RUSS COLLEGE of Engineering and Technology

Results from Instrumentation of WAY30 Perpetual Pavement

September 12, 2007
Flexible Pavements of Ohio
Cleveland

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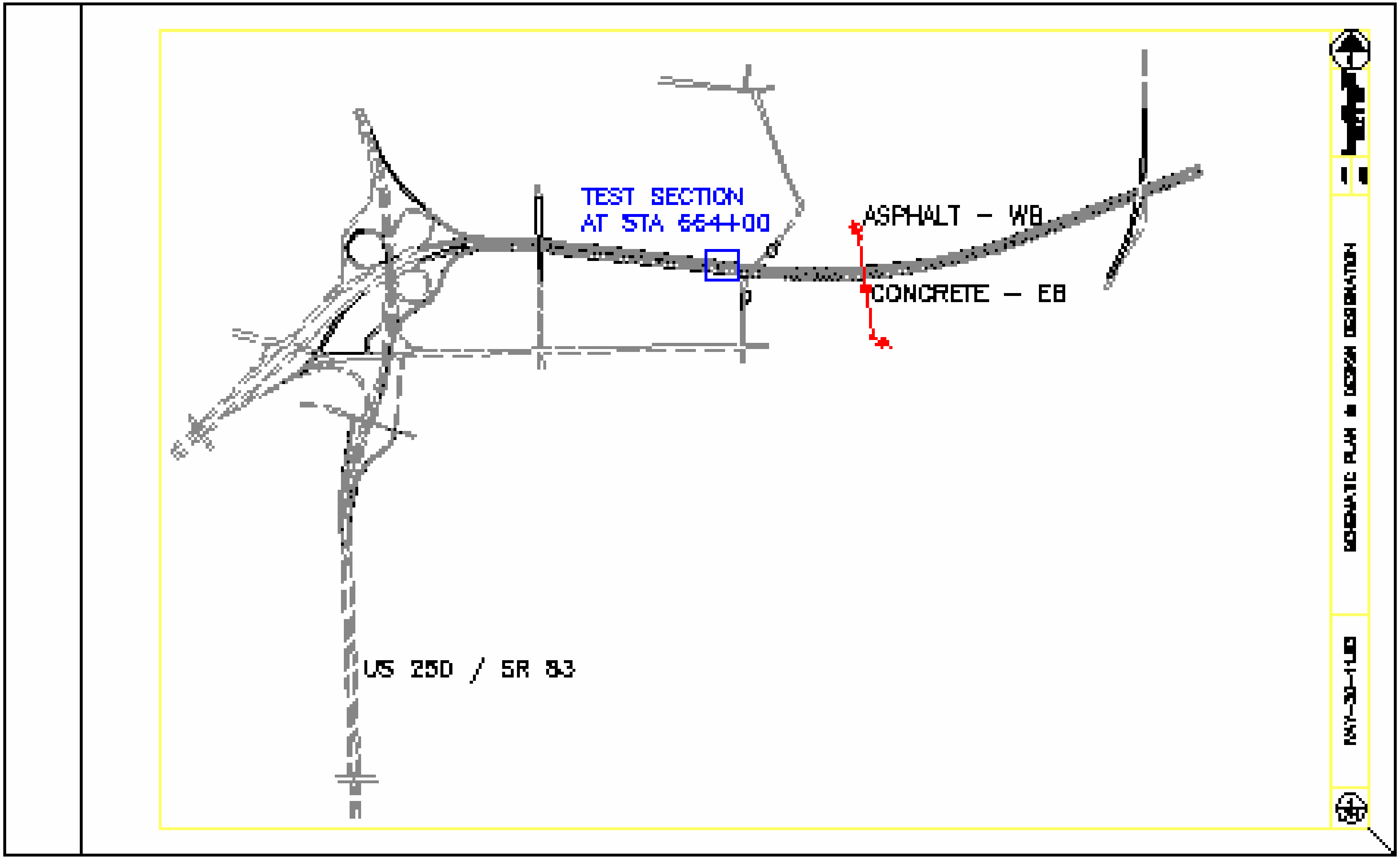
Ohio University

OHIO UNIVERSITY

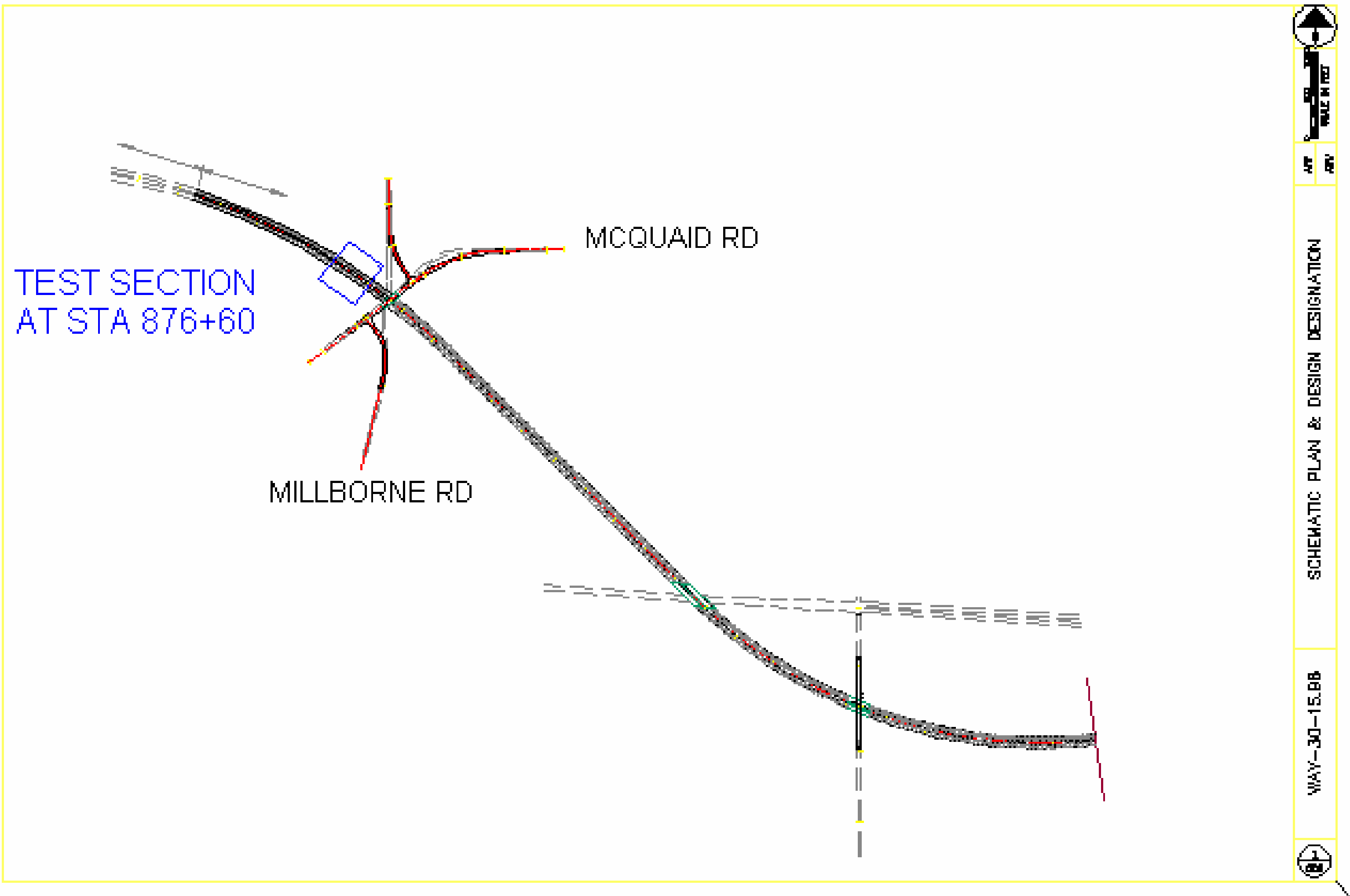
WAY-30 Instrumentation

US 30 Bypass of Wooster, Ohio



Test Section at Geyer's Chapel

WAY-30 Instrumentation



Test Section at McQuaid Road

Instrumentation Plan

- ORITE's instrumentation plan is to monitor environmental and response parameters in each pavement type.
- Instruments will be purchased and calibrated, then installed during the construction process
- Environmental parameters to be monitored in only one section of each pavement type.
- Dynamic load responses will be collected in duplicate sections of both pavements

Instrumentation

Asphalt Concrete Test Sections

Environmental Parameters

MEASUREMENT	LAYERS	MANUFACTURER	SENSOR
Temperature	Pavement, Base and Subgrade	Measurement Research Corp.	MRC Thermistor
Moisture	Base and Subgrade	Campbell Scientific, Inc.	TDR Probes

Automatic weather station installed to collect data related to air temperature, precipitation (rain and snow), wind speed and direction, relative humidity, and incoming solar radiation.

Instrumentation

Asphalt Concrete Test Sections

Response Parameters

MEASUREMENT	PARAMETERS	MANUFACTURER	SENSOR
Displacement	Load Response and Seasonal Response	Macro Sensors	Macro Sensors LVDTs (Linear Variable Displacement Transducer)
Pressure	Load Response and Seasonal Response	Geokon Inc.	Geokon 3500 Pressure Cell
Strain	Longitudinal and Transverse Strain	Dynatest	Dynatest PAST II Strain Transducer

AC Section A

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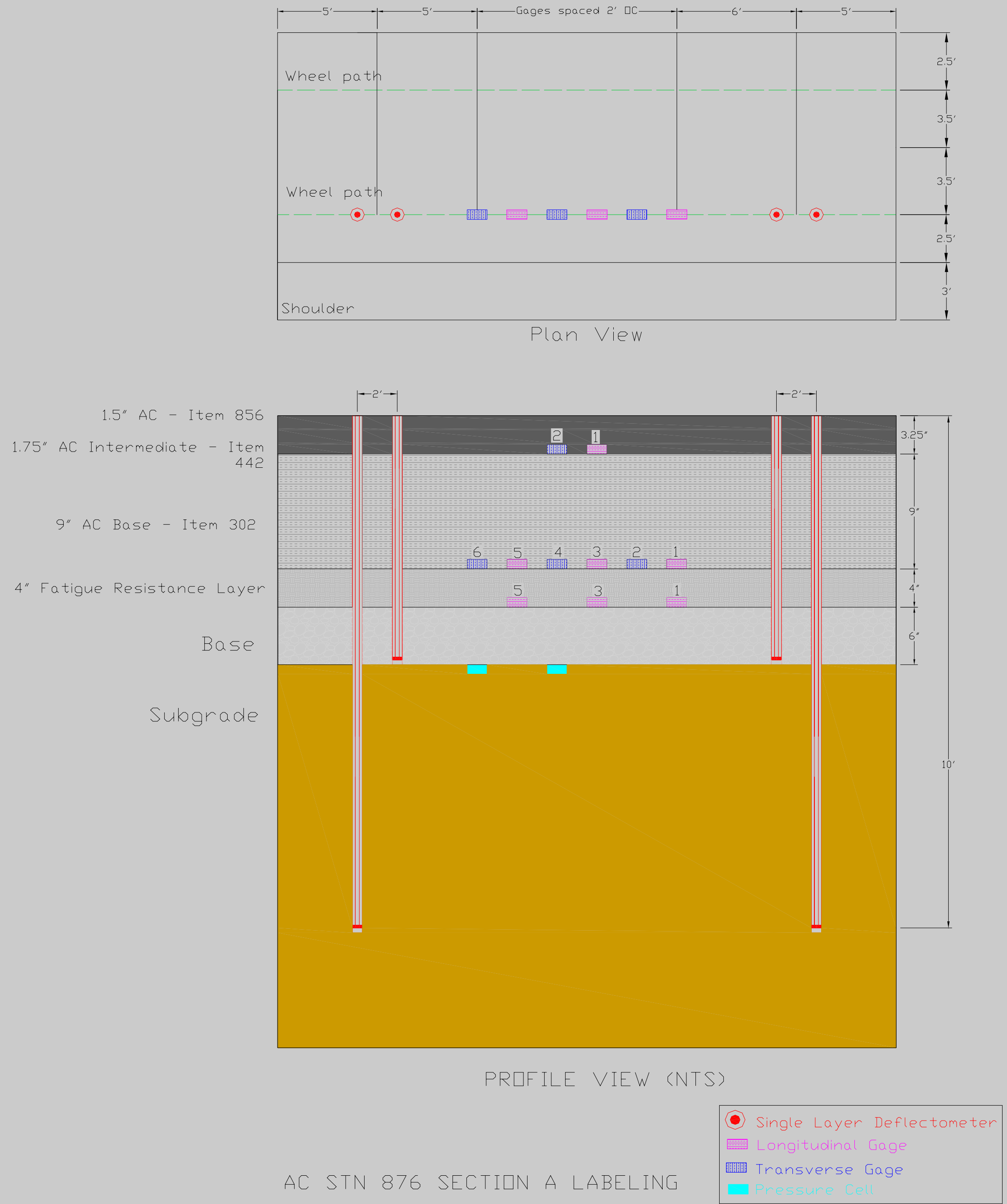


AC STN 876 SECTION A LABELING

Instrumentation

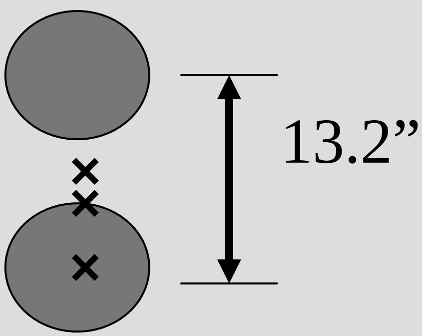
- Shallow LVDTs will monitor displacement above the subgrade
- Deep LVDTs will monitor the total displacement in the pavement system
- This combination of LVDTs help distinguish the movement between the subgrade and base.
- Two pressure cells will measure the vertical pressure applied to the base as a measure of support in each section.
- Strain gauges are placed in the wheel path of varying layers to measure transverse and longitudinal strain during controlled vehicle testing.

Controlled Vehicle Load (CVL) Testing

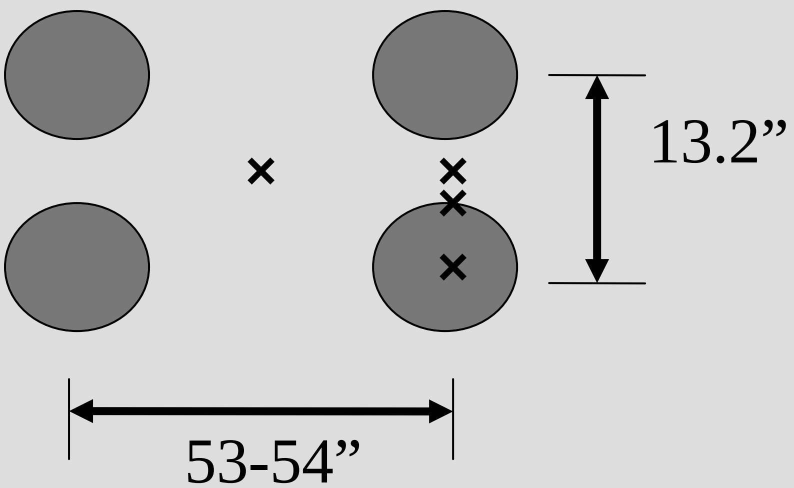
- December 2005
- July 2006
- Single axle and tandem axle loads
- Speeds 5 mph, 25 mph (July) or 30 mph (Dec), 45 mph, and 55 mph (July) or 60 mph (Dec)

CVL Load Configurations

- **Single Axle**
  - 28.2 kip (December) and 20.35 kip (July)
  - Tire Pressure =100 psi

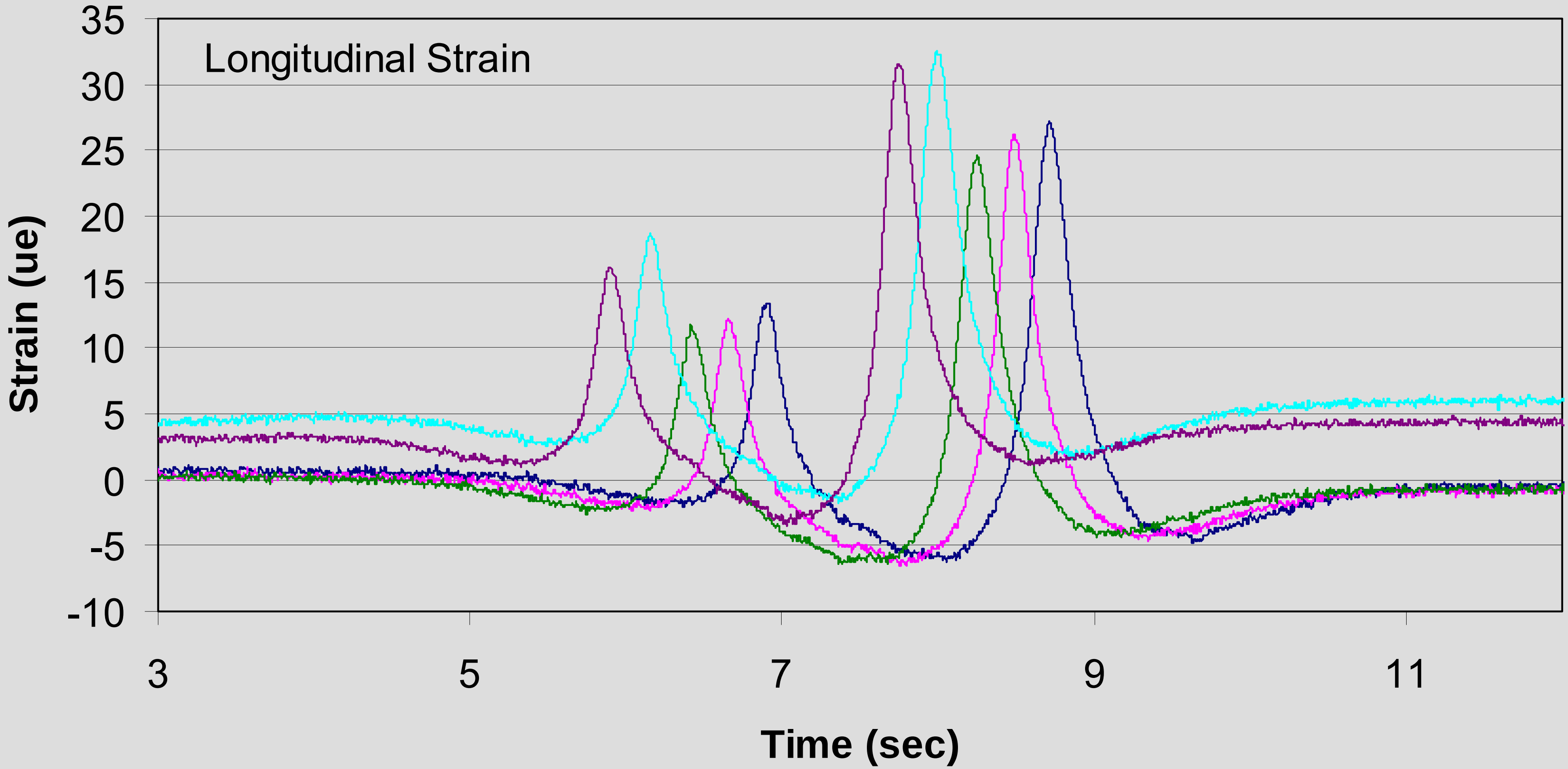


- **Tandem Axle**
  - Loads: 40.15 kip (December) and 34.55 kip (July)
  - Tire Pressure =100 psi



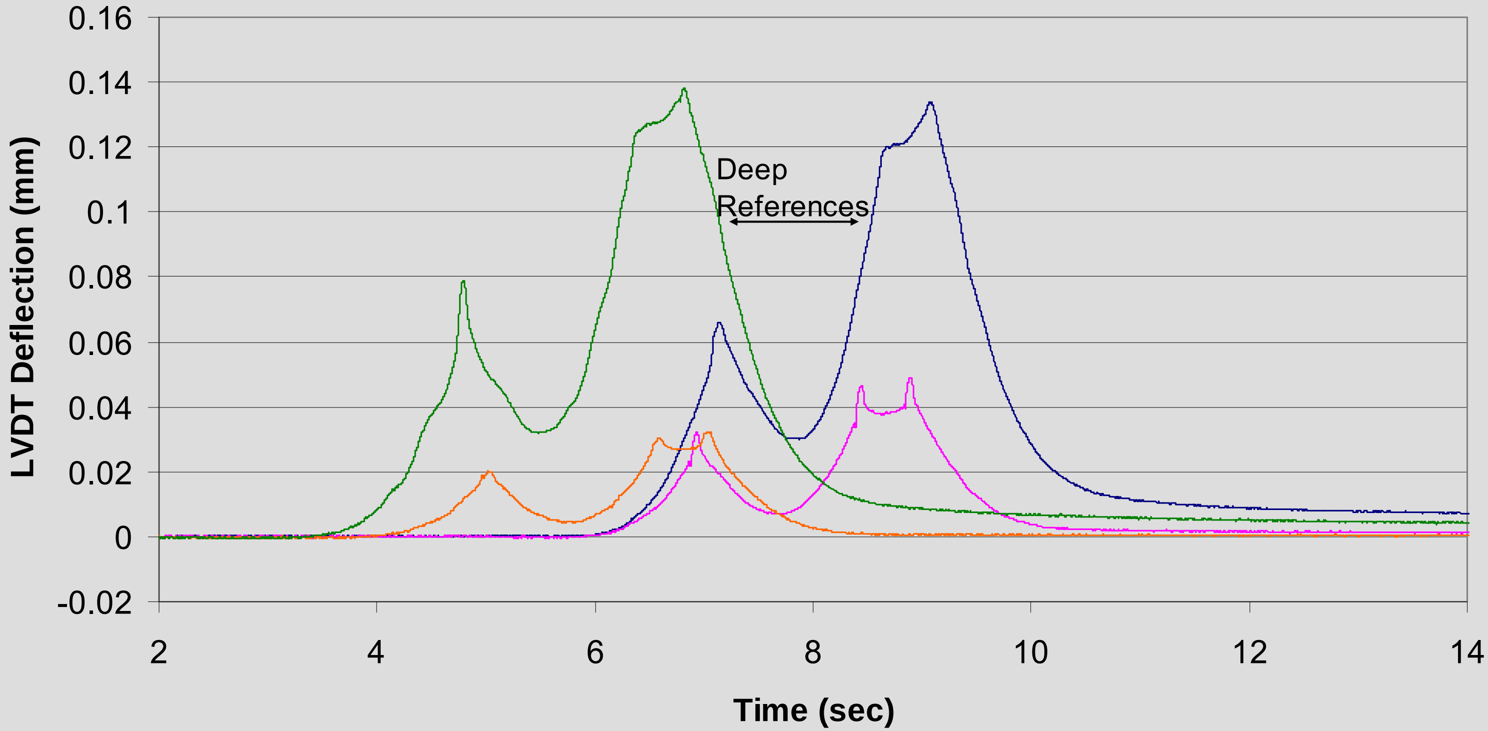
WAY-30 FRL Strain Response Dec. 2005

5 mph Test: ODOT 28.2 Kip Single Axle Truck



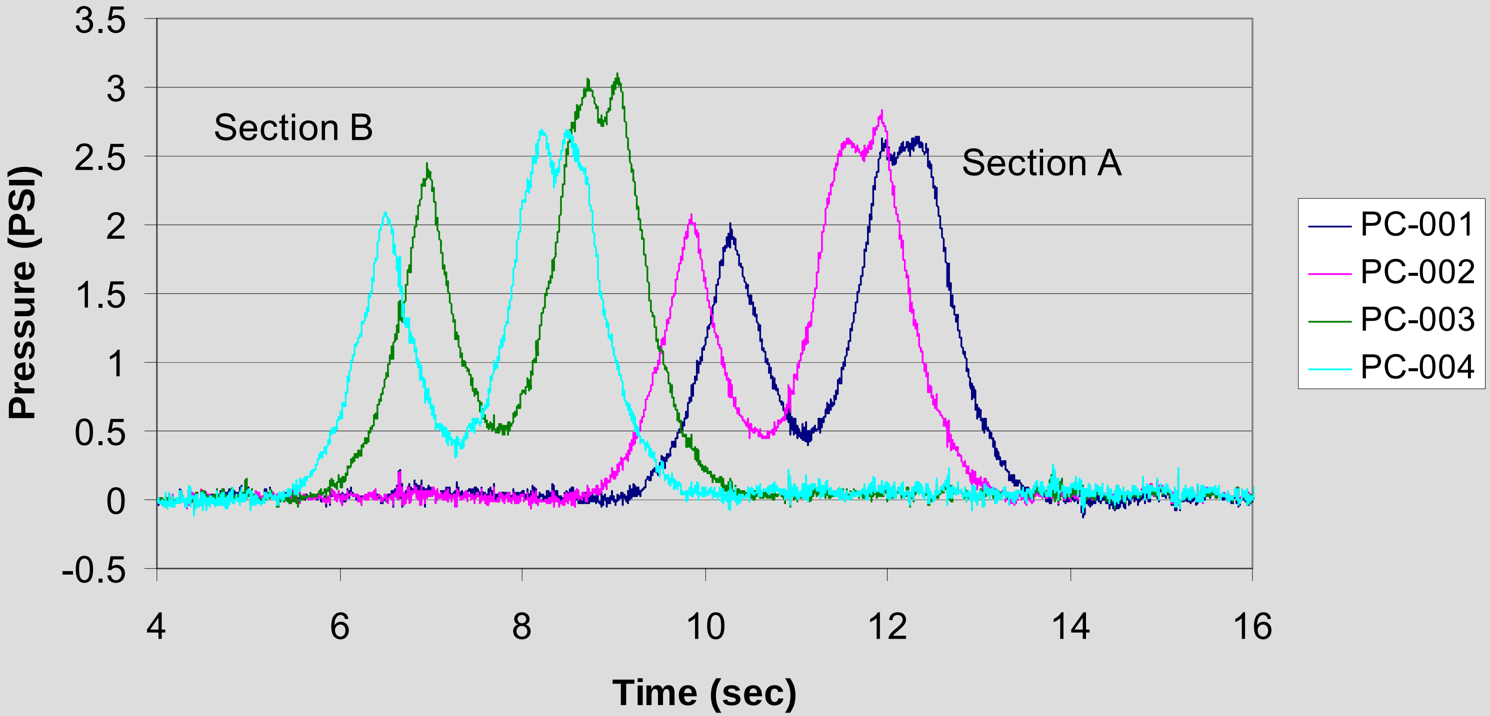
WAY-30 LVDT Response Dec. 2005

5 mph Test: ODOT 40 Kip Tandem Axle Truck



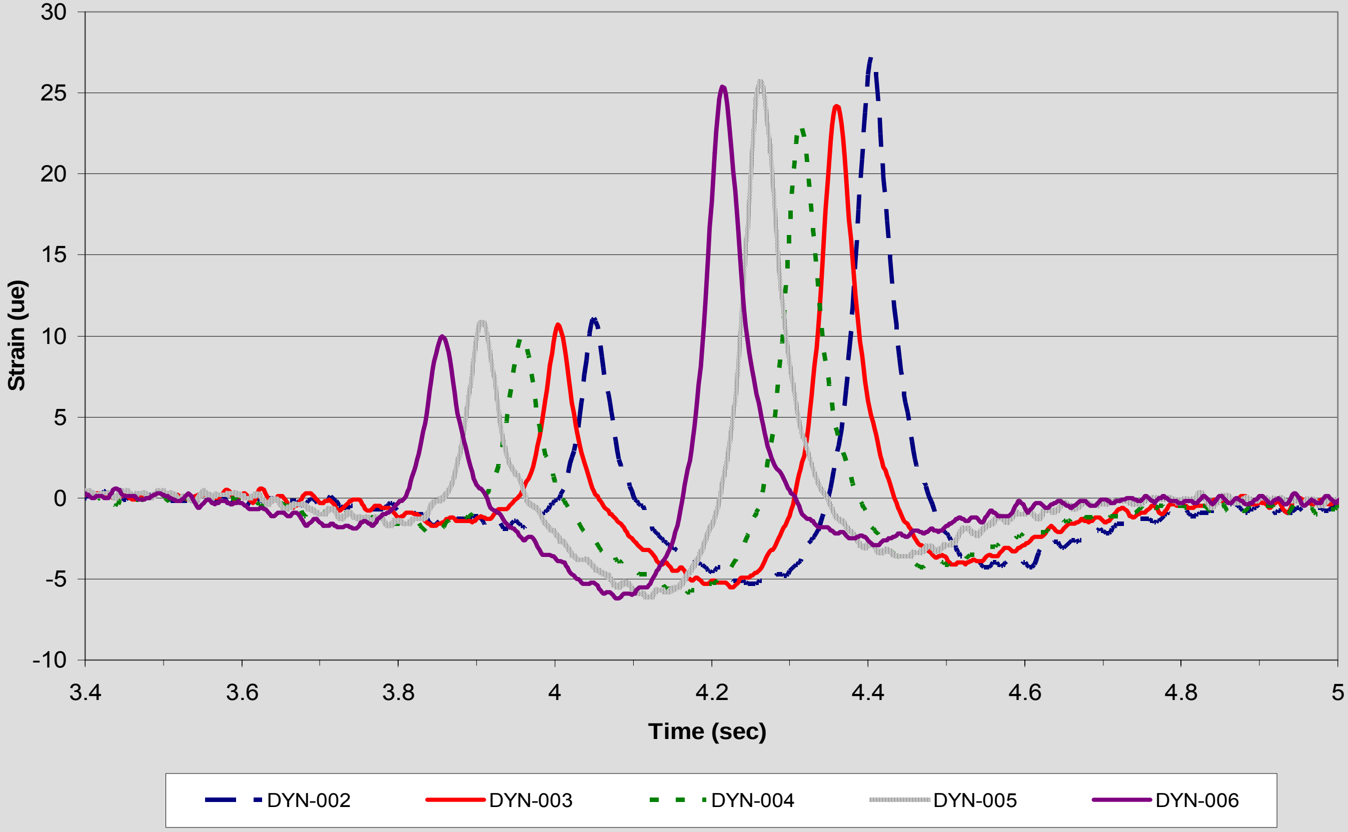
WAY-30 Pressure Cell Readings Dec. 2005

5 mph Test: ODOT 40 Kip Tandem Axle Truck



Longitudinal Strain – Sect. 664 (AC2-390182) FRL Layer Dec. 2005

30 mph Test: ODOT 28.2 Kip Single Axle Truck



Maximum Tensile Strains in Fatigue Resistant Layer Test Section 664 (AC2 - 390182) Dec. 2005

	Max.Tensile Strain, ue			
Speed (mph)	28.5k Single Axle		40 k Tandem Axle	
	Maximum	Average	Maximum	Average
5	32.6	29.0	19.5	17.1
30	27.2	23.9	19.6	17.7
45	27.4	25.1	21.5	17.4
60	27.7	24.9	19.9	18.3

Note: 1 mph = 1.6 km/h
1 kip = 4.448 kN

Maximum Tensile Strains in Fatigue Resistant Layer Test Section 876A (AC1 - 390181) Dec. 2005

Speed (mph)	Max.Tensile Strain, ue			
	28.5k Single Axle		40 k Tandem Axle	
	Maximum	Average	Maximum	Average
5	23.1	20.5	15.3	13.9
30	18.8	16.8	14.9	13.0
45	18.6	15.5	15.4	14.3
60	18.5	16.8	15.0	12.0

Note: 1 mph = 1.6 km/h
1 kip = 4.448 kN

Maximum Tensile Strains in Fatigue Resistant Layer Test Section 876A (AC1 - 390181) Dec. 2005

	Max.Tensile Strain, ue			
Speed (mph)	17.5k Single Axle		28.5 k Tandem Axle	
	Maximum	Average	Maximum	Average
5	14.9	12.8	12.7	11.4
30	12.9	11.4	11.1	10.2
45	11.5	10.8	10.2	9.0
60	11.8	10.2	10.3	9.7

Note: 1 mph = 1.6 km/h
1 kip = 4.448 kN

Maximum Tensile Strain in the Intermediate Layer Dec. 2005

8 km/h (5 mph)

Test Section	Maximum Tensile Strain, ue			
	28.5k Single Axle		40k Tandem Axle	
	Max	Average	Max	Average
664	19.9	17.8	12.1	10.9
876A	12.9	11.8	8.2	7.7

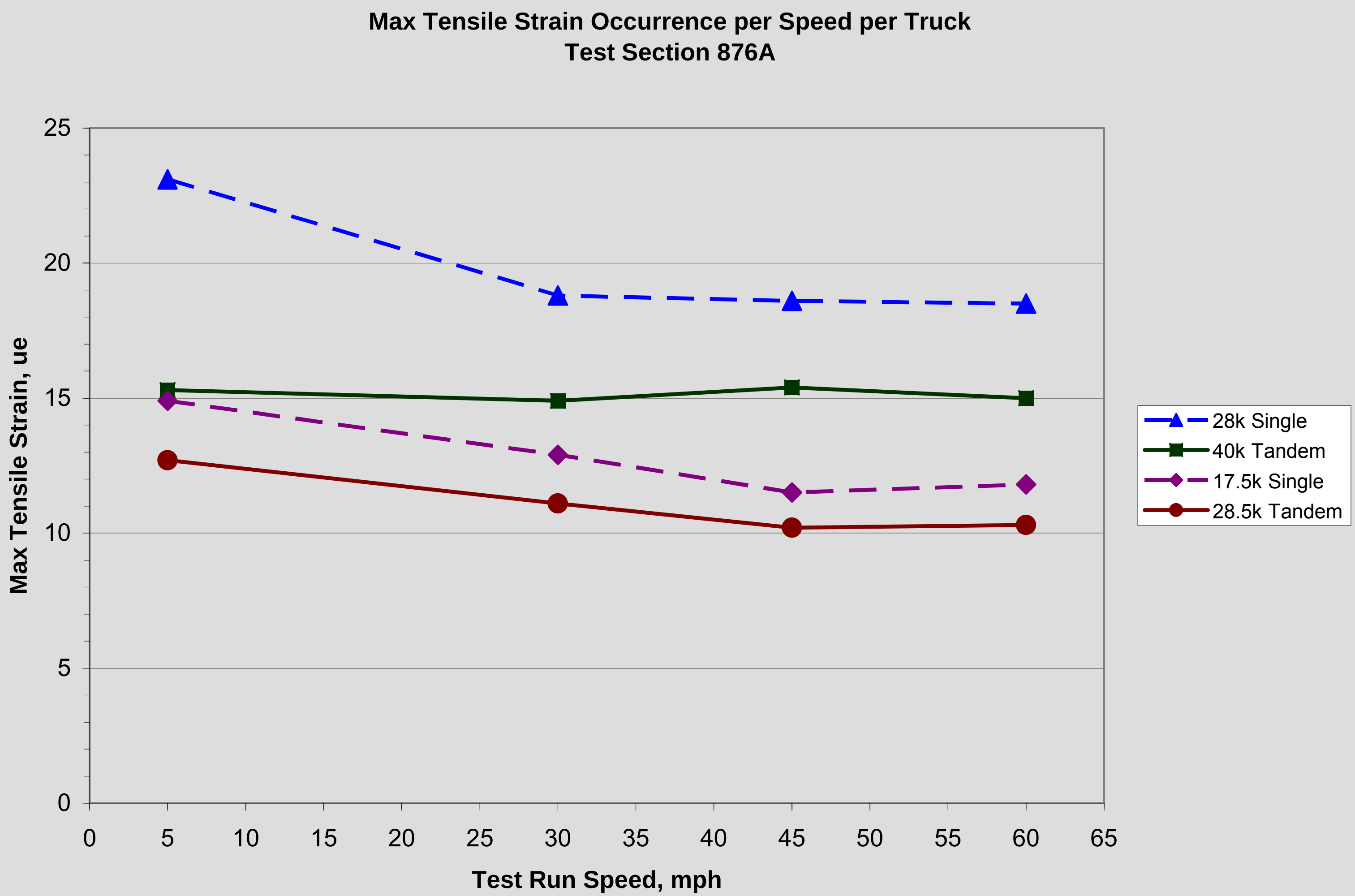
Maximum Transverse Strains in the Intermediate Layer Dec. 2005

8 km/h (5 mph)

Test Section	Maximum Transverse Strain, ue			
	28.5k Single Axle		40k Tandem Axle	
	Max	Average	Max	Average
664	14.2	12.4	11.4	10.9
876A	8.8	8.3	7.7	7.3

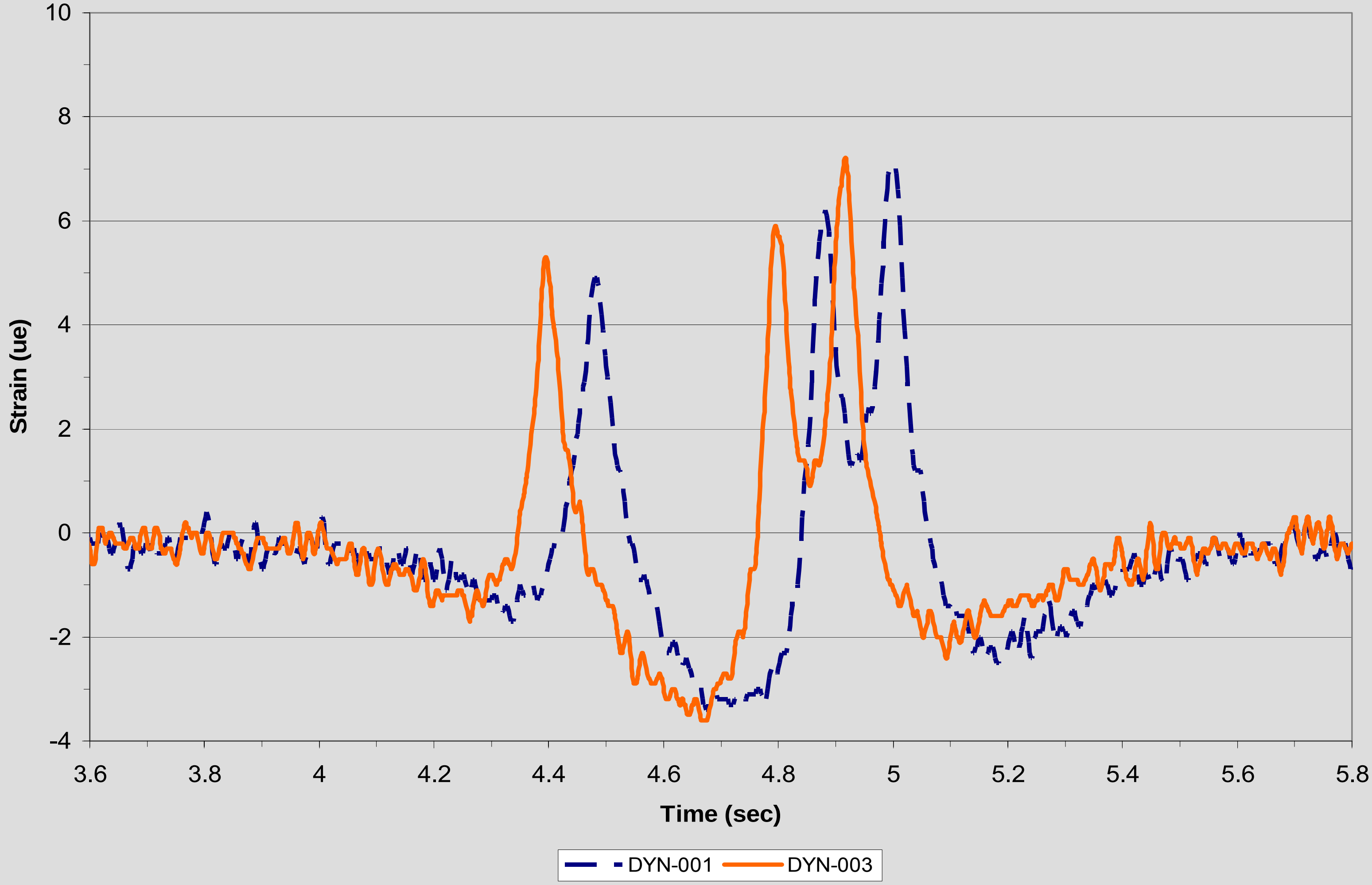
Maximum Tensile Strain Variation vs. Speed and Axle Type Dec. 2005

Section 876A (AC1 - 390181)



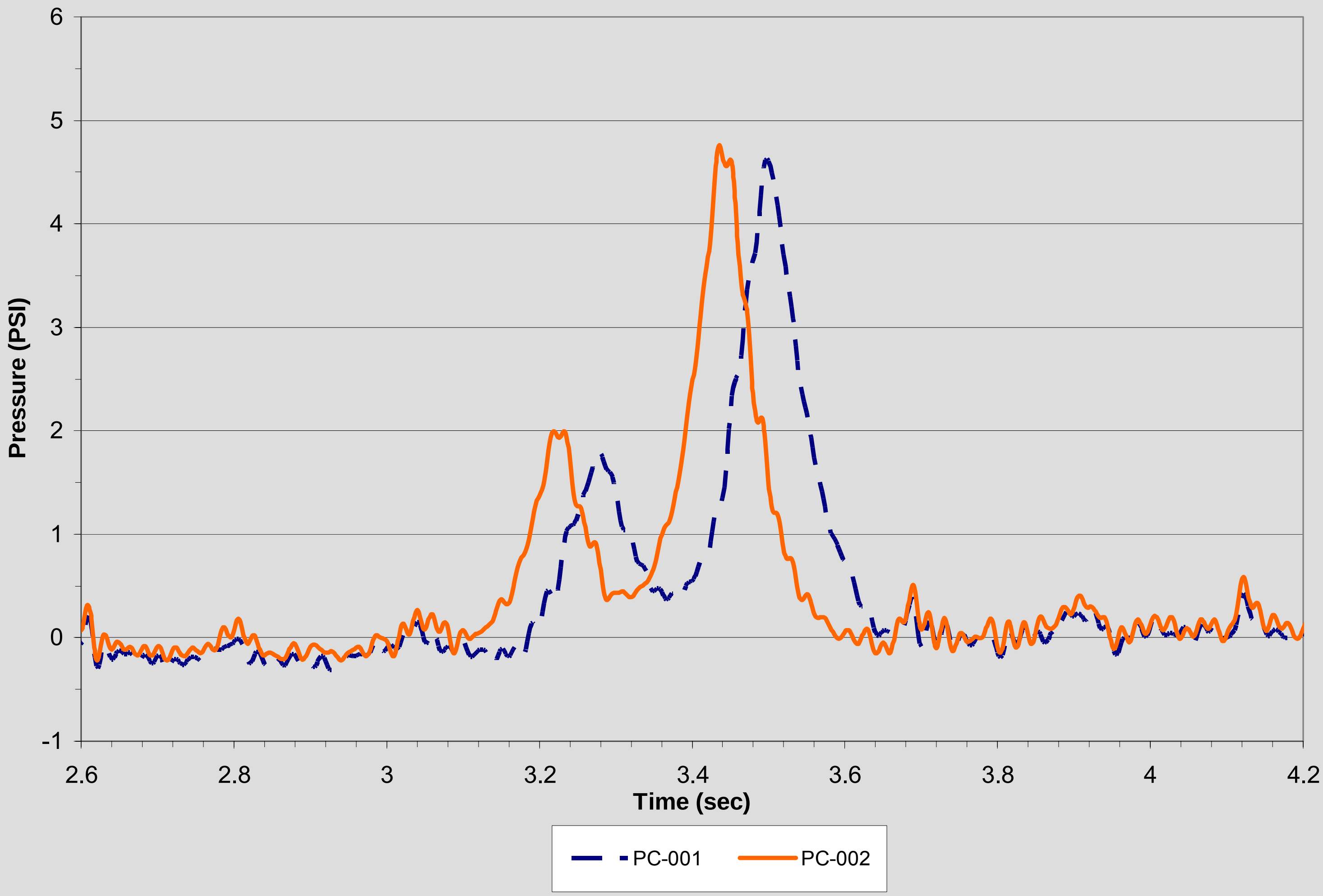
Longitudinal Strain: Section 876A (AC1-390181) – FRL Layer Dec. 2005

30 mph Test: ODOT 40 Kip Tandem Axle Truck



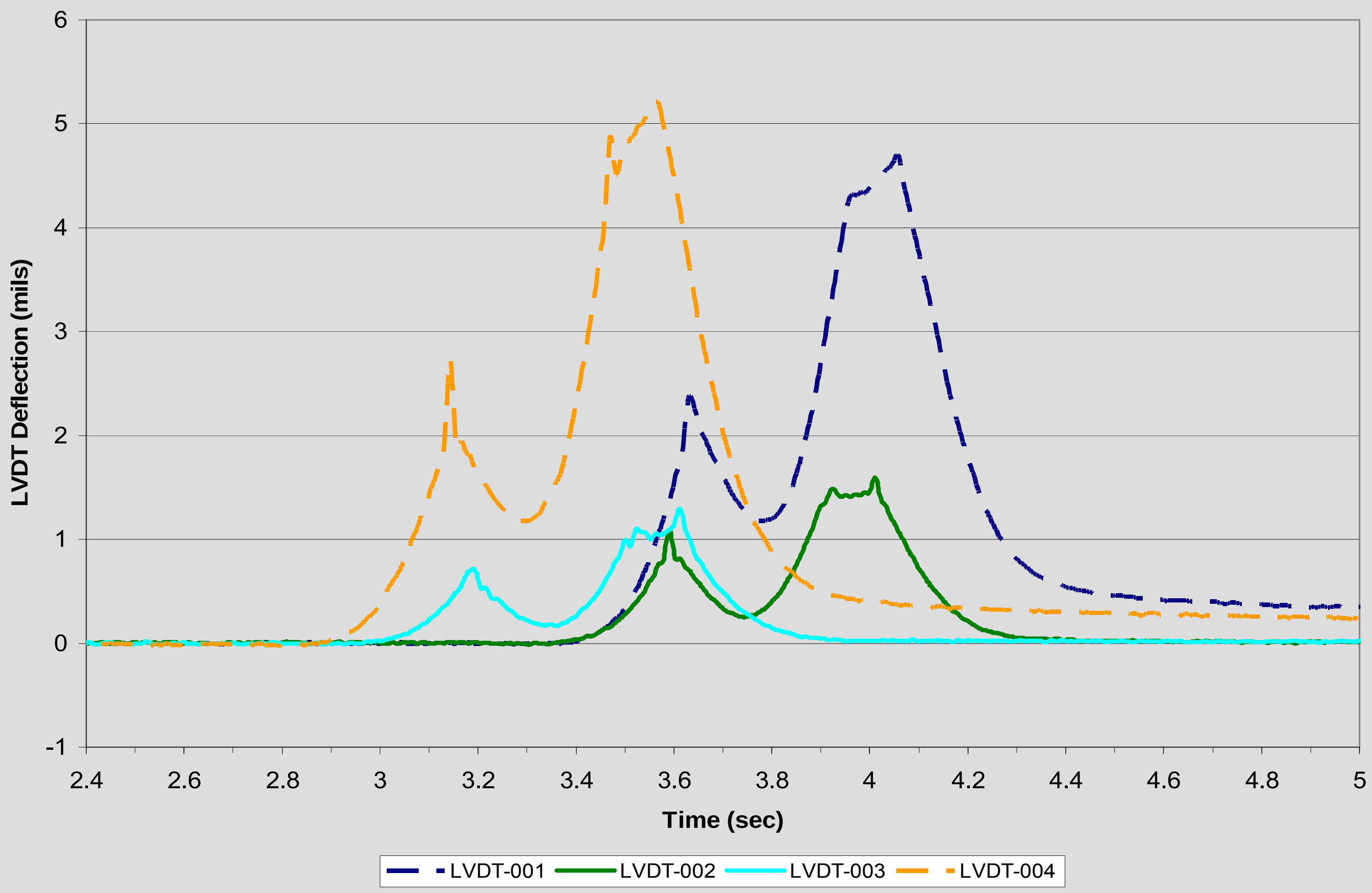
Pressure Readings: Section 664 (AC2-390182) Dec. 2005

(28 kip Single Axle Load, 45 mph)

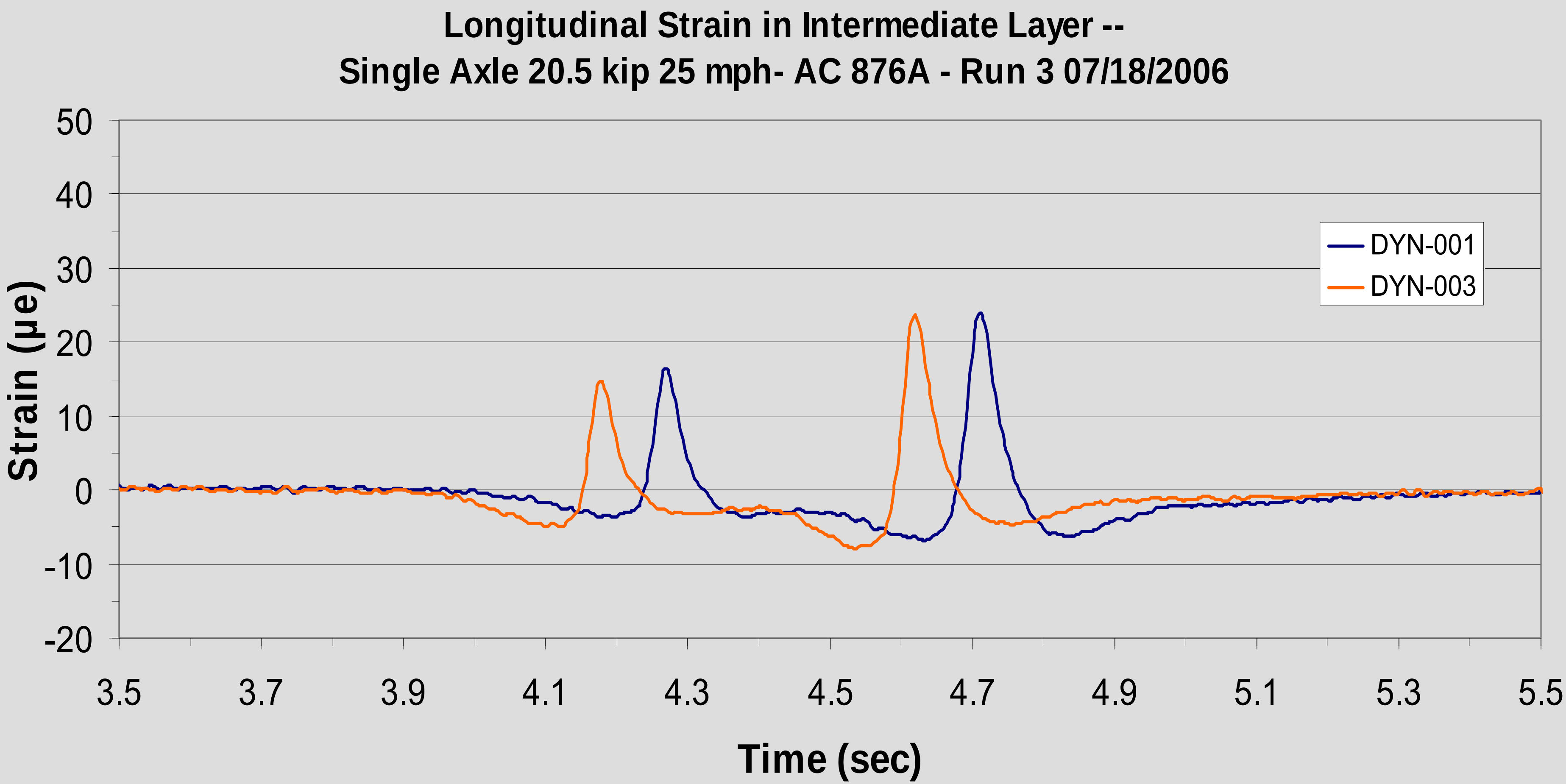


LVDT Deflections: Section 664 (AC2-390182) Dec. 2005

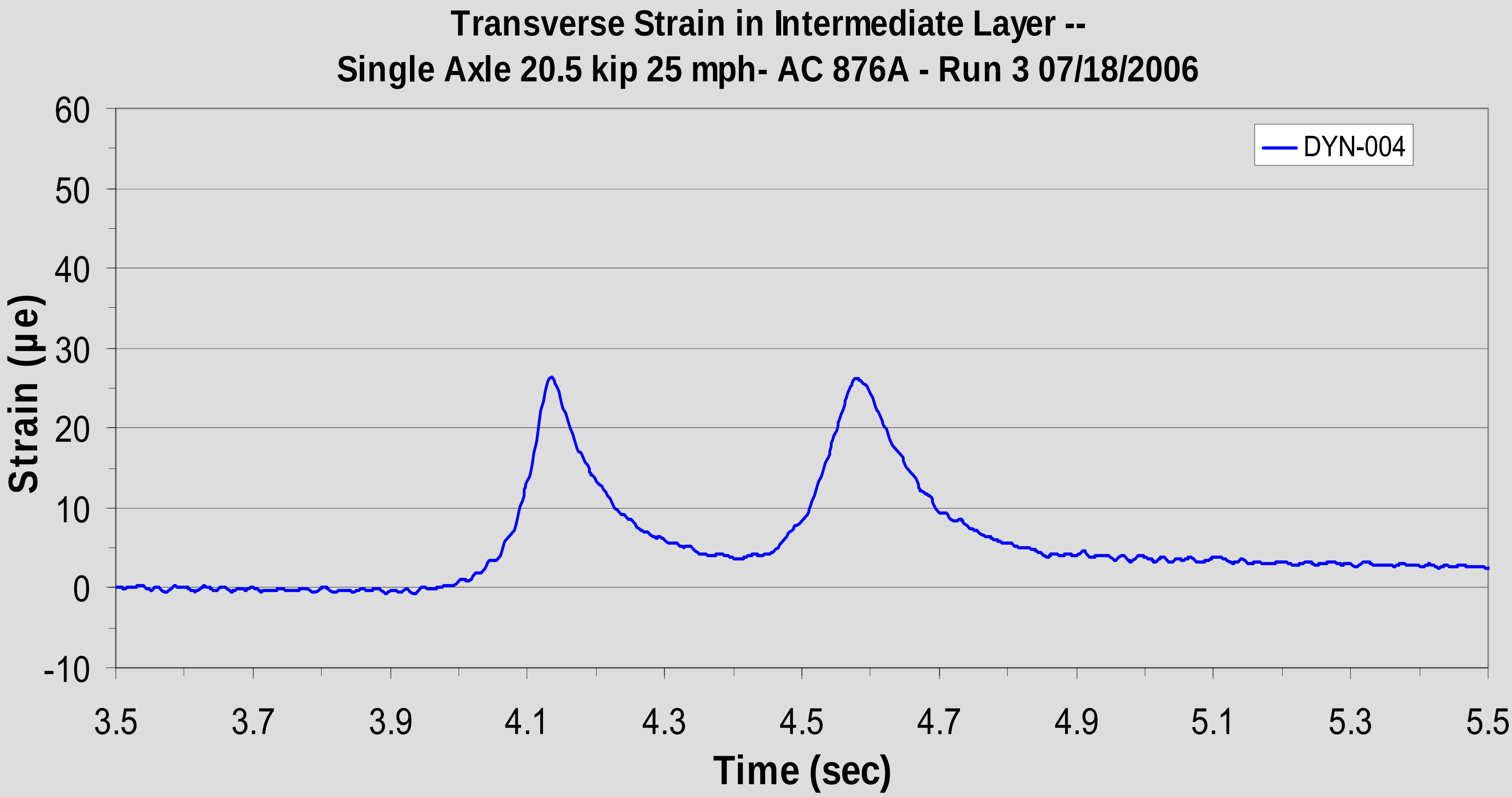
40 kip. Tandem Axle Load – 30 mph



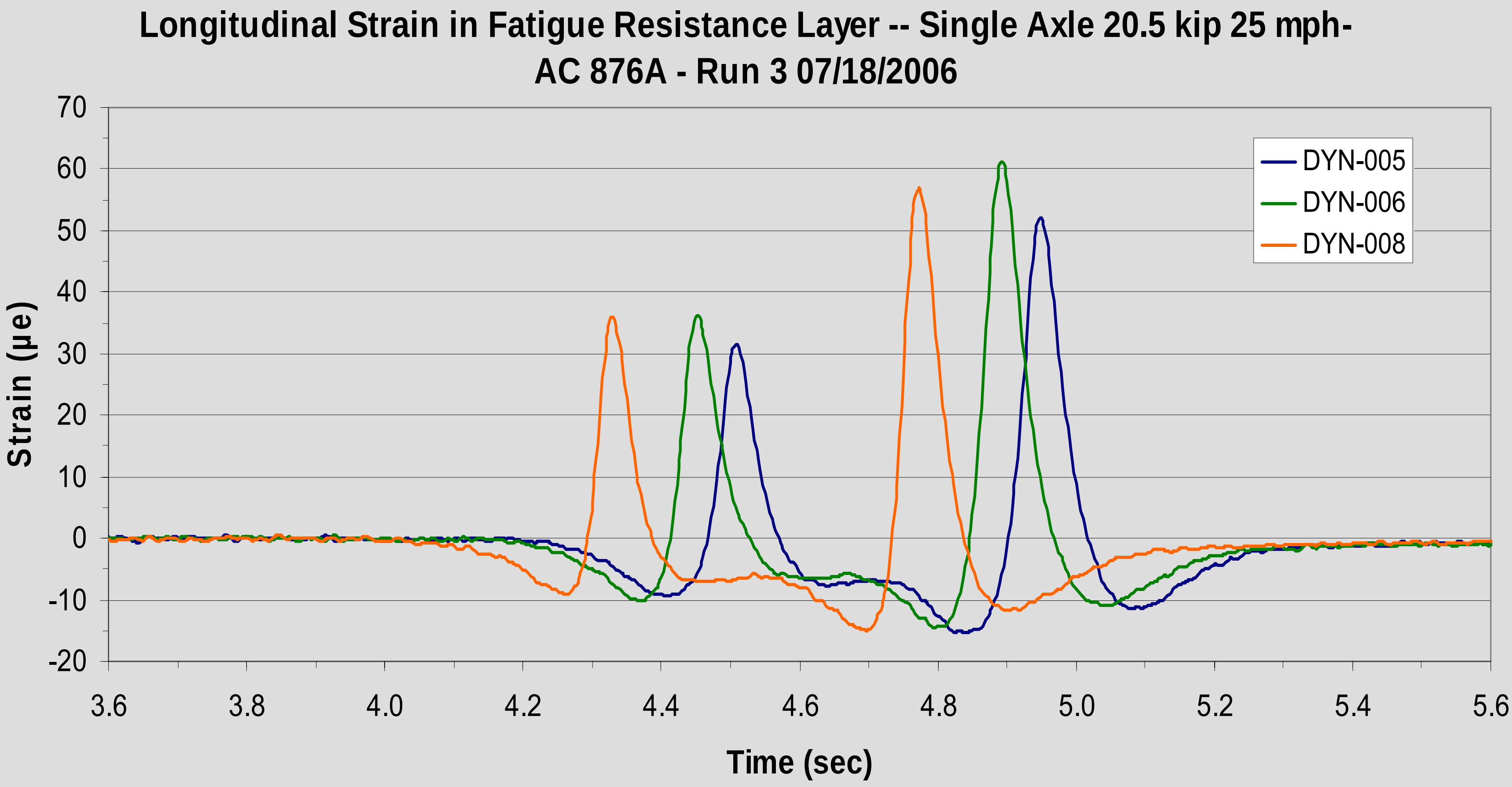
AC CVL Test, July 2006



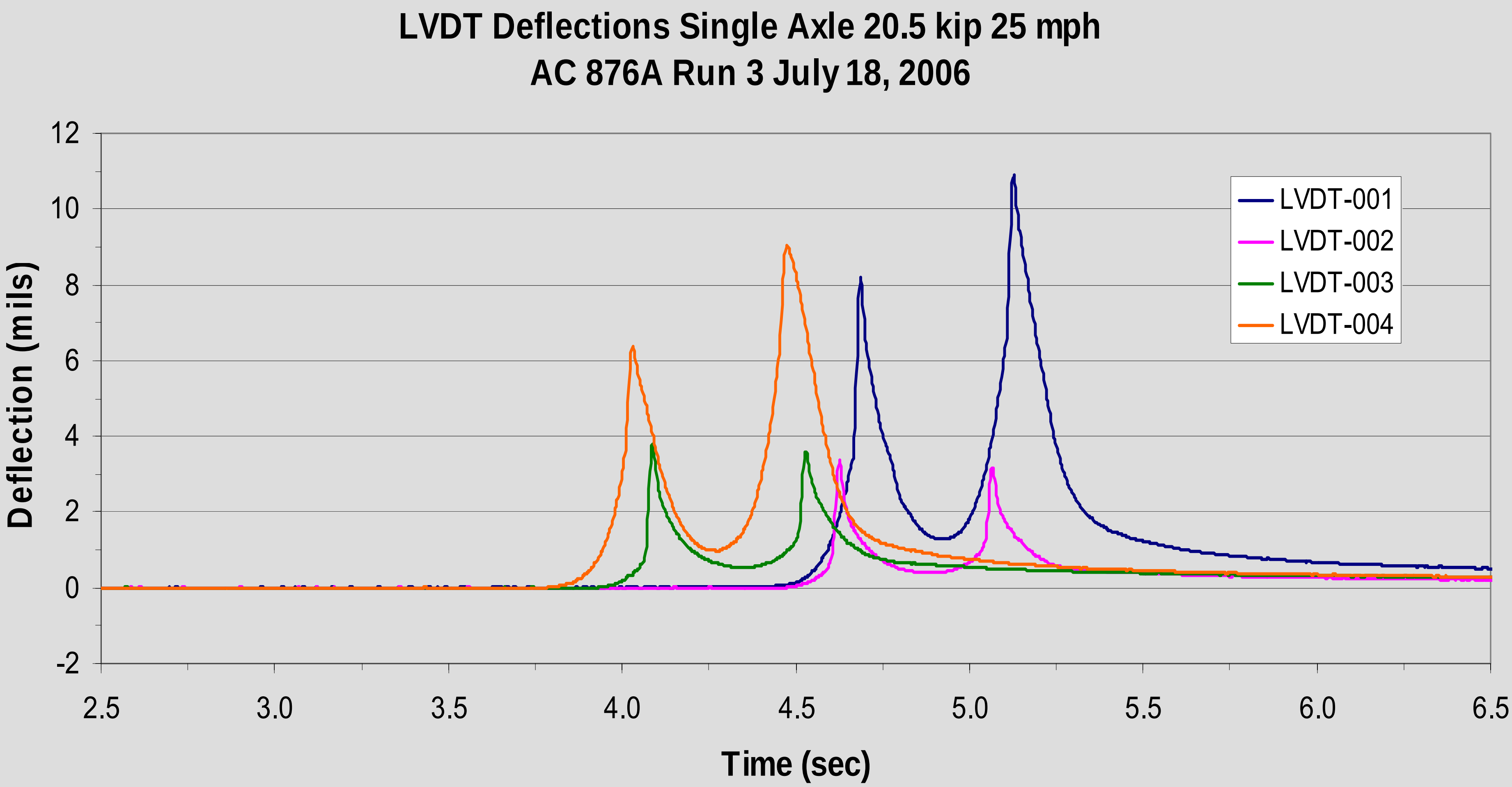
AC CVL Test, July 2006



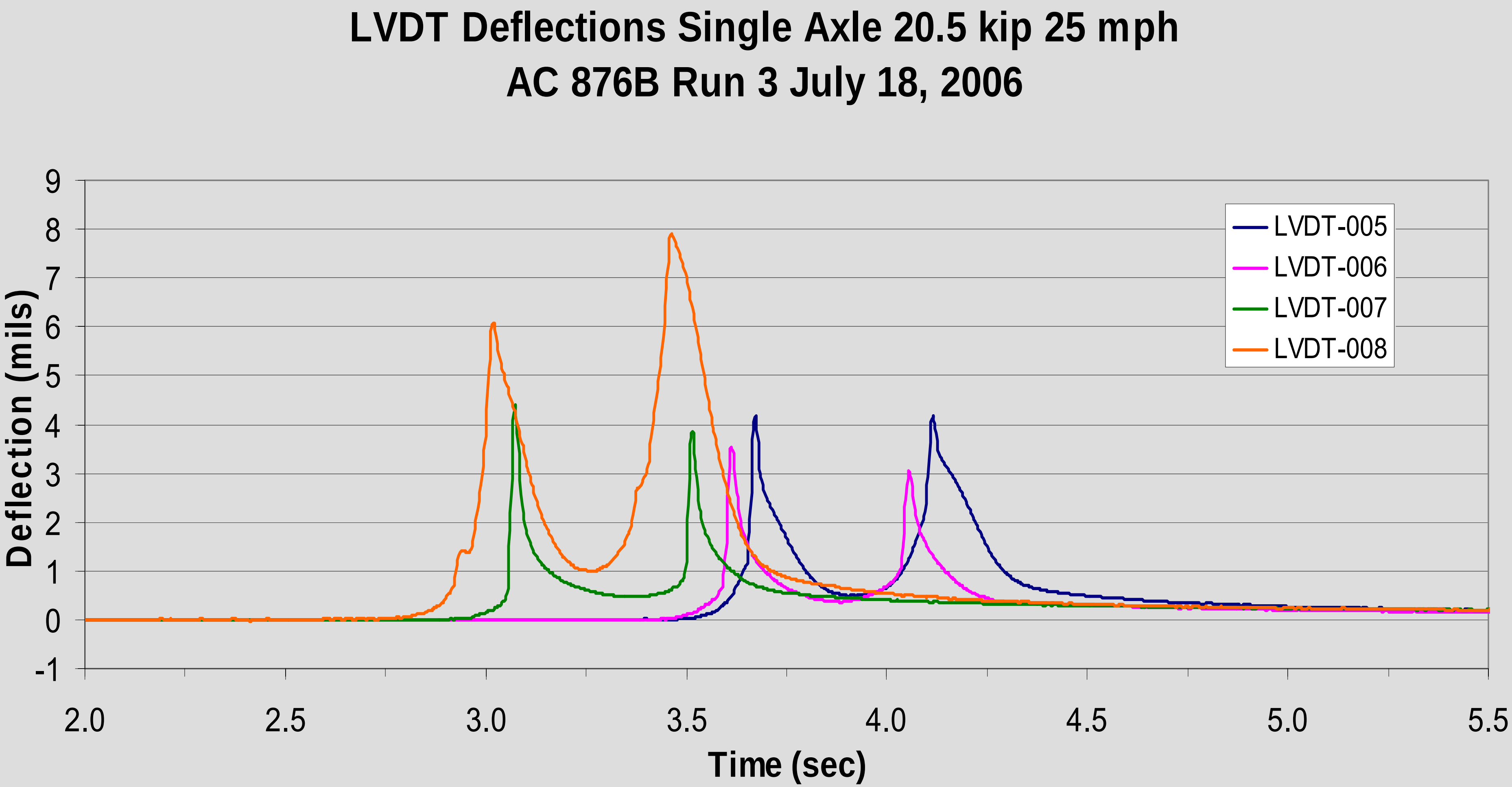
AC CVL Test, July 2006



AC CVL Test, July 2006



AC CVL Test, July 2006



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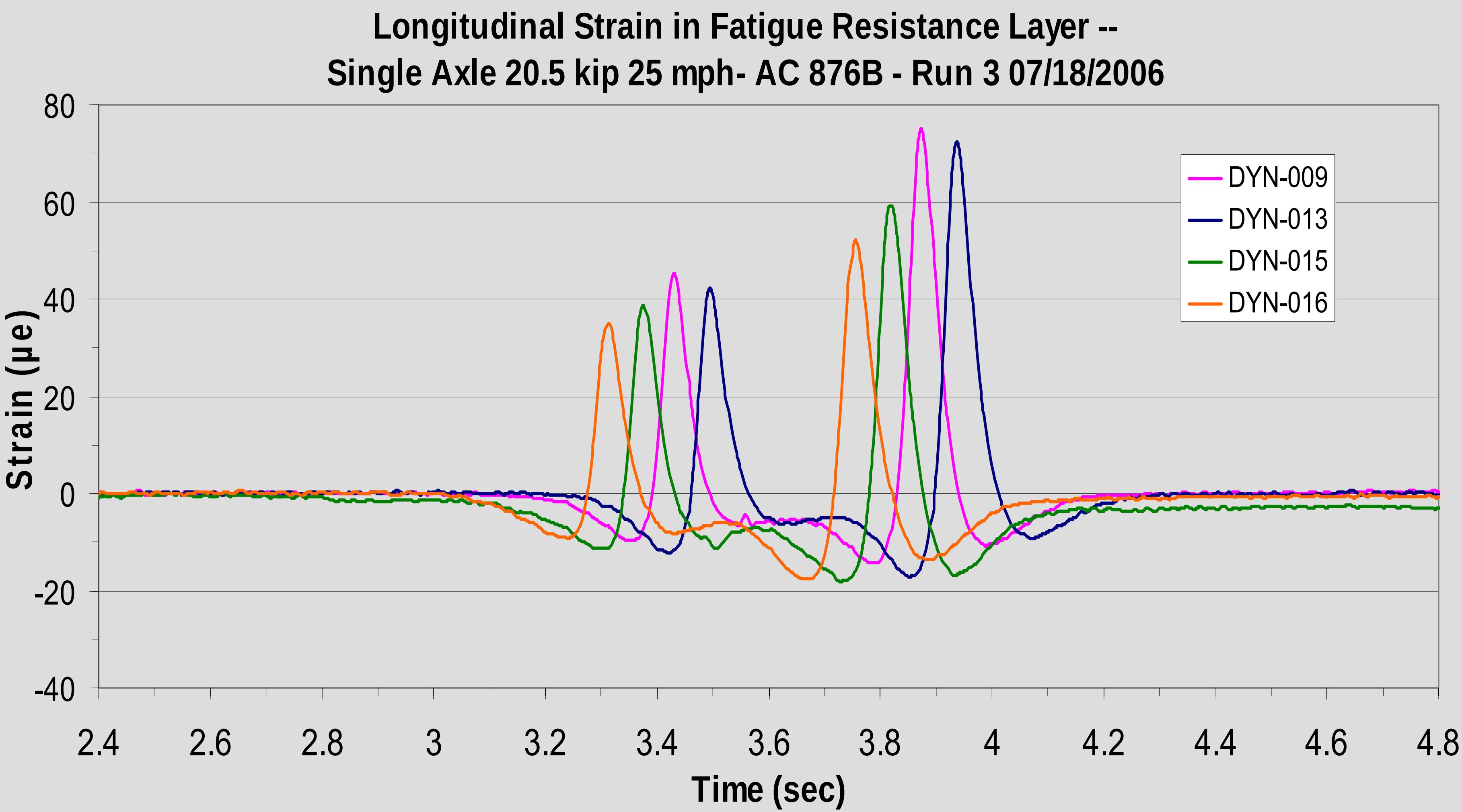
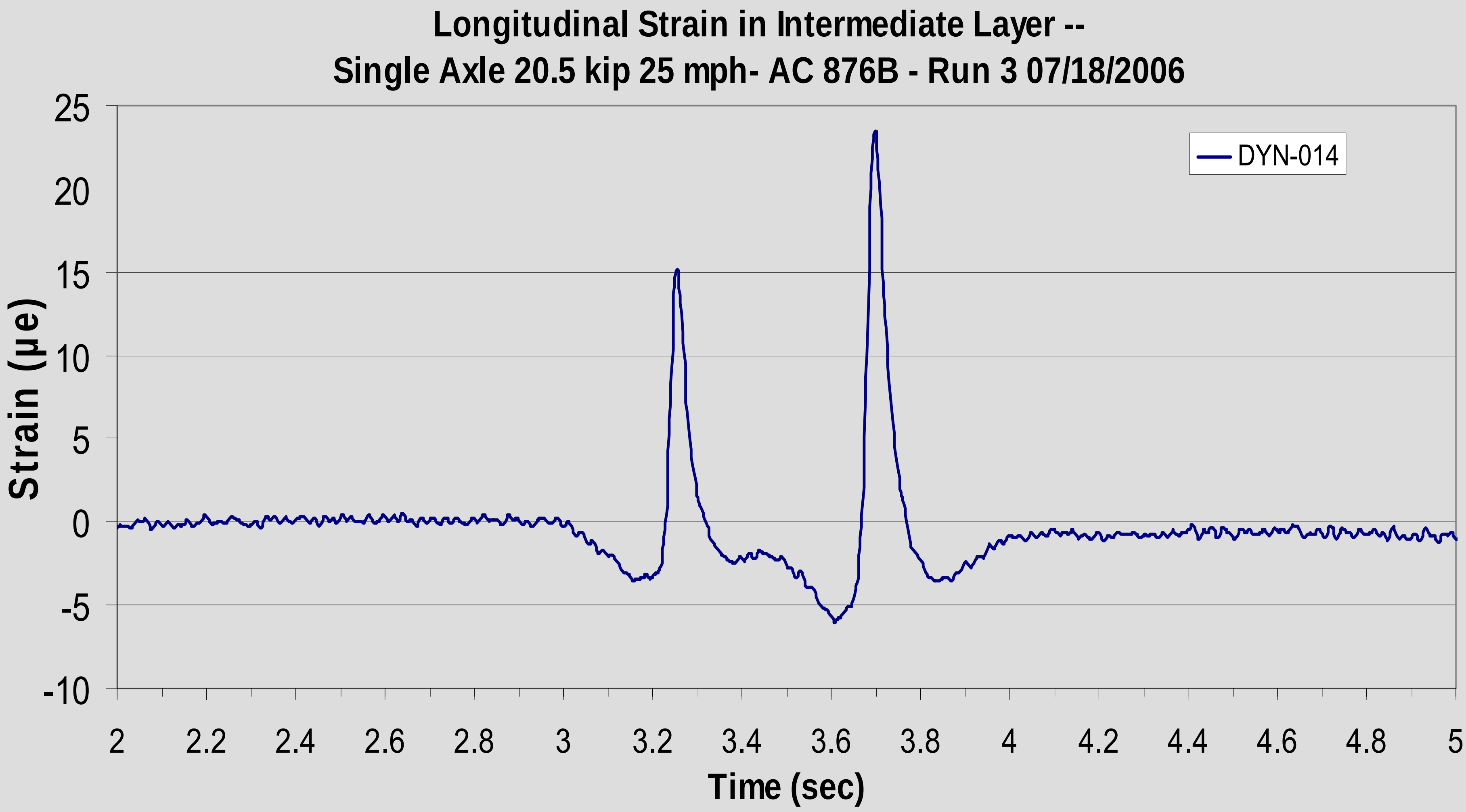
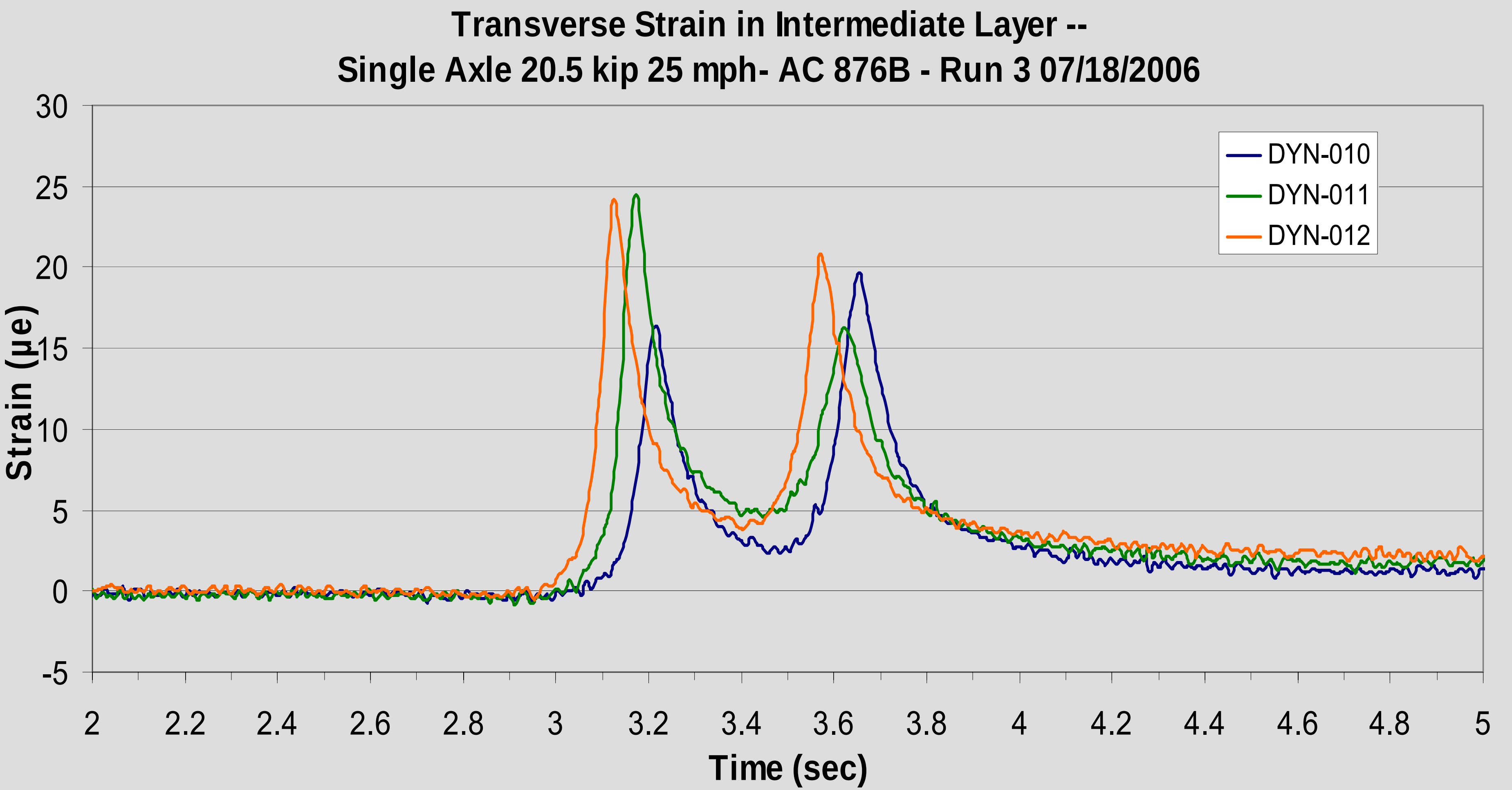


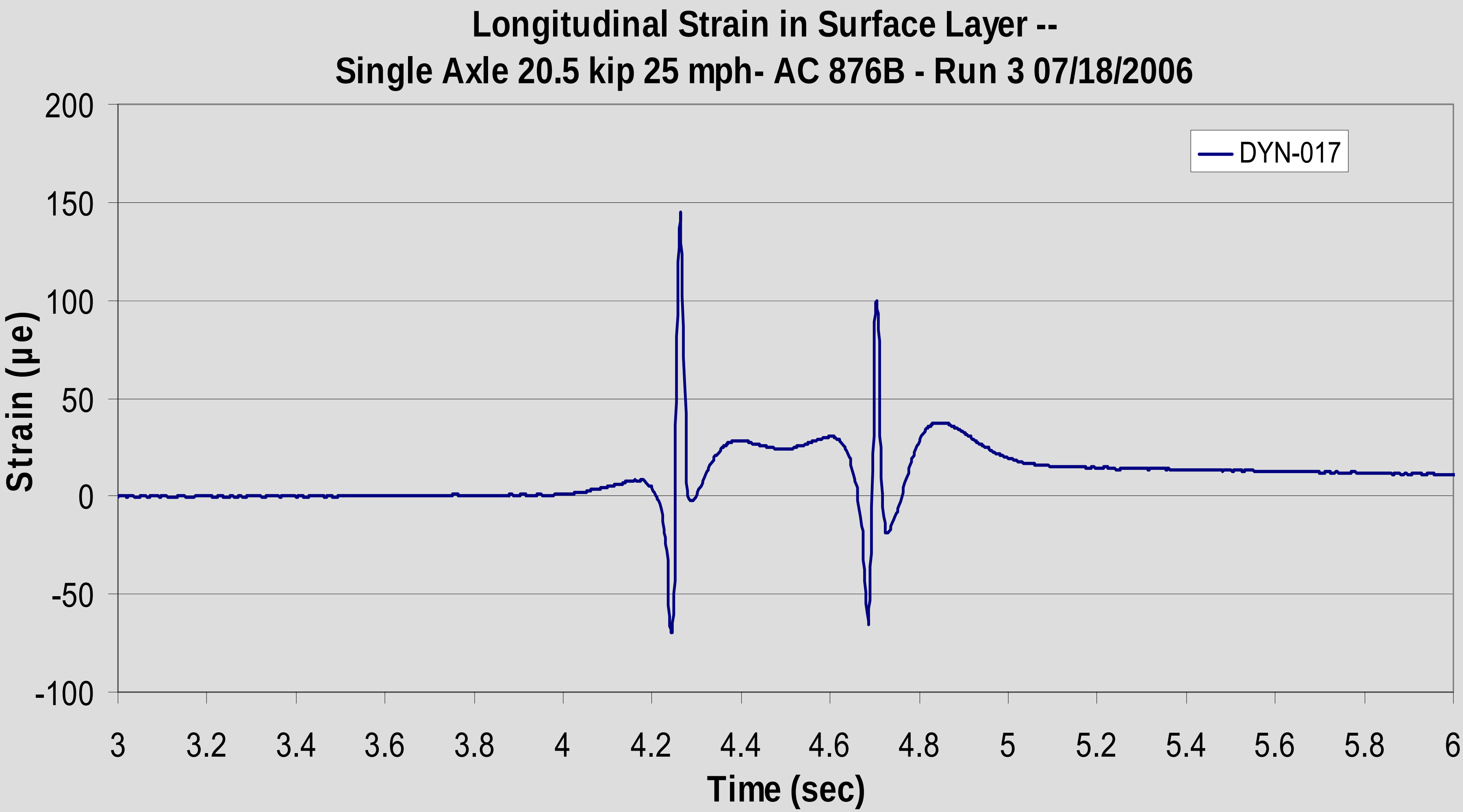
AC CVL Test, July 2006



AC CVL Test, July 2006

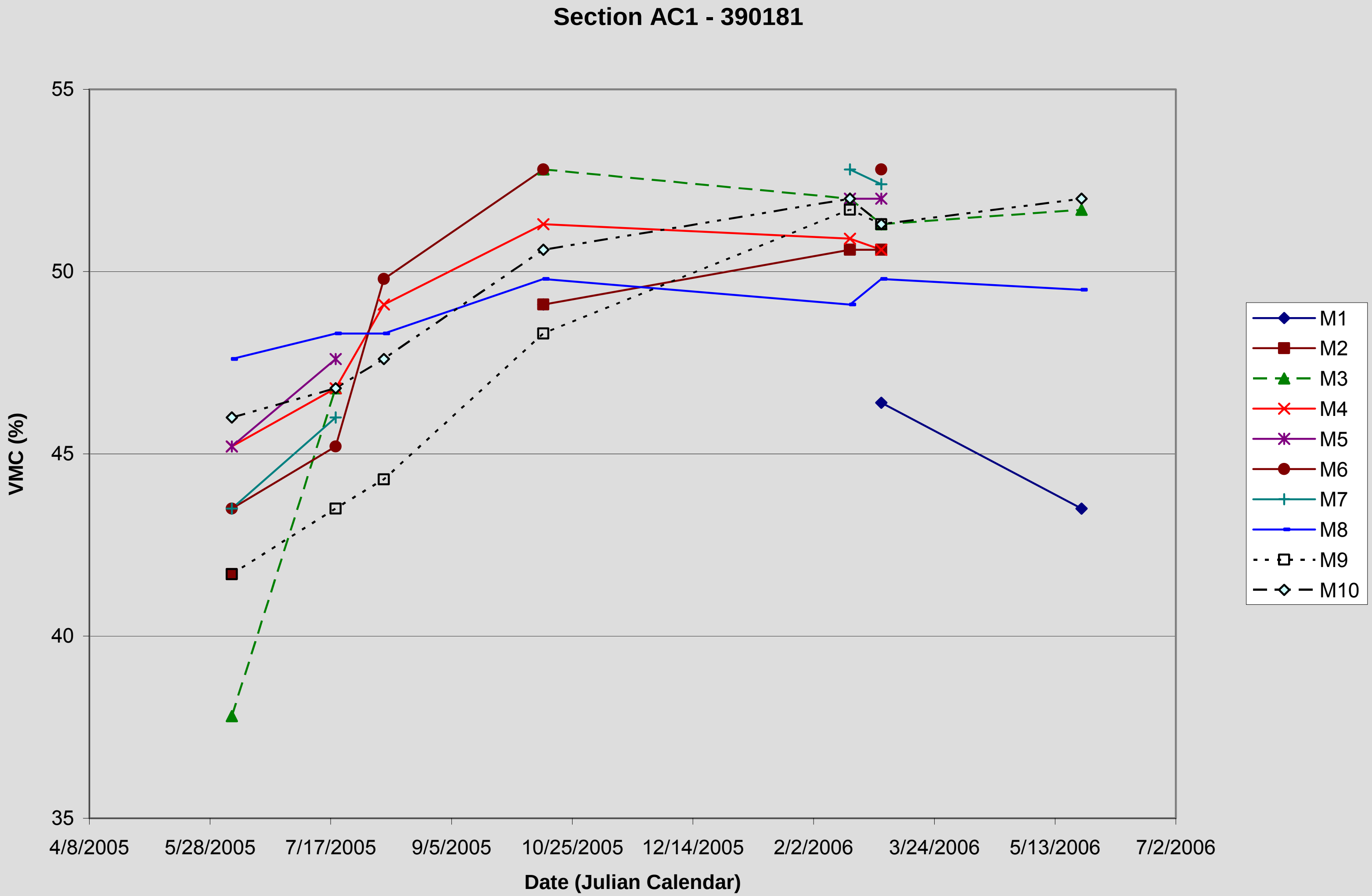


AC CVL Test, July 2006

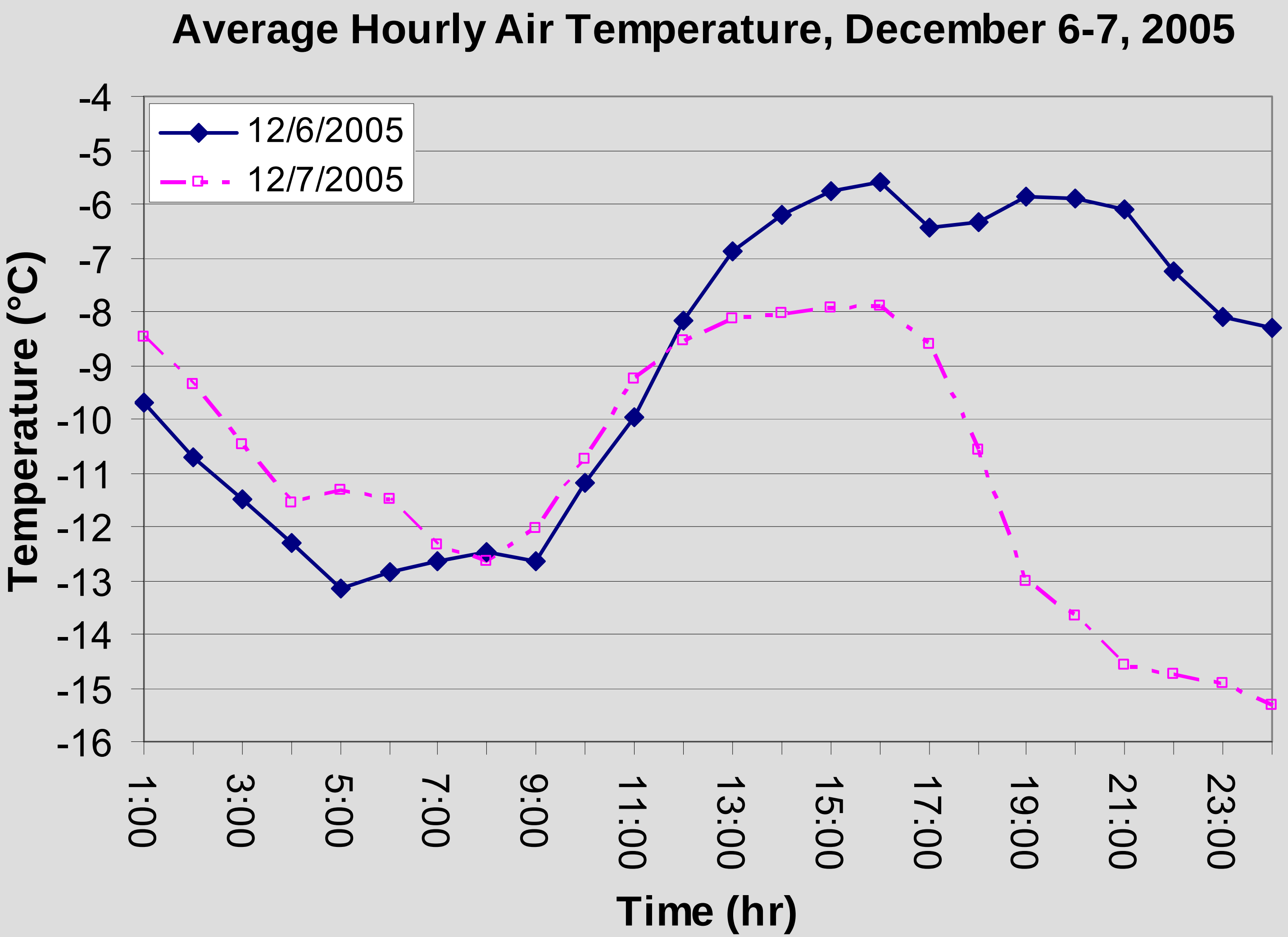


VMC Variation – Section 876 (AC1 – 390181)

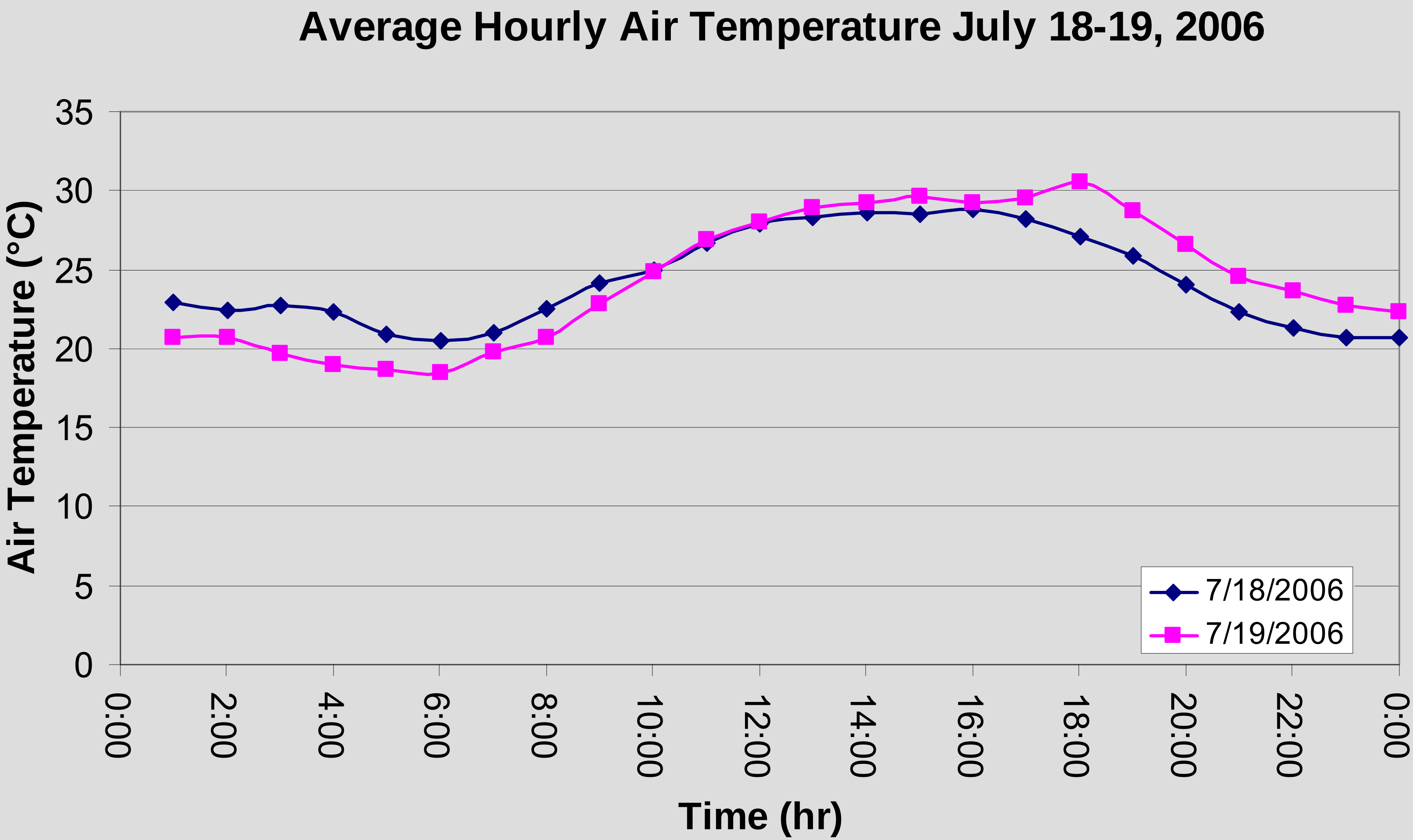
10 TDR Sensors



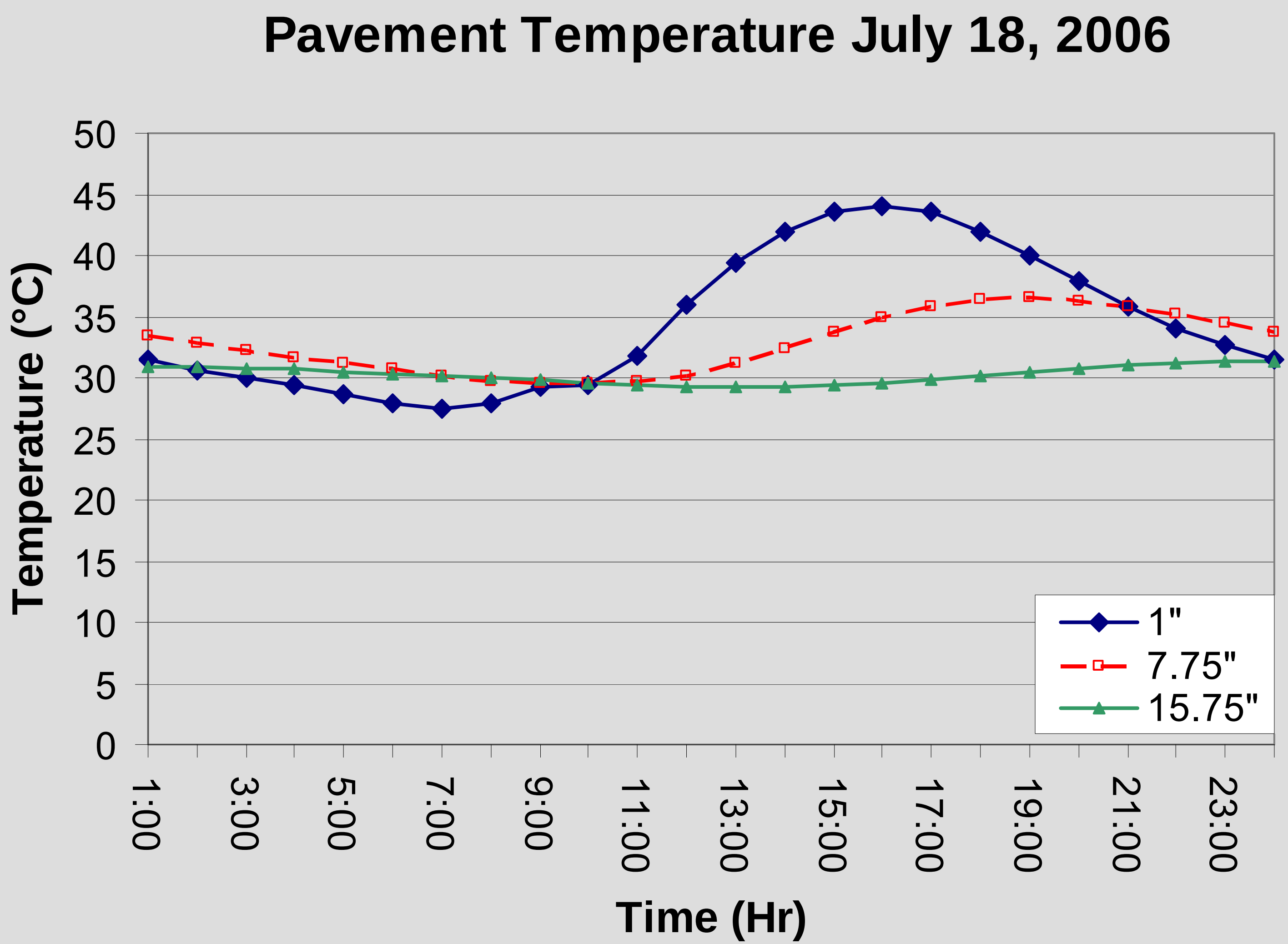
Air Temperatures during CVL Test December 2005



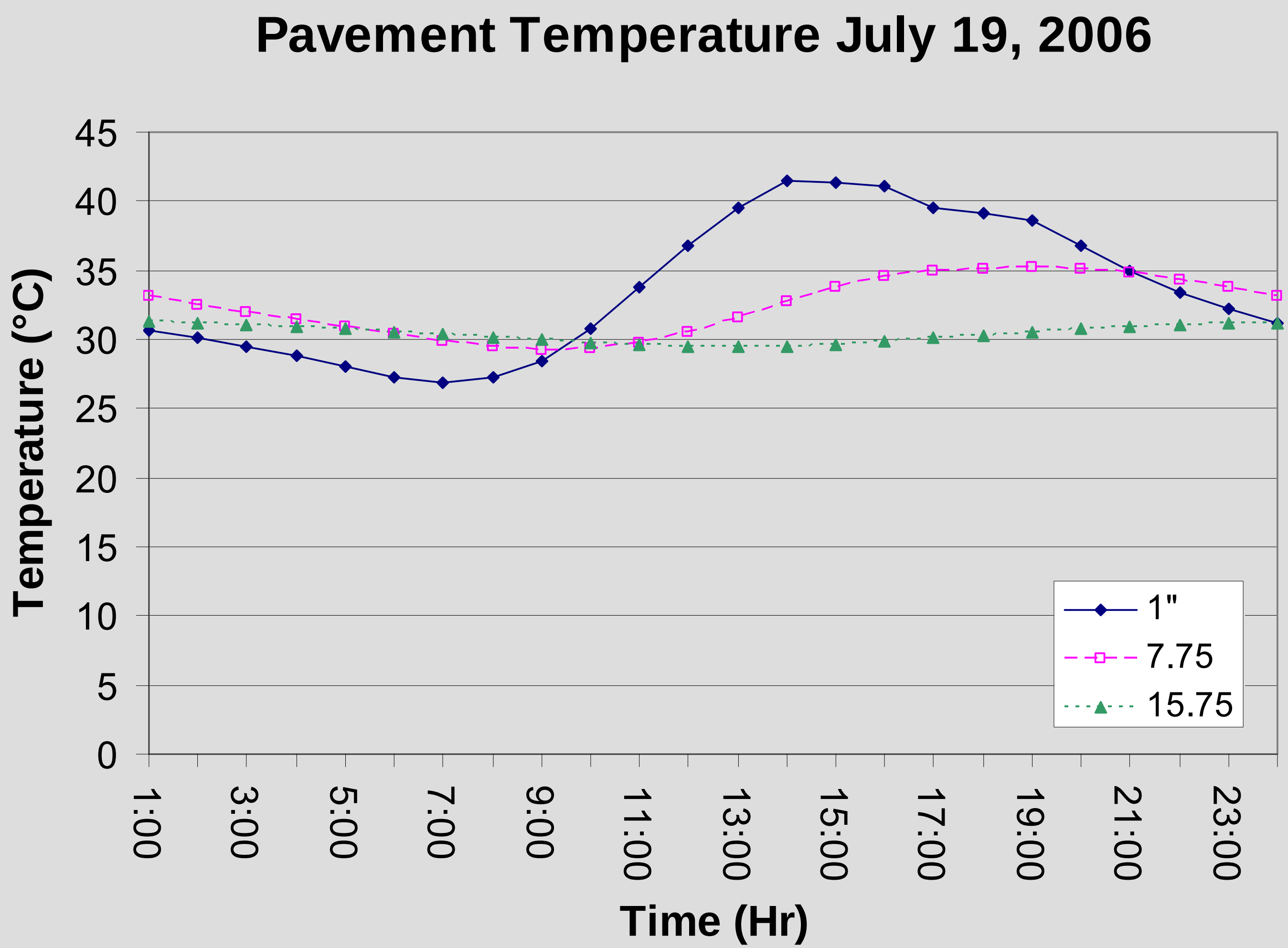
Air Temperatures during CVL Test
July 2006



Pavement temperatures during CVL Test July 18, 2006



Pavement temperatures during CVL Test July 19, 2006



Conclusions

Fatigue Resistance Layer

- During December 2005 CVL test, longitudinal strain on FRL remained ≤35με, even at slowest speed
- During July tests at highway speeds of 45 mph and 55 mph, the strain in the FRL remained close to the design value under even the heaviest loads
  - In everyday use, such high-load strains will be rare
  - High-load strains at slower speeds will be even more rare (during traffic stoppage or slowdowns), though these did exceed design strain

Conclusions

Intermediate Layer and Subgrade

- Strains at bottom of intermediate layer are lower than at bottom of FRL, as expected.
- Maximum longitudinal strains are slightly higher than maximum transverse strains for all December runs and all single axle runs in July.
- Maximum subgrade observed pressure during CVL tests was 6.5 psi at 45 mph under 40 kip tandem axle load.

http://webce.ent.ohiou.edu

Pavement Analysis Program Principal Characteristics

- Materials are considered
  - homogeneous
  - isotropic
  - follow a linear stress-strain relationship
  - modulus of elasticity is same for compression and tension.
- All layers are
  - horizontal
  - have different specific elastic modulus and Poisson’s Ratio
  - weightless
  - extend to infinity in the horizontal direction.
  - bottom layer also extends to infinity in the horizontal direction, but it is semi-infinite in the vertical direction.
- Stresses and displacements are zero at infinite depth within the semi-infinite bottom layer.

Pavement Analysis Program Principal Characteristics (ctd)

- The top layer is free from shear stresses at the surface
- The load is applied at the surface of the top layer
  - distributed in a circular pattern
  - constant throughout the area
  - No normal stresses exist outside of the circular area.
- The layers are in continuous contact
- The layer interfaces are rough
- The layers act similarly to a composite medium.
- Both the horizontal and vertical displacements and the normal and shear stresses are the same very close to the interface of either one of the two layers.

Pavement Analysis Program Inputs

- vertical displacement
- Stresses and strains:
  - vertical
  - horizontal
  - shear
  - Both stresses and strains are parallel to the three orthogonal axes.

Analysis based on field core testing

REAR DUAL WHEEL AC664 Dec'05 Averages and Calculated

RUN	speed	S2-S6	Calcul	S7,9,11	Calcul	S8,10,12	Calcul	LV1&4	Calcul	LV2&3	Calcul	P1&P2	Calcul
	mph	ue	ue	ue	ue	ue	ue	in	in	in	in	psi	psi
2	5	26.44	21.48	16.70	9.97	10.80	8.15	0.0053	0.0128	0.0017	0.00049	4.336	0.594
6	30	25.12	22.35	15.97	10.36	10.43	8.52	0.0048	0.0134	0.0014	0.00047	4.784	0.619
12	45	25.30	22.18	15.23	10.30	10.30	8.57	0.0035	0.0132	0.0012	0.00050	4.694	0.606
22	60	25.04	22.16	15.37	10.33	10.50	8.55	0.0041	0.0133	0.0014	0.00049	5.454	0.611
		@ Longit Bottom FRL	16.25	@ Longit Bottom	12.25 302	@ Transv Bottom	12.25 302	Surface		D_{surf} -	$D_{22.25}$		

REAR DUAL WHEELS AC664 July'06 Average and Calculated

RUN	Speed	S1-S6	Calcul	S7,9,11	Calcul	S10,12	Calcul	LV1&4	Calcul	LV2&3	Calcul	P1&P2	Calcul
	mph	ue	ue	ue	ue	ue	ue	in	in	in	in	psi	psi
47	5	118.73	68.96	72.93	29.16	64.20	20.59	0.0116	0.01784	0.0052	0.00097	4.419	1.219
55	25	86.80	68.72	51.57	29.18	40.30	22.27	0.0128	0.02005	0.0062	0.00278	4.715	1.297
61	45	77.27	69.48	43.33	29.20	40.50	20.95	0.0084	0.01852	0.0041	0.00133	4.025	1.267
69	55	70.63	70.27	37.90	29.17	35.95	20.88	0.0074	0.01866	0.0035	0.00137	4.305	1.282
		@ Longit Bottom	16.25 FRL	@ Longit Bottom	12.25 302	@ Transv Bottom	12.25 302	Surface		D_{surf} -	$D_{22.25}$		

Analysis based on laboratory sample testing

REAR DUAL WHEEL AC664 Dec'05 Averages and Calculated

RUN	speed	S2-S6	Calcul	S7,9,11	Calcul	S8,10,1	Calcul	LV1&4	Calcul	LV2&3	Calcul	P1&P2	Calcul
	mph	ue	ue	ue	ue	ue	ue	in	in	in	in	psi	psi
2	5	26.44	13.30	16.70	5.92	10.80	4.97	0.0053	0.0100	0.0017	0.00030	4.336	0.418
6	30	25.12	13.94	15.97	6.17	10.43	5.23	0.0048	0.0107	0.0014	0.00029	4.784	0.449
12	45	25.30	13.75	15.23	6.10	10.30	5.21	0.0035	0.0104	0.0012	0.00030	4.694	0.435
22	60	25.04	13.84	15.37	6.13	10.50	5.22	0.0041	0.0106	0.0014	0.00030	5.454	0.441
		@	16.25	@	12.25	@	12.25						
		Longit		Longit		Transv		Surface		D_{surf} -	$D_{22.25}$		
		Bottom	FRL	Bottom	302	Bottom	302						

REAR DUAL WHEELS AC664 July'06 Average and Calculated

RUN	Speed	S1-S6	Calcul	S7,9,11	Calcul	S10,12	Calcul	LV1&4	Calcul	LV2&3	Calcul	P1&P2	Calcul
	mph	ue	ue	ue	ue	ue	ue	in	in	in	in	psi	psi
47	5	118.73	38.26	72.93	15.20	64.20	11.33	0.0116	0.01484	0.0052	0.00055	4.419	0.844
55	25	86.80	39.31	51.57	15.67	40.30	12.51	0.0128	0.01539	0.0062	0.00143	4.715	0.901
61	45	77.27	39.02	43.33	15.42	40.50	11.68	0.0084	0.01503	0.0041	0.00073	4.025	0.881
69	55	70.63	39.43	37.90	15.39	35.95	11.64	0.0074	0.01514	0.0035	0.00075	4.305	0.891
		@	16.25	@	12.25	@	12.25						
		Longit		Longit		Transv		Surface		D_{surf} -	$D_{22.25}$		
		Bottom	FRL	Bottom	302	Bottom	302						

Analysis based on laboratory sample testing sigmoidal equation

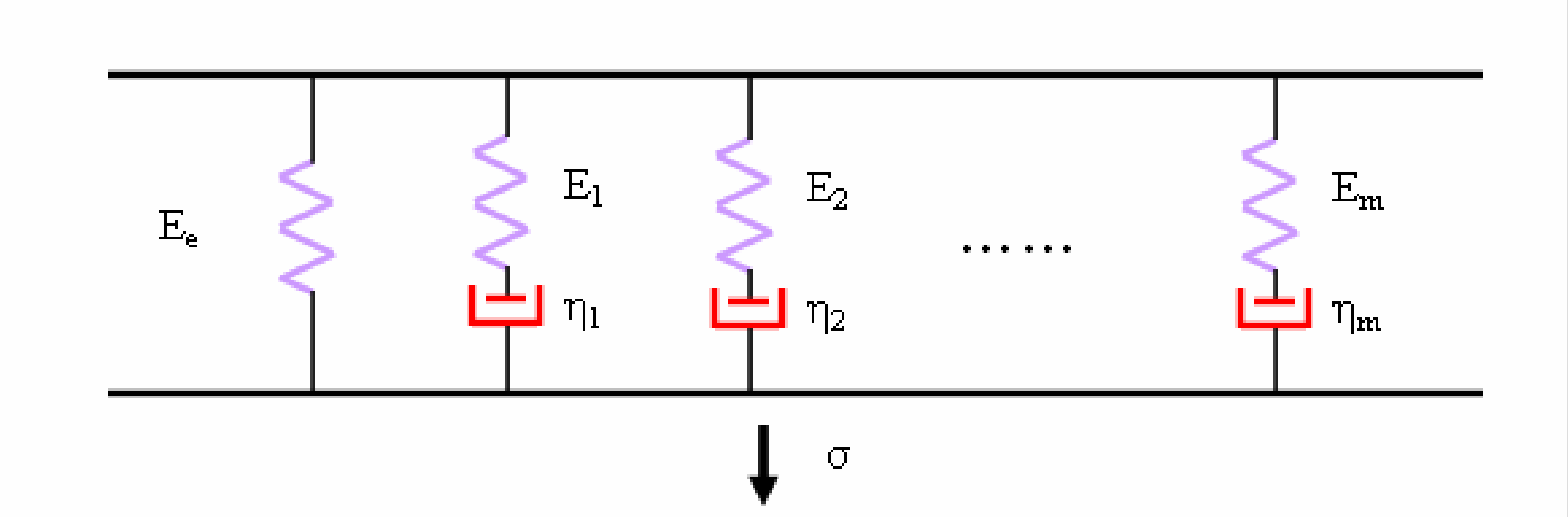
REAR DUAL WHEEL AC664 Dec'05 Averages and Calculated

RUN	speed	S2-S6	Calcul	S7,9,11	Calcul	S8,10,12	Calcul	LV1&4	Calcul	LV2&3	Calcul	P1&P2	Calcul
	mph	ue	ue	ue	ue	ue	ue	in	in	in	in	psi	psi
2	5	26.44	19.12	16.70	8.17	10.80	6.76	0.0053	0.0123	0.0017	0.00040	4.336	0.558
6	30	25.12	18.86	15.97	8.17	10.43	6.81	0.0048	0.0125	0.0014	0.00041	4.784	0.560
12	45	25.30	18.42	15.23	8.04	10.30	6.78	0.0035	0.0121	0.0012	0.00042	4.694	0.540
22	60	25.04	18.35	15.37	8.02	10.50	6.74	0.0041	0.0122	0.0014	0.00041	5.454	0.542
		@ Longit Bottom FRL	16.25	@ Longit Bottom	12.25 302	@ Transv Bottom	12.25 302	Surface		D_{surf} -	$D_{22.25}$		

REAR DUAL WHEELS AC664 July'06 Average and Calculated

RUN	Speed	S1-S6	Calcul	S7,9,11	Calcul	S10,12	Calcul	LV1&4	Calcul	LV2&3	Calcul	P1&P2	Calcul
	mph	ue	ue	ue	ue	ue	ue	in	in	in	in	psi	psi
47	5	118.73	47.51	72.93	20.15	64.20	14.81	0.0116	0.01574	0.0052	0.00067	4.419	0.948
55	25	86.80	37.65	51.57	15.72	40.30	12.61	0.0128	0.01472	0.0062	0.00118	4.715	0.859
61	45	77.27	34.12	43.33	14.04	40.50	10.81	0.0084	0.01408	0.0041	0.00060	4.025	0.794
69	55	70.63	33.45	37.90	13.60	35.95	10.49	0.0074	0.01401	0.0035	0.00060	4.305	0.787
		@ Longit Bottom	16.25 FRL	@ Longit Bottom	12.25 302	@ Transv Bottom	12.25 302	Surface		D_{surf} -	$D_{22.25}$		

Mechanical Model - The Generalized Maxwell model



$$E(t) = E_e + \sum_{i=1}^{m} E_i e^{-(t/\tau_i)}$$

Material Properties

Layer	Instantaneous Elastic Modulus Used in ABAQUS (ksi)	Measured Relaxation Modulus (ksi)
SMA	706	726.6
ODOT442	529	501.8
ODOT302	1118	1169.0
FRL	1176	1518.5
Base	20$	10 – 40*$
Subgrade	8$	7.5$

$ these are resilient modulus;

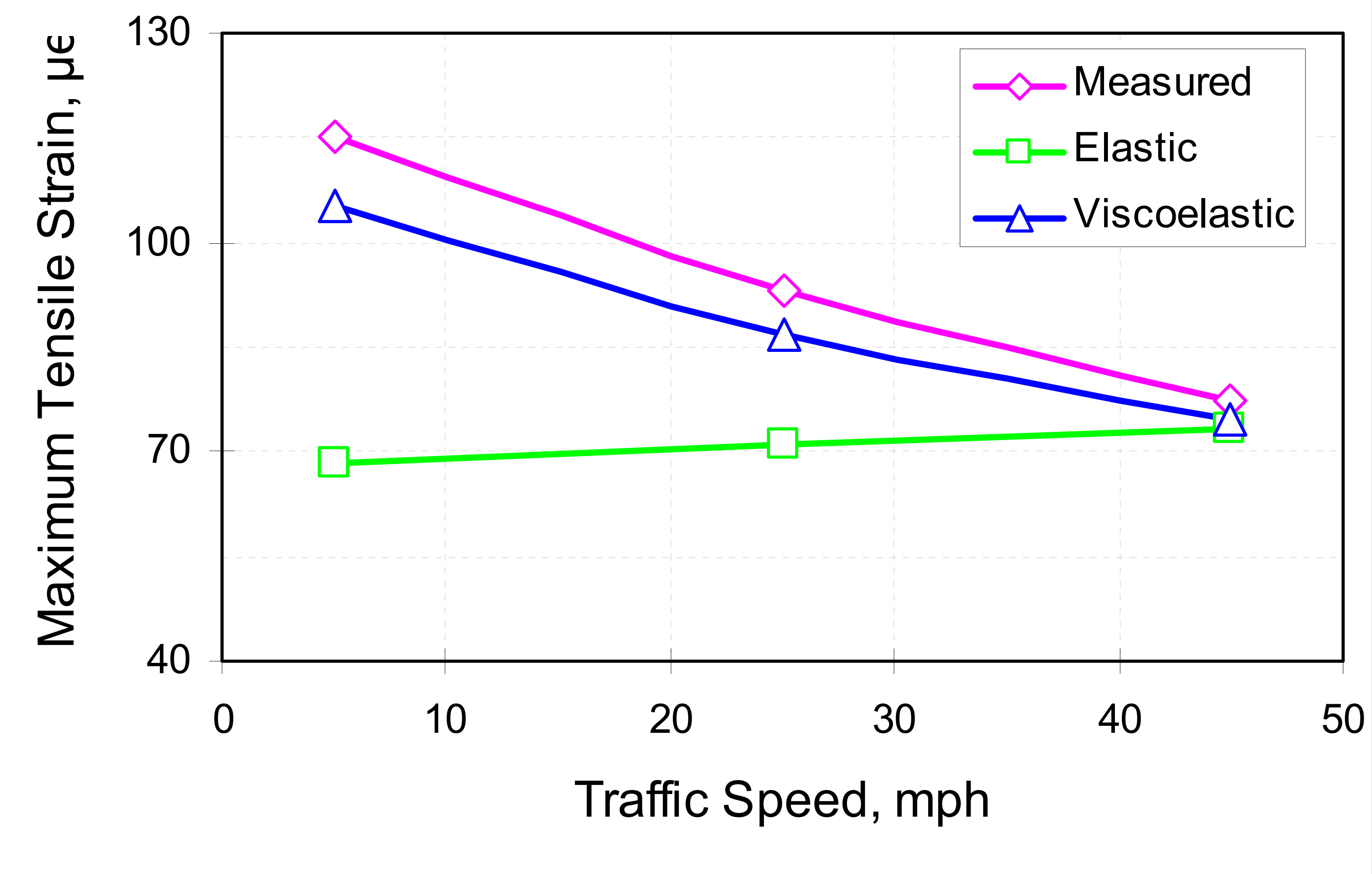
*This is the normal range for aggregates;

All HMA moduli are referred at a temperature of 21.1 C.

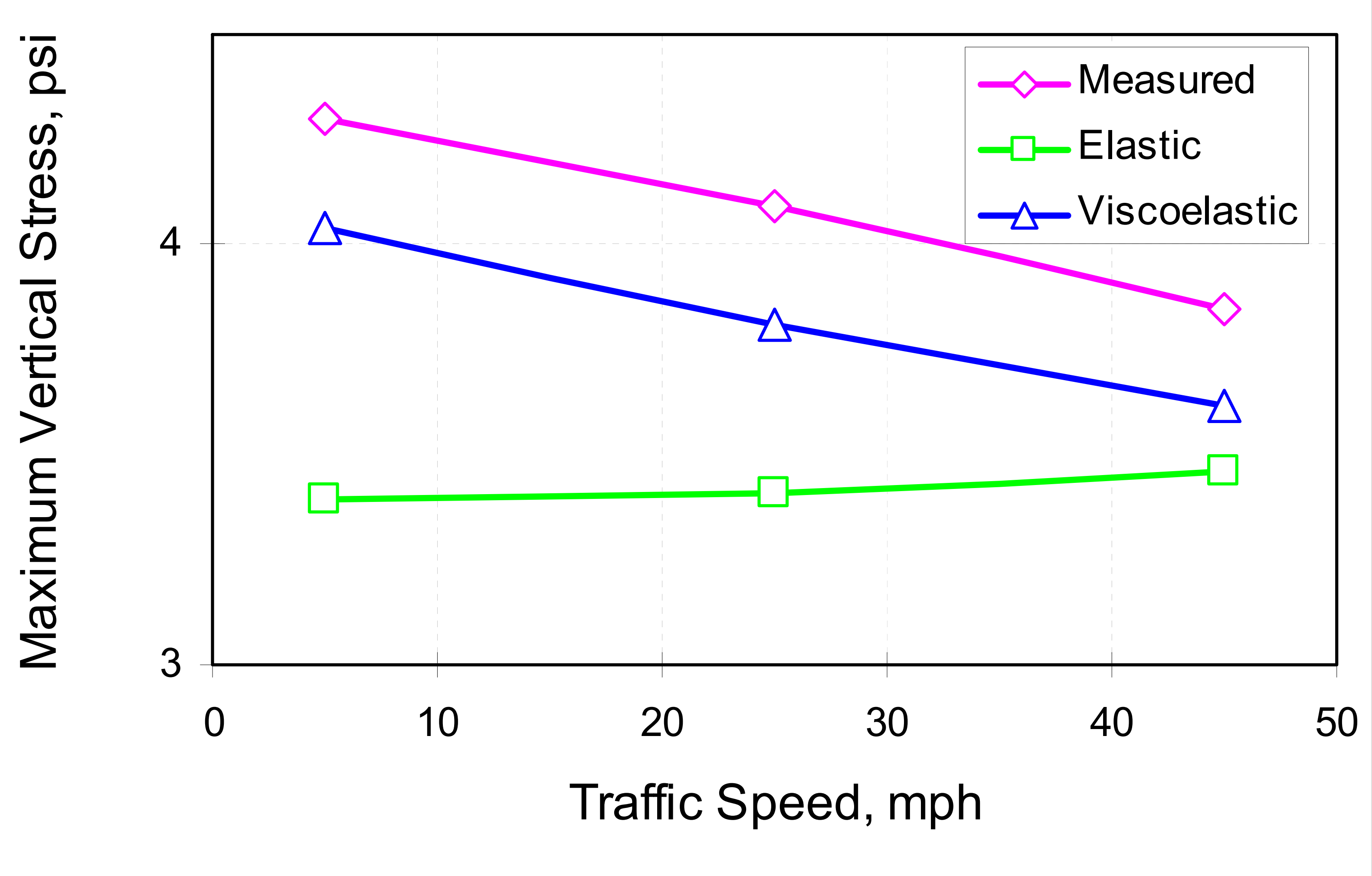
Elastic FE Model vs. Viscoelastic FE Model

- To compare their relative performance in predicting pavement response at different truck speeds of 5 mph, 25 mph, and 45 mph.
- Pavement response was collected at the U.S. 30 test section.
- In the elastic FE model, the effect of pavement temperature is included.
- Both models are calibrated to pavement response at a truck speed of 55 mph.
- It is noted that pavement temperature slightly decreased when truck speed decreased from 45 mph to 5 mph.

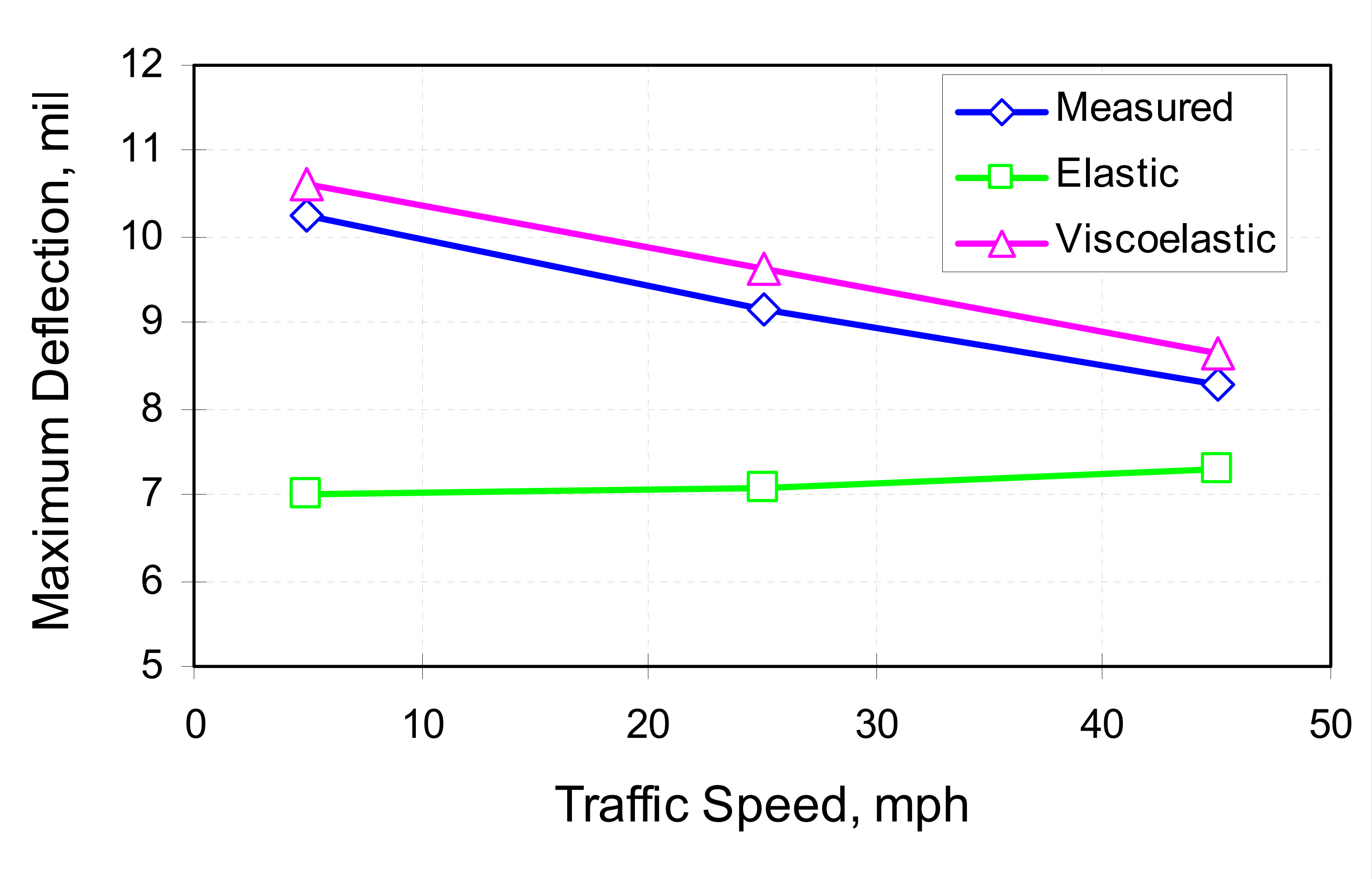
Elastic FE Model vs. Viscoelastic FE Model



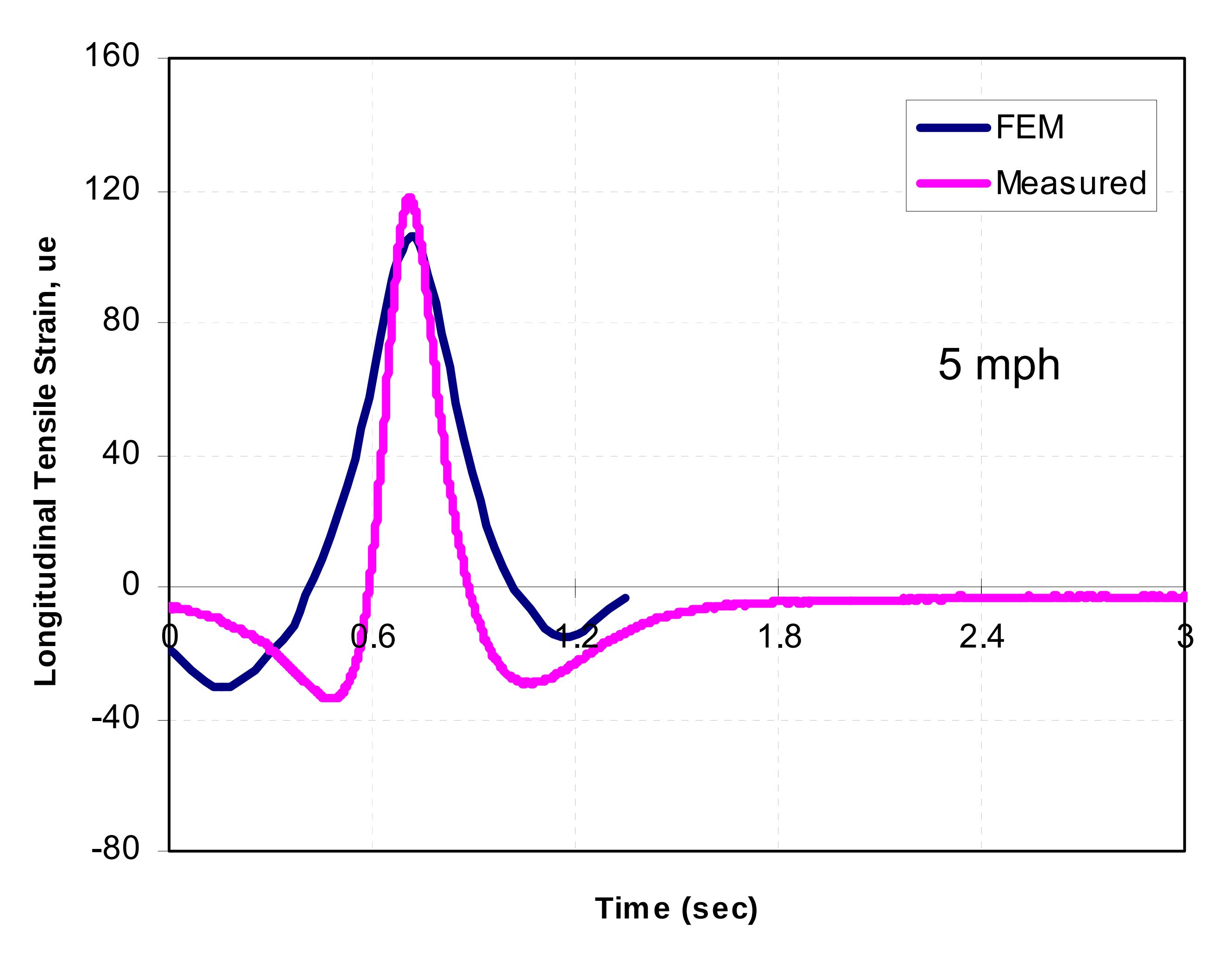
Elastic FE Model vs. Viscoelastic FE Model



Elastic FE Model vs. Viscoelastic FE Model



Comparison of Longitudinal Tensile Strain



Conclusions

Elastic Layer Analysis

- General agreement between computed and measured values of longitudinal strain at bottom of FRL only when using resilient modulus from field cores, and only at higher speeds.
- Calculated longitudinal and transverse strains at bottom of intermediate layer are are always lower than measured values.
- Calculated surface deflections are always higher than measured values.
- Both the calculated net pavement deflection and the subgrade pressure are lower than the measured values.

Conclusions

Elastic Layer Analysis

- Using dynamic modulus of laboratory-prepared specimens with sigmoidal equation does not yield reasonably close verification of any parameters.
- Using resilient modulus of laboratory-prepared specimens does not yield reasonably close verification of any parameters.
- Using resilient modulus of field cores generally yields correct trends, though not values matching measurements.
- ELS theory is capable of matching one parameter but not all.
- ELS not appropriate for simulating time-dependent loading due to trucks.
- Some discrepancies may arise from differences in air void content and density between field cores and laboratory prepared samples.

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