Materials Characterization for the MEPDG at MDOT

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Outline

- Materials Characterization within Framework of MDOT Implementation of MEPDG
- Difference in Materials Characterization
- Some Details for:
  - Subgrade
  - Unbound Aggregates
  - HMA
  - Concrete
  - Cementitious Stabilized Soils
  - Drainage Layer
- Some Practical Applications of MEPDG Materials Characterization

Materials Characterization within Framework of MDOT Implementation of MEPDG

- SS No. 170 “Implement the 2002 Design Guide for MDOT (Phase II)
- Primary study to implement MEPDG
- Applied Research Associates, Inc. (ARA)
- One aspect of SS No. 170 - Facilitate establishment of materials libraries
- Some materials being characterized by subcontractor to SS No. 170

Materials Characterization via SS No. 170

- Subcontractor - Burns, Cooley, & Dennis, Inc. (BCD)
- Performing M_r testing of typical MS subgrade soils
- Unbound aggregates
- Testing cementitious stabilized soils
  - Lime
  - LFA
  - Cement
- Test data included in materials library

SS No. 170

- State studies separate from SS No. 170 were developed for:
  - HMA
  - PCC
  - Low asphalt content drainage layer
- ARA Coordinates with PIs of all material characterization studies to:
  - Ensure tests provides requisite inputs for the MEPDG
  - Most up to date test protocols are used
  - Review test results

Constant Material Properties

- MDOT currently uses 1972 AASHO Design Guide for flexible pavements
- Uses structural layer coefficients to characterize pavement layer material properties
- Basically equivalency factors
  - Hot Mix Asphalt (HMA) – 0.44
  - Soil Cement & Lime-Fly Ash (LFA) base – 0.20
  - Crushed stone – 0.14
- Set values, do not change with stress state, rate of loading, moisture, temperature, etc.

MEPDG Allows Material Properties to Vary

- Fundamental engineering properties
  - – Modulus
  - – Poisson's Ratio
- Modulus not a set value for a given material, it varies
- Example - HMA
  - – Modulus varies with rate of loading; i.e., how fast the traffic is going
  - – Modulus varies with temperature; i.e., a given HMA layer becomes stiffer as its temperature decreases

BCD Tested 30 Subgrade Soils

USCS	No. Spec.
CH	1
CL	3
ML	2
ML-CL	1
SC	10
SC-SM	1
SM	1
SMd	2
SP	2
SP-SC	1
SP-SM	1

AASHTO	No. Spec.	Range GI
A-2-4	5	
A-2-6	3	0 - 1
A-3	2	
A-4	9	2 - 10
A-6	8	10-Feb
A-7-6	2	28 - 34

BCD Testing 10 Unbound Aggregates

Crushed Stone Granular Base		
3/4" and down	No. 610	No. 825 B

Clay Gravel Base

	Class									
Group	1	2	3	4	5	6	7	8	9	10
A	**X**									
B				**X**						
C			**X**		**X**		**X**			
D										**X**
E									**X**	

Resilient Modulus Test used for Subgrade and Unbound Aggregate

- Harmonized test procedure resulting from NCHRP 1-28A
- Interlaken Soil and Asphalt Testing Machine

Typical Subgrade Results

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
1	14.8	7.9	7.9	30.6	3.3	6.9	14272	14823
2	12.4	5.9	5.9	24.2	3.1	6.5	12267	12364
3	10.1	3.9	3.9	17.9	2.9	6.2	9701	9685
4	7.6	1.9	1.9	11.4	2.7	5.7	7252	6742
5	17.8	7.9	7.9	33.6	4.7	9.9	13582	13826
6	15.5	5.9	5.9	27.3	4.5	9.6	11605	11729
7	13.1	3.9	3.9	20.9	4.3	9.2	9484	9500
8	10.7	1.9	1.9	14.5	4.1	8.8	7236	7069
9	20.9	7.9	7.9	36.7	6.1	13.0	12963	12917
10	18.5	5.9	5.9	30.3	5.9	12.6	11159	11149
11	16.0	3.9	3.9	23.8	5.7	12.1	9125	9262
12	13.7	1.9	1.9	17.5	5.6	11.8	6854	7204
13	24.9	7.9	7.9	40.7	8.0	17.0	12723	11894
14	22.6	5.9	5.9	34.4	7.9	16.7	11009	10417
15	20.1	3.9	3.9	27.9	7.6	16.2	8913	8879
16	17.8	1.9	1.9	21.6	7.5	15.9	6601	7211

BCD Project:	04070-1
Project Name:	MDOT Study 170
Date:	12/9/2007
Sample I.D.:	Subgrade Sample No. 30
	(see Summary Sheet)
Replicate Test:	3

K_1 =	796.3
K_2 =	0.862
K_3 =	-1.981

n = 16

SES = 0.005
Sy = 0.111

Se = 0.019
Se/Sy = 0.175
R^2 = 0.969

Subgrade Summary Results

Sample No.	AASHTO	USCS	% Passing # 10	% Passing # 40	% Passing # 60	% Passing # 200	LL	PL	PI	Shrink Limit	Shrink Ratio	Volume Change	Compaction		Blows Per Layer	M_R Results		
													$\delta_{max.}$	w_{opt}		k_1	k_2	k_3
1	A-6 (10)	CL	100	100	99	68	36	18	18	19	1.63	27	107	18.3	8	1363.1	0.517	-2.877
2	A-2-4 (0)	SC	100	98	82	35	23	14	9	16	1.75	12	124.4	12.2	12	1,800.4	0.658	-2.325
3	A-4 (4)	CL	100	ND	ND	71.8	24	15	9	16.6	1.9	14.4	117.4	12.5	8	1618.7	0.752	-2.68
4	A-4 (0)	SC	99.6	ND	ND	31.4	23	14	9	18.8	1.8	20.0	120.0	11.8	7	1548.7	0.816	-2.494
5	A-4 (9)	CL	100	ND	ND	85.1	29	16	13	13.7	1.9	31.8	114.3	13.9	13 (H)	2373.3	0.646	-1.595
6	A-4 (?)	CL	?	?	?	?	25	15	10	13.6	1.9	26.6	119.8	11.8	11 (H)	2253.7	0.689	-1.814
7	A-6 (4)	SC	100	---	---	50.5	28	12	16	15	1.9	29.6	115.9	13.4	7	1720.8	0.632	-3.398
8	A-2-4(1)	SP	95	64	33	2	OK	N/A	NP	N/A	N/A	N/A	106.1	12.2	N/A	1254.8	0.88	-1.258
9	A-3	SP	99.5	51.1	23.6	8.2	---	---	NP	---	---	---	109.3	11.4	N/A	992.5	0.897	-1.363
10	A-2-6 (1)	SC	100	99.8	99.1	33.9	28	12	16	18.5	1.7	23.6	110.0	12.9	8	1694	0.54	-2.052
11	A-7-6 (28)	CL	100	99.9	99.8	92.1	43	13	30	15.1	1.9	72.9	103.3	17.7	8	1043.6	0.324	-2.674
12	A-6 (7)	SC	100	98.2	86.7	51.7	36	14	22	14.3	1.9	49.3	110.8	13.1	10	2461.7	0.46	-1.73
13	A-6 (2)	SC	100	99	89.9	46.4	27	14	13	16.1	1.8	29.7	115.9	12.3	7	1660.3	0.623	-2.379
14	A-2-4 (0)	SC-SM	100	94.6	81.4	31	23	16	7	16.1	1.8	17.5	119.8	11.4	7	2078.2	0.699	-2.472
15	A-7-6 (34)	CH	100	99.9	99.6	90.6	52	16	36	15.1	1.8	69.1	102.7	19.3	9	1695.8	0.336	-2.816
16	A-6 (5)	SC	---	87	---	47	34	14	20	---	---	---	116.3	13.9	7	2054.3	0.544	-2.523
17	A-6 (4)	SC	---	97	---	46	30	14	16	---	---	---	117.6	13.6	8	2164.7	0.531	-2.105
18	A-6 (6)	CL	---	82	---	67	24	10	14	---	---	---	116.9	12.9	10	2308.4	0.395	-3.045
19	A-2-4 (0)	SM	---	83	---	25	21	14	7	---	---	---	123	10.7	6	1921.4	0.79	-2
20	A-6 (6)	CL	---	95	---	78	26	15	11	---	---	---	116.5	13	9	2630.4	0.453	-2.111
21	A-4 (2)	ML-CL	---	97	---	74	21	14	7	---	---	---	117.7	12.7	8	2007.5	0.558	-1.873
22	A-4 (0)	SMd	---	86	---	44	18	12	6	---	---	---	123.3	10.8	8	2022.3	0.664	-3.186
23	A-2-4 (0)	SMd	---	88	---	50	22	NP	0	---	---	---	116.7	13.6	7	2036.4	0.888	-2.553
24	A-4 (0)	SC	---	91	---	37	20	11	9	---	---	---	121.1	11.6	7	2478.2	0.602	-2.259
25	A-2-4(0)	SP-SM	---	92	---	12	20	NP	0	---	---	---	117.8	12.5	6	1738	0.787	-1.78
26	A-2-6 (0)	SP-SC	71.1	21.0	8.7	7	29	14	15	19.48	1.75	23.2	120.4	8.9	N/A	N/A	N/A	N/A
27	A-2-6 (0)	SC	100.0	73.0	45.9	20.1	27	13	14	15.6	1.76	17.6	122.3	11.1	6	1806.2	0.99	-2.761
28	A-4 (1)	ML	100	100	100	99.3	27	26	1	23.57	1.58	9.1	104.4	16.9	7	607.9	0.587	-1.134
29	A-4 (0)	ML	100	100	99.9	99.8	NP	NP	NP	24.19	1.57	11.3	101.0	18.1	4	744.7	0.6	-1.384

Typical Unbound Aggregate Results

Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi	Pred. M_R psi
1	5.7	3.0	3.0	11.7	1.3	2.7	14232	12692
2	10.7	6.0	6.0	22.7	2.2	4.7	24697	23965
3	17.6	10.0	10.0	37.6	3.6	7.6	34811	37810
4	26.1	15.0	15.0	56.1	5.2	11.1	47687	53185
5	34.6	20.0	20.0	74.6	6.9	14.6	61961	66822
6	7.1	3.0	3.0	13.1	1.9	4.1	14380	13793
7	13.8	6.0	6.0	25.8	3.7	7.8	25023	25544
8	22.6	10.0	10.0	42.6	5.9	12.6	37405	38924
9	33.7	15.0	15.0	63.7	8.8	18.7	52541	52927
10	44.7	20.0	20.0	84.7	11.6	24.7	67603	64660
11	10.2	3.1	3.1	16.4	3.3	7.1	16676	16258
12	19.8	6.0	6.0	31.8	6.5	13.8	29826	28169
13	32.7	10.0	10.0	52.7	10.7	22.7	45155	40867
14	48.7	15.0	15.0	78.7	15.9	33.7	60443	53030
15	64.8	20.0	20.0	104.8	21.1	44.8	69479	62565
16	13.1	3.0	3.0	19.1	4.8	10.1	18019	17879
17	25.9	6.0	6.0	37.9	9.4	19.9	31844	30404
18	42.7	10.0	10.0	62.7	15.4	32.7	45523	42500
19	63.7	15.0	15.0	93.7	23.0	48.7	55537	53506
20	84.8	20.0	20.0	124.8	30.5	64.8	66733	61822
21	19.3	3.0	3.0	25.3	7.7	16.3	19945	21291
22	38.1	6.0	6.0	50.1	15.1	32.1	34131	33994
23	60.7	10.0	10.0	80.7	23.9	50.7	44677	44954
24	94.2	15.0	15.0	124.2	37.3	79.2	53924	54845
25	126.1	20.0	20.0	166.1	50.0	106.1	64500	61860
26	24.7	3.0	3.0	30.7	10.2	21.7	18993	23787
27	50.9	6.0	6.0	62.9	21.2	44.9	32396	36940
28	82.9	10.0	10.0	102.9	34.4	72.9	40762	47417
29	124.2	15.0	15.0	154.2	51.5	109.2		
30	20.0	20.0	20.0	60.0	0.0	0.0		

BCD Project: 04070

Project Name: MDOT Design Guide

Date: 12/9/2007

Sample I.D.: 825B Limestone

Replicate Test: Rep 5

K_1 =	1,169.4
K_2 =	1.030
K_3 =	-0.821

n = 28

SES = 0.037

Sy = 0.217

Se = 0.039

Se/Sy = 0.178

R^2 = 0.968

SS No. 166 “Hot Mix Asphalt (HMA) Characterization for the 2002 AASHTO Design Guide”

- Mississippi State University (MSU) study
  - Dr. Shane Buchanan
  - Dr. Tom White
- Characterize typical MDOT HMA mixes
- Test results included in Materials Library

Test Matrix

Gradation	Aggregate Type	Binder PG	NMAS Gradation	N_{design}	Replicates
Coarse	Gravel	67-22	9.5	50	3
				65	3
			12.5	50	3
				65	3
			19.0	50*	3 (3)
				65	3
				85	3
		76-22	9.5	85	3
			12.5	85	3
			19.0	85	3
		82-22	9.5	85	3
			12.5	85	3
	Limestone / Gravel	67-22	9.5	50	3
				65	3
			12.5	50	3
				65	3
			19.0	50	3
				65	3
				85	3
		76-22	9.5	85	3
			12.5	85	3
			19.0	85	3
		82-22	9.5	85	3
			12.5	85	3

*** - Mix Designed at 4% and 3% Air Voids**

HMA Mix Designs

	Mix Type	Design Asphalt Content (%)	Gmm	VMA (%)	VFA (%)	Pba (%)	Pbe (%)	Air Voids (%)	Dust/Effective Asphalt
1	9.5GR67-50	7.30	2.3054	15.7	74.6	0.9	6.5	4.0	0.7
2	9.5GR67-65	6.70	2.3054	15.2	73.7	0.9	5.9	4.0	0.8
3	9.5GR76-85	7.02	2.3312	14.5	72.5	1.4	5.7	4.0	0.8
4	9.5GR82-85	6.77	2.3438	13.9	71.1	1.6	5.2	4.0	0.9
5	12.5GR67-50	7.30	2.3019	15.4	74.1	1.0	6.4	4.0	0.7
6	12.5GR67-65	7.01	2.3019	15.2	73.6	1.0	6.1	4.0	0.8
7	12.5GR76-85	6.73	2.2983	15.0	73.4	0.9	5.8	4.0	0.8
8	12.5GR82-85	7.04	2.3159	14.7	72.7	1.3	5.8	4.0	0.8
9	19.0GR67-50	6.36	2.3035	14.1	71.7	1.2	5.2	4.0	0.9
10	19.0GR67-65	6.27	2.3035	14.0	71.5	1.3	5.1	4.0	0.9
11	19.0GR67-85	6.00	2.3035	13.8	71.0	1.3	4.8	4.0	1.0
12	19.0GR76-85	6.00	2.2874	14.4	72.2	0.9	5.1	4.0	0.9
13	9.5L/GR67-50	5.11	2.3991	13.2	69.8	1.3	3.9	4.0	1.1
14	9.5L/GR67-65	5.63	2.3991	13.7	70.8	1.3	4.4	4.0	1.0
15	9.5L/GR76-85	5.54	2.3890	14.0	71.4	1.1	4.5	4.0	1.0
16	9.5L/GR82-85	6.37	2.3898	14.7	72.8	1.1	5.3	4.0	0.8
17	12.5L/GR67-50	5.15	2.3745	14.3	72.0	0.8	4.4	4.0	1.3
18	12.5L/GR67-65	4.95	2.3745	14.1	71.7	0.8	4.2	4.0	1.4
19	12.5L/GR76-85	5.00	2.3748	14.2	71.7	0.8	4.3	4.0	1.4
20	12.5L/GR82-85	6.66	2.3897	15.1	73.6	1.1	5.7	4.0	1.0
21	19.0L/GR67-50	4.26	2.3846	13.6	70.7	0.7	3.6	4.0	1.7
22	19.0L/GR67-65	4.06	2.3846	13.5	70.3	0.7	3.4	4.0	1.8
23	19.0L/GR67-85	4.37	2.3846	13.7	70.9	0.7	3.7	4.0	1.6
24	19.0L/GR76-85	4.06	2.3796	13.6	70.7	0.6	3.5	4.0	1.7
25	19.0GR67-50	6.76	2.3035	15.3	73.9	2.3	4.6	3.0	1.0

Dynamic Modulus Specimen Preparation

Dynamic Modulus Specimen Preparation

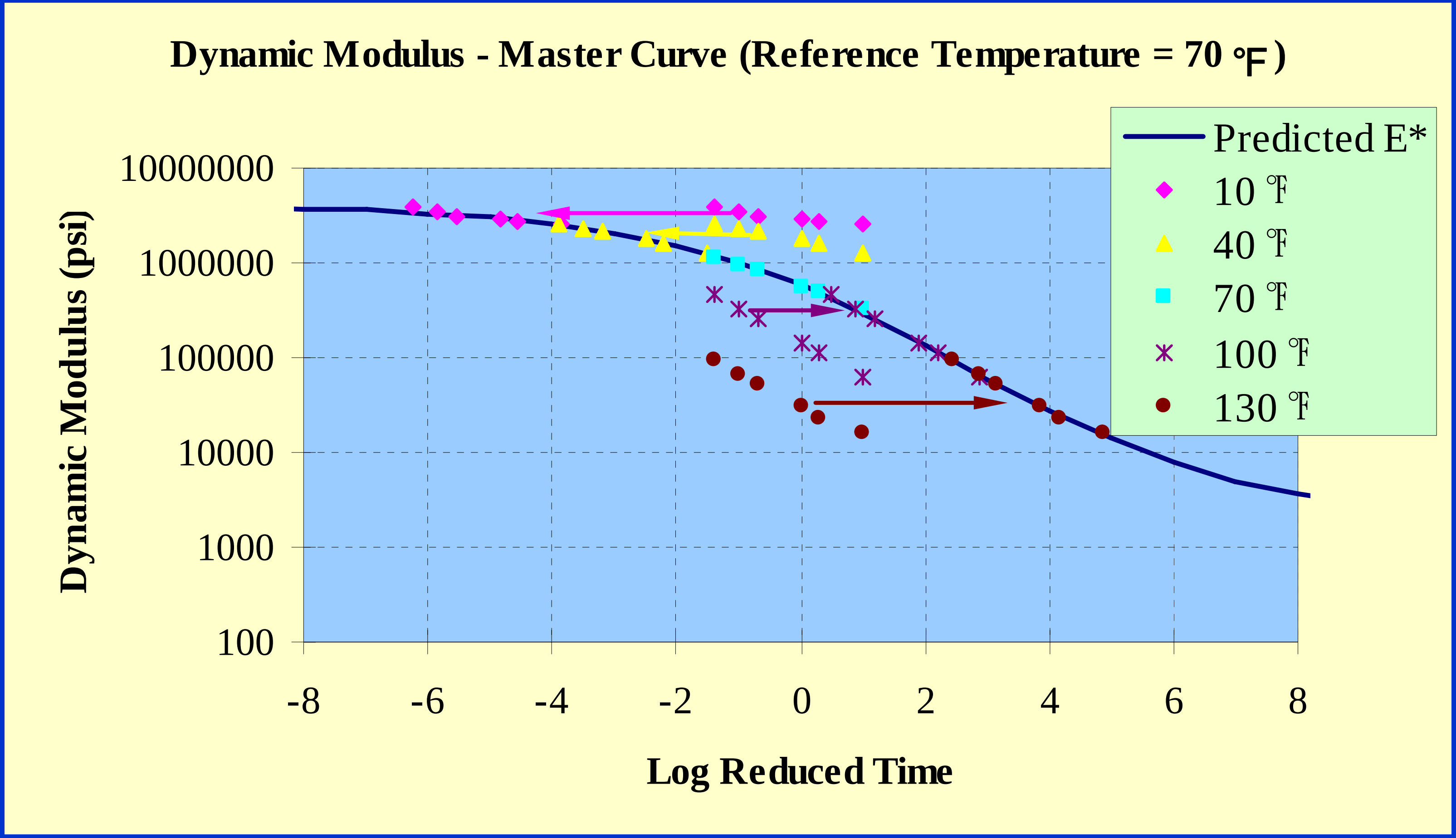
Test parameters for each replicate

Mix	Temperature - °C	Load Frequency Sweep - Hz
"X"	-10	25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
	4	25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
	21	25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
	37	25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
	54	25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1
		25, 10, 5, 1, 0.5, 0.1

Dynamic Modulus Spreadsheet

Temperature, °C	Frequency, Hz	Dynamic Modulus, psi			
		A	B	C	Average
-10	25	2637304	1761973	2387725	2262334
	10	2529084	1670636	2306228	2168649
	5	2438805	1614603	2229588	2094332
	1	2240194	1464418	2037050	1913887
	0.5	2141993	1396979	1943819	1827597
	0.1	1891148	1241528	1702177	1611618
4	25	1825279	1447866	1741300	1671482
	10	1657567	1279496	1569146	1502070
	5	1546643	1189964	1459427	1398678
	1	1272673	991296	1196245	1153405
	0.5	1152306	907609	1070749	1043555
	0.1	876746	705849	788478	790358
21	25	838131	802233	508602	716322
	10	685207	643618	643095	657307
	5	569005	545852	554946	556601
	1	359648	345229	359410	354762
	0.5	281586	278091	284038	281238
	0.1	294560	162568	161735	206288
37	25	406667	385005	304619	365431
	10	276736	240085	172388	229736
	5	205601	174511	132748	170953
	1	100004	79635	59608	79749
	0.5	76283	64253	46644	62393
	0.1	47587	39774	30387	39249
54	25	127529	115039	81451	108006
	10	62529	54685	45985	54400
	5	34171	28451	23846	28822
	1	20496	16884	13860	17080
	0.5	16903	14273	12407	14528
	0.1	13265	11306	10018	11530

Raw Data | Master Curve


Dynamic Modulus - Master Curve (Reference Temperature = 70 °F)
Predicted E*
10 °F
40 °F
70 °F
100 °F
130 °F
10000000
1000000
100000
10000
1000
100
Dynamic Modulus (psi)
-8
-6
-4
-2
0
2
4
6
8
Log Reduced Time

Master Curve Spread Sheet

Sample 1: 9.5 GR, 67-22, N=50

$$\log\left(\left|E^*\right|\right) = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log(f_r)}}$$

Reference Temperature= 21°C

Sum of Error^2 = 0.088915216

Temp (°C)	Frequency (Hz)	|E*| (psi)	Time	Log Reduced	Log E [illegible]	Log E [illegible]	Error^2
-10	25	2262334	0.040	-6.1194	6.3546	6.3273	0.000744005
-10	10	2168649	0.10	-5.7215	6.3362	6.3174	0.000351341
-10	5	2094332	0.20	-5.4205	6.3210	6.3086	0.000155543
-10	1	1913887	1.00	-4.7215	6.2819	6.2820	7.70695E-09
-10	0.5	1827597	2.00	-4.4205	6.2619	6.2674	3.05225E-05
-10	0.1	1611618	10.00	-3.7215	6.2073	6.2240	0.000280547
4	25	1671482	0.04	-3.6207	6.2231	6.2165	4.39593E-05
4	10	1502070	0.10	-3.2228	6.1767	6.1829	3.91548E-05
4	5	1398678	0.20	-2.9218	6.1457	6.1532	5.54699E-05
4	1	1153405	1.00	-2.2228	6.0620	6.0665	2.01646E-05
4	0.5	1043555	2.00	-1.9218	6.0185	6.0204	3.44926E-06
4	0.1	790358	10.00	-1.2228	5.8978	5.8894	7.16005E-05
21	25	716322	0.04	**-1.3979**	5.8551	5.9256	0.004962274
21	10	657307	0.10	**-1.0000**	5.8178	5.8399	0.000488889
21	5	556601	0.20	**-0.6990**	5.7455	5.7667	0.000446588
21	1	354762	1.00	**0.0000**	5.5499	5.5678	0.00031984
21	0.5	281238	2.00	**0.3010**	5.4491	5.4699	0.000434687
21	0.1	206288	10.00	**1.0000**	5.3145	5.2174	0.009431027
37	25	365431	0.04	0.2432	5.5628	5.4893	0.005403622
37	10	229736	0.10	0.6411	5.3612	5.3511	0.00010226
37	5	170953	0.20	0.9421	5.2329	5.2394	4.31909E-05
37	1	79749	1.00	1.6411	4.9017	4.9625	0.003688552
37	0.5	62393	2.00	1.9421	4.7951	4.8386	0.001891192
37	0.1	39249	10.00	2.6411	4.5938	4.5513	0.001807712
54	25	108006	0.04	1.8454	5.0334	4.8786	0.023993164
54	10	54400	0.10	2.2433	4.7356	4.7141	0.000462274
54	5	28822	0.20	2.5444	4.4597	4.5906	0.017116381
54	1	17080	1.00	3.2433	4.2325	4.3153	0.006858604
54	0.5	14528	2.00	3.5444	4.1622	4.2048	0.00181114
54	0.1	11530	10.00	4.2433	4.0618	3.9732	0.007858054

Empirical Constants

δ	α	β	γ	C
3.206442085	3.164078005	-1.07902192	0.522936994	0

Predicted E*

Log Reduced Time	logE	E
-10	6.364768905	2316162
-9	6.360830084	2295250
-8	6.354207613	2260516
-7	6.343098468	2203426
-6	6.324534285	2111224
-5	6.293710081	1966573
-4	6.243068995	1750125
-3	6.161302699	1449782
-2	6.032911336	1078726
-1	5.839878871	691638
0	5.567821489	369676
1	5.217359789	164953
2	4.814699347	65268
3	4.408612199	25622
4	4.049500216	11207
5	3.767011104	5848
6	3.564572287	3669
7	3.428991179	2685
8	3.342254065	2199
9	3.288380528	1943
10	3.255530983	1801

Raw Data | **Master Curve**

Prediction Equation Coefficients and Shift Factors for All Mixtures

Mix	Coefficients				Shift Factors				
	δ	α	β	γ	-10°C	4°C	21°C	37°C	54°C
1	3.2064	3.1641	-1.0790	0.5229	4.7215	2.2228	0.0000	-1.6411	-3.2433
2	3.4203	3.0148	-1.1554	0.5659	4.5998	2.2532	0.0000	-1.6217	-3.2070
3	3.8108	2.5865	-0.8166	0.5950	4.4009	2.0596	0.0000	-1.6552	-2.9341
4	3.7831	2.6176	-1.1739	0.5588	5.1276	2.0294	0.0000	-1.7690	-3.0459
5	3.1748	3.2177	-1.4625	0.5457	5.4290	2.0296	0.0000	-2.3027	-3.7863
6	3.3403	3.0456	-1.4103	0.5733	5.4504	1.9846	0.0000	-2.2565	-3.6225
7	3.9670	2.3493	-0.7667	0.6473	4.0693	2.2224	0.0000	-1.2958	-2.6153
8	3.9021	2.4262	-0.7133	0.6287	4.1866	2.1743	0.0000	-1.3455	-2.4989
9	3.4578	2.8671	-0.9708	0.6108	4.2245	2.1440	0.0000	-1.1636	-2.8369
10	3.3989	2.9266	-0.9988	0.6035	4.2504	2.1543	0.0000	-1.3557	-2.8817
11	3.4769	2.8466	-0.9636	0.6174	4.2078	2.1323	0.0000	-1.1839	-2.6857
12	3.7515	2.6699	-0.8859	0.5494	4.6854	1.8690	0.0000	-1.2823	-2.6040
13	3.8861	2.5259	-0.9606	0.6583	4.5444	2.1347	0.0000	-1.5539	-2.9432
14	3.9811	2.4390	-0.9423	0.6759	4.3838	2.0895	0.0000	-1.4922	-2.9390
15	3.9821	2.5136	-0.7239	0.5659	4.5858	2.2007	0.0000	-1.4388	-2.7401
16	3.9823	2.3224	-0.9016	0.6504	3.6740	1.9551	0.0000	-1.7082	-2.9477
17	3.9796	2.5228	-1.0170	0.6421	4.6568	2.1130	0.0000	-1.5561	-3.0730
18	3.9904	2.5210	-0.8502	0.6040	5.2092	2.3326	0.0000	-1.6478	-3.0384
19	4.1267	2.2556	-0.8004	0.6494	4.3684	1.9557	0.0000	-1.2949	-2.7197
20	4.0392	2.4633	-0.8347	0.6260	5.3152	2.3092	0.0000	-2.1596	-3.3747
21	3.9349	2.5797	-0.8776	0.5941	5.1852	2.3405	0.0000	-1.0927	-2.6627
22	3.8774	2.6395	-0.9064	0.5830	5.2087	2.3575	0.0000	-1.0736	-2.5952
23	3.6548	2.8599	-1.1335	0.5364	5.8499	2.1906	0.0000	-1.3778	-2.9443
24	4.0129	2.4887	-0.7730	0.5578	5.4879	2.2106	0.0000	-1.6209	-2.8250
25*	2.4967	3.9736	-1.3659	0.4443	4.6798	2.3757	0.0000	-1.7377	-2.9990

***For Mix 25, at a temperature of 54°C, dynamic modulus results for testing at frequencies of 0.5-Hz and 0.1-Hz were not obtained. The test failed at these frequencies due to deformation of the core tested at the lowest specified loading.**

SS No. 177 “Inputs of Portland Cement Concrete Parameters Needed for the Design of New and Rehabilitated Pavements in Mississippi”

- Dr. Ahmed Al-Ostaz – University of MS
- Typical MDOT PCC mixes used for rigid pavement construction characterized

Aggregate	Source	Cement
Light Weight Chert (Gravel 2-54-2)	Northern part of Mississippi (B&B Concrete, Oxford-MS)	Cement Type I
		Cement Type I+ FA Class F
		Cement Type I+ FA Class C
		Cement Type I+ Slag
Dense Chert (Gravel 57)	Central part of Mississippi Breen Brothers Gravel Co., Inc	Cement Type I
		Cement Type I+ FA Class F
		Cement Type I+ FA Class C
		Cement Type I+ Slag
Small Maximum Size Chert (Gravel #69) TXI 6-L-20	Southern part of Mississippi (Gulf Concrete, LLC)	Cement Type I
		Cement Type I+ FA Class F
		Cement Type I+ FA Class C
		Cement Type I+ Slag
Alabama Lime Stone (A-8-L)	B&B Concrete, Oxford-MS	Cement Type I
		Cement Type I+ FA Class F
		Cement Type I+ FA Class C
		Cement Type I+ Slag
Kentucky Lime Stone (Lime Stone #57)	Kentucky (MMC)	Cement Type I
		Cement Type I+ FA Class F
		Cement Type I+ FA Class C
		Cement Type I+ Slag

Mix Designs 1-12

Mix	CA Type	Cement (lbs)	FA		slag	CA	Sand	water	Admix 200N (oz)	Admix 90 (oz)
			C	F						
1	North MS Chert	548.00	-	-	-	1866.2	1226.1	219.2	16.4	3.0
2		411.00	-	137	-	1866.2	1205.0	219.2	16.4	3.0
3		411.00	137	-	-	1866.2	1205.0	219.2	16.4	3.0
4		274.00	-	-	274	1866.2	1205.9	219.2	16.4	3.0
5	AL limest one	548.00	-	-	-	1944.0	1226.9	219.2	16.4	3.0
6		411.00	-	137	-	1944.0	1205.7	219.2	16.4	3.0
7		411.00	137	-	-	1944.0	1205.7	219.2	16.4	3.0
8		274.00	-	-	274	1944.0	1206.7	219.2	16.4	3.0
9	KT limest one	548.00	-	-	-	1982.9	1188.7	219.2	16.4	3.0
10		411.00	-	137	-	1982.9	1167.5	219.2	16.4	3.0
11		411.00	137	-	-	1982.9	1167.5	219.2	16.4	3.0
12		274.00	-	-	274	1982.9	1168.5	219.2	16.4	3.0

Mix Designs 13-20

Mix	CA Type	Cement (lbs)	FA		Slag	CA	Sand	water	Admix 200N (oz)	Admix 90 (oz)
			C	F						
13	Jackson Chert	548.00	-	-	-	1924.6	1134.6	219.2	16.4	3.0
14		411.00	-	137		1924.6	1113.5	219.2	16.4	3.0
15		411.00	137	-	-	1924.6	1113.5	219.2	16.4	3.0
16		274.00	-	-	274	1924.6	1114.5	219.2	16.4	3.0
17	Gulf Coast Washed chert	548.00	-	-	-	1907.1	1160.8	219.2	16.4	3.0
18		411.00	-	137	-	1907.1	1139.6	219.2	16.4	3.0
19		411.00	137	-	-	1907.1	1139.6	219.2	16.4	3.0
20		274.00	-	-	274	1907.1	1140.6	219.2	16.4	3.0

28 Day Summary

Mix No.	Compressive Strength (psi)	Flexural Strength (psi)	Splitting Tensile Strength (psi)	Modulus of Elasticity (psi)	Poisson's Ratio	Coefficient of Thermal Expansion	Unit Weight (lb/ft^3)
1	5456	554	363	5604164	0.17	7.981	146
2	5668	598	418	5487278	0.17	8.513	147
3	5506	596	402	5518442	0.19	8.022	142
4	5692	714	455	5882199	0.18	7.943	146
5	5674	740	432	5405447	0.19	6.312	144
6	5724	689	430	5448507	0.17	6.186	146
7	5899	748	389	5276084	0.22	6.106	147
8	5734	855	510	5480000	0.26	6.05	145
9	5617	760	474	5630902	0.24	6.36	146
10	6089	776	487	6027757	0.22	6.631	150
11	7260	748	477	5736640	0.24	6.667	148
12	6747	910	485	5908602	0.2	6.564	147
13	5789	631	398	5854845	0.14	5.968	147
14	5918	684	448	5829696	0.18	7.899	145
15	5850	695	424	5725702	0.16	8.224	146
16	5518	768	437	5509169	0.19	7.963	146
17	5887	707	426	5410646	0.18	8.748	141
18	5550	682	422	5333850	0.17	6.772	143
19	5813	649	440	5201584	0.18	7.255	140
20	5338	739	439	5341522	0.19	8.476	140

FHWA Mobile Concrete Laboratory

- Workshop on Implementation of Rigid Pavement portion of MEPDG
  - University of Mississippi
  - August 2, 2005
- Utilized for interlaboratory comparison testing between the MCL and UM
  - AASHTO TP 60 Standard Test Method for the Coefficient of Thermal Expansion of Hydraulic Cement Concrete

Cementitious Stabilized Soils

- BCD to perform testing as part of SS No 170
- Will use test protocols called for in current version of MEPDG (Table 24)
- Interim Mechanistic-Empirical Pavement Design Guide Manual of Practice
- “the fatigue cracking prediction equation for semi-rigid pavements was not calibrated within the NCHRP Projects 1-37A and 1-40D. As such, these layers should not be used until the prediction model is calibrated.” Page 116

New NCHRP Research Project

- TRB AFS80 Cementitious Stabilization Committee
- 04-36 Characterization of Cementitiously Stabilized Layers for the Mechanistic-Empirical Pavement Design Guide (MEPDG)
- Obtain fundamental understanding of how traffic loads are distributed throughout a semi-rigid pavement to the subgrade
  - HMA surface, cementitious stabilized aggregate or soil base/subbase layer(s)

Pavement Type/Load Transfer

- Flexible pavement – HMA surface, unbound aggregate base/subbase
  - thick layered system protects the subgrade
- Rigid pavement – Concrete
  - concrete layer spreads load over wide area
- Load-distributing behavior of semi-rigid pavement will vary from flexible to rigid
- Cementitious stabilized aggregate/soil:
  - Significant variation in interparticle bond from lean concrete to lime stabilized
  - LFA and lime properties vary with time due to ongoing pozzolanic reactions

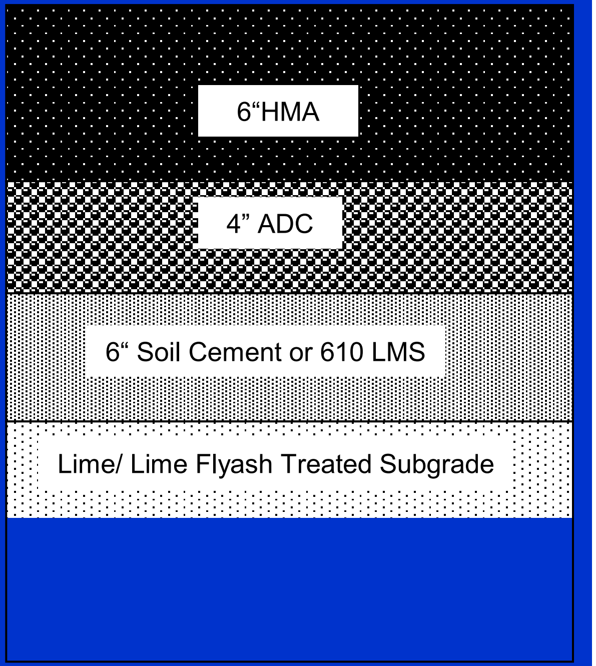
SS No 181 “Structural Characterization of Asphalt Drainage Course Layers

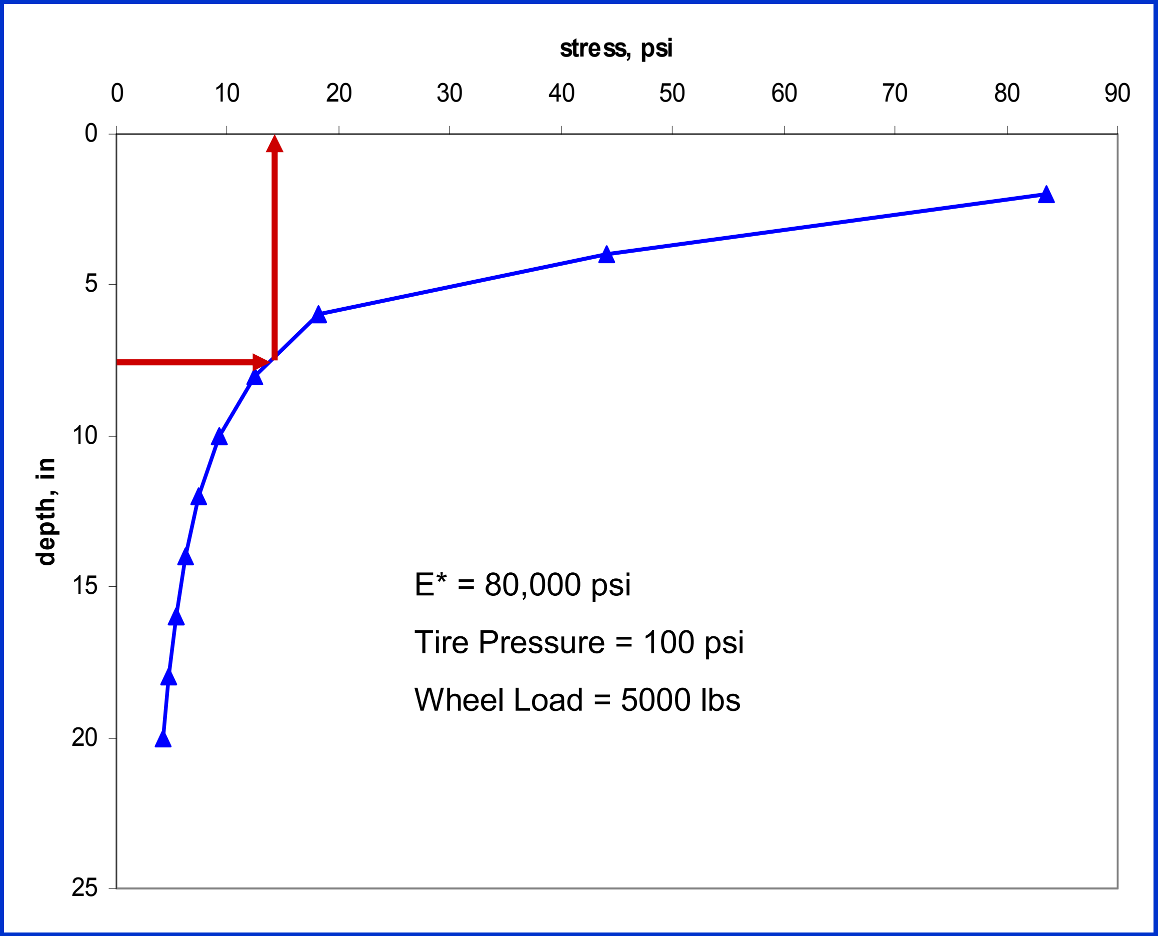
- Dr. Allen Cooley with Burns Cooley & Dennis, Inc.
- MDOT Drainage layer:
  - 4” drainage layer required in new construction of divided routes
  - #57 crushed limestone, sandstone, or granite
  - Crushed gravel and/or blended mixtures of crushed gravel, limestone, sandstone, granite or reclaimed concrete pavement
  - 2.5% PG67-22

How do you Test these Materials?

- Aggregate base?
  - Resilient Modulus Test
  - Haversine loading
- HMA?
  - Dynamic Modulus Test
  - Sinusoidal loading
- Resilient modulus test selected due to assumption that the drainage layer is located deep enough within the pavement that the traffic loading imparts a haversine load form to the drainage layer

WESLEA used to Evaluate for Range of Test Stresses





Laboratory Test Parameters

	Testing Temperature		
	4.4 °C	15.6°C	26.7°C
Confining (psi)	5	10	15
Deviator Stress (psi)	2	2	2
	5	5	5
	10	10	10
	15	15	15

- Temperatures
  - SHRP Temperature at Depth Equations

Test Sample Size/Preparation

- 170 mm height by 150 mm diameter
  - couldn’t core test specimen from pill
- Compressive load used to compact specimen
  - Interlaken Servo-Hydraulic Load Frame
  - gyratory compacted specimens can not be trimmed
- 30% voids based on field tests of in-situ drainage layers

Typical Drainage Layer Results

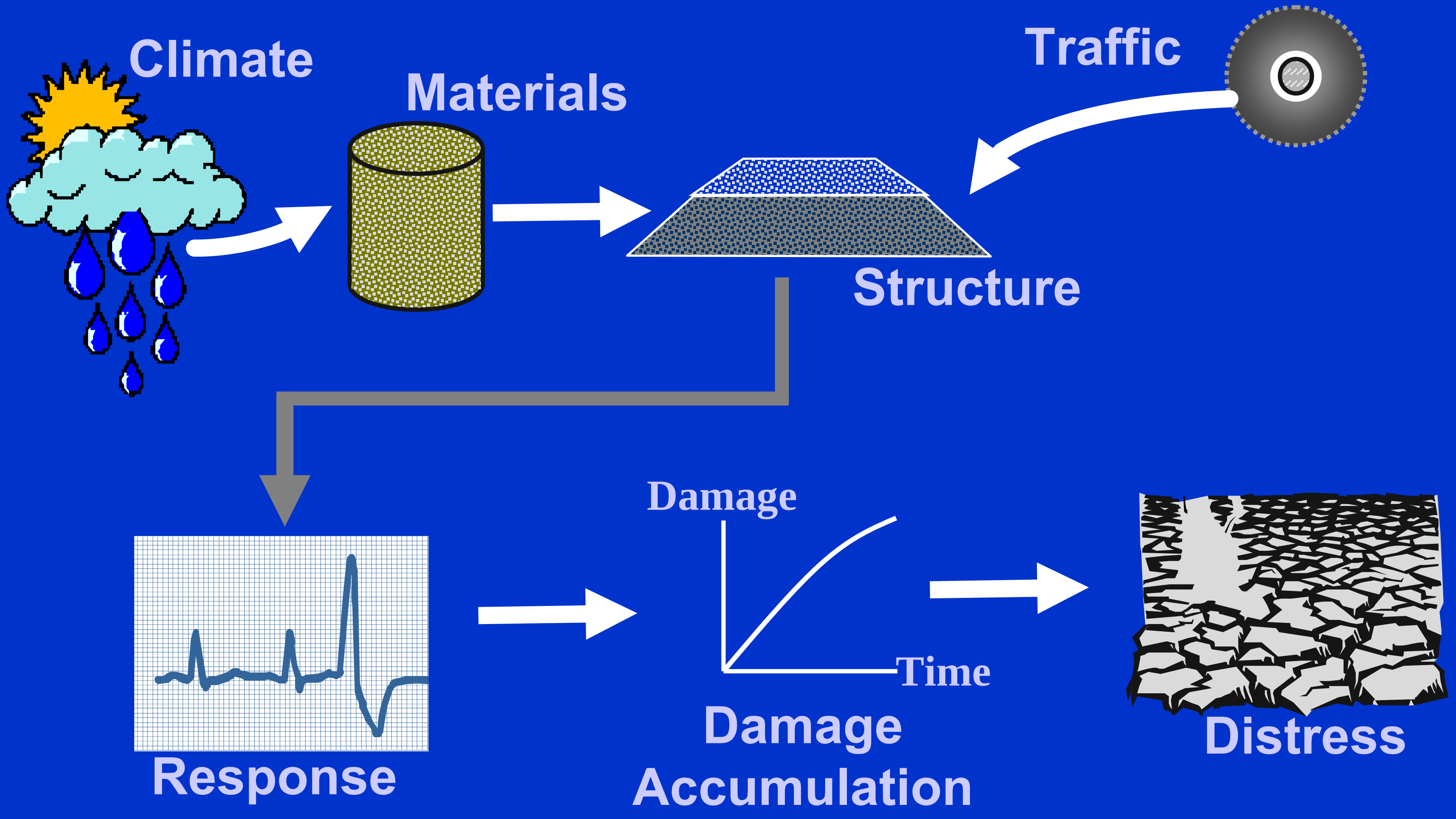
Sequence	σ_1 psi	σ_2 psi	σ_3 psi	θ psi	τ_{oct} psi	$\sigma_1 - \sigma_3$ psi	M_R psi
1	7.0	4.8	4.8	16.6	1.0	2.2	180907
2	11.8	9.7	9.7	31.2	1.0	2.1	205855
3	16.7	14.6	14.6	45.9	1.0	2.1	229792
4	9.9	4.8	4.8	19.5	2.4	5.1	179534
5	14.9	9.7	9.7	34.3	2.5	5.2	190637
6	20.0	14.7	14.7	49.4	2.5	5.3	198442
7	24.8	14.6	14.6	54.0	4.8	10.2	174777
8	19.8	9.7	9.7	39.2	4.8	10.1	170850
9	15.0	4.8	4.8	24.6	4.8	10.2	161862
10	29.8	14.6	14.6	59.0	7.2	15.2	164826
11	25.1	9.7	9.7	44.5	7.3	15.4	164724
12	20.0	4.8	4.8	29.6	7.2	15.2	157796

BCD Project:	060122
Project Name:	ADC
Date:	12/10/2007
Sample I.D.:	Calera
	Rep 1
Replicate Test:	4.4 C

Some Practical Applications of MEPDG Materials Characterization

- Evaluate method of pavement layer construction
  - Variation of in-situ material quality
  - Variation of in-situ pavement layer thickness
- Provide answers to upper management when contractors want to lower construction standards

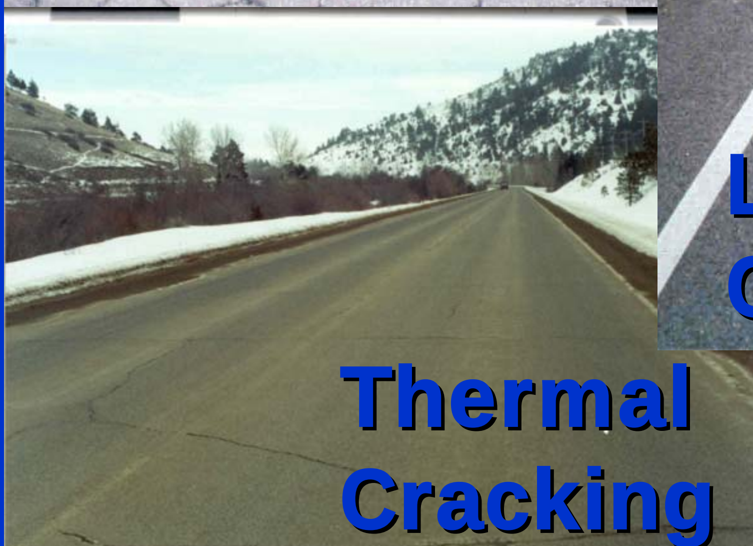
Mechanistic-Empirical Design

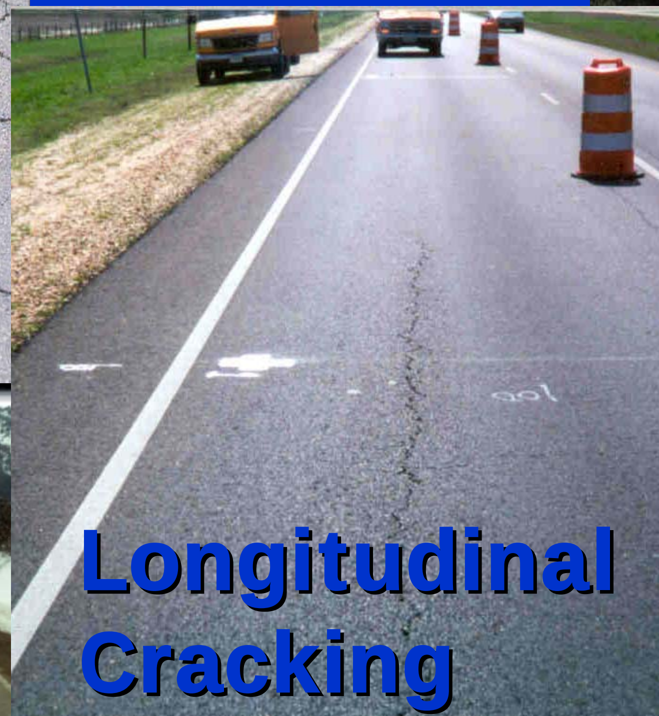


ME PDG Pavement Responses

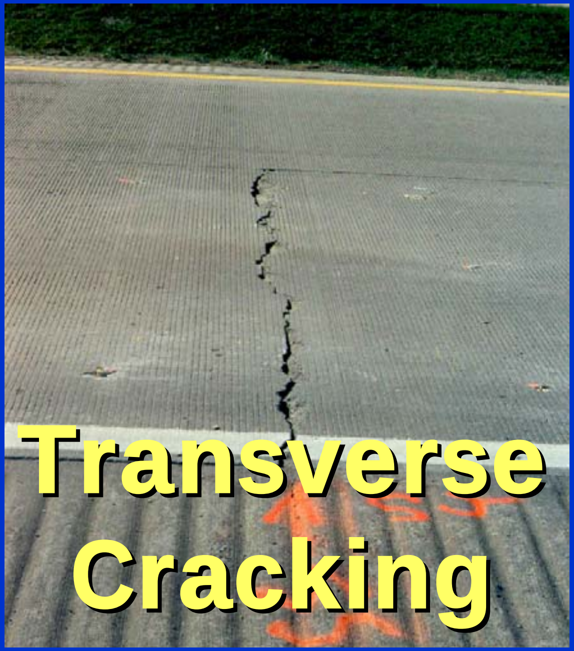
- **Design of new and rehabilitated pavement structures based on engineering mechanics principles**

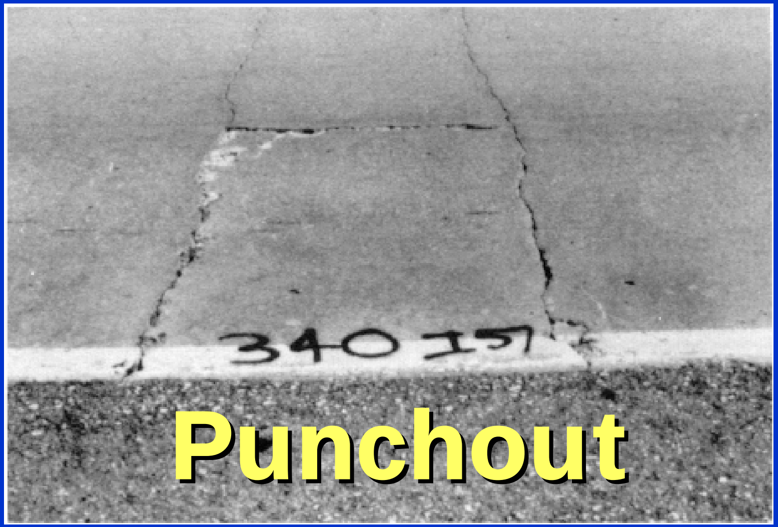
Flexible Pavement Distresses





Rigid Pavement Distresses





Non-Uniform Distribution of Lime and Fly Ash

Non-Uniform Distribution of Water

Field Mixing

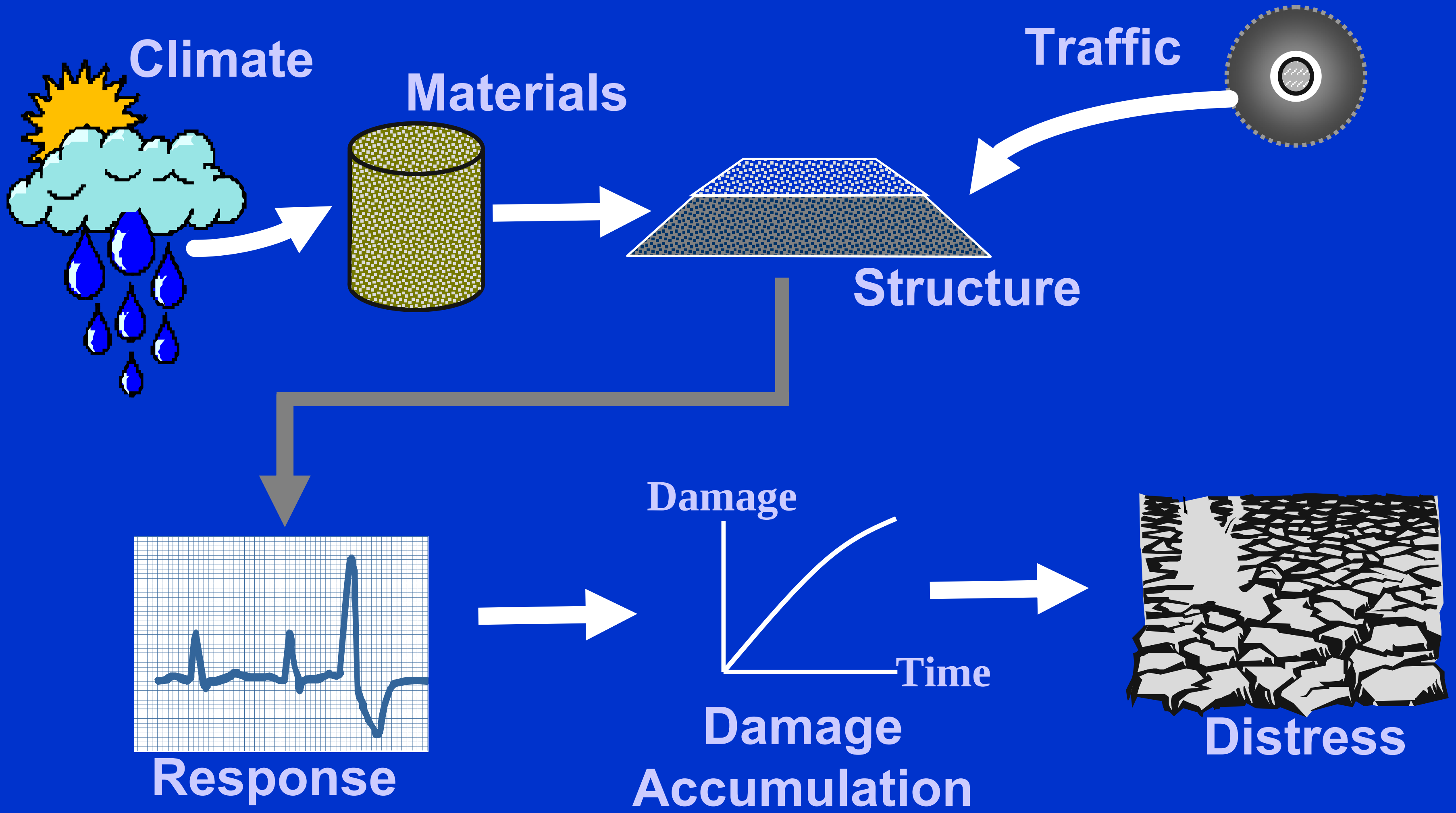
Example of Poor Field Mixing

Evaluate In-Situ Modulus

Station 619+00 E_{back} = 156.4 ksi

Station 628+00 E_{back} = 65 ksi

Mechanistic-Empirical Design

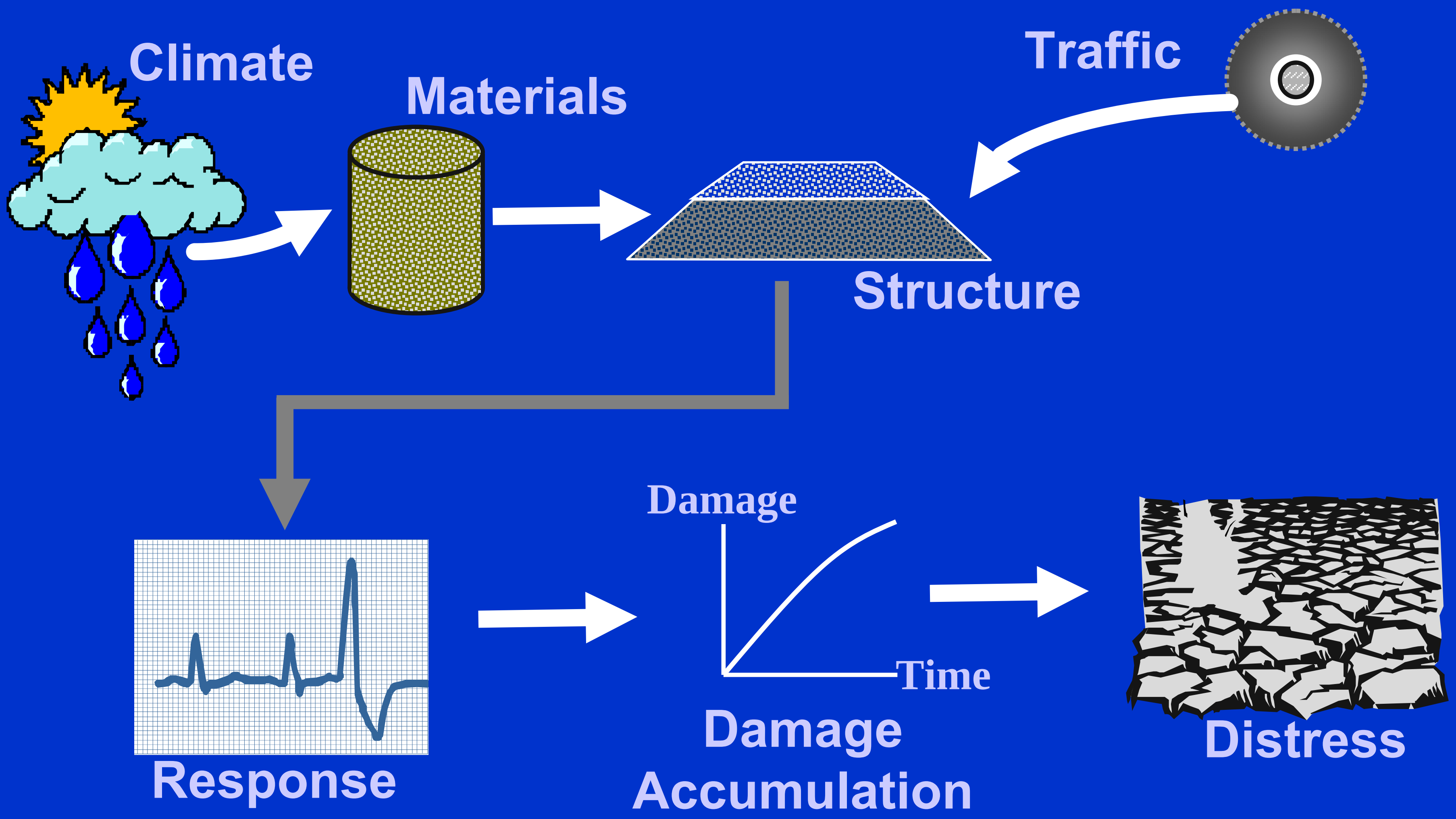


In-Situ LFA Layer Thickness of the Newer Pavements

County	Design Thickness	Average Thickness	Percent of Design	Maximum Thickness	Minimum Thickness
Bolivar	6	6.8	13.3	9.5	5.5
Clarke	6	6.02	0.3	7.0	5.0
Smith	6	6.04	0.7	7.8	4.5
Tippah	8	7.34	-8.3	8.5	6.5
Wilkinson	6	5.91	-1.5	9.0	4.3

Design Thickness – 6”
In-Situ Thickness – 4”

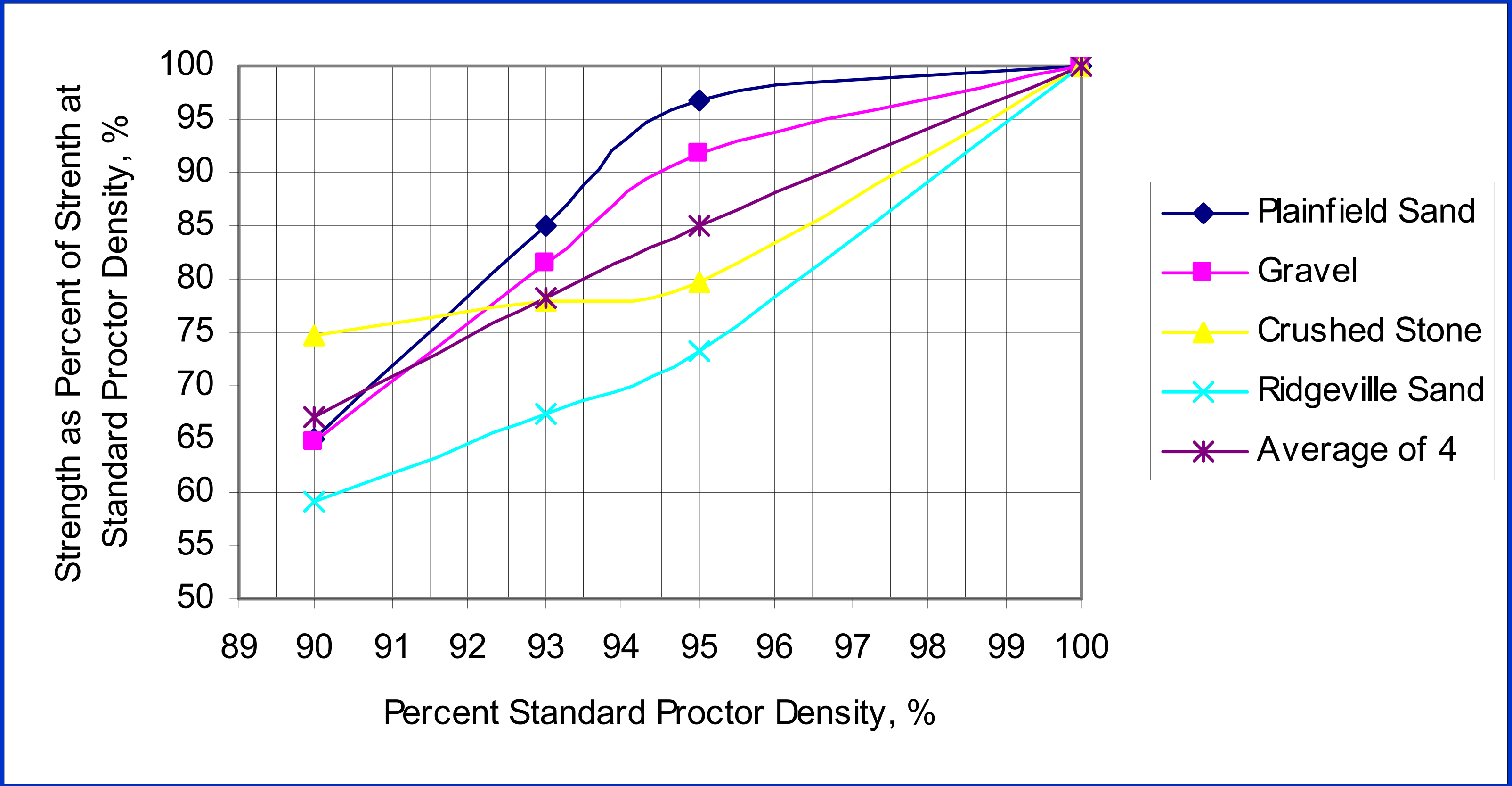
Mechanistic-Empirical Design



Lower Construction Standards?

- Example: Lower required field density of soil cement base
- Materials people can discuss affect on the soil cement
- Current pavement design method does not allow designers to predict affect on pavement performance
- No good answer for upper management

LFA Stabilized Soil Strength Versus Change in Density



Soil Cement Durability Versus Change in Density

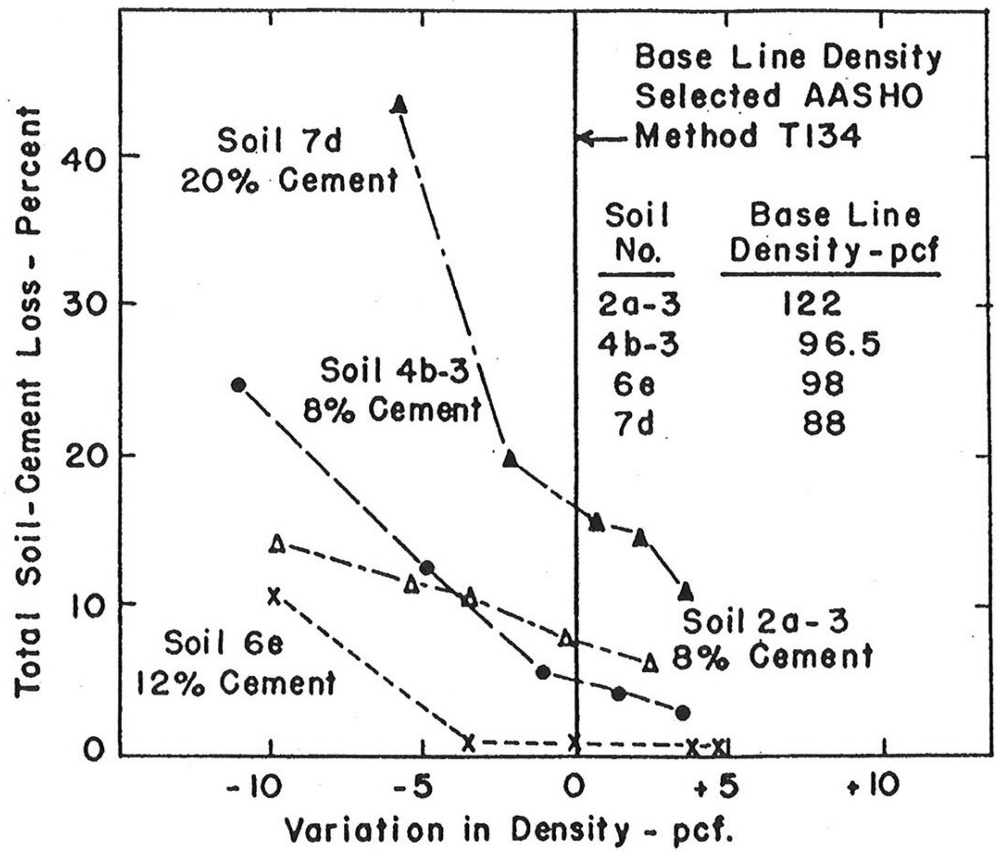


Figure 2. Effect of density on soil-cement loss from wet-dry test.

SS No. 205 Chemically Stabilized Soils

- Cementitiously stabilized soils
  - Lime
  - Lime-Fly Ash
  - Cement
- Strength = f (% Proctor Density)
- Modulus = f (% Proctor Density)
- Use variation in modulus in MEPDG to predict variation in predicted distresses
- Predicted fatigue cracking = f (% Proctor Density)

Access MDOT Studies

- http://www.gomdot.com
- Select “Research Division”
- Select “Research Reports”
- For ongoing studies with no published report select “Research Project Progress Reports”
- For studies with a published report select “Interim and Final Reports”


QUESTIONS?