A Comprehensive Evaluation of Environmental Conditioning System

by

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Evaluation of ECS for Predicting Damage Susceptibility of HMAC

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16. Abstract

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A study was undertaken at the University of Texas at El Paso (UTEP) to evaluate the ECS. Based on the results from this study, the ECS needs improvements both in terms of conditioning of asphalt concrete mixture, as well as, resilient modulus test setup. Specifically, the resilient modulus test setup of the ECS needs improvement in the precision and accuracy of the measurements.

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Abstract

Many highway agencies face the problem of premature failure of asphalt concrete pavements due to moisture damage. Various laboratory tests have been used to predict the moisture susceptibility of asphalt concrete mixtures. Unfortunately, none of the available laboratory tests are able to accurately discriminate between well and poor performing mixes; that is, the laboratory test results do not necessarily correlate well with the field performance. Recent studies performed under the Strategic Highway Research Program (SHRP) indicate that the environmental conditioning system (ECS) is a device that better simulates the field conditions. Based on the initial studies, the ECS seemed to be able to distinguish moisture susceptible mixes. A recent study conducted by the Colorado DOT suggested that the ECS device and testing procedure needed further evaluation before it could be incorporated in the routine use.

A study was undertaken at the University of Texas at El Paso (UTEP) to evaluate the ECS. Based on the results from this study, the ECS needs improvement both in terms of conditioning of asphalt concrete mixture, as well as, resilient modulus test setup. Specifically, the resilient modulus test setup of the ECS needs improvement in terms of precision and accuracy of the measurements.

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EVALUATION OF ECS FOR PREDICTING DAMAGE SUSCEPTIBILITY OF HMAC

INTRODUCTION

The TxDOT has been experiencing significant damage to pavements due to stripping. Two test methods, Tex-531-C and Tex-530-C, are commonly used to evaluate the stripping potential of asphalt concrete in the laboratory. However, neither of these two test methods are good indicators of field performance. To better predict field performance, the Environmental Conditioning System (ECS) was developed at the Oregon State University (OSU) under a contract from the Strategic Highway Research Program (SHRP). The ECS was developed with the objective of simulating field conditions in the laboratory, thus providing a better indication of moisture susceptibility of asphalt concrete mixtures. The initial studies at the OSU exhibited that the ECS has the potential for identifying moisture-susceptible mixtures in the laboratory. However, a study conducted by the Colorado DOT indicated that the ECS needs to be more critically evaluated and modified.

The basic objectives of this project are: 1) to evaluate the ECS device under conditions encountered in Texas, 2) to compare its versatility with other methodologies already used in Texas and other states, 3) to define the strengths and weaknesses of the device, 4) to determine the cost effectiveness of the device, and 5) to outline modified test protocols applicable to the diverse climatic conditions of Texas. The project was divided into two phases. The first phase of the project was to achieve the first three objectives, while the second phase was to implement the information obtained to achieve the last two objectives. The research done in the first phase of this project is discussed in this report.

TEST METHODS FOR PREDICTING STRIPPING

Ecs Test Procedure

The specimens used in the ECS procedure are 102 ± 4 mm in diameter and 102 ± 4 mm in height. The air void contents of all specimens are in the range of 7.5 ± 0.5%. The loose asphalt concrete mixtures are prepared (as per AASHTO TP4-93, Edition 1b) and short-term aged (in accordance with AASHTO PP2-94, First Edition). The short-term aged mixtures are compacted using a SHRP gyratory compactor (as per AASHTO TP4-93, Edition 1b). The compacted specimens are left at room temperature over-night to cool down, and then encapsulated in a latex membrane with silicone, and set aside for a minimum of 15 hours to dry.

The air permeability and dry resilient modulus (MR) of the specimen are determined soon after being placed inside the ECS load frame. The air permeability is determined by flowing air through the specimen at a vacuum level of 68 kPa. The resilient modulus is determined by applying a load in the form of a haversine wave with a loading period of 0.1 sec and a rest period of 0.9 sec. The specimen is then saturated by pulling de-aired distilled water through it at a vacuum level of 68 kPa. In the next step, the water permeability of the specimen is determined.

The saturated specimen is subjected to a "hot cycle"; that is the specimen's temperature is elevated to 60° C for six hours while it is subjected to the haversine loading. The specimen is cooled down to a temperature of 25° C for at least two hours. At the end of the eight hours, the conditioned MR and the water permeability are determined. The process is repeated for two more cycles, i.e. six hours of loading and heating at 60 ° C followed by two hours of cooling. If the ratio of the conditioned MR to the unconditioned MR (or dry MR) falls below 0.7, the mixture will be considered as moisture susceptible and vice versa.

The ECS test procedure described above is similar to the AASHTO TP34-94 procedure (First Edition) with two exceptions. First, the specimens in this research are prepared using a SHRP Gyratory Compactor, while the ECS protocol suggests to use a Rolling Wheel Compactor. This was done to minimize the cost of acquiring equipment. Since the SHRP Gyratory Compactor will be available to TxDOT, this method of sample preparation seems to be more reasonable and practical.

The AASHTO TP34-94 procedure suggests the specimen to be split into two halves, so that, the amount of stripping can be visually estimated. We found this to be a difficult and subjective task, therefore, a visual inspection of the specimen was not done.

One of the objectives of this research project is to compare the results of the ECS and Tex-531-C test procedures. While the ECS test procedure uses resilient modulus as an indicator of stripping, Tex-531-C uses indirect tensile strength (ITS). Therefore, it was decided to also obtain the indirect tensile strength (ITS) ratios (based on Tex-226-F) for the ECS conditioned specimens. The ITS ratios obtained from the two test procedures can be compared to determine the severity of conditioning involved in each method. After the ECS-conditioned resilient modulus was determined, the specimen was broken using the indirect tensile test. In addition, several very similar unconditioned specimens were simply subjected to the indirect tensile tests. The ratio of the conditioned modulus and unconditioned modulus from each experiment was compared to that of Tex-531-C test procedure. Since no guidelines for the use of the measured air and water permeabilities were provided, specific comparisons were not carried out.

Finally, the ECS procedure recommends a freezing cycle for some regions. This cycle was omitted in this study, because it was not deemed necessary for the climate of Southwestern U.S.

Tex-531-C Test Procedure

Eight similar asphalt-concrete specimens of a mixture are prepared. The moisture susceptibility of a mixture is evaluated based on the average strengths of four conditioned and four unconditioned specimens.

Each specimen is prepared by mixing heated asphalt and aggregates. The loose mix is then subjected to a minimum of 2.5 hours of cooling at room temperature, followed by a short-term aging at 60° C for a period of 15 hours. The short-term aged mixture is heated at 135° C for a period of 2 hours, before being shaped into specimens with an air void content of 7.0 ± 0.5% using a SHRP Gyratory compactor. The compacted specimens (102 ± 4 mm in diameter by 63.5 ± 1 mm in height) are cooled at room temperature for a period of 24 hours.

The eight specimens are then divided into two groups of four. One group is left in a desiccator until tested for their indirect tensile strengths. Meanwhile, the second group is subjected to vacuum saturation at 68 kPa for 5 to 10 minutes, so that 60 to 80% of the specimen's air voids are filled with water. The saturation period depends on the air void content and permeability of the specimen. The saturated specimens are placed in plastic bags (two per bag) along with 10 ml of distilled water. The bags are kept in a freezer, maintained at a temperature of -18° C, for a span of 15 hours. The specimens are transferred to a water bath maintained at 60° C for 24 hours, followed by a water bath at a temperature of 25° C for 4 hours.

The specimens, including the four specimens kept in the desiccator, are tested for their indirect tensile strengths at a loading rate of 50 mm/min. The ratio of the average tensile strengths of the conditioned specimens, and of the unconditioned specimens is then determined. If the ratio is below 0.7, the mixture will be considered as susceptible to moisture susceptible.

ORIGINAL PROBLEMS WITH ECS

The operation and testing protocol of the environmental conditioning system needed several modifications before the system could be used for routine testing. The major issues were as follows:

- The modifications to the original SHRP prototype, and changes to the testing protocol were not reflected in the instruction manuals.
- The vacuum system was not air tight and had to be extensively tested and modified.

- The bottom of the temperature-control chamber is uneven and quite flexible causing a poor support condition for the loading frame. The base plate of the loading frame was modified to provide a better support.
- The test procedure called for the usage of distilled water, when the system needed de-aired, distilled water. A de-airing system was devised and manufactured at UTEP.

The device was delivered to UTEP in late December, 1994. Resolving the above issues and other minor problems took four months.

EVALUATION OF ECS

Tests were performed with the ECS to establish the accuracy and precision of the system. In this manner, the repeatability of the test results and the ability of the ECS system in predicting the moisture susceptibility of different asphalt-concrete mixtures could be determined. Three mixtures were selected for the analysis: two mixes not susceptible to stripping (El Paso and Colorado) and one which usually strips (Atlanta). To evaluate the precision of the system, each mix was tested five times (i.e. five specimens were prepared from each mix and then tested using the ECS system). Since the versatility of the system needed to be compared with the existing tests, Tex-531-C tests were also performed on the three mixtures.

ECS Test Results

As indicated before, the moisture-susceptibility of a mix is determined based on the ratio of the unconditioned and conditioned resilient moduli. This ratio is called the MR ratio. The MR ratios of the El Paso mix, after three conditioning cycles, varied from 0.27 to 0.80, indicating a poor precision (see Table 1). Specimen numbers 1, 2, 4, and 5 can be classified as moisture susceptible, while specimen number 3 indicates that the mix is acceptable. Historically, the El Paso mix has not exhibited any moisture susceptibility.

The detailed results of the ECS tests are shown in Figure 1. In terms of MR ratios, only specimens 1 and 2 follow the same pattern from one cycle to another, while the other specimens exhibit different behaviors.

For the Colorado mix, the MR ratios vary from 0.62 to 0.82 (Table 2). The results from specimens 1 and 3 indicate the mix is moisture susceptible. On the other hand, according to the results from specimens 2, 4, and 5 the mix should be suitable. The Colorado mix is historically considered as a satisfactory mixture. Figure 2 depicts the MR ratio values after each cycle for each specimen. Contrary to the El Paso mix, all specimens (except specimen 5) yield similar MR ratios after the second cycle.

TABLE 1. - Summary of ECS Test Results For El Paso Mix.

NO.	VTM (%)	Cycle No.	Average Resilient Modulus (GPa)	Resilient Modulus Ratio	ITS** (MPa)	ITSR$^+$
1	8	0*	0.94	1.00	0.54	
		1	0.65	0.70	N/A	
		2	0.48	0.51	N/A	
		3	0.55	**0.59**	0.37	**0.69**
2	7.5	0	0.99	1.00	0.57	
		1	0.55	0.56	N/A	
		2	0.48	0.50	N/A	
		3	0.53	**0.54**	0.32	**0.56**
3	7.7	0	0.77	1.00	0.53	
		1	0.66	0.86	N/A	
		2	0.68	0.88	N/A	
		3	0.62	**0.80**	0.42	**0.81**
4	7.2	0	1.02	1.00	0.49	
		1	0.50	0.49	N/A	
		2	0.48	0.47	N/A	
		3	0.28	**0.27**	0.32	**0.65**
5	8.0	0	0.80	1.00	0.53	
		1	0.40	0.50	N/A	
		2	0.48	0.60	N/A	
		3	0.40	**0.50**	0.36	**0.67**

* Cycle 0 represents tests before conditioning

** ITS denotes indirect tensile strength

$^+$ ITSR denotes indirect tensile strength ratio

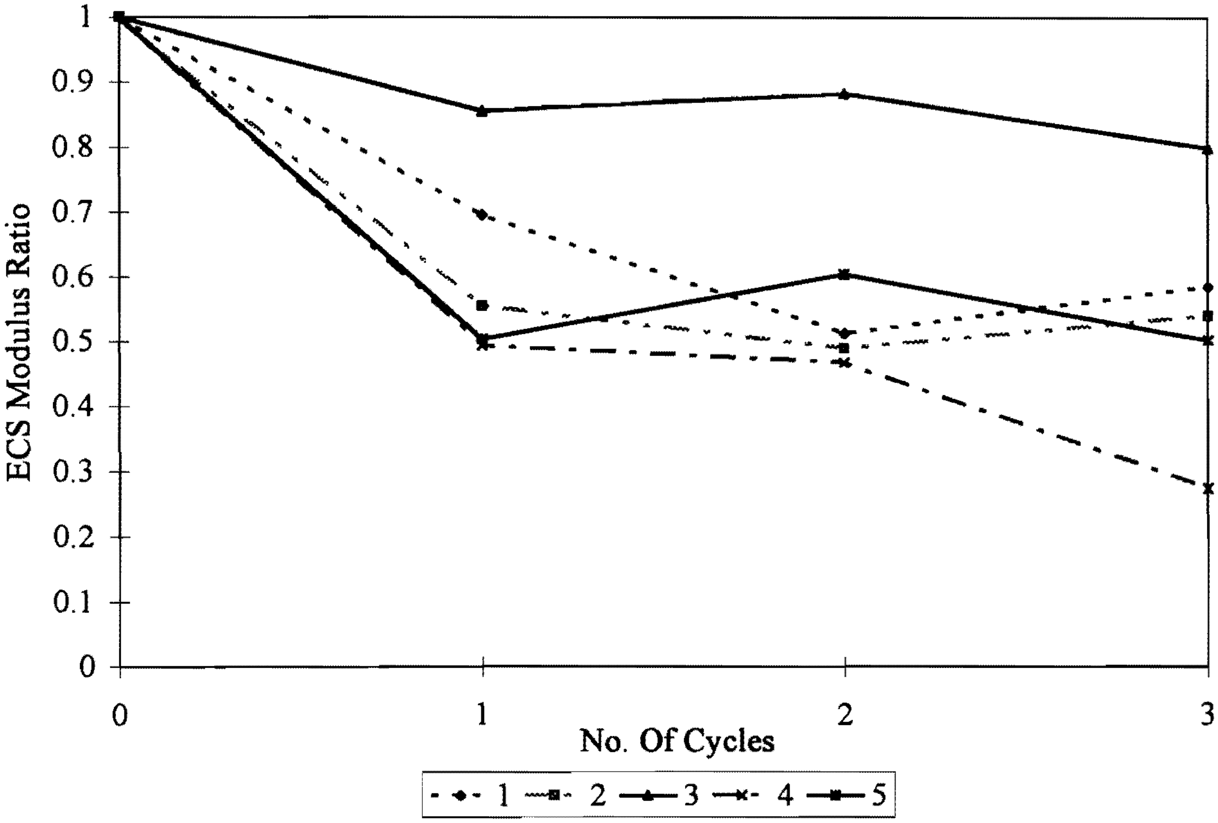


Figure 1. - Resilient Modulus Ratios for El Paso Mix.

TABLE 2. - Summary of ECS Test Results For Colorado Mix.

NO.	VTM (%)	Cycle No.	Average Resilient Modulus (GPa)	Resilient Modulus Ratio	ITS** (MPa)	ITSR⁺
1	7.7	0*	1.40	1.00	0.56	
		1	0.94	0.68	N/A	
		2	1.04	0.75	N/A	
		3	0.86	**0.62**	0.54	**0.96**
2	7.3	0	1.47	1.00	0.66	
		1	0.91	0.62	N/A	
		2	1.08	0.74	N/A	
		3	1.03	**0.71**	0.59	**0.90**
3	7.9	0	1.49	1.00	0.64	
		1	0.88	0.59	N/A	
		2	1.04	0.70	N/A	
		3	0.99	**0.66**	0.54	**0.86**
4	7.5	0	1.74	1.00	0.67	
		1	1.52	0.87	N/A	
		2	1.26	0.73	N/A	
		3	1.23	**0.71**	0.56	**0.83**
5	7.9	0	1.01	1.00	0.64	
		1	0.98	0.97	N/A	
		2	1.04	1.03	N/A	
		3	0.82	**0.82**	0.66	**1.03**

* Cycle 0 represents tests before conditioning

** ITS denotes indirect tensile strength

⁺ ITSR denotes indirect tensile strength ratio

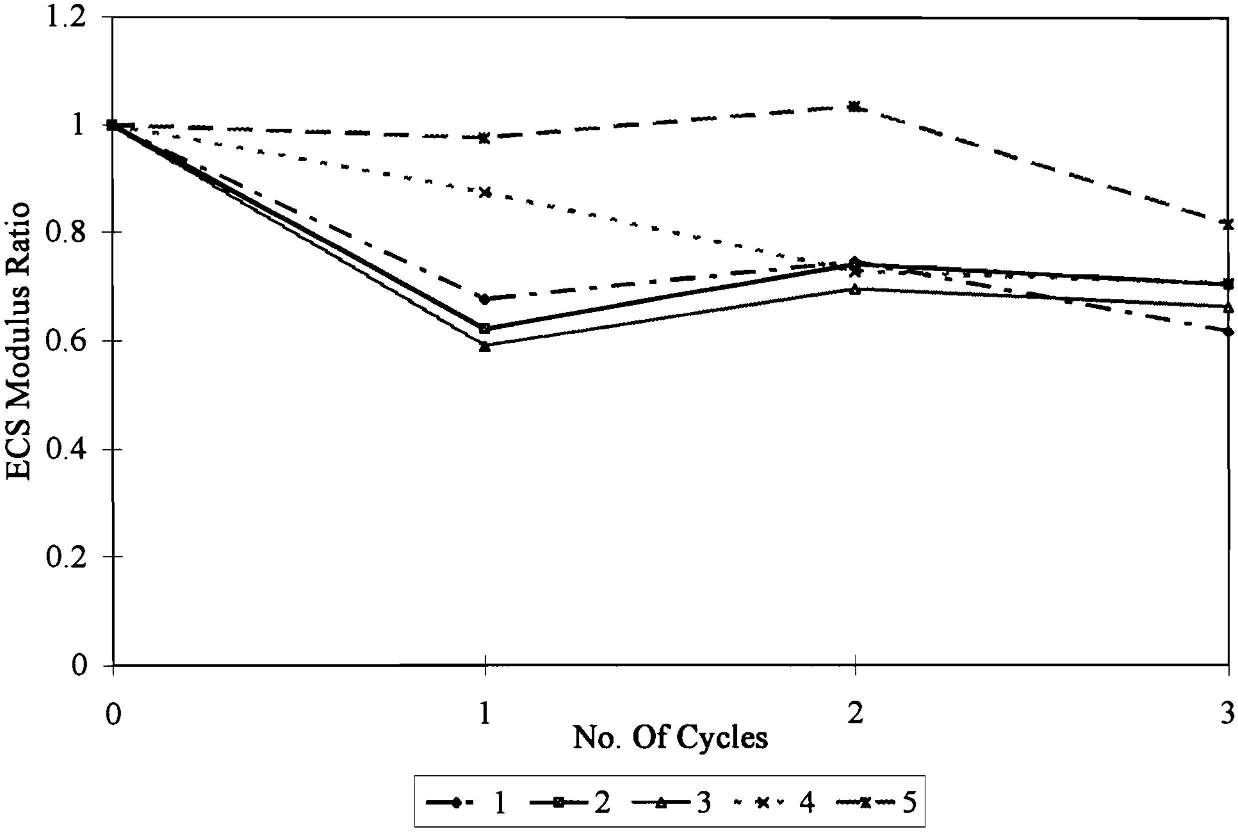


Figure 2. - Resilient Modulus Ratios for Colorado Mix.

The MR ratios for the Atlanta mix, a moisture-susceptible mix, varied from 0.64 to 1.42 indicating a lack of repeatability. As per Table 3, only the results from specimen 5 indicate any moisture susceptibility. The other specimens passed the criteria of MR ratio value of 0.7. The Atlanta mix is considered moisture susceptible, and usually modified with an anti-stripping agent. Figure 3 shows the MR ratio after each cycle is different for each specimen of the Atlanta mix, indicating a large variability in the results.

Tex-531-C Test Results

The results obtained from this test procedure are summarized in Table 4. The average indirect tensile strength (ITS) ratios for the El Paso mix varied from 0.59 to 0.98. All specimens, except number 4, yield strength ratios in excess of 0.7, indicating that the mixture is not moisture susceptible. This conclusion is in concurrence with the historical field performance of the El Paso mix.

The ITS ratios of all specimens prepared from the Colorado mix are about 0.9 indicating that the mixture should not be moisture susceptible. Based on historical performance, the Colorado mix is not prone to moisture damage. The results from the five tests are quite repeatable and do not vary by more than 0.1.

The Atlanta mix should perform well based on the ITS ratios obtained from the specimens. The average tensile strength ratios of the five tests varied from 0.96 to 1.13. Unfortunately, this conclusion is not supported by the historical performance of this site. Once again, the results are quite repeatable.

Comparison of Two Methodologies

The test results obtained from the two test procedures indicate the Tex-531-C test method yields more precise (repeatable) results as compared to the ECS test procedure. However, neither of the two tests are accurate enough to consistently discriminate between a well-performing and a poor-performing mix.

Shown in Table 5 are the averages, standard deviations and coefficients of variation corresponding to each mixture for three parameters. The three parameters are: 1) the resilient modulus ratios from the ECS, 2) the ITS ratios from tests performed on the specimens that were conditioned in the ECS, and 3) the ITS ratios from the Tex-531-C tests.

The repeatability of the test methods can be determined by comparing the coefficients of variation reported for the three parameters. For the MR ratios obtained with the ECS, the coefficient of variation seems to be dependent on the mix. For two of the mixes, the CV's are about 35 percent, whereas for the third one it is about 10 percent. Such variation cannot be attributed to the operator since all tests were performed by one person, nor can

TABLE 3. - Summary of ECS Test Results For Atlanta Mix.

NO.	VTM (%)	Cycle No.	Average Resilient Modulus (GPa)	Resilient Modulus Ratio	ITS** (MPa)	ITSR$^+$
1	7.4	0*	1.55	1.00	0.71	
		1	0.44	0.28	N/A	
		2	0.93	0.60	N/A	
		3	1.13	**0.73**	0.81	**1.14**
2	7.5	0	1.93	1.00	0.69	
		1	2.83	1.47	N/A	
		2	2.50	1.30	N/A	
		3	2.73	**1.42**	0.76	**1.11**
3	7.8	0	2.12	1.00	0.67	
		1	2.43	1.15	N/A	
		2	3.03	1.43	N/A	
		3	2.50	**1.18**	0.88	**1.32**
4	7.6	0	3.33	1.00	0.64	
		1	2.67	0.80	N/A	
		2	2.96	0.89	N/A	
		3	2.73	**0.82**	0.75	**1.16**
5	7.3	0	4.18	1.00	0.69	
		1	3.65	0.87	N/A	
		2	3.42	0.82	N/A	
		3	2.67	**0.64**	0.74	**1.07**

* Cycle 0 represents tests before conditioning

** ITS denotes indirect tensile strength

$^+$ ITSR denotes indirect tensile strength ratio

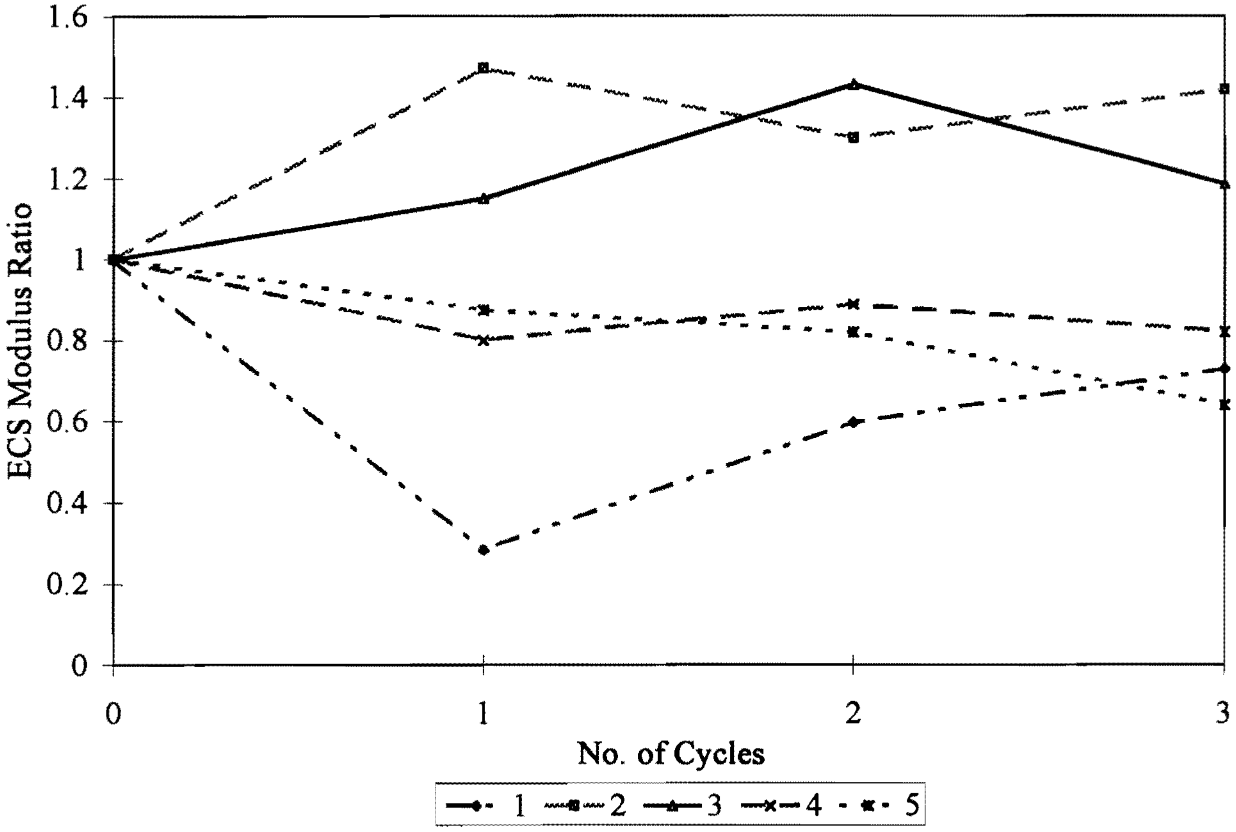


Figure 3. - Resilient Modulus Ratios for Atlanta Mix.

Table 4. - Summary of Results Obtained for Tex-531-C Test.

a) El Paso Mix

No.	Average Indirect Tensile Strength (kPa)		Indirect Tensile Strength Ratio
	Unconditioned	Conditioned	
1	584	571	0.98
2	348	277	0.80
3	542	467	0.86
4	598	354	0.59
5	587	515	0.88

b) Colorado Mix

No.	Average Indirect Tensile Strength (kPa)		Indirect Tensile Strength Ratio
	Unconditioned	Conditioned	
1	609	626	1.03
2	685	620	0.91
3	713	632	0.89
4	688	625	0.91
5	697	634	0.91

c) Atlanta Mix

No.	Average Indirect Tensile Strength (kPa)		Indirect Tensile Strength Ratio
	Unconditioned	Conditioned	
1	695	785	1.13
2	749	748	1.00
3	1509	1509	1.00
4	727	701	0.96
5	808	806	0.99

Table 5. - Statistical Analyses of ECS and Tex-531-C Test Results.

Mix Type	Resilient Modulus Ratio (MR)			ECS Indirect Tensile Strength Ratio			Tex- 531-C Indirect Tensile Strength Ratio		
	Average	Standard Deviation	Coeff. of Variation (%)	Average	Standard Deviation	Coeff. of Variation (%)	Average	Standard Deviation	Coeff. of Variation (%)
El Paso	0.54	0.19	35.2	0.68	0.09	13.2	0.82	0.14	17.2
Colorado	0.70	0.07	10.0	0.92	0.08	8.7	0.93	0.06	6.5
Atlanta	0.96	0.33	34.4	1.16	0.10	8.6	1.02	0.07	6.9

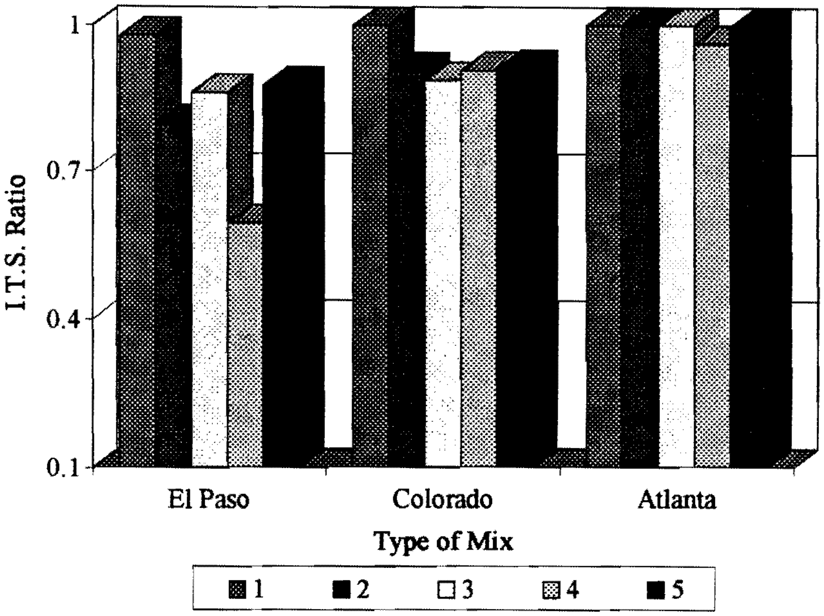


Figure 4. Indirect Tensile Strength Test (I.T.S.) Ratios for ECS Conditioned Specimens

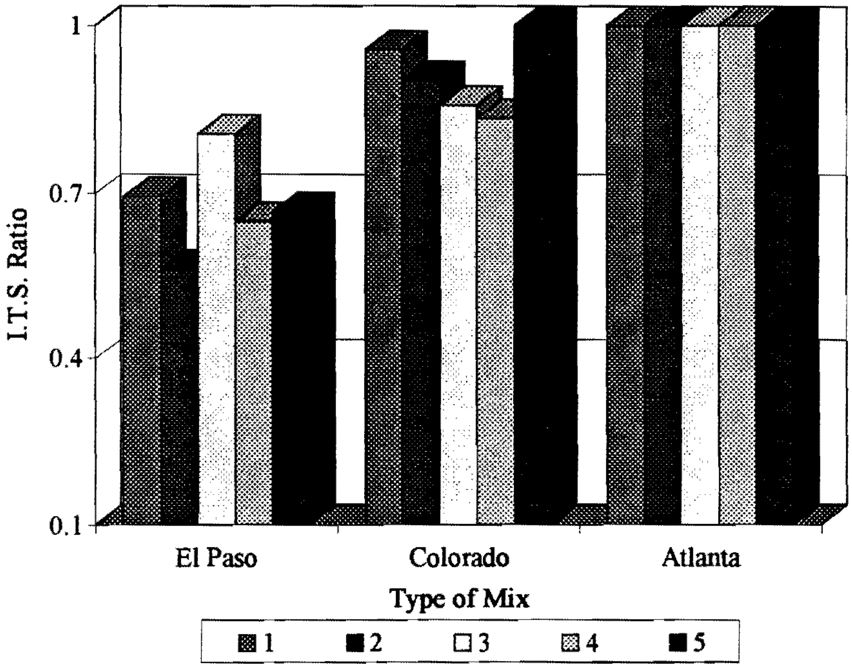


Figure 5. Indirect Tensile Strength (I.T.S.) Ratios for Tex-531-C Conditioned Specimens

it be due to the variability in preparing the specimens, because the coefficients of variation associated with the ITS tests performed on the identical specimens are about 10 percent.

In our opinion, the source of the deficiency is the resilient modulus set-up. As compared with the rigidity of the specimen, the compliance of the test frame may not be adequate. This maybe remedied by redesigning the loading system. The other source of problem is the method of mounting of the LVDT's. At this time, the LVDT's are being replaced with non-contact probes to minimize problems with measuring displacements. These subjects are further discussed in the next section.

The repeatability of the Tex-531-C seems to be satisfactory , since the coefficients of variation (CV) are typically about 7 to 10 percent. For the El Paso mix, the CV is about 17 percent because of one obvious outlier (see Table 4).

The degree of moisture conditioning of the ECS and Tex-531-C can be compared by inspecting the averages of the ITS ratios from the two tests, (Figures 4 and 5). For the three mixtures tested, it seems that the two systems more or less provide the same level of conditioning. The average ITS ratios for the El Paso mix are 0.68 and 0.82 for the ECS and Tex-531-C tests, respectively. Therefore, the ECS provides a slightly harsher conditioning, for the El Paso mix. For the Colorado mix, the ITS ratios are about 0.9 for both test methods, which can be interpreted as similar levels of conditioning. Finally, for the Atlanta mix, it seems the effects of specimen conditioning is nil, since the ITS ratios are close or greater than unity.

WEAKNESSES OF ECS

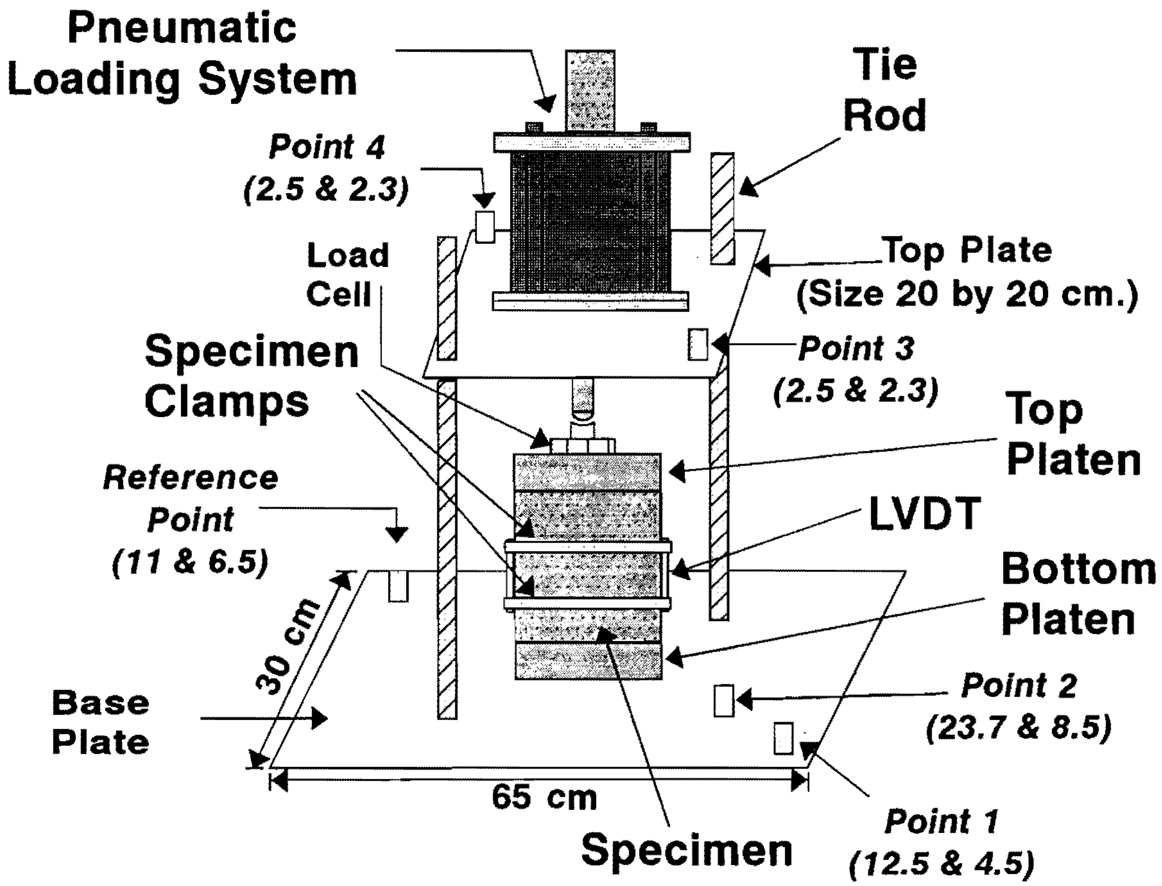
The evaluation of the ECS indicates that the system requires some improvement before it can yield reasonable results. The following issues should be considered.

Rigidity of Loading System

One factor that can contribute to the lack of repeatability of the results can be the rigidity of the loading system. The effects of insufficient rigidity becomes more prominent for stiffer specimens. The rigidity of the loading system is controlled by at least two factors: stiffness of the loading system, and the support under the loading system.

To evaluate the rigidity of the loading system in the ECS, two sets of tests were carried out: 1) when the loading system was inside the temperature-control chamber, and 2) when the loading system was placed on a rigid support.

For both tests, an accelerometer was used to measure the levels of vibration of the system under dynamic loads. A reference point was selected as shown in Figure 6. One



Numbers in Parantheses Indicate Distance(cm) in X and Y Directions from the Nearest Edge of the Plate

Figure 6. - Location of Vibration Measurement Points on the Loading Frame.

accelerometer was fixed at the reference point and another one was moved to different locations on the loading system (Figure 6). Typical results obtained from the accelerometers, when the loading system was inside the temperature control chamber are shown in Figures 7 and 8. The acceleration time-histories obtained from the reference accelerometer and the accelerometer placed at point 3 are shown in the two figures. The responses from the two accelerometers follow quite well the applied load (i.e. 0.1 seconds of haversine loading and 0.9 seconds of rest). The amplitudes of vibration for point 3 are higher and are in the opposite direction, when compared to the results from the reference point. The higher levels of vibration indicate that the top plate is vibrating more as compared to the bottom plate. The change in the direction of acceleration indicates that the top and bottom plates are moving in the opposite directions.

The acceleration time-histories obtained from the accelerometers can be easily translated to displacement by transforming them into the frequency domain using a FFT algorithm. The frequency-domain data are then differentiated twice to obtain the displacement spectra. The displacement spectra for Figures 7 and 8 are shown in Figures 9 and 10, respectively. Since the period of loading cycle is 0.1 sec for a half sine or 0.2 seconds for full cycle, the amplitudes at a frequency of 5 Hz were used for comparison.

Table 6 contains the displacements at a frequency of 5 Hz when the system was inside the temperature-control chamber, and when the loading system was placed on a relatively rigid support. When the loading system was inside the temperature-control chamber, the displacements vary from 0.5 μm to 2.7μm at different locations within the loading system. When the loading system was placed on a relatively rigid support, the levels of vibration of the top plate reduced from about 2.7 μm to about 1.1 μm at point 3, however, the displacements in the bottom plate increased from about 0.9 μm to about 1.8 μm at point 1.

The levels of vibration are higher in the top plate, when the loading system was inside the chamber, and are higher in the bottom plate when the loading system was on the rigid surface. The increase in the levels of vibration in the bottom plate can be attributed to the unevenness of the rigid surface. Since the loading system was not bolted down, the uneven rigid surface created a rocking motion in the bottom plate, hence, increase in the level of vibrations. The decrease in the level of vibrations on the top plate can be attributed to the lack of rigidity of the bottom plate support. The bottom plate was able to move more on the flexible base and was able to create more reaction forces on the top plate, which increased the levels of vibration on the top plate.

The displacements of the bottom and top plates can be significantly reduced by securely bolting the bottom plate to a rigid surface. This was not done because with the existing system it is not practical.

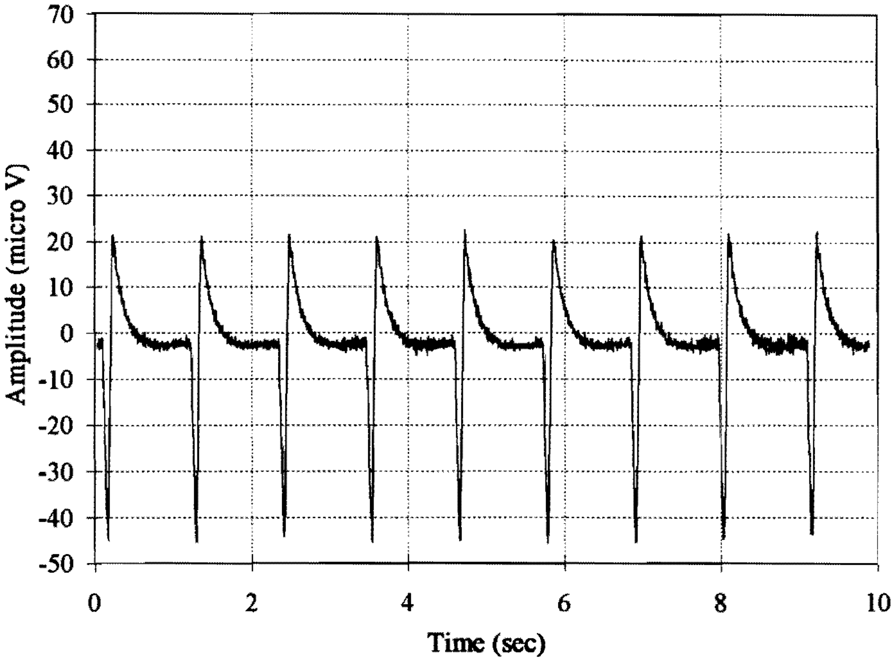


Figure 7. - Raw Acceleration Time History of Reference Point.

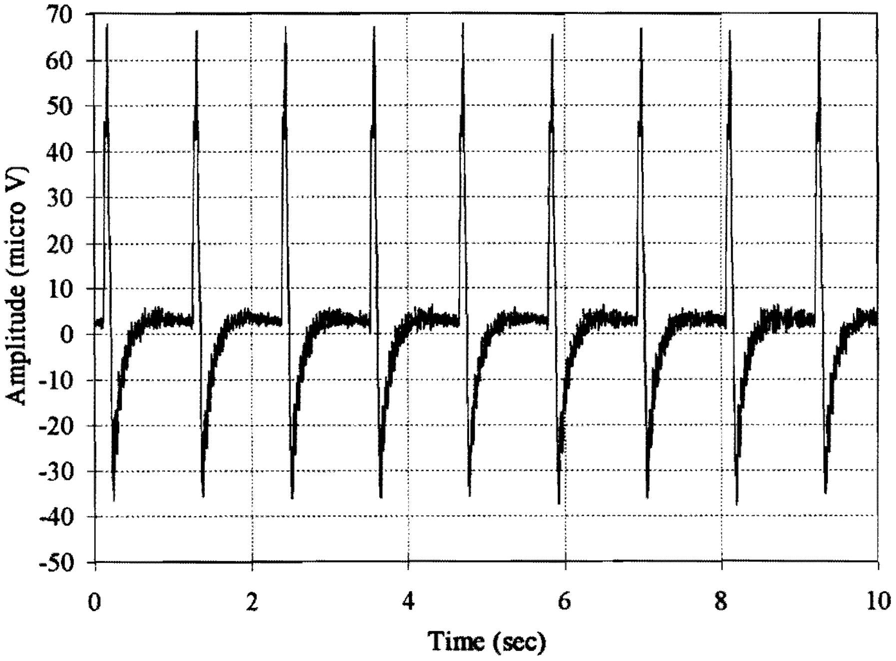


Figure 8. - Raw Acceleration Time History of Point 3.

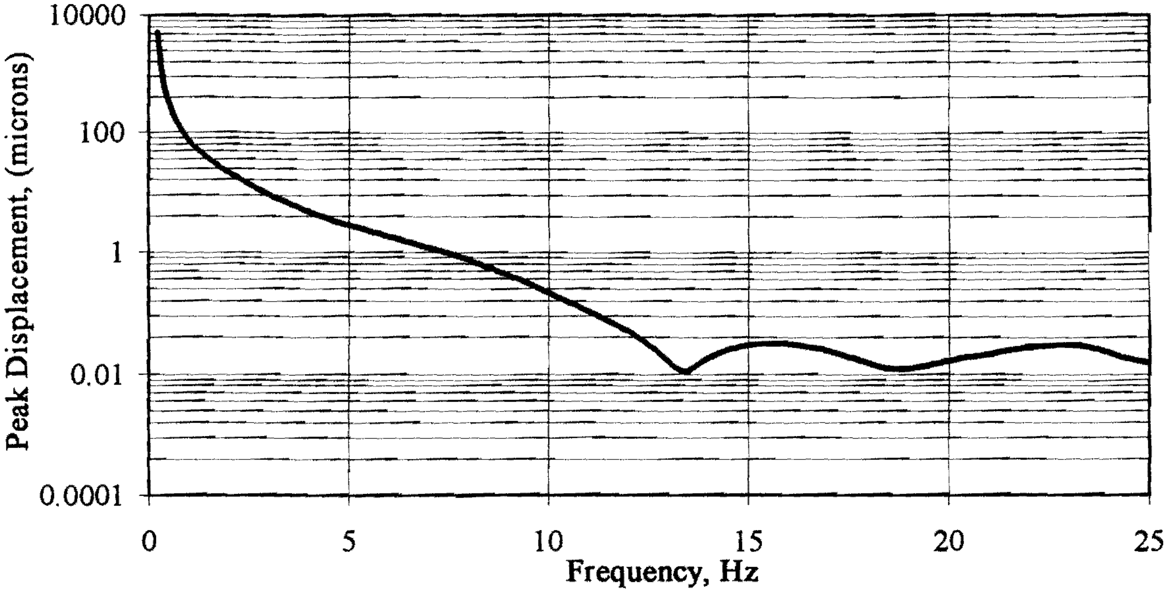


Figure 9. - Actual Displacement Spectrum of Accelerometer at Reference Point.

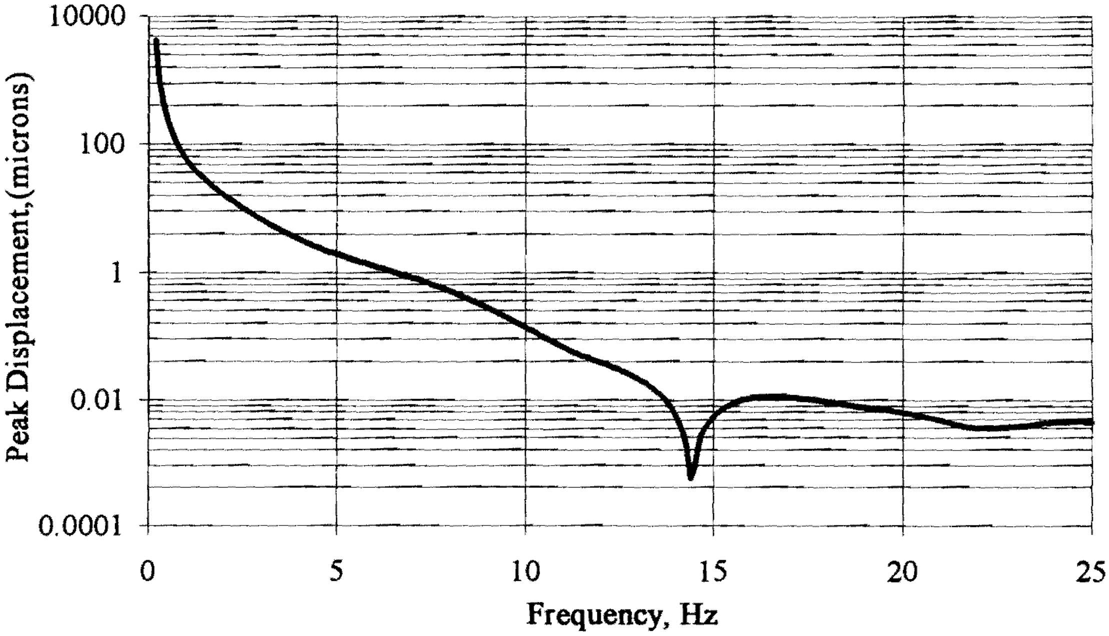


Figure 10. - Actual Displacement Spectrum of Accelerometer at Point 3.

Table 6. - Levels of Vibration at Various Locations on the Loading Frame.

Accelerometer Location	Displacement at 5 Hz (microns)	
	Loading Frame Inside Chamber	Loading Frame on Rigid Surface
1	0.9 (1.9)	1.8 (1.9)
2	0.5 (1.8)	0.9 (2.1)
3	2.7 (1.8)	1.1 (2.1)
4	2.3 (1.8)	0.8 (2.1)

Numbers in Parenthesis Denote Levels of Vibration at Reference Point in microns

LVDT Assembly System

Any loading system used for measuring the strength or modulus of a specimen should be at least ten times more rigid than the specimen being tested. The displacements of the ECS loading system are quite comparable with the displacements measured with the LVDT's during the MR testing, i.e. 1.27 to 2.54 μm From the above analyses, the loading system of the ECS lacks rigidity and needs improvement before the system can yield reasonable results.

The ECS measures the loads using a load cell and the axial deformation using a yoke assembly. The yoke assembly, which is a critical component of the system for repeatable and accurate measurement of the MR, is evaluated here.

Different components of the yoke assembly are manufactured from different materials. For example, the clamp frames are made of aluminum, screws used for fixing the LVDT's on clamps are made of plastic, and the rods, used to ensure that the LVDT's are within the linear range, are made of steel. The specimen's temperature has to be alternated between 25 and 60° C. Since the coefficients of expansion are different for different materials, the yoke assembly has to be frequently readjusted. The readjustment of the yoke assembly is not only tedious, but it may contribute to inaccuracies in the measurement of the resilient modulus. This matter had to be evaluated.

To quantify the impact of these concerns on the accuracy and precision of the resilient modulus testing with the ECS, the resilient modulus of the specimen was determined 15 times following the protocol proposed in the AASHTO TP34-94. The specimen was first tested nine times by completely dismantling and reassembling the yoke assembly. In the second stage, the specimen and the yoke assembly were not dismantled between different tests. The first series of tests was designed to evaluate the effects of yoke assembly on the repeatability, while the second series was designed to evaluate the effect of the system on the repeatability. The modulus obtained from each test is reported in Table 7.

For the first set of tests, the modulus varied between 1.6 GPa and 3.5 GPa. The average modulus is about 2.2 GPa with a coefficient of variation of 30.5 percent. When the yoke assembly was not dismantled, the modulus varied between 2.6 GPa and 2.9 GPa with an average of 2.7 GPa and a coefficient of variation of 4.8 percent. This experiment shows that the yoke assembly significantly contributes to the repeatability of the results, and should be improved.

Another problem that might affect the resilient modulus measurements is the placement of the specimen in the loading system. The specimen is kept in between a top and a bottom loading platen. Since the bottom platen is not fixed to the bottom plate, a slippage between the loading platen and base plate is likely. In addition, with this configuration the specimen may tilt causing an improper distribution of the load in the specimen.

Servo Valve Capacity

In the ECS test procedure, the resilient modulus tests should be performed at strain levels between 50 to 100 μm/m (or 50 to 100 μ in./in.). In some instances, these strain levels cannot be achieved because the system cannot apply high enough loads. Even though, the loading system has a nominal capacity of 350 Kg, applying loads in excess of 200 Kg is typically not possible.

Conditioning of Specimen

According to the ECS test procedure, the conditioning step consists of subjecting the specimen to cyclic loads at 60° C for six hours, while water is continuously passed through the specimen at rate of 4 cc/min. Even though the specimen is maintained at 60° C, the specimen may never achieve this temperature because the water is circulated at 25° C. This cooling of the specimen might affect the proper conditioning of the specimen. This problem can be eliminated by diverting the flow of water through a heating system before it reaches the specimen.

The water may not continuously flow through the asphalt concrete pavement in the field, therefore, it may be more appropriate to discontinue the flow of water after the specimen is saturated. In this manner, it is not necessary to heat the water, and much less water will be necessary to perform the test.

Table 7. - Average Modulus of Synthetic Specimen.

a) Yoke Assembly Reassembled

Stress (kPa)	Strain (μm/m)	Average Resilient Modulus (GPa)
163	99.84	1.63
186	110.31	1.68
172	100.09	1.72
177	98.97	1.78
181	100.83	1.79
181	85.82	2.11
193	77.46	2.48
179	61.40	2.92
176	49.86	3.53
Average		2.18
Standard Deviation		0.66
Coefficient of Variation (%)		30.5

b) Yoke Assembly Not Dismantled

Stress (kPa)	Strain (μm/m)	Average Resilient Modulus (GPa)
176	68.26	2.58
184	70.03	2.63
176	66.97	2.63
172	63.53	2.71
187	66.42	2.83
196	67.51	2.92
Average		2.70
Standard Deviation		0.13
Coefficient of Variation (%)		4.80

SUGGESTED IMPROVEMENTS

The following aspects of the testing procedure are currently being modified:

- The top and bottom load plates of the loading frame provided by the manufacturer are connected by only two tie rods. The two loading plates need to be connected more rigidly, i.e. at least two more tie rods should be used. To improve the compliance of the test frame, the loading frame should also be fixed to a more rigid support.

- The bottom platen is not fixed to the bottom plate which may cause slippage. A mechanism should be developed to fix the bottom platen to the bottom plate.

- The software and the hardware of the system should be modified such that higher loads can be applied to the specimen. In this manner, the specimen can be strained to the levels suggested in the test protocol before MR measurements are made.

- The displacement measuring mechanism should be modified, so that the effects of yoke assembly on the measured resilient modulus are minimized. A more robust proximeter system for measuring the deformations should be implemented and evaluated.

- The conditioning of the ECS can be modified by: 1) increasing the water temperature to 60 °C, 2) saturating the specimen at higher vacuum levels, and 3) eliminating the flow of water after saturation.