Recycling and WMA Fatigue Cracking Update Accelerated Load Facility

Fall 2015 Expert Task Group

Oklahoma City

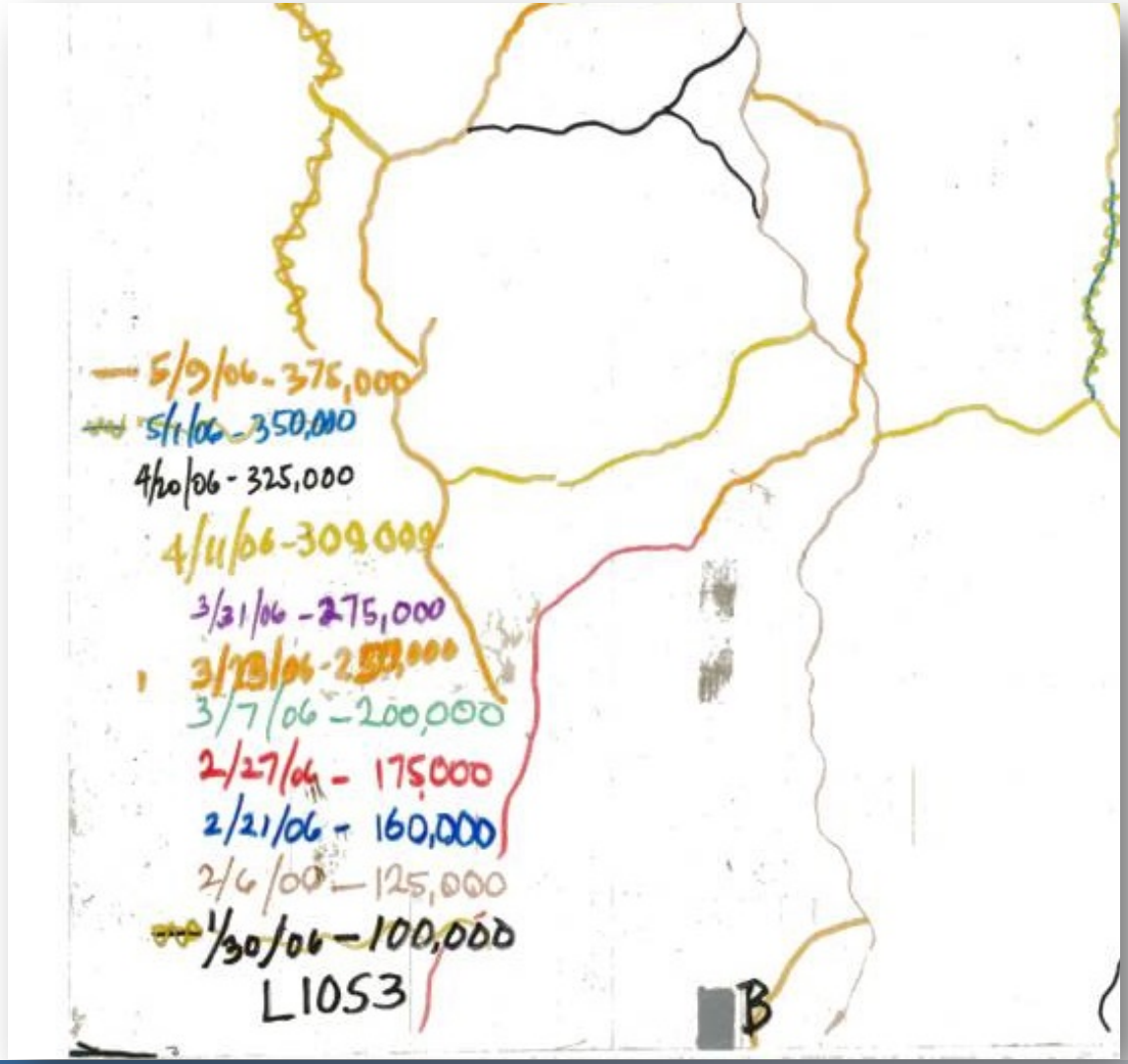
ALF Experimental Design

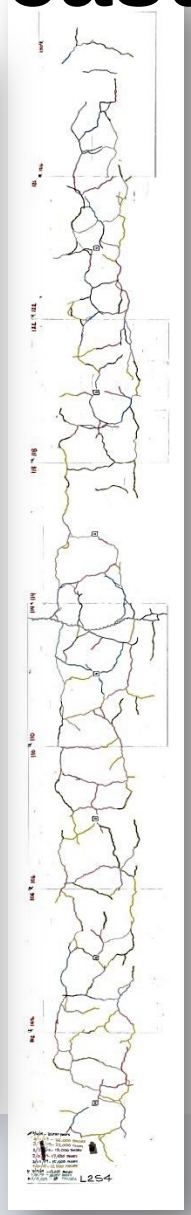
ALF Lane	% RBR		Virgin Binder PG	WMA Process
	RAP	RAS		
1	0	-	64-22	-
2	40	-	58-28	Water
3	-	20	64-22	-
4	20	-	64-22	Chemical
5	40	-	64-22	-
6	20	-	64-22	-
7	-	20	58-28	-
8	40	-	58-28	-
9	20	-	64-22	Water
11	40	-	58-28	Chemical

85% Complete

Lane 9	WMA-Foam 20% ABR	Complete
Lane 11	WMA-Chem 40% ABR 58-28	Complete
Lane 5	HMA 40% ABR	Complete
Lane 1	HMA 0% Control	Complete
Lane 3	HMA 20% ABR RAS	Complete
Lane 4	WMA-Chem 20% ABR	Complete
Lane 7	HMA 20% ABR RAS 58-28	Complete
Lane 2	WMA-Foam 40% ABR 58-28	Loading Now…
Lane 8	HMA 40% ABR 58-28	Loading Now…
Lane 6	HMA 20% ABR	Next

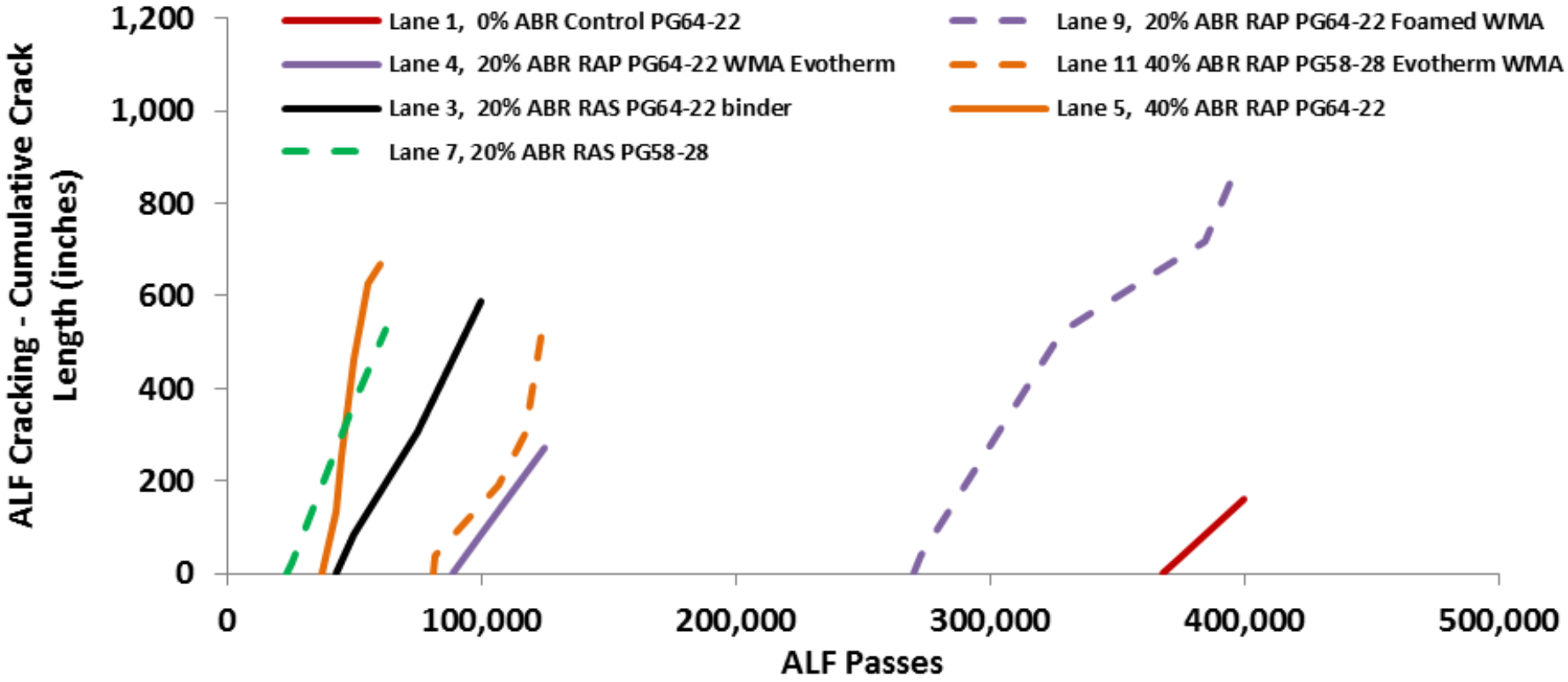
Cracking Performance Measured…





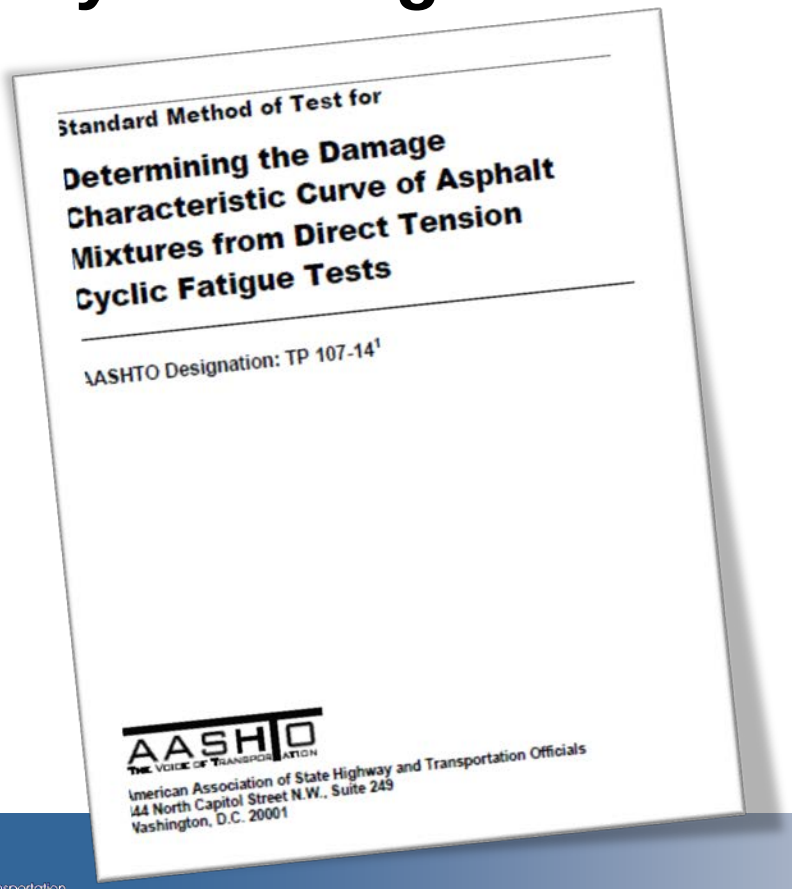
Crack lengths are individually traced with "map-measure"

Cracking Performance Measured…



Laboratory Performance Tests

- Cyclic Fatigue withOUT Structural Analysis
- Cyclic Fatigue WITH Structural Analysis

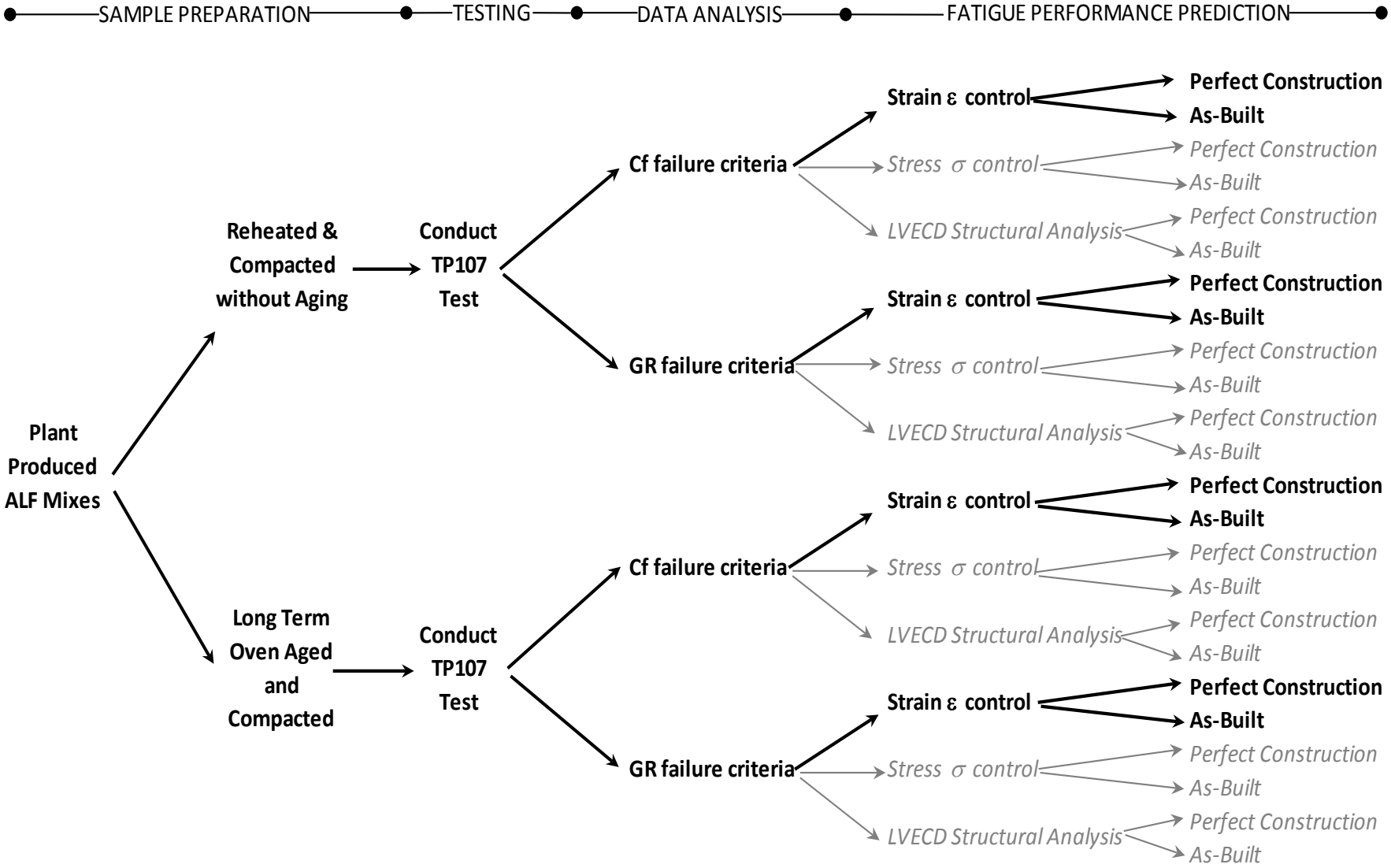

Standard Method of Test for

Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests

AASHTO Designation: TP 107-14[1]

AASHTO
THE VOICE OF TRANSPORTATION

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001


SAMPLE PREPARATION
TESTING
DATA ANALYSIS
FATIGUE PERFORMANCE PREDICTION
Plant Produced ALF Mixes
Reheated & Compacted without Aging
Long Term Oven Aged and Compacted
Conduct TP107 Test
Conduct TP107 Test
Cf failure criteria
GR failure criteria
Cf failure criteria
GR failure criteria
Strain ε control
Stress σ control
LVECD Structural Analysis
Strain ε control
Stress σ control
LVECD Structural Analysis
Strain ε control
Stress σ control
LVECD Structural Analysis
Strain ε control
Stress σ control
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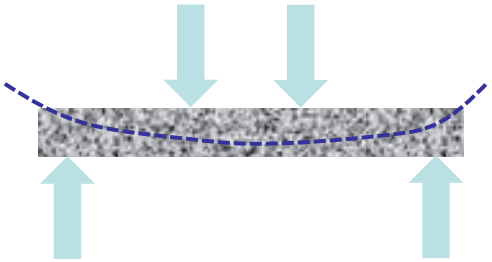
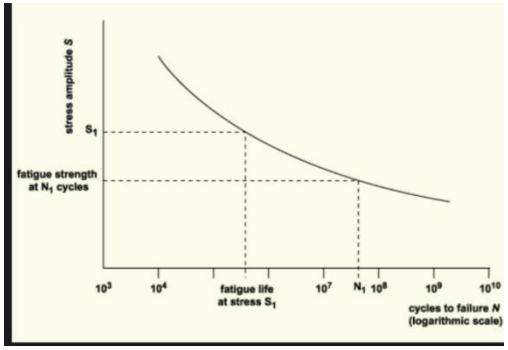
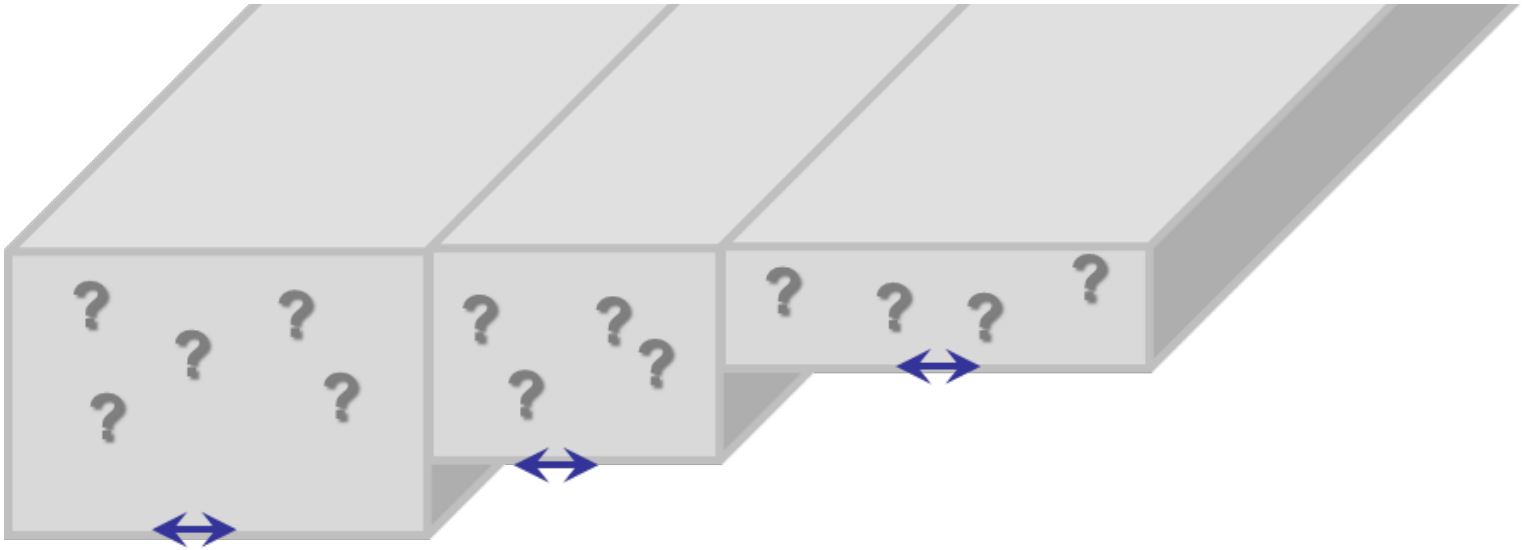
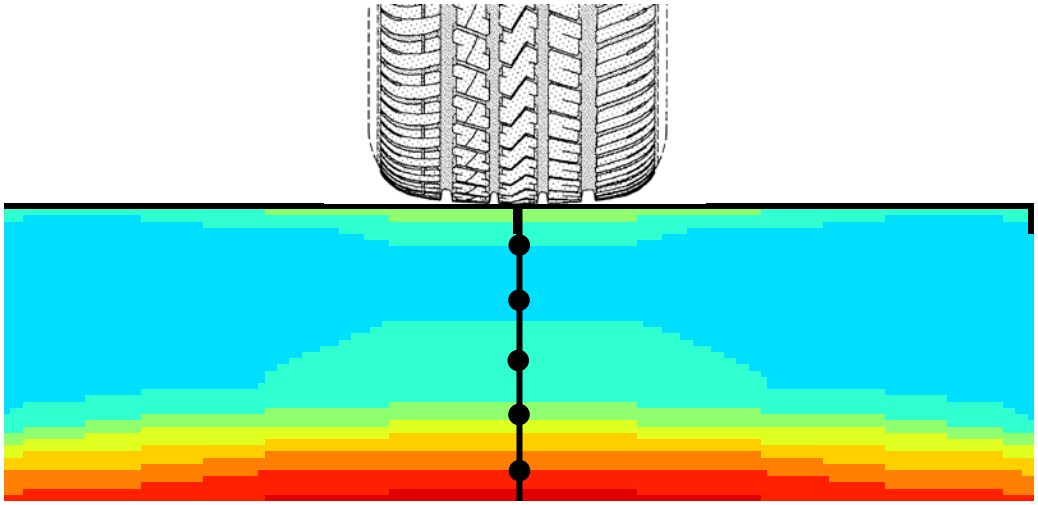




“Classic” fatigue life curves representing uniaxial or flexural laboratory strains are used to interpret a single point in the pavement, but not the entire thickness





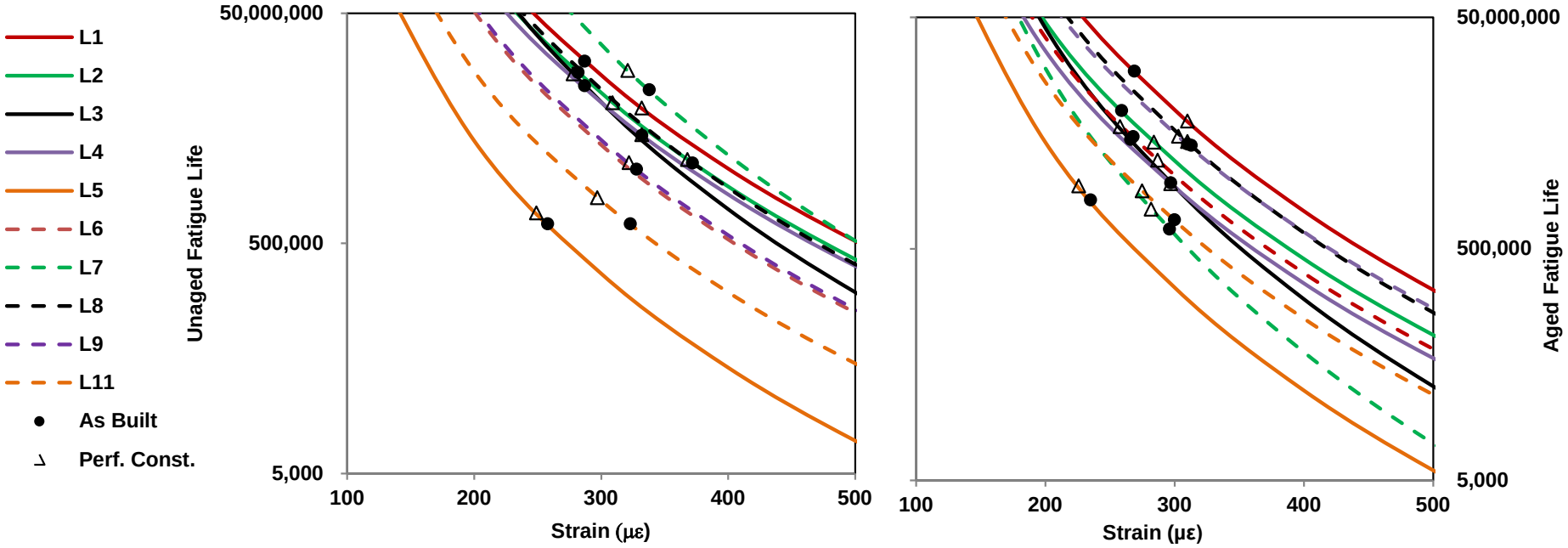
LVECD provides insight into damage throughout the depth and should provide a more complete picture of pavements structural response to:

- **Supporting Layers**
- **Traffic**
- **Temperature**

These affect more than just an infinitesimal point.

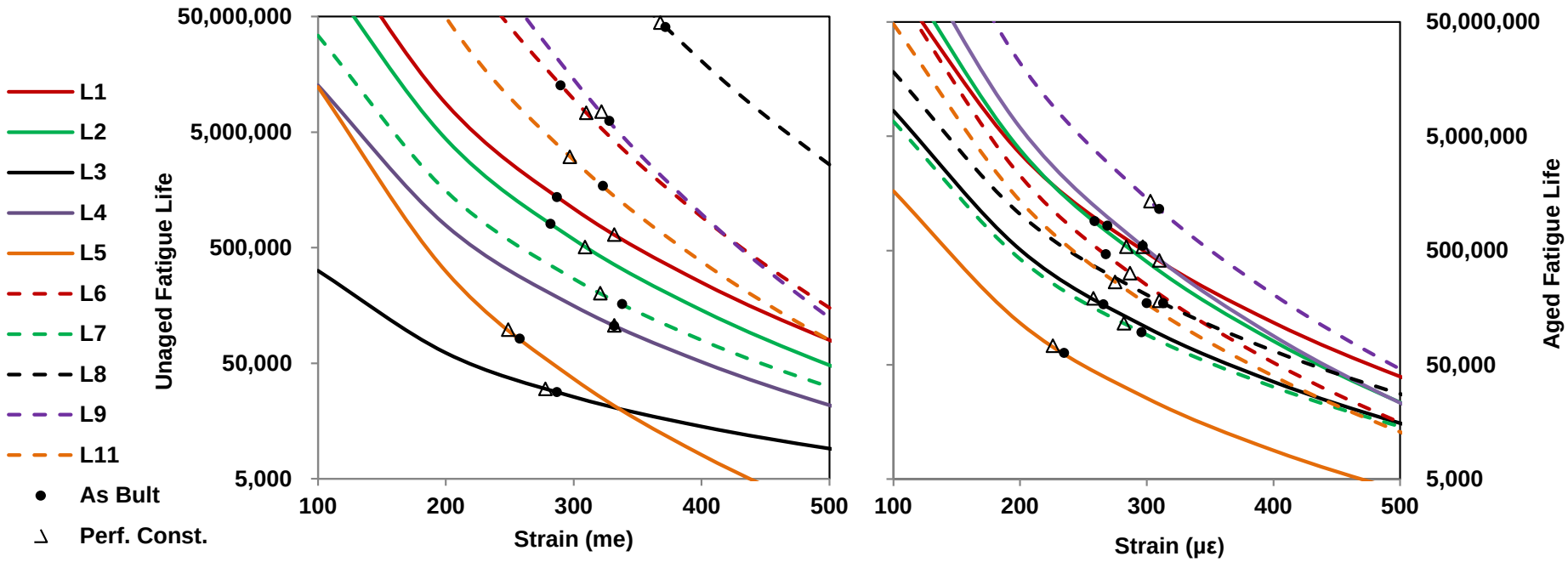
Fatigue Life Curves

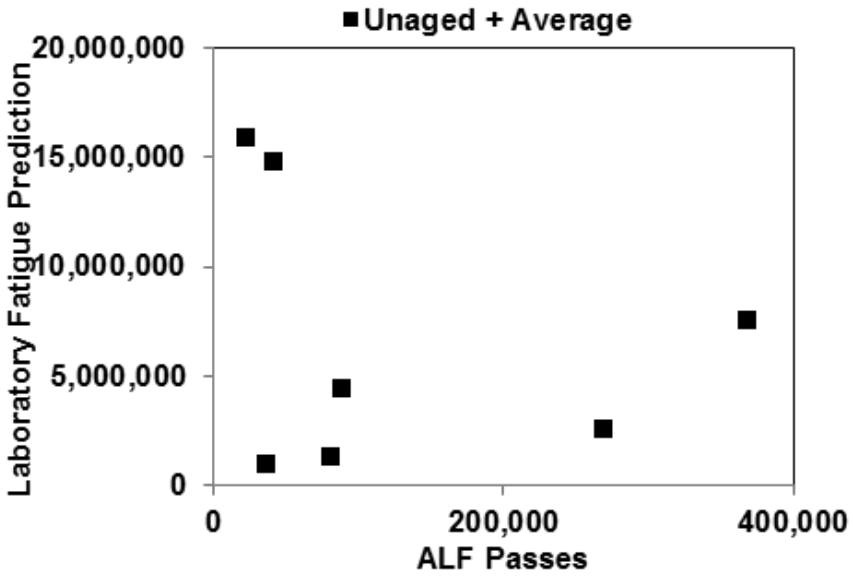
C_f failure criteria

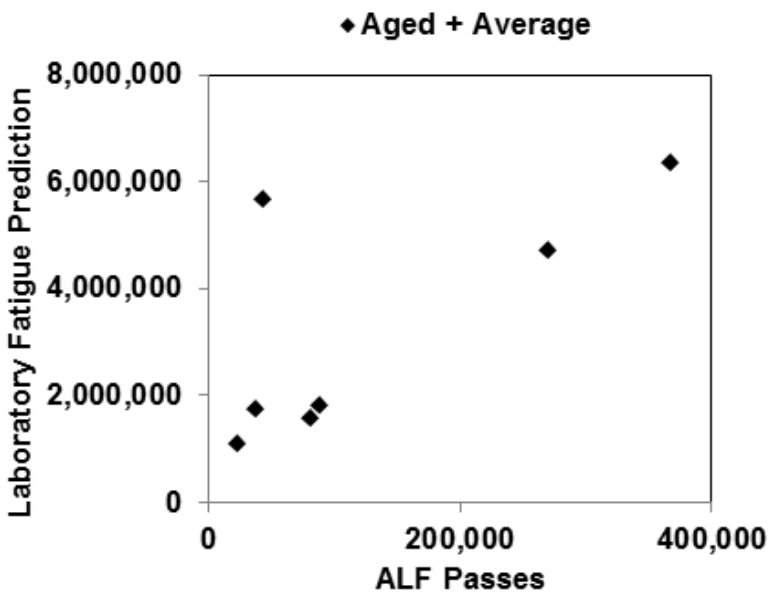


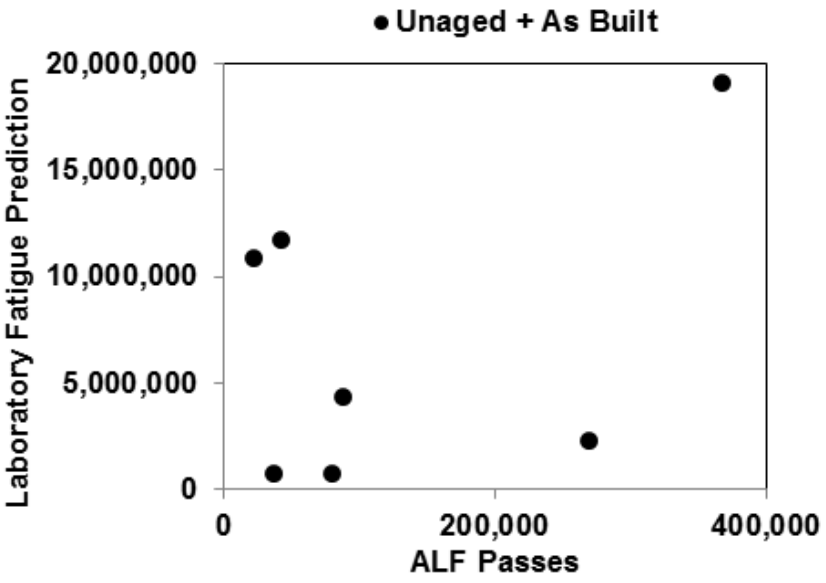
Fatigue Life Curves

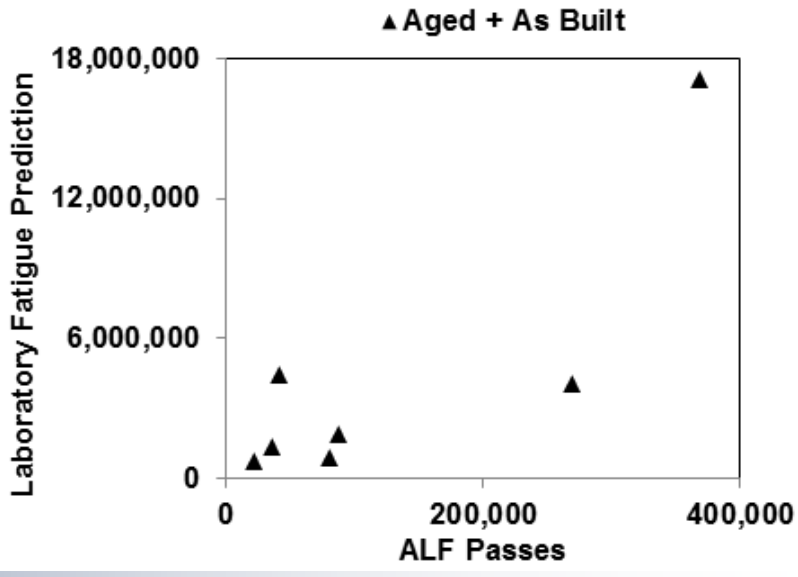
G_R failure criteria




Unaged + Average
Laboratory Fatigue Prediction
20,000,000
15,000,000
10,000,000
5,000,000
0
0
200,000
400,000
ALF Passes


Aged + Average
Laboratory Fatigue Prediction
8,000,000
6,000,000
4,000,000
2,000,000
0
0
200,000
400,000
ALF Passes


Unaged + As Built
Laboratory Fatigue Prediction
20,000,000
15,000,000
10,000,000
5,000,000
0
0
200,000
400,000
ALF Passes


Aged + As Built
Laboratory Fatigue Prediction
18,000,000
12,000,000
6,000,000
0
0
200,000
400,000
ALF Passes

Ranking – AMPT Fatigue withOUT Structural Analysis

Ranking	ALF Pavement Cracking	Laboratory Failure Criteria									
		Sample Breaks in AMPT* (Figure 4e&f)		Pseudostiffness at peak phase angle, C_f				Dissipated Pseudostrain Energy, G^R			
				Unaged		Aged		Unaged		Aged	
		Unaged	Aged	AB	PC	AB	PC	AB	PC	AB	PC
Best Three	L1	L8	*L9*	*L1*	L7	*L1*	*L1*	L8	L8	*L9*	*L9*
	L9	*L1*	*L1*	*L2*	L3	*L2*	L3	L6	*L9*	*L2*	*L2*
	L4	L4	L8	L3	*L2*	L6	*L9*	*L9*	L6	*L1*	L4
Middle Four	L11**	*L2*	*L2*	L7	L1	L3	*L8*	*L11*	*L11*	*L4*	L1
		L6	*L4*	*L4*	*L4*	L9	*L2*	L1	L1	*L6*	*L6*
		L9	*L6*	*L8*	*L8*	*L8*	*L6*	*L2*	*L2*	*L8*	*L11*
		L11	*L11*	L9	L9	*L4*	*L4*	L7	L7	*L11*	L3
Worst Three	L3	*L3*	*L3*	L6	L6	*L5*	*L5*	L4	L4	*L3*	L8
	L5	*L5*	*L5*	*L5*	L11	L11	*L7*	*L5*	*L5*	*L7*	*L7*
	L7	*L7*	*L7*	L11	*L5*	*L7*	L11	*L3*	*L3*	*L5*	*L5*

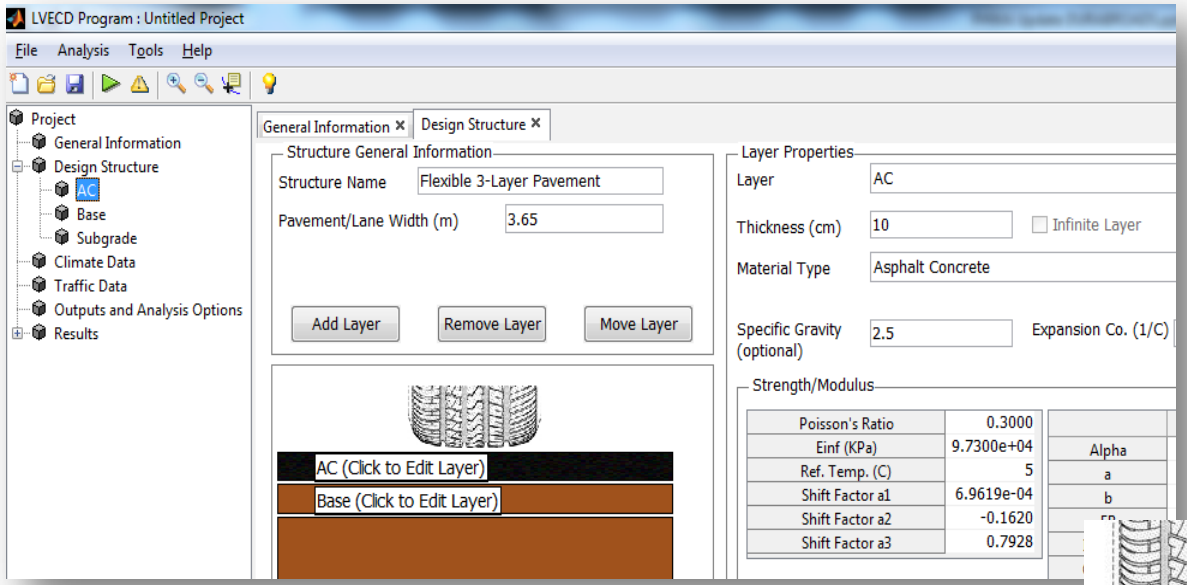
**No S-VECD analysis, only the outcome of the physical tests*

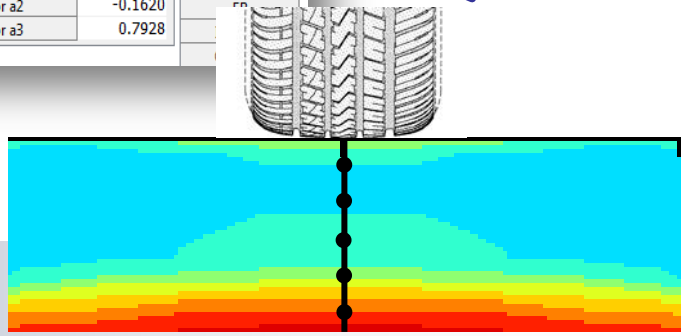
*** 7 of 10 ALF lanes have performance available at the time of publication*

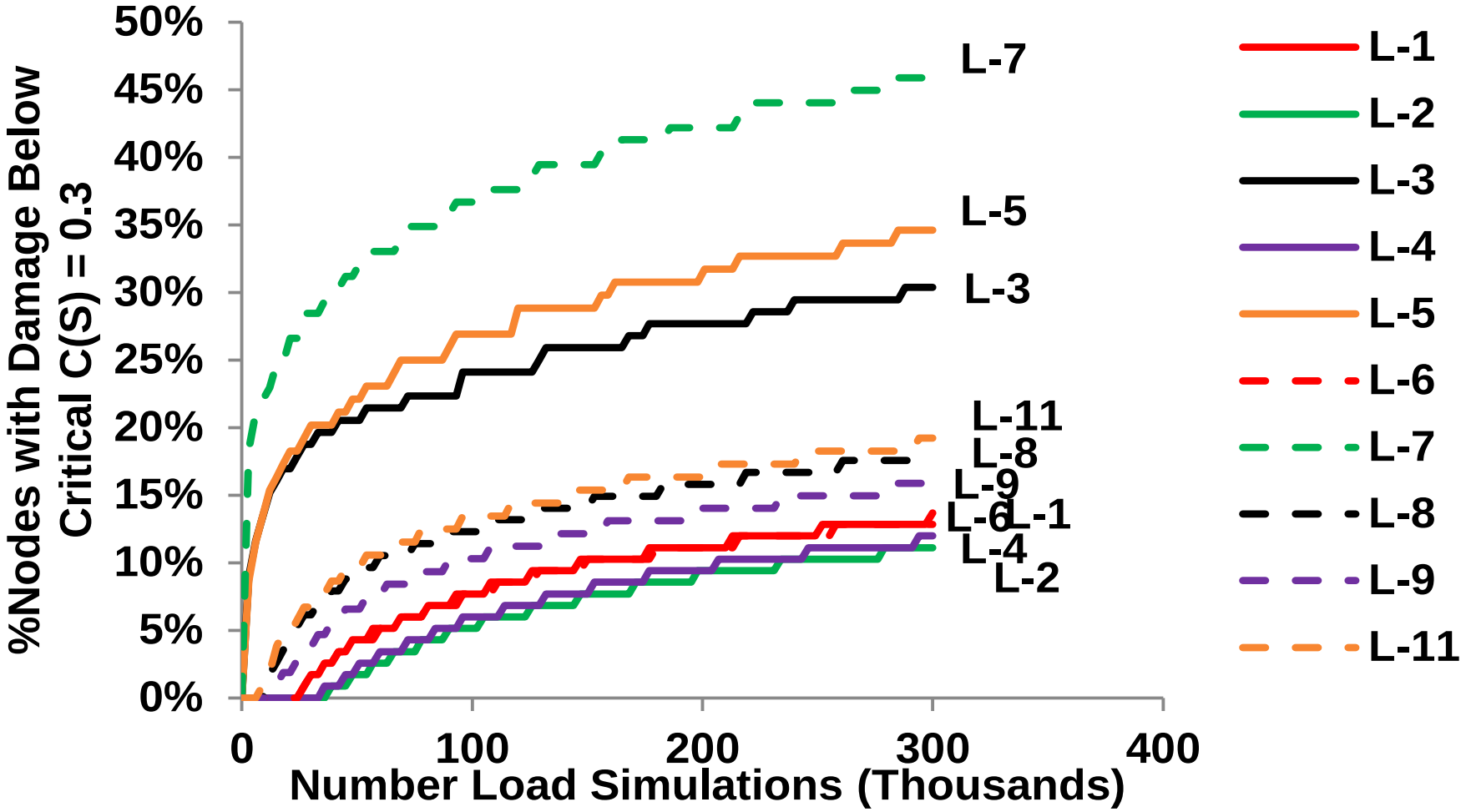
AB = As Built & PC = Perfect Construction

AMPT Fatigue + Structural Analysis

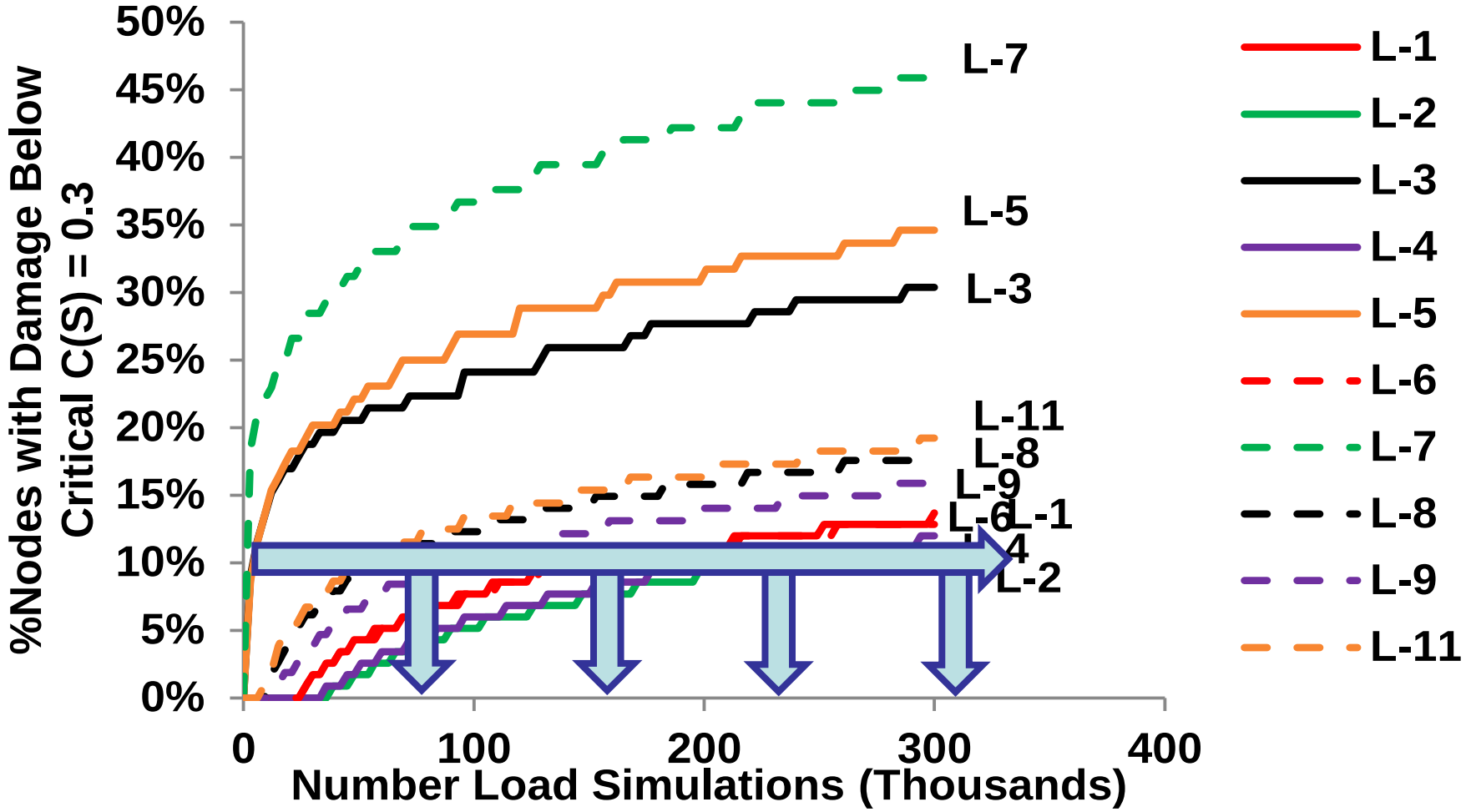
Quantify the damage throughout the whole depth rather than relying on a single point at the bottom of the asphalt layer.



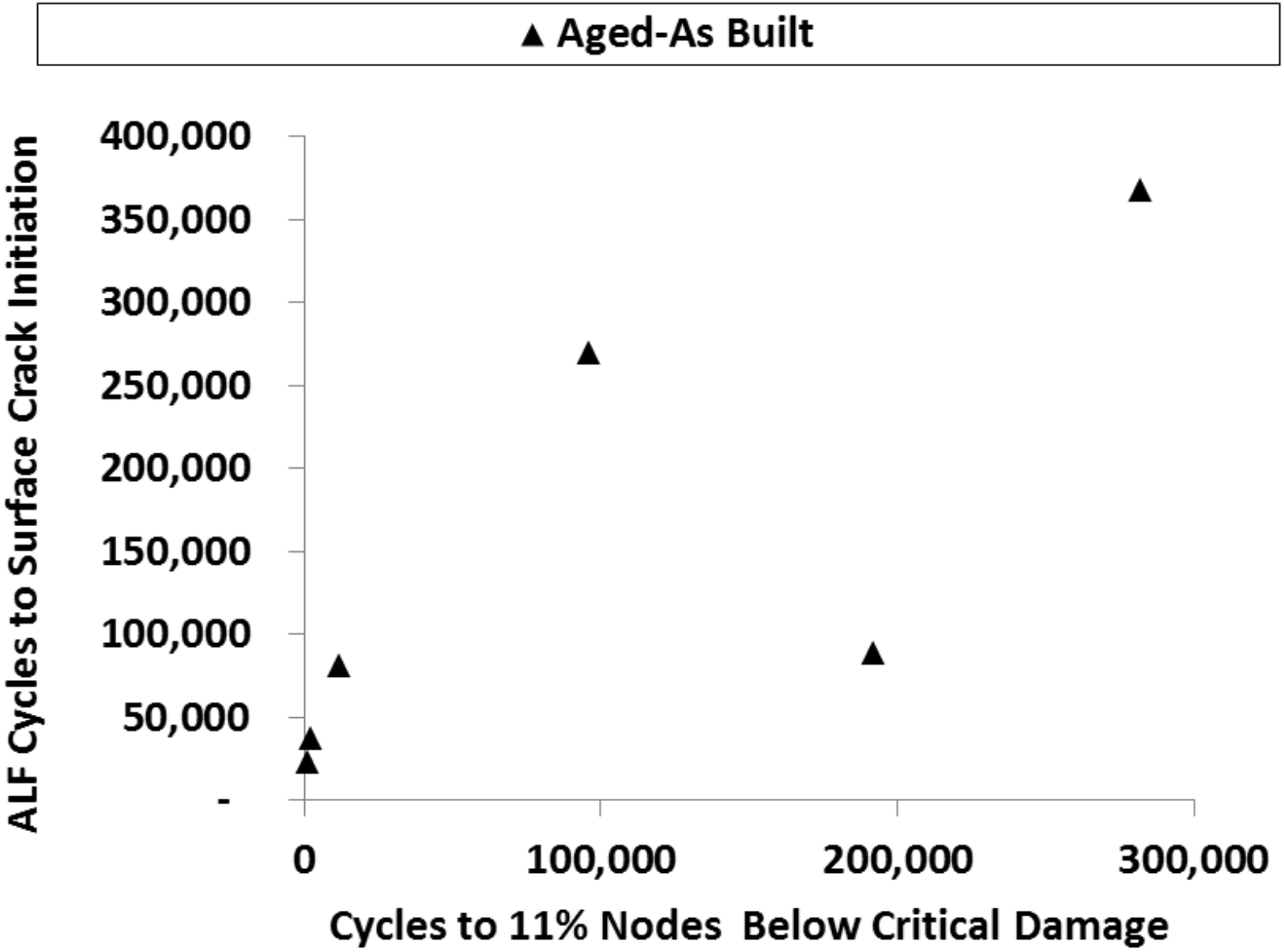


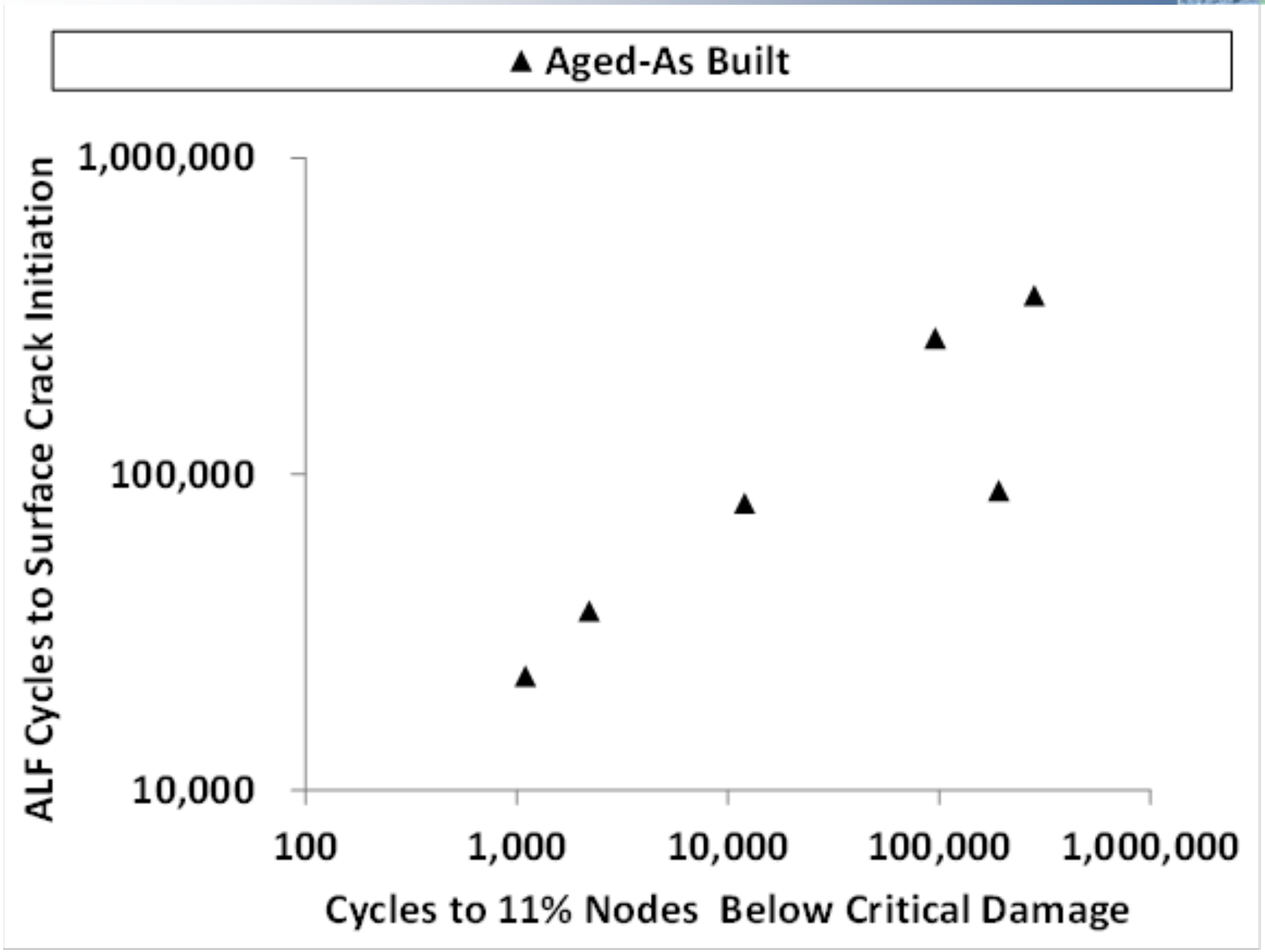


Perfect Construction-Unaged.



Perfect Construction-Unaged.


▲ Aged-As Built
ALF Cycles to Surface Crack Initiation
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
-
0
100,000
200,000
300,000
Cycles to 11% Nodes Below Critical Damage


▲ Aged-As Built
ALF Cycles to Surface Crack Initiation
1,000,000
100,000
10,000
100
1,000
10,000
100,000
1,000,000
Cycles to 11% Nodes Below Critical Damage

Ranking – AMPT Fatigue WITH Structural Analysis

LVECD Structural Prediction % Nodes Below Critical Damage								Measured ALF Performance	
Unaged				Aged					
As Built		Perfect Construction		As Built		Perfect Construction			
L2	9%	L2	11%	L1	12%	L4	12%	L1	368,254
L1	10%	L4	12%	L4	14%	L1	14%	L9	270,058
L4	13%	L6	13%	L9	16%	L9	17%	L4	88,740
L6	13%	L1	14%	L2	18%	L2	19%		
L9	15%	L9	16%	L6	19%	L6	19%	*Lanes 2, 6, and 8 remain to be tested*	
L8	18%	L8	17%	L8	22%	L8	21%		
L11	19%	L11	18%	L11	29%	L11	28%	L11	81,044
L3	31%	L3	31%	L5	42%	L5	47%	L3	42,399
L7	-	L5	35%	L7	66%	L7	62%	L5	36,946
L5	-	L7	46%	L3	-	L3	-	L7	23,005

Ranking	ALF Pavement Cracking	Laboratory Failure Criteria									
		Sample Breaks in AMPT* (Figure 4e&f)		Pseudostiffness at peak phase angle, C_f				Dissipated Pseudostrain Energy, G^R			
				Unaged		Aged		Unaged		Aged	
		Unaged	Aged	AB	PC	AB	PC	AB	PC	AB	PC
Best Three	L1	L8	*L9*	*L1*	L7	*L1*	*L1*	L8	L8	*L9*	*L9*
	L9	*L1*	*L1*	*L2*	L3	*L2*	L3	L6	*L9*	*L2*	*L2*
	L4	L4	L8	L3	*L2*	L6	*L9*	*L9*	L6	*L1*	L4
Middle Four	L11**	*L2*	*L2*	L7	L1	L3	*L8*	*L11*	*L11*	*L4*	L1
		L6	*L4*	*L4*	*L4*	L9	*L2*	L1	L1	*L6*	*L6*
		L9	*L6*	*L8*	*L8*	*L8*	*L6*	*L2*	*L2*	*L8*	*L11*
		L11	*L11*	L9	L9	*L4*	*L4*	L7	L7	*L11*	L3
Worst Three	L3	*L3*	*L3*	L6	L6	*L5*	*L5*	L4	L4	*L3*	L8
	L5	*L5*	*L5*	*L5*	L11	L11	*L7*	*L5*	*L5*	*L7*	*L7*
	L7	*L7*	*L7*	L11	*L5*	*L7*	L11	*L3*	*L3*	*L5*	*L5*

**No S-VECD analysis, only the outcome of the physical tests*
*** 7 of 10 ALF lanes have performance available at the time of publication*
AB = As Built & PC = Perfect Construction

LVECD Structural Prediction % Nodes Below Critical Damage								Measured ALF Performance	
Unaged				Aged					
As Built		Perfect Construction		As Built		Perfect Construction			
L2	9%	L2	11%	L1	12%	L4	12%	L1	368,254
L1	10%	L4	12%	L4	14%	L1	14%	L9	270,058
L4	13%	L6	13%	L9	16%	L9	17%	L4	88,740
L6	13%	L1	14%	L2	18%	L2	19%		
L9	15%	L9	16%	L6	19%	L6	19%	*Lanes 2, 6, and 8 remain to be tested*	
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Chart Area

Ranking	ALF Pavement Cracking	Laboratory Failure Criteria									
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				Unaged		Aged		Unaged		Aged	
		Unaged	Aged	AB	PC	AB	PC	AB	PC	AB	PC
Best Three	L1	L8	***L9***	***L1***	L7	***L1***	***L1***	L8	L8	***L9***	***L9***
	L9	***L1***	***L1***	***L2***	L3	***L2***	L3	L6	***L9***	***L2***	***L2***
	L4	L4	L8	L3	***L2***	L6	***L9***	***L9***	L6	***L1***	L4
Middle Four	L11**	***L2***	***L2***	L7	L1	L3	***L8***	***L11***	***L11***	***L4***	L1
		L6	***L4***	***L4***	***L4***	L9	***L2***	L1	L1	***L6***	***L6***
		L9	***L6***	***L8***	***L8***	***L8***	***L6***	***L2***	***L2***	***L8***	***L11***
		L11	***L11***	L9	L9	***L4***	***L4***	L7	L7	***L11***	L3
Worst Three	L3	***L3***	***L3***	L6	L6	***L5***	***L5***	L4	L4	***L3***	L8
	L5	***L5***	***L5***	***L5***	L11	L11	***L7***	***L5***	***L5***	***L7***	***L7***
	L7	***L7***	***L7***	L11	***L5***	***L7***	L11	***L3***	***L3***	***L5***	***L5***

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L5	-	L7	46%	L3	-	L3	-	L7	23,005

Chart Area

Summary

- More consistent agreement was found between the structural prediction of the damage distribution through the thickness of the simulated pavement and the measured ALF fatigue cracking

Summary

- **Complete data set is almost complete but it might indicate 4 clusters** in decreasing order of performance
  - 0% Recycle
  - 20% RAP-BR 64-22
  - 40% RAP-BR 58-28
  - "Poor": RAS & 40% RAP-BR 64-22

Next Steps

- **Will determine how much binder needs to be added for RAS & 40% RAP-BR mixes to exhibit equivalent performance.**
- **Will be conducting performance tests on 40% RAS & RAP-BR + 0.5%, 1.0% binder.**
- **Which mix is the reference mix that should be the equivalent performance target?**
  - **0% or 20% RAP-BR?**

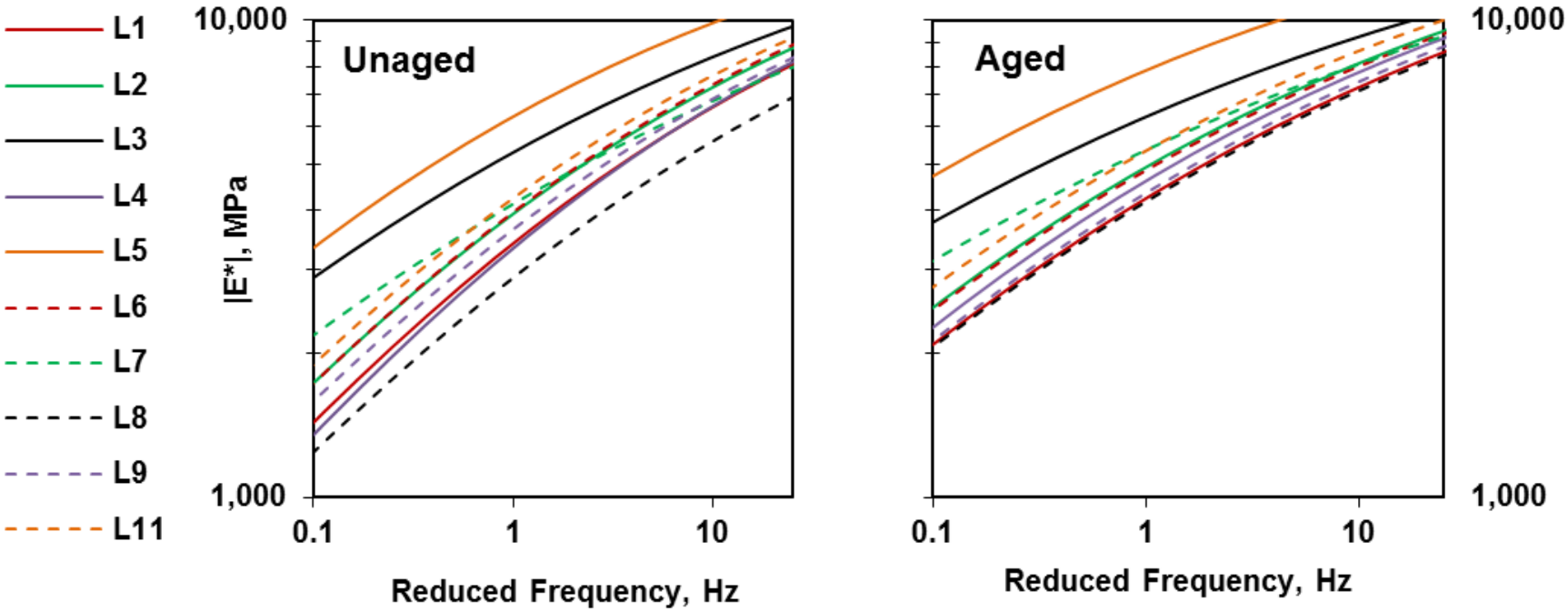
Thank You

Questions?

Comments?

Concerns?

Dynamic Complex Modulus



ALF Experimental Design

HMA / WMA Production Temperature	300°F - 320°F		240°F - 270°F	
Warm Mix Technology	-		Foam	Chem.
Recycle Content				
0%	✔ PG64-22		-	-
20% ABR RAP ≈ 23% by weight	✔ PG64-22		✔ PG64-22	✔ PG64-22
20% ABR RAS ≈ 6% Shingle by weight	✔ PG64-22	✔ PG58-28		
40% ABR RAP ≈ 44% by weight	✔ PG64-22	✔ PG58-28	✔ PG58-28	✔ PG58-28

"Classic" Fatigue Life Curves

Complete Failure in Test