Evaluation of Resilient Modulus and Structural Layer Coefficient of NovaChip Ultrathin Bonded Wearing Course

Prepared for:

Koch Pavement Solutions
Terre Haute, Indiana

Prepared By:
Maghsoud Tahmoressi, P.E.
and
Timothy Chow,E.I.T.

PaveTex Engineering & Testing, Inc

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Authorization:

PaveTex Engineering and Testing, Inc. was authorized by Mr. Marvin Exline of Koch Pavement Solutions to perform Resilient Modulus testing on laboratory prepared NovaChip specimens and determine structural layer coefficient of this material.

Scope:

The scope of this work was limited to conducting Indirect Tensile Resilient Modulus Test at three different testing temperatures and analyzing the test results to evaluate characteristics of NovaChip under dynamic tensile loading. In addition structural layer coefficient of NovaChip was to be determined from resilient modulus results at 68 degrees Fahrenheit.

Research Approach:

Test specimens utilized in this study were prepared by Koch Pavement Solutions laboratory in Terra Haute, Indiana and shipped to PaveTex laboratory in Dripping Springs for Resilient Modulus testing. The methodology outlined in the 1986 AASHTO Guide For Design of Pavements was utilized to estimate Structural Layer Coefficient from Resilient Modulus data obtained at 68 Degrees Fahrenheit. In addition to conducting resilient modulus test at 68 F for the purpose of determining Structural Layer Coefficient, resilient modulus was determined at 39 F and 104 F in order to determine temperature susceptibility of NovaChip mixtures. Two different aggregate mixtures and three different binder grades were utilized in the study. Each mixture was tested at three different binder contents in order to determine effects of binder content on resilient modulus and layer coefficient. Experimental Design is shown in Table 1.

Resilient Modulus Test:

Indirect Tensile Resilient Modulus Test was conducted in accordance with ASTM test method D4123, " Indirect Tensile Test for Resilient Modulus of Bituminous Mixtures ". This test is conducted by applying a compressive load with a haversine waveform. The load is applied vertically in the vertical diametral plane of a cylindrical specimen of asphalt concrete as shown in Figure 1. The resulting horizontal deformation of the specimen is measured and, with an assumed Poisson's ratio, is used to calculate a resilient modulus. A typical deformation output is shown in Figure 2. Interpretation of the deformation data shown in Figure 2 can yield two resilient modulus values. The instantaneous resilient modulus (Eri) is calculated using the recoverable deformation that occurs instantly during the unloading portion of one load cycle. The total resilient modulus (Ert) is calculated using the total recoverable deformation which includes both the instantaneous recoverable and the time dependant recoverable deformation during the unloading and the rest-period of one load cycle. The test is typically performed over a range of temperatures and loading frequencies in order to determine temperature and load duration sensitivity of the bituminous mixtures.

Determination of Layer Coefficient:

The 1986 AASHTO Pavement Design Guide contains a methodology for determining layer coefficient of bituminous mixtures based of resilient modulus results at 68 Degrees Fahrenheit. The chart for estimating layer coefficient based on resilient modulus (Eri) is shown in Figure 3. There are some limitations in using this chart for determination of layer coefficient. The data used in developing the chart is from dense graded mixes and at the time this chart was developed majority of dense graded mixtures were made using AC-10 and AC-20 This method, however, is currently the only recognized method for estimating load carrying capacity of bituminous mixtures.

Materials:

Test specimens consisted of 4 inches diameter by 2.5 inches tall specimens compacted in a Superpave Gyratory compactor. Two different NovaChips mixtures proposed for use in two Texas Department of Transportation projects were utilized for this study. These mixtures are identified as San Antonio and Dallas mixtures. Combined gradation of each mixture and the asphalt content are presented in Table 2. Koch Pavement Solutions Laboratory in Terra Haute designed both mixtures. Koch mixture design summaries are shown in attachments 1 and 2 for San Antonio and Dallas mixtures, respectively. As shown in Table 2, combined gradations of both mixtures are very similar.

Three different binder grades were utilized with each mixture. These binder grades were PG 64-22, PG 70-28 and PG 76-22. The aggregates utilized in this study were limestone and sandstone for San Antonio and Dallas Mixtures, respectively. NovaChip mixtures in Texas are typically designed using PG 76-22. The purpose of evaluating these mixtures with three different binder grades was to determine influence of binder grade on layer coefficient and resilient modulus of NovaChip. Each mixture was compacted and tested at three different binder contents.

Testing Program:

Resilient modulus is a non-destructive test. Each test specimen was tested at each of the three different test temperatures. Specimens were tested at 39 F and allowed to rest at room temperature for one day then tested at 68 F. After testing at 68 F, specimens were allowed to rest at room temperature for at least one day, and then tested at 104 F. Specimens were placed in an environmental chamber for three hours at test temperature prior to testing. At each test temperature, specimens were tested at testing frequency of 0.33, 0.5 and 1.0 cycles per second. As mentioned previously, determination of layer coefficient from resilient modulus is based on resilient modulus results obtained at 68 F at a frequency of 1.0 cycle per second. The additional test temperatures and frequencies were utilized in order to evaluate the elastic properties NovaChip over a range of loading frequencies and test temperatures.

Discussion of Test Results:

Test results for individual specimens are presented in Tables 3A, 3B, 3C and 4A, 4B, 4C for San Antonio and Dallas mixtures, respectively. As shown in these tables, for each specimen at each testing condition two separate resilient modulus values are measured and reported. These values are identified at **Eri** and **Ert** . Both resilient modulus values (Er) are calculated in accordance with the formula for calculating resilient modulus presented contained in ASTM test method D4123. Eri designates resilient modulus calculated using instantaneous portion of the recovered deformation while Ert is calculated using the total recovered deformation. The difference between total and instantaneous deformation is the amount of permanent deformation, which is retained by the specimen and never recovered. A large differences between Eri and Ert maybe an indicator of propensity of the mixture to rutting. As shown in Tables 3A, B, C and 4A, B, C, the differences between Eri and Ert for NovaChip mixtures utilized in this study appear to be insignificant. Average Eri for each test condition are presented in Tables 3 and 4. Average Eri values are used to calculate layer coefficient.

Relationships between testing frequency and resilient modulus are shown in figures 4 and 5 for San Antonio and Dallas mixtures, respectively. As shown in these figures, testing frequency does not influence resilient modulus of NovaChip mixtures. As expected, test temperature has a significant effect on resilient modulus.

Relationships between binder content and resilient modulus are shown in figures 6 and 7 for San Antonio and Dallas mixtures, respectively. As shown in these figures, neither the binder content nor the binder grade does significantly effect resilient modulus. This lack of dependence on binder content or grade is likely due to the aggregate structure of NovaChip. NovaChip mixtures are designed to have an aggregate skeleton, which yields rock-on-rock contact between the coarse aggregates. Due to this rock-on-rock skeleton, the aggregate skeleton and not the binder carry load. Therefore, within limits of the mixture design, variations in binder content will not influence load carrying capacity of NovaChip. However, as with any other bituminous mixture, extremely low or high binder contents may result in raveling or flushing. Binder grade is also likely to influence raveling or flushing susceptibility.

As mentioned in preceding sections, one of the objectives of this study was to determine structural layer coefficient of NovaChip mixtures. As shown in figure 3, structural layer coefficient is a function of resilient modulus at 68 degrees Fahrenheit. The maximum value of structural layer coefficient shown in figure 3 is approximately 0.45 which corresponds to approximately 500 Ksi resilient modulus. As shown in Tables 3 and 4 and illustrated in figures 6 and 7, resilient modulus of NovaChip mixtures exceeds 500 Ksi at 68 degrees Fahrenheit and 1 cycle per second for all binder grades and binder contents. The lowest calculated layer coefficient is 0.469 (San Antonio mixture at 5% PG 70-28 for 533 Ksi) and the highest calculated layer coefficient is 0.548 (Dallas mixture at 4.5% PG

76-22 for 840 Ksi). Therefore, NovaChip mixtures evaluated in this study may be assigned a layer coefficient of at least 0.45.

Conclusions:

Based on the results obtained in this study and discussed in proceeding sections, the following conclusions are warranted:

1. For all binder grades and binder contents, Structural Layer Coefficient of both NovaChip mixtures evaluated in this study, exceeded the maximum value shown in the figure contained in AASHTO design guide and presented in this report. Therefore, NovaChip mixtures evaluated in this study maybe assigned layer coefficient of at least 0.45. This value exceeds the layer coefficient value of 0.35, which is currently assigned to most hot mix pavement layers by most agencies.
2. There is no practically significant difference between Eri and Ert in the majority of specimens tested in this study. This would indicate low propensity of these mixtures to rutting as evaluated in resilient modulus test. However, resilient modulus test results may not be a good indicator of rutting susceptibility, due to tensile nature of the loads applied in this test.
3. The relationship between Eri and frequency was found to be inconsistent with varying temperatures.
4. In general there is no consistent relationship between binder content and resilient modulus of NovaChip mixtures.
5. Resilient Modulus of NovaChip mixtures is not significantly affected by binder grade.
6. Although binder content and binder grade may not have a significant effect on load carrying capacity as measured by resilient modulus, as with other bituminous mixtures, they may have a significant effect on other mixture properties such as raveling or flushing.

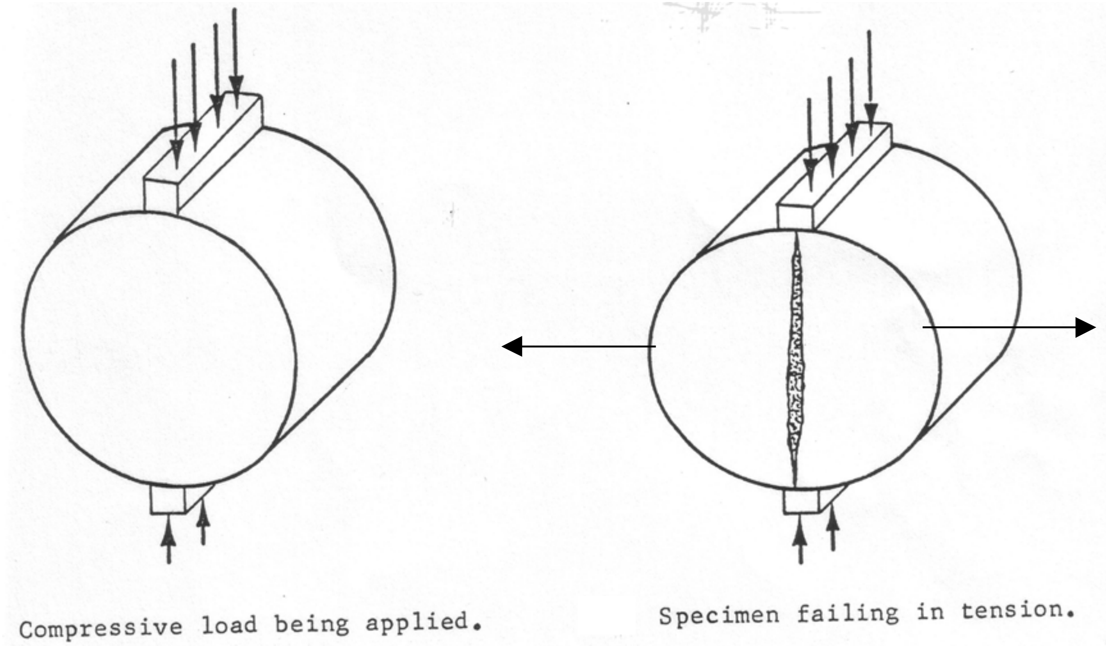


Figure 1. Indirect Tension Test

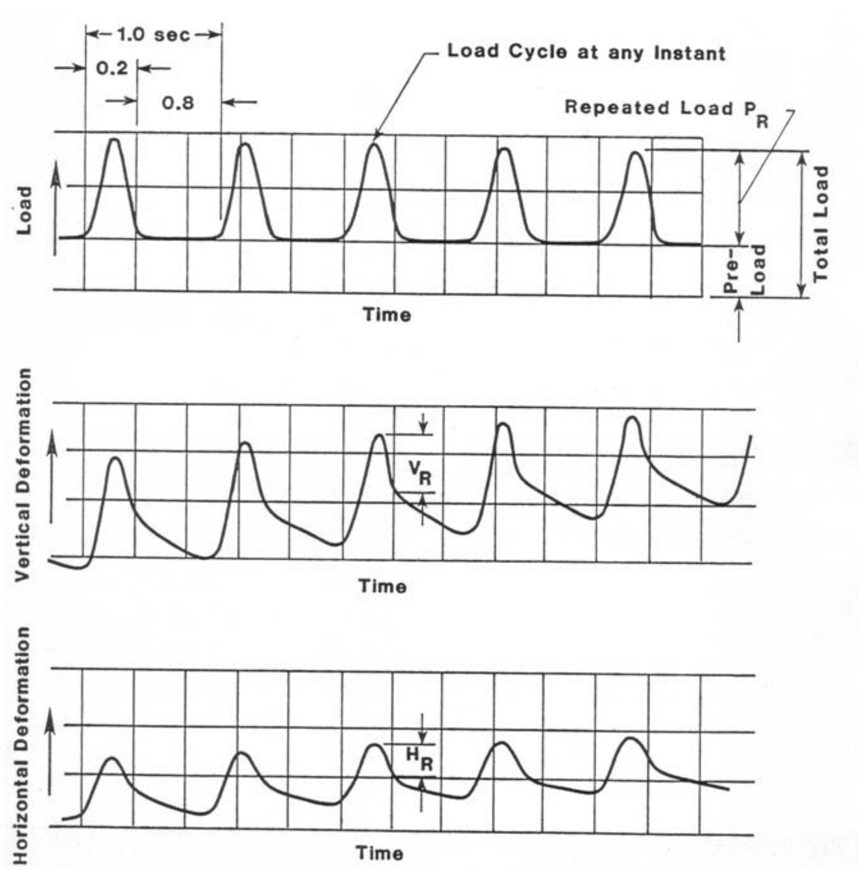
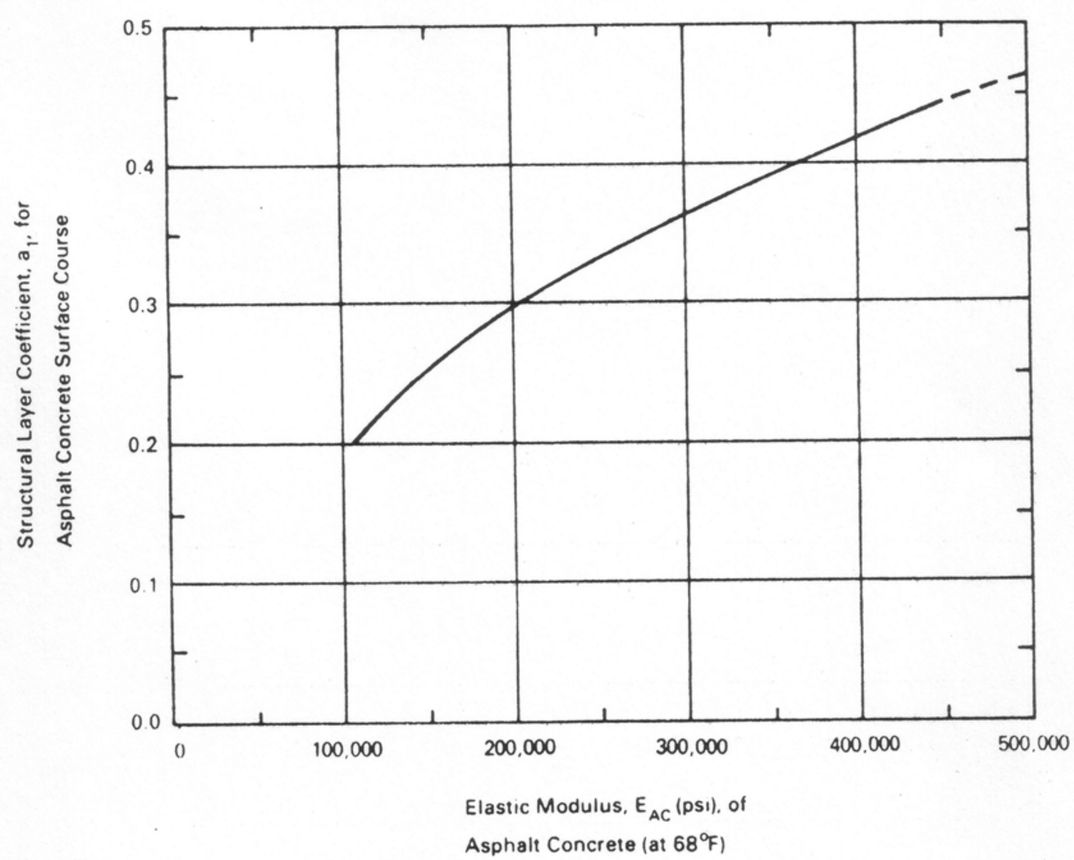


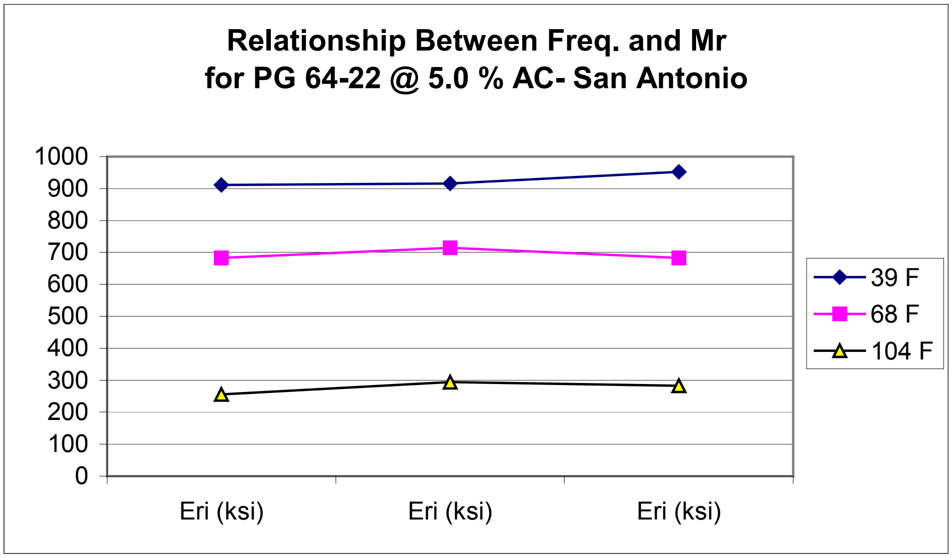
Figure 2. Typical load and deformation plot.

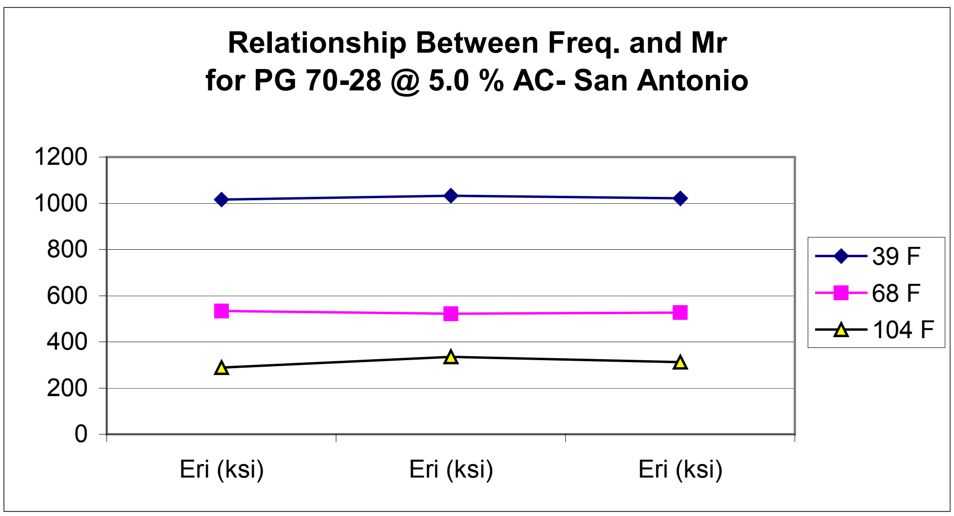
Figure 2. Resilient Modulus Load and Deformation plots

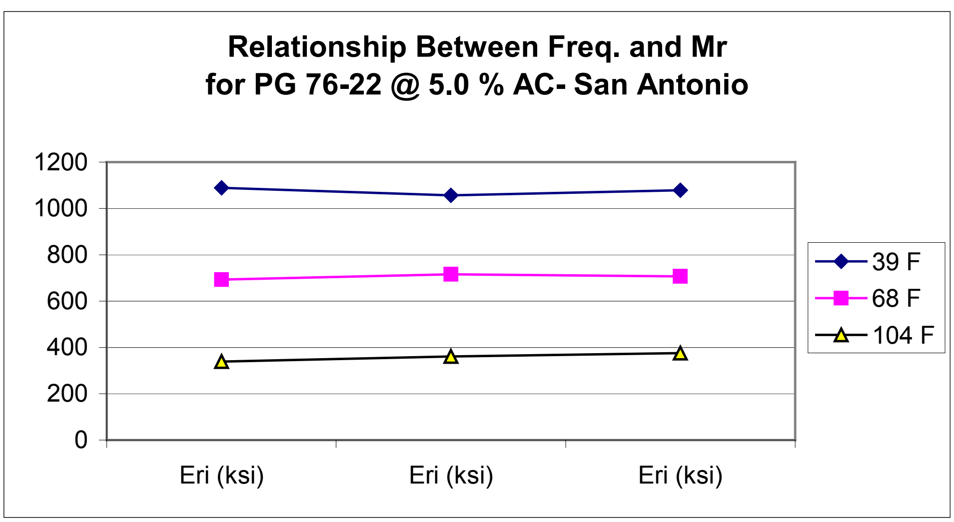


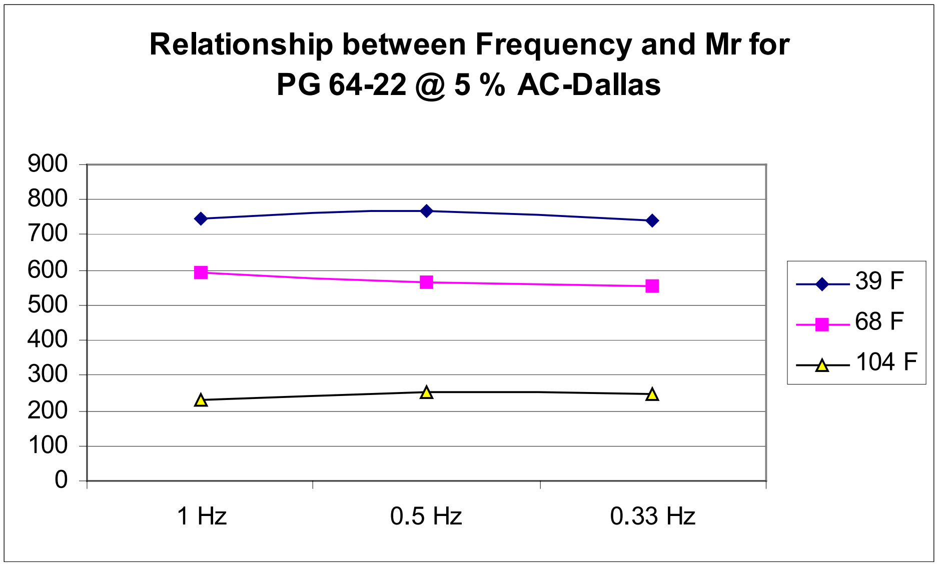
$$a1 = (0.4 \, Log(Mr/450)+0.44)$$

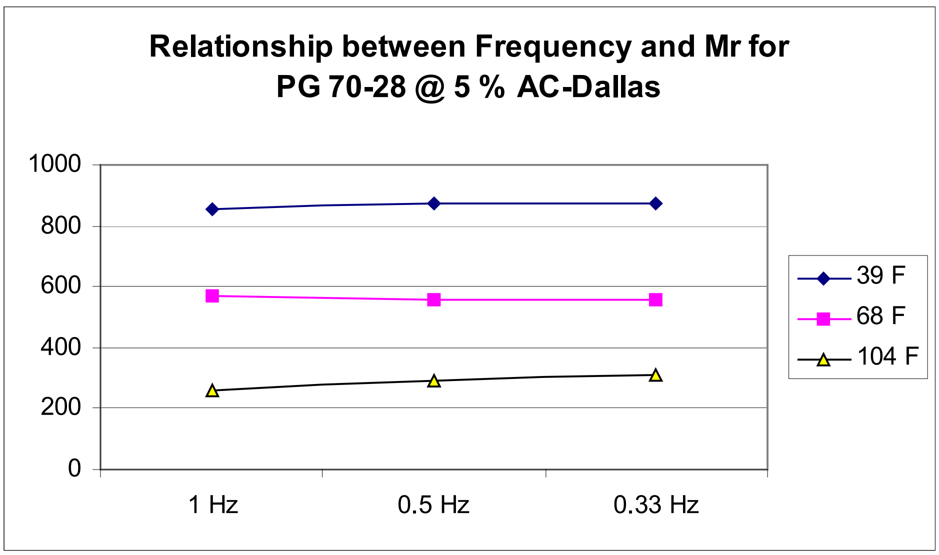
Figure 3. Relationship between Layer Coefficient and resilient modulus (Ref. AASHTO design guide)

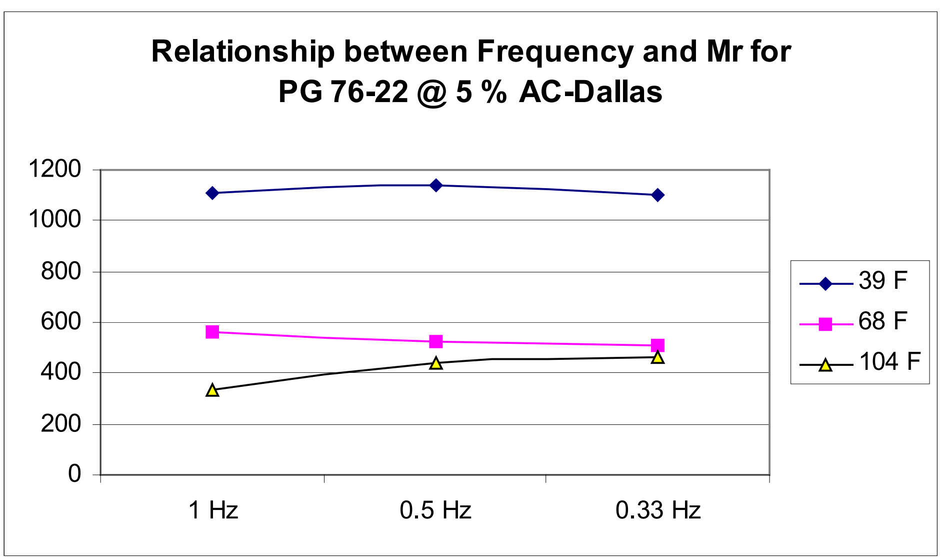

Relationship Between Freq. and Mr
for PG 64-22 @ 5.0 % AC- San Antonio
1000
900
800
700
600
500
400
300
200
100
0
Eri (ksi)
Eri (ksi)
Eri (ksi)
39 F
68 F
104 F

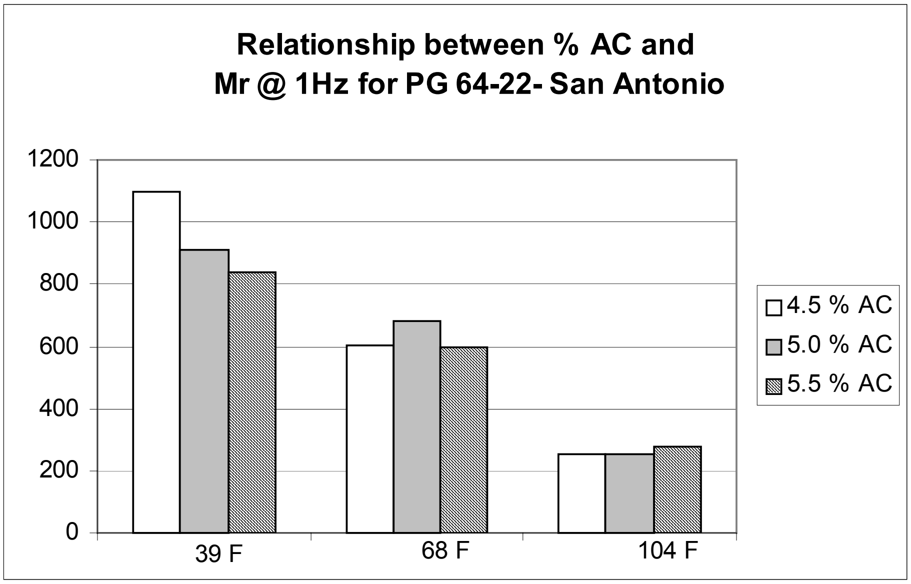

Relationship Between Freq. and Mr
for PG 70-28 @ 5.0 % AC- San Antonio
1200
1000
800
600
400
200
0
Eri (ksi)
Eri (ksi)
Eri (ksi)
39 F
68 F
104 F

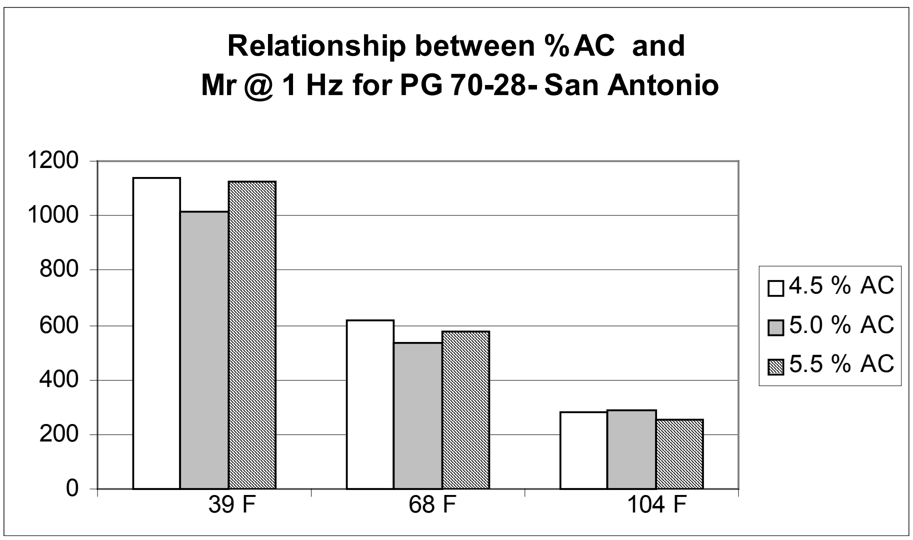

Relationship Between Freq. and Mr
for PG 76-22 @ 5.0 % AC- San Antonio
1200
1000
800
600
400
200
0
Eri (ksi)
Eri (ksi)
Eri (ksi)
39 F
68 F
104 F

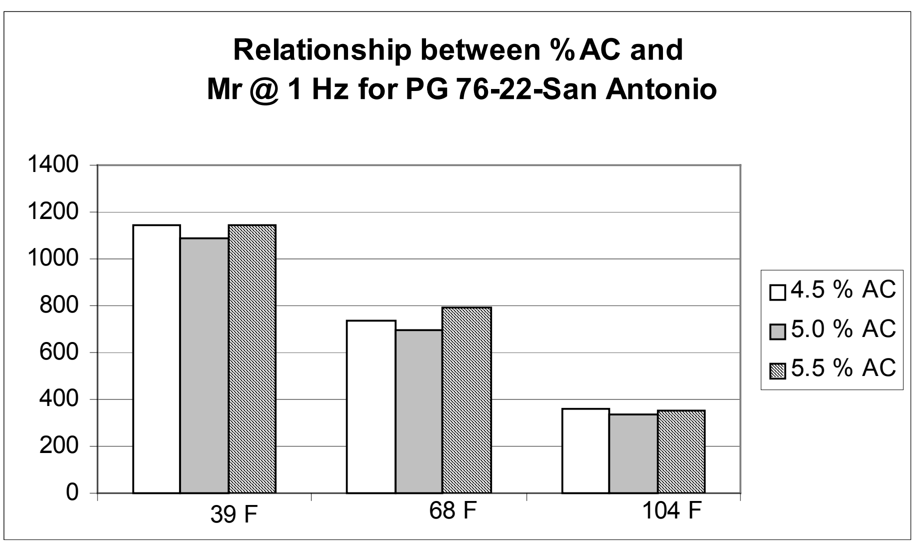

Relationship between Frequency and Mr for
PG 64-22 @ 5 % AC-Dallas
900
800
700
600
500
400
300
200
100
0
1 Hz
0.5 Hz
0.33 Hz
39 F
68 F
104 F

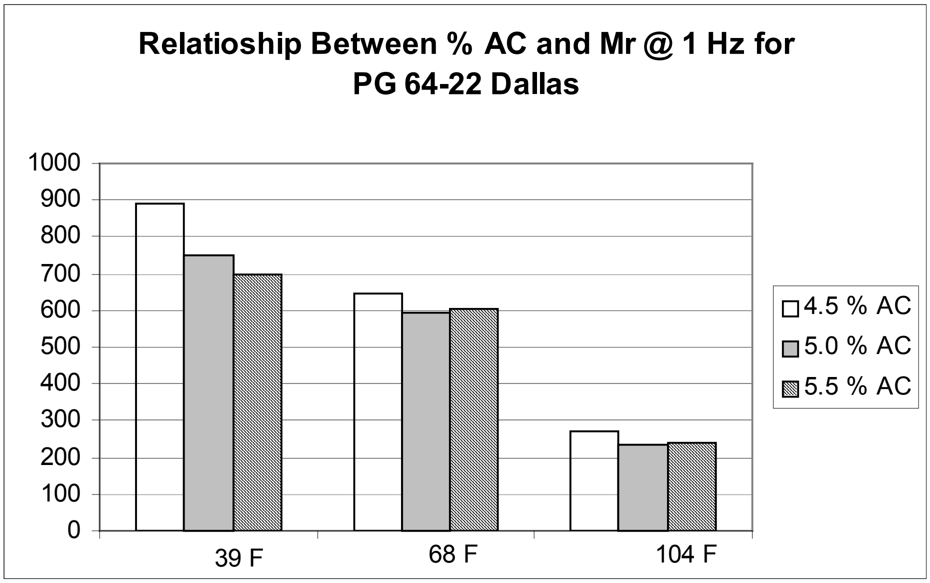

Relationship between Frequency and Mr for
PG 70-28 @ 5 % AC-Dallas
1000
800
600
400
200
0
1 Hz
0.5 Hz
0.33 Hz
39 F
68 F
104 F


Relationship between Frequency and Mr for
PG 76-22 @ 5 % AC-Dallas
1200
1000
800
600
400
200
0
1 Hz
0.5 Hz
0.33 Hz
39 F
68 F
104 F

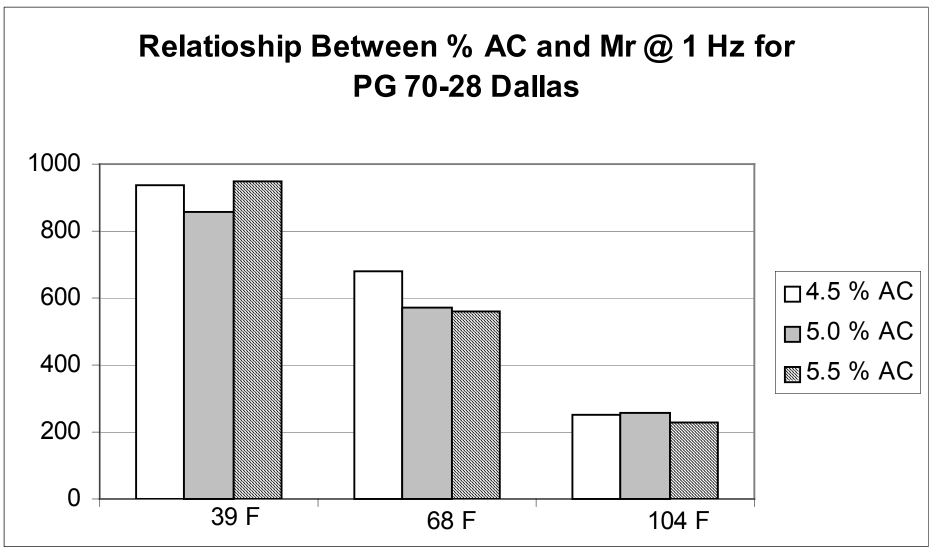

Relationship between % AC and
Mr @ 1Hz for PG 64-22- San Antonio
1200
1000
800
600
400
200
0
39 F
68 F
104 F
4.5 % AC
5.0 % AC
5.5 % AC


Relationship between %AC and
Mr @ 1 Hz for PG 70-28- San Antonio
1200
1000
800
600
400
200
0
39 F
68 F
104 F
4.5 % AC
5.0 % AC
5.5 % AC

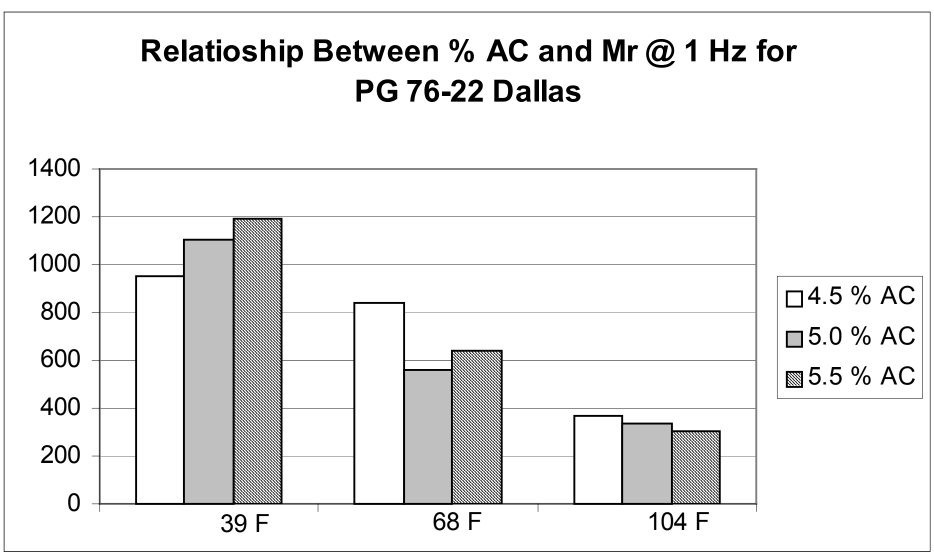

Relationship between %AC and
Mr @ 1 Hz for PG 76-22-San Antonio
1400
1200
1000
800
600
400
200
0
39 F
68 F
104 F
4.5 % AC
5.0 % AC
5.5 % AC



Relatioship Between % AC and Mr @ 1 Hz for
PG 64-22 Dallas
1000
900
800
700
600
500
400
300
200
100
0
39 F
68 F
104 F
4.5 % AC
5.0 % AC
5.5 % AC



Relatioship Between % AC and Mr @ 1 Hz for
PG 70-28 Dallas
1000
800
600
400
200
0
39 F
68 F
104 F
4.5 % AC
5.0 % AC
5.5 % AC



Relatioship Between % AC and Mr @ 1 Hz for
PG 76-22 Dallas
1400
1200
1000
800
600
400
200
0
39 F
68 F
104 F
4.5 % AC
5.0 % AC
5.5 % AC

Table 1. Experimental Design

	San Antonio			Dallas		
Binder Grade	**64-22**	**70-28**	**76-22**	**64-22**	**70-28**	**76-22**
4.5 % Binder	X	X	X	X	X	X
5.0 % Binder	X	X	X	X	X	X
5.5 % Binder	X	X	X	X	X	X

Table 2. Mixture Design Information

Sieve, % Passing	San Antonio	Dallas
1/2 "	90.0	92.0
3/8 "	71.0	65.0
# 4	38.0	35.0
# 8	25.0	25.0
# 16	18.0	19.0
# 30	14.0	15.0
# 50	10.0	12.0
# 100	7.0	9.0
# 200	4.5	4.9
Optimum Binder, %	5.0	5.0

Table 3. Summary of Resilient Modulus Average Values for San Antonio

		39 F			68 F			104 F		
		1 Hz	0.5 Hz	0.33 Hz	1 Hz	0.5 Hz	0.33 Hz	1 Hz	0.5 Hz	0.33 Hz
Binder	% AC	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)
64-22	4.5	1095	1101	1067	601	585	601	252	284	296
	5	911	916	952	682	715	683	256	294	282
	5.5	840	867	810	594	610	594	276	302	314
70-28	4.5	1137	1091	1062	614	657	692	278	335	322
	5	1017	1033	1021	533	521	526	288	336	311
	5.5	1123	1192	1171	578	548	574	252	286	301
76-22	4.5	1144	999	1023	733	778	756	363	385	393
	5	1089	1056	1078	693	717	708	339	361	375
	5.5	1147	1104	1060	794	793	783	351	398	394

Table 4. Summary of Resilient Modulus Average Values for Dallas Mixture

		39 F			68 F			104 F		
		1 Hz	0.5 Hz	0.33 Hz	1 Hz	0.5 Hz	0.33 Hz	1 Hz	0.5 Hz	0.33 Hz
Binder	%AC	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)	Eri (ksi)
64-22	4.5	891	855	826	648	652	613	271	280	300
	5	748	770	740	595	564	556	233	252	249
	5.5	698	690	697	605	612	618	239	313	292
70-28	4.5	939	919	948	683	658	669	254	315	312
	5	856	876	870	572	556	555	260	294	311
	5.5	946	903	828	561	556	531	231	248	263
76-22	4.5	953	953	911	840	825	803	371	371	371
	5	1108	1141	1105	560	527	509	336	440	465
	5.5	1189	1187	1161	638	644	626	307	358	372

Table 3A. Test Results for Dallas Mixture with PG 64-22

		39 F						68 F						104 F					
		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz	
%AC	Specimen ID	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)
	50	890	910	850	850	825	815	650	920	650	640	615	600	272	250	280	280	300	300
4.5	51	904	918	880	865	822	810	653	627	688	670	631	611	262	248	301	295	320	316
	52	880	903	836	839	830	823	641	617	619	620	592	595	278	257	259	276	281	276
	AVG.	891	910	855	851	826	816	648	721	652	643	613	602	271	252	280	284	300	297
	STD	12	8	22	13	4	7	6	172	35	25	20	8	8	5	21	10	20	20
	COV	1	1	3	2	0	1	1	24	5	4	3	1	3	2	8	4	6	7
	53	702	693	714	702	668	670	606	586	549	566	550	565	230	215	227	218	242	236
5	54	750	755	765	720	750	710	580	551	583	557	563	554	236	220	278	277	259	254
	55	792	820	832	848	803	788	600	570	560	560	555	560	233	217	250	250	245	245
	AVG.	748	756	770	757	740	723	595	569	564	561	556	560	233	217	252	248	249	245
	STD	45	64	59	80	68	60	14	18	17	5	7	6	3	3	26	30	9	9
	COV	6	8	8	11	9	8	2	3	3	1	1	1	1	1	10	12	4	4
	56	700	685	690	700	695	690	603	580	611	600	650	600	240	211	315	295	290	300
5.5	57	736	712	696	719	712	712	606	588	624	613	627	629	250	222	331	318	311	317
	58	659	665	685	686	683	677	606	575	600	592	577	571	228	205	293	284	276	281
	AVG.	698	687	690	702	697	693	605	581	612	602	618	600	239	213	313	299	292	299
	STD	39	24	6	17	15	18	2	7	12	11	37	29	11	9	19	17	18	18
	COV	6	3	1	2	2	3	0	1	2	2	6	5	5	4	6	6	6	6

Table 3B. Test Results for Dallas Mixture with PG 70-28

		39 F						68 F						104 F					
		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz	
%AC	Specimen ID	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)
	59	940	960	900	920	950	910	680	640	660	650	675	650	255	235	315	300	312	310
4.5	60	917	924	854	892	893	860	706	658	646	639	652	622	268	254	319	328	316	331
	61	961	997	1004	997	1000	977	662	620	668	656	679	669	239	218	310	290	307	298
	AVG.	939	960	919	936	948	916	683	639	658	648	669	647	254	236	315	306	312	313
	STD	22	37	77	54	54	59	22	19	11	9	15	24	15	18	5	20	5	17
	COV	2	4	8	6	6	6	3	3	2	1	2	4	6	8	1	6	1	5
	62	850	850	860	850	875	860	570	556	550	540	554	545	255	250	295	290	312	307
5	63	763	788	794	790	808	773	573	559	584	572	580	563	289	266	277	276	314	305
	64	954	986	973	982	928	923	573	558	535	516	531	524	236	218	310	305	308	310
	AVG.	856	875	876	874	870	852	572	558	556	543	555	544	260	245	294	290	311	307
	STD	96	101	91	98	60	75	2	2	25	28	25	20	27	24	17	15	3	3
	COV	11	12	10	11	7	9	0	0	5	5	4	4	10	10	6	5	1	1
	65	950	945	900	823	820	810	560	540	565	530	530	525	231	200	250	245	260	260
5.5	66	972	925	863	826	784	768	550	536	531	515	511	496	230	204	241	233	246	246
	67	917	965	947	920	880	898	574	545	573	539	553	557	233	196	254	250	282	275
	AVG.	946	945	903	856	828	825	561	540	556	528	531	526	231	200	248	243	263	260
	STD	28	20	42	55	48	66	12	5	22	12	21	31	2	4	7	9	18	15
	COV	3	2	5	6	6	8	2	1	4	2	4	6	1	2	3	4	7	6

Table 3C. Test Results for Dallas Mixture with PG 76-22

		39 F						68 F						104 F					
		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz	
%AC	Specimen ID	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)
	68	955	990	950	975	900	920	840	770	825	835	800	810	370	345	375	360	370	360
4.5	69	952	998	936	960	952	959	783	730	750	711	748	764	352	319	337	338	382	377
	70	953	984	972	980	881	894	896	877	899	860	860	841	391	374	400	379	360	346
	AVG.	953	991	953	972	911	924	840	792	825	802	803	805	371	346	371	359	371	361
	STD	2	7	18	10	37	33	57	76	75	80	56	39	20	28	32	21	11	16
	COV	0	1	2	1	4	4	7	10	9	10	7	5	5	8	9	6	3	4
	71	1148	1149	1114	1118	1045	1059	539	527	508	489	479	466	389	350	455	438	465	460
5	72	1075	1114	1168	1098	1168	1156	565	540	530	515	505	500	330	298	435	430	465	480
	73	1100	1130	1140	1100	1101	1103	576	569	542	531	542	528	288	258	430	439	466	485
	AVG.	1108	1131	1141	1105	1105	1106	560	545	527	512	509	498	336	302	440	436	465	475
	STD	37	18	27	11	62	49	19	22	17	21	32	31	51	46	13	5	1	13
	COV	3	2	2	1	6	4	3	4	3	4	6	6	15	15	3	1	0	3
	74	1200	1240	1200	1200	1165	1125	640	630	635	639	625	623	310	290	360	355	375	370
5.5	75	1169	1297	1100	1150	1144	1052	598	585	615	608	579	581	319	299	359	349	364	368
	76	1198	1170	1262	1234	1175	1184	676	664	682	669	673	656	293	270	354	352	378	365
	AVG.	1189	1236	1187	1195	1161	1120	638	626	644	639	626	620	307	286	358	352	372	368
	STD	17	64	82	42	16	66	39	40	34	31	47	38	13	15	3	3	7	3
	COV	1	5	7	4	1	6	6	6	5	5	8	6	4	5	1	1	2	1

Table 4A . Test Results for San Antonio Mixture with PG 64-22

		39 F						68 F						104 F					
		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz	
% AC	Specimen ID	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)
	1	1100	1105	1103	1095	1070	1055	600	601	590	580	600	605	255	240	275	280	300	300
4.5	2	1188	1243	1200	1167	1153	1092	573	560	569	537	593	595	241	228	278	282	287	295
	3	997	973	1000	1005	977	997	630	624	597	613	609	604	259	243	300	292	302	306
	AVG.	1095	1107	1101	1089	1067	1048	601	595	585	577	601	601	252	237	284	285	296	300
	STD	96	135	100	81	88	48	29	32	15	38	8	6	9	8	14	6	8	6
	COV	9	12	9	7	8	5	5	5	2	7	1	1	4	3	5	2	3	2
	4	910	925	920	930	955	941	685	665	720	660	680	650	260	240	290	295	283	280
5	5	959	980	960	980	1015	995	639	608	692	621	681	645	246	230	283	280	276	275
	6	865	867	868	869	887	885	723	720	732	697	687	660	262	244	310	308	288	283
	AVG.	911	924	916	926	952	940	682	664	715	659	683	652	256	238	294	294	282	279
	STD	47	57	46	56	64	55	42	56	21	38	4	8	9	7	14	14	6	4
	COV	5	6	5	6	7	6	6	8	3	6	1	1	3	3	5	5	2	1
	7	840	860	865	870	811	838	600	580	605	595	597	580	279	265	305	298	315	306
5.5	8	909	919	988	993	925	964	559	549	569	556	563	555	299	279	325	316	337	321
	9	772	796	747	755	693	705	624	604	655	623	621	611	249	239	277	275	289	285
	AVG.	840	858	867	873	810	836	594	578	610	591	594	582	276	261	302	296	314	304
	STD	69	62	121	119	116	130	33	28	43	34	29	28	25	20	24	21	24	18
	COV	8	7	14	14	14	15	6	5	7	6	5	5	9	8	8	7	8	6

Table 4B . Test Results for San Antonio Mixture with PG 70-28

		39 F						68 F						104 F					
		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz	
% AC	Specimen ID	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)
	10	1140	1125	1100	1095	1065	1070	612	605	660	625	695	665	285	260	340	315	320	328
4.5	11	1149	1151	1115	1119	1047	1061	547	547	591	579	605	572	273	254	327	321	334	336
	12	1123	1095	1059	1063	1075	1084	684	656	721	667	776	767	276	259	339	318	313	309
	AVG.	1137	1124	1091	1092	1062	1072	614	603	657	624	692	668	278	258	335	318	322	324
	STD	13	28	29	28	14	12	69	55	65	44	86	98	6	3	7	3	11	14
	COV	1	2	3	3	1	1	11	9	10	7	12	15	2	1	2	1	3	4
	13	1020	1045	1030	1025	1025	980	535	525	518	535	528	530	290	288	340	320	315	300
5	14	991	1053	1067	1053	1087	1073	467	455	465	477	472	471	315	294	383	366	347	341
	15	1039	1029	1001	1007	952	875	597	584	581	603	579	580	260	247	284	279	272	269
	AVG.	1017	1042	1033	1028	1021	976	533	521	521	538	526	527	288	276	336	322	311	303
	STD	24	12	33	23	68	99	65	65	58	63	54	55	28	26	50	44	38	36
	COV	2	1	3	2	7	10	12	12	11	12	10	10	10	9	15	14	12	12
	16	1100	1135	1200	1175	1170	1165	585	540	545	535	575	560	255	230	289	280	300	302
5.5	17	1212	1225	1239	1220	1192	1145	583	561	529	517	555	524	255	238	305	300	317	311
	18	1056	1031	1137	1115	1152	1165	567	512	569	561	591	583	246	226	265	257	286	282
	AVG.	1123	1130	1192	1170	1171	1158	578	538	548	538	574	556	252	231	286	279	301	298
	STD	80	97	51	53	20	12	10	25	20	22	18	30	5	6	20	22	16	15
	COV	7	9	4	5	2	1	2	5	4	4	3	5	2	3	7	8	5	5

Table 4C . Test Results for San Antonio Mixture with PG 76-22

		39 F						68 F						104 F					
% AC	Specimen ID	1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz		1 Hz		0.5 Hz		0.33 Hz	
		Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)	Eri (ksi)	Ert (ksi)
	19	1150	1100	1002	1020	1025	995	730	730	780	785	760	715	360	330	389	385	390	400
4.5	20	1101	1047	863	905	939	896	728	689	732	724	716	689	312	287	341	326	338	336
	21	1180	1165	1133	1149	1104	1097	740	761	821	836	793	751	416	386	426	433	450	460
	AVG.	1144	1104	999	1025	1023	996	733	727	778	782	756	718	363	334	385	381	393	399
	STD	40	59	135	122	83	101	6	36	45	56	39	31	52	50	43	54	56	62
	COV	3	5	14	12	8	10	1	5	6	7	5	4	14	15	11	14	14	16
	22	1090	1085	1060	1050	1075	1065	695	690	715	700	705	695	340	315	365	370	379	373
5	23	1184	1116	1065	1075	1131	1095	705	700	768	729	709	700	318	293	328	338	369	366
	24	993	1041	1044	1031	1029	1027	679	671	667	656	709	676	359	333	390	386	378	378
	AVG.	1089	1081	1056	1052	1078	1062	693	687	717	695	708	690	339	314	361	365	375	372
	STD	96	38	11	22	51	34	13	15	51	37	2	13	21	20	31	24	6	6
	COV	9	3	1	2	5	3	2	2	7	5	0	2	6	6	9	7	1	2
	25	1150	1135	1105	1110	1065	1078	800	790	795	780	785	745	350	340	400	410	395	399
5.5	26	1059	1053	1021	1013	1016	1016	836	864	900	859	863	800	362	348	419	425	415	406
	27	1232	1209	1185	1192	1100	1128	745	721	685	692	700	697	341	317	374	393	371	376
	AVG.	1147	1132	1104	1105	1060	1074	794	792	793	777	783	747	351	335	398	409	394	394
	STD	87	78	82	90	42	56	46	72	108	84	82	52	11	16	23	16	22	16
	COV	8	7	7	8	4	5	6	9	14	11	10	7	3	5	6	4	6	4