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Precision of the Dynamic Test (AASHTO T62-07) for Hot Mix Asphalt

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Acknowledgements

- Stacy Williams of University of Arkansas
- Funding provided by NJDOT Research Bureau
- Eileen Sheehy and Robert Sauber of NJDOT Materials Bureau and Robert Blight of NJDOT Pavement Technology

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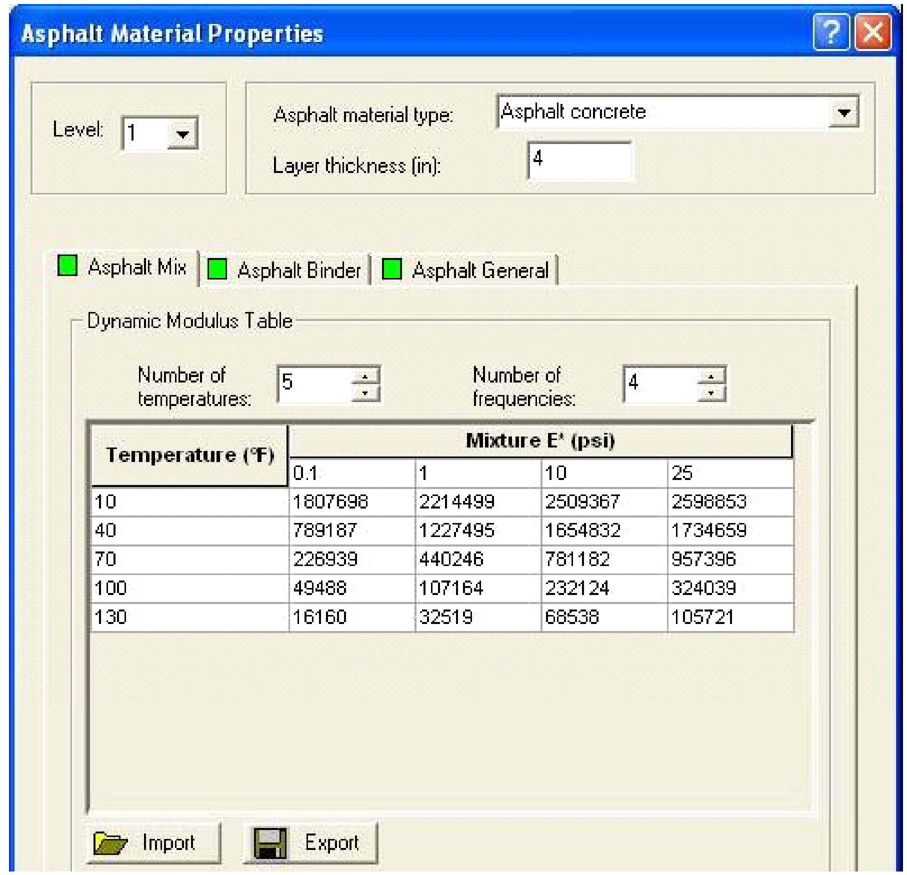
Background

- E* used as the primary input parameter for the MEPDG
  - E* used to calculate stress and strain in the HMA
  - Stress and strain used in distress predictions
- E* testing also being used to evaluate performance of different HMA materials and additives
  - Higher RAP, WMA, asphalt rubber, etc.



Temperature (°F)	Mixture E* (psi)			
	0.1	1	10	25
10	1807698	2214499	2509367	2598853
40	789187	1227495	1654832	1734659
70	226939	440246	781182	957396
100	49488	107164	232124	324039
130	16160	32519	68538	105721

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Overview of Study

- Current test procedure, AASHTO TP62-07
  - 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 TP62-07
  - Data also used in MEPDG to determine how precision may affect outputs

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Precision Evaluation

- Conducted Round Robin testing with 7 labs
  - 2 different mixes (NJDOT 9.5H64 and 25H64) – 3 samples each
  - Loose mix prepared at Rutgers, boxed in wax-lined boxes, sealed and shipped to labs
  - Labs asked to condition (AASHTO R30) and compact, core/cut, and test according to AASHTO TP62-07
- Data evaluated under ASTM E691, *Standard Practice for Conducting an Inter-laboratory Study to Determine the Precision of a Test Method*

Round Robin Partners

- Thomas Bennert (Rutgers U.)[1]
- Ray Bonaquist (AAT)[1]
- Allen Cooley (Burns, Cooley, Dennis)[1]
- Nam Tran/Randy West (NCAT)[1]
- Arif Chowdhury (TTI)[1]
- Rebecca McDaniel (Purdue/NCSC)[2]
- Walaa Mogawer (U of Mass, Dartmouth)[2]

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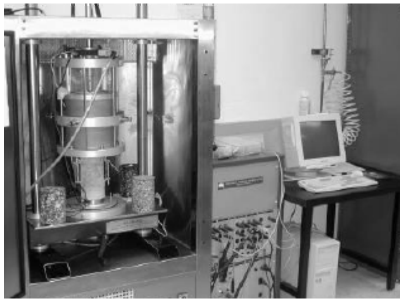
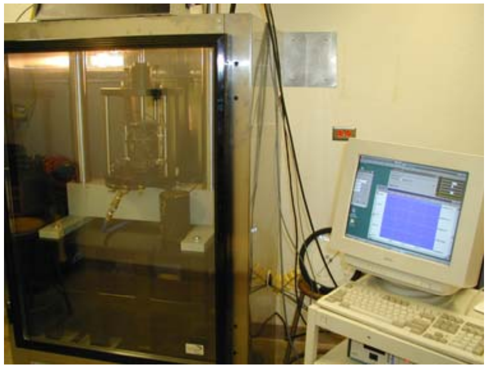
[1] – Current AMRL Accredited [2] – Were recently AMRL Accredited

Test Equipment Info







Lab No	Gyratory Compactor Type	E* Test Equipment	# of LVDT's	Frictionless End Treatments
# 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
# 6	Interlaken	IPC SPT (B)	3	Teflon
# 7	Pine AFGC125X	Interlaken (T)	3	Greased Latex

- (T) = Top Loading Device; (B) = Bottom Loading Device

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E* Test Procotol

Dynamic Modulus Test

AASHTO TP 62-07

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

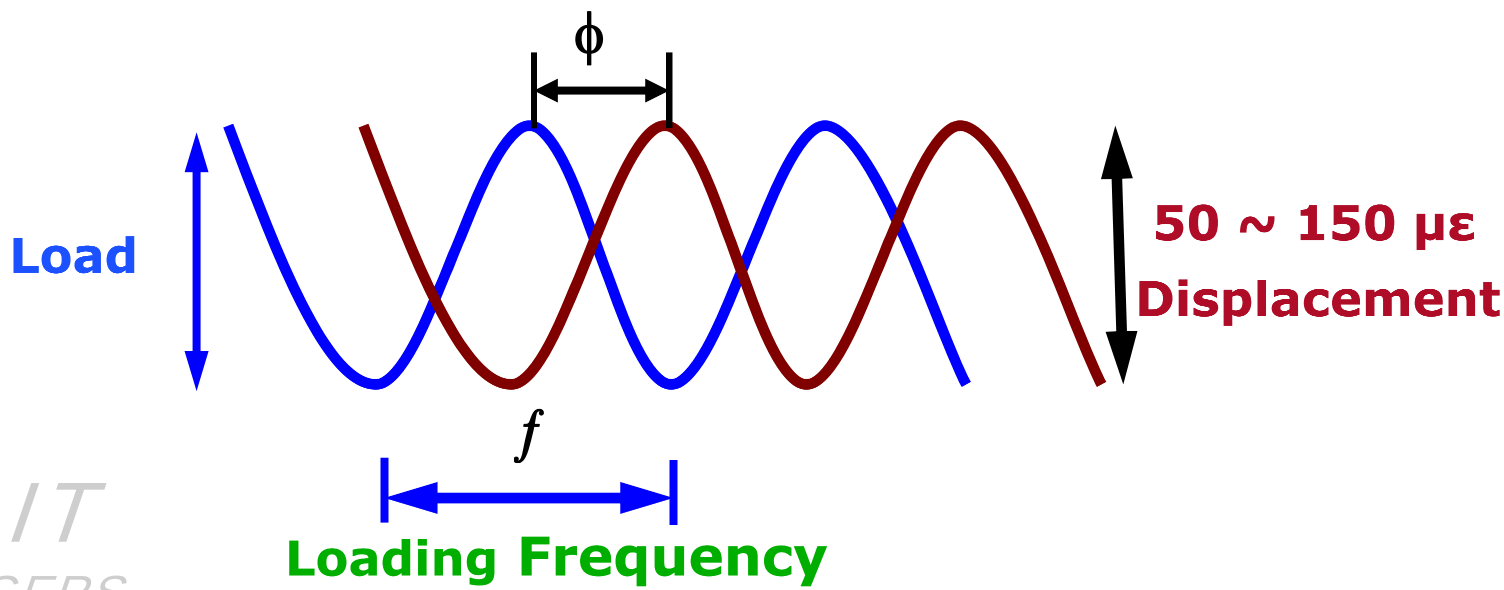
AASHTO TP 62-07

σ_0 **= dynamic stress**

ε_0 **= recoverable axial strain**

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

Phase Angle (ϕ)



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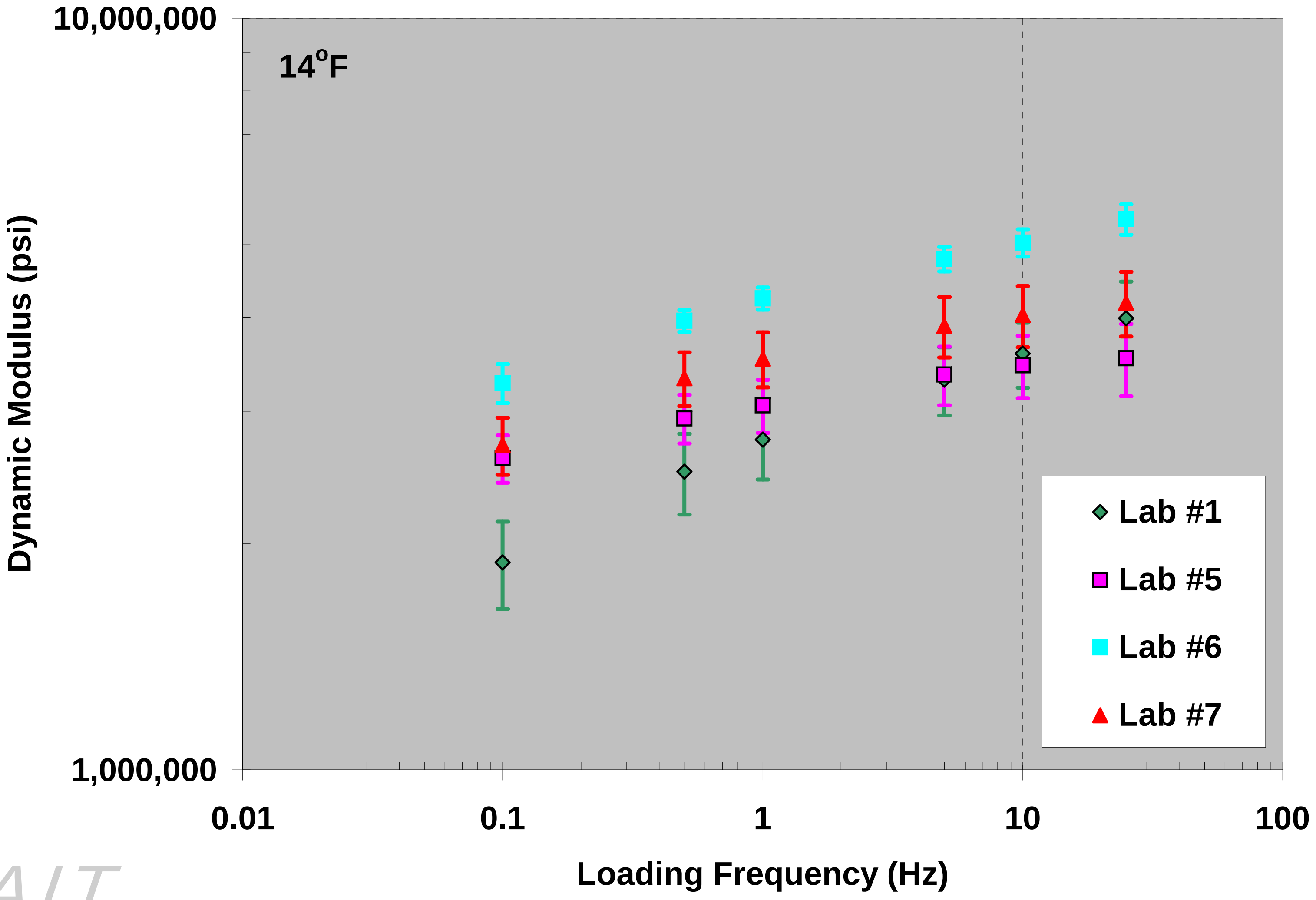
Test Temp (F)	Loading Freq (Hz)	9.5mm Dynamic Modulus (psi)		
		Average	Std Dev	Range
14F	25	4,275,759	799,575	1,873,273
	10	4,021,098	715,261	1,577,246
	5	3,835,141	686,879	1,479,671
	1	3,391,218	648,642	1,489,884
	0.5	3,175,624	620,801	1,464,441
	0.1	2,615,162	567,928	1,383,142
40F	25	2,622,030	618,924	1,677,729
	10	2,375,032	544,161	1,418,881
	5	2,174,073	498,964	1,310,321
	1	1,758,664	424,615	1,043,268
	0.5	1,529,755	347,693	936,621
	0.1	1,155,031	289,807	700,798
70F	25	1,317,087	309,417	845,314
	10	1,064,023	203,803	599,934
	5	895,096	170,835	500,343
	1	598,537	160,008	407,117
	0.5	461,619	95,460	270,412
	0.1	283,905	89,692	225,845
100F	25	397,912	68,164	183,186
	10	287,878	85,329	277,302
	5	216,223	68,596	220,595
	1	121,013	69,679	210,539
	0.5	81,645	31,134	79,449
	0.1	50,982	27,000	62,760
130F	25	112,499	33,550	91,132
	10	78,592	29,240	75,075
	5	54,657	26,878	67,195
	1	33,796	20,463	43,484
	0.5	25,035	17,055	42,486
	0.1	21,015	15,838	35,557

Test Temp (F)	Loading Freq (Hz)	25mm Dynamic Modulus (psi)		
		Average	Std Dev	Range
14F	25	5,018,577	648,706	1,404,617
	10	4,768,662	599,029	1,392,022
	5	4,578,915	597,033	1,412,745
	1	4,100,163	605,187	1,466,550
	0.5	3,865,131	616,883	1,505,115
	0.1	3,295,093	632,159	1,544,038
40F	25	3,150,148	605,038	1,690,377
	10	2,907,729	540,402	1,556,939
	5	2,692,854	501,407	1,435,836
	1	2,238,969	406,768	1,205,143
	0.5	1,994,296	377,691	1,059,310
	0.1	1,562,608	275,358	786,947
70F	25	1,692,328	338,398	966,260
	10	1,439,046	268,147	821,897
	5	1,242,623	244,346	726,743
	1	875,896	213,266	576,554
	0.5	705,012	175,695	508,386
	0.1	456,864	140,788	389,435
100F	25	595,103	69,602	184,669
	10	446,599	97,680	293,884
	5	348,169	83,769	251,728
	1	204,684	92,369	271,356
	0.5	144,981	38,662	102,248
	0.1	88,120	40,531	110,136
130F	25	184,532	46,894	138,585
	10	131,452	44,284	141,708
	5	94,459	40,364	125,354
	1	56,835	31,341	87,017
	0.5	41,029	22,169	58,591
	0.1	33,404	19,816	47,480

E* Data – 9.5mm, 14^{o}F



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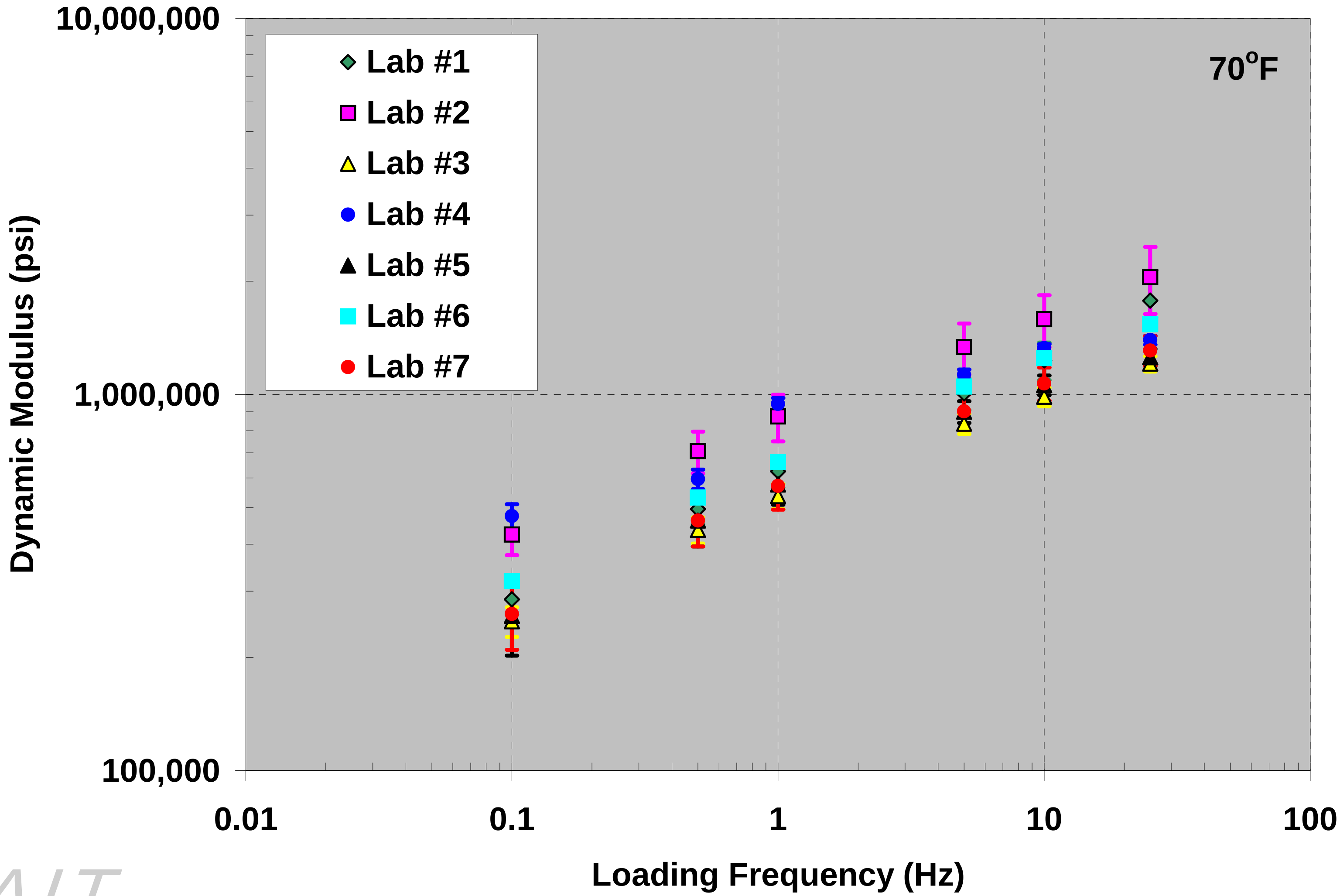
E* Data – 9.5mm, 70^{o}F



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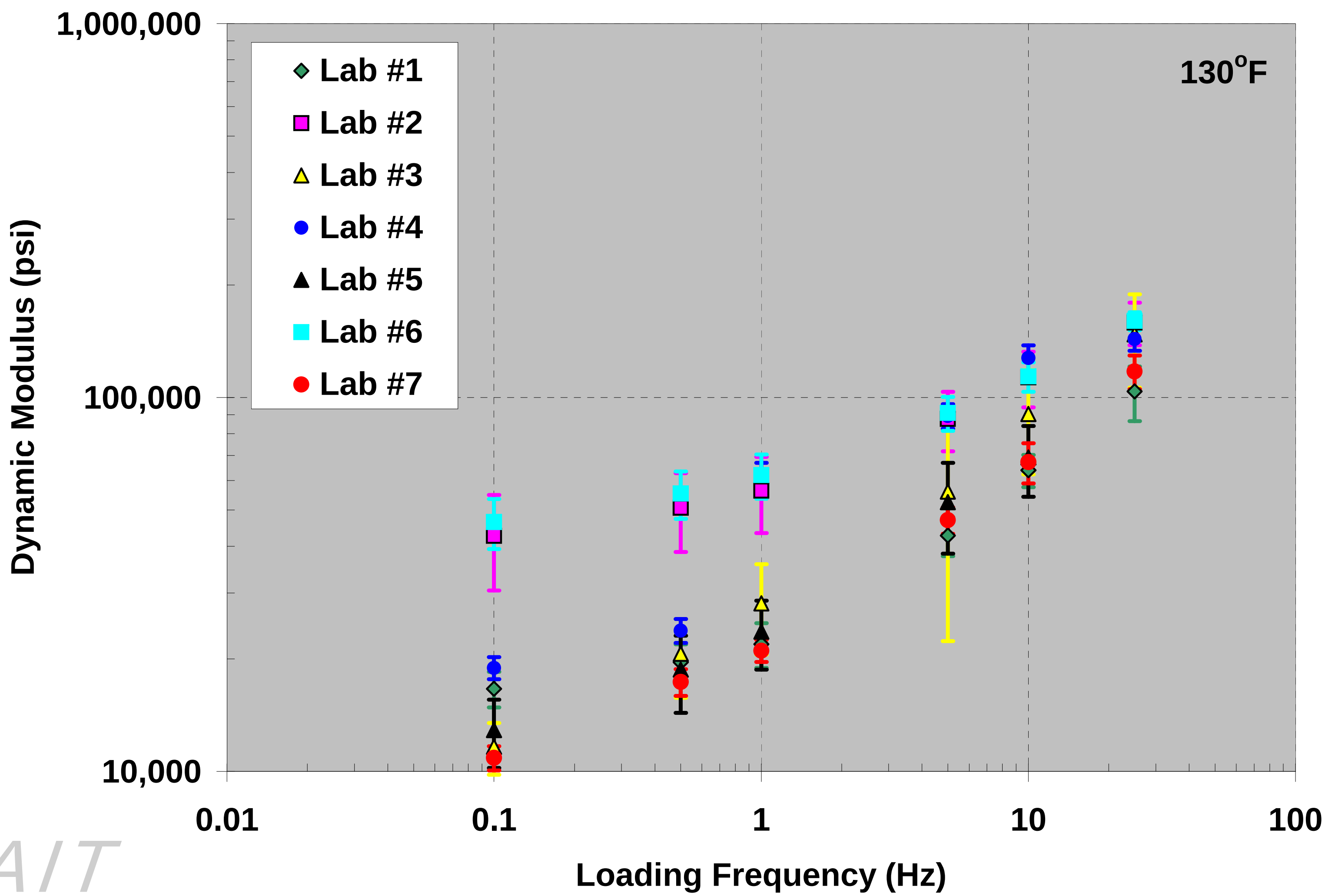
E* Data – 9.5mm, 130ºF



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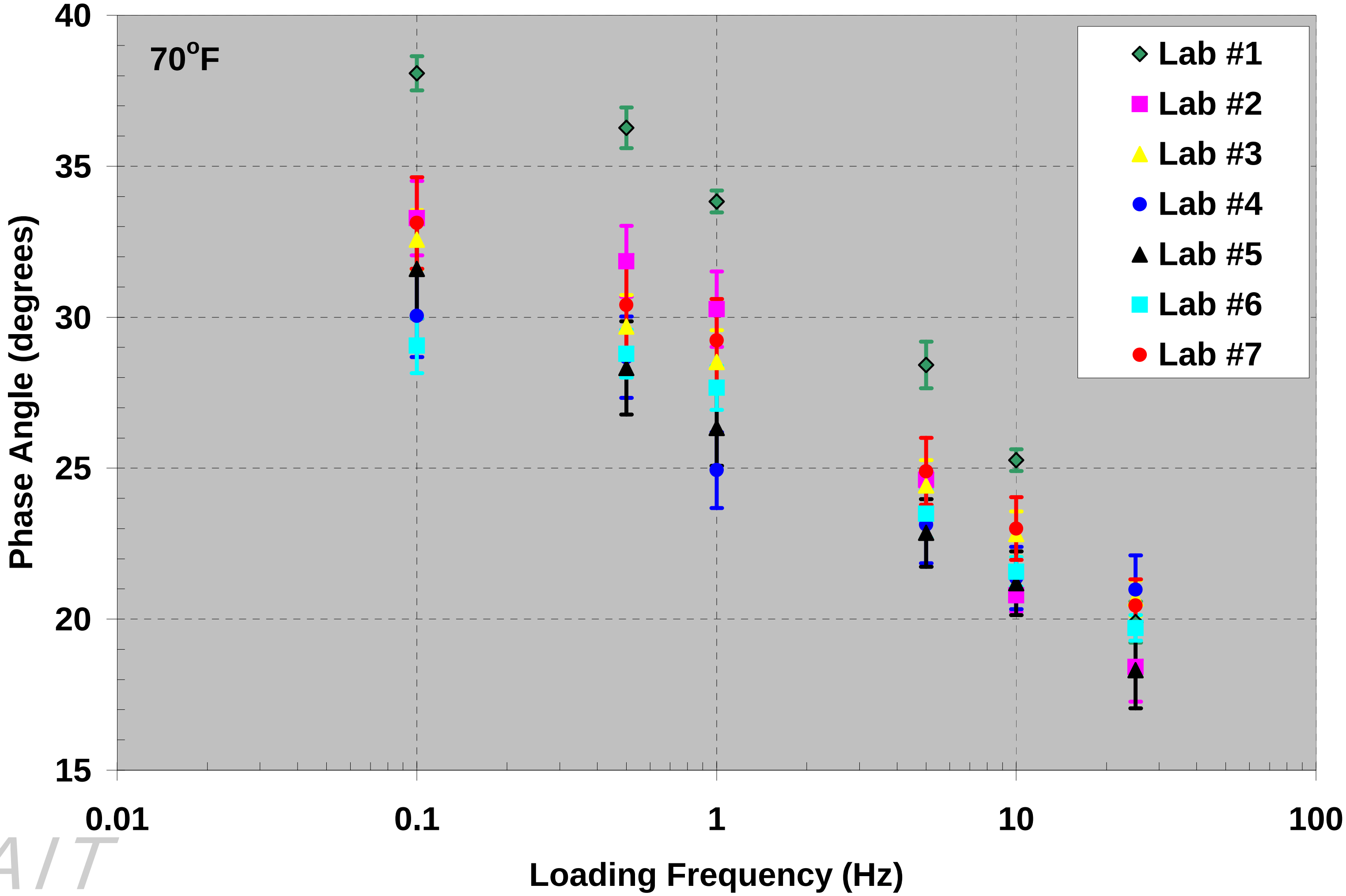
Phase Angle – 9.5mm, 70^{o}F



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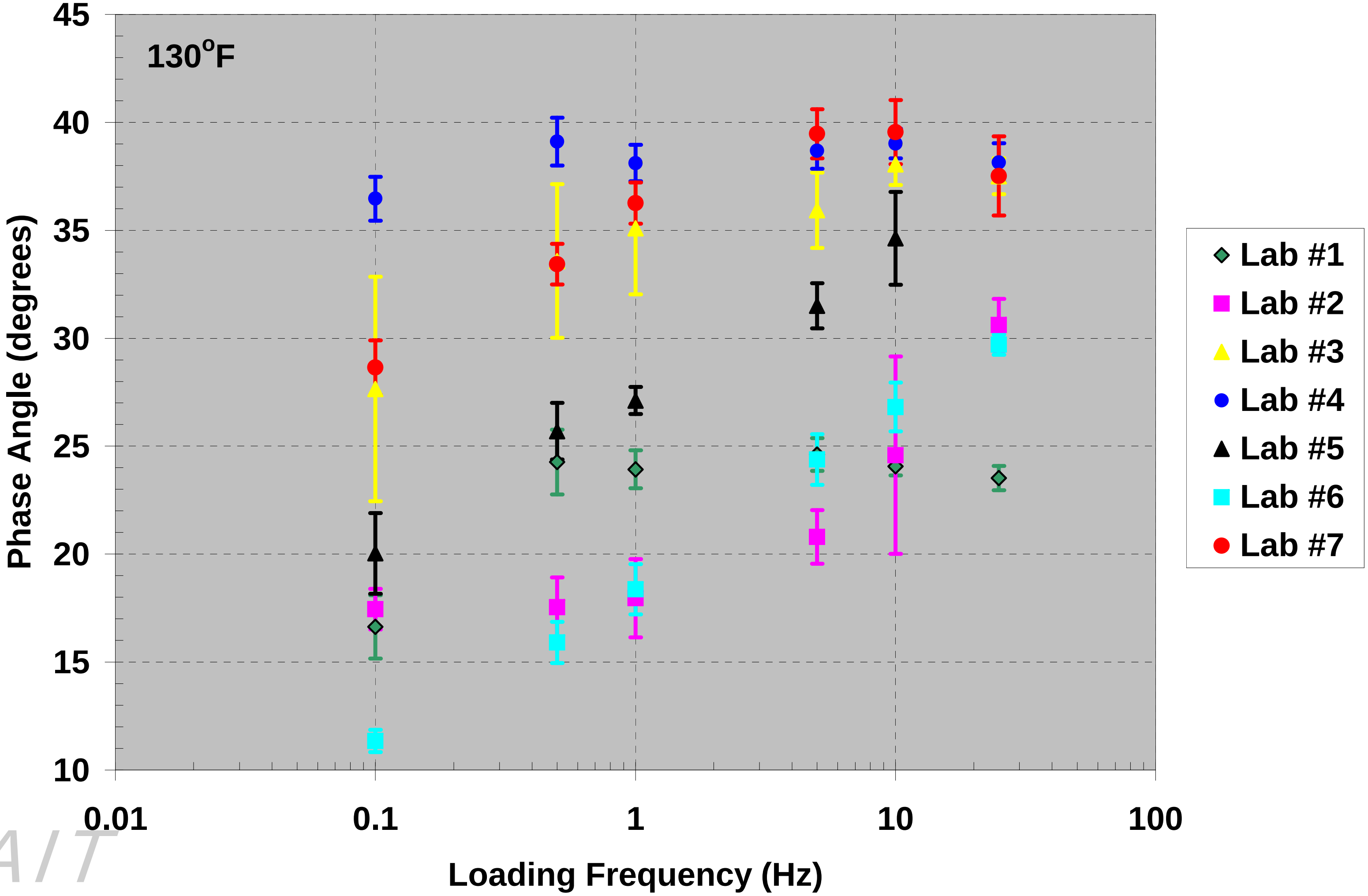
Phase Angle – 9.5mm, 130°F



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ASTM E691

Standard Practice for Conducting an Inter-laboratory Study to Determine the Precision of a Test Method

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Variance (Repeatability)

- For each combination of temperature and frequency, the variance components associated with E* and phase angle were estimated
- In general, the experimental variance (i.e., repeatability) was relatively low
  - the largest proportion of error was attributed to the laboratory error, or reproducibility term
- Material variability was also larger than the pure experimental error
  - Means that the intentional variability in the data created through the use of different materials was readily detected by the dynamic modulus test

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Analysis of Variance (ANOVA)

- Analysis of variance (ANOVA) was used to investigate the effect of the various equipment types
- SPT and non-SPT devices provided statistically significant differences in measures of both E* and phase angle
  - Greatest precision was achieved at intermediate test temperatures, with the SPT devices exhibiting much less variability between laboratories than the non-SPT devices

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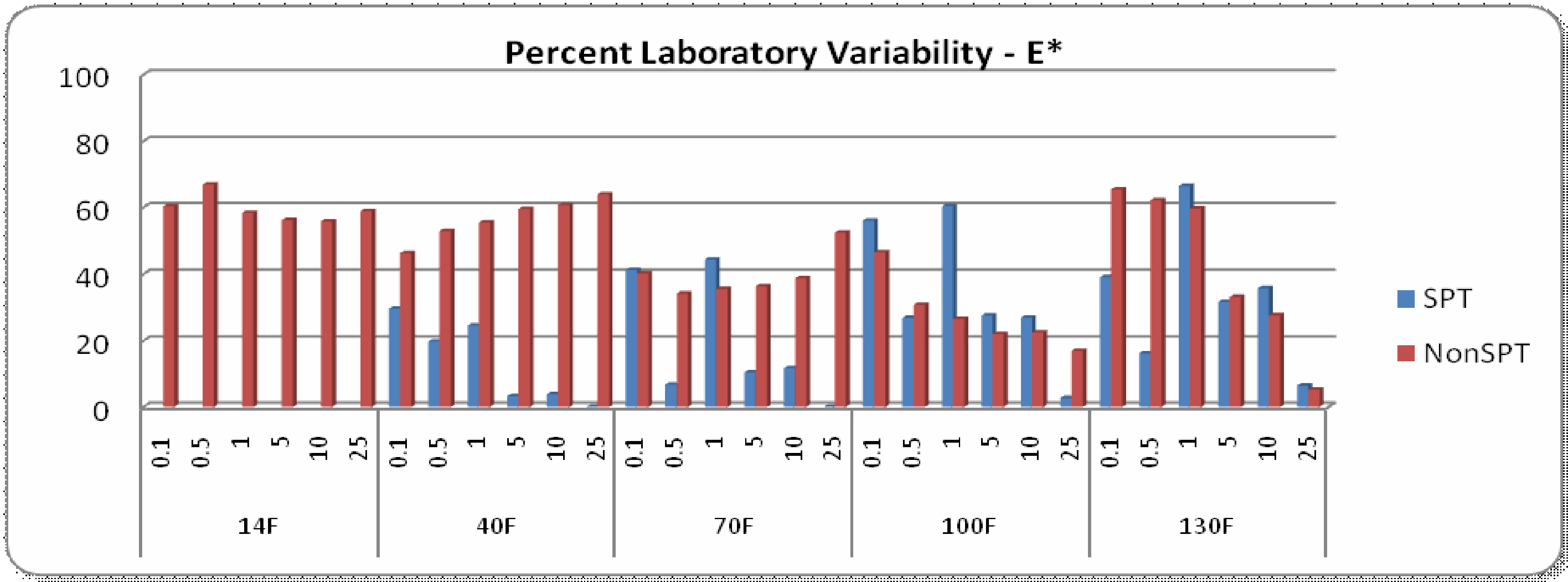
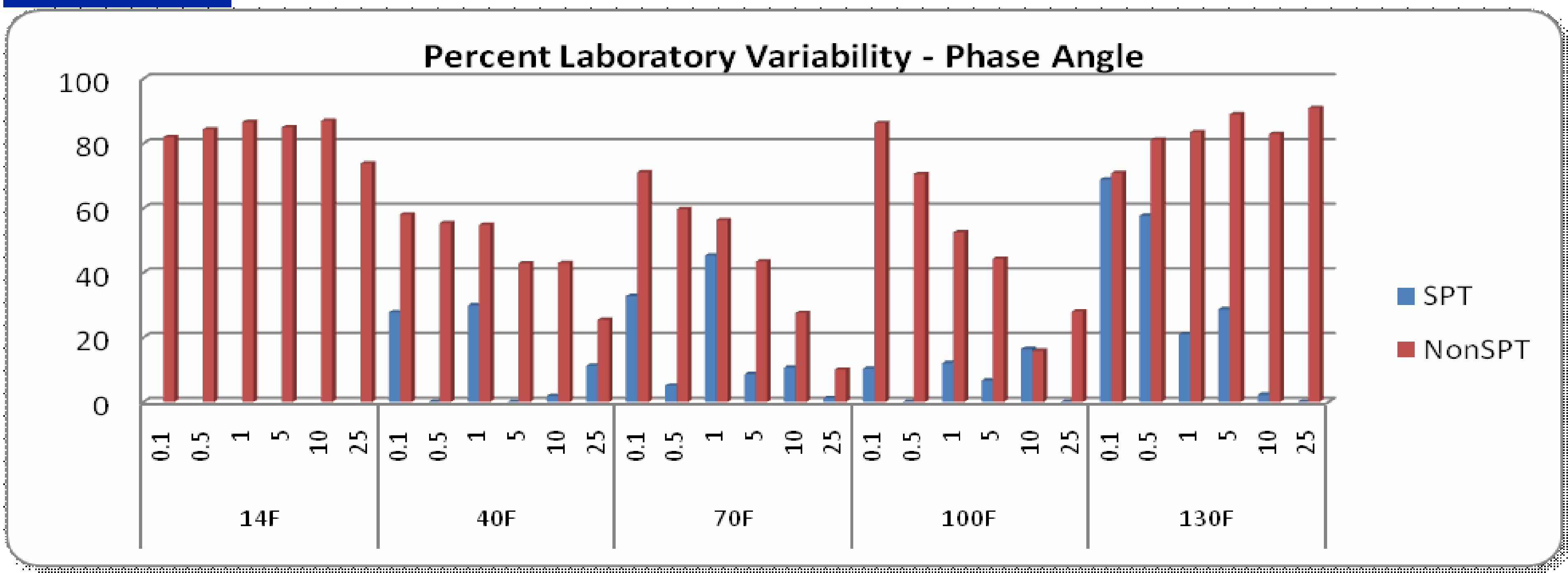


Percent Laboratory Variability - E*
100
80
60
40
20
0
0.1
0.5
1
5
10
25
14F
40F
70F
100F
130F
SPT
NonSPT



Percent Laboratory Variability - Phase Angle
100
80
60
40
20
0
0.1
0.5
1
5
10
25
14F
40F
70F
100F
130F
SPT
NonSPT

Initial Precision Statement of AASHTO TP62-07

Analysis Condition	Precision Mode	Parameter	1S%	D2S%
All Test Devices, All Temperatures	Single Operator Precision	Dynamic Modulus	13.03	36.47
		Phase Angle	6.76	18.93
	Multi-Laboratory Precision	Dynamic Modulus	26.89	75.3
		Phase Angle	19.46	54.49

- 1S% = Coefficient of Variation
- D2S% = Acceptable Range of 2 Results

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 = 10,000
- Newark, NJ Climatic Conditions

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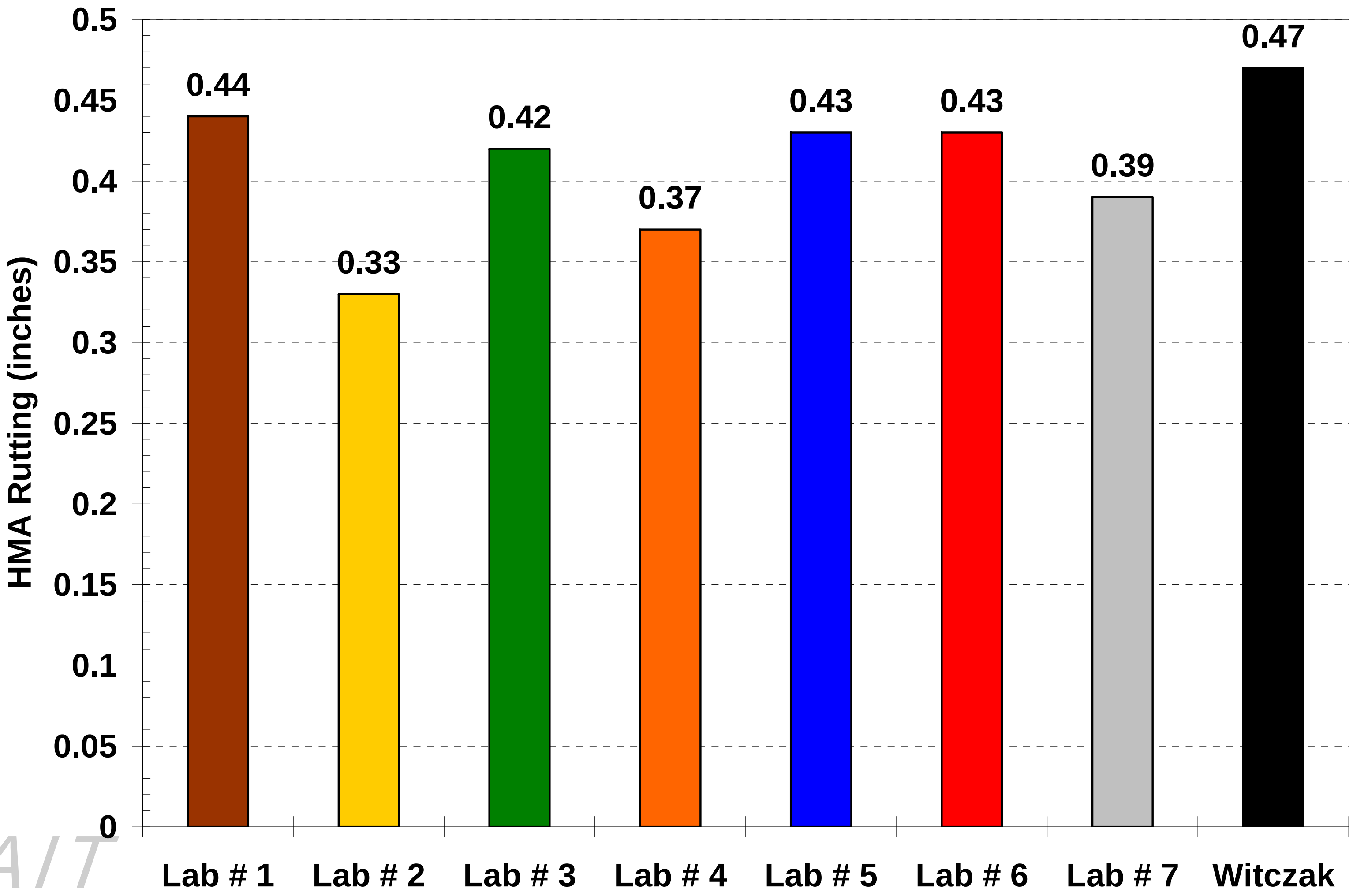
MEPDG Outputs – HMA Rutting



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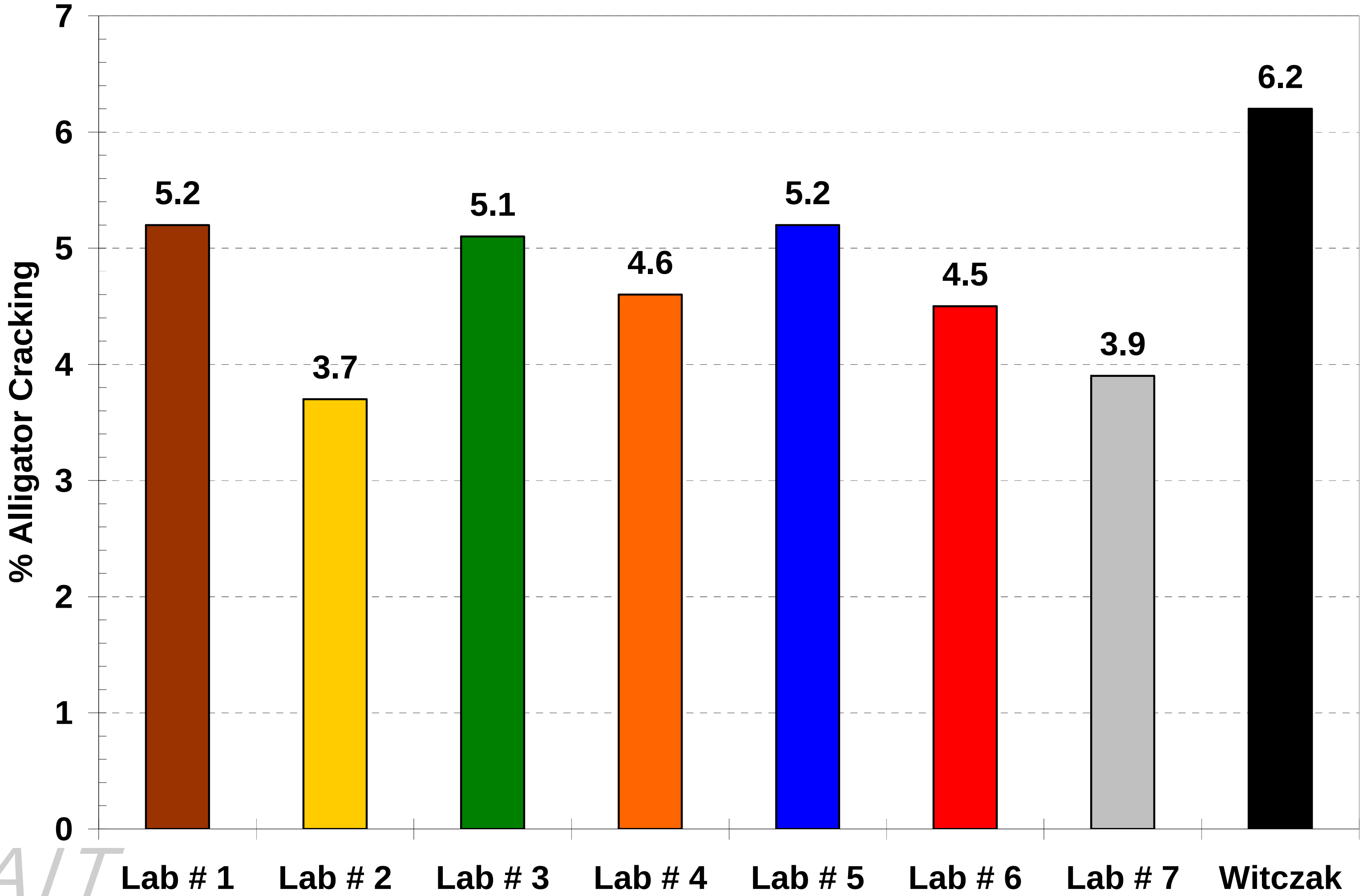
MEPDG Outputs – Alligator Cracking



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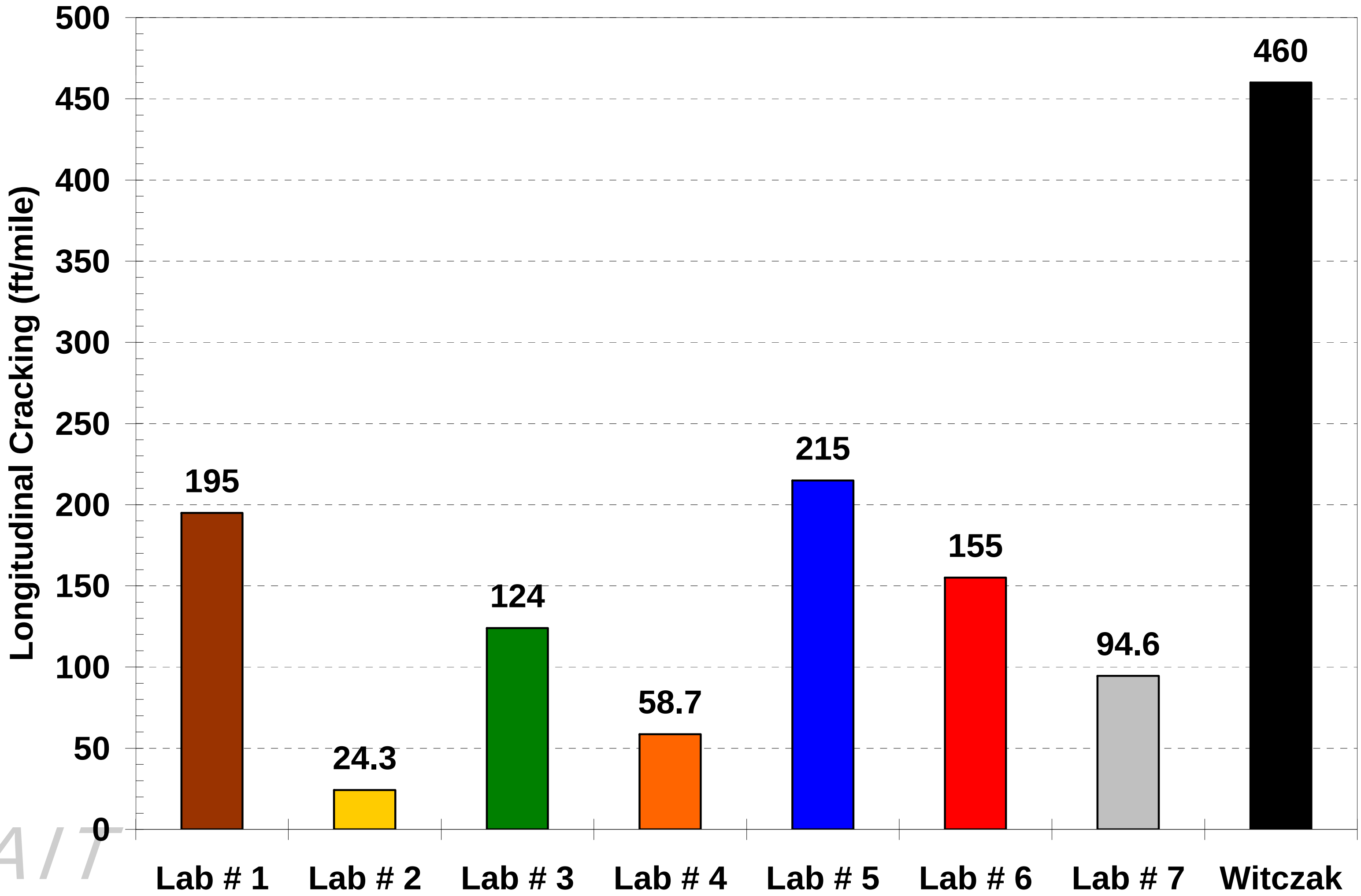
MEPDG Outputs – Longitudinal Cracking



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Improving Dynamic Modulus Precision

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Increasing Dynamic Modulus Precision

- Greatest precision at intermediate temperatures (40, 70, and 100^{o}F)
- Precision of AASHTO TP62-07 could be improved by eliminating 14 and 130^{o}F
  - Current SPT's and other devices can not test at 14^{o}F
  - Others have already recommended eliminating high and low temperatures
    - Bonaquist and Christensen (TRR #1929, 2005)
    - Dongré (FHWA Mix ETG, 2007)

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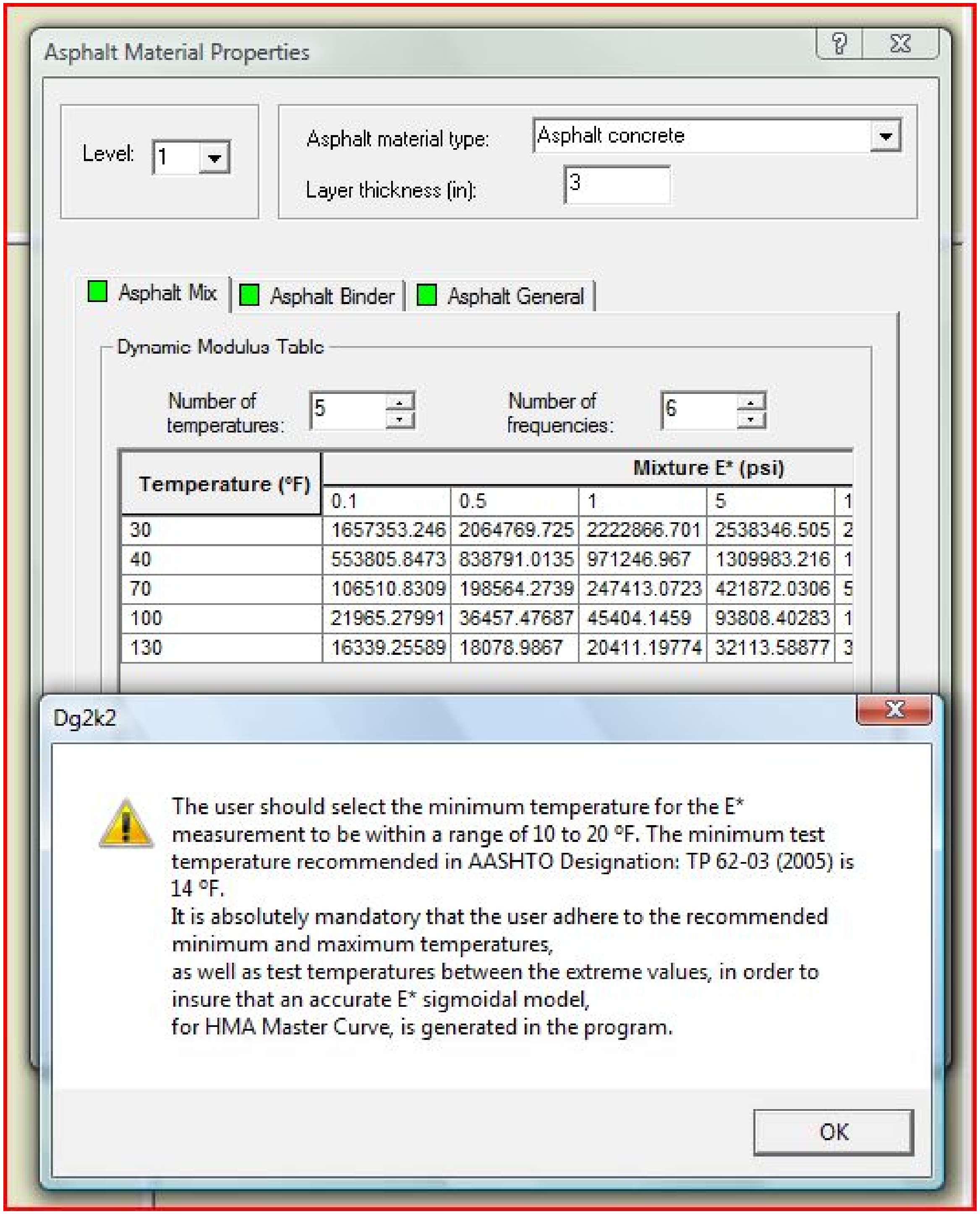

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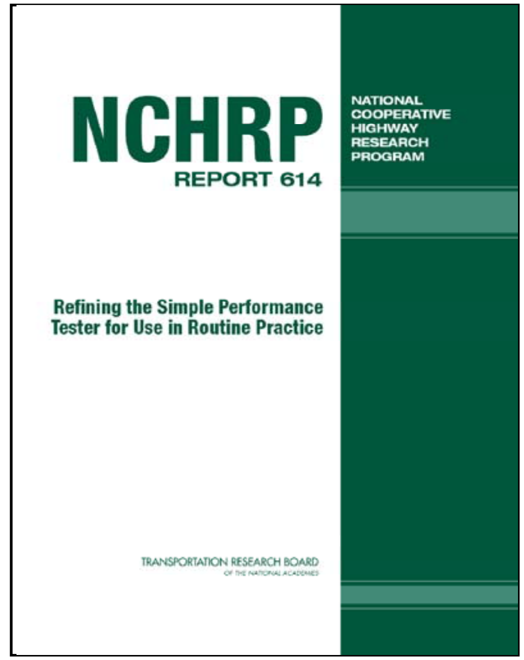
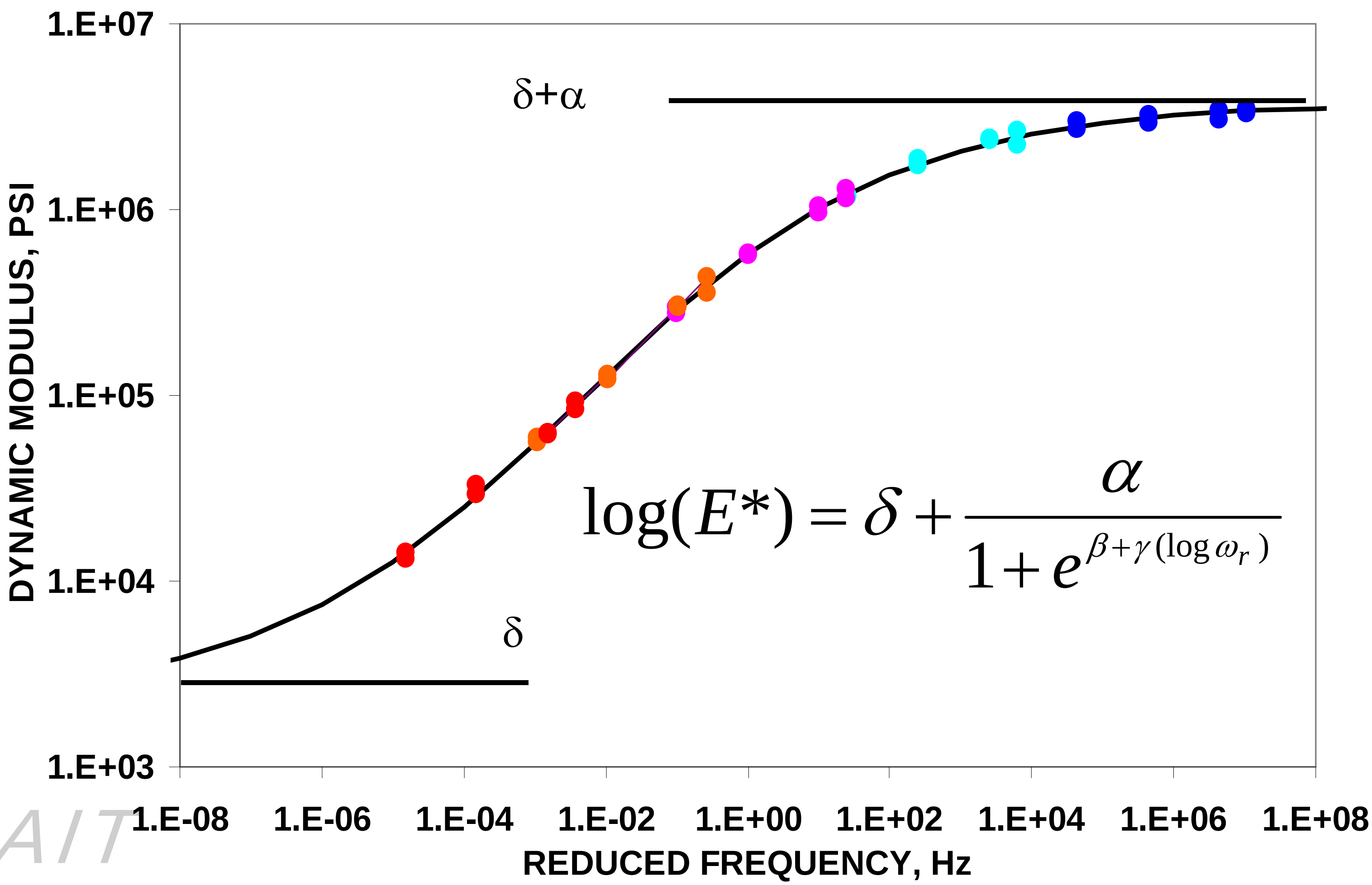
Increasing Dynamic Modulus Precision

- NCHRP Report 614
  - Overview of E* testing with SPT (AMPT) devices
  - Test method and stiffness master curve development
  - Eliminates 14ºF and 130ºF test temperatures



PG 58-XX and softer		PG 64-XX & PG 70-XX		PG 76 –XX and stiffer	
Temperature °C	Loading Frequencies Hz	Temperature °C	Loading Frequencies Hz	Temperature °C	Loading Frequencies Hz
4	10, 1, 0.1	4	10, 1, 0.1	4	10, 1, 0.1
20	10, 1, 0.1	20	10, 1, 0.1	20	10, 1, 0.1
35	10, 1, 0.1, and 0.01	40	10, 1, 0.1, and 0.01	45	10, 1, 0.1, and 0.01

Master Stiffness Curve – All 5 Temperatures



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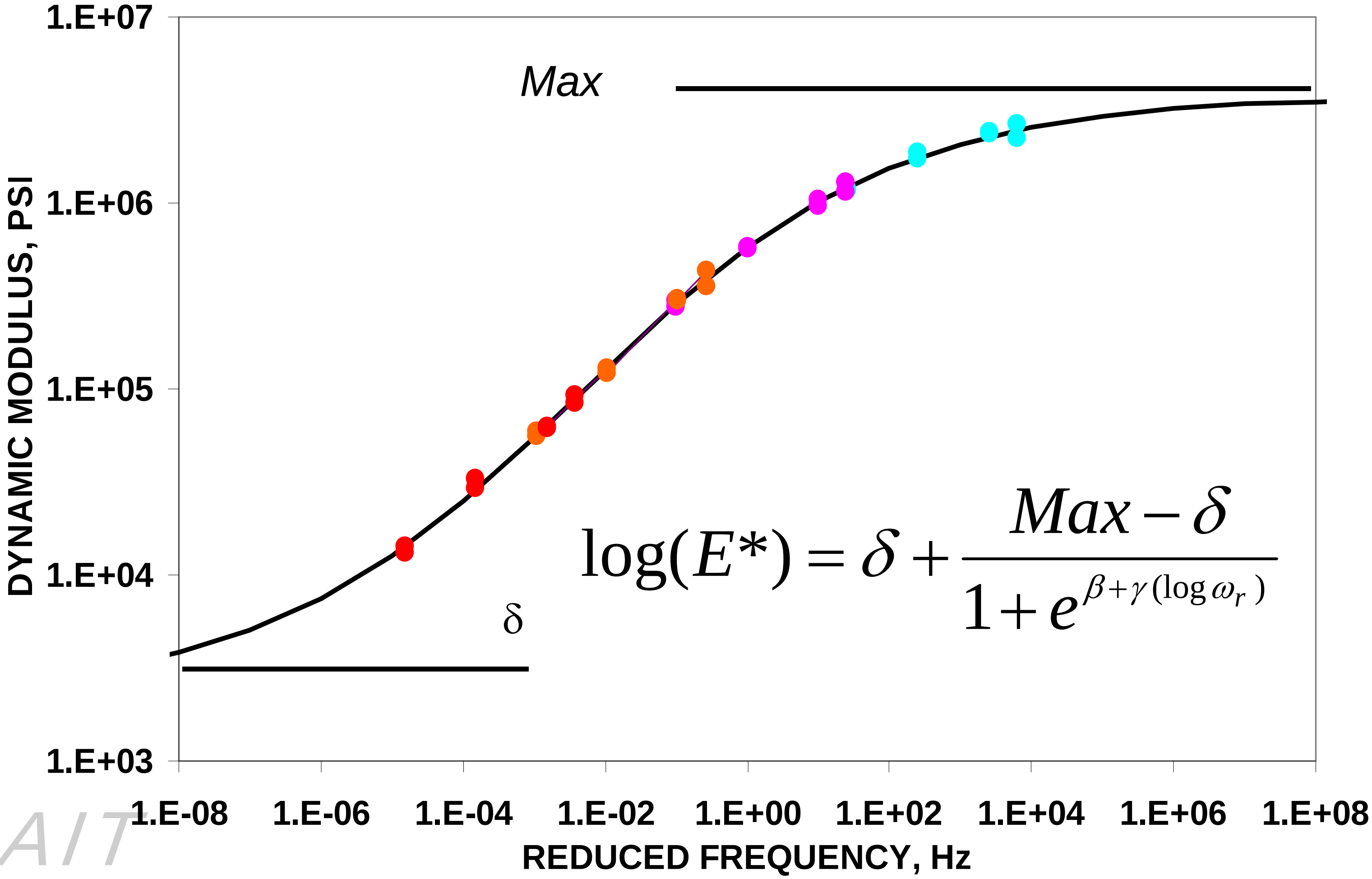
Master Stiffness Curve – 4 Test Temperatures (No 14^{o}F)



$$\log(E^*) = \delta + \frac{Max - \delta}{1 + e^{\beta + \gamma(\log \omega_r)}}$$

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Precision Statement

Analysis Condition	Precision Mode	Parameter	1S%	D2S%
All Test Devices, All Temperatures	Single Operator Precision	Dynamic Modulus	13.03	36.47
		Phase Angle	6.76	18.93
	Multi-Laboratory Precision	Dynamic Modulus	26.89	75.3
		Phase Angle	19.46	54.49
All Test Devices, Eliminating High and Low Temperatures	Single Operator Precision	Dynamic Modulus	12.24	34.26
		Phase Angle	5.06	14.17
	Multi-Laboratory Precision	Dynamic Modulus	24.98	69.94
		Phase Angle	10.09	28.25
SPT Devices Only, Eliminating High and Low Temperatures	Single Operator Precision	Dynamic Modulus	10.87	30.44
		Phase Angle	3.92	10.99
	Multi-Laboratory Precision	Dynamic Modulus	22.05	61.74
		Phase Angle	5.07	14.19
Non-SPT Devices Only, Eliminating High and Low Temperatures	Single Operator Precision	Dynamic Modulus	12.33	34.53
		Phase Angle	5.6	15.69
	Multi-Laboratory Precision	Dynamic Modulus	25.43	71.2
		Phase Angle	11.28	31.58

- 1S% = Coefficient of Variation
- D2S% = Acceptable Range of 2 Results
- Low Temperature = 14^{o}F
- High Temperature = 130^{o}F

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Conclusions

- E* widely used to characterize HMA mixtures
  - MEPDG, influence on additives, higher RAP contents
- Generated precision statement for AASHTO TP62-07 indicates issues with precision
  - For Single Operator:
    - Dynamic Modulus: 1S% = 13.03; D2S% = 36.47
    - Phase Angle: 1S% = 6.76; D2S% = 18.93
  - Multi-Laboratory:
    - Dynamic Modulus: 1S% = 26.89; D2S% = 75.3
    - Phase Angle: 1S% = 19.46; D2S% = 54.49

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Conclusions - continued

- E* precision will have impact on MEPDG outputs
  - Pavement structure and climatic condition will dictate impact on distress magnitude
- Precision can be improved by eliminating high and low temperatures
  - Recommend following method in NCHRP Report 614
    - Low temp portion of stiffness master curve generated by Hirsch model
    - High temp portion of stiffness master curve generated by using 0.01 Hz
    - Master curve can be used to provide 14 and 130F E* for MEPDG
    - SPT (AMPT) already uses range of 75 to 125 micro-strains

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Thank you for your time!

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