| 1. Report No.<br>TX - 01/ 1826 - 1F | 2. Government Accession No. | 3. Recipient's Catalog No. | |
|---|---|---|---|
| 4. Title and Subtitle<br>Modified Environmental Conditioning System:<br><br>Validation and Optimization | | 5. Report Date<br>February 2001 | |
| | | 6. Performing Organization Code | |
| 7. Authors<br>V. Tandon and S. Nazarian | | 8. Performing Organization Report No.<br>Research Report 1826-1F | |
| 9. Performing Organization Name and Address<br>Center for Highway Materials Research<br>The University of Texas at El Paso<br>El Paso, Texas 79968-0516 | | 10. Work Unit No. | |
| | | 11. Contract or Grant No.<br>Study No. 0-1826 | |
| 12. Sponsoring Agency Name and Address<br>Texas Department of Transportation<br>P.O. Box 5051<br>Austin, Texas 78763 | | 13. Type of Report & Period Covered<br>Summary Report 9/98 - 2/00 | |
| | | 14. Sponsoring Agency Code | |
| 15. Supplementary Notes<br>Research Performed in Cooperation with TxDOT<br>Research Study Title:    Evaluation Of Environmental Conditioning System For Predicting Moisture Damage Susceptibility Of HMAC (Continuation of UTEP Project 0-1455) | | | |

**16. Abstract**

Moisture damage is a common problem faced by highway agencies. Over the years, several laboratory test methods have been developed to identify moisture susceptible asphalt concrete mixtures. However, none of them has been successful in consistently discerning moisture susceptible asphalt concrete mixtures.

The Environmental Conditioning System, developed under the Strategic Highway Research Program, had a distinct advantage over the existing methods because it could simulate field conditions. A comprehensive evaluation of the test method showed that although the ECS was a promising concept, it needed further modification and evaluation. The original Environmental Conditioning System was modified under a research project sponsored by TxDOT (Research Project 0-1455). The preliminary results from Project 0-1455 demonstrated that the modified system had the potential for successfully identifying the moisture susceptibility of asphalt concrete mixtures.

In this study, the modified test procedure was further evaluated using mixtures of unknown (to the operator) performance. The results from blind tests were not satisfactory. A post mortem investigation indicated that the mixtures provided for blind testing deviated from their job mix formulae. When specimens prepared following their respective job mix formulae, the moisture-susceptibility of the materials was accurately predicted. This indicates one of the limitations of any moisture-susceptibility laboratory test that relies on mechanical properties; since the modulus or strength of a material is dependent on parameters such as the gradation, AC content and air void content, any deviation from the job mix formula during construction or laboratory testing may impact, favorably or unfavorably, the moisture-susceptibility of the mixture. After port mortem investigation, the test protocol was optimized to reduce the testing time and several aspects of the modified system were further evaluated and modified. Based on the evaluation, a new test setup and protocol were recommended.

| 17. Key Words<br>Moisture Susceptibility, Asphalt Concrete, Resilient Modulus, Conditioning System, Test Procedure | | 18. Distribution Statement<br>No restrictions. This document is available to the public through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 | |
|---|---|---|---|
| 19. Security Classified (of this report)<br>Unclassified | 20. Security Classified (of this page)<br>Unclassified | 21. No. of Pages<br>67 | 22. Price |

Form DOT F 1700.7 (8-69)

# Modified Environmental Conditioning System: Validation and Optimization

by

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and

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Research Project 0-1826

Conducted for

The Texas Department of Transportation in Cooperation with the Federal Highway Administration

Research Report 1826 - 1F

February 2001

The Center for Highway Materials Research
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El Paso, TX 79968-0516

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# Acknowledgments

# Abstract

Moisture damage is a common problem faced by highway agencies. Over the years, several laboratory test methods have been developed to identify moisture susceptible asphalt concrete mixtures. However, none of them has been successful in consistently discerning moisture susceptible asphalt concrete mixtures.

The Environmental Conditioning System, developed under the Strategic Highway Research Program, had a distinct advantage over the existing methods because it could simulate field conditions. A comprehensive evaluation of the test method showed that although the ECS was a promising concept, it needed further modification and evaluation. The original Environmental Conditioning System was modified under a research project sponsored by TxDOT (Research Project 0-1455). The preliminary results from Project 0-1455 demonstrated that the modified system had the potential for successfully identifying the moisture susceptibility of asphalt concrete mixtures.

In this study, the modified test procedure was further evaluated using mixtures of unknown (to the operator) performance. The results from blind tests were not satisfactory. A post mortem investigation indicated that the mixtures provided for blind testing deviated from their job mix formulae. When specimens prepared following their respective job mix formulae, the moisture-susceptibility of the materials was accurately predicted. This indicates one of the limitations of any moisture-susceptibility laboratory test that relies on mechanical properties; since the modulus or strength of a material is dependent on parameters such as the gradation, AC content and air void content, any deviation from the job mix formula during construction or laboratory testing may impact, favorably or unfavorably, the moisture-susceptibility of the mixture. After port mortem investigation, the test protocol was optimized to reduce the testing time and several aspects of the modified system were further evaluated and modified. Based on the evaluation, a new test setup and protocol were recommended.

# Implementation Statement

New guidelines and specifications for testing of the moisture susceptibility of asphalt concrete mixtures in the laboratory are proposed as part of this study. A test setup similar to the one developed at UTEP is manufactured for TxDOT. TxDOT can immediately implement the findings of this study to evaluate its usefulness and weakness as a practical method. The protocol is not applicable to mixtures made with binders containing additives.

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# Chapter 1

# Introduction

## Problem Statement

Moisture damage (i.e., stripping of asphalt from aggregate) in the asphalt concrete (AC) layer of flexible pavements occurs due to a loss of adhesion and/or cohesion (Hicks, 1991). The stripping of the asphalt from the aggregate results in a reduction in strength or stiffness of the asphalt concrete layer. The reduction in stiffness contributes to the development of various forms of pavement distress (Solaimanian et al., 1993).

Although various laboratory test methods have been developed over the years, none of them have been successful in consistently identifying moisture susceptible AC mixes (Hicks, 1991). The most commonly reported drawbacks are a lack of quantitative pass/fail criterion and/or a lack of simulation of field conditions (Terrel and Al-Swailmi, 1994). To overcome these problems, the Environmental Conditioning System (ECS) was developed under the Strategic Highway Research Program (SHRP) (Al-Swailmi and Terrel, 1992). A preliminary evaluation of the ECS conducted by Aschenbrener et al. (1996) called for a comprehensive evaluation of the device and modifications of the testing protocol before it can be implemented in everyday projects.

In view of the above discussion, TxDOT funded a research project entitled "Evaluation of Environmental Conditioning System for Predicting Moisture Damage Susceptibility of HMAC" at UTEP. A test protocol for identifying moisture susceptible asphalt-concrete mixes was proposed as a result of that study. However, the development and verification of test protocol and test setup were performed using mixtures of known performance. Hence, it was essential to validate the test procedure using blind mixes (with unknown performance to the operator). In addition, the proposed test procedure required five days to finish the testing of a specimen. This process needed optimization.

## Research Objective and Approach

The objectives of this study were to validate the proposed test protocol, to reduce the test time, to improve the ruggedness of the conditioning system, and to transfer the technology to TxDOT. To achieve these objectives, the study was divided into three separate tasks. In the first task, the validation of the test protocol was performed using three mixes of unknown performance. In the

second task, various conditioning steps were evaluated and optimized. In the third task, the complex fluid control panel proposed by SHRP and a water-heating unit were redesigned. The prediction capabilities of the system were further verified before transfer of technology to TxDOT. The results of the proposed study are presented in this report.

The report contains four chapters. In Chapter 2, the weaknesses of the ECS system and work plan to minimize or eliminate them are discussed. The results from the proposed work plan are presented and discussed in Chapter 3. The conclusions and recommendation for future research are presented in Chapter 4.

# Chapter 2

# Background

The original ECS test protocol was modified as part of TxDOT Project 0-1455. The major operational changes to the system have been in the conditioning procedure, and the major improvements to the setup have been in the instrumentation used to perform the resilient modulus tests. The modified test protocol is discussed in this section to identify drawbacks in the test setup and/or protocol. A work plan is then proposed to address these drawbacks.

## Modified ECS Test Protocol and Setup

The specimen preparation for the modified procedure is similar to the AASHTO procedures, PP2 and TP4, with one change. The specimen to be tested shall have a VTM between 7% and 8% with a height of $4 \pm 0.15$ in. ($102 \pm 4mm$) rather than 4% VTM. To achieve this objective, sufficient material is mixed, short-term aged and compacted using different number of gyrations. This is a trial and error process, where the number of gyrations and amount of material depends on the mix design. The prepared specimen is removed from the mold and cooled at room temperature for one hour. Four internal square targets, 0.2 in. (5 mm) in dimension, are attached on the specimen after cooling. Two of the targets are attached 0.75 in. (19 mm) apart from the center of the specimen to provide a gage length of 1.5 in. (38 mm). The other two targets are attached to the specimen in the diametrically opposite side of the specimen (180°apart). The internal targets are affixed to the specimen using "Super Glue." The specimen preparation and target placement takes approximately five hours.

On the next day, the specimen is subjected to static immersion saturation with a vacuum level of 26 in.-Hg (88 KPa) for five minutes (Tex -531-C). After static saturation, the specimen is removed from the water bath, and any excess water surrounding the specimen is wiped off. Two caulk trim tapes with lengths equal to the circumference of the specimen are attached to the specimen. A groove is cut on both caulk trim tapes to ensure that the tapes do not cover the attached targets.

The specimen is then enclosed within a membrane and placed between the top and bottom end platens of the resilient modulus ($M_R$) test setup. After this step, water at room temperature is circulated through the specimen at a rate of 0.55 in$^3$/min ($9 \pm 1$ cc/min) for one hour with a vacuum

level of 2.5 in.-Hg (8.5 KPa). The rate of water flow can be controlled by a flow meter and by changing the height of the water container.

After one hour of waiting, the water flow is stopped, the vacuum is released, and the unconditioned resilient modulus is measured. The waiting period is necessary to drain the excess water trapped between the specimen and end platens. For the resilient modulus test, a static load of $100 \pm 2.5$ lbf ($450 \pm 15$ N) is applied for proper seating of the specimen. In addition, a haversine dynamic loading cycle of 0.1 sec and a rest period of 0.9 sec is used to measure $M_R$. The magnitude of dynamic loads is adjusted by trial and error such that the strain levels remain within $100 \pm 10$ $\mu$in./in. ($100 \pm 10$ $\mu$m/m) range. In addition, the deformation along the two sides of the specimen is measured. If the deformation from the two sides is not within 15% of each other, the specimen will be discarded, and a new specimen will be selected for the analysis.

After the $M_R$ measurement, the specimen is conditioned either for six or eighteen hours. During the conditioning, the flow of water is maintained at 0.55 in.$^3$/min ($9 \pm 1$ cc/min) and the vacuum level is maintained at 2.5 in.-Hg (8.5 KPa). The environmental chamber and the water (at the specimen inlet) temperature are maintained at 140°F (60°C). An axial compressive static load of $50 \pm 3$ lbf ($225 \pm 15$ N) is maintained throughout the conditioning process. In addition, a loading cycle of 0.1 sec and a rest period of 0.9 sec is applied during the conditioning period, and the magnitude of the dynamic load is maintained at $200 \pm 3$ lbf ($900 \pm 15$ N).

After six hours of conditioning, the chamber door is opened, conditioning is stopped and the circumference of the specimen is measured. If the circumference of the specimen increases by more than 2%, the material will be considered as moisture-susceptible. At this point, the conditioning process is stopped, and the specimen is removed from the setup. Otherwise, the specimen is conditioned for twelve additional hours followed by cooling at room temperature for twenty-four hours. After the cooling period, the resilient modulus of the specimen is measured again and is considered as the conditioned resilient modulus. If the $M_R$ ratio (ratio of the conditioned and unconditioned resilient moduli) falls below 0.8, the mixture will be considered as marginal. If the $M_R$ ratio is equal to or above 0.8, the mixture will be considered as a well performing mix.

## Weaknesses of Test Protocol and Setup

The above test procedure was modified based on the original ECS test procedure. The test protocol needed further evaluation and modification before it could be transferred to TxDOT. In this section, a critical evaluation of test setup and protocol is presented.

Although the test setup and protocol consistently identified the moisture susceptibility of the asphalt concrete mixes, the operator knew the performances of the mixes. In addition, the test protocol was verified using the same mixes that were used to develop the protocol. New mixes (performance unknown) were used to validate the modified test protocol.

The proposed test procedure needed approximately five days to finish the testing of one specimen. According to the original ECS protocol, a minimum of three specimens should be tested to precisely identify the moisture susceptibility of a mix, which means three weeks of testing at a minimum. The test period was reduced to a practical level while maintaining the accuracy or precision of the test protocol. In addition, the test protocol suggests discarding specimens that show

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more than 15% deviation between the deformations of the two sides. An attempt was made to minimize the discarding of the specimens.

The proposed test protocol suggested measuring the unconditioned resilient modulus after flowing water through the specimen for one hour and a waiting period of one hour. However, the original ECS procedure suggested measuring the unconditioned resilient modulus before saturating the specimen. Tandon et al. (1997) modified the original procedure based on studies conducted by Fwa (1995) and Alam (1997). Fwa (1995) suggested that the resilient modulus of an AC mix depends on the degree of saturation and temperature with no apparent pattern. Alam (1997) also unsuccessfully attempted to identify a relationship between moisture content and resilient modulus. To measure the conditioned and unconditioned $M_R$ at similar saturation levels, Alam (1997) identified that after one hour of water flow and eighteen hours of conditioning the specimen's saturation levels were similar. Therefore, Tandon et al. (1998) suggested that the unconditioned resilient modulus should be measured after one hour of water flow and one hour of waiting. A waiting period of one hour was added to allow the drainage of excess water trapped between the end platens and the specimen.

Although the saturation level affects the resilient modulus of the AC mix, the effect of change in resilient modulus on the $M_R$ ratio was not known and was investigated. The performance of the AC mix is identified based on the $M_R$ ratio. If the change in resilient modulus does not change the performance, i.e., from marginal to well or vice versa, the unconditioned resilient modulus could be measured right after the static saturation, thus, saving two hours of test time.

To further evaluate the relationship between the saturation level and the resilient modulus, five stages of conditioning similar to those propose by Tandon et al. (1998) were identified. The resilient modulus was measured at each selected stage. The five stages were:

- I:   At zero saturation level, i.e., when the specimen is dry,
- II:   After static saturation of the specimen,
- III:   One hour of waiting after Stage II,
- IV:   After circulating water through the specimen for one hour at room temperature after Stage III,
- V:   After waiting for one hour after Stage IV.

The original ECS conditioning setup, developed during the SHRP project, had features to measure additional properties of asphalt concrete mixes like water permeability, etc. The modified protocol does not contain provisions for measuring those properties, and thus, there is no need for certain gauges and valves. For technology transfer to TxDOT, a simpler fluid-conditioning panel had to be developed. In addition, a hot water bath unit was added to the modified test procedure so that the water supplied to the specimen had temperatures similar to the specimen temperature (i.e., 140°F). Originally, the bath unit was made in-house and was not suitable for continuous testing. The water bath unit had to be replaced with a rugged new unit.

## Work Plan

In view of the above discussion, it was necessary to validate the proposed conditioning protocol, reduce the testing time, and increase the ruggedness before the test setup could be transferred to TxDOT. To achieve these goals, the project was divided into three tasks, as described below.

### *Validation of Test Protocol*

The proposed conditioning procedure was developed based on the known performance of the mixtures. The UTEP research team and project director agreed to validate the proposed test protocol by performing tests on two additional mixes. The performances of these mixes were known to the TxDOT personnel, but were unknown to the UTEP research team. The test results of the blind mix study were communicated to TxDOT to identify the validity of the test protocol.

### *Accelerated Testing Protocol*

As indicated before, mainstreaming the previously mentioned steps can reduce the testing time. The UTEP research team and the project director agreed to concentrate on the reduction in conditioning time by measuring the conditioned $M_R$ during conditioning, reducing specimen cooling time, reducing the number of specimens rejected, and, additionally, reducing the testing time (by measuring the unconditional resilient modulus after static saturation). The conditioning protocol was studied using a marginal mix (i.e., El Paso).

### *Modified Conditioning Test Setup*

A fluid control panel developed for the original ECS consisted of various controls that were eliminated in the modified ECS procedure. A new fluid control panel and a more robust water bath unit were manufactured, evaluated, and transferred to TxDOT.

The results of the critical evaluation of the modified protocol are discussed in the following chapters. Although few tasks were carried out simultaneously, the results are presented in order of the proposed work plan.

# Chapter 3

# Results and Discussion

The individual tasks of the work plan were evaluated and the results of the evaluation are discussed in this chapter. Also, a newer version of the moisture susceptibility test procedure is proposed.

## Validation of Test Protocol

To evaluate the validity of the test protocol, new materials were requested from TxDOT. Six mixes, in three batches, were sent to UTEP. For each batch, the mixes were labeled A and B. To reduce the chances of identifying the performance from raw materials, the asphalt and aggregates were mixed before shipping to UTEP. The mixes were received in December, March, and May. The validation of the test protocol was performed as described in Chapter 2. For validation purposes, the unconditioned resilient modulus measured at Stage V (see Chapter 2) was used.

For each AC mix, the number of gyrations to achieve a VTM of 7% to 8% had to be determined by trial and error. By the time this step was completed, not enough material was left to prepare and test five specimens of each mix. The results of the study are shown in Tables 3.1 through 3.6.

For mix A1 (Table 3.1), only four specimens were prepared and tested. All four specimens deformed within six hours of conditioning. The change in circumference varied from 2 % to 9 %, indicating that the mix should be poor performing.

Only three specimens were prepared and tested for mix B1 (Table 3.2). The tested specimens did not deform within six hours of conditioning. However, the resilient modulus ratios (after versus before conditioning) were less than 0.8, indicating that the mix should be marginal.

Only three specimens were prepared and tested for mix A2 (Table 3.3). The tested specimens deformed within six hours of conditioning. The circumferences of the specimens increased about 3% to 4% indicating that the mixture should perform poorly.

For mix B2 (Table 3.4), only four specimens were prepared and tested. The specimens did not excessively deform within the six hours of conditioning. However, two specimens deformed excessively after eighteen hours of conditioning. The circumference of the two specimens increased by 9% and 13%, respectively. The other two specimens were further tested to measure the resilient modulus ratios. The ratios were less than 0.7. The phenomenon of excessive deformation after

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**Table 3.1 - Test Results of Mix A1 Received in December 1998**

| Spec. No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.2 | 716 | 548 | N/A* | N/A | 653 | N/A | N/A | N/A | N/A | N/A | N/A | 5.1 | Poor |
| 2 | 7.5 | 806 | 663 | N/A | N/A | 708 | N/A | N/A | N/A | N/A | N/A | N/A | 2.0 | Poor |
| 3 | 7.4 | 657 | 640 | 671 | 603 | 602 | N/A | N/A | N/A | N/A | N/A | N/A | 6.9 | Poor |
| 4 | 7.0 | 1,045 | 722 | 711 | 796 | 728 | N/A | N/A | N/A | N/A | N/A | N/A | 9.0 | Poor |

* Not available

**Table 3.2 - Test Results of Mix B1 Received in December 1998**

| Spec. No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.1 | 629 | 597 | N/A | N/A | 480 | 303 | 0.48 | 0.51 | N/A | N/A | 0.63 | N/A | Marginal |
| 2 | 7.5 | N/A | 815 | N/A | N/A | 709 | 513 | N/A | 0.63 | N/A | N/A | 0.72 | N/A | Marginal |
| 3 | 7.4 | 950 | 742 | 771 | 776 | 798 | 357 | 0.47 | 0.60 | 0.58 | 0.57 | 0.56 | N/A | Marginal |

**Table 3.3 – Test Results of Mix A2 Received in March 1999**

| Spec. No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.2 | 879 | 990 | 1,011 | 947 | 947 | N/A | N/A | N/A | N/A | N/A | N/A | 3.00 | Poor |
| 2 | 7.2 | 609 | 779 | 795 | 763 | 766 | N/A | N/A | N/A | N/A | N/A | N/A | 4.04 | Poor |
| 3 | 7.6 | 896 | 877 | 886 | 898 | 912 | N/A | N/A | N/A | N/A | N/A | N/A | 4.00 | Poor |

**Table 3.4 – Test Results of Mix B2 Received in March 1999**

| Spec. No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.3 | 890 | 864 | 877 | 860 | 835 | 590 | 0.66 | 0.68 | 0.67 | 0.69 | 0.71 | N/A | Marginal |
| 2 | 7.2 | 1,038 | 1,035 | 1,032 | 1,102 | 1,101 | N/A | N/A | N/A | N/A | N/A | N/A | 9.09[+] | Marginal |
| 3 | 7.9 | 634 | 602 | 605 | 673 | 639 | N/A | N/A | N/A | N/A | N/A | N/A | 13.13[+] | Marginal |
| 4 | 7.2 | 950 | 742 | 771 | 776 | 798 | N/A | N/A | N/A | N/A | N/A | N/A | 6.00[+] | Marginal |

[+] The specimens deformed after eighteen hours of conditioning rather than six hours of conditioning. Therefore, the percent increase in circumference is based on lateral deformation after eighteen hours of conditioning.

eighteen hours of conditioning had not been observed before and should be incorporated into the testing procedure. Since two specimens had resilient modulus ratios of less than 0.8, it is preliminarily suggested that if the specimen deforms more than 5% after eighteen hours of conditioning, the mix may be considered marginal.

For mix A3 (Table 3.5), five specimens were prepared and tested. The specimens deformed excessively within the six hours of conditioning. The circumferences of the specimens increased from 3% to 13%. Only four specimens were prepared and tested for mix B3 (Table 3.6). The specimens did not deform excessively after 18 hours. The conditioned resilient moduli were measured, and the modulus ratios were above 0.8 for all specimens, indicating that the mix was a well performing mix.

Since the UTEP research team was not aware of the mix design, the process of specimen preparation was rather lengthy because of the trial and error process discussed above. In addition, the MTS system experienced some mechanical problems. As such, the loose mixes, shipped in gallon containers, were not tested for 3 to 6 months. In that period, the loose mixtures were maintained in the original containers in a cool room. The impact of aging process on the accuracy of the results reported is unknown and should be studied.

The results of the study were reported to TxDOT via a technical memorandum, after which the identity of the mixes was revealed to the UTEP research team. The actual and the predicted performances are compared in Table 3.7. The present test setup was unable to accurately identify the performances of most mixes. All A mixes were modified with lime, and the test protocol was developed without using any additives. There is a possibility that the test protocol failed because of these reasons. However, the B mixes were similar to the ones tested at UTEP but with finer aggregate, and their performance should have been accurately identified.

A meeting was held between UTEP and TxDOT to identify the sources of error. One source of the problem considered was the mix design. Although the aggregate and AC were provided from sources similar to those used in the original study, the number of gyrations to achieve 7% to 8% VTM differed by a factor of three. One source of uncertainty lied in the mixing method utilized by UTEP during the initial study and those used by TxDOT laboratory. To understand the reasons for the lack of predictive power and repeatability of the results a post mortem study was carried out. The results from the post mortem study are discussed below.

*Post Mortem Study*

The following two possible sources of discrepancy between the laboratory results and the field performance were identified and studied here:
1. The inadequacy of the modified ECS test protocol developed under Project 0-1455 in consistently discriminating between poor and well performing mixes.
2. Differences in specimen preparation technique between UTEP and TxDOT.

To systematically study the significance of the two items enumerated above, raw aggregates and asphalt from the Atlanta and Austin mixtures used during the validation process were shipped to UTEP. Triplicate specimens were prepared for each mixture according to the job mix formula provided using the suggested protocol. Each specimen was then subjected to the modified ECS tests

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**Table 3.5 - Test Results of Mix A3 Received in May 1999**

| Spec. No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.2 | 683 | 848 | N/A | 705 | 637 | N/A | N/A | N/A | N/A | N/A | N/A | 4.00 | Poor |
| 2 | 7.5 | 592 | 628 | N/A | 602 | 603 | N/A | N/A | N/A | N/A | N/A | N/A | 5.88 | Poor |
| 3 | 7.2 | 695 | 645 | 644 | 732 | 698 | N/A | N/A | N/A | N/A | N/A | N/A | 3.00 | Poor |
| 4 | 7.1 | 953 | 798 | 906 | N/A | 1,043 | N/A | N/A | N/A | N/A | N/A | N/A | 13.00 | Poor |
| 5 | 7.6 | 558 | 571 | 571 | 560 | 550 | N/A | N/A | N/A | N/A | N/A | N/A | 6.93 | Poor |

**Table 3.6 - Test Results of Mix B3 Received in May 1999**

| Spec. No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.5 | 510 | 548 | 554 | 540 | 564 | 600 | 1.18 | 1.10 | 1.08 | 1.11 | 1.06 | N/A | Well |
| 2 | 7.2 | 745 | 798 | 708 | 857 | 722 | 796 | 1.07 | 1.00 | 1.13 | 0.93 | 1.10 | N/A | Well |
| 3 | 7.6 | 505 | 492 | 470 | 480 | 493 | 493 | 0.98 | 1.00 | 1.05 | 1.03 | 1.00 | N/A | Well |

**Table 3.7 - Expected Versus Actual Performance of Blind Mix Study**

| Date | Blind Mix | Mix Type | Reported Performance | Expected Performance |
|------|-----------|----------|----------------------|----------------------|
| December 1998 | A1 | Atlanta (with Lime) | Poor | Marginal/Well |
| | B1 | Atlanta (without Lime) | Marginal | Poor |
| March 1999 | A2 | Austin (with Lime) | Poor | Well |
| | B2 | Austin (without Lime) | Marginal | Well |
| May 1999 | A3 | Atlanta (with Lime) | Poor | Marginal/Well |
| | B3 | Atlanta (without Lime) | Well | Poor |

to determine the applicability of the protocols. The test results are reported in Table 3.8. The specimens with additives were not tested. As indicated in Report 1455-2F, the protocol has not been developed to be functional under those circumstances. For each of the three Austin specimens, the MR ratio of 0.8 or higher was obtained after 18 hours of conditioning of the specimen. This indicates that the material should perform well under conditions prone to stripping. On the other hand, all three specimens of the Atlanta mixture failed within 6 hours of conditioning due to excessive deformation, indicating that the mixture is moisture susceptible.

**Table 3.8 - Test Results from Austin and Atlanta Mixtures when Specimens Prepared at UTEP**

a) Austin Mix (Well Performing Mixture)

| Specimen No. | VTM (%) | Initial Circum. (in.) | Final Circum. (in.) | Unconditioned Resilient Modulus (ksi) | Conditioned Resilient Modulus (ksi) | MR Ratio | % Circum. Increase | Predicted Performance |
|--------------|---------|------------------------|----------------------|----------------------------------------|--------------------------------------|----------|---------------------|------------------------|
| 1 | 7.6 | 12.50 | 12.55 | 982 | 785 | 0.80 | 0.4 | Well |
| 2 | 7.5 | 12.44 | 12.47 | 832 | 741 | 0.89 | 0.2 | Well |
| 3 | 7.5 | 12.47 | 12.47 | 605 | 559 | 0.92 | 0.0 | Well |

b) Atlanta Mix (Poor Performing Mix)

| Specimen No. | VTM (%) | Initial Circum. (in.) | Final Circum. (in.) | Unconditioned Resilient Modulus (ksi) | Conditioned Resilient Modulus (ksi) | MR Ratio | % Circum. Increase | Predicted Performance |
|--------------|---------|------------------------|----------------------|----------------------------------------|--------------------------------------|----------|---------------------|------------------------|
| 1 | 7.7 | 12.50 | 13.33 | 483 | N/A | N/A | 6.6 | Poor |
| 2 | 7.3 | 12.50 | 13.01 | 535 | N/A | N/A | 4.1 | Poor |
| 3 | 7.5 | 12.50 | 12.88 | 423 | N/A | N/A | 3.0 | Poor |

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In Table 3.8a, the modulus values of the three specimens differ significantly. As described in detail in Report 1455-2F, given the specimen length-to-diameter ratio and the equipment used, one should expect variability in the absolute values. However, as demonstrated in that report, the modulus ratios should be quite consistent. In the modified ECS protocol, the absolute values are not used at all. As such, this limitation should not significantly impact the results.

The above exercise indicated that the developed test protocol, when followed, can consistently discriminate between well and poor performing mixes and is not limited to the original mix design. Although further modification and fine-tuning of the test protocol may be necessary, for the two specimens tested in this study, other parameters may play a major role in the inconsistencies reported in Table 3.7.

The next focus was on the issue of differences in preparing specimens. One initial clue of possible mix-related differences was the significant differences in the number of gyrations required to prepare specimens with nominal VTMs of 7% to 8%. For example, the Atlanta mixture provided by TxDOT required in excess of 30 gyrations to achieve the desired VTM, whereas the specimens prepared by UTEP required only 9 gyrations. This may point to the possibility of problems with short-term aging of the mixture, absorption of aggregates, or can be due to reheating of mixtures. Mixture segregation was also considered as a factor because of differences in the results amongst replicate specimens of the same mixture. In Table 3.4, three of the specimens of mixture B2 exhibited excessive deformation after 18 hours of conditioning while the one specimen deformed only slightly. To investigate this matter, the gradation and the asphalt content for each surviving specimen from the blind tests of mixtures B2 (Austin) and B3 (Atlanta) were determined using an ignition oven. The calibration of ignition oven was verified using the bag materials send to us for this study.

The gradations for the four specimens from the Austin mix are shown in Figure 3.1. The design gradation as well as the upper and lower bounds permitted by TxDOT are included in the figure. The overall gradation and asphalt content were quite consistent, demonstrating the care taken by TxDOT personnel to provide a high quality mixture. However, the gradations from three specimens did not follow the specified gradation at one or two sieves or are outside the specified upper and lower bounds. Specimen 1 was clearly finer than the other three specimens.

As shown in Table 3.9, the asphalt contents of three of the specimens were within 0.5% of the design AC content. However, the AC content of Specimen 1 was as high as 6.3%, which is about 1.4% above the design AC content. This may point to the possibility of material segregation for this mixture. A careful examination of Table 3.4 indicates that under the modified ECS tests, three specimens exhibit similar behaviors while the fourth one behaves quite differently.

The gradation curves for the three specimens from Atlanta are similarly shown in Figure 3.2. For all three specimens, the actual gradations are quite similar, but for one or two sieves differ from the design gradation and falls outside the upper and lower bound of TxDOT specifications. The asphalt contents of the three specimens, as shown in Table 3.9, are reasonably close to the design asphalt content.

Further information about specimen preparation was obtained. The TxDOT employee assisting us in obtaining the materials used in the blind tests was also the graduate student who conducted most of the developmental work for the modified ECS at UTEP under Project 0-1455. He pointed out that the TxDOT and UTEP specimen preparation procedures differ only in terms of the
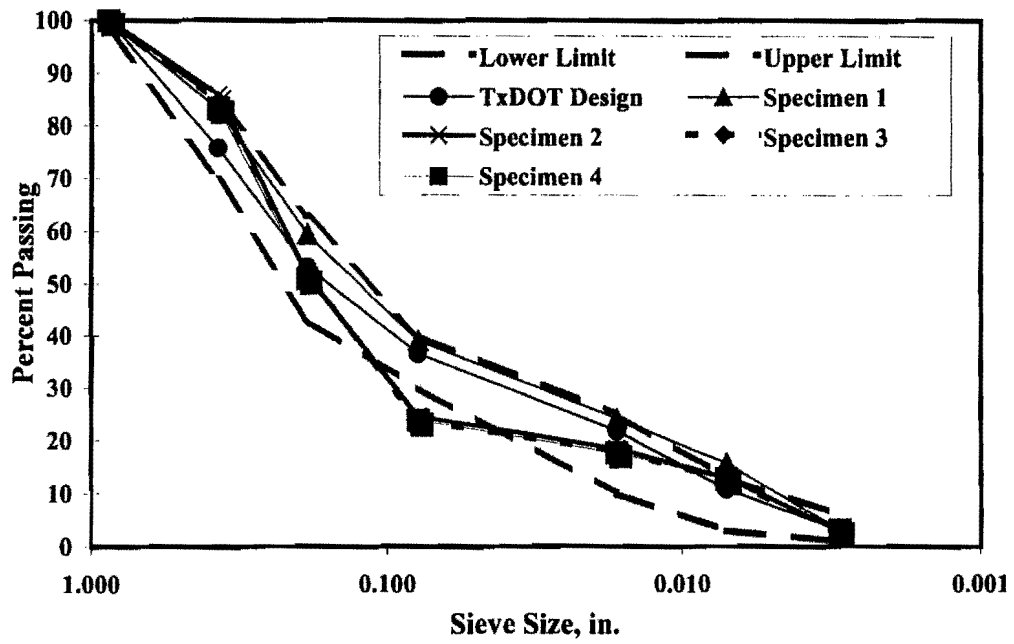
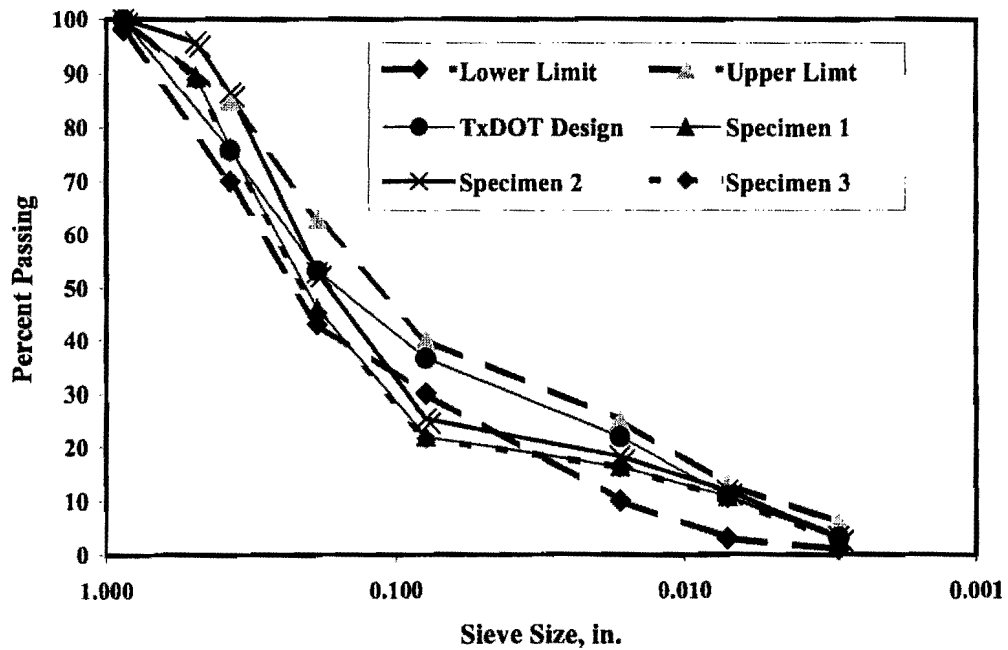Figure 3.1 – Gradation Curves of Austin Specimens



Figure 3.2 – Gradation Curves of Atlanta Specimens

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**Table 3.9 – Asphalt Contents of Austin and Atlanta Mixtures
Based on Ignition Oven Test**

| Mixture | Specimen No. | Asphalt Content (%) |
|---------|--------------|---------------------|
| Atlanta | 1 | 4.7 |
| | 2 | 4.6 |
| | 3 | 5.0 |
| | Target Mix Design | 4.9 |
| Austin | 1 | 6.3 |
| | 2 | 5.0 |
| | 3 | 5.2 |
| | 4 | 5.1 |
| | Target Mix Design | 4.9 |

amount of material mixed. At UTEP, the mixing is carried out one specimen at a time, while TxDOT laboratories mixed material for up to six specimens at a time. This practice might have been the source of differences in the mixtures tested under the blind tests and the subsequent tests carried out at UTEP. The loose mixtures could have also been segregated during the packing and shipping process since they were shipped to UTEP in one-gallon containers. To reduce the chances of aging, we did not reheat and remix the contents of the several containers that contained the same mixtures.

Based on this limited study, the newly developed protocol and device seems precise and yield consistent results. Also, this small post mortem study indicates that the results from the modified ECS are sensitive to mix design. It seems that, similar to the APA and Hamburg Wheel Tester, the 18-hour "torture test" may identify failure prone mixtures as well as moisture susceptible ones.

Since the test procedure seems to be precise and repeatable, with more experience under controlled laboratory conditions along with field observations the failure criteria can be fine-tuned to an implementable and potentially valuable tool.

## Accelerated Testing Protocol

To accelerate the testing protocol, the following alternative options were considered: 1) reducing the conditioning period from eighteen hours to six hours, 2) measuring the resilient modulus while conditioning to eliminate the time necessary to cool the specimen, 3) minimizing the number of specimens rejected, 4) reducing the cooling period, and 5) measuring the unconditioned $M_R$ at earlier stages rather than Stage V. The results are discussed in the following sections.

## Reduction in Conditioning Period

One possible way of reducing the test period is to reduce the conditioning period from 18 hours to 6 hours. The test protocol suggests that testing should be stopped after 6 hours of conditioning and that the change in circumference should be measured. If the circumference increases by more than 2%, the specimen should be removed from the test setup. It is quite possible that conditioning can be stopped at this point and that the specimen can be cooled to measure the conditioned resilient modulus. This conditioning alternative reduces the test period by twelve hours.

The impact of reducing the conditioning period from eighteen hours to six hours was assessed using a marginal mix from El Paso. Testing well performing and poor performing mixes was not feasible. According to the proposed ECS protocol, a poor performing mix has to deform excessively after six hours. Therefore, there is no point of conducting tests for eighteen hours anyway. Similarly, the well performing mix exhibited a $M_R$ ratio, which is close to 1.0, irrespective of conditioning period.

The results from three specimens of El Paso material are shown in Table 3.10. The resilient modulus ratio, using all five stages of unconditioned resilient modulus, was higher than 0.8. Since similar specimens conditioned for eighteen hours consistently exhibited $M_R$ ratios less than 0.8, a reduction in conditioning period will negatively impact the ability of the test protocol in identifying marginal mixes. Thus, this option was not further pursued.

## Measurement of Resilient Modulus at 60 °C

Tandon et al. (1997) have suggested that the specimen should be cooled to room temperature for twenty-four hours before measuring the conditioned resilient modulus. The reason for such a cooling period was to ensure that the conditioned and unconditioned resilient moduli were measured at the same specimen temperature. To eliminate the twenty-four hour cooling period, it was proposed that the resilient modulus be measured while the specimen is conditioned. A new correlation can then be developed to identify the performance of an AC mix with the end result being a reduction in testing time.

It was not possible to measure the resilient modulus at 60°C (140°F) because of the limitation of the data acquisition system and transducers. To improve the accuracy of the deformation measurement, a proximitor system with a small range is typically used. The proximitor system has a linear range of 8 mils (200 µm) with an average scale factor of 2V/mil (80 V/mm). Thus, the total output voltage range is 16 V (or ±8V) for measuring deformations of up to 8 mils (200 µm). The load cell has a capacity of 2 kips (10 KN), and the average scale factor is 2 mv/lb. The data acquisition board used by the ATS is a 12 bit board that can measure a maximum voltage of 20 V (or ±10 V). At the maximum range, the systems accuracy is within 4.8 mv. In other words, the system is transparent to a 1 lb or 2 lb loads. To improve the accuracy of the test setup, the acceptable limit of the board can be set to 10 V (or ± 5 V) and the accuracy of system can be increased from 4.8 mv to 2.4 mv. However, this reduces the proximitor range from 8 mils to 5 mils (16V versus 10V).

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**Table 3.10 - Resilient Modulus Ratios of El Paso Mix (after six hours of conditioning)**

| Spec No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.2 | 513 | 439 | 487 | 396 | N/A | 409 | 0.80 | 0.93 | 0.84 | 1.03 | N/A | N/A | Well |
| 2 | 7.1 | 467 | 443 | 439 | 431 | 433 | 373 | 0.80 | 0.84 | 0.85 | 0.87 | 0.86 | N/A | Well |
| 3 | 7.4 | 650 | N/A | 666 | 663 | N/A | 567 | 0.81 | N/A | 0.83 | 0.83 | N/A | N/A | Well |

The process of adjusting the gap between the target and proximitor is rather cumbersome and time-consuming (may take as long as 10 minutes). Due to the small range of displacement that can be measured with the proximitors and due to the relatively large coefficient of expansion associated with the deformation measurement setup, the target adjusted at room temperature may go out of range at higher temperatures 140°F (60°C). A typical response of a proximitor in the chamber at a temperature of 140°F (60°C) with time is shown in Figure 3.3. After about 2000 seconds, the proximitor output corresponds to a gap of 2.5 mils, i.e., its maximum range. In addition, it is difficult to readjust the targets at 140°F (60°C) because the operator has to open the chamber door to readjust the targets. By the time the operator is able to finish this task, the chamber becomes cooler. The targets may go out of range again when the operator closes the chamber door. Another alternative explored was to initially set the proximitors in an out of range position with the anticipation that they would move in-range at 60°C. This option does not seem to be robust enough for production testing. One other solution would have been to modify the test setup by using proximitors with more than an 8 mils range. In a meeting with the Project Director, it was agreed that test setup would not be modified because of monetary and time limitations.
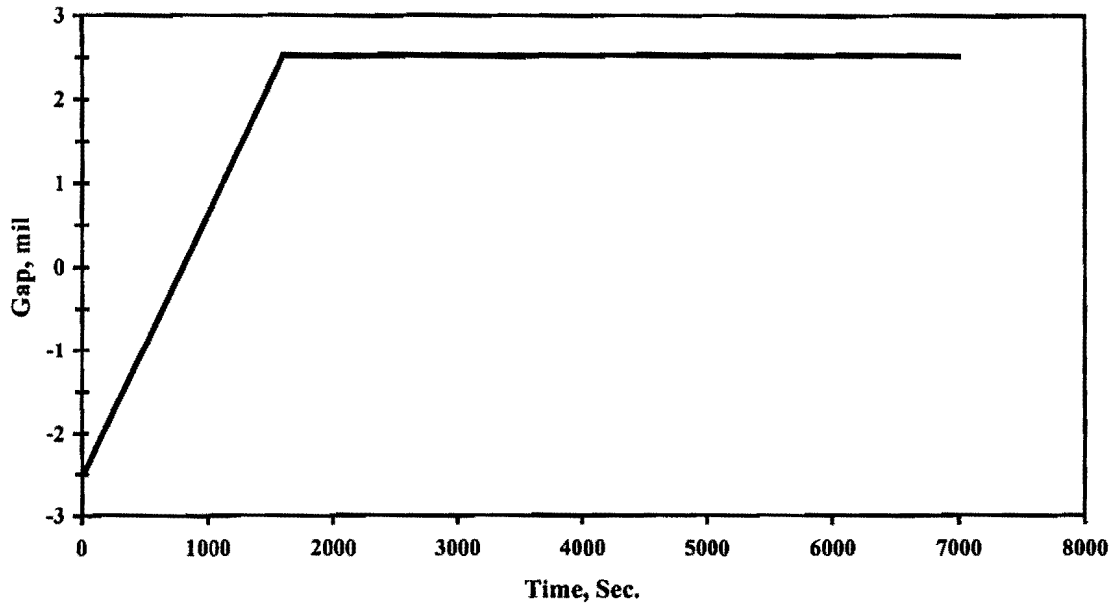


**Figure 3.3 – Variability in Proximitor Movement with Time in 140°F Oven**

Tayebali et al. (1998) suggested that the axial resilient modulus of asphalt concrete mixes is independent of asphalt type at 40°C. They concluded that changes in stress level, asphalt content, and frequency yielded similar axial resilient modulus at 40°C. The $M_R$ ratio of the AC mix, at a higher temperature, will not be a good indicator of moisture susceptibility because the decrease in the conditioned $M_R$ can be attributed to the loss of bonding between the asphalt and aggregate. In other words, the axial $M_R$ of an AC mix at a higher temperature depends mainly on the aggregate structure of the mix rather than the asphalt and aggregate matrix.

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## Minimizing Specimen Rejection

At UTEP, students have been preparing five to six specimens at a time. Typically, two specimens have been rejected because the VTM has not been within the 7% to 8% range. An additional specimen has been usually discarded because the difference in deformation along the two diametrically opposite sides is greater than 15% during the $M_R$ tests. To minimize the rejection of specimens, a new method of placing targets was evaluated. The height of the specimen, at two diametrically opposite sides, is measured six times at 30° intervals. (See Figure 3.4) The targets are placed on the diameter ends with the smallest difference in height and on the sides with the second smallest difference. This method of placing targets removed the guesswork, reduced the testing time, and reduced the frequency of discarding specimens to a minimum level.
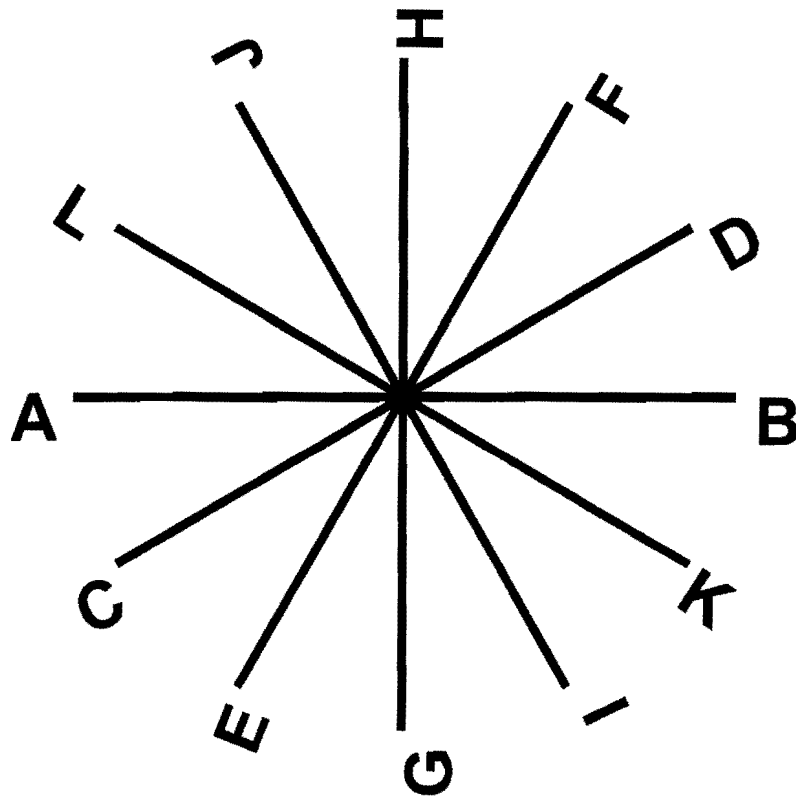


**Figure 3.4 – Orientations of Measurement of Specimen Height**

## Cooling of Specimens

The test protocol proposed in Project 0-1455 suggested that, after eighteen hours of conditioning, the specimen should be allowed to cool down for twenty-four hours before the conditioned resilient modulus was measured. The cooling period was suggested to permit the specimen to cool down to the temperature at which the unconditioned modulus was measured.

To reduce the cooling period from twenty-four hours, a preliminary study was conducted to identify the time required for cooling the specimen to 75°F (24°C) and to identify the effect, if any, of cooling on the specimen property. Several similar specimens were prepared using an El Paso Type D mix. Each specimen was first heated in an environmental chamber to 140°F (60°C). The specimen was then transferred to a chamber with a set temperature of 75°F (19°C), 60°F (15°C), 40°F (4°C), and 32°F (0°C). The modulus of the specimen was periodically measured until an equilibrium temperature of 75°F (19°C) was reached. The procedure proposed by Nazarian et al. (1998) was used for this process. The variations in modulus with temperature for four specimens are shown in Figure 3.5. Independent of the cooling temperature, the specimens yielded similar moduli at 75°F (60°C). This indicated that the accelerated cooling process does not negatively impact the measurement of moduli.

The variation in temperature of the specimen with time, placed in the lower temperature chamber, is included in Table 3.11. Although it may take four hours for the specimen to cool to 77°F (25°C) when placed in a 77°F (25°C) chamber, the cooling periods are less than an hour for the 60°F (15°C), 40°F (4°C), and 32°F (0°C) chamber temperatures. A temperature of 60°F (15°C) is recommended for practical reasons.
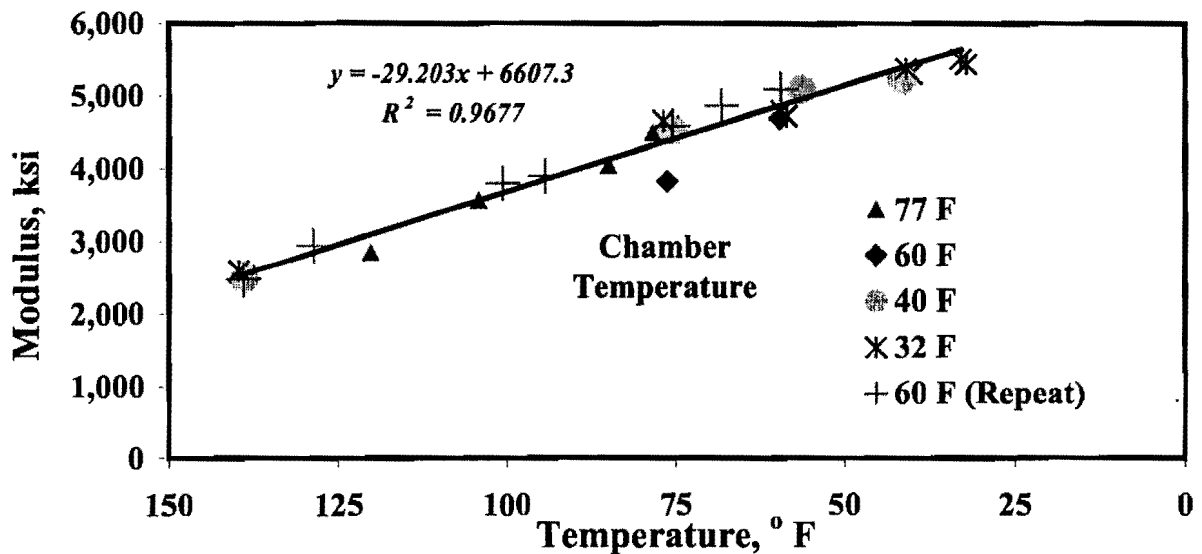


Figure 3.5 - Effect of Cooling on Seismic Modulus

Based on the preliminary promise of the cooling process to reduce the test period, the ECS procedure was modified to incorporate this step into it. The temperature chamber of the ECS was retrofitted with liquid nitrogen activated cooling mechanism so that the temperature could be reduced. Based on the above-mentioned study, the chamber temperature was maintained at 60°F (15°C) for one hour, after which it was increased to 75°F ( 24°C). After allowing 15 minutes for stabilization, the conditioned resilient modulus was measured. The results of the study applied to

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**Table 3.11 – Cooling Time and Seismic Modulus of AC Mix**

| Chamber Temperature (°F) | Time (minutes) | Temp (° F) | Modulus (Ksi) |
|---|---|---|---|
| 77 | 0 | 139.8 | 2542 |
|  | 30 | 120.4 | 2842 |
|  | 65 | 104.2 | 3560 |
|  | 160 | 84.9 | 4038 |
|  | 220 | 78.4 | 4486 |
| 60 | 0 | 139.8 | 2461 |
|  | 50 | 76.3 | 3825 |
|  | 80 | 59.5 | 4688 |
| 40 | 0 | 138.9 | 2488 |
|  | 35 | 75.6 | 4519 |
|  | 60 | 56.3 | 5092 |
|  | 120 | 41.5 | 5211 |
| 32 | 0 | 139.8 | 2598 |
|  | 55 | 76.8 | 4653 |
|  | 75 | 59.4 | 4793 |
|  | 100 | 41.0 | 5378 |
| 60 | 0 | 139.1 | 2474 |
|  | 13 | 128.7 | 2943 |
|  | 28 | 100.6 | 3800 |
|  | 33 | 94.5 | 3903 |
|  | 48 | 75.4 | 4585 |
|  | 58 | 68.2 | 4865 |
|  | 78 | 59.4 | 5092 |

three specimens of El Paso Type D mix are shown in Table 3.12. Since the El Paso mix was a marginal material, a $M_R$ ratio below 0.8 was anticipated. The estimated ratio was 0.5, which is lower than previously observed (0.6 or higher). One possible explanation for such a trend is that the specimen's internal temperature was higher than 75°F. To verify this concept, three thermocouples were installed within a specimen at three locations. One of the thermocouples was placed at the center of the specimen; while the two other were placed at the top and bottom end of the specimen. The specimen was conditioned and cooled for 60 minutes. The temperature of the specimen was then monitored. The results, as shown in Table 3.13, indicate that the chamber temperature itself dropped from 140°F (60°C) to 60°F (15°C) in 60 minutes. However, the specimen temperature stabilized at about 75°F (24°C) after 150 minutes. The data also suggested that approximately 2 hours of cooling was required at 60°F (15°C), to make sure that the temperature throughout the specimen is approximately 75°F (24°C).

**Table 3.12 - ECS Test Results from Specimens Prepared with El Paso Mix Subjected to 60 Minutes of Cooling at 60°F**

| Spec No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.4 | 792 | 879 | 738 | 864 | 866 | 405 | 0.51 | 0.46 | 0.55 | 0.47 | 0.47 | N/A | Marginal |
| 2 | 7.2 | 890 | 863 | 858 | 857 | 663 | 403 | 0.45 | 0.47 | 0.47 | 0.47 | 0.61 | N/A | Marginal |
| 3 | 7.7 | 696 | 757 | 706 | 718 | 690 | 278 | 0.40 | 0.37 | 0.39 | 0.39 | 0.40 | N/A | Marginal |

Table 3.13 - Variation in Specimen Temperature with Time During Cooling at 60°F

| Time (minute) | Controller Temperature (°F) | Chamber Temperature (°F) | Specimen Temperature (°F) | | |
|---|---|---|---|---|---|
| | | | Bottom | Center | Top |
| 5 | 60.0 | 130.0 | 137.7 | 136.4 | 137.5 |
| 10 | 60.0 | 98.6 | 136.9 | 134.8 | 136.6 |
| 15 | 60.0 | 96.2 | 134.7 | 133.0 | 134.6 |
| 20 | 60.0 | 92.0 | 132.0 | 131.5 | 131.5 |
| 25 | 60.0 | 88.7 | 130.9 | 128.2 | 129.6 |
| 30 | 60.0 | 88.3 | 128.8 | 126.0 | 127.7 |
| 35 | 60.0 | 86.5 | 126.9 | 123.9 | 125.5 |
| 40 | 60.0 | 85.0 | 124.8 | 121.8 | 123.2 |
| 45 | 60.0 | 84.3 | 123.2 | 120.2 | 121.6 |
| 50 | 60.0 | 83.1 | 121.3 | 118.3 | 119.8 |
| 55 | 60.0 | 82.5 | 119.5 | 116.4 | 117.8 |
| 60 | 60.0 | 81.6 | 118.8 | 114.9 | 116.2 |
| **65** | **60.0** | **60.0** | 116.5 | 113.6 | 115.0 |
| 70 | 60.0 | 60.0 | 111.2 | 108.9 | 110.6 |
| 75 | 60.0 | 60.0 | 107.0 | 105.0 | 106.2 |
| 80 | 60.0 | 60.0 | 102.0 | 100.4 | 101.5 |
| 85 | 60.0 | 60.0 | 96.9 | 96.0 | 96.7 |
| 90 | 60.0 | 60.0 | 92.7 | 92.70 | 92.7 |
| 95 | 60.0 | 60.0 | 89.0 | 89.2 | 89.2 |
| 100 | 60.0 | 60.0 | 85.7 | 86.5 | 86.0 |
| 105 | 60.0 | 60.0 | 83.3 | 84.2 | 83.1 |
| 110 | 60.0 | 60.0 | 80.3 | 82.0 | 81.0 |
| 115 | 60.0 | 60.0 | 77.9 | 79.8 | 78.7 |
| 120 | 60.0 | 60.0 | 76.5 | 78.6 | 77.4 |
| **125** | **60.0** | **60.0** | **75.0** | **77.3** | **76.0** |
| 130 | 75.0 | 75.0 | 73.8 | 76.1 | 74.8 |
| 135 | 75.0 | 75.0 | 73.2 | 75.5 | 74.1 |
| 140 | 75.0 | 75.0 | 73.5 | 75.7 | 74.3 |
| 145 | 75.0 | 75.0 | 74.2 | 76.3 | 75.0 |
| 150 | 75.0 | 75.0 | 74.5 | 76.5 | 75.3 |

The reason for the discrepancy between the cooling time in the preliminary study reported in Table 3.11 and the result obtained during the ECS trial (see Table 3.13) is simple to explain. In the preliminary study the chamber temperature was already at 60°F (15°C) when the specimen was placed in it, but in the ECS experiments, the chamber temperature is still at 140°F (60°C) when the liquid nitrogen is introduced. Some of the cooling energy is wasted to reduce the chamber temperature.

Based on this study, the chamber temperature was reduced from 140°F (60°C )to 60°F (15°C) for 2 hours and 15 minutes, and then, the chamber temperature was raised to 75°F (24°C). To verify the appropriateness of the new procedure, two specimens each of El Paso and Austin materials were tested. The test results are shown in Table 3.14. The resilient modulus ratio numbers are similar to the ones previously observed. The resilient modulus ratios of the specimens prepared with the Austin mix is greater than 0.8; whereas the resilient modulus ratios of the specimens prepared with the El Paso mixes is less than 0.8.

## *Unconditioned Resilient Modulus*

Alam (1997) suggested that the resilient modulus measured at Stage V should be used as the unconditioned resilient modulus. To measure unconditioned resilient modulus at Stage V, the statically saturated specimen is placed in the test setup and water at lab temperature is circulated through specimen for one hour, after which a wait period of an hour (to drain the excess water) is recommended before measuring the unconditioned resilient modulus. The reason for this process is to make sure that the unconditioned and conditioned resilient moduli are measured at similar saturation levels.

The resilient modulus of a specimen varies with degree of saturation. However, it is difficult to develop a relation between the resilient modulus and saturation levels. For example, specimen 1 (mix B1) had an $M_R$ ratio of 0.51 at Stage II and 0.63 at Stage III (Table 3.2). On the other hand, specimen 3 (mix B1) had an $M_R$ ratio of 0.60 at Stage II and 0.56 at Stage III (Table 3.2). It is also difficult to determine at which stage the resilient moduli are more consistent. For example, the $M_R$ ratio varied between 0.98 and 1.18 for Stage I and varied between 1.00 and 1.10 for Stage V (Table 3.8). On the other hand, the data reported in Tables 3.1 through 3.6 indicate that, despite variations in modulus ratios, the prediction power of Stage I is equally as accurate as Stage V. However, the specimen is taken out of the test setup for static saturation after Stage I resilient modulus measurement. The assembly and disassembly of the specimen might affect the unconditioned resilient modulus. Therefore, it is recommended that the unconditioned resilient modulus be measured at Stage II. This will reduce the test time by two hours.

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**Table 3.14 – Resilient Modulus Ratios of Specimens Subjected to 135 Minutes of Cooling at 60°F**

**a) El Paso Mix**

| Spec No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.4 | 647 | 584 | 679 | 718 | 753 | 409 | 0.63 | 0.70 | 0.60 | 0.57 | 0.54 | N/A | Marginal |
| 2 | 7.3 | 622 | 635 | 645 | 673 | 666 | 442 | 0.71 | 0.70 | 0.69 | 0.66 | 0.66 | N/A | Marginal |

**b) Austin Mix**

| Spec No. | VTM | Unconditioned Resilient Modulus (ksi) | | | | | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | | | | | % Increase in Circumference | Predicted Performance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage I | Stage II | Stage III | Stage IV | Stage V | | Stage I | Stage II | Stage III | Stage IV | Stage V | | |
| 1 | 7.5 | 650 | 668 | 666 | 663 | N/A | 567 | 0.87 | 0.93 | 0.84 | 1.03 | N/A | N/A | Well |
| 2 | 7.2 | 789 | 819 | 842 | 786 | 645 | 747 | 0.95 | 0.91 | 0.89 | 0.95 | 1.16 | N/A | Well |

## Ruggedness of the System

### Water Bath Unit

A water-heating unit was developed as a part of TxDOT Project 0-1455. The purpose of the unit is to heat conditioning water before it enters the test specimen. The unit was built in-house (Figure 3.6) and consisted of a stainless-steel container, heating element, thermostat, and helical aluminum tube. The stainless-steel container is filled with regular tap water and heated using the heating element. The aluminum tube is placed inside the container and submerged in the tap water bath. The conditioning water temperature increases as it passes through the aluminum tube. The heating element is set to a temperature such that the conditioning water temperature is 140°F (60°C) before it enters the test specimen.
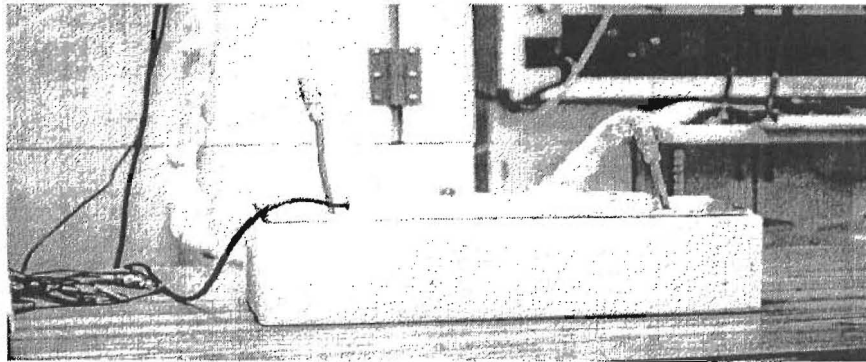


**Figure 3.6 - In-house Built Water Bath Unit**

The in-house unit had three major drawbacks: 1) the corrosion of heating element due to continuous usage, 2) the lack of power of the heating element, and 3) the excessive time (roughly twelve hours) necessary to heat the water bath to 140°F (60°C).

A new heating unit, as shown in Figure 3.7, was procured for this study. The heating unit has a higher temperature capacity and can be used continuously. The helical aluminum tube of the in-house unit is transferred to the new heating unit. In addition, the tap water is replaced by heating oil to increase heat transfer efficiency. The conditioning water achieves 140°F (60°C) temperature in two hours as compared to twelve hours (the in-house unit).

### *Conditioning System*

The original ECS system used in this study was developed by OEM, Inc. As reflected in Tandon et al (1997), the test procedure has been significantly modified. For instance, in the modified test procedure, the air and water permeability measurements were eliminated. A new conditioning instrument panel was manufactured to be used by TxDOT. The new conditioning system,

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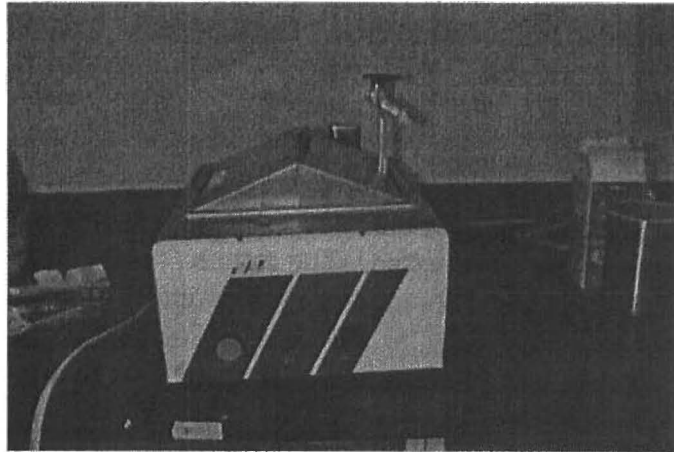
**Figure 3.7 – Rugged Water Bath Unit**
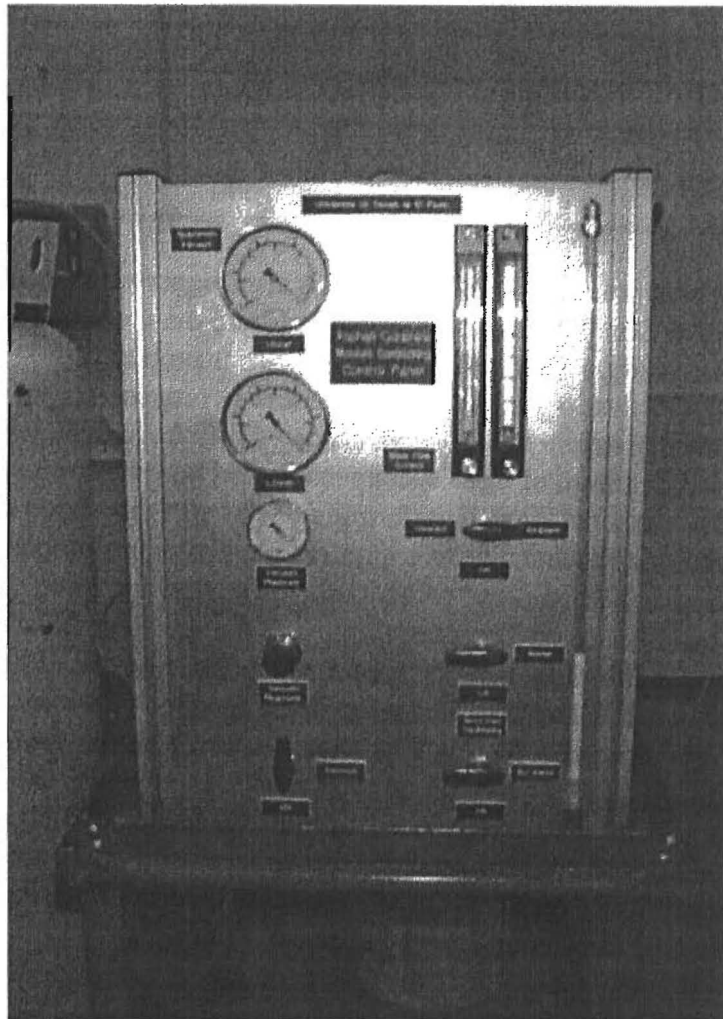


**Figure 3.8 – Rugged Conditioning Control Panel**

shown in Figure 3.8, is smaller and simpler to use. The new panel is equipped with the necessary vacuum regulator, vacuum gages, and flow meters.

*Evaluation of New Test Setup*

The newly developed rugged test setup was evaluated to identify any problems. Two specimens each of the El Paso and Austin mixes were tested. The results are shown in Table 3.15. The new conditioning system consistently identifies moisture susceptibility of known AC mixes.

**Table 3.15 - Evaluation of Rugged Test Setup**

| Mix Type | Specimen No. | Unconditioned Resilient Modulus (ksi) | Conditioned Resilient Modulus (ksi) | Resilient Modulus Ratio | Predicted Performance |
|---|---|---|---|---|---|
| Austin | 1 | 648 | 537 | 0.83 | Well |
|  | 2 | 1,007 | 896 | 0.89 | Well |
| El Paso | 1 | 929 | 663 | 0.76 | Marginal |
|  | 2 | 813 | 590 | 0.72 | Marginal |

In the work plan proposed to TxDOT, it was also suggested that ordinary epoxy glue can be used instead of "Super Glue" to affix proximitor targets to the specimen to reduce the curing time. Through a validation study, a curing time of 30 minutes is proposed.

Based on the evaluation, a new test procedure is proposed in Appendix A, and the ATS software instructions to perform the moisture susceptibility test can be found in Appendix B. It is recommended that a minimum of three specimens should be tested before identifying a mix to be moisture susceptible, marginal, or well performing. Testing of three specimens can be performed in five days rather than one specimen in five days (as per procedure proposed in TxDOT Project 0-1455). The specimens can be prepared on a Monday. The first specimen can be saturated, placed on the test setup, and conditioned on Tuesday morning. If the specimen fails, i.e., deforms excessively, within six hours of conditioning, then the specimen can be removed. The other specimens can be tested on Wednesday and Thursday. However, if the specimen does not deform on Tuesday, the conditioning can be continued for eighteen hours. On Wednesday morning, the specimen's circumference and the resilient modulus can be measured to identify the performance of the mix. Another specimen can be saturated, placed on the test setup, and conditioned on Wednesday afternoon. The conditioned resilient modulus can be measured on Thursday morning and another specimen can be conditioned on Thursday afternoon. In this fashion, the performance of a mix can be evaluated within five days using three specimens.

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# Chapter 4

# Closure

## Conclusions

In this study, the test procedure proposed in TxDOT Project 0-1455 was further evaluated to validate, accelerate the test period, and improve the ruggedness of the test setup. The UTEP research team performed validation using three blind mixes (performance unknown to the operator). The test procedure was unable to accurately identify the performances of most mixes. A post mortem evaluation indicated that the adherence to the job mix formula is necessary to obtain reasonable results.

The test period was optimized to accelerate the test time. Specifically, the following modifications are proposed:

- Specimen cooling time after conditioning is reduced from 24 hours to 2 ½ hours by using a cooling system to reduce the temperature.
- Unconditioned resilient modulus is measured after static saturation, thus, saving two hours of conditioning time.
- 

To improve the ruggedness of the setup, an in-house built water bath unit was replaced by a commercially manufactured unit, and a simpler control panel with less controllers and gadgets was developed. The new test setup is ready to be transferred to TxDOT.

## Recommendations for Future Research

Based on this study, the following recommendations are suggested for future research:

- Further development of the test protocol in terms of the pass-fail limits.
- More thorough study of the effect of mix design on prediction capabilities of test protocol.
- Modify the protocol to be applicable to mixes containing anti-stripping.

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# Appendix A

# Test Procedure to Identify Moisture Susceptibility of AC Mix (Ver. 1.0)

# DRAFT

## Test Procedure to Identify Moisture Susceptibility of AC Mix (Ver 1.0)

## 1. SCOPE

1.1 This method determines the water sensitivity or stripping characteristics of compacted asphalt concrete mixtures under Texas climatic conditions. This method can be used to evaluate laboratory mixtures.

1.2 The values stated in English units are to be regarded as standards.

1.3 This standard may involve hazardous materials, operations, and equipments. This standard does not try to address all of the safety problems associated with its use. It is responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

## 2. REFERENCE DOCUMENTS

2.1 AASHTO DOCUMENTS

- TP4 Practice for Preparation of AC Specimens by means of the SHRP Gyratory Compactor.
- PP2 Practice for Short and Long Term Aging of Hot Mix Asphalt (HMA).
- T2 Method for Sampling Aggregates.
- T40 Method for Sampling Bituminous Materials.
- T167 Method for Compressive Strength of Bituminous Mixtures.
- T168 Method for Sampling Bituminous Mixtures.
- T269 Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures.

## 2.2 ASTM DOCUMENTS

- D8 Standard Definitions of the Terms Relating to Materials for Roads and Pavements.
- D 3549 Method for thickness or Height of Compacted Bituminous Paving Mixtures Specimens.

## 3. TERMINOLOGY

3.1    Definition for many terms pertaining to asphalt may be found in ASTM D8 and MP1.

## 4. SUMMARY OF TEST METHOD

4.1    Compacted asphalt concrete specimens are subjected to a water and temperature conditioning process. The water sensitivity characteristics of the compacted mixtures are determined based upon measurements of resilient modulus.

## 5. SIGNIFICANCE AND USE

5.1    The water sensitivity characteristic of an asphalt concrete mixture can be used to determine, evaluate or characterize its suitability for use as a highway paving material.
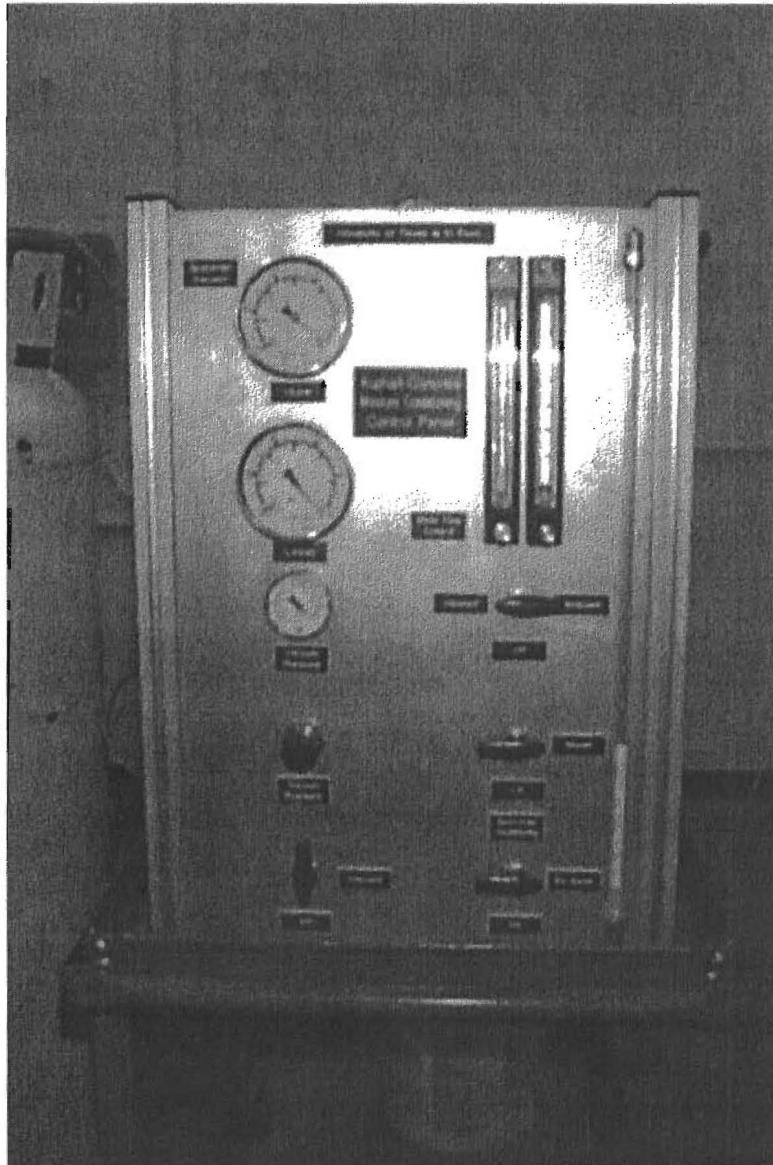
## 6. APPARATUS

6.1    Material Test System (MTS) – The MTS must be capable of applying static axial loads of $100 \pm 3$ lbs and dynamic axial load pulses of $2000 \pm 3$ lbs in a haversine wave form with a load duration of 0.1 s and a rest period of 0.9 s between load pulses. The System is illustrated in Figure A.1.

6.2    Environmental Conditioning Chamber – This chamber must be capable of maintaining a constant temperature of 140 °F for at least 18 hours.

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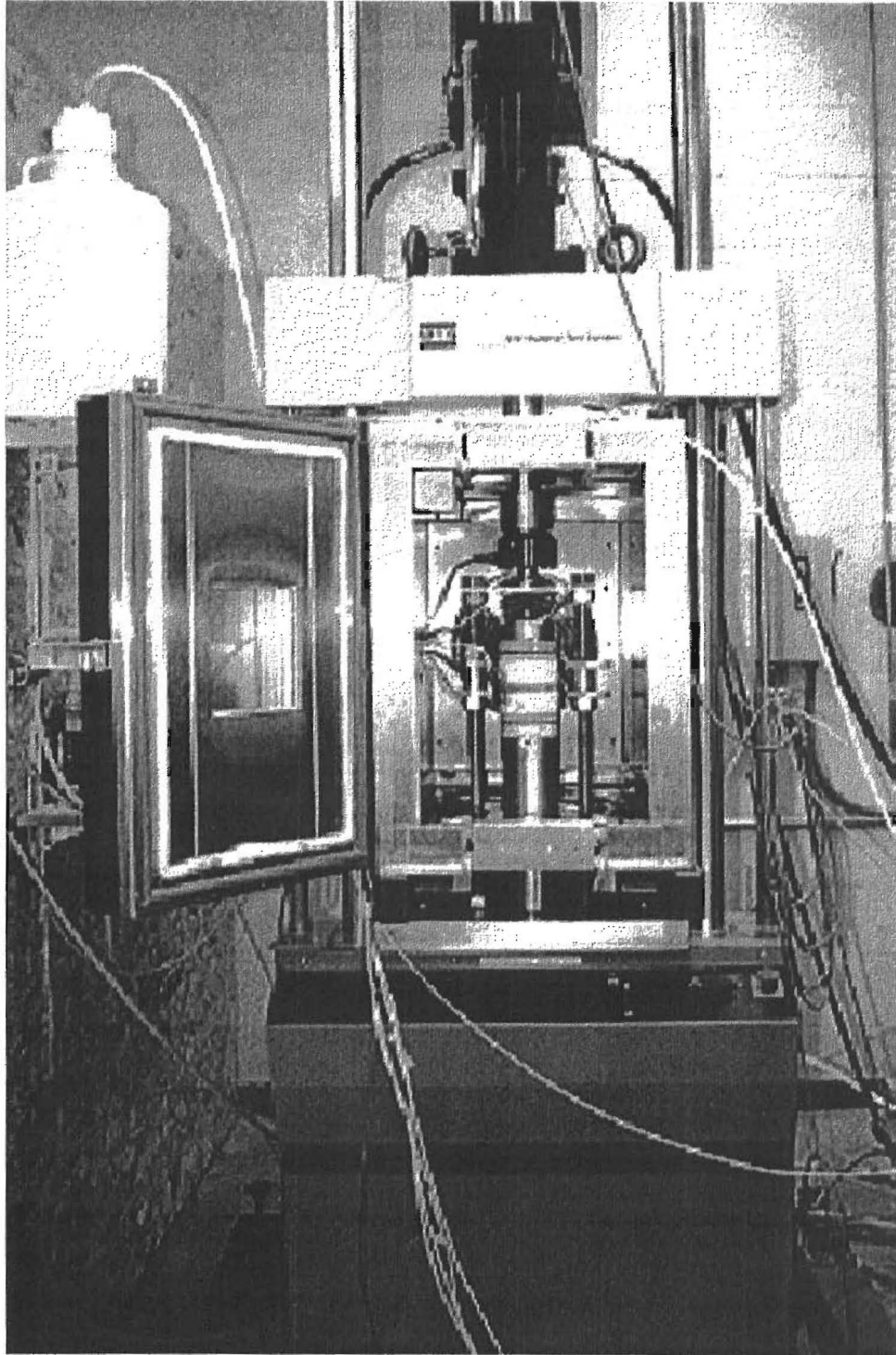
**Figure A.1 – Modified ECS Resilient Modulus Test Setup**

6.3    Fluid Conditioning Subsystem – It must be capable of "pulling" distilled and deaired hot water through a specimen at specified vacuum levels. The system must also be able to maintain a constant flow of water through the specimen and constant confining pressure to the specimen. This subsystem is shown in Figure A.2.



**Figure A.2 – Rugged Conditioning Control Panel**

6.4 Testing Machine – A hydraulic pneumatic testing machine that meets the requirements for testing machines specified in the apparatus in T167.

6.5 Specimen End Platens – Two stainless steel end platens as shown in Figure A.3. The end platens shall be 4 in. in diameter by 2.5 in. thick. Each end platen shall have a hole at its center of 0.2 in. in diameter for drainage of water through the specimen. The side of the platens, which will face the specimen, shall be patterned with grooves around the perimeter. The width and depth of the grooves shall be sufficient to hold the O-rings described in 6.7.
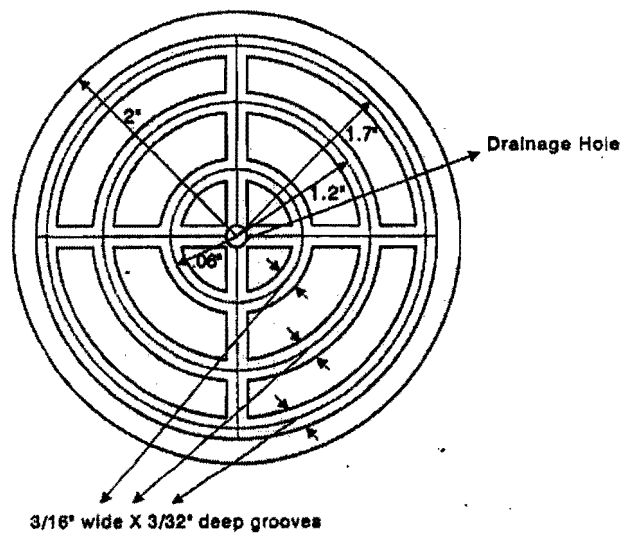


**Figure A.3 - Groove Pattern for End Platen**

6.6 Rubber Membrane – A rubber membrane of approximately 6 in. in length with a 4 in. nominal diameter.

6.7 O-Rings – Two O-rings with a 4 in. nominal diameter.

6.8 Vacuum Pycnometer - A vacuum pycnometer installed with a vacuum gauge and connected to the vacuum pump.

6.9 A Heating Bath - A bath capable of maintaining a constant temperature of at least 200 °F. It has an inlet of 4 in. diameter. A coiled brass/aluminum pipe of 0.5 in. in diameter shall be submerged in the heated oil bath.

6.10 Miscellaneous Apparatus – Calipers, spatula and heating oil.

# 7. MATERIALS

7.1     Commercially available caulk trim tape of 1.5 in. width.

7.2     15 gal of distilled and deaired water.

# 8. SAMPLING

8.1     Sample of asphalt binder in accordance with T40.

8.2     Sample the aggregate in accordance with T2.

8.3     Sample the asphalt concrete mixtures in accordance with T168.

# 9. SPECIMEN PREPARATION

9.1     Prepare the asphalt concrete mixture sample in accordance with TP4. This mixture should be sufficient for two specimens of final compacted dimensions equal to 4 in. in diameter by 4 in. in length.

9.2     Subject the prepared concrete mixtures to short-term aging in accordance with PP2 (SHRP 1025).

9.3     Heat or cool the asphalt concrete mixtures to the specified compaction temperature.

9.4     Compact the mixtures in accordance with TP4. Compact a sufficient amount of material to ensure that the final compacted test specimen is $4 \pm 0.08$ in. in height.

9.5     Determine the air void of the two specimens in accordance with T269. Air voids of the specimens to be tested shall be within 7% to 8%. Otherwise, discard the specimen.

9.6     Measure the diameter of the specimen at four locations and record the average diameter, as described in ASTM D3549. Measure and record the height of specimen at twelve locations as shown in Figure A.4.
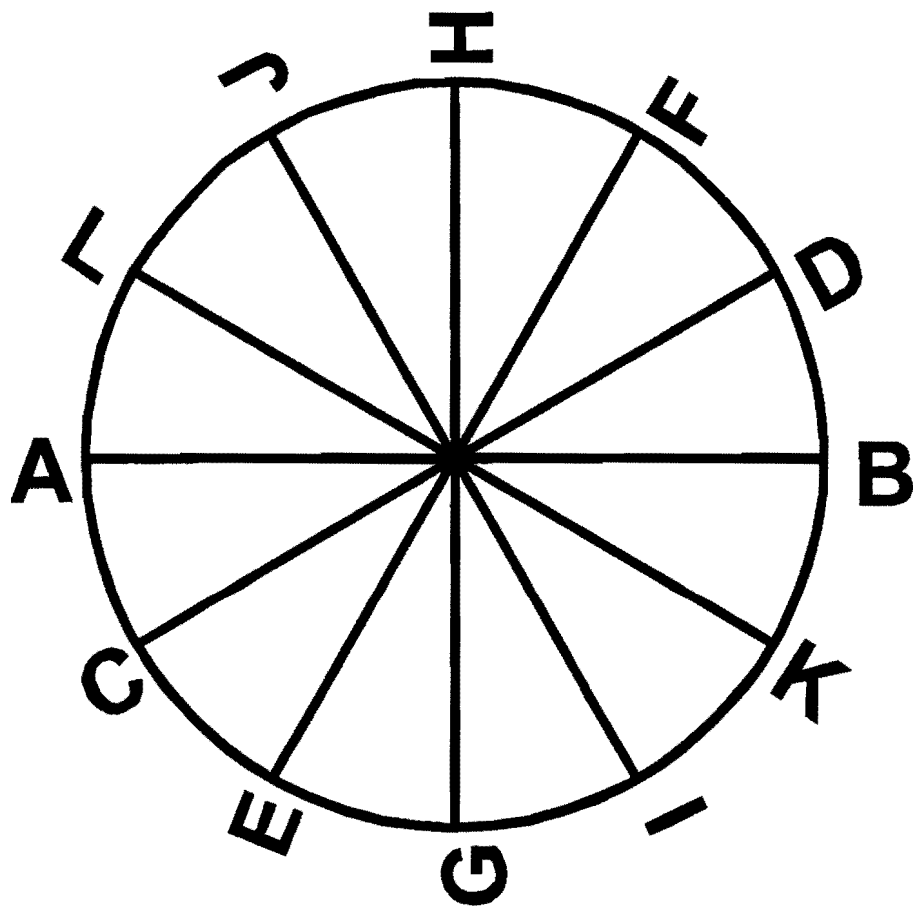
**Figure A.4 - Orientations of Measurement of Specimen's Height**

9.7     Attach eight targets (0.2 in$^2$. metallic iron) on the specimen using "Super Glue." The targets should be placed at two diametrically opposite sides of the specimen width with the smallest and second smallest variation. The targets are placed $180^{\circ}$ apart horizontally and 1.5 in. apart vertically.

## 10. STATIC IMMERSION SATURATION OF SPECIMEN

10.1    Place the specimen in the vacuum pycnometer filled with distilled water. Make sure that the specimen is completely submerged in the water. Connect the vacuum pycnometer to the vacuum source.

10.2    Start the stopwatch immediately after gauge reads 25 in Hg (635 mm Hg) and allow the specimen to be subjected to vacuum for five minutes.

10.3    Calculate the percent of saturation for the specimen according to the Tex 531-C procedure.

## 11. TEST SET-UP

11.1    Remove the specimen from the water bath and wipe the extra water surrounding the specimen.

11.2    Affix two caulk trim tapes of lengths equal to the circumference of the specimen (12.5 in.) and equal to 1.5 in., from the top and bottom edge of the specimen. Then enclose the specimen within the membrane so that there is an approximately 1 in. overlap.

11.3    Place the specimens vertically on top of the end platen.

11.4    Place the top end platen on top of the specimen. The grooved surface of the platen shall face the specimen.

11.5    Extend the rubber membrane to the top and bottom end platens and seal by placing O-rings over the membrane on each groove of the end platens. Place a spherical stainless steel ball at the center of the top end platen. Align this assembly such that the load cell is in line with the axis of the end platens and the specimen. Connect all the quick disconnect fittings. Make sure that the connections include the heating apparatus between the source of water and the specimen.

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## 12. DETERMINATION OF UNCONDITIONED MODULUS

12.1    Maintain the temperature of the specimen at 75 ± 1 °F.

12.2    Apply a static load of 100 ± 3 lbf.

12.3    Attach the targets to the specimen and adjust the proximitors in such a position that the reading on the monitor due to the proximitors is between −4 and −3 Volts.

12.4    Measure resilient modulus by applying a static load of 100 ± 3 lbs. and dynamic pulse load of 500 ± 3 lbs. The dynamic load shall have a haversine wave form. The load duration shall be of 0.1 s and a rest period of 0.9 s between the pulses. The number of loading cycles shall be 25. Record the data from the last 5 cycles. Analyze the data according to the calculations specified in Section 17 to obtain the resilient modulus. The strain shall be between 100 ± 10 micro in./in. and the variation between the displacements on the two opposite sides of the specimen shall not be more that 15 percent.

12.5    If the strain is not within the limit, adjust the dynamic pulse load accordingly. Increase the dynamic load to increase the strain, or decrease the dynamic load to decrease the strain. If the variation of displacements between two sides is not within the limit, discard the specimen and use another specimen for testing.

## 13. WARMING CLIMATE CONDITIONING

13.1    Maintain the temperature of the heating oil in the heating apparatus at the marked position (200 °F). Open the vacuum valve and set vacuum pressure to 2.5 ± 0.5 in. Hg at the outlet gage. Open the water valve and the water flow meter. Adjust the water flow to obtain an average flow of 0.55 in$^3$/min. Make sure the temperature of the water flowing is at 140 ± 1 °F. Close the bypass valve.

13.2    Maintain the temperature of the environmental cabinet at 140 ±1 °F. Apply an axial compressive static load of 50 ± 3 lbs and axial compressive dynamic pulse load of 50 ± 3 lbs to the test specimen. The dynamic load should be a haversine waveform with a load duration of 0.1 s and a rest period of 0.9 s between the load pulses. Apply the loads continuously throughout a hot conditioning period of 18 hours ± 5 minutes. Measure and record the

circumference at mid section of the specimen after 6 hours of conditioning. Stop the loading and take out the specimen if circumference exceeds 2 percent of the initial circumference of the specimen after 6 hours of conditioning.

13.3    Reduce the temperature of the environmental chamber to 60 ±1 °F for two hours to cool the specimen and then raise the chamber temperature to 75 ±1 °F. Close the vacuum valve, water valve, and flow meter. Open the bypass valve to, therefore, open the system to the atmospheric pressure and wait for 30 minutes.

## 14. DETERMINATION OF CONDITIONED MODULUS

14.1    After cooling, determine the conditioned resilient modulus of the specimen according to the procedure explained in Section 12.

## 15. EVALUATION BASED ON RESILIENT MODULUS

**15.1**    Determine the ratio of the unconditioned to the conditioned resilient moduli. Categorize the mix as 1) moisture susceptible if the circumferencial deformation is more than 2 percent after 6 hours: 2) moderately moisture susceptible if the modulus ratio is below 0.8 or if the circumference deformation is more than 2 percent of the average diameter after 18 hours of conditioning; and 3) well-performing mix if the ratio is more that 0.8 after conditioning for 18 hours.

## 16.CALCULATIONS

16.1    Calculate Cross Sectional Area (in$^2$)

$$A = \frac{\pi d^2}{4}$$    (1)

Where:

d= average diameter of the test specimen, in.

16.2 From the recorded data of the last five cycles of loading for the resilient modulus measurement test determine the following.

16.2.1 Peak stress per load cycle:

$$\sigma_i = \frac{p_i}{A} \tag{2}$$

Where:

$p_i$ = difference in peak and minimum load per load cycle, lb.

A= area of the specimen

16.2.2 Recoverable axial strain per cycle:

$$\varepsilon_{i,1} = \frac{(\delta_{i,1,u} - \delta_{i,1,l})}{h} \tag{3}$$

$$\varepsilon_{i,2} = \frac{(\delta_{i,2,u} - \delta_{i,2,l})}{h} \tag{4}$$

$$\varepsilon_i = \frac{(\delta_{i,1} - \delta_{i,2})}{2} \tag{5}$$

Where:

$\delta_{i,1,u}$ = deformation measured by the upper proximate in side 1

$\delta_{i,1,l}$ = deformation matured by the lower proximate in side 1

$\delta_{i,2,u}$ = deformation measured by the upper proximitor in side 2

$\delta_{i,2,l}$ = deformation measured by the lower proximitor in side 2

$\varepsilon_{i,1}$ = strain in side 1

$\varepsilon_{i,2}$ = strain in side 2

$\varepsilon_i$ = strain of the specimen

16.2.3 Resilient modulus per cycle:

$$M_{R,i} = \frac{\sigma_1}{\varepsilon_1} \tag{6}$$

16.3 Determine the average resilient modulus of the last five cycles

$$M_R = \frac{\sum_{i=1}^{5} M_{R_i}}{5} \tag{7}$$

## 17. REPORT

17.1    Report the asphalt binder grade, aggregate type, gradation, and the asphalt binder content to the nearest 0.1 percent.

17.2    Laboratory Mixing Temperature to nearest 1 °F.

17.3    Laboratory compaction temperature to nearest 1 °F.

17.4    Laboratory compaction method.

17.5    Compacted Specimen Height to nearest 0.1 in.

17.6    Compacted Specimen Diameter to nearest 0.1 in.

17.7    Compacted Specimen Area to nearest 0.1 in$^2$.

17.8    Compacted Specimen Density to nearest 0.1 pcf.

17.9    Compacted Specimen Air Voids to nearest 0.1 percent.

17.10  Report the water conditioning results in a table listing the unconditioned MR and conditioned MR and their ratio.

## 19. PRECISION AND BIAS

19.1    Precision – Data to support a precision statement for this test method has not been developed.

19.2    Bias – No justifiable statement can be made on the basis of this test method because there is no reference value available.

**20. KEYWORDS** – Asphalt concrete, bituminous mixtures, bituminous paving mixtures, moisture sensitivity, stripping, resilient modulus, and asphalt concrete permeability.

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# Appendix B

**ATS Software Instructions to Perform Moisture Susceptibility Test (ATS Ver. 3.13)**

# Getting Started

In order to use the system, the hydraulic pump must first be turned on. A series of easy steps are included.

1) **Pull** the large <u>Red Switch</u> on the <u>Hydraulic pump</u>.
2) **Turn** the <u>knob</u> to the start position, and wait for fifteen minutes. The <u>knob</u> will automatically go to low position.
3) Now **turn** the <u>knob</u> to high and wait for another fifteen minutes. This step will cause a sudden "jump" in the hoses.

While waiting for the hydraulic system to warm up, the computer and all other equipment should be turned on using these steps. **(Do not deviate from this order)**

1) **Turn** everything on except for the <u>solenoid valve controllers</u>. If the solenoid valve controllers are turned on first, control of the MTS may be lost.
2) **Click** on ATS3.13a. This is the software that will be used during testing.
3) Now, **click** on the red <u>ATS icon</u>.
4) **Go** to <u>setup</u>.
   a) Go to <u>channels</u>. This is where all the calibrated values for the load cells are located.
   b) **Select** the proper channel.
5) **Click** on <u>control</u>.
   a) **Click** on <u>svo</u>.
   b) **Click** on <u>reset</u>.
   c) **Click** on the <u>negative polarity</u>, which enables the user to control the load cell.
   d) **Adjust** the load to zero N, and then **turn** on the <u>solenoid valve controller</u>, then the <u>manual 1 switch</u>. Once this is done, there will be another "jump" in the hoses due to the hydraulic pump.

## Resilient Modulus Testing

At this point, testing can begin. The load cell can be moved to the desired position and adjusted to the appropriate load. The following steps will be used to test for the resilient modulus of the specimen.

1) Make sure the specimen is centered.
2) **Click** on display.
   a) **Select** <u>monitor</u>. This will indicate what position the targets are in.
   b) By **pressing** the <u>alt and tab</u> keys simultaneously, go back to the <u>controller</u>.
   c) **Click** on <u>display</u>, and **select** <u>scope</u>. This indicates the load cycle.
   d) Repeat step b.

3) **Adjust** the <u>targets</u> by using the <u>monitor screen</u> as a guide.
4) **Apply** a load of 50 lbf from the <u>svo controller</u>. This allows the seating of the specimen. Also, do not apply a high load all at once because the specimen may be damaged.
5) Go to <u>monitor</u> again just to see that the <u>targets</u> are in the same position.
    a) **Apply 100 lbf.**
6) **Click** on <u>test</u>.
    a) **Select** <u>run</u>.
    b) **Select** <u>ecsmr.tst</u>.
    c) **Type** in the proper file name.
        For example: ep-1-1.ats, which means El Paso #1 test1.
    d) **Select** <u>cyl.spec</u>.
    e) **Click** on all of the <u>channels</u>. These channels include the lvdt, the two load cells, and the four proximeters. By doing this, the computer is set up to record information from these channels.
    f) **Click** on <u>ecsmr.tst</u> from the <u>control panel</u>. This is the resilient modulus test.
    g) **Click** on <u>test</u> from the <u>control panel</u> and then **click** on <u>start</u>.

At this point, the test has begun and will last for 25 seconds. Once the test is done, the load needs to be removed and the following values need to be found: resilient modulus, strain, and displacement. In order to do this, Excel must be opened, which is done by using the <u>ctrl+tab</u> command to get into the <u>program manager</u>.

### *Data Manipulation*

The necessary values are easily obtained in Excel by following these steps.
1) **Open** the <u>ecs.xls</u> file.
2) **Click** on C:\, then **click** on ats, and then on data.
3) **Open** all files
4) **Select** the desired file.
5) **Click** on <u>delimited</u>, then on <u>space</u>, and finally on <u>finish</u>. **Copy** and **Paste** this file onto the <u>ecs.xls</u> file.

All of the values will be at the bottom of the sheet.

## Conditioning Cycle

During this cycle, water will be flowing through the specimen. Here is how to get started on the conditioning cycle. Before doing anything, make sure that the <u>hose</u> connected to the <u>hot water bath</u> is also connected to the <u>drainage control panel</u>. Check to see that the <u>hot water valve</u> is open and that the <u>lab temperature-water valve</u> is closed. Also, make sure that there is enough water in the bottle. Furthermore, make sure that all the valves on the <u>drainage control panel</u> are closed and that the <u>hoses</u> are connected to the <u>top and bottom platens</u>.

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1) **Turn** on the vacuum located behind the **drainage control panel** by **pressing** the **yellow button.**
2) Check the hose to see that water is flowing in.
3) Allow water to flow through the specimen by **opening** the valve bypass.
4) Now control the water flow to 0.55 in³ /min, and maintain the suction at 2.5 in.Hg.

Don't spend too much time adjusting here. Adjustments can be made after a couple of minutes.

5) Apply 50 lbf to the specimen. Now **click** on test and select ecscond.tst or ecscond6.tst depending on the type of specimen being tested.
6) **Save** the file as ecscond.tst or ecscond6.tst.
7) **Click** on all channels.
8) Then, **click** on test from the control panel.
9) Finally, **click** on start.
10) Go back and adjust the water flow and pressure.

SAVING DATA ON DISK

Once the test is done, a prompt may ask if the data should be saved onto a disk. To do so, follow these steps.

1) Go to the main menu, **click** on MS DOS, and **type** the following commands
   a) cd.
   b) cd ats
   c) cd data
   d) C:\ATS\DATA  C:\ATS\DATA>edit-ecs18.ats(this is the file name)
   e) Press the ALT key and go to file
   f) Save as a:*name*

2)    Once this is done type exit.