Quality Base Material Produced Using Full Depth Reclamation on Existing Asphalt Pavement Structure

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Task 5 Report: Development of Standardized Laboratory Testing Method

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The objective of this task is to conduct performance testing of FDR materials, including: modulus of rupture, dynamic modulus, and repeated load triaxial tests. FDR materials studied include cement, fly ash, asphalt emulsion, and foamed asphalt. Modulus of rupture tests were conducted on cement and fly ash stabilized base materials, whereas dynamic modulus and repeated load triaxial tests were conducted on asphalt emulsion and foamed asphalt stabilized base materials. The optimum mixtures used in this study were determined from the previous task (Task 4: Development of FDR Mix Design Guide). The results show that the three types of tests conducted were viable means of evaluating the FDR stabilized base material.</td></tr>
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Abstract

The purpose of this study is to advance the knowledge on an in-place asphalt pavement recycling technology known as Full Depth Reclamation (FDR) through the creation and validation of a mix design guide. The objective of this task is to conduct performance testing of FDR materials, including: modulus of rupture, dynamic modulus, and repeated load triaxial tests. FDR materials studied include cement, fly ash, asphalt emulsion, and foamed asphalt. Modulus of rupture tests were conducted on cement and fly ash stabilized base materials, whereas dynamic modulus and repeated load triaxial tests were conducted on asphalt emulsion and foamed asphalt stabilized base materials. The optimum mixtures used in this study were determined from a previous task of the research (Task 4: Determination of FDR Mix Design Process). The results show that the three types of tests conducted were viable means of evaluating FDR stabilized base material.

The results of the modulus of rupture testing indicated that cement stabilization appears to work for most combinations of FDR mixtures, while the fly ash stabilization worked for a limited number of FDR mixes. In the case of the dynamic modulus property, lime additive seemed to increase dynamic modulus for samples with high water contents, while lowered the modulus for dryer samples. It was also shown that FDR with 50% recycled asphalt pavement (RAP) mixtures typically had the highest dynamic modulus for emulsion samples. Foamed asphalt samples consistently showed that FDR with 25% RAP had the highest dynamic modulus. The repeated load triaxial testing showed that the test was conclusive and did show the performance of the stabilized RAP. Overall, the results of this study were successful in showing that these three tests were good candidate for evaluating the performance of stabilized FDR and the variability of the results is acceptable.

Conversion Table

1 psi = 6.895 kPa
1 kPa = 0.145 psi

Temperature (^oC)	Temperature (^oF)
4.4	39.9
21.1	70.0
30.0	86.0
37.8	100.0
40.0	104.0
50.0	122.0
54.0	129.2

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1.0 Introduction

The purpose of Task 5 is to develop the laboratory testing procedures to test and analyze the use of full depth reclamation (FDR) in modern pavement design and to determine if modulus of rupture, dynamic modulus, and repeated load triaxial testing are applicable testing methods for this material. The mixtures tested in Task 5 were determined in Task 4 of this research project that has been summarized in Report: "Task 4 - Development of FDR Mix Design Process". The mixtures consisted of different percentages of recycled asphalt pavement (RAP) and four types of virgin materials. Recycled materials refer to recycled asphalt pavement that is produced through cold milling of the asphalt concrete layer. Virgin materials refer to virgin aggregates that are used to alter the gradation of the FDR material. FDR material is a mixture of RAP and base material. The four virgin materials used were as follows: good clean, good dirty, poor clean, and poor dirty. The distinction given for these types are based on aggregate type and percent fines in the virgin material. Clean and dirty characteristics denote the low and high percentage of fines, respectively. Fines are defined as materials passing No. 200 US Standard Sieve (P200). A full description of these materials can be found in the Task 4 report. FDR samples were created using 25%, 50%, and 75% of RAP with the remaining quantity being made up of one of the four virgin materials.

The four types of stabilizers used were Portland cement, fly ash, asphalt emulsion, and foamed asphalt. If only virgin aggregate is added to the FDR material, it is referred to as mechanically stabilized FDR. Please note that this type of FDR was not evaluated in this research. If Portland cement or fly ash is added to the FDR material, it is referred to as chemically stabilized FDR. If asphalt emulsion or foamed asphalt is added to the FDR material, it is referred to as bituminous stabilized FDR.

The properties evaluated in Task 5 consisted of modulus of rupture for cement and fly ash stabilized FDR materials, dynamic modulus and permanent deformation through the repeated load triaxial testing for the asphalt emulsion and foamed asphalt samples. The measured raw data from dynamic modulus and repeated load triaxial testing were used to develop the E* master curves and a rutting model for FDR base material.

This report includes the testing procedures, calculations, and sample production methods. A review of the summarized data is presented followed by a discussion of the results and methodology. Finally, a conclusions and recommendations section is presented to generalize what can be inferred from the results of the testing.

2.0 Testing Procedures and Calculations

The following sections discuss the background, methods of data collection and analysis, and the methodology for each test used in this study. Any deviations from standard practice are specifically indicated.

2.1 Modulus of Rupture

The modulus of rupture (MR) property was evaluated for FDR materials stabilized with Portland cement and fly ash. According to the ASTM D1635-00 (Standard Test Method for Flexural

Strength of Soil Cement using Simple Beam with Third Point Loading), the modulus of rupture is defined as " the flexural strength of soil-cement. Flexural strength is significant in pavement design and is used to determine the slab thickness." The testing and calculations for modulus of rupture were conducted according to ASTM D1635-00 (reapproved 2006) and AASHTO T97 (Standard Method of Test for Flexural Strength of Concrete Using Simple Beam with Third-Point Loading). The samples were tested on a Geotac Sigma-1 load frame using a steel load plate fabricated to specifications and a 10,000 lbs load cell as shown in *Figure 1*.

Figure 1: Modulus of rupture sample ready for testing

To analyze the data, the average tensile strength, standard deviation and coefficient of variation (COV) were calculated for each sample set. A COV range of 0% - 15% was used to determine if the data was acceptable and for a COV of 16% or greater, the outlier was omitted and the COV was recalculated.

2.2 Dynamic Modulus and E* Curves

The dynamic modulus property was measured for FDR materials stabilized with asphalt emulsion and foamed asphalt. The dynamic modulus of a material is defined by the American Association of State Highway and Transportation Officials (AASHTO) as "the absolute value of the complex modulus calculated by dividing peak-to-peak stress by the peak-to-peak strain for a material subjected to a sinusoidal loading." This is shown in the following equation:

$$|E^*| = \sigma_0/\varepsilon_0 \qquad (1)$$

The dynamic modulus is a performance test that evaluates the stiffness of a mixture by subjecting the sample to dynamic stress and measuring the strain response of the sample. The testing procedures used for the dynamic modulus was AASHTO TP62-07 (Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures) and Report NCHRP 9-29: PT01. Testing was done on four inch diameter cylinders compacted in the Superpave Gyratory Compactor (SGC). This is a deviation from TP62-07 which called for four inch diameter samples cored from six inch diameter samples compacted in the SGC. Testing was conducted in an Interlaken Simple-Performance Tester (SPT), which conforms to AASHTO TP62-07 and the report NCHRP 9-29: PT01. A picture of the SPT machine is shown in *Figure 2.* Samples were cured at different temperatures before testing as stated in the procedure. The temperatures used for dynamic modulus testing were, 4.4, 21.1, 37.8, and 54^{o} C. Samples were then subjected to six different loading frequencies to determine the dynamic modulus. The six frequencies used were 25, 10, 5, 1, 0.5, 0.1 hertz.

Figure 2: The Interlaken simple performance testing machine

For each FDR mixture a total of five samples were fabricated and tested. After the raw data was obtained, the dynamic modulus of all samples was averaged at each combination of temperature and frequency. Along with the average values, standard deviation (STD) and COV was calculated for each temperature and frequency. The averaged data of all five samples were used to calculate the E* master curve for each FDR type.

The E* mater curve is used in the Mechanistic-Empirical Pavement Design Guide (MEPDG) to determine the mechanistic responses of flexible pavement under various combinations of pavement temperature and vehicle speed. The E* master curves were developed according to Report NCHRP 9-29: PP02, following Equation 2.

$$\log|E^*| = \delta + \frac{Max - \delta}{1 + e^{\beta + \gamma \log f_r}} \qquad (2)$$

where $|E^*|$ is the dynamic modulus (psi), f_r is the reduced frequency (Hz), *Max* is the limiting maximum modulus (psi) and δ, β, γ are fitting parameters. To create the E* master curve, the dynamic modulus data files obtained from the Interlaken SPT machine were used. The data was input into an Excel sheet that shifts all of the raw dynamic modulus data and curves to a selected temperature and provides a single curve for comparison. The Excel sheets can be found on the accompanied DVD. For detailed instructions on creating the E* master curves, refer to Section 10.8 of the Appendix.

2.3 Repeated Load Triaxial Test

The repeated load triaxial test (RLT) is used to determine the rutting potential of a material. AASHTO TP62-07 defines the repeated load triaxial test as "the number of load cycles corresponding to the minimum rate of change of permanent axial strain." The term “repeated load triaxial" refers to a specific testing condition where the vertical load is repeated in the form of pulse, hence the term "repeated load". And the sample is subjected to a constant confining pressure, hence the term "triaxial". The testing procedure used for the various FDR materials followed AASHTO TP62-07 and the report NCHRP 9-29: PT01.

Testing was conducted in the Interlaken Simple Performance Tester. Samples were tested at three temperatures: 30, 40, and 50^{o}C. Samples were loaded with a constant repeated stress until a 5% permanent axial strain is reached. Multiple deviatoric stresses were used on the sample combinations so that the 5% strain was established within 30,000 load cycles (the maximum of the SPT machine). Initially, the combination of deviatoric stress of 226 kPa and a confining pressure of 35 kPa were used. After testing with these stresses, it was noted that samples were not reaching the 5% permanent strain. The deviatoric stress was increased at increments of 69 kPa (10 psi) until the samples would reach 5% permanent strain within the 30,000 load cycles. The deviatoric stresses used on the various combinations varied greatly depending on the type of FDR materials.

To analyze data from the repeated load triaxial test, a model from the Mechanistic-Empirical Pavement Design Guide (MEPDG) was used. Using regression analysis, coefficients were obtained to model the ratio of permanent strain to resilient strain ratio. Microsoft Excel has built-in regression tools to obtain these coefficients: *a*, *b*, and *c*. Equation 3 is the model found in MEPDG where ε_p is the permanent axial strain, ε_r is the resilient axial strain, Nr is the number of load repetitions, T is the temperature of the HMA mix (°F), and *a*, *b* and *c* are experimentally determined coefficients.

$$\frac{\varepsilon_p}{\varepsilon_r} = 10^a (T)^b (N_r)^c \qquad (3)$$

3.0 Sample Production

This section discusses the methods used to prepare samples for the testing conducted in Task 5. All samples created for dynamic modulus and repeated load triaxial testing were four inch diameter by six inch height as defined by Report NCHRP 9-29: PP01. These samples were created using the SGC. All RAP and virgin aggregates were provided by the South Dakota Department of Transportation (SDDOT).

3.1 Portland Cement and Fly Ash FDR Samples

The beams for modulus of rupture testing were made in accordance with ASTM D1632-06 (Standard Practice for Making and Curing Soil Cement Compression and Flexure Test Specimens in the Laboratory) and AASHTO T97. A more in-depth and specific procedure for making the beams for this testing can be found in Section 10.5 in the Appendix. *Figure 3* shows a beam sample compacted using the combination of tamping and static load. Once the beams were made, they were allowed to cure in a hydration room for seven days before testing. The cement was obtained from GCC America in Rapid City, SD, and the fly ash was obtained from the Black Hills Power Ben French power plant in Rapid City, SD.

Figure 3: Modulus of rupture sample is shown in mold

The molds used to make the beams were not the standard size listed in ASTM D1632-06 (6”x6”x21”), but were 4”x4”x14”. The sample size deviation is allowed according to ASTM D1632-06 Section 6.1. To calculate the needed material, a compaction height of three inches was used, along with the optimum densities obtained in Task 4. Therefore, the final beam size was 3”x4”x14”, where four inches was the height of the sample and three inches was the width. The sample material did require compaction after tamping took place and was compacted using a one inch thick steel plate and a steel mallet. Most samples were able to be compacted to the proper height, but some samples were slightly taller.

3.2 Asphalt Emulsion FDR Samples

Asphalt emulsion samples were mixed according to the mixture procedures found in Section 10.4 of the Appendix. To mix samples, an industrial mixer was used with a whip attachment. A standard scale was used with an accuracy of 0.1 grams to measure the proper amounts of material. Typical materials and tools required for making asphalt emulsion samples are seen in *Figure 4*. The asphalt emulsion was supplied by Road Science, LLC. The lime material was obtained from Pete Lien and Sons in Rapid City, SD and the fine material was crushed kaolinite from The Feldspar Company in Edgar, FL.

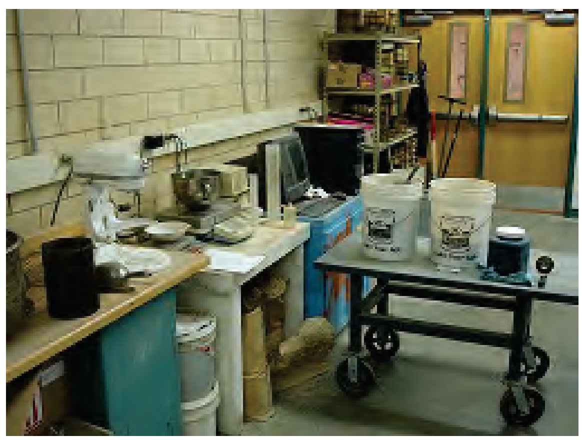


Figure 4: Getting ready to mix asphalt emulsion samples

3.3 Foamed Asphalt FDR Samples

The foamed asphalt samples were mixed according to the procedures in Section 10.10 of the Appendix. The sample materials were mixed using a foaming machine provided by Wirgten America, Antioch, TN. All materials were measured using a standard scale to an accuracy of 0.1 grams. *Figure 5* shows the Wirtgen asphalt foaming unit and mixer.

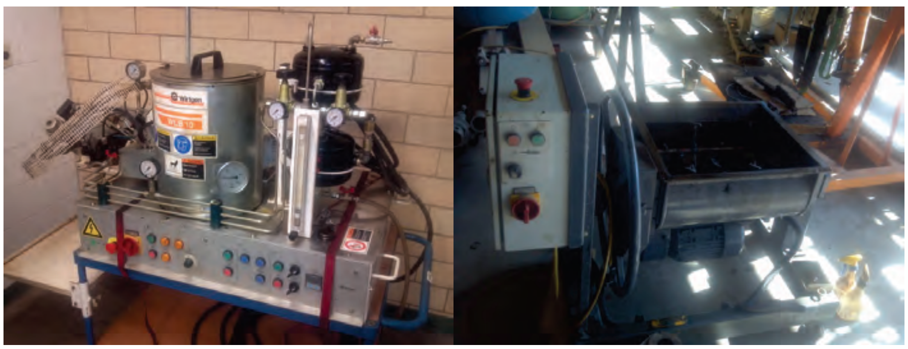


Figure 5: Wirtgen asphalt foamed unit and mixer

3.4 Superpave Gyratory Compactor

The final asphalt emulsion and foamed asphalt samples were made with a Superpave Gyratory Compactor as shown in *Figure 6*. The procedure for the Superpave gyratory compactor can be found in Section 10.3, of the Appendix. The gyratory compactor was set to make samples to six inches in height. The compaction pressure was set at 600 kPa for all samples.

Figure 6: The Superpave gyratory compactor

Gyrations varied depending on the FDR type. Once the samples were made with the compactor, they were allowed to cure for 48 hours in an oven at 40°C before being tested.

4.0 Results

This section presents the results of the modulus of rupture, dynamic modulus, and repeated load triaxial testing in tabular and graphical forms. Examples of raw data for the various testing methods can be found in the Appendix. The accompanying DVD contains all raw data for the modulus of rupture, dynamic modulus, and repeated load triaxial testing.

Multiple replicates (i.e. 3 – 5 samples) were tested to measure each of the identified properties of the various FDR materials. As expected, when testing road paving materials, a certain degree of variability was present in the various measurements. In the absence of standard precision statements for the evaluated test methods with FDR materials and in order to be consistent among all of the measured properties, the following process listed below was followed to identify outliers which were removed from the data sets prior to final analyses:

- Compute the average of the replicate measurements
- Compute the standard deviation of the replicate measurements
- Identify as outlier any measurement that lies outside the range of; average +/- 1.5 standard deviation
- Remove the identified outliers from the data set prior to further analyses

4.1 Modulus of Rupture

The following section covers the summarized results of the modulus of rupture testing of this study. Only RAP stabilized with cement and fly ash were tested for modulus of rupture. The optimum mixtures for sample testing were determined in Task 4.

4.1.1 Cement Stabilized FDR

The summarized results of average modulus of rupture (psi) are shown in Table 1 for the cement stabilized RAP. The highest modulus of rupture was obtained on the good clean with 25% RAP and 7% cement. The plotted average modulus of rupture results of good and poor mixtures with cement are shown in Figure 7. Table 2 shows the COVs of the MR property of cement stabilized FDR with outliers removed.

Table 1: Average modulus of rupture results for cement stabilized mixtures

Mix	RAP (%)	Optimum Moisture Content	Average Modulus of Rupture (psi)
Good Clean	25	7%	359.53
	50	7%	135.02
	75	7%	117.36
	25	5%	70.03
Good Dirty	75	7%	122.33
	50	5%	86.42
	25	3%	64.12
Poor Clean	75	5%	95.19
	50	5%	95.77
	25	3%	54.81
Poor Dirty	75	5%	79.10
	50	3%	71.71
	25	3%	103.42

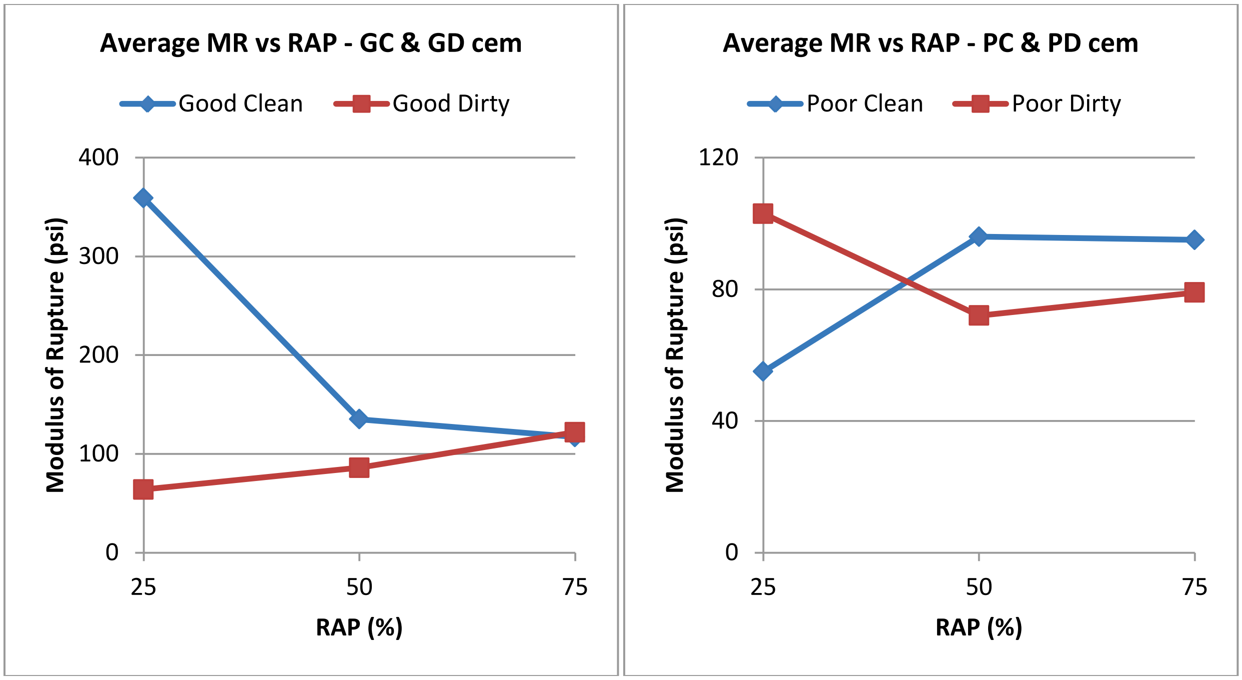


Figure 7: Average modulus of rupture results of good and poor mixtures with cement

Table 2: COV values for modulus of rupture testing with cement.

Sample	Coef. of Variation for Modulus of Rupture (%)
GC 25% RAP 7% CEM	8%
GC 50% RAP 7% CEM	5%
GC 75% RAP 7% CEM	8%
GC 25% RAP 5% CEM	5%
GD 75% RAP 7% CEM	7%
GD 50% RAP 5% CEM	9%
GD 25% RAP 3% CEM	15%
PC 75% RAP 5% CEM	9%
PC 50% RAP 5% CEM	8%
PC 25% RAP 3% CEM	8%
PD 75% RAP 5% CEM	11%
PD 50% RAP 3% CEM	1%
PD 25% RAP 3% CEM	12%

4.1.2 Fly Ash Stabilized FDR

The summarized results of average MR are shown in *Table 3* for the fly ash stabilized FDR. The highest result was obtained for the good clean with 25% RAP and 12% fly ash. The plotted average modulus of rupture results of good and poor mixtures with fly ash are shown in *Figure 8*. Shown in *Table 4* are the COV values of the MR values after outliers have been removed.

Table 3: Average modulus of rupture results for fly ash stabilized mixtures.

Mix	RAP (%)	Optimum Moisture Content	Average Modulus of Rupture (psi)
Good Clean	75	12%	25
	50	12%	36
	25	12%	70
Good Dirty	75	10%	25
	50	10%	35
	25	12%	58
Poor Clean	75	10%	12
	25	10%	31
	75	12%	7
	50	12%	28
	25	12%	13
Poor Dirty	75	15%	48
	50	15%	9
	25	15%	23

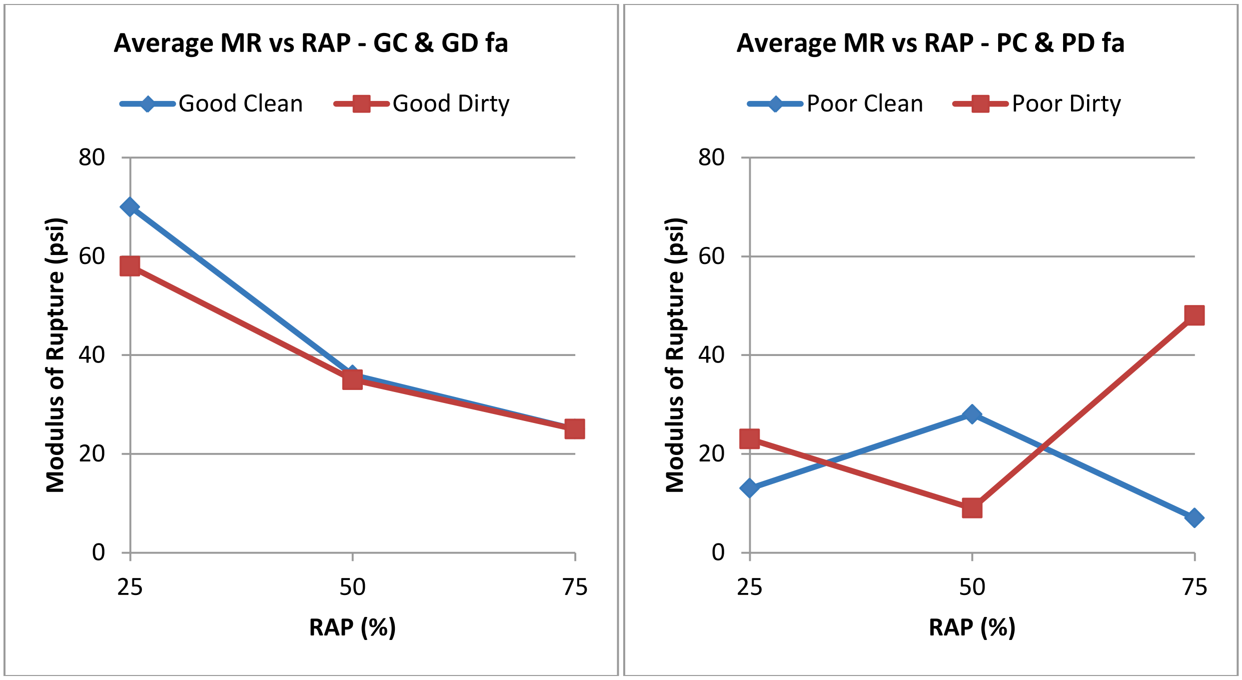


Figure 8: Average modulus of rupture results for good and poor mixtures with fly ash

Table 4: COV values for modulus of rupture testing with fly ash.

Sample	**Coef. of Variation for Modulus of Rupture (%)**
GC 75% RAP 12% Fly Ash	**1%**
GC 50% RAP 12% Fly Ash	**16%**
GC 25% RAP 12% Fly Ash	**7%**
GD 75% RAP 10% Fly Ash	**8%**
GD 50% RAP 10% Fly Ash	**11%**
GD 25% RAP 12% Fly Ash	**12%**
PC 75% RAP 10% Fly Ash	**7%**
PC 50% RAP 12% Fly Ash	**5%**
PC 25% RAP 12% Fly Ash	**19%**
PD 75% RAP 15% Fly Ash	**24%**
PD 50% RAP 15% Fly Ash	**17%**
PD 25% RAP 15% Fly Ash	**14%**
PC 75% RAP 12% Fly Ash	**55%**
PC 25% RAP 10% Fly Ash	**16%**

Note: The highlighted data represents COVs higher than 15%.

4.2 Dynamic Modulus Master Curves

4.2.1 Asphalt Emulsion Stabilized FDR

4.2.1.1 Asphalt Emulsion Samples Without Lime

Table 5 summarizes the average dynamic modulus results of poor dirty asphalt emulsion samples without lime. The highlighted data represents COVs higher than 15% even with omitting one outlier. Shown in *Figures 9 and 10* are the average dynamic modulus values at the testing frequencies for the poor dirty samples without lime at each of the four testing temperatures. Shown in *Figure 11* are the developed E* master curves for the poor dirty RAP samples without lime.

Table 6 summarizes the average dynamic modulus results for the good dirty asphalt emulsion stabilized RAP samples without lime. The highlighted data represent COV's higher than 15% even with omitting one outlier. Shown in *Figures 12 and 13* is the average dynamic modulus at the testing frequencies for the good dirty samples without lime and each of the four testing temperatures. *Figure 14* shows the developed E* master curves for the good dirty RAP samples without lime.

Table 5: Average dynamic modulus results of poor dirty asphalt emulsion samples without lime

TEMP(°C)	Hz	Poor Dirty - 25% RAP - No Lime		Poor Dirty - 50% RAP - No Lime		Poor Dirty - 75% RAP - No Lime	
		Avg E* (psi)	COV	Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	550130	8%	715119	4%	682534	6%
	10	494170	8%	649081	4%	615469	5%
	5	455110	8%	603348	5%	568766	6%
	1	371787	10%	503539	5%	462104	8%
	0.5	324678	10%	457426	4%	416018	7%
	0.1	238378	11%	357042	4%	315466	8%
21.1	25	267029	8%	336140	5%	301424	13%
	10	224185	7%	286018	5%	250345	13%
	5	196413	8%	248209	5%	213175	14%
	1	149194	7%	180429	6%	145144	17%
	0.5	134767	7%	158005	7%	126568	12%
	0.1	104960	7%	116379	8%	91974	11%
37.8	25	150090	4%	162206	6%	147768	5%
	10	124568	5%	131710	7%	114581	4%
	5	109207	6%	112834	7%	94761	5%
	1	82821	8%	78623	11%	63572	4%
	0.5	73161	8%	72521	8%	57285	5%
	0.1	60077	8%	55592	12%	44423	6%
54	25	125752	12%	103135	9%	74415	14%
	10	105565	13%	83526	9%	59140	14%
	5	92063	12%	70302	10%	48177	13%
	1	74223	14%	55590	9%	35417	13%
	0.5	67815	14%	50531	10%	31767	13%
	0.1	58336	14%	43896	10%	27428	12%

Note: The highlighted data represents COVs higher than 15%.

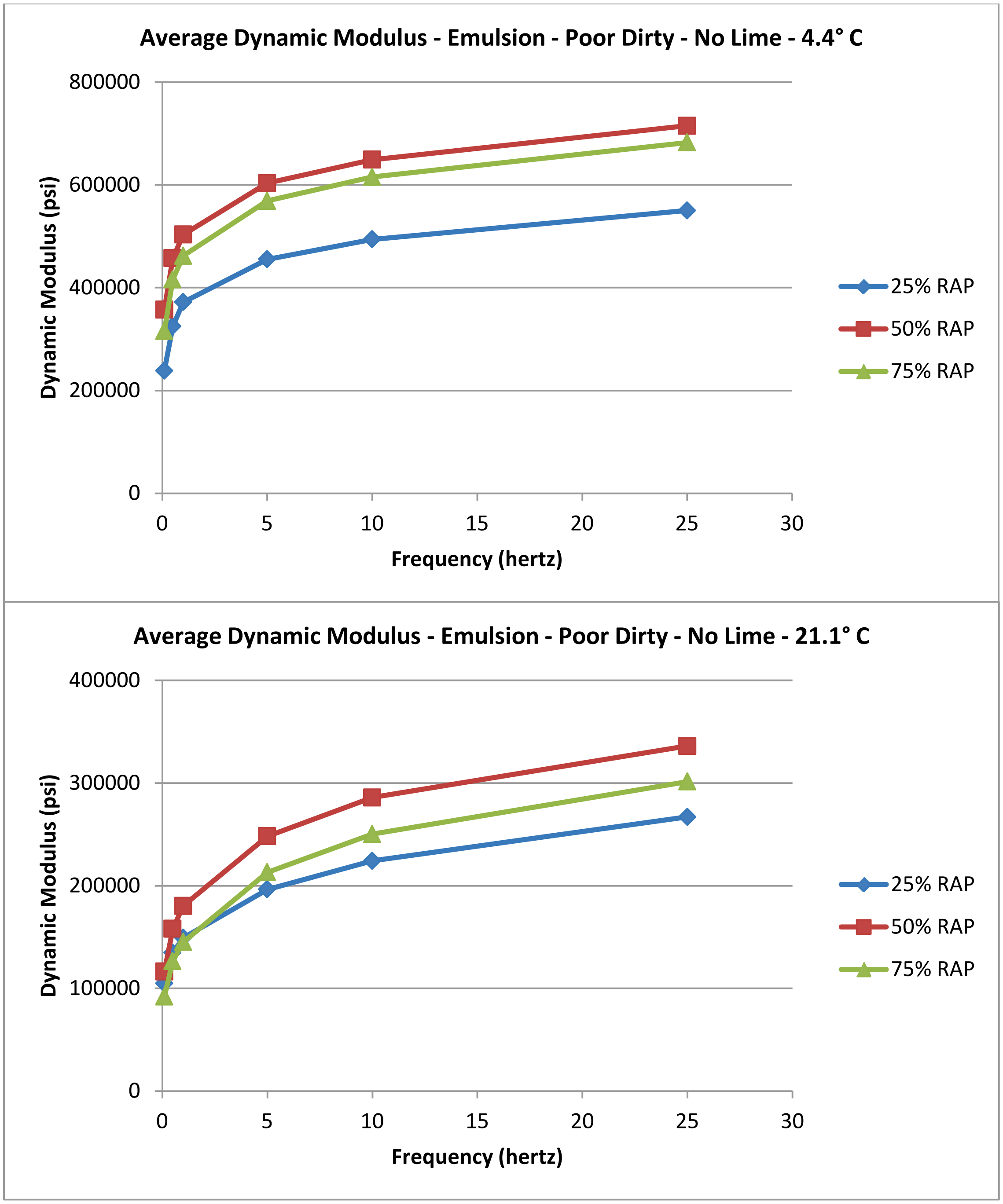
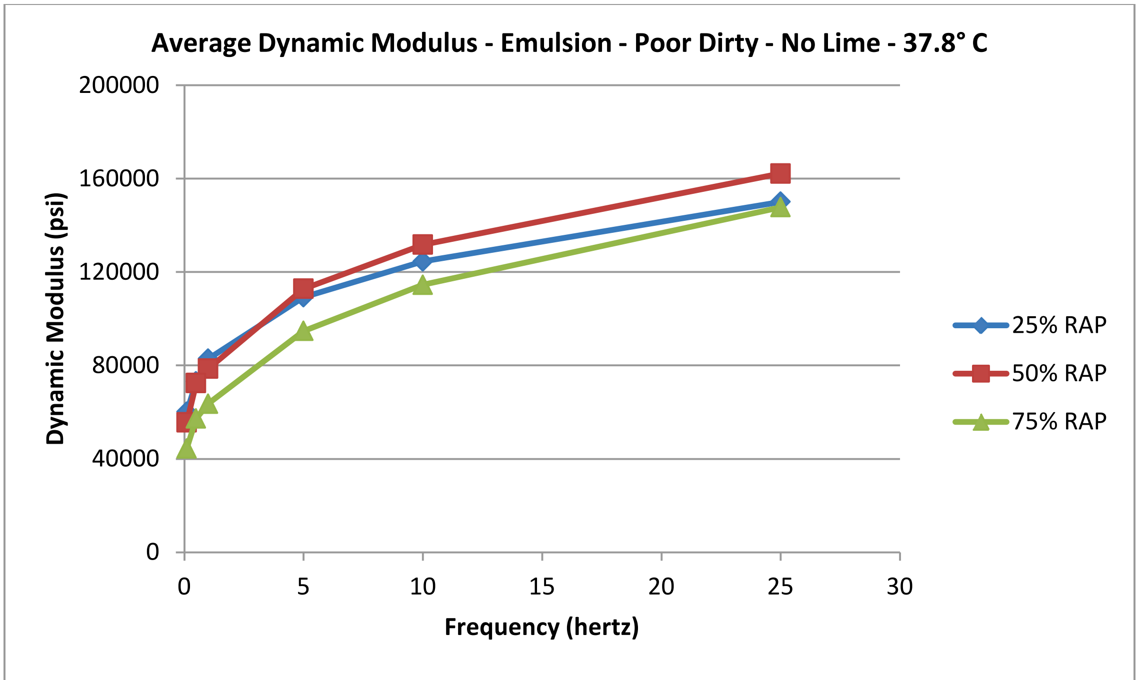


Figure 9: Average dynamic modulus at varying frequencies for the poor dirty asphalt emulsion samples without lime at 4.4 and 21.1^{o}C



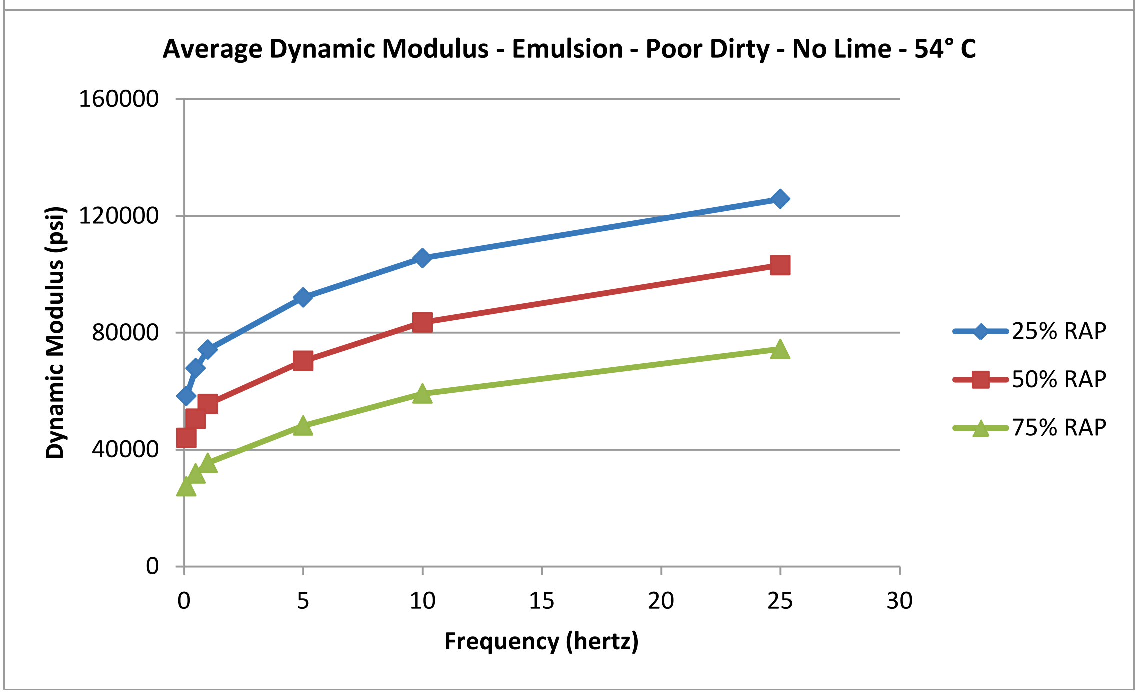
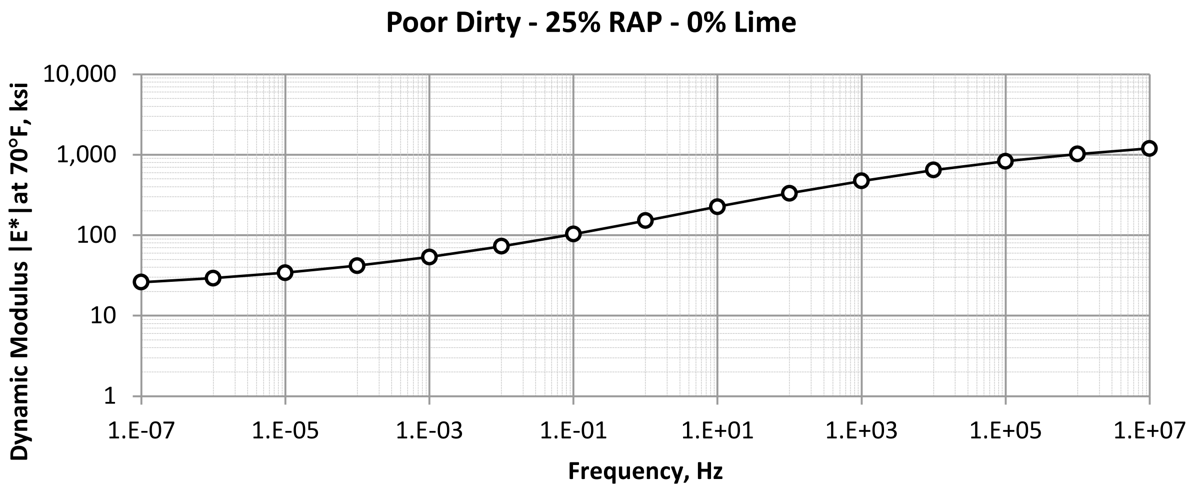
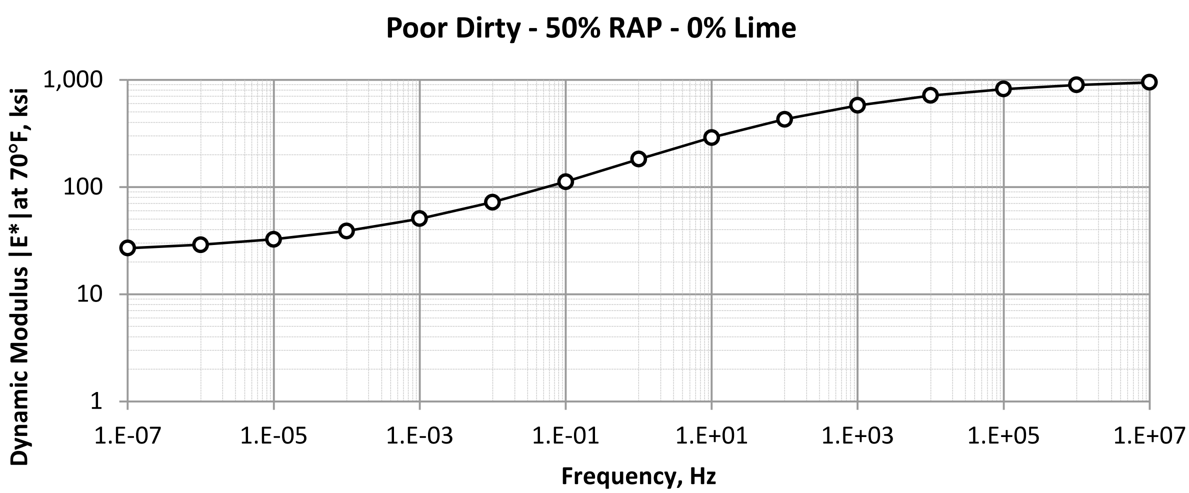


Figure 10: Average dynamic modulus at varying frequencies for the poor dirty asphalt emulsion samples without lime at 37.8 and 54°C





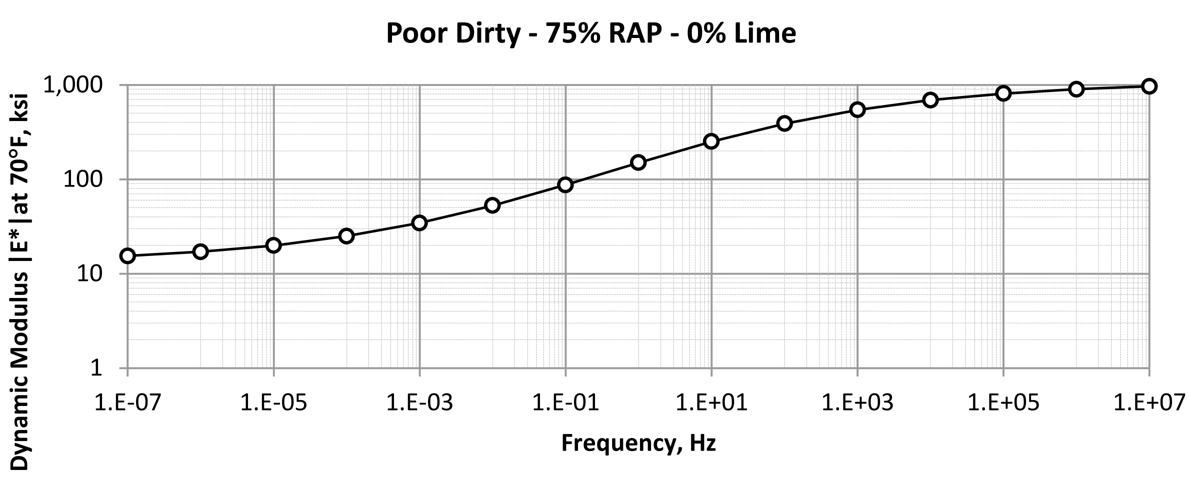


Figure 11: MEPDG E* master curves for the three percentages of RAP for poor dirty asphalt emulsion samples without lime

Table 6: Average dynamic modulus results of good dirty asphalt emulsion samples without lime

TEMP(°C)	Hz	Good Dirty - 25% RAP - No Lime Avg E* (psi)	Good Dirty - 25% RAP - No Lime COV	Good Dirty - 50% RAP - No Lime Avg E* (psi)	Good Dirty - 50% RAP - No Lime COV	Good Dirty - 75% RAP - No Lime Avg E* (psi)	Good Dirty - 75% RAP - No Lime COV
4.4	25	853618	12%	834980	5%	735752	5%
	10	746848	12%	746817	5%	656007	5%
	5	666409	13%	683224	5%	599163	5%
	1	490404	15%	538523	7%	477491	5%
	0.5	420313	14%	474703	8%	420713	6%
	0.1	265043	12%	322305	11%	291941	8%
21.1	25	282653	7%	277907	10%	224781	10%
	10	218680	7%	217733	10%	175754	13%
	5	180063	7%	181901	10%	143331	9%
	1	111787	7%	106371	8%	98843	14%
	0.5	109646	8%	102057	13%	83712	9%
	0.1	74275	12%	74695	13%	55689	7%
37.8	25	121069	4%	117403	5%	92710	7%
	10	94146	2%	88052	4%	70093	7%
	5	79608	3%	71962	5%	53870	10%
	1	56522	3%	48510	5%	38080	7%
	0.5	50597	2%	41737	6%	30949	14%
	0.1	43550	4%	31955	6%	23682	7%
54	25	60994	15%	70919	4%	41690	18%
	10	49888	16%	54214	10%	31336	15%
	5	42165	13%	45090	10%	26719	15%
	1	34795	15%	28242	6%	17104	16%
	0.5	29976	4%	26746	8%	14921	15%
	0.1	30922	15%	25524	9%	12738	12%

Note: The highlighted data represents COVs higher than 15%.

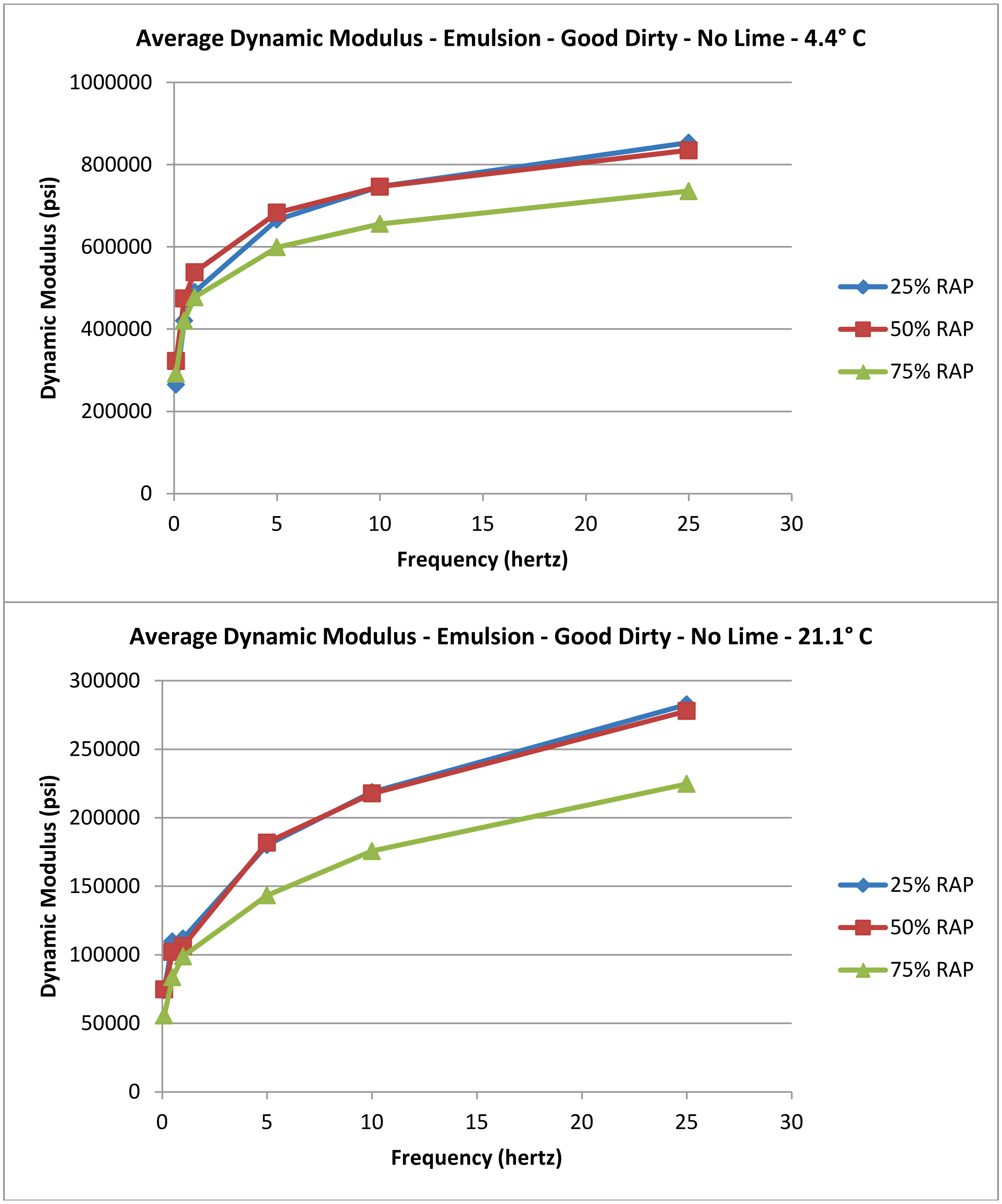


Figure 12: Average dynamic modulus at varying frequencies for the good dirty asphalt emulsion samples without lime at 4.4 and 21.1^{o}C

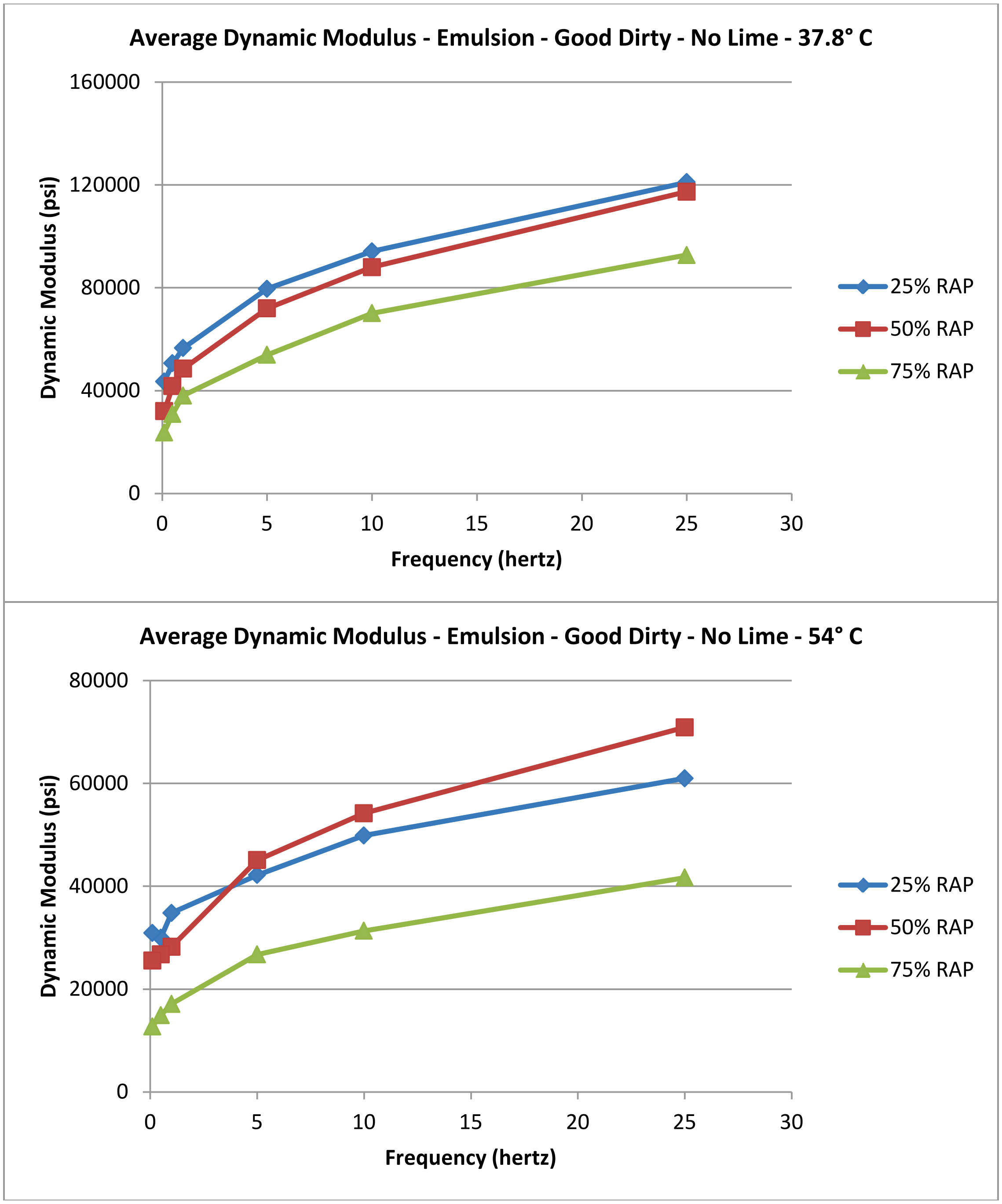


Figure 13: Average dynamic modulus at varying frequencies for the good dirty asphalt emulsion samples without lime at 37.8 and 54°C

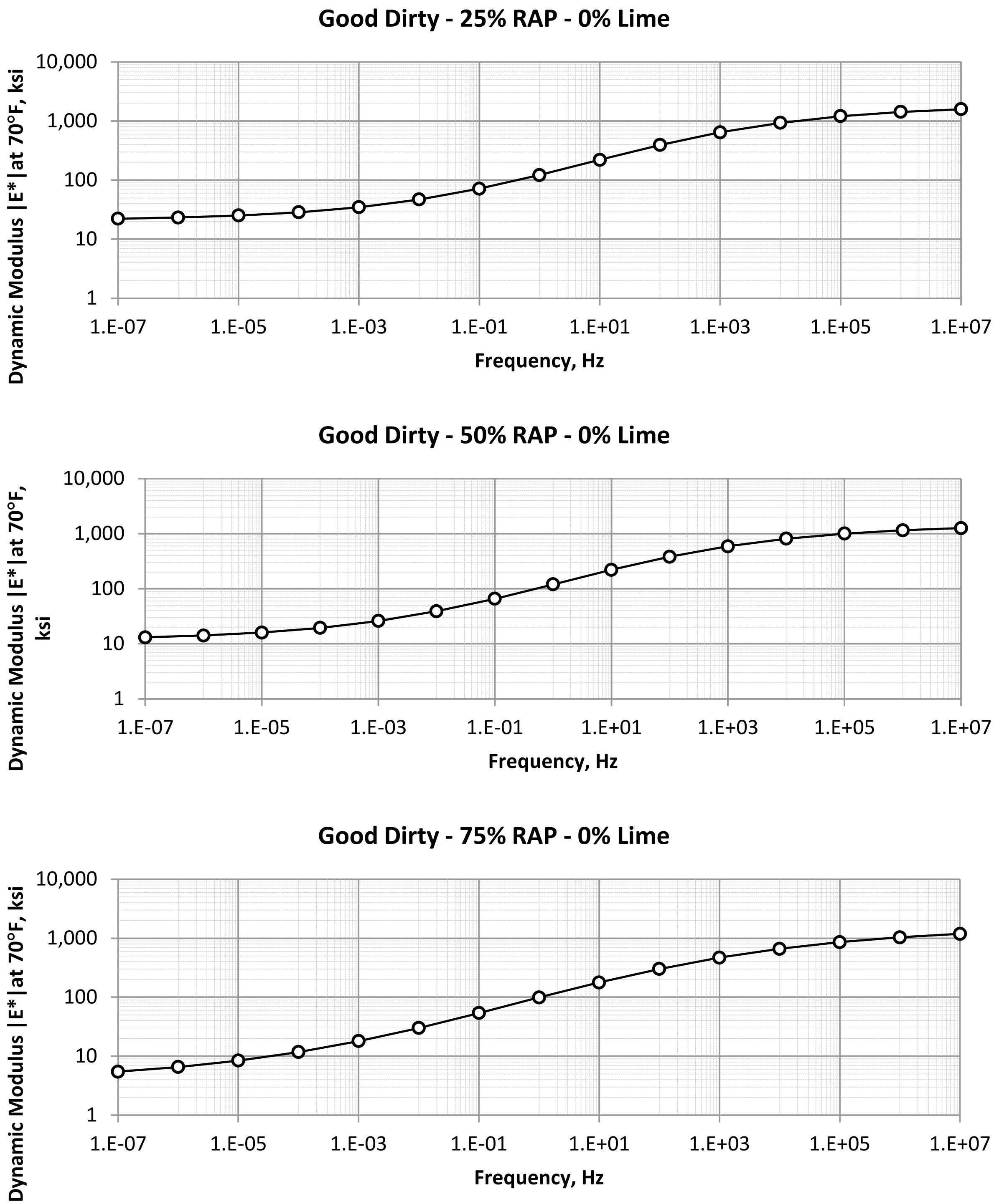


Figure 14: MEPDG E* master curves for the three percentages of RAP for good dirty asphalt emulsion samples without lime

4.2.1.2 Asphalt Emulsion Samples With 1% Lime

Table 7 summarizes the average dynamic modulus results of poor dirty asphalt emulsion samples with 1% lime. The highlighted data represent COVs higher than 15% even with omitting one outlier. Shown in *Figure 15and 16* are the average dynamic modulus values at the testing frequencies for the poor dirty samples with lime and each of the four testing temperatures. *Figure 17* shows the E* master curves for the three percentages of poor dirty RAP samples with 1% lime.

Table 8 summarizes the average dynamic modulus results of good dirty asphalt emulsion samples with 1% lime. The highlighted data represents COVs higher than 15% even with omitting one outlier. Shown in *Figures 18 and 19* is the average dynamic modulus at the testing frequencies for the good dirty samples with 1% lime and each of the four testing temperatures. *Figure 20* is the E* master curves for the three percentages of good dirty RAP samples with lime.

Table 7: Average dynamic modulus results of poor dirty asphalt emulsion samples with 1% lime

TEMP(°C)	Hz	Poor Dirty - 25% RAP - 1% Lime		Poor Dirty - 50% RAP - 1% Lime		Poor Dirty - 75% RAP - 1% Lime	
		Avg E* (psi)	COV	Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	634200	10%	862045	10%	873108	9%
	10	579573	12%	793929	10%	794406	9%
	5	543504	12%	746294	10%	740124	9%
	1	462195	15%	641239	12%	617723	10%
	0.5	416150	17%	589882	13%	562447	11%
	0.1	324362	19%	468262	15%	433799	13%
21.1	25	200138	8%	224610	6%	250099	5%
	10	171846	8%	186434	7%	205469	4%
	5	149479	10%	163464	7%	177028	4%
	1	120663	8%	115492	7%	117819	3%
	0.5	110372	8%	103882	7%	105873	4%
	0.1	90258	8%	79357	8%	76761	3%
37.8	25	110096	10%	131852	10%	122033	9%
	10	94385	10%	108150	10%	96811	10%
	5	85074	10%	94245	9%	83313	9%
	1	68486	10%	69834	11%	57659	7%
	0.5	59073	13%	61382	11%	50022	11%
	0.1	50768	13%	50374	12%	39299	11%
54	25	91014	2%	92140	10%	84638	7%
	10	79293	2%	78220	10%	68866	7%
	5	72492	2%	69117	10%	59769	7%
	1	61473	1%	54104	10%	44291	7%
	0.5	59197	2%	50239	11%	41448	8%
	0.1	54348	2%	44628	11%	36091	9%

Note: The highlighted data represents COVs higher than 15%.

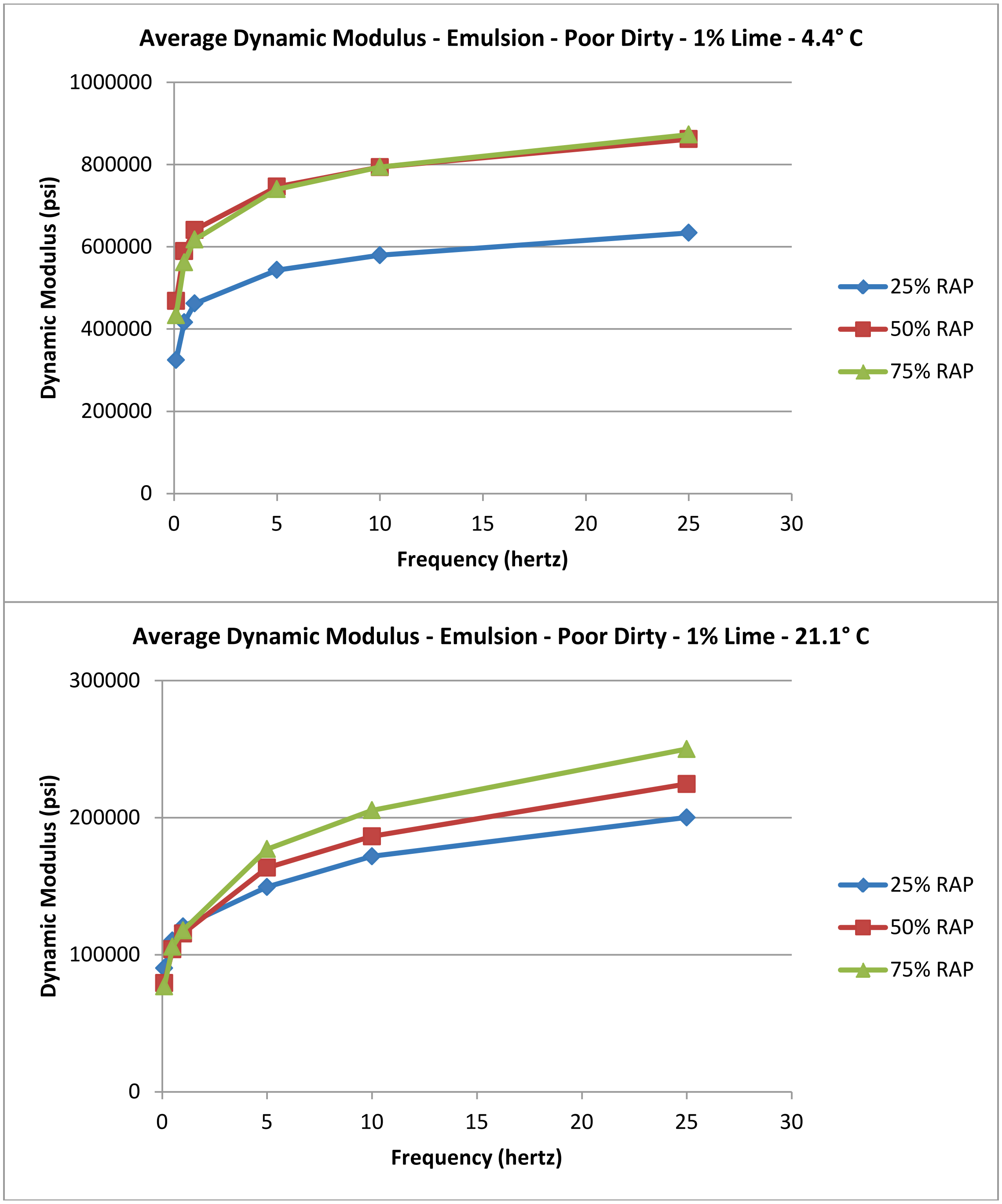


Figure 15: Average dynamic modulus at varying frequencies for the poor dirty asphalt emulsion samples with 1% lime at 4.4 and 21.1^{o}C

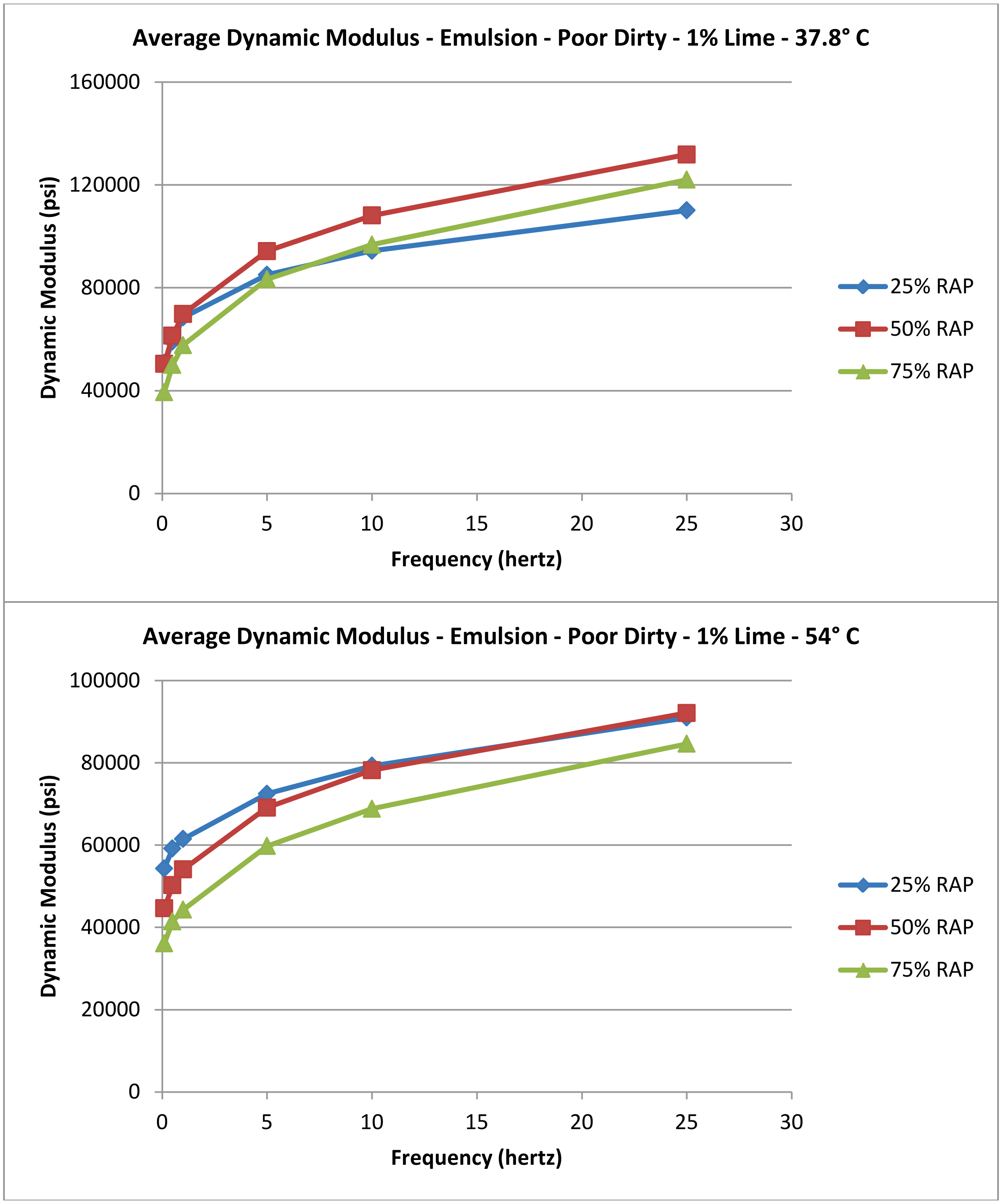
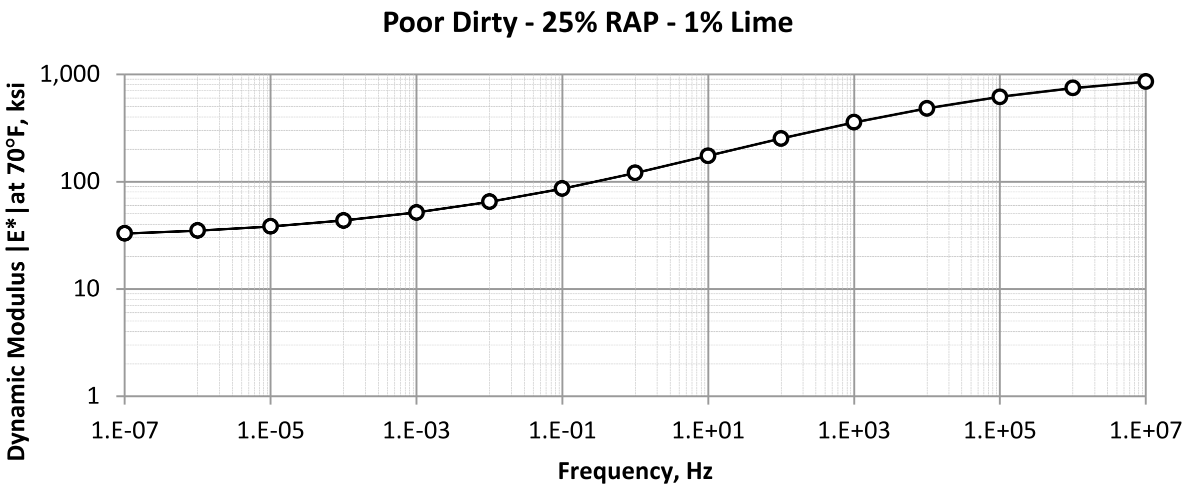
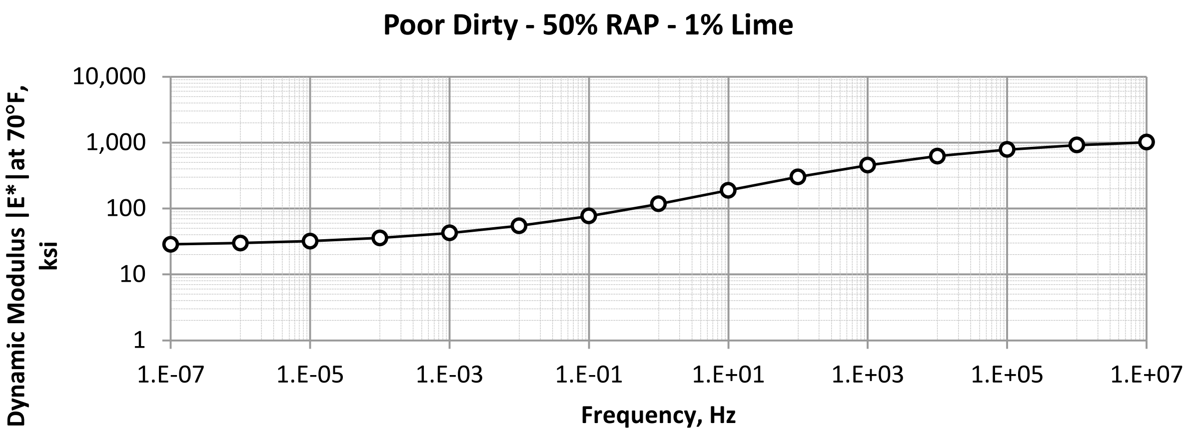


Figure 16: Average dynamic modulus at varying frequencies for the poor dirty asphalt emulsion samples with 1% lime at 37.8 and 54^{o}C





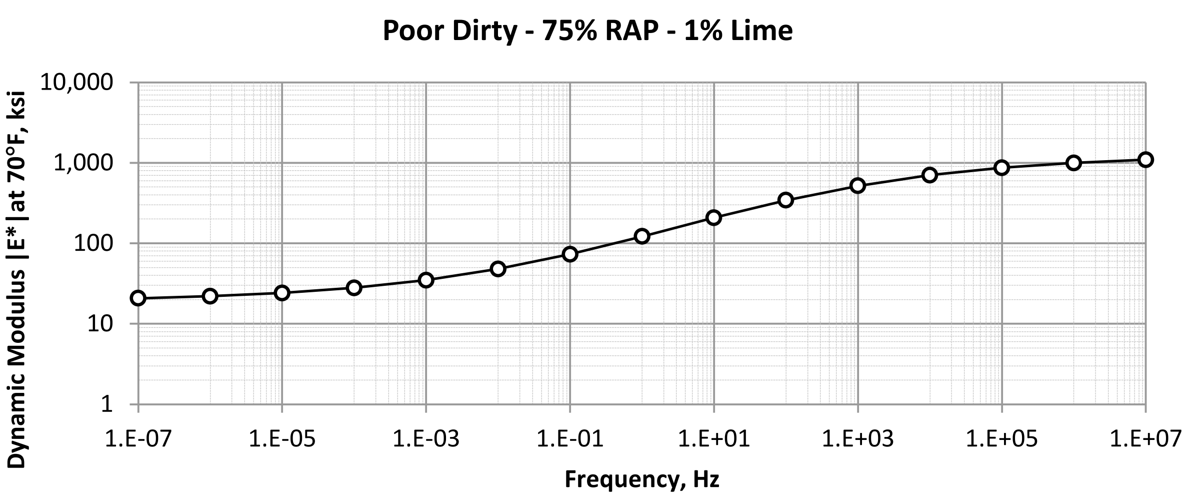
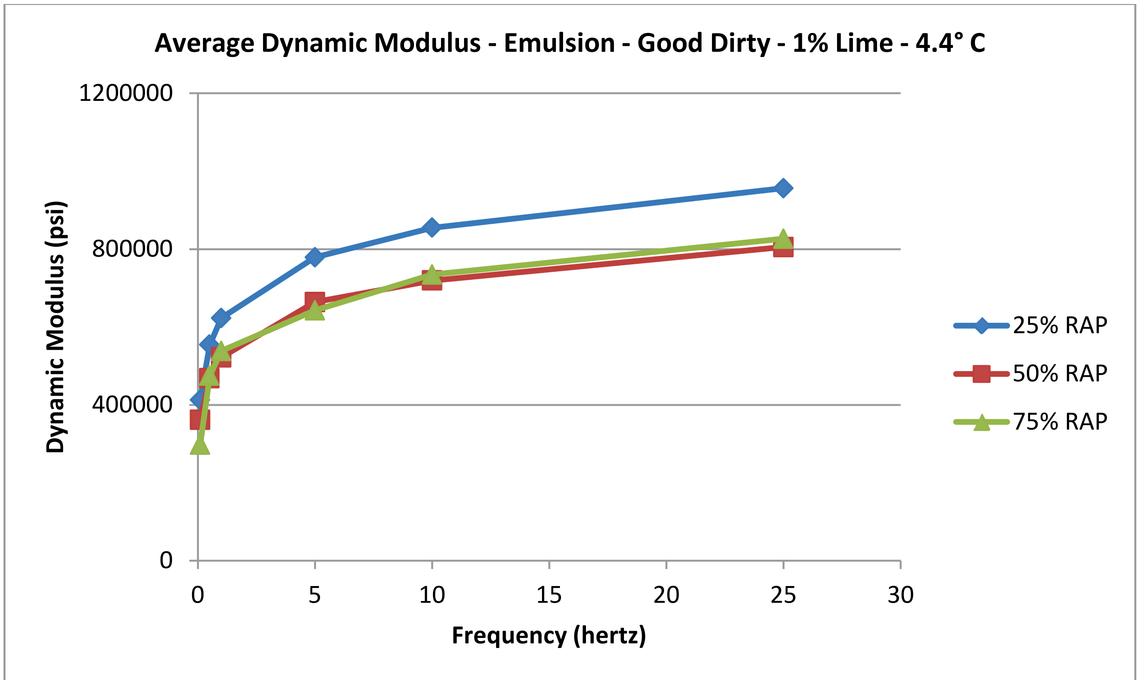


Figure 17: MEPDG E* master curves for the three percentages of RAP for poor dirty asphalt emulsion samples with 1% lime

Table 8: Average dynamic modulus results of good dirty asphalt emulsion samples with 1% lime

TEMP(°C)	Hz	Good Dirty - 25% RAP - 1% Lime		Good Dirty - 50% RAP - 1% Lime		Good Dirty - 75% RAP - 1% Lime	
		Avg E* (psi)	COV	Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	956344	3%	805096	7%	826547	10%
	10	854888	2%	719404	8%	734551	11%
	5	778714	5%	664074	8%	642432	11%
	1	622783	3%	521883	8%	538193	15%
	0.5	554183	5%	468420	10%	474850	16%
	0.1	412595	6%	361662	11%	297116	21%
21.1	25	362618	9%	308944	8%	235434	10%
	10	295026	9%	253341	8%	180892	12%
	5	250169	10%	217646	7%	149550	14%
	1	173338	14%	136865	10%	95936	17%
	0.5	154705	10%	126521	8%	86529	12%
	0.1	115526	11%	90670	6%	55222	10%
37.8	25	162042	13%	148143	7%	116614	10%
	10	123792	10%	115005	8%	91101	11%
	5	104948	11%	96350	9%	76427	11%
	1	72925	8%	64677	10%	51215	14%
	0.5	71325	11%	59882	11%	43791	12%
	0.1	56089	11%	48107	11%	34723	14%
54	25	88482	8%	75617	7%	54824	22%
	10	71532	8%	59290	7%	42391	22%
	5	62137	8%	50327	7%	36083	24%
	1	53584	8%	40103	8%	24257	22%
	0.5	50093	9%	36610	8%	23500	31%
	0.1	43023	10%	29396	8%	20800	21%

Note: The highlighted data represents COVs higher than 15%.



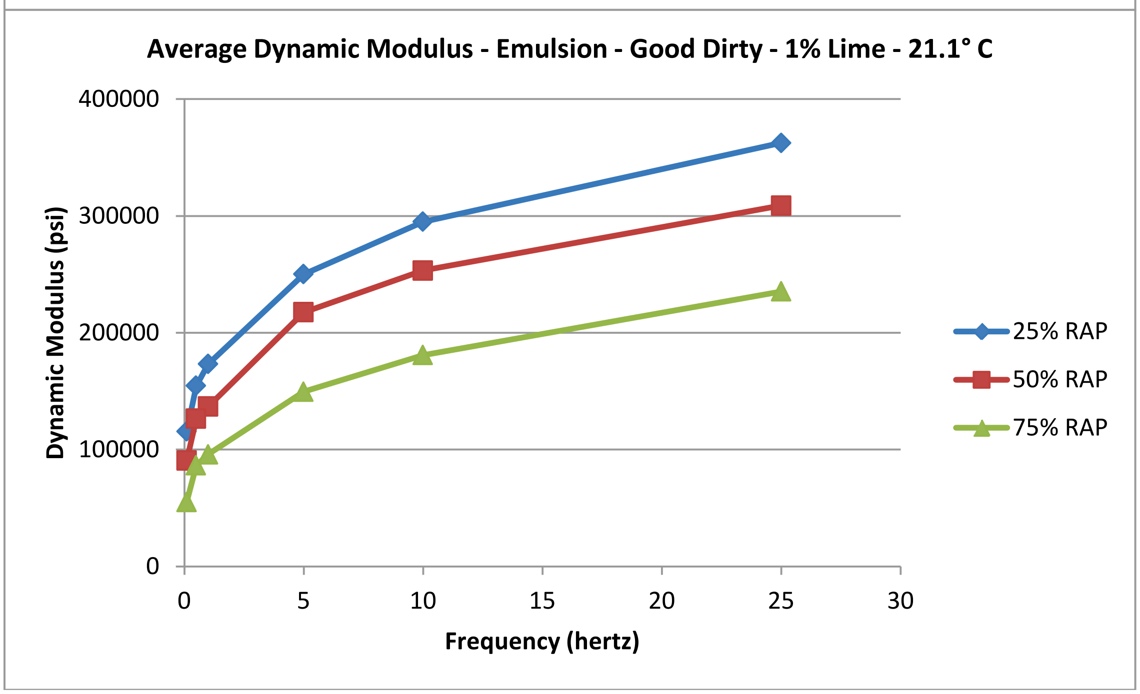


Figure 18: Average dynamic modulus at varying frequencies for the good dirty asphalt emulsion samples with 1% lime at 4.4 and 21.1^{o}C

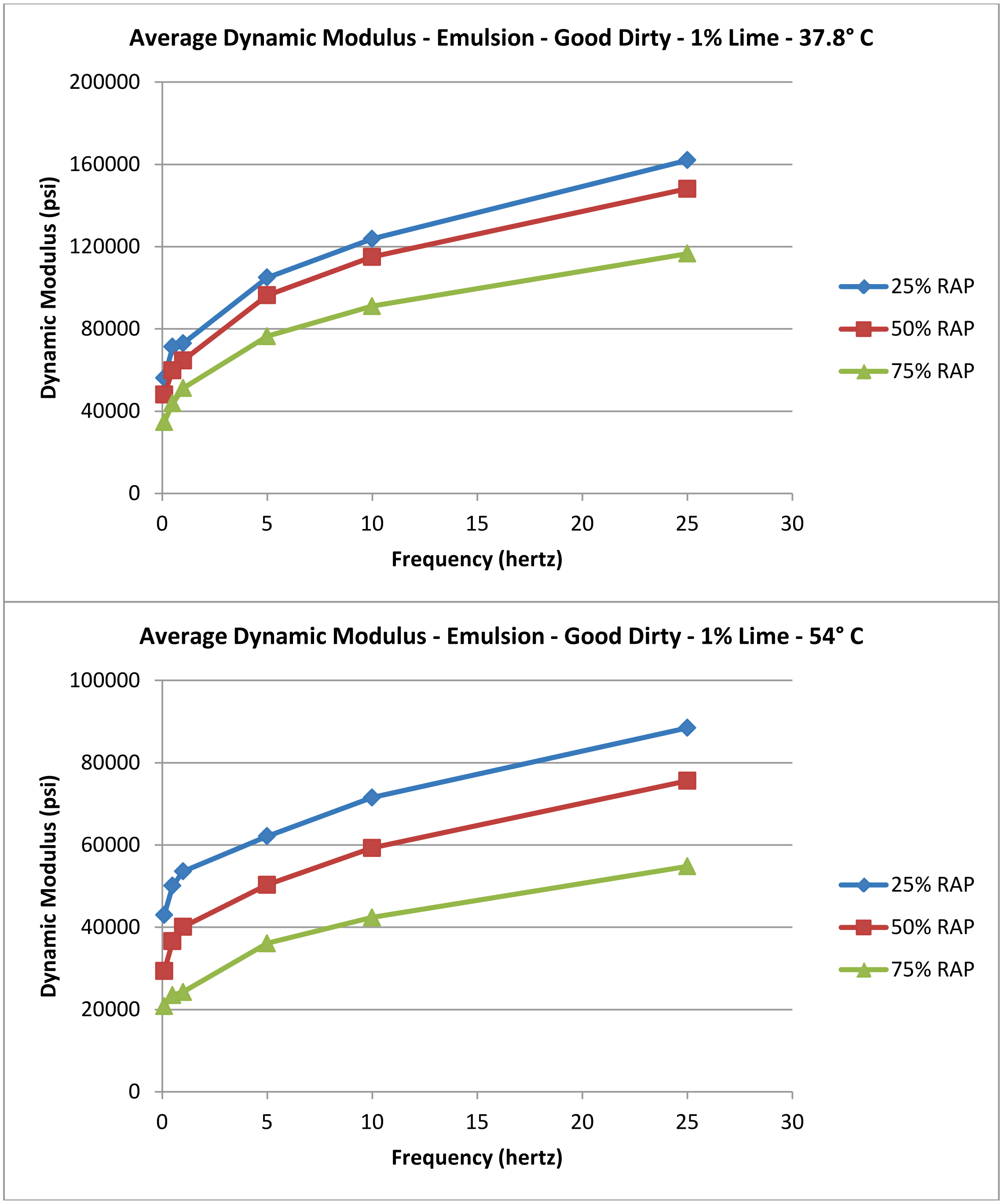


Figure 19: Average dynamic modulus at varying frequencies for the good dirty asphalt emulsion samples with 1% lime at 37.8 and 54^{o}C

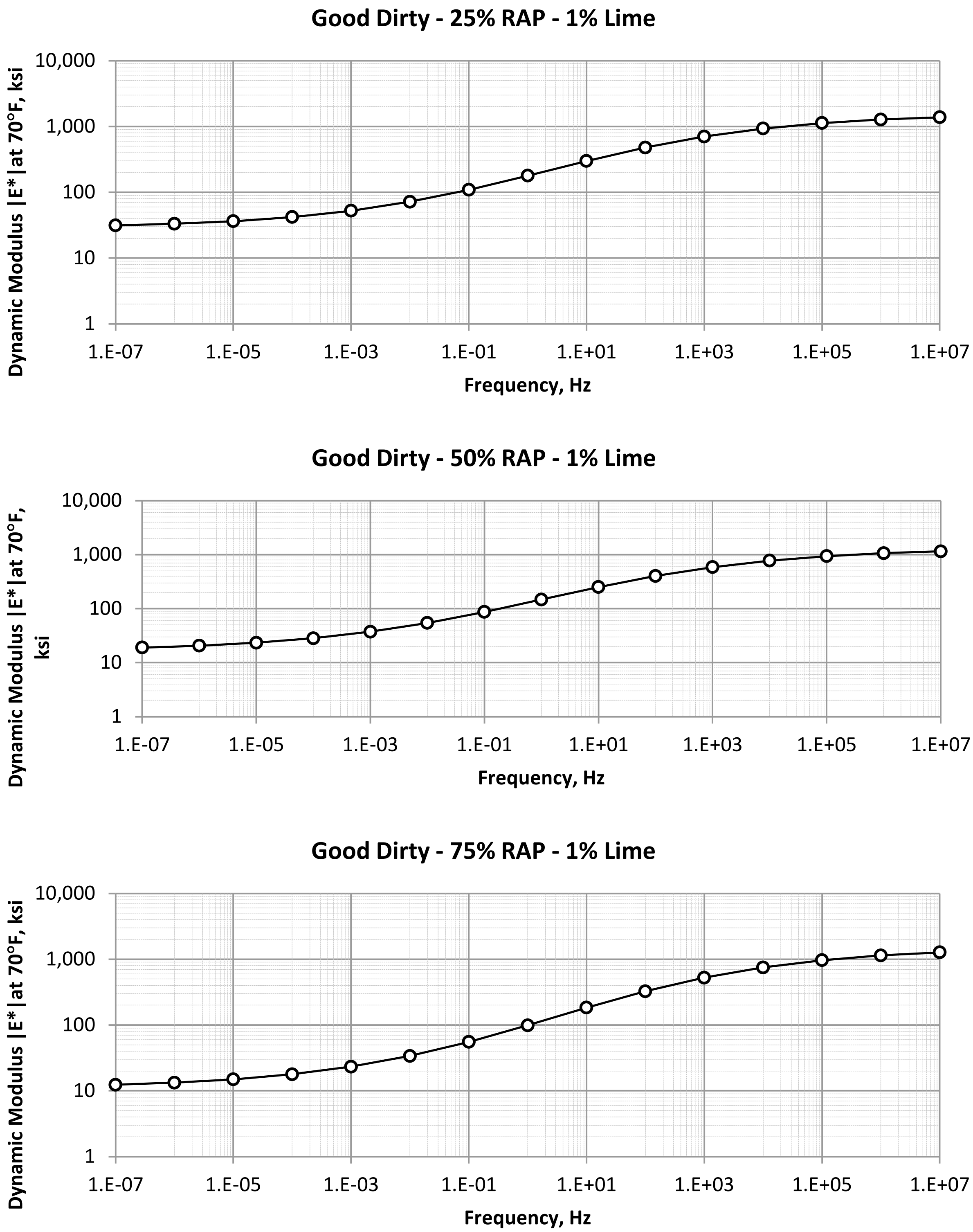


Figure 20: MEPDG E* master curves for the three percentages of RAP for good dirty asphalt emulsion samples with 1% lime

4.2.2 Foamed Asphalt Samples

4.2.2.1 Foamed Asphalt Samples With 1% Cement

Table 9 summarizes the average dynamic modulus results of poor clean foamed asphalt samples with 1% cement. The highlighted data represents COVs higher than 15% even with omitting one outlier. Shown in *Figures 21 and 22* are the average dynamic modulus values at the testing frequencies for the poor clean samples with 1% cement and each of the four testing temperatures. *Figure 23* shows the developed E* master curves for the three percentages of poor clean RAP samples with 1% cement.

Table 10 summarizes the average dynamic modulus results of poor dirty foamed asphalt samples with 1% cement. The highlighted data represents COVs higher than 15% even with omitting one outlier. Shown in *Figures 24 and 25* are the average dynamic modulus values at the testing frequencies for the poor dirty samples with 1% cement and each of the four testing temperatures. *Figure 26* shows the developed E* master curves for the three percentages of poor dirty RAP samples with 1% cement.

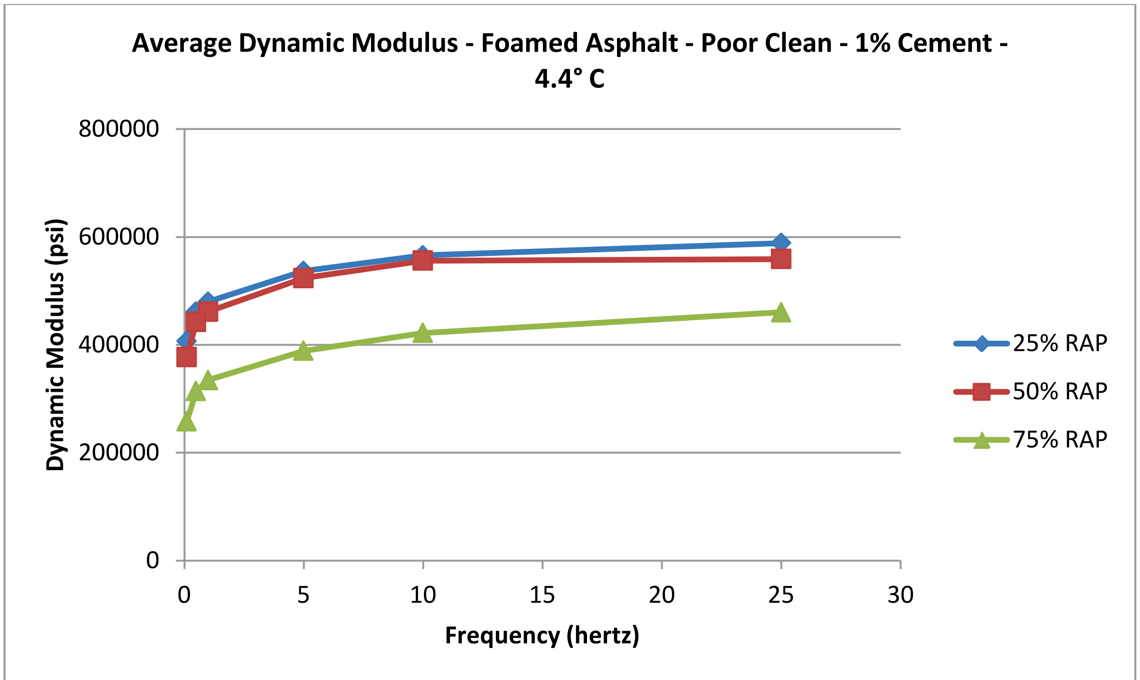
Table 11 summarizes the average dynamic modulus results of good clean foamed asphalt samples with 1% cement. The highlighted data represents COVs higher than 15% even with omitting one outlier. Shown in *Figures 27 and 28* are the average dynamic modulus values at the testing frequencies for the good clean samples with 1% cement and each of the four testing temperatures. *Figure 29* shows the developed E* master curves for the three percentages of good clean RAP samples with 1% cement.

Table 12 summarizes the average dynamic modulus results of good dirty foamed asphalt samples with 1% cement. The highlighted data represents COVs higher than 15% even with omitting one outlier. Shown in *Figures 30 and 31* are the average dynamic modulus values at the testing frequencies for the good dirty samples with 1% cement and each of the four testing temperatures. *Figure 32* shows the developed E* master curves for the three percentages of good dirty RAP samples with 1% cement.

Table 9: Average dynamic modulus results of poor clean foamed asphalt samples with 1% cement

TEMP(°C)	Hz	Poor Clean - 25% RAP - 1% Cement		Poor Clean - 50% RAP - 1% Cement		Poor Clean - 75% RAP - 1% Cement	
		Avg E* (psi)	COV	Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	588682	5%	558962	12%	460229	4%
	10	565919	6%	555963	11%	422187	6%
	5	536888	6%	523863	10%	388928	5%
	1	479845	8%	461555	10%	334717	9%
	0.5	461377	8%	442467	10%	314238	9%
	0.1	406803	9%	377349	10%	257925	10%
21.1	25	374674	15%	278297	16%	221963	3%
	10	341056	15%	253119	16%	202452	3%
	5	312318	16%	219558	13%	176172	3%
	1	245668	15%	161000	14%	121425	2%
	0.5	239014	13%	161475	9%	111160	2%
	0.1	194580	12%	126100	7%	84285	1%
37.8	25	259964	6%	162271	12%	129467	9%
	10	225435	6%	134805	11%	108322	8%
	5	200211	4%	115252	10%	93566	10%
	1	146150	3%	79360	9%	64579	9%
	0.5	127052	3%	74862	6%	58706	5%
	0.1	98174	3%	57614	3%	45145	3%
54	25	145173	8%	97975	12%	80579	6%
	10	117469	7%	76880	11%	65872	6%
	5	100535	7%	63000	12%	58569	2%
	1	69505	7%	44011	7%	39132	9%
	0.5	63961	6%	39813	8%	34034	6%
	0.1	52447	13%	30162	9%	26945	8%

Note: The highlighted data represents COVs higher than 15%.



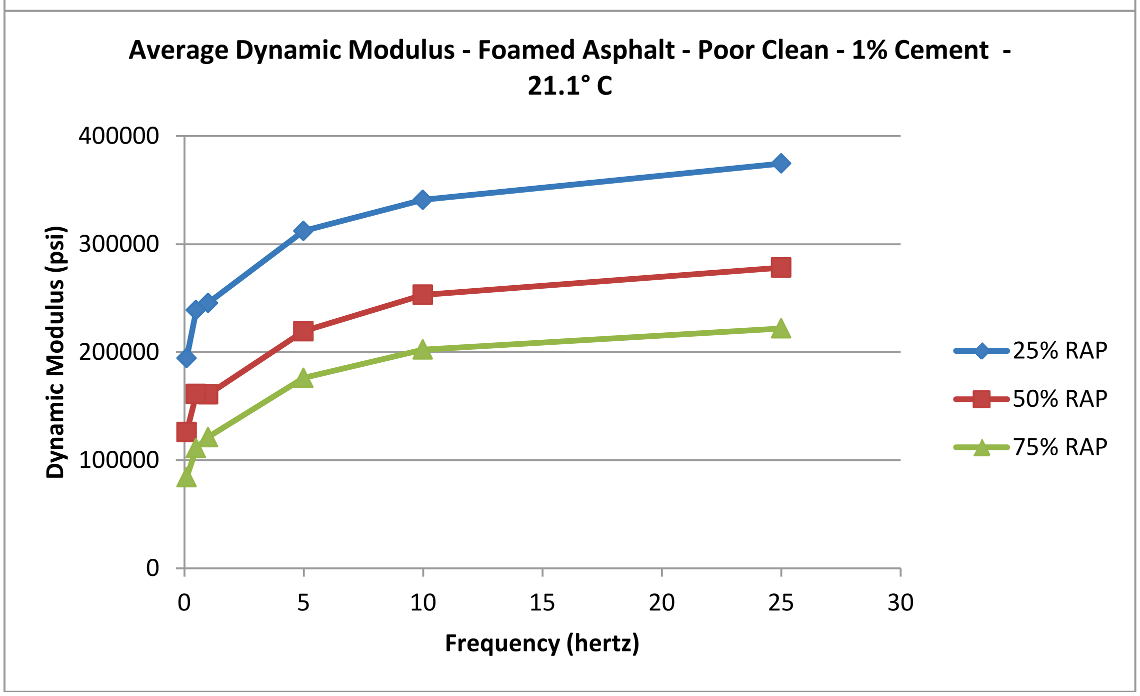
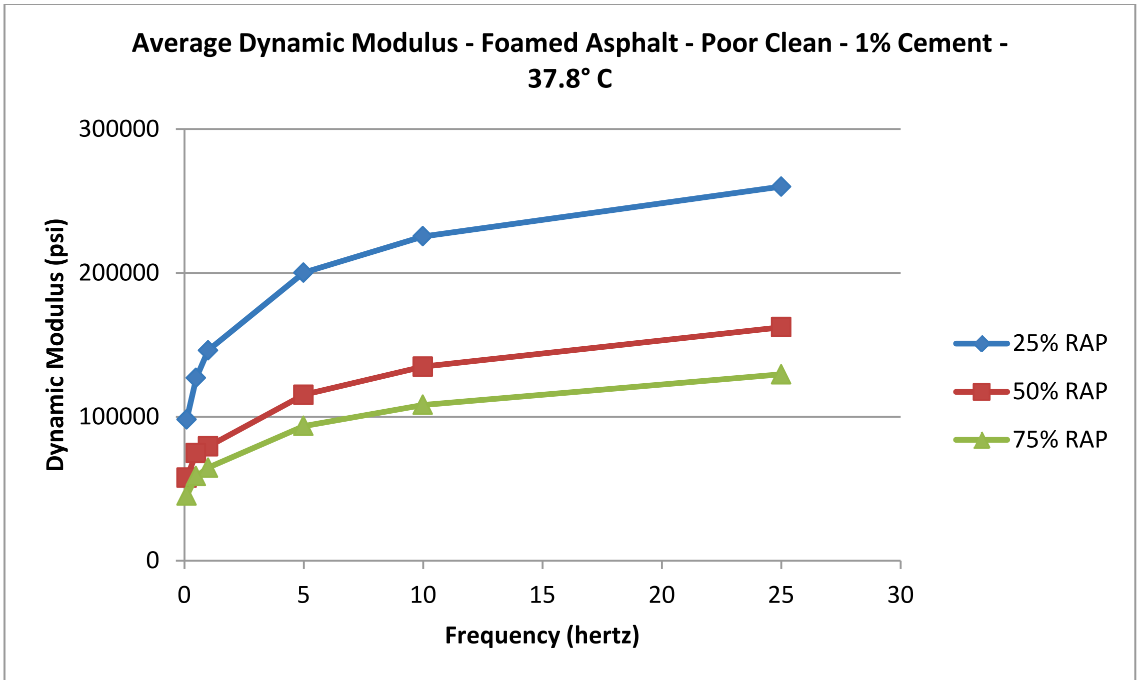


Figure 21: Average dynamic modulus at varying frequencies for the poor clean foamed asphalt samples with 1% cement at 4.4 and 21.1^{o}C



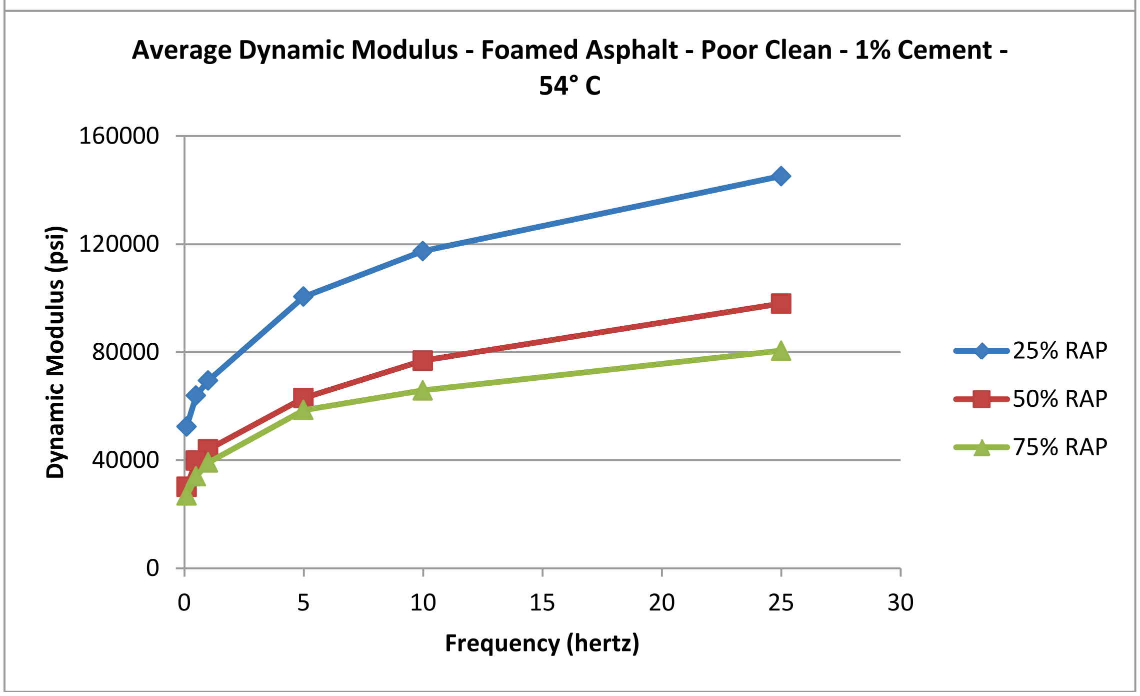
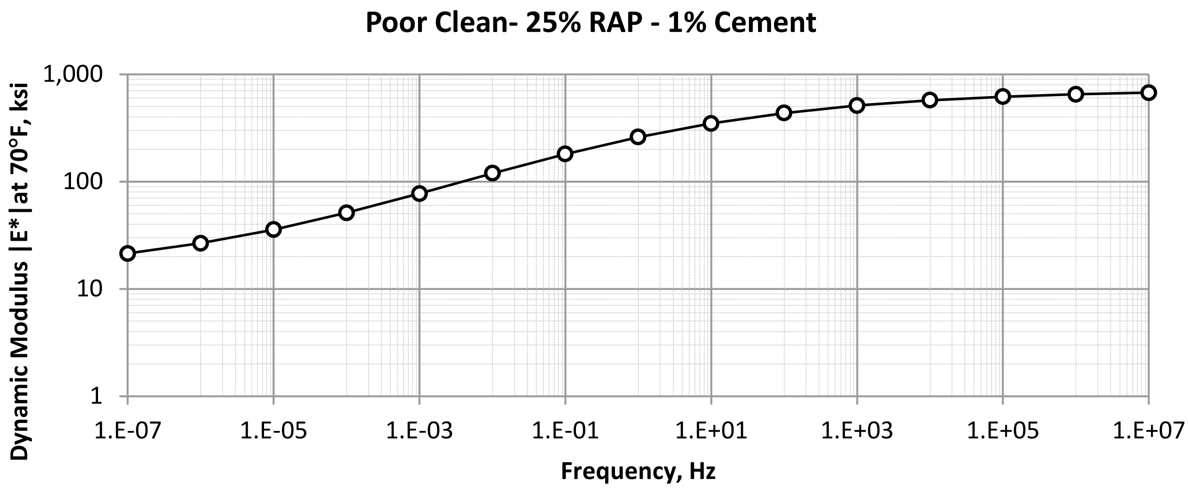
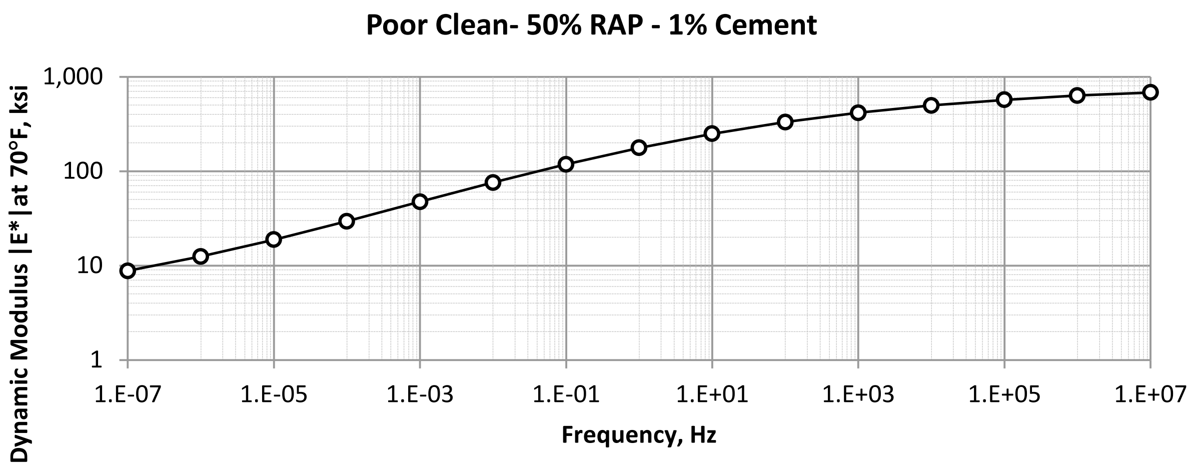


Figure 22: Average dynamic modulus at varying frequencies for the poor clean foamed asphalt samples with 1% cement at 37.8 and 54^{o}C





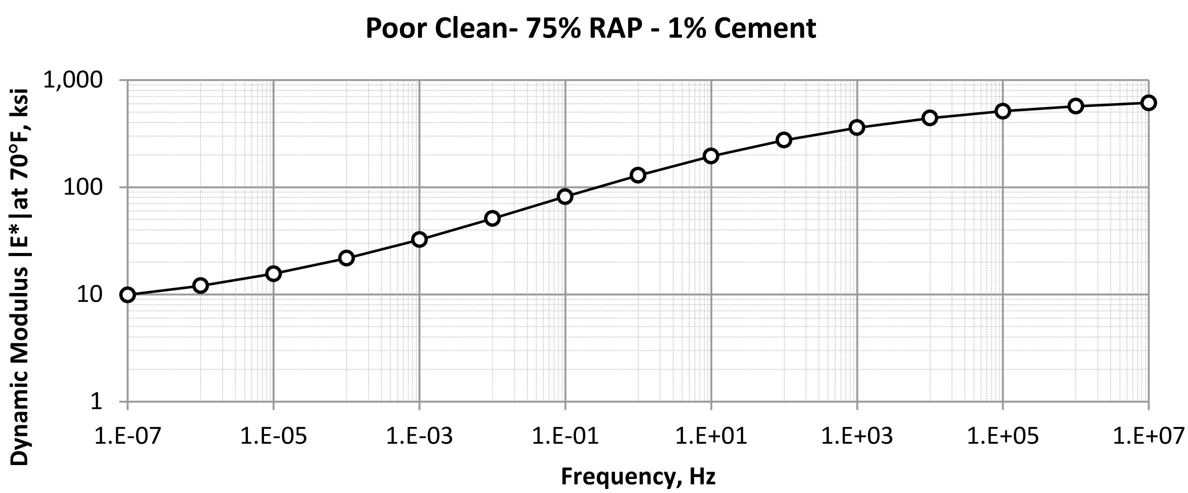


Figure 23: MEPDG E* master curves for the three percentages of RAP for poor clean foamed asphalt samples with 1% cement

Table 10: Average dynamic modulus results of poor dirty foamed asphalt samples with 1% cement

TEMP(°C)	Hz	Poor Dirty - 25% RAP - 1% Cement		Poor Dirty - 50% RAP - 1% Cement		Poor Dirty - 75% RAP - 1% Cement	
		Avg E* (psi)	COV	Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	455981	7%	409846	9%	894642	8%
	10	433262	7%	391816	10%	844599	9%
	5	422194	8%	379664	10%	807709	9%
	1	391391	10%	338596	9%	713232	10%
	0.5	368115	13%	325332	11%	672006	10%
	0.1	344264	7%	289031	11%	579314	11%
21.1	25	343346	4%	302087	10%	532113	3%
	10	319871	3%	280876	12%	481602	3%
	5	302787	3%	264632	14%	440451	3%
	1	262401	10%	219852	15%	349242	3%
	0.5	246123	9%	209572	12%	319578	3%
	0.1	205117	10%	175146	12%	247014	3%
37.8	25	239199	2%	176793	16%	311340	6%
	10	209840	2%	152000	13%	269170	6%
	5	190854	2%	137235	14%	235029	7%
	1	144973	2%	104277	16%	165894	8%
	0.5	134503	4%	98176	14%	147145	8%
	0.1	103546	5%	79076	14%	108076	8%
54	25	158867	12%	122846	15%	175236	3%
	10	135849	13%	104419	14%	139598	5%
	5	119140	12%	92901	14%	118436	5%
	1	85540	13%	68795	15%	79223	5%
	0.5	71155	10%	60815	11%	69597	5%
	0.1	54461	15%	48913	11%	51825	6%

Note: The highlighted data represents COVs higher than 15%.

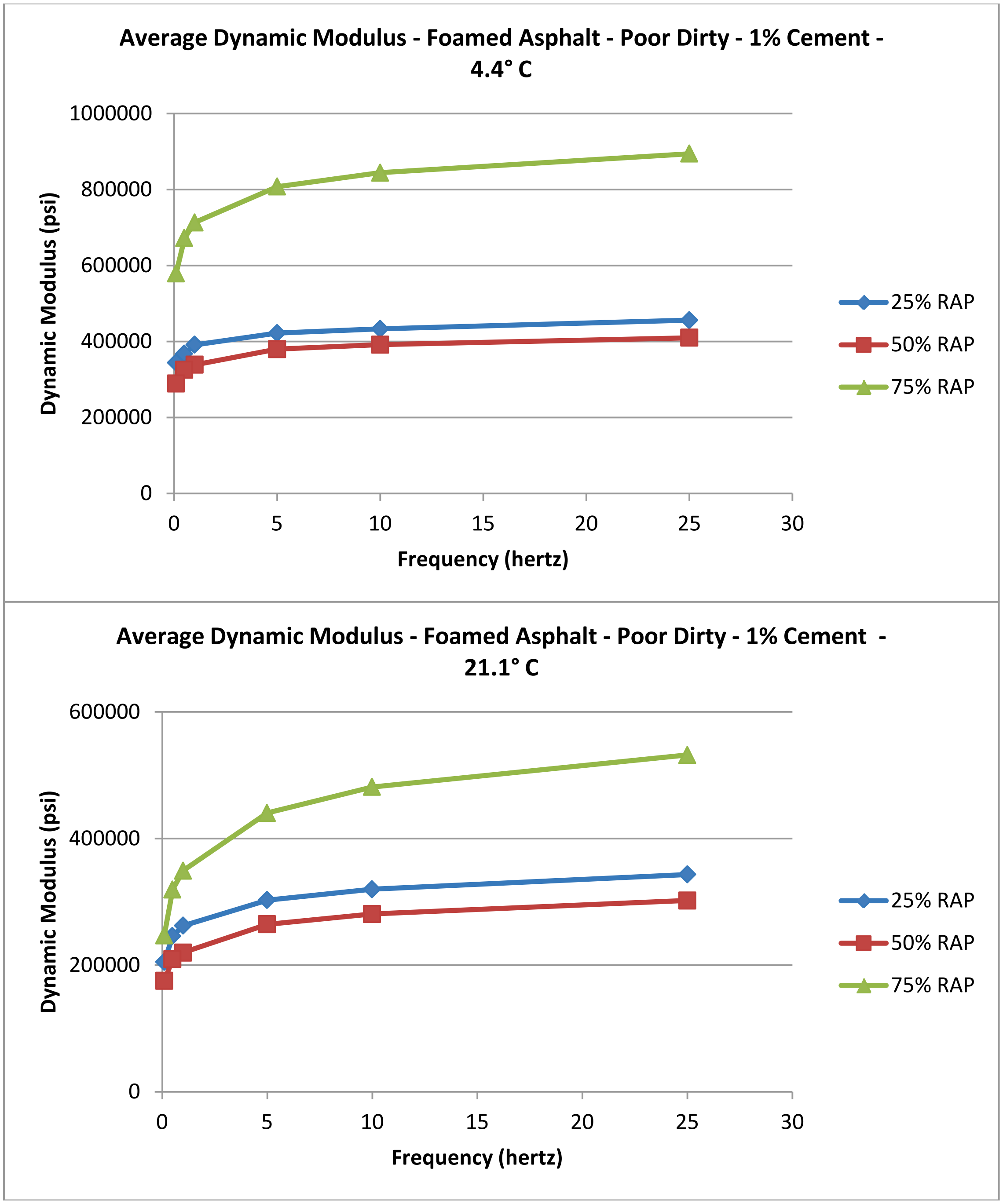


Figure 24: Average dynamic modulus at varying frequencies for the poor dirty foamed asphalt samples with 1% cement at 4.4 and 21.1^{o}C

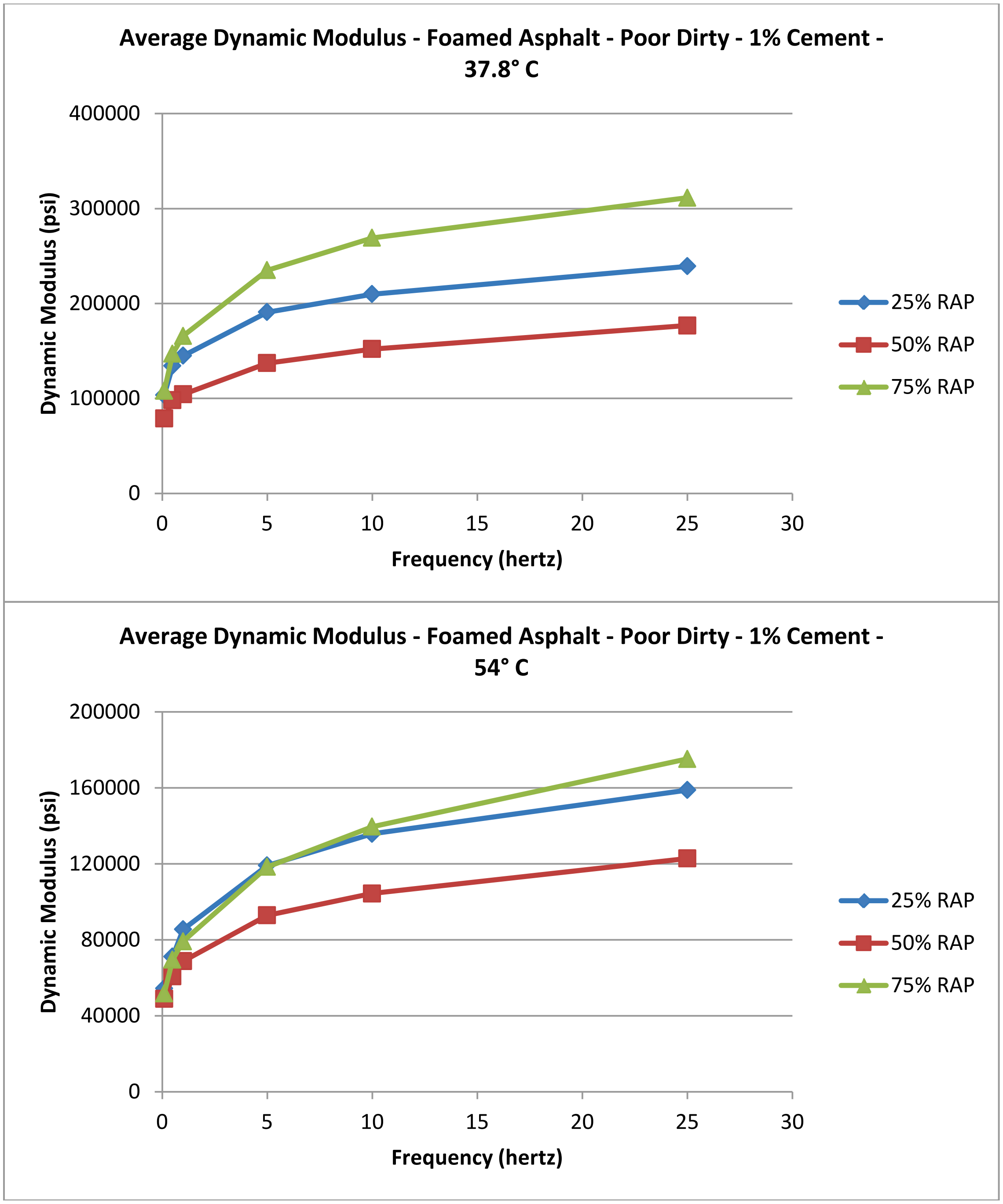
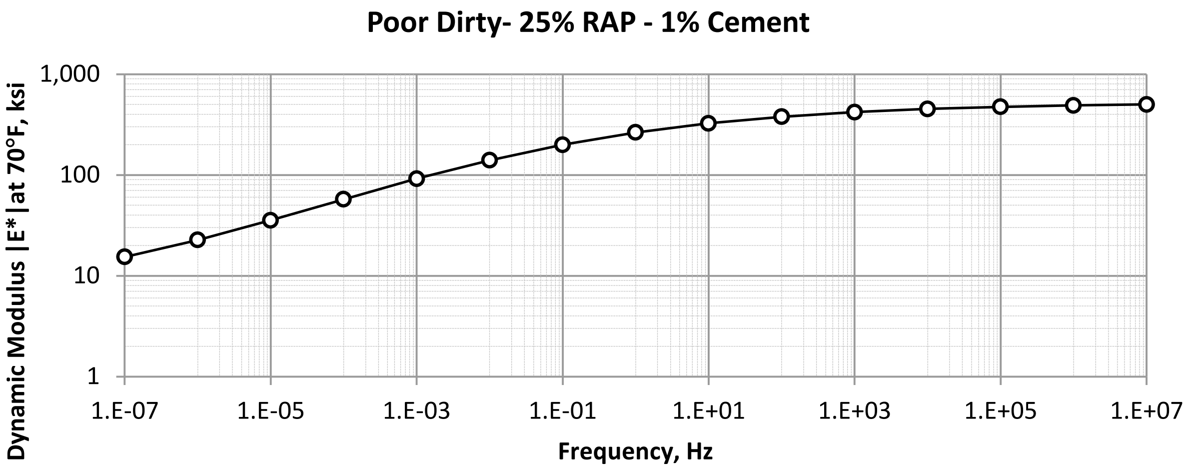
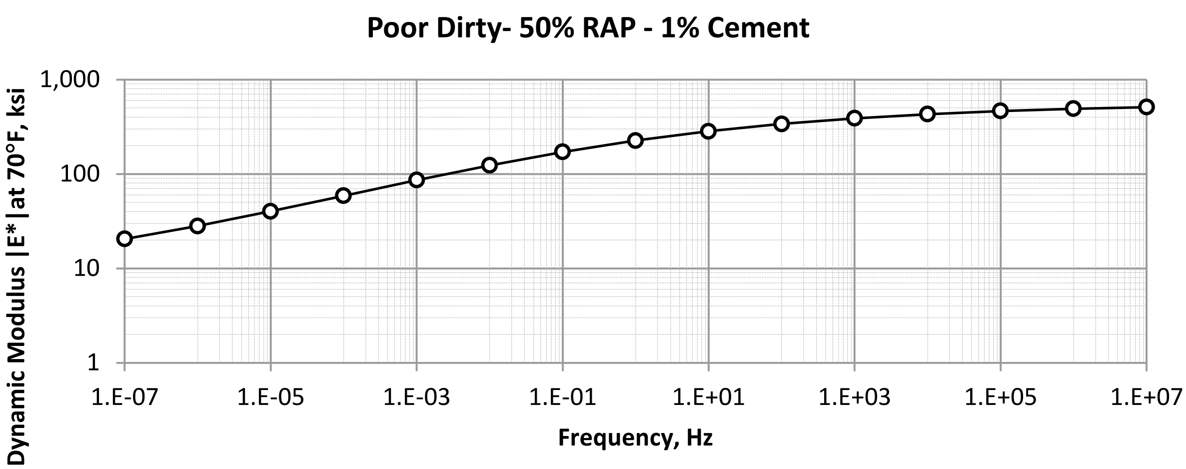


Figure 25: Average dynamic modulus at varying frequencies for the poor dirty foamed asphalt samples with 1% cement at 37.8 and 54°C





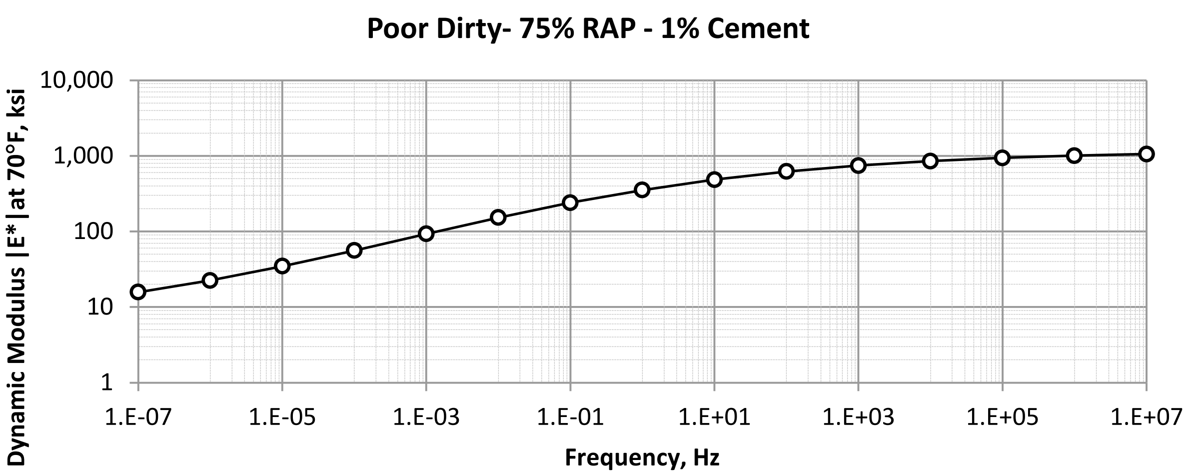


Figure 26: MEPDG E* master curves for the three percentages of RAP for poor dirty foamed asphalt samples with 1% cement

Table 11: Average dynamic modulus results of good clean foamed asphalt samples with 1% cement

TEMP(°C)	Hz	Good Clean - 25% RAP - 1% Cement		Good Clean - 50% RAP - 1% Cement		Good Clean - 75% RAP - 1% Cement	
		Avg E* (psi)	COV	Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	685242	18%	663156	17%	572017	21%
	10	640559	20%	637133	13%	483120	27%
	5	604596	21%	619735	9%	426554	28%
	1	512897	23%	537477	8%	374806	22%
	0.5	473962	23%	502453	9%	345644	21%
	0.1	399907	24%	424180	9%	287025	21%
21.1	25	444819	7%	377360	7%	294766	15%
	10	372644	9%	339987	10%	250810	16%
	5	336281	10%	320773	7%	202472	22%
	1	254312	10%	242986	11%	153952	20%
	0.5	243127	8%	219094	6%	141013	17%
	0.1	191791	8%	170830	10%	104763	16%
37.8	25	238635	16%	195437	12%	140860	11%
	10	202981	15%	160774	13%	117568	12%
	5	179444	16%	139102	14%	101877	13%
	1	130862	16%	100807	15%	68443	15%
	0.5	107305	11%	91592	10%	60409	14%
	0.1	98632	11%	69925	9%	45347	12%
54	25	134577	21%	107143	8%	86120	11%
	10	112707	20%	84208	13%	69215	12%
	5	98807	19%	72241	15%	59586	11%
	1	75883	19%	49987	14%	41759	9%
	0.5	68269	17%	47696	8%	36367	3%
	0.1	56948	17%	40650	3%	28129	9%

Note: The highlighted data represents COVs higher than 15%.

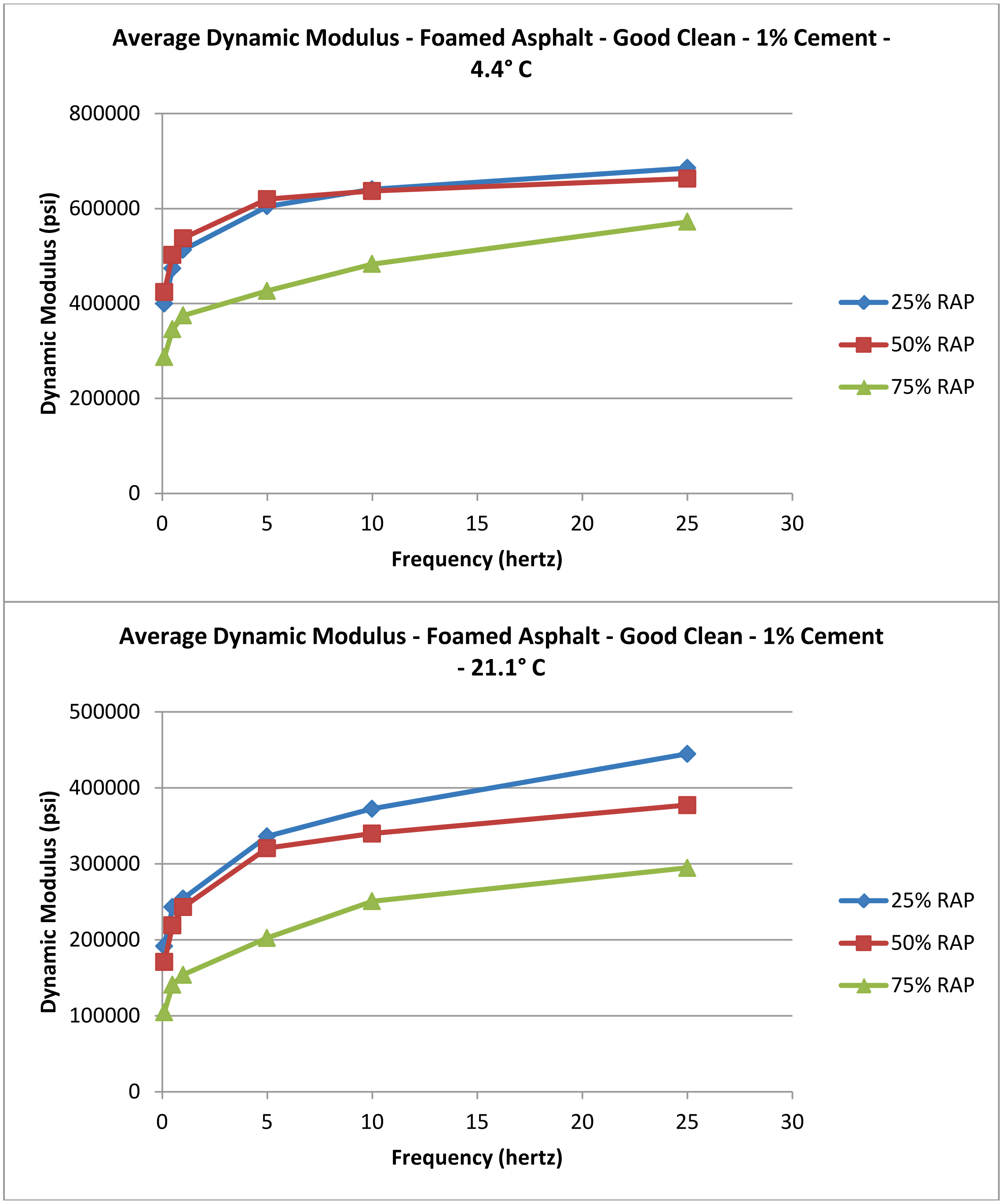


Figure 27: Average dynamic modulus at varying frequencies for the good clean foamed asphalt samples with 1% cement at 4.4 and 21.1^{o}C

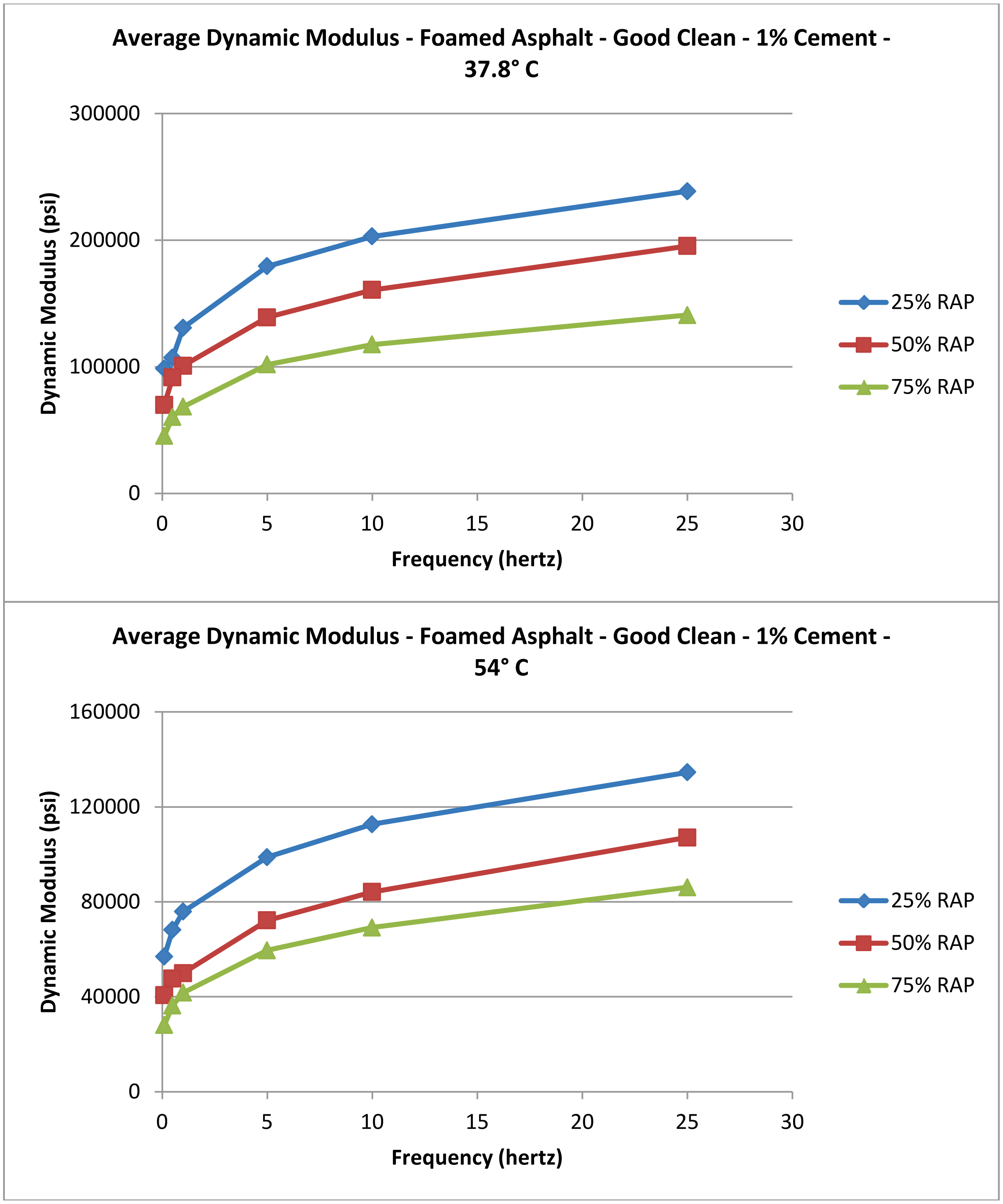


Figure 28: Average dynamic modulus at varying frequencies for the good clean foamed asphalt samples with 1% cement at 37.8 and 54^{o}C

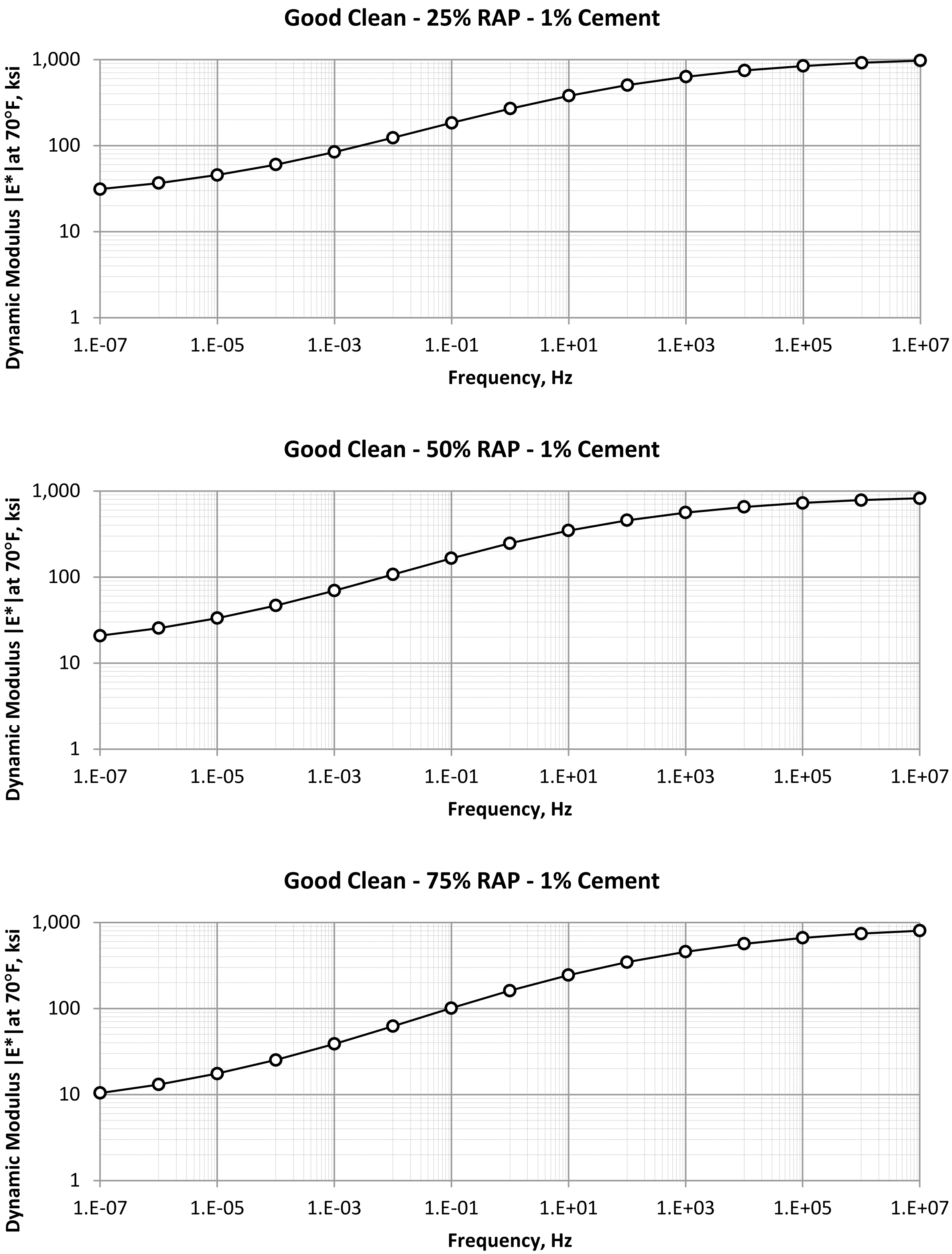


Figure 29: MEPDG E* master curves for the three percentages of RAP for good clean foamed asphalt samples with 1% cement

Table 12: Average dynamic modulus results of good dirty foamed asphalt samples with 1% cement

TEMP(°C)	Hz	Good Dirty - 25% RAP - 1% Cement		Good Dirty - 50% RAP - 1% Cement		Good Dirty - 75% RAP - 1% Cement	
		Avg E* (psi)	COV	Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	1033515	2%	945882	3%	350915	14%
	10	1000724	4%	897314	4%	317466	14%
	5	953629	5%	857775	4%	294417	11%
	1	854419	10%	736295	5%	255700	13%
	0.5	747789	14%	687572	6%	256867	10%
	0.1	682696	7%	573535	8%	197855	14%
21.1	25	663915	3%	530524	14%	184912	4%
	10	618746	2%	479964	14%	159066	4%
	5	573247	2%	435166	13%	136355	5%
	1	454998	2%	341405	15%	94192	4%
	0.5	416085	2%	311779	15%	100912	1%
	0.1	332179	3%	242244	15%	79418	1%
37.8	25	374771	5%	271078	13%	119971	7%
	10	318202	5%	231190	14%	100611	7%
	5	283491	8%	199340	13%	88968	6%
	1	202529	10%	134891	13%	58878	6%
	0.5	176685	9%	114188	14%	53019	9%
	0.1	137419	10%	75314	5%	40680	9%
54	25	183078	9%	145522	8%	68616	4%
	10	149383	10%	118466	8%	53772	5%
	5	129758	13%	97011	7%	46258	5%
	1	94491	12%	68987	10%	34939	6%
	0.5	81195	13%	56617	3%	30961	5%
	0.1	66315	14%	41456	4%	25778	5%

Note: The highlighted data represents COVs higher than 15%.

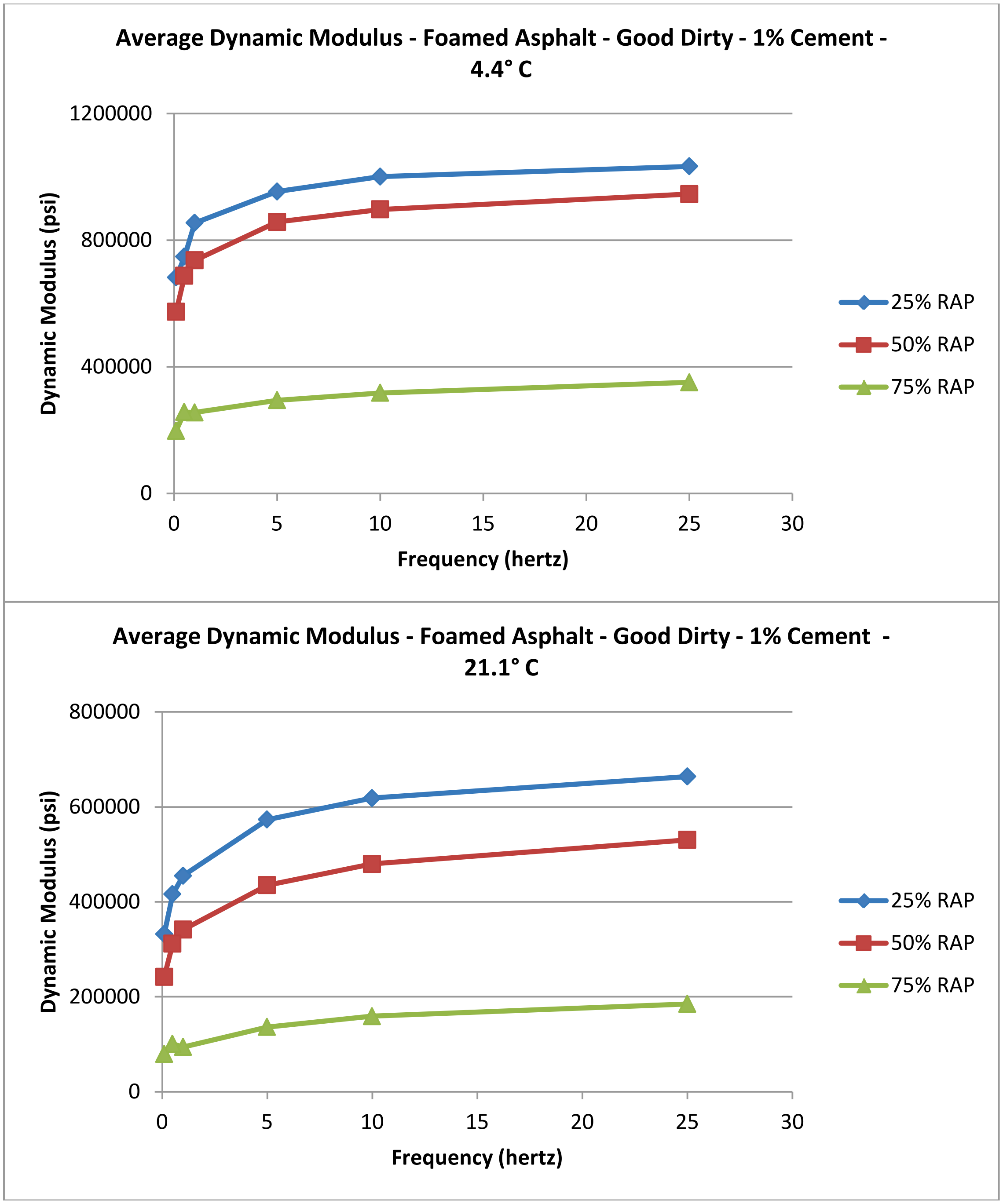


Figure 30: Average dynamic modulus at varying frequencies for good dirty foamed asphalt samples with 1% cement at 4.4 and 21.1°C

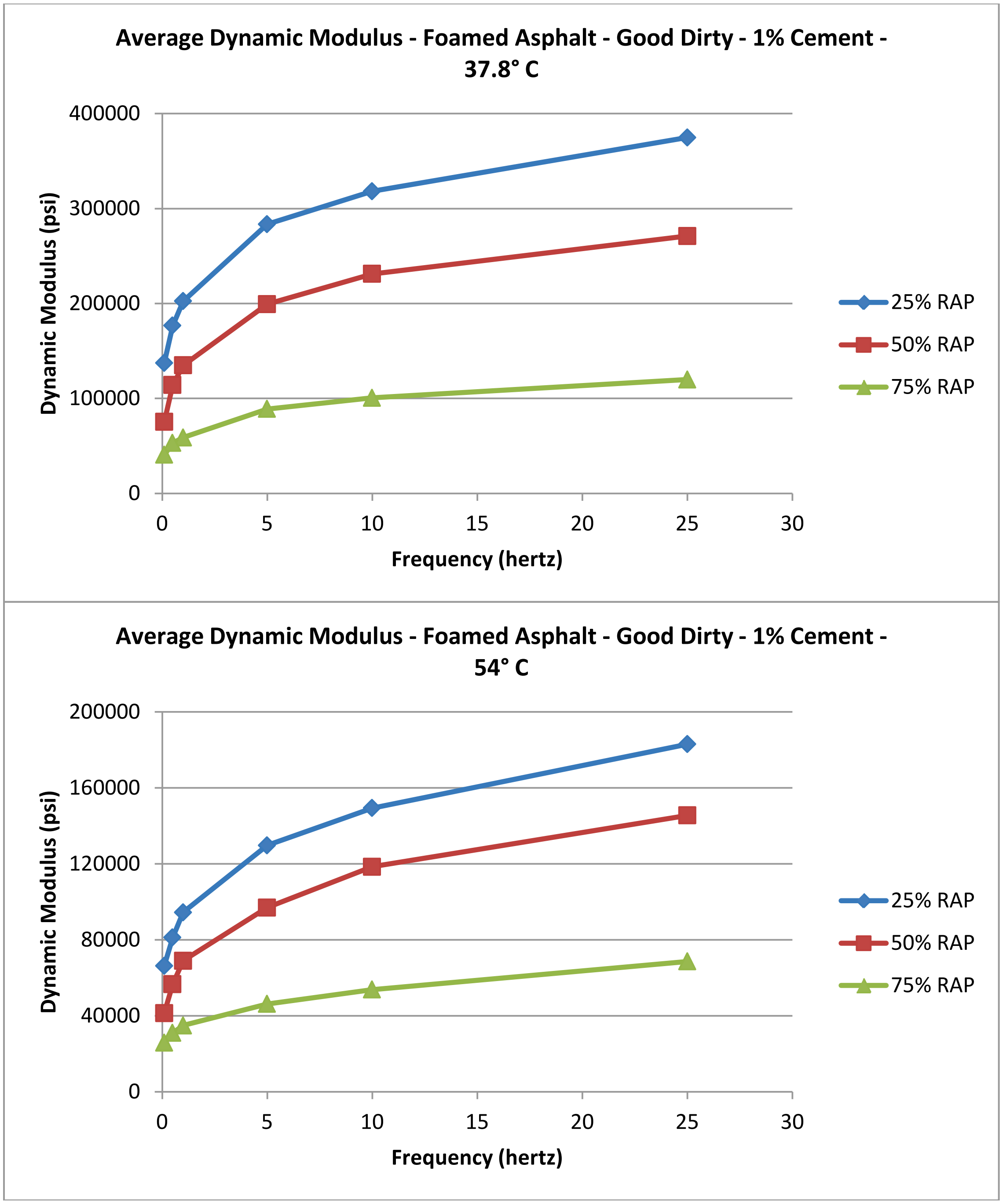
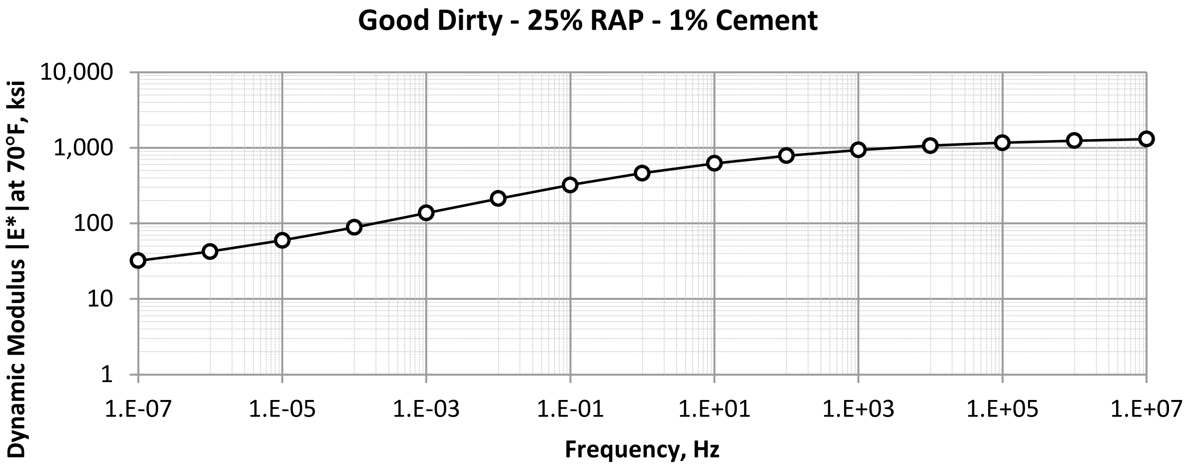
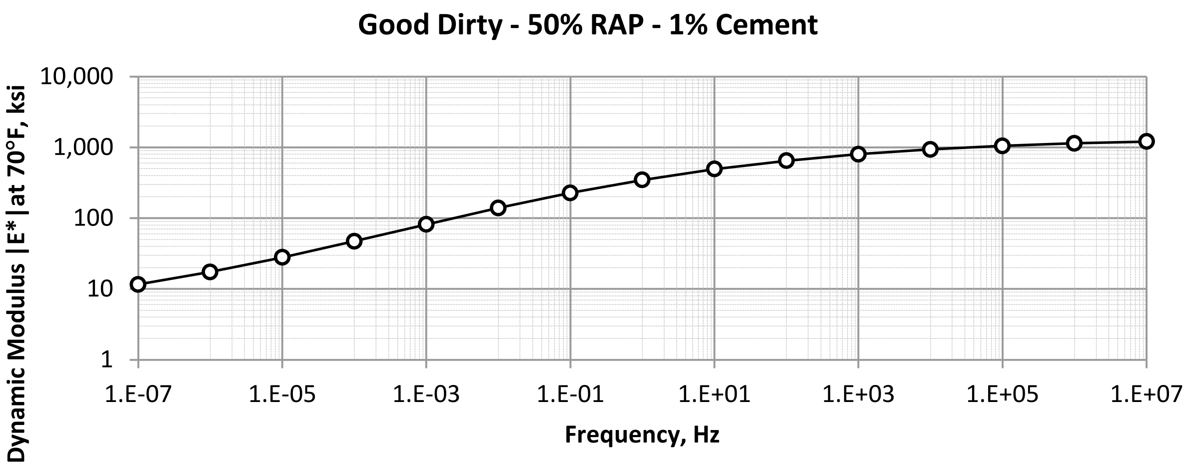


Figure 31: Average dynamic modulus at varying frequencies for good dirty foamed asphalt samples with 1% cement at 37.8 and 54^{o}C





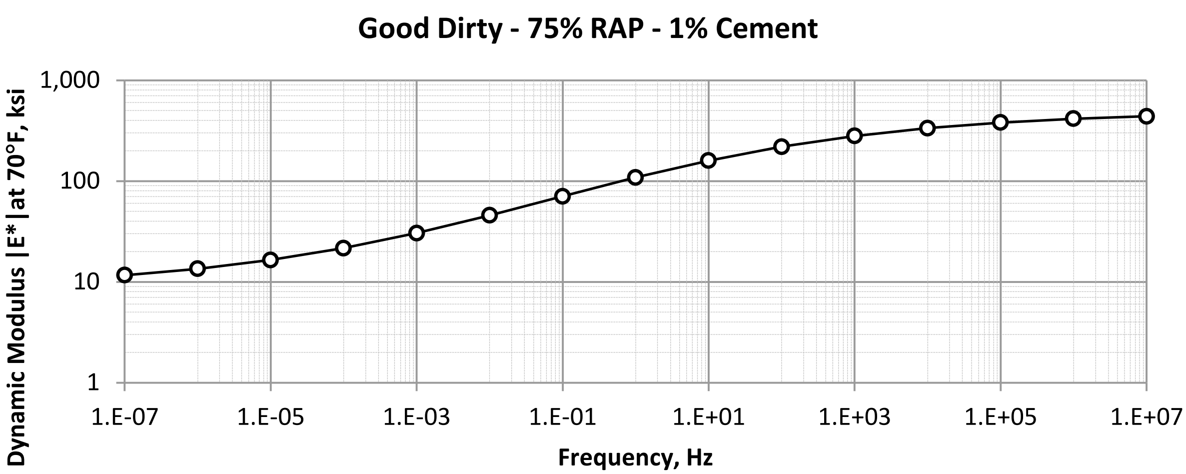


Figure 32: MEPDG E* master curves for the three percentages of RAP for good dirty foamed asphalt samples with 1% cement

4.2.2.2 Foamed Asphalt Samples With 2% Cement

Table 13 summarizes the average dynamic modulus results of poor clean foamed asphalt with 2% cement samples. The highlighted data represents COVs higher than 15% even with omitting one outlier. Shown in *Figures 33 and 34* are the average dynamic modulus values at the testing frequencies for the poor clean samples with 2% cement and each of the four testing temperatures. *Figure 35* shows the developed E* master curves for the three percentages of poor clean RAP samples with lime.

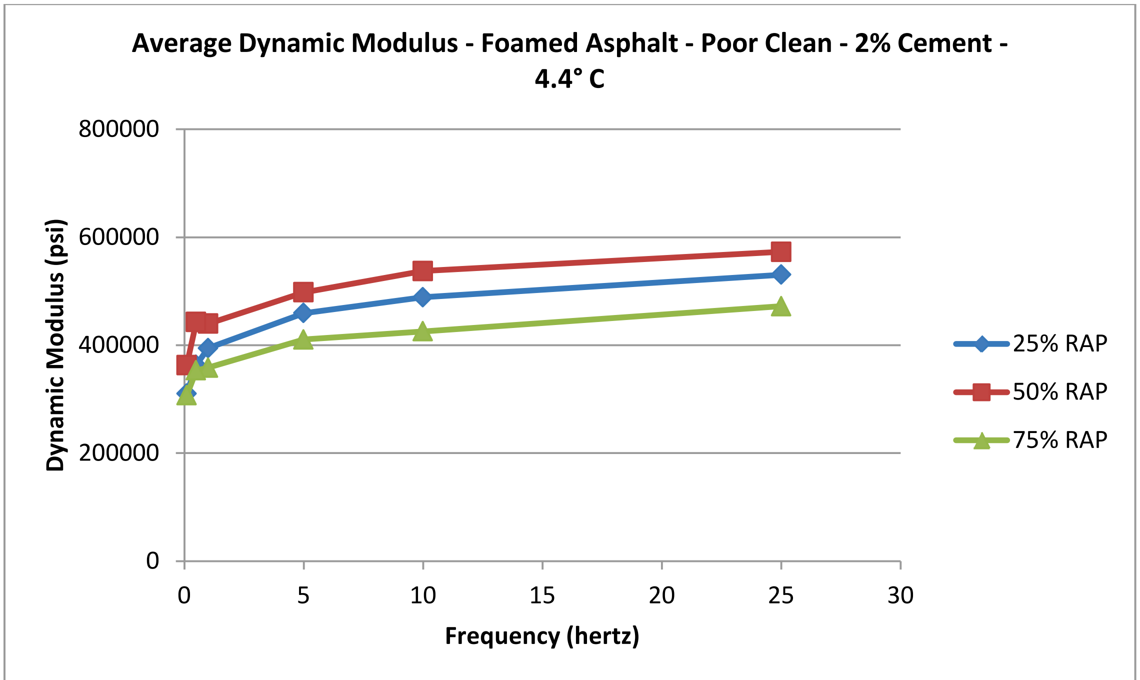
Table 14 summarizes the average dynamic modulus results of good clean foamed asphalt with 2% cement samples. The highlighted data represents COVs higher than 15% even with omitting one outlier. Shown in *Figures 36 and 37* are the average dynamic modulus values at the testing frequencies for the good clean samples with 2% cement and each of the four testing temperatures. *Figure 38* shows the developed E* master curves for the three percentages of good clean RAP samples with lime.

Table 15 summarizes the average dynamic modulus results of good and poor dirty foamed asphalt with 2% cement samples. The highlighted data represents COVs higher than 15% even with omitting one outlier. Shown in *Figures 39 and 40* are the average dynamic modulus values at the testing frequencies for the good and poor dirty samples with 2% cement and each of the four testing temperatures. *Figure 41* shows the developed E* master curves for the three percentages of good and poor dirty RAP samples with lime.

Table 13: Average dynamic modulus results of poor clean foamed asphalt samples with 2% cement

TEMP(°C)	Hz	Poor Clean - 25% RAP - 2% Cement		Poor Clean - 50% RAP - 2% Cement		Poor Clean - 75% RAP - 2% Cement	
		Avg E* (psi)	COV	Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	530514	5%	573129	10%	472197	2%
	10	488955	6%	537293	11%	425583	5%
	5	459538	6%	498023	14%	410652	3%
	1	394557	7%	439790	10%	358404	6%
	0.5	363541	7%	443185	10%	353257	2%
	0.1	310282	7%	363267	14%	307083	3%
21.1	25	289578	8%	322263	3%	222078	13%
	10	257056	8%	282446	3%	198766	13%
	5	232583	8%	256080	4%	180086	13%
	1	178786	9%	197881	5%	140188	13%
	0.5	169995	6%	191135	3%	138928	9%
	0.1	138005	5%	148144	3%	110649	9%
37.8	25	211636	12%	211494	7%	148244	15%
	10	180302	10%	174228	7%	128596	14%
	5	159612	10%	151139	8%	113391	14%
	1	115945	9%	107697	4%	83650	12%
	0.5	109944	8%	95492	3%	77296	11%
	0.1	87327	7%	70026	4%	63954	7%
54	25	131700	13%	112612	6%	78847	8%
	10	117199	10%	87625	4%	65049	8%
	5	102724	12%	72452	6%	54778	9%
	1	70800	10%	50605	8%	41674	7%
	0.5	62246	13%	45819	5%	36934	7%
	0.1	51765	13%	32382	6%	29264	4%

Note: The highlighted data represents COVs higher than 15%.



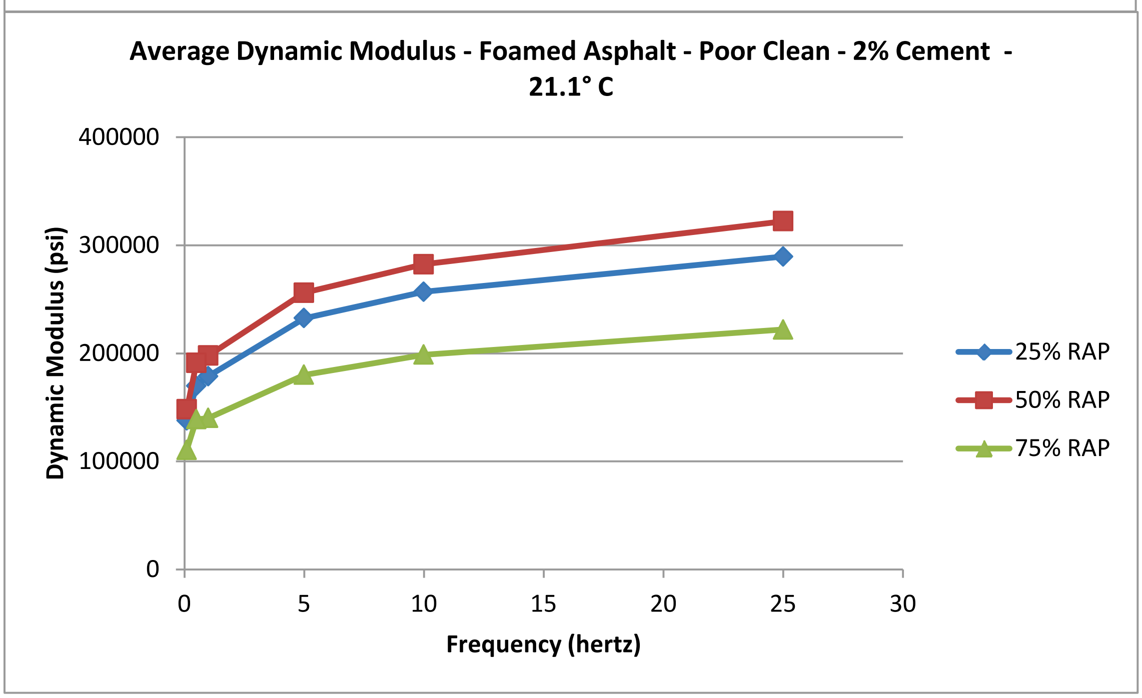
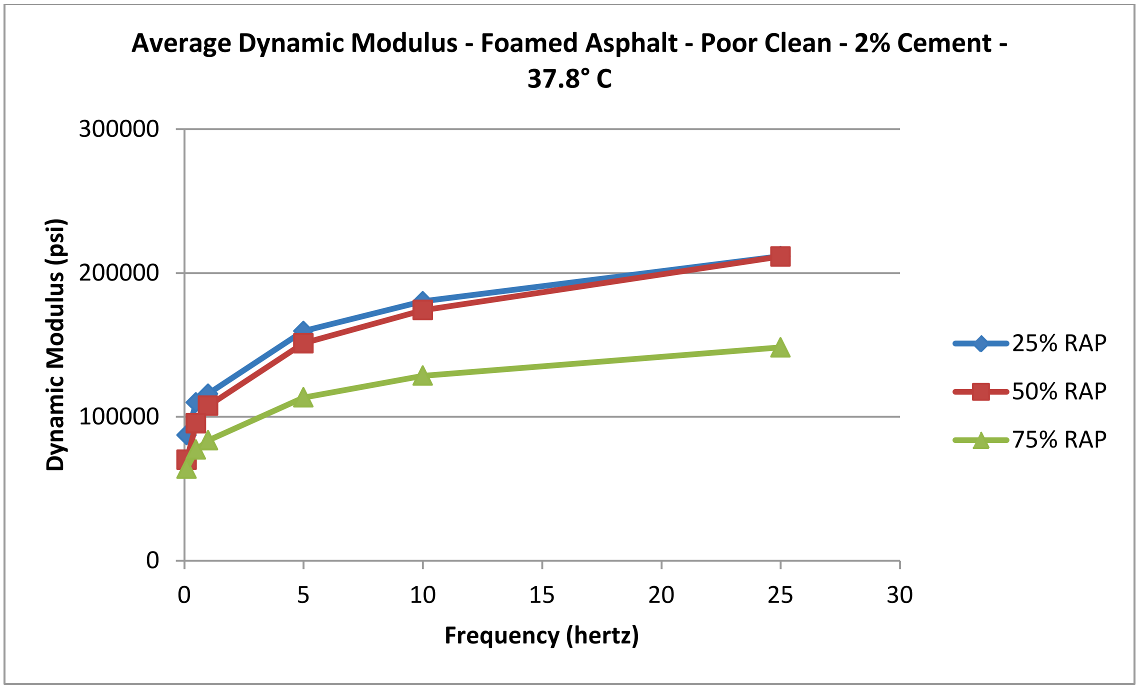


Figure 33: Average dynamic modulus at varying frequencies for the poor clean foamed asphalt samples with 2% cement at 4.4 and 21.1°C



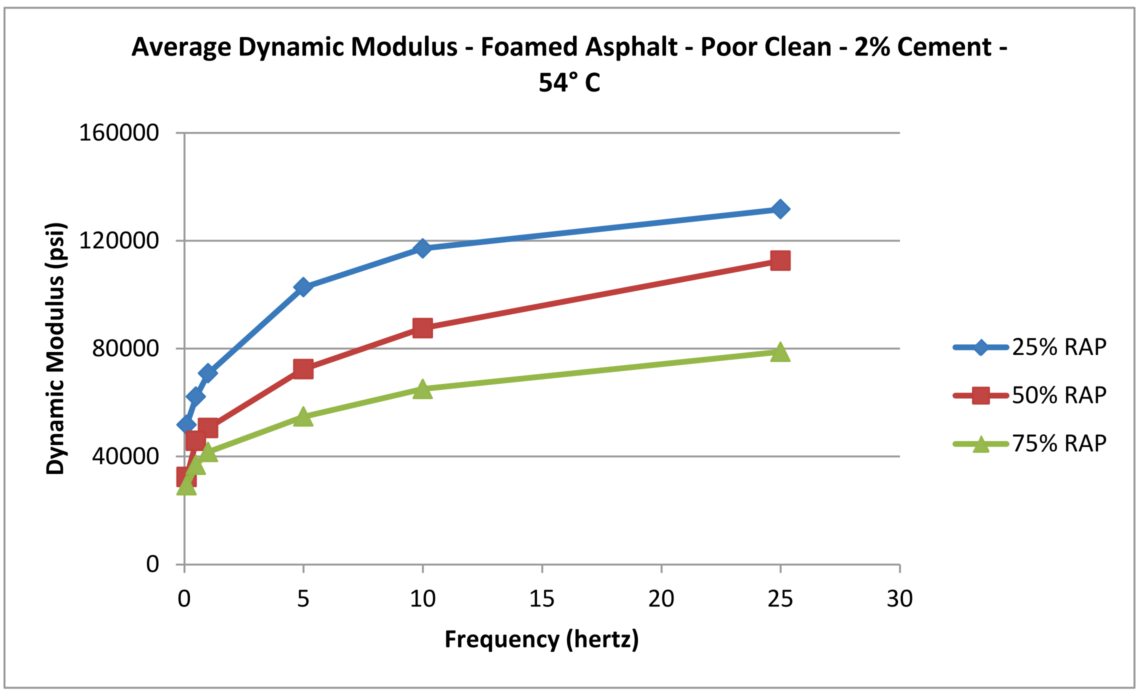
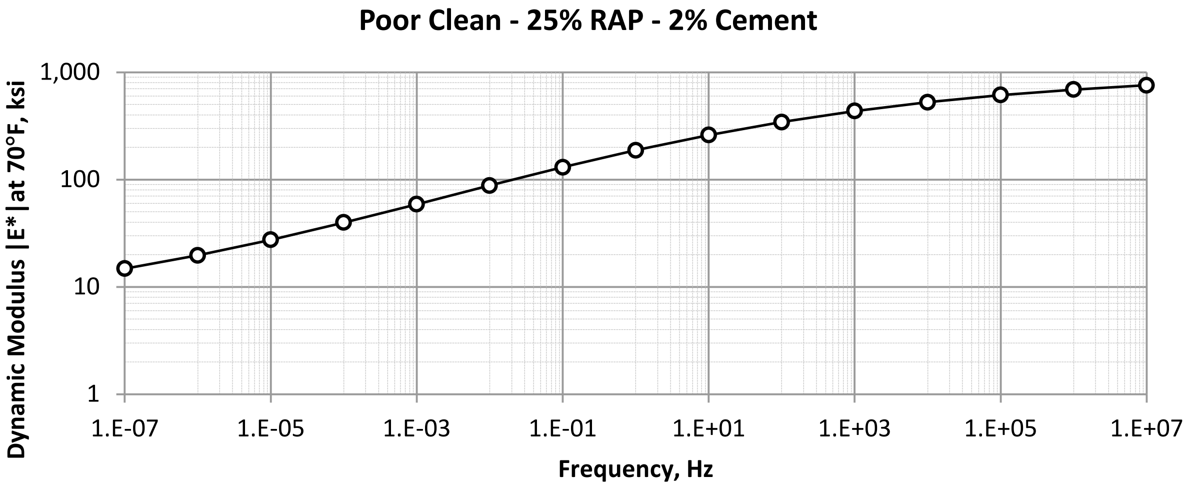
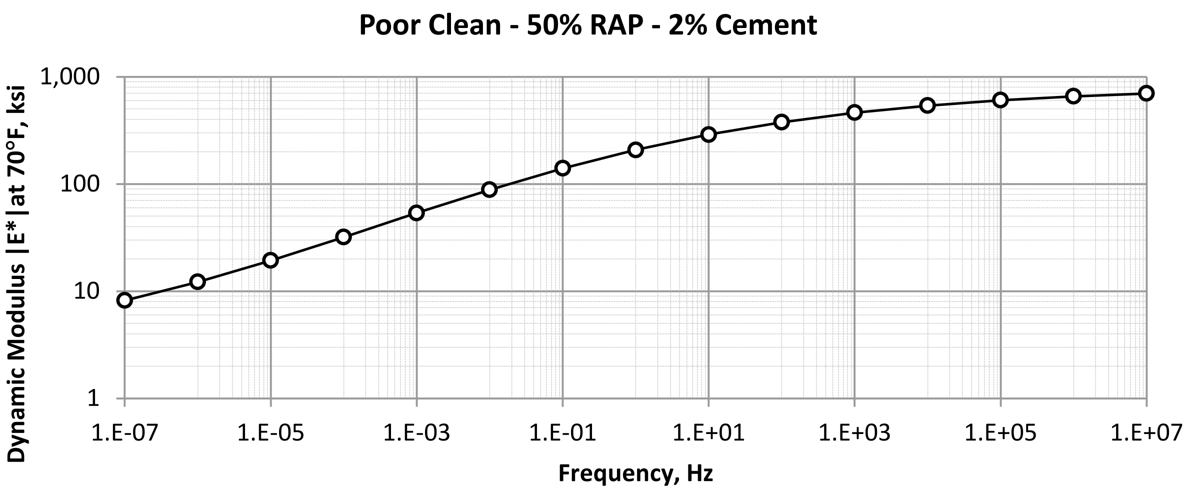


Figure 34: Average dynamic modulus at varying frequencies for the poor clean foamed asphalt samples with 2% cement at 37.8 and 54°C





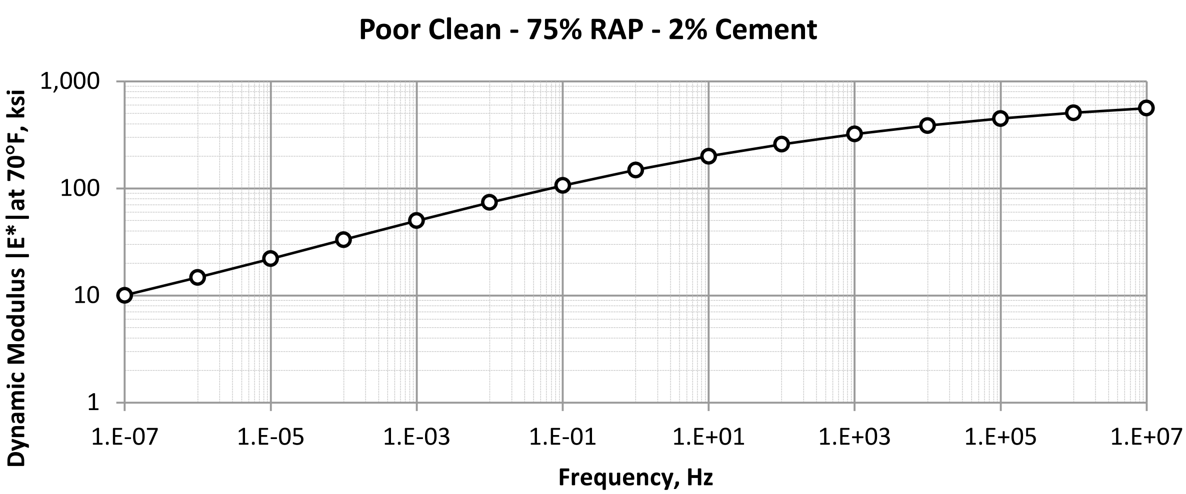
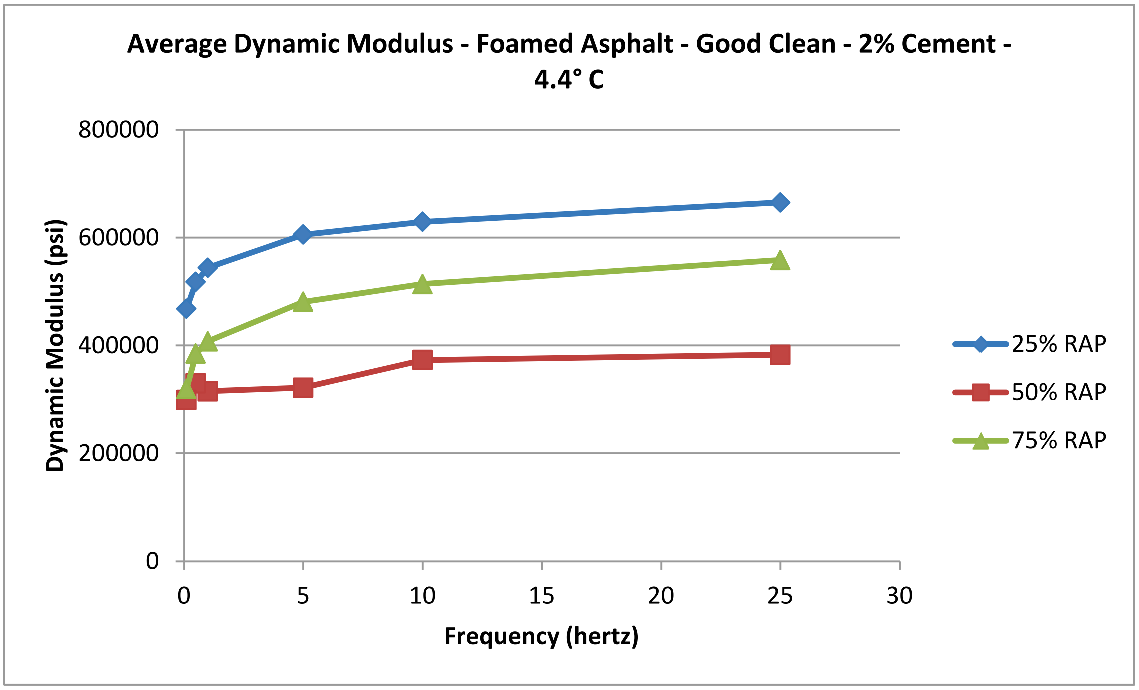


Figure 35: MEPDG E* master curves for the three percentages of RAP for poor clean foamed asphalt samples with 2% cement

Table 14: Average dynamic modulus results of good clean foamed asphalt samples with 2% cement

TEMP(°C)	Hz	Good Clean - 25% RAP - 2% Cement		Good Clean - 50% RAP - 2% Cement		Good Clean - 75% RAP - 2% Cement	
		Avg E* (psi)	COV	Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	665406	15%	382978	19%	558579	15%
	10	629373	14%	373243	16%	514027	14%
	5	605637	14%	321710	18%	481092	14%
	1	544310	15%	315339	16%	407814	14%
	0.5	518009	15%	330044	15%	385057	14%
	0.1	468192	16%	299238	15%	319191	14%
21.1	25	282072	12%	242540	11%	280536	11%
	10	250096	13%	217329	13%	243808	10%
	5	230867	13%	200851	12%	216985	10%
	1	186910	16%	158512	12%	162032	10%
	0.5	190789	17%	169606	10%	150681	7%
	0.1	161464	18%	138840	9%	115519	6%
37.8	25	258940	29%	170205	13%	170870	13%
	10	230578	30%	149562	14%	142873	14%
	5	210833	30%	141947	13%	125676	13%
	1	169655	31%	103468	14%	90476	12%
	0.5	161271	38%	95430	13%	84670	14%
	0.1	123163	27%	80107	15%	66962	13%
54	25	118653	13%	93612	7%	82101	14%
	10	102840	13%	78933	7%	68432	14%
	5	92954	13%	67608	4%	63372	10%
	1	76077	14%	53568	8%	48389	9%
	0.5	71421	15%	48922	8%	40681	12%
	0.1	63863	14%	41473	8%	34368	10%

Note: The highlighted data represents COVs higher than 15%.



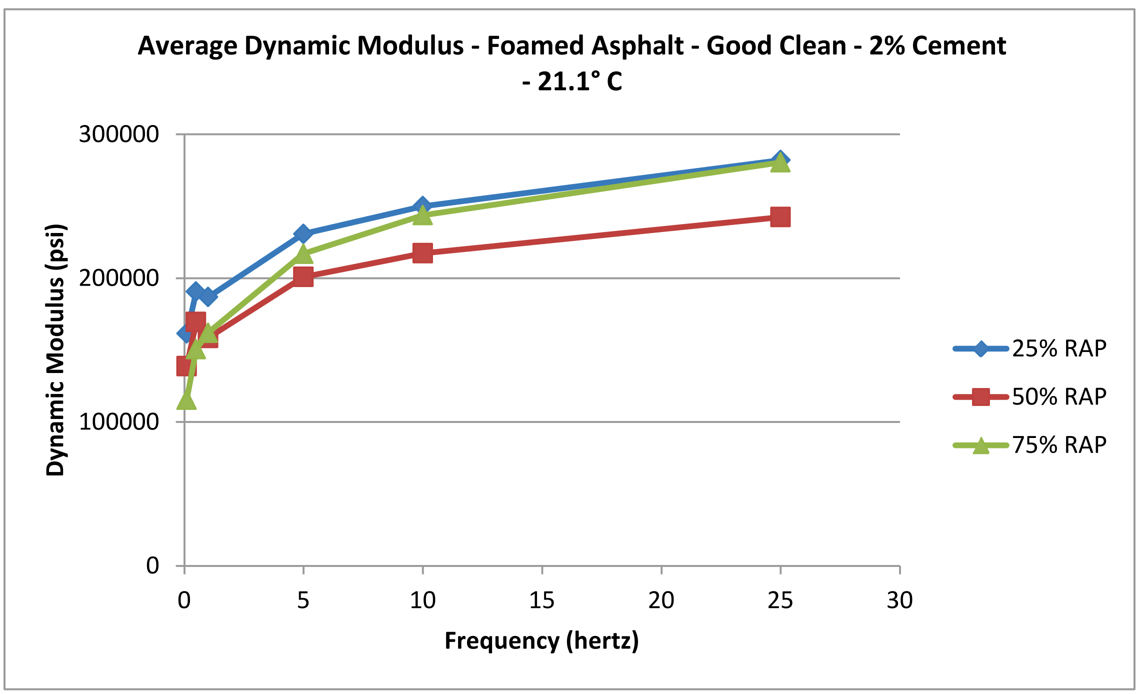
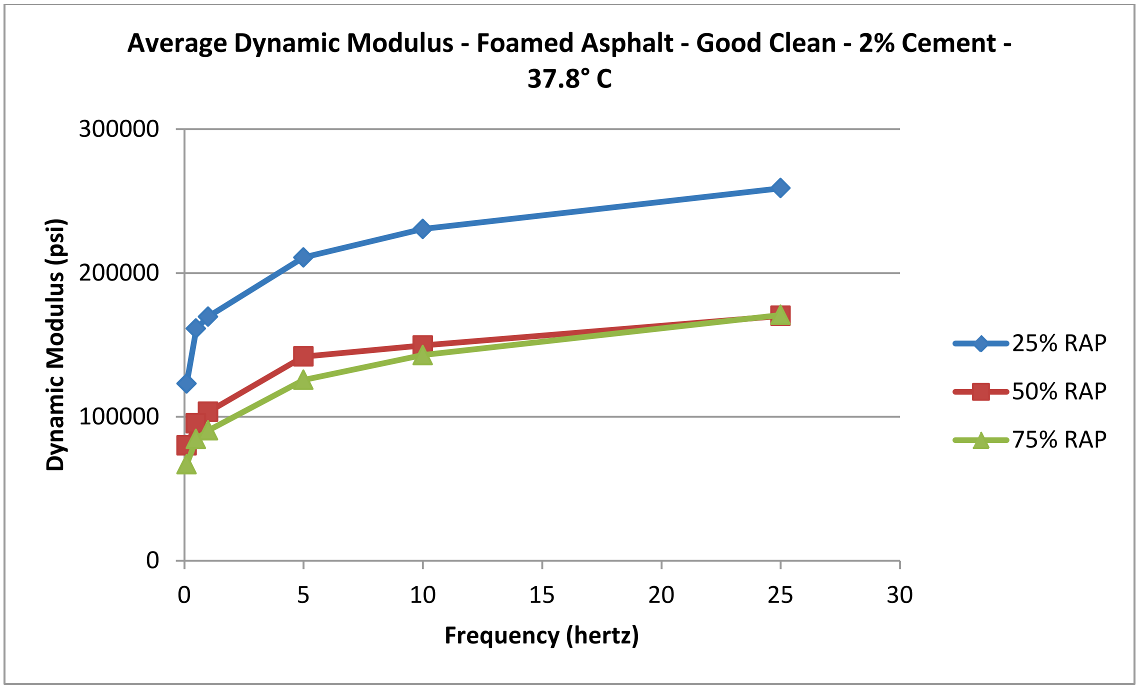


Figure 36: Average dynamic modulus at varying frequencies for the good clean foamed asphalt samples with 2% cement at 4.4 and 21.1^{o}C



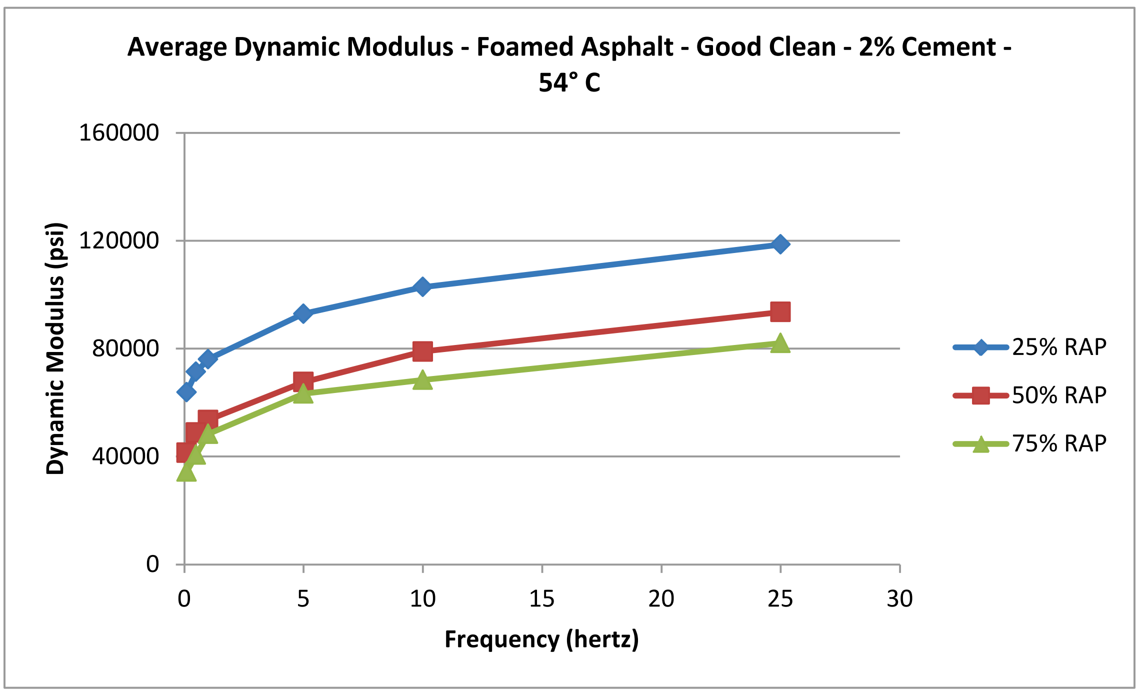
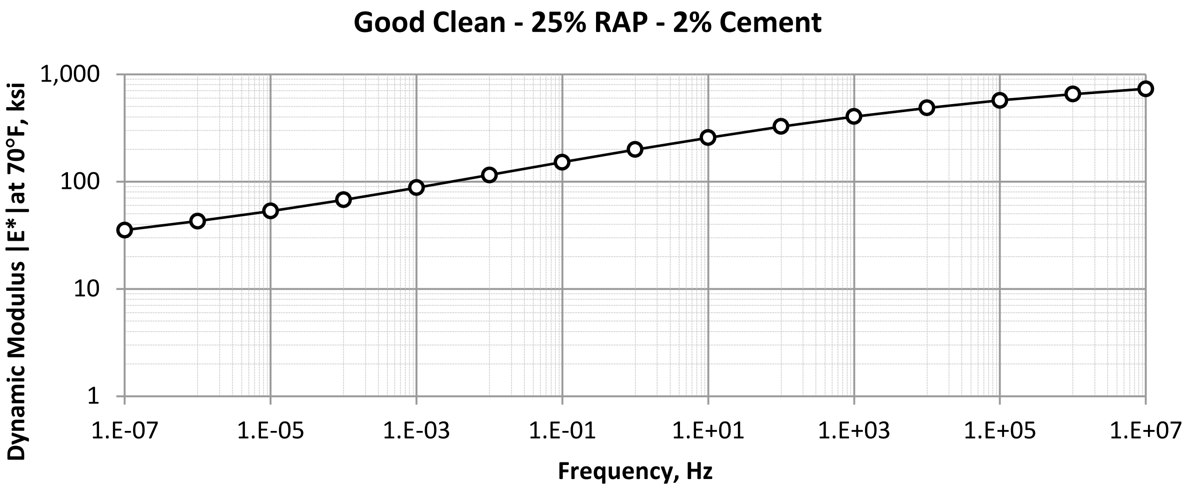
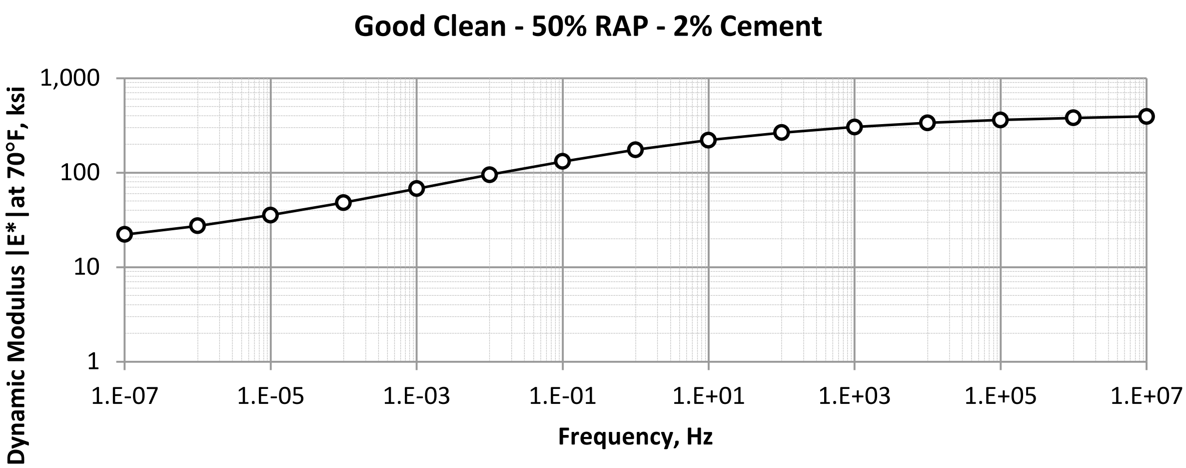


Figure 37: Average dynamic modulus at varying frequencies for the good clean foamed asphalt samples with 2% cement at 37.8 and 54°C





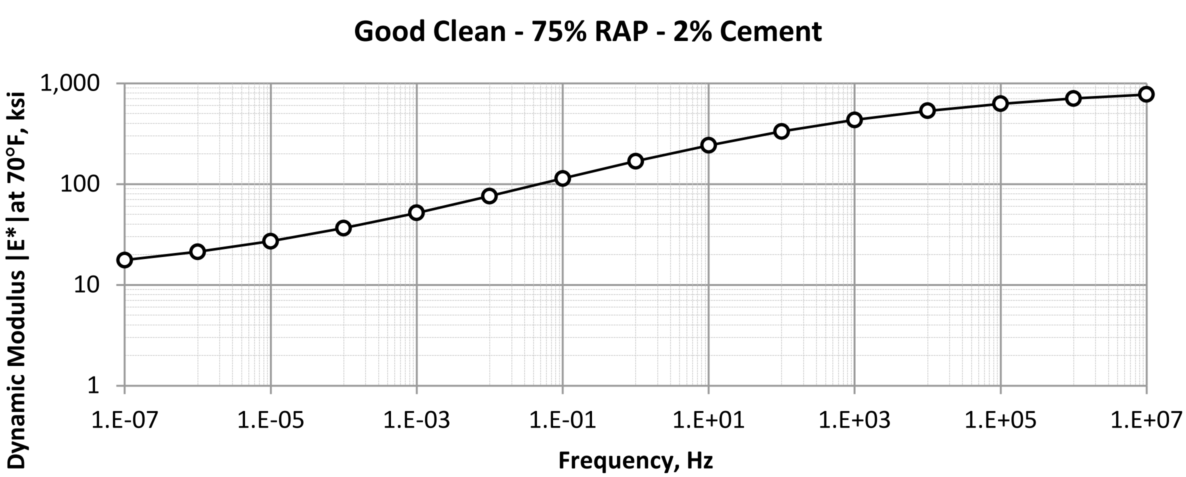
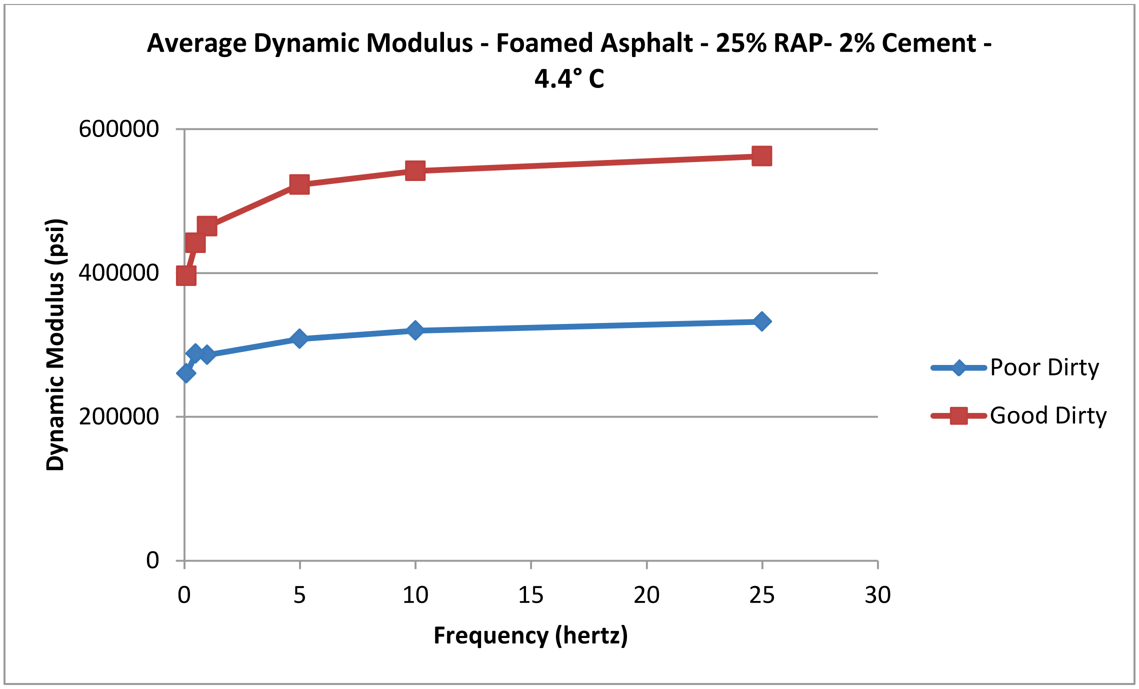


Figure 38: MEPDG E* master curves for the three percentages of RAP for good clean foamed asphalt samples with 2% cement

Table 15: Average dynamic modulus results of poor dirty and good dirty foamed asphalt samples with 2% cement

TEMP(°C)	Hz	Poor Dirty - 25% RAP - 2% Cement		Good Dirty - 25% RAP - 2% Cement	
		Avg E* (psi)	COV	Avg E* (psi)	COV
4.4	25	332420	11%	562353	10%
	10	319795	10%	541890	9%
	5	308230	11%	522790	9%
	1	285958	12%	464980	11%
	0.5	288064	10%	442142	10%
	0.1	260191	12%	396004	10%
21.1	25	230523	6%	368576	7%
	10	214845	6%	337422	7%
	5	203685	6%	314886	7%
	1	171201	6%	258757	8%
	0.5	173028	5%	241624	7%
	0.1	149702	5%	202987	7%
37.8	25	162572	6%	224594	16%
	10	147039	7%	196712	16%
	5	135178	6%	181321	17%
	1	107651	7%	145525	17%
	0.5	103308	6%	136350	15%
	0.1	83899	4%	123696	15%
54	25	114025	6%	157598	7%
	10	98194	6%	137895	6%
	5	87594	6%	125590	6%
	1	67021	6%	103505	6%
	0.5	59949	8%	94384	5%
	0.1	49605	6%	84156	5%

Note: The highlighted data represents COVs higher than 15%.



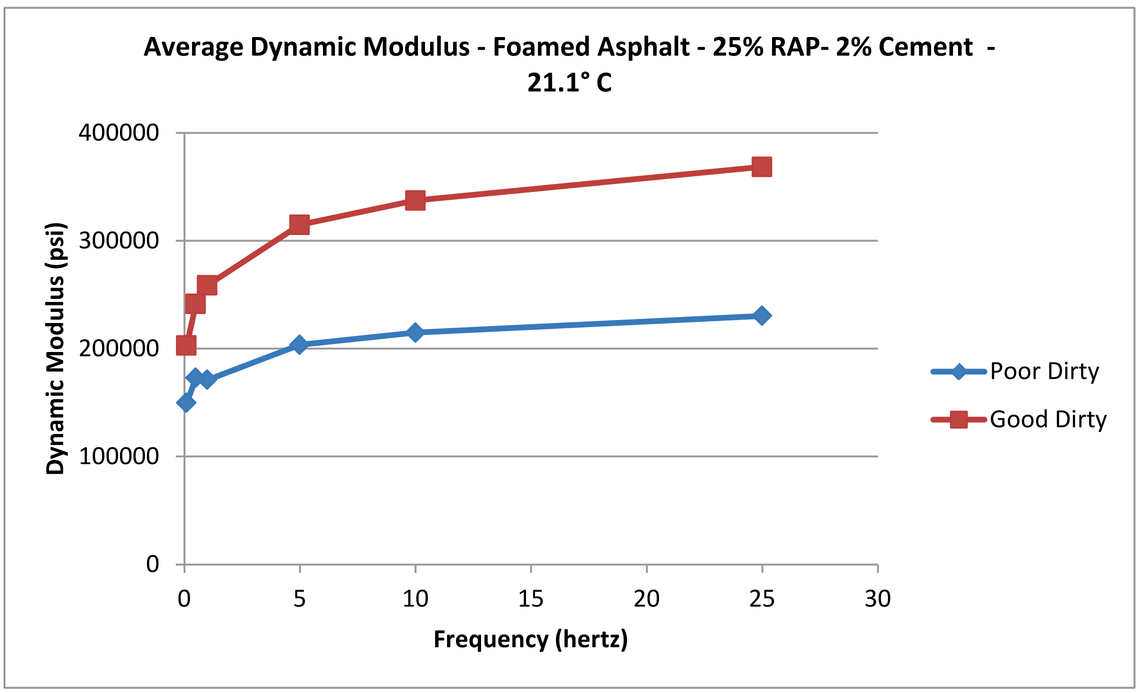
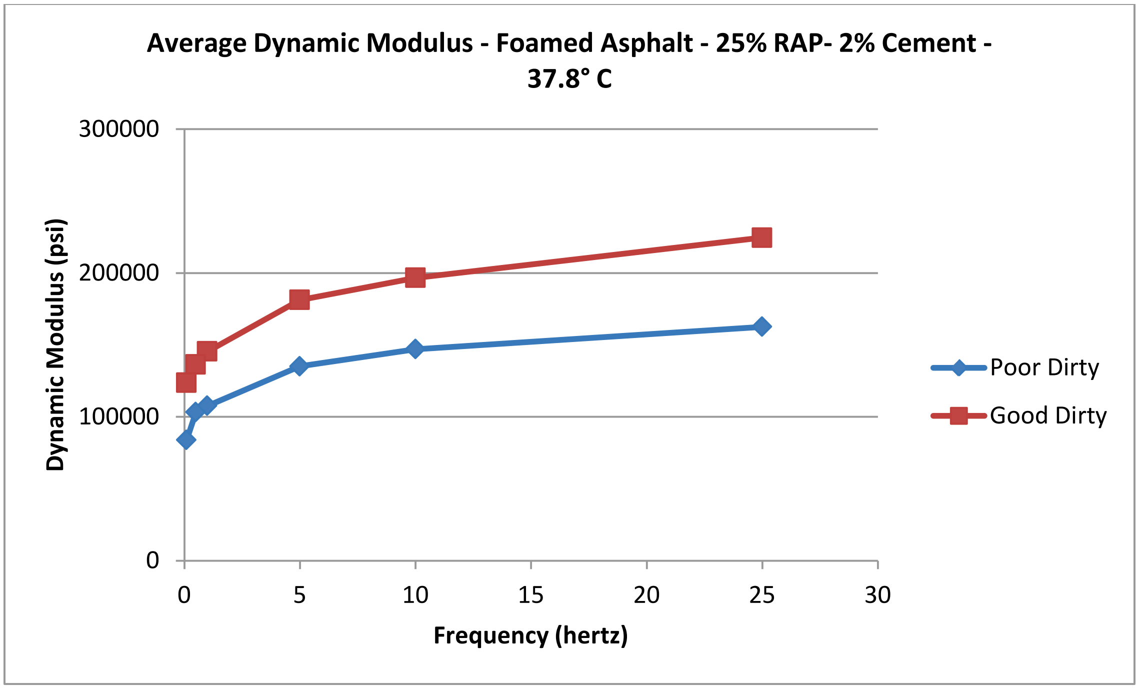


Figure 39: Average dynamic modulus at varying frequencies for the poor dirty and good dirty foamed asphalt samples with 2% cement at 4.4 and 21.1°C



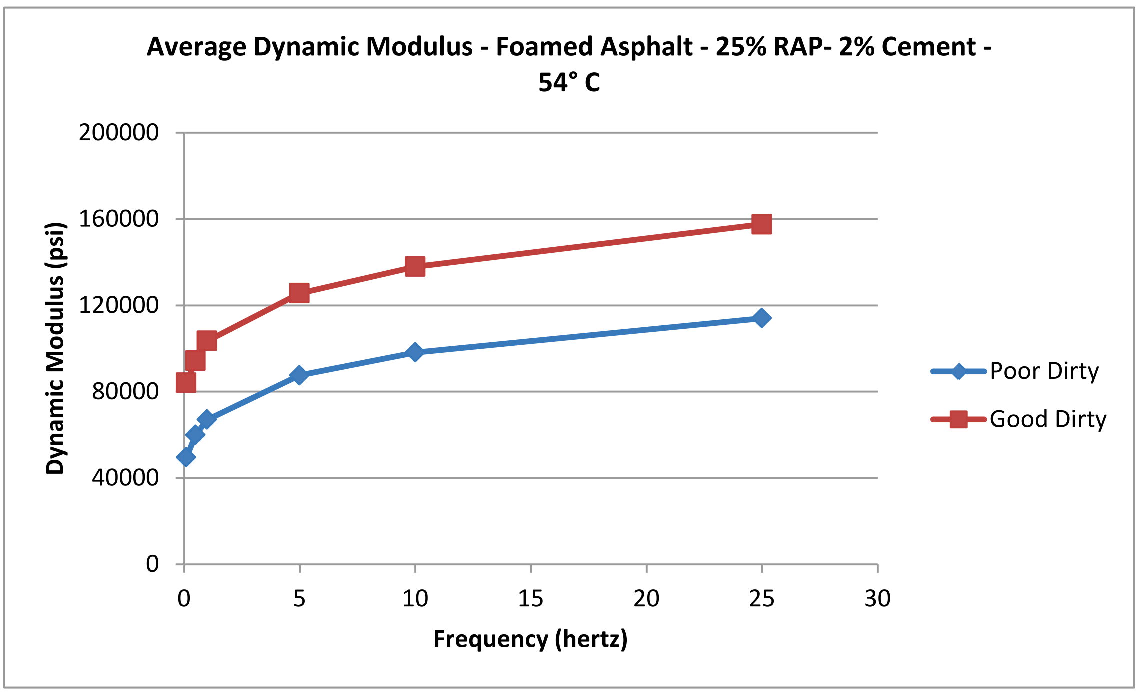
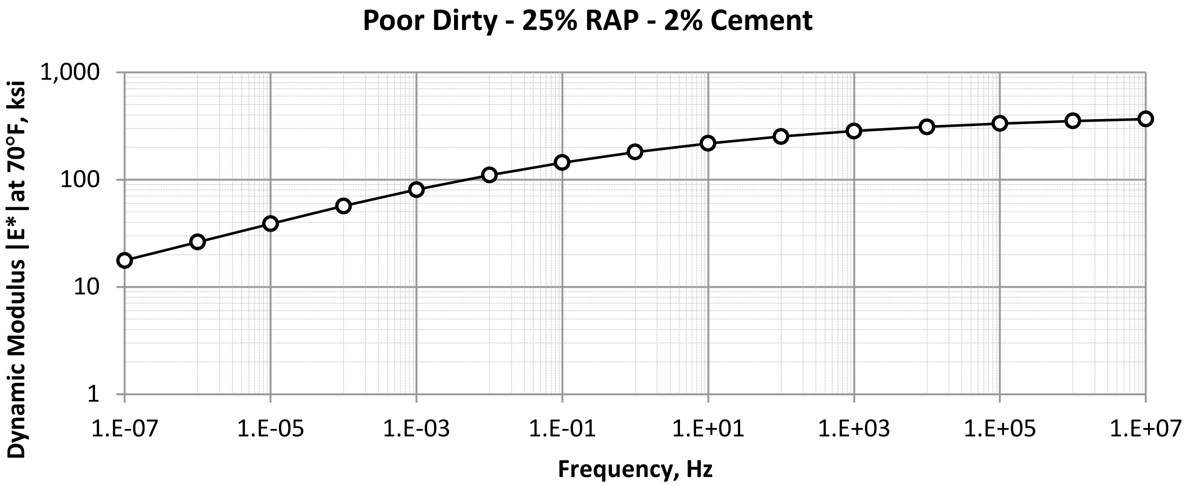


Figure 40: Average dynamic modulus at varying frequencies for the poor dirty and good dirty foamed asphalt samples with 2% cement at 37.8 and 54°C



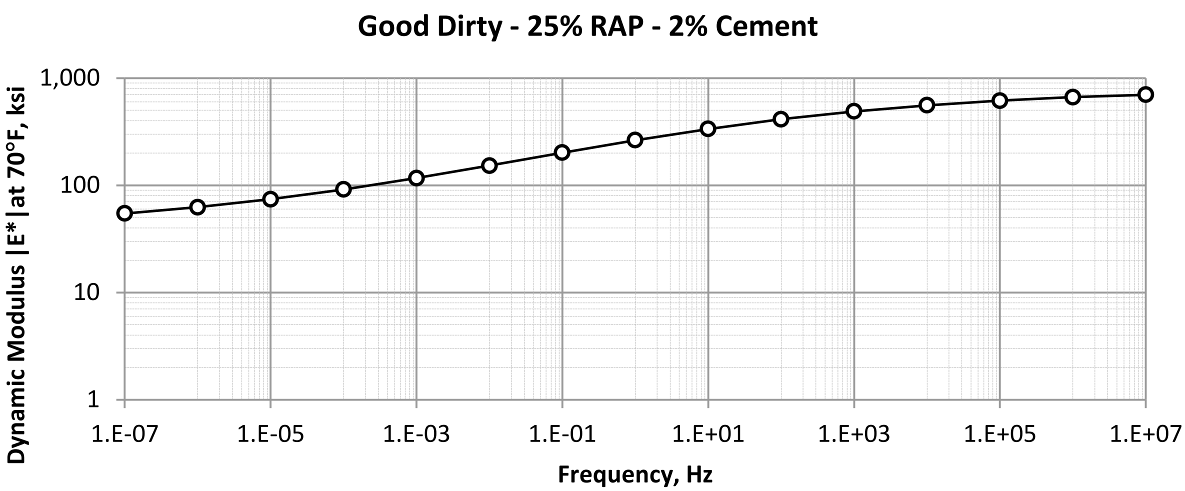


Figure 41: MEPDG E* master curves for the three percentages of RAP for poor dirty and good dirty foamed asphalt samples with 2% cement

4.3 Repeated Load Triaxial Test

4.3.1 Asphalt Emulsion Stabilized FDR

FDR stabilized with asphalt emulsion were evaluated using repeated load triaxial testing. Two samples were tested at each temperature to assess the repeatability of the RLT in evaluating FDR materials. The results listed below are created using the first samples at each temperature.

4.3.1.1 Asphalt Emulsion Samples Without Lime

Asphalt emulsion samples were tested with combinations of good dirty and poor dirty aggregates with no lime. *Table 16* summarizes the coefficients developed for the MEPDG rutting equation along with the R^2 value.

Figure 42 shows the graphical regression analysis from the equation along with the 30°C deviatoric stress.

Table 16: Coefficients and R^2 values for all asphalt emulsion samples without lime

	Good Dirty - 25% RAP	Good Dirty - 25% RAP	Good Dirty - 25% RAP
a:	-3.057	-0.521	-2.887
b:	1.864	0.458	1.622
c:	0.590	0.566	0.725
$R^{2:}$	0.891	0.807	0.871

	Poor Dirty - 25% RAP	Poor Dirty - 25% RAP	Poor Dirty - 25% RAP
a:	3.634	-3.078	-5.918
b:	-2.255	1.635	3.575
c:	0.428	0.573	0.569
$R^{2:}$	0.546	0.901	0.941

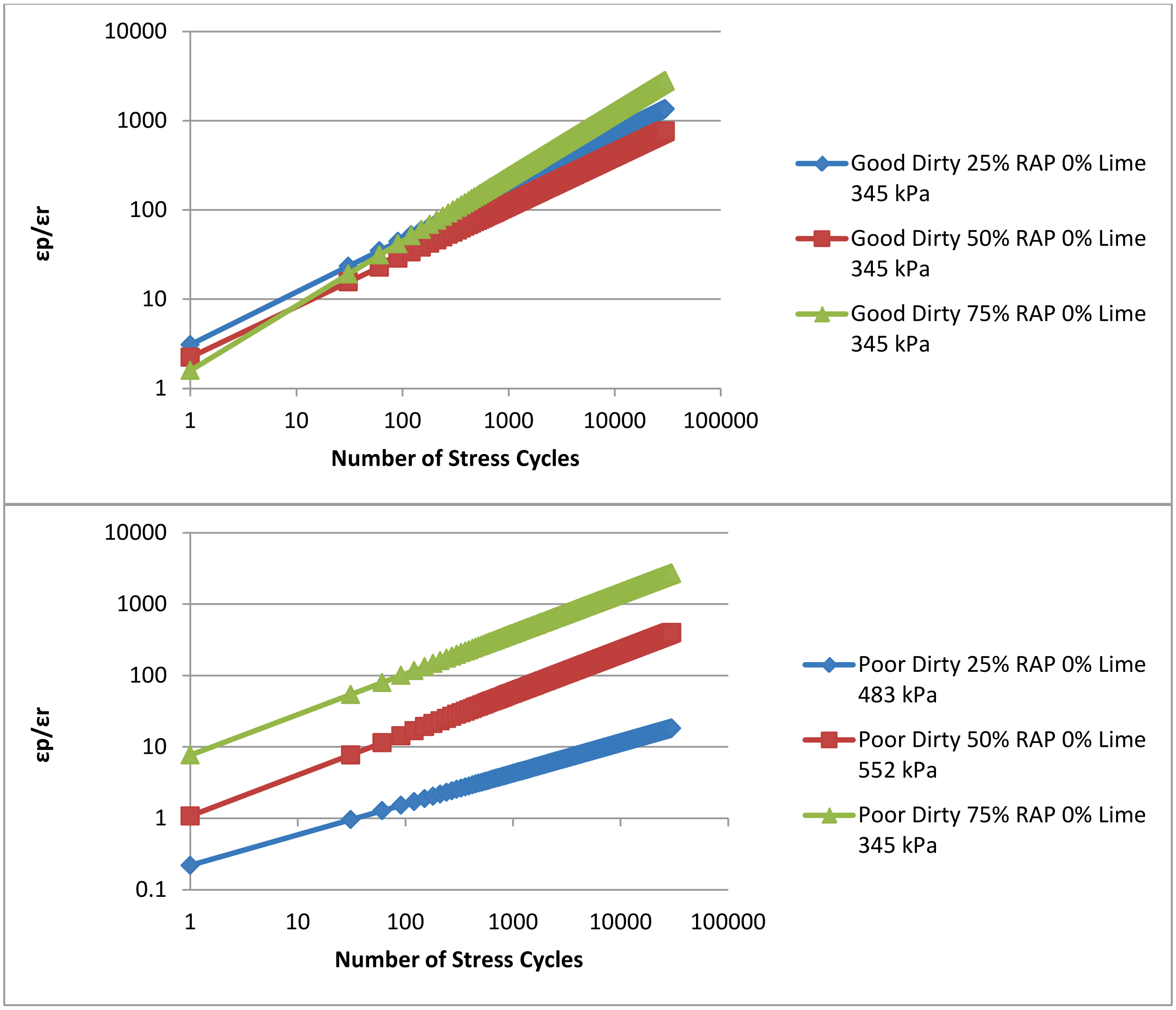


Figure 42: Results of repeated load regression analysis for asphalt emulsion samples without lime

4.3.1.2 Asphalt Emulsion Samples With 1% Lime

Asphalt emulsion samples were tested with combinations of good dirty and poor dirty aggregates with 1% lime added. *Table 17* summarizes the coefficients developed for the MEPDG rutting model along with the R^2 value.

Figure 43 shows the graphical regression analysis from the equation along with the 30°C deviatoric stress.

Table 17: Coefficients and R^2 values for all asphalt emulsion samples with 1% lime

	Good Dirty - 25% RAP	Good Dirty - 25% RAP	Good Dirty - 25% RAP
a:	-4.269	-2.829	-1.239
b:	2.611	1.856	0.633
c:	0.509	0.438	0.712
$R^{2:}$	0.891	0.899	0.841

	Poor Dirty - 25% RAP	Poor Dirty - 25% RAP	Poor Dirty - 25% RAP
a:	-9.309	-5.961	-4.849
b:	5.781	3.480	2.887
c:	0.425	0.529	0.584
$R^{2:}$	0.860	0.893	0.906

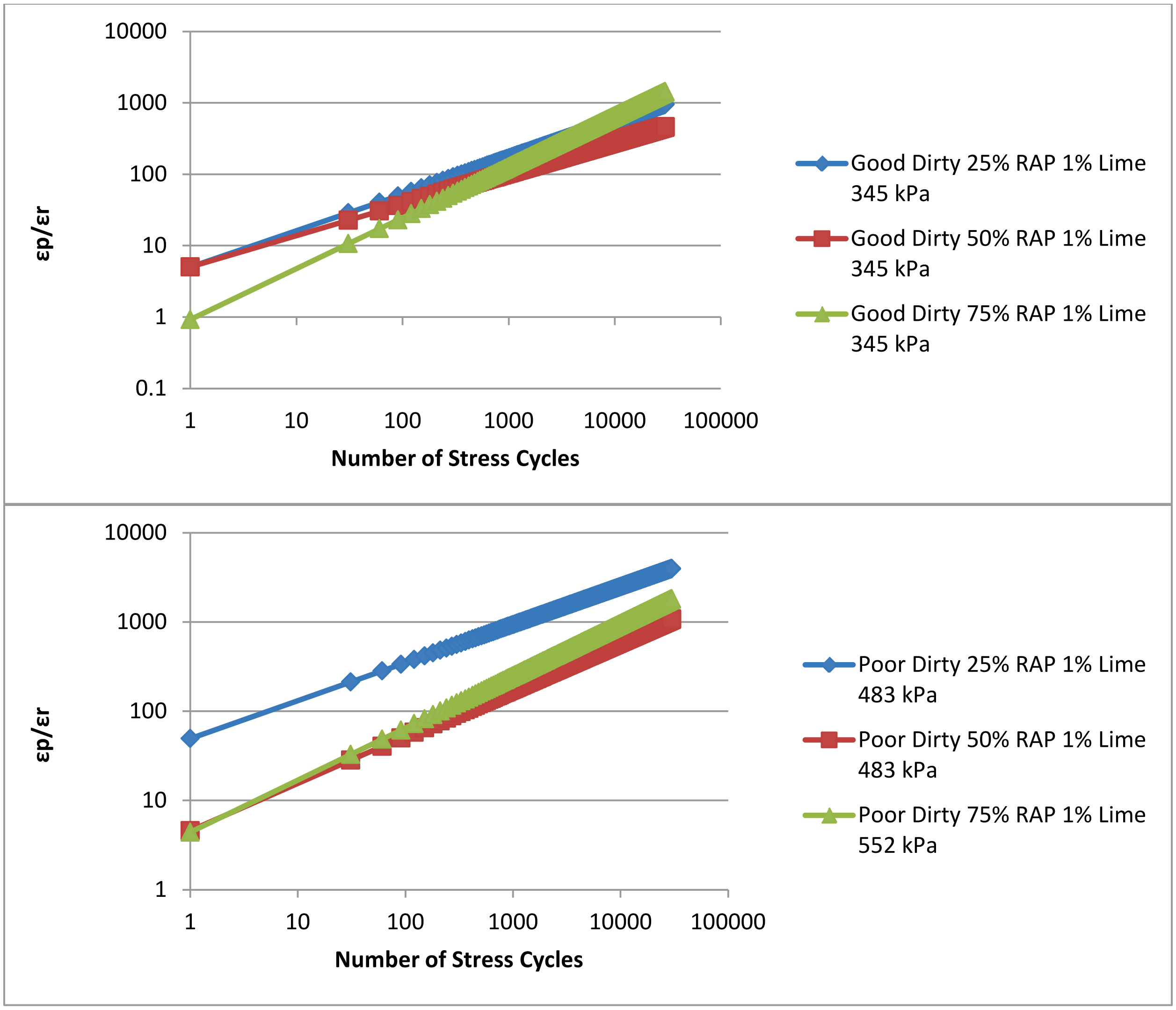


Figure 43: Results of repeated load regression analysis for asphalt emulsion samples with 1% lime

4.3.2 Foamed Asphalt Stabilized FDR

FDR stabilized with foamed asphalt were evaluated using repeated load triaxial testing. Two samples were tested at each temperature to assess the repeatability of the RLT in evaluating FDR materials. The results listed below are created using the first samples at each temperature.

4.3.2.1 Foamed Asphalt Samples With 1% Cement

Foamed asphalt samples were tested with combinations of all four base materials and 1% cement added. *Table 18* summarizes the coefficients developed in the MEPDG rutting model along with the R^2 value. *Figures 44 and 45* show the graphical regression analysis from the equation along with the 30°C deviatoric stress.

Table 18: Coefficients and R^2 values for all foamed asphalt samples with 1% cement

	Good Clean - 25% RAP	Good Clean - 50% RAP	Good Clean - 75% RAP
a1:	-6.149	-0.032	-3.404
a2:	3.529	-0.743	1.681
a3:	0.664	0.581	0.582
$R^{2:}$	0.812	0.755	0.822

	Good Dirty - 25% RAP	Good Dirty - 50% RAP	Good Dirty - 75% RAP
a1:	-4.984	-0.777	-6.780
a2:	2.149	-0.200	3.907
a3:	0.677	0.519	0.633
$R^{2:}$	0.676	0.503	0.893

	Poor Clean - 25% RAP	Poor Clean - 50% RAP	Poor Clean - 75% RAP
a1:	-2.495	-9.989	-4.920
a2:	0.914	5.441	2.975
a3:	0.534	0.640	0.516
$R^{2:}$	0.574	0.822	0.932

	Poor Dirty - 25% RAP	Poor Dirty - 50% RAP	Poor Dirty - 75% RAP
a1:	-9.262	-3.067	-1.619
a2:	5.067	1.557	0.383
a3:	0.571	0.465	0.534
$R^{2:}$	0.846	0.719	0.793

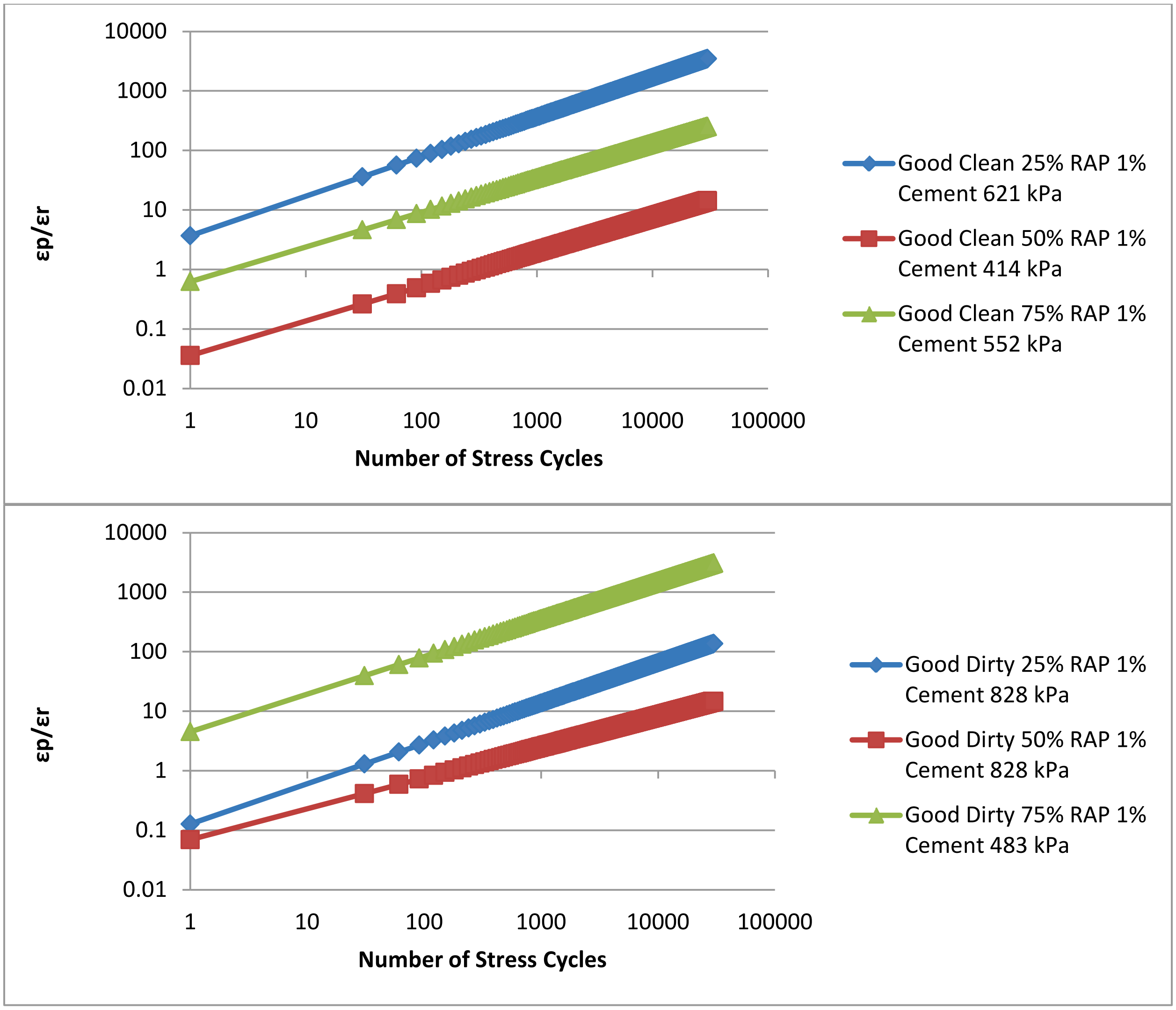


Figure 44: Results of repeated load regression analysis for good clean and good dirty foamed asphalt samples with 1% cement

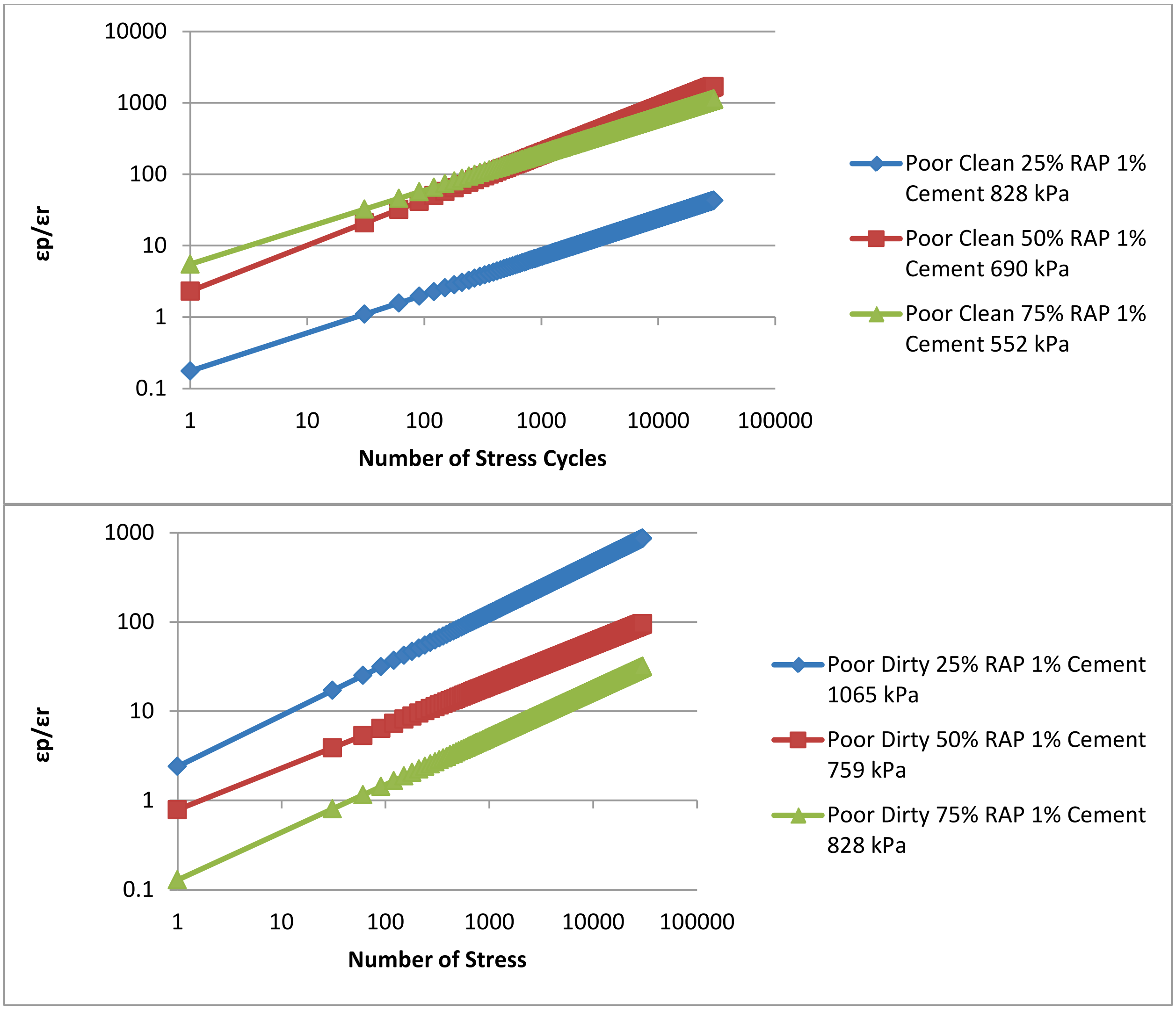


Figure 45: Results of repeated load regression analysis for poor clean and poor dirty foamed asphalt samples with 1% cement

4.3.2.2 Foamed Asphalt Samples With 2% Cement

Foamed asphalt samples were tested with combinations of all four base materials and 2% cement added. *Table 19* summarizes the coefficients developed for the MEPDG rutting model along with the R^2 value. *Figures 46 and 47* show the graphical regression analysis from the equation along with the 30^{o}C deviatoric stress.

Table 19: Coefficients and R^2 values for all foamed asphalt samples with 2% cement

	Good Clean - 25% RAP	Good Clean - 50% RAP	Good Clean - 75% RAP
a1:	-0.032	-0.364	-2.404
a2:	-0.743	-0.100	1.389
a3:	0.581	0.542	0.416
$R^{2:}$	0.755	0.745	0.787

	Good Dirty - 25% RAP
a1:	3.863
a2:	-2.556
a3:	0.653
$R^{2:}$	0.689

	Poor Clean - 25% RAP	Poor Clean - 50% RAP	Poor Clean - 75% RAP
a1:	-3.220	-1.291	-2.406
a2:	2.130	0.710	1.226
a3:	0.275	0.267	0.526
$R^{2:}$	0.823	0.629	0.801

	Poor Dirty - 25% RAP
a1:	-5.673
a2:	3.085
a3:	0.472
$R^{2:}$	0.776

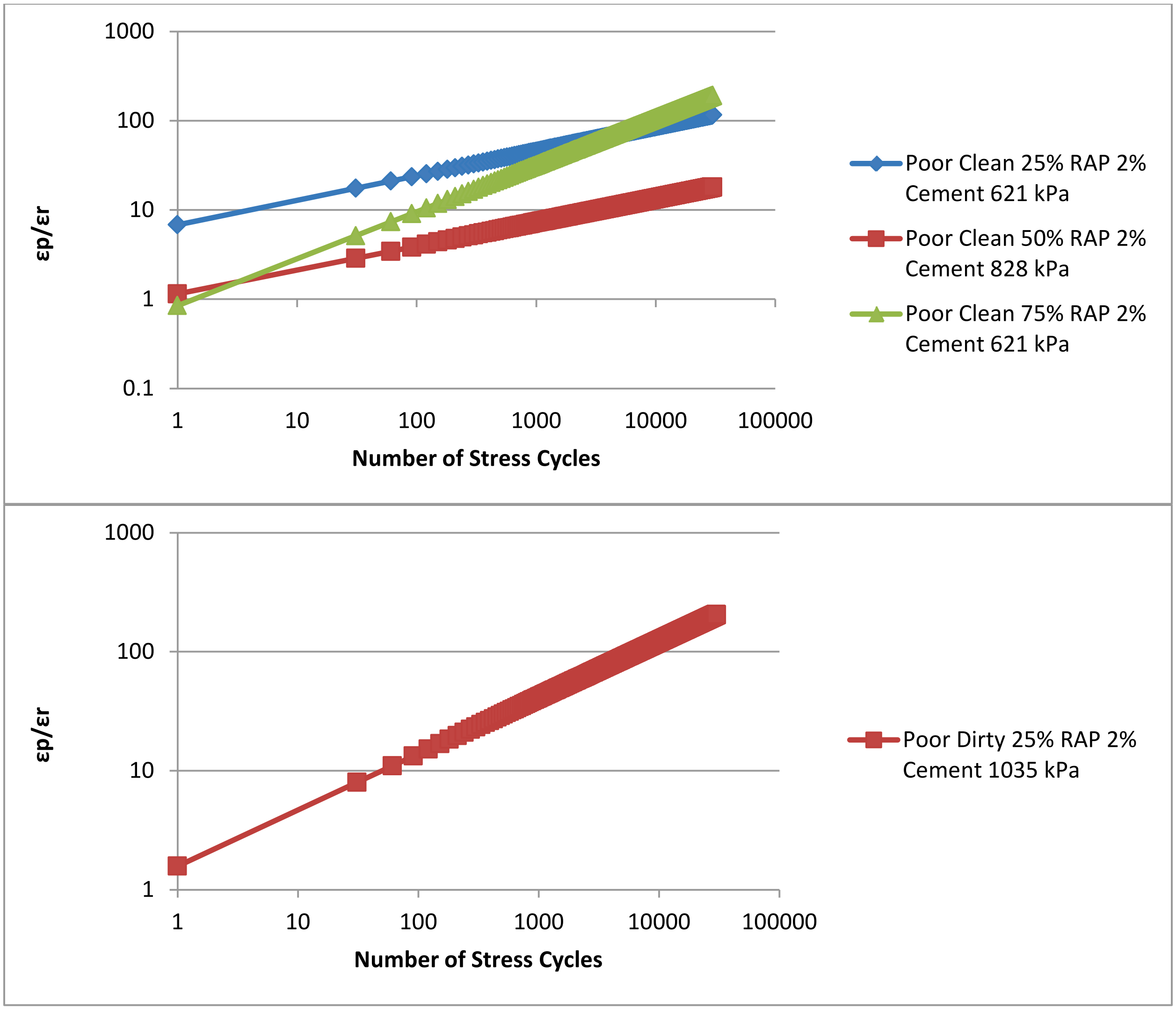


Figure 46: Results of repeated load regression analysis for poor clean and poor dirty foamed asphalt samples with 2% cement

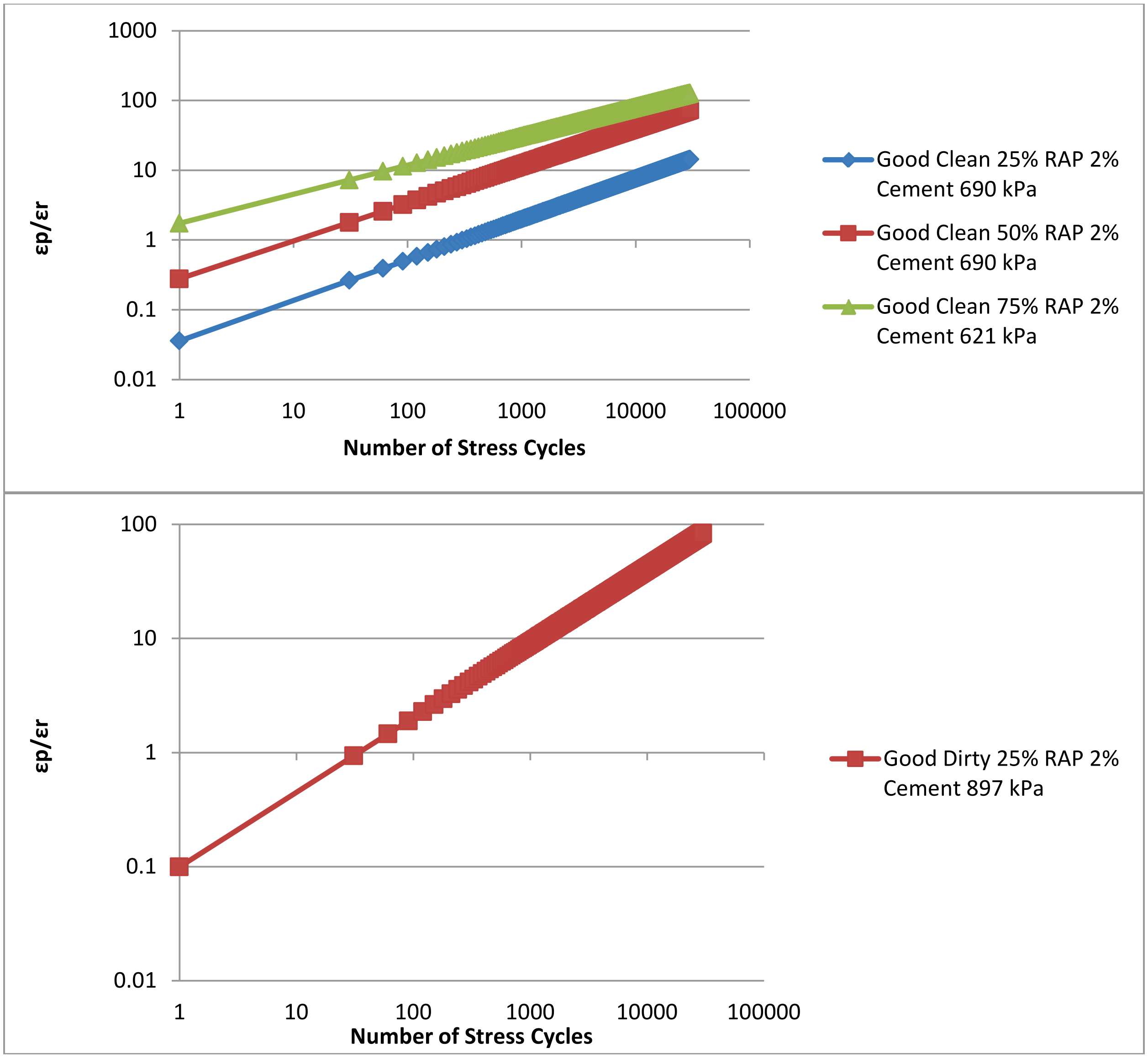


Figure 47: Results of repeated load regression analysis for good clean and good dirty foamed asphalt samples with 2% cement

5.0 Discussion

5.1 Modulus of Rupture

5.1.1 Sample Production

The modulus of rupture test was conducted on the cement and fly ash stabilized FDR materials. The production of samples for the modulus of rupture was based on ASTM D1635-00 (reapproved 2006) and AASHTO T97 specifications. Few problems were encountered while making of the samples, but some significant problems did arise.

One major problem encountered during making samples for MR was the ability to compact the material within the molds. Due to the fact that the RAP material was not fluid, it did require compaction to make a useable sample. ASTM D1635-00 (reapproved 2006) and AASHTO T97 provide guidance on this issue and it was up to the lab personnel to follow a process for performing this compaction after the tamping was completed. A steel plate approximately one inch thick was used with a steel mallet to compact the mixture to the desired height. The process worked effectively; however, many of the mixes with fly ash were dry and segregated during compaction, thereby resulting in a poor sample. In addition, very dense FDR materials were difficult to compact to the

Figure 48: Fly ash modulus of rupture sample broken while handling.

proper height. Even though no specific guidance on compaction is provided in this report, devising a new method of compaction may improve some of the results of the fly ash stabilized FDR.

Another issue that became apparent while making the samples was removing the samples from the molds without damage as shown in *Figure 48*. Many of the samples were very easy to break and would crumble with the slightest amount of disturbance making it difficult to remove mold without damaging them. A lubricant was used to avoid adhesion between the material and he sides of the mold. Mainly, the fly ash samples had this problem that persisted throughout the entire task. Large size aggregates tend to fall off the samples' edges making it difficult to test the sample with the three point loading according to the ASTM D1635-00 (reapproved 2006) and AASHTO T97.

5.1.2 Testing Procedures

Conducting the modulus of rupture testing was fairly straightforward with few problems encountered. One problem that occurred a few times while testing was the sample breaking when the loading plate was set on top after being placed into the load frame. The steel plate used to load the samples was very heavy and likely too heavy for some samples. This could have been remedied by using a lighter weight loading plate; however, it was also noticed that some of

Figure 49: Typical set of modulus of rupture samples.

these samples would break at very low loads and likely be undesirable mixtures.

5.1.3 Results

The results of the modulus of rupture testing were shown in *Tables 1 and 3*. As seen in *Figure 49,* beams which broke in the middle third of the sample were common for most of the testing. The cement stabilized RAP material typically had a higher modulus of rupture as compared to the fly ash stabilized RAP in sample mixtures. The highest average modulus of rupture for the cement stabilized RAP was 360 psi, which occurred for the good clean, 25% RAP mixture with 7% cement. While the highest MR of 70 psi for fly ash stabilized RAP was also for the good clean, 25% RAP samples with 12%. Fly ash stabilization may have a potential use since some of its higher MR values were similar to the lower MR values for the cement stabilized FDR.

Tables 2 and 4 show the COV values for cement stabilized FDR are all under 15% and were easily made and tested without worrying about damaging the samples and could easily be repeated. For fly ash, due to many of the samples being so fragile, a large portion of the COV values occurred above the 15% criteria. It should also be noted that many fly ash samples were remade trying to get a set of three complete samples, but this was not always possible for the very weak bonding mixtures.

5.2 Dynamic Modulus and E* Curves

5.2.1 Sample Production of Asphalt Emulsion Samples

The dynamic modulus test was used to evaluate asphalt emulsion and foamed asphalt stabilized FDR materials. Producing asphalt emulsion samples are quite easy for the operator. Some of the steps involved in making the samples can be seen in

Figure 50.

Since these samples were created using the SGC and not cored from a larger sample, production to testing was relatively quick. There are only minor difficulties when preparing asphalt emulsion samples for testing. The main issue is to ensure complete uniformity of the emulsion prior to the start of the mixing process. If the asphalt emulsion is left to set, the mixture will start to disassociate and the water will withdraw from the oil. If this occurs new fresh emulsion should be obtained.

Figure 50: Four of the steps during making of asphalt emulsion test samples

The main problem attributed to making asphalt emulsion samples was the height requirement. Samples were specified to be six inches tall by Report NCHRP 9-29: PP01 before they can be tested. The good dirty samples were able to be compacted to this height very easily. The poor dirty samples had a much higher density compared to the good dirty samples. Because of this increased density, the poor dirty samples were not able to be compacted to the six inch height. Some samples were compacted to 300 gyrations but still did not meet the six inch height requirement. For this study, samples were gyrated to a maximum of 150 revolutions. A typical sample from the gyratory compactor is shown in *Figure 51*. It may be possible for the poor dirty samples to reach the height of 6 inches, but this may take a high number of gyrations. This is not a recommended procedure due to the excess of time to make samples and the wear on the gyratory compactor.

Figure 51: Typical sample from gyratory compactor after gyrations

5.2.2 Testing Procedure of Asphalt Emulsion Samples

Using the Interlaken SPT machine for dynamic modulus testing is straight forward. Samples need to be cured at different temperatures for various periods as described in the NCHRP 9-29 protocol. For asphalt emulsion samples the application of the set points for the linear variable directional differential transformers (LVDT) needed to be changed. For a typical hot mix asphalt sample (HMA), the LVDT set points could be attached to the surface with an epoxy. Because of the rough uneven surface of the compacted samples, it was impossible to glue the LVDT set points. For this study, the LVDT set points were welded to a metal surface and then attached to the sample surface using rubber bands. Other methods to attach the set points were attempted, but through trial and error it was found that rubber bands gave the most reliable results. The evaluated methods for attaching the LVDT set points to the specimens will be discussed later in this section. The LVDTs are magnetic and attach to the metal set points very easily. It is very important before starting a test that the LVDTs are placed close to their zero deformation position. If a LVDT measures a deformation past its maximum deformation distance, all results in the dynamic test become unusable. A typical FDR sample ready for dynamic modulus testing is shown in

Figure 52. The SPT machine comes equipped with software to run the test. The software needs inputs such as height, diameter, frequencies to test, and loads applied to the specimen. The deviator and confining pressures were determined from specified ranges for HMA dynamic testing in AASHTO TP-62-07. It is important to use the lower values of these ranges for testing FDR material since FDR material is typically weaker than HMA.

Figure 52: Typical FDR sample in SPT machine ready for dynamic modulus testing

For this study, the SPT machine was allowed to use an auto strain feature. This feature automatically adjusts the specimen load so that the specimen reaches a desired strain. In this case, the desired strain was set to 80 microns. For temperatures from 4.4^{o} to 37.8^{o} C, the SPT machine was able to load the specimen correctly to reach 80 microns. A problem occurred at the higher temperature of 54^{o} C. Asphalt emulsion samples at this high temperature become very weak and do not take much pressure to deform. When testing was done at 54^{o} C, the SPT machine could not decrease the pressure enough to reach the desired 80 microns. For just the high temperature samples, the autostrain feature was turned off so that results could be obtained. The dynamic stress on the samples were set on the SPT machine as low as 30 kPa. Lower stress would result in the SPT machine presenting physical errors to the user such as moving the sample away from the load cell.

The rubber band method chosen to attach the LVDT set points to the sample (*Figure 53*) presented their own unique challenges. Samples were made and tested with increasing number of rubber bands to attach the set points. During the test the operator can see if the set points are attached properly by analyzing the sinusoidal displacement from the loading. If the set points were not attached properly, the sinusoids would not form correctly and high errors would occur. After trial and error using different numbers of rubber bands, it was determined that using ten rubber bands are sufficient to keep the set points fixed in location on the sample. One rubber band was used to hold one row of set points in the set point jig before two double rubber bands were placed on the top of the set points and two more double rubber bands were placed on the bottom of the set points. This process was repeated for the other row of set points. It is very important that after a sample has been tested to remove the rubber bands. If the rubber bands are left on a sample for an extended period of time, they lose their strength and cannot hold the set points in place, and at high temperatures the rubber bands have enough tension to squeeze the samples. After a test is completed the rubber bands should be removed. The method that seemed to work the best for this is to simply cut the rubber bands off the sample. This allowed little chance for the rubber bands to damage the samples if the user were to try to pull them off.

Figure 53: Set points attached to emulsion and foamed asphalt samples with rubber bands

Other methods were attempted to attach the LVDT set points to the sample surface. One possibility was the use of canvas straps. These straps are similar to the type of straps used for backpacks. These straps were used like the rubber bands and tightened around the sample to keep the metal set points in place. This method had some positive results, but was ultimately discarded in favor of the rubber band method. The confining pressure that an operator could put on a sample may vary greatly using the straps method. The rubber band method has the ability to be more repeatable since the same type and size of rubber bands were used every time.

Another method evaluated to hold the LVDT was the use of an in-house created jig. The LVDT's were fitted with sharp points instead of magnets. These points could then be held onto the samples by a jig fitted with springs. After some preliminary testing, it was determined that the current jig method produced highly variable results when testing various materials. Once again, the rubber band method was chosen over this method because of its apparent low variability.

5.2.3 Results of Asphalt Emulsion Samples

The results of the dynamic modulus testing on asphalt emulsion stabilized FDR samples show that the dynamic modulus test for this type of material is a good test of mixture performance. This is based on the asphalt emulsion stabilized samples having relatively low COVs. This would suggest that the results of the dynamic modulus testing on asphalt emulsion stabilized samples can be repeated.

Tables 20 and 21 summarize the ratios of the E* of the asphalt emulsion stabilized FDR with 1% lime over the E* of the same mixtures without lime. A ratio over 100% would indicate a positive impact of the lime addition on the E* property of the asphalt emulsion stabilized FDR. *Table 20* shows that lime seems to have a positive effect on the good dirty samples. On almost every frequency and temperature, the dynamic modulus increased an average of 26% on various RAP contents. The data seems to suggest that adding lime will increase the dynamic modulus for the good dirty specimens.

Table 21 shows adding lime to poor dirty samples does not make a significant change in dynamic modulus values. In most cases, it seems the dynamic modulus is actually lowered by adding lime. The theory of why poor dirty FDR materials reacted so differently than good dirty FDR is based on a visual inspection. When poor dirty samples are made, they are much drier than the good dirty counterparts. The lime needs water to activate, and in the case of poor dirty samples it seems that the lime does not have adequate water to hydrate. Therefore, specific moisture-density curves have to be established to effectively identify the optimum moisture contents for FDR with lime presence in the mix. This step was conducted in the research.

Table 20: Effect of 1% lime to dynamic modulus on good dirty samples (Values indicate the ratios between the dynamic modulus of asphalt emulsion stabilized FDR with lime and that without lime)

TEMP(°C)	Hz	Good Dirty - 25% RAP	Good Dirty - 50% RAP	Good Dirty - 75% RAP
4.4	25	112%	96%	112%
	10	114%	96%	112%
	5	117%	97%	107%
	1	127%	97%	113%
	0.5	132%	99%	113%
	0.1	156%	112%	102%
21.1	25	128%	111%	105%
	10	135%	116%	103%
	5	139%	120%	104%
	1	155%	129%	97%
	0.5	141%	124%	103%
	0.1	156%	121%	99%
37.8	25	134%	126%	126%
	10	131%	131%	130%
	5	132%	134%	142%
	1	129%	133%	134%
	0.5	141%	143%	141%
	0.1	129%	151%	147%
54	25	145%	107%	132%
	10	143%	109%	135%
	5	147%	112%	135%
	1	154%	142%	142%
	0.5	167%	137%	157%
	0.1	139%	115%	163%
	Average:	138%	119%	123%

Table 21: Effect of 1% lime to dynamic modulus on poor dirty samples (Values indicate the ratios between the dynamic modulus of asphalt emulsion stabilized FDR with lime and that without lime)

TEMP(°C)	Hz	Poor Dirty - 25% RAP	Poor Dirty - 50% RAP	Poor Dirty - 75% RAP
4.4	25	115%	121%	128%
	10	117%	122%	129%
	5	119%	124%	130%
	1	124%	127%	134%
	0.5	128%	129%	135%
	0.1	136%	131%	138%
21.1	25	75%	67%	83%
	10	77%	65%	82%
	5	76%	66%	83%
	1	81%	64%	81%
	0.5	82%	66%	84%
	0.1	86%	68%	83%
37.8	25	73%	81%	83%
	10	76%	82%	84%
	5	78%	84%	88%
	1	83%	89%	91%
	0.5	81%	85%	87%
	0.1	85%	91%	88%
54	25	72%	89%	114%
	10	75%	94%	116%
	5	79%	98%	124%
	1	83%	97%	125%
	0.5	87%	99%	130%
	0.1	93%	102%	132%
	Average:	91%	93%	106%

To create the E* master curves, the average dynamic modulus, standard deviation, and COV were needed. To get the COV values at a reasonable value, some outlier values needed to be removed from the data. By having five samples, it was fairly simple to determine if a dynamic modulus value was skewed. The highest COV for asphalt emulsion samples was 31%. This occurred at 54^o C, which correlates with the problems discussed before when trying to run the dynamic modulus test on asphalt emulsion at high temperatures.

5.2.4 Production of Foamed Asphalt Samples

The fabrication of foamed asphalt samples is slightly more difficult than asphalt emulsion samples. The steps to create these samples are very similar to the asphalt emulsion samples with the exception of the use of the foaming asphalt machine provided by Wirtgen America. Foamed asphalt samples require more preparation than asphalt emulsion samples. The asphalt binder needs to be heated overnight so that it is in liquid form to be sprayed into the FDR material. It is important to make sure that the operator has enough material on hand to make the samples. The Wirtgen mixer for the foaming process requires 20 kg – 30 kg of material to operate properly.

Good clean and good dirty samples were able to be compacted to the proper six inch height. Poor clean and poor dirty samples were unable to reach the required height due to their density. Again, a limit of 150 gyrations was set so that samples would not have to be gyrated for a significant amount of time.

5.2.5 Testing Procedure of Foamed Asphalt Samples

The testing procedure for foamed asphalt FDR followed the same steps as the asphalt emulsion FDR samples. The rubber band method to attach the LVDT set points was also used for the testing. Foamed asphalt FDR is stronger than the asphalt emulsion FDR samples and that was noticed at the higher temperature testing. Foamed asphalt samples were able to be tested at 54^o C and have the autostrain feature of the SPT machine work correctly.

Care should be taken with the foamed asphalt samples just as the emulsion samples. Removing the rubber bands for instance can cause material to be broken off the sample. For this reason cutting the rubber bands off the sample each time the sample is tested should be done.

5.2.6 Results of Foamed Asphalt Samples

The results of the dynamic modulus testing on foamed asphalt FDR samples show that the dynamic modulus is applicable to FDR material stabilized with foamed asphalt. This is based on the foamed asphalt samples having relatively low COVs. This would suggest that the results of the dynamic modulus testing on foamed asphalt FDR samples can be repeated.

Tables 22 and 23 summarize the ratios of the E* of the foamed asphalt stabilized FDR with 2% cement over the same mixtures with 1% cement. A ratio over 100% would indicate a positive impact of the additional 1% cement on the E* property of the foamed asphalt stabilized FDR.

Table 22 shows that the additional cement to the good clean samples did not make a significant change in dynamic modulus values. In most cases, it seems that the dynamic modulus is actually lowered by adding 1% cement but the average overall change to the good clean specimens is negligible.

Table 22: Effect of 2% cement to dynamic modulus on good clean samples (Values indicate the ratios between the dynamic modulus of foamed asphalt stabilized FDR with 2% cement and that with 1% cement)

TEMP(°C)	Hz	Good Clean - 25%	Good Clean - 50%	Good Clean - 75%
4.4	25	97%	58%	98%
	10	98%	59%	106%
	5	100%	52%	113%
	1	106%	59%	109%
	0.5	109%	66%	111%
	0.1	117%	71%	111%
21.1	25	63%	64%	95%
	10	67%	64%	97%
	5	69%	63%	107%
	1	73%	65%	105%
	0.5	78%	77%	107%
	0.1	84%	81%	110%
37.8	25	109%	87%	121%
	10	114%	93%	122%
	5	117%	102%	123%
	1	130%	103%	132%
	0.5	150%	104%	140%
	0.1	125%	115%	148%
54	25	88%	87%	95%
	10	91%	94%	99%
	5	94%	94%	106%
	1	100%	107%	116%
	0.5	105%	103%	112%
	0.1	112%	102%	122%
	Average:	100%	82%	113%

Table 23 shows that the additional cement to the poor clean samples did not make a significant change in dynamic modulus values. Through the entire analysis, it can be seen that the difference between 2% and 1% cement content is about 15%.

Table 23: Effect of 2% cement to dynamic modulus on poor clean samples (Values indicate the ratios between the dynamic modulus of foamed asphalt stabilized FDR with 2% cement and that with 1% cement)

TEMP(°C)	Hz	Poor Clean - 25%	Poor Clean - 50%	Poor Clean - 75%
4.4	25	90%	103%	103%
	10	86%	97%	101%
	5	86%	95%	106%
	1	82%	95%	107%
	0.5	79%	100%	112%
	0.1	76%	96%	119%
21.1	25	77%	116%	100%
	10	75%	112%	98%
	5	74%	117%	102%
	1	73%	123%	115%
	0.5	71%	118%	125%
	0.1	71%	117%	131%
37.8	25	81%	130%	115%
	10	80%	129%	119%
	5	80%	131%	121%
	1	79%	136%	130%
	0.5	87%	128%	132%
	0.1	89%	122%	142%
54	25	91%	115%	98%
	10	100%	114%	99%
	5	102%	115%	94%
	1	102%	115%	106%
	0.5	97%	115%	109%
	0.1	99%	107%	109%
	Average:	84%	114%	112%

Table 24 results show that the additional cement has a negative effect on the dirty foamed asphalt samples. The average dynamic modulus at 2% cement is almost 30% lower for the poor dirty and good dirty materials. It can be assumed that the fines in the FDR material have a role in the results. Similar to the results from the asphalt emulsion samples, it can be assumed that not enough water is available for the cement to fully hydrate.

Table 24: Effect of 2% cement to dynamic modulus on good dirty and poor dirty samples (Values indicate the ratios between the dynamic modulus of foamed asphalt stabilized FDR with 2% cement and that with 1% cement)

TEMP(°C)	Hz	Poor Dirty - 25% RAP	Good Dirty - 25% RAP
4.4	25	73%	54%
	10	74%	54%
	5	73%	55%
	1	73%	54%
	0.5	78%	59%
	0.1	76%	58%
21.1	25	67%	56%
	10	67%	55%
	5	67%	55%
	1	65%	57%
	0.5	70%	58%
	0.1	73%	61%
37.8	25	68%	60%
	10	70%	62%
	5	71%	64%
	1	74%	72%
	0.5	77%	77%
	0.1	81%	90%
54	25	72%	86%
	10	72%	92%
	5	74%	97%
	1	78%	110%
	0.5	84%	116%
	0.1	91%	127%
	Average:	74%	72%

To develop the E* curves, the same process was used from the asphalt emulsion samples. The five samples were analyzed for dynamic modulus and any outliers were discarded. The COV's for the foamed asphalt samples are mostly below 15%. There are a significant number of frequencies that had higher than 15% COVs for the good clean combinations with both the 1%

and 2% cement. This would lead to the conclusion that good clean materials can potentially be quite variable and special attention needs to be taken when dealing with this type of materials.

5.3 Repeated Load Triaxial Testing

The repeated load triaxial test was used to evaluate the permanent deformation characteristics of the asphalt emulsion and foamed asphalt stabilized FDR materials.

5.3.1 Testing Procedure of Asphalt Emulsion and Foamed Asphalt Samples

The repeated load triaxial testing was again straightforward with conditioning the samples, loading into the chamber of the SPT machine and entering the proper test criteria. For repeated load triaxial testing, LVDTs were not needed and therefore gauge points were not required. This eliminated one of the major problems that occurred during the dynamic modulus testing.

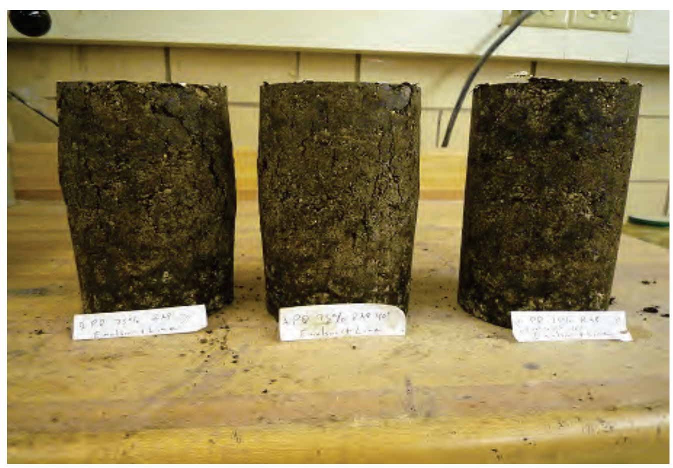


Figure 54: Tested repeated load triaxial samples with the right sample that did not fail.

The main issue that arose during the repeated load triaxial testing was samples not achieving a limit strain of 5% which is imperative for obtaining complete results for analysis. With the initial repeated dynamic pressure determined from Task 4 data, it was suggested to try and use a single pressure for all test samples. This did not work, since many samples did not fail as shown in *Figure 54*. There is a high variation on the strength of the samples depending on RAP content and aggregate type.

Many samples needed to be tested at different deviatoric stresses in order to reach the 5% permanent axial strain within the 30,000 load cycle limit of the machine.

5.3.2 Results of Asphalt Emulsion Samples

The results of the repeated load triaxial testing show that this test is a good indicator of performance and predicting rutting potential of asphalt emulsion stabilized FDR. The materials tested exhibit different characteristics over the varying testing temperatures The plots shown in Section 4.3 represents the data at 80°F and 30,000 N using the MEPDG model and the coefficients. The plots show that the lower the curve, the lower the amount of permanent strain in the sample. As the curves reach higher N values, the sample is straining more and more permanent deformation is generated. By looking at the plots for good dirty with and without lime, it appears that lime has slight effect on the results. Adding lime seems to lower the curves slightly in the good dirty samples. *Figure 55* is an example of the comparison between samples with and without lime.

Poor dirty samples seem to be hindered by adding lime. Consistent with the dynamic modulus results, the poor dirty samples seem to perform worse with the addition of lime. Once again, this may be due to the moisture content in the samples. There may not be enough water in the samples to activate the lime and obtain a better performance. This further emphasizes the need to develop specific moisture density curves for each type of FDR material with and without lime. *Figure 56* demonstrates the typical results of repeated load triaxial testing on a poor dirty sample.

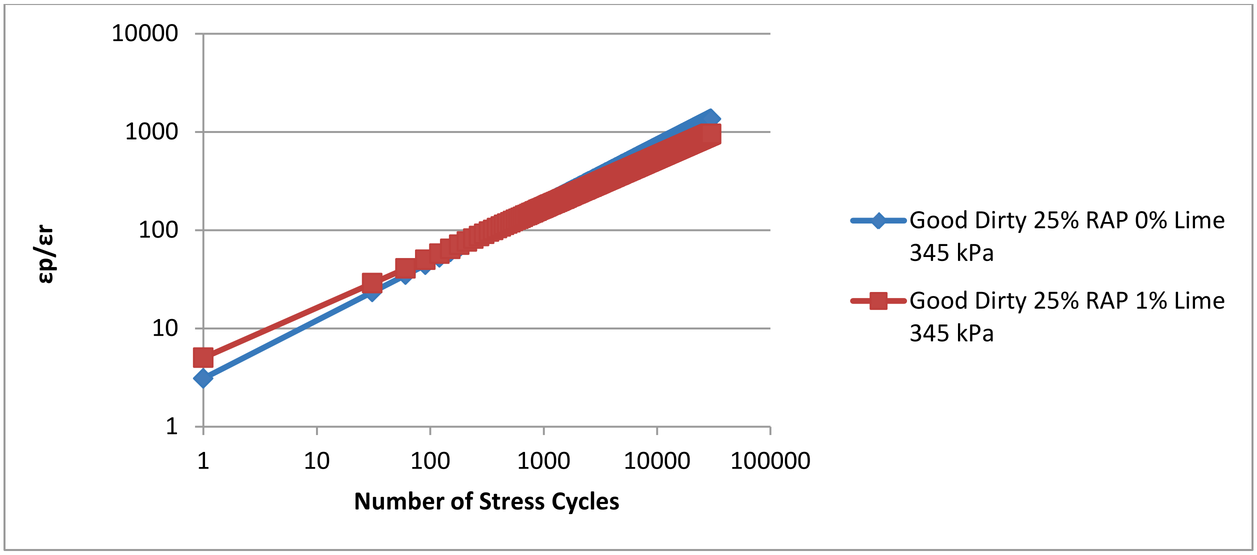


Figure 55: Comparison of repeated load regression for good dirty samples with additional 1% lime

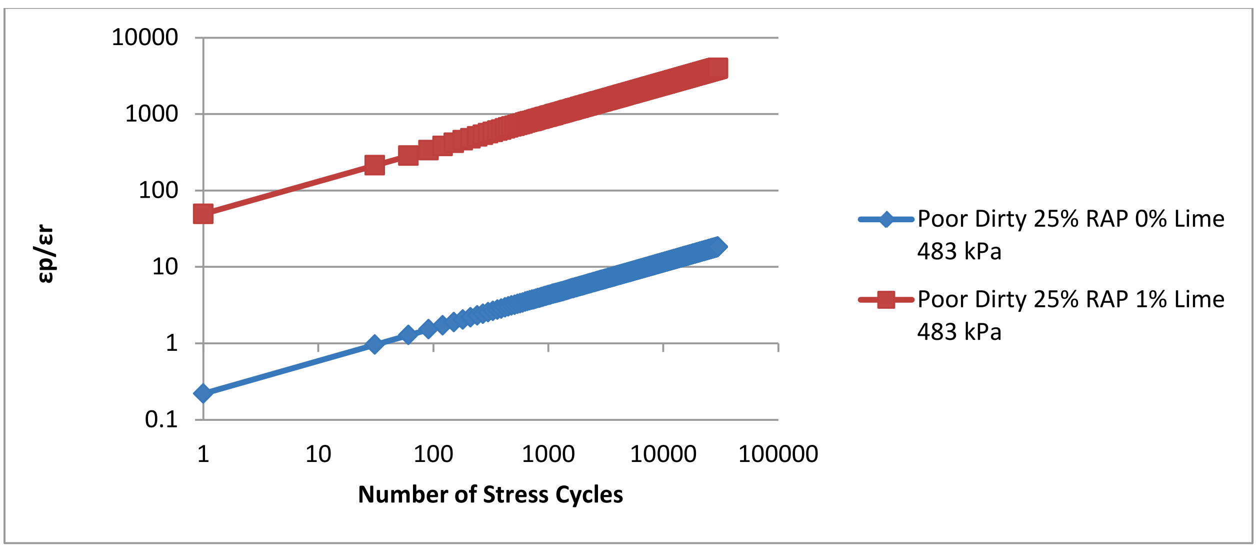


Figure 56: Comparison of repeated load regression for poor dirty samples with additional 1% lime

5.3.3 Results of Foamed Asphalt Samples

The results from repeated load triaxial testing on foamed asphalt samples indicate it can be used to predict performance and permanent deformation characteristics of FDR stabilized with foamed asphalt. By comparing FDR combinations tested at similar deviatoric stresses, it can be inferred that the additional cement can lower the permanent strain generated in the samples. *Figure* 57 shows typical results from this comparison.

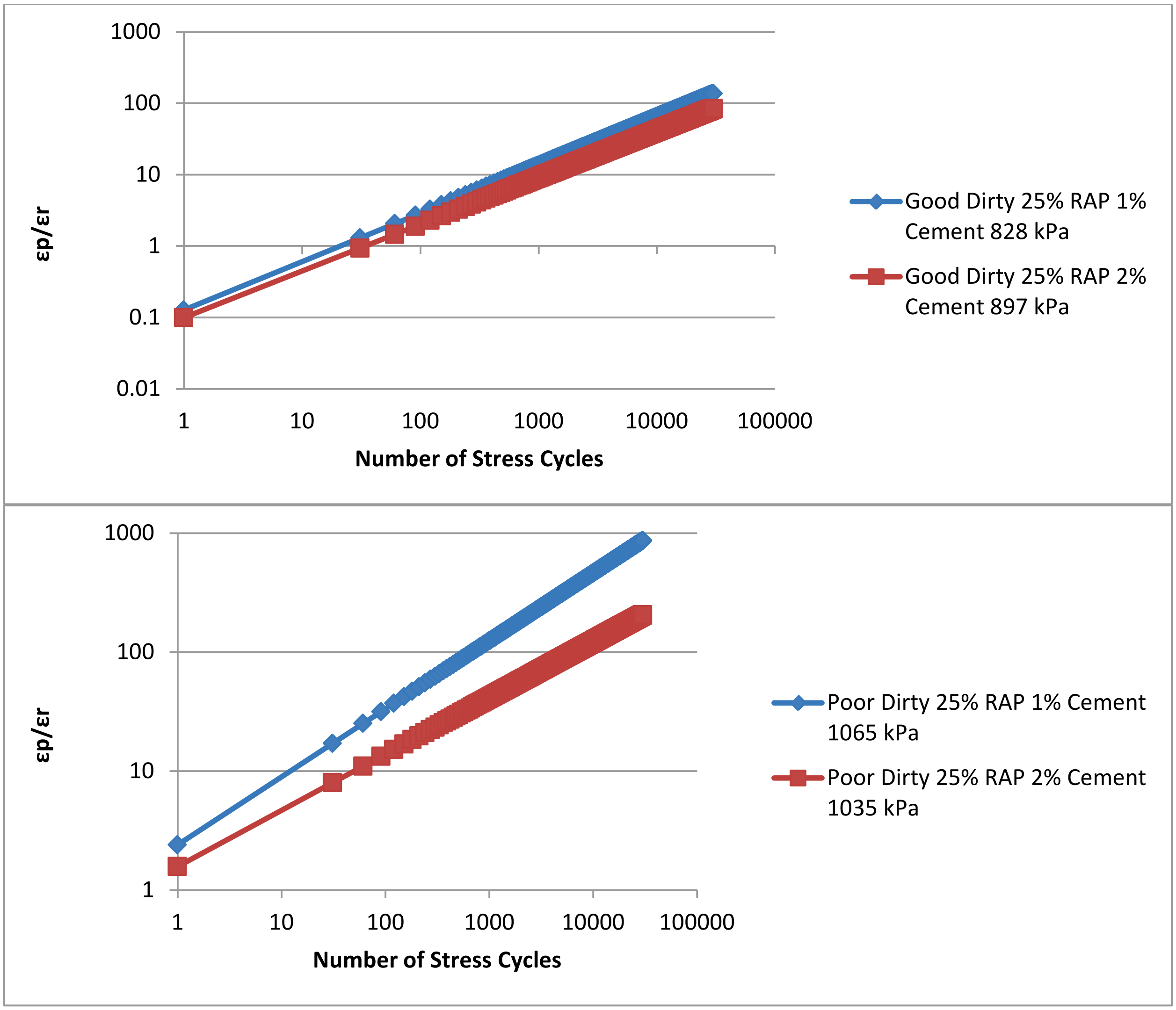


Figure 57: Comparison of repeated load regression for poor dirty and good dirty samples with 2% cement

6.0 Findings

6.1 Modulus of Rupture

The results of the modulus of rupture testing for cement and fly ash stabilized FDR show that the test is a good indicator for the strength of the stabilizing materials. The cement stabilized FDR possessed a higher strength when compared to the fly ash stabilized FDR. For the cement stabilized FDR, the highest modulus of rupture was 360 psi for the good clean source with 25% RAP and 7% cement and the lowest was for the poor clean source with 25% RAP and 3% cement at 55psi. For the fly ash stabilized FDR, the highest modulus of rupture was 70 psi for the good clean source with 25% RAP and 12% fly ash and the lowest was for the poor clean source with 75% RAP and 12% fly ash at 7psi. The COV values show that the testing for cement stabilized FDR went exceptionally well and could easily be repeatable, but for the fly ash stabilized FDR, the results were not as favorable and may prove to not be a good way to test the fly ash stabilized FDR.

6.2 Dynamic Modulus

The results of the dynamic modulus testing show that the test is viable for characterizing the strength of asphalt emulsion and foamed asphalt stabilized FDR mixtures. The results also show that the lime additive had little to no effect on samples' performance unless there was high enough moisture content to activate the lime. This correlates with the results of Task 4 dry and wet tensile testing that concluded the lime made little difference due to the presence of limited moisture. Results of the dynamic modulus on foamed asphalt stabilized FDR indicate that additional cement content has no significant impact. Samples with low fines content and higher RAP content seem to do better with additional cement.

6.3 Repeated Load Triaxial Testing

The results of the repeated load triaxial testing show that this test can be a good indicator of rutting resistance of FDR stabilized with asphalt emulsion and foamed asphalt. The testing concluded that the lime was not effective for the poor dirty samples, but was beneficial for the good dirty samples most likely due to higher moisture content. Foamed asphalt samples had better results with the additional 2% cement.

Overall, all three tests (modulus of rupture, dynamic modulus, and repeated load triaxial) conducted were able to assess the performance of the stabilized FDR materials. The testing conducted also showed that the test results could have good repeatability. The results of the testing were also shown to follow good engineering principles when analyzed.

7.0 Recommendations

As stated in the Introduction section of this report, the scope of this task is to assess the applicability of the currently available test methods in evaluating the engineering properties of FDR materials. The three major testing methods that were assessed in this task include: modulus of rupture, dynamic modulus, and repeated load triaxial.

In general, the modulus of rupture test was found to be applicable for the evaluation of modulus or rupture of FDR materials stabilized with Portland cement and fly ash. Therefore, the test method specified in ASTM D1635 can be used to evaluate the modulus of rupture of FDR materials stabilized with Portland cement and fly ash with modifications made. The modifications include: (1) A steel plate approximately one inch thick with a steel mallet to compact the mixture to the desired height and (2) a lubricant to avoid adhesion between the material and he sides of the mold.

In the case of dynamic modulus and repeated load triaxial testing of FDR materials stabilized with asphalt emulsion and foamed asphalt, modifications of the standard method as specified in AASHTO TP62 are needed as listed below:

- Sample Fabrication: AASHTO TP 62 calls for coring a 4.0 inch diameter from 6.0 inch diameter sample compacted in the Superpave gyratory compactor. The following modification is needed:
    - It is not practical to core the 4.0 inch diameter test sample from a 6.0 diameter sample due to the instability of the FDR materials in the presence of water during the coring process. Therefore, it is recommended that a 4.0 diameter sample be compacted in the Superpave gyratory compactor and directly tested in AASHTO TP62.
- Attachment of the Displacement Sensors: AASHTO TP62 calls for the attachment of the displacement sensors holders directly on the face of the cored 4.0 inch samples using epoxy. The following modification is needed:
    - This procedure could not be used on FDR materials due to the extremely open surface of the sample face (i.e. air voids 13 – 15%). A significantly larger sensor holder and a large amount of epoxy would have been needed to attach the sensors holders on the sample face. It was felt that the use of larger holders and large quantity of epoxy would have impacted the behavior for the FDR sample.

- Based on these observations, several methods were examined for connecting the sensors holders to the face of the FDR sample. However, recognizing that the scope of this task is not to develop an entirely new test setup which requires significantly more time and funds than what is available through this project, it was decided to use a simple approach such as rubber bands to attach the sensors holders to the FDR sample. The number of rubber bands needed to attach the sensors holders was optimized through numerous trial measurements on the various asphalt stabilized FDR materials. After several trial measurements, it was concluded that the use of 10 rubber bands would give adequate holding strength as well as minimum chance of deforming the FDR sample. It is recognized that the use of rubber bands to attach the sensors holders is not the ideal approach and recommends that further research be conducted into the development of a new technique to attach the sensors holders to the FDR sample.

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10.0 Appendix

10.1 Raw Data

The raw data can be found on accompanied DVDs.

10.2 Example Dynamic Modulus Output

Shown is an example of the dynamic modulus output file for an individual frequency.

Dynamic Modulus Standard Report

Date:	11/12/2010		Dynamic Modulus:	6753636. kPa
Time:	8:33:17 AM		Phase Angle:	6.36 Deg

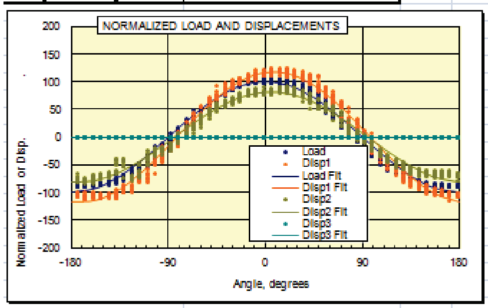
Specimen ID:	GD25%-1%-01			
Project:	Foamed Asphalt			
Test Freq:	25.0000	Hz		
Specimen Gauge Length:	70	mm		
Operating Technician:	PMK			
File Name:	C:\ITC\Data\Dynamic Mod - Paul\Foamed Asphalt\Good Dirty\25% RAP\1% Cement\4.4deg GD 25 RAP 1Cement 01 - REDO .5 HertzFreq1			
Specimen Dia.:	99.950	mm		
Specimen Hieght:	153.420	mm		
Cross Sec. Area:	7846.129	mm^2	imen Conditioning Time:	720 Min
Target Test Temp:	4.4	C	Remarks:	
Target Confining Pressure:	0.	kPa	Post Test Remarks:	

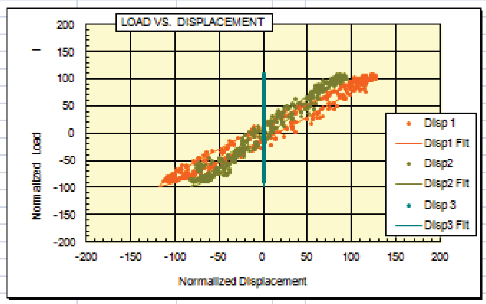
Data Quality Indicators

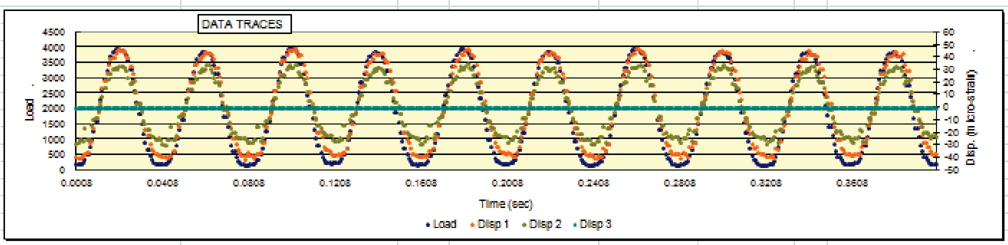
Drift for Load (%):	-1.72
Std. Error for Load (%):	8.34
Average Drift for Deformations (%):	-1.73
Avg. Std. Error for Deformations (%):	9.85
Uniformity Coef. for Deformations (%):	26.30
Uniformity Coef. for Phase Angles (Deg):	1.17

Average Actual Temperature:	4.1 C
Average Actual Confining Stress:	0. kPa

Warnings







Shown in the following is an example of the dynamic modulus output for a whole test.

Time:	8:35:37
Date:	11/12/2010
Specimen ID:	GD25%-1%-01
Project Name:	Foamed Asphalt
Operating Tech:	PMK
Specimen Gauge Length (mm)	70
Specimen Dia. (mm):	99.95
Specimen Height. (mm):	153.42
Cross Sec. Area (mm^2)	7846.129
Test Temp (C):	4.1
Conf. Pres. (kPa):	0

Frequency (Hz)	Dynamic Modulu	Phase Angle (De	Average Temp. (	Average Conf. P	Load Drift (%)	Deformation Drif	Std. Error for Lo	Std. Error for De	Uniformity Coef.	Uniformity Coef.	Load Amplitude	LVDT Amplitude Avg (mm)
25	6753636	6.36	4.1	0	-1.72	-1.73	8.34	9.85	26.3	1.17	3918.27	0.0052
25	6756560	6.52	4.1	0	1.37	1.87	7.93	9.56	25.93	1.13	3978.05	0.0053
1	5008555	9.7	4.1	0	6.58	17.31	9.67	9.83	25.64	0.52	2684.13	0.0048
0.5	4749637	10.28	4.1	0	-6.96	3.65	2.37	3.76	25.44	0.64	2557.69	0.0048

10.3 Superpave Gyratory Machine Instructions

Superpave Gyratory Compactor
Pine Instrument Company, Grove City, PA
Model #AFGC125X

Materials:

- 4” cylinder mold
- 4” Platens
- Filter papers
- Rubber gloves
- Oven
- Sieves
- Sample Material
- Rubber Mallet

Making 4” cylinder Steps:

1. Make sure sample material has cured properly before making cylinders.
2. Turn compactor on. Set height and diameter in millimeters for sample. Also, be sure to set machine to compact to height and not gyrations. Install 4” diameter head on compactor.
3. Make sure mold is clean. Place bottom platen into mold and place one piece of filter paper in the bottom. Begin to fill mold with material and be careful not to spill any over the edges. If necessary, compact material with top platen and rubber mallet until all material is inside of mold.
4. Place one piece of filter paper and top platen on mold and compact more if platen is not level or below top.
5. Slide mold into gyrator and press start.
6. The machine will now gyrate the sample.
7. When finished, the sample will generally be fairly wet, if working with FDR material, so be sure to have plenty of paper towels handy to clean up excess water in between samples.
8. Move mold over to mold removal press and be sure it is pushed all the way into the removal arms.
9. Press sample out of mold using the hydraulic ram and first, stop once the top platen has been exposed. Remove platen by sliding carefully sideways.
10. Now, proceed to extract the sample the rest of the way out of the mold. Have a sieve ready and place on bottom of sample.
11. Gently flip sample over by grabbing hold of the bottom of the sieve and the bottom platen of the sample. Some samples can be very soft so quickly flipping the sample is best and try not to use too much force. If a sample does fail during this process, clean up and remix the material.
12. Place label on sample and put into oven for 48 hours at 40°C.

NOTE: Some samples will not reach actual height entered. This can and will happen if the mixture is very dense. Be sure to note this if it does occur. When the sample is gyrating, just allow the sample to gyrate until it hits the maximum number of gyrations set on the machine.

10.4 Asphalt Emulsion Mixing Process

Materials:

- Dried RAP and Aggregate
- Water
- Lime
- Fines
- Scoop (2)
- Dry Lube
- Labels
- Scale
- Spatula
- Ladle for oil
- Mixing bowl
- Mixer
- Oven (40°C)
- Oven safe containers (black plastic)
- Fortress Asphalt Emulsion

Making AE Steps:

1. First, calculate all weights of materials as necessary for mixture.
2. Be sure there is enough dried material and oil available for mixing.
3. Spray black containers with dry lube and prepare all labels.
4. Set oven to 40°C.
5. Oil must be mixed properly beforehand if it has been sitting for some time. The emulsion must be heated for a short time and then mixed thoroughly. This will be apparent when there is no oil stuck to the sides of the container and the inside of the container feels smooth when mixing. Wearing latex gloves is very much advised as the oil can be very messy and hard to remove.
6. Begin by placing the mixing bowl on the scale and weighing out RAP and aggregate as necessary for mixture.
7. Place into mixer and begin mixing.
8. Next, weigh out fines, lime and cement as necessary and begin adding to mixing bowl. Allow to mix for 60 seconds.
9. Then add water and mix another 60 seconds. If necessary scrape bowl with spatula to be sure all material is properly mixed.
10. Place mixture onto scale and tare. Begin to slowly add emulsion oil with ladle until proper amount is added.
11. Place back into mixer and mix until thoroughly mixed. Again, use spatula as needed to make sure all material is mixed.
12. Now, remove bowl from mixer and take a second scoop and begin to remove material into black containers. Remove as much material as possible.
13. Place material with label into oven to cure for a 30 minutes.
14. Then proceed to mix the rest of the material and be sure to clean all equipment properly of oil and mixture when done.
15. Proceed to make samples using Superpave Gyratory Compactor (see Gyrator instructions)

10.5 Modulus of Rupture Mixing Process

Materials:

- Dried RAP and Aggregate
- Water
- Fines
- Fly Ash
- Lime
- Mixing Bowl
- Large Mixer
- Scoop
- Beam Molds
- Spatula
- Steel mallet
- Steel Plate (>1")
- Dry Lube
- Labels
- Tamping rod
- Hydration room
- Scale

Mixing Steps:

1. Prepare molds by cleaning, assembling and spraying dry lube onto surfaces.
2. Place mixing bowl on scale and weigh out RAP and aggregate as per calculated weight.
3. Place in mixer and begin mixing. Add fines and continue mixing. Then add fly ash and cement as necessary.
4. Add water and begin mixing again. Scrape sides of bowl if necessary to be sure of proper mixing.
5. Measure out enough material for the three lifts and place into separate containers.
6. Place the first lift mixture into mold and begin tamping 90 times. Repeat mixing procedure and tamping two more times.
7. On last lift, material will need to be compacted to height. Compact with mallet and steel plate to roughly 1" below surface of the molds top surface. Different mixtures do require different amounts of force to compact, so be sure to have proper ear and eye protection. Some beams were unable to be compacted to the three inch height due to the high density of material.
8. Once compacted, label and place into hydration room for one week.
9. After one day, remove samples from molds and place back in hydration room.
10. Once one week has passed in the hydration room, the samples are now ready to be tested.

10.6 Dynamic Modulus Testing with Interlaken SPT Machine

Running a dynamic modulus test is very simple once you enter the proper data into the software and have a sample prepared.

1. First, the sample must be cured for a specified time in the oven to bring it up to temperature. The criterion for dynamic modulus used was in AASHTO TP 62-07. At this point, open the chamber and hook up the LVDT's if they are not plugged in. Then close the chamber making sure not to pinch or cut a cable.
2. While the samples are curing, start the ITC software and set the program for the desired temperature (low – 4.4°C, mid - 30° & 40°C, high - 50°C). Then once the program has started enter the desired temperature and send it to the chiller.
3. Once the sample is cured and the machine is up to temperature, a test is ready to start.
4. Select dynamic modulus test by clicking the little dot on the lower right of the screen.
5. First, turn on hydraulics and move ram up and down a little in case it is stuck slightly. **Do not put sample in until after the hydraulics are turned on.**
6. Open chamber and place sample in with the Teflon sheets and top platen. The ram may need to be moved down for the sample to fit properly. Click the down arrow to lower ram. Move ram up close to the top, but do not go too far as the ram will crush the sample easily. Also, move the ram in small steps as it can be rather touchy and may move somewhat more even after you have let of the mouse button.
7. Attach the LVDT's to the sample. The sample may need to be rotated somewhat otherwise the LVDT's hit the chamber supports. Make sure LVDT's are attached properly and are free to move. Sometimes, material will get in between the gauge points and LVDT's or possibly the LVDT becomes stuck so gently make sure it moves before attaching it. Typically, this will be noticed once a test is started when looking at the results as the test progresses. Close the chamber now and be sure not to pinch or cut cables on the LVDT's.
8. Click on define and fill in the blanks with name of sample, sample diameter, sample height and any other pertinent data for the test and sample.
9. Click the next tab at the top and hit "read" to determine platen location.
10. Then "data" tab, tell the software where to save your data.
11. The next tab has the criteria for each hertz of the test. Two 25 hertz are always run to essentially "seat" the sample. Most likely this data will be filled in, but may not be right for the temperature, especially the "mid" program. Make sure you have "7" frequencies and that it should progress down: 25, 25, 10, 5, 1, 0.5, 0.1 Hz. Then looking in the criterion from AASHTO TP 62-07 in *Table 5*, the temperatures are listed with the Dynamic stress levels in kPa next them. These values to be entered are

initial loads and not what the test will run at, so there is some adjustability to be had. When entering the initial dynamic load it has proven best to start with the low end of the range listed in *Table 5* for 25 Hz and then progressively lower the load as you fill in the blanks down to 0.1Hz. Then for the next column, this is the amount of cycles the machine will try to adjust the load for until it reaches the desired strain. These most likely will be filled in already.

12. In the bottom of this pop-up window there is a pull down menu. This menu tells you what you are saving this "test" as so when you go to run another test all the defined data is pre-loaded and you don't have to fill out all of the same information for the individual hertz and what not. Hit save and close this window after you have named the test.
13. Make sure the small hose running out of side of machine is not clipped shut for dynamic modulus testing.
14. Hit "run" to bring up the test.
15. Hit next, the machine will set "home".
16. Hitting the "next" button will now apply deviator stress. At times, some samples have failed at this point. Lower the ram and clean out the machine and try again with another sample. The stress may need to be adjusted or what has worked is lowering the initial contact stress when defining the test.
17. Hit the "run" button and the test will begin.
18. Once a test is running it is advised to watch the results as they appear in the box on the lower right and watch the graph as the test is running. In the results you can see the criteria set for in AASHTO TP 62-07 for what is determined as good data and in the graph you can see how the machine is testing your sample. At times, straight lines will appear in the graph, this is the machine missing a pulse and generally leads to bad data. If a test comes out to not have good data, the sample can generally be rerun completely which typically can work or individual hertz can be run by just defining on single hertz instead of 7 and saving the test as something else.

10.7 Repeated Load Triaxial Testing with Interlaken SPT Machine

Running a repeated load triaxial test is very simple once you enter the proper data into the software.

1. First, the sample must be cured for a specified time in the oven to bring it up to temperature. The criterion for dynamic modulus was used for this where 30°C were cured for one hour, 40°C two hours and 50°C three hours.
2. While the samples are curing, start the ITC software and set the program for the desired temperature (mid - 30° & 40°C high - 50°C). Then once the program has started enter the desired temperature and send it to the chiller.
3. Once the sample is cured and the machine is up to temperature, a test is ready to start.
4. Select flow number test by clicking the little dot on the lower right of the screen.
5. First, turn on hydraulics and move ram up and down a little in case it is stuck slightly. **Do not put sample in until after the hydraulics are turned on.**
6. Open chamber and place sample in with the Teflon sheets and top platen. The ram may need to be moved down for the sample to fit properly. Click the down arrow to lower ram. Move ram up close to the top, but do not go too far as the ram will crush the sample easily. Also, move the ram in small steps as it can be rather touchy and may move somewhat more even after you have let of the mouse button.
7. Click on define and fill in the blanks with name of sample, sample diameter, sample height and any other pertinent data for the test and sample.
8. Click the next tab at the top and hit “read” to determine platen location.
9. Under the “test” tab fill in the following information:
   - **a. Conditioning time: 60, 120 or 180 minutes**
   - **b. Pulse sampling interval: 1 pulse**
   - **c. Max. number of cycles: 30000 (do not go higher than this)**
   - **d. Target test temperature: whatever you choose**
   - **e. Target confining Pressure: 35 KPa**
   - **f. Target contract deviator stress: 18 KPa**
   - **g. Target repeated deviator stress: 345 KPa**
   - **h. Data Rate: 400 Hz (do not change this)**
10. Then “data” tab, tell the software where to save your data.
11. The small pull down menu at the bottom of this pop-up allows you to save this test for future use. So name the test something general and then reuse this test if you have multiple samples to run and just change the specifics of the sample each time.
12. Then hit “save” on the “data” tab and close the window.
13. Make sure the small hose running out of side of machine is clipped shut or else pressure will not be maintained.

14. Hit run, the machine will set “home.” Then hit next, the machine now applies confining pressure. The temperature will rise quite a bit at this time, so make sure to give it some time for temperature to settle within the range you desire.
15. Hitting the “next” button will now apply deviator stress.
16. Hit the “run” button and the test will begin.
17. Once the test is over look at how many cycles the test ran through before saving. If 30000, then the sample did not fail. Look at the strain of the sample and see how high it made. Now, the repeated deviator stress will need to be increased by some amount to be sure your sample will fail. Most likely, the sample will need to be remade.

10.8 E* Master Curve Generation Instructions

To develop the E* master curves a few simples steps are all that is need when using the Excel sheet provided by the Western Regional Superpave Center. All shift coefficients are calculated and shown as well and should be presented with each developed master curve.

1. First, the dynamic modulus raw data will need to be analyzed and compiled before it is copied into the Excel sheet. If all the data is good in one run proceed to next step.

Many times, when running the dynamic modulus test on base material more than one test run was required or individual hertz needed to be re-run to achieve acceptable data. So, the data will needs to be processed to “pick” the best set of data to use that meets the test criteria.

   a. Start by opening a summary dynamic modulus file – there will be two types of outputs one is a summary of the test and the other files are all individual hertz results. There should only be text and no graphs.
   b. Now, compare this data to the second run or copy and paste any individual hertz that needed to be rerun.

2. Open file “SPT_Estar-00H2_wo_AVTS.xlsm”
3. At A42 is a table where the dynamic modulus data should be copied and pasted into.
4. To make copying and pasting easier, start a new Excel file for compiled data.
5. Copy and paste the dynamic modulus data into this file making sure to label mixture, hertz and temperature of test results.
6. Organize data and calculate average dynamic modulus and then the standard deviation and coefficient of variation based on the average dynamic modulus for each mixture.
7. Now, copy this data into the “SPT_Estar-00H2_wo_AVTS.xlsm” file.
8. Put a label somewhere in the file to know what mixture you are working with.
9. If all data is in the correct location, click on sheet “SolverE_star” and hit “Click for Solver.”
10. The E* master curve should generate itself along with the coefficients required to shift.

10.9 Steps for Repeated Load Regression Analysis

Completing the regression analysis for the repeated load triaxial test is very straightforward. The goal of this regression is solving for the coefficients a, b and c of the following model:

$$\frac{\varepsilon_p}{\varepsilon_r} = 10^a (T)^b (N_r)^c$$

Where: ε_p is the permanent axial strain in in/in, ε_r is the resilient axial strain in in/in, Nr is the number of load repetitions, T is the temperature of the HMA mix in (°F), and a, b and c are experimentally determined coefficients.

1. First, obtain the repeated load triaxial test data files for each temperature and mixture. There will be two output files, one an Excel sheet and the other a *.dat file. The file that is required is the *.dat file.
2. Open the Excel sheet "MEPDG perm def model.xlsx"
3. Click on the tab with the temperature you are going to copy first and copy all of the data from the *.dat file into this sheet. Rename these sheets if a different temperature is being used.
4. Once the three *.dat files have been copied any zero or negative values in the column of data called "Resilient Strain (%)" needs to be deleted. So, highlight the entire set of data including the column labels and hit sort by "Resilient Strain (%)" smallest to largest. Delete any zero or negative rows completely and then resort again by the first column "Pulse Number."
5. Once the data is in order, click on the analysis sheet. The first four columns show what data needs to be copied into this sheet: Pulse Number (N), temperature (T), Axial Strain and Resilient Strain.
6. Copy all data for each temperature into these columns making sure not to overlap data.
7. Be sure the column "εp/εr" is copied all the way to the end of your data and the next three columns as well.
8. The regression analysis is nothing more than just using Excel's built in regression tools. Click on column "log(εp/εr)" to be the "y" data and the next two columns are the "x" data.
9. Click to have it create a new sheet called "regression" and hit ok.
10. A new sheet should generate and the three coefficients are listed in column b17-b19 as shown below.
11. Now that the coefficients are developed the model can be analyzed for any temperature (T) and any number of pulses (N) using the model.
12. An analysis was plotted as "N" on the x-axis and "εp/εr" on the y-axis.

	Coefficients
Intercept	-4.31365 = a
log(T)	2.730688 = b
log(N)	0.48264 = c

10.10 Foamed Asphalt Mixing Process

Materials:

- Dried RAP and Aggregate
- Water
- Cement
- Fines
- Scoop
- Dry Lube
- Labels
- Scale
- Oven (40°C)
- Oven safe containers (black plastic)
- Wirtgen F.A. Machine
- 64-22 oil (heated)

Making FA Steps:

13. Place oil into oven the night before with tray underneath to catch any leaking oil. Set oven at 100°C.
14. The morning of making samples, turn oven up to 120°C. Then proceed to turn on Wirtgen Foamed Asphalt machine.
15. Be sure to calculate out all sample material weights. Then weigh out in individual containers. Also, be sure you have enough material dried before mixing day.
16. Refer to Wirtgen operating manual for steps to running machine.
17. Once mixture has been made, prepare oven containers by cleaning and spraying dry lube onto inside surfaces.
18. Place container on scale and weigh out mixed foamed asphalt as per calculated weight.
19. Label sample as necessary and place in oven.
20. Once all samples have been weighed out properly proceed to make samples with the Superpave Gyratory Compactor (see directions). Do not discard material until all samples have been made in case of sample failure while making.