Equivalent Loading Frequencies to Simulate Asphalt Layer Pavement Responses Under Dynamic Traffic Loading

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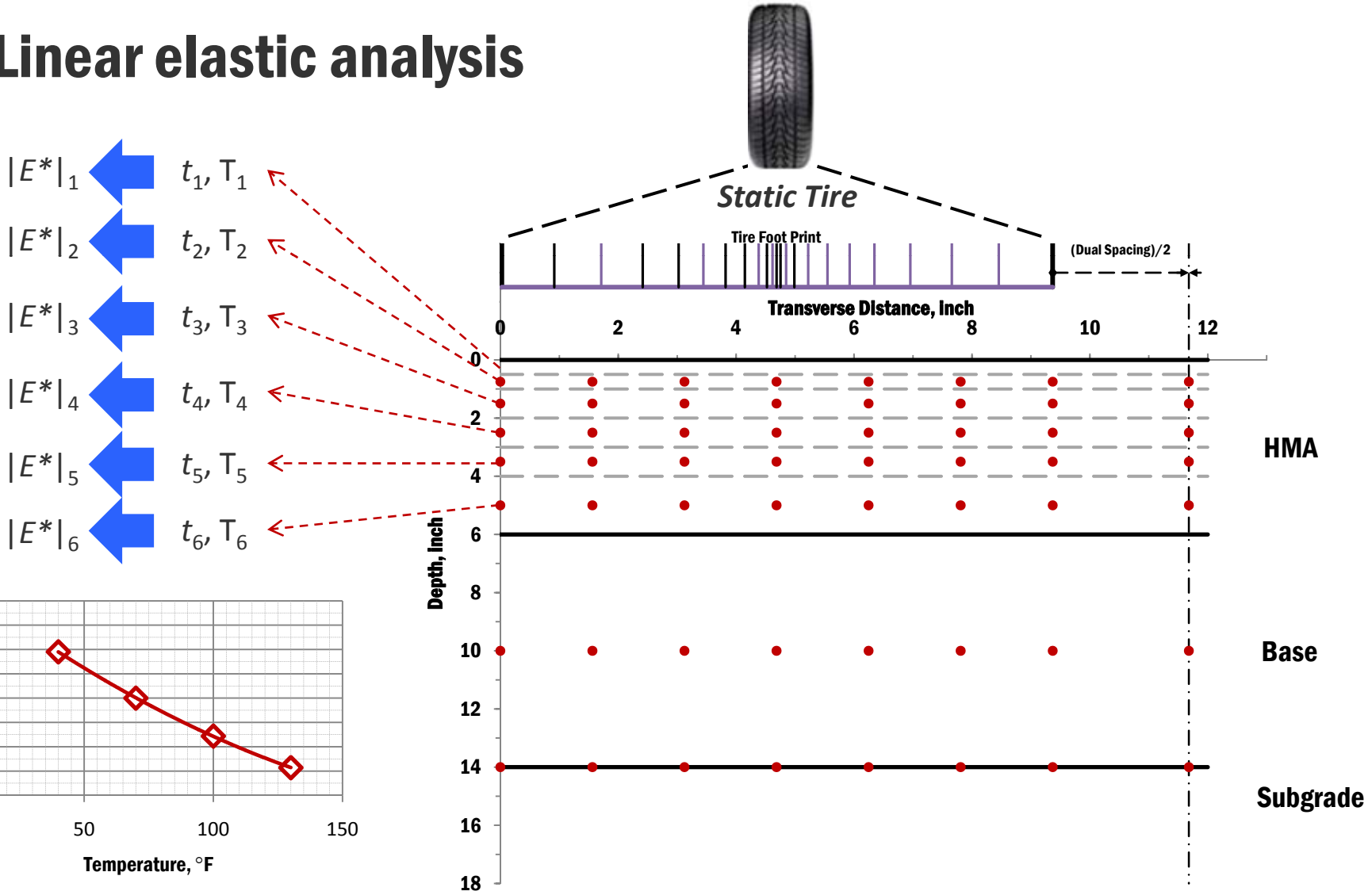
Introduction

- *Dynamic response* of AC pavements under moving load is a key component for accurate prediction of *flexible pavement performance.*
- *Reliable determination* of pavement responses to moving load is essential for a successful mechanistic design procedure.
- *Time and temperature dependency* of asphalt must be considered in the mechanistic analysis response model.

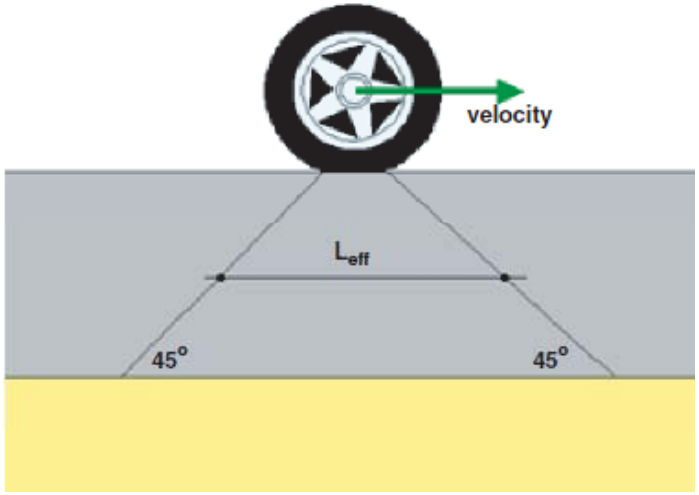
AASHTO MEPDG Approach

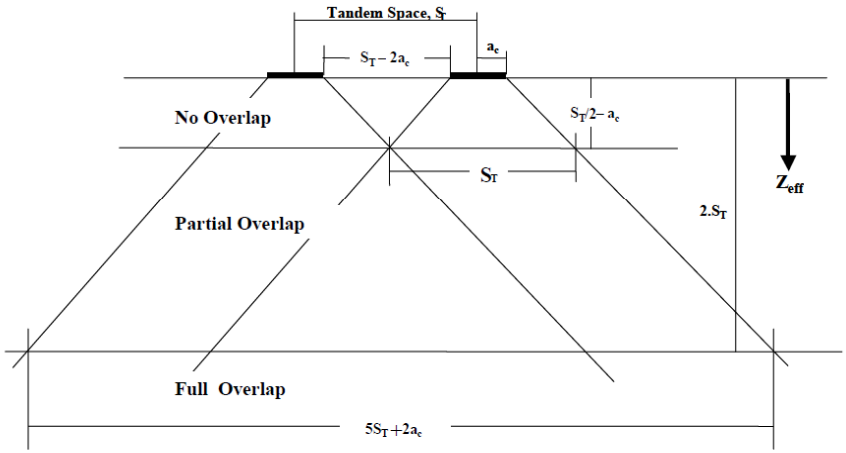
- Linear elastic analysis



AASHTO MEPDG

- **Vertical stress distribution used to estimate traffic-induced loading time.**
  - **Axle load configuration, Vehicle speed & Pavement structure**

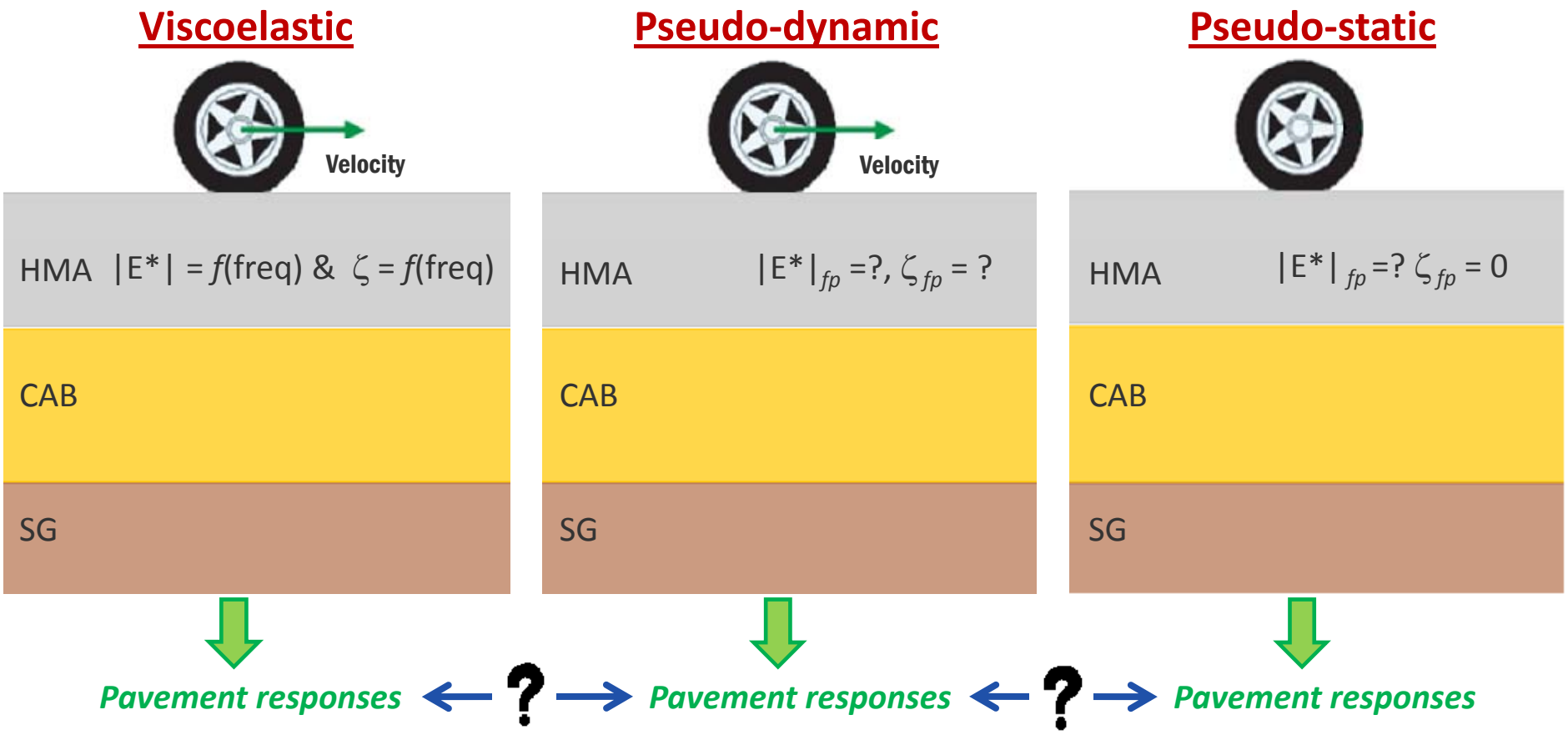




$$t = \frac{L_{eff}}{17.6\,V_s} \quad \Rightarrow \quad f = \frac{1}{t}$$

$$Z_{eff} = \sum_{i=1}^{n-1}\left(h_i \sqrt[3]{\frac{E_i}{E_{SG}}}\right) + h_n \sqrt[3]{\frac{E_n}{E_{SG}}}$$

Viscoelastic vs. Pseudo Analysis



Objective

- Investigate the existence of one or more *predominant frequencies* (f_p) associated with the AC layer that controls the dynamic response of pavements.

- ***AC Critical Reponses*** :
  - Longitudinal & transverse tensile strains
  - Vertical compressive strains

Pavement Analysis

3D-Move Analysis Software

Complex surface

Asphalt Research Consortium

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Software

3D-Move

Announcements

DISCUSSION GROUP" at 3d-move.finddiscussion.com to provide your feedback or post your questions on the 3D-Move Analysis Software.

Free Softwares

3D-Move (NEW: Version 1.2) ***Now Available Online!***

Announcement to 3D-Move Users (Posted on August 29, 2010):
Inconsistency Between Text and Excel Output Files of Ver. 1.1

The last beta-version of the 3D-Move Analysis (ver 1.1) was released on July, 2010. In 3D-Move, output is provided in formats: Text and Excel. An inconsistency has inadvertently occurred when these two formats were integrated. The **inconsistency was present only in the Excel file**, while the **Text file output is correct**. The origin of the slip-up was traced to the allocation of the columns when the data sharing between Text and Excel output files occurred. Further, there were concerns about the units of the 3D-Move responses being not prominently displayed. These issues have been corrected and a modified beta-version of 3D-Move (ver 1.2) is now available for download.

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Freeware Download at:
http://www.arc.unr.edu/Software.html

Pavement Analysis

3D-Move Analysis Software - Validation

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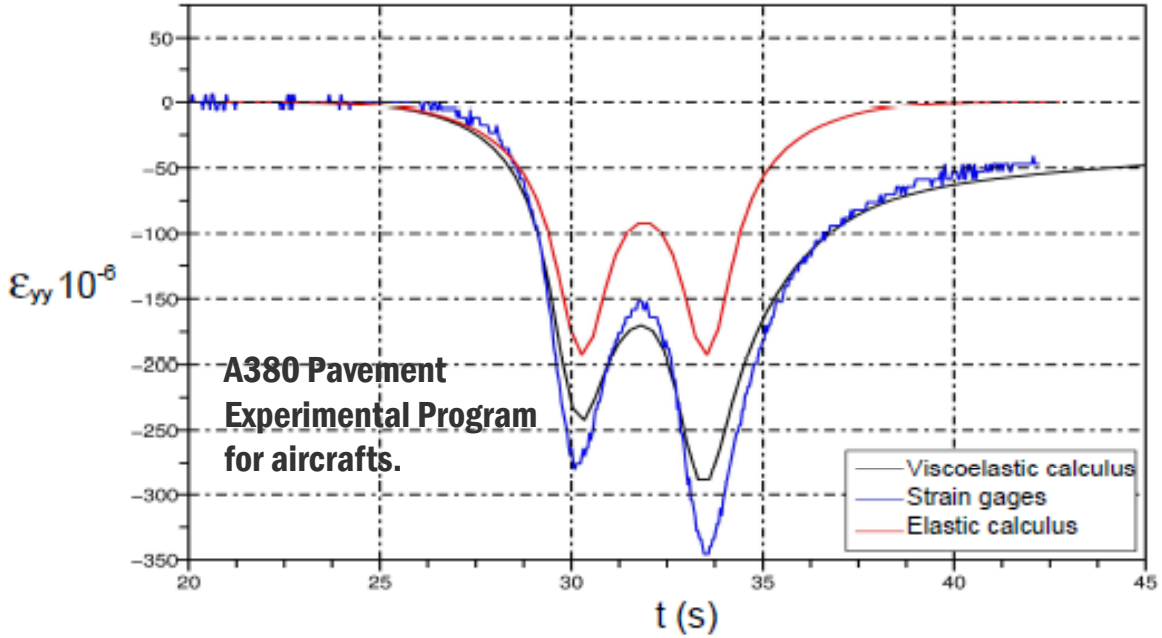
1. 3D-Move vs. ViscoRoute (2010)

- ViscoRoute: moving circular loaded areas with uniform contact pressure, viscoelastic material properties



Comparison between elastic computations, ViscoRoute1.0 simulations and transversal strain measurements at the bottom of bituminous layers for a 4-wheels moving load

Reference:
Chabot, A., Chupin, O., Deloffre, L., and Duhamel, D., "Viscoroute 2.0: a tool for the simulation of moving load effects on asphalt pavement," Road Materials and Pavement Design an International Journal, Volume 11/2, 2010, pp. 227-250.

Loft A., "Evaluation de Viscoroute-v1 pour l'étude de quelques chaussées souples", Msc. Dissertation, Dresden University of Technology speciality Urban and Road construction, 2005.

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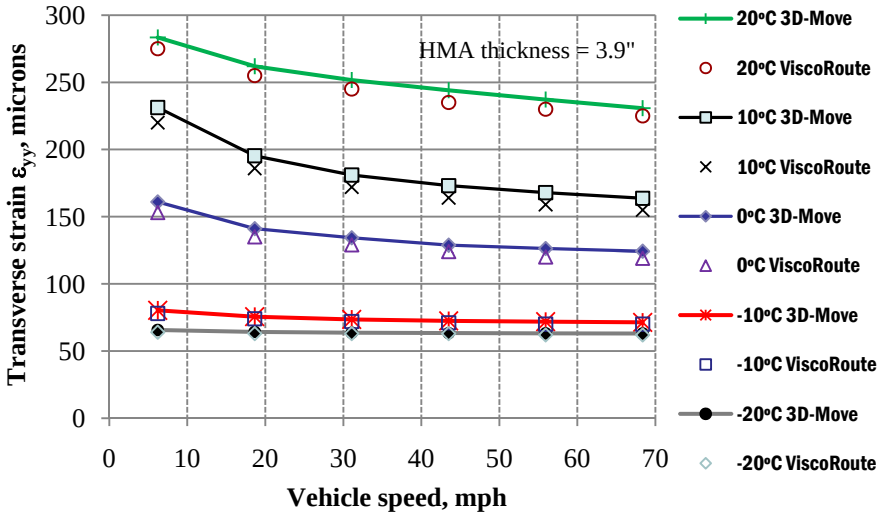
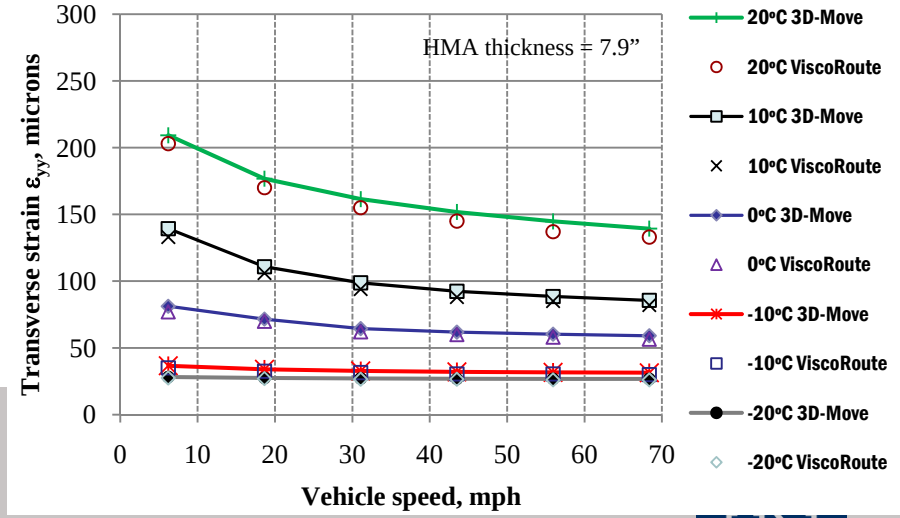


3D-Move vs. ViscoRoute
Vehicle speed = 6 to 70 mph
Pavement temperature = -20°C to 20°C



ViscoRoute Test Results Refer to:
Chabot, A., Chupin, O., Deloffre, L., and Duhamel, D., "Viscoroute 2.0: a tool for the simulation of moving load effects on asphalt pavement," Road Materials and Pavement Design an International Journal, Volume 11/2, 2010, pp. 227-250.

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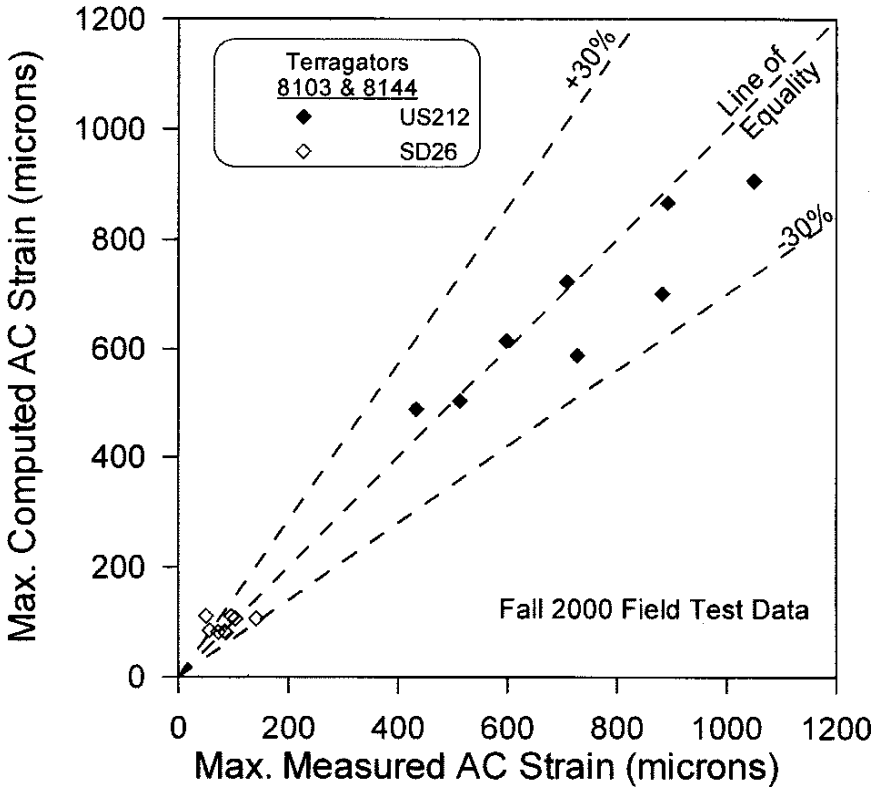
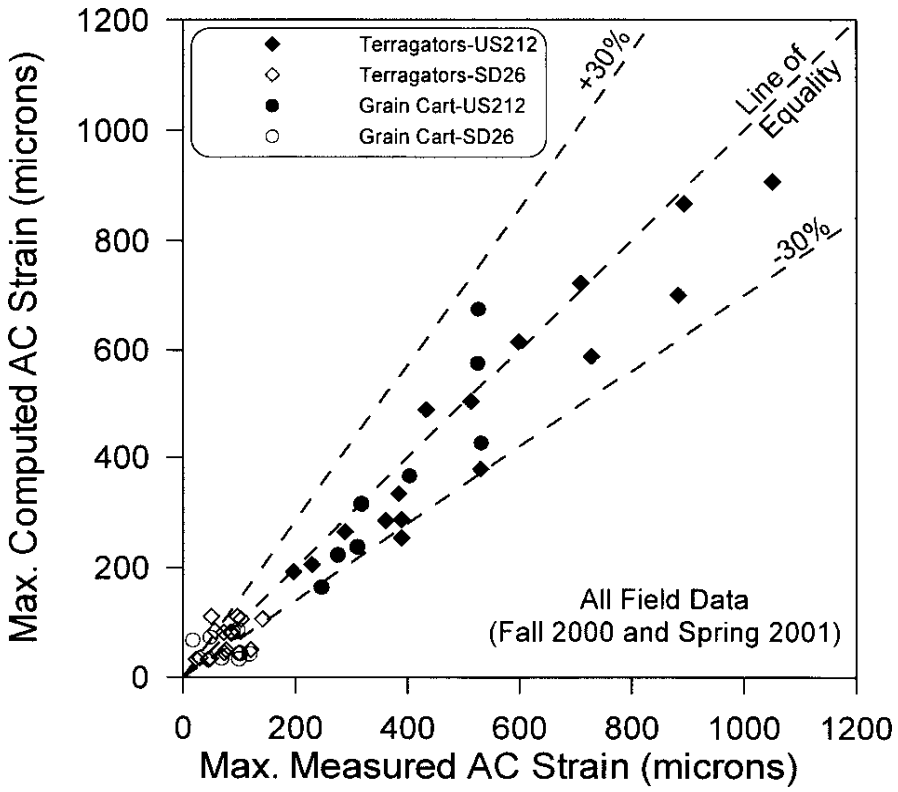
2. SD Heavy Off-Road Vehicle Field Sections (2000)





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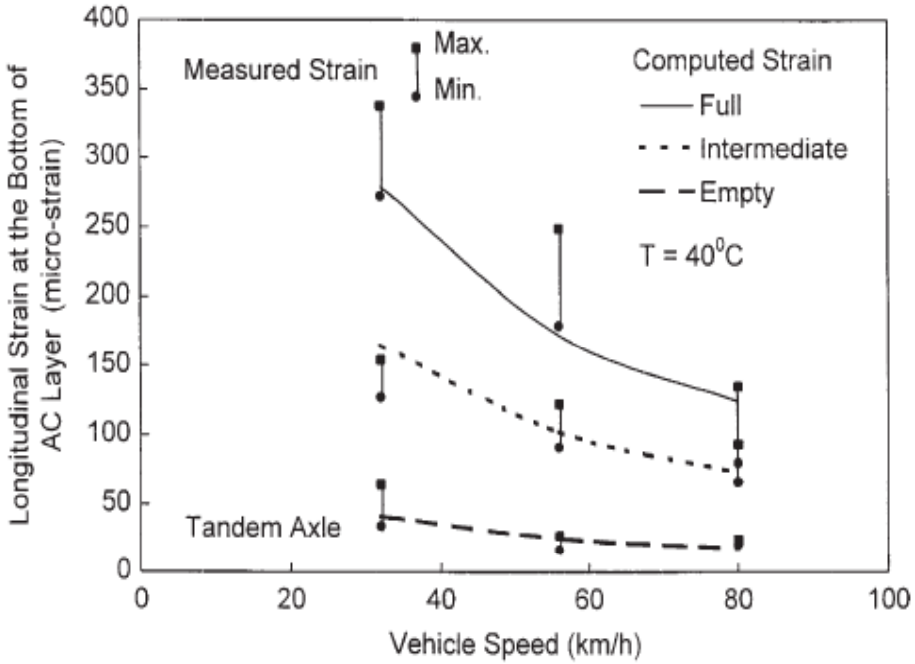
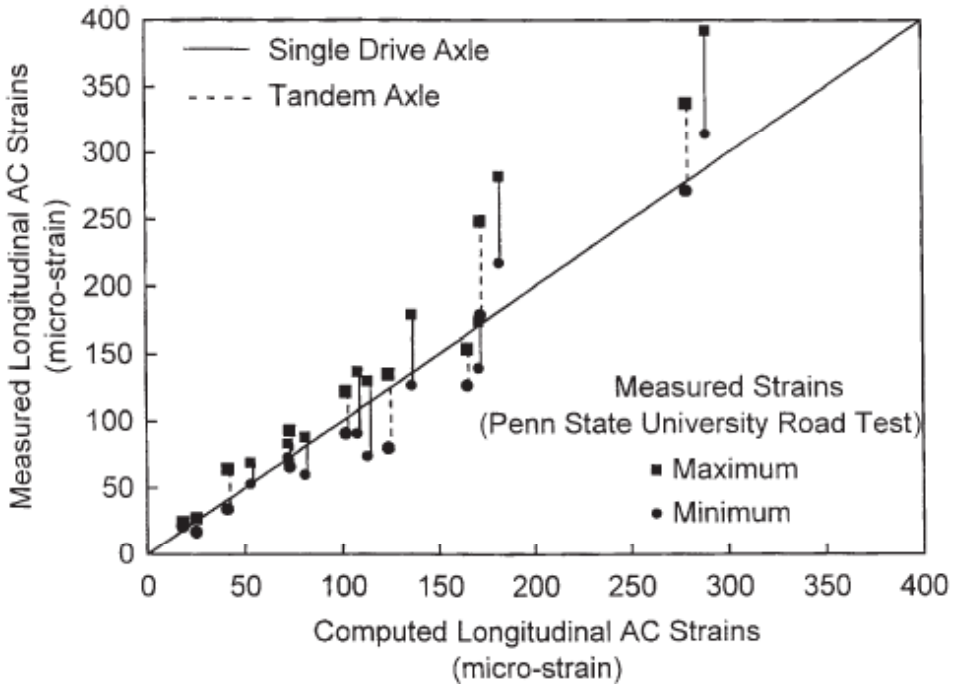
3. PennState University Test Track (1999)





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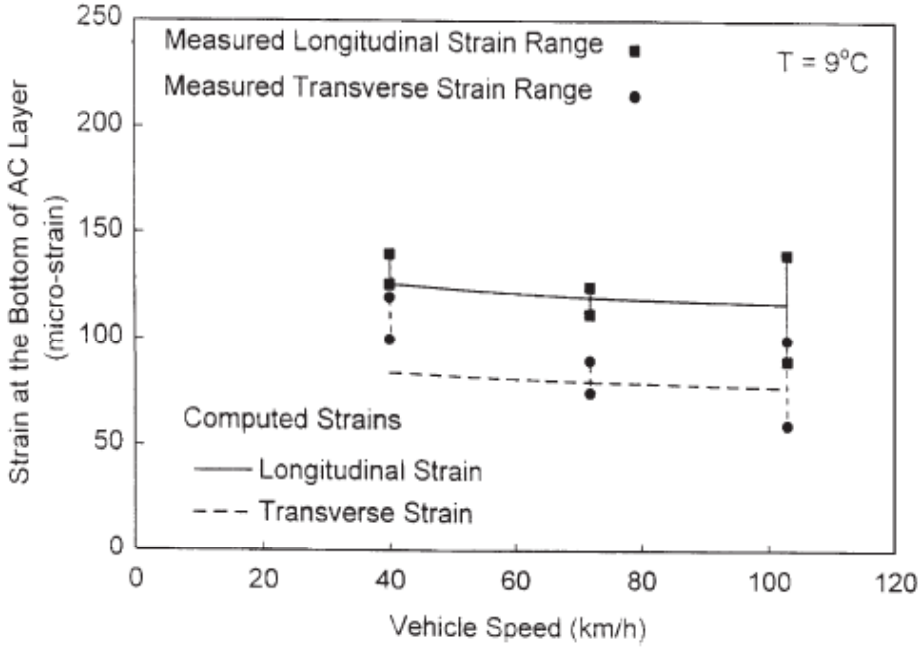
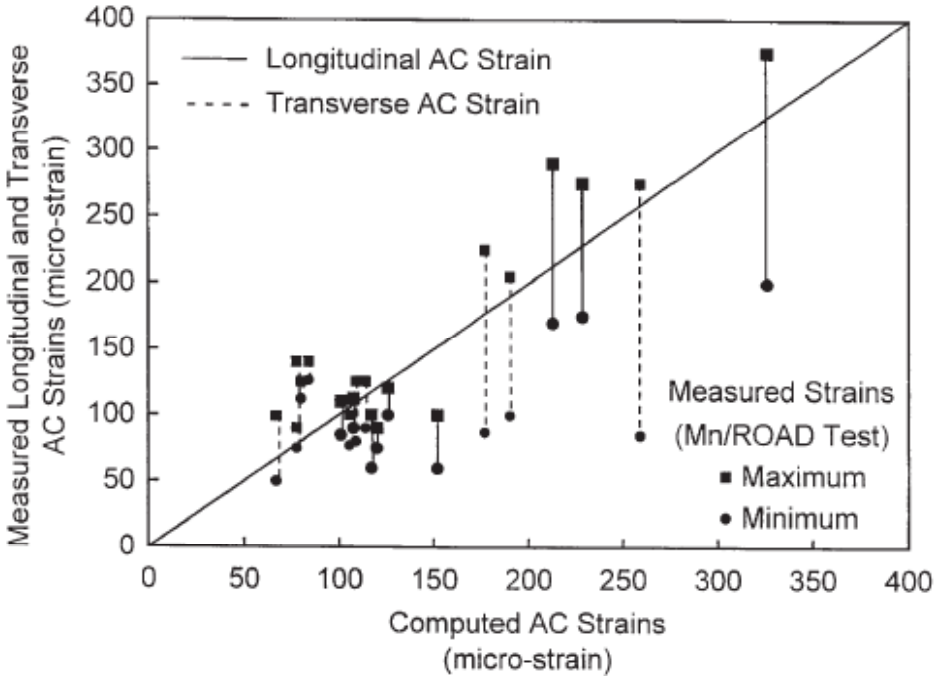
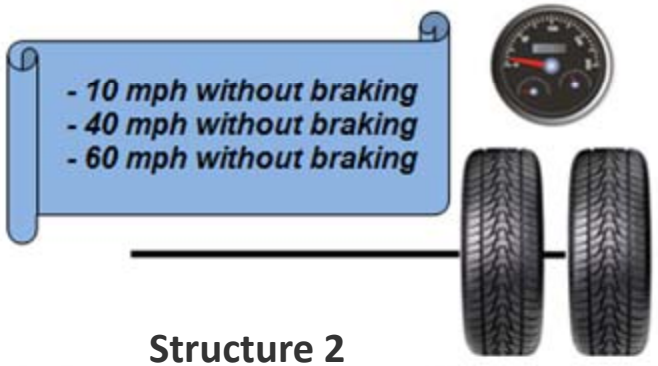
4. MnRoad (1997)



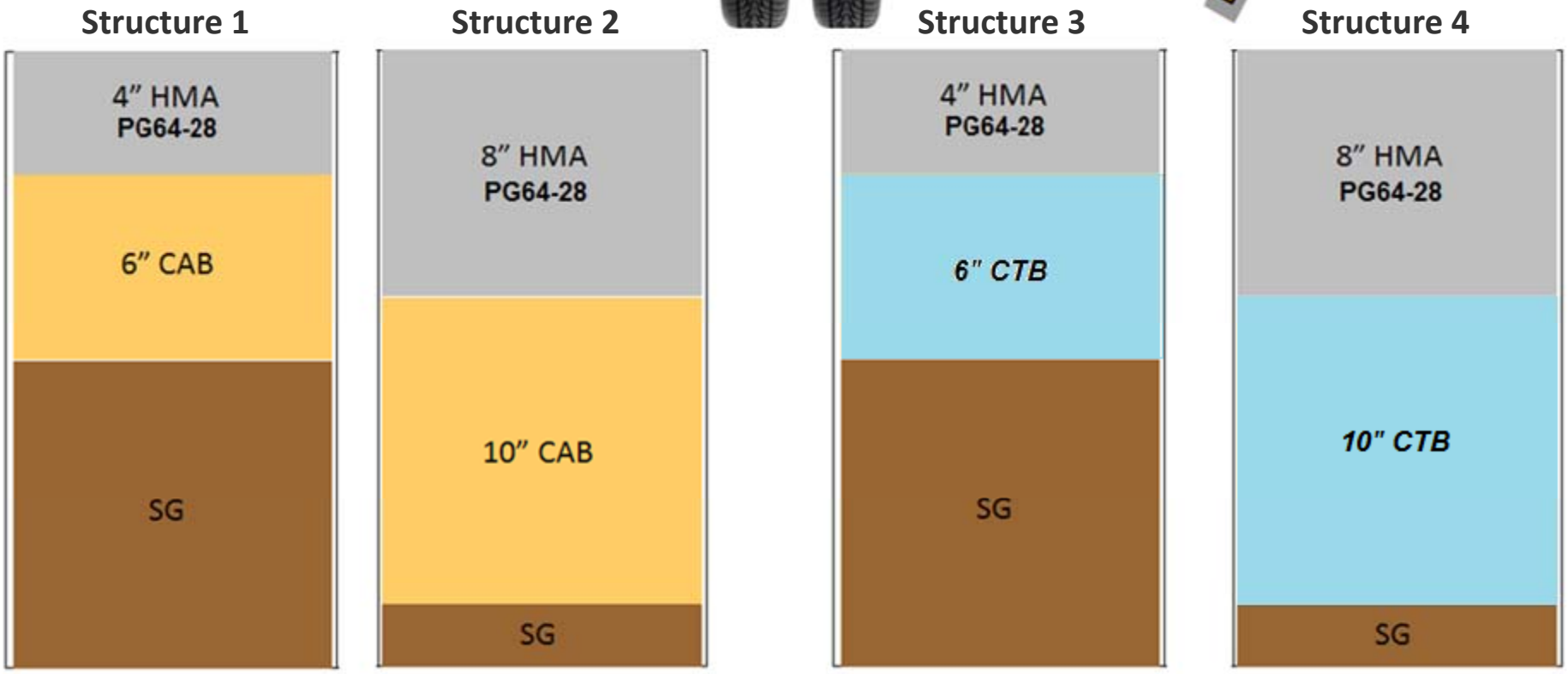


Database of pavement responses



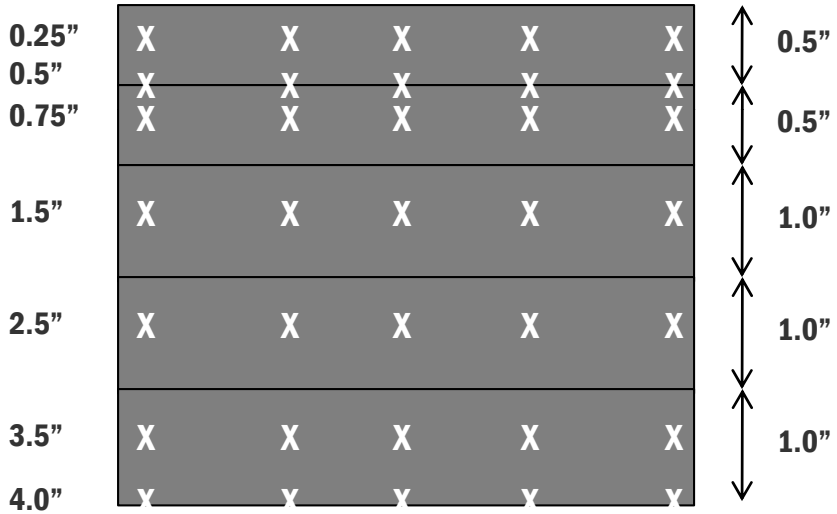
HMA layer temp:
70°F and 104°F

Structures 1 & 2 pavement analyses completed

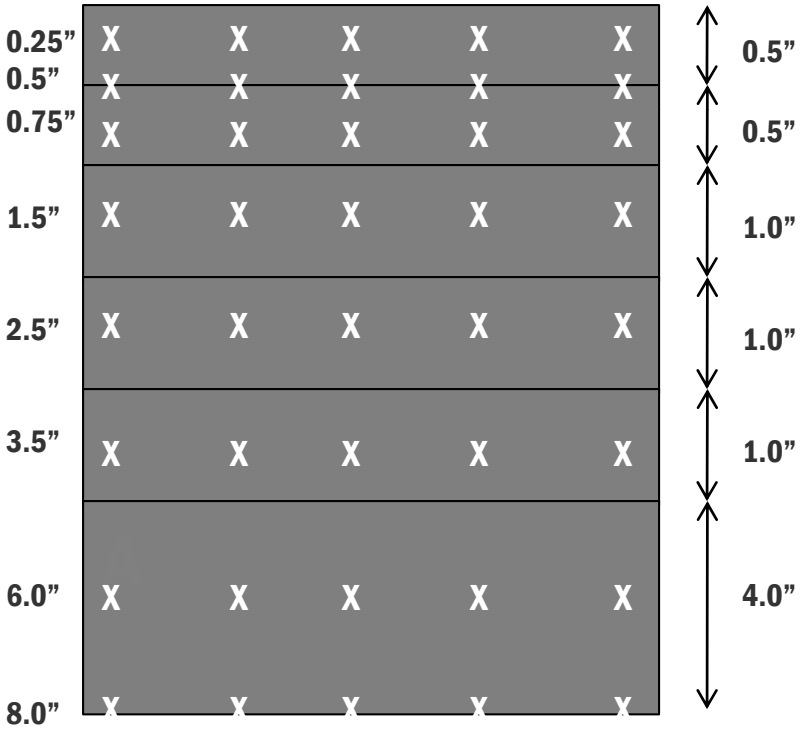


Pavement Responses Locations

4 inch HMA layer



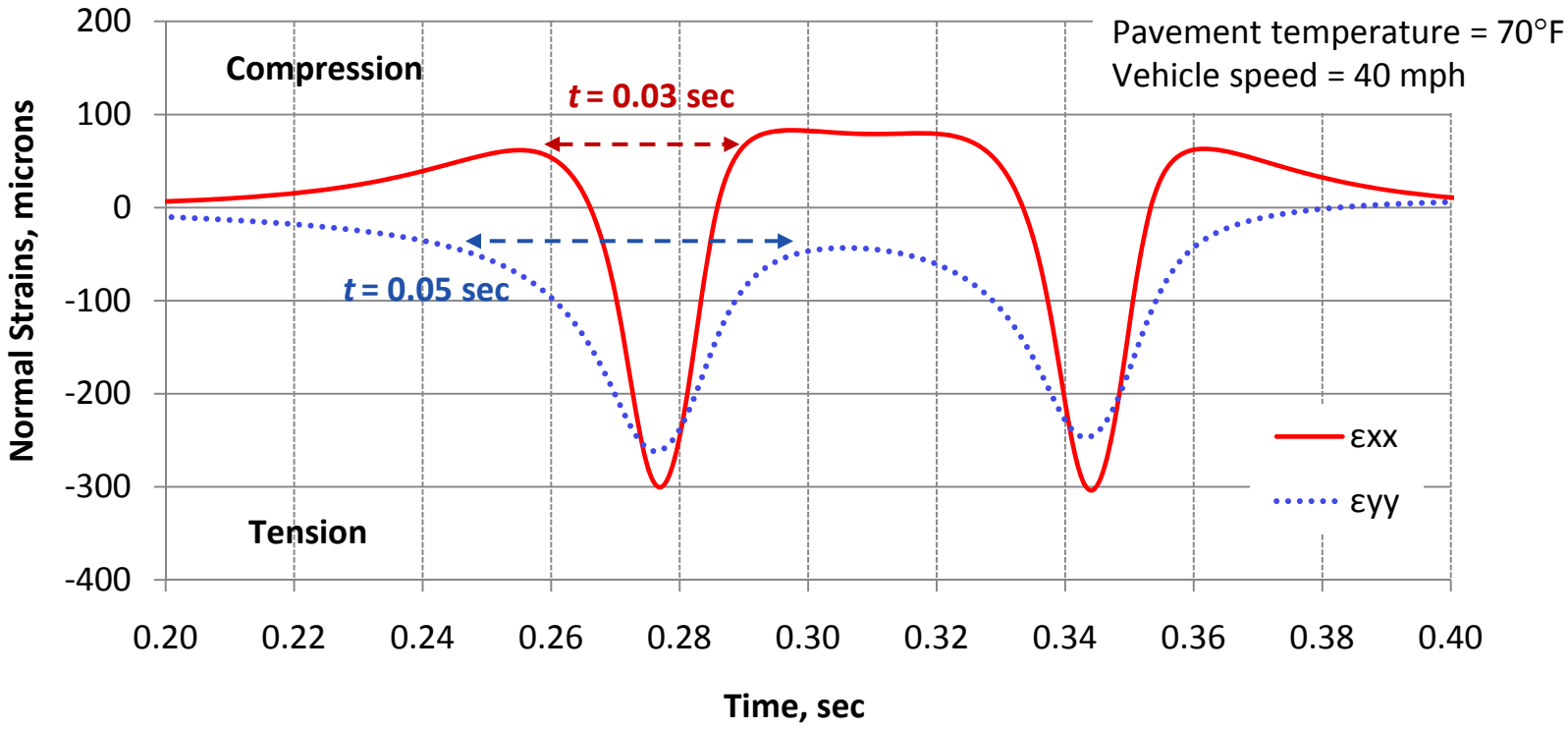
8 inch HMA layer



Data analysis completed for responses at center line of the load

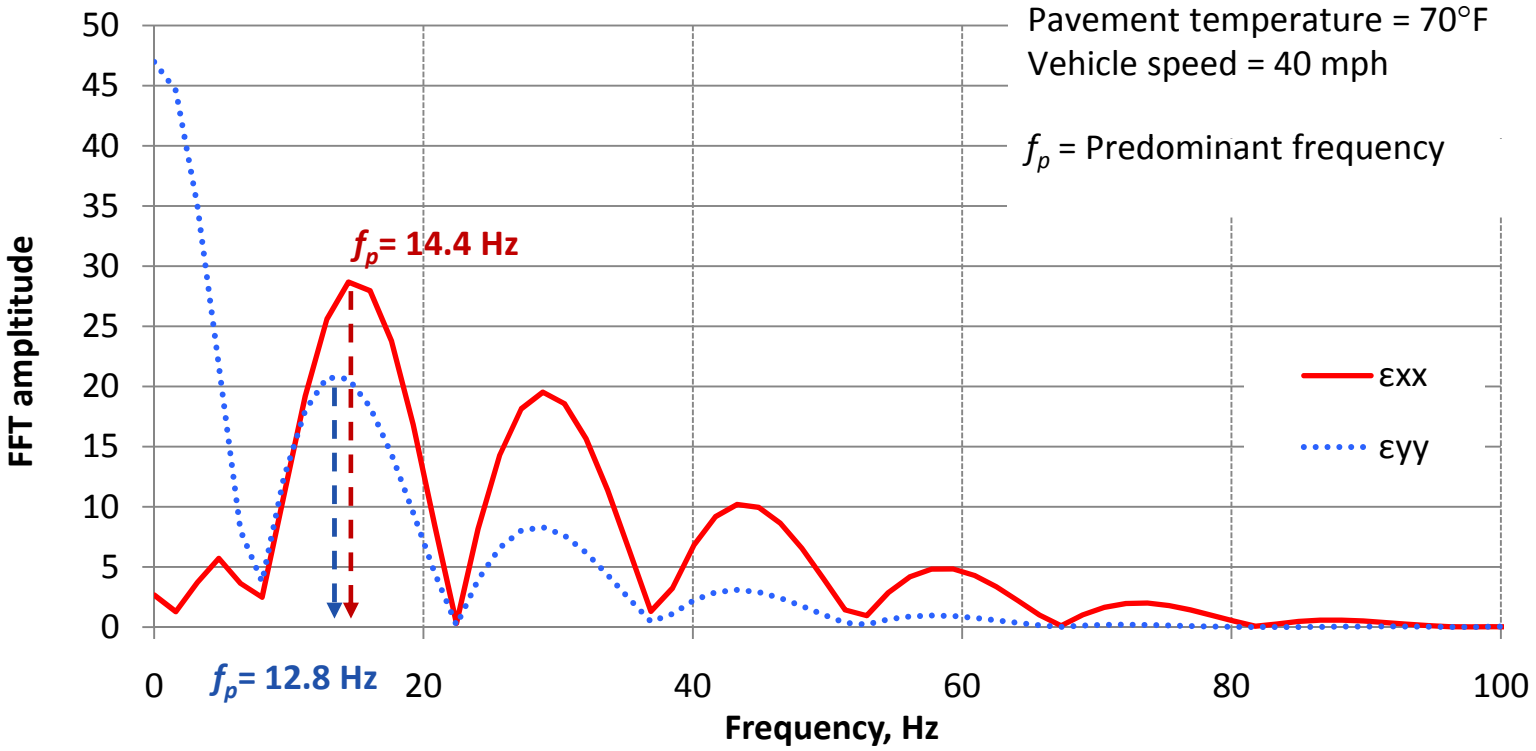
Proposed approach to determine f_p

- **Example: Bottom of the 4-inch HMA layer:**



Proposed approach to determine f_p

- FFT amplitudes of the normal strains of the 4-inch HMA



f_p for the 4-inch HMA layer

Case Study	Depth (in)	Predominant frequency, (Hz)							
		ε_{xx}		ε_{yy}		ε_{zz}		σ_{zz}	
		f_p	f_{pseudo}	f_p	f_{pseudo}	f_p	f_{pseudo}	f_p	f_{pseudo}
Case 1: 70°F and 40 mph	0.25	14.4	14.4	12.8	14.4	14.4	14.4	14.4	14.4
	0.5	14.4		12.8		14.4		14.4	
	0.75	14.4		12.8		14.4		14.4	
	1.5	14.4		12.8		14.4		14.4	
	2.5	14.4		12.8		14.4		14.4	
	3.5	14.4		12.8		14.4		14.4	
	4	14.4		12.8		14.4		14.4	
Case 2: 104°F and 40 mph	0.25	14.4	14.4	14.4	14.4	14.4	30.4	14.4	14.4
	0.5	14.4		12.8		30.4		14.4	
	0.75	14.4		14.4		30.4		14.4	
	1.5	12.8		14.4		30.4		14.4	
	2.5	30.4	30.4	14.4		14.4	14.4	14.4	
	3.5	30.4		14.4		14.4		14.4	
	4	28.8		14.4		14.4		14.4	
Case 3: 70°F and 60 mph	0.25	21.6	21.6	19.4	21.6	21.6	21.6	21.6	21.6
	0.5	21.6		19.4		21.6		21.6	
	0.75	21.6		19.4		19.4		21.6	
	1.5	21.6		16.8		21.6		21.6	
	2.5	21.6		21.6		21.6		21.6	
	3.5	21.6		19.4		21.6		21.6	
	4	21.6		19.4		21.6		21.6	
Case 4: 104°F and 60 mph	0.25	21.6	21.6	21.6	21.6	43.3	43.3	21.6	21.6
	0.5	21.6		19.2		43.3		21.6	
	0.75	21.6		19.2		43.3		21.6	
	1.5	21.6		21.6		43.3		21.6	
	2.5	43.3	43.3	21.6		21.6	21.6	21.6	
	3.5	43.3		21.6		21.6		21.6	
	4	43.3		21.6		21.6		21.6	
Case 5: 70°F and 10 mph	0.25	3.6	7.6	3.2	3.6	3.6	7.6	3.6	3.6
	0.5	3.6		3.2		3.6		3.6	
	0.75	3.6		3.2		3.6		3.6	
	1.5	3.2		3.2		7.6		3.6	
	2.5	7.6		3.6		7.6		3.6	
	3.5	4		3.6		3.6	3.6	3.6	
	4	4		3.6		3.6		3.6	
Case 6: 104°F and 10 mph	0.25	7.6	7.6	3.2	3.6	7.6	7.6	3.6	3.6
	0.5	7.6		3.2		7.6		3.6	
	0.75	7.6		3.2		7.6		3.6	
	1.5	11.2	11.2	3.6		3.6	3.6	3.6	
	2.5	11.2		3.6		3.6		3.6	
	3.5	11.2		3.6		3.6		3.6	
	4	11.2		3.6		3.6		3.6	

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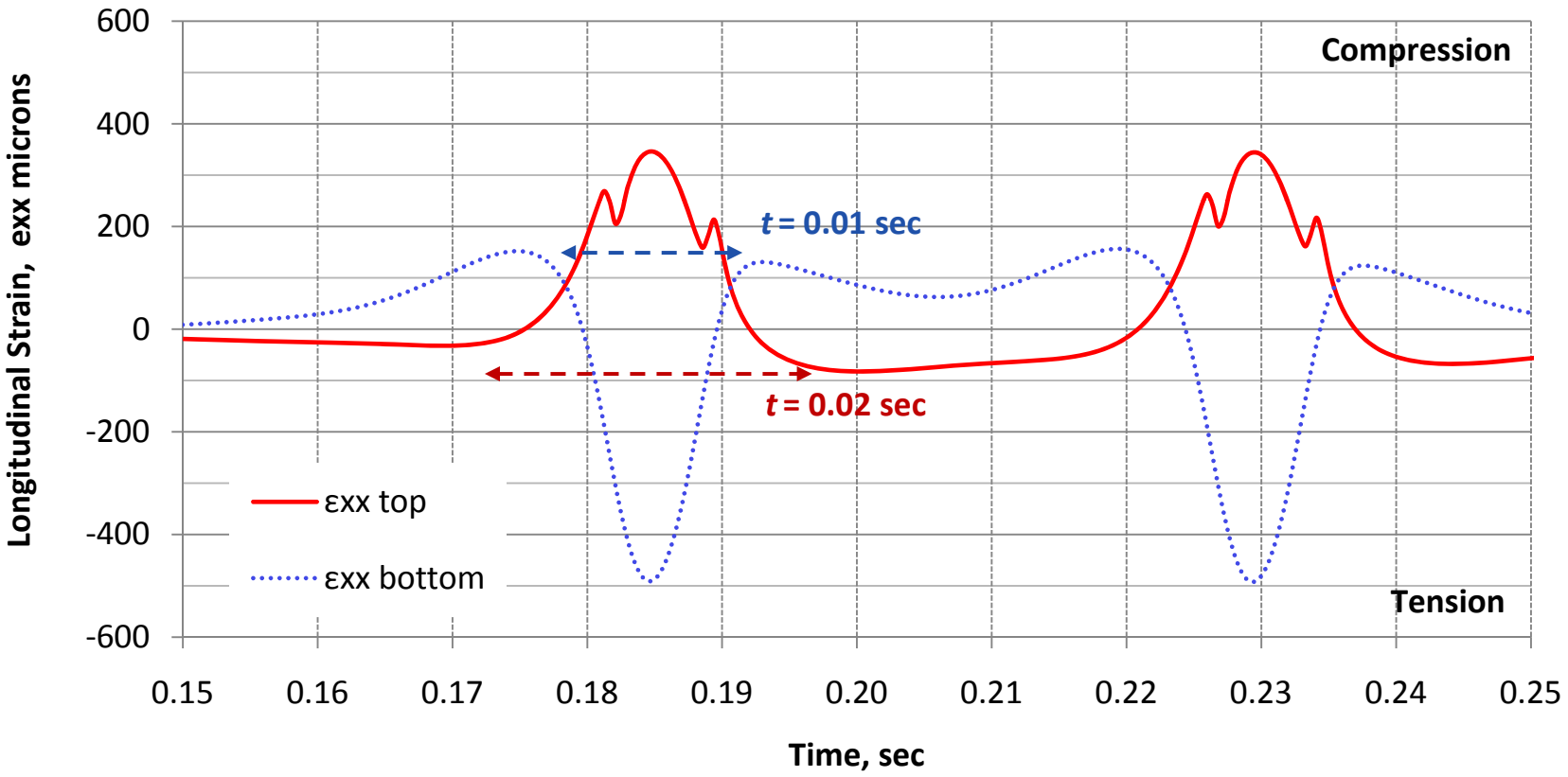
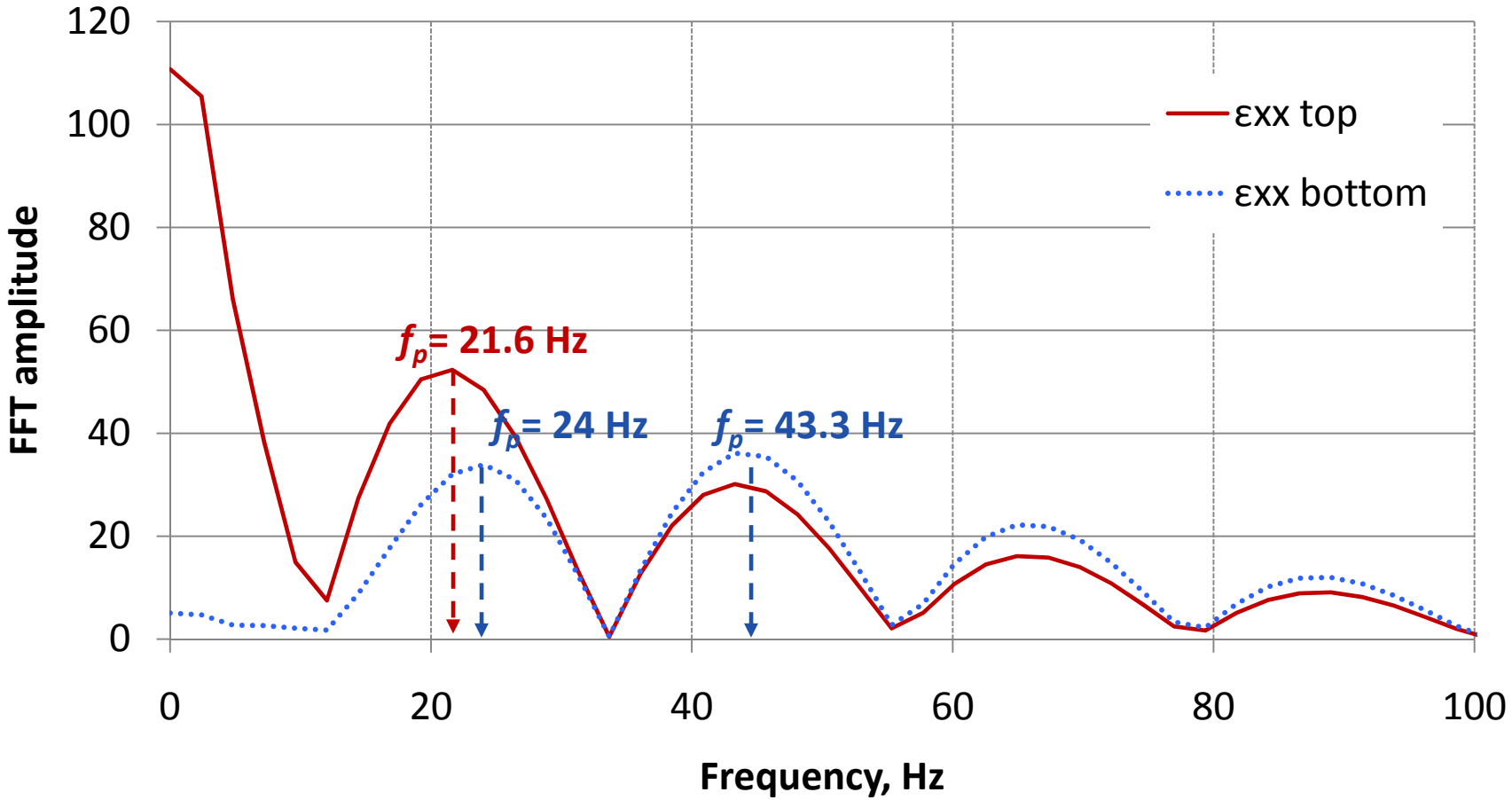
Case 4 Predominant Frequencies

Temp = 104°F, V = 60 mph, Tensile Strain ε_{xx}

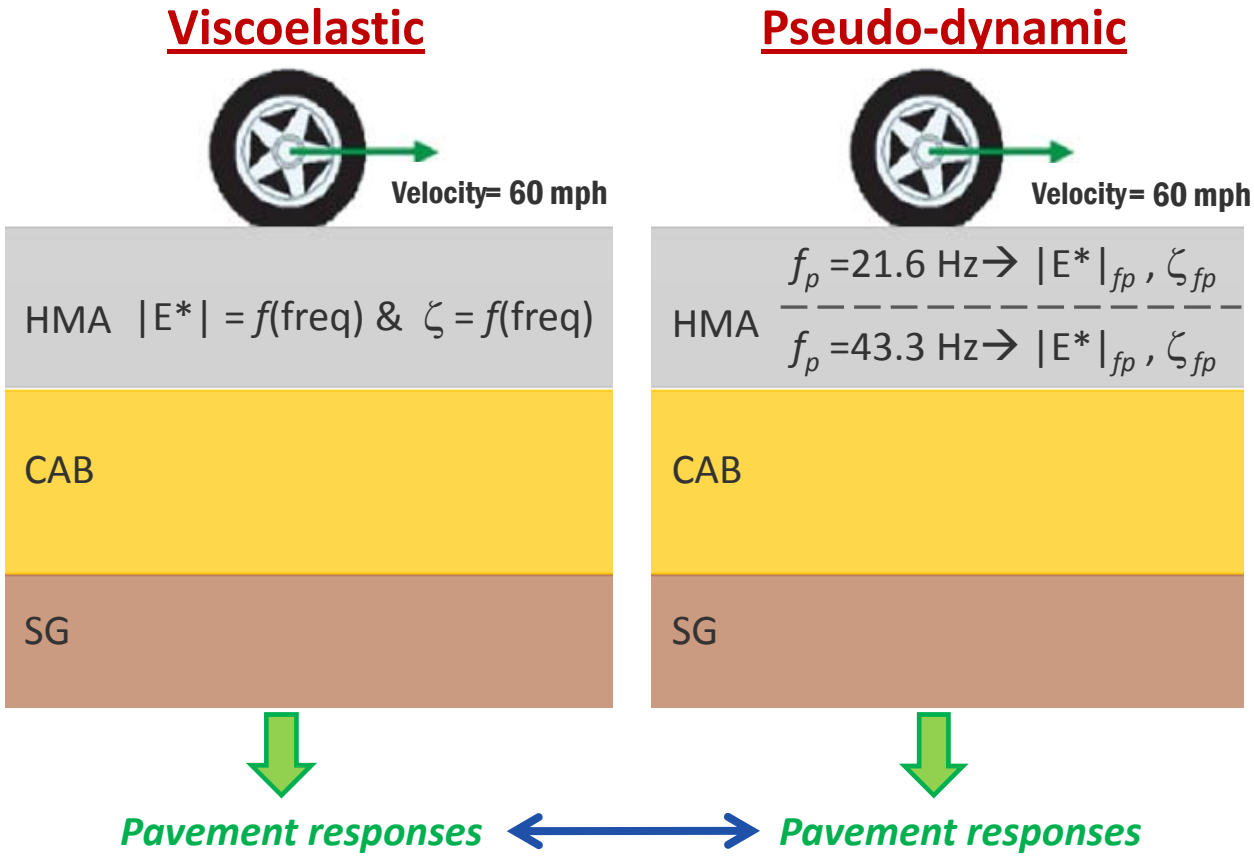


Case 4 Predominant Frequencies

Temp = 104°F, V = 60 mph, Tensile Strain ε_{xx}

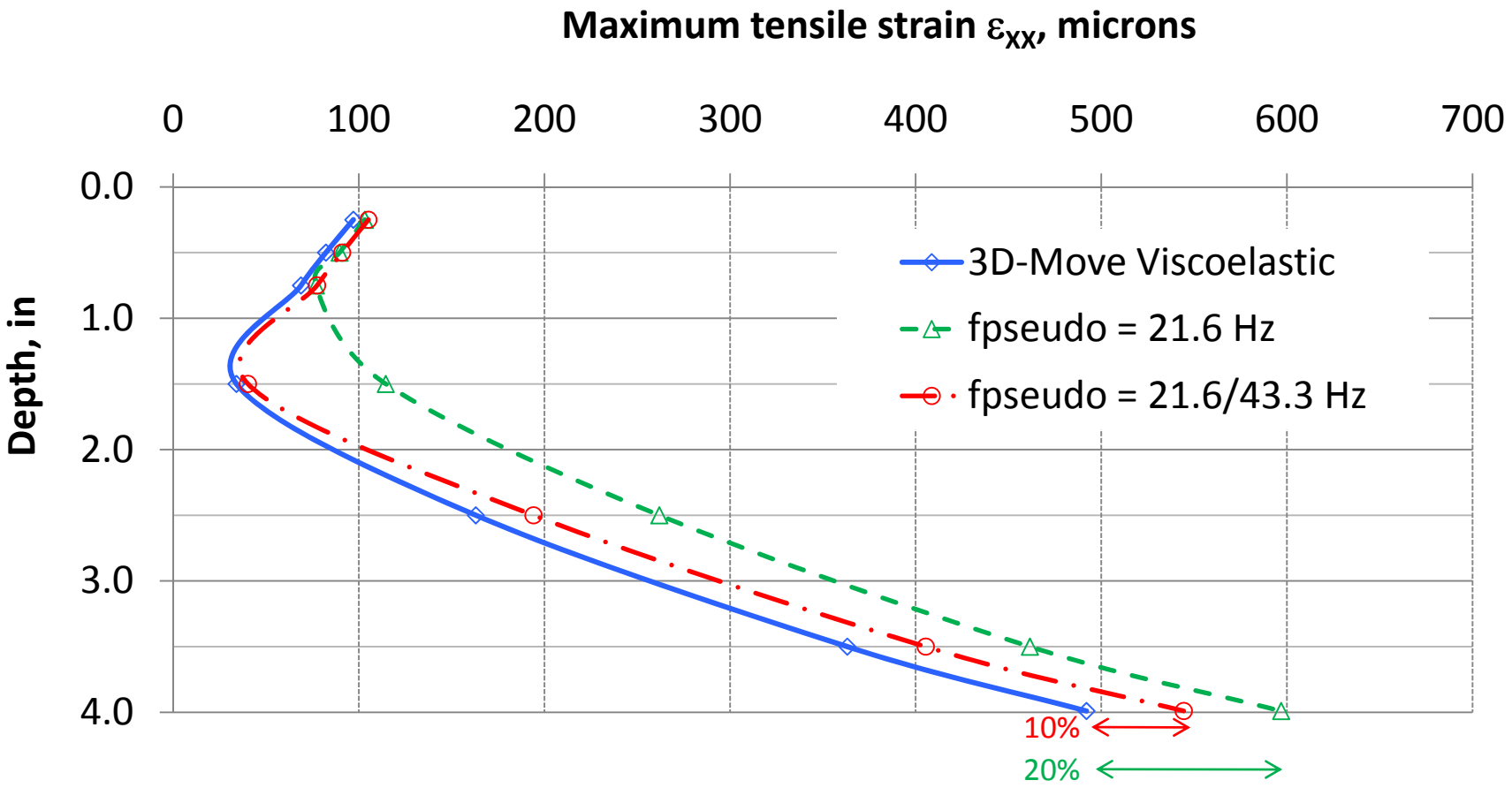


Pseudo-Dynamic Analysis



Case 4 Pseudo-Dynamic Analysis

Temp = 104°F, V = 60 mph, Tensile Strain ε_{xx}



f_p for the 8-inch HMA layer

Case Study	Depth* (in)	Predominant frequency, (Hz)							
		ε_{xx}		ε_{yy}		ε_{zz}		σ_{zz}	
		f_p	f_{pseudo}	f_p	f_{pseudo}	f_p	f_{pseudo}	f_p	f_{pseudo}
Case 7: 70ºF and 40 mph	0.25	12.8	12.8	16	12.8	30.4	30.4	14.4	14.4
	0.5	12.8		11.2		30.4		14.4	
	0.75	12.8		9.6		30.4		14.4	
	1.5	12.8		14.4		30.4		14.4	
	2.5	12.8		14.4		30.4		14.4	
	3.5	30.4	30.4	14.4		14.4	12.8	14.4	
	6	30.4		12.8		12.8		14.4	
	8	14.4		12.8		12.8		14.4	
Case 8: 104ºF and 40 mph	0.25	14.4	14.4	12.8	14.4	30.4	30.4	14.4	14.4
	0.5	14.4		12.8		30.4		14.4	
	0.75	14.4		11.2		30.4		14.4	
	1.5	12.8		12.8		30.4		14.4	
	2.5	30.4	30.4	12.8		14.4	14.4	14.4	
	3.5	30.4		12.8		14.4		14.4	
	6	30.4		12.8		14.4		14.4	
	8	30.4		12.8		14.4		14.4	
Case 9: 70ºF and 60 mph	0.25	19.2	19.2	19.2	19.2	19.2	45.7	21.6	21.6
	0.5	19.2		16.8		40.8		21.6	
	0.75	19.2		16.8		45.7		21.6	
	1.5	19.2		19.2		45.7		21.6	
	2.5	19.2		19.2		43.2		21.6	
	3.5	45.7	45.7	21.6		21.6	19.2	21.6	
	6	45.7		19.2		19.2		21.6	
	8	45.7		19.2		19.2		21.6	
Case 10: 104ºF and 60 mph	0.25	21.6	21.6	19.2	21.6	45.7	45.7	21.6	21.6
	0.5	21.6		19.2		45.7		21.6	
	0.75	19.2		16.8		45.7		21.6	
	1.5	45.7	45.7	21.6		21.6	21.6	21.6	
	2.5	45.7		21.6		21.6		21.6	
	3.5	43.3		21.6		21.6		21.6	
	6	43.3		21.6		21.6		21.6	
	8	43.3		19.2		21.6		21.6	
Case 11: 70ºF and 10 mph	0.25	3.6	3.6	3.2	3.6	7.6	7.6	3.6	3.6
	0.5	3.6		3.2		7.6		3.6	
	0.75	3.6		3.2		7.6		3.6	
	1.5	3.6		3.6		7.6		3.6	
	2.5	3.6		3.6		7.6		3.6	
	3.5	7.6	7.6	3.6		7.6	3.6	3.6	
	6	3.6		3.2		3.6		3.6	
	8	3.6		3.2		3.6		3.2	
Case 12: 104ºF and 10 mph	0.25	3.6	11.2	3.2	3.6	7.6	7.6	3.6	3.6
	0.5	3.6		3.2		7.6		3.6	
	0.75	3.2		3.6		7.6		3.6	
	1.5	11.2		3.6		3.6	3.6	3.6	
	2.5	11.2		3.6		3.6		3.6	
	3.5	11.2		3.6		3.6		3.6	
	6	4		3.2		3.6		3.6	
	8	3.6		3.2		3.6		3.2	

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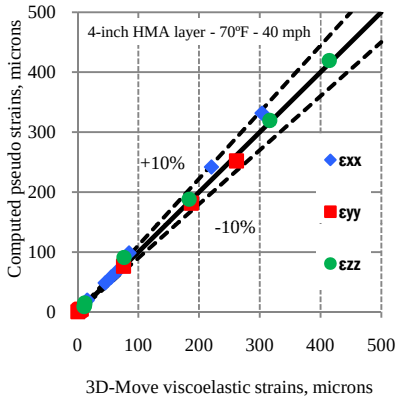
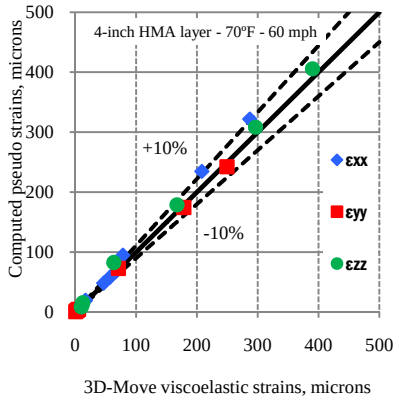
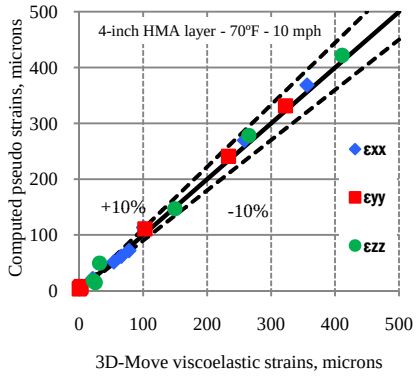
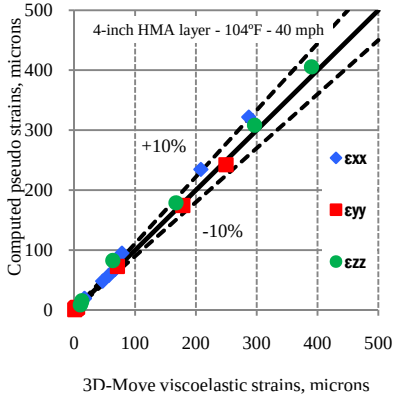
Viscoelastic vs. Pseudo-Dynamic analysis

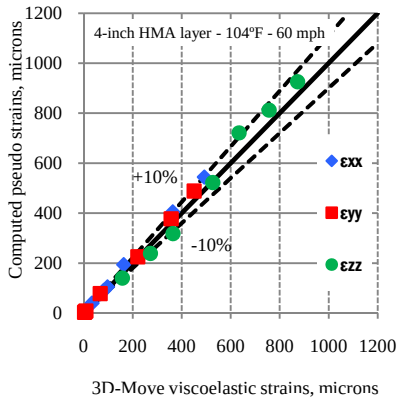
4-inch HMA layer

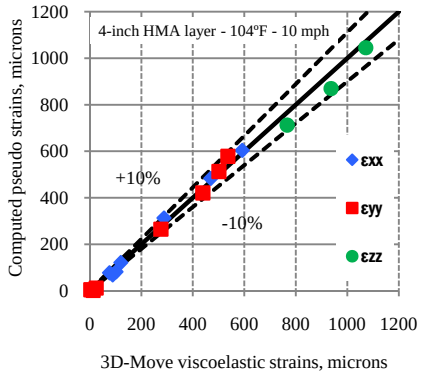






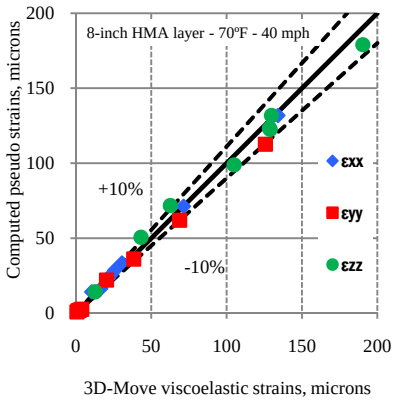


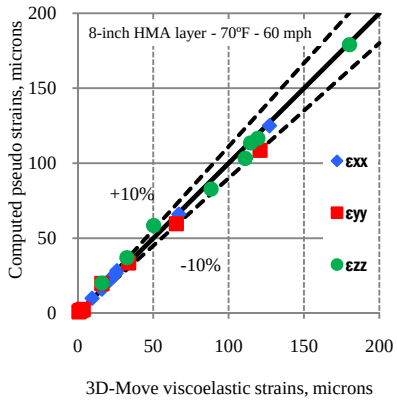


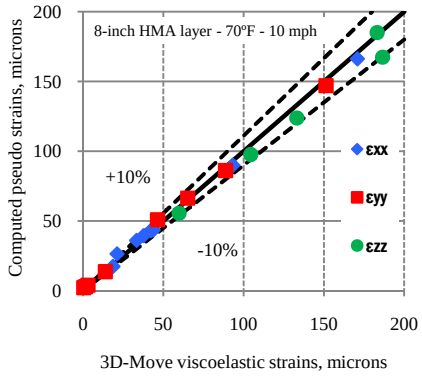


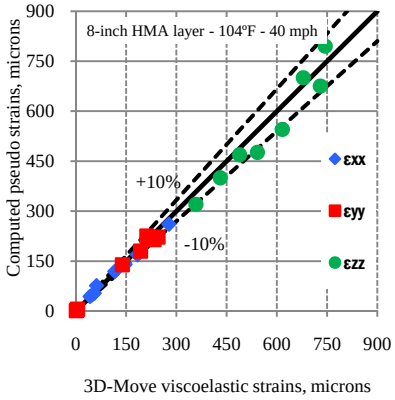
Viscoelastic vs. Pseudo-Dynamic analysis

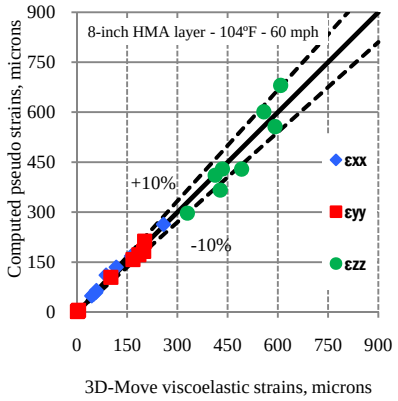
8-inch HMA layer

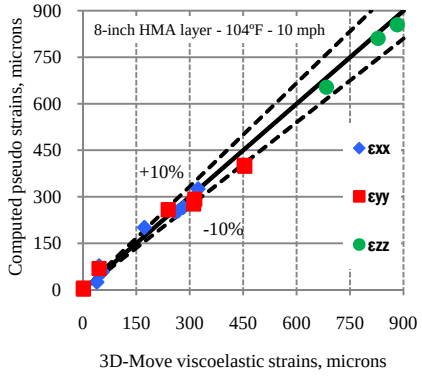












Pseudo-Static Analysis

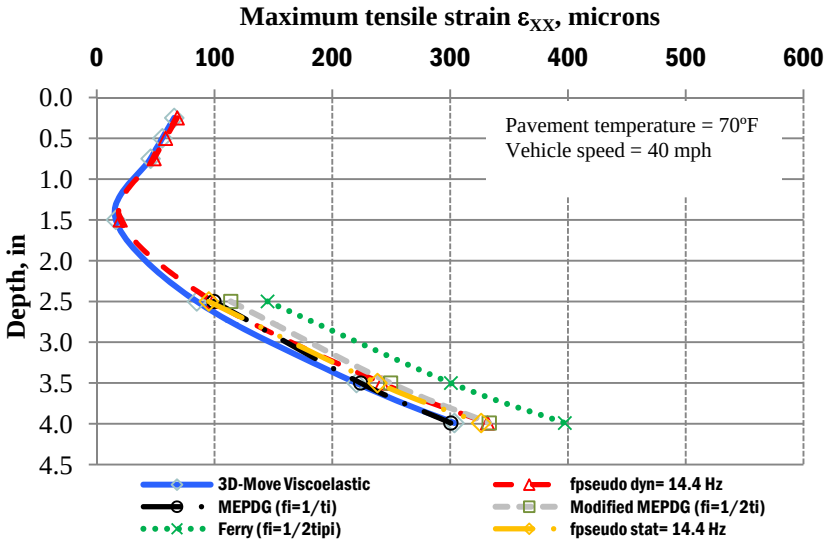
- **Pseudo-Static:**
  - Vehicle speed = 0
  - Linear Elastic Analysis (LEA)
  - Use f_p to select $|E^*|_{fp}$
  - Damping $\zeta_{fp} = 0$
- **Also Compare pavement responses following**
  - MEPDG approach ($f = 1/t$)
  - Modified MEPDG ($f = 1/(2t)$)
  - Ferry ($f = 1/(2\pi t)$)

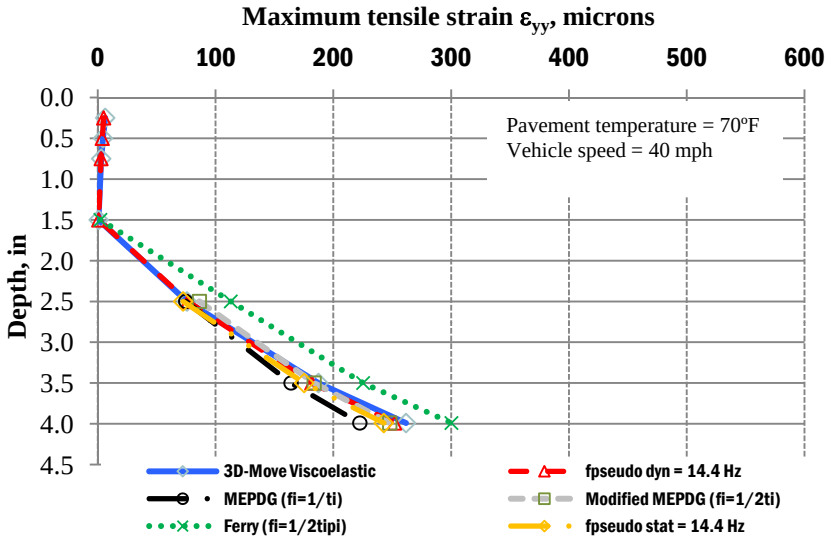
MEPDG Loading Time Calculation

4-inch HMA layer – 70°F and 10 mph

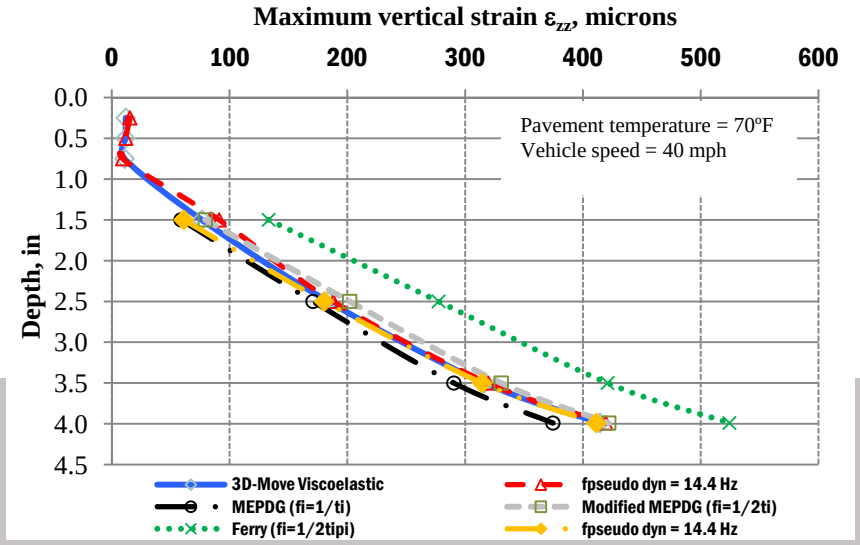
Sublayer	Thickness (in)	Cummulated Thickness (in)	Z_{eff} (in)	Condition	L_{eff} (in)	t (sec)	$f = 1/t$ (Hz)	E* (psi)
1	0.5	0.5	1.59	No overlap	10.7	0.061	16.4	485,868
2	0.5	1	3.15	No overlap	13.8	0.078	12.8	451,966
3	1	2	6.11	Partial overlap	23.1	0.131	7.6	387,689
4	1	3	8.97	Partial overlap	31.3	0.178	5.6	352,161
5	1	4	11.77	Partial overlap	38.9	0.221	4.5	328,345

Pavement responses comparison

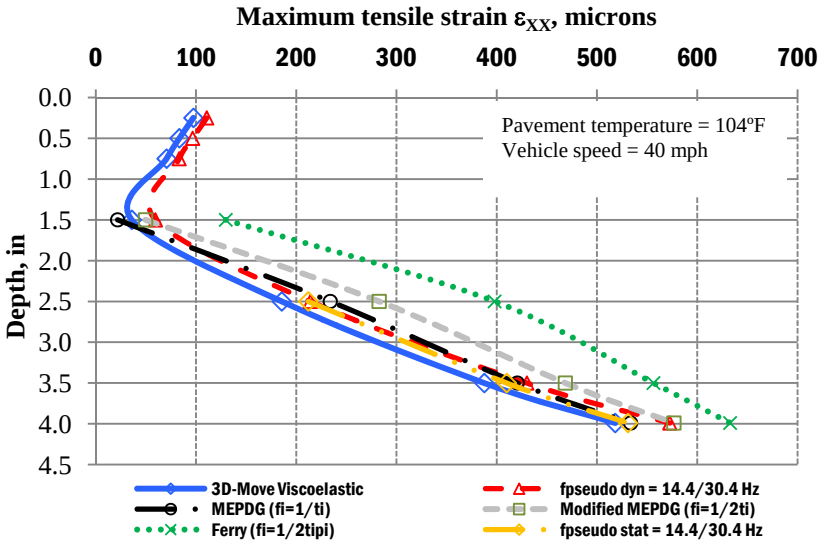


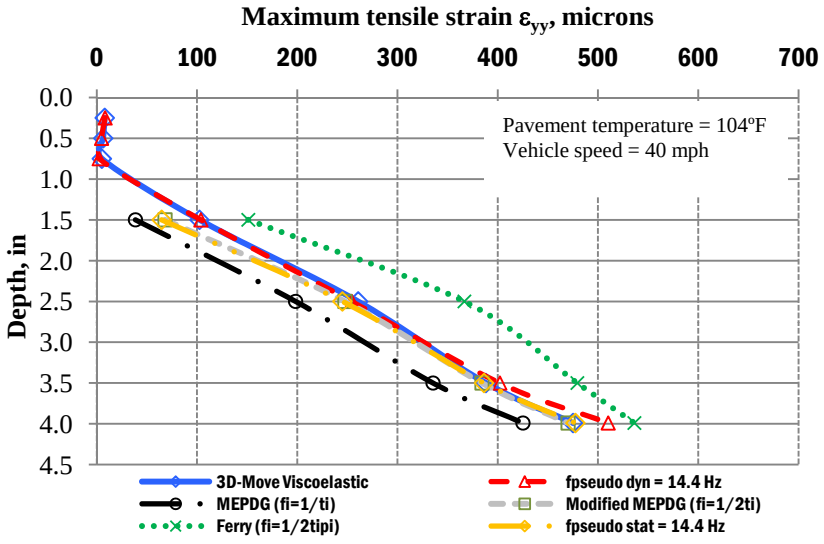


Pavement temperature = 70 °F
4-inch HMA layer
40 mph

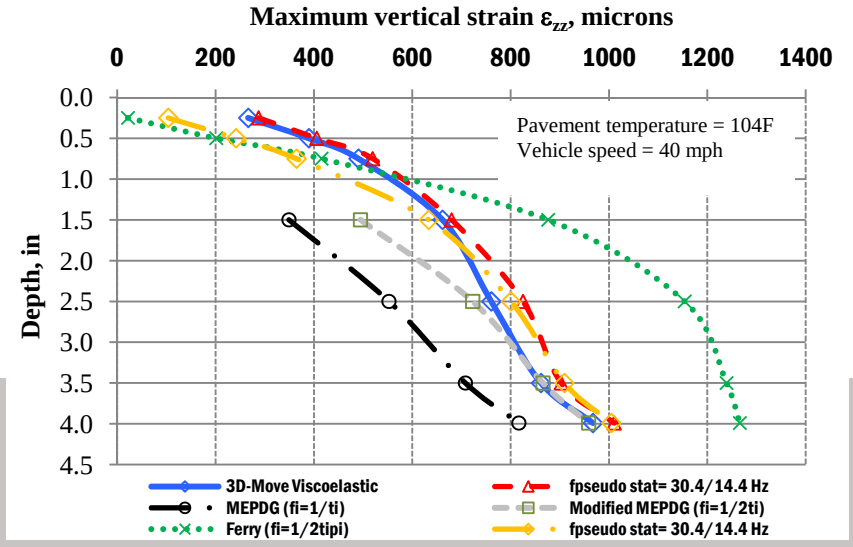


Pavement responses comparison

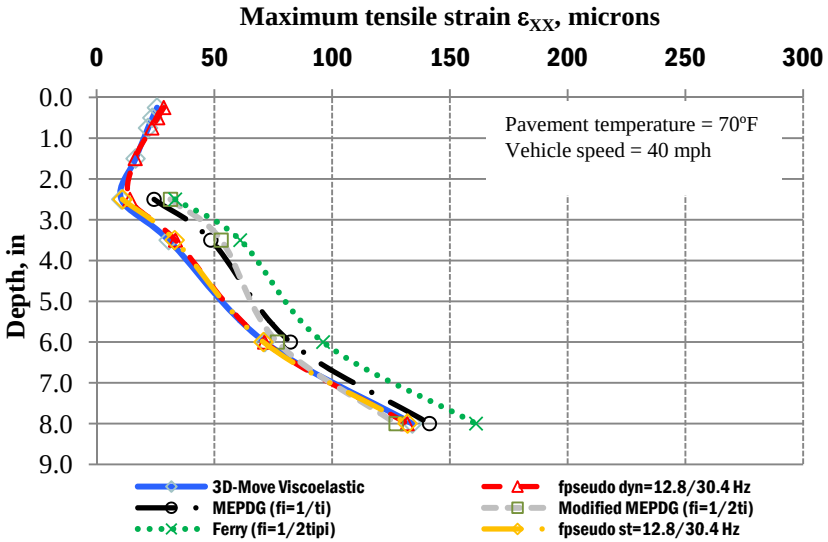


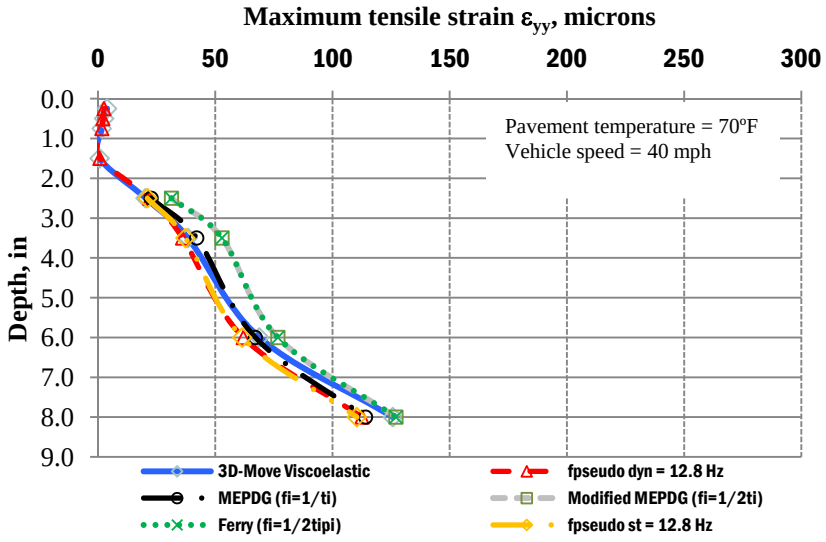


Pavement temperature = 104 °F
4-inch HMA layer
40 mph

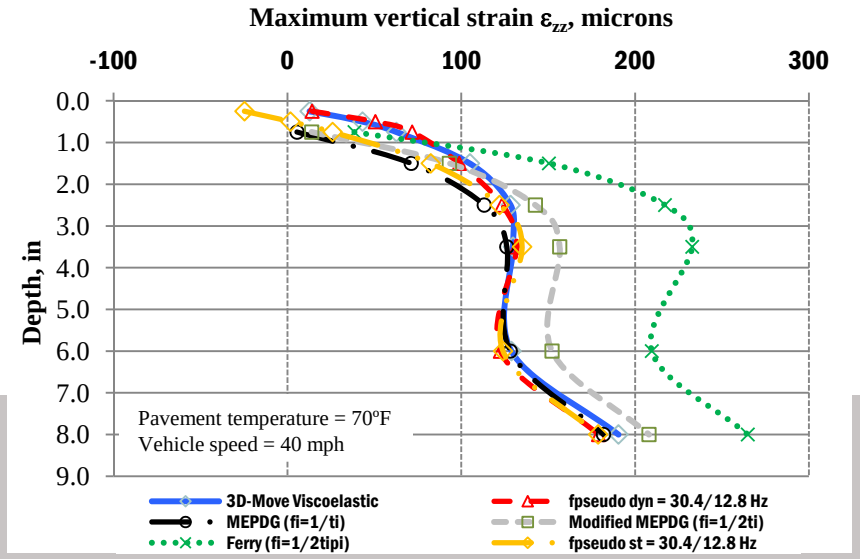


Pavement responses comparison

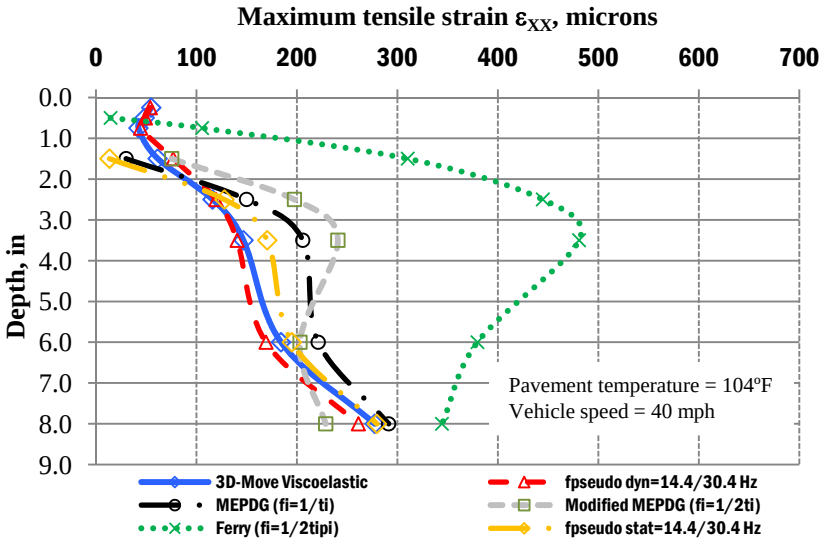


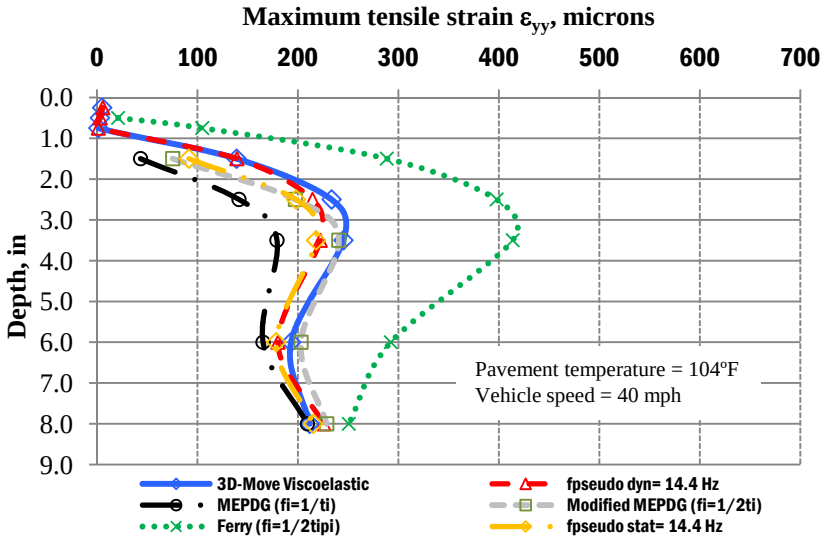


Pavement temperature = 70 °F
8-inch HMA layer
40 mph

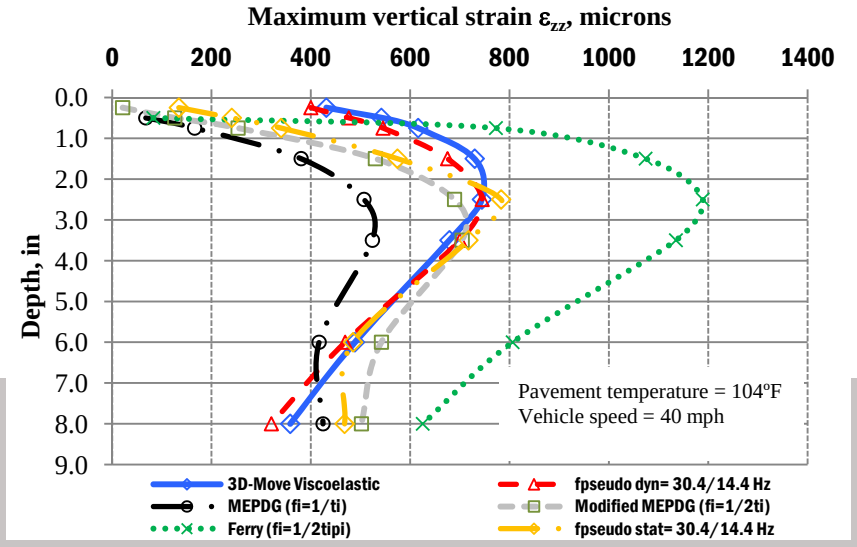


Pavement responses comparison

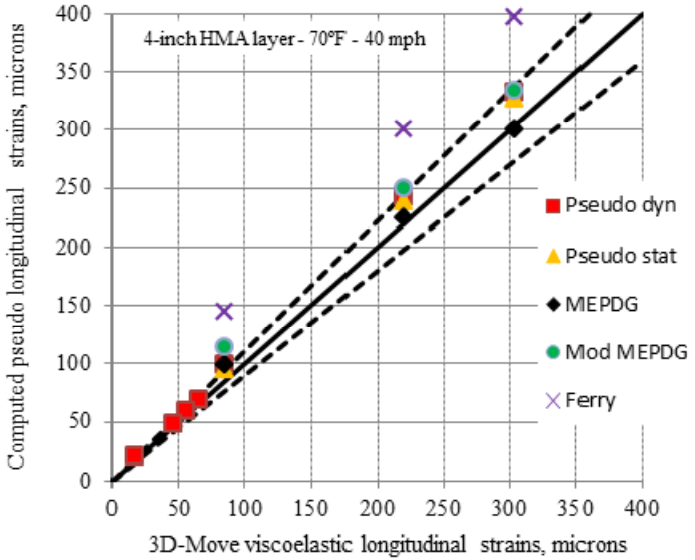


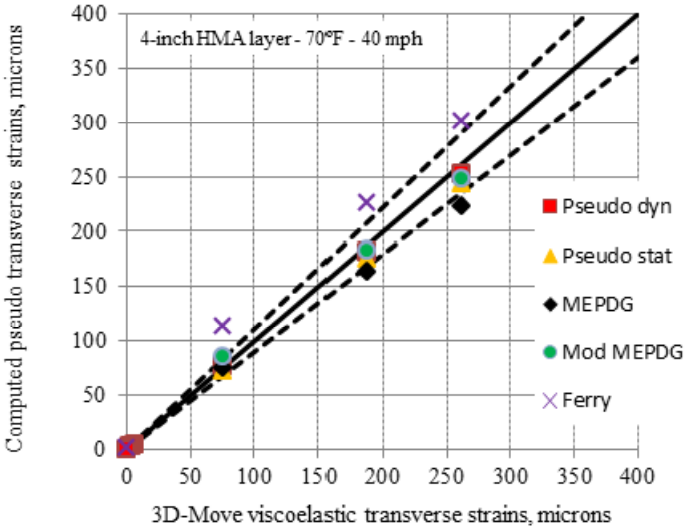


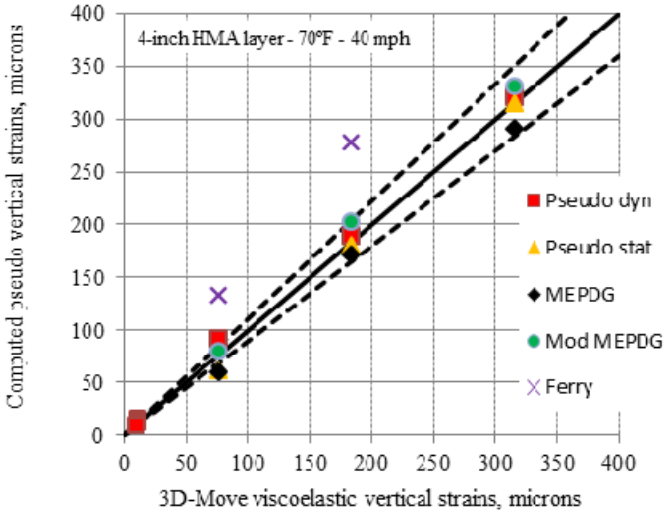
Pavement temperature = 104 °F
8-inch HMA layer
40 mph



Pavement responses comparison

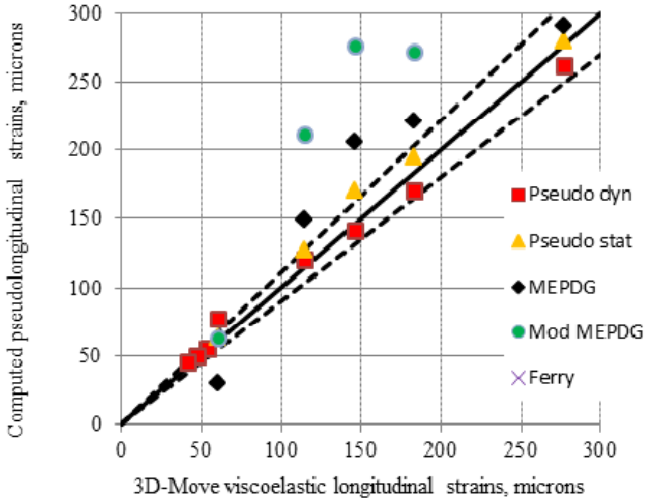


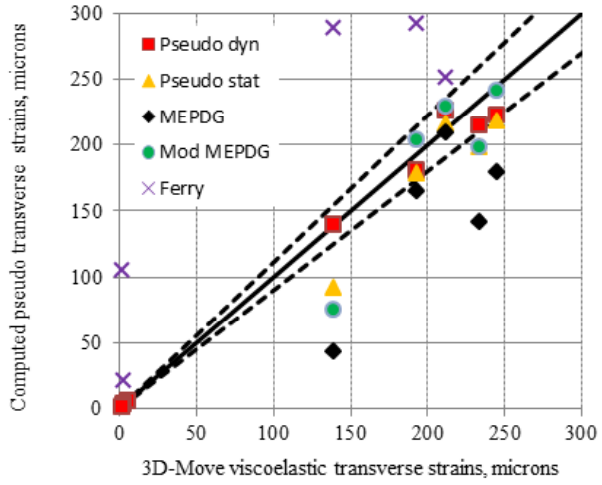


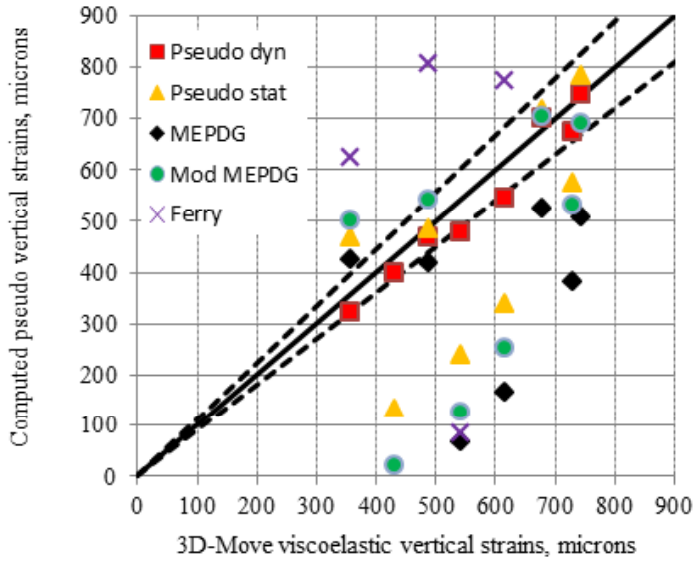


Pavement temperature = 70 °F
4-inch HMA layer

Pavement responses comparison

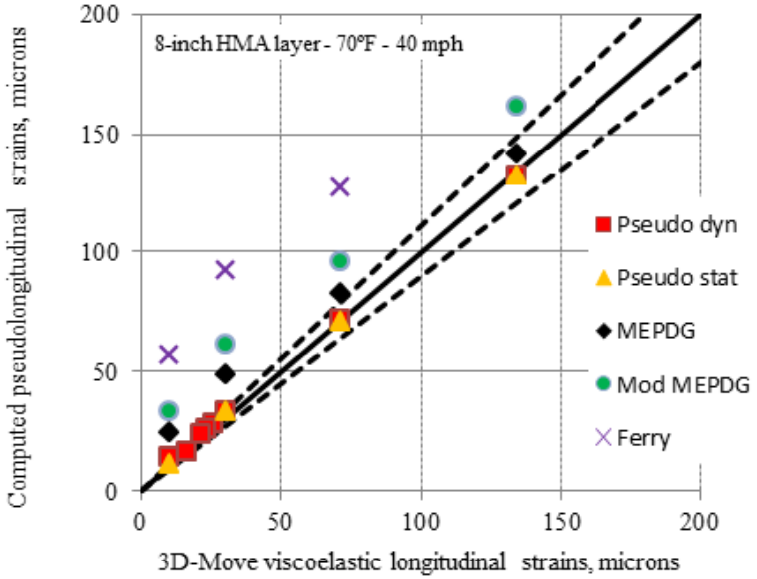


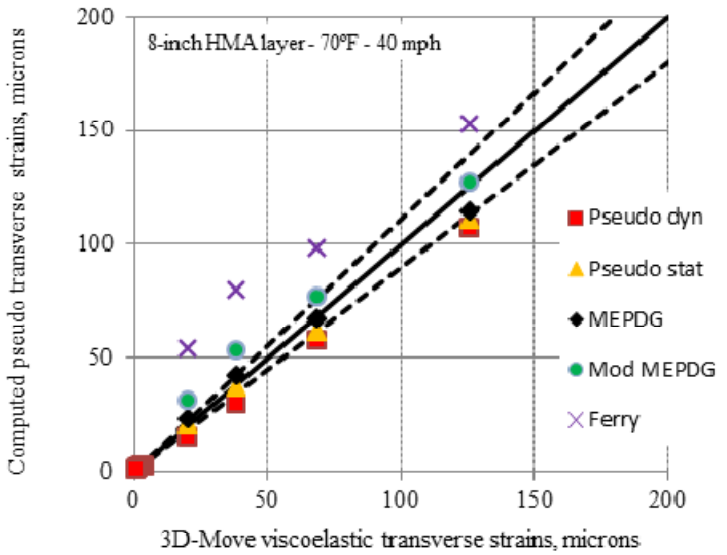


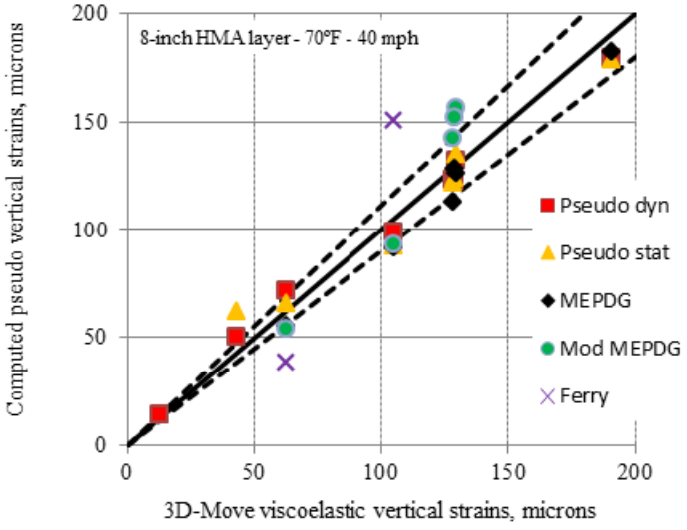


Pavement temperature = 104 °F
4-inch HMA layer

Pavement responses comparison

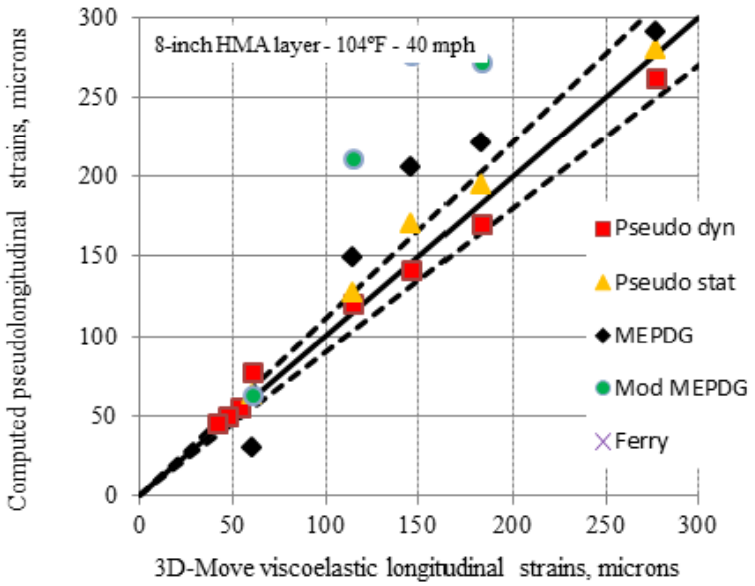


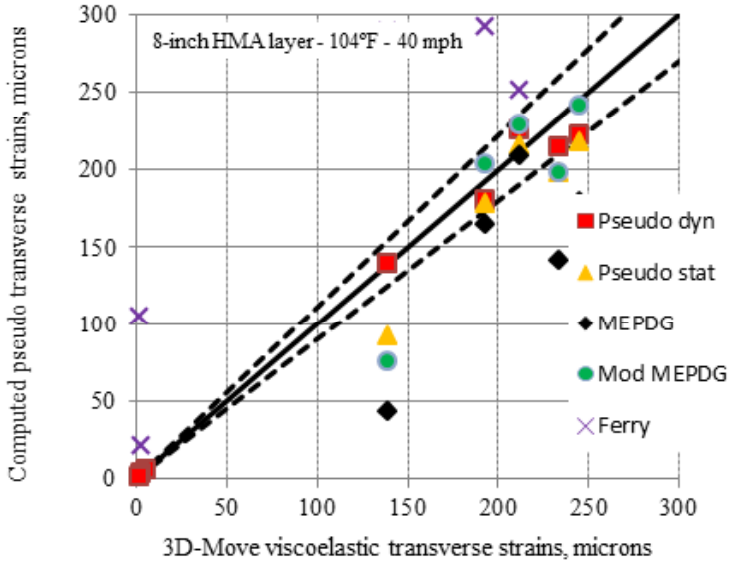




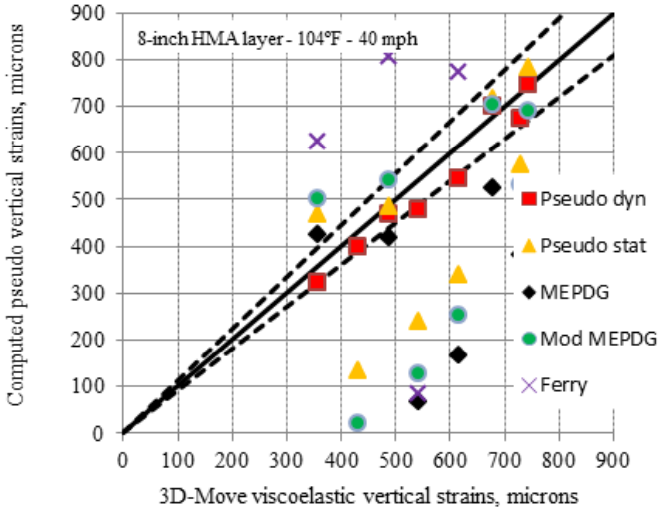
Pavement temperature = 70 °F
8-inch HMA layer

Pavement responses comparison





Pavement temperature = 104 °F
8-inch HMA layer



Overall Findings

- Use of one single set of f_p cannot be assigned to the AC layer to study all responses.
- Pavement responses can be successfully predicted (within ±10%) by *Pseudo-Dynamic* equivalent approach.
- MEPDG approach derives in comparable pavement responses only when asphalt layer is stiff and there are no multiple f_p within the asphalt layer.

Additional needed work…

- Do the analysis at locations other than the center line
- Investigate influence of axle load, response location and axle configuration on f_p.
- Investigate influence of CTB on f_p.
- Evaluate different time-frequency conversions.
- Other!

…Feedback…

Acknowledgment

- This work is part of the overall effort in the Asphalt Research Consortium (ARC) work element E2d. (www.arc.unr.edu)

- FHWA support gratefully acknowledged.

- Contents reflect the views of the authors and do not necessarily reflect the official views & policies of FHWA.