



Characteristics of the Loading Pulse for the Flow Number Performance Test

Elie Y. Hajj, Alvaro Ulloa, Raj Siddharthan, Peter E. Sebaaly

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Introduction

Asphalt Layer Behavior

Stress State

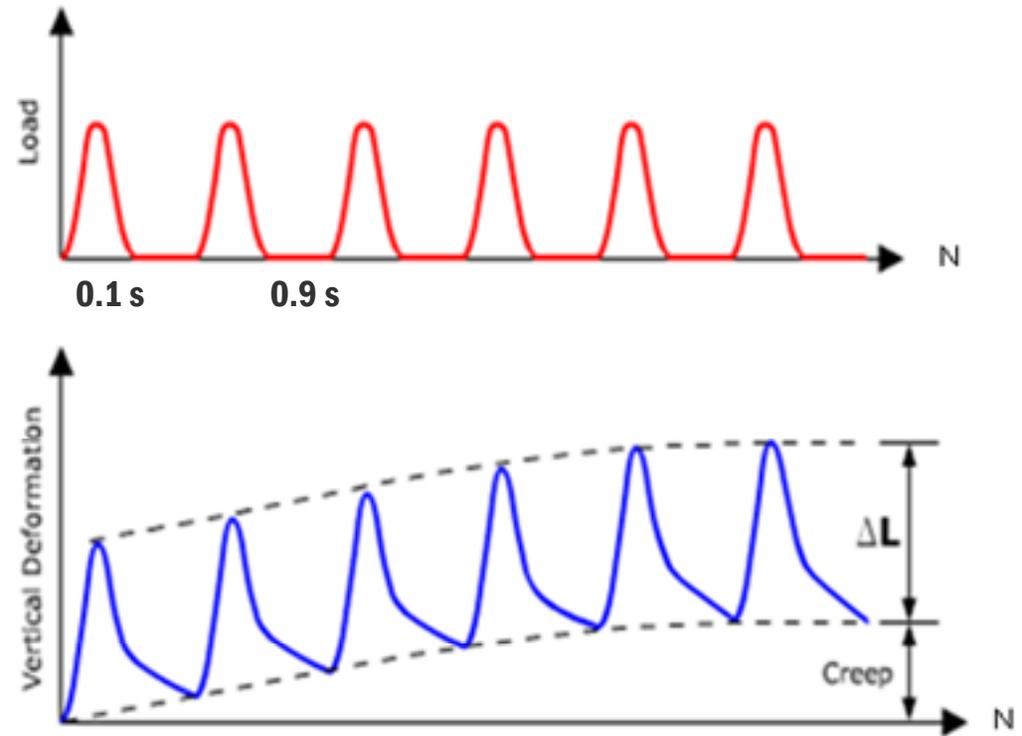
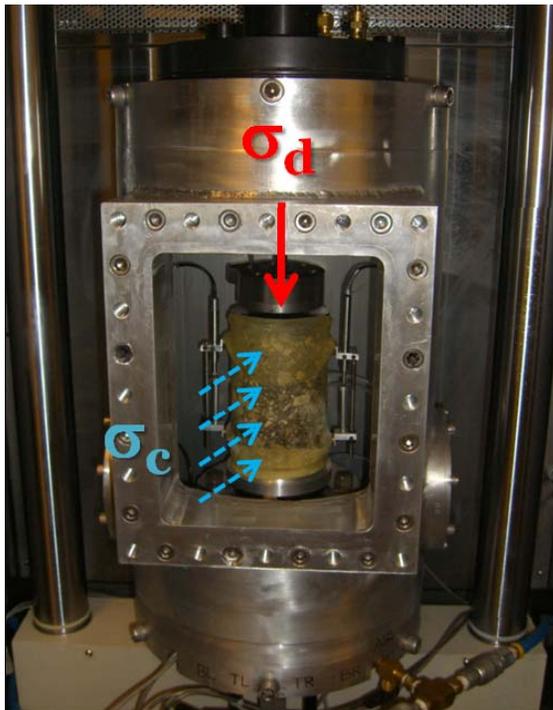
Loading Rate

Temperature



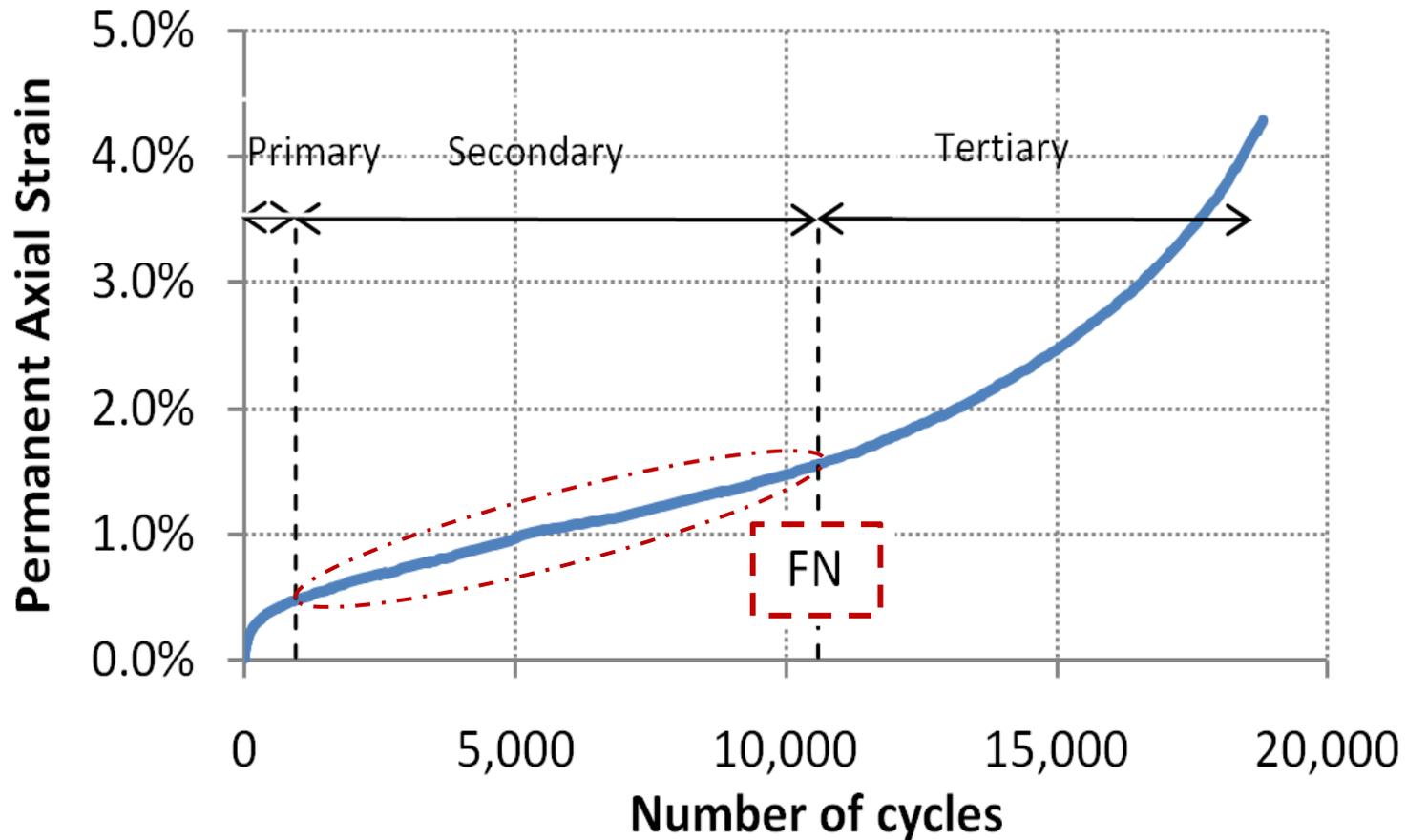
Lab test that simulates field conditions

Flow number (FN) test

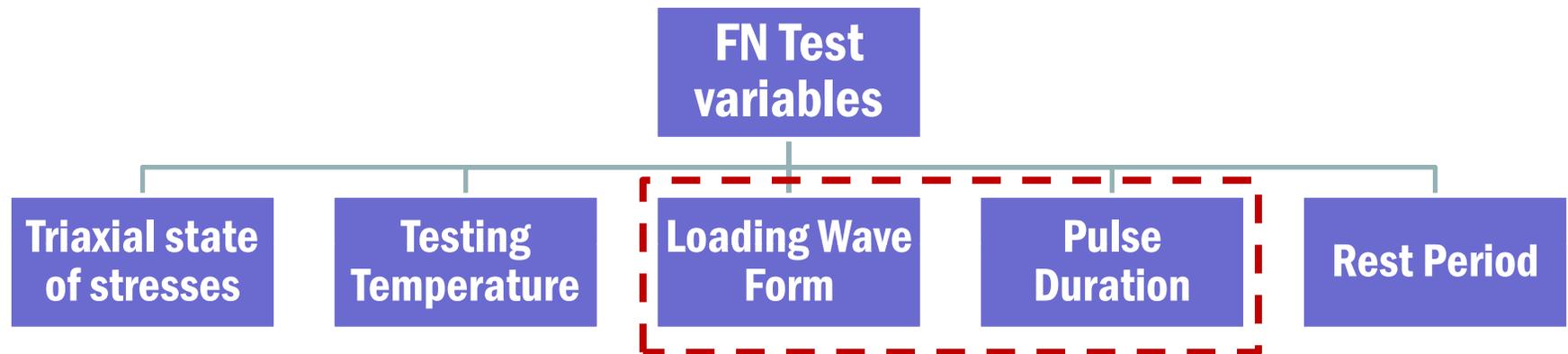


Flow number (FN) test

Permanent deformation Characterization



Objective



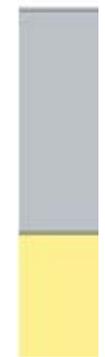
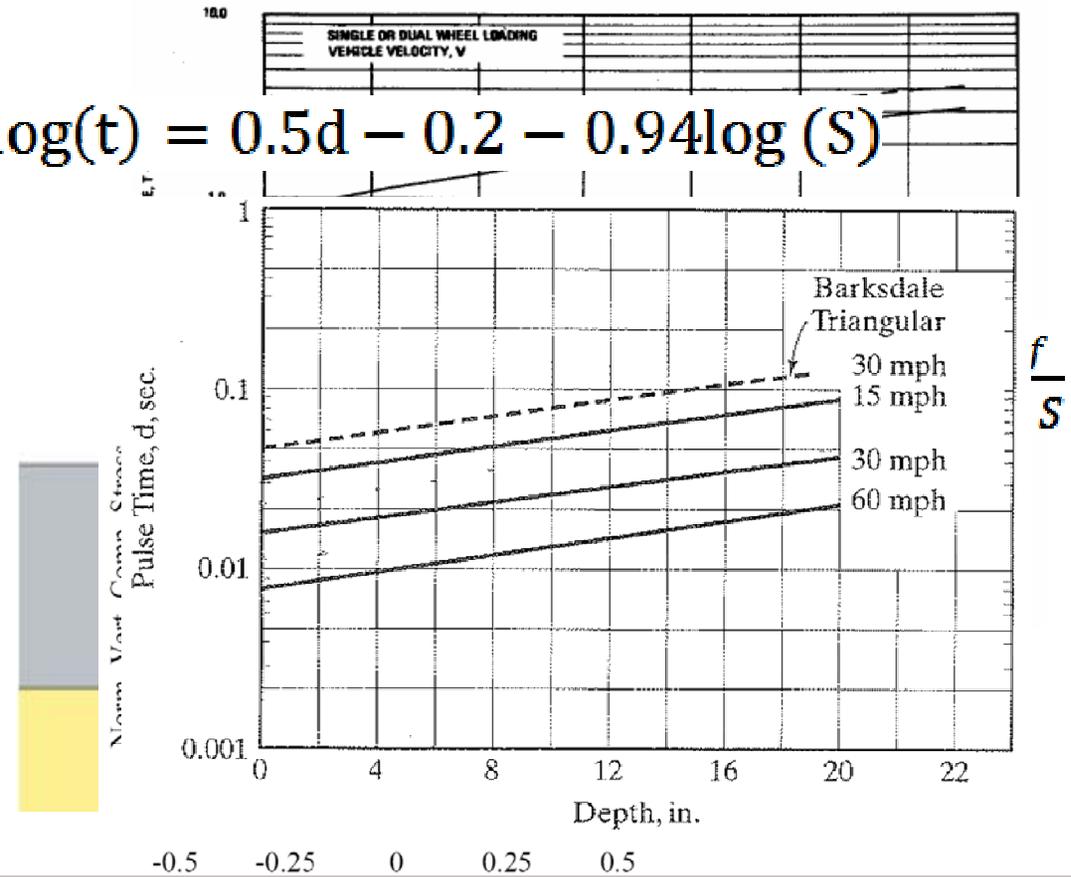
Provide recommendations for the characteristics of the deviator loading pulse in the flow number test

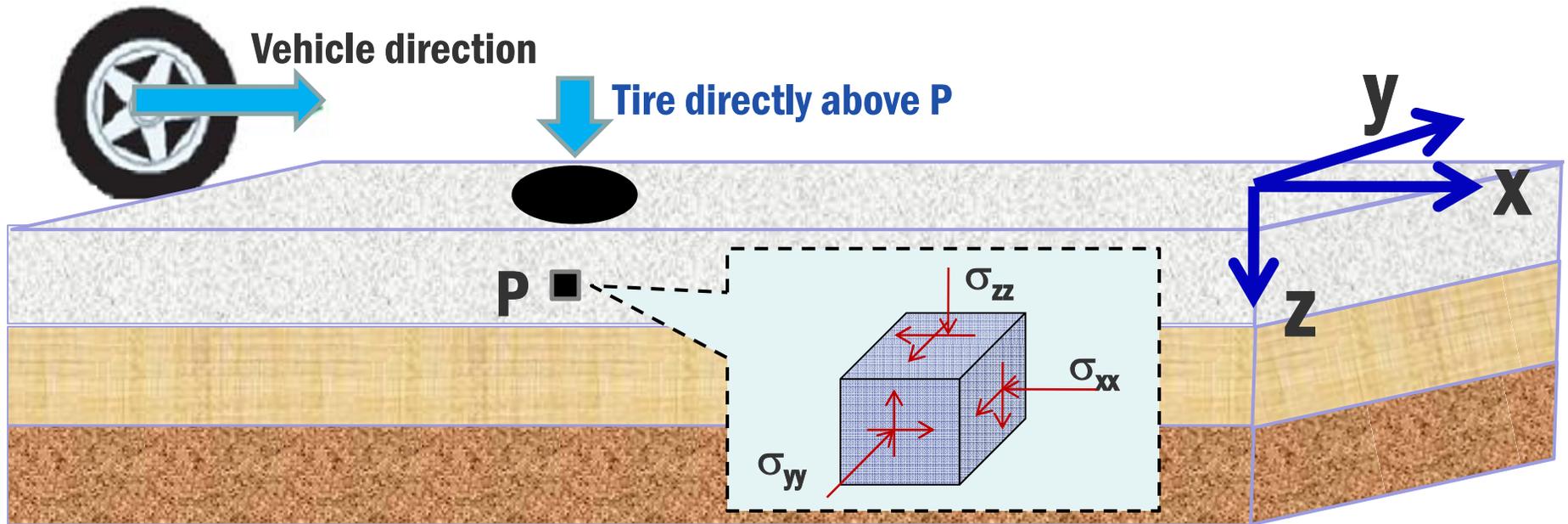
Pulse duration prediction

- ▣ Barksdale, 1971
- ▣ Brown, 1973
- ▣ McLean, 1974
- ▣ MEPDG, 2002
- ▣ Al-Qadi, 2008
- ▣ ...

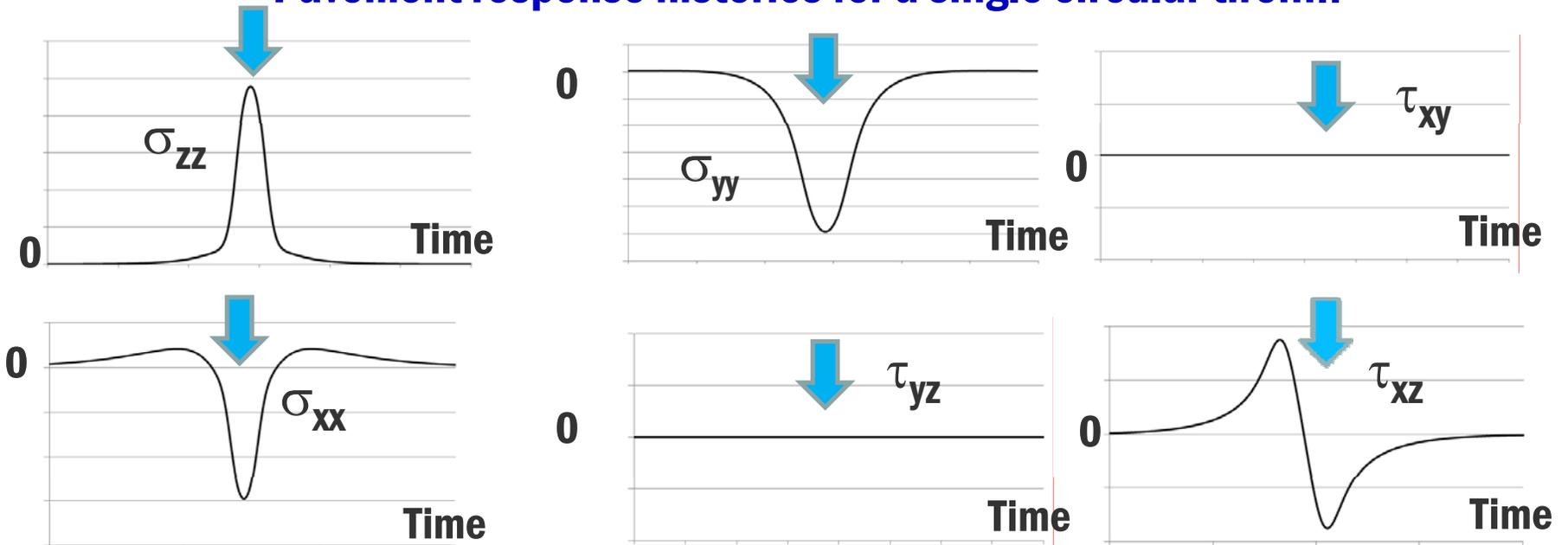


$$\log(t) = 0.5d - 0.2 - 0.94\log(S)$$



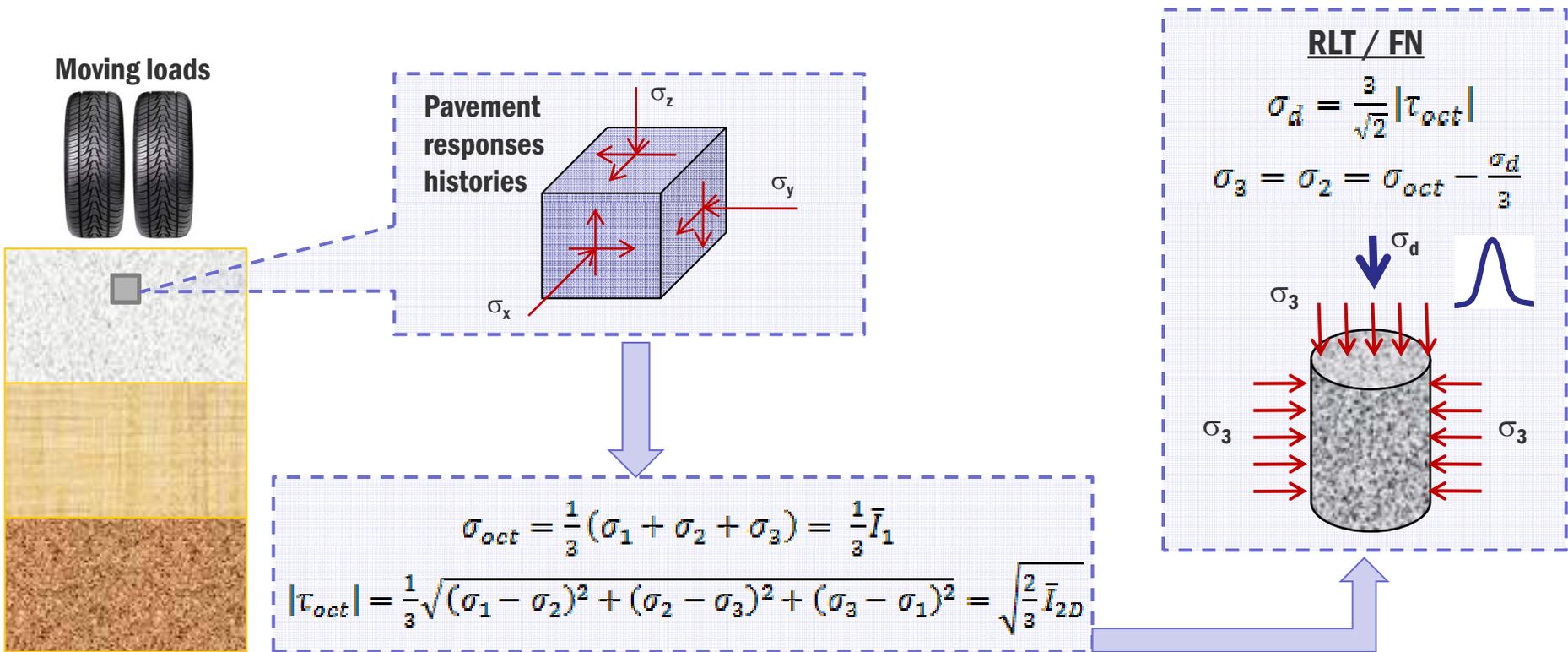


Pavement response histories for a single circular tire.....

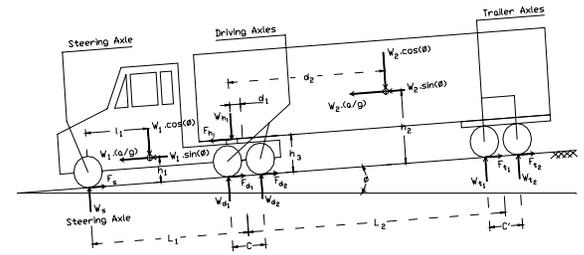


Question: What stress pulse shape to use in triaxial test?

Stress State in the Triaxial FN Test



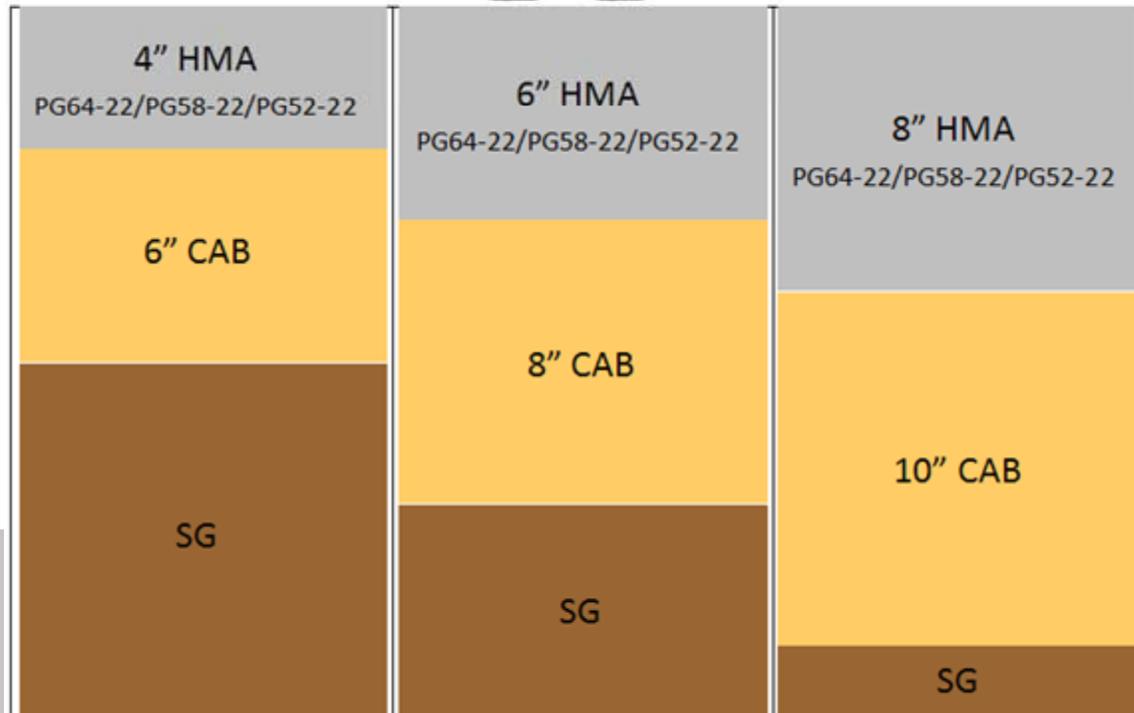
Database of pavement stresses time-histories



- 60 mph without braking
- 40 mph without braking
- 20 mph without braking
- 2 mph with braking
- 10 mph with braking
- 20 mph with braking



HMA layer temp:
 104 °F, 122 °F,
 140 °F, and 158 °F



3D-Move Model

The image shows a screenshot of the 3D-Move Model software interface. A central blue starburst contains the text "3D-Move Model". Three callout boxes point to specific features: "Complex surface loadings in all three directions.", "Moving loads of any shape (braking forces)", and "Visco-elastic properties".

Complex surface loadings in all three directions.

Moving loads of any shape (braking forces)

Visco-elastic properties

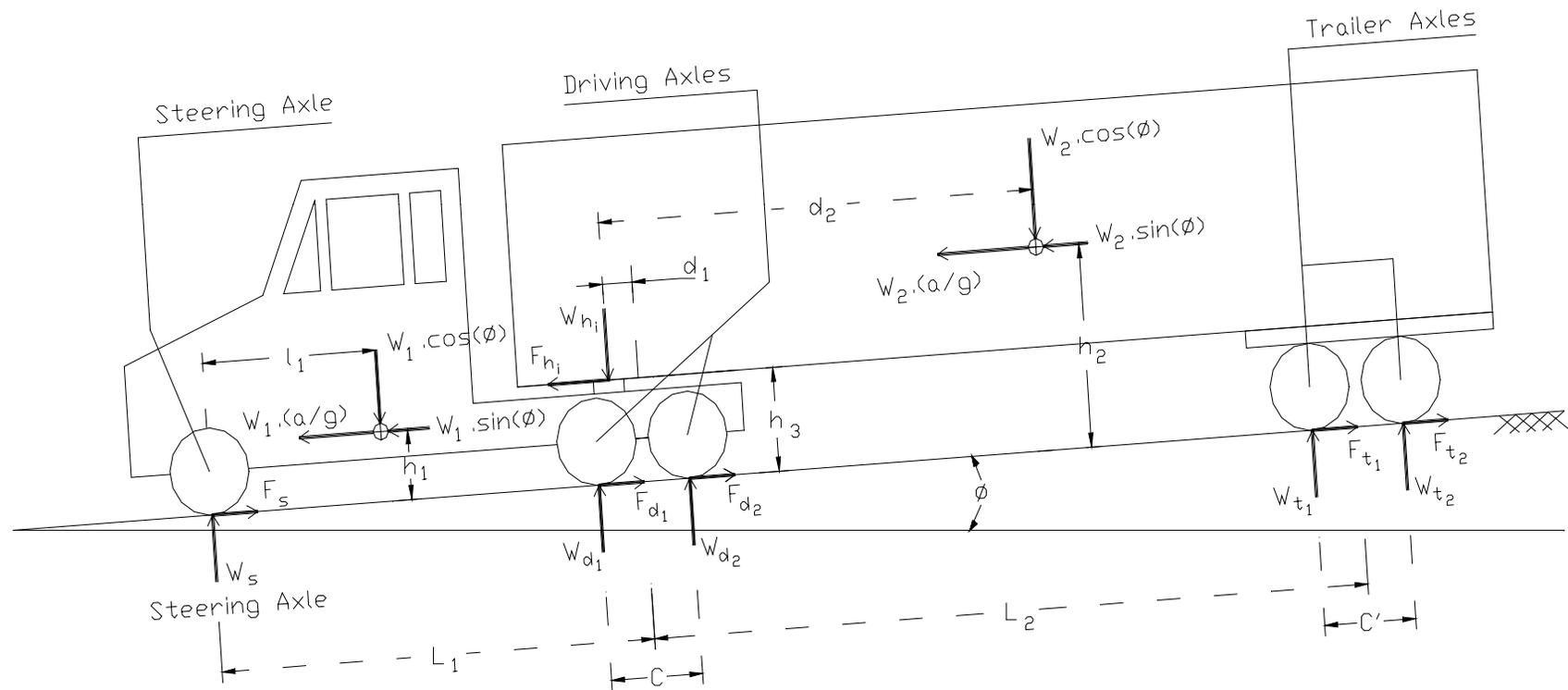
3D-Move Model

The software interface includes a menu bar (File, Edit, Tools, Help, UnitConverter), a project tree on the left, a main workspace, and a "Project Information" panel on the right. The project tree shows a hierarchy: Project --(C:\Users\Witha\Desktop\Project 1 -PG64-22)\Project 1 -PG64-22.3dwp) > Site / Project Identification > Static / Dynamic Analysis. The "Inputs" section includes: Axle Configuration and Contact Pressure Distribution, Vehicle Suspension and Road Roughness, Pavement Structure, Pavement Layer Properties (Layer1-Asphalt, Layer2-Base, Layer3-Subgrade), Response Points, and Output. The "Project Information" panel shows a table with columns "Parameter" and "Value".

Parameter	Value
4-22	
/Units	
ysis - (2mph)	
oad Cases	
(in)	

Semi-trailer Truck

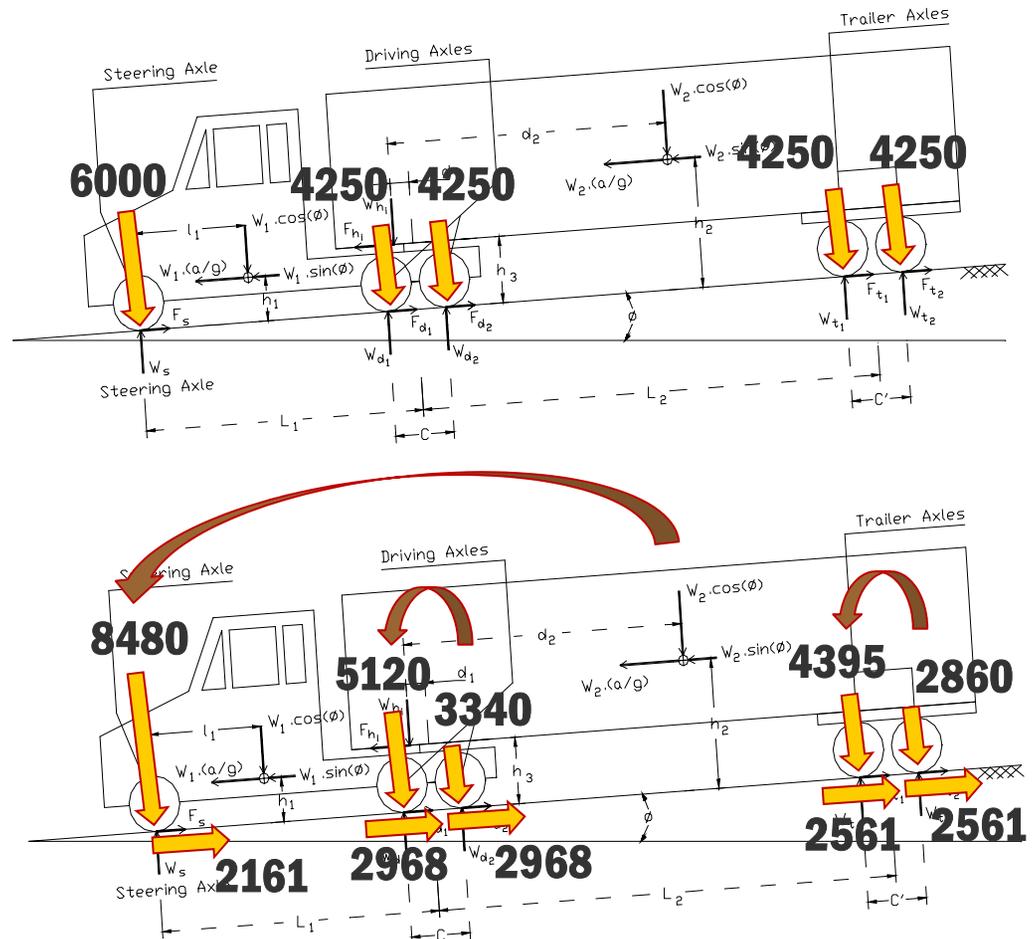
dynamic load transfer → vertical loads on tires additive (+ or -) to static load



Braking = f(deceleration “a”, braking forces)

Semi-trailor Truck

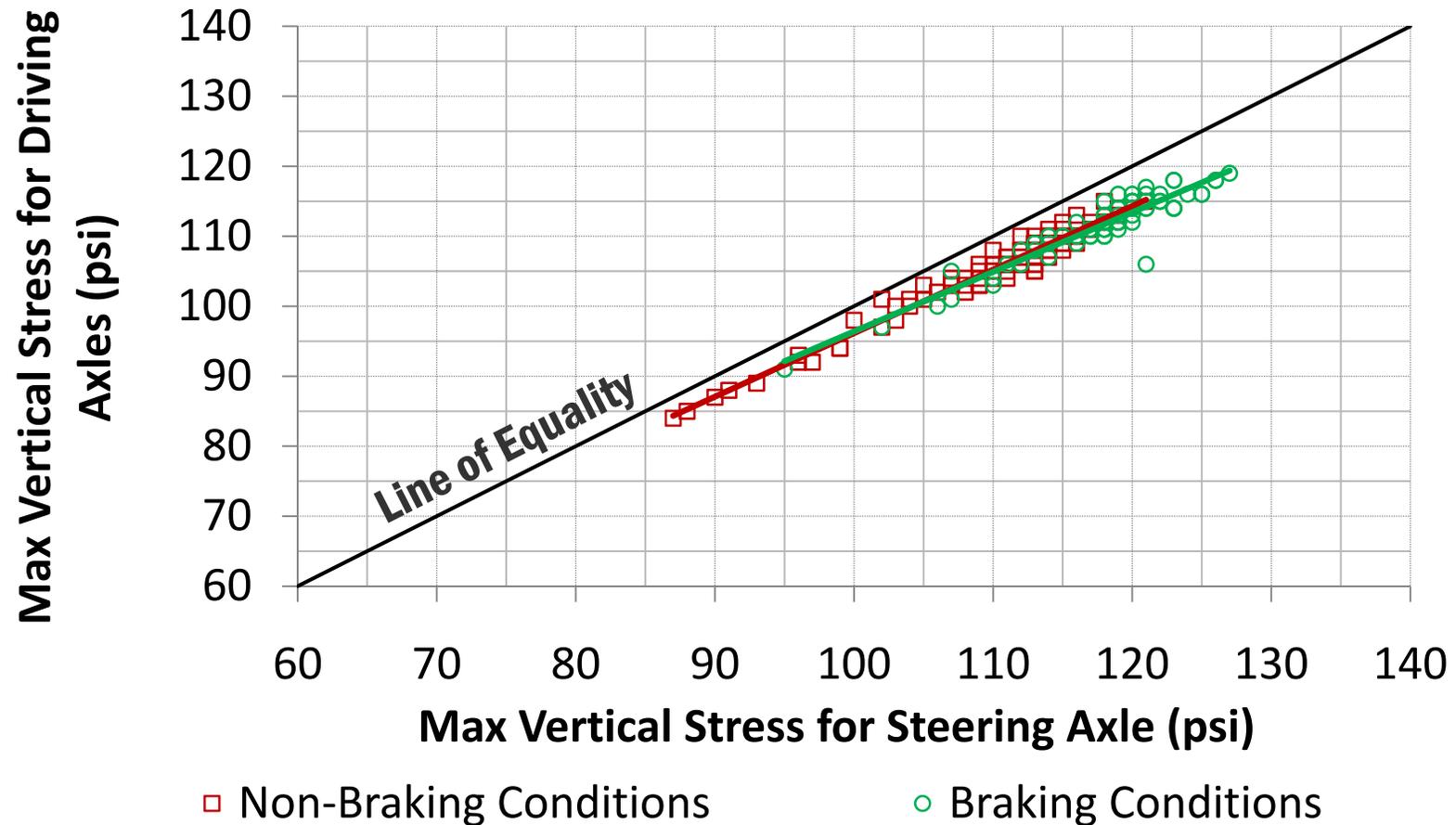
- **Load Distribution During Braking: 14 Unknowns**
 - **11 equilibrium equations**
 - **3 characteristic equations:**
 - **Application (treadle output) vs. actuation (brake chamber) pressure/axle**
 - **Brake force vs. actuation pressure on each axle.**
 - **Dynamic load transfer coefficient.**



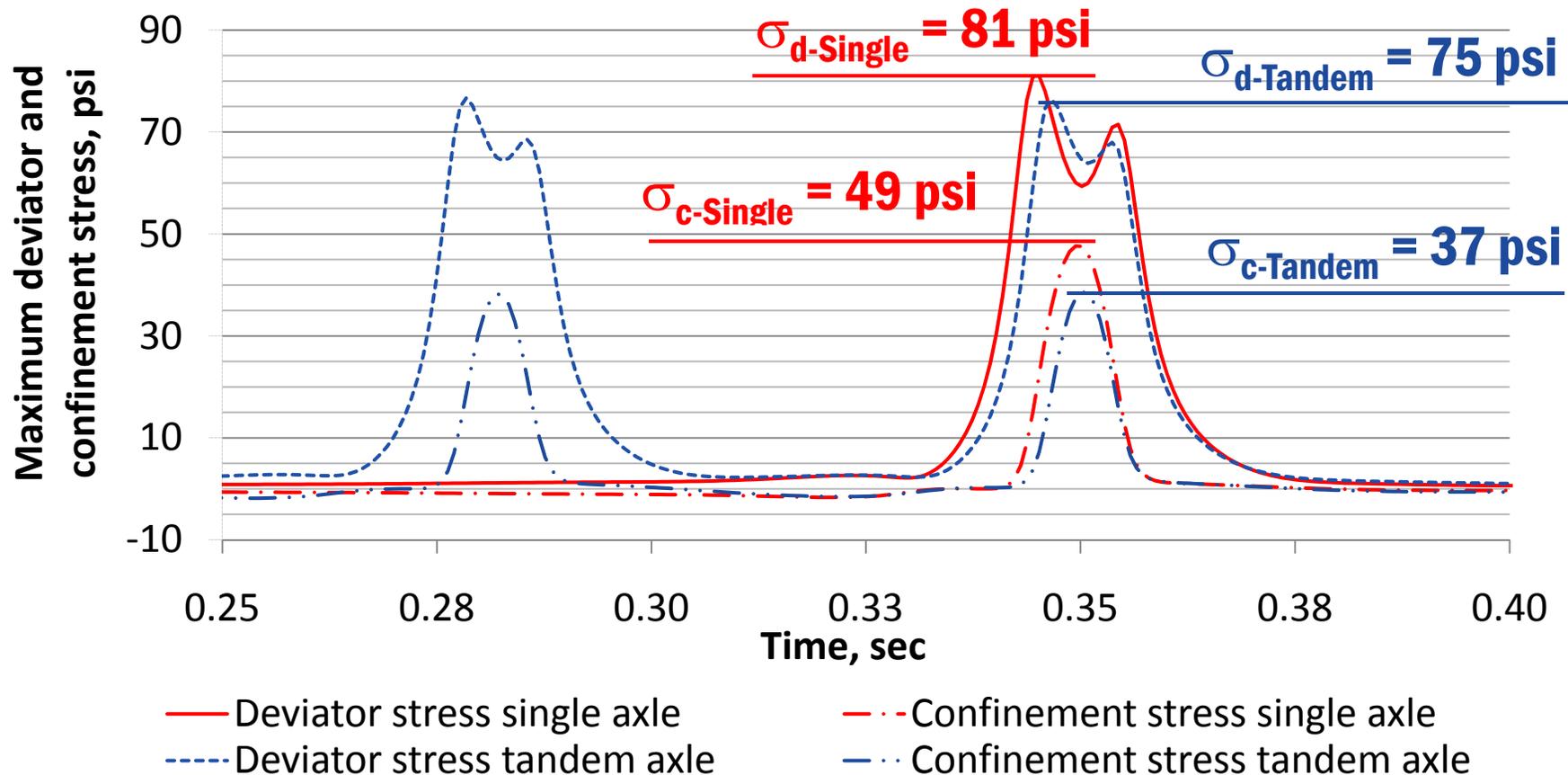
Equivalent deviator and confining stresses time-histories

- σ_d & σ_c were analyzed under **Single** and **Tandem** axles for every:
 - pavement structure
 - mixture type
 - pavement temperature
 - braking and non-braking conditions.

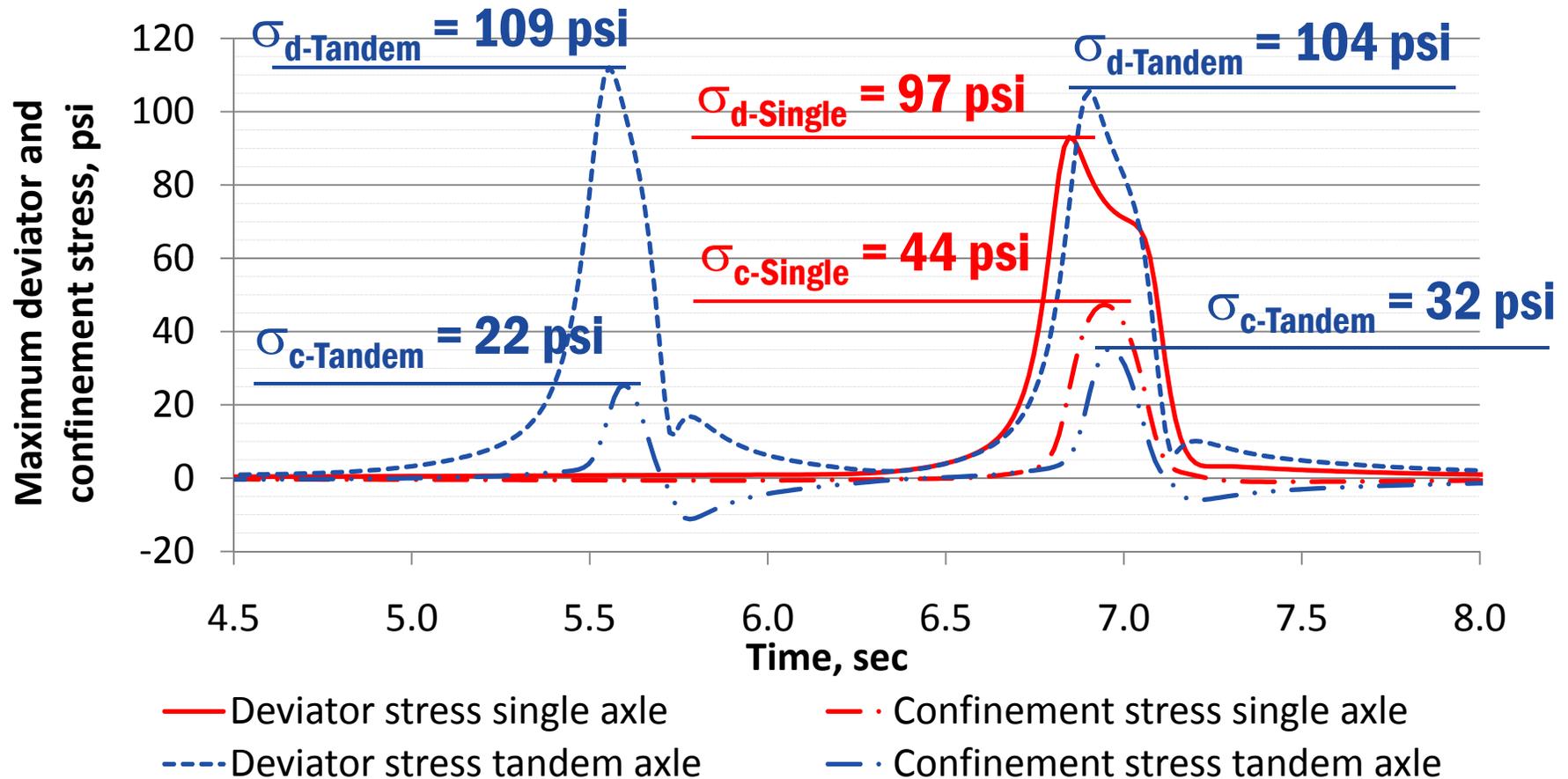
Equivalent deviator and confining stresses time-histories Single vs. Tandem Axles



Equivalent deviator and confining stresses time-histories Single vs. Tandem Axles (Non-braking)



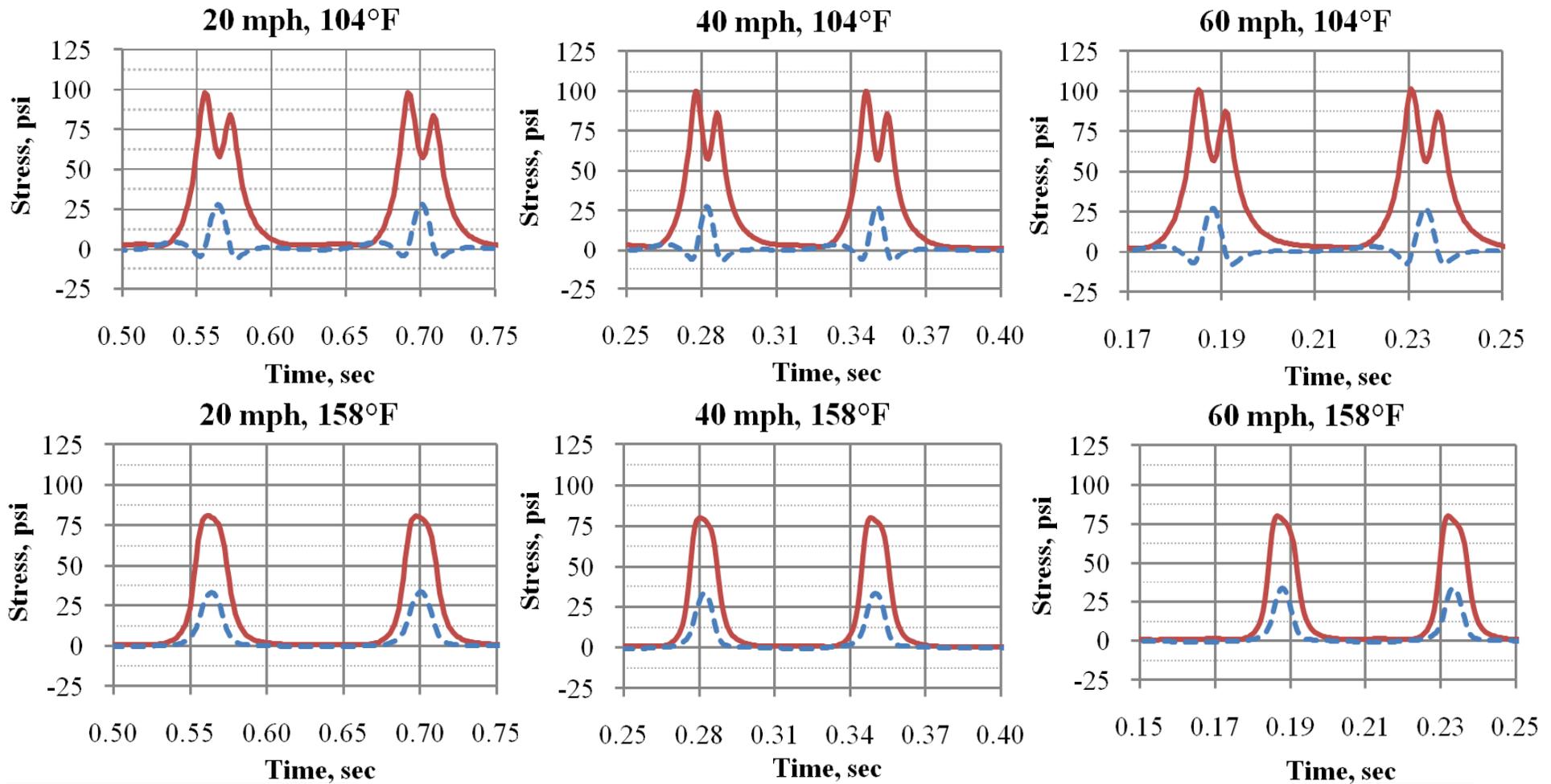
Equivalent deviator and confining stresses time-histories Single vs. Tandem Axles (Braking)



Equivalent deviator and confining stresses time-histories

- **Tandem axle generates a more critical stress condition than the steering axle when the 3D state of stresses is analyzed.**
- **Stresses evaluated under tandem axles at 2-inch below pavement surface.**

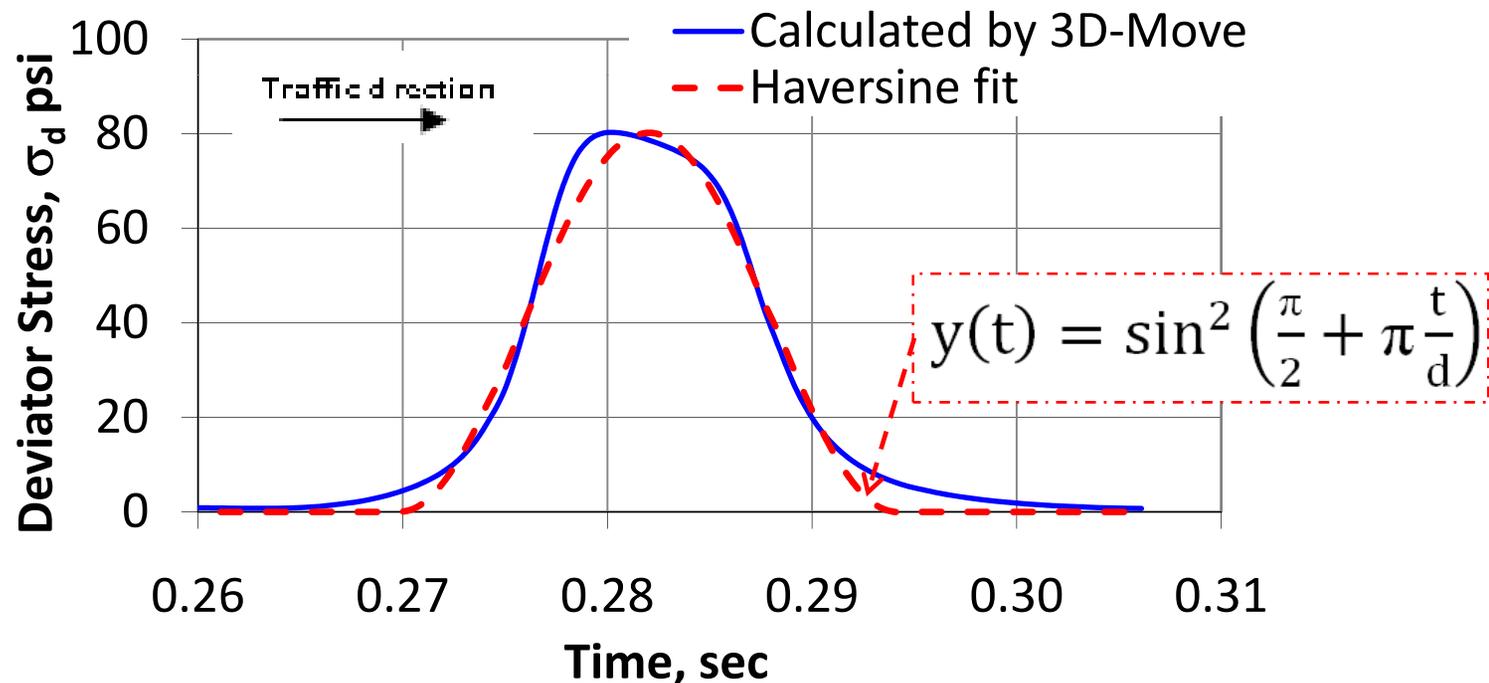
Equivalent deviator and confining stresses time-histories



— Deviator Stress
- - - Confining Stress

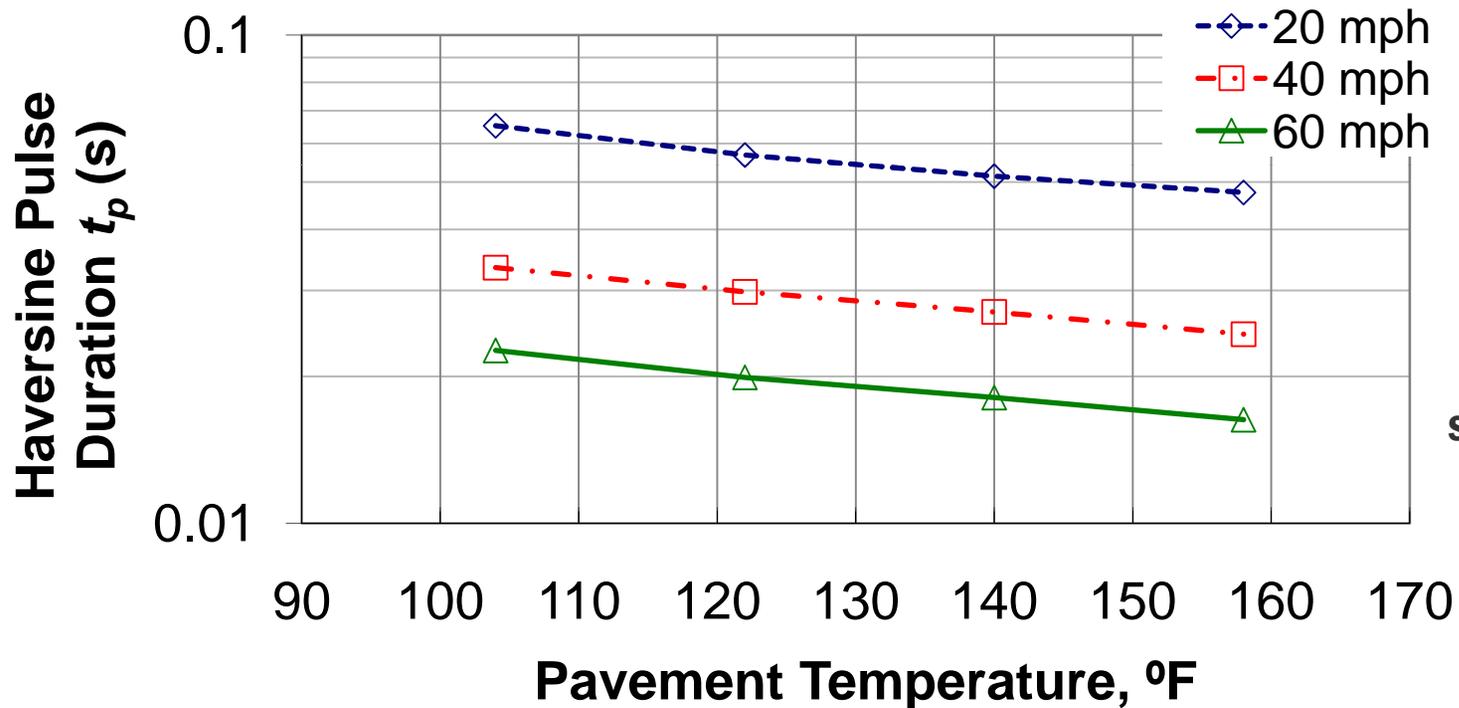
Equivalent deviator stress pulse duration

- Loading pulse characterized using σ_d at 2 inches.
- Best-fitting haversine wave shape.



Equivalent deviator stress pulse duration *under tandem axle, 2 inches below pavement surface*

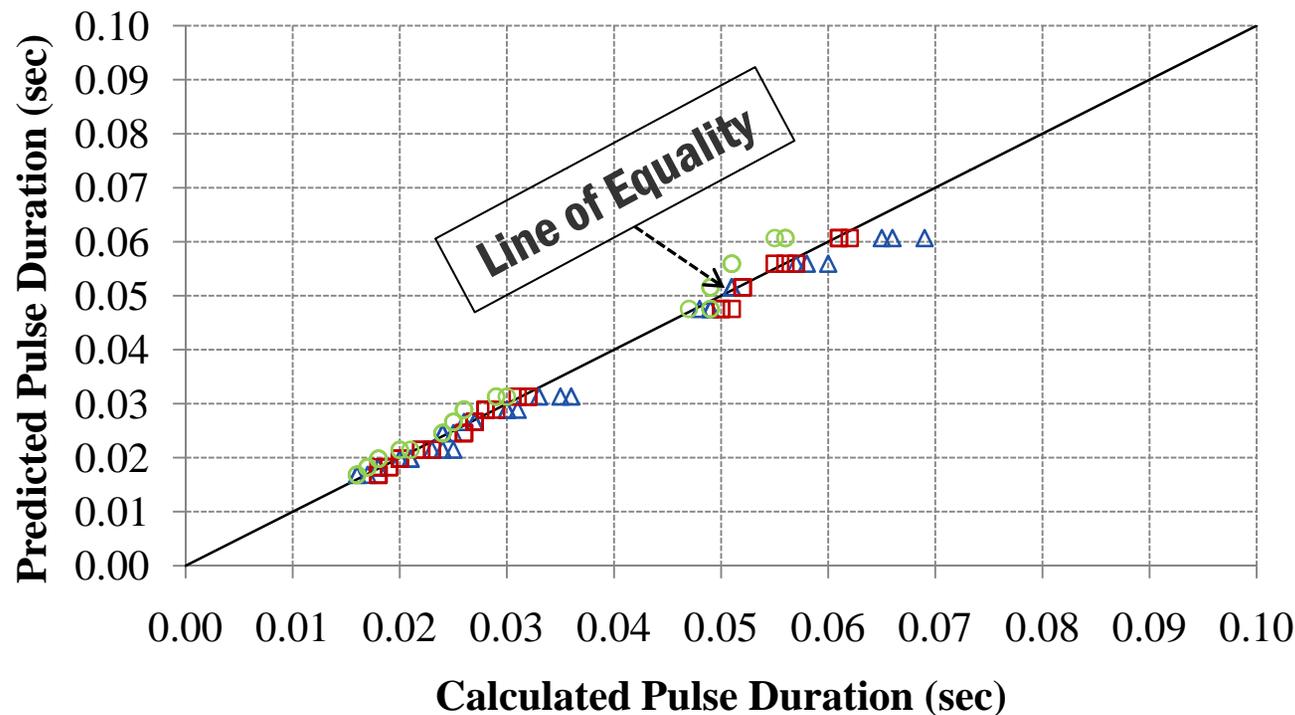
PG64-22 Mix Non-braking



Pavement
structure: 4" HMA
over 6" base

Equivalent t_p at 2" below pavement surface Non-braking Conditions (20-60 mph, 104-158°F)

$$\log(t_p) = -0.00353(T) - 0.0236(S) + 0.00015(S)^2 - 0.6654$$

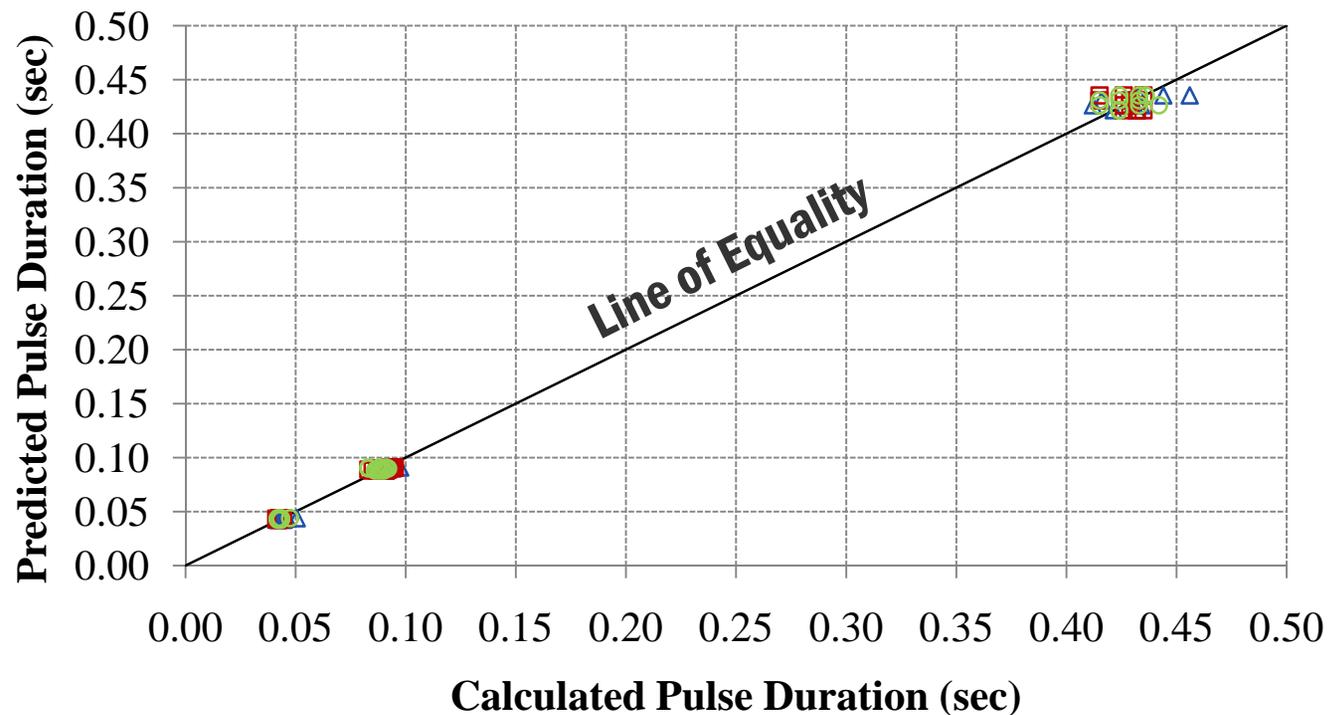


- T = asphalt layer temperature, °C
- S = vehicle travelling speed, mph.

△ PG64-22 (Non-braking) □ PG58-22 (Non-braking) ○ PG52-22 (Non-braking)

Equivalent t_p at 2" below pavement surface Braking Conditions (2-20 mph, 104-158°F)

$$\log(t_p) = -0.000387(T) - 0.05531(S) - 0.23603$$



- T = asphalt layer temperature, °C
- S = vehicle travelling speed, mph.

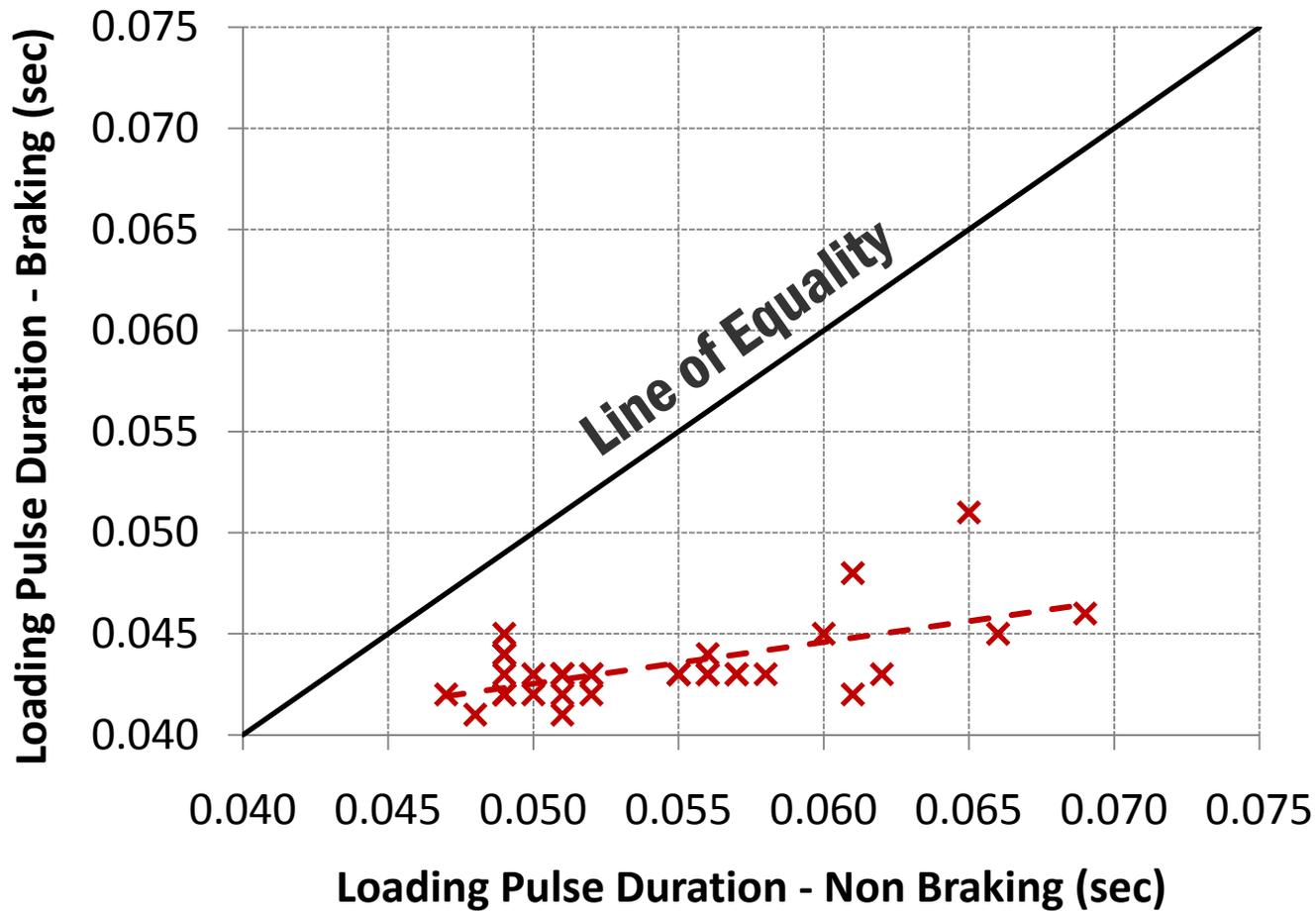
△ PG64-22 (Braking) □ PG58-22 (Braking) ○ PG52-22 (Braking)

Equivalent Deviator Stress Pulse Duration (t_p) at 2" below pavement surface

	Non-Braking	Braking
Speed	20-60 mph	2-20 mph
Equivalent Deviator stress pulse (t_p)	0.016-0.069 sec	0.041-0.456 sec

**< 0.1 sec typically applied to FN test
(*except for braking at 2 mph*)**

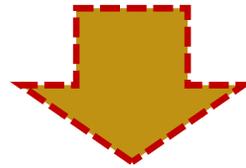
Equivalent deviator stress pulse duration Braking vs. Non-braking at 20 mph



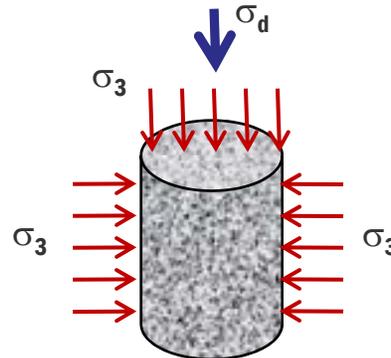
12% to 29%
reduction in
pulse time

Equivalent Deviator Stress Pulse Duration (t_p) at 2" below pavement surface

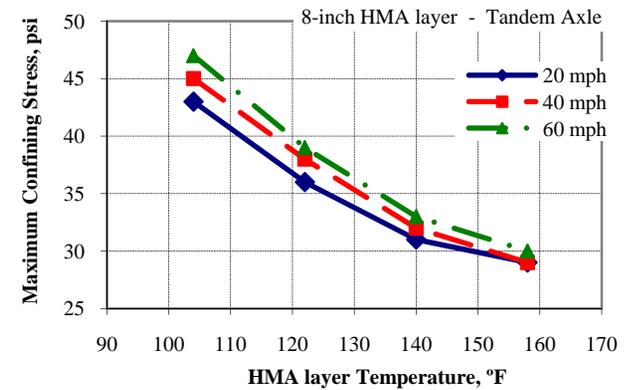
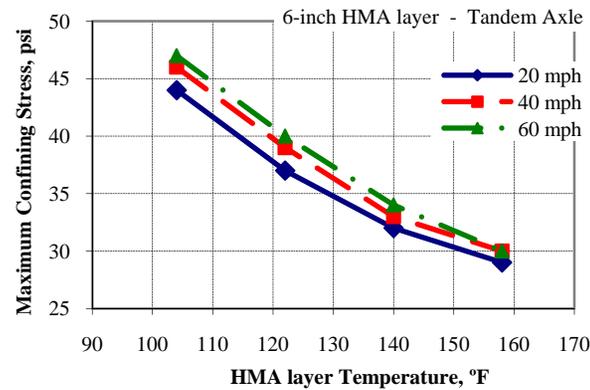
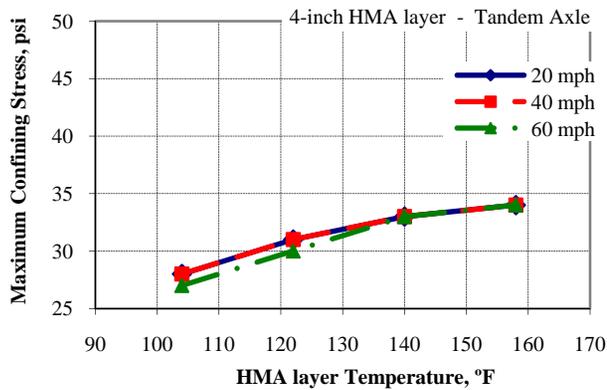
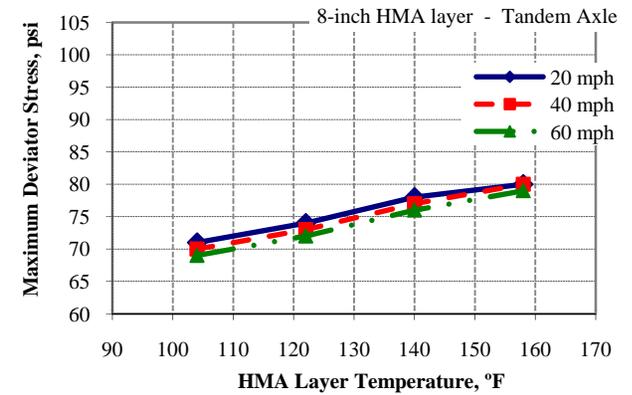
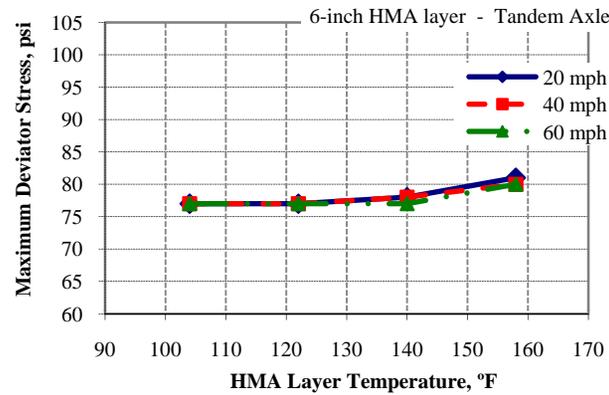
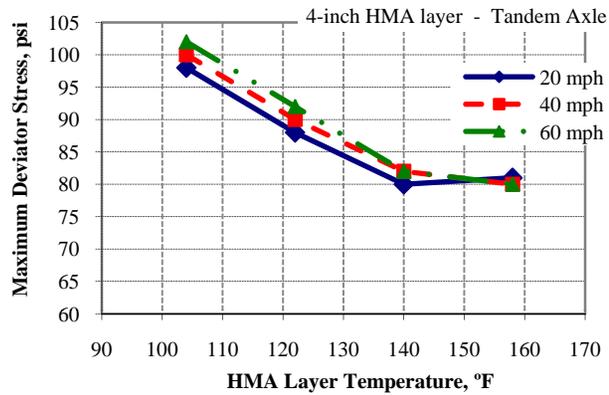
Non-braking condition seems to result in a more critical condition than braking condition.



Evaluate the magnitudes of σ_d and σ_c under braking and non-braking conditions

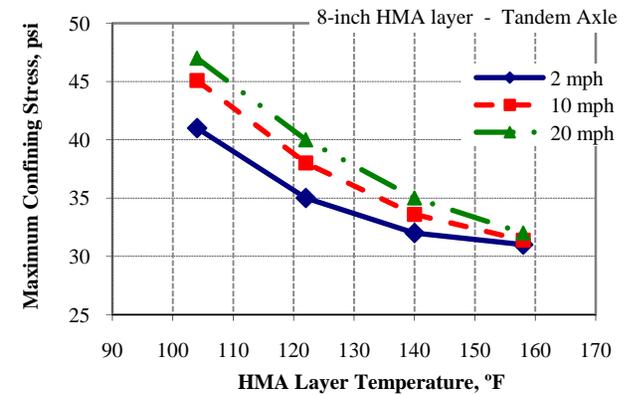
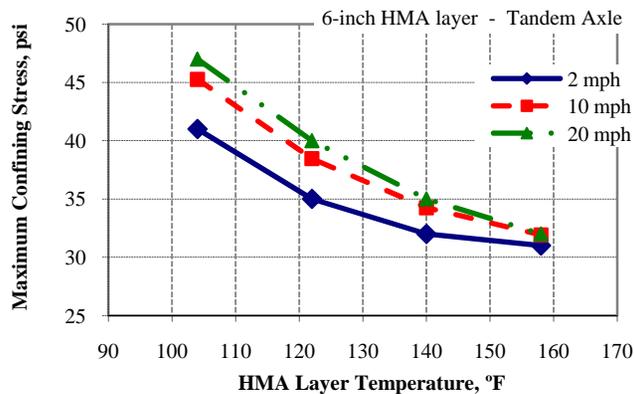
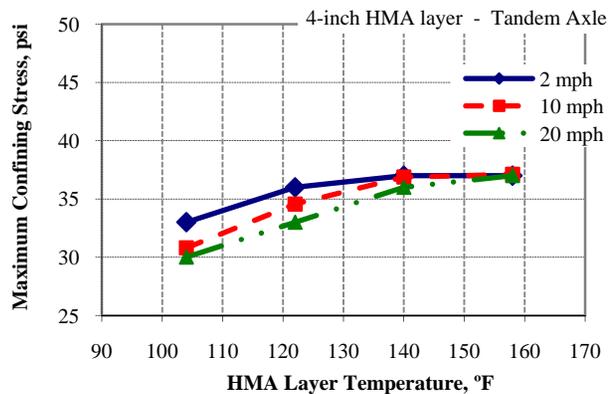
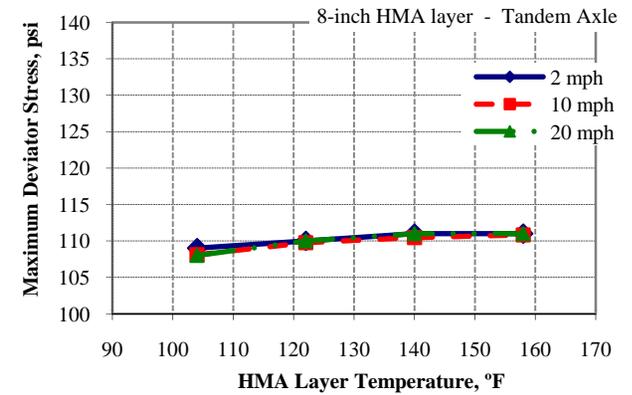
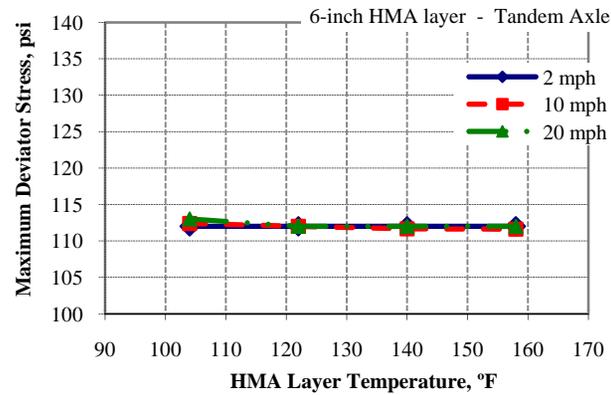
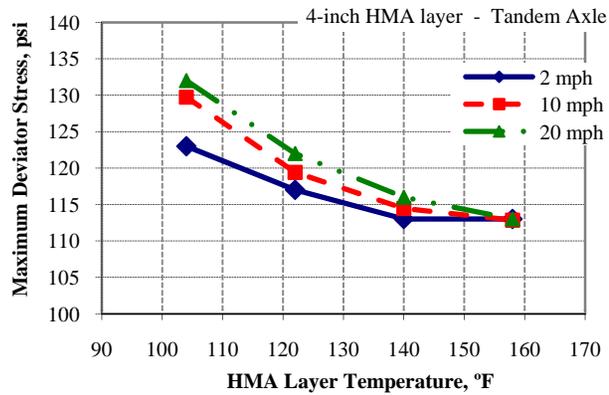


Maximum equivalent σ_d and σ_c stresses



PG64-22 Mix for non-braking conditions

Maximum equivalent σ_d and σ_c stresses



PG64-22 Mix for braking conditions

Maximum equivalent σ_d and σ_c stresses

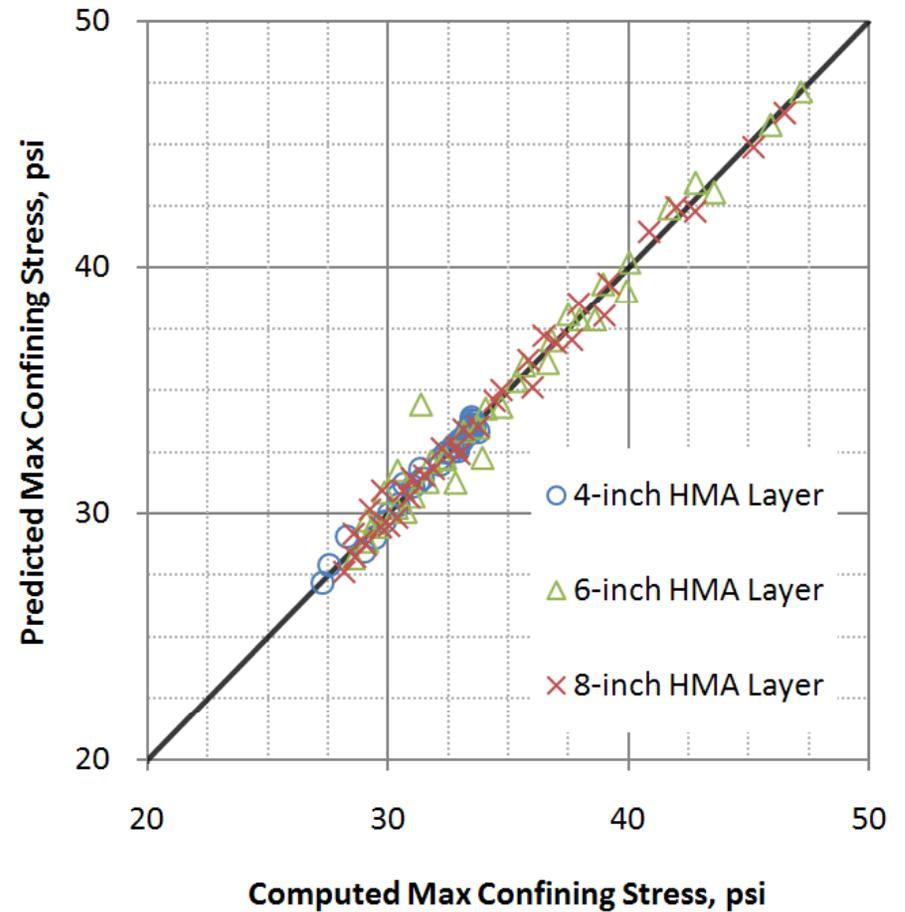
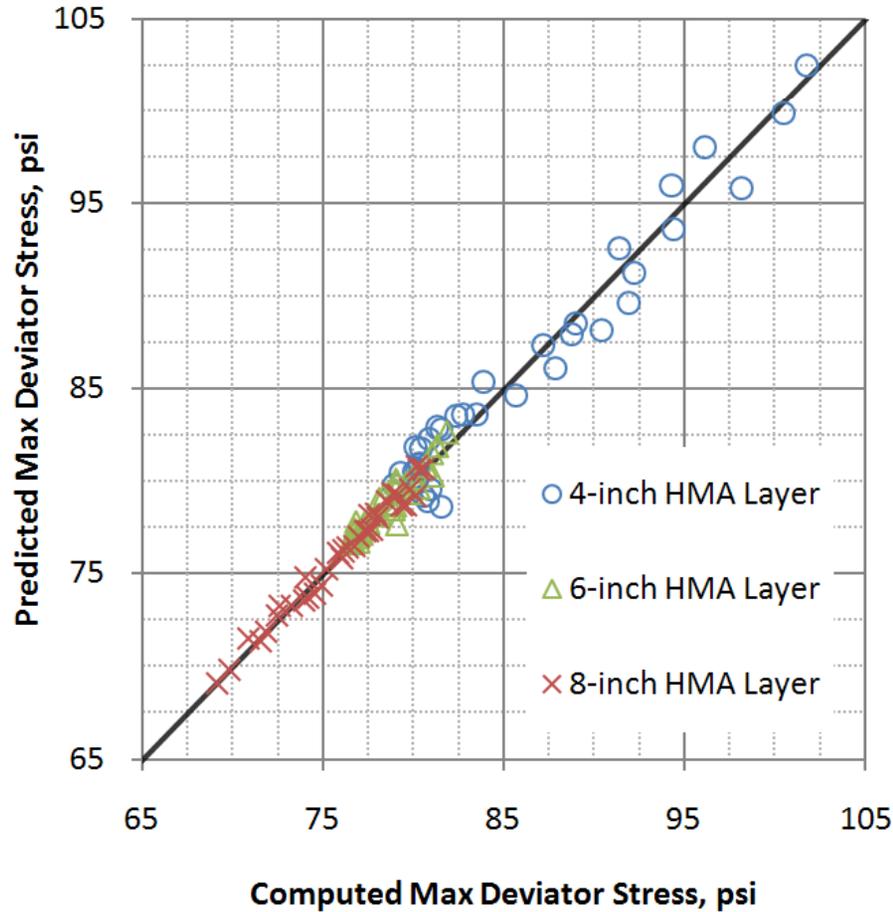
- Predictive Equations for:
 - Equivalent max deviator stress, σ_d
 - Equivalent max confining stress, $\sigma_c = \sigma_3$

at 2 inches below pavement surface
Braking and Non-Braking Conditions

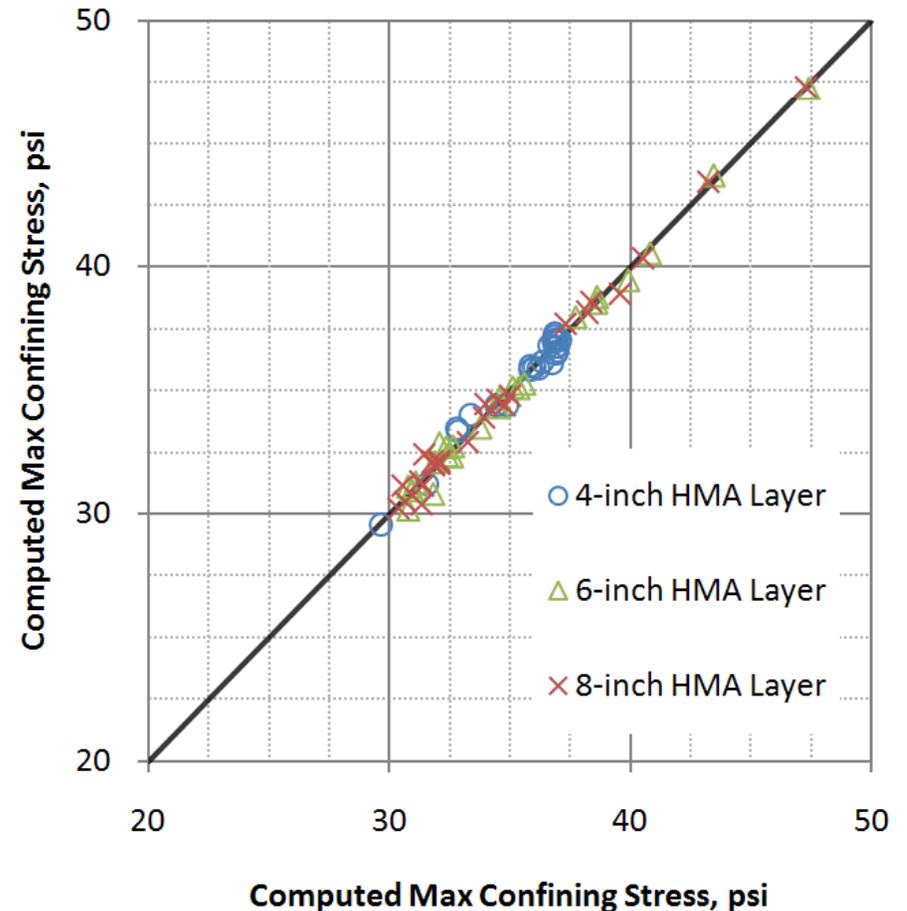
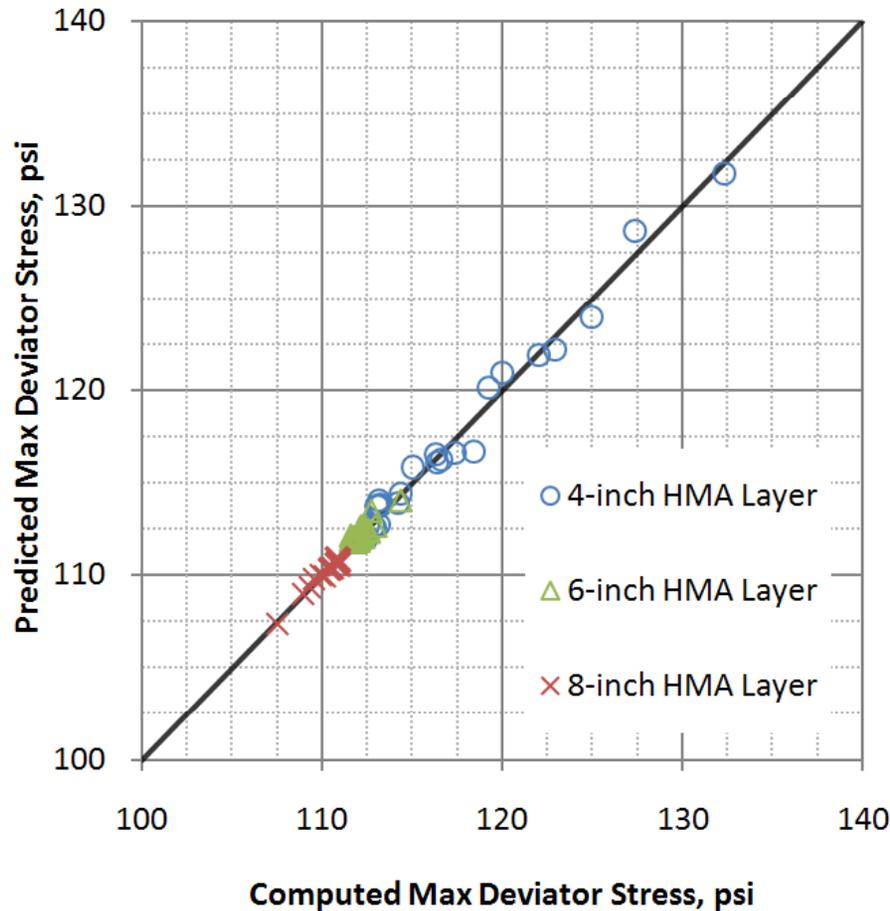


Function of *AC layer thickness, T , E^* , S , interaction terms*

Equivalent Deviator & Confining Stresses at 2" Non-Braking Conditions



Equivalent Deviator & Confining Stresses at 2" Braking Conditions



Equivalent Deviator & Confining Stresses at 2" Below Pavement Surface

Non-braking conditions:

- σ_d ranged from 69 to 102 psi
- σ_c ranged from 27 to 47 psi

slight increase
(5%) in σ_c

Braking conditions:

- σ_d ranged from 108 to 132 psi
- σ_c ranged from 30 to 47 psi

40% increase
in σ_d

Summary and conclusions

- **Equivalent deviator stress pulse duration (t_p) at 2” below the pavement is function of**
 - **vehicle speed, and**
 - **pavement temperature.**
- **Neither pavement thickness nor mixture properties significantly impacted t_p at 2” below pavement surface.**

Summary and conclusions

- **Standard pulse time loading of 0.1 sec does not simulate actual traffic-induced deviator stress pulse duration.**
- **Braking conditions, though it generates interface shear stresses, leads to lower deviator pulse duration & higher amplitude.**

Summary and conclusions

- **Amplitude of the equivalent triaxial deviator and confining stresses are highly affected by:**
 - **Mixture's stiffness**
 - **Pavement effective temperature**
 - **Vehicle speed.**

Thank you for your attention!!!

- **Acknowledgments**

- This work is part of the overall effort in the Asphalt Research Consortium (ARC) work element E2c: “Critically Designed HMA Mixtures.” (www.arc.unr.edu)
- Authors gratefully acknowledge the FHWA support.