

# ARC Deliverables/Products Presentation and Workshop

<http://www.arc.unr.edu/>

***Western Regional Superpave Center (WRSC)  
University of Nevada, Reno***

*Washington, DC – January 15, 2015*

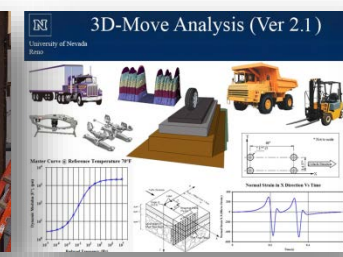
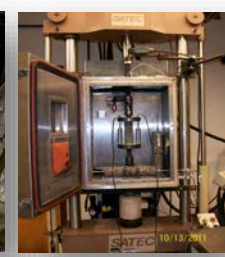
**ARC**  
**Asphalt Research Consortium**



# ARC Deliverables/Products Presentation and Workshop

## University of Nevada, Reno

- 11:05 – 11:30:** Pavement Engineering Software: Pavement Response Model to Dynamic Loads (3D-Move).
- 11:35 – 12:00:** Rutting Performance of Asphalt Mixtures Under Critical Conditions.
- 1:00 – 1:25:** Mix Design for Cold in-Place Recycling (CIR).
- 1:30 – 1:55:** Pavement Engineering Software: Thermal Cracking Analysis Package (TCAP).



# ARC Deliverables/Products Presentation and Workshop

## Pavement Response Model to Dynamic Loads:

# 3D-Move Analysis Software

**N** 3D-Move Analysis (Ver 2.1)  
University of Nevada  
Reno <http://www.arc.unr.edu/Software.html>

Master Curve @ Reference Temperature 70°F

Normal Strain in X Direction Vs Time



# How to Download 3D-Move!

Visit ARC website @ <http://www.arc.unr.edu/Software.html>



www.arc.unr.edu/Software.html

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### Software

3D-Move Analysis  
PANDA Model  
TEMPS

### Free Softwares

#### 3D-Move Analysis Software (Version 2.1)

Release Date: June 2013

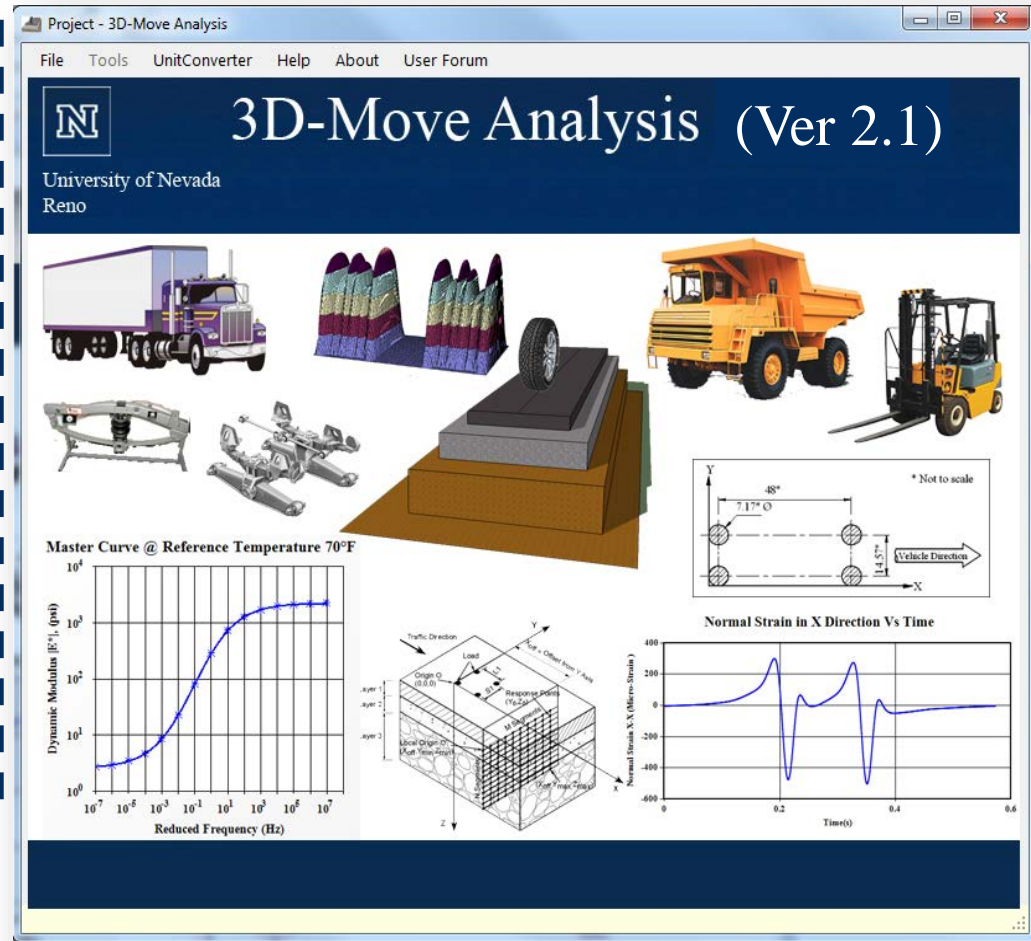
#### About 3D-Move

The analytical model (3D-Move) adopted here to undertake the pavement response computations uses a continuum-based finite-layer approach. The 3D-Move Analysis model can account for important pavement response factors such as the moving traffic-induced complex 3D contact stress distributions (normal and shear) of any shape, vehicle speed, and viscoelastic material characterization for the pavement layers. This approach treats each pavement layer as a continuum and uses the Fourier transform technique; therefore, it can handle complex surface loadings such as multiple loads and non-uniform tire pavement contact stress distribution. Since the tire imprint can be of any shape, this approach is suitable to analyze tire imprints, including those generated by wide-base tires (Siddharthan et al. 1998; 2000; 2002). The finite-layer method is much more computationally efficient than the moving load models based on the finite element method (Huhtala and Pihlajamaki 1992; Al-Qadi and Wang 2009). This is because often times the pavements are horizontally layered and pavement responses are customarily required only at a few selected locations and for such problems the finite layer approach of 3D-Move Analysis is ideally suited. Since rate-dependant material properties (viscoelastic) can be accommodated by the approach, it is an ideal tool to model the behavior of asphalt concrete (AC) layer and also to study pavement response as a function of vehicle speed. Frequency-domain solutions are adopted in 3D-Move Analysis, which enables the direct use of the frequency sweep test data of HMA mixture in the analysis.

Many attempts that included field calibrations (e.g., Penn State University test track, Mn/Road and UNR Off-road Vehicle study) that compared a variety of independently-measured pavement responses (stresses, strains, and displacements) with those computed have been reported in the literature (Siddharthan et al. 2002, 2005). These verification studies have validated the applicability and versatility of the approach. The 3D-Move Analysis (ver. 2.0) includes Pavement Performance Models, using which many important pavement distress modes can be investigated. In addition, a variety of non-highway vehicles (e.g., End-Dump Truck and Forklift et.) can also be considered.

#### What's New in the 3D-Move Analysis Version 2.1?

Release Note  
Download 3D-Move Version 2.1  
System Requirements  
Additional Release Information  
References

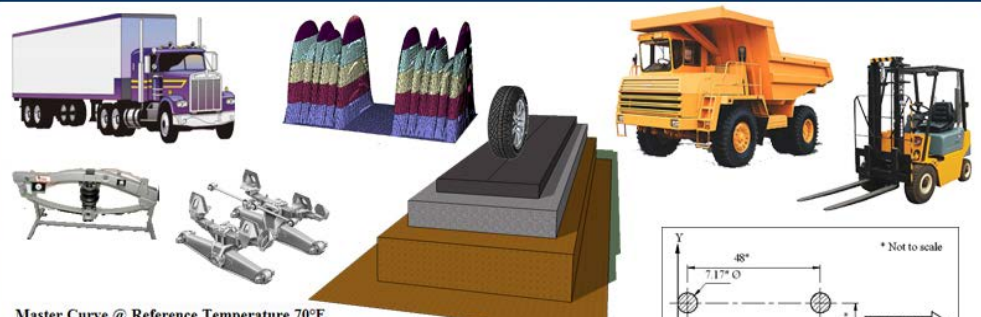


Project - 3D-Move Analysis

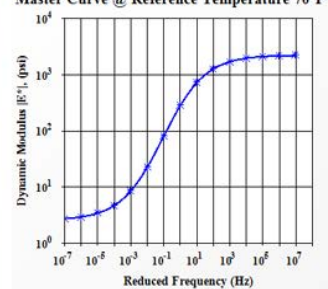
File Tools UnitConverter Help About User Forum

## 3D-Move Analysis (Ver 2.1)

University of Nevada  
Reno

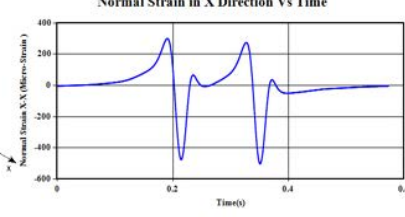


### Master Curve @ Reference Temperature 70°F



Reduced Frequency (Hz)	Dynamic Modulus E* (psi)
10 <sup>-7</sup>	10 <sup>0</sup>
10 <sup>-6</sup>	10 <sup>1</sup>
10 <sup>-5</sup>	10 <sup>2</sup>
10 <sup>-4</sup>	10 <sup>3</sup>
10 <sup>-3</sup>	10 <sup>4</sup>
10 <sup>-2</sup>	10 <sup>5</sup>
10 <sup>-1</sup>	10 <sup>6</sup>
10 <sup>0</sup>	10 <sup>7</sup>

### Normal Strain in X Direction Vs Time

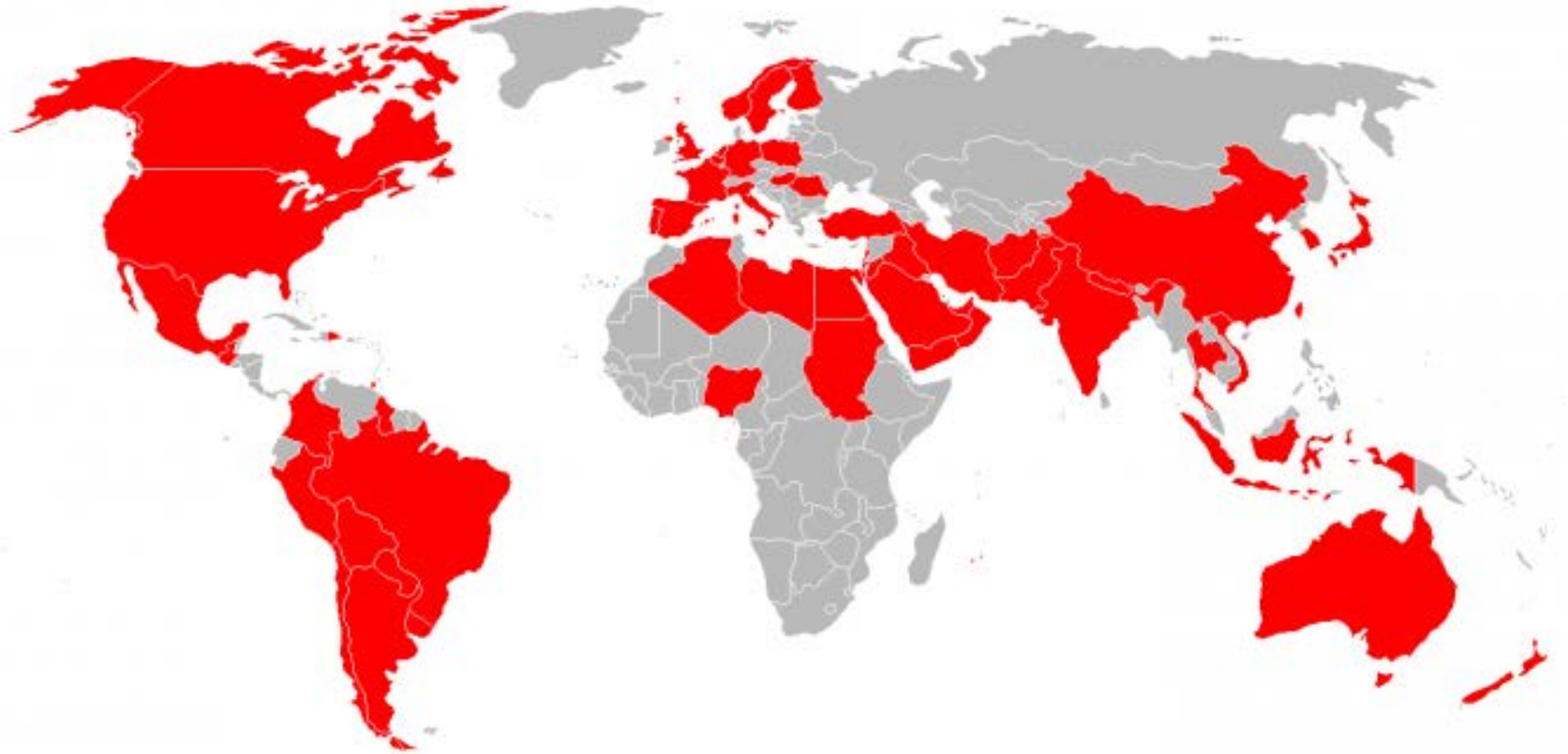


Time (s)	Normal Strain (Micro-Strain)
0.0	0
0.1	100
0.2	300
0.3	-300
0.4	100
0.5	0



# 3D-Move Analysis Software

## Over 750 Users from around the world!



# Summary:

## Elements of the 3D-Move Analysis Software

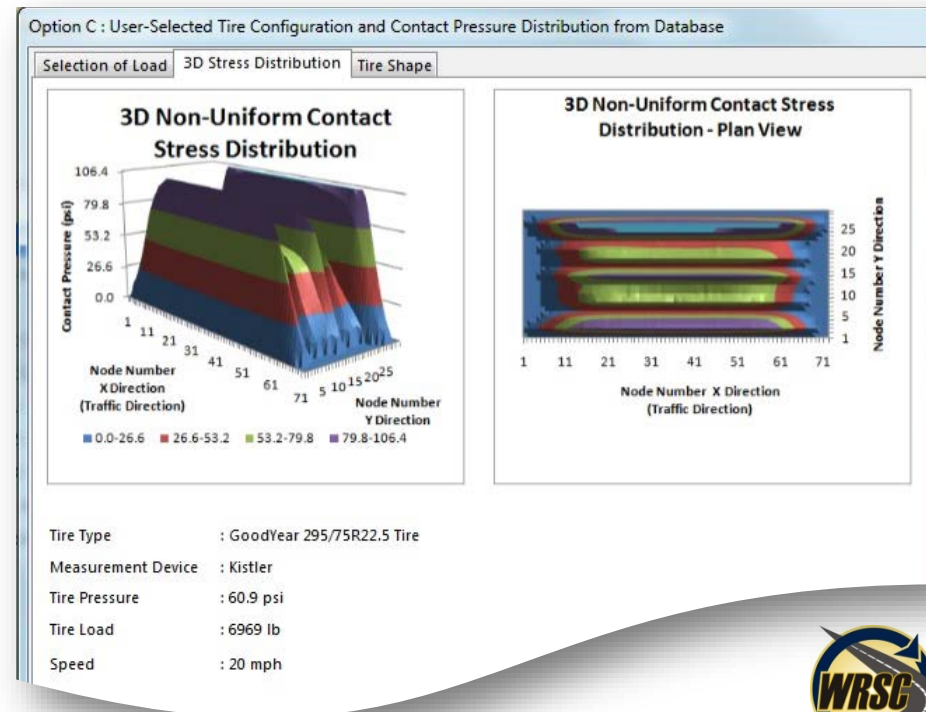
- (1) **Uses Finite-Layer Continuum Approach** – Takes Advantage of Horizontally-Layered Pavement Layers; No Discretization; No Lateral Boundary Effects. – **Computer Efficient.**
- (2) **Models Moving 3D-Surface Stresses (Dynamic; Normal & Shear Contact Stresses)** – **Handles Vehicle Speed and Vehicle Braking.**
- (3) **Direct Use of Frequency-Sweep Data (Viscoelastic Modeling).**
- (4) **Ideally-Suited when Responses are Needed at a Selected Few Locations - Computer Efficient.**

# Important Attributes of Pavement Modeling

Factor	Layered Elastic Analysis (LEA)	Finite Element Method (FEM)	3D-Move Model
Important Attributes of Pavement Modeling: Load-Related			
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 Angle)	NO	YES	YES
Vehicle Speed	NO	YES	YES
Direct Use of Freq. Sweep Data	NO	NO	YES

# Attributes of 3D-Move<sub>1</sub> Non-Uniform Contact Stress Distribution<sub>1</sub>

- Non-Uniform 3D Contact Stress Distributions (Normal and Shear Contact Stresses)
  - Vertical, Longitudinal, and Transverse Directions
- Shear interface stresses are needed for braking and sloping pavements.

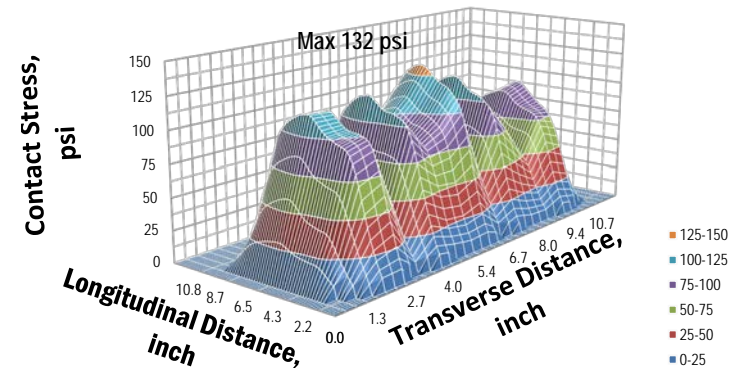




# Attributes of 3D-Move<sub>2</sub>

## Non-Uniform Contact Stress Distribution<sub>2</sub>

- Hajj et al. (2012)<sup>a</sup>:
  - Impact of non-uniform contact stress distribution on pavement responses & performance found to be *significant*.
  - Effect of vehicle braking on pavement responses *should be considered* when designing pavements that are to be placed at intersections and stopping areas.



<sup>a</sup> Hajj et al. (2012). [Influence of tire-pavement stress distribution, shape, and braking on performance predictions for asphalt pavement](#). Transportation Research Record: Journal of the Transportation Research Board, Vol 2306, pp.73-85.

# Attributes of 3D-Move<sub>3</sub>

## Non-Uniform Contact Stress Distribution<sub>3</sub>

- Ready-to-use database:
  - Council for Scientific and Industrial Research (CSIR)
  - University of California at Berkeley (UCB)
  - Nevada Automotive Test Center (NATC)
    - VRSPTA: 123 (Single)+ 38 (Supersingle)+15 (Dual) = **176**
    - Kistler: 64 (Dual) + 64 (Singled out Dual) + 64 (widebase) + 48 (Dual with differential Pressure) = **240**
    - Others

# Attributes of 3D-Move<sub>4</sub> Non-Standard Vehicles

- End Dump Trucks
  - Belaz (5)
  - Caterpillar (6)
  - Komatsu (11)
  - Terex (6)
- Fork Lift
  - Hyster (9)



Option E : Special Non-Highway Vehicles

Vehicle Type	Manufacturer	Product ID	(For User Defined Case, Enter ID here)
End Dump Truck	BELAZ	BELAZ-7513 Series	<input type="text"/>
Fork Lift	Caterpillar	BELAZ-7530 Series	
	Komatsu	BELAZ-7540 Series	
	Terex	BELAZ-7547 Series	
		BELAZ-7555 Series	

[Click for Table of Vehicle Specification](#)

Vehicle Configuration

Front Axle: Single Axle - Single Tire

Rear Axle: Single Axle - Dual Tire

L1:  in S1:  in

Tire data

Tire Type: GoodYear 33.00-51

Loaded Area:  in<sup>2</sup>

Load Distribution

Front Tire Load (When Empty):  lb

Rear Tire Load (When Empty):  lb

Pay Load:  lb

(Max Pay Load is 286,631 lb)

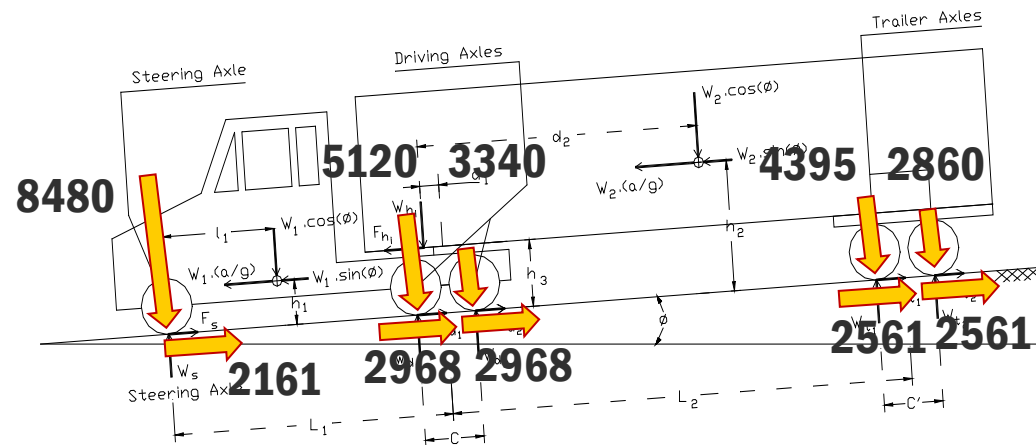
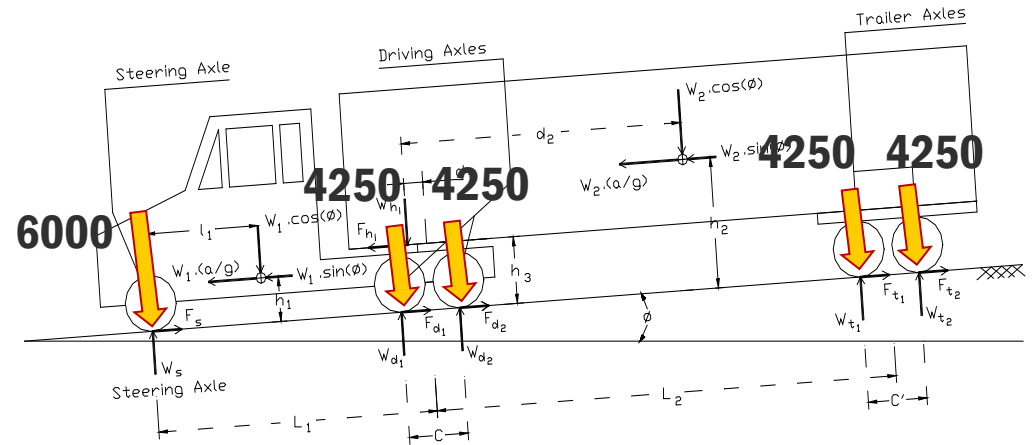
	Front Axle	Rear Axle
Load Distribution As Percentage	<input type="text" value="33"/>	<input type="text" value="67"/>
Load Distribution as Load Value	<input type="text"/> lb	<input type="text"/> lb

# Attributes of 3D-Move<sub>5</sub>

## Built-in Model for Braking of a Semi-Trailer Truck

- Load Distribution During Braking:

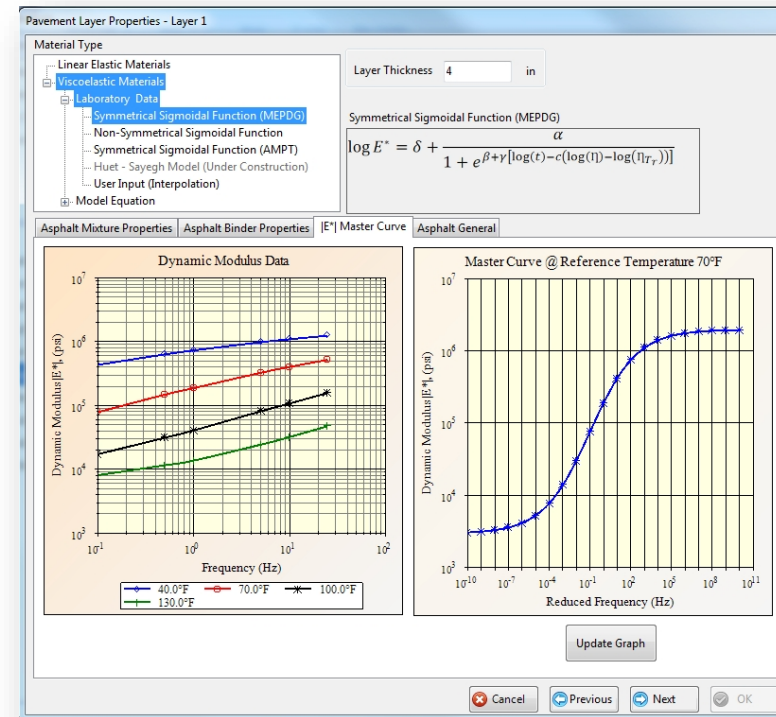
- 11 equilibrium equations
- 3 characteristic equations:
  - Application (treadle output) v/s actuation (brake chamber) pressure/axle – linear brake system.
  - Brake force v/s actuation pressure on each axle.
  - Dynamic load transfer coefficient.



# Attributes of 3D-Move<sub>6</sub>

## Materials Input: Viscoelastic Property of AC

- Dynamic Modulus and Phase Angle data:
  - Symmetrical Sigmoidal Function (MEPDG)
  - Non-Symmetrical Sigmoidal Function
  - Symmetrical Sigmoidal Function (AMPT)
  - User Input (Interpolation)
- Model Equation
  - Witczak Model (1-37A)



# Attributes of 3D-Move<sub>8</sub> Pavement Performance Predictions

Performance Models

**NCHRP (1-37A) Models** [Info](#)

- AC Top Down Cracking (ft/mile)
- AC Bottom Up Cracking (%)
- AC Rutting (in)
- Base Rutting (in)
- Subbase Rutting (in)
- Subgrade Rutting (in)

Limiting Values	Reliability
2000	90
25	90
0.25	90
0.30	90
0.25	90
0.20	90

**VESYS Models** [Info](#)

- Fatigue Cracking (%)
- Layer Rutting (in)
- System Rutting (in)
- Roughness (Slope Variance)

Pavement Layers

Layer 1 - Asphalt  
Layer 2 - Base  
Layer 3 - Asphalt  
Layer 4 - Subbase  
Layer 5 - Subgrade

AC Top Down Cracking | AC Bottom Up Cracking | AC Rutting | Transfer Functions

NCHRP (1-37A) Models Info

$$N_f = 0.00432CC_H k_{r1} \beta_{f1} \left(\frac{1}{\epsilon_t}\right)^{k_{f2}} \beta_{f2} \left(\frac{1}{E}\right)^{k_{f3}} \beta_{f3}$$

$$C = 10^{-4.84 \left[ \frac{V_{va}}{v_a} + \frac{V_{be}}{v_{be}} - 0.69 \right]}$$

$$C_H = \frac{1}{0.01 + \frac{12.00}{1 + e^{(15.676 - 2.8186H_{ac})}}}$$

$N_f$  - Number of repetitions to fatigue cracking  
 $\epsilon_t$  - Tensile strain at the critical location (in/in)  
 $E$  - Stiffness of the material (psi)  
 $H_{ac}$  - Thickness of AC layer (in)

Analysis Types

- Nationally Calibrated Model
- User Defined Model

Volumetric Properties

Air Voids ( $V_a$ ) 4.1 (%)  
Effective Binder Content ( $V_{be}$ ) 7.6 (% By Volume)

Regression Coefficients

$k_{f1}$  0.007566     $\beta_{f1}$  1  
 $k_{f2}$  3.9492     $\beta_{f2}$  1  
 $k_{f3}$  1.281     $\beta_{f3}$  1

Performance Model Output Summary - MEPDG

Layers	Individual Layer's Distress Summary						
	Combined Layer	Distress Type	Distress Target	Reliability Target	Distress Predicted	Reliability Predicted	Acceptable
Asphalt (1)		AC Top Down Cracking (ft/mile)	2000	90	0.00	100	Pass
		AC Bottom UP Cracking (%)	25	90	5.67	96	Pass
		AC Rutting (in)	0.25	90	0.49	1.7	Fail
Base (2)		Base Rutting (in)	0.30	90	0	100	Pass
Asphalt (3)		AC Bottom UP Cracking (%)	25	90	0.15	100	Pass
		AC Rutting (in)	0.25	90	0	100	Pass
Subgrade (5)		Subbase Rutting (in)	0.25	90	0.02	100	Pass
		Subgrade Rutting (in)	0.20	90	0.07	99.9	Pass

## Examples of 3D-Move Applications

### (1) Estimate of Damage Under Off-Road Farm Vehicles<sub>1</sub>

- South Dakota DOT (Project SD99-15) – Objectives:
  - What additional damage off-road vehicles impose?
  - Should they be allowed on public roads?
- Experimental Approach:
  - Construct instrumented field sections
  - Measure pavement responses
  - Use measured response to validate 3D-Move
  - Use 3D-Move to evaluate damage

# Examples of 3D-Move Applications

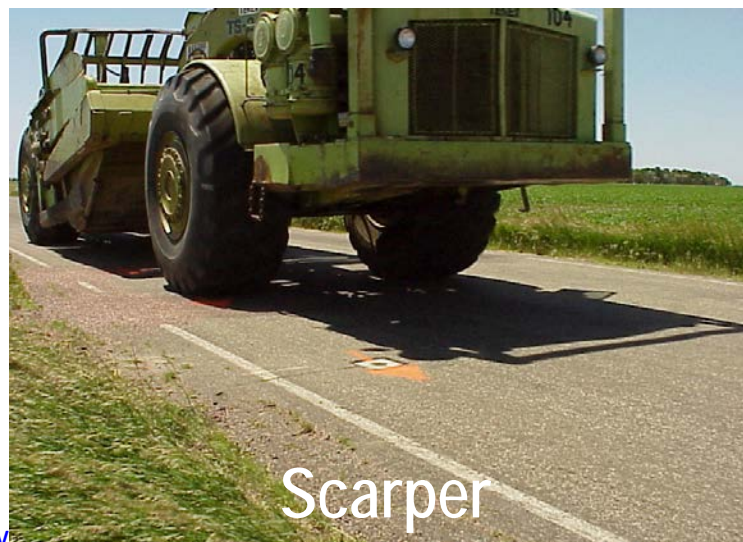
## (1) Estimate of Damage Under Off-Road Farm Vehicles<sub>2</sub>



Terragator 8103



Grain Cart Pulled by a Tractor



Scarper



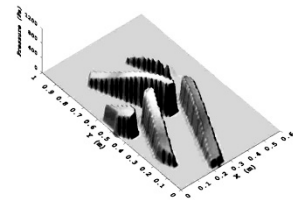
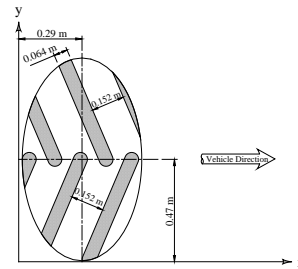
Tracked Tractor



# Examples of 3D-Move Applications

## (1) Estimate of Damage Under Off-Road Farm Vehicles<sub>3</sub>

- Characteristics of Off-Road Equipment
  - Massive Tires: **0.95 m** vs. 0.20 m (Conventional)
  - Tire Lugs: off-road vs. conventional tires
  - Tire Loads: **100 kN** vs. 22.5 kN (Conventional)
  - Tire Pressure: **250 kPa** vs. 850 kPa (Conventional)
  - Vehicle Speed: **60 km/h** vs. 100 km/h (Conventional)



## Examples of 3D-Move Applications

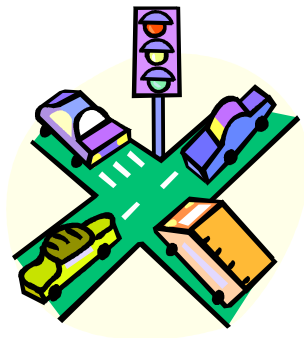
# (1) Estimate of Damage Under Off-Road Farm Vehicles<sub>4</sub>

- Implementation:
  - Do not ban agriculture equipment on highways.
  - Allow empty Terragators and Grain Carts to move over highway pavements.
  - Use legally loaded standard trucks to move fertilizers and grains to the field locations.

# Examples of 3D-Move Applications

## (2) Analysis of Pavement Performance at Intersection<sub>1</sub>

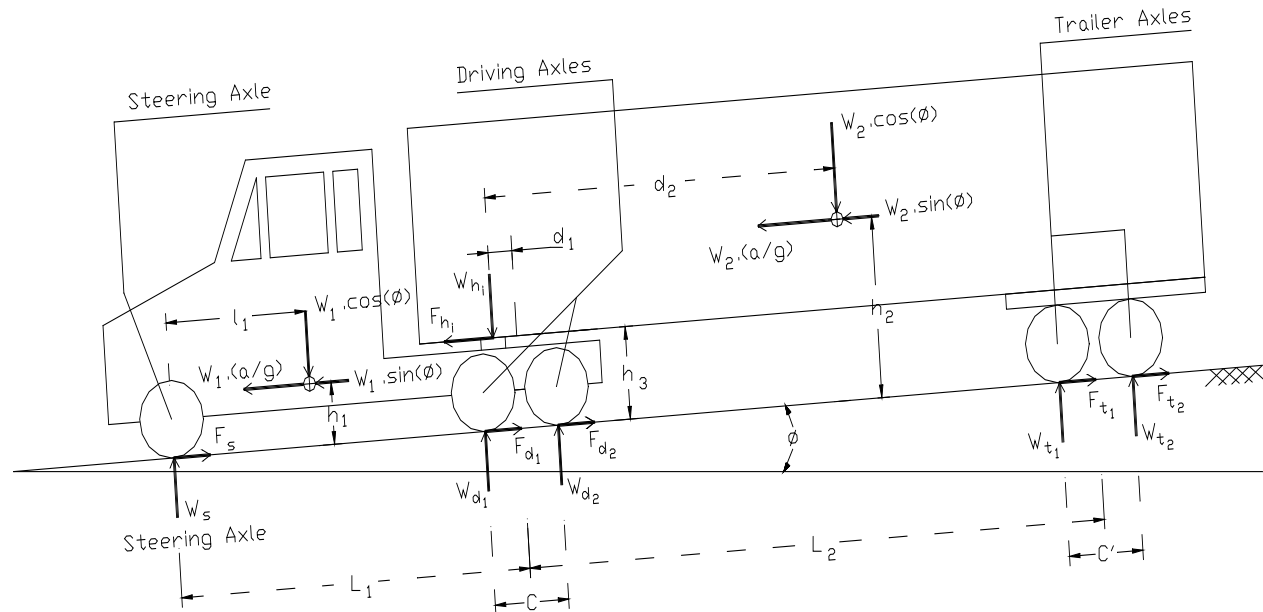
- Vehicle loads at intersections (on/off ramps) are significantly different from those at highways.
- Asphalt Mixtures at/near a braking stop:
  - ⑩ Subjected to more complex stresses due to braking.
  - ⑩ Behaves weaker as subjected to slow moving or stopped vehicles.



# Examples of 3D-Move Applications

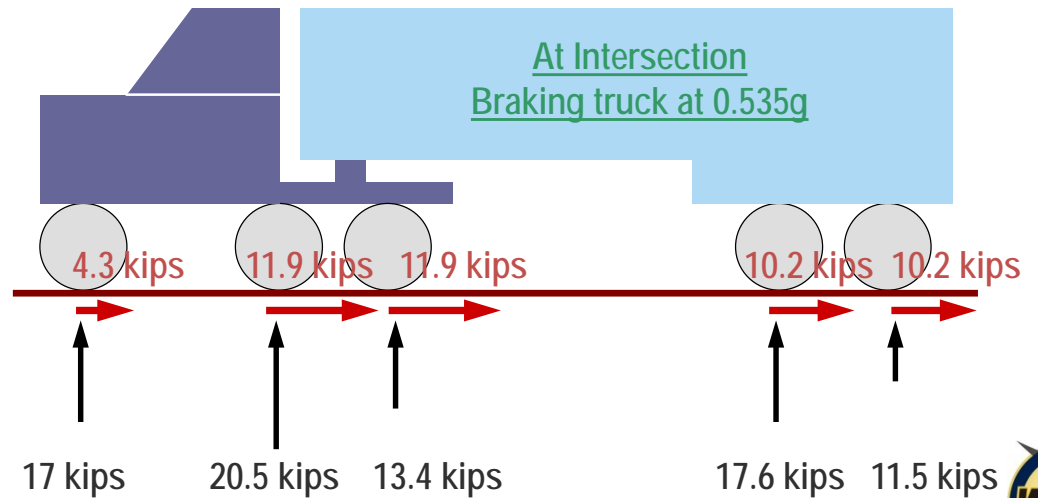
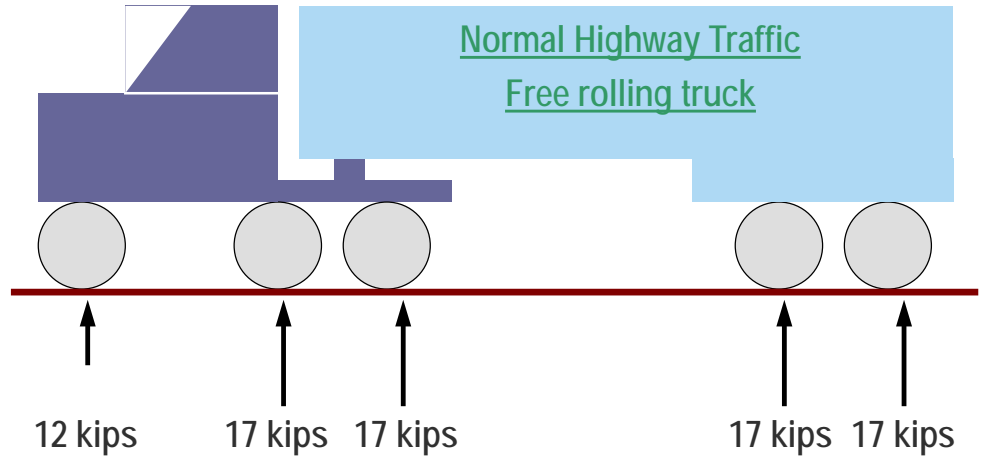
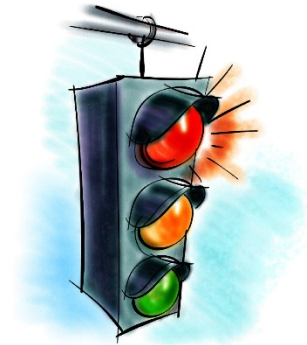
## (2) Analysis of Pavement Performance at Intersection<sub>2</sub>

- Vehicle *load redistribution* during braking.
- Additional *interface shear stresses* due to braking.
- *Single vs. wide base* tires.
- Non-uniform tire contact pressure distribution.
- etc...



# Examples of 3D-Move Applications

## (2) Analysis of Pavement Performance at Intersection<sub>3</sub>



# Examples of 3D-Move Applications

## (3) Assessing Damage from Bus Rapid Transits,



	Front	Drive	Rear
GAWR Load, lbs	15,653	20,944	14,330
Axle Configuration	Single Axle/ Single Tire	Single Axle/ Dual Tires	Single Axle/ Single Tire
Tire Pressure, psi	120	85	110
Tire Type	Michelin XZU/305/70R 22.5		



	Front	Drive	Rear
GAWR Load, lbs	16,094	28,660	25,574
Axle Configuration	Single Axle/ Single Tire	Single Axle/ <b>Widebase</b> Tire	Single Axle/ <b>Widebase</b> Tire
Tire Pressure, psi	130	130	130
Tire Type	275/70R 22.5	494/45 R22.5	494/45 R22.6



	Front	Drive	Rear
GAWR Load, lbs	14,780	24,250	27,760
Axle Configuration	Single Axle/ Single Tire	Single Axle/ Dual Tires	Single Axle/ Dual Tire
Tire Pressure, psi	120	120	120
Tire Type	Michelin XZU/305/70R 22.5		

# Examples of 3D-Move Applications

## (4) Pavement Damage Due to OS/OW or SHL Moves,

- “Non-Generic” axle and tire configurations.
- Slow moving loads.



<http://www.folsomlakefordfleet.com/thingsyouneedtoknow/weightsizelimits.html>



# Thank You!



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**Thank You!**

