ASPHALT MIX CHARACTERIZATION USING DYNAMIC MODULUS AND APA TESTING

Final Report

SPR 610

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by

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16. Abstract

This final report summarizes two research efforts related to asphalt mix characterization: dynamic modulus and Asphalt Pavement Analyzer testing.

One phase of the research consisted of a laboratory-based evaluation of dynamic modulus of Oregon dense-graded hot mix asphalt mixes. Gyratory compacted specimens were prepared using a single aggregate source and gradation and four binder grades. After coring and sawing, specimens were tested following AASHTO TP 62-03. Differences in mix design versus field compacted air voids were investigated for typical surface-course mixes and mixes proposed for use in rich base-course mixes in long-life pavements. Master curves were developed for all combinations (sixteen) and made available for ODOT pavement design engineers. Laboratory results did not compare well with the dynamic modulus values predicted using the regression-based equation available in the NCHRP Project 1-37A final report.

The other phase of the research evaluated Asphalt Pavement Analyzer test results on six ODOT projects that exhibited premature permanent deformation. For three of the six projects, suitable aggregates and binder were available to replicate the field mixes. Results were mixed, but it appeared that a 5.0 mm limiting criterion may be suitable for the mix design phase of mix evaluation. Additional testing was recommended.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
	NOTE: Volumes greater than 1000 L shall be shown in m^3.			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DISCLAIMER

ASPHALT MIX CHARACTERIZATION USING DYNAMIC MODULUS AND APA TESTING

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1.0 INTRODUCTION

1.1 BACKGROUND

The Dynamic Modulus and Asphalt Pavement Analyzer tests provide pavement designers with information useful to the design of flexible pavements, particularly if they choose to use a mechanistic-empirical approach.

The Dynamic Modulus results allow the designer to understand changes in mix stiffness, as changes in temperature and rate of loading occur. Dynamic modulus results are proposed for inclusion in the Oregon Department of Transportation's (ODOT) upcoming mechanistic-empirical design guide.

The Asphalt Pavement Analyzer (APA) allows the designer to feel confident that the mix will not permanently deform in service. ODOT presently incorporates the APA device in their mix design process for some projects as a "go/no-go" test.

ODOT wished to gain additional experience on these two tests, to improve their understanding of their hot-mix asphalt (HMA) mixes and to better incorporate the tests into their design procedures.

1.1.1 Dynamic Modulus

The Mechanistic-Empirical Pavement Design Guide developed under NCHRP 1-37A requires that asphalt mixes be characterized using the dynamic modulus for Level 1 designs. At present, ODOT does not have dynamic modulus information on commonly used mixes. Although default values will be available in the new pavement design procedure, the use of these values could lead to conservative or non-conservative thicknesses and therefore more costly designs.

In addition to the use of default values, dynamic modulus can be estimated using a regression equation proposed by Witczak et al. (*NCHRP 2004*). The model for estimating dynamic modulus was generated from a large amount of data consisting of 1,429 points from 149 distinct asphalt mixtures. Improvements were made to earlier models, taking into account hardening effects from short- and long-term aging, as well as extreme temperature conditions. This model was further refined by Witczak during NCHRP 1-37A (*NCHRP 2004*). The model is shown below:

$$\log|E^*| = 3.750063 + 0.029232P_{200} - 0.001767(P_{200})^2 - 0.002841P_4 - 0.058097V_a - 0.802208\frac{V_{beff}}{(V_{beff}+V_a)} + \frac{[3.871977 - 0.0021P_4 + 0.003958P_{38} - 0.000017(P_{38})^2 + 0.00547P_{34}]}{1+e^{(-0.603313-0.313351\log f-0.393532\log\eta)}} \quad \textbf{(1-1)}$$

where

$|E^*|$ = asphalt mix complex modulus, in psi

η = bitumen viscosity, in 10^6 poise

f = load frequency, in Hz

V_a = percent air voids in the mix, by volume

V_{beff} = percent effective bitumen content, by volume

P_{34} = percent retained on ¾ in. sieve, by total aggregate mass (cumulative)

P_{38} = percent retained on 3/8 in. sieve, by total aggregate mass (cumulative)

P_4 = percent retained on No. 4 sieve, by total aggregate mass (cumulative)

P_{200} = percent passing on No. 200 sieve, by total aggregate mass

Laboratory measurements of dynamic modulus are preferred. Lab data can be used to develop a master curve for the mixture. The form of the master curve is a nonlinear sigmoidal function as shown below in Figure 1.1 (*Pellinen, et al. 2002*). Witczak and colleagues introduced the sigmoidal function to model the behavior of asphalt mixes in conjunction with predicting mix stiffness from volumetric and material information (*Fonseca and Witczak 1996, Andrei, et al. 1999*).

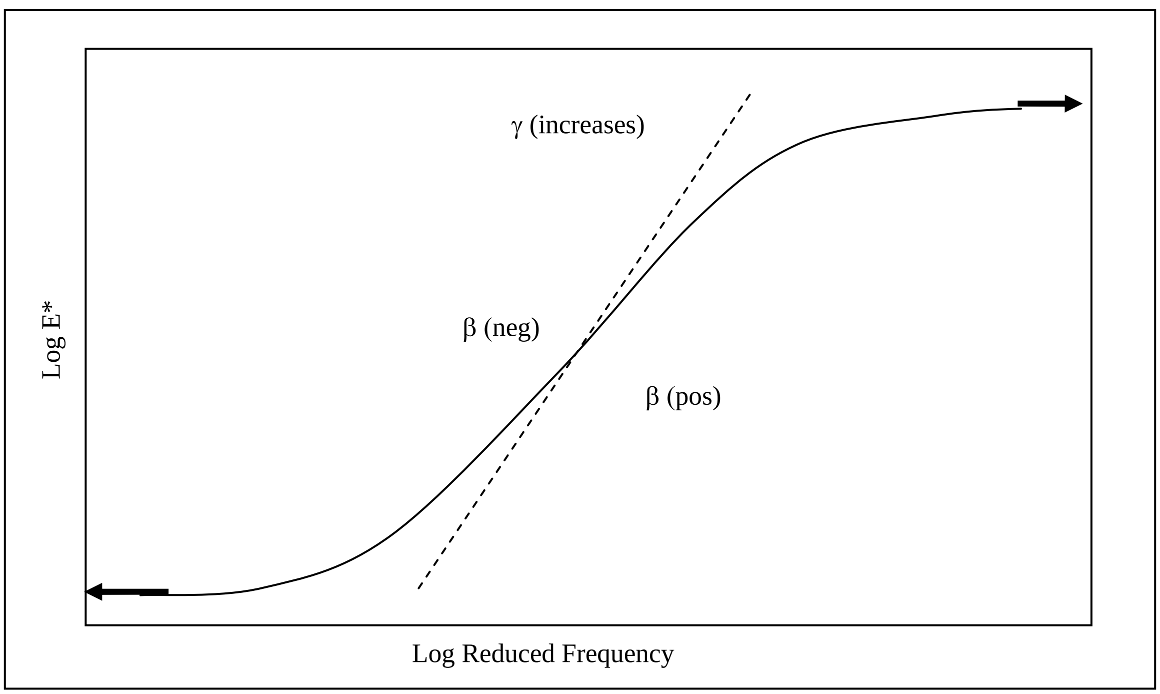


Figure 1.1: Sigmoidal function (after *Pellinen, et al. 2002*)

Physical observations support the use of a sigmoidal function to describe the behavior of asphalt mixes. At the upper end of the function, the mix stiffness is bound by the limiting of the binder stiffness. At the lower end of the function, the mix stiffness is governed by aggregate influences. The parameter γ influences the steepness of the function (that is the rate of change between minimum and maximum values), and β influences the horizontal position of the inflection point.

$$\log\left(\left|E^*\right|\right) = \delta + \frac{\alpha}{\left[1 + e^{\beta - \gamma(\log \varepsilon)}\right]} \qquad \textbf{(1-2)}$$

where $|E^*|$ = dynamic modulus

δ = minimum modulus value

ε = reduced frequency

α = span of modulus values

β, γ = parameters describing the shape of the sigmoidal function

Once the master curve is developed for a mix, it is possible to derive values of dynamic modulus for any combination of temperature or time of loading within the range of testing. It also allows results from different laboratories to be compared when different sets of test conditions (temperature & frequency) were used.

1.1.2 Asphalt Pavement Analyzer

There have been a number of studies conducted on the use of laboratory wheel trackers to predict the likelihood of permanent deformation in field-placed mixes (*Collins, et al. 1996, Choubane, et al. 1998, Williams and Prowell 1999*). A recent report by the National Center for Asphalt Technology (NCAT) has recommended the Asphalt Pavement Analyzer (APA) test for evaluating permanent deformation in conjunction with Superpave Volumetric Mix Design (*Kandhal and Cooley 2003*). One recommendation limits the depth of rut in APA specimens to 8-mm after 8,000 wheel load cycles. Other states (e.g., Georgia) are using a 5-mm maximum rut depth after 8,000 cycles. Details on the test procedure and equipment may be found elsewhere (*Kandhal and Cooley 2003*).

Oregon has been performing the APA test for several construction seasons. The test looks very promising and distinguishes well between different binder grades, binder contents and other mix properties. However, before the test can be incorporated into the mix design procedure, an acceptance criterion needs to be established for Oregon mixes. Most test results to date are well below the 8 mm recommendation, and it is possible that a different limiting criterion should be applied in Oregon.

1.2 OBJECTIVES

The objectives of this research were twofold:

1. To establish dynamic modulus values for typical asphalt mixes used in Oregon to aid in the implementation of mechanistic-empirical pavement design procedures; and

2. To determine if the APA device is capable of identifying Oregon mixes that are prone to permanent deformation and investigate the maximum rut depth criterion for APA testing to minimize the probability that mixes prone to permanent deformation are placed.

1.3 SCOPE

All dynamic modulus testing was conducted on laboratory-compacted specimens. A single aggregate source and gradation were used.

Specimens used in the APA testing were either prepared to model the job mix formula or the as-placed mixes in ODOT projects that exhibited early permanent deformation. For the APA testing, whenever possible aggregates were drawn from the original project source and binders of the same grade were used.

2.0 DYNAMIC MODULUS

2.1 EQUIPMENT & TEST PROCEDURES

Researchers followed AASHTO TP 62-03, "Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures," when conducting tests. An existing MTS servo-controlled test apparatus with environmental cabinet was modified to allow the Dynamic Modulus test to be conducted (see Figure 2.1). The MTS system is capable of applying the required load within the frequency range specified (0.1 to 25 Hz). Heating and cooling (a range of 54 to -10 °C) were accomplished using resistance heating and CO_2, respectively. Details of the modifications and a user's guide are included in the Appendices.

Figure 2.1: Test apparatus

Two linear variable displacement transducers (LVDT) were used to measure the displacement of the specimen under load. LVDT assemblies were cemented to each side of the prepared specimen, as shown in Figure 2.2. Appendix B includes details on the process of attaching the assemblies to the specimen.

The 100-mm diameter specimens were cored from a 150-mm diameter specimen prepared using a SHRP gyratory compactor. After coring (Figure 2.3), the ends were sawn perpendicular to the long axis of the specimen. Descriptions of the apparatus and procedures are described in Appendix B.

Figure 2.2: Specimen ready for test

Figure 2.3: Gyratory specimen after coring

2.2 EXPERIMENT

As previous noted, the goal of the experimental design was to provide ODOT pavement design engineers with dynamic modulus values for design. To achieve this goal, four air void levels were targeted: 1) the standard mix design level (4 percent); 2) the in-place void level (about 7 percent); 3) a desirable mix design void level for rich mixes that might be used base courses in long-life pavements (3 percent); and 4) the expected in-place voids for these rich mixes (5 percent). Specimens of each of the four air voids levels were prepared using the four binder grades commonly used in Oregon. Factors to be investigated included the following:

- Binder grade – 4 levels
- Binder content – 2 levels
- Air voids – 4 levels

Only one aggregate source was used, and the gradation was held constant for all mixes. Table 2.1 shows the combinations included in the experiment.

Table 2.1: Experiment design

Target Air Voids, percent	Binder content, percent	Compactive Effort, gyrations	Identifier*
4.0	5.8	100	1-x
7.0	5.8	As required to achieve desired air voids	2-x
3.0	6.0	100	3-x
5.0	6.0	As required to achieve desired air voids	4-x

*Where x is replaced by a number indicating the binder grade:
1 – PG 64-22
2 – PG 70-22
3 – PG 70-28
4 – PG 76-22

The same gradation was used for all specimens, as shown in Figure 2.4. Six specimens were compacted using a SHRP Gyratory Compactor (SGC) for each combination, yielding a total of 96 specimens. As noted above, the binder type and content were adjusted depending on the test series. Compactive efforts were adjusted to achieve the desired air void contents in Series 2 and 4.

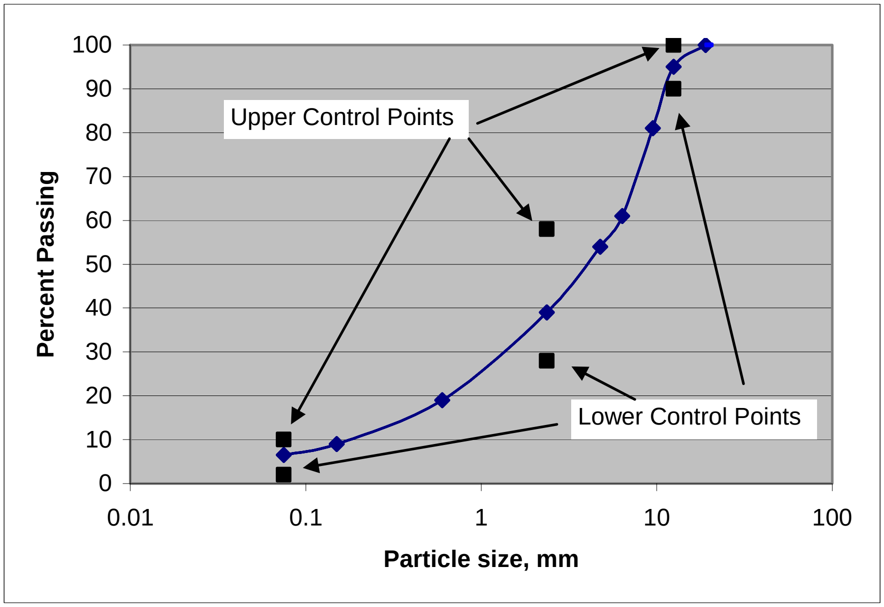


Figure 2.4: Aggregate gradation used in all mixes

2.3 RESULTS

Binder characterization was conducted by the ODOT Materials Laboratory. Results are shown in Table 2.2.

Table 2.2: Binder characterization results

Grade	Rotational Viscosity, Pa s	RTFO Abs. Viscosity, P	Original DSR, kPa	Original Phase Angle, degrees	RTFO DSR, kPa	RTFO Phase Angle, degrees	PAV DSR, kPa	PAV Phase Angle, degrees	BBR Stiffnes, MPa	BBR m-value
PG 64-22	0.412	6580	1.49	87.2	3.23	84.6	3100	49.9	177	0.333
PG 70-22	0.738	14000	1.24	84.9	2.73	82.2	2934	49.6	236	0.31
PG 70-28	0.725	18600	1.33	81.7	3.31	75.2	1990	47.2	268	0.32
PG 76-22	1.075	28900	1.13	84.2	2.35	80.1	1875	50.4	196	0.318

Bulk specific gravity tests were conducted on the gyratory specimens as compacted and again after coring and sawing to the dynamic modulus specimen size. Results are shown in Table 2.3. These results indicated that the central region of the gyratory specimen was more densely compacted than the area around the perimeter of the specimen. The average reduction in air voids was 1.1 percent. This result was less than that reported by Dougan, et al., where the average reduction was 1.5 to 2.5 percent (*2003*).

Table 2.3: Air voids before and after coring and sawing, average of six specimens

	Air Void, percent			
Series	Target Voids	Voids Before Coring/Sawing	Voids After Coring/Sawing	Difference (Before - After)
1-1	4.0	4.1	2.8	1.2
1-2	4.0	4.1	2.9	1.2
1-3	4.0	3.7	2.6	1.2
1-4	4.0	3.9	2.6	1.3
2-1	7.0	7.1	5.8	1.3
2-2	7.0	6.9	5.8	1.1
2-3	7.0	6.7	5.3	1.4
2-4	7.0	6.8	5.7	1.1
3-1	3.0	3.2	2.3	1.0
3-2	3.0	3.2	2.2	1.0
3-3	3.0	2.7	1.7	1.0
3-4	3.0	2.9	1.9	1.0
4-1	5.0	5.0	3.9	1.1
4-2	5.0	5.1	4.0	1.1
4-3	5.0	4.9	3.7	1.2
4-4	5.0	5.0	3.9	1.1

Following coring and sawing, each of the specimens was prepared for testing using the procedures described in Appendix B. Each specimen was tested at six different loading frequencies and five difference temperatures. Typical results are shown in Figure 2.5. The results for all test series are shown in Table 2.4

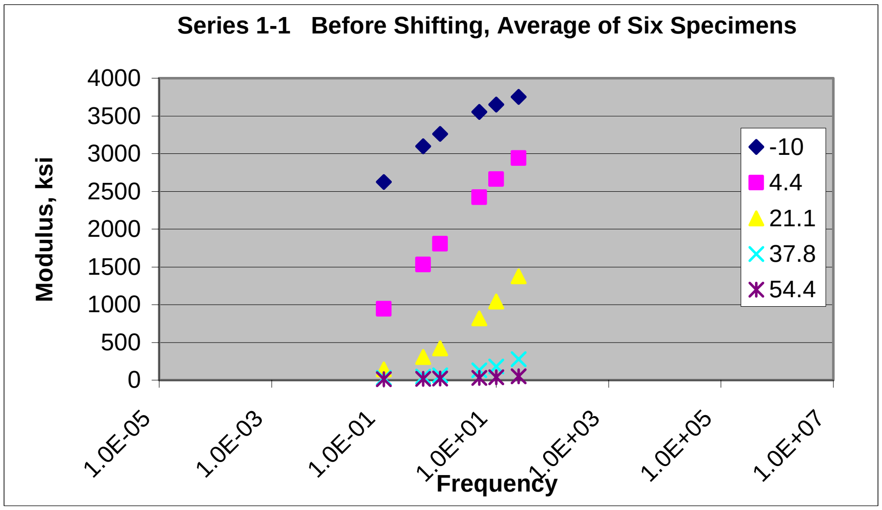


Figure 2.5: Typical results for dynamic modulus testing

Table 2.4: Dynamic modulus results, ksi

Mix	Binder	Series	Test Temp., C	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
5.8% Binder, 4.0% Air, 100 Gyrations	PG 64-22	Series 1-1	-10	2,623	3,097	3,260	3,554	3,649	3,750
			4.4	945	1,533	1,807	2,424	2,662	2,943
			21.1	143	308	423	818	1,042	1,377
			37.8	27	47	63	130	180	279
			54.4	13	17	19	29	36	51
	PG 70-22	Series 1-2	-10	2,696	3,236	3,442	3,849	3,994	4,159
			4.4	1,118	1,664	1,921	2,527	2,778	3,091
			21.1	272	483	611	1,008	1,219	1,530
			37.8	67	109	137	243	312	433
			54.4	30	40	46	70	86	114
	PG 70-28	Series 1-3	-10	2,681	3,207	3,398	3,754	3,873	4,004
			4.4	958	1,522	1,793	2,427	2,685	2,998
			21.1	183	351	463	836	1,048	1,367
			37.8	46	74	93	171	225	327
			54.4	24	30	34	48	58	77
	PG 76-22	Series 1-4	-10	2,612	2,967	3,090	3,313	3,386	3,466
			4.4	1,208	1,722	1,946	2,428	2,611	2,825
			21.1	294	527	667	1,081	1,291	1,585
			37.8	73	118	150	269	347	483
			54.4	35	44	51	75	92	123
5.8% Binder, 7.0% Air, Gyrations, as required	PG 64-22	Series 2-1	-10	1,891	2,349	2,527	2,886	3,016	3,165
			4.4	657	1,052	1,248	1,730	1,938	2,203
			21.1	119	235	311	563	708	930
			37.8	24	43	56	109	146	215
			54.4	9	13	16	26	33	46
	PG 70-22	Series 2-2	-10	2,246	2,659	2,806	3,078	3,168	3,267
			4.4	853	1,337	1,563	2,077	2,281	2,524
			21.1	153	306	408	742	928	1,203
			37.8	32	54	70	135	183	272
			54.4	15	19	22	33	41	56
	PG 70-28	Series 2-3	-10	1,897	2,349	2,525	2,878	3,005	3,151
			4.4	652	1,032	1,222	1,696	1,902	2,166
			21.1	138	251	324	566	704	918
			37.8	37	59	73	128	166	233
			54.4	18	23	27	38	46	61
	PG 76-22	Series 2-4	-10	2,647	3,056	3,200	3,464	3,552	3,647
			4.4	1,100	1,637	1,879	2,417	2,626	2,875
			21.1	237	442	571	972	1,184	1,489
			37.8	56	91	117	215	283	404
			54.4	26	34	39	57	70	95

Table 2.4 (continued): Dynamic modulus values, ksi

			Test Temp., C	Frequency, Hz 0.1	0.5	1	5	10	25
6% Binder, 3.0% Air, 100 Gyrations	PG 64-22	Series 3-1	-10	2,567	3,065	3,245	3,582	3,695	3,820
			4.4	956	1,508	1,768	2,370	2,611	2,904
			21.1	172	343	456	832	1,041	1,354
			37.8	36	61	79	154	208	308
			54.4	16	21	25	38	47	65
	PG 70-22	Series 3-2	-10	2,826	3,282	3,447	3,762	3,870	3,990
			4.4	1,231	1,789	2,040	2,605	2,830	3,101
			21.1	285	519	660	1,087	1,308	1,624
			37.8	63	109	140	258	337	473
			54.4	26	35	42	66	83	114
	PG 70-28	Series 3-3	-10	2,732	3,258	3,450	3,814	3,938	4,075
			4.4	1,027	1,587	1,854	2,480	2,735	3,047
			21.1	223	409	528	915	1,129	1,448
			37.8	59	92	115	204	264	373
			54.4	31	38	43	61	74	97
	PG 76-22	Series 3-4	-10	3,180	3,635	3,801	4,117	4,226	4,349
			4.4	1,461	2,042	2,301	2,882	3,113	3,392
			21.1	403	677	836	1,298	1,531	1,861
			37.8	110	175	218	369	464	624
			54.4	50	65	75	111	135	177
6% Binder, 5.0% Air, Gyrations, as required	PG 64-22	Series 4-1	-10	2,236	2,653	2,796	3,049	3,129	3,214
			4.4	747	1,251	1,491	2,038	2,251	2,500
			21.1	104	224	311	624	810	1,095
			37.8	23	37	48	96	134	208
			54.4	12	15	17	24	30	40
	PG 70-22	Series 4-2	-10	2,573	2,945	3,073	3,308	3,385	3,468
			4.4	1,108	1,634	1,866	2,370	2,562	2,788
			21.1	217	425	556	960	1,170	1,469
			37.8	41	74	98	194	261	383
			54.4	17	23	27	43	55	78
	PG 70-28	Series 4-3	-10	2,005	2,514	2,709	3,090	3,224	3,373
			4.4	643	1,071	1,290	1,835	2,070	2,366
			21.1	121	230	304	564	718	962
			37.8	33	50	63	112	147	212
			54.4	18	22	25	34	41	53
	PG 76-22	Series 4-4	-10	2,696	3,191	3,374	3,723	3,844	3,979
			4.4	1,145	1,699	1,956	2,545	2,782	3,069
			21.1	279	499	634	1,049	1,269	1,587
			37.8	72	116	145	256	329	458
			54.4	35	44	51	74	90	119

The dynamic modulus values shown in Table 2.4 appear reasonable. For a given temperature, an increase in loading frequency resulted in an increase in measured dynamic modulus. Similarly for a given frequency of loading, a decrease in testing temperature resulted in an increase in measured modulus.

The master curve (see Figure 2.6) for a given mix was developed by shifting the measured modulus data to the right or left, depending on whether the test temperature was below or above the chosen reference temperature (for this project 21.1°C) to best fit a sigmoidal function of the form shown in Equation 1-2. The magnitude of the shift was determined by minimizing the sum of the differences squared between the measured and the predicted E* values. This was accomplished by adjusting the shift factors, a(T) and β, γ using the Solver routine in Microsoft Excel™.[1]

$$\log\left(\left|E^*\right|\right) = \delta + \frac{\alpha}{\left[1 + e^{\beta - \gamma(\log \varepsilon)}\right]} \qquad \textbf{(1-2)}$$

where $|E^*|$ = dynamic modulus

δ = minimum modulus value

ε = reduced frequency

where

$$\varepsilon = \frac{f}{a(T)} \; or \; \log(\varepsilon) = \log(f) - \log[a(T)]$$

$a(T)$ = shift factor

f = frequency of loading

α = span of modulus values

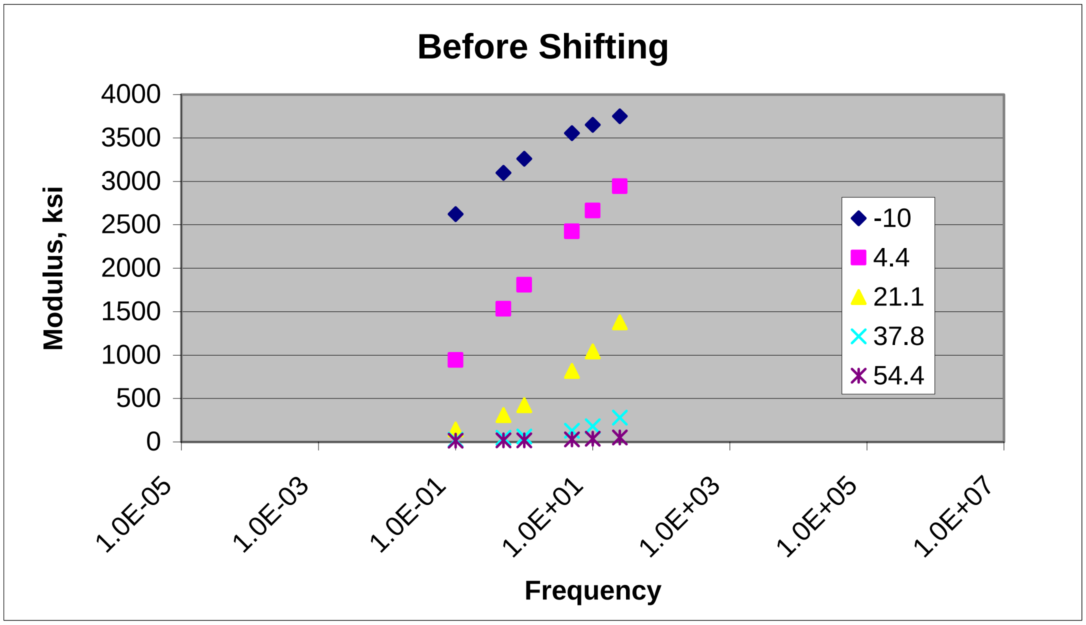
β, γ = parameters describing the shape of the sigmoidal function

Figure 2.6 shows a typical data plot before and after shifting. For this study a reference temperature of 21°C was chosen. Thus, modulus values for test temperatures lower than 21°C are shifted to the right while modulus values for test temperatures higher than 21°C are shifted to the left.

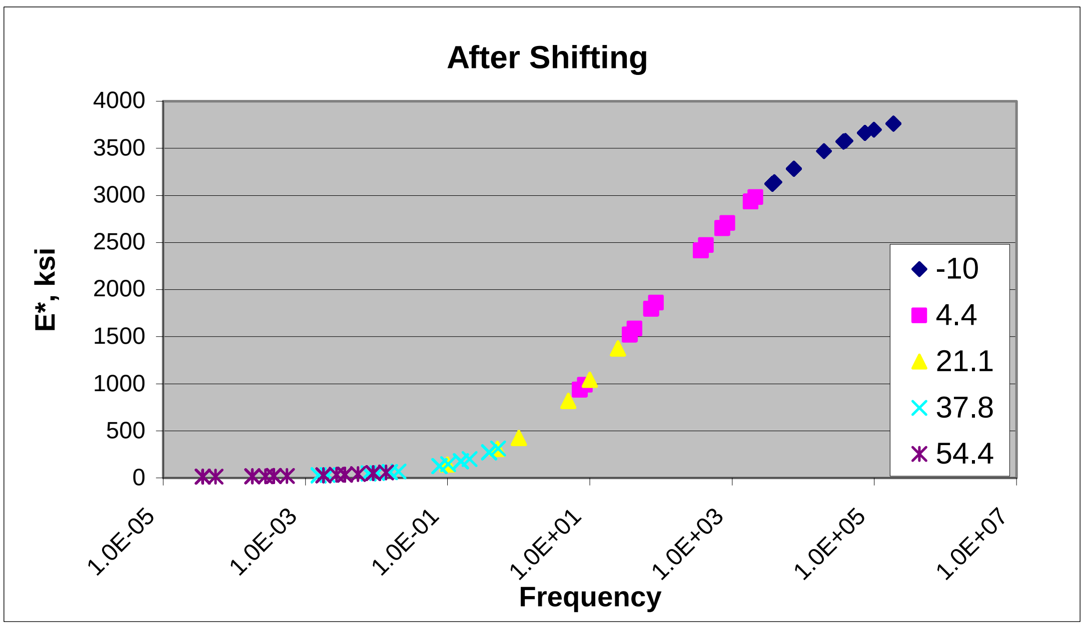
Another way to consider this shifting process is to consider the dynamic modulus data collected at -10°C. As one would expect, asphalt mixes are very stiff (i.e., high modulus) when tested at cold temperatures. The same modulus values would have been measured if the mix were tested at 21°C but at very high frequencies. As an example, consider the modulus result of about 3,750,000 psi when the mix was tested at -10°C and 25 Hz. The same modulus result would have been recorded if the mix was tested at 21°C but at a frequency of approximately 185,000 Hz – clearly not possible with existing technology.

The advantage of knowing the modulus over a wide range of frequencies is that pavement designers can incorporate the speed of traffic (frequency of loading) into their designs. Because time of loading and temperature at loading can be interchanged, it is possible to determine the dynamic modulus of a given mix at any combination of frequency and temperature that one might encounter in the design. Using the example from above, the asphalt mix response to a given load would be the same if the temperature were -10°C and the frequency of load were 25 Hz or the temperature was 21°C and the frequency was 185,000 Hz.

[1] Microsoft Corporation, Redmond, WA 98052



(a)



(b)

Figure 2.6: Typical data (a) before shifting; and (b) after shifting

The master curve parameters and shift factors for all test series are shown in Tables 2.5 and 2.6, respectively. The master curves for all test series are shown in Appendix A.

Table 2.5: Master curve parameters

Binder & Nominal Air Contents	Binder Grade	Series ID	δ	α	β	γ	Sum of Squared Differences between Observed and Predicted E* Values
5.8/4.0	PG 64-22	1-1	0.930	2.681	-0.544	0.715	0.190
5.8/4.0	PG 70-22	1-2	1.170	2.521	-0.580	0.574	0.079
5.8/4.0	PG 70-28	1-3	1.196	2.456	-0.398	0.663	0.116
5.8/4.0	PG 76-22	1-4	1.320	2.254	-0.695	0.657	0.147
5.8/7.0	PG 64-22	2-1	0.605	2.981	-0.545	0.570	0.111
5.8/7.0	PG 70-22	2-2	0.961	2.598	-0.553	0.669	0.183
5.8/7.0	PG 70-28	2-3	1.013	2.568	-0.336	0.581	0.065
5.8/7.0	PG 76-22	2-4	1.199	2.402	-0.611	0.655	0.180
6.0/3.0	PG 64-22	3-1	0.982	2.650	-0.545	0.653	0.091
6.0/3.0	PG 70-22	3-2	1.087	2.565	-0.734	0.599	0.067
6.0/3.0	PG 70-28	3-3	1.297	2.366	-0.417	0.640	0.123
6.0/3.0	PG 76-22	3-4	1.409	2.279	-0.682	0.581	0.153
6.0/5.0	PG 64-22	4-1	0.943	2.599	-0.390	0.743	0.144
6.0/5.0	PG 70-22	4-2	0.950	2.627	-0.770	0.659	0.088
6.0/5.0	PG 70-28	4-3	1.079	2.519	-0.231	0.643	0.118
6.0/5.0	PG 76-22	4-4	1.307	2.348	-0.561	0.620	0.183

Table 2.6: Shift factors for all series

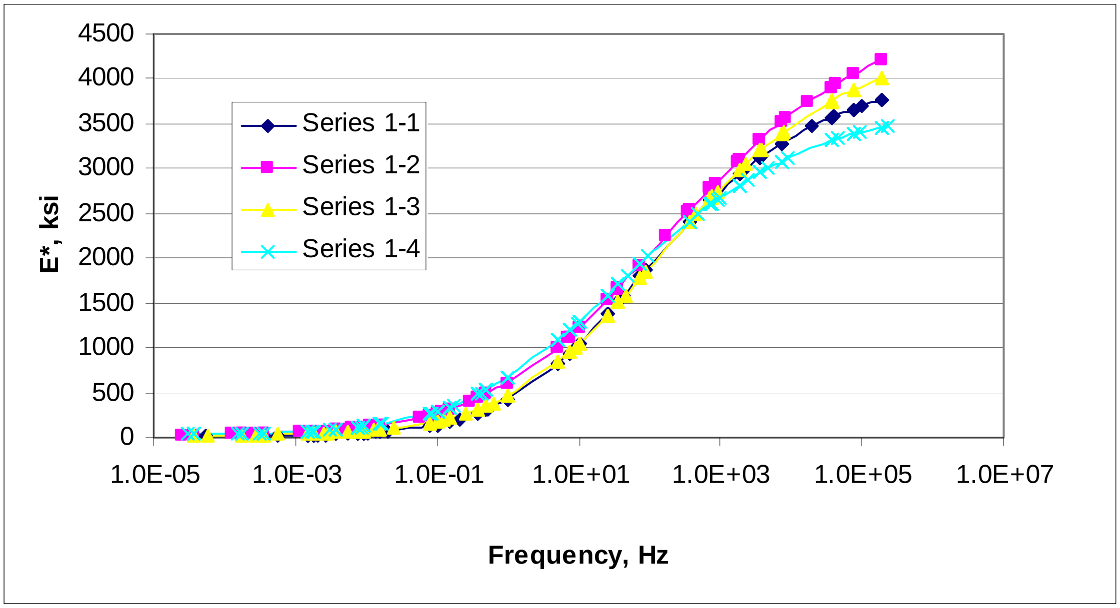
Binder & Nominal Air Contents	Binder Grade	Series ID	Shift Factors (Log a(T)) for Temperatures Shown				
			-10°C	4.4°C	21°C	37.8°C	54.4°C
5.8/4.0	PG 64-22	1-1	-3.824	-1.874	0.000	1.792	3.414
5.8/4.0	PG 70-22	1-2	-3.763	-1.860	0.000	1.835	3.471
5.8/4.0	PG 70-28	1-3	-3.872	-1.877	0.000	1.778	3.412
5.8/4.0	PG 76-22	1-4	-3.884	-1.883	0.000	1.806	3.456
5.8/7.0	PG 64-22	2-1	-3.827	-1.897	0.000	1.793	3.409
5.8/7.0	PG 70-22	2-2	-3.830	-1.882	0.000	1.822	3.464
5.8/7.0	PG 70-28	2-3	-3.882	-1.890	0.000	1.787	3.428
5.8/7.0	PG 76-22	2-4	-3.918	-1.885	0.000	1.803	3.454
6.0/3.0	PG 64-22	3-1	-3.826	-1.882	0.000	1.809	3.424
6.0/3.0	PG 70-22	3-2	-3.892	-1.898	0.000	1.811	3.448
6.0/3.0	PG 70-28	3-3	-3.857	-1.861	0.000	1.805	3.441
6.0/3.0	PG 76-22	3-4	-4.015	-1.911	0.000	1.814	3.511
6.0/5.0	PG 64-22	4-1	-3.878	-1.901	0.000	1.773	3.379
6.0/5.0	PG 70-22	4-2	-3.932	-1.912	0.000	1.810	3.443
6.0/5.0	PG 70-28	4-3	-3.777	-1.860	0.000	1.788	3.412
6.0/5.0	PG 76-22	4-4	-3.730	-1.833	0.000	1.805	3.471

2.4 DISCUSSION & CONCLUSIONS

The effect of changing binder type is shown in Figures 2.7 – 2.10. Two figures were developed for each test series to allow the effects of binder grade to be evaluated at low and high loading frequencies (high and low temperatures). The first figure in each set uses a linear scale for dynamic modulus to allow the high loading frequencies (low temperatures) to be examined, while the second set uses a log scale for modulus to allow the low loading frequencies (high temperature) to be explored.

When a mix is loaded at high temperatures (low frequency) the aggregate structure plays a greater role in resisting the load than the binder. Therefore one would expect that for a given test series (void level), the dynamic modulus values would be similar, since the aggregate structures are similar. However, these results show that the mix with PG 76-22 binder consistently has the highest modulus and the PG 64-22 binder mix is the lowest. The two PG 70 grade binders fall between these limits.

At the higher loading rates (cold temperatures), one expects binder properties, particularly low temperature properties, to play a greater role in the measured dynamic modulus. By extension, one would expect the PG 70-28 to have a lower modulus than the PG 70-22. This is the case, though the difference is small (less than 5 percent). For Series 2, 3 and 4, the PG 76-22 binder has the highest and PG 64-22 has the lowest modulus value, though again, the difference between the minimum and maximum is fairly small (about 15 percent).



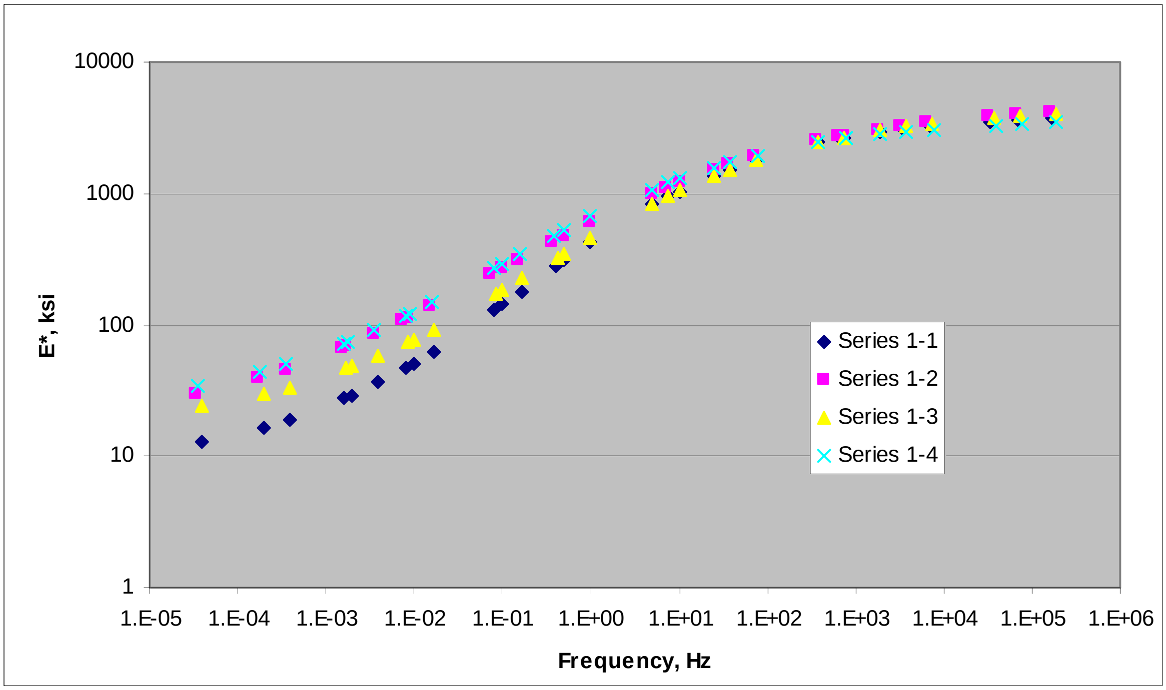


Figure 2.7: Binder grade effects for Series 1 mix type

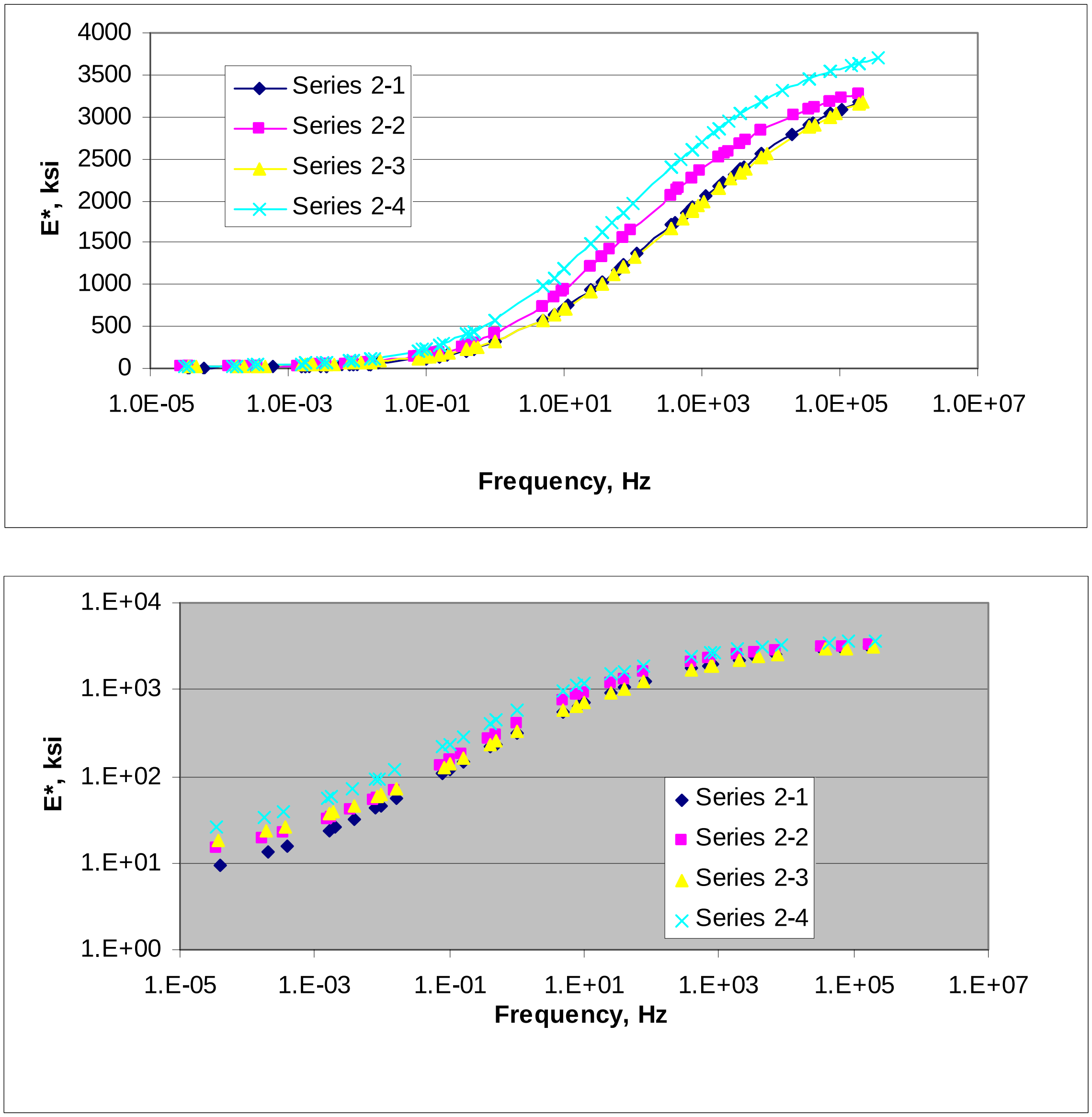
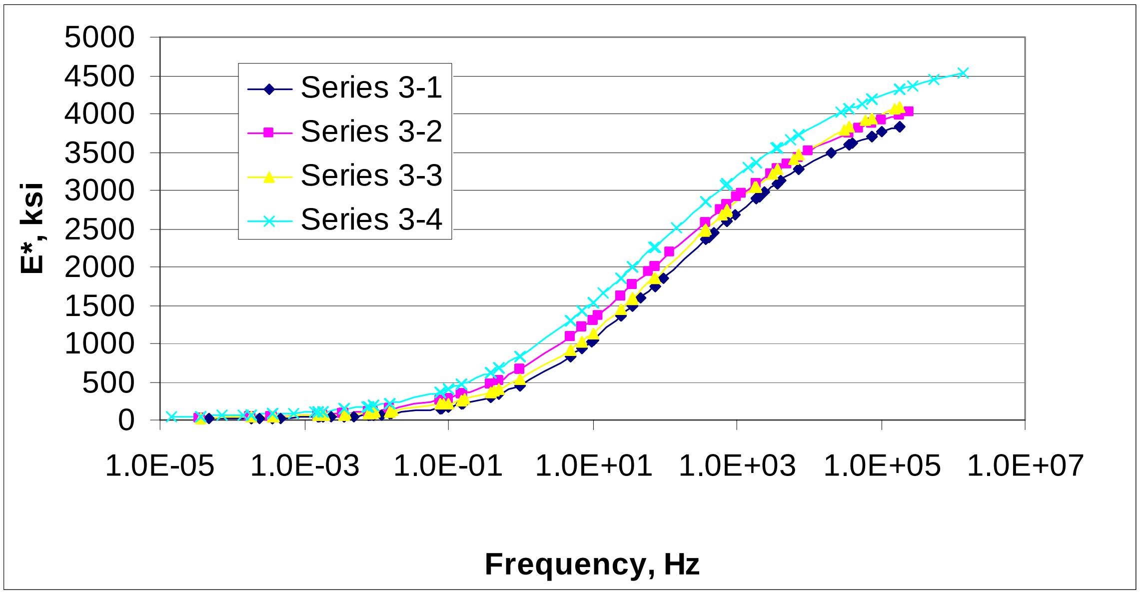


Figure 2.8: Binder grade effects for Series 2 mix type



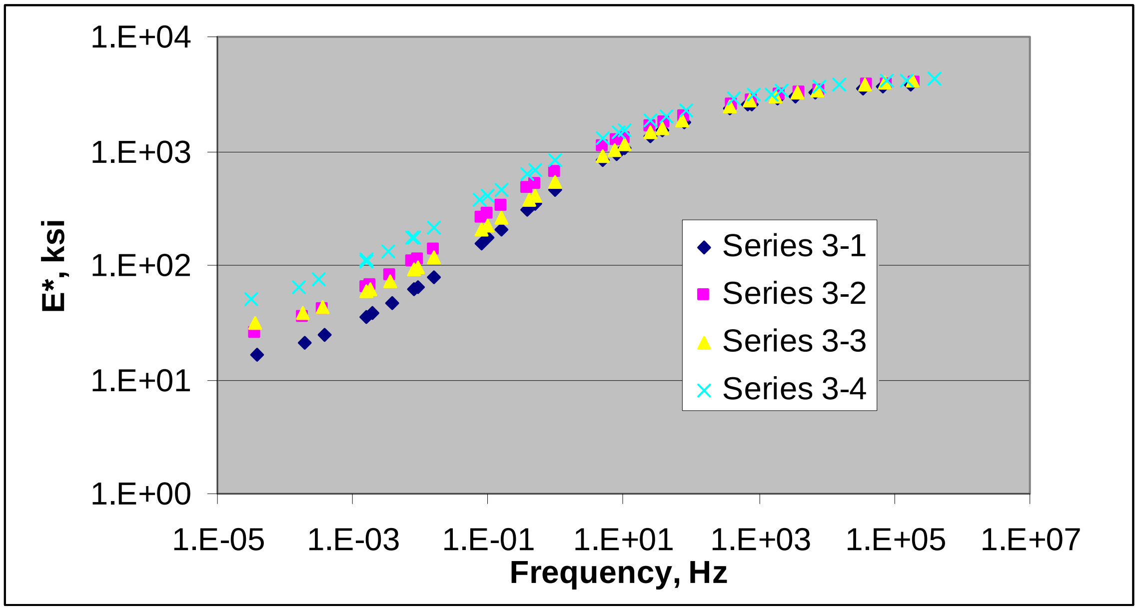
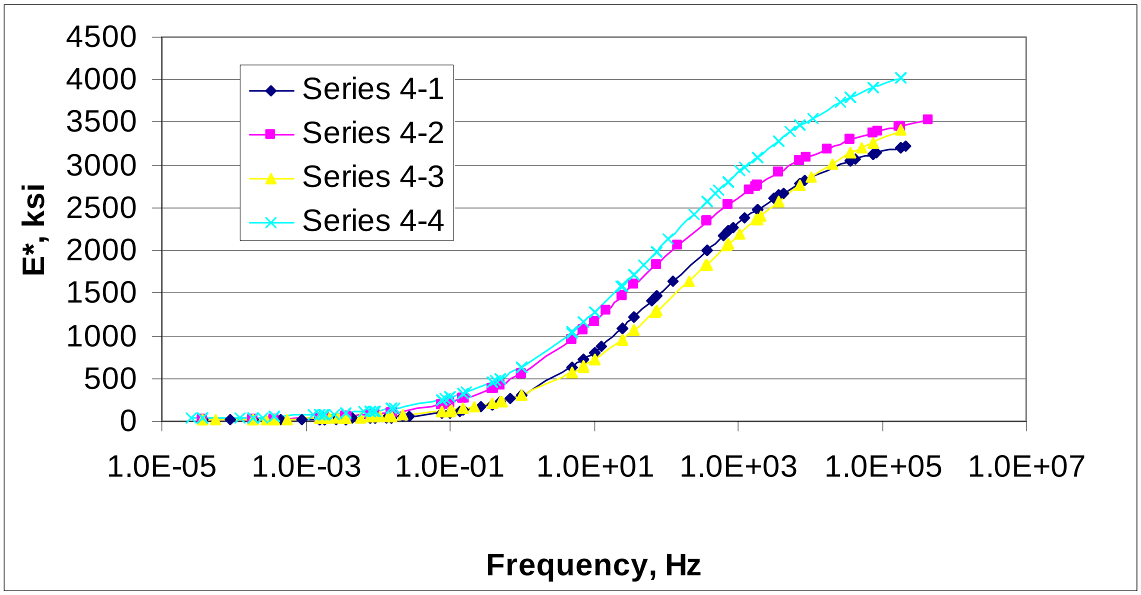


Figure 2.9: Binder grade effects for Series 3 mix type



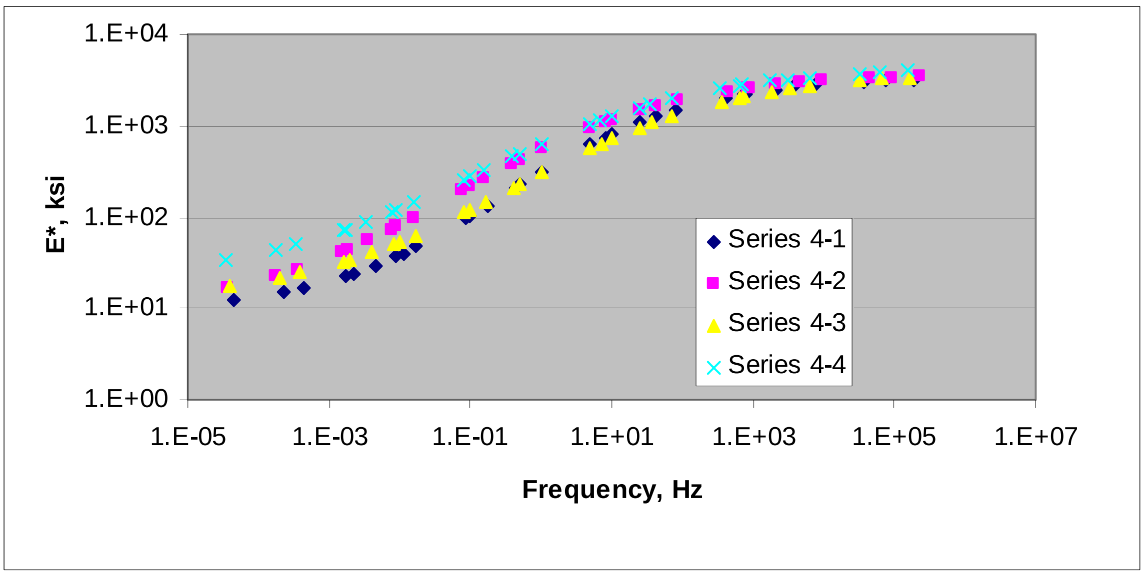


Figure 2.10: Binder grade effects for Series 4 mix type

The effects of changing the high temperature binder grade when the low temperature is held constant is seen in Figures 2.11 and 2.12, for mixes with 4 and 7 percent air voids after gyratory compaction, respectively. At 4 percent air, the modulus values at high frequency loading (low temperature) are approximately equal while at low frequency loading (high temperature) the binder effects are apparent. The effects of different binders are apparent across all load frequencies (temperatures) when the modulus tests are conducted at the higher air content.

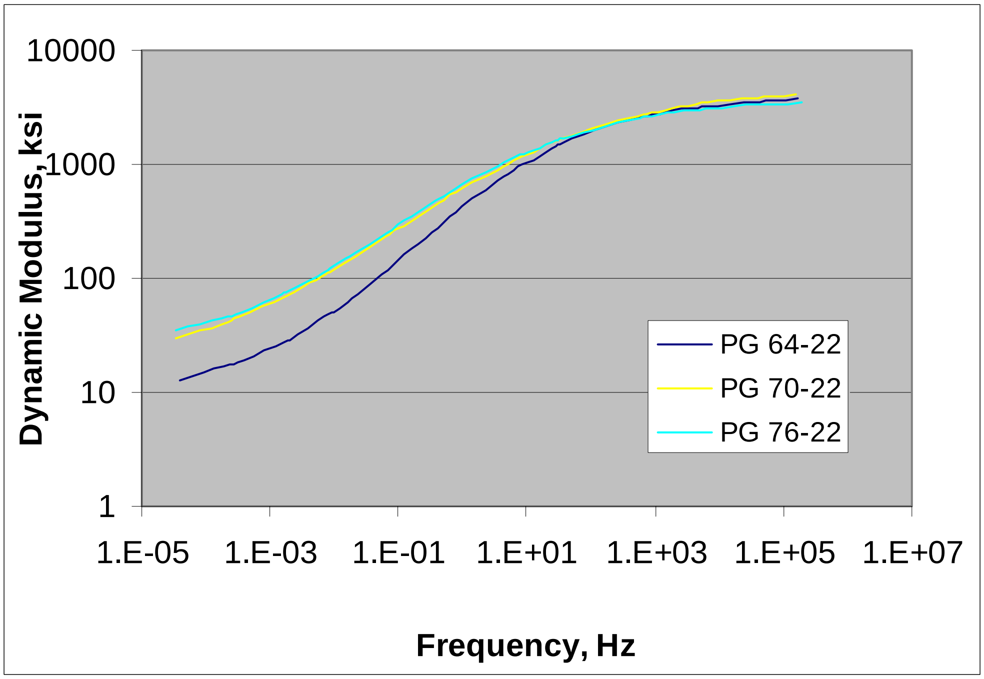


Figure 2.11: Effect of binder grade on mixes with 4 percent air

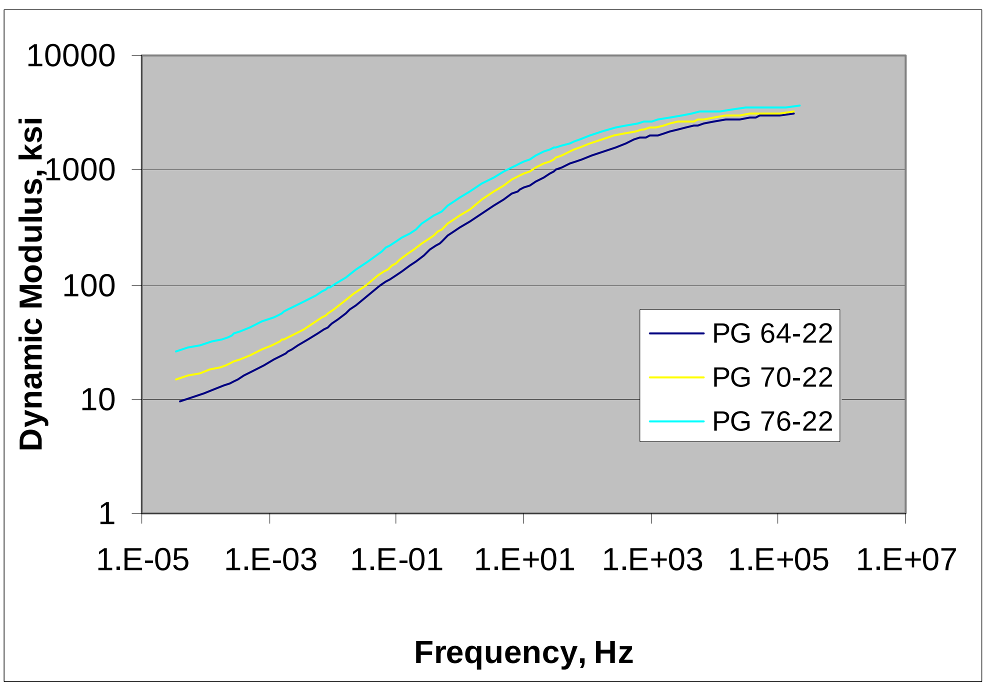
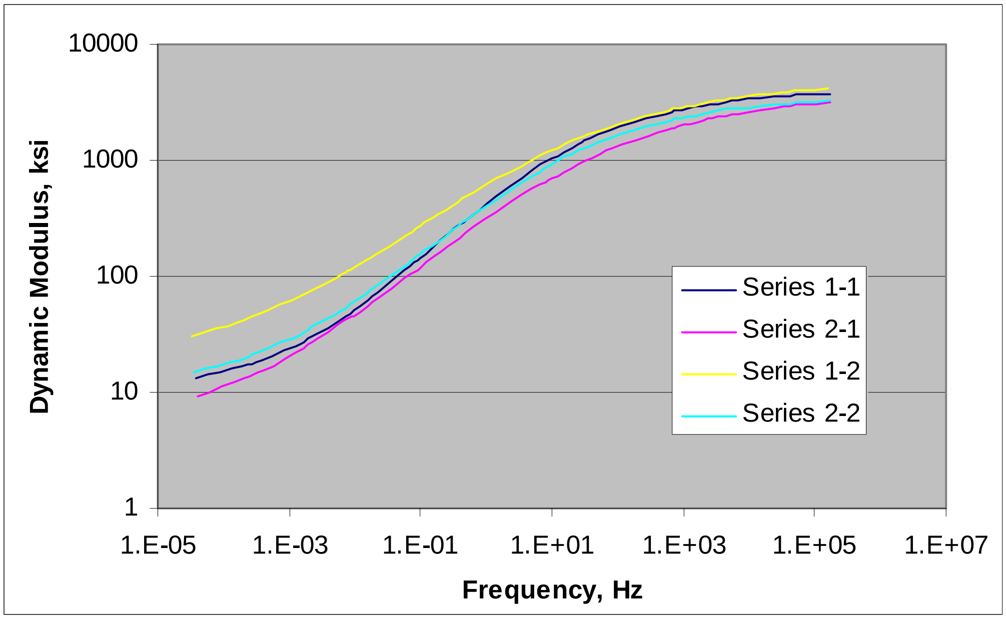


Figure 2.12: Effect of binder grade on mixes with 7 percent air

The effect of changing air voids can be seen in Figures 2.13 – 2.16. For any given binder content and type, an increase the air content results in a reduction in the dynamic modulus value. For example, the dynamic modulus is reduced by 20 to 30 percent when the air content is increased by to 2 to 3 percent, as might occur between the lab compacted mix and the same mix compacted in the field. Witczak's predictive equation suggests a modulus reduction of about 12 percent for a 3 percent increase in air voids content.



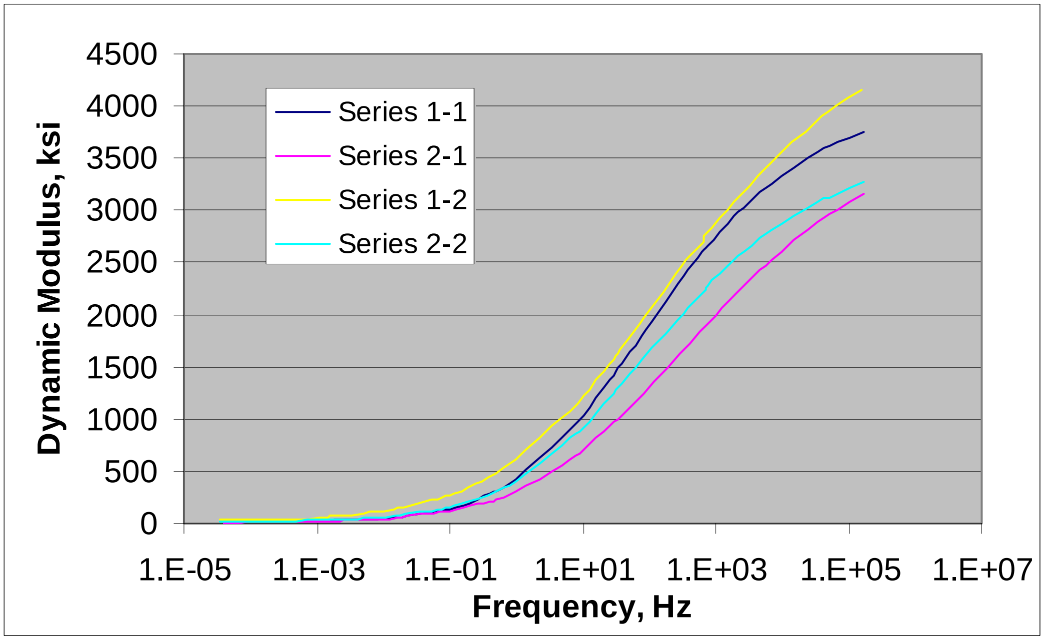
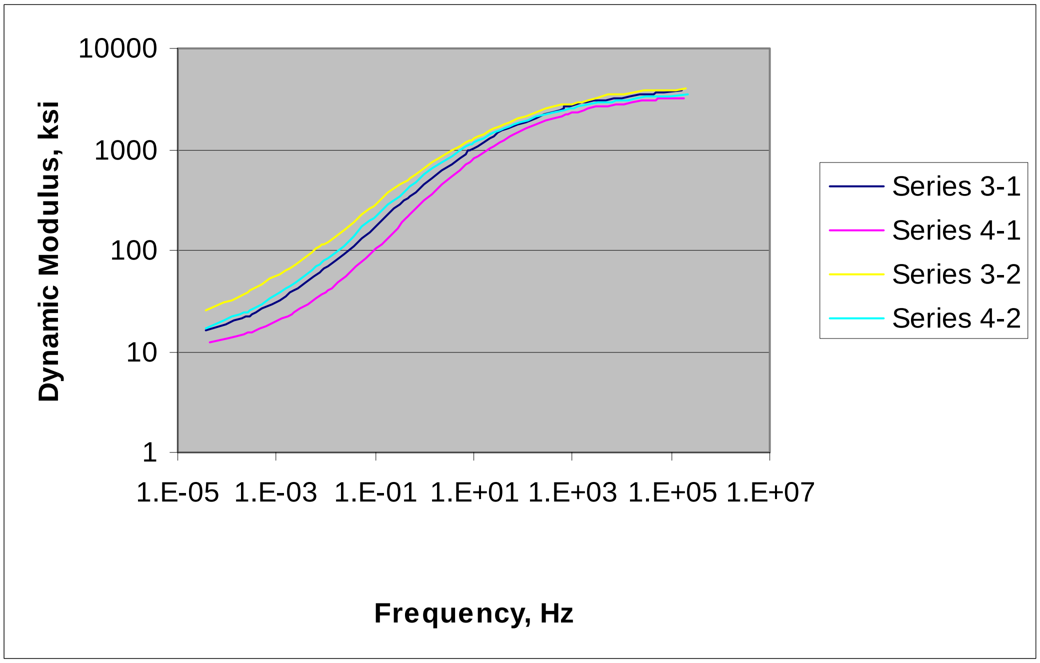


Figure 2.13: Compaction effects for 4 and 7 percent air with PG 64-22 & PG 70-22



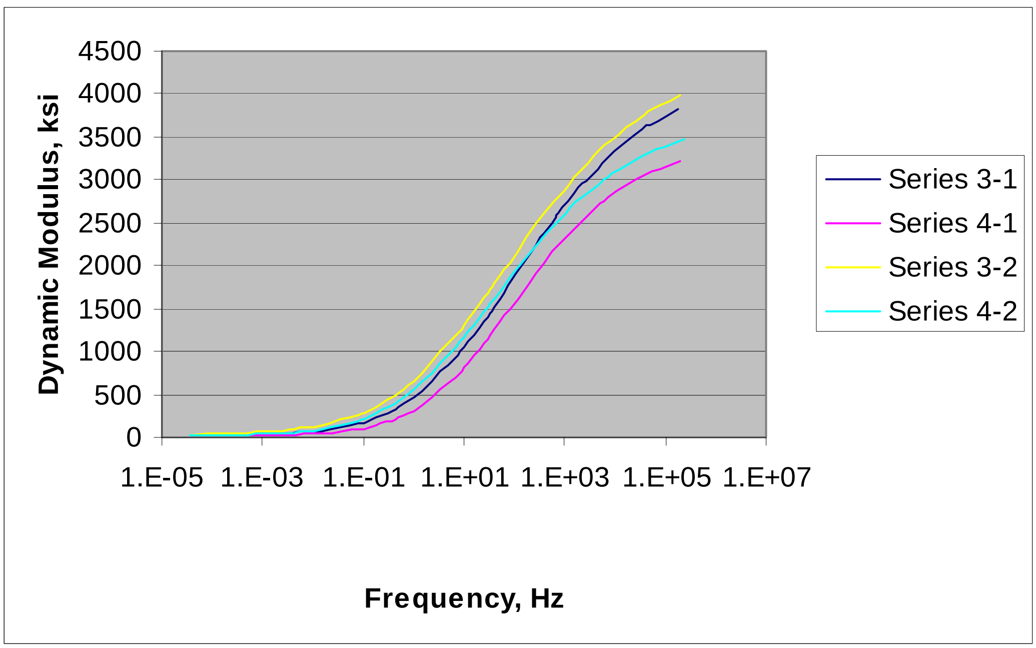
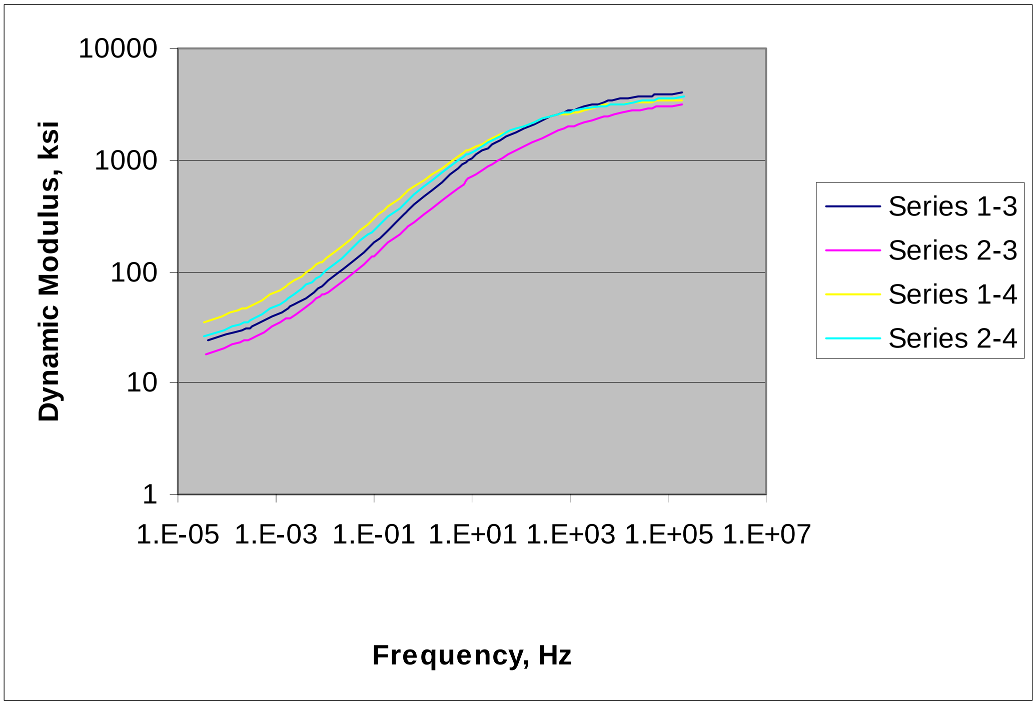


Figure 2.14: Compaction effects for 3 and 5 percent air with PG 64-22 & PG 70-22



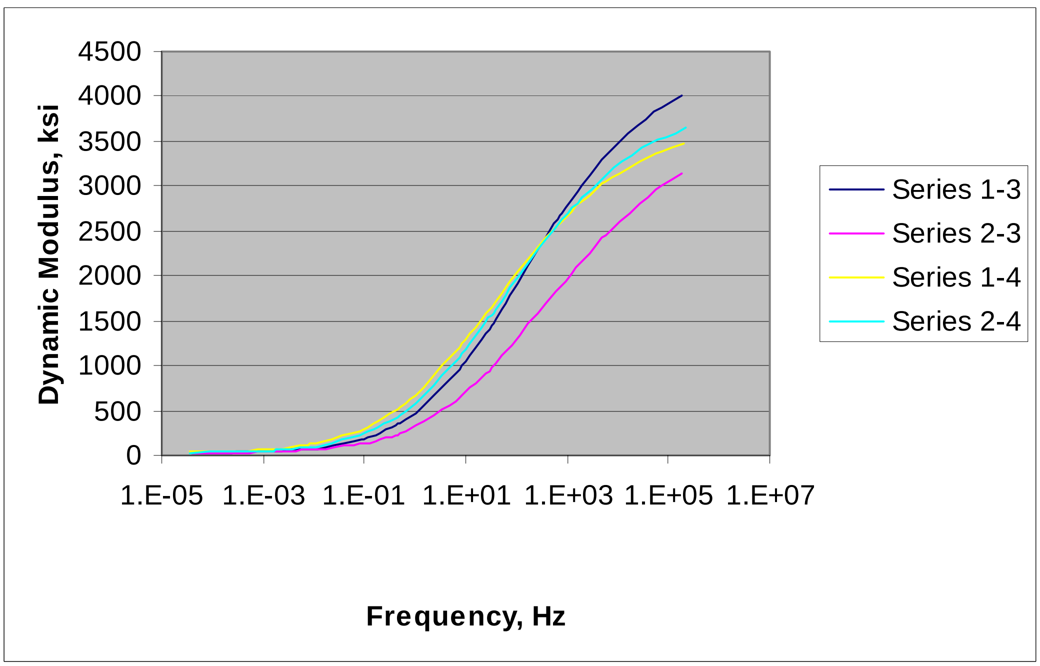
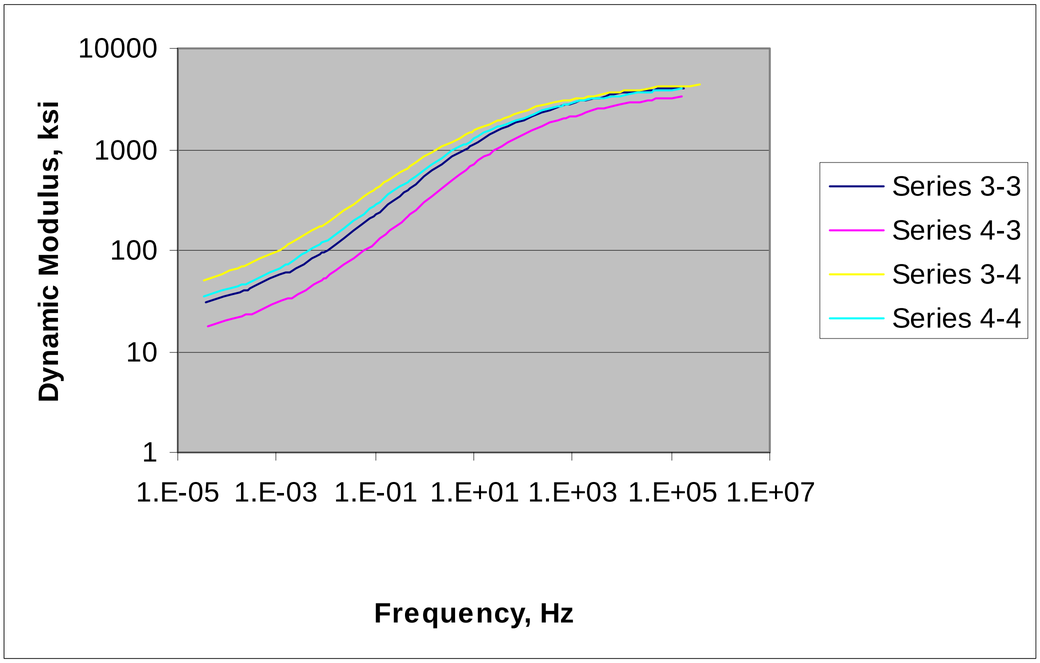


Figure 2.15: Compaction effects for 4 and 7 percent air with PG 70-28 & PG 76-22



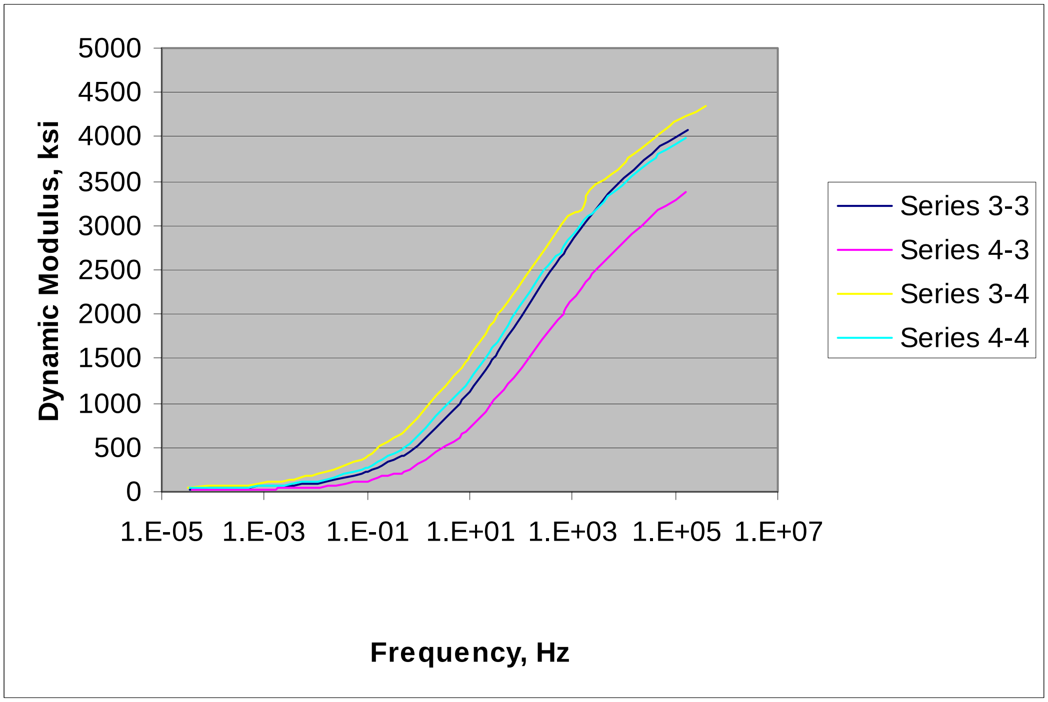


Figure 2.16: Compaction effects for 3 and 5 percent air with PG 70-28 & PG 76-22

The dynamic modulus at 21°C was estimated using the equation provided in NCHRP Project 1-37A and the DAMA software (*NCHRP 2004; Hwang and Witczak 1979*). The calculation requires that the aggregate gradation, mix volumetrics and binder viscosity be known. Binder information was known for all binders (see Table 2.2), but not at the specific temperature of interest. NCHRP Project 1-37A provides a means of estimating the binder viscosity. The estimated viscosities for the binders are shown in Table 2.7.

The calculated dynamic modulus values for all series are shown in Table 2.8 at a single temperature (21.1°C) and a single frequency of loading (1 Hz). The DAMA results do not compare well with the laboratory-measured values. The results calculated using the regression equation from NCHRP Project 1-37A provide better agreement with the laboratory values. For some mixes the predictions were in close agreement (< 15 percent difference). Even with the better predictive capability of the NCHRP Project 1-37A equation, however, the average percent difference is about 30 percent, and some differences are greater than 70 percent.

Table 2.7: Estimated binder viscosity (after NCHRP Project 1-37A)

	PG 64-22	**PG 70-22**	**PG 70-28**	**PG 76-22**
Temperature, degrees Celsius	21.1	21.1	21.1	21.1
Tempeature, degrees Rankine	529.67	529.67	529.67	529.67
VTS	-3.680	-3.426	-3.217	-3.208
A	10.98	10.299	9.715	9.715
Visocity at 21.1°C, cP	1,070,107,854	1,814,936,369	893,439,015	2,957,257,779
Visocity at 21.1°C, P	10,701,079	18,149,364	8,934,390	29,572,578

Table 2.8: Estimated dynamic modulus values using Witczak equation

	Test Series							
	1-1	**1-2**	**1-3**	**1-4**	**2-1**	**2-2**	**2-3**	**2-4**
h = bitumen viscosity, in 10^6 poise	10.70	18.15	8.93	29.57	10.70	18.15	8.93	29.57
f = load frequency, in Hz	1	1	1	1	1	1	1	1
V_a = percent air voids in the mix, by volume	2.8	2.8	2.6	2.6	5.8	5.7	5.3	5.6
V_{beff} = percent effective bitumen content, by volume	10.95	10.97	10.97	10.98	10.62	10.64	10.68	10.65
P_{34} = percent retained on ¾ in. sieve, by total aggregate mass (cumulative)	0	0	0	0	0	0	0	0
P_{38} = percent retained on 3/8 in. sieve, by total aggregate mass (cumulative)	19	19	19	19	19	19	19	19
P_4 = percent retained on No. 4 sieve, by total aggregate mass (cumulative)	46	46	46	46	46	46	46	46
P_{200} = percent retained on No. 200 sieve, by total aggregate mass	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Witczak estimated E*, psi	562,000	655,000	535,000	754,000	496,000	582,000	483,000	670,000
DAMA estimated E*, psi	1,751,300	5,842,900	1,333,400	37,768,900	1,431,000	4,811,700	1,110,700	30,861,400
Measured E*, psi	423,000	611,000	463,000	667,000	311,000	408,000	324,000	571,000
Percent difference (witzcak:Meas.)	33%	7%	16%	13%	59%	43%	49%	17%

Table 2.8 (continued): Estimated dynamic modulus values using Witczak equation

	Test Series							
	3-1	**3-2**	**3-3**	**3-4**	**4-1**	**4-2**	**4-3**	**4-4**
h = bitumen viscosity, in 10^6 poise	10.70	18.15	8.93	29.57	10.70	18.15	8.93	29.57
f = load frequency, in Hz	1	1	1	1	1	1	1	1
volume	2.3	2.2	1.7	1.9	3.8	4	3.7	3.9
V_{beff} = percent effective bitumen content, by volume	11.21	11.21	11.45	11.41	11.01	11.00	11.21	11.18
P_{34} = percent retained on ¾ in. sieve, by total aggregate mass (cumulative)	0	0	0	0	0	0	0	0
sieve, by total aggregate mass (cumulative)	19	19	19	19	19	19	19	19
P_4 = percent retained on No. 4 sieve, by total aggregate mass (cumulative)	46	46	46	46	46	46	46	46
P_{200} = percent retained on No. 200 sieve, by total aggregate mass	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Witczak estimated E*, psi	565,000	660,000	538,000	757,000	543,000	627,000	513,000	717,000
DAMA estimated E*, psi	1,770,600	5,969,800	1,357,500	38,050,500	1,606,400	5,287,500	1,189,100	33,270,600
Measured E*, psi	456,000	660,000	528,000	836,000	311,000	556,000	304,000	634,000
Percent difference (Witczak:measured	24%	0%	2%	-9%	75%	13%	69%	13%

3.0 ASPHALT PAVEMENT ANALYZER

3.1 SITE SELECTION & TEST PLAN

Oregon Department of Transportation personnel identified (by visual observation) projects paved within the past ten years that demonstrated unexpected, early, permanent deformation. Seven projects were initially identified. At least a portion of all seven projects involved paving in an urban area with slow moving or stopping traffic.

These seven sites were then candidates for further investigation to determine whether Asphalt Pavement Analyzer (APA) testing would have correctly identified those mixes as prone to permanent deformation. After a site was identified, ODOT personnel gathered file information on the project, including the job mix formula (JMF), field mix adjustment information, aggregate gradation and source, binder type and source. Availability of material from the aggregate source used in the original mix was investigated. Of the original seven sites identified, aggregates used on one project were no longer available, so it was dropped from the research effort. The six remaining projects are listed in Table 3.1

The Asphalt Paving Association of Oregon (APAO) batched materials to match either the original mix design or the adjusted mix design, as appropriate for each project. Since the mixes for the earlier projects were not Superpave designs, specimens were compacted to 100 gyrations in the Superpave compactor to confirm that they were a feasible mix design. Once the original mix design was confirmed, specimens were compacted to 7.0 +/- 0.5% air voids for testing in the Asphalt Pavement Analyzer.

The APAO batched and compacted two sets of six specimens for each of the sites identified above. The first set of six specimens was compacted at the JMF, that is, the mix that was originally intended for the project. The second set of six specimens was prepared to replicate the "field adjusted" mix, at the gradation and binder content selected after field adjustment. Both sets of specimens were compacted following standard ODOT protocol (i.e., 100 gyrations) and tested at a test temperature appropriate for the project site. If the project was located in an intersection, then the test temperature was increased as appropriate.

Table 3.1: Projects selected for APA testing

Contract	Project Name	Year Paved	Design 20-yr ESALs, millions	Field Rut Depth (Avg), mm	Dense Mix Type, mm	Mix Design	Design Binder Grade	Original APA Rut	Test Temp, °C	Test Air Voids, %	Research APA Rut, mm	Test Asphalt Grade	Test Temp, °C	Test Air Voids, %	Adjusted JMF	Remarks
C12156	Silvies R. - Jct US 395	1997	2.5	5.3 mm (0.21 in)	19	98-005916	PBA-3(1)	NA	-	-	3.7	PBA-3	64	6.9%	No	
C11981	Hines - Silvies R.	1998	2.5	6.6 mm (0.26 in)	12.5	98-003482	PBA-3(1)	NA	-	-	NA	NA	NA	-	Yes	9.6% air voids. (Not tested)
C11841	E. Idaho Ave	1997	6.7	11.4 mm (0.45 in)	19	97-002235	PBA-3(1)	NA	-	-	2.7	PBA-3	64	1.9%	No	
C12690	Pendleton Paving Proj	2002	2.3	4.6 mm (0.18 in)	12.5	02-003803	PG 64-28	4.5mm	64	7.0	5.4	PG 64-28	70	6.7%	Yes	
C12535	Madras NCL - SCL	2001	3.4	5.3 mm (0.21 in)	19	01-002456	PG 64-28	4.6mm	64	7.0	5.8	PG 64-28	70	7.0%	No	
C12370	Hwy 238 - Jackson St.	2001	4.6	3.3 mm (0.13 in)	12.5	01-000188	PG 64-22	2.0mm	64	7.0	3.7	PG 64-22	70	6.8%	No	

(1) PBA-3 is approximately equivalent to a PG 58-34

LTPPBind v3 Recommend High Temp Grade adjusted for traffic speed and volume

Project	20-yr ESALs Traffic Volume	Traffic Speed	Pavement Design Temp	Adjusted Pavement Design Temp	LTPP Binder High Temp Grade
C12156	2.5 million	Slow	57.6 °C	60.3 °C	PG 64
C11981	2.5 million	Slow	57.6 °C	60.3 °C	PG 64
C11841	6.7 million	Slow	65.7 °C	74.5 °C	PG 76
C12690	2.3 million	Slow	61.0 °C	63.7 °C	PG 64
C12535	3.4 million	Slow	60.2 °C	69.2 °C	PG 70
C12370	4.6 million	Slow	63.7 °C	72.0 °C	PG 76

3.2 RESULTS

The mix for one of the projects, Silvies River - Jct Hwy 395, could not be compacted to less than 9.6% voids at 100 gyrations despite several attempts. It was determined that an APA test at this void level would be unrealistic and that adjustments to the mix to achieve the desired voids would so alter the mix design as to invalidate the testing. Therefore, further efforts were abandoned and the mixture was not tested in the APA.

The mixture for the E. Idaho Ave. project compacted to 1.9% air voids at 100 gyrations and it was tested in the APA at that void level. Again, adjusting the mix to achieve the desired void level would have invalidated the testing.

The two older mixes tested in the APA were tested at the ODOT standard test temperature of 64°C. The three newer mixes were tested at 70°C because they had been tested in the APA during mix design development at 64°C. The Technical Advisory Committee suggested a higher test temperature as a method of simulating the additional stress on these pavements in areas of slow moving and stopping traffic.

Table 3.2: APA test results

Project Name	Mix Type	Rut Result	Field Adjusted JMF	Rut Result	Remarks
Silvies River – Jct Hwy 395	Std Duty C-Mix	N/A	Yes	N/A	Lab Air Voids at Adjusted JMF = 9.6%
Hines - Silvies River	Std Duty B-Mix	3.7mm (0.15 in)	No	N/A	Lab Air Voids at Batched JMF = 6.9%
E. Idaho Ave. (Ontario)	Std Duty B-Mix	2.7mm (0.11 in)	No	N/A	Lab Air Voids at Batched JMF = 1.9%
Pendleton Paving Project	Level 3 12.5mm	4.6mm* (0.18 in)	Yes	5.4mm (0.21 in)	*JMF Tested September 2002 under ODOT Contract
Madras NCL – SCL	Level 4 19.0mm	5.8mm (0.23 in)	No	N/A	
Hwy 238 – Jackson St.	Level 3 12.5mm	3.7mm (0.15 in)	No	N/A	

3.2.1 Field Rutting

Rut depths on the selected projects were measured in 2004 with a five-laser profiler and mobile data recorder manufactured by International Cybernetics Corporation.[2] The unit takes multiple rut depth measurements and computes and reports an average rut depth for each tenth-mile increment. Separate measurements were taken for the left and right wheel track. The greater rut depth of the two wheel tracks was used for purposes of this report. Rut depths calculated by a simple average of all the tenth mile sections in the project are shown in Table 3.1.

[2] International Cybernetics Corporation, Largo, FL 33777

For pavement condition rating, ODOT considers a rut depth of less than ¼ in (6.4 mm) as no rutting, ¼ in (6.4 mm) to less than ½ in (12.7 mm) as low rutting, ½ in (12.7 mm) to less than ¾ in (19.0 mm) as moderate rutting and greater than ¾ in (19.0 mm) as high rutting. Index values of 100 for no rutting, 95 for low rutting, 55 for moderate rutting and 30 for high rutting are assigned.

Despite the selection of these projects as having early permanent deformation, only three of the 156 tenth-mile sections on all the projects were rated as "high" rutting. All three were on the oldest project, E. Idaho Ave. Another ten were rated as "moderate" rutting. The remaining 92% of the sections within these projects were either low rutting or no rutting.

Silvies River – Jct Hwy 395: Only a small portion of this project was applicable to this study. Rutting on this portion is included in the Hines – Silvies River project.

Hines – Silvies River: 0.26 inches (6.6 mm) average rut depth. Individual tenth-mile section rut depths ranged from 0.05 to 0.72 inches

East Idaho Avenue: 0.45 inches (11.4 mm) average rut depth. Individual tenth-mile sections had rut depths ranging from 0.13 to 1.09 inches.

Pendleton Paving Project: 0.18 inches (4.6 mm) average rut depth throughout. Individual test sections had rut depths ranging from 0.04 to 0.31 inches

Madras NCL – SCL: 0.21 inches (5.3 mm) average rut depth. Individual tenth-mile sections had rut depths ranging from 0.04 to 0.52 inches

Hwy 238 – Jackson St.: 0.13 inches (3.3 mm) average rut depth. Individual tenth-mile sections had rut depths ranging from 0.01 to 0.38 inches

In considering the data, the following points should be noted:

Significant rutting was visually noted at some intersections. Because the laser system averages measurements within a tenth mile section, the rut depths at an intersection may be offset by those within 100 or 200 feet of the intersection by the averaging. In addition, when the measuring vehicle slows to less than 15 mph, as when approaching stopped traffic at an intersection, the system ceases measuring.

Only the laser rut measurements from the main route and only the right lane through a project are included. Some of the rutting may have been noted in another lane.

3.3 DISCUSSION & CONCLUSIONS

Limited data makes conclusions difficult. In general, the projects did not have significant rutting, despite the fact that the appropriate binder grade was not always used. The greatest rutting occurred in the East Idaho Avenue project, with the largest discrepancy between the binder grade recommended in LTPPBind v3 software and the binder grade actually used.

NCHRP Report 508 suggested tentative acceptance criteria of 9.5 mm (0.37 in) for 2 million ESALs, 8.0 mm (0.32 in) for 3 million and 5.5 mm (0.22 in) for 5 million ESALs when tested at the standard temperature appropriate for the project location. These criteria were for gyratory cylinders compacted to approximately 4% air voids (*Kandhal and Cooley 2003*).

By these criteria all the mixes tested in the APA at 64°C were acceptable (if one assumes a test condition of 7% air voids will not significantly affect results, compared to 4% voids). The APA results then confirmed that these mixes were not at high risk of significant rutting.

One of the mixes, the East Idaho Avenue project, should have been tested at 70°C because the temperature for its location was 65.7°C according to LTPPBind. With the test result available (2.7 mm (0.11 in) at 1.9% voids), it is difficult to predict what the rut depth would have been, had the mix been tested at the higher temperature.

The three projects from 2001 and 2002 (last three rows in Table 3.2) provided reasonable results. Each is discussed below.

The Pendleton Paving Project was tested during the mix design phase and had a 4.6 mm (0.18 in) rut. The subsequent field adjusted mix rutted to 5.4 mm (0.21 in) after 8,000 passes. The adjustments in the field were to coarsen the mix and change the void target from 4.0 to 5.0 percent. The construction notes state this was to improve compaction. Perhaps this was to compensate for the unusually high densities on the grade and to avoid adding binder to the mix to bring the voids down to 4.0 percent. ODOT allowed the contractor to leave the voids high and coarsened the mix to stabilize or reduce densities on the grade.

The Madras project predated the rut testing program, and thus APA testing was not conducted as part of the mix design. The recreated mix design produced a 5.8 mm (0.23 in) rut. This suggests that the proposed permanent deformation limit of 5.0 mm (0.20 in) may be an appropriate upper limit. No field adjustments were reported.

The Hwy 238 project in Medford also predated the rut testing program in the mix design phase. The recreated mix design produced only a 3.7 mm (0.15 in) rut. No field adjustments were reported.

It was possible to complete testing on only three of the six projects originally identified as having significant permanent deformation. Materials could not be obtained for the projects constructed in 1997 and 1998. For projects constructed in 2001 and 2002, materials could be obtained and APA testing completed.

Unfortunately, only three projects were available for which APA testing could be completed. The results suggest that the 5.0 mm (0.20 in) upper limit of allowable rut depth may be an appropriate criterion to apply during the mix design phase. Given the very limited test results available, however, additional testing would be necessary to test this hypothesis. The data from the Pendleton job also suggests that mixes that pass the APA test during the mix design phase may exhibit field rutting if inappropriate field adjustments are made.

4.0 RECOMMENDATIONS

Within the scope of this project, the following recommendations appear warranted.

4.1 DYNAMIC MODULUS

The Oregon Department of Transportation should consider additional dynamic modulus testing to expand the database of available master curves for use in mechanistic-empirical pavement design.

When designing pavement sections using the lab-based dynamic modulus values, it is important that the impact of field air voids is taken into account. Lab specimens compacted to four percent air in the gyratory compactor will be tested at approximately three percent air. The same mix in the field may be compacted to seven percent air. The modulus may be 25 percent lower in the field at these higher air contents.

The impact of binder grade on modulus – and therefore pavement design – is less apparent in lab compacted mixes than at air void contents typical of those found in the field. Oregon pavement engineers are cautioned to use dynamic modulus values that represent the in-place void levels in design.

The measured and estimated dynamic modulus values do not agree well. The estimated modulus values might be improved if the binder viscosity were tested over a range of temperatures to allow measured values to be directly input into the regression equation.

4.2 ASPHALT PAVEMENT ANALYZER

The APA criterion for mix acceptance could not be established with certainty due to the limited number of project sites in this study, but there is limited evidence to suggest that the maximum permissible rut depth at 8,000 passes should be 5.0 mm (0.20 in). Additional tests should be conducted to confirm or reject this limit.

5.0 REFERENCES

Andrei, D., Witczak, M.W., Mirza, M.W. *Development of Revised Predictive Model for Dynamic (Complex) Modulus of Asphalt Mixtures.* Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures. NCHRP 1-37A. Interim Team Technical Report. Department of Civil Engineering, University of Maryland at College Park, MD. 1999.

Choubane, B., Page, G.C., Musselman, J.A. *Investigation of the Asphalt Pavement Analyzer for Predicting Pavement Rutting.* Research Report FL/DOT/SMO/98-427. Florida Department of Transportation. 1998.

Collins, R., Shami, H., Lai, J.S. Use of Georgia loaded wheel tester to evaluate rutting of asphalt sample prepared by Superpave Gyratory Compactor. *Transportation Research Record.* No. 1545. Transportation Research Board of the National Academies. Washington, DC. 1996.

Dougan, C.E., Stephens, J.E., Mahoney, J., Hansen, G. *E* - Dynamic Modulus, Test Protocol – Problems and Solutions*. Report Number CT-SPR-0003084-F003-3. Connecticut Department of Transportation. April 2003.

Fonseca, O.A. and Witczak, M.W. A prediction methodology for the dynamic modulus of in-place aged asphalt mixture. *Journal of the Association of Asphalt Paving Technologists*. Vol. 65. 1996.

Hwang, D. and Witczak, M.W. *Program DAMA (Chevron), User's Manual*. Department of Civil Engineering, University of Maryland. College Park, MD. 1979.

Kandhal, P.S. and Cooley, L.A. *Accelerated Laboratory Rutting Tests: Evaluation of the Asphalt Pavement Analyzer*. NCHRP Report 508. National Cooperative Highway Research Program. Transportation Research Board. National Academy Press. Washington, DC. 2003.

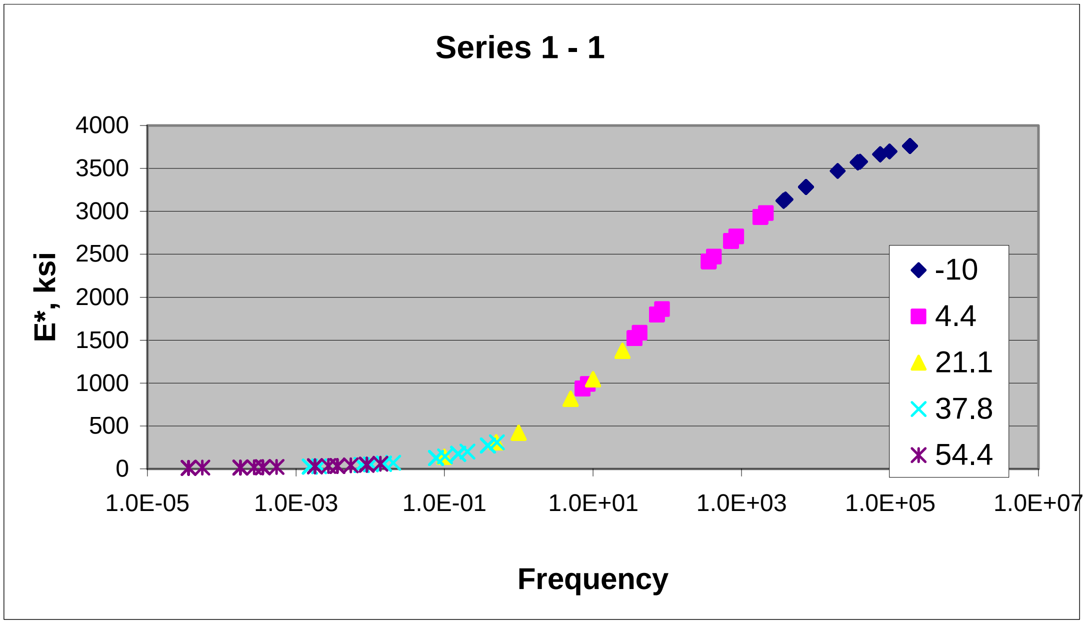
National Cooperative Highway Research Program. Applied Research Associates, Inc., ERES Consultants Division. *Guide for mechanistic-empirical design of new and rehabilitated pavement structures*. NCHRP Project 1-37A. Transportation Research Board. http://www.trb.org/mepdg/guide.htm. Washington DC. March 2004.

Pellinen, T.K., Witczak, M.W., Bonaquist, R.F. Asphalt Mix Master Curve Construction Using Sigmoidal Fitting Function with Non-Linear Least Squares Optimization Technique. 15th ASCE Engineering Mechanics Conference. Columbia University, New York, NY. June 2-5, 2002.

Williams, C.R. and Prowell, B.D. Comparison of Laboratory Wheel-Tracking Test Results with WesTrack Performance. *Transportation Research Record.* No. 1681. Transportation Research Board of the National Academies. Washington, DC. 1999.

APPENDICES

APPENDIX A: MASTER CURVES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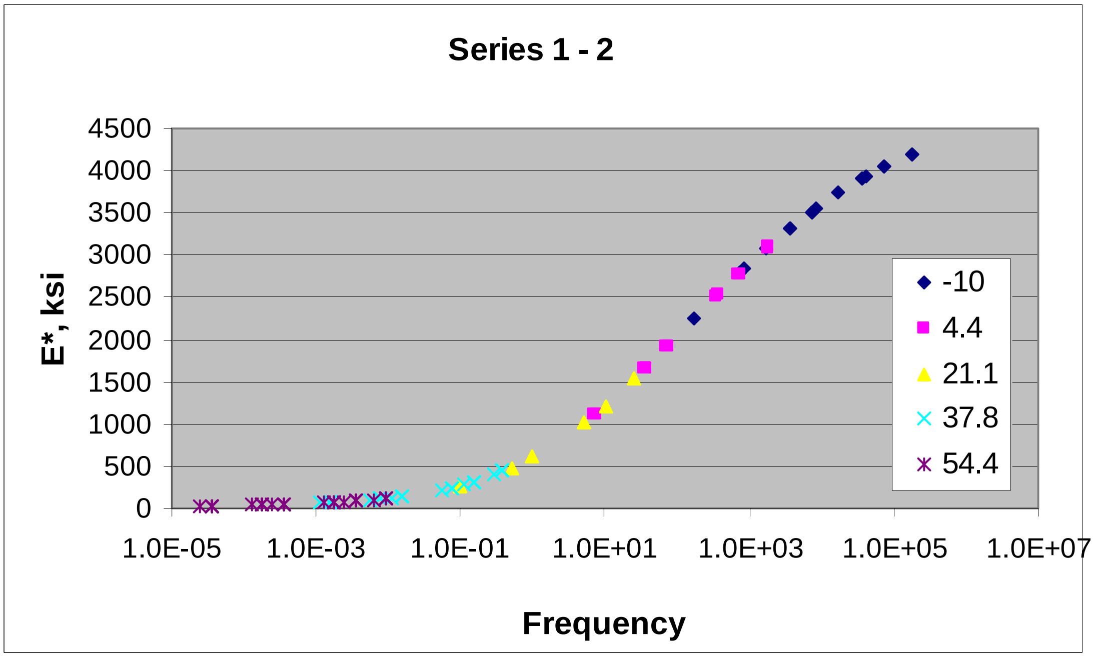
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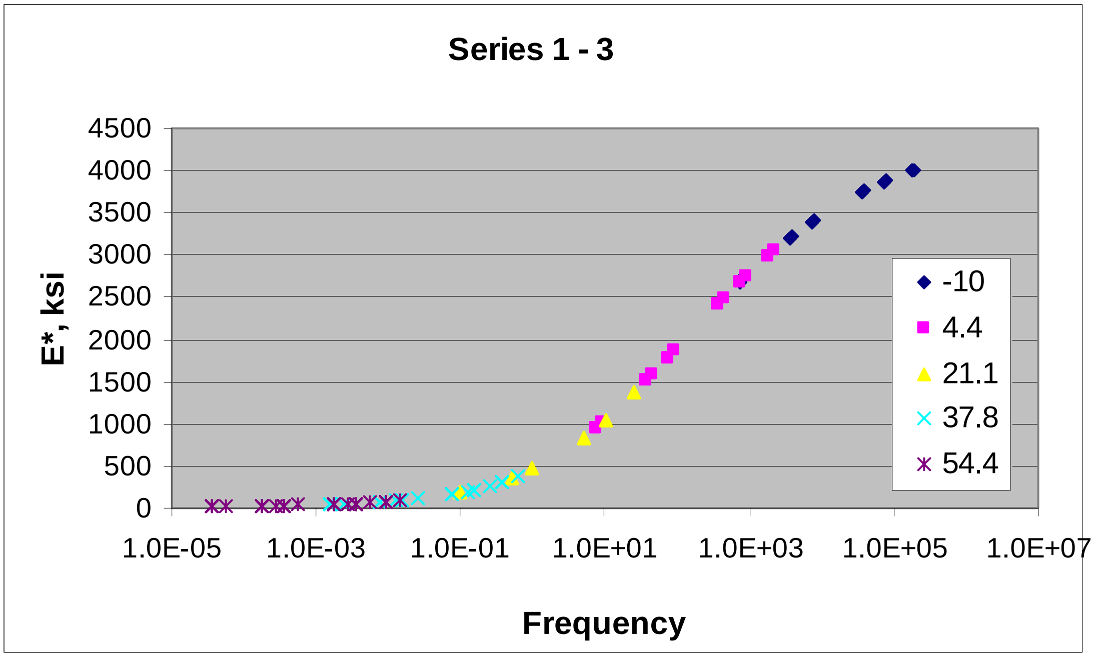
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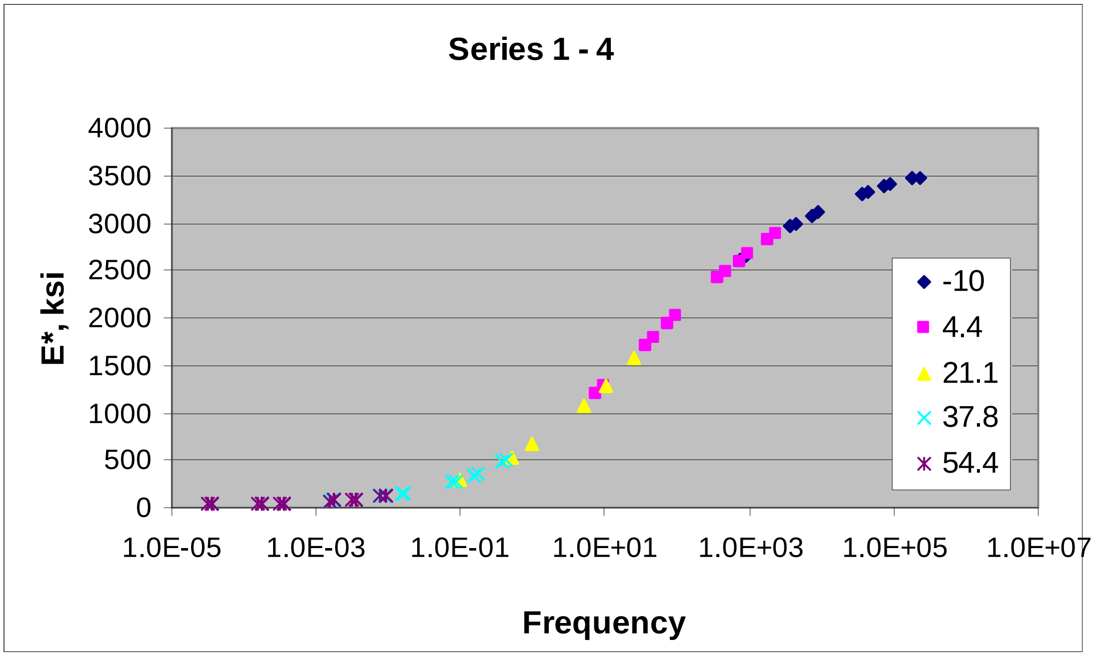
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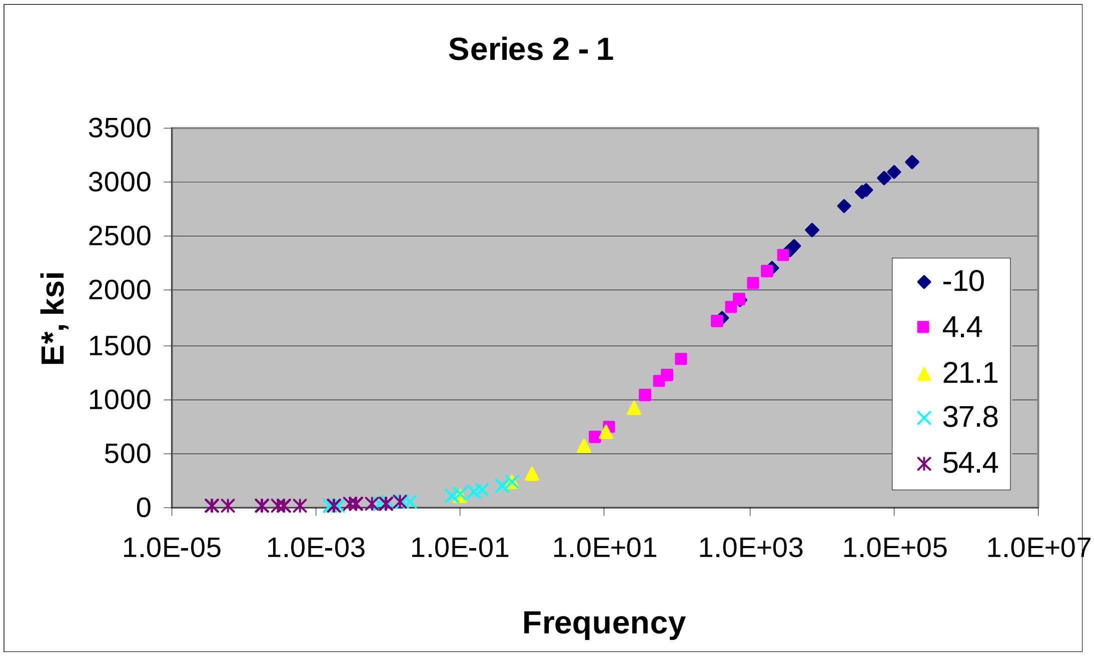
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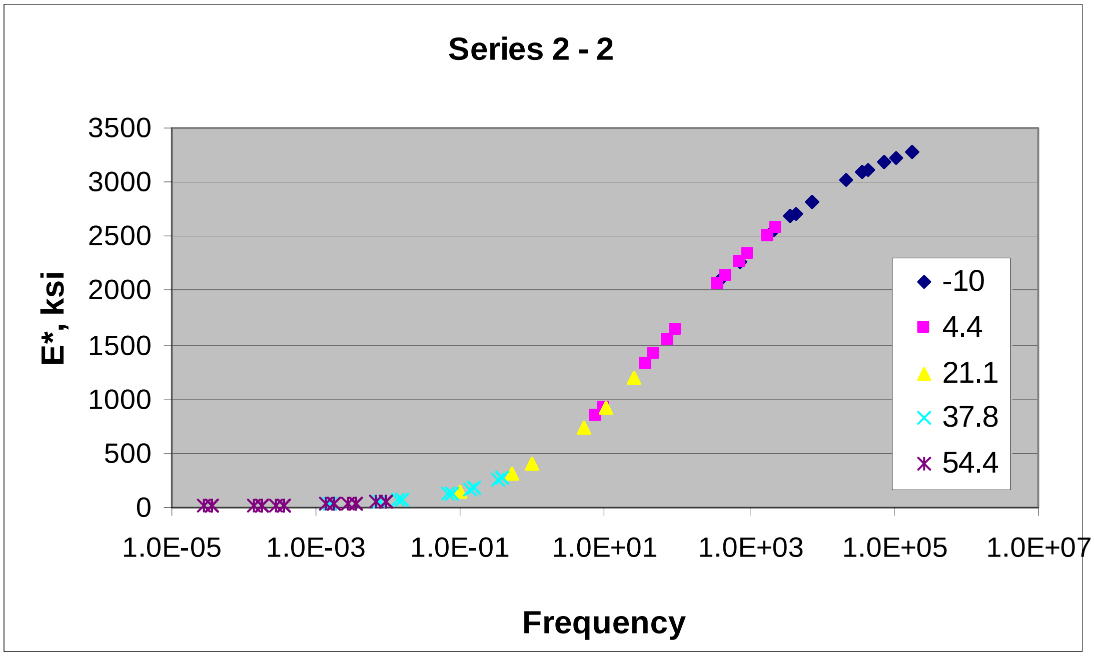
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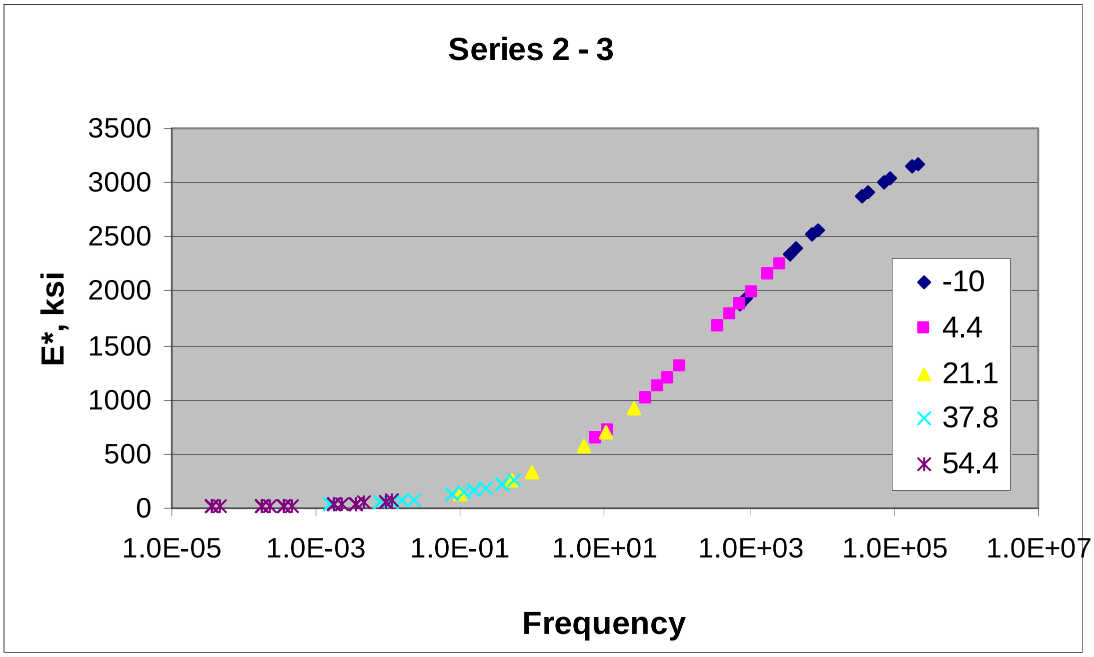
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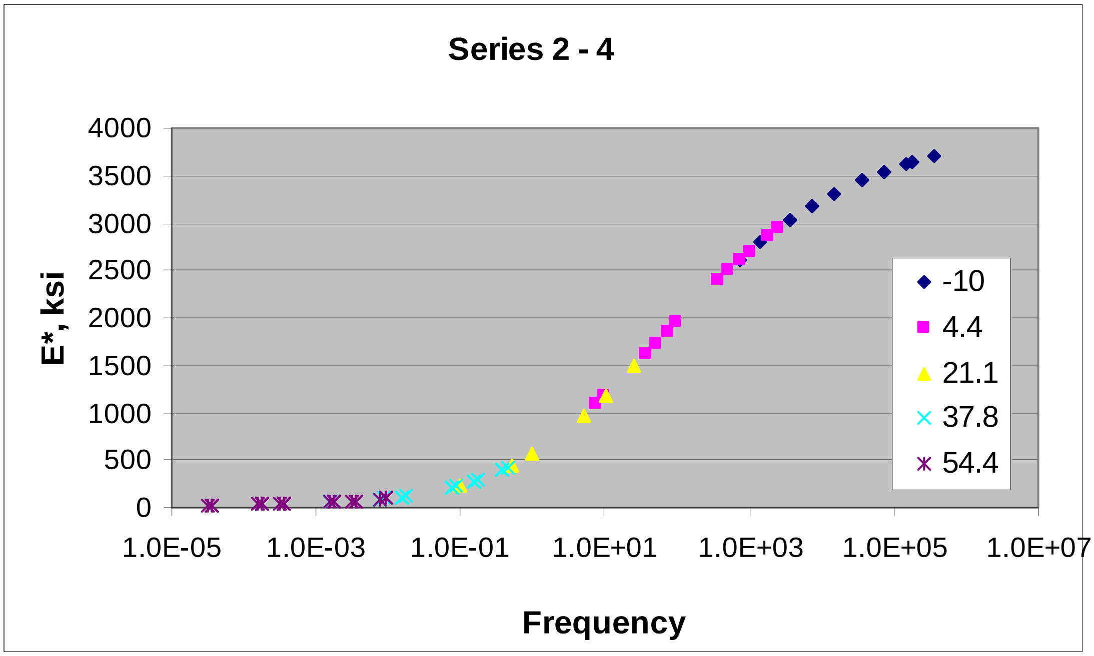
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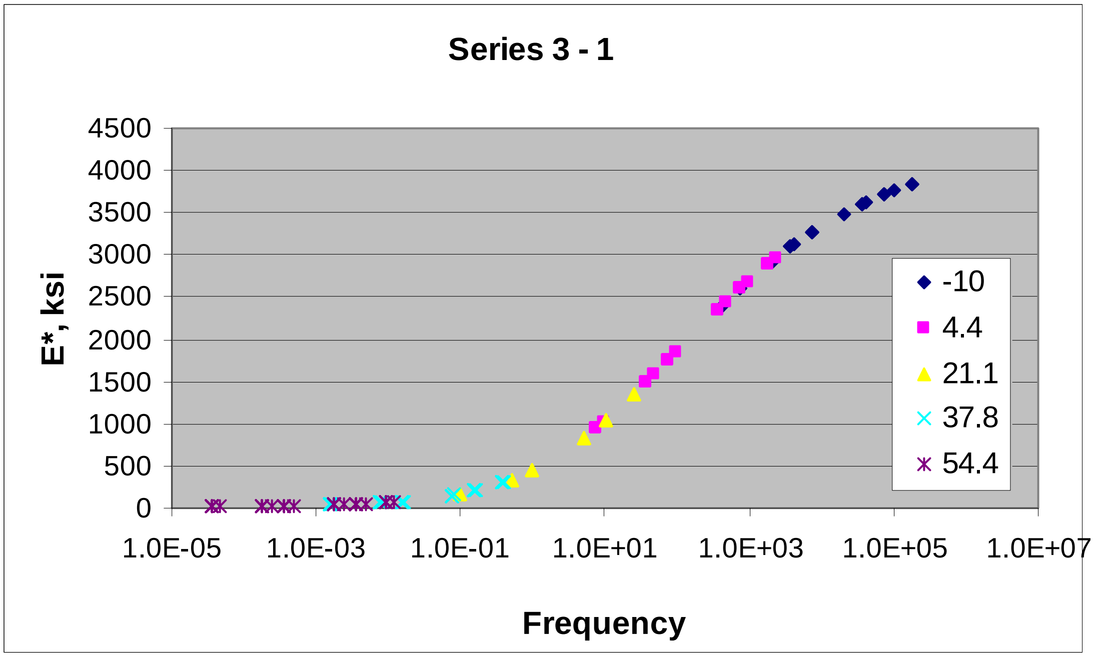
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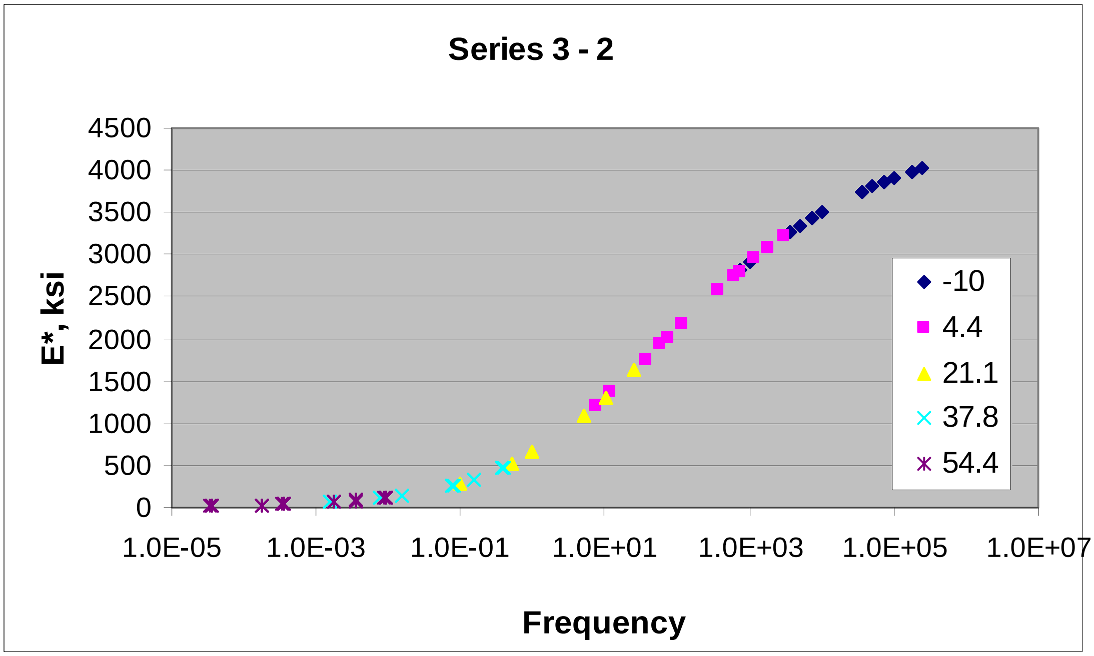
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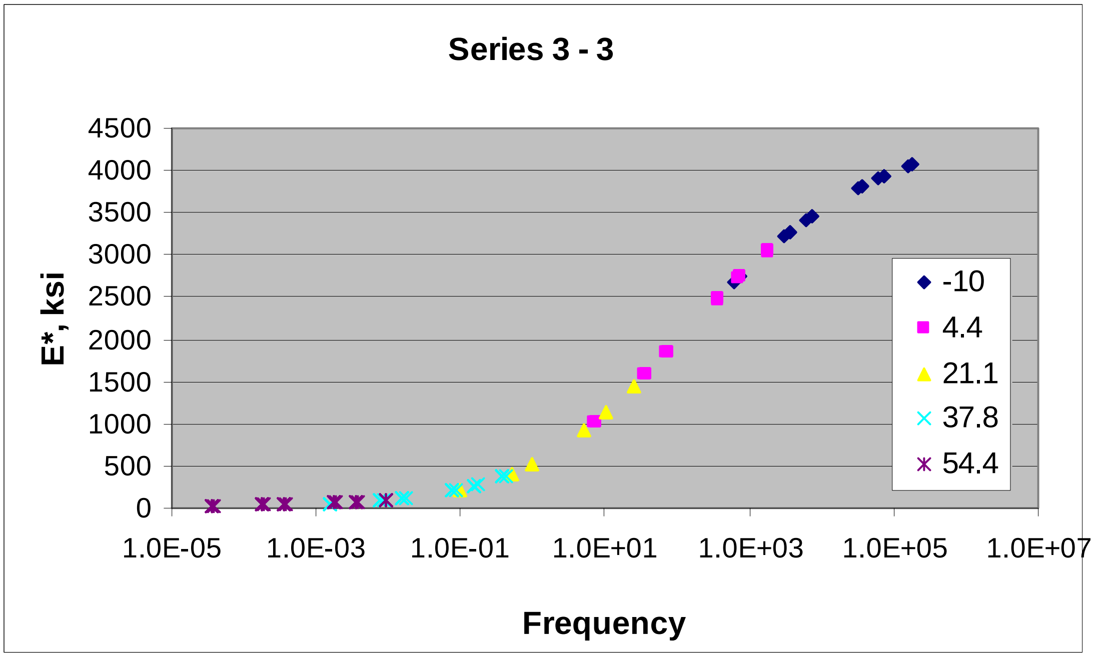
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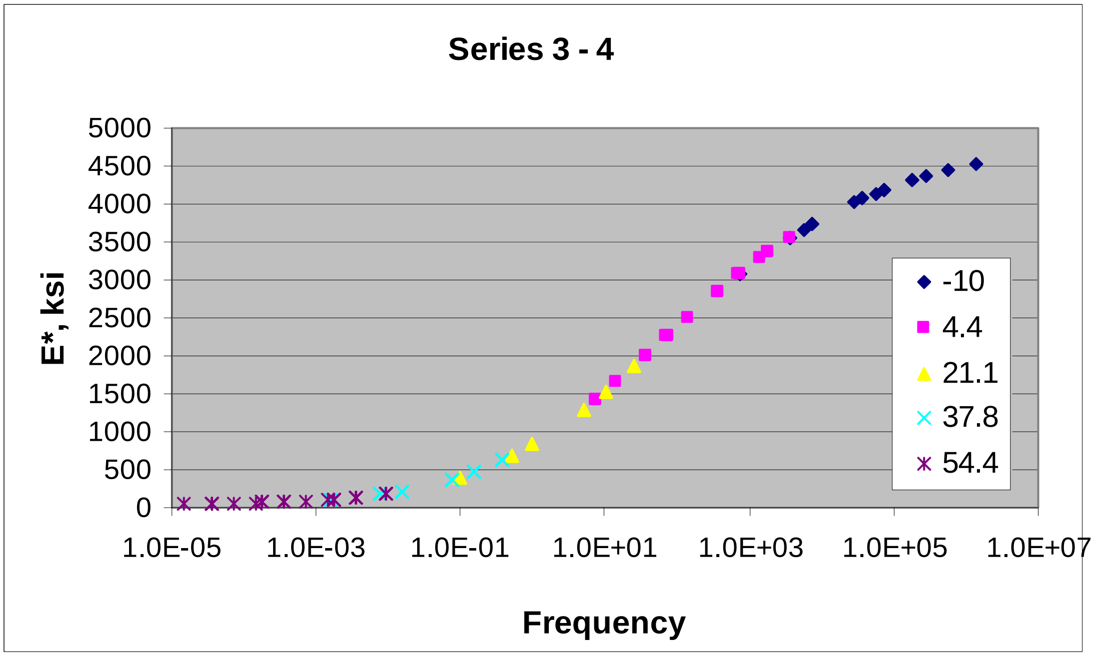
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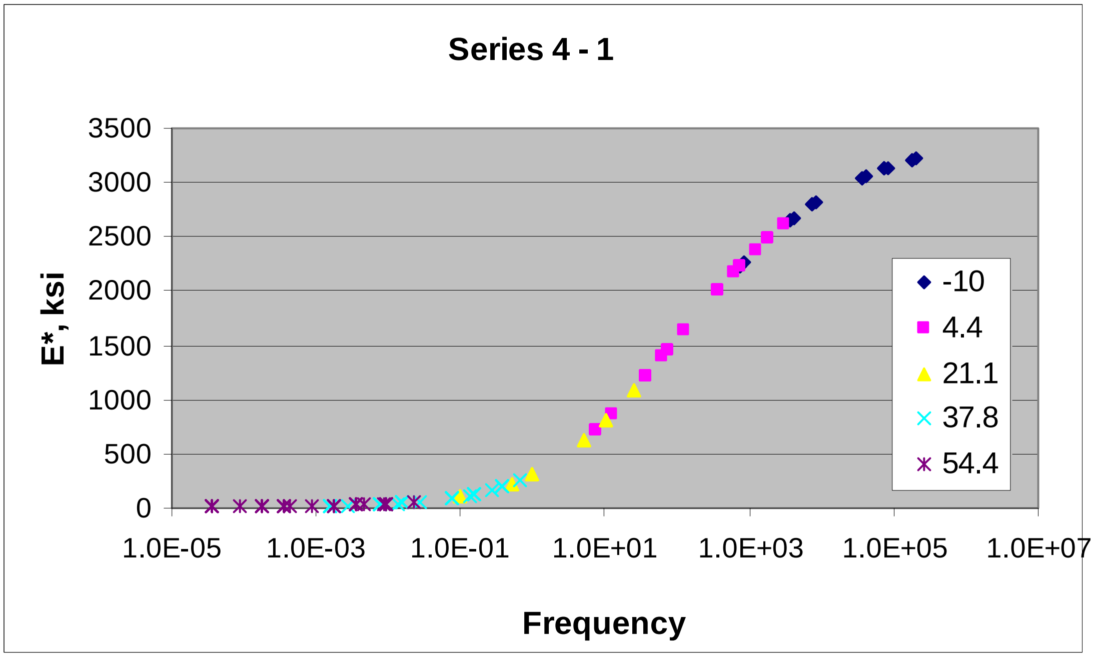

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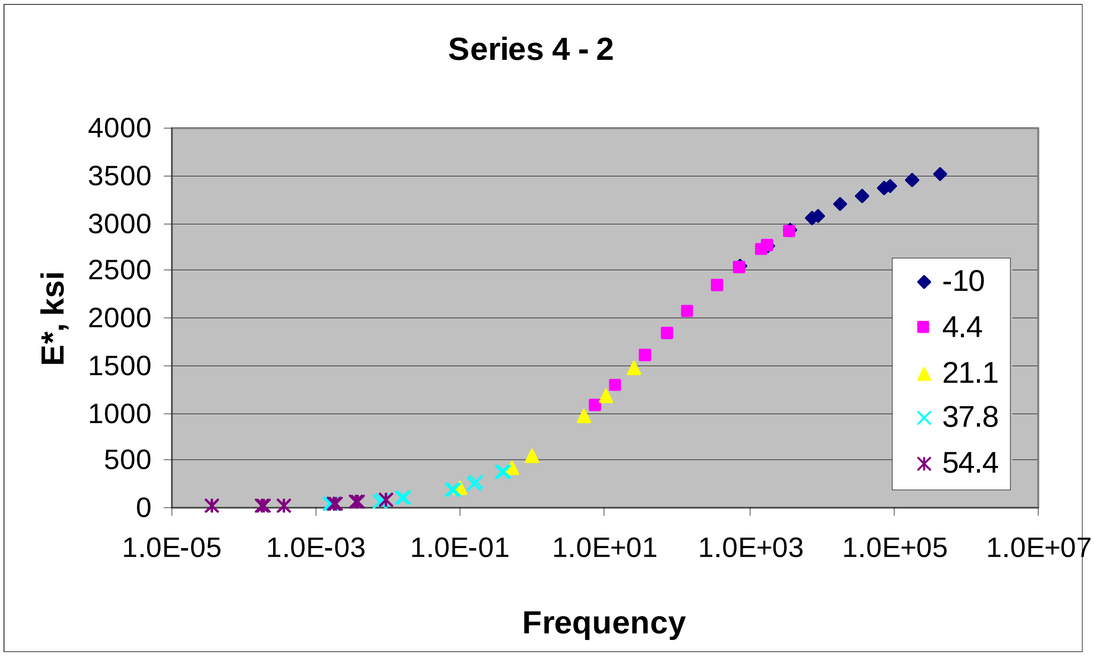

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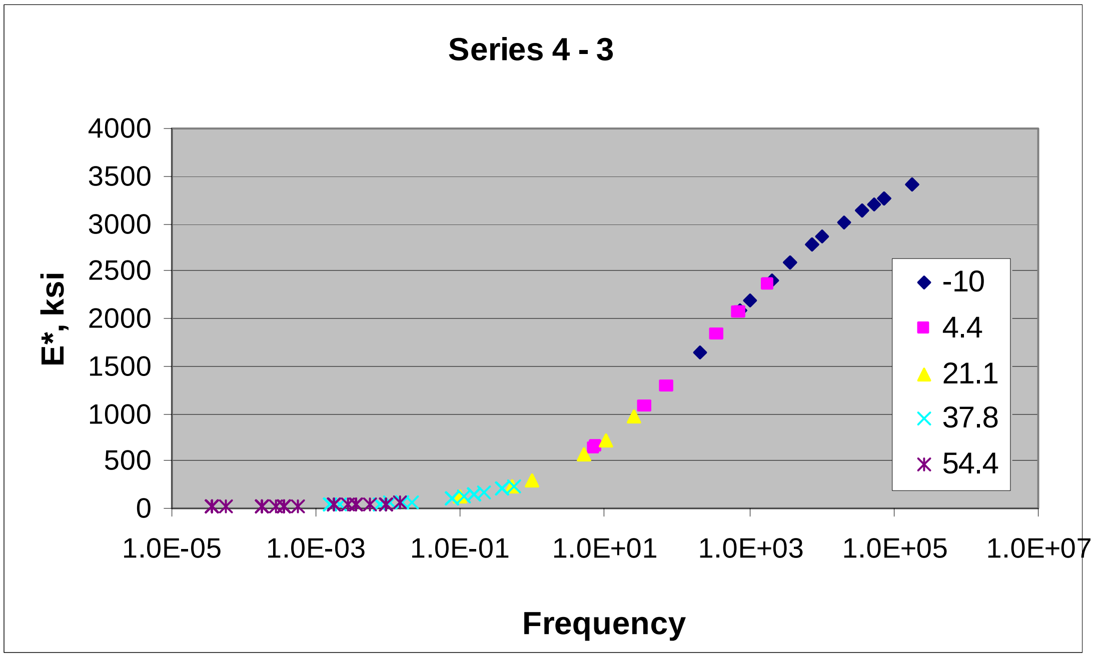
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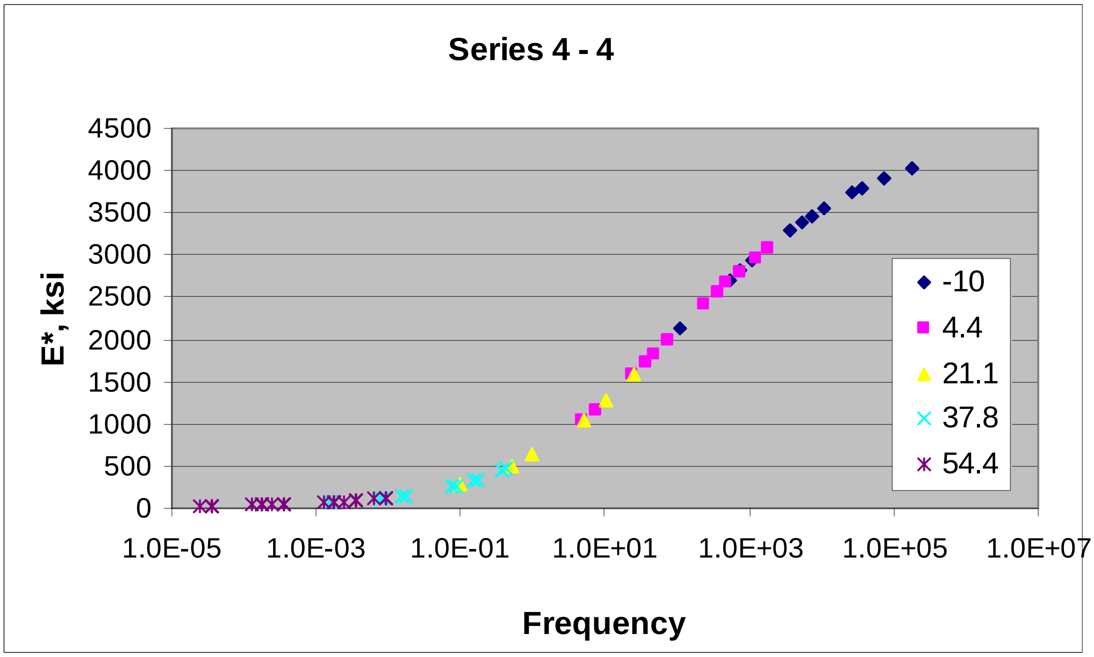
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APPENDIX B: PROCEDURE FOR COMPLEX MODULUS TESTING

APPENDIX B: PROCEDURE FOR COMPLEX MODULUS TESTING

Summary

A system was assembled and refined at OSU Civil Engineering Materials Lab to perform dynamic modulus of hot mix asphalt test specimens. The goal was to follow the Methods and Apparatus described in AASHTO TP 62-03 “Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures” as closely as practicable.

The major components of the OSU system were as follows:

1. Specimen preparation equipment.
   A diamond coring drill was used which meets the requirements of AASHTO TP 62-03, that is, the drill has a very rigid controlled feed to obtain smooth-sided specimens. A diamond-blade cut-off saw with a precision vee-block was used to trim specimens to length. Trimmed specimens were bulked using methods prescribed in AASHTO T 166, “Bulk Specific Gravity of Compacted Bituminous Mixtures.”
2. Loading machine.
   An MTS servo-hydraulic test machine was used for sine wave loading at a prescribed frequency and number of cycles. This machine had been adapted to take an external load-control signal from the PC running the control and data acquisition.
3. Temperature control chamber and temperature monitoring.
   An environmental chamber made by Applied Test Systems, capable of holding set point temperatures within +/- 0.5C, was tested and found suitable. Extra insulation and seals were added to reduce consumption of CO_2 coolant. Temperatures were monitored as prescribed in AASHTO TP 62-03, using a dummy specimen with a temperature probe and a calibrated thermometer.
4. Sensors and Signal Conditioning.
   A 5,000-lb load cell, Linear Variable Differential Transformers (LVDTs) and suitable amplifiers were used for detecting load and displacement of the specimen under test. These were tested and found to be responsive at the required range of frequencies.
5. Data Acquisition and Control System.
   A PC was used for control and data acquisition. Running ATS software, the computer generated sinusoidal loading waveforms to control the MTS loading machine. These waveforms were of prescribed frequency and number of cycles. Simultaneously, the ATS software sampled and recorded the specimen load and displacements. In addition, the software provided analysis of the acquired data and a report summarizing the calculations required in AASHTO TP 62-03.

This document describes in sequence the procedures used to accomplish the TP 62-03 test method on a batch of specimens using the OSU system of assembled equipment. Each major procedure was a separate section. Each section presents a step-by-step protocol, with enough detail for the technician to run the test.

Other appendices describe each of the system elements, focusing on initial setup, and details of operation.

Trimming Modulus Specimens to Size

Specimens received for testing were 150mm x 150mm cylindrical specimens which had been lab-compacted in a gyratory compactor. Bulk Specific Gravity weighings were made on the specimens, before and after the trimming described below.

The specimens were reduced to 100mm diameter using a diamond core drill, then the ends were 'trued' using a diamond cut-off saw. This 'truing' operation was done to make the ends flat, smooth, and perpendicular to the axis of the cylindrical specimen.

A problem was encountered sawing the ends off the specimens to true them. That is, when the disk of material being sawn off would finally fall away from the specimen, it would take with it a small (up to 1-cm) chunk of the specimen. This was due to the disk of waste being unsupported, and somewhat due to vibration of the saw. The resulting specimens had a 'notch' or void at the corner end circumference, which would result in uneven stress concentrations.

Two solutions were devised and both were used:

1. Duct tape was applied tightly around the specimen at the location of the saw-cut so as to provide confinement and avoid 'flaking' when the waste-cut piece fell off.
2. A matching 100mm diameter piece of waste specimen was glued onto the end of the real specimen using hot glue, carefully aligning it so that the resulting combination was a long cylinder which would fully span the vee-block support used for sawing. Thus a complete saw-cut through the specimen could be made without an unsupported piece falling off.

Briefly, the steps performed in this operation were:

1. **Receive 150mm x 150mm specimens from ODOT.**

   Verify the number and type of specimens received and label each with its unique ID number.

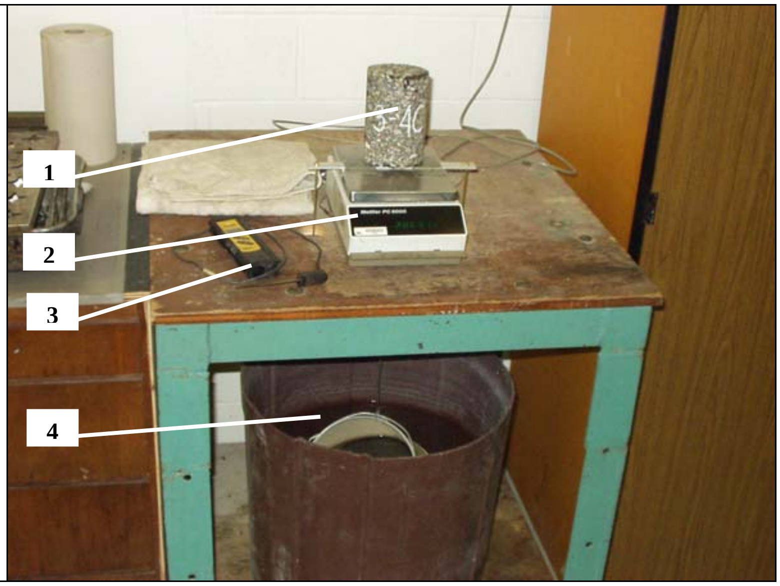
2. **Bulk these 150mm x 150mm specimens.**

   Using the steps in AASHTO T 166, "Bulk Specific Gravity of Compacted Bituminous Mixtures," do bulk specific gravity weighings of the 150 x 150-mm specimens.

Figure B-1: Specific Gravity Weighing

Key:

1. Specimen
2. Balance
3. Thermometer
4. Basket submerged in water



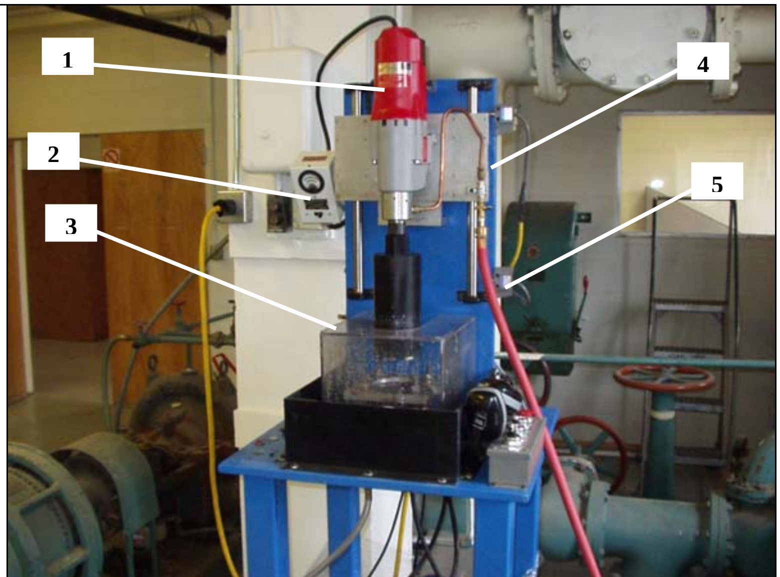
3. **Core the specimen, to obtain a 100mm diameter specimen.**

   Clamp the 150mm x 150mm specimen in the holder of the coring drill. Be sure the four clamp rods are tightened equally, and just tight enough to hold securely. Over-tightening will deform the specimen.

Figure B-2: Coring Apparatus

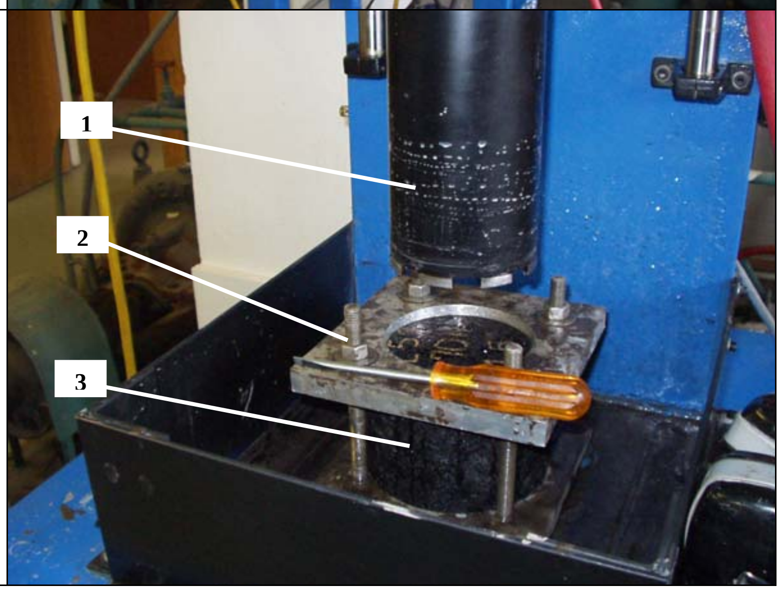
Core Drill Features:

1. Power head
2. Current meter and ON/OFF switch
3. Safety shield
4. Water valve
5. Feed Control Box



Details:

1. Coring bit
2. Specimen clamp with clamp rods
3. Specimen



Wear hearing and face protection for the next steps.

Place the clear plastic safety shield over the specimen, start a slight flow of water down through the coring bit, and then turn on the drill with the ON/OFF switch. The drill will start turning.
Press the START button on the Feed Control Box, and the drill will advance automatically under hydraulic control, to complete the coring operation. When it has fully penetrated the specimen, it will retract back up to its rest position.

Turn the drill off with the ON/OFF switch. Remove the cored specimen from the specimen clamp, and drain off the residue from the pan of the core drill as needed.

<u>Immediately label the cored 100-mm diameter specimen with its correct identification.</u>

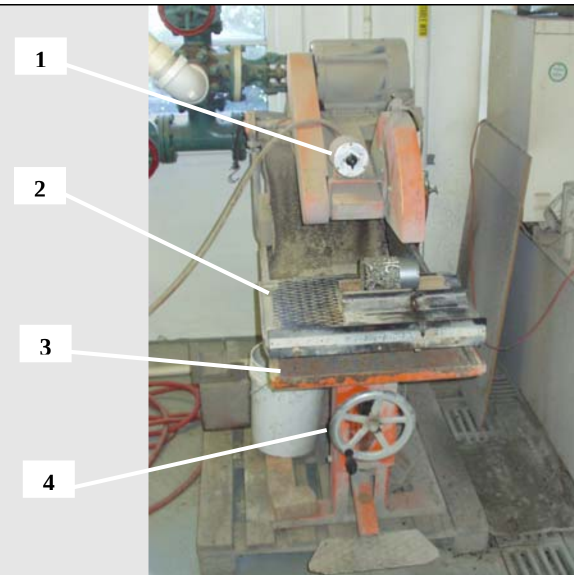
4. **Saw the ends true using a method described above to avoid having corner 'chunks' break off.**

   Both ends of the specimen need to be trimmed to true them, so they are perpendicular to the axis of the cylinder. The AASHTO TP-9 requires that ends be within 1-degree of perpendicular. This can be verified with a square and feeler gauges. <u>Practice on some scrap specimens first to be sure the saw is cutting straight</u>.

Figure B-3: Contractor Diamond-Blade Saw Features

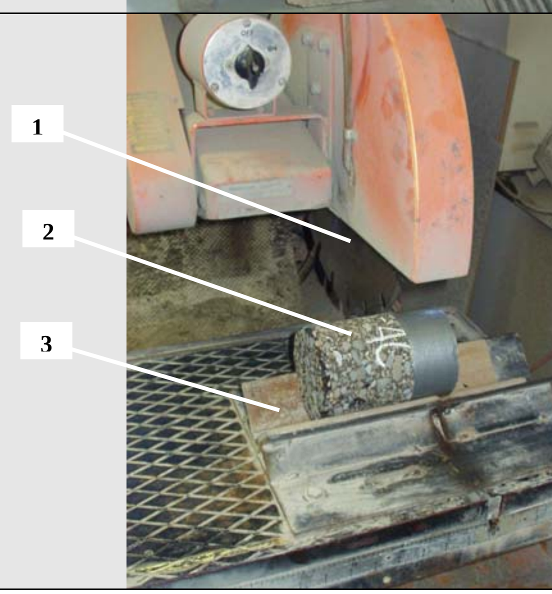
Contractor Saw Features:

1. ON/OFF switch
2. Miter table
3. Pan for cooling water
4. Height adjustment



Details:

1. Diamond blade in guard.
2. Specimen with duct tape to prevent 'flaking'.
3. Vee-block aligned on miter table to get perpendicular cutting.



Prepare the diamond-blade contractor's saw for cutting by filling its tray about 2/3 full of water. When the saw is turned on, water needs to be flowing to the blade so that the cutting area receives good cooling and chip clearing.

Wear hearing and eye protection while running the saw. Cut slowly and allow the blade to 'eat' its way through the specimen. Do not force the specimen against the blade; this will always result in a crooked cut!

If the blade is not cutting well, it can be 'sharpened' by cutting a standard red brick, or some sandstone. When cutting is done, check for perpendicularity.

5. **Label the specimen clearly on both sides.**

   Because the label must be seen through the window of the Temperature Chamber, it is important to have a large clear label on both sides.

6. **Bulk the 100mm diameter specimens.**

Preparing a Batch of Three Specimens for Testing

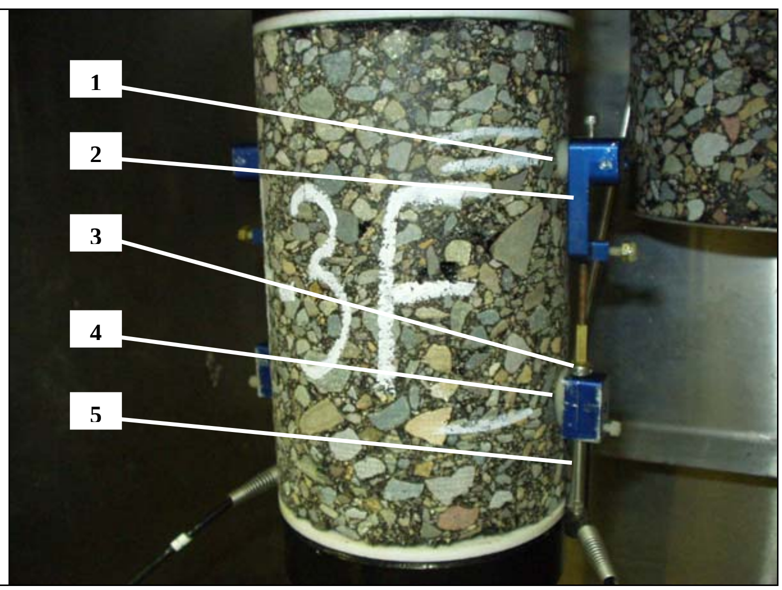
This procedure involves attaching the LVDT hardware onto each of three specimens so deformations can be accurately measured. Each specimen will have two LVDT assemblies attached during testing (See Figure B-4, where there are two LVDT assemblies). Each assembly is attached using '5-minute' epoxy cement, and the hardware pieces are held in alignment during the cure by means of metal spacing plates which provide the proper alignment and spacing.

Each LVDT holder and its target is a matched pair, indicated by a number engraved on it. These must be arranged on the specimen as matched pairs, so the targets do not need to be re-zeroed each time the LVDTs are placed into the holders on the specimen.

Figure B-4: LVDT and Target on Specimen

Key:

1. Target post cemented on with epoxy
2. Target holder fastened onto target post
3. Target for LVDT tip
4. LVDT holder cemented on with epoxy
5. LVDT body



The steps with details are listed below:

1. **Pair up the LVDT holders.**

   Sort the LVDT holders and targets into pairs, and get set up to use #1 and 2 on one specimen, #3 and 4 on another, and #5 and 6 on the third.

2. **Select and mark specimens.**

   Choose three replicate 100mm specimens. On each, mark the four locations for the LVDT gauge points. These points are 70mm apart on the specimen, centered end-to-end, and 180º apart on the circumference.

3. **Cement the holders onto the specimens. (Note: can do three at once)**

   Place a specimen onto the specimen holder with its gauge point marks facing straight upwards. Make sure it is stable and can't roll or move (see Figure B-5).

4. Place an LVDT holder and target post into a spacing plate using stainless steel screws.

5. Squeeze out and thoroughly mix a small amount of epoxy cement. Note: It should be stirred for about one full minute, taking care to mix the entire amount. More stirring is better than less.

6. Apply a suitable amount of epoxy to the round pad of the LVDT holder, and to the round end of the target post. Do not apply so much that it dribbles down.

7. Invert the spacing plate and carefully place it in position onto the specimen. Carefully re-check the position and see that the epoxy forms a nice 'fillet' between each metal post and the specimen surface.

8. Allow the epoxy to cure for at least 45 to 60 minutes; then remove the screws and carefully lift off the spacing plate.

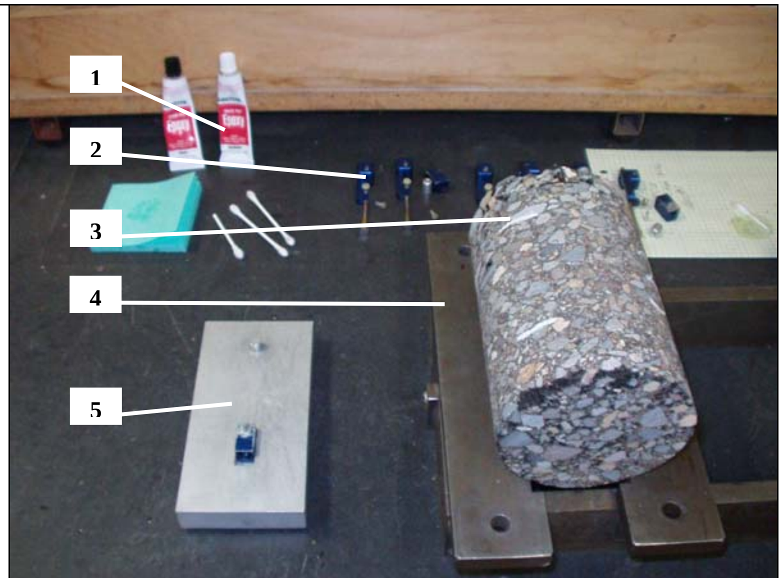
9. Place target holders onto the three specimens. Be sure to match the number of the target holder to the number on the LVDT holder at each position. Also be sure to align the target holders so the targets 'point' at the center of each LVDT holder. Check to see that the nylon setscrew which secures the threaded rod of each target is tightened snugly so the target rod holds its position.

10. Place the prepared specimens upright in a cool place until ready to test them.

Figure B-5: Details of Cementing Gauge Points

Key:

1. Epoxy and stirrers: Post-it notepad and Q-tips cut off
2. Targets to be attached after epoxy sets
3. Specimen with marks
4. Specimen cradle for stability
5. Spacing plate with LVDT holder and target post



Key:

1. Target post, 1 of 6
2. LVDT holder, 1 of 6

Placing Specimens in the Chamber Ready for Testing

The test protocol calls for testing at five temperatures: -10°C, 4.4°C, 21°C, 37.8°C and 54.4°C, starting with the lowest and proceeding to the highest. Starting with the specimens and chamber at room temperature, the cooling to -10°C takes about 5 hours. A convenient method to get the most testing done in a day was to set up the specimens in the chamber at the end of a day, with a timer set to start cooling at 5 hours before the morning starting time for testing. These steps describe this method.

1. **Lower the MTS pedestal and place a specimen on it.**

   WARNING: The MTS test machine is a fast-acting 20,000-lb hydraulic loading device. DO NOT attempt to run it until you have received first-hand training from an

experienced operator! Severe equipment damage and personal injury may result.

Turn on the MTS and lower the load pedestal to its lowest position. (Refer to Appendix E for instructions on running the MTS.) Place a Teflon disk on the pedestal; then place a specimen on the disk, positioned so its LVDT holder is downward. Place another Teflon disk on top of the specimen, and finally place the load cap with its ball on the upper Teflon disk. (See Figure B-6.)

2. **Put the LVDTs on the specimen.**

   Insert the LVDTs into the LVDT holders, LVDT #1 on the left and LVDT #2 on the right. Orient the LVDT wires so they point toward the door of the chamber in such a manner that they will not impose excess pulling force on the LVDTs and specimen. Tighten the LVDT holding screws so they are secure; do not over tighten them.

3. **Bring the specimen into testing position ready for cooling.**

   Carefully center the specimen, Teflon disks and load cap in line with the pedestal. Be sure the LVDTs are not rubbing on the Teflon or on the pedestal. Raise the MTS actuator and load pedestal so the loading ball on top of the load cap is within about ¼-inch (6mm) of the loading socket on the load cell. **Do not allow the ball to touch the socket at this time!** Place the PVC pipe spacer under the actuator to prevent downward drift (See Figure B-6); then turn the MTS hydraulics OFF.

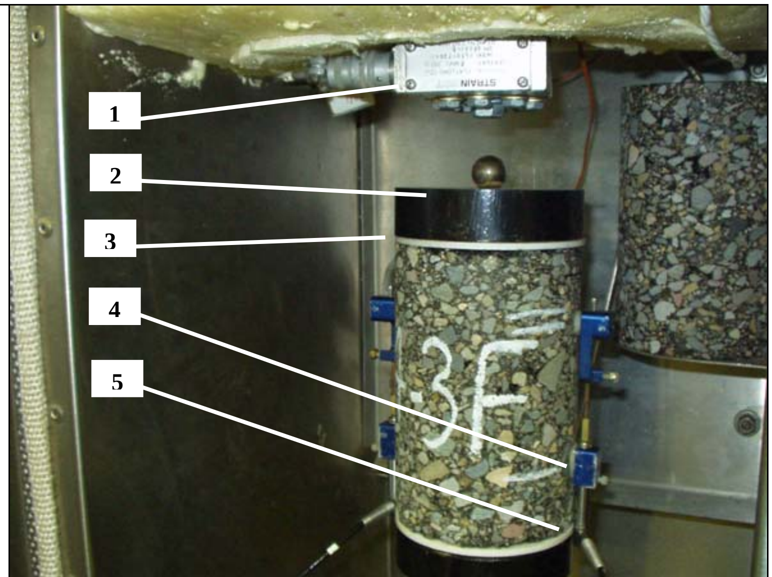
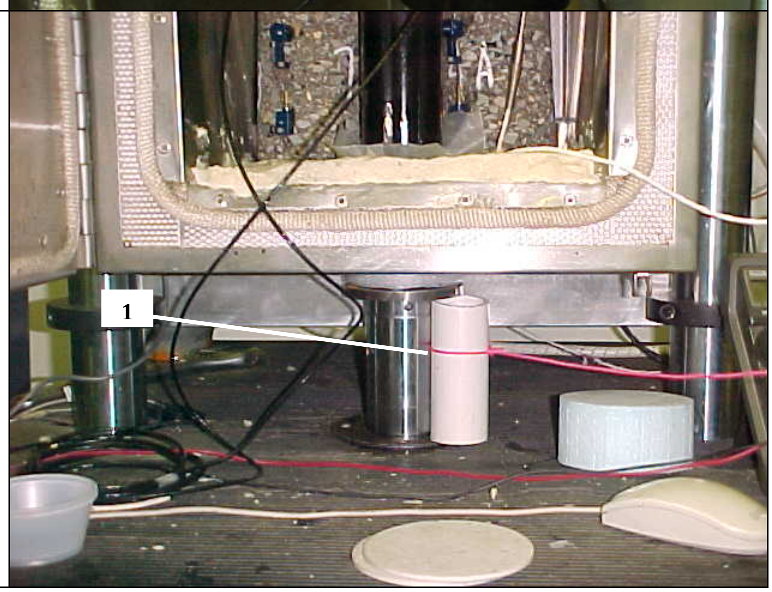
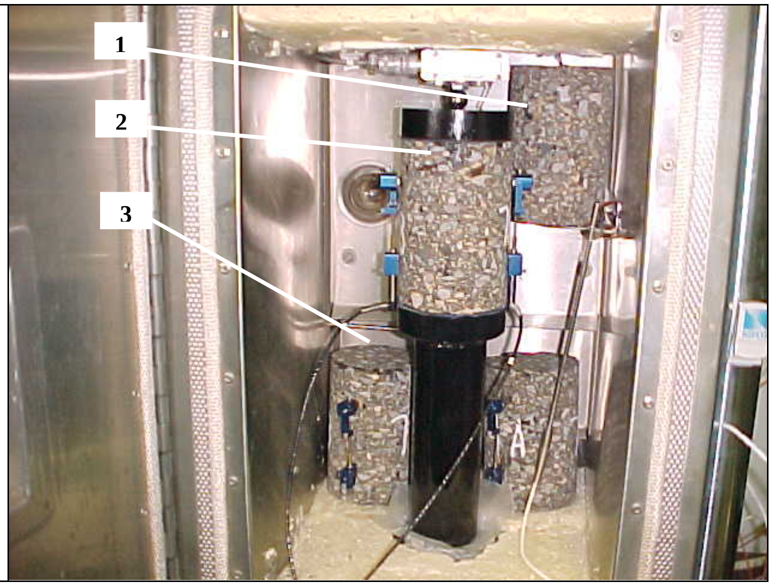
Figure B-6: Specimen Placed onto Load Pedestal with LVDTs Key: 1. Load cell and socket 2. Load cap and ball 3. Teflon disk top and bottom of specimen 4. Insert LVDTs into holders and tighten setscrews 5. Be sure LVDTs do not touch Teflon disk or bottom platen	
Key: 1. PVC pipe piece placed to prevent load ram from drifting down while at rest.	

Figure B-7: Cabinet with 3 Specimens, Ready for Cooling

Key:

1. Dummy specimen for temperature reference
2. Test specimen in place on actuator, with LVDTs ready
3. Specimens on floor or cabinet for temperature conditioning



4. **Finish readying the specimens.**

   Carefully place the other two specimens on the floor of the cabinet. Locate them such that they cannot interfere with the downward stroke of the load pedestal.
   On the first specimen, check the signal from each LVDT on the Signal Conditioner. Adjust the LVDT target rods as necessary to get each LVDT signal at about -8.5 volts. (Refer to Appendix C for instructions on setting up the Signal Conditioner.)

5. **Get the cooling ready.**

   Put a full bottle of CO_2 in place by the MTS and connect it to the gas line from the temperature chamber. Leave the valve on the bottle closed. Leave the door on the chamber open.

Setting Up the Chamber for -10C Cooling

With three specimens in the temperature chamber and one of them in place to be tested, the chamber can now be set for cooling to the first test temperature, -10°C. The automatic timer will be set so cooling starts 5 hours before the morning lab startup time. Here are the steps:

1. **Turn on the power to the chamber controller:**

   On the Automatic Timer, repeatedly press the ON/OFF/AUTO button till the LOCK ON annunciator is displayed; then set the chamber controller so it is ON (small toggle switch on front panel ON, black circuit breaker on rear panel UP), and its lamp is OFF (small toggle switch on rear of chamber controller). The chamber fan should be running now.

2. **Adjust the controller Set Point temperature to -10°C:**

   Set the Digital Temperature Controller as follows:

   a. If ‘SP’ does not show on the lower line of the display, press the DISPLAY button until they do show. This line now shows the intended Set Point.
   b. Press the (UP ARROW) or (DOWN ARROW) buttons as needed to change the Set Point to -10°C.

3. **Check that the chamber is ready for cooling:**

   Open the CO_2 cylinder valve just slightly. If a loud hissing sound is heard, the system is ready for cooling; turn the valve off for now.

4. **Program the Automatic Timer to start cooling at an early enough time:**

   Check that the Automatic Timer will turn the Temperature Chamber ON at about 4 AM the next day. Refer to Appendix D if necessary. (Cooling to -10°C takes 5 hours from 20°C, so a 4 AM cooling start time allows testing to be started at 9 AM.) Then press the ON/OFF/AUTO button on the timer till the AUTO annunciator is displayed. The chamber controller and fan will shut off, and will not re-start till the programmed ON time.

5. **Close the chamber door and OPEN THE CO_2 VALVE.**

   The system is now ‘armed’ and ready to start cooling at the pre-set time.

Testing the Cooled Specimens

When specimens have stabilized at –10°C inside the ATS Environmental Cabinet, they are ready to be tested. Verify the specimen temperatures by reading the Dummy Specimen Temperature Monitor (see Figure B-8).

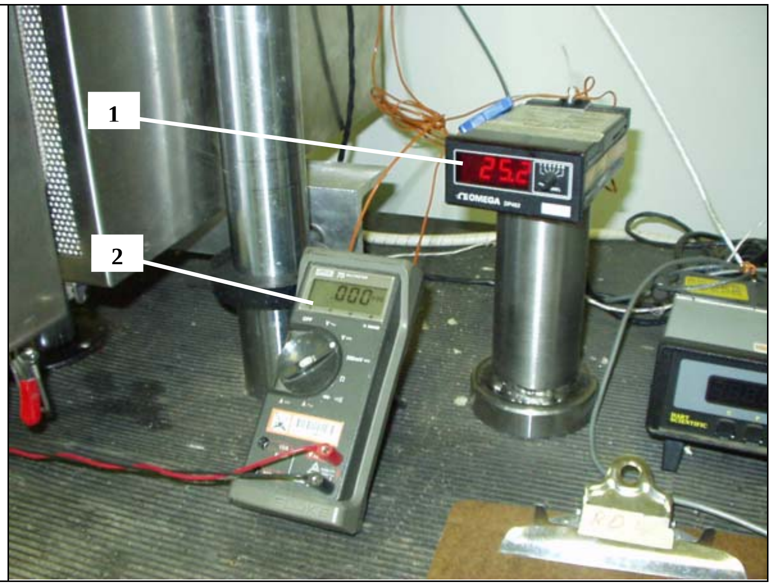


Figure B-8: Meters for Monitoring Temperature and Load Signal

Key:

1. Temperature Monitor for Dummy Specimen.
2. Fluke DVM Load Signal Monitor.

1. **Switch on the MTS electronic console.**

   Turn on the MTS Console (switch at bottom left of panel) so it warms up, but DO NOT start MTS Hydraulic Pressure yet. The console can be left on for extended periods, and reaches best stability after about 30 minutes of warm-up.

2. **Set up and check the ATS data acquisition and control program.**

   The following steps set up and check operation of the ATS software on the host PC. Specifically, you are starting the program, zeroing the load output signal, and taking the following steps:

   a. Turn on the Fluke model 75 DVM (Digital Voltmeter) which is connected to monitor the ATS control signal. Set it to DC Volts (V==). Press the small gray button repeatedly till the display reads to two decimal points (for example, 0.00).

   b. Turn on the data acquisition PC and start Windows by typing “win/s” at the DOS prompt.

   c. Select (double-click) the ATS folder in Program Manager, then select the ATS program icon to start the ATS program.

   d. Select Display, Monitor to show the ATS real-time data. Select Control, ep0 to show the ep0 control box. On the ep0 control box, select Display, Units so the box shows “lb” as the control signal (see Figure B-9).

   e. Use the mouse cursor to move the box slider down to the lowest (minimum) position. This should show about -30.0 lb in the ep0 window. As you do this, notice that the DVM voltage changes from about –5 volts to 0.00v when the slider is moved to its minimum position. This sets the load command signal to its lowest value, a seating load of about 30lb.

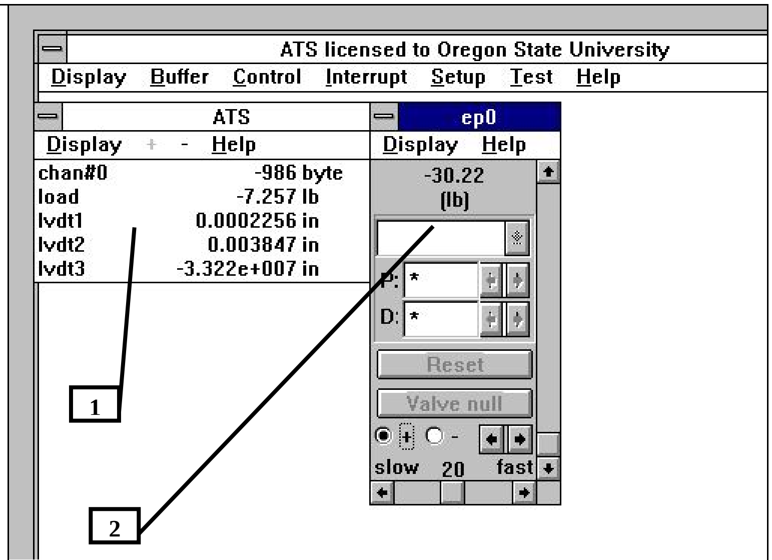


Figure B-9: Setting up the ATS Software

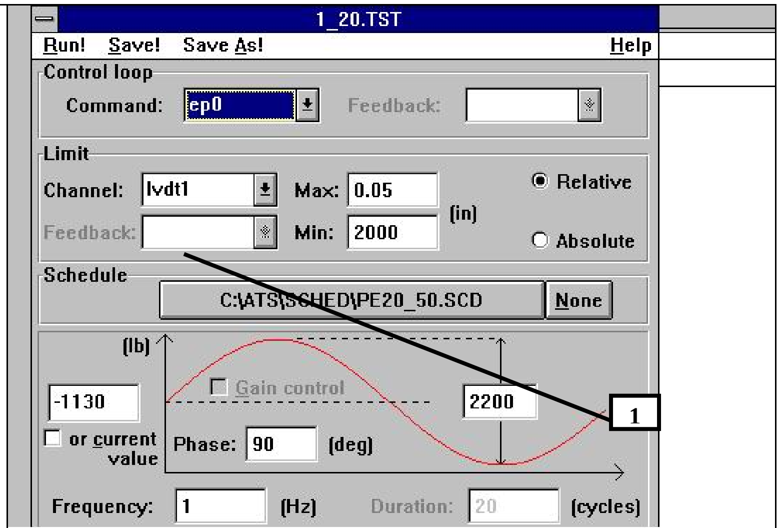
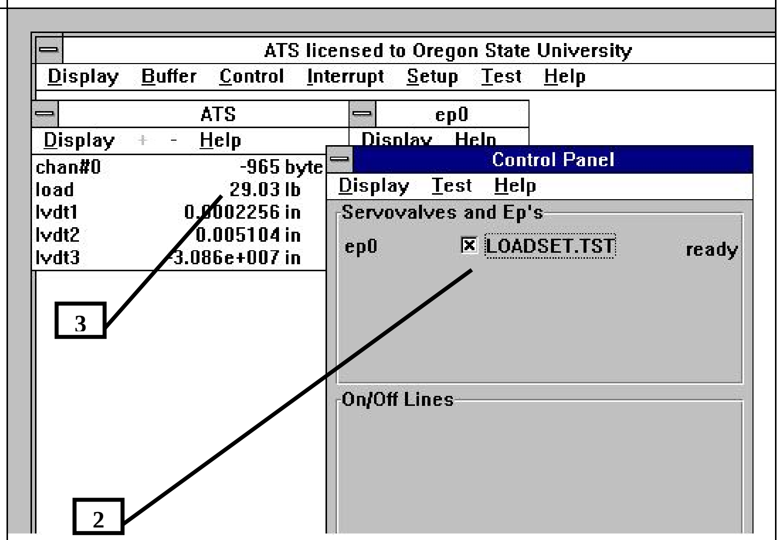
1. Box for monitoring real-time Load and LVDT signals, Select 'Display, Monitor' in the ATS OSU Window.
2. Box for controlling and monitoring the static load. Select 'Control, ep0' from the ATS OSU window. (Note that the Load slider has been set to minimum, and 'lb' has been selected as the displayed units.)

f. In the ATS window, select Test, Edit; then select 1_20.tst. The window that appears should show a full-magnitude (2200-lb) sine wave of load, frequency 1-Hz and duration 20 cycles. The Schedule portion of this window should show C:\ATS\SCHED\PE20_50.SCD (see Figure B-10, upper box.)

g. Select Run!; then enter a filename, OK; then select ab_cyl.spc, OK. Then select (highlight) "load, LVDT1 and LVDT2" in the Record Channels box, then click OK. When the control panel window appears, click the box for 1_20.TST, then click Test, Start. The ATS program will now put out a sine wave command signal to the MTS.

h. Observe the display of Fluke DVM, especially the zero-to-30-unit bar-graph at the bottom, and note that a varying signal is being shown on the bar graph at the bottom of the DVM display. Observe that the signal varies from zero to about 10 volts, the full span of the command signal to the MTS. The test continues for 20 seconds.

i. When the test is finished, the little box in the Control Panel will be grayed out, and data will be then written to the proper directory in the ATS directory structure. Close the Control Panel box. Observe that the ep0 control box has come to rest showing its minimum (approximately -30 lb). This concludes the pre-testing check of the AST software.

Figure B-10: Screenshots of Pre-Testing ATS software (upper box), and the Loadset testing (lower box). Key: 1. Use the ‘**1_20.TST**’ to test out the ATS program without the hydraulics on.…then if all is well, you can…	
2. Set the specimen loading level using the LOADSET.TST test file. 3. Be sure to check and adjust the seating load just before each test.. The Seating Load should be about 5% of the peak testing load.	

3. **Apply active seating load to the specimen.**

WARNING: The MTS test machine is a fast-acting 20,000-LB hydraulic loading device. DO NOT attempt to run it until you have received first-hand training from an experienced operator! Severe equipment damage and personal injury may result.

Using the procedure in Appendix E (‘Setting Up and Operating the MTS Testing Machine for Load Control’), turn on the MTS hydraulic pump and set the specimen load to the proper value for the current temperature.

(Note: If the current temperature is -10°C, the proper seating load is about 35 lb. If at a higher temperature, see the **Dynamic Modulus Test Record** form for other required values of seating load.)

4. **Set up the LOADSET waveform so you can set the strain.**

   In the ATS Window on the PC, select Test, Run; then select loadset.tst, OK. Accept the File Name loadset.ats in the 'Save test data as' window, OK. Then select ab_cyl.spcc in the Select specimen window, OK. Verify that load, LVDT1 and LVDT2 are highlighted in the Record channels window, OK. Click the box for 'LOADSET.TST' in the Control Panel window. This test is now ready to run and record data.

   Again verify that the MTS seating load is at the desired level, you may need to move the Control Panel box. The seating load should be checked and adjusted just before each test. (See Figure B-10, lower box.)

5. **Increase the strain to the proper level.**

   With one hand ready to turn the MTS SPAN1 control up from zero, start the ATS conditioning waveform (select Test, Run in the Control Panel). Then rapidly increase the MTS SPAN1 control carefully until the Oscilloscope waveform spans 4 divisions (4 cm) on its screen. This sets the MTS loading to produce the required strain in the specimen.

   At the end of the test, close the Control Panel box.

6. **Check data to see if the strain was OK.**

   When the test ends, check the results using ATS Report to be sure the desired 100-microstrain level was reached; if not, repeat the LOADSET.TST and adjust SPAN1 to get the desired strain.

   a. In the ATS program group, select and start the Report module.
   b. Choose the menu items Analyze, Edit Template. In the Select data file box, choose the LOADSET.ATS file that was just generated, OK. A box opens 'COL_AB2.TPL' which shows all the items which will be in the report which will be generated. Click OK.
   c. Accept the file name LOADSET.DAT in the Save Results As … box, OK.
   d. Notepad opens with columnar data showing the test results. Immediately inspect the bottom of the fourth column, 'Amp._axial_strain'. Ignore the very last line, but note the values of strain in the last four or five lines above the last line. These are the cycle-by-cycle strains of the specimen for the last SPAN 1 adjustment.
   e. If the strain is satisfactory, you can close this LOADSET.DAT report and proceed with the specimen testing. If the strains are too small or too large, re-do the LOADSET.TST adjustment procedure and set SPAN1 as needed.

7. **Test at all six frequencies. Adjust Seating Load as needed, and SPAN1 as prescribed on the Test Form.**

   Proceed to test the specimen at the six prescribed frequencies: 25, 10, 5, 1, 0.5 and 0.1 Hz. There is a separate ATS '.TST' file for each frequency, and they are loaded and run just like the LOADSET.TST file was run above. The steps are as follows:

   a. Check and adjust the Seating Load for the temperature you are currently testing at. (The seating load should be about 5% of the peak load which caused a 70 to 100 microstrain level.)
   b. Adjust the SPAN1 control downward, if necessary, for the particular frequency of this test. See the Test Form.
   c. In the ATS Window on the PC, select Test, Edit, then select the current test file for the current frequency:
      i. 25 HZ select 25_200.TST
      ii. 10 Hz select 10_200.TST
      iii. 5 HZ select 5_100.TST
      iv. 1 HZ select 1_20.TST
      v. 0.5 Hz select p5_15.TST
      vi. 0.1 Hz select p1_15.TST
   d. Choose default file name for the test; always select ab_cyl.spc, then run each test, but always just prior to the 'Run' command: <u>Again check and adjust the Seating Load.</u>
   e. Check strain results as described above for the LOADSET procedure. If strains are trending low or high, adjust the SPAN1 control slightly for the next test, above or below what is called for in the Test Form SPAN1 schedule. Strains will increase as frequency is lowered, so be sure to lower the SPAN1 control slightly for each lower frequency test so as not to over-strain the specimen.

8. **Remove and replace the specimen.**

   When the last frequency test is finished, lower the MTS actuator about ¼" (6mm) so the specimen can be removed. Place the PVC prop tube under the actuator and turn off the MTS hydraulics.

   NOTE: The following steps - swapping specimens - must be done rapidly to avoid warming the specimens! Note the temperature of the dummy specimen before and after swapping specimens to be sure testing can proceed immediately, or if additional cooling time is needed after the swap is completed.

   a. Shut off the valve on the CO_2 cylinder during the swapping, to save gas.
   b. Open the chamber door and remove the two LVDTs from the test specimen, then swap it with one of the waiting ones, carefully positioning the disk and top cap.

c. Insert the two LVDTs in their holders, being sure they are fully inserted AND neither LVDT body is touching against the Teflon disk or the loading platen. Check the LVDT output voltages on the signal conditioner and adjust as needed so each LVDT is indicating about between -8 and -9 volts.

d. Close the chamber door and TURN ON THE CO_2 TANK VALVE.

9. Re-check the dummy specimen temperature to verify that it hasn't warmed too much; then proceed to test the second specimen at all six frequencies.

10. Repeat the steps above to complete the test on the third specimen.

Saving and Transferring the Data before Testing the Next Specimen

Raw test data generated by the ATS program is placed in the directory **C:\ats\data** on the test PC. Thus, each specimen generates six 'data' files and six 'report' files at one test temperature. In addition, the 'loadset' operation generates a test file and a report file. So in all there will be 14 new files in the **C:\ats\data** directory at completion of testing for each specimen at a given temperature.

These data files must be moved and archived into a unique directory on the hard drive of the testing PC <u>before another specimen is tested</u>. These directory/file structures can then be copied to a 'zip' file for transfer to another PC, by writing to a floppy disk.

The following procedure is used to place (i.e., archive) these 14 new data files into a directory structure which is consistent with the data reduction, which is used later.

1. Assumed: The testing PC is on and booted up. Windows is running.

2. Open the Windows File Manager from the Main program group.

3. Navigate to the C:\ats\data\ directory. Notice that there are six subdirectories: -10, 21, 378, 4, 544, and 'datazips.' Five of these represent the testing temperatures, and the last is for storing zipped data. (See Figure B-11.)

4. In each of the five temperature directories, create new subdirectories which are the names of the three specimens currently being tested.

5. Navigate back to the ATS data directory (**C:\ats\data**) and use File Manager to Move all the new files to the appropriate directory. For instance, if the all six frequency tests have just been completed on specimen 'ABC123' at 37.8°C, then create directory **C:\ats\data\378\ABC123** , and move all 14 files from **C:\ats\data** to this new directory.

6. As each subsequent specimen of the group is tested, move its group of files into the appropriate directory.

When testing is completed on each group of three specimens, data should be ‘zipped’ to a file and transferred to another PC on a floppy diskette. For this, the operator can use ‘WinZip’ or any DOS-based ‘zip’ program, but the option to zip with directory structure intact should be used.

1. Zip the directory/file structure to a zip file on the Testing PC; then check to be sure the zip file is smaller than 1.4MB (one floppy diskette capacity). If it is larger, you will need to split the test files up, to create two smaller zip files.

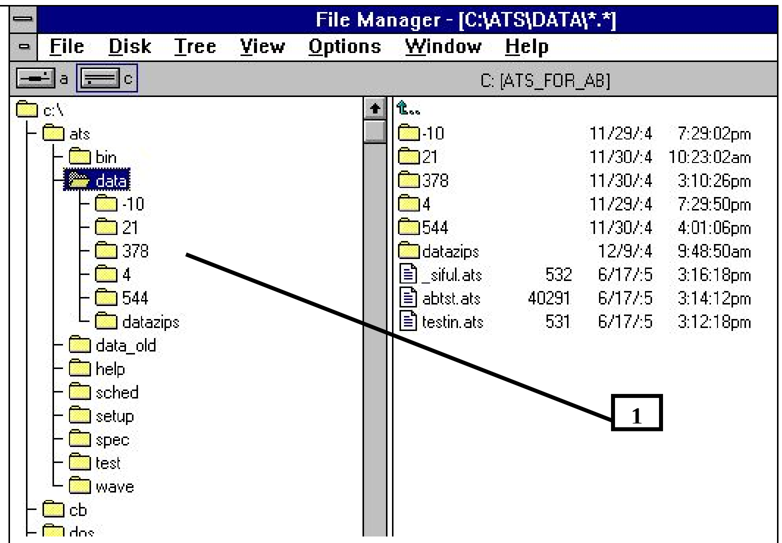
2. Copy the zip file onto a floppy diskette and transfer the data onto a workstation PC for data analysis.

(Note: A DOS program, ‘Xtree Gold’ was found to be most direct for this zip function. See Appendix F: Using the Dos Xtree Gold Program to Zip Files.)

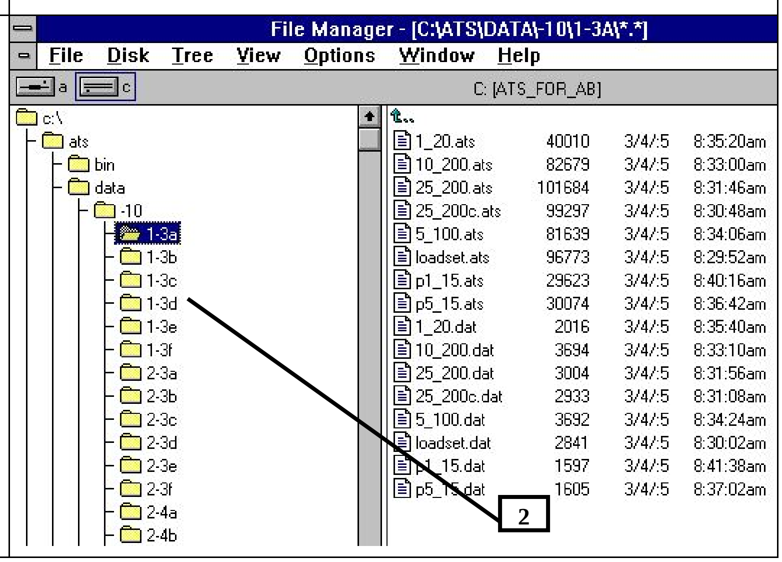
Figure B-11: File and Directory Structure

Key:

1. Test data is stored first by Temperature…



2. Then by Specimen ID within each temperature.



Preparing for Testing at the Next Temperature

After all three specimens have been tested at the current temperature, perform these steps to prepare for testing at the next temperature:

1. **Lock ON the Automatic Timer.**
   Set the Automatic Timer control to 'LOCK ON' so it can't accidentally turn off the temperature controller.

2. **Enter the next Set Point temperature.**
   Adjust the set point on the temperature controller to the next test temperature.

3. **Check LVDTs.**
   Check the LVDT voltages on the test specimen and adjust if needed so they are between -8 and -9 volts.

4. **Allow warm-up; then test.**
   Wait about 2 to 3 hours and check the Dummy Specimen Temperature Monitor. If the Dummy Specimen Temperature is within 0.5 C of the prescribed testing temperature, testing may proceed.

NOTE: About 2 to 3 hours is required for the Dummy Specimen Temperature to stabilize at each temperature step. Be sure the Temperature Chamber interior lamp is off during cooling and warming periods (switch is on rear of Temperature Chamber control box).

APPENDIX C: SYSTEMS AND SETUP PROCEDURES

APPENDIX C: SYSTEMS AND SETUP PROCEDURES

Setting up the Oscilloscope

<u>Description</u>:

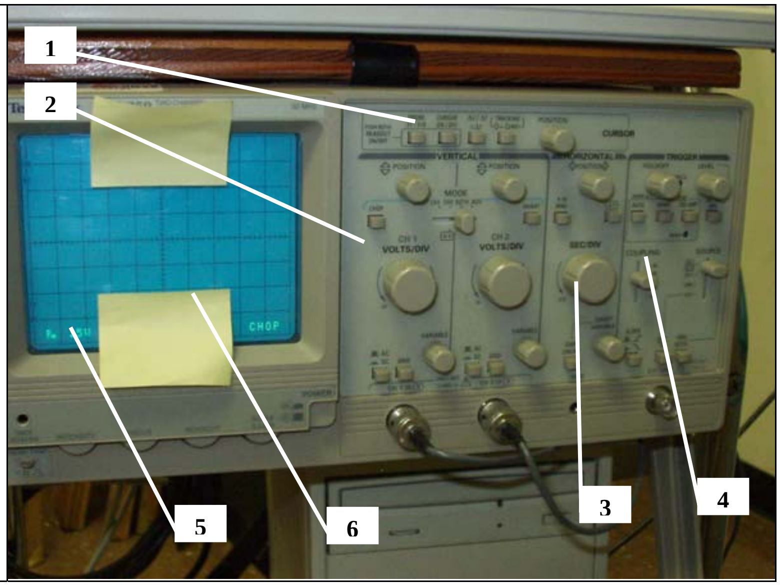
A Tektronix Oscilloscope is used to indicate LVDT displacements, and thus strain, in real-time. It is a simple analog (non-storage, non-digital) oscilloscope and is connected to show the outputs from the two LVDT amplifiers.

The Tek scope controls must be set as described here in order to view the traces as needed. However, once set up, no further adjustment is needed except to the SEC/DIV control for sweep speed.

Figure C-1: Tektronix Oscilloscope Settings

Key:

1. Cursor control area
2. Vertical control area
3. Horizontal control area and SEC/DIV control knob
4. Trigger control area
5. On-screen prompts
6. Post-It notes forming 4-cm vertical window



<u>Setup and Operation</u>:

Turn the scope ON and adjust the control knobs at the bottom of the screen for a clear trace, not too bright. Set the other controls as follows:

1. CURSOR control area:
   a. PROBE X1/X10: Press until P_{10} shows in lower left corner of the display.
   b. CURSOR ON/OFF: Press until no dotted lines show on screen.
   c. Other buttons and knob do not matter for this application.
2. VERTICAL control area:
   a. Adjust each POSITION knob so both traces are centered vertically on the scope face, with just a little space between them.
   b. MODE: BOTH; CHOP button in; INVERT button out.

c. VOLTS/DIV knobs: set both CH1 and CH2 so each reads 0.5V on bottom of the display.

d. VARIABLE knobs: set both fully clockwise.

e. AC/DC and GND buttons: set all four OUT.

3. HORIZONTAL control area:
   a. HORIZONTAL POSITION: so trace is centered on screen horizontally.
   b. X10 and X-Y buttons both OUT
   c. SEC/DIV set so 50 ms shows on bottom of the display.
   d. SWP UNCAL button OUT.
4. TRIGGER control area:
   a. HOLDOFF knob: fully counterclockwise to NORMAL.
   b. LEVEL knob: set so dot is straight up.
   c. MODE: AUTO.
   d. COUPLING: HF REJECT
   e. SOURCE: XY
   f. SLOPE, EXT/10 and TRIG BOTH: all these should be OUT
5. On-screen prompts- These should appear at bottom of the oscilloscope screen:

P_{10} .5V P_{10} .5V 50ms CHOP

The Instrumentation and Data Acquisition System and Listing of Equipment

Description:

Data Acquisition and Control for the testing are achieved using a PC with a Windows operating system. The software is ATS version 2.5 which runs under Windows 3.11 in ‘standard’ mode. The ATS software is configured to run with a Metrabyte DAS-16 data acquisition card. Following is description of how this system is used to perform a test at one frequency:

1. The MTS has been set to ‘Load Control’ mode, that is, Load is the controlled variable. With MTS hydraulics running, the operator sets an appropriate ‘seating’ load for the specimen using the MTS ‘Set Point’ control. This is the static or quiescent load seen by the specimen. The operator then selects and starts the appropriate test file within the ATS software.
2. The ATS software generates a sine wave load signal of appropriate frequency and full 10-volt amplitude. The sine wave signal will continue for exactly the prescribed number of cycles. This voltage signal is delivered to the MTS and applied to the Span control, which has been set so the amplitude of load follows it faithfully using a closed-loop feedback system to control its hydraulics. This Span (time-varying) signal is added to the Set Point (steady) signal and the resulting summation is called the ‘Command’ signal It represents the desired total load to be applied to the specimen.
3. The MTS servo controlled hydraulic system faithfully converts the Command signal into a time-varying sinusoidal load on the specimen. The resulting load and displacements are sensed by the load cell and a pair of LVDTs, respectively.
4. Signals from these sensors are amplified and sent to the PC, where they are digitized and recorded by a suitable A to D (analog to digital) card, and the ATS software. At the end of each test frequency, the operator re-checks the seating load and the test results, then proceeds to the next frequency.

Setup and Operation:

1. It is assumed that the PC is ready with the following items already set up:
    a. Windows 3.11 operating system and ATS software installed.
    b. DAS-16 A to D card installed and functional.
    c. UPS power supply present and powering the PC, Signal Conditioner, oscilloscope, and monitor.
2. The PC and Signal Conditioner can be left on for long periods of time; however it is recommended that the oscilloscope and the monitor be turned off to prevent ‘burn’ of their screens.
3. When starting the PC and Windows 3.11, use the DOS command ‘win/s’ in order to start Windows in ‘standard’ mode. This is required for the ATS software to run.
4. Signal Conditioner has sensors attached to the appropriate channels:
    d. Load Cell to channel # 1, gain set to Range 3.

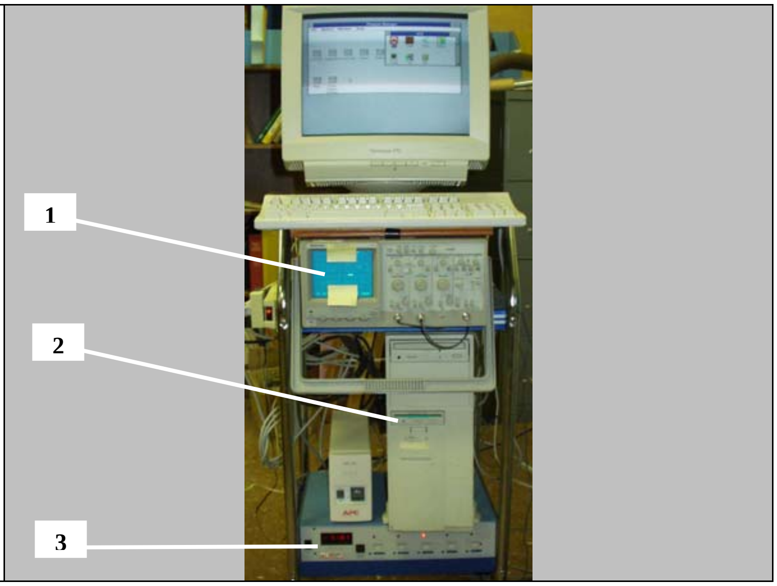
   e. LVDTs to channels # 2 and 3, gains set to Range 5.

5. Keep the LVDT #1 at the left side of the specimen and #2 on the right side, so that when adjustments are needed, little time is lost in getting the appropriate channel displayed on the signal conditioner.

Figure C-2: Signal Conditioning and Data Acquisition

Key:

1. Oscilloscope
2. PC and UPS
3. Signal Conditioner amplifier



6. The oscilloscope can be set up using the settings in Appendix C.

The PC and Signal Conditioner can be left on for long periods of time, however it is best to turn off the oscilloscope to avoid 'burning' the trace into the screen. TURN OFF the oscilloscope between temperature runs.

Listing of Equipment

Equipment listing			
Item	**Make**	**Model**	**Serial no**
PC	Dell	Dimension P90	OSU 311225
Signal Conditioner	P. Gross	SC5-A	890522
Load cell	Strainsert	FL5U2SGKT	Q7556-1
LVDTs	Lucas/Schaevitz	LBB-315-PA-020	None
Data Acquisition card	Metrabyte	DAS16	===
Loading machine	MTS	Series 812	Various (many)
Chamber	ATS	Series 3710	D89 1143 7/89
Chamber Control Unit	ATS	Series 2010	891143-7-89
Oscilloscope	Tektronix	TAS 250	TW10215
Uninterruptible P.S.	APC	Back-Ups 400	PB9732841934
Cutoff Saw	Felker Dresser		
Coring Drill rig	Pass Industries	Job # 313-01	
Coring bit	Asphalt Specialties	AR4.25 C-8	Ordered from Kor-it, 888-727-4560 www.kor-it.com
Thermometer	Omega	DP462	900 400 73
Digital Voltmeter	Fluke	75	47600740

APPENDIX D: THE ATS CONTROLLED-TEMPERATURE CHAMBER

APPENDIX D: THE ATS CONTROLLED-TEMPERATURE CHAMBER

Description: The ATS Controlled-Temperature Chamber is an optional accessory for the MTS testing machine. It is attached to the uprights of the load frame so the load cell and the actuator extend through ports in the top and bottom.

A separate cabinet houses the control items. It contains a circuit breaker, switches, and a digital temperature controller for the chamber. Temperature is sensed by a platinum RTD sensor in the chamber. Tight control of temperature is provided by active heating and cooling. Heat input is provided by resistance heaters and cooling is accomplished using direct injection of liquid CO_2.

Cool-down to the first (-10°C) test temperature takes about 4 hours; so for convenience an Automatic Timer switch was used to turn on the chamber early in the morning, so it would be ready for testing at the start of the workday. Subsequent heatings to the next temperature in the sequence for the TP-9 procedure take about 2 to 3 hours.

Setup and Operation:

1. **Set up the CO_2 cylinder.**

   Position a fresh CO_2 cylinder (siphon-type for cooling) at the left end of the MTS machine and secure it so it cannot fall over. Remove the protective top, and connect the CO_2 hose from the chamber. Be sure there is a standard white plastic gasket inside the connection, and tighten it adequately with a wrench. Leave the cylinder valve OFF at this time.

2. **Turn the chamber and the timer ON.**

   Plug the power cord from the ATS temperature controller box into the Automatic Timer for automatic ON/OFF control. Turn on the power to the chamber controller by repeatedly pressing the timer ON/OFF/AUTO button till the LOCK ON annunciator is displayed; then set the chamber controller so it is ON (small toggle switch on front panel ON, black circuit breaker on rear panel UP), and its lamp is OFF (small toggle switch on rear of chamber controller). The chamber fan should be running now.

Figure D-1: Automatic Timer

Key:

1. Automatic timer plugged into wall outlet
2. Display panel and programming buttons
3. Plug and power cord for ATS Temperature Control box

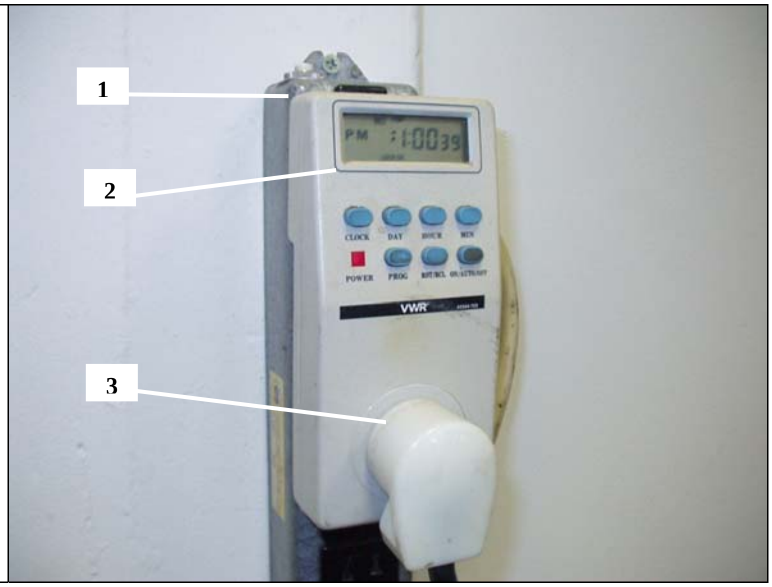
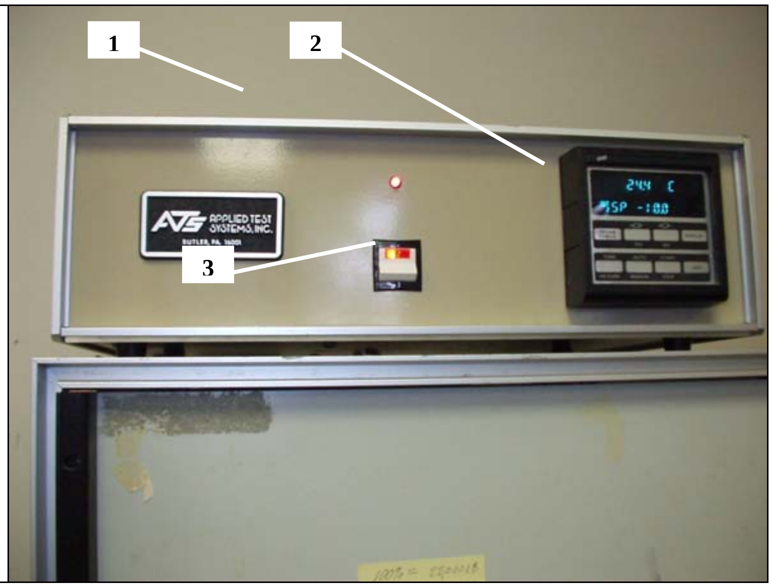


Figure D-2: Temperature Controller for Chamber

Key:

1. On Rear Panel: Circuit Breaker (leave in UP position); Lamp Switch for inside chamber (leave OFF except during adjustment of specimen).
2. Temperature Controller
3. Power Switch



3. **Adjust the Set Point temperature to -10°C.**

   Adjust the controller Set Point temperature to -10°C at the digital control unit as follows:

   a. If 'SP' does not show on the lower line of the display, press the DISPLAY button until they do show. This line now shows the intended Set Point.

   b. Press the (UP ARROW) or (DOWN ARROW) buttons as needed to change the Set Point to -10°C.

4. **Program and set up for automatic start of cooling.**

Note that the timer is a 7-day 24-hour programmable device. It is a good idea to practice by setting an ON time just 10 minutes from present, then wait to see if the cabinet starts up OK. This is how to set the Timer's internal day/time clock, and to set a program:

a. To set the day and time: Press and hold the CLOCK button; then press the DAY button repeatedly until the correct day is displayed. Hour and minute are set the same way.

b. To set a programmed ON time:

    a. Press the PROG button repeatedly. Notice that there are six programs, each with an assigned ON and OFF event. Each ON and OFF event has a day and time assignment. Press the button till the '1 ON' indicator is showing, to set the day and time parameters for this event.

    b. Now press the DAY button repeatedly. The '1 ON' event can be assigned to occur any one weekday, or several combinations of days. Likewise this event can be assigned a time at which to occur.

    c. If today is Tuesday, and you want the chamber to 'wake up' and start cooling early tomorrow morning at 5:30AM, you would set the '1 ON' event to be "Wed" at 5:30AM.

    d. Press the PROG button again, and the '1 OFF' event is ready to be assigned. Now press the RST/RCL button to display '----'; this disables '1 OFF'.

    e. Scroll through all the other programs to be sure none will turn off the chamber at 6:30AM Wednesday!

    f. Press the CLOCK button to display the clock, then press the ON/AUTO/OFF button till the AUTO indicator shows, and the timer is 'armed' to turn on at the programmed time.

c. Verify the following for successful startup of cooling:

    a. CO_2 bottle valve turned ON.

    b. Automatic Timer set to AUTO.

    c. Chamber controller set to ON and correct Set Point temperature

    d. Chamber light switch set to OFF so it won't warm chamber during cooling.

    e. Chamber door shut tight.

APPENDIX E: SETTING UP AND OPERATING THE MTS TESTING MACHINE FOR LOAD CONTROL

APPENDIX E: SETTING UP AND OPERATING THE MTS TESTING MACHINE FOR LOAD CONTROL

Description: The following procedure describes how to set up and run the MTS machine for Complex Modulus testing in Load Controlled mode.

First, all the settings of the control panel must be checked, a procedure which only needs to be done once at the outset of testing. Then starting of the hydraulics and setting of the actuator to the desired position and load are described.

WARNING: The MTS machine is a fast 20,000-LB servo-hydraulic test machine. Improper or careless use can cause severe damage to equipment and personal injury. DO NOT use the machine until you receive personal training from experienced personnel!

Figure E-1: MTS Control Unit Features

Key:

1. 442 Controller.
2. 413 Master Control Panel.
3. Console Power switch.

Checking MTS Settings for Load Control Mode

1. Turn Console Power to ‘ON’ (lower left corner, MTS control cabinet, see Figure E-1). The power can be left on for extended periods (hours and days) with no ill effects. It is recommended to leave the power on (WITHOUT THE HYDRAULIC PUMP RUNNING) during idle periods of the two-to-three-day duration of any Complex Modulus Testing sequence (be sure that the Blue ‘RESET’ button is lit on the 413 Master Control Panel).

2. 442 Controller settings (see Figure E-2):

   a. Press these +/- PERCENT buttons in sequence: STROKE button, the STRAIN button, and finally the LOAD button. You should hear a slight ‘click’ as each is pressed. Be sure the last one you press is the LOAD button. This assures the MTS is in LOAD control mode.

b. Check that the following indicators are lighted under the VARIABLE EXCITATION array (these can be changed inside the front panel of this panel (see Figure E-2):

   i. LOAD: 10%, this sets the MTS loading range to 2,200-lb full-scale (10% of the full 22,000-lb capacity).

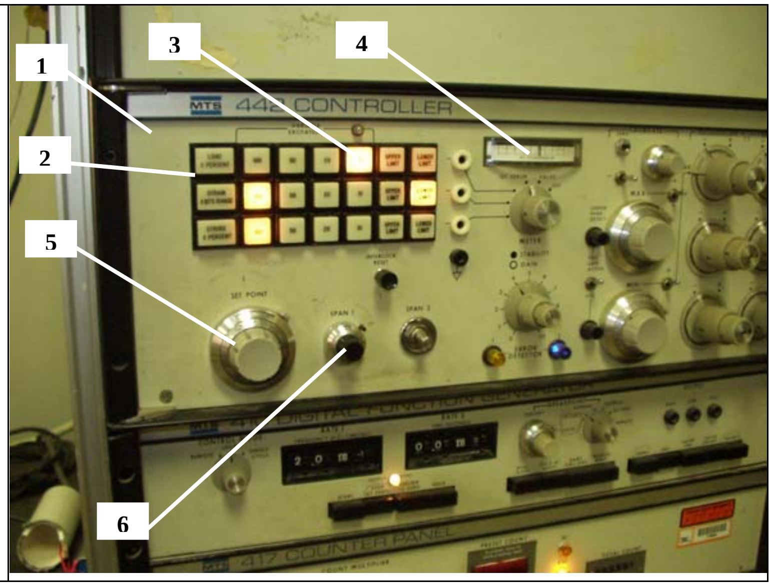
   ii. STRAIN: 100% (does not matter; this channel isn't used).

   iii. STROKE: 100%, this allows full +/- 3-inch actuator motion.

Figure E-2: 442 Controller

Key to Figure :

1. 442 Controller.
2. LOAD, STRAIN and STROKE buttons.
3. Range lamps showing 10%, 100%, and 100%.
4. Meter.
5. SET POINT control (10-turn).
6. SPAN 1 control (10-turn).



c. METER set to 'DC ERROR' and STABILITY and GAIN knobs set to about 4.

d. SET POINT set to 5.0 (this is a 10-turn control, turn it so 5 shows in the little window, 0 on the graduated knob. Span 1 set to 0.0 (again, a 10-turn control, turn it fully counter clockwise).

e. Controls to the right of the panel meter are not used for this testing.

f. Interior control settings (open the 442 front panel door):

   i. Limit Detector LOAD: Upper +10, Lower -10, Intlk

   ii. Limit Detector STROKE: Upper +10, Lower -10, Indicate

   iii. Limit Detector STRAIN: N/A.

   iv. AC Conditioner (STROKE) Range 1, DC Conditioner (LOAD) Range 4.

Turning on Hydraulic Power and Setting the Actuator

1. Press the INTERLOCK RESET button on the 442 CONTROLLER. The UPPER and LOWER LOAD limit buttons should glow dimly. This indicates that the Limit Detector is on and will shut the hydraulics off if the load should exceed about 2,200-lb compression.

2. Check that the "output zero" lamp is lit on the 410 DIGITAL FUNCTION GENERATOR.

3. Press the lighted blue RESET button on the 413 master control panel. It should go out; this indicates that the hydraulic power supply is now 'armed' and can be started.

NOTE: Be sure to watch the MTS actuator loading platen closely during this next step!! If control is lost, press the LARGE RED EMERGENCY STOP button!

4. Place your hand on the SET POINT control. Remember: clockwise makes the actuator go down (tension) and counter-clockwise makes the actuator go up (compression).

5. As you watch the actuator, press the hydraulic pressure button (on the 413 Master control panel) ONCE for LOW hydraulic pressure, then AGAIN for HIGH pressure. The MTS is now active in Load Controlled mode.

6. IMMEDIATELY CONTROL THE POSITION of the actuator and specimen using the SET POINT control, and very slowly and gently raise the specimen into contact with the load cell to apply the desired seating load.

7. Monitor the seating load for 10 to 30 seconds, especially if the MTS hydraulics haven't been run for a while (thus are starting from cold).

8. You are now ready to start a test.

9. To turn off the hydraulics, turn the SET POINT control clockwise slightly so the actuator withdraws (lowers) the specimen from the load cell; then press the HYDRAULIC OFF button.

This completes the setup procedure and manual actuator control for the MTS machine.

APPENDIX F: USING THE DOS XTREE GOLD PROGRAM TO ZIP FILES

APPENDIX F: USING THE DOS XTREE GOLD PROGRAM TO ZIP FILES

Description: This section describes how to use the XTree Gold DOS file manager (XTG) to zip the data files, maintaining the directory structure. Zipped files can then be transferred from the data acquisition PC to the Workstation PC using a floppy disk.

Note: A keypress is indicated by <key>, for instance <S> means press the “S” key.	
Do this action…	**…the action results in this.**
Boot the PC or Close Windows.	Get a DOS prompt… **C:**
Put an empty diskette in the A: drive.	
XTG <enter>	Starts XTree Gold DOS file program XTG). The highlight should be on C:\ATS\DATA.
< * >	XTG command: Log all files in this dir and all dirs under this. Logs C:\ATS\DATA w/all dirs. (Note: press F1 in Xtree for ‘Help’ window.)
< S >	XTG command: Show all logged files. Screen shows all logged files under C:\ATS\DATA
Verify that the files are sorted by date, newest first.	If not, use <ALT>-<S> to sort by Date, Size, Name, or Extension. Also select Ascending or Descending.
<T> on each file you want to zip.	This XTG command tags a file for batch processing. A diamond shows on each tagged file.
As you tag files, watch the box at lower right to verify that the files selected do not exceed about 6 MB.	WHY? Zipping compresses about 5:1. Floppy only holds 1.4 MB.
<CTRL>-<F5>	XTG command: Zip the Tagged files.
<up arrow>	Shows the XTG History of zip paths, names.
Use <up arrow>, <down arrow> to highlight the desired path name.	
<enter> on selected zip path, name	

Edit name as needed, <enter>	
Verify the Zip settings.	Paths = Full, Encryption = Off, Archive, Size = Smallest
<enter>	Zip process starts.
Select the new zip file using <up arrow>, <down arrow> and <enter> as needed…	
<C>	XTG command: Copy the highlighted file.
A:, <enter>	Copies the selected zip file to the A: floppy disk. Disk must be empty or you'll get an error.
Take the diskette to another PC and copy the zip file onto a fixed drive. Then unzip, it should de-compress the files into the identical directory structure as exists in the testing PC.	

APPENDIX G: FORMS FOR DYNAMIC MODULUS TEST RECORDS

APPENDIX G: FORMS FOR DYNAMIC MODULUS TEST RECORDS

The five pages following this page are the forms to be filled out during testing of one set of three specimens.

Important, please note the following:

- There is one specific form for each of the five testing temperatures, and each form has spaces for data to be entered for each of the three specimens in the batch.

- For each temperature, the recommended MTS Load Range (in % percent) is shown. Thus, when setting up for the next temperature in a test series, ALWAYS check that the MTS is set to the correct Load Range.

- For a given specimen at a given testing temperature, note that the MTS SPAN must be decreased for each new lower frequency (see the column 'Rel. SPAN') in the test sequence.

    (Reason: Because asphalt cement is a visco-elastic material, slower loading cycles at a given level of load bring about larger deformations than do faster loading cycles at the same load. Therefore, slower loading cycles need to be at reduced load to cause the same deformations.)

Dynamic Modulus Test Record for One Temperature Session, Three Specimens

-10.0C Test Temperature

Specimen IDs:				Seating Load:	
Date:		Start time:		MTS (%)	20

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	100%						
5-100	100%						
1-20	93%						
0.5-15	93%						
0.1-15	85%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	100%						
5-100	100%						
1-20	93%						
0.5-15	93%						
0.1-15	85%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	100%						
5-100	100%						
1-20	93%						
0.5-15	93%						
0.1-15	85%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Dynamic Modulus Test Record for One Temperature Session, Three Specimens

4.4C Test Temperature

Specimen IDs:				Seating Load:	
Date:		Start time:		MTS (%)	20

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	100%						
5-100	84%						
1-20	84%						
0.5-15	73%						
0.1-15	62%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	100%						
5-100	84%						
1-20	84%						
0.5-15	73%						
0.1-15	62%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	100%						
5-100	84%						
1-20	84%						
0.5-15	73%						
0.1-15	62%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Dynamic Modulus Test Record for One Temperature Session, Three Specimens

21.1C Test Temperature

Specimen IDs:				Seating Load:	
Date:		Start time:		MTS (%)	20

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	100%						
5-100	66%						
1-20	50%						
0.5-15	33%						
0.1-15	27%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	100%						
5-100	66%						
1-20	50%						
0.5-15	33%						
0.1-15	27%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	100%						
5-100	66%						
1-20	50%						
0.5-15	33%						
0.1-15	27%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Dynamic Modulus Test Record for One Temperature Session, Three Specimens

37.8C Test Temperature

Specimen IDs:				Seating Load:	
Date:		Start time:		MTS (%)	10

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	76%						
5-100	56%						
1-20	33%						
0.5-15	18%						
0.1-15	11%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	76%						
5-100	56%						
1-20	33%						
0.5-15	18%						
0.1-15	11%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	76%						
5-100	56%						
1-20	33%						
0.5-15	18%						
0.1-15	11%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Dynamic Modulus Test Record for One Temperature Session, Three Specimens

54.4C Test Temperature

Specimen IDs:				Seating Load:	
Date:		Start time:		MTS (%)	10

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	70%						
5-100	50%						
1-20	25%						
0.5-15	11%						
0.1-15	0.02%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	70%						
5-100	50%						
1-20	25%						
0.5-15	11%						
0.1-15	0.02%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	

Spec ID:		**Time:**		**T(dummy):**		**T(Hart):**	
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	
f_cycles	Rel. SP	MTS SP	Strain				
25_200C	100%						
25_200	100%						
10-200	70%						
5-100	50%						
1-20	25%						
0.5-15	11%						
0.1-15	0.02%						
LVDT1(in):		LVDT2(in):		LVDT1(V):		LVDT2(V):	