Northeast Asphalt User/Producer Group

Precision of the E* Test for Use in M-E Design of Flexible Pavement Construction

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Overview of Study

- Dynamic Modulus (E*) of hot mix asphalt required for stress/strain calculations in the MEPDG
- Current test procedure, AASHTO TP62-03
  - Currently, no precision statement associated
  - Some recommendations for quality of data (load standard error; deformation standard error, load drift)
- Round Robin study initiated to evaluate expected precision of AASHTO TP62 and influence on outputs from MEPDG software

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E* Study – Test Specimens

- All samples shipped out by last week of July
  - 9.5mm Superpave (N_{design} = 100; PG64-22; 5.0% AC)
  - 25mm Superpave (N_{design} = 100; PG64-22; 4.2% AC)
  - Mixed at Rutgers and placed in wax-lined sample boxes (7,400 ± 5 grams)
    - Every 5th sample used for QC testing (gradation, G_{mm})
  - Numbers assigned to each box and randomly distributed (Excel Random Number Generator)
  - 4 boxes of each mix sent to labs, told to only test 3 per mix
  - Labs responsible for using all mix provided in box for sample (5 to 6% air voids)
    - Compact, cut, core, and test according to AASHTO TP62-03
- Currently, 5 of 8 labs completed testing

Example of Lab QC Testing

Particle Size		Standard Deviation	JMF - Ave (%)	COV (%)
Sieve Number	(mm)			
2"	50	0.000	0.00	0.00
1.5"	37.5	0.000	0.00	0.00
1.0"	25	0.000	0.00	0.00
3/4"	19	0.542	-0.49	0.55
1/2"	12.5	1.659	-0.45	2.21
3/8"	9.5	1.959	-0.04	3.34
#4	4.75	1.259	0.23	3.16
#8	2.38	0.749	1.15	2.56
#16	1.18	0.803	0.79	3.47
#30	0.6	0.780	0.37	4.25
#50	0.3	0.674	-0.75	5.25
#100	0.15	0.545	-0.69	6.55
#200	0.075	0.312	-0.36	5.91

Sample #	G_{mm} Value (T209)
#1	2.757
#2	2.741
#3	2.765
#4	2.768
#5	2.756
#6	2.754
#7	2.762
#8	2.760
Average	2.758
Std Dev	0.0083

QC Data from 25mm HMA Production

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Round Robin Partners

- Thomas Bennert (Rutgers U.)
- Ray Bonaquist (AAT)
- Kevin Hall (U of Arkansas)
- Allen Cooley (Burns, Cooley, Dennis)
- Arif Chowdhury (TTI)
- Rebecca McDaniel (Purdue/NCSC)
- Walaa Mogawer (U of Mass, Dartmouth)
- Nam Tran/Randy West (NCAT)

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E* Test Procotol

Dynamic Modulus Test

AASHTO TP 62

Temperature	
°C	°F
-10	14
4.4	40
21.1	70
37.8	100
54.4	130

Frequency (Hz)
0.1
0.5
1
5
10
25

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E* Test Protocol – Generated Data

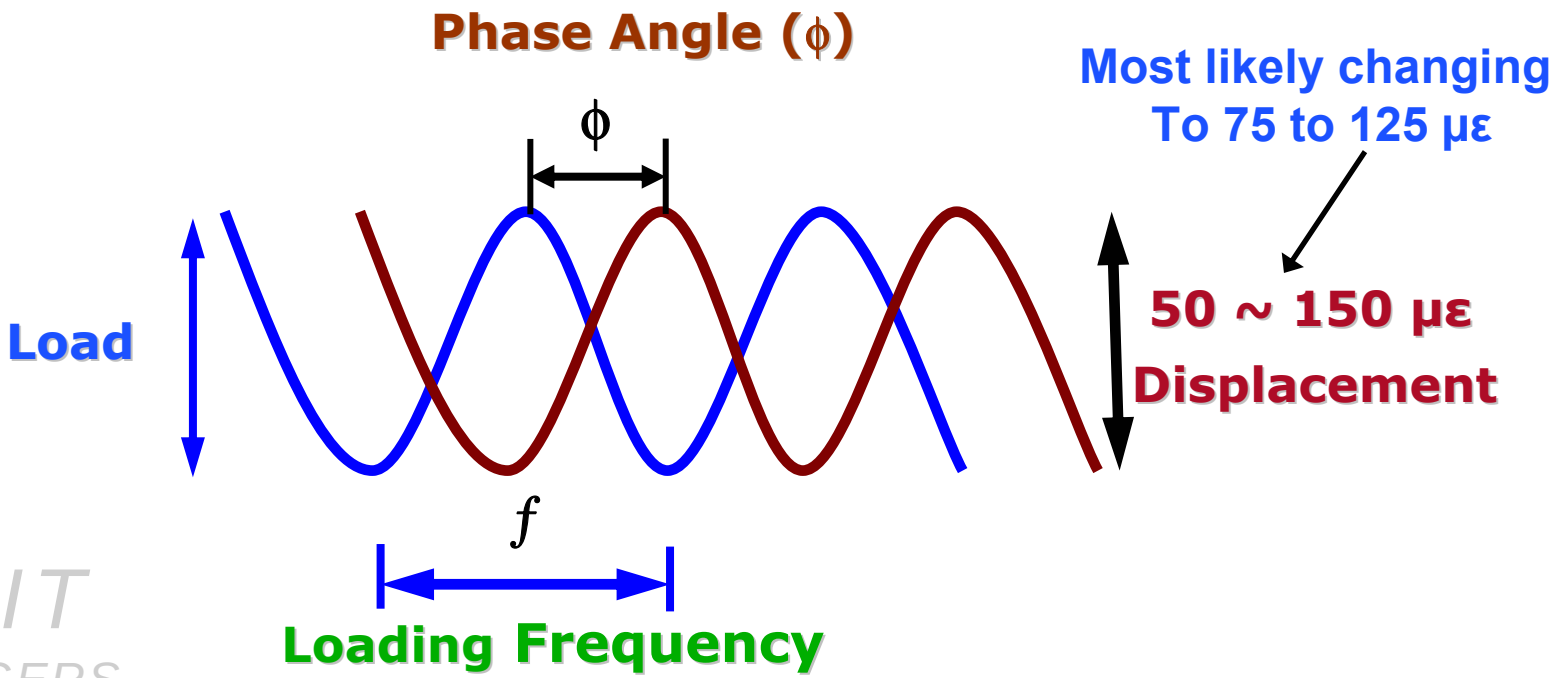
Dynamic Modulus Test

AASHTO TP 62

σ_0 = **dynamic stress**

ε_0 = **recoverable axial strain**

$$|E^*| = \frac{\sigma_0}{\varepsilon_0}$$



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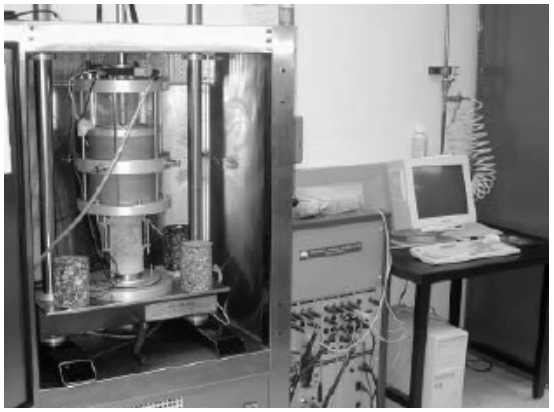
Test Equipment Info



Lab Number	Gyratory Compactor	E* Test Equipment	# of LVDT's	Frictionless End
#1	IPC Servopac	UTM-25 (T)	3	Greased Latex
#2	Pine	UTM-25 (T)	3	Greased Latex
#3	Pine AFG1A	IPC SPT (B)	3	Teflon
#4	Pine AFG1A	IPC SPT (B)	3	Greased Latex
#5	Interlaken	Interlaken (T)	2	Teflon

(B) – Bottom Loading
(T) – Top Loading

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Test Specimen Data

9.5mm Mix

Lab No.	Average	Stdev	Air Voids
Lab #1	2.536	0.015	6.17
Lab #2	2.527	0.002	6.50
Lab #3	2.558	0.004	5.36
Lab #4	2.565	0.005	5.09
Lab #5	2.546	0.007	5.81

For All Samples: Ave. = 2.547
Stdev = 0.016

Inter-lab Ave. Standard Deviation = 0.006

AASHTO T166 After Cutting And Coring According to AASHTO TP62-03

25mm Mix

Lab No.	Average	Stdev	Air Voids
Lab #1	2.601	0.006	5.70
Lab #2	2.576	0.010	6.61
Lab #3	2.605	0.005	5.55
Lab #4	2.604	0.006	5.57
Lab #5	2.594	0.012	5.93

For All Samples: Ave. = 2.596
Stdev = 0.013

Inter-lab Ave. Standard Deviation = 0.008

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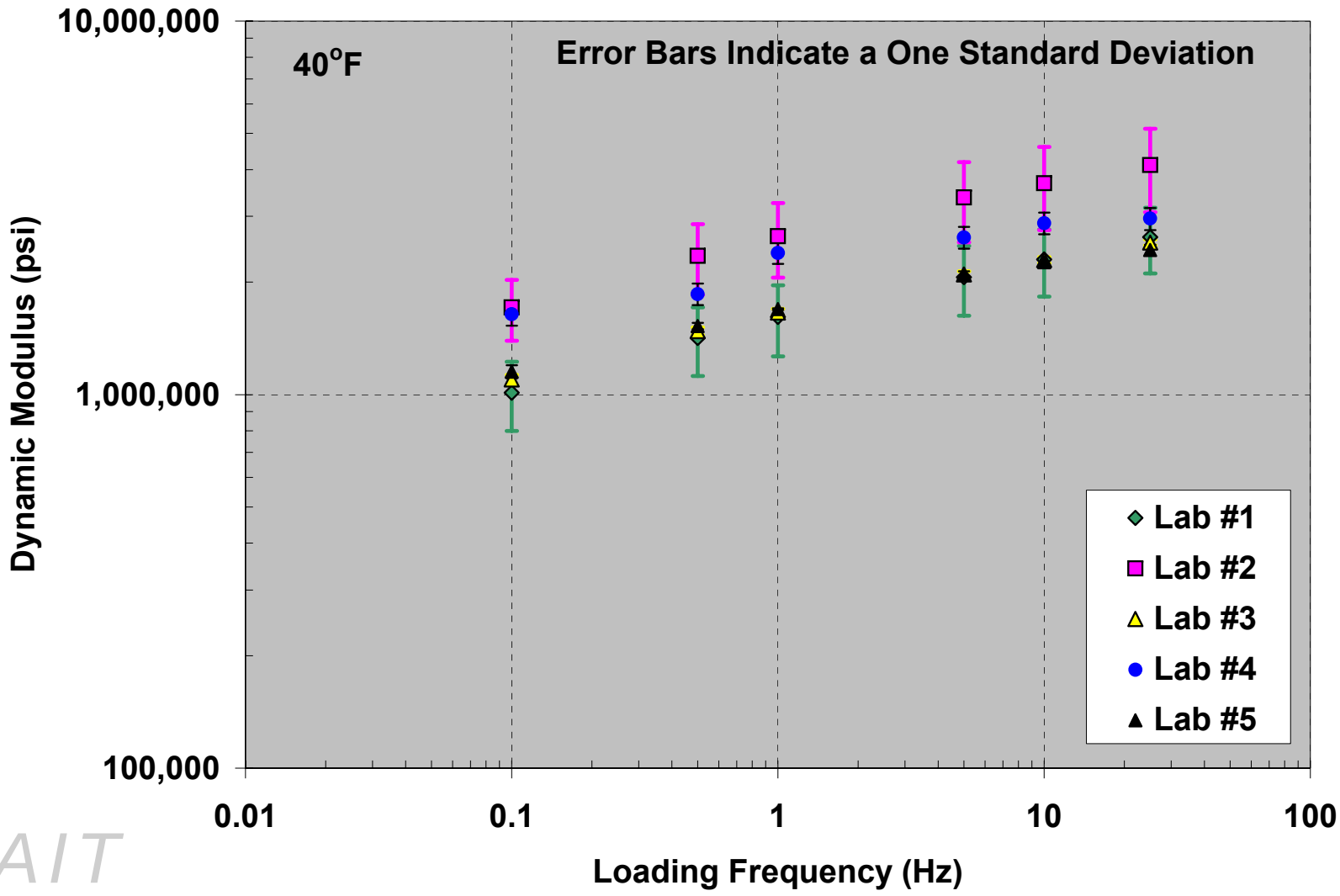
E* Data – 9.5mm, 40°F



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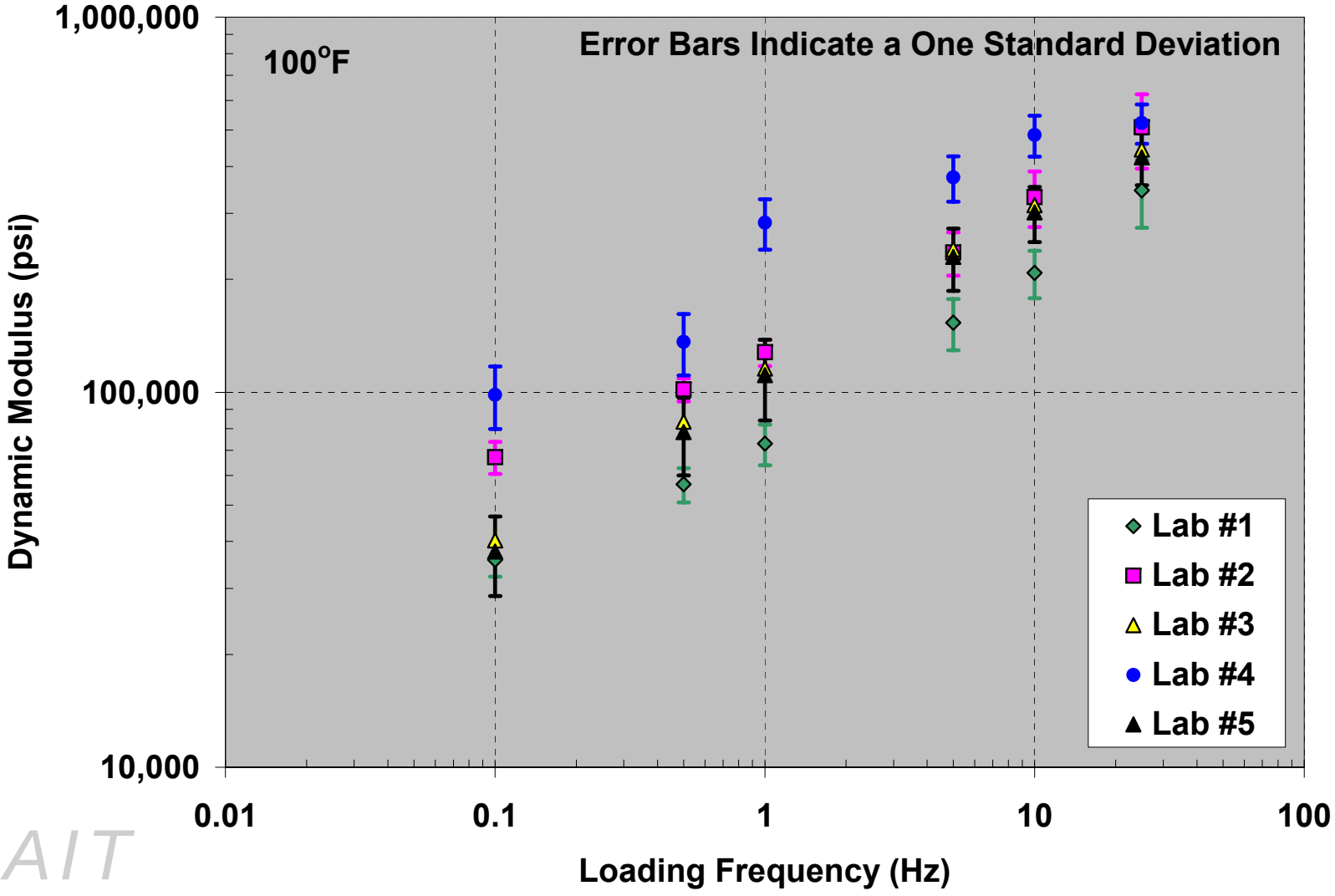
E* Data – 9.5mm, 100°F



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E* Data – 9.5mm

14°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	3,758,934	462,888.0	12.3
10 Hz	3,514,946	314,461.7	8.9
5 Hz	3,330,235	290,442.2	8.7
1 Hz	2,901,376	303,692.9	10.5
0.5 Hz	2,713,098	339,128.4	12.5
0.1 Hz	2,242,503	436,849.3	19.5

40°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	2,940,750	775,948.7	26.4
10 Hz	2,681,909	694,630.3	25.9
5 Hz	2,454,390	634,030.5	25.8
1 Hz	2,003,164	524,984.9	26.2
0.5 Hz	1,726,898	426,222.1	24.7
0.1 Hz	1,322,251	339,612.9	25.7

70°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	1,537,970	382,150.9	24.8
10 Hz	1,238,587	247,349.2	20.0
5 Hz	1,041,867	205,924.7	19.8
1 Hz	711,256	181,825.2	25.6
0.5 Hz	539,630	114,427.1	21.2
0.1 Hz	338,287	102,060.2	30.2

100°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	448,653	90,440.9	20.2
10 Hz	328,573	100,351.7	30.5
5 Hz	246,665	79,498.2	32.2
1 Hz	142,236	78,195.9	55.0
0.5 Hz	91,317	30,260.9	33.1
0.1 Hz	55,848	26,411.3	47.3

130°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	138,303	31,716.8	22.9
10 Hz	92,850	30,010.6	32.3
5 Hz	65,647	25,321.4	38.6
1 Hz	38,456	19,014.6	49.4
0.5 Hz	26,678	13,751.7	51.5
0.1 Hz	20,541	12,828.7	62.5

E* Data – 9.5mm (SPT's Only)

40°F

SPT (Lab #3 vs Lab #4)		
Ave	Stdev	COV
2,755,715	86033.45	3.1
2,584,627	36541.49	1.4
2,366,095	34055.3	1.4
2,026,629	31258.27	1.5
1,668,847	39193.04	2.3
1,368,710	47058.82	3.4
		2.2

70°F

SPT (Lab #3 vs Lab #4)		
Ave	Stdev	COV
1,301,854	60799	4.7
1,157,273	67375.47	5.8
982,679	61040.15	6.2
740,459	54126.77	7.3
516,329	50310.57	9.7
362,156	38241.54	10.6
		7.4

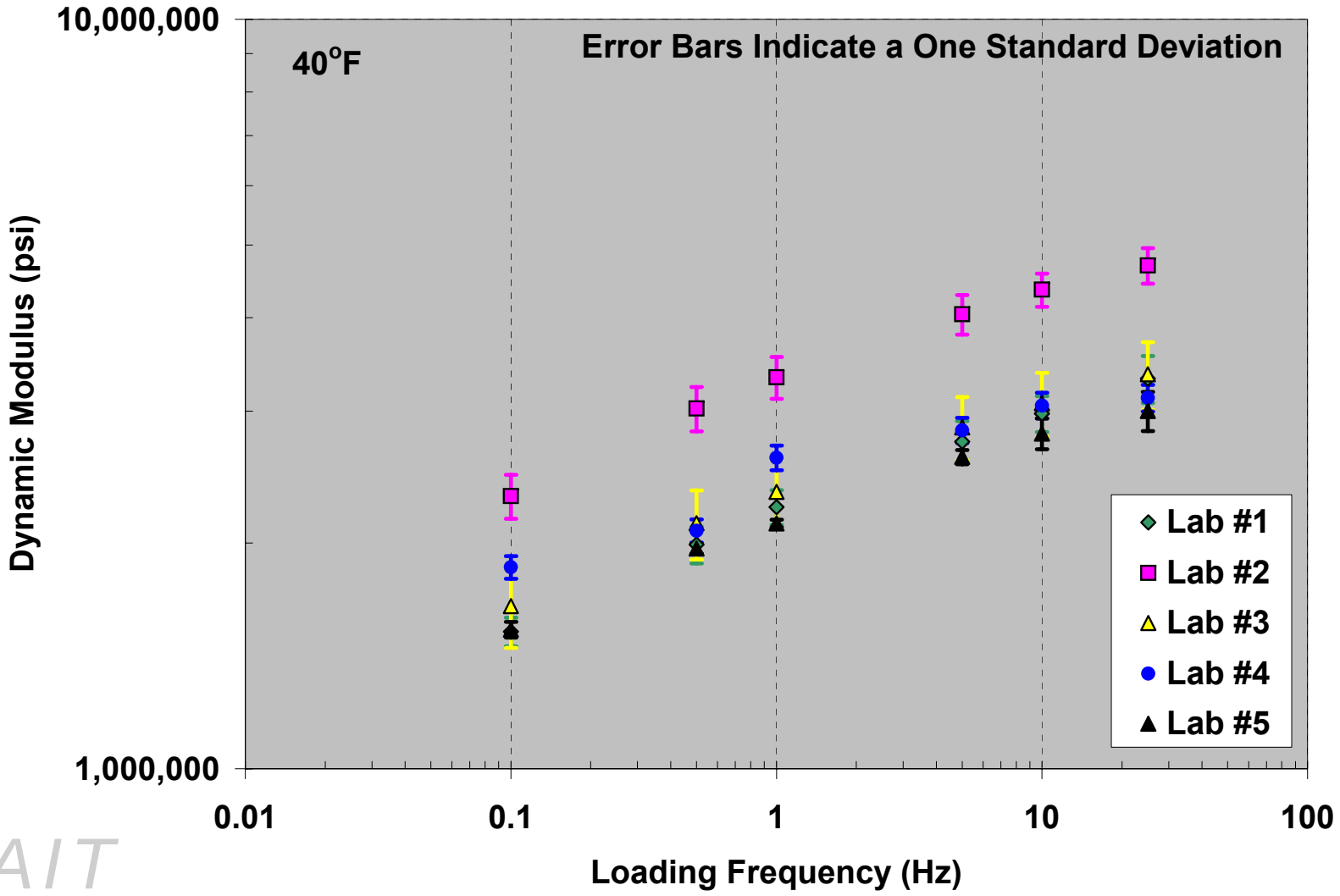
100°F

SPT (Lab #3 vs Lab #4)		
Ave	Stdev	COV
483,261	44908.14	9.3
400,410	34033.62	8.5
307,280	28987.7	9.4
199,612	17746.6	8.9
109,843	12326.45	11.2
69,377	6143.294	8.9
		9.4

130°F

SPT (Lab #3 vs Lab #4)		
Ave	Stdev	COV
145,425	41311.66	28.4
108,981	23233.21	21.3
72,641	23265.83	32.0
45,176	6263.917	13.9
22,221	4291.019	19.3
15,273	2165.05	14.2
		21.5

E* Data – 25mm, 40°F



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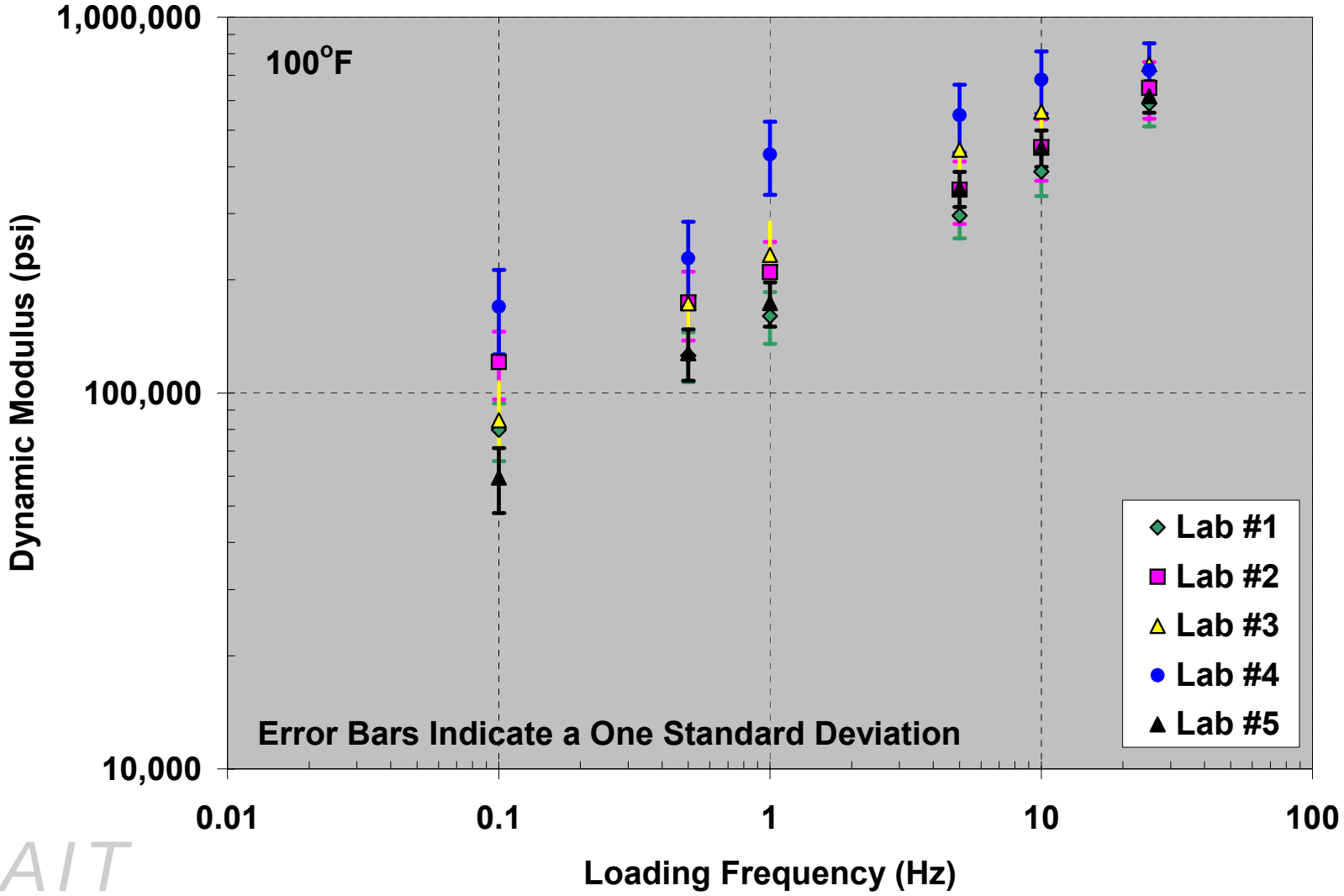
E* Data – 25mm, 100°F



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E* Data – 25mm

14°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	4,602,627	569,197.2	12.4
10 Hz	4,375,066	553,828.9	12.7
5 Hz	4,185,174	511,719.8	12.2
1 Hz	3,700,299	494,209.9	13.4
0.5 Hz	3,470,374	485,635.6	14.0
0.1 Hz	2,937,961	537,040.8	18.3

40°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	3,499,232	664,325.4	19.0
10 Hz	3,252,760	604,702.9	18.6
5 Hz	3,012,969	563,872.1	18.7
1 Hz	2,526,219	467,063.7	18.5
0.5 Hz	2,238,001	431,283.5	19.3
0.1 Hz	1,774,772	320,900.3	18.1

70°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	1,950,467	397,320.0	20.4
10 Hz	1,668,826	321,841.7	19.3
5 Hz	1,444,873	299,195.3	20.7
1 Hz	1,039,241	252,509.7	24.3
0.5 Hz	828,437	218,514.7	26.4
0.1 Hz	546,575	171,183.4	31.3

100°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	664,903	104,310.6	15.7
10 Hz	506,214	129,585.3	25.6
5 Hz	397,278	110,654.9	27.9
1 Hz	241,573	111,711.7	46.2
0.5 Hz	165,786	50,248.5	30.3
0.1 Hz	102,926	45,644.4	44.3

130°F

Freq	Ave (psi)	Stdev	COV (%)
25 Hz	232,257	30,601.7	13.2
10 Hz	157,674	44,182.3	28.0
5 Hz	117,629	31,621.0	26.9
1 Hz	67,730	31,986.7	47.2
0.5 Hz	47,053	19,487.9	41.4
0.1 Hz	35,025	19,201.8	54.8

E* Data – 25mm (SPT's Only)

40°F

SPT (Lab #3 vs Lab #4)		
Ave	Stdev	COV
3,242,579	315629.6	9.7
3,063,428	256269.4	8.4
2,842,315	224993.2	7.9
2,471,128	194262.7	7.9
2,102,323	168252.2	8.0
1,752,716	142493.5	8.1
		8.3

70°F

SPT (Lab #3 vs Lab #4)		
Ave	Stdev	COV
1,705,200	143131.7	8.4
1,532,979	118842.4	7.8
1,329,916	100977.2	7.6
1,027,133	84103.71	8.2
762,510	78762.89	10.3
550,809	63468.4	11.5
		9.0

100°F

SPT (Lab #3 vs Lab #4)		
Ave	Stdev	COV
735,750	101896.2	13.8
621,268	87287.3	14.0
496,218	74937.32	15.1
332,268	48325.61	14.5
200,694	38547.55	19.2
127,180	21006.64	16.5
		15.5

130°F

SPT (Lab #3 vs Lab #4)		
Ave	Stdev	COV
245,466	32789.38	13.4
191,663	30708.08	16.0
140,004	22638.89	16.2
84,769	11892.78	14.0
43,616	8382.417	19.2
28,896	3899.567	13.5
		15.4

Initial Precision Comparisons

- Coefficient of Variation (COV) used to compare initial precision at different temperatures and loading frequencies
- On average, poorest precision (highest COV) at 0.1 Hz

Average Coefficient of Variation (COV), %		
Test Temp. (F)	**9.5mm Mix**	**25mm Mix**
10	12.1	13.8
40	25.8	18.7
70	23.6	23.7
100	36.4	31.7
130	42.9	35.3

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Influence on MEPDG Distress Predictions

- Used Level 1 Inputs for E* and asphalt binder data (PG64-22)
- Same pavement structure (3” of 9.5mm; 5” of 25mm; 8” base)
- MEPDG Traffic Default Conditions with 2-Way AADTT = 2,500
- Newark, NJ Climatic Conditions

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Issues with Low Temperature Data

- 3 of 5 labs could not test at 14°F
  - Issues with cooling systems
  - Test equipment more expensive
- For MEPDG inputs require test data between 10 and 20°F
- For MEPDG comparisons, used approach proposed by Bonaquist and Christensen (2005), TRR 1929
  - Using Hirsch model and "Max" modulus to limit Master Stiffness Curve
  - E* = f (G*, VMA, VFA)

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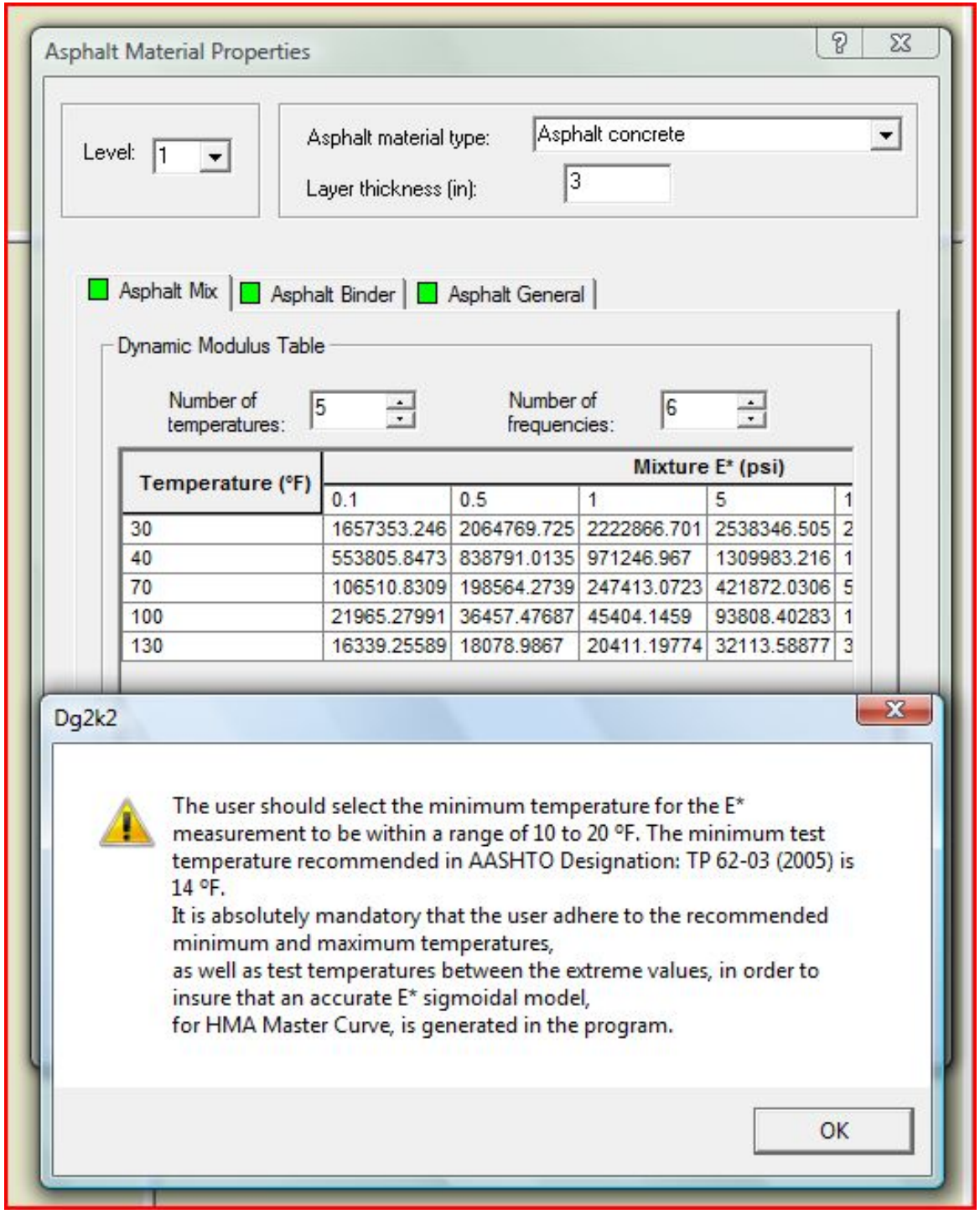

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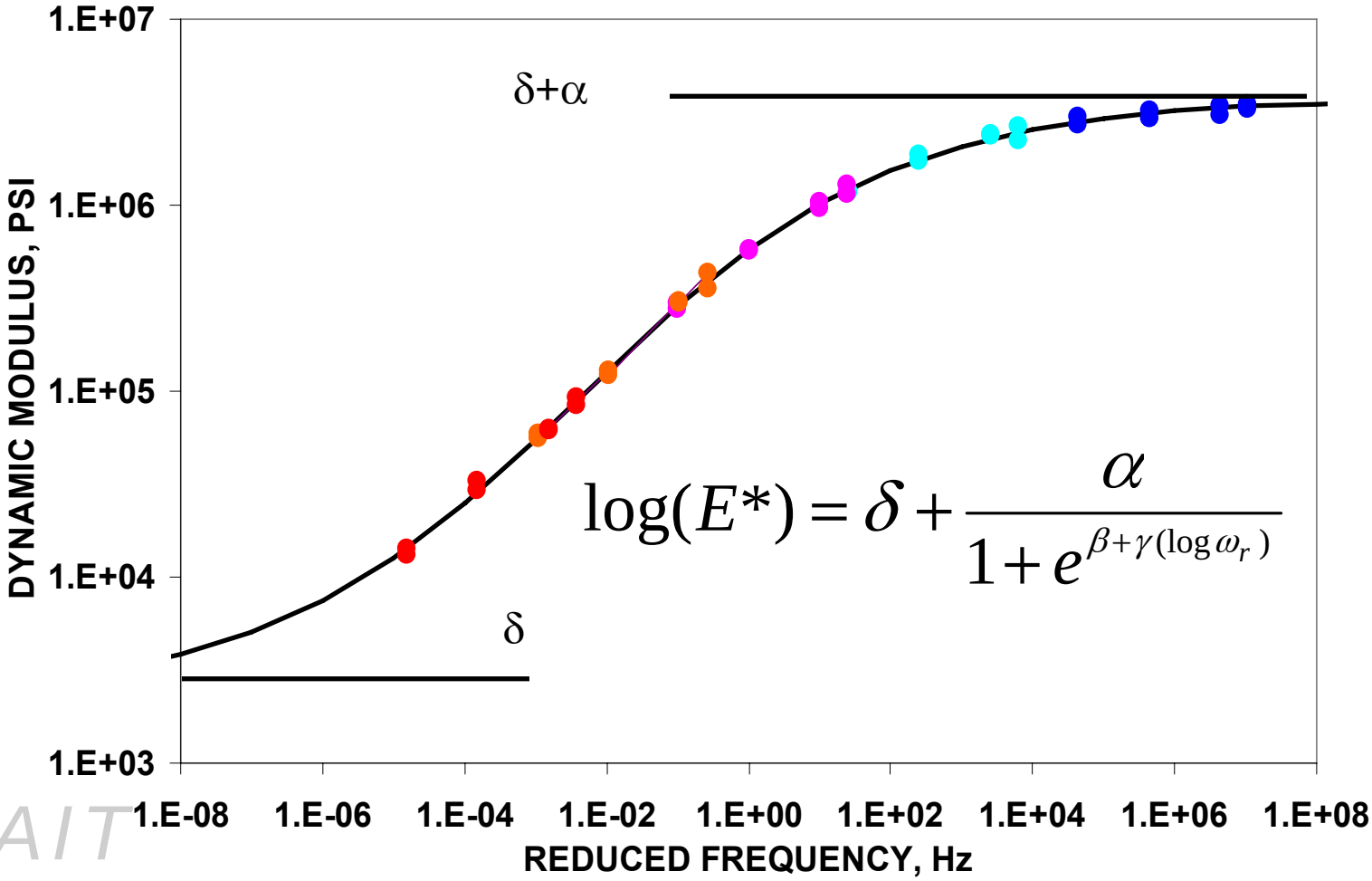
Master Stiffness Curve – All 5 Temperatures



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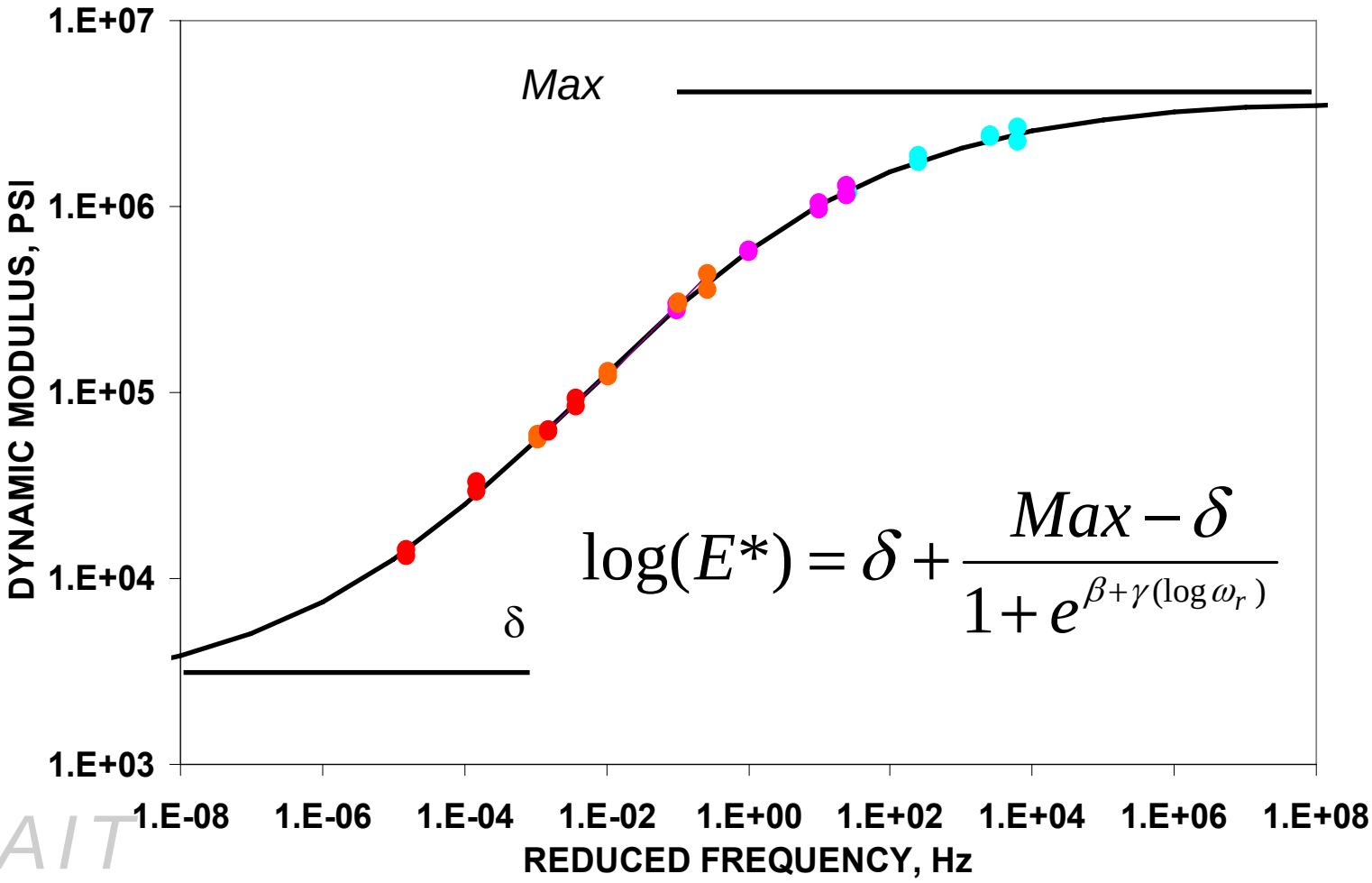
Master Stiffness Curve – 4 Test Temperatures (No 14°F)



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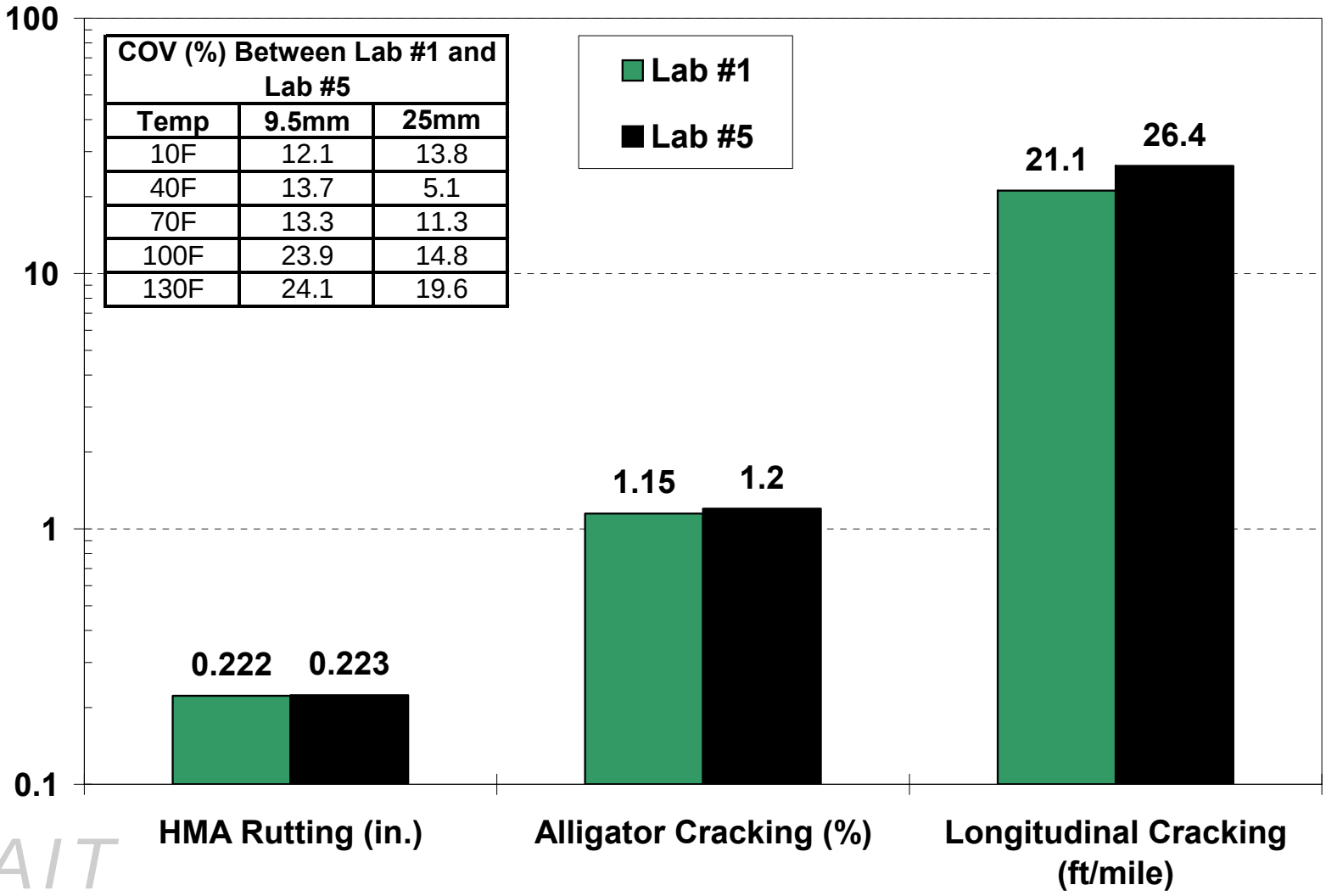
Lab #1 vs Lab #5

COV (%) Between Lab #1 and Lab #5		
Temp	9.5mm	25mm
10F	12.1	13.8
40F	13.7	5.1
70F	13.3	11.3
100F	23.9	14.8
130F	24.1	19.6



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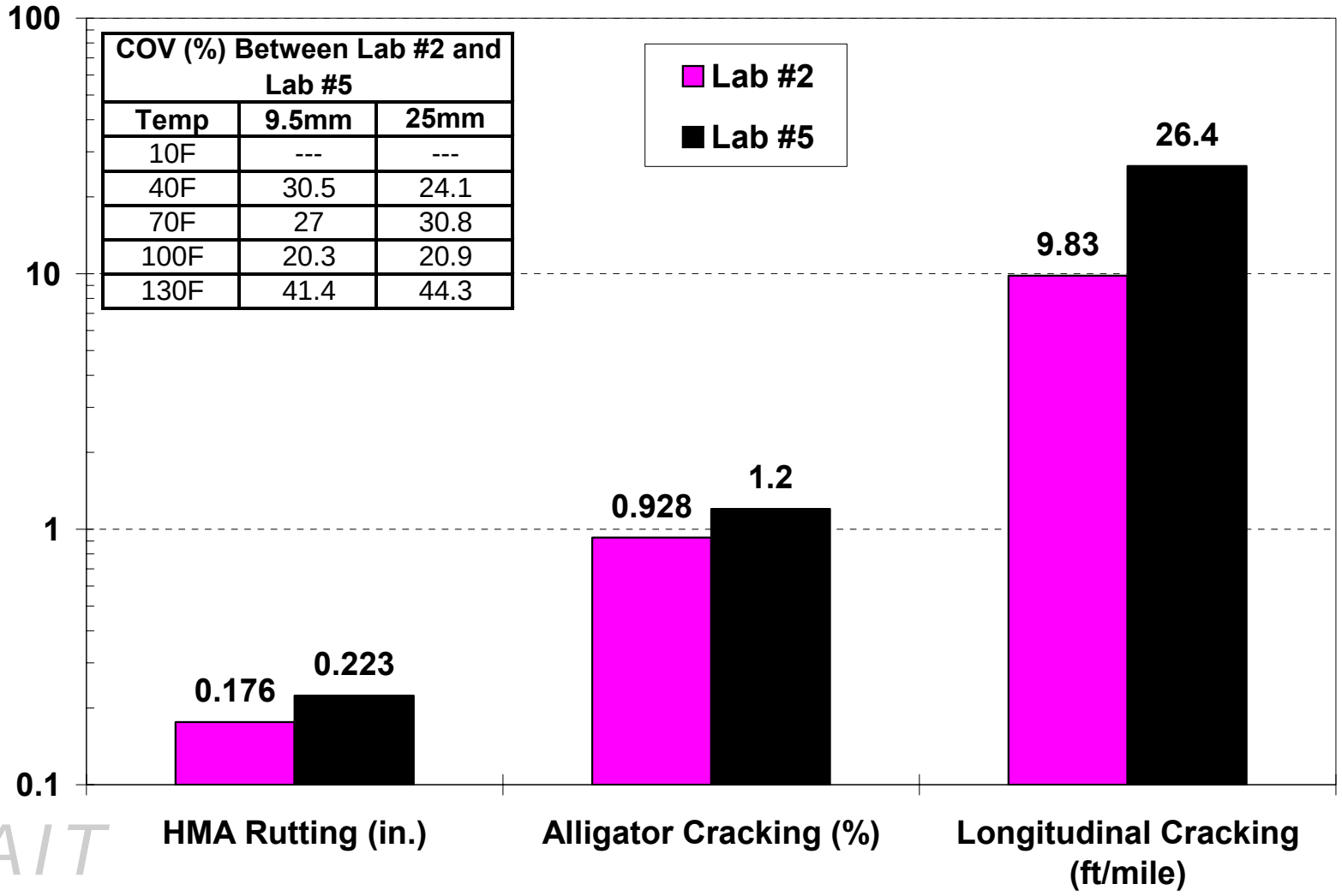
Lab #2 vs Lab #5

COV (%) Between Lab #2 and Lab #5		
Temp	9.5mm	25mm
10F	---	---
40F	30.5	24.1
70F	27	30.8
100F	20.3	20.9
130F	41.4	44.3



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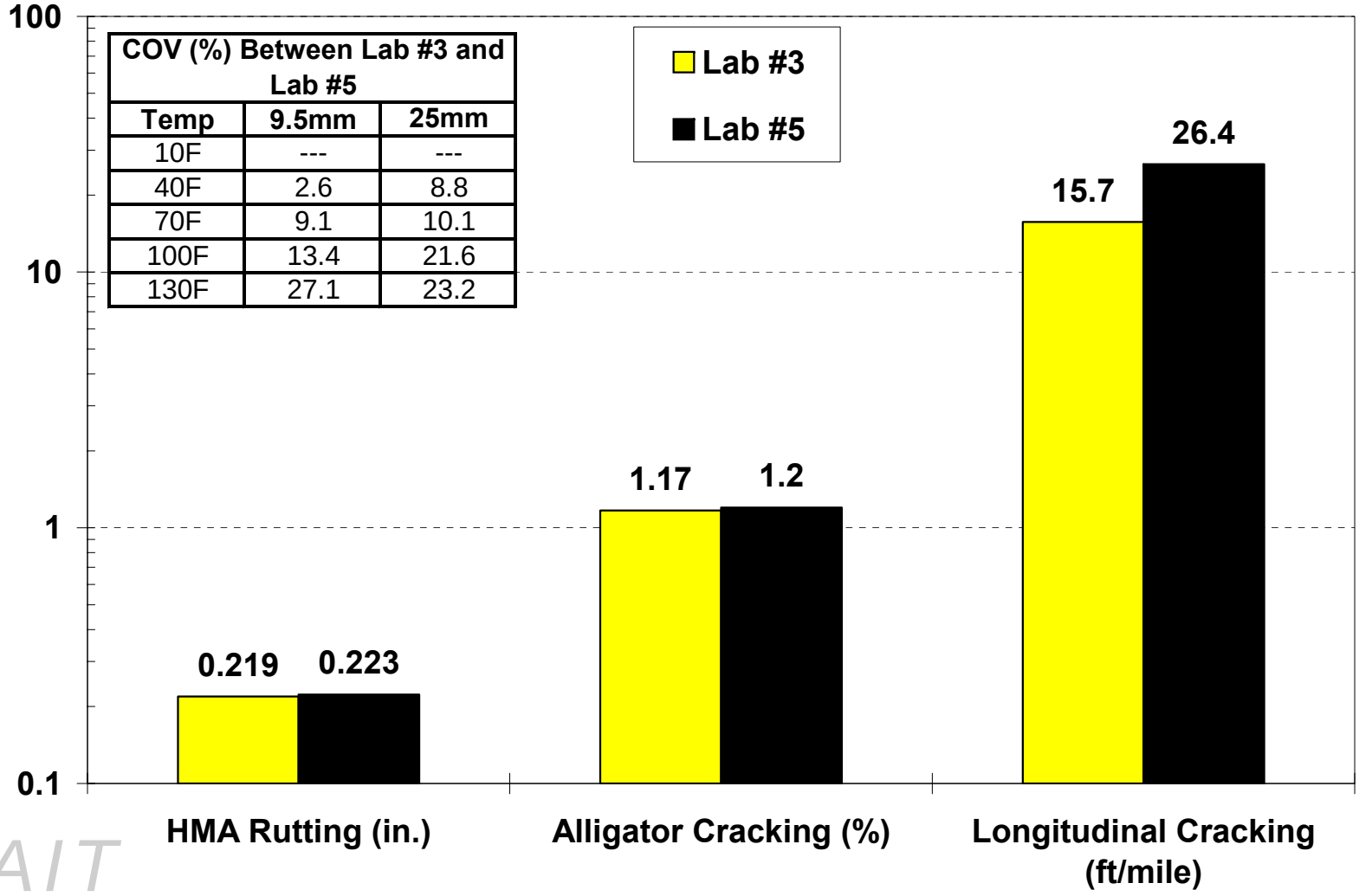
Lab #3 vs Lab #5

COV (%) Between Lab #3 and Lab #5		
Temp	9.5mm	25mm
10F	---	---
40F	2.6	8.8
70F	9.1	10.1
100F	13.4	21.6
130F	27.1	23.2



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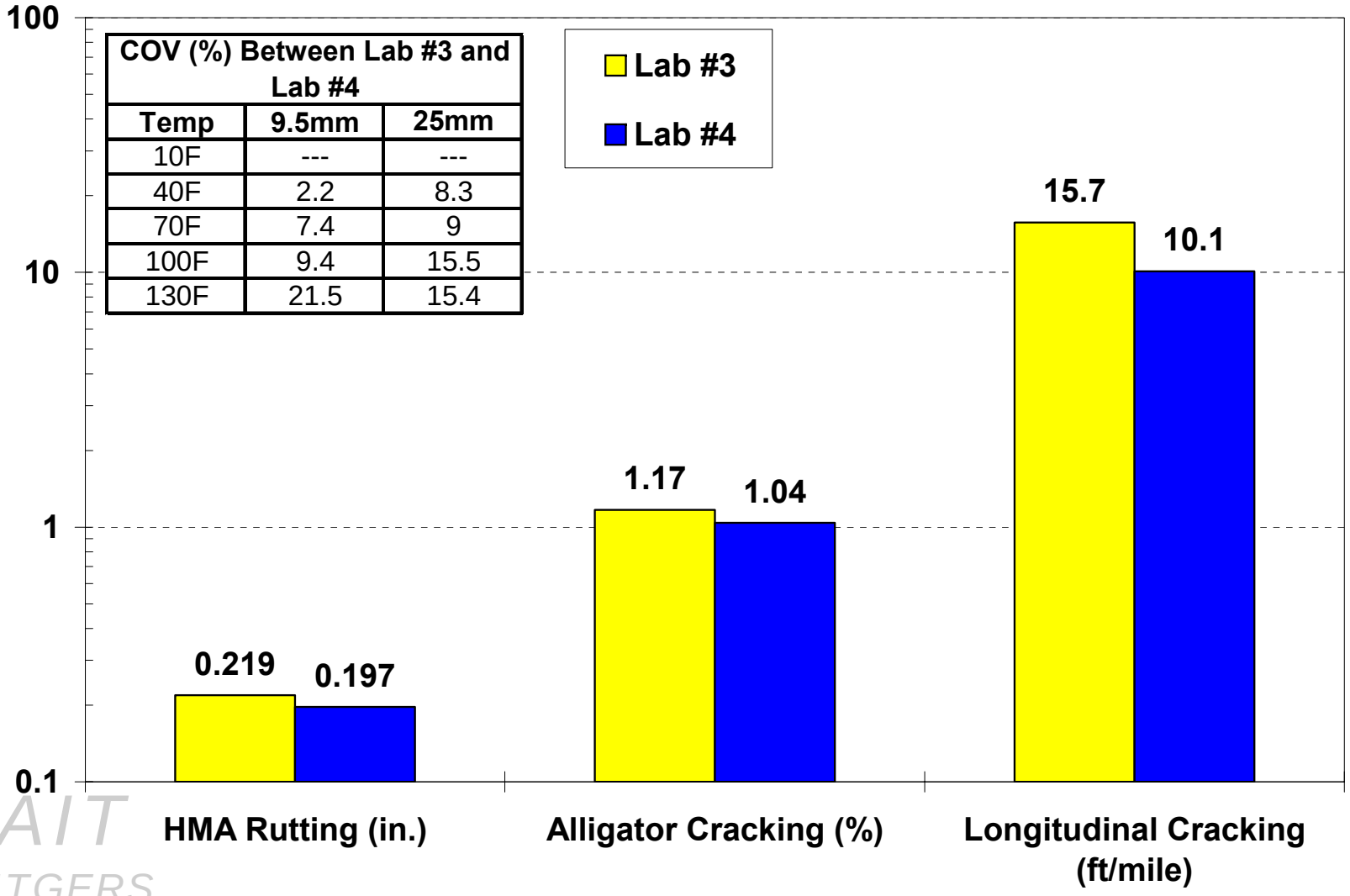
Lab #3 vs Lab #4 (SPT's)

COV (%) Between Lab #3 and Lab #4		
Temp	9.5mm	25mm
10F	---	---
40F	2.2	8.3
70F	7.4	9
100F	9.4	15.5
130F	21.5	15.4



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Initial Conclusions

- Based on the 5 labs that have submitted data, the initial precision is poor.
  - Average COV% for all labs was *approximately 25%*
    - Poorest precision at higher temperatures and lower frequencies
  - Precision between the 2 SPT's was the best for all combinations – average COV% for all data was 11%
- Why poor precision?
  - Bulk gravity data for all specimens had COV < 0.6%
  - Difference in aging?
    - 4 hours at 135°C (AASHTO R30); heat to 145°C and compact
  - Accurate measurement of conditioning and test temp?
  - Quality of data? (within consistent με and TP62-03)
    - Better precision with 75 to 125 με (Labs #3, #4, and #5); Lab #1 and #2 consistently failed TP62-03
    - Within Linear-Elastic Range?

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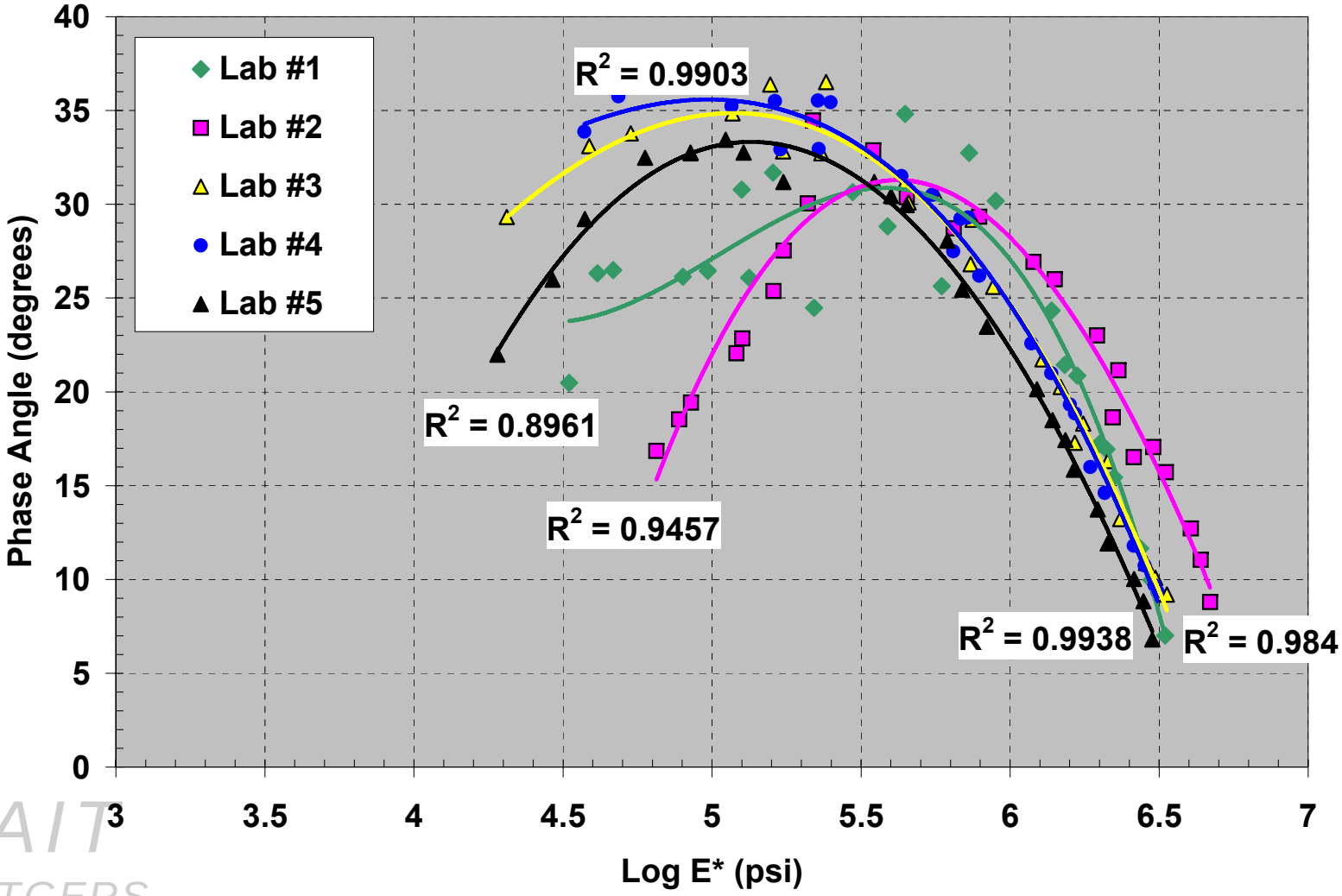
Assessment of Data Quality – Black Space (25mm Samples)



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Initial Conclusions - continued

- Comparable MEPDG Distress Predictions when COV < 15%
  - Pavement structure, climate and traffic will have broader influence, continuing to look at various scenarios
  - Preliminary Inter-laboratory precision (COV) is recommended for < 13%
- MEPDG Distress Predictions more influenced at intermediate to higher test temperatures (≥70°F)
  - Minimal damage accumulating when pavement temperatures are colder (higher stiffness)

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Thank You!

Precision of the E* Test for Use in M-E Design of Flexible Pavement Construction

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