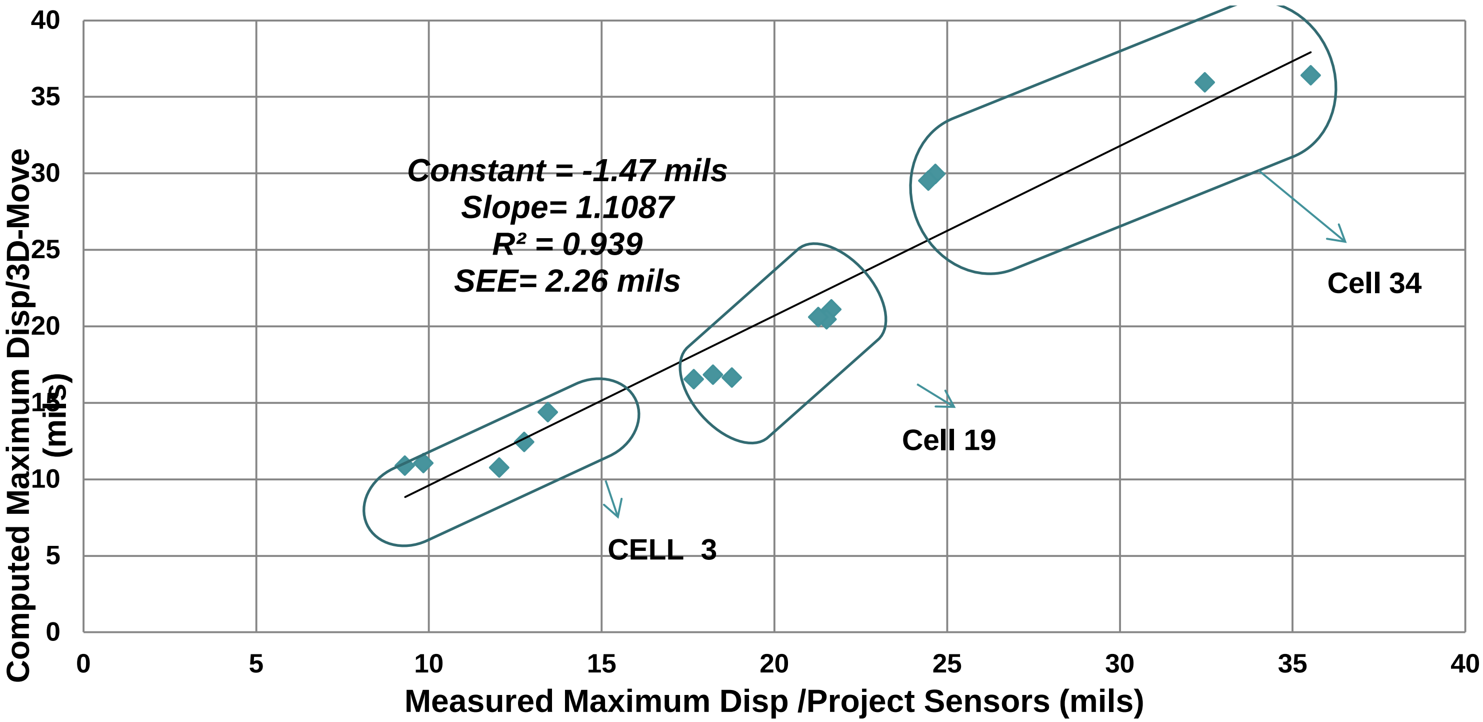
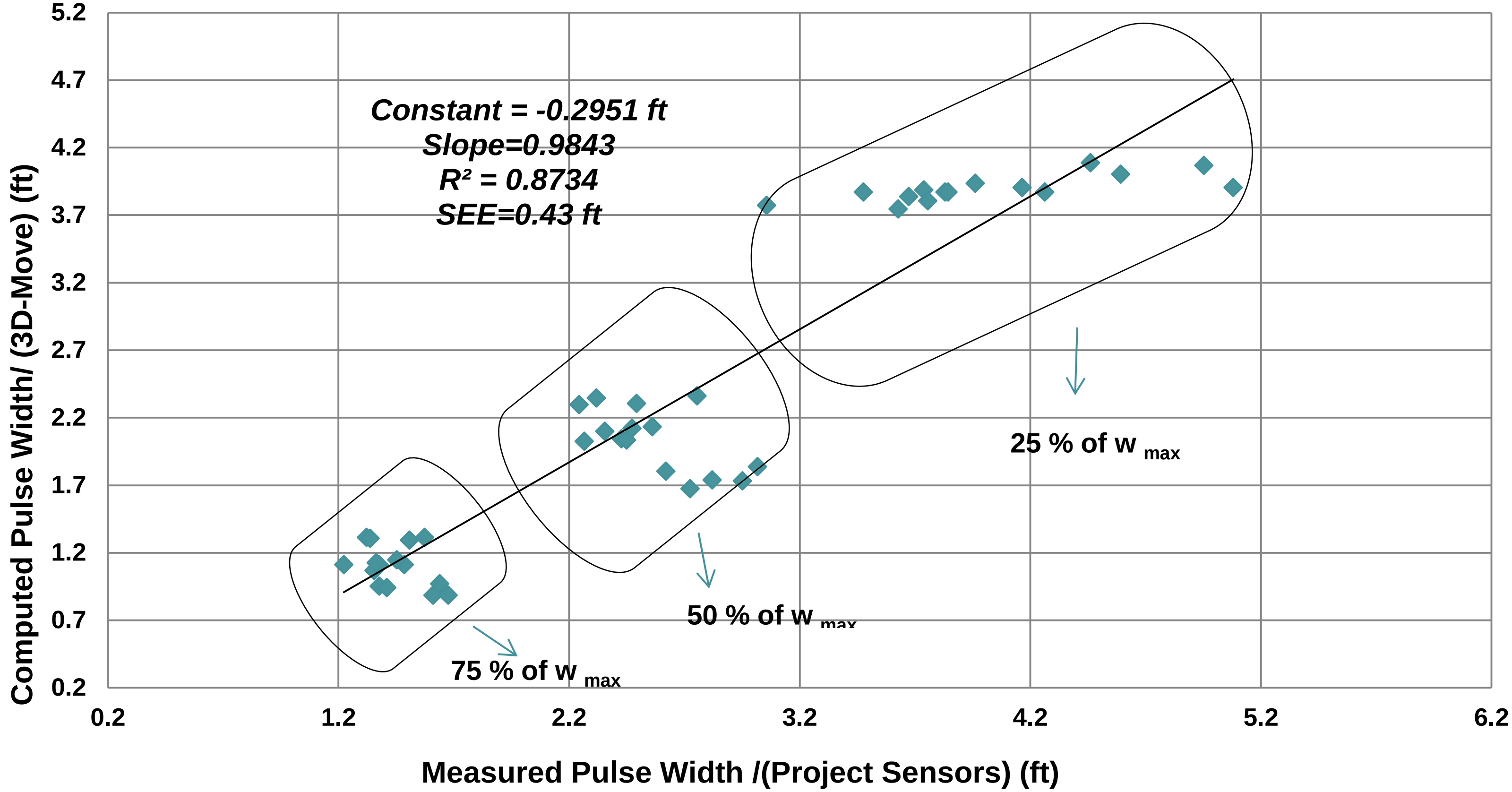
Computed vs Measured Maximum Displacements



15 Datasets (TSD & RWD)

Computed vs Measured Pulse Width

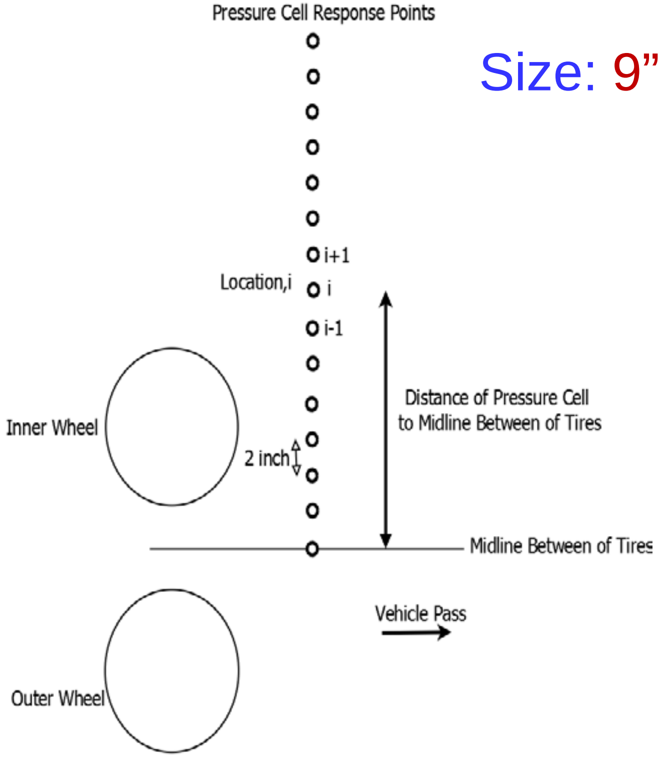


45 Datasets (TSD & RWD)

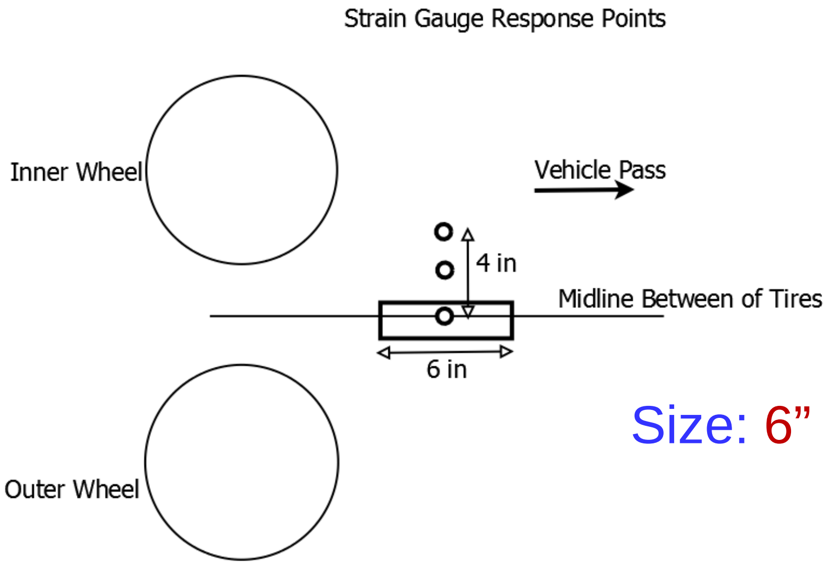
3D-Move Comparisons with MnROAD Measurements

Vertical Earth Pressures and Long. Strains in HMA

Issues: Lateral wheel wander
Size of sensors



Size: 9”



Size: 6”

Computed and Measured MnROAD Earth Pressures in TSD Trials

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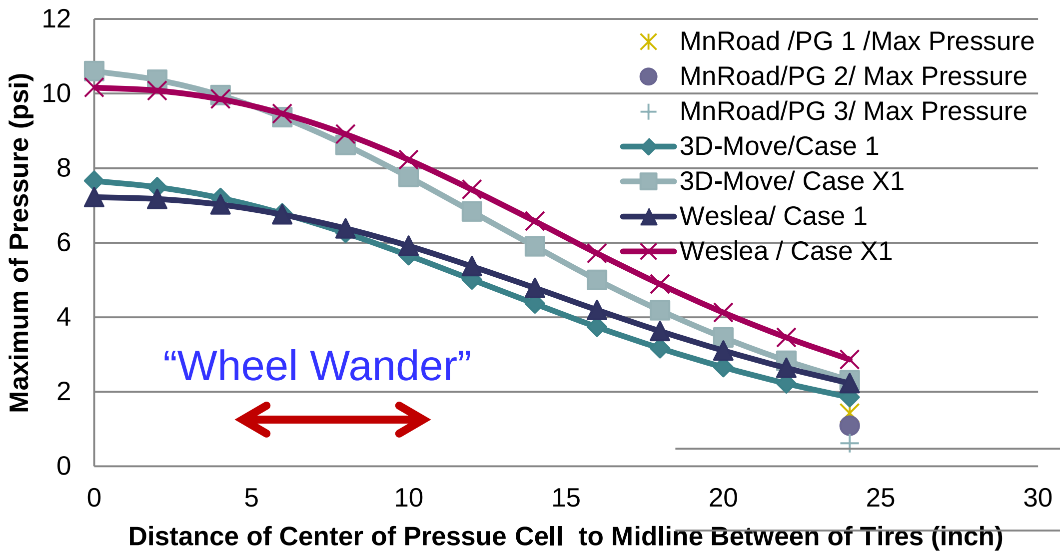

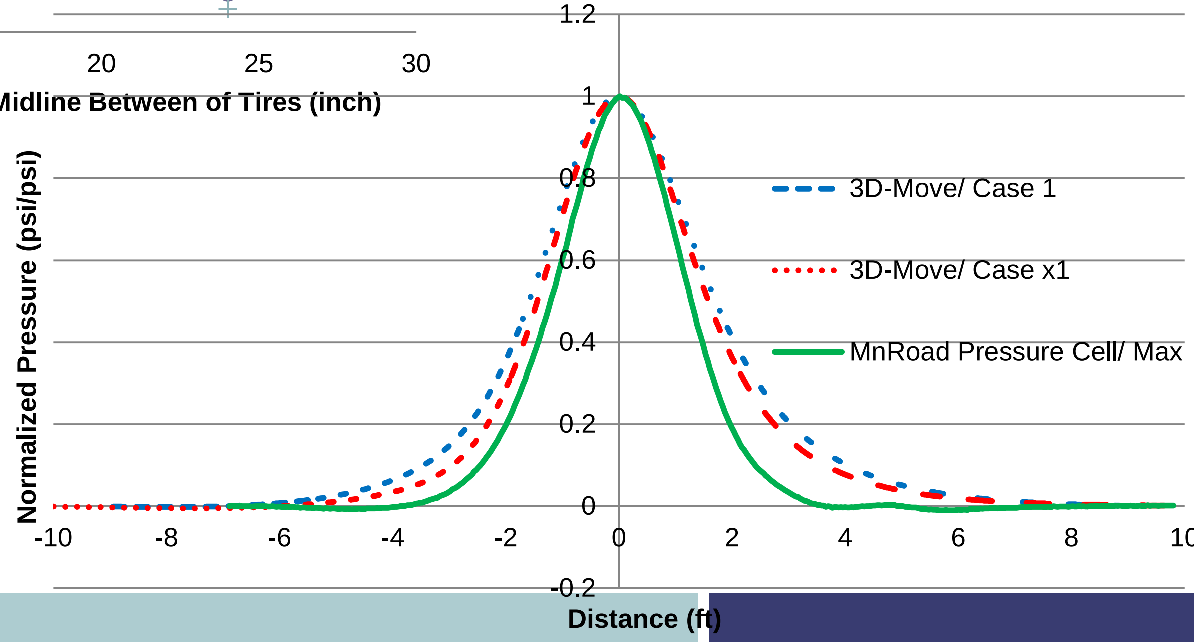

Computed and Measured Longitudinal Strains in TSD Trials

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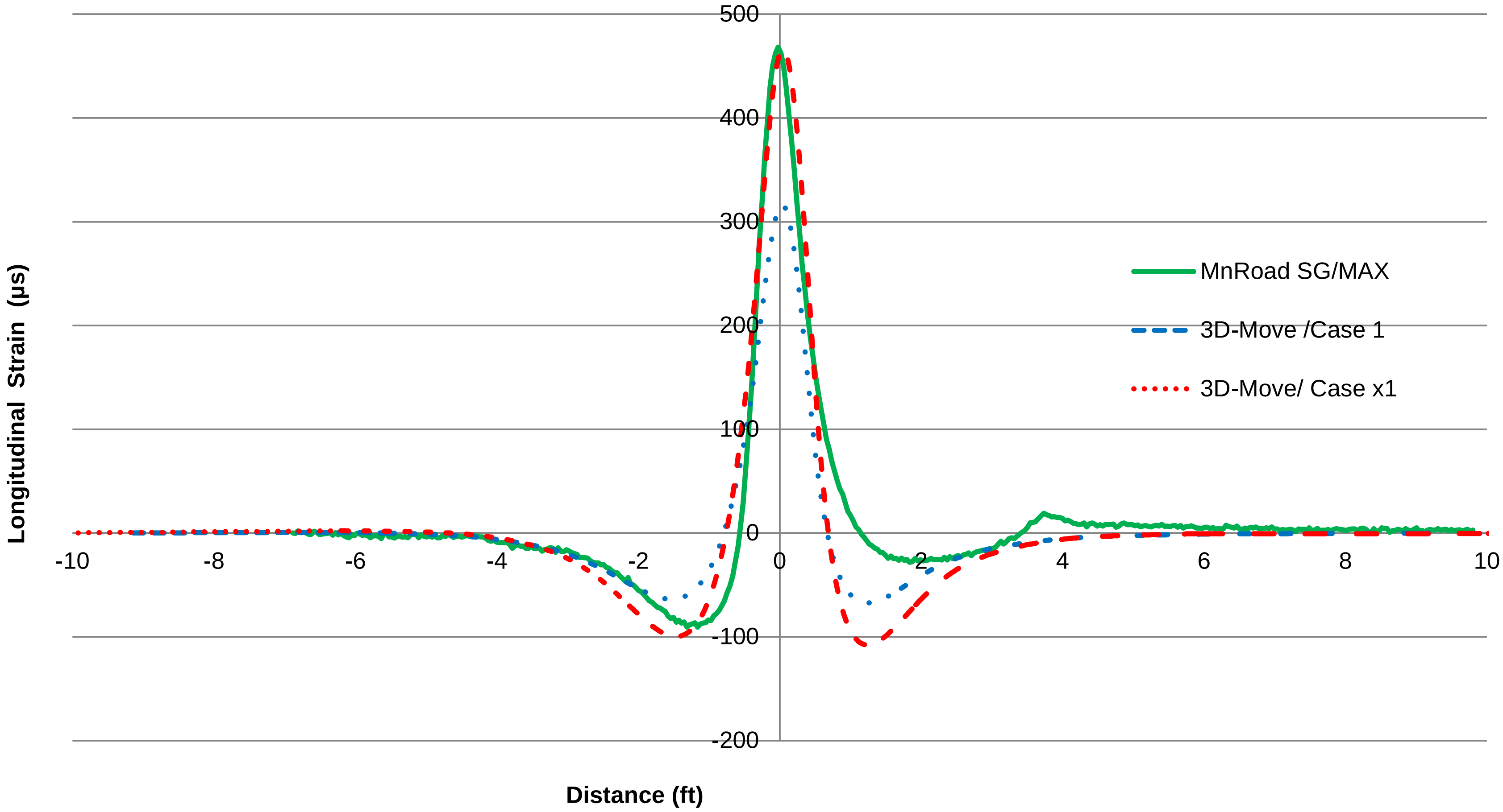
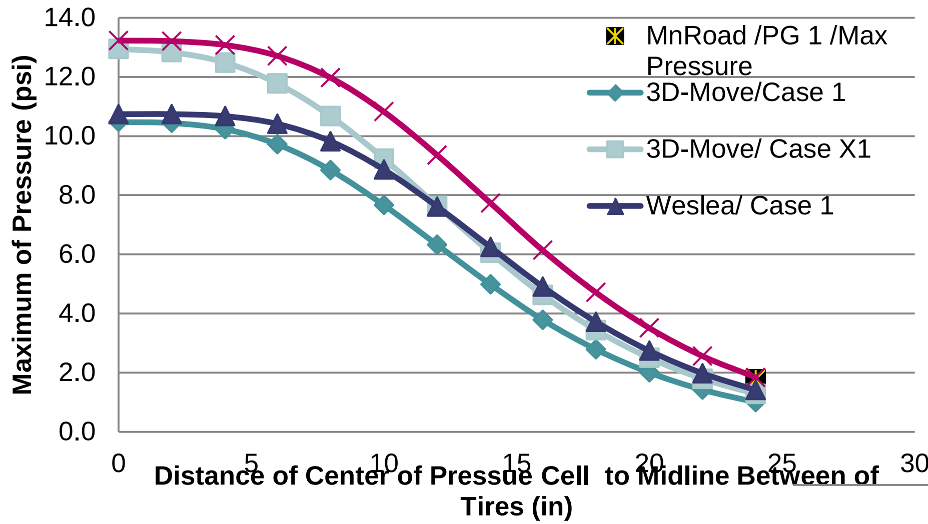
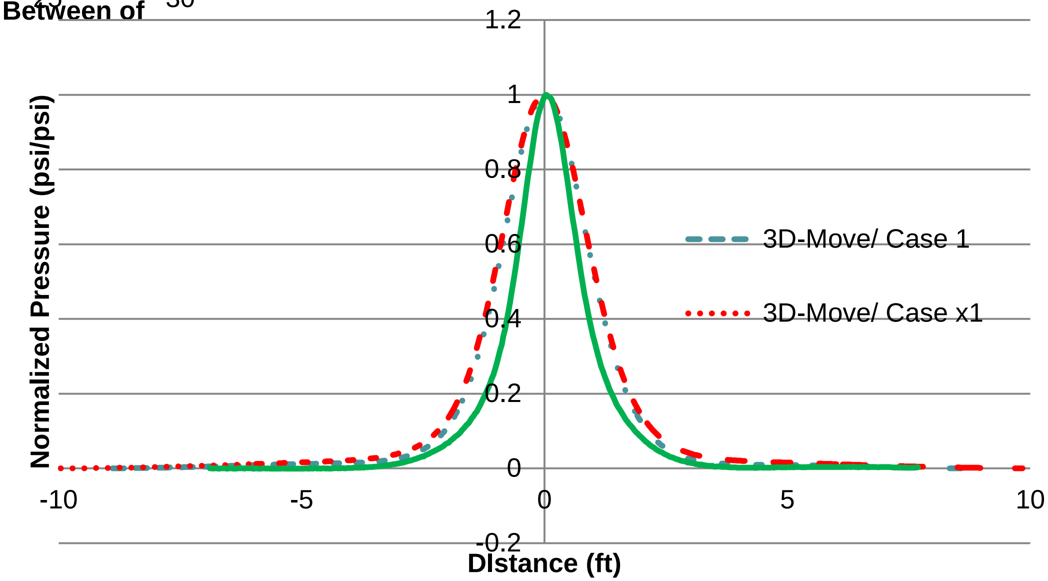
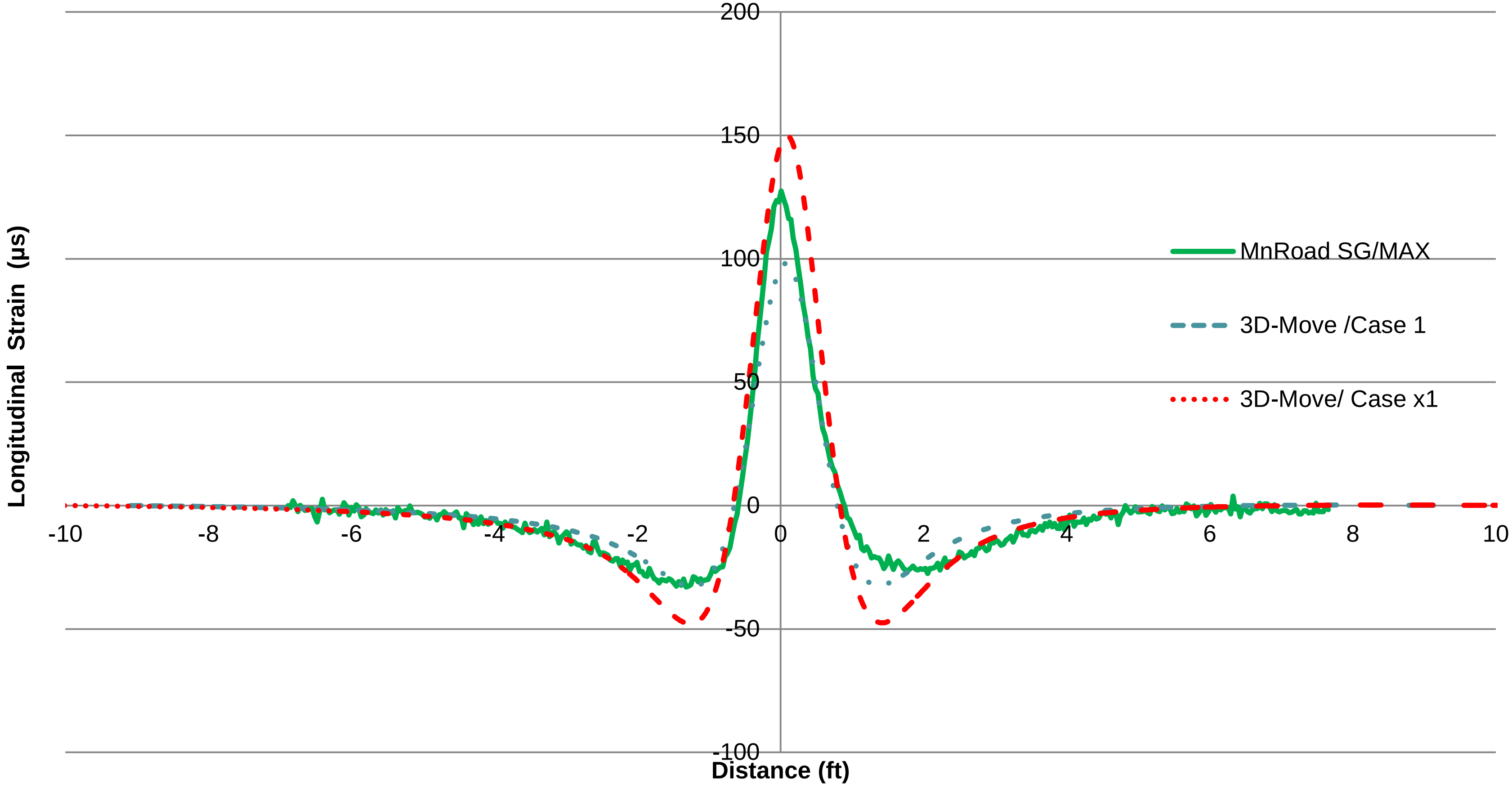


Computed and Measured Normal Pressure in RWD trial

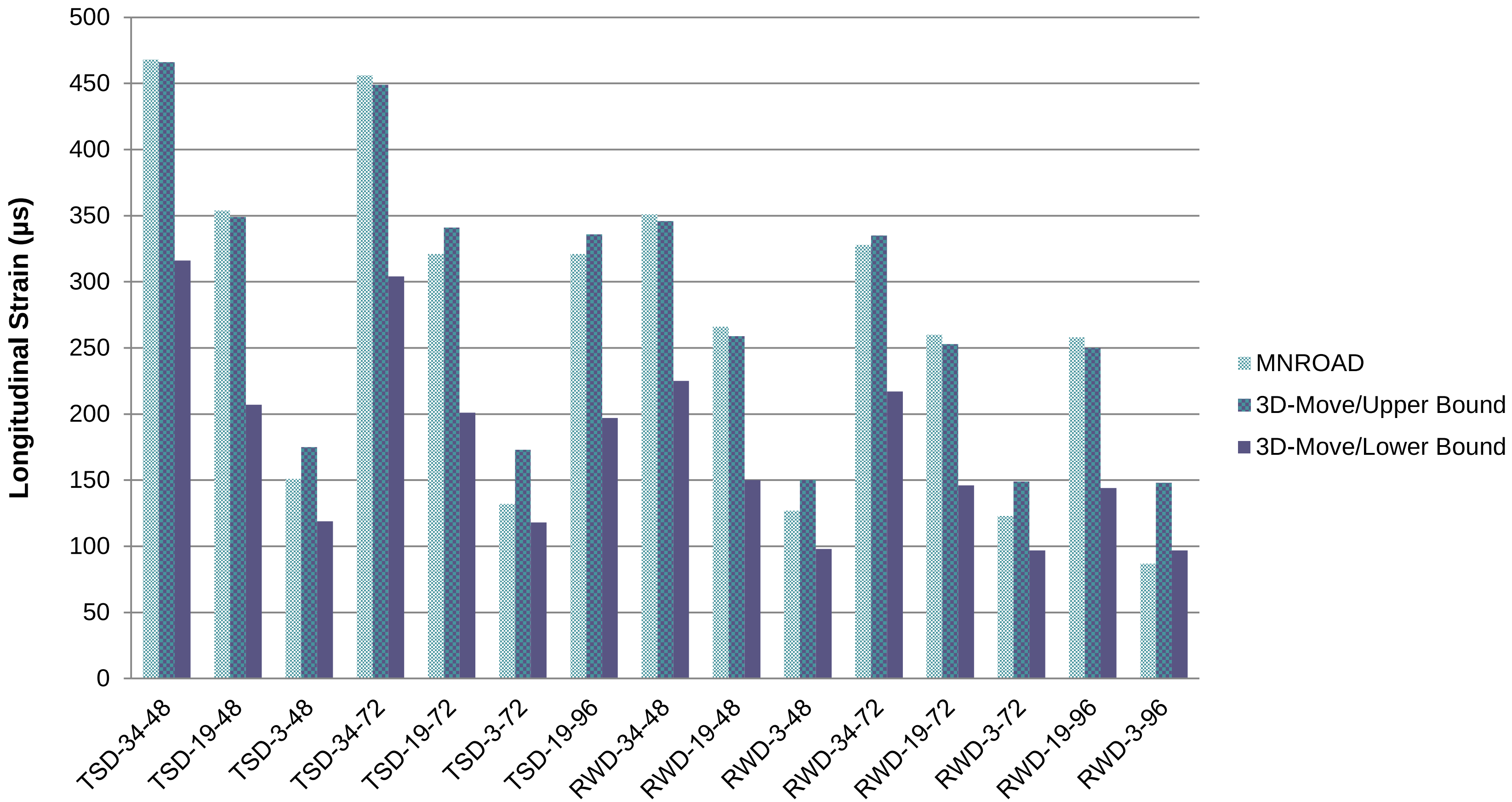




Computed and Measured Longitudinal Strain in RWD trial



Maximum longitudinal strains from MnROAD sensors and 3D-Move computations



Phase 2: What are the Robust Indicators that can Capture HMA Deterioration?

Following Issues are to be Investigated by 3D-Move Solutions:

(1) What is the sensitivity of measured deflections in HSDDs with respect to: *(a) speed of test vehicle; (b) change in material properties of all pavement layers (i.e., temperature, aging and moisture related stiffness changes); and (c) sloping pavements (require inclusion of interface shear);*

(2) Are there any other pavement response parameters that may be sensitive to pavement condition? *For example, can the velocities measured in TSD be directly used as indicators, instead of relying on displacement bowl obtained using the slopes at a few locations (potentially introducing errors) recognizing that the focus is on surface bound layer;*

Phase 2: 3D-Move Investigations

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(3) 3D-Move analyses to understand best way to implement devices
a) What are the ideal locations for measurements (e.g., between the tires, in front or back of the tires)
b) Are there any pavement response parameters other than the deflection between tires (RWD) and SCI 300 (TSD) that may be sensitive to pavement condition?
c) Are there any indices that can be used where the existing measurements made by HSDDs can be utilized? (e.g., w_o, SCI300, Thompson: $(5D_0 - 2D_{12"} - 2D_{24"} - D_{36"})/2$; BCI = $D_{24"} - D_{36"}$; SD = $\tan^{-1}(D_0 - D_r)/r$ etc.)

(4) What are the "error" margins when periodically measured HSDD responses obtained at various times of a year during the life of a pavement are compared?
This is important, when looking for progressive deterioration of pavement.

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