AN ABSTRACT OF THE THESIS OF

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Title: Evaluation of Water Damage on Asphalt Concrete Mixtures Using The Environmental Conditioning System

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Asphalt concrete pavement is subjected to several damaging actions from traffic loads, water (from precipitation and/or groundwater sources), and temperature. The durability of the asphalt-aggregate mixture, its ability to withstand these damaging actions for long periods, is a very important engineering property. While the durability of the asphalt-aggregates mixture depends on several factors such as the mixture's properties, construction methods, traffic loads and environmental conditions, they have to be evaluated to predict their field performance. Based on mixture evaluations, the mixtures that fail the test would have to be modified by additives or by changing the materials.

The first objective of this thesis was to evaluate asphalt-aggregate mixtures for water damage using the Environmental Conditioning System (ECS), and rank the asphalt and aggregate types based on water sensitivity. The second objective was to relate the ECS ranking of the asphalt and aggregate types to Oregon State University (OSU) and University of Nottingham, UK (SWK/UN) wheel tracking test results, and to Net Adsorption Test (NAT) results. The third objective was to evaluate open-graded mixtures and rubber modified mixtures for water sensitivity using the ECS.

The ECS test results indicate that performance ranking of mixtures by asphalt type or aggregate type alone cannot be made for the ECS test results due to the significant interaction between asphalt and aggregate. Water sensitivity in the ECS is

significant for combinations of asphalt and aggregate. The ECS test results have shown that ECS performance ranking after one cycle is not statistically significant and does not correlate with ranking after three cycles. The results show that the ECS test program has similar aggregate rankings to those of the NAT and SWK/UN test program, while good agreement exists between SWK/UN wheel tracking results and the NAT test program results. However, poor agreement exists between the OSU wheel tracking results and those of the other two tests. Poor or very little agreement exists among the wheel tracking test results, ECS, and NAT test results in terms of asphalt type rankings.

When considering the comparisons of materials ranking by different test procedures, one must keep in mind that the mechanisms leading to varying "performance" are not the same. The testing reported herein was aimed at measuring water sensitivity, but all the tests do not do so directly. The NAT procedure addresses only the potential for stripping (adhesion) and is not capable of evaluating cohesion loss. The other tests (ECS, OSU and SWK/UN wheel tracking) included all the mechanisms simultaneously, and these provided a gross effect without clearly separating the cause of failure in each case.

Open-graded mixtures used by Oregon Department of Transportation (ODOT) performed well in the ECS in terms of water sensitivity. In the ECS evaluation, six mixtures passed the criteria of 75 % established for Indirect Retained Strength (IRS) test by ODOT, and one mixture was marginal. However, only one mixture passed the IRS evaluation, and another mixture was marginal. This confirms that the IRS test is a very severe test and is not suitable for water sensitivity evaluation of open-graded mixtures. Finally, the IRS test evaluation would suggest that these mixtures would fail prematurely after construction, but all of these mixtures have been used in projects which have been in service for more than three years with no visible signs of distress, or failures.

EVALUATION OF WATER DAMAGE ON ASPHALT CONCRETE MIXTURES USING THE ENVIRONMENTAL CONDITIONING SYSTEM

by

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

PAGE

APPENDICES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF APPENDICES FIGURES

LIST OF APPENDICES FIGURES (Continued)

LIST OF APPENDICES TABLES

EVALUATION OF WATER DAMAGE ON ASPHALT CONCRETE MIXTURES USING THE ENVIRONMENTAL CONDITIONING SYSTEM

1.0 INTRODUCTION

1.1 PROBLEM DEFINITION

Asphalt concrete pavement is subjected to several damaging actions from traffic loads, water (from precipitation and/or groundwater sources), and temperature. The durability of the pavement, the ability of the pavement to withstand these damaging actions for long periods, is a very important engineering property. While the durability of the asphalt concrete pavement depends on several factors such as mixture properties, construction methods, traffic loads and environmental conditions, asphalt concrete mixtures have to be evaluated to predict their field performance. Based on mixture evaluations, those mixtures that fail the test would have to be modified by additives or by changing the materials.

The main goal is to design and construct a pavement that, in the long term, can resist all damaging actions, whether they are from the environment (water, and temperature), or traffic loads. Since the 1930's, researchers have been trying to develop a test that would determine the susceptibly of water damage on asphalt concrete mixtures (Terrel and Shute, 1989). Several tests have been developed that try to simulate water damage on asphalt mixtures, and then assess the damage by evaluating mixture strength loss. However, most of the different water sensitivity tests have been unsuccessful in predicting the premature failures in asphalt concrete pavements due to water damage.

The problem with some of these tests is that they do not relate to field conditions. Typically, water sensitivity tests are two-step procedures: mixture conditioning, and mixture evaluation. In the first step, the mixture is subjected to a conditioning process that attempts to simulate the damage caused by environmental conditions in the field. Next, the mixture is evaluated for any deterioration in strength caused by water damage by evaluating the mixture strength before and after conditioning. Some of the evaluation methods used are strength or modulus testing, then the ratio of before and after conditioning is determined. If the ratio is less than a specified value, then the mixture has failed the water sensitivity test. Visual evaluation of stripping is also used where the percentage of retained asphalt coating on the aggregate is determined.

The laboratory conditioning process by which the water damage is induced does not relate to what actually occurs in the field. Also, some of these tests do not relate to water damage failure mechanisms that would develop. Damage caused by water is a combination of several failure mechanisms: adhesion loss, cohesion loss, and aggregate degradation (Hicks, 1991).

One of Strategic Highway Research Program (SHRP) goals was to develop a performance based test that could predict the influence of water damage on asphalt-aggregate mixtures. The Environmental Conditioning System was developed at OSU as part of SHRP's efforts to develop a test that could rank asphalt aggregate mixtures with respect to susceptibility to water damage (Terrel, and Al-Swailmi, 1991). Although the ECS test cannot separate the different failure mechanisms, the ECS test has a more realistic conditioning procedure and can evaluate the physical behavior of asphalt concrete mixtures when water is present.

1.2 OBJECTIVES

Part of this research effort was conducted as part of SHRP project A-003A "Performance Related Testing and Measuring of Asphalt-aggregate Interactions and Mixtures." The primary objective of the A-003A project was to validate the relationships between asphalt binder properties and asphalt concrete mixtures performance. The secondary objective was to develop accelerated mixture performance test procedures to be included in the SHRP mix design specifications. The primary purpose of this portion of the SHRP A-003A project was to validate the ECS and preliminary ranking of asphalts developed by other SHRP projects (Schloz et al., 1993). The objectives of this research were to:

1) Evaluate thirty-two SHRP asphalt-aggregate mixtures for water damage using the ECS, and rank the asphalt and aggregate types based on water sensitivity tests,

2) Relate the ECS ranking of the asphalt and aggregate types to OSU and SWK/UN wheel tracking test results, and to NAT results,

3) Evaluate open-graded asphalt mixtures from the Washington Department of Transportation (WSDOT) and the Oregon Department of Transportation (ODOT) for water sensitivity using the ECS,

4) Evaluate modified asphalt-aggregate mixtures from Australia for water sensitivity using the ECS, and

5) Evaluate the ECS conditioning cycle duration.

2.0 LITERATURE REVIEW

The literature review of the water sensitivity problem was divided into three parts. First, water sensitivity failure mechanisms and factors that might influence water damage were reviewed. Second, a review of existing methods to evaluate water damage potential was performed. Finally, factors that lead to the selection of the Environmental Conditioning System as a suitable test to evaluate the susceptibility of mixtures to water damage were completed.

2.1 DEFINITION OF WATER DAMAGE

Water damage is a major phenomenon that causes distress and failures in asphalt concrete pavement due to the presence of water, temperature, and traffic loading. The best analogy that illustrates water damage theory and the factors influencing water damage potential is shown in Figure 2.1, "Water Damage Triangle" (Graf, 1986). First, the material's sensitivity in the presence of water and any of the distress can affect the water damage. In some regions of the USA where the climate is mild and there are good quality aggregates and asphalt cement, the major contribution to pavement deterioration may be due to traffic loading. However, in other regions of the country where there are poor aggregates and/or asphalt cement, coupled with severe weather and traffic loading, premature failure may occur.

The water damage triangle analogy shows the complexity involved in understanding this problem. The understanding of the water damage phenomenon is tied very much to our understanding of the failure mechanisms that occur, causing premature failures in the pavement. There are several factors that can affect water damage potential and the performance of asphalt concrete mixture in the presence of water. These factors can be grouped into three categories (Hicks, 1991):

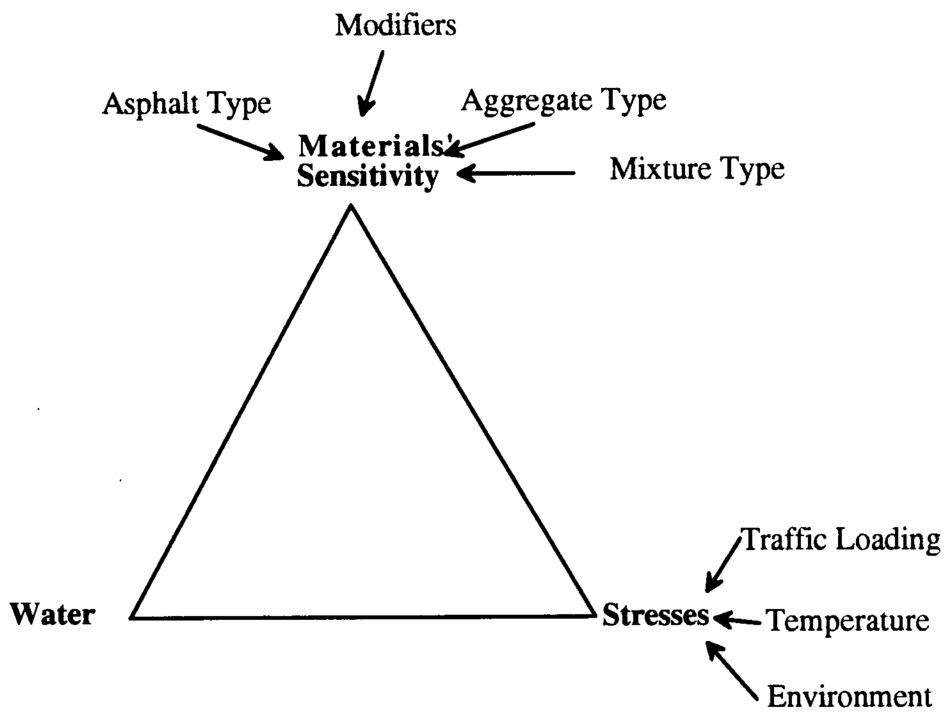


Figure 2.1 Water Damage Triangle (Graf, 1986)

1) Mixture characteristics, which include aggregate, asphalt, mixture type,

2) Weather during construction, and

3) Environmental conditions after construction.

Table 2.1 summarizes the factors that might influence water damage potential in asphalt concrete mixtures and their desirable characteristics.

Although aggregates constitute about 90 to 95 percent of the asphalt concrete mixture weight, the aggregate effect on the mixture's performance is not proportionally dependent on the relative weight of aggregate to asphalt. The surface texture of the aggregate affects the coatability of the aggregate by asphalt, and the mechanical retention of the asphalt coating as well. Aggregates that have rough surfaces when coated with asphalt require more energy to be displaced by water, thus improving the water resistance. Also, the surface coating affects the adhesion, and porosity promotes adhesion due to mechanical lock.

Mineralogical and chemical composition affect the aggregate's surface chemical reactivity. Aggregates possessing certain chemicals tend to behave differently when moisture is present, and the potential of asphalt being displaced by water is dependent on the aggregate's chemical composition. Aggregate types which are classified as "acidic" aggregates have been shown to have more affinity for water than "basic" aggregates (Rice, 1958). In other words, acidic aggregates tend to strip more, thus causing premature failure in the asphalt concrete pavement.

However, other researchers have found that the notion that "acidic" rocks have a higher potential for stripping than "basic" aggregate is inaccurate (Terrel and Shute, 1989). Aggregate surface zeta potential in water and/or pH of water penetrating the aggregate could be used as a measure of stripping potential, where higher zeta potential and/or pH value would lead to higher stripping potential (Terrel and Shute, 1989).

Table 2.1 Factors Influencing Water Damage (Hicks, 1991)

Factor	Desirable Characteristics
1) Aggregate Type	
- Surface Texture	Rough
- Porosity	Depends on pore size
- Mineralogy	Basic aggregates are more resistant
- Dust Coatings	Clean
- Surface Moisture	Dry
- Surface Chemical Composition	Able to share electrons or form hydrogen bond
- Mineral Filler	Increases viscosity of asphalt
2) Asphalt Cement	
- Viscosity	High
- Chemistry	Nitrogen and phenols
- Film Thickness	Thick
3) Type of Mixture	
- Voids	Very low or very high
- Gradation	Very dense or very open
- Asphalt Content	High
4) Weather Conditions	
- Temperature	Warm
- Rainfall During Construction	None
- Rainfall after Construction	Minimal
- Freeze-Thaw	Minimal
5) Traffic Loading	Low Traffic

Knowledge or theories to link asphalt properties to water damage have not been developed. There is evidence that viscous asphalts are not affected as much by moisture as less viscous asphalts. The asphalt viscosity has been reported as an important asphalt property in determining the water damage potential (Majidzadeh and Brovold, 1968). Asphalt types with higher viscosity values can resist the displacement by water more than asphalts with lower viscosity, because higher viscosity asphalt coats the aggregate surface with a thicker film which protects the aggregate from the action of water. Adhesion stripping studies on different asphalt types have not shown any correlation between the asphalt properties and stripping-adhesion failure mechanisms.

Premature failure of asphalt concrete pavement due to water damage is caused by a combination of several failure mechanisms (Hicks, 1991):

1) Adhesion loss,

2) Cohesion loss, and

3) Aggregate degradation.

Adhesion loss occurs when the asphalt film is partially separated from the aggregate by water; this is the case when an aggregate has a greater affinity for water than for asphalt. There are a number of theories that have been developed to explain adhesion loss, but no single theory seems to explain adhesion. All of the adhesion theories have been developed around material properties that would relate to the asphalt-aggregate interface (see Table 2.1).

In a compacted mixture, cohesion can be described as being the over all integrity of the material when subjected to load or stress. Cohesive strength can be measured by the resilient modulus test, or tensile strength test. The cohesion is influenced by the viscosity of the asphalt filler system. Cohesion loss occurs when asphalt film is separated by water, i.e., when rupture in the asphalt film occurs.

The third failure mechanism is aggregate degradation, and this is aggregate failure in the asphalt concrete mixture due to water saturation, environmental factors, and loading stresses. This failure mechanism occurs with poor aggregates in terms of strength and not necessarily in terms of water sensitivity. Aggregates that have high water absorption, coupled with lower strength, tend to absorb water and disintegrate, thus leading to mixture failure. The different failure mechanisms cannot be separated, because in one way or another these mechanisms act together (Terrel, 1991). The evaluation methods such as the resilient modulus test, tend to measure gross effects of these failure mechanisms, and cannot be separated.

2.2 EXISTING METHODS TO EVALUATE WATER DAMAGE

Since the 1930's numerous studies have been conducted in the water damage area, and several test methods have been developed to test asphalt concrete mixtures for water damage potential (Terrel and Shute, 1989). Table 2.1 shows factors that should be considered when developing a water sensitivity test. The water sensitivity tests are divided into two categories:

1) Tests which coat a "standard" aggregate with an asphalt cement with or without an additive. The loose uncompacted mixture is immersed in water, either at 25 C or at boiling temperature. The loose mixture is evaluated visually, by assessing the separation or stripping of asphalt from the aggregate.

2) Tests which use laboratory compacted specimens, or cores from the field. The specimens are conditioned in a certain procedure to simulate the field conditions. The specimens are evaluated by taking the ratio of conditioned and unconditioned test results, e.g. diametral resilient modulus test, diametral tensile strength, etc..

These water sensitivity tests rate the performance of the asphalt concrete mixture by using such terms as "reasonable," "good," and "fair." The problem with all of these tests is that the evaluation method and rating seldom relate to field performance. Variability in the test parameters can affect the evaluation and decrease the precision of the results. The mixture evaluated in the lab might have a "good," or pass rating, but still fail prematurely in the field.

Different tests, like AASHTO T 283, Tunnicliff and Root, Boiling, Freeze-Thaw Pedestal, and Immersion-Compression tests have been used to predict mixture field performance (Hicks, 1991). Each test has its advantages and disadvantages. The major problem with existing tests is a lack of good correlation with field performance with respect to water induced damage (Hicks, 1991). Also, some of these tests do not relate to water damage failure mechanisms that would develop. The most important disadvantage of water sensitivity tests is that the conditioning is too severe (torture test), and laboratory conditioning does not relate to conditioning in the field. Moreover, the evaluation methods of some of these tests are very subjective and do not relate to any engineering evaluation method.

2.3 SELECTION OF ECS

For the research presented here, the Environmental Conditioning System (ECS) was selected as the primary test for water sensitivity evaluation of asphalt concrete mixtures. The ECS was developed as part of the SHRP project. The goal was to relate asphalt mixture properties to performance of mixtures. The ECS was devised, and assembled for water sensitivity testing and evaluation. The ECS test procedure was developed as part of an extensive testing program (Terrel, and Al-Swailmi, 1992). In the development phase of the ECS, many variables were considered and tested. For example, some of the variables were permeability, conditioning level, cycle duration, conditioning time, rate of wetting, aging, loading, air voids, etc. (see Table 2.2).

Table 2.2 Factors Influencing Water Sensitivity of Asphalt-Aggregate Mixtures (Terrel and Shute, 1989)

Variable	Factor
Existing Condition	- Compaction Method - Voids - Permeability - Environment - Time - Water Content
Materials	- Asphalt - Aggregate - Modifiers and/or Additives
Conditioning	- Curing - Dry vs. Wet - Soaking - Vacuum saturation - Freeze-thaw - Repeated Loading - Drying
Other	- Traffic - Environmental history - Age

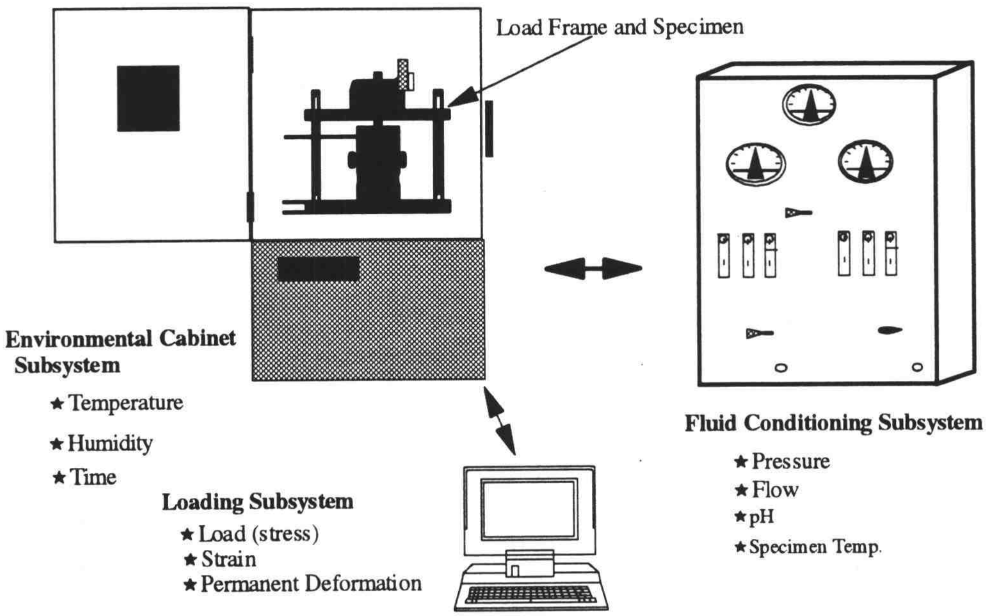


Figure 2.2 Schematic of Environmental Conditioning System

Figure 2.2 shows a schematic of the ECS equipment and its subsystems:

1) Fluid conditioning subsystem,

2) Environmental conditioning chamber, and

3) Loading subsystem.

The fluid conditioning subsystem was designed to perform air and water permeability, and water conditioning tests. The unit uses vacuum to pull air or water through the specimen and measure the flow and pressure across the specimen. Also, a thermocouple controller with four thermocouples was installed to monitor temperature of water before entering the specimen, after specimen, and inside a dummy specimen in the chamber. The environmental conditioning chamber is for temperature and humidity conditioning. The chamber can be programmed to execute the ECS conditioning procedure with minimum user involvement.

The loading subsystem is an electro-pneumatic, closed loop system which includes a personal computer, an anolog-to-digital/digital-to-anolog interface card, a transducer signal conditioning unit, a servo-valve amplifier, and a loading frame. The computer-controlled loading and data acquisition system applies axial loads, and monitors the axial deformation to determine the specimen resilient modulus (ECS-M_R). The loading system applies repeated loading during the conditioning cycles, and collects the permanent deformation throughout the conditioning cycle.

The ECS test procedure consists of inducing and monitoring water damage to 4 in. (102 mm) diameter by 4 in. (102 mm) high asphalt concrete cores. The ECS test is carried out to quantitatively assess the effect water has on the stiffness and permeability of an asphalt-aggregate mixture. The procedure is briefly described in Table 2.3 (Terrel and Al-Swailmi, 1992), and the detailed protocol is in Appendix B.

Table 2.3 ECS Test Procedure (Terrel and Al-Swailmi, 1992)

Step	Description
1	Determine the geometric and gravimetric quantities of the specimen.
2	Place a silicone seal around the circumference of the specimen with a 6 inch membrane and allow the silicone cement to cure overnight (24 hours).
3	Mount the specimen in the ECS load frame and determine the air permeability at various flow levels.
4	Determine the unconditioned (dry) resilient modulus.
5	Apply 20 inches (508 mm) Hg vacuum for 10 minutes.
6	Wet the specimen by pulling distilled water through the specimen for 30 minutes using a 20 inches (508 mm) Hg vacuum.
7	Determine the unconditioned water permeability.
8	Heat the wet specimen to 140 F (60 C) for six hours and apply axial repeated loading of 18 psi (124 KPa).
9	Cool the wet specimen to 77 F (25 C) for two hours and measure the water permeability and resilient modulus. Steps 8 and 9 constitute a hot cycle.
10	Repeat Steps 8 and 9 for two more hot cycles.
11	Cool the wet specimen to 0 F (-18 C) for six hours.
12	Heat the specimen to 77 F (25 C) for two hours and measure the water permeability and resilient modulus. Steps 11 and 12 constitute a freeze cycle.
13	Split the specimen and assess the percentage of stripping.
14	Plot water permeability and resilient modulus ratios (conditioned to unconditioned) versus conditioning cycle.

There are several advantages to ECS test procedure over previous test methods:

1) The variability of the resilient modulus test is decreased since only one specimen setup is required.

2) Errors caused by handling and transferring the specimen from water bath to testing device are eliminated.

3) The evaluation of ECS specimen is performed after each conditioning cycle to monitor strength loss and assess the failure progression.

4) The ECS conditions and tests compacted asphalt specimens with any level of air voids.

5) The ECS conditioning is more representative of what happens in the field, e.g., there is repeated loading to simulate traffic loading.

6) The ECS has shown better repeatability than current methods represented by AASHTO T-283.

7) Only two specimens are required for mix design evaluation using the ECS, less than what is required by other tests.

3.0 EXPERIMENT DESIGN

The experimental design developed for this research was part of the SHRP project. The objective of the evaluation of SHRP mixtures was to evaluate the ECS and relate the ECS material rankings to ranking from other tests. Table 3.1 shows the experiment design and the coding scheme of each mixture, the first two digits being the aggregate code (RC, and RJ codes are 00, and 11 respectively). The last three digits are the asphalt code (AAA-1, and AAG-1 codes are 000, and 101 respectively). Originally only eight mixtures were chosen to be replicated (shown in Table 3.1). However, all the thirty-two mixtures were actually replicated (i.e. two specimens from each mixture). The evaluation of the SHRP mixtures was divided into two tasks:

1) Laboratory evaluation, using the ECS, and
2) Field evaluation using two wheel tracking systems, OSU (Jung Ju, 1991) and SWK/UN (Monismith and Rowe, 1992).

As indicated, an eight asphalt by four aggregate (8 x 4) matrix was designed for this work. The primary purpose of the different tests is to identify the water sensitivity of the mixtures using either rutting (OSU and SWK/UN wheel tracking) or reduction in modulus (ECS) as the objective criteria. The test program provides information to evaluate the relative performance of the eight asphalts and four aggregates based on all the tests, thus enabling a comparison of results from the different test programs. The following sections provide details regarding the experiment design including the variables considered, the materials used, the specimen preparation procedure, and the test procedures used to carry out the work.

Table 3.1 Experiment Design for ECS Evaluation of 32 SHRP Mixtures - Water Sensitivity

Mixture Number	Mixture Code	MRL Aggregate	MRL Asphalt	Required Replicate
1	00000	RC	AAA-1	RC & AAA-1
2	10000		AAB-1	
3	01000		AAC-1	
4	11000		AAD-1	
5	00100		AAF-1	
6	10100		AAG-1	
7	01100		AAK-1	RC & AAK-1
8	11100		AAM-1	
9	00010	RD	AAA-1	
10	10010		AAB-1	
11	01010		AAC-1	
12	11010		AAD-1	RD & AAD-1
13	00110		AAF-1	
14	10110		AAG-1	RD & AAG-1
15	01110		AAK-1	
16	11110		AAM-1	
17	00001	RH	AAA-1	
18	10001		AAB-1	
19	01001		AAC-1	
20	11001		AAD-1	RH & AAD-1
21	00101		AAF-1	
22	10101		AAG-1	RH & AAG-1
23	01101		AAK-1	
24	11101		AAM-1	
25	00011	RJ	AAA-1	RJ & AAA-1
26	10011		AAB-1	
27	01011		AAC-1	
28	11011		AAD-1	
29	00111		AAF-1	
30	10111		AAG-1	
31	01111		AAK-1	RJ & AAK-1
32	11111		AAM-1	

3.1 VARIABLES CONSIDERED

The testing program consisted of eight asphalt types and four aggregate types. The asphalt and aggregate material properties are discussed in the sections to follow. The ECS evaluation program variables considered for this phase of the research are shown in Table 3.2 and discussed below. Specimen density (air voids), mixture asphalt content, and gradation of the aggregate were all held as constant as possible (see Table 3.3). The aggregate gradation was held constant because gradation can affect the results of the ECS test program (Terrel and Al-Swailmi, 1992).

The aggregate gradation can influence the mixture's permeability, thus affecting its potential for water damage. The permeability, which is a measure of the water penetration potential, can be affected by aggregate gradation. If the mixture has high permeability values, the water can easily penetrate the mixture; thus the water can damage water sensitive mixtures (Hein and Shmidt, 1961). Therefore, to have a better control on the evaluation and the comparisons of the thirty-two mixtures (based on asphalt and aggregate types alone), the aggregate gradation was held constant.

The asphalt content was held constant because it has been shown that the asphalt content can affect the water damage potential (Hicks, 1991). Mixtures with the same asphalt-aggregate type and same mixture parameters but with different asphalt contents have shown different water damage potential. Asphalt concrete mixtures that have higher asphalt content would coat the aggregates more and would have thicker asphalt films, thus it would shield the susceptible aggregate from water. The thick asphalt film can clog the asphalt-aggregate interface and reduce the permeability and air voids, thus preventing or minimizing the penetration of water into the mixture.

Permeability was used as a measure of the moisture damage susceptibility. Generally, mixtures that have higher air voids tend to have higher permeability, when compared with mixtures of the same aggregate gradation. Also, asphalt concrete mixtures having higher permeability are easily accessed by water, thus increasing the

Table 3.2 Experiment Design of ECS Evaluation of 32 SHRP Mixtures - Water Sensitivity

Variables	Level of Treatment 1	2	3	No. of Levels
Aggregate				
* Stripping potential	Low	2 Medium	High	4
* Gradation		Medium		1
Asphalt				
* Grade	2 Low	5 Medium	High	8
* Content		Optimum		1
Compaction				
* Air voids			8±1%	1
Test Conditions				
* Test temperature		25 C		1
* 3 hot + Freeze cycle				1
* Cycle Duration			6 Hrs.	1
* Repeated load			Continuous	1
			Total	32

Complete Factorial	32
Replicate	32
Total Number of Samples	64

Table 3.3 Job-Mix Formula Used for SHRP Mixtures - Water Sensitivity

Sieve Size	Percent Passing			
	RC	RD	RH	RJ
1 in.	100	100	100	100
3/4 in.	95	95	95	95
1/2 in.	80	80	80	80
3/8 in.	68	68	68	68
#4	48	48	48	48
#8	35	35	35	35
#16	25	25	25	25
#30	17	17	17	17
#50	12	12	12	12
#100	8	8	8	8
#200	5.5	5.5	5.5	5.5
Asphalt content by weight of aggregate, %	6.3	4.5	5.2	5.0
Asphalt content by total weight of mixture, %	5.9	4.3	4.9	4.8

water damage potential. Therefore, permeability is used to assess the water damage potential of the mixtures. Normally, air voids is not a good indicator of the accessibility or penetration of water in the mixture, thus air voids can be a misleading indicator for water damage potential. The permeability measures the interconnection of the voids rather than an account of the voids, leading to a better assessment of the water penetration potential of the mixture; and thus leading to the mixture's water damage potential.

Temperatures that were applied during conditioning were hot (60 C) for the first three cycles, and freeze (-18 C) for the fourth cycle. These temperatures were established by the ECS test protocol. The three hot cycles simulate the water damage sustained under hot climates. The addition of the freeze cycle was to simulate the damage sustained under the cold climates. Also, repeated loading was applied during the first three hot cycles, and static loading during the freeze cycle. The repeated loading was applied to simulate traffic loading and water damage under traffic loading conditions.

The resilient modulus (ECS-M_R) test was conducted at 25 C after each cycle. The resilient modulus obtained in the ECS is termed, ECS-$M_{R,}$, to distinguish it from the traditional diametral and triaxial resilient moduli as well as from the dynamic modulus. The ECS-M_R is a triaxial resilient modulus with zero confining stress (i.e.,$\sigma 2=\sigma 3=0$) conducted on a 4 in. (102 mm) diameter by 4 in. (102 mm) tall asphalt-aggregate mixture test specimen (Terrel and Al-Swailmi, 1992).

The specimen was preconditioned or saturated with distilled water at 20 in. (508 mm) Hg of vacuum for 30 minutes. This preconditioning stage was to wet the specimen before the hot conditioning cycle with repeated loading. The duration of each cycle was six hours, and each test had three hot cycles and one freeze cycle. The response variables are:

1) ECS-M_R was measured after each conditioning cycle. The ratio of dry ECS-M_R to ECS-M_R after each cycle determines the relative change in stiffness due to water damage.

2) Permeability was measured after each conditioning cycle, to monitor the change in moisture damage susceptibility. Also, permeability was a relative measure of the change in the mixture matrix, or volume change.

3) Visual estimation of the percentage of retained asphalt coating on the aggregate was observed at the end of the test. The specimen was broken diametrically by using the indirect tensile test setup.

For the OSU and SWK/UN (Scholz et al., 1993) wheel tracking test programs, the variables considered in the experiment design included the asphalt and aggregate types. Specimen density (air voids), mixture asphalt content, gradation of the aggregate, and test specimen conditioning were all held as constant as possible. Specimen air voids contents here "held constant" at 8±1%; the mixture asphalt contents were based on the content established by the Hveem Method (Harvey, 1990) and are given in Table 3.3. The aggregate gradation was that of a medium gradation (see Table 3.3); and each test program employed a conditioning procedure that remained the same for all specimens tested (each method is described in further detail below).

3.2 MATERIALS

The materials used in this study included eight asphalts and four aggregates from the SHRP Materials Reference Library (MRL). The following paragraphs provide details of these materials.

3.2.1 Aggregates and Their Properties

Two limestones (RC and RD) and two siliceous aggregates (RH and RJ) were used for this research effort. Table 3.4 summarizes the properties of the aggregates.

Table 3.4 Aggregate Characteristics (Scholz et al., 1993)

MRL Code	RC	RD	RH *	RJ
Major Element Oxide				
SiO_2	5.58 (11.79)	16.68 (14.84)	75.91	75.4 (63.98)
TiO_2	0.06 (0.18)	0.13 (0.21)	0.46	0.15 (0.41)
Al_2O_3	1.18 (1.46)	3.31 (1.95)	10.68	12.88 (14.6)
Fe_2O_3	0.76 (0.89)	1.2 (0.96)	4.83	2.01 (4.54)
CaO	48.92 (35.04)	38.8 (33.71)	1.84	1.73 (6.09)
MgO	2.35 (11.76)	3.47 (11.43)	2.28	0.39 (1.52)
Na_2O	0.17 (0.21)	0.12 (0.08)	2.76	3.4 (1.67)
K_2O	0.18 (0.51)	1.56 (2)	0.74	3.31 (3.31)
Sulfer Trioxide	(0.48)	(0.34)		(0.1)
Phosphorus Pentoxide	(<0.01)	(<0.01)		(0.11)
Manganic Oxide	(0.03)	(0.02)		(0.13)
LOI	40.62 (37.64)	33.96 (34.45)	2.41	1.13 (3.54)
Composition %	Limestone 100	Limestone 53.3 Limestone 26.8 Arenaceous Limestone 19.7	Micaceous Sandstone 71.3 Misc. 11.2 Granite 10.9 Chert 6.6	Sandstone 47.4 Granite 28.4 Misc. 23.7 Basalt 0.4
Porosity (ASTM D-4404)				
Avg. Pore Dia. (mx10-6)	(0.0611)	(0.0111)	*	(0.0151)
Total Pore Area (m2/g)	(2.548)	(1.465)		(1.888)
Mercury Porosimetry Data				
Pore Size A	Pore Vol. cc/g	Pore Vol. cc/g	Pore Vol. cc/g	Pore Vol. cc/g
>300	0.0099	0.0013	0.0128	0.0026
500-3000	0.1085	0.0301	0.0905	0.0071
<500	0.0045	0.0003	0.0023	0.0002
Total Vol.	0.12	0.03	0.11	0.01
pH	9.7	9.8	9	9.6
L.A. Abrasion (AASHTO T-96) %Wear	(39.1)	(23.4)		(29.5)
Water Absorption (AASHTO T-84, T-85) % Absorption	(3.7)	(0.3)		(0.7)

Table 3.4 Aggregate Characteristics (Continued)

MRL Code	RC	RD	RH *	RJ
Specific Gravity (AASHTO T-84, T-85) Bulk Saturated Surface Dry Apparent	 (2.536) (2.595) (2.682)	 (2.704) (2.717) (2.739)	 (2.550) (2.741)	 (2.625) (2.646) (2.68)
BET Surface Area, m2/g Rootare-Prenzlow Surface area (m2/g) Acid Insolubles (%) Water Insolubles (%) Zeta Potential	2.90 0.84 7.9 (4.8) 8.1 (2.4) -6.1@pH9.82 (-23.8)	0.72 0.14 23.5 (18.1) 5.1 (1.9) -13.6@pH9.87 (-20.3)	2.74 0.53 92.1 9.7 -20.5pH8.27	1.32 0.05 96.2 (99.2) 6.3 (4.1) -27.5@pH9.45 (-49)
CKE (AASHTO T-270) Uncorrected (%) Oil Retained (%)	 (8.5) (3.9)	 (3.8) (2.7)		 (1.8) (2.6)
Flakiness Index (%) (Asphalt Inst.) Sand Equivalent (%) (AASHTO T-176)	(22.6) (32)	(34.7) (69)		(9.6) (60)
Magnesium Soundness (AASHTO T-104) %Loss: Fine Fraction %Loss: Coarse Fraction	 (6.32) (0.51)	 (1.52) (0.04)		 (1.29) (0.16)
Polish Value (ASTM D-3319) BPN Before Polish BPN After Polish	 (42) (31)	 (38) (28)		 (41) (22)

Data from University of Kentucky; (1991) from Southwestern Lab, Inc., Texas

* Some of RH material properties were not available.

The chemical analysis of the aggregates establishes that RC and RD have high percentages of basic oxide elements, mainly CaO. Aggregate RH and RJ have high percentages of acidic oxide, SiO_2. Aggregate types, which are classified as acidic aggregates, have been shown to have more affinity for water than basic aggregate (Rice, 1958). In other words, acidic aggregates tend to strip more, thus causing water damage in the asphalt concrete mixture.

Note that the RC limestone aggregate has a high water adsorption and California Kerosene Equivalent (CKE) values relative to the other aggregates. The RD aggregate showed very low absorption values. In addition, the RC aggregate has a low bulk specific gravity relative to the other aggregates (the gravimetric data for the RH aggregate was unavailable). In the soundness test, the RC aggregate exhibited high values of percent loss of fine and coarse fraction relative to the other aggregates.

Aggregate RC which exhibited high water absorption values and low soundness test values, demonstrating that RC is a weak aggregate which could disintegrate in the presence of water, thus causing water damage in the asphalt concrete mixture. Aggregate RD, with its' basic composition, leads us to believe that it might show water resistant characteristics. Aggregate RJ has an acidic chemical composition; and since acidic aggregates tend to displace asphalt in the presence of water, RJ could exhibit water damage. Aggregate RH, which has an acidic chemical composition, could exhibit asphalt stripping. Unfortunately the gravimetric data for the RH aggregate was unavailable, so comparison based on other properties was not possible.

3.2.2 Asphalts and Their Properties

Eight asphalts from differing sources (crudes), and having differing grades, were used in this research effort. The MRL codes for these asphalts are AAA-1, AAB-1, AAC-1, AAD-1, AAF-1, AAG-1, AAK-1, and AAM-1. Table 3.5 summarizes the properties of these asphalts. Note the wide range of asphalt viscosities as determined

Table 3. 5 Asphalt Characteristics (Scholz et al., 1993)

MRL Code	AAA-1	AAB-1	AAC-1	AAD-1	AAF-1	AAG-1	AAK-1	AAM-1
Grade	150/200	AC-10	AC-8	AR-4000	AC-20	AR-4000	AC-30	AC-20
Crude	Lloyd-minister	WY Sour	Red Water	CA	WTX Sour	CA Valley	Boscan	WTX Inter
Original Asphalt Viscosity								
140 F, poise	864	1029	419	1055	1872	1862	3256	1992
275 F, cSt	283	289	179	309	327	243	562	569
Penetration, 0.1 mm								
(77 F, 100g, 5s)	160	98	133	135	55	53	70	64
(39.2 F, 100g, 5s)	15	6	7	9	0	2	2	4
Ductility, cm								
(39.2 F, 1 cm/min)	150+	40.1	137	150+	7.6	0	27.8	4.6
Softening Point (R&B)F	112	118	109	118	122	120	121	125
Component Analysis, %								
Asphaltenes (n-heptane)	18.3	18.2	11.0	23.0	14.1	5.8	21.1	3.9
Asphaltenes (iso-Octane)	3.4	2	3.1	3.4	3.1	3.3	2.8	
Polar Aromatics	37.3	38.3	37.4	41.3	38.3	51.2	41.8	50.3
Napthene Aromatics	31.8	33.4	37.1	25.1	37.7	32.5	30	41.9
Saturates	10.6	8.6	12.9	8.6	9.6	8.5	5.1	1.9

Table 3.5 Asphalt Characteristics (Continued)

MRL Code	AAA-1	AAB-1	AAC-1	AAD-1	AAF-1	AAG-1	AAK-1	AAM-1
Grade	150/200	AC-10	AC-8	AR-4000	AC-20	AR-4000	AC-30	AC-20
Crude	Lloyd-minister	WY Sour	Red Water	CA	WTX Sour	CA Valley	Boscan	WTX Inter
IEC Separations (wt%)								
Strong Acid*	6.4	15	7.5	11	15.4	18.1	3.7	4.7
SA Mol.Wt,VPO,Toluene	2790	2390		2500	1170	1080	2780	3040
Amphoterics*	11			15			15	9
Strong Base	6.4	9.2	7.4	7.8	6.1	12	8	10.4
Weak Acid	8.7	8.6	8.3	7.8	9.8	11.4	8.6	10
Weak Base	5.0	6.5	7.2	5.5	8.5	9.1	7.5	9.1
Neutral	59.6	56.9	68.2	51.7	56.7	50.4	52.5	53.4
Neutrals plus acids**				60		67.6	61.6	65
Amphoterics**				25.7		18.5	24.3	18.5
Bases**				9.3		12	9.9	14.3
Viscosity, poise, 77 F	355	1553	3100	197	4795	2605	463	11910
SEC Fraction, MW VPO, Toluene								
I	11000	9200	7380	7000	8690	7900	10000	4600
SEC I, TFAAT Aged	11500	9800	8400	13900	10100	7800	13000	5700
II								
Fraction II-wt%	78.2	78.3	85.8	76.6	85.6	87.1	74.1	69.5
Visc. w/SEC Fraction I removed (77 F, poise)	5064	13675	86020	3366	533500	623800	11240	263500
Visc. of whole asphalt, 77 F, Poisex10E-3	275.4	1125	945.4	405.7	3078	3540	1077	1123

* Calculated ** New method

Table 3.5 Asphalt Characteristics (Continued)

MRL Code	AAA-1	AAB-1	AAC-1	AAD-1	AAF-1	AAG-1	AAK-1	AAM-1
Grade	150/200	AC-10	AC-8	AR-4000	AC-20	AR-4000	AC-30	AC-20
Crude	Lloyd-minister	WY Sour	Red Water	CA	WTX Sour	CA Valley	Boscan	WTX Inter
Elemental Analysis								
C, %	83.9	82.3	86.5	81.6	84.5	85.6	83.7	86.8
H, %	10	10.6	11.3	10.8	10.4	10.5	10.2	11.2
O, %	0.6	0.8	0.9	0.9	1.1	1.1	0.8	0.5
Nitrogen, %	0.5	0.54	0.66	0.77	0.55	1.1	0.7	0.55
Sulfer, %	5.5	4.7	1.9	6.9	3.4	1.3	6.4	1.2
Vanadium, ppm	174	220	146	310	87	37	1480	58
Nickel, ppm	86	56	63	145	35	95	142	36
Fe, ppm	<1	16		13	100	48	24	255
Aromatic C, %	28.1	31.9	24.7	23.7	32.8	28.3	31.9	24.7
Aromatic H, %	7.68	7.12	6.41	6.81	8.66	7.27	6.83	6.51
Molecular wt. (Toluene)	790	840	870	700	840	710	860	1300
Aged Asphalt (Thin Film Oven Test)								
Mass Change, %	-0.3115	-0.0362	-0.259	-0.8102	-0.0921	-0.1799	-0.5483	-0.0516
Viscosity								
140 F, poise	1901	2380	1014	3420	4579	3253	9708	3947
275 F, cSt	393	393	239	511	472	304	930	744
Viscosity Ratio (140 F)	2.2	2.31	2.42	3.24	2.45	1.75	2.98	1.98

Table 3.5 Asphalt Characteristics (Contioued)

MRL Code	AAA-1	AAB-1	AAC-1	AAD-1	AAF-1	AAG-1	AAK-1	AAM-1
Grade	150/200	AC-10	AC-8	AR-4000	AC-20	AR-4000	AC-30	AC-20
Crude	Lloyd-minister	WY Sour	Red Water	CA	WTX Sour	CA Valley	Boscan	WTX Inter
Viscoelastic Properties								
G',dyne/cm2x-E06	1.243	1.47	1.07	1.498	1.066	0.472	1.596	1.701
G" "x-E06	3.957	3.942	4.05	3.888	4.125	4.024	3.935	3.928
Visc (p) x-E06	0.16	0.506	0.572	0.195	2.376	2.318	0.782	1.389
tan delta (G"/G')	3.183	2.682	3.786	2.596	3.87	8.914	2.466	2.309
G*,dyne/cm2x-E06	4.148	4.207	4.189	4.166	4.26	4.23	4.247	4.28
Specification Properties								
Td, Tank, C	-19.3	-11.6	-5.5	-17.1	-7	-3.9	-14.7	1
Td, TFOT, C	-14.3	-5.3	-3.8	-13.3	-1.4	0.8	-9.3	4.8
Td, PAV, C	-14.5	-6	3.5	-8.7	5.2	2.7	-9.2	6
R, Tank	1.5	1.76	1.63	1.66	1.6	1.24	1.6	1.93
R, TFOT	1.75	2.06	1.8	1.8	1.77	1.35	1.8	2.21
R, PAV	1.9	2.13	2.1	2.07	2.02	1.44	1.94	2.61
m, (0.1s) (0 C)	0.53	0.42	0.39	0.5	0.32	0.28	0.42	0.29
Limiting Stiffness, 200MPa S(t)@2hr., C	-31	-28	-25	-30	-21	-18	-27	-24
Ultimate Strain at Failure Strain,-26 C,2hr,%	3.1	1.7	1.5	2.5	1.2	0.8	1.7	1.5
Visous Stiffness@20 C log Sv, 0.1 s, Pa	6.77	7.2	7.17	7.07	7.67	7.5	7.58	7.82

by the traditional viscosity and penetration tests. It can be seen from these data that the AAC-1 asphalt is the softest while the AAK-1 asphalt is the hardest of the asphalts, based on original asphalt viscosity at 140 F.

3.3 Specimen Preparation

Specimen preparation for this research effort was accomplished by means of rolling wheel compaction (Scholz, et al. 1993). Table 3.6 shows a brief description of the procedure while Appendix A provides a detailed protocol. The specimen preparation procedures described in this protocol were developed at OSU specifically for the ECS, the OSU wheel tracker (LCPC rutting tester), and the SWK/UN wheel tracker test programs.

The specimen preparation process is shown schematically in Figure 3.1. The mixer used consisted of a conventional concrete mixer modified to include infrared propane heaters (see Figure 3.2) to preheat the mixer bowl prior to mixing, as well as to reduce heat loss during the mixing process. The preheated and pre-weighed aggregate was added to the mixer followed by the asphalt. The mixture, typically 275 to 290 lb. (125 to 132 Kg), is mixed in one batch.

After mixing, the asphalt-aggregate mixture was placed in a forced draft oven set to 275 F (135 C), and "short-term aged" for four hours in order to simulate the amount of aging which occurs in a batch or drum dryer plant. The mixture was stirred once each hour to promote uniform aging. At the completion of the aging process, the mixture was placed in the mold and compacted to a predetermined density using a small steel wheel compactor with tandem rollers, e.g., a roller for compacting sidewalks and bike paths. The compactor used at OSU is a static compactor weighed 3260 lb. (1480 Kg).

Table 3.6 Summary of Specimen Preparation Procedure for ECS Evaluation of SHRP Mixtures - Water Sensitivity

Step	Description
1	Calculate the quantity of materials (asphalt and aggregate) needed based on the volume of the mold, the theoretical maximum (Rice) specific gravity of the mixture, and the desired percent air voids. Batch weights ranged between 275 and 290 lb. (125 to 132 Kg) at an air void content of 8±1%.
2	Prepare the asphalt and aggregate for mixing.
3	Heat the materials to the mixing temperature for the asphalt (170±20 cS). Mixing temperatures ranged between 279 and 320 F (137 and 160 C).
4	Mix the asphalt and aggregate for four minutes in a conventional concrete mixer fitted with infrared propane burners and preheated to the mixing temperature for the asphalt.
5	Age the mixture at 275 F (135 C) in a forced draft oven for four hours stirring the mixture every hour to represent the amount of aging which occurs in the mixing plant.
6	Assemble and preheat the compaction mold using infrared heat lamps.
7	Place the mixture in the compaction mold and level it using a rake while avoiding segregation of the mixture.
8	Compact the mixture when it reaches the compaction temperature using a rolling wheel compactor until the desired density is obtained. This is determined by the thickness of the specimen (the only volumetric dimension that can be varied during compaction for a set width and length of slab). Steel channels with depth equal to the thickness of the specimen prevent over compaction of the mixture. Compaction temperatures (based on 630±20 cS) ranged between 234 and 271 F (112 and 133 C).
9	Allow the compacted mixture to cool to room temperature (15 hours).
10	Disassemble the mold and remove the slab. Dry cut (saw) beams for the OSU and SWK/UN wheel trackers. Dry cut cores for the ECS.

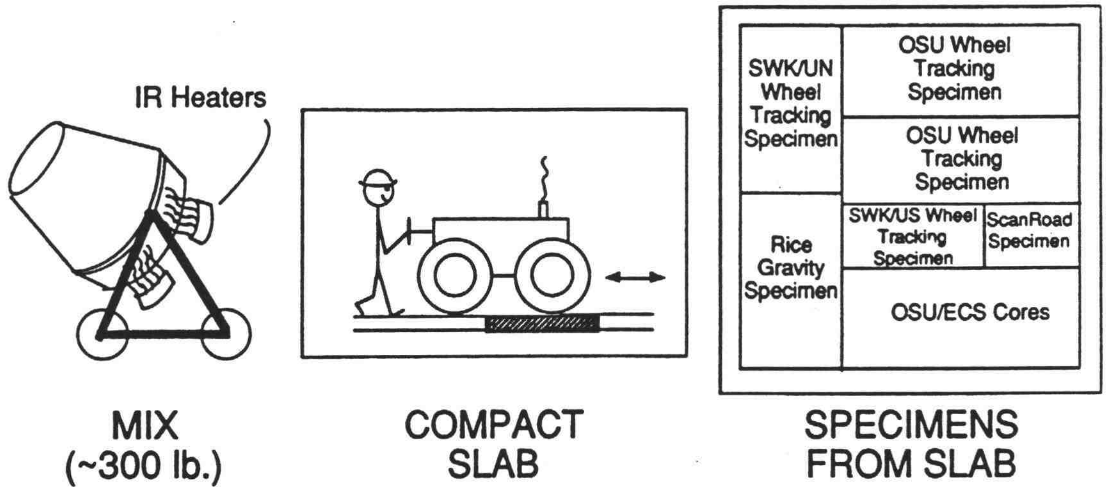


Figure 3.1 Schematic of the Specimen Preparation Process

Figure 3.2 Asphalt-aggregate Mixer Used at OSU

The compacted slab (see Figure 3.3) was then allowed to cool overnight (15 hours) after which beam specimens were sawn and core specimens were drilled from the slab (see Figure 3.4). The beams were sawn and the cores were drilled without the use of water to prevent errors in density and void analysis, as well as initial air permeability tests. For air permeability and bulk specific gravity tests the specimen must be dry, because water in voids can hinder the air flow through the specimen thus giving wrong air flow numbers and air permeability results.

3.4 TESTING METHODS

Each test program (ECS, OSU wheel tracking, and SWK/UN wheel tracking) applied specimen conditioning in its test procedure which subjected the specimen to water damage followed by measurement of rutting (OSU and SWK/UN wheel trackers) or the reduction in modulus (ECS). Each section below briefly describes these procedures while detailed test methods are provided in Appendix B.

3.4.1 OSU ECS Test

The test procedure employed in the ECS program consisted of inducing and monitoring water damage to 4 in. (102 mm) diameter by 4 in. (102 mm) high asphalt concrete cores. The procedure was described in section 2.2 and Table 2.3 (Terrel and Al-Swailmi, 1992). The ECS test is carried out to quantitatively assess the effect water has on the stiffness and permeability of an asphalt-aggregate mixture.

Prior to testing, gravimetric data (specific gravities) are obtained for the core specimens. The specimen is then encapsulated in a latex membrane with silicon. In the test, the air permeability and dry (unconditioned) ECS-M_R are determined prior to introduction of water. The specimen is then "wetted" by flowing distilled water through it under the action of a negative pressure relative to atmospheric pressure (i.e., 20 in. Hg vacuum) for 30 minutes. Upon completion of the wetting process, the water permeability of the specimen is determined.

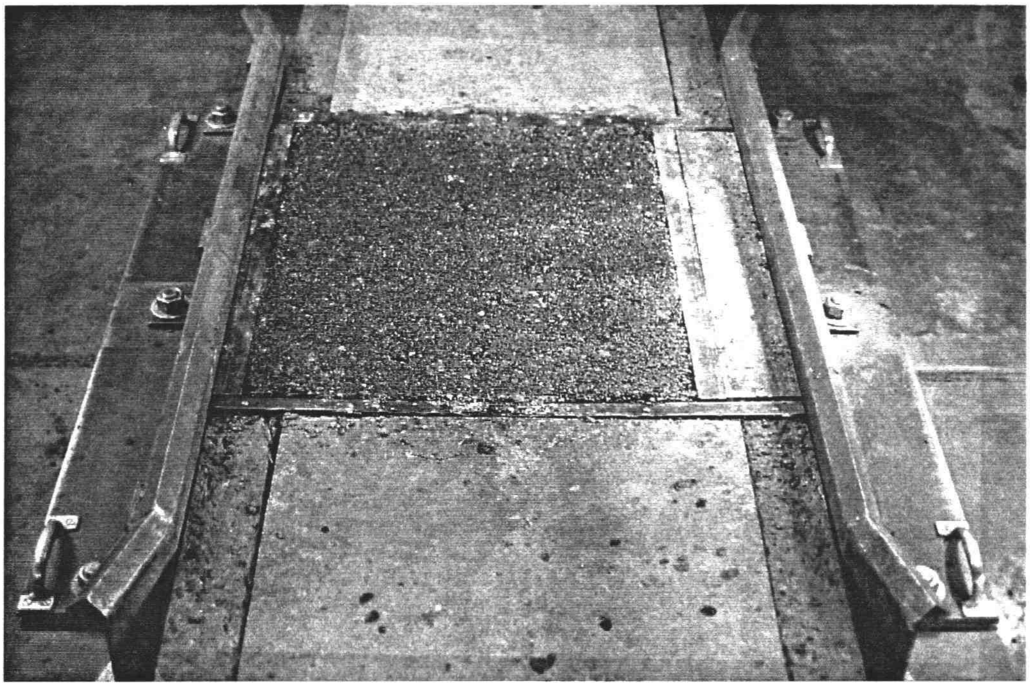


Figure 3.3 The Compacted Slab

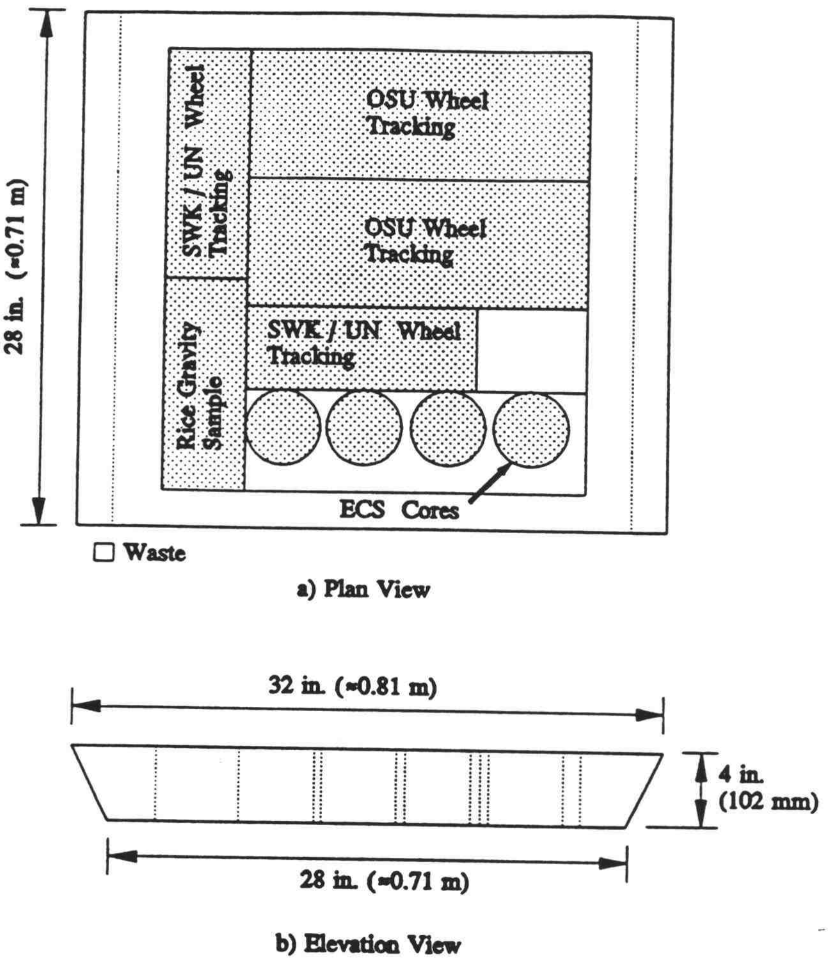


Figure 3.4 Layout of Specimens Cut From the Slab

The specimen is then subjected to thermal conditioning cycles, consisting of three "hot" cycles by heating the specimen to 140 F (60 C) and one "freeze" cycle by cooling the specimen to 0 F (-18 C). The duration of each thermal cycle is six hours, and after each cycle there is a cooling period to bring the specimen to 77 F (25 C). The specimen is tested to determine the conditioned water permeability and ECS-M_R, thus monitoring the effect water has on these properties as a function of the type and amount of environmental conditioning.

Test parameters of importance in the ECS test include the following:

1) All material property testing (modulus and permeability) is conducted at a temperature of 77 F (25 C). Also, only one specimen setup is needed, which eliminates errors caused by handling when modulus or permeability tests are conducted.

2) The modulus test is a triaxial test with a zero confining pressure ($\sigma2=\sigma3=0$), herein referred to as an axial resilient modulus test. The load (i.e., deviator stress), in the form of a true haversian waveform, having a duration of 0.1 s followed by a dwell time of 0.9 s, is targeted to be 40 psi (275 kPa). Sufficient "conditioning" loads with magnitudes equal to the target load are applied to the specimen prior to obtaining modulus data to ensure constant plastic deformation at the time data is obtained.

3) Loading of the test specimen is accomplished in an automated fashion by means of a computer program, which utilizes a closed-loop proportional-derivative (PD) feedback algorithm in conjunction with additional hardware to drive a servo-valve air piston system, and acquire load and deformation data. Such a system helps to minimize user errors.

4) Repeated loading of 18 psi (124 KPa) is applied through the hot cycles to simulate traffic loading. The repeated loading is controlled by the computer loading system.

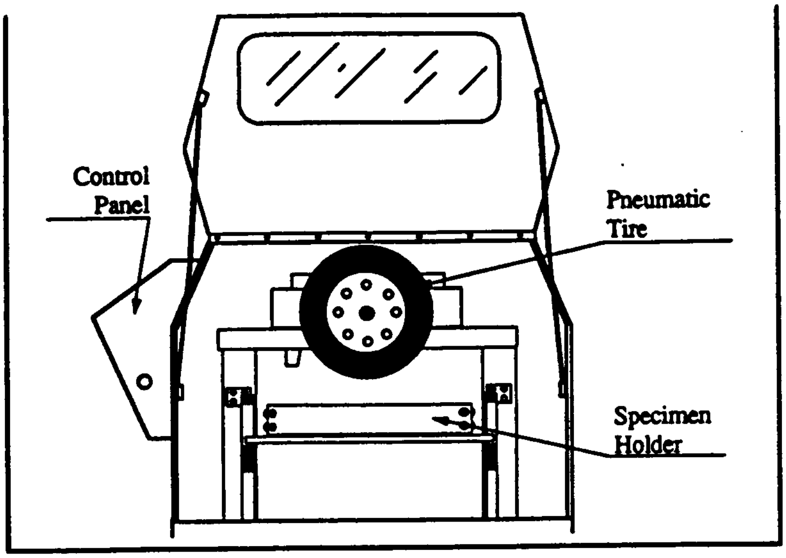
3.4.2 OSU Wheel Tracking Test

The test procedure employed in the OSU wheel tracking program consisted of inducing water damage to beams of asphalt-aggregate mixtures having dimensions of approximately 19 in. long by 6-1/2 in. wide by 4 in. deep (483 x 165 x 102 mm), and monitoring the rut depth developed in the OSU wheel tracker (Scholz et al., 1993). Figure 3.5 shows the OSU wheel tracker, while Figure 3.6 is a detailed schematic of this equipment. The procedure is briefly described in Table 3.7, while Appendix B gives a detailed test procedure. The OSU wheel tracking program tested only water conditioned beams, and did not test dry beams.

The OSU wheel tracking test applies a "torture" test which is carried out to obtain a relative measure of the rutting resistance among asphalt-aggregate mixtures after the mixtures have been subjected to water conditioning. Prior to testing, gravimetric data are obtained for the beam specimen, followed by subjecting the specimen to water conditioning. The conditioning procedure used to wet the specimen and induce water damage in the beams for the OSU wheel tracking program is essentially the same as that for the ECS test program, except for the following minor differences:

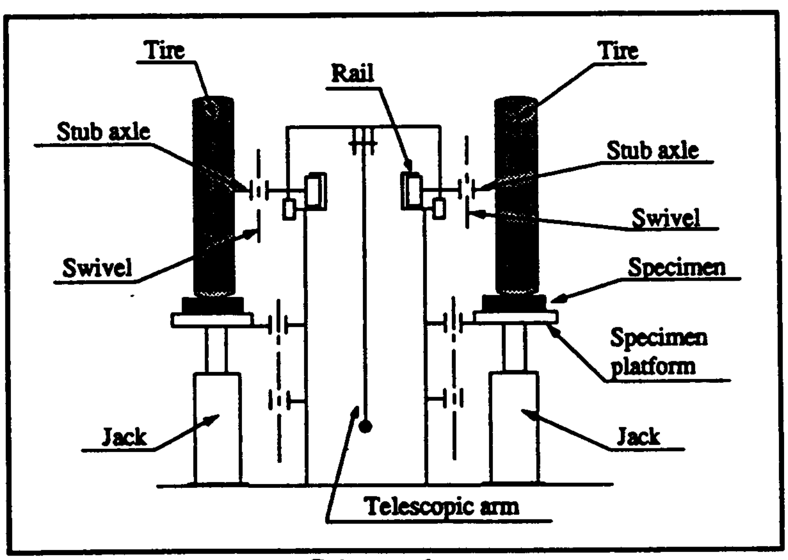
1) The wetting procedure for the wheel tracking test program employs a slightly higher vacuum level and a significantly longer wetting time than that for the ECS test. These were necessary to achieve the target saturation level of 60-80% in the larger beam specimens. A few of the beams did not reach the target saturation level due to impermeability of the beams.

2) The duration of some of the conditioning cycles are longer in the OSU wheel tracking test procedure, relative to the ECS test procedure, due to scheduling constraints of some of the equipment used for thermal conditioning.



Side View

Figure 3.5 The OSU Wheel Tracker



Schematic

Figure 3.6 Schematic of the OSU Wheel Tracker

Table 3.7 Summary of OSU Wheel Tracking Test Procedure

Step	Description
1	Prepare test specimens as described in Section 3.3 and Appendix A.
2	Determine the gravimetric quantities of the beam.
3	Place a circumferential silicone cement seal around the beam at mid-height and allow the silicone cement to cure overnight (24 hours).
4	Apply 20 in. in Hg (508 mm.) Hg vacuum for 10 minutes.
5	Wet the beam specimen by pulling distilled water through the specimen under a 23 in. (584 mm) vacuum level for up to 2 hours or until a degree of saturation of at least 60 is obtained.
6	Subject the wet beam specimen to wet thermal conditioning cycles as follows: Heat the specimen to 140 F (60 C) in a distilled water bath for six hours. Cool the specimen to 77 F (25 C) in a distilled water bath for ten hours. Heat the specimen to 140 F (60 C) in a distilled water bath for six hours. Cool the specimen to -4 F (-20 C) in a distilled water bath for eight hours. Heat the specimen to 140 F (60 C) in a distilled water bath for ten hours. Cool the specimen to 77 F (25 C) in a distilled water bath for ten hours.
7	Wrap the specimen in plastic (e.g., Saran wrap) to retain moisture in the specimen during the rutting phase.
8	Place the conditioned beam specimen in the rutting tester and heat the specimen to 104 F (40 C).
9	Perform the OSU wheel tracking (rutting) test on the conditioned beam specimen until 10,000 wheel passes have elapsed, taking rut depth measurements at 0, 200, 500, 1000, 2000, 5000, and 10,000 wheel passes.
10	Plot rut depth versus wheel passes.
11	Core the rutted beam specimen along the wheel track so as to obtain cores for stripping evaluation. Split the cores and assess the percentage of stripping.

3) The order of conditioning cycles is slightly different for the wheel tracking test program relative to the ECS test program. Again, this was due to scheduling constraints of some of the equipment used for thermal conditioning.

Once the beam specimen has undergone water and thermal conditioning, the specimen is wrapped in plastic (e.g., Saran wrap) to prevent moisture loss. The specimen is then placed in a mold for subsequent testing in the OSU wheel tracker. Thin expanded foam sheets are placed between the specimen and the mold walls to prevent movement under the action of the rolling wheel. A teflon sheet 1/8 in. (3 mm) thick, and having the same plan dimensions as the specimen, is placed under the specimen to minimize friction which develops between the specimen and base platen during the test. The mold is then placed in the wheel tracker and brought to the test temperature of 104 F (40 C). The plastic wrap is removed from the top surface of the specimen so as to prevent the plastic from being picked up by the pneumatic tire.

When the specimen reaches the test temperature, determined by a thermocouple probe inserted in a hole drilled in the specimen, it is subjected to preconditioning wheel loads of 50 wheel passes at 92 psi (635 kPa). The preconditioning wheel loads are applied to eliminate the high plastic deformations characteristic of asphalt-aggregate mixtures at the onset of loading. After preconditioning, the load is removed and measurements are obtained to establish the baseline specimen surface profile. Figure 3.7 shows the fifteen positions where surface profile measurements are obtained. These measurements are obtained electronically, i.e., via computer, using a displacement transducer specifically designed for these measurements. The measurement positions are concentrated near the center of the specimen along its longitudinal axis so as to avoid measurement of high plastic deformations, which occur in the region where the rolling wheel slows down, stops, and finally reverses direction (i.e., at the ends of the wheel travel).

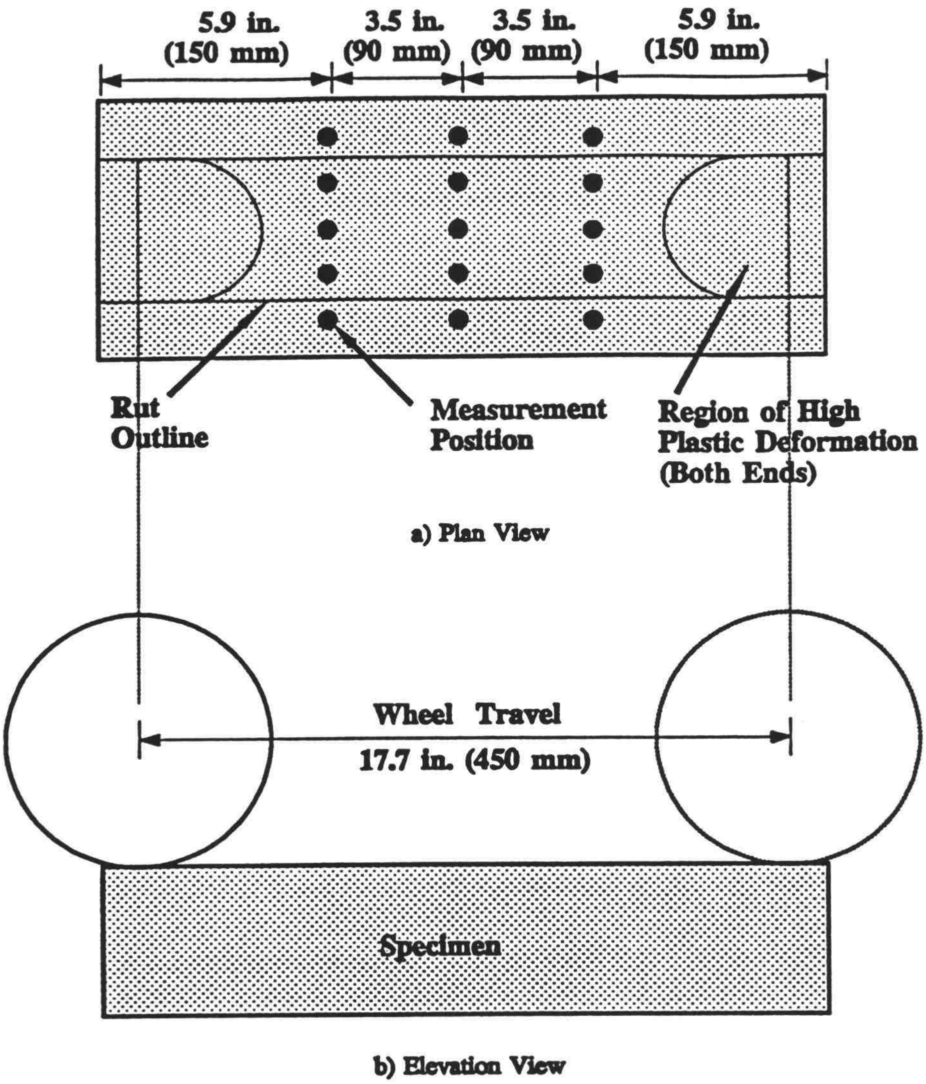


Figure 3.7 **Deformation Measurement Positions in the OSU wheel Tracker**

The wheel load is then reapplied and increased to 100 psi (690 kPa). Testing is completed by applying up to 10,000 wheel passes, or until failure occurs (as established by a sudden and significant increase in plastic deformation). The surface profile measurements are determined at intervals of 100, 200, 500, 1,000, 2,000, and 5,000 wheel passes, while the load is temporarily removed. After 10,000 wheel passes (or when loading is terminated due to specimen failure), the final surface profile is determined. From these data the rut depth is determined as a function of the number of wheel passes. Important test parameters regarding the OSU wheel tracking test include the following (Scholz et al., 1993):

1) "Wheel" pressurized pneumatic tire, 16 in. (406 mm) diameter by 4 in. (102 mm) width; smooth tread with 3.25 in. (83 mm) width.

2) Preconditioning load: 50 wheel passes at 92 psi (635 kPa) actual contact pressure.

3) Test load: 10,000 wheel passes at 100 psi (690 kPa) actual contact pressure (1600 lb. load with tire tread contact area of 16 in^2).

4) Load frequency: 60 cycles per minute (120 wheel passes per minute).

5) Test specimen temperature: 104 F (40 C).

6) Confinement: base provides reaction to the load; initially unconfined on sides, partially confined as specimen deforms.

7) Environment: conditioned specimen wrapped in plastic (except for the top surface) tested in air at 104 F (40 C).

3.4.3 SWK/UN Wheel Tracking Test

The test procedure used in the SWK/UN wheel tracking program consisted of inducing water damage to beams of asphalt-aggregate mixtures having dimensions of approximately 12 in. long by 3-1/2 in. wide by 1 in. deep (305 x 90 x 25 mm), and monitoring the specimen surface deformation developed by the SWK/UN wheel tracker. Schematic of the SWK/UN wheel tracker is shown in Figure 3.8. The SWK/UN wheel tracking test, also a "torture" test, is carried out to obtain a relative measure of the rutting resistance among asphalt-aggregate mixtures after the mixtures have been subjected to water conditioning.

Prior to testing, gravimetric data are obtained for the beam specimens. The specimen is then bonded in the mold for subsequent conditioning and testing. The specimen is then subjected to water conditioning. There are significant differences between the wheel tracking test conditioning procedures at SWK/UN and OSU (see Tables 3.6 and 3.7). In particular, note that the duration and number of cycles are quite different, but the temperatures for conditioning and testing are the same.

Once the specimen has been water conditioned, it is placed in the wheel tracker and conditioned to the temperature of 104 F (40 C). The specimen is submerged in a water bath during the SWK/UN wheel tracking test. The specimen is then loaded with the wheel and testing starts. The test continues until failure (as determined by a sudden and significant increase in plastic deformation of the specimen), or until seven days of loading (500,000 wheel passes) have occurred. Deformation data are obtained every twenty wheel passes, and consist of measurements of the vertical position of the wheel via LVDTs and a strip chart recorder.

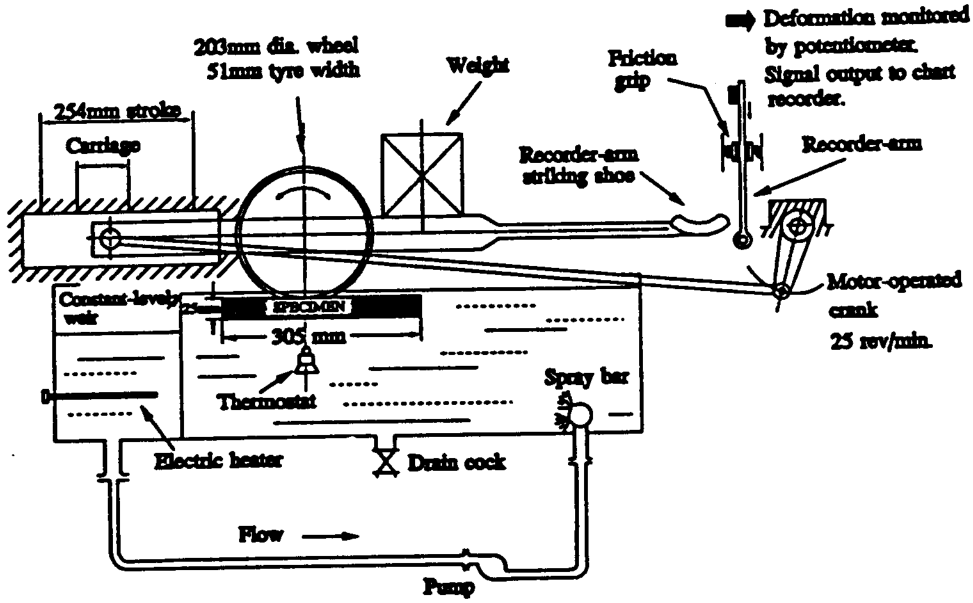


Figure 3.8 Schematic of the SWK/UN Wheel Tracker

Table 3.8 Summary of SWK/UN Wheel Tracking Procedure

Step	Description
1	Prepare specimens (at OSU) as described in Section 3.3 and Appendix A. Ship these to the University of Nottingham.
2	Saw the specimen to size and determine gravimetric quantities for the beam specimen.
3	Condition the beam specimen as follows: Soak specimen in water at 140 F (60 C) for 120 hours. Freeze specimen in air at -4 F (-20 C) for 24 hours. Soak specimen in water at 140 F (60 C) for 24 hours. Soak specimen in water at 104 F (40 C) for 2 hours.
5	Perform the SWK/UN wheel tracking test on the conditioned specimen until failure or, alternatively, if no failure occurs after seven days of testing (500,000 wheel passes). The specimen is submerged in 104 F (40 C) water during the test. Deformation measurements, as determined by the vertical position of the wheel, are recorded every 20 wheel passes.
6	Report time to failure in hours.

Key parameters regarding the SWK/UN wheel tracking test include the following:

1) Wheel: steel wheel, 7.9 in. (201.6 mm) diameter by 2 in. (50.4 mm) width.

2) Preconditioning load: none.

3) Test load: up to 500,000 wheel passes at 41 lb. (181 N).

4) Load frequency: 25 cycles per minute (50 wheel passes per minute).

5) Test specimen temperature: 104 F (40 C).

6) Confinement: confined on all sides throughout the test; the base provides reaction to the load.

7) Environment: conditioned specimen tested submerged in water at 104 F (40 C).

4.0 TEST RESULTS

This chapter presents the results of ECS evaluation of the thirty-two SHRP mixtures for water sensitivity. Also included are the results obtained on thirty-two SHRP mixtures in the OSU wheel tracking programs conducted at Oregon State University as well as those obtained in the SWK/UN wheel tracking program conducted at the University of Nottingham (UK). The open-graded mixtures evaluation for water damage potential is also included.

4.1 ECS TEST PROGRAM

The mixtures tested in the ECS program are summarized in Tables 4.1 through 4.4. As indicated before, two specimens were tested on each mixture, thus all figures and tables show average data for each mixture. Tables 4.1 through 4.4 summarize the ECS test program data by aggregate: RC, RD, RH, and RJ respectively. This set of tables includes average data for each mixture, and all data are included in Appendix C.

The test results for the ECS test program are shown graphically in Figures 4.1 through 4.4. Note that each data point represents the average of two tests and that the line connecting the data points represents the trend in the retained resilient modulus (ECS-M_R) ratio as a function of the conditioning level. Each conditioning cycle is six hours with the first three cycles being "hot" cycles, and the last cycle being the "freeze" cycle. The plots show the ratios of the conditioned resilient modulus to the unconditioned resilient modulus for several conditioning cycles. Thus, the ECS-M_R ratio provides an indication of the amount of water damage sustained by the test specimen with the dry (and unconditioned) ECS-M_R being the datum.

Figure 4.5 is an example of water permeability plots for RC aggregate; additional permeability figures are in Appendix D. Figure 4.5 shows the change in water permeability ratios after each conditioning cycle. The mixture permeability shows

Table 4.1 : Summary of ECS Tests Data For RC Mixes

Asphalt Type	Air Voids (%)	Cycle No.	ECS MR (Ksi)	Retained MR Ratio	Water Perm. E-3 cm/s	Retained Perm. Ratio	Stripping Rate
AAA-1	8.7	0	190	1.00	4.4	1.00	
	8.7	1	184	0.97	3.6	0.81	
	8.7	2	180	0.95	2.9	0.66	
	8.7	3	173	0.91	2.9	0.65	
	8.7	4	163	0.86	2.6	0.58	15.0
AAB-1	9.4	0	253	1.00	4.7	1.00	
	9.4	1	246	0.97	3.5	0.76	
	9.4	2	228	0.90	2.8	0.59	
	9.4	3	226	0.90	2.8	0.59	
	9.4	4	207	0.82	2.5	0.53	15.0
AAC-1	9.0	0	305	1.00	5.0	1.00	
	9.0	1	263	0.86	3.7	0.74	
	9.0	2	255	0.84	3.2	0.65	
	9.0	3	252	0.82	2.7	0.55	
	9.0	4	229	0.75	2.3	0.46	20.0
AAD-1	9.0	0	238	1.00	1.9	1.00	
	9.0	1	202	0.85	2.0	1.08	
	9.0	2	193	0.81	1.9	0.99	
	9.0	3	186	0.78	1.7	0.91	
	9.0	4	181	0.76	1.6	0.87	10.0
AAF-1	8.7	0	486	1.00	5.8	1.00	
	8.7	1	468	0.96	2.5	0.43	
	8.7	2	423	0.87	2.1	0.37	
	8.7	3	385	0.79	1.8	0.31	
	8.7	4	375	0.77	1.6	0.28	20.0
AAG-1	10.3	0	363	1.00	9.0	1.00	
	10.3	1	354	0.98	5.0	0.56	
	10.3	2	339	0.93	4.1	0.46	
	10.3	3	322	0.89	3.5	0.39	
	10.3	4	292	0.81	2.3	0.25	20.0
AAK-1	9.3	0	265	1.00	7.4	1.00	
	9.3	1	238	0.90	4.7	0.63	
	9.3	2	236	0.89	4.0	0.54	
	9.3	3	231	0.87	3.6	0.49	
	9.3	4	218	0.82	3.4	0.46	15.0
AAM-1	10.1	0	255	1.00	9.6	1.00	
	10.1	1	245	0.96	5.9	0.62	
	10.1	2	236	0.93	4.9	0.51	
	10.1	3	236	0.92	4.2	0.43	
	10.1	4	226	0.89	4.0	0.42	10.0

ksi= 6890 kPa

Table 4.2 : Summary of ECS Tests Data For RD Mixes

Asphalt Type	Air Voids (%)	Cycle No.	ECS MR (Ksi)	Retained MR Ratio	Water Perm. E-3 cm/s	Retained Perm. Ratio	Stripping Rate
AAA-1	8.1	0	187	1.00	1.9	1.00	
	8.1	1	183	0.98	3.4	1.77	
	8.1	2	179	0.96	3.0	1.55	
	8.1	3	176	0.94	2.8	1.46	
	8.1	4	175	0.93	2.7	1.42	10.0
AAB-1	8.0	0	278	1.00	4.8	1.00	
	8.0	1	263	0.95	4.7	0.98	
	8.0	2	245	0.88	4.1	0.86	
	8.0	3	242	0.87	4.0	0.82	
	8.0	4	235	0.85	3.6	0.74	5.0
AAC-1	8.6	0	265	1.00	9.9	1.00	
	8.6	1	255	0.96	7.2	0.73	
	8.6	2	249	0.94	6.7	0.68	
	8.6	3	240	0.91	6.4	0.65	
	8.6	4	235	0.89	6.4	0.65	5.0
AAD-1	9.0	0	207	1.00	7.2	1.00	
	9.0	1	202	0.98	5.4	0.75	
	9.0	2	183	0.89	4.2	0.58	
	9.0	3	174	0.84	4.8	0.66	
	9.0	4	175	0.85	4.7	0.66	10.0
AAF-1	9.7	0	570	1.00	4.4	1.00	
	9.7	1	548	0.96	5.8	1.33	
	9.7	2	515	0.90	5.5	1.26	
	9.7	3	499	0.88	5.2	1.19	
	9.7	4	490	0.86	5.0	1.15	10.0
AAG-1	8.2	0	528	1.00	1.1	1.00	
	8.2	1	492	0.93	2.4	2.10	
	8.2	2	474	0.90	2.2	1.94	
	8.2	3	465	0.88	2.2	1.93	
	8.2	4	488	0.92	2.1	1.91	15.0
AAK-1	8.4	0	290	1.00	2.4	1.00	
	8.4	1	275	0.95	3.4	1.40	
	8.4	2	271	0.93	3.5	1.43	
	8.4	3	270	0.93	3.4	1.42	
	8.4	4	276	0.95	3.4	1.42	5.0
AAM-1	10.3	0	358	1.00	1.4	1.00	
	10.3	1	343	0.96	3.1	2.11	
	10.3	2	325	0.91	2.6	1.76	
	10.3	3	317	0.89	2.8	1.93	
	10.3	4	319	0.89	2.8	1.94	5.0

ksi= 6890 kPa

Table 4.3 : Summary of ECS Tests Data For RH Mixes

Asphalt Type	Air Voids (%)	Cycle No.	ECS MR (Ksi)	Retained MR Ratio	Water Perm. E-3 cm/s	Retained Perm. Ratio	Stripping Rate
AAA-1	8.0	0	127	1.00	5.8	1.00	
	8.0	1	119	0.94	4.6	0.79	
	8.0	2	114	0.90	4.3	0.73	
	8.0	3	120	0.95	3.5	0.59	
	8.0	4	119	0.94	3.8	0.65	7.5
AAB-1	8.3	0	230	1.00	0.1	1.00	
	8.3	1	227	0.98	2.5	45.05	
	8.3	2	209	0.91	2.1	37.66	
	8.3	3	213	0.92	2.1	37.66	
	8.3	4	209	0.91	1.8	32.25	10.0
AAC-1	6.9	0	231	1.00	0.0		
	6.9	1	252	1.09	0.1	1.00	
	6.9	2	270	1.17	0.1	0.74	
	6.9	3	260	1.13	0.1	0.60	
	6.9	4	260	1.13	0.1	0.55	10.0
AAD-1	7.3	0	201	1.00	0.0		
	7.3	1	192	0.96	1.4	1.00	
	7.3	2	191	0.95	1.9	1.32	
	7.3	3	186	0.92	1.4	1.01	
	7.3	4	184	0.92	1.6	1.13	7.5
AAF-1	7.3	0	565	1.00	0.1	1.00	
	7.3	1	472	0.84	1.4	17.58	
	7.3	2	431	0.76	1.2	15.19	
	7.3	3	447	0.79	1.2	14.44	
	7.3	4	444	0.79	1.1	14.25	10.0
AAG-1	6.4	0	625	1.00	0.1	1.00	
	6.4	1	567	0.91	2.3	46.50	
	6.4	2	556	0.89	0.1	2.60	
	6.4	3	553	0.89	0.1	1.80	
	6.4	4	551	0.88	0.1	1.30	10.0
AAK-1	8.0	0	365	1.00	1.7	1.00	
	8.0	1	307	0.84	2.6	1.57	
	8.0	2	301	0.83	2.7	1.60	
	8.0	3	288	0.79	2.2	1.32	
	8.0	4	284	0.78	2.0	1.20	15.0
AAM-1	7.0	0	415	1.00	0.0		
	7.0	1	346	0.83	2.3	1.00	
	7.0	2	322	0.78	0.1	0.06	
	7.0	3	332	0.80	1.5	0.65	
	7.0	4	327	0.79	1.4	0.63	10.0

ksi= 6890 kPa

Table 4.4 : Summary of ECS Tests Data For RJ Mixes

Asphalt Type	Air Voids (%)	Cycle No.	ECS MR (Ksi)	Retained MR Ratio	Water Perm. E-3 cm/s	Retained Perm. Ratio	Stripping Rate
AAA-1	8.2	0	146	1.00	2.1	1.00	
	8.2	1	135	0.93	1.3	0.60	
	8.2	2	129	0.89	0.9	0.45	
	8.2	3	129	0.88	0.3	0.16	
	8.2	4	127	0.87	0.1	0.04	7.5
AAB-1	8.4	0	338	1.00	4.5	1.00	
	8.4	1	329	0.97	1.7	0.37	
	8.4	2	286	0.85	0.5	0.12	
	8.4	3	282	0.83	0.1	0.03	
	8.4	4	273	0.81	0.1	0.03	12.5
AAC-1	7.2	0	300	1.00	4.3	1.00	
	7.2	1	242	0.81	4.0	0.92	
	7.2	2	220	0.73	3.0	0.71	
	7.2	3	212	0.71	2.4	0.56	
	7.2	4	209	0.70	2.3	0.53	7.5
AAD-1	7.5	0	185	1.00	3.7	1.00	
	7.5	1	158	0.85	1.9	0.50	
	7.5	2	148	0.80	0.1	0.03	
	7.5	3	145	0.79	0.1	0.03	
	7.5	4	139	0.75	0.1	0.02	10.0
AAF-1	8.5	0	426	1.00	1.9	1.00	
	8.5	1	424	0.99	0.9	0.47	
	8.5	2	406	0.95	0.7	0.38	
	8.5	3	385	0.90	0.3	0.17	
	8.5	4	355	0.83	0.0	0.02	20.0
AAG-1	8.8	0	353	1.00	5.8	1.00	
	8.8	1	303	0.86	2.7	0.47	
	8.8	2	265	0.75	2.4	0.40	
	8.8	3	237	0.67	2.1	0.36	
	8.8	4	241	0.68	2.0	0.34	10.0
AAK-1	8.5	0	265	1.00	4.2	1.00	
	8.5	1	219	0.82	3.7	0.88	
	8.5	2	214	0.81	3.3	0.79	
	8.5	3	203	0.77	3.2	0.76	
	8.5	4	213	0.80	3.4	0.80	5.0
AAM-1	8.6	0	299	1.00	2.4	1.00	
	8.6	1	273	0.91	2.1	0.88	
	8.6	2	261	0.87	2.0	0.83	
	8.6	3	246	0.82	1.6	0.66	
	8.6	4	234	0.78	0.9	0.36	12.5

ksi= 6890 kPa

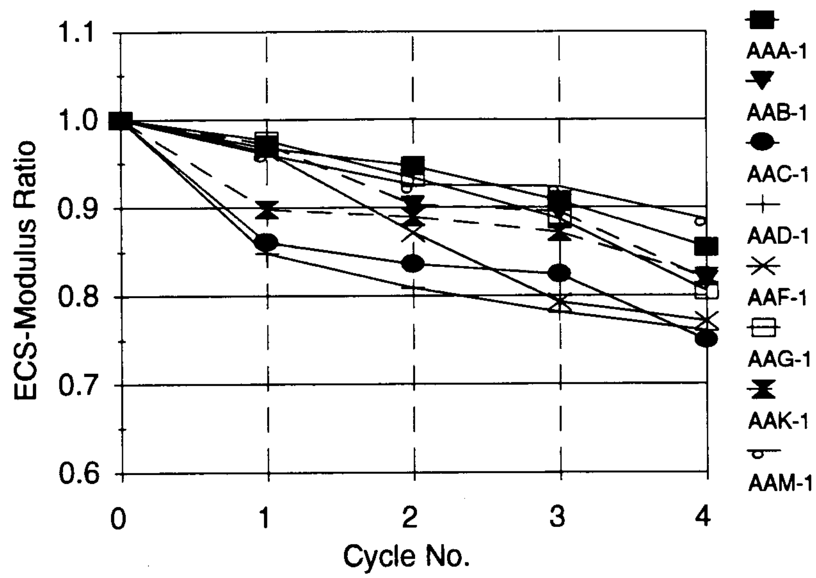


Figure 4.1 ECS Test Results for the RC Aggregate

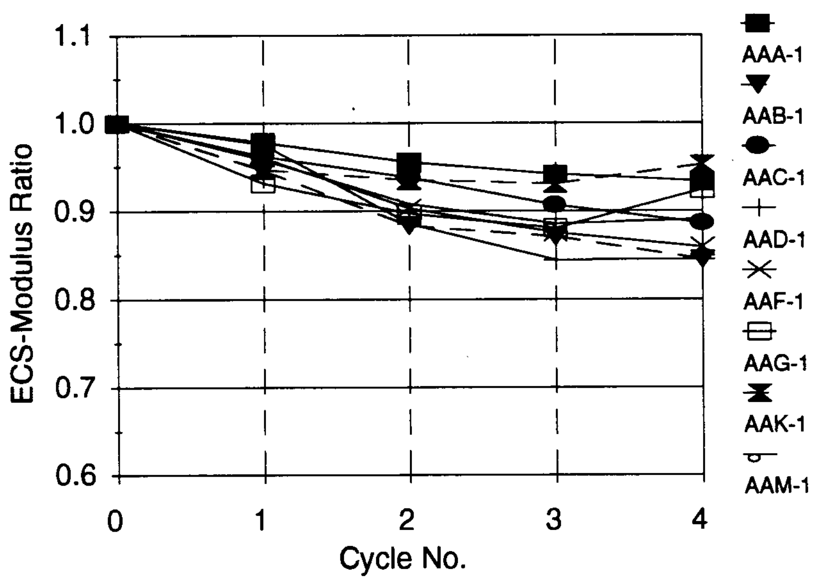


Figure 4.2 ECS Test Results for the RD Aggregate

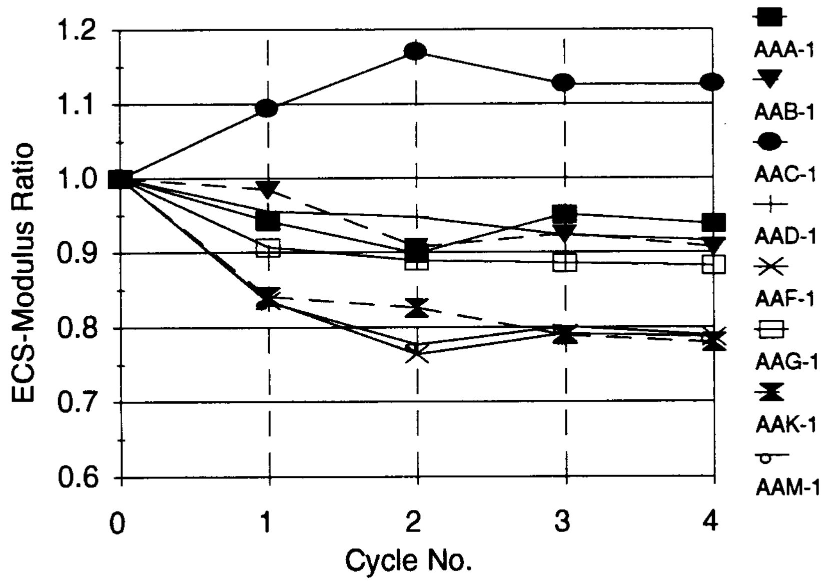


Figure 4.3 ECS Test Results for the RH Aggregate

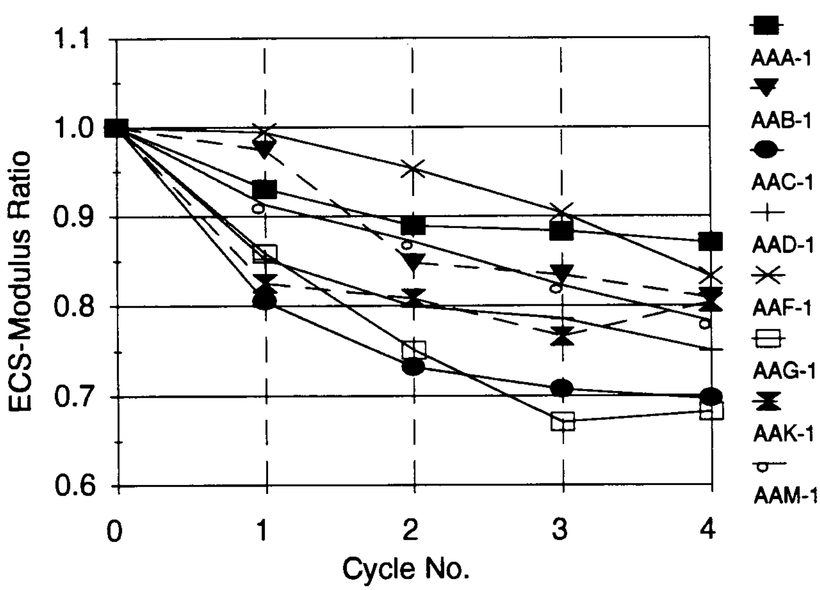


Figure 4.4 ECS Test Results for the RJ Aggregate

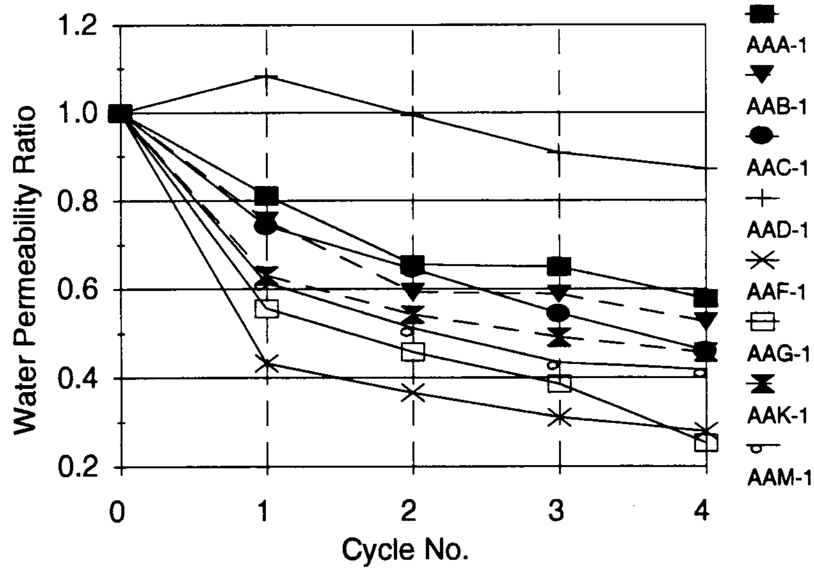


Figure 4.5 **The Effect of ECS Conditioning on Water Permeability of RC Mixes**

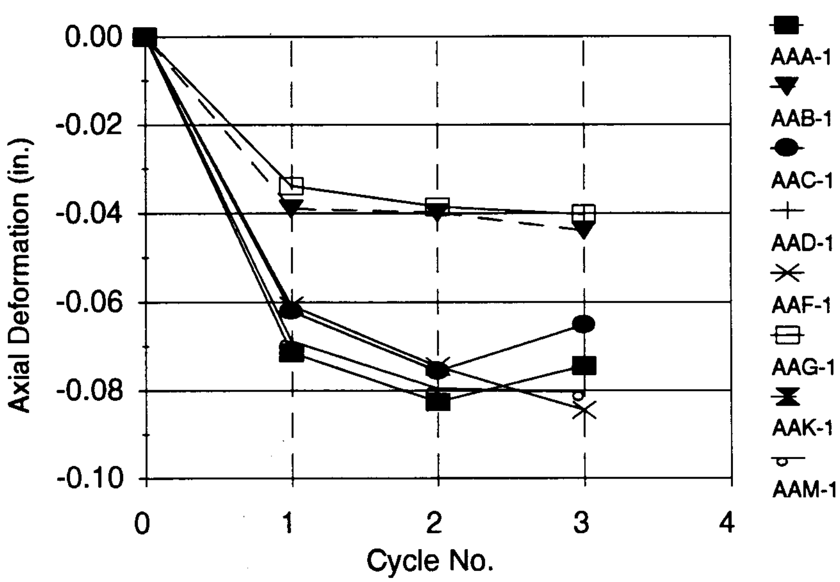


Figure 4.6 **The Effect of ECS Conditioning on Axial Deformation of RD Mixes**

the changes in water penetration through the mixture matrix of the specimen. Generally, the water permeability tends to decrease after each cycle because repeated loading at hot temperatures will rearrange and densify the mixture.

4.1.1 Discussion of ECS Test Program Results

The preconditioning stage and first conditioning cycle in most cases only cause the asphalt to soften and the mixture to exhibit some cohesion loss. Cohesion loss is the first step of water damage, and cohesion loss tends to enhance or accelerate the adhesion loss mechanism; since, regardless of the initial water permeability of the mixture, specimens that are susceptible to damage (loss of strength) will lose strength after the first cycle.

Impermeable specimens that have not been wetted cannot develop adhesion loss because water is not present; therefore, the strength loss must be other than adhesion loss. For most of the mixtures, just the fact that water is in the mixture for only one cycle is not enough to develop adhesion loss. There are exceptions to this point; mixtures that are highly sensitive (normally with bad aggregates) to water damage and initially permeable will develop adhesion loss after one conditioning cycle and will have substantial strength loss after one cycle.

After these observations, it can be said that the strength loss (ECS-M_R) after one cycle is believed to be attributed to softening of the asphalt film and may be cohesion loss. The loss in strength thereafter can be attributed to several failure mechanisms. One could say that the loss in strength between the first and third cycle is either cohesion loss, adhesion loss, or a combination of the two.

Generally, for mixtures with very low visual stripping rate (below 10) after the third or fourth cycle, most of the strength that was lost through the ECS test can be attributed to cohesion loss. For mixtures that have very bad stripping data (above 20), the strength loss can be attributed to combination of the water damage failure mechanisms. Now, with this understanding in mind, the ECS data will be discussed.

Figure 4.1 shows the effect of ECS conditioning on all RC mixture combinations. After the first cycle, mixtures that have good cohesion properties (i.e., did not lose strength after first cycle) are not affected by successive ECS conditioning cycles (i.e., good cohesion improves adhesion or hinders the adhesion loss). Other mixtures that are susceptible to cohesion loss tend to lose substantial strength after the first cycle. After the first cycle, mixtures that are susceptible to moisture damage through adhesion loss tend to continue losing strength with each conditioning cycle.

Figure 4.1 shows that after one cycle of ECS conditioning, the different asphalts fall into two groups. Asphalts that are at or below 0.9 ECS-M_R ratio (AAK-1, AAD-1, and AAC-1) are highly susceptible to moisture damage, and tend to continue losing strength with each cycle (cohesion loss in the first cycle leads to more adhesion loss). The other asphalts, not affected by the first cycle, tend to exhibit small and gradual loss of strength with each cycle. Mixture RC/AAF-1 is an exception to these observations, because of its initial permeability is very low. Mixtures which are not thoroughly wetted because of low initial permeability, have minimal cohesion loss. However, after the first cycle permeability increases and leads to further water damage.

Although the curves for the different asphalts criss-cross, this only emphasizes that ECS results are dependent on the asphalt type for any given aggregate. Also, ECS results show that the behaviors of the different mixtures change with each cycle (i.e., ranking of mixtures changes with each cycle), which only emphasizes how complicated the water damage failure mechanisms are.

In the fourth cycle (freeze) all eight mixtures have lost strength. It was observed in the ECS tests that through the freeze cycle poor aggregates tend to disintegrate, and demonstrating another moisture damage phenomenon. In aggregate processing and sample preparation, aggregate RC has been observed to disintegrate. Also, RC aggregate tends to absorb water. This absorptive character enhances the disintegration potential when subjected to the freeze cycle.

Figure 4.2 shows the ECS conditioning effects on all RD aggregate mixtures. RD mixture combinations were less susceptible to ECS conditioning. All RD mixtures demonstrated very slow and gradual decreases in strength indicative of good water damage resistance. After three cycles, all of RD mixtures have showed good water damage resistance. The freeze cycle did not significantly affect the strength of the mixtures, which can be explained by the fact that RD aggregate is non-absorptive.

Figure 4.3 is a plot of all RH mixtures, and shows a wide spread of data. After one cycle three asphalts had lost more than 10 percent of their ECS-M_R ratio (AAF-1, AAK-1, and AAM-1). The other five mixtures showed an ECS-M_R ratio of 0.9 or better. Each group maintained its set of mixtures after each cycle, and both groups of asphalts continued losing strength at very slow rates. This emphasizes that the three asphalt mixtures that showed the ECS-M_R ratio below 0.9 after one cycle showed cohesion loss behavior and little adhesion loss.

The other five asphalt mixtures that have an ECS-M_R ratio above 0.9 showed little cohesion and adhesion loss (i.e., high moisture damage resistance). Through the freeze cycle, constant strength was maintained, that, is little moisture damage and aggregate degradation. Mixture RD/AAC-1, which was impermeable initially, and maintained very low permeability thereafter, indicated an increase in strength. This increase in strength can be attributed to densification of the specimen.

Figure 4.4 shows a plot of aggregate RJ results, and the same observations that were made in aggregate RC can be made here. RJ mixtures show significant moisture susceptibility, especially continued ECS-M_R loss after the first cycle. The RJ aggregate has been proven to be stripper aggregate (Curtis et al., 1992). All mixture combinations show gradual decreases in strength after each conditioning cycle.

Figure 4.5 is an example of water permeability plots for RC aggregate; additional permeability figures are in Appendix D. The water permeability normally will decrease after each cycle, because repeated loading tends to rearrange and densify the mixture. In a few incidences, the water permeability has increased after the first cycle. This was the case with specimens which were impermeable or had very low initial permeability. Mixtures with high air voids (8% ± 1) develop low permeability because of lack of interconnections between the air voids. However, after one cycle of repeated loading at 60 C, the voids tend to become better connected and the permeability increases. RC and RJ mix combinations exhibit about the same loss in water permeability, with average final permeability ratios of about 0.5 and 0.4 respectively.

Figure 4.6 shows an example of the cumulative axial deformation data for RD aggregate mixtures. The axial deformation was collected through the three hot cycles and repeated loading. The freeze cycle did not include repeated loading, hence the axial deformation was not collected. The axial deformation shows that some mixtures are more susceptible to repeated loading then others. However, the axial deformation data did not show any correlation with any variable and could not be well explained. The range of deformation data was between 0.02 and 0.08 in because the specimens were under confinement pressure and specimens were saturated. The confinement pressure (3 psi) which was constant for all specimens restrained the specimens from deforming under the repeated loading. The major problem comes when the water in the voids creates high pore pressure and resists the deformation, and this pore pressure is dependent on the degree of saturation since some specimens were more permeable than others.

4.2 OSU WHEEL TRACKING PROGRAM

Table 4.5 summarizes the mixtures tested as well as void content and percent saturation data for each mixture. The last column in Table 4.5 indicates the stripping percentage for as many of the mixtures as were available. Percent of saturation on most of the mixtures was not in the desired range of 60-80%, because of low initial permeability. In retrospect, it would probably have been more informative to test both dry and wet conditioned beams (one each) rather than duplicate wet beams to provide some measure of water sensitivity.

The OSU wheel tracking test results are summarized in Table 4.6. Note that an average value for the rut depth was used where the mixture was replicated (i.e., the results tabulated for replicated mixtures are the average of the two tests performed on the mixture). Detailed rut depth data for each mixture is provided in Appendix C. Graphical representations of the data presented in Table 4.6 are shown in Figures 4.7 through 4.10. It is clear from these plots that mixtures comprised of the AAA-1 and AAC-1 asphalts performed the worst, while mixtures comprised of the AAK-1 and AAM-1 asphalts performed the best in terms of rut resistance.

4.3 SWK/UN WHEEL TRACKING PROGRAM

The test results for the SWK/UN wheel tracking program are shown in Table 4.7. Note that SWK/UN reports a time to failure in hours, where failure is defined as a sudden and significant increase in plastic deformation. A "Pass" is reported if the specimen does not experience failure within seven (7) days of testing (500,000 wheel passes). Also included in Table 4.7 are void contents of the "parent" beam and test specimen, as well as the percent saturation of the test specimen. The "parent" beam is the oversized beam fabricated at OSU and sent to SWK/UN. SWK/UN subsequently cut the beam to the test specimen dimensions. The ten columns on the right side of the table show the time in hours to attain 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 mm of deformation.

Table 4.5 Summary of Mixtures Tested in OSU Wheel Tracking Program

Mixture Number	Aggregate Type	Asphalt Type	Mixture Code[a]	Sample ID[b]	Percent Voids	Percent Saturation	Percent Stripping
1	RC	AAA-1	00000	RR0	7.1	33	25
1		AAA-1	00000	RR1	7.8	55	40
2		AAB-1	10000	RR0	6.9	63	5.0
2		AAB-1	10000	RR1	6.9	73	25
3		AAC-1	01000	RR0	7.7	64	N/A[b]
3		AAC-1	01000	RR1	7.8	59	30
4		AAD-1	11000	RR0	8.0	65	0.0
4		ADD-1	11000	RR1	7.4	60	30
5		AAF-1	00100	RR0	7.6	92	5.0
5		AAF-1	00100	RR1	7.7	66	17.5
6		AAG-1	10100	RR6	7.9	72	0.0
7		AAK-1	01100	RR0	7.8	79	5.0
7		AAK-1	01100	RR1	8.9	61	5.0
8		AAM-1	11100	RR0	7.7	73	0.0
8		AAM-1	11100	RR1	8.0	47	5.0
9	RD	AAA-1	00010	RR2	8.2	52	N/A
9		AAA-1	00010	RR3	8.0	60	5.0
10		AAB-1	10010	RR2	8.7	45	15
10		AAB-1	10010	RR3	8.4	52	17.5
11		AAC-1	01010	RR2	8.9	40	5.0
12		AAD-1	11010	RR0	8.4	57	N/A
12		AAD-1	11010	RR1	8.6	56	N/A
13		AAF-1	00110	RR0	9.0	56	N/A
13		AAF-1	00110	RR1	8.6	49	10
14		AAG-1	10110	RR2	8.7	61	5.0
14		AAG-1	10110	RR3	8.6	61	0.0
15		AAK-1	01110	RR2	8.1	51	N/A
15		AAK-1	01110	RR3	9.0	63	5.0
16		AAM-1	11110	RR1	8.6	44	N/A

Table 4.5 Summary of Mixtures Tested in OSU Wheel Tracking Program (Continued)

Mixture Number	Aggregate Type	Asphalt Type	Mixture Code[a]	Sample ID	Percent Voids	Percent Saturation	Percent Stripping
17	RH	AAA-1	00001	RR4	8.2	54	0.0
17		AAA-1	00001	RR5	7.5	63	12.5
18		AAB-1	10001	RR3	8.8	42	10
19		AAC-1	01001	RR1	6.9	44	7.5
19		AAC-1	01001	RR3	6.9	32	5.0
20		AAD-1	11001	RR0	7.6	46	15
20		AAD-1	11001	RR1	7.8	56	5.0
21		AAF-1	00101	RR0	8.7	40	30
21		AAF-1	00101	RR1	8.5	57	0.0
22		AAG-1	10101	RR4	8.7	65	45
22		AAG-1	10101	RR5	8.7	61	35
23		AAK-1	01101	RR0	8.7	43	7.5
23		AAK-1	01101	RR1	8.8	46	7.5
24		AAM-1	11101	RR0	7.7	71	5.0
24		AAM-1	11101	RR1	7.7	38	2.5
25	RJ	AAA-1	00011	RR2	8.4	53	N/A
25		AAA-1	00011	RR3	8.4	55	N/A
26		AAB-1	10011	RR2	7.7	80	5.0
26		AAB-1	10011	RR3	7.7	55	N/A
27		AAC-1	01011	RR7	9.0	63	25
28		AAD-1	11011	RR0	7.2	57	7.5
28		AAD-1	11011	RR1	7.4	66	N/A
29		AAF-1	00111	RR0	8.1	57	N/A
29		AAF-1	00111	RR1	8.0	41	N/A
30		AAG-1	10111	RR4	8.4	53	70
31		AAK-1	01111	RR0	7.2	47	N/A
31		AAK-1	01111	RR1	7.1	50	N/A
32		AAM-1	11111	RR3	9.2	54	N/A

a The mixture code is an accounting system established to distinguish among the 32 asphalt-aggregate combinations (see Table 3.1).

b Sample ID is specimen or replicates number.

Table 4.6 Rut Depths for the OSU Wheel Tracking Program

Rut Depth, mm[a]								
Wheel Passes	AAA-1	AAB-1	AAC-1	AAD-1	AAF-1	AAG-1	AAK-1	AAM-1
RC Aggregate								
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200	2.38	1.54	2.14	2.19	2.22	1.98	1.30	2.08
500	4.29	2.51	3.65	3.42	3.19	3.00	2.17	3.15
1000	6.10	3.89	4.99	4.99	4.52	4.09	2.72	4.47
2000	8.06	5.21	6.88	5.59	6.32	5.06	4.48	5.65
5000	12.16	7.69	12.29	6.98	8.28	6.65	6.05	7.55
10000	24.00[b]	10.83	36.00[b]	9.87	10.72	9.82	10.17	9.53
RD Aggregate								
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200	1.03	0.74	1.22	0.77	0.47	0.62	0.39	1.04
500	1.72	1.66	2.47	1.66	1.42	1.52	0.92	1.58
1000	2.22	2.67	3.12	2.54	2.13	2.43	1.32	2.17
2000	3.68	3.77	4.35	4.07	3.33	3.99	2.12	3.32
5000	5.23	5.68	5.91	5.97	4.96	7.08	3.70	4.56
10000	6.16	6.84	7.16	7.18	6.31	9.47	4.90	5.19
RH Aggregate								
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200	1.05	0.63	1.19	0.78	0.80	1.22	0.47	0.95
500	1.86	1.31	1.72	1.42	1.62	2.26	0.93	1.33
1000	2.88	1.90	2.63	2.26	1.62	3.06	1.05	1.72
2000	4.69	3.41	3.71	3.66	3.2	4.22	2.20	2.62
5000	6.98	5.87	6.40	5.75	5.58	6.09	3.99	4.41
10000	8.82	7.88	8.68	7.51	7.96	7.70	6.07	6.27
RJ Aggregate								
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200	0.65	0.49	0.75	0.65	0.60	1.11	0.46	0.59
500	1.58	1.04	2.18	1.25	1.40	2.43	1.16	0.95
1000	2.52	1.99	3.16	1.71	1.77	3.14	1.59	1.28
2000	4.42	3.00	4.43	2.49	2.59	4.36	2.48	1.96
5000	6.62	3.94	6.91	3.74	4.25	5.81	3.39	2.59
10000	8.30	4.92	8.79	5.53	6.23	8.65	4.32	2.65

[a] 1 inch = 25.4 mm [b] Estimated rut depth.

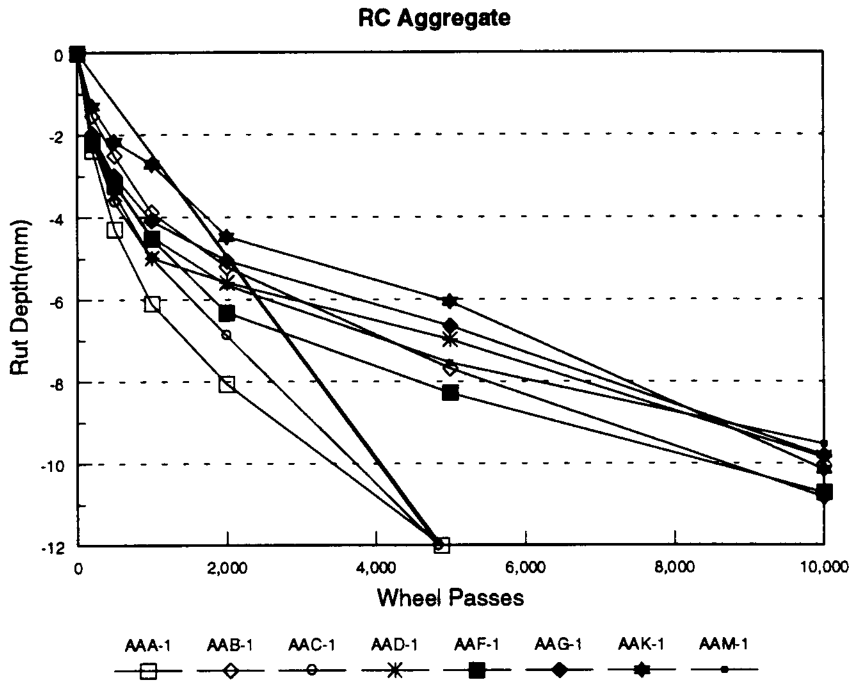


Figure 4.7 OSU Wheel Tracking Test Results for the RC Aggregate

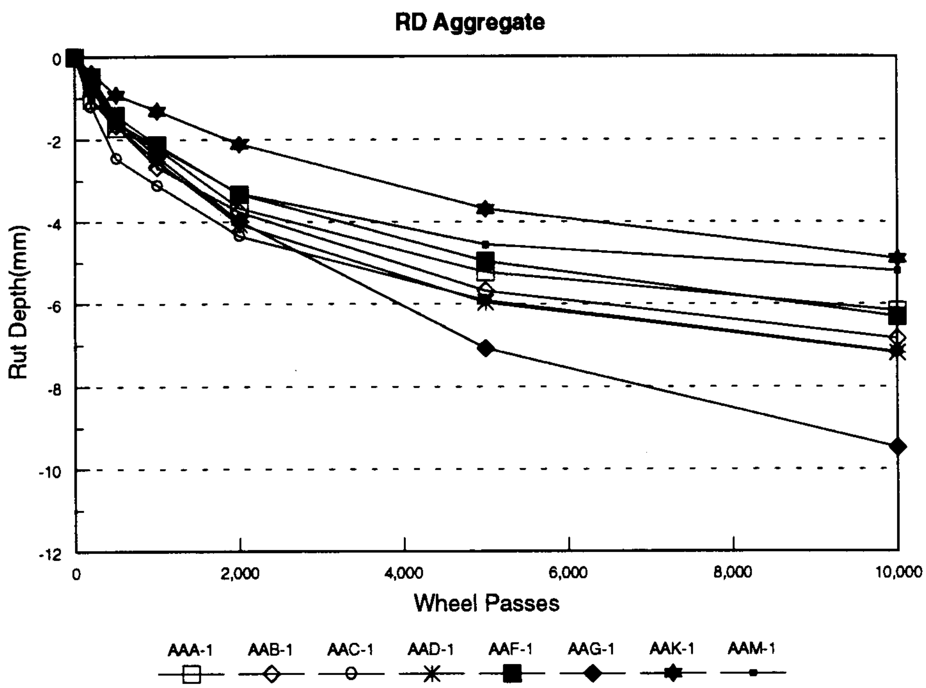


Figure 4.8 OSU Wheel Tracking Test Results for the RD Aggregate

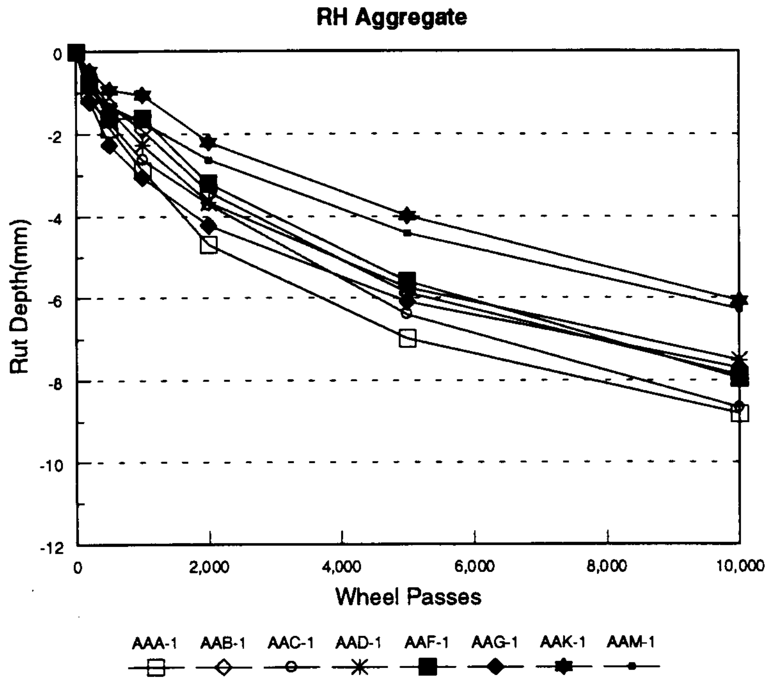


Figure 4.9 OSU Wheel Tracking Test Results for the RH Aggregate

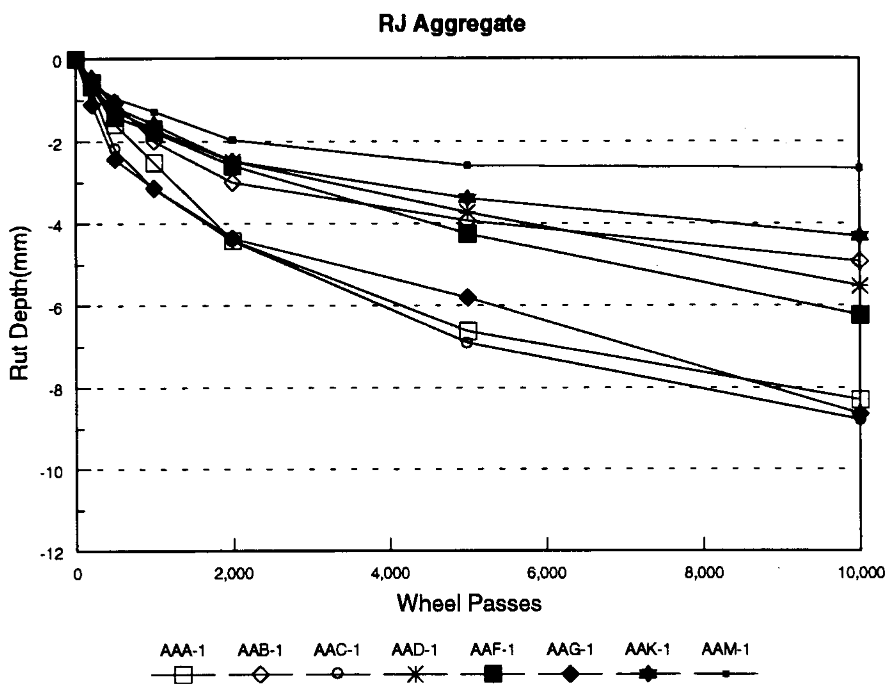


Figure 4.10 OSU Wheel Tracking Test Results for the RJ Aggregate

Table 4.7: Summary Results of SWK/UN Wheel Tracker Test Program

Agg Code	Asph Code	Slab Void Content (%)	Spec Void Content (%)	Saturation (%)	Time (hr) to Deformation (mm)					Time (hr) to Deformation (mm)					Time to Failure (hr)
					1	2	3	4	5	6	7	8	9	10	
RC	AAA	7.0	8.4	64.8	0.5	64.0	*	*	*	*	*	*	*	*	Pass
RC	AAA	8.6	11.5	84.7	0.5	0.5	1.0	2.0	3.0	4.5	5.5	7.0	8.0	8.5	5
RC	AAB	8.9	12.4	72.9	0.5	26.0	56.0	62.0	78.0	87.0	91.0	*	*	*	58
RC	AAC	8.0	11.7	69.0	0.5	1.0	3.0	5.5	10.5	16.5	24.0	24.5	25.0	25.5	24
RC	AAD	8.8	11.4	95.8	0.5	10.0	*	*	*	*	*	*	*	*	Pass
RC	AAF	9.0	10.9	90.0	0.5	3.0	26.0	54.0	70.0	98.0	163.0	164.0	165.0	165.0	165
RC	AAG	9.2	12.8	70.0	3.0	8.5	10.0	10.0	10.0	10.0	10.0	10.5	10.5	11.0	10
RC	AAK	8.8	9.2	59.4	6.0	*	*	*	*	*	*	*	*	*	Pass
RC	AAK	8.2	9.4	66.0	2.0	*	*	*	*	*	*	*	*	*	Pass
RC	AAM	8.9	12.1	75.4	0.5	13.0	*	*	*	*	*	*	*	*	Pass
RD	AAA	9.0	8.5	51.9	20.0	*	*	*	*	*	*	*	*	*	Pass
RD	AAA	6.3	4.3	30.5	30.0	*	*	*	*	*	*	*	*	*	Pass
RD	AAB	9.1	8.9	67.9	1.0	*	*	*	*	*	*	*	*	*	Pass
RD	AAC	7.0	11.1	65.4	0.5	1.5	5.0	5.5	6.0	6.0	6.5	6.5	7.0	7.5	6
RD	AAD	8.7	8.0	51.4	*	*	*	*	*	*	*	*	*	*	Pass
RD	AAD	8.7	7.6	54.4	0.5	3.0	*	*	*	*	*	*	*	*	Pass
RD	AAF	8.9	8.2	42.4	*	*	*	*	*	*	*	*	*	*	Pass
RD	AAG	7.0	6.0	73.3	13.0	*	*	*	*	*	*	*	*	*	Pass
RD	AAG	7.0	5.8	42.9	0.5	6.0	*	*	*	*	*	*	*	*	Pass
RD	AAK	8.9	8.4	55.5	*	*	*	*	*	*	*	*	*	*	Pass
RD	AAK	6.4	7.6	35.7	20.0	*	*	*	*	*	*	*	*	*	Pass
RD	AAM	9.0	10.2	49.4	0.5	6.0	*	*	*	*	*	*	*	*	Pass
RH	AAA	8.0	9.0	77.3	0.5	24.0	*	*	*	*	*	*	*	*	Pass
RH	AAB	10.4	12.1	64.2	4.0	89.0	*	*	*	*	*	*	*	*	Pass
RH	AAC	7.5	9.2	24.3	2.0	47.0	49.5	50.0	51.0	52.0	54.0	55.0	55.5	56.5	54
RH	AAD	7.9	10.8	55.6	0.5	49.0	55.0	56.0	56.5	56.5	57.0	57.5	57.5	58.0	56
RH	AAD	9.9	12.4	81.1	0.5	5.0	12.5	13.5	13..5	14.0	15.5	15.5	16.0	16.5	14
RH	AAF	8.1	9.8	39.1	0.5	11.5	13.0	14.0	14.0	14.0	14.0	14.5	14.5	15.0	13
RH	AAG	7.9	10.6	44.4	3.0	55.0	81.0	86.0	86.5	89.0	93.0	94.0	95.0	95.5	90
RH	AAG	9.5	12.3	74.3	7.0	21.5	24.0	25.5	26.0	26.0	26.0	26.0	26.5	27.0	26
RH	AAK	8.4	9.3	92.0	5.0	*	*	*	*	*	*	*	*	*	Pass

Table 4.7: Summary Results of SWK/UN Wheel Tracker Test Program (Continued)

Agg Code	Asph Code	Slab Void Content (%)	Spec Void Content (%)	Saturation (%)	Time (hr) to Deformation (mm)					Time (hr) to Deformation (mm)					Time to Failure (hr)
					1	2	3	4	5	6	7	8	9	10	
RH	AAM	7.0	8.1	76.3	0.5	13.0	*	*	*	*	*	*	*	*	Pass
RJ	AAA	9.3	10.6	58.4	4.0	7.0	9.0	10.0	10.5	11.0	11.0	11.0	11.0	11.5	10.0
RJ	AAA	7.9	8.3	50.3	0.5	4.0	16.0	19.0	20.0	21.0	21.5	21.5	22.0	22.0	20.0
RJ	AAB	11.7	14.0	82.5	0.5	2.0	3.0	3.0	3.5	3.5	3.5	3.5	4.0	4.0	3.0
RJ	AAC	12.8	9.2	74.3	0.5	2.0	3.0	4.0	5.5	8.0	8.5	9.0	9.0	9.5	9.5
RJ	AAD	7.1	8.4	41.9	3.0	7.5	9.0	9.5	10.5	12.0	13.0	15.0	17.0	17.0	17.0
RJ	AAF	8.0	8.2	38.4	1.5	2.0	2.5	3.5	5.0	6.0	6.0	6.0	6.5	6.5	2.0
RJ	AAG	9.9	9.7	75.0	1.5	5.0	6.5	7.0	7.5	8.0	9.0	9.5	9.5	9.5	6.0
RJ	AAK	9.5	11.6	84.4	1.0	28.0	36.5	38.5	41.5	43.0	44.5	46.0	47.0	47.5	45.0
RJ	AAK	9.9	11.2	83.0	0.5	1.0	4.0	6.0	10.5	15.0	15.0	15.0	15.5	16.0	15
RJ	AAM	11.0	11.7	63.6	0.5	6.0	57.0	61.0	64.5	66.0	67.0	67.0	67.0	67.0	67.0

4.4 UNR NET ADSORPTION TEST PROGRAM

The NAT test results are shown in Table 4.8. The table includes the mean NAT, standard deviation of the test, and coefficient of variation for each aggregate-asphalt combination. The amount of asphalt remaining on the aggregate indicates how well the aggregate will withstand water conditioning, while the lower NAT values indicate mixtures that might be water sensitive. Also, the NAT results are shown graphically in Figure 4.11. The NAT test shows that aggregate RJ is the worst (or most water sensitive) and that aggregate RD is the best.

Table 4.8 Net Adsorption Test Results

Aggregate	Asphalt	Mean NAT (%)	Sdev.	C.V.
RC	AAA-1	77.05	1.70	2.18
RC	AAB-1	76.84	4.00	5.20
RC	AAC-1	80.79	0.20	0.25
RC	AAD-1	81.50	0.56	0.70
RC	AAF-1	77.80	7.47	9.60
RC	AAG-1	78.86	4.32	5.48
RC	AAK-1	75.18	2.86	3.80
RC	AAM-1	71.90	2.21	3.11
RD	AAA-1	74.32	3.30	4.43
RD	AAB-1	73.97	2.59	3.50
RD	AAC-1	77.63	2.24	2.89
RD	AAD-1	81.63	2.49	3.05
RD	AAF-1	76.99	3.28	4.27
RD	AAG-1	77.17	2.94	3.81
RD	AAK-1	81.57	6.66	8.16
RD	AAM-1	66.52	3.13	4.17
RH	AAA-1	73.29	1.94	2.64
RH	AAB-1	74.20	3.65	4.91
RH	AAC-1	74.73	2.74	3.66
RH	AAD-1	76.33	1.79	2.34
RH	AAF-1	73.06	3.66	5.00
RH	AAG-1	55.72	4.86	8.72
RH	AAK-1	81.48	3.82	4.69
RH	AAM-1	62.23	0.80	1.29
RJ	AAA-1	70.09	3.24	4.62
RJ	AAB-1	63.78	3.31	5.27
RJ	AAC-1	59.63	3.55	5.96
RJ	AAD-1	63.50	0.61	0.96
RJ	AAF-1	56.01	3.60	6.43
RJ	AAG-1	58.75	8.15	13.87
RJ	AAK-1	61.57	1.72	2.80
RJ	AAM-1	58.90	1.45	2.46

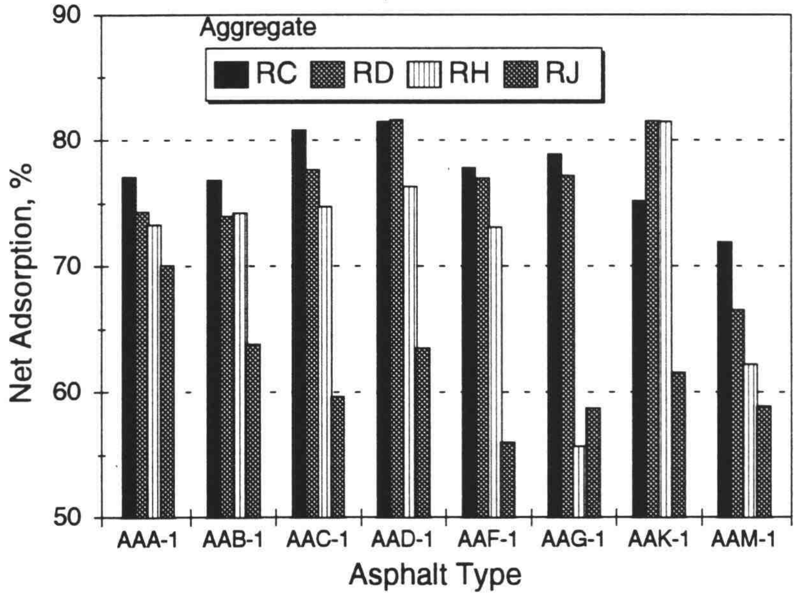


Figure 4.11 Net Adsorption Test Results

5.0 ANALYSIS OF RESULTS

This chapter presents an analysis of the results summarized in Chapter 4. Included is a description of the statistical analyses for the ECS, OSU wheel tracking, SWK/UN wheel tracking, University of Nevada (Reno) Net Adsorption (NAT/UNR), and open graded mixtures test programs as well as the performance rankings of the materials as determined by each program. Also presented is a comparison of the performance rankings for each program to those proposed by other SHRP projects (based on materials properties).

5.1 STATISTICAL ANALYSIS

Each test program included thirty-two asphalt-aggregate mixtures according to the experiment design presented in Chapter 3. The test program for the thirty-two mixtures was primarily designed to identify the water sensitivity of the mixtures using either rutting (OSU and SWK/UN wheel tracking) or reduction in modulus (ECS) as the objective function; the ECS test program used full replication (total of 67 specimens, exceeding full replication). The test program provides information to rank the relative performance of the eight asphalts and four aggregates, thus enabling a comparison of results provided by other SHRP contractors. Provided in this section are the statistical analyses conducted on the results obtained from the ECS, OSU wheel tracking, and SWK/UN wheel tracking programs.

5.1.1 ECS Test Results

The analysis of the ECS test results employed a General Linear Model (GLM) procedure to investigate the significance of the effect of all the different variables and their interactions on the ECS-M_R ratio (the dependent variable). GLM procedure uses the method of least squares to fit general linear models, i.e., testing each variable in a given model reveals how significant the variable (or its interaction with other variables) is to the model. GLM procedure can analyze classification variables which have discrete levels as well as continuous variables. Also, GLM can create output data of the dependent variable (ECS-M_R) based on the prescribed model, i.e., the original ECS-M_R data will be changed to show the effects of the different variables in the model.

One of the statistical methods available in GLM procedure is analysis of variance (ANOVA) for unbalanced data which is utilized in ECS analysis. This method was used because the ECS test program has unbalanced data (29 mixtures had 2 replicates and 3 mixtures had 3 replicates). GLM procedure is the only statistical method for unbalanced experiments, hence GLM procedure can test any hypothesis for the effects of the model regardless of the number of missing cells. The statistical model prescribed includes effects which can be a variable or combinations of variables. The example below illustrates the statistical method employed:

Model : ECS-M_R = AGGR ASPH AV AGGR*ASPH

where :

ECS-M_R = ECS modulus ratio,

AGGR = Aggregate type,

ASPH = Asphalt type,

AV = Percent air voids of the test specimen, and

AGGR*ASHP = Aggregate asphalt type interactions.

The model above will test each variable against the model, i.e., test how significant each variable is to the model.

The ECS analyses were performed on the results obtained after each conditioning cycle, i.e., after one, two, three, and four cycles of conditioning. Table 5.1 shows the variables which were included in the statistical analysis. There are two types

Table 5.1 Variables Considered in the Statistical Analyses of the ECS Test Results

Variable	Type	Levels
Aggregate Type (AGGR)	Class	RC, RD, RM, RJ
Asphalt Type (ASPH)	Class	AAA-1, AAB-1, AAC-1, AAD-1, AAF-1, AAG-1, AAK-1, and AAM-1
Time (cycle number)	Class	6, 12, 18, 24, hours (1, 2, 3, 4 cycles)
Percent Air Voids (AVOID)	Covariant	8 ± 1.5%
Water Permeability (WK)	Covariant	0.0 12.0 E-3 cm/s
Water Permeability Ratio (WKR)	Covariant	0.03 15.0
Initial Air Permeability (AK)	Covariant	0.0 20.0 E-5 cm/s
Initial Water Permeability (WK0)	Covariant	0.0 12.0 E-3 cm/s
Initial Modulus	Covariant	100 700 ksi
ECS-M_R Ratio	Dependent	0.6 1.1

of independent variables: classification variables (categorical, qualitative, discrete, or nominal variables), and continuous variables (numeric values which do not have to be discrete). In the model statement of GLM procedure, any variable that was not defined as a classification variable will be considered as a continuous variable. The aggregate and asphalt type, and the time (cycle number) were considered as class variables. The other variables were considered as independent (or covariant) variables.

The statistical analyses were done using an iterative approach. First, a model was selected in which the ECS-M_R ratio was related to all the variables (see Table 5.1), and asphalt aggregate interactions. The asphalt aggregate interaction is believed to be the only two-way interaction that would have any engineering significance, or would have sound engineering interpretation. After each iteration, the least significant variable was removed from the model; then the new model was used in the following iteration. The least significant variable was determined based on type III error, which checks the significance of the independent variable to the model. The hypotheses to be tested in type III error are invariant to the ordering of the effects in the model, unlike type I error.

Table 5.2 shows the results of each iteration; X in front of the variable means the variable was not significant at 0.05 significance level. The variable that was not significant at the 0.05 significance level was eliminated from the model in the following iteration (for more details on the analyses see Appendix E). The final model that best represents the effects of asphalt type, initial modulus, and asphalt-aggregate interactions on the ECS-M_R ratio is shown in Table 5.3. Table 5.3 shows the output of statistical analysis; the class variables, number of levels, and the class values are shown. The analysis was performed by cycle number; that is, for each cycle the model was analyzed (with data for that cycle only).

Table 5.2 An Overview of the ECS Statistical Analyses

Iteration No. 1				
Variable/Cycle No.	1	2	3	4
Aggregate	Y	Y	X	Y
Asphalt	X	Y	Y	Y
Air Voids	X	X	X	X
Water Perm.	X	X	X	X
Water Perm. Ratio	X	X	X	X
Air Perm.	X	X	Y	X
Initial Water Perm.	X	Y	X	X
Initial Modulus	Y	Y	Y	Y
Aggregate*Asphalt	Y	Y	Y	Y

Iteration No. 2				
Variable/Cycle No.	1	2	3	4
Aggregate	Y	Y	X	Y
Asphalt	Y	Y	Y	Y
Water Perm.	Y	X	X	X
Water Perm. Ratio	X	X	X	X
Air Perm.	X	X	Y	X
Initial Water Perm.	X	Y	X	X
Initial Modulus	Y	Y	Y	Y
Aggregate*Asphalt	Y	Y	Y	Y

Iteration No. 3				
Variable/Cycle No.	1	2	3	4
Aggregate	Y	Y	X	Y
Asphalt	Y	Y	Y	Y
Water Perm.	X	X	X	X
Air Perm.	X	X	Y	X
Initial Water Perm.	X	Y	X	X
Initial Modulus	Y	Y	Y	Y
Aggregate*Asphalt	Y	Y	Y	Y

Iteration No. 4				
Variable/Cycle No.	1	2	3	4
Aggregate	Y	Y	Y	Y
Asphalt	Y	Y	Y	Y
Air Perm.	X	X	Y	X
Initial Water Perm.	Y	Y	X	X
Initial Modulus	Y	Y	Y	Y
Aggregate*Asphalt	Y	Y	Y	Y

Table 5.2 An Overview of the ECS Statistical Analyses (Continued)

Iteration No. 5				
Variable/Cycle No.	1	2	3	4
Aggregate	Y	Y	Y	Y
Asphalt	Y	Y	Y	Y
Initial Water Perm.	X	Y	X	X
Initial Modulus	Y	Y	Y	Y
Aggregate*Asphalt	Y	Y	Y	Y

↵

Iteration No. 6				
Variable/Cycle No.	1	2	3	4
Aggregate	Y	Y	Y	Y
Asphalt	Y	Y	Y	Y
Initial Modulus	Y	Y	Y	Y
Aggregate*Asphalt	Y	Y	Y	Y

X means the variable was not significant at 0.05 level, and eliminate this variable ↵ .

Y means the variable was significant at 0.05 level.

Table 5.3 GLM Analysis of the ECS Results for Asphalt and Aggregate Type

Class Variables	Levels	Values
AGGR	4	RC, RD, RH, and RJ
ASPH	8	AAA-1, AAB-1, AAC-1, AAD-1, AAF-1, AAG-1 AAK-1, and AAM-1

Time = 6

Model: $R^2 = 0.79$, CV = 4.88, ECS-MR ratio mean = 0.93

Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
AGGR	3	0.03275601	5.35	0.0037
ASPH	7	0.04715846	3.30	0.0079
MR0	1	0.00894455	4.38	0.0433
AGGR*ASPH	21	0.14340240	3.34	0.0007

Time = 12

Model: $R^2 = 0.85$, CV = 5.22, ECS-MR ratio mean = 0.88

Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
AGGR	3	0.07121460	11.13	0.0001
ASPH	7	0.04083428	2.73	0.0216
MR0	1	0.02653206	12.44	0.0011
AGGR*ASPH	21	0.25769088	5.75	0.0001

Time = 18

Model: $R^2 = 0.81$, CV = 6.21, ECS-MR ration mean = 0.86

Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
AGGR	3	0.10603905	12.28	0.0001
ASPH	7	0.04310104	2.14	0.0634
MR0	1	0.00825944	2.87	0.0987
AGGR*ASPH	21	0.23901440	3.95	0.0001

Time = 24

Model: $R^2 = 0.89$, CV = 4.65, ECS-MR ratio mean = 0.84

Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
AGGR	3	0.15659618	33.88	0.0001
ASPH	7	0.02909552	2.70	0.0231
MR0	1	0.00953970	6.19	0.0175
AGGR*ASPH	21	0.23805089	7.36	0.0001

For each cycle, the summary of the statistical analysis is shown in a separate set of data (Table 5.3). Independent variables (aggregate type, asphalt type, initial modulus, and asphalt-aggregate interactions) with degree of freedom, type III sum of squares, F values, and P-values were given. For each variable, F-values and P-values (based on type III error) can be checked for significance.

Type III sum of squares is used to test the significance of each variable because type III test is invariant to the order of variables in the model, and the test of significance for a variable does not involve the parameters of other variables. At time 6 the initial modulus P-value was 0.0433 and is below the significance level of 0.05, so initial modulus is significant to the model at this cycle. For each cycle (time) the model R^2, coefficient of variance (CV), and ECS-M_R ratio mean are shown. The coefficient of variance gives a relative measure of the variability in the model in percent; that is, CV can be used to compare one model to another. The given model showed low coefficient of variation, and good R^2 values relative to the other models.

Based on the analysis at the end of three cycles, initial air permeability has shown significance to the ECS-M_R ratio. This means that initial air permeability influences the outcome of ECS test results at the end of three cycles. The most important observation from this analysis is that the asphalt-aggregate interaction is highly significant; i.e., the moisture susceptibility of one aggregate in a mixture is dependent on the type of asphalt and visa-versa. The ECS results for any particular mixture will depend on the aggregate type as well as the asphalt type.

However, this analysis does not mean that all the variables that were eliminated do not contribute to the results of the ECS. The analysis that was done above (Table 5.2) was performed for each cycle, i.e., for each cycle the model was tested for the variable's significance. In another model where the analysis was not done for each cycle separately, the stripping rate, initial water permeability, and water permeability at the end of three cycles were significant to the model, as shown Table 5.4 (for more details

Table 5.4 GLM Analysis of the ECS Results

Class	Levels	Values
AGGR	4	RC, RD, RH, and RJ
ASPH	8	AAA-1, AAB-1, AAC-1, AAD-1, AAF-1, AAG-1 AAK-1, and AAM-1

Model: R^2 = 0.91, CV = 4.61, ECS-MR ratio mean = 0.84

Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
AGGR	3	0.02895	6.38	0.0020
ASPH	7	0.04312	4.07	0.0034
WK0[1]	1	0.00596	3.94	0.0571
WK3[2]	1	0.00817	5.40	0.0276
STRIPPING[3]	1	0.00603	3.99	0.0557
AGGR*ASPH	21	0.21586	6.80	0.0001

1 Initial water permeability.

2 Water Permeability at the end of the third cycle.

3 Visual stripping rate at the end of the fourth cycle.

see Appendix E). The analysis indicates the stripping rate and initial water permeability to be marginally significant (based on a 0.05 significance level), thus the initial water permeability has an affect on the final results of the ECS. Also, this model has high R^2 value when compared to the model in Table 5.3, thus the model yields a superior representation to ECS final results.

The repeatability of the ECS test or the measure of variability within the test system is explained in terms of Coefficient of Variations (CV) and using the ECS data statistical analysis. Coefficient of Variations measures the relative variation within the data, i.e., CV expresses the standard deviation as a percent of the mean (Peterson, 1985).

$$CV = \left(\frac{S}{X}\right) * 100 \qquad 5.0$$

where:

S = Sample standard deviation, and

X = Mean

Table 5.3 shows very good CV 4.88%, 5.22%, 6.21%, and 4.65% for cycle number one, two, three, and four, respectively. Based on equation 5.0 and statistical output shown in Table 5.3 (ECS-M_R ratio mean and CV), the standard deviation (error) of ECS-M_R ratio for each cycle one through four is 0.045, 0.046, 0.053, and 0.039, respectively. Assuming that sample standard deviation is for normal distribution, the 95% confidence limits is approximated by $1.65* S/\sqrt{2}$ or 0.06 and 0.05 for ECS-M_R ratio after three and four cycles, respectively. When comparing the ECS results after four cycles of two mixtures, the variability of the reading of ECS-M_R ratio is approximately ±0.05 (95% confidence).

The ECS results were statistically analyzed to determine the correlation between the ECS-M_R ratio and the material's properties. The material properties that were used were the asphalt and aggregate properties tabulated in Chapter 3. The analysis was like the analysis shown in Table 5.2 (an iterative analysis). The dependent variable was the ECS-M_R ratio at the end of four cycles, while the independent variables included all the variables in Table 5.1, and all the variables represented by the material's properties. The final model that best describes the ECS-M_R ratio is shown in Table 5.5. The cycle number, initial water permeability and percent air voids showed very high significance to the model.

From the asphalt properties the softening point was the only significant variable from the list of variables in Table 3.5. The significant aggregate properties included two major elements in the aggregates' composition (SiO_2, and Al_2O_3) and zeta potential. However, note that the model R^2 was very low in comparison to previous models in Tables 5.3 and 5.4. Also, the coefficient of variations was very high compared to the previous models. Therefore, the materials' properties did not explain the ECS results as well as the materials classification variable did using only the aggregates' and asphalts' types as a class variable.

5.1.2 OSU Wheel Tracking Test Results

The analysis of the OSU wheel tracking test results employed a General Linear Model (GLM) procedure to investigate the significance that asphalt type, aggregate type, air voids, stripping rate, and asphalt aggregate interaction have on the rut depth developed after 5,000 wheel passes in the OSU wheel tracker. The results of the analysis are provided in Table 5.6.

Unlike the analysis of the ECS test program results, initial analysis of the OSU wheel tracking test results has shown that asphalt-aggregate interaction has no effect on rut depth developed at 5,000 wheel passes. The analysis shows very high correlation between rutting at 5,000 wheel passes and stripping rate, asphalt type, aggregate type, and percent air voids, at a 0.05 significance level (95 percent confidence level).

Table 5.5 GLM Analysis of the ECS Results and Materials' Properties

Class	**Levels**	**Values**		
Cycle Number	4	1,2,3,and 4		
Model: R^2 = 0.33, CV = 8.48, ECS-MR ratio mean = 0.88				
Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
Cycle	3	0.32881	19.68	0.0001
AVOID	1	0.07204	12.94	0.0004
WK	1	0.11400	20.47	0.0001
SiO_2	1	0.25379	45.57	0.0001
Al_2O_3	1	0.26955	48.4	0.0001
ZETA*	1	0.19618	35.23	0.0001
SOFTPT**	1	0.19460	34.94	0.0001

* Aggregates' zeta potential

** Asphalts' softening Point

Table 5.6 GLM Analysis of the OSU Wheel Tracking Test Results

Class	**Levels**	**Values**		
AGGR	4	RC, RD, RH, and RJ		
ASPH	8	AAA-1, AAB-1, AAC-1, AAD-1, AAF-1, AAG-1 AAK-1, and AAM-1		
Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
AGGR	3	142.94961295	29.86	0.0001
ASPH	7	70.99560815	6.36	0.0001
AV2[1]	1	8.79590144	5.51	0.0234
STRIPPING[2]	1	10.82167482	6.78	0.0125

1 AV2 is air voids of LCPC rutted core after OSU wheel Tracking Test

2 STRIPPING is visual evaluation of broken specimen after OSU wheel Tracking Test.

The second statistical analysis method that was used in the OSU wheel tracking test program included more variables. The model included variables in Table 5.6 in addition to; beam saturation degree, ECS-M_R of a core from the rutted beam, initial water permeability, and aggregate asphalt interactions (see Table 5.7). All the variables were significant at 0.05 level with M_R showing marginal significance. Also, this model has very high R^2 and low CV when compared with the previous models, hence this model well represents the testing program results.

5.1.3 SWK/UN Wheel Tracking Test Results

The statistical analysis of the SWK/UN wheel tracking tests utilized a Bayesian "Survival Analysis" with time (to failure) distributed as a Weibull random variable (Scholz et al., 1993). The Weibull model employed a shape factor (C) of 2 (i.e., skewed to the right), a minimum value (A) of zero (A=0 seemed appropriate since the smallest observed time to failure was 2 hours and A must be less than the smallest observation), and a scale parameter (B) as follows:

$$B = e^{-\left(\frac{AV-B}{B_{AV(i)}}\right)} B_{ASPH^{(i)}} B_{AGR^{(k)}} \text{ ; AV} > 8 \qquad (5\text{-}1)$$

$$B = B_{ASPH*}{}^{(j)} B_{AGGR}{}^{(k)}\text{; AV} \quad 8 \qquad (5\text{-}2)$$

where:

AV = percent air voids of the test specimen.

BAV(i) = weighting for air voids with values of 6, 7, 8, 9, or 10.

BASPH(j) = weighting for asphalt type with values of 2, 6, 10, 14, or 18.

BAGGR(k) = weighting for aggregate type with values of 2, 6, 10, 14, or 18.

As shown, the scale parameter is a multiplicative function of asphalt, aggregate, and air voids with the contribution from air voids decreasing exponentially for values greater than 8 percent, and having no contribution (i.e., equal to unity) for air voids less

Table 5.7 Extended GLM Analysis of the OSU Wheel Tracking Test Results

Class	Levels	Values
AGGR	4	RC, RD, RH, and RJ
ASPH	8	AAA-1, AAB-1, AAC-1, AAD-1, AAF-1, AAG-1 AAK-1, and AAM-1

Model: R^2 = 0.94, CV = 15.91, RUT5 mean = 6.11

Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
AGGR	3	47.774	16.86	0.0001
ASPH	7	55.025	8.32	0.0001
SAT[1]	1	7.588	8.04	0.0102
AV2[2]	1	9.385	9.94	0.0050
STRIPPING[3]	1	13.202	13.98	0.0013
MR[4]	1	3.882	4.11	0.0561
WK0	1	4.838	5.12	0.0349
AGGR*ASPH	21	52.854	2.67	0.0162

1 Percentage saturation

2 AV2 is air voids of LCPC rutted core after OSU wheel Tracking Test

3 STRIPPING is visual evaluation of broken specimen after OSU Wheel Tracking Test.

4 ECS-M_R of core from the rutted beam.

than or equal to 8 percent. It is through the shape parameter (B) that these factors have their effect on the distribution of time to failure. The SWK/UN wheel tracking data was tested to determine the probability (Pr) of the time to failure (T) being less than or equal to some reasonable time value (in this case 7 days of testing). The test is mathematically represented as follows:

$$\Pr [T \leq t] = 1 - e^{-\left(\frac{t^*-A}{B}\right)} C \qquad (5\text{-}3)$$

where:

A = the minimum allowed time value (zero in this case).

B = the scale parameter as previously defined.

C = the shape factor (2 in this case).

t* = predetermined cut-off time value.

The above analysis method allows the ranking of asphalt types and aggregate types, while at the same time gives some importance to the air voids content of the test specimen, provided it is greater than 8 percent (air void contents greater than 8 percent were considered detrimental to the probability of the specimen surviving beyond 7 days with exponentially increasing detriment the farther away the specimen was from 8 percent air voids).

The results of the analysis are shown in Table 5.8. For each asphalt and aggregate the table lists, the probabilities of attaining the score of 2, 6, 10, 14 and 18 (a range of scores which embraces the whole of the data set) and the expected score for the mixture components. The expected score is computed by first multiplying the probabilities by their respective scores, then summing the values. A higher expected score indicates a greater probability of obtaining a pass (not failing after 7 days of testing) in the SWK/UN wheel tracker. Thus, as indicated, the AAM-1 and AAK-1 asphalts and the RC and RD aggregates performed the best, while the AAC-1 and AAG-1 asphalts and the RJ aggregate performed the worst.

Table 5.8 Bayesian Survival Analysis of the SWK/UN Test Results

Mixture Component	Probability of Attaining a Score of					Expected Score[a]
	2	6	10	14	18	
Asphalts						
AAA-1	0.0000	0.0225	0.6351	0.2743	0.0681	11.55
AAB-1	0.0000	0.0047	0.3004	0.4293	0.2655	13.82
AAC-1	0.0188	0.9135	0.0606	0.0061	0.0010	6.23
AAD-1	0.0000	0.0000	0.1382	0.4934	0.3683	14.92
AAF-1	0.0000	0.0914	0.5258	0.2806	0.1022	11.57
AAG-1	0.0000	0.7532	0.2252	0.0197	0.0020	7.08
AAK-1	0.0000	0.0000	0.0006	0.1961	0.8032	17.21
AAM-1	0.0000	0.0000	0.0005	0.0143	0.9852	17.94
Aggregates						
RC	0.0000	0.0000	0.0948	0.5035	0.4017	15.23
RD	0.0000	0.0000	0.0526	0.6212	0.3262	15.09
RH	0.0000	0.0006	0.4745	0.3930	0.1318	12.62
RJ	0.9862	0.0138	0.0000	0.0000	0.0000	2.06

a Expected score = $(\text{Probability})_i\ (\text{score})_i$; $i = 2, 6, 10, 14, 18$.

5.1.4 UNR Net Adsorption Test Results

GLM procedure was used to investigate the effect of aggregate type, asphalt type, and asphalt-aggregate interactions on NAT results. The statistical analysis was one iteration analysis, unlike the ECS results analysis (see Table 5.9). Analysis shows the aggregate, asphalt type, and interactions to be highly significant at 0.05 significance level. Also, the statistical model used shows a high R^2 value. Because asphalt-aggregate type interactions are significant, caution must be exercised in interpreting the ranking of aggregate types and asphalt types (similar to ECS).

Table 5.9 GLM Analysis of the NAT Results for Asphalt and Aggregate Type

Class Variables	**Levels**	**Values**		
AGGR	4	RC, RD, RH, and RJ		
ASPH	8	AAA-1, AAB-1, AAC-1, AAD-1, AAF-1, AAG-1 AAK-1, and AAM-1		
Model: $R^2 = 0.89$, CV = 5.00, NAT mean = 71.57				
Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
AGGR	3	3725.3464	97.21	0.0001
ASPH	7	1112.5515	12.44	0.0001
AGGR*ASPH	21	1327.7960	21.95	0.0001

5.2 PERFORMANCE RANKING

In addition to investigating which independent variables influence the dependent variable for each test program, analyses were also performed on the test results with the objective of ranking the materials (asphalts and aggregates) in terms of water damage potential (ECS) and rutting resistance (OSU and SWK/UN wheel tracking). This section presents the performance rankings of the materials obtained from the analyses of the ECS, OSU and SWK/UN wheel tracking test results.

5.2.1 Aggregates

Analysis of the ECS test program results shows the interaction of asphalt type and aggregate type (i.e., ASPH x AGGR) to be significant (Table 5.3). Ranking of the ECS results by aggregate type is inappropriate, thus aggregate ranking presented in Table 5.10 should be interpreted with caution. Ranking of the aggregates based on ECS test results was done per cycle (for each ECS-M_R ratio after each cycle). These values are not the arithmetic (true) mean of all ECS-M_R ratio values for any given aggregate with the eight asphalts. However, these values are the mean of the adjusted ECS-M_R ratio values, or, using least squares mean (M_RR LSMEAN), for a given aggregate with the eight asphalts. In GLM statistical analysis, the ECS-M_R ratio LSMEAN is the expected value of the ECS-M_R ratio if the experiment was balanced, and all the covariant variables were at their mean.

For comparison purposes, it does not make sense to compare one mixture to another if these mixtures have different statistical significant variables values. For example, to compare aggregate RD to aggregate RC, each aggregate specimen has to be adjusted to account for the difference in initial modulus (initial modulus was significant covariant variable), and be compared at the same cycle number. The analysis of ECS test results shows that after three cycles of conditioning, aggregate RH and RD are the best (moisture resistant), aggregate RC is in the middle, and aggregate RJ is the

Table 5.10 Performance Ranking of Aggregates Based on ECS Test

Aggregate	$M_R R$ LSMEAN	Aggregate	$M_R R$ LSMEAN
First Hot Cycle		Second Hot Cycle	
RD	0.952	RD	0.911
RC	0.931	RH	0.897
RH	0.921	RC	0.889
RJ	0.899	RJ	0.840
Third Hot Cycle		Freeze Cycle	
RH	0.897	RH	0.874
RD	0.892	RD	0.861
RC	0.860	RC	0.847
RJ	0.801	RJ	0.797

Table 5.11 Performance Ranking of Aggregates (OSU Wheel Tracking Program)

Level	Least Square Means	Homogenous Groups	Performance Ranking
RJ	4.34	A	Good
RD	5.09	A	
RH	6.19	B	Intermediate
RC	8.67	C	Poor

worst (moisture sensitive). After four conditioning cycles, aggregate RD and RH are still the best, and aggregate RC and RJ are the worst. In Chapter 4, it was mentioned that RC aggregate is highly absorptive, and tends to disintegrate. The freeze cycle affected aggregate RC (loss in strength) the most of all the other aggregates.

The analysis of the OSU wheel tracking program results shows the interaction of asphalt type and aggregate type (ASPH x AGGR) not to be significant. Thus, in this case, ranking the results by aggregate is appropriate. The performance ranking of aggregates (based on least squares means) for the OSU wheel tracking program is summarized in Table 5.11. As indicated, the analysis shows the RJ aggregate performs the best and the RC aggregate performs the worst. The performance ranking of aggregates based on SWK/UN wheel tracking test results is summarized in Table 5.12. The ranking indicates RC and RD aggregates to be good performers, and the RJ aggregate to be a poor performer. The net adsorption test program performance ranking of aggregate types is shown in Table 5.13, aggregate RC and RD being the best, or, having the least desorption characteristics, and aggregate RJ being the worst.

5.2.2 Asphalts

The analysis of results for the ECS test program shows the interaction of asphalt type and aggregate type (ASPH x AGGR) to be significant; thus, ranking the results by asphalt type is inappropriate (Table 5.14). In the ranking of asphalt types, LSMEANs of ECS-M_R ratio was used, similar to the procedure used in aggregate ranking. Asphalts AAA-1, AAC-1, and AAB-1 performed better than the other asphalts in the ECS test, while asphalts AAF-1, AAG-1, and AAD-1 demonstrated sensitivity to moisture damage.

The analysis of results for the OSU wheel tracking program shows that significance does not exist for the asphalt-aggregate interaction. Thus, a ranking by asphalt type can be accomplished. The performance ranking of asphalts (based on least

Table 5.12 Performance Ranking of Aggregates (SWK/UN Wheel Tracking Program)

Level	Least Square Means	Homogenous Groups	Performance Ranking
RC RD	15.23 15.09	A A	Good
RH	12.62	B	Intermediate
RJ	2.06	C	Poor

Table 5.13 Performance Ranking of Aggregates (NAT/UNR Test Program)

Level	Least Square Means	Homogenous Groups	Performance Ranking
RC RD	77.49 76.05	A A	Good
RH	71.39	B	Intermediate
RJ	61.53	C	Poor

Table 5.14 Performance Ranking of Asphalt Based on ECS Test

First Hot Cycle			Second Hot Cycle		
Asphalt	**M_RR LSMEAN**	**LSMEAN Number**	**Asphalt**	**M_RR LSMEAN**	**LSMEAN Number**
AAB-1	0.968	1	AAC-1	0.924	1
AAA-1	0.956	2	AAA-1	0.922	2
AAC-1	0.934	4	AAB-1	0.895	3
AAF-1	0.926	5	AAG-1	0.874	4
AAG-1	0.923	5	AAM-1	0.867	5
AAD-1	0.910	6	AAF-1	0.865	6
AAM-1	0.910	7	AAK-1	0.865	7
AAK-1	0.880	8	AAD-1	0.861	8
Third Hot Cycle			**Freeze Cycle**		
AAA-1	0.921	1	AAA-1	0.894	1
AAB-1	0.894	2	AAC-1	0.876	2
AAC-1	0.894	3	AAG-1	0.851	3
AAM-1	0.855	4	AAB-1	0.847	4
AAK-1	0.840	5	AAK-1	0.831	5
AAD-1	0.834	6	AAM-1	0.830	6
AAF-1	0.834	7	AAD-1	0.814	7
AAG-1	0.828	8	AAF-1	0.814	8

Table 5.15 Performance Ranking of Asphalts (OSU Wheel Tracking Program)

Level	Least Square Means	Homogenous Groups[a]	Performance Ranking
AAF-1	3.505	A	Good
AAK-1	4.454	AB	Good
AAG-1	4.767	AB	
AAM-1	5.178	AB	Intermediate
AAD-1	5.379	AB	Intermediate
AAB-1	6.366	B	Intermediate
AAC-1	9.209	C	Poor
AAA-1	9.710	C	Poor

[a] Groups with the same letter designation are not significantly different

squares means) for the OSU wheel tracking program is summarized in Table 5.15. Asphalts AAK-1 and AAM-1 are best (or least rut depth values), and asphalts AAG-1, AAA-1, and AAC-1 are the worst (or highest rut depth values).

The performance ranking of asphalts based on the SWK/UN wheel tracking test results is summarized in Table 5.16. Ranking of asphalt types based on the SWK/UN wheel tracking test results have shown that asphalt AAM-1 and AAK-1 to be best (or least failures), and asphalt AAC-1 and AAG-1 to be the worst (or most test failures). The performance rankings of asphalt types based on NAT results is shown in Table 5.17. Asphalt AAD-1 is the best (or least desorption values), while asphalts AAG-1 and AAM-1 are the worst (or highest desorption values).

5.2.3 Mixtures

The statistical analysis of the ECS results indicates that the asphalt-aggregate interaction is very significant, based on 0.05 significance level (95 percent confidence). This conclusion would reject any rankings by asphalt types only, or aggregate type only. To say that aggregate RD performs much better than RJ in moisture susceptibility, a single common asphalt would need to be matched with either of these aggregates. The statistical analysis of OSU wheel tracker results has shown that there are no asphalt-aggregate interactions, so it would be inappropriate to include rankings based on mixtures here. Table 5.18 shows ECS ranking based on ECS-M_R ratio after each cycle, and the mixtures are ranked from 1 to 32.

The data present in Table 5.18 is based on the LSMEAN procedure of the GLM statistical method, similar to that applied in the ranking of asphalts and aggregate types. Table 5.18 does not show the breakdown between poor aggregates (water susceptible) and good aggregates (water resistant), nor the breakdown between poor and good asphalts. The mixtures are not grouped by homogenous groups, where mixtures within the same group are not significantly different, and then each group is

Table 5.16 **Performance Ranking of Asphalts (SWK/UN Wheel Tracking Program)**

Level	Expected Score	Homogenous Groups	Performance Ranking
AAM-1	17.94	A	Very Good
AAK-1	17.21	A	
AAD-1	14.92	B	Good
AAB-1	13.82	B	
AAF-1	11.57	C	Fair
AAA-1	11.55	C	
AAG-1	7.08	D	Poor
AAC-1	6.23	D	

Table 5.17 **Performance Ranking of Asphalts (NAT/UNR Test Program)**

Level	Least Square Means	Homogenous Groups	Performance Ranking
AAD-1	75	A	Good
AAK-1	74.950	A B	Intermediate
AAA-1	73.688	A B	
AAC-1	73.198	A B	
AAB-1	72.199	A B	
AAF-1	70.964	B	
AAG-1	66.759	C	Poor
AAM-1	64.912	C	

Table 5.18 Ranking of 32 Mixes After Each ECS Cycle

First Hot Cycle				Second Hot Cycle			
Aggregate	Asphalt	ECS M_RR LSMEAN	LSMEAN Number	Aggregate	Asphalt	ECS M_RR LSMEAN	LSMEAN Number
RH	AAC-1	1.090	1	RH	AAC-1	1.170	1
RJ	AAF-1	0.993	2	RJ	AAF-1	0.957	2
RH	AAB-1	0.985	3	RD	AAA-1	0.953	3
RD	AAA-1	0.980	4	RH	AAD-1	0.950	4
RD	AAD-1	0.975	5	RC	AAA-1	0.945	5
RC	AAG-1	0.975	6	RD	AAC-1	0.940	6
RC	AAB-1	0.970	7	RC	AAG-1	0.935	7
RC	AAA-1	0.970	8	RD	AAK-1	0.935	8
RD	AAC-1	0.965	9	RC	AAM-1	0.920	9
RJ	AAB-1	0.965	10	RD	AAM-1	0.915	10
RC	AAF-1	0.965	11	RC	AAB-1	0.905	11
RC	AAM-1	0.960	12	RH	AAB-1	0.905	12
RD	AAM-1	0.960	13	RD	AAB-1	0.903	13
RH	AAD-1	0.955	14	RH	AAA-1	0.900	14
RD	AAK-1	0.950	15	RD	AAG-1	0.897	15
RD	AAB-1	0.950	16	RJ	AAA-1	0.890	16
RH	AAA-1	0.940	17	RH	AAG-1	0.890	17
RJ	AAA-1	0.935	18	RD	AAD-1	0.885	18
RD	AAG-1	0.930	19	RC	AAK-1	0.885	19
RJ	AAM-1	0.915	20	RJ	AAM-1	0.875	20
RD	AAF-1	0.907	21	RC	AAF-1	0.870	21
RJ	AAG-1	0.905	22	RJ	AAB-1	0.865	22
RC	AAK-1	0.895	23	RD	AAF-1	0.857	23
RJ	AAG-1	0.880	24	RC	AAC-1	0.840	24
RC	AAC-1	0.865	25	RH	AAK-1	0.830	25
RJ	AAD-1	0.860	26	RC	AAD-1	0.810	26
RC	AAD-1	0.850	27	RJ	AAK-1	0.810	27
RH	AAK-1	0.845	28	RJ	AAD-1	0.800	28
RH	AAF-1	0.840	29	RH	AAF-1	0.775	29
RJ	AAK-1	0.830	30	RJ	AAG-1	0.775	30
RJ	AAC-1	0.815	31	RH	AAM-1	0.757	31
RH	AAM-1	0.807	32	RJ	AAC-1	0.745	32

Table 5.18 Ranking of 32 Mixes After Each ECS Cycle (Continued)

Third Hot Cycle				Freeze Cycle			
Aggregate	Asphalt	ECS M_RR LSMEAN	LSMEAN Number	Aggregate	Asphalt	ECS M_RR LSMEAN	LSMEAN Number
RH	AAC-1	1.125	1	RH	AAC-1	1.125	1
RH	AAA-1	0.950	2	RD	AAK-1	0.955	2
RD	AAA-1	0.943	3	RH	AAA-1	0.940	3
RD	AAK-1	0.930	4	RD	AAA-1	0.933	4
RH	AAB-1	0.925	5	RD	AAG-1	0.927	5
RC	AAM-1	0.920	6	RH	AAB-1	0.910	6
RH	AAD-1	0.915	7	RH	AAD-1	0.910	7
RD	AAB-1	0.907	8	RD	AAM-1	0.890	8
RC	AAA-1	0.905	9	RD	AAC-1	0.885	9
RD	AAC-1	0.905	10	RC	AAM-1	0.885	10
RJ	AAF-1	0.903	11	RH	AAG-1	0.880	11
RC	AAB-1	0.895	12	RJ	AAA-1	0.870	12
RD	AAM-1	0.895	13	RC	AAA-1	0.860	13
RC	AAG-1	0.885	14	RD	AAB-1	0.860	14
RJ	AAA-1	0.885	15	RD	AAD-1	0.845	15
RH	AAG-1	0.885	16	RC	AAK-1	0.840	16
RD	AAG-1	0.873	17	RJ	AAF-1	0.840	17
RC	AAK-1	0.870	18	RD	AAF-1	0.830	18
RJ	AAB-1	0.850	19	RJ	AAB-1	0.820	19
RD	AAD-1	0.845	20	RC	AAB-1	0.815	20
RD	AAF-1	0.837	21	RC	AAG-1	0.810	21
RC	AAC-1	0.830	22	RJ	AAK-1	0.805	22
RJ	AAM-1	0.825	23	RH	AAF-1	0.795	23
RH	AAF-1	0.800	24	RH	AAK-1	0.785	24
RH	AAK-1	0.795	25	RJ	AAM-1	0.785	25
RC	AAF-1	0.795	26	RC	AAF-1	0.770	26
RJ	AAD-1	0.795	27	RH	AAM-1	0.763	27
RH	AAM-1	0.780	28	RC	AAD-1	0.760	28
RC	AAD-1	0.780	29	RJ	AAD-1	0.750	29
RJ	AAK-1	0.765	30	RC	AAC-1	0.750	30
RJ	AAC-1	0.715	31	RJ	AAC-1	0.710	31
RJ	AAG-1	0.670	32	RJ	AAG-1	0.685	32

ranked. However, it shows the breakdown between moisture susceptible mixtures and moisture damage resistive mixtures. After each cycle, mixtures that tended to be moisture susceptible progressively lost stiffness, but the mixtures that were least susceptible to moisture damage maintained about the same stiffness.

Table 5.18 indicates that mixtures which performed well after one cycle did not maintain the same ranking with respect to other mixtures (see Figure 5.1). Figure 5.1 shows the ranking of the 32 mixtures (based on LSMEAN of ECS-M_R ratio) after one and three conditioning cycles, with a ranking of 1 being poor, or water sensitive, and a ranking of 32 being good, or water resistant. The significance of this observation is that one ECS conditioning cycle is not sufficient and results are unpredictable, hence ranking of the mixtures might not have good basis. The difference in performance rankings between one and three cycles shows the ECS sensitivity to the mixture's evaluation.

Figure 5.2 shows the mixtures' performance rankings based on LSMEAN of the ECS-M_R ratio after three and four cycles. The figure shows that the rankings after three cycles conform with rankings after four cycles in almost all the thirty-two mixtures, except in mixtures that lost strength during the fourth cycle. These mixtures, which are mostly constituted of aggregate RC, probably experienced aggregate disintegration failure in the fourth cycle, since RC aggregate has high absorption and low soundness properties.

Figure 5.3 shows the performance rankings of mixtures by stripping rate and ECS-M_R after three cycles. The plot shows the inconsistency of the stripping results, since the stripping evaluation is very subjective and relates to the adhesion failure. Finally, one should note that the range of data presented in Table 5.18 is relatively small, i.e., the ECS-M_R ratio of all 32 mixtures varies between 1.12 and 0.685.

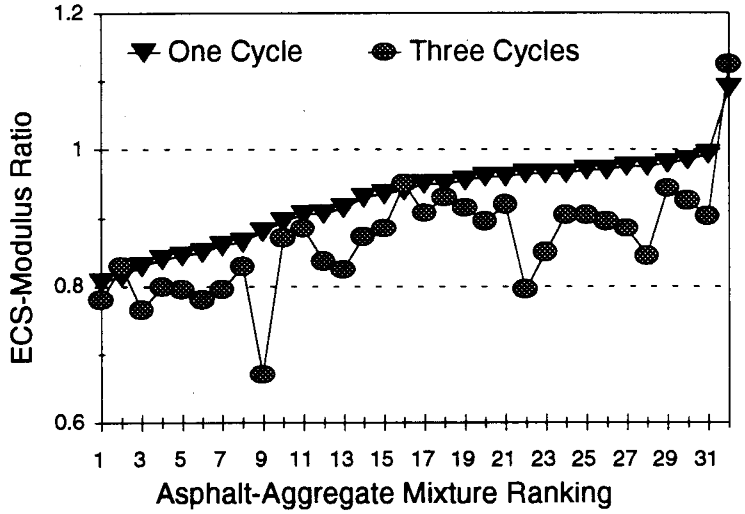


Figure 5.1 ECS Performance Ranking of Mixtures Based on One and Three Cycles

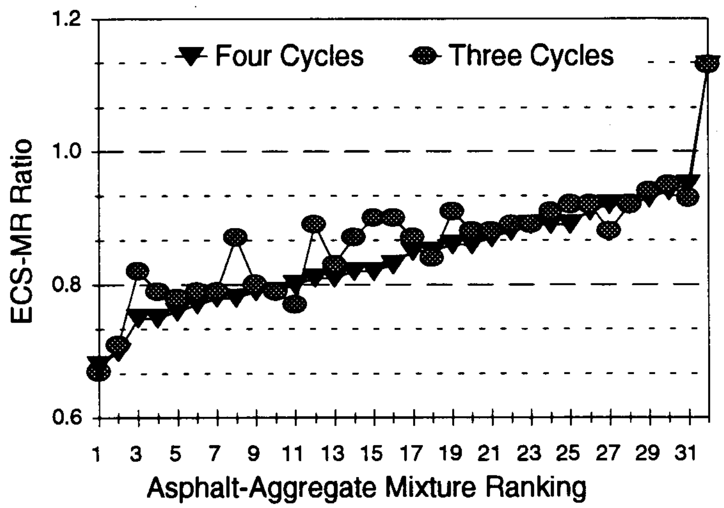


Figure 5.2 ECS Performance Ranking of Mixtures Based on Three and Four Cycles

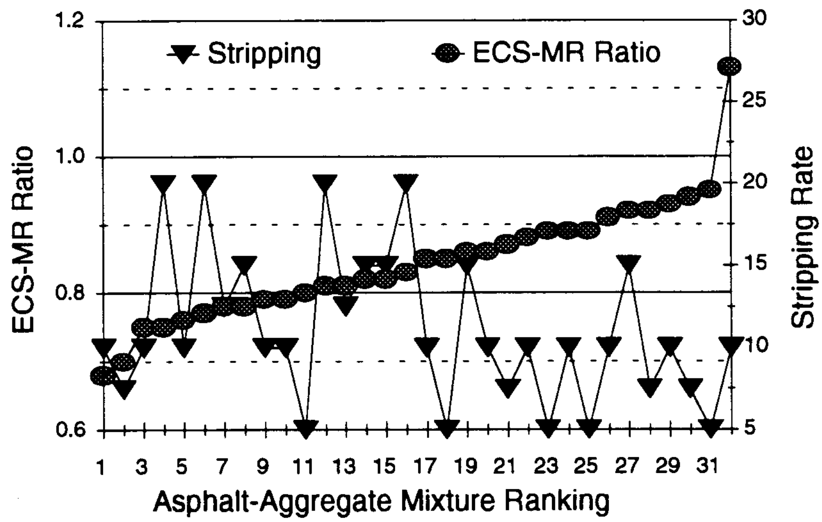


Figure 5.3 Comparisons between Performance Rankings of Mixtures by Stripping and ECS-M_R

5.3 PERFORMANCE RANKING COMPARISONS

This section compares the performance rankings obtained in the ECS test program and wheel tracking test programs, with the NAT test program as shown in Table 5.19. The results show that the ECS test program has similar aggregate type rankings to the NAT and SWK/UN test program, while good agreement exists between SWK/UN wheel tracking results and the NAT test program net adsorption results. However, poor agreement exists between the OSU wheel tracking results and those of the other two tests in terms of performance rankings based on aggregate type.

The rankings of asphalts from the ECS, NAT, and OSU and SWK/UN wheel tracking test programs are summarized in Table 5.20. As indicated, poor or very little agreement exists among the wheel tracking test results, ECS, and NAT test results. Again, the statistical analysis has shown asphalt-aggregate interactions to be significant, thus any comparison of the asphalt types alone would not be possible.

When considering the comparisons of materials ranking by different test procedures, one must keep in mind that the mechanisms leading to varying "performance" are not the same. The testing reported herein was aimed at measuring water sensitivity, but all the tests do not do so directly. The ECS and NAT tests both evaluate the mixture before and after conditioning, but the OSU and SWK/UN rutting tests only evaluate the mixtures after wet-conditioning state. Because of the large specimen size of the beams tested, compared to ECS or NAT specimens, the water conditioning applied to the beams may not have been severe enough to induce true water damage.

Further, the NAT procedure addresses only the potential for stripping (adhesion) and is not capable of evaluating cohesion loss. The other tests (ECS, OSU and SWK/UN wheel tracking) included all the mechanisms simultaneously, providing a gross effect without clearly separating the cause of failure in each case. Figure 5.4 shows the NAT and ECS-M_R results plotted versus the ECS rankings.

Table 5.19 Summary of Aggregate Rankings

Performance Ranking	Water Sensitivity		Rutting	
	ECS	NAT	OSU Wheel Tracking	SWK/UN Wheel Tracking
Good	RD, RH	RC, RD	RJ, RD	RC, RD
	RC	RH	RH	RH
Poor	RJ	RJ	RC	RJ

Table 5.20 Summary of Asphalt Rankings

Performance Ranking	Water Sensitivity		Rutting	
	ECS	NAT	OSU	SWK/UN
Good	AAA-1	AAD-1	AAF-1	AAM-1
	AAC-1	AAK-1	AAK-1	AAK-1
	AAG-1		AAG-1	
		AAA-1		AAD-1
		AAC-1	AAM-1	AAB-1
	AAB-1	AAB-1	AAD-1	
	AAK-1	AAF-1	AAB-1	AAF-1
	AAM-1			AAA-1
		AAG-1		
	AAD-1	AAM-1	AAC-1	AAG-1
Poor	AAF-1		AAA-1	AAC-1

The plot shows about sixteen of the thirty-two mixtures to have similar ranking, and the rest are different. It is suspected that the sixteen mixtures that had similar rankings in both NAT and ECS are mostly adhesion failures, while the other mixtures are combination of the other failure mechanisms. Figure 5.5 compares the ranking based on the NAT and stripping; and again, stripping evaluation is found to be inconsistent. Mixtures that would fail the NAT test have passed the stripping evaluation.

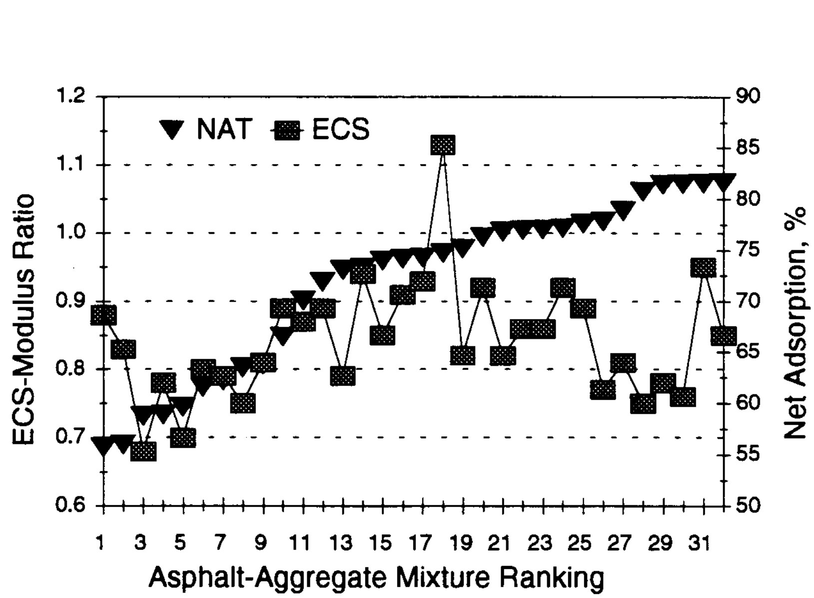


Figure 5.4 **Comparisons of Performance Rankings by ECS and NAT Test**

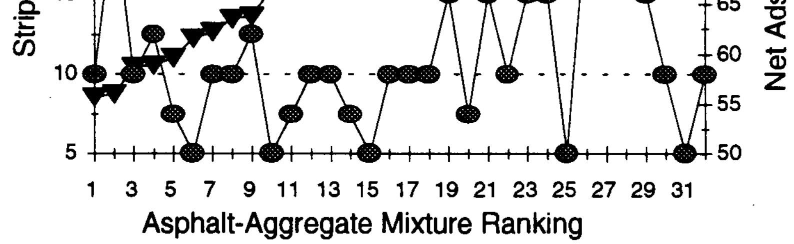


Figure 5.5 **Comparisons of Performance Rankings by Stripping and NAT Tests**

6.0 EXTENDED TEST PROGRAM

This chapter presents a summary of ECS evaluation of the open graded mixtures and modified mixtures for water sensitivity. Also included are the results of ECS cycle duration evaluation.

6.1 EVALUATION OF OPEN GRADED MIXTURES

Open-graded mixtures have been used for many years, in surface and base courses. Porous mixtures have reduced splash and spray during wet weather, thus improving safety. The states' highway agencies have not been able to accurately predict water damage potential of open graded mixtures. Conventional water sensitivity tests have not been able to detect the potential for water damage. Existing water sensitivity evaluation tests are thought to be conservative, thus requiring additives for mixtures to pass the test and which is costly.

Open-graded mixtures were evaluated in the ECS for water sensitivity and results were compared to conventional water sensitivity test (Indirect Retained Strength). Also, the open-graded mixtures' results were used to evaluate the ECS capabilities to evaluate different mixture types.

6.1.1 Oregon Open-graded Mixtures

The objective of this study was to evaluate the open graded mixtures and develop an improved evaluation procedure and guidelines for water sensitivity. Specific objectives include:

1) Evaluate the selected projects that have experienced water damage;

2) Compare the results of the ECS test with ODOT conventional evaluation method; and

3) Recommend modification to existing procedures if needed.

Specimens measuring 4 in. (102 mm) dia. by 4 in. (102 mm) height were received from ODOT; projects mix designs and materials data are included in Appendix F. There were few mixtures that included antistripping additive and others did not. The mixtures had different aggregate sources and asphalt sources. Summary table of ECS results is included in Appendix F. Two specimens were tested from each mixture. Each mixture represents a project that has been selected for ECS evaluation for water damage.

The selection of the two specimens to test in ECS was based on air voids and diametral resilient modulus test results. The two selected specimens best represented the other specimens in the group regarding air voids versus diametral resilient modulus. For example, specimens that fell outside the trends of air voids versus diametral M_R were not selected as shown in Figure 6.1. This method is good for eliminating specimens that might have unusual performances and do not represent the other specimens of the same group.

ECS results summary are included in Appendix F. The data include results from ECS-M_R and water permeability (if permeable) initially and after the second, third, and fourth cycles. Also, the stripping rate at the end of the test is shown. The results of the IRS test (Index of Retained Strength) that was performed at the ODOT laboratory are also included. The IRS test represents a ratio of the mixtures' unconditioned compressive strength to their conditioned compressive strength, while lower values indicate water damage sensitive mixtures.

Figure 6.2 shows the results of the ECS conditioning on one specimen from each mixture of the Oregon open graded mixtures. All the mixtures that have experienced water damage are represented by loss in strength (ECS-M_R), except for mixture A. Mixture A did not have any additives and did not show any visual stripping. The mixture could have densified and gained the ten percent (10 %) in strength (ECS-M_R). All the other seven mixtures have shown water sensitivity, especially mixtures B and F.

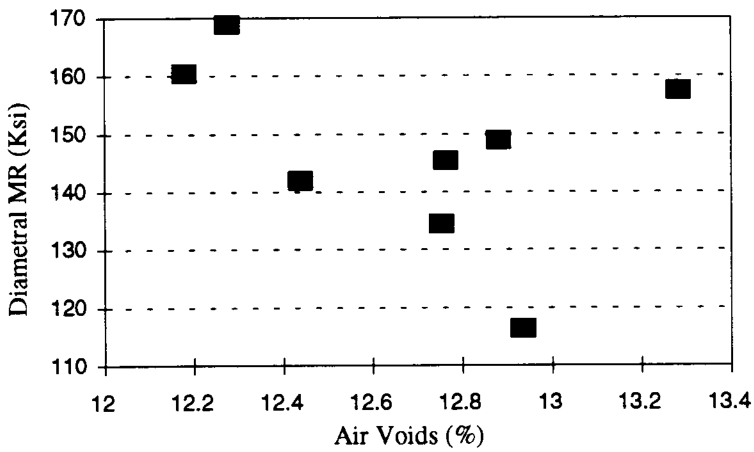


Figure 6.1 Plot of Diametral and Air Voids Results For Mix A- ODOT

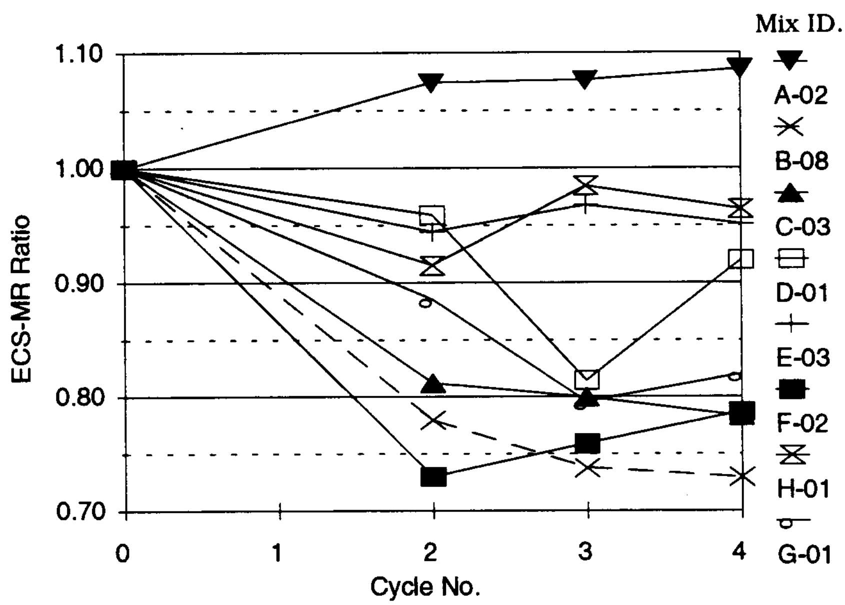


Figure 6.2 Summary of Open-graded Mixtures Results - ODOT

For a seventy percent (70 %) IRS failure criterion, all mixtures have failed the IRS test except for two, and one mixture is marginal. The results indicate that either the IRS test or the failure criterion is conservative. On the other hand, the ECS test would have passed all the mixtures with mixtures F and G being only marginal. Also, stripping of the mixtures was somewhat consistent with IRS results, except for mixture A. Mixtures that showed higher stripping rates (or water damage) have shown lower IRS values.

6.1.2 Washington Open-graded Mixtures

The purpose of this project was to evaluate cores from the open graded rubber asphalt mixture placed on I-5 near Centralia, Washington. The testing program included moisture sensitivity evaluation using the Environmental Conditioning System (ECS), and resistance to permanent deformation using the shear test device at University of California, Berkeley. There were four sets of ten cores taken from different areas throughout the project. All of the cores were taken from the left shoulder one foot left of the fog line. The mix design process and data sheets are included in Appendix G. The following is a brief description of the sets:

1) Cores 1-10 were taken in the area where PBA-6 asphalt was used, and air temperature was between 60 and 70 F when it was paved. This section of the project was compacted with a vibratory roller.

2) Cores 11-20 were taken in the area where PBA-6GR asphalt was used and air temperature was between 50 and 60 F when it was paved. This section of the project was compacted with a static roller.

3) Cores 21-30 were taken in the area where PBA-6GR asphalt was used and air temperature was between 60 and 70 F when it was paved. This section of the project was compacted with a static roller.

4) Cores 31-40 were taken in the area where PBA-6GR asphalt was used and air temperature was between 60 and 65 F when it was paved. This section of the project was compacted with a vibratory roller.

When the cores were received at OSU, each core was sawed from both ends. The cores were cut to eliminate error caused by end effects; about 1/8 in. was cut from each end. A dry saw was used with CO_2 as coolant, because wetting the core can affect the permeability and gravimetric tests. For the air permeability test the specimen must be dry, water in voids can hinder the air flow through the specimen, thus giving wrong air flow values and air permeability results.

The cores gravimetric data (specific gravities) were determined using the parafilm method, and air voids were calculated. Based on air voids results for each set, three cores were chosen from the same set with similar air voids. The three cores were stacked on top of each other and glued using epoxy resin, the objective of which was to obtain a 4 in. (102 mm) high specimen that could be tested in the ECS. For each mixture, two specimens were tested in the ECS.

Figure 6.3 shows the ECS conditioning effects on the different mixes. Mixture D exhibited susceptibility to water damage; at the end of the test, the average ECS-M_R ratio was 0.78 for the two specimens. The other three mixes did not show the same decrease in ECS-M_R . One specimen of mix B indicated lower strength after the ECS test, but there was no noticeable stripping present after the ECS test. For more results, analyses, and discussion see Appendix G.

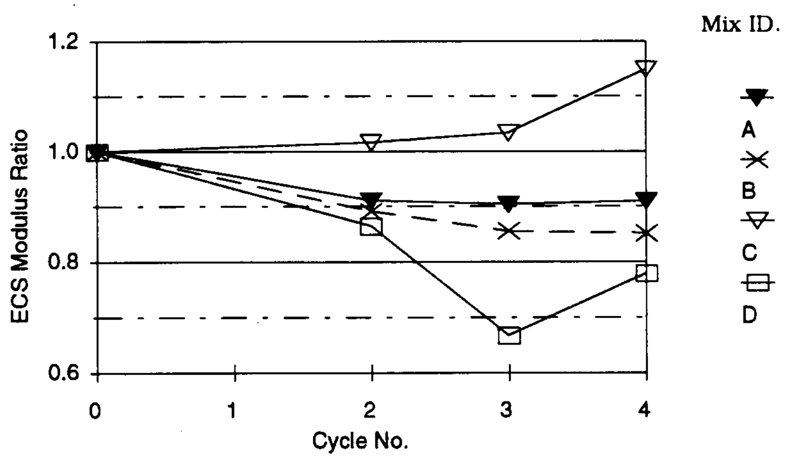


Figure 6.3 Effect of ECS Test on Open-graded Mixtures - WSDOT

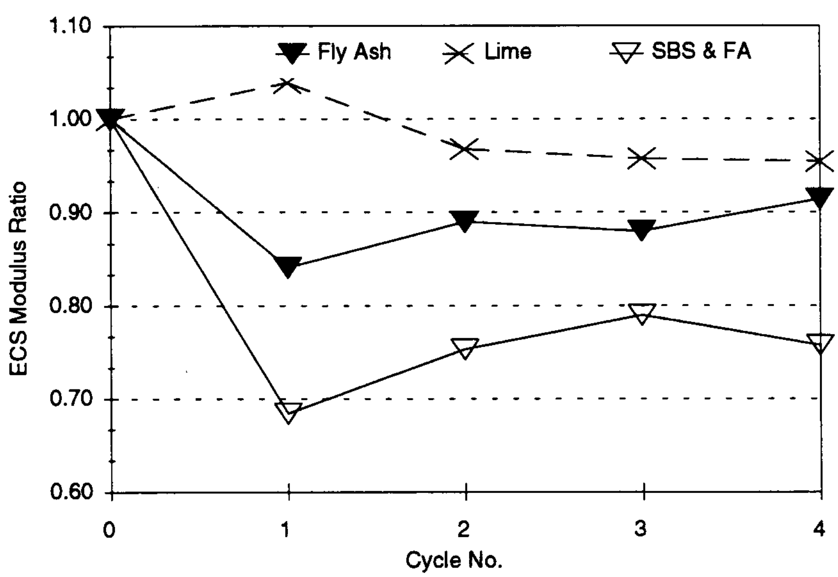


Figure 6.4 ECS Evaluation of Australian Modified Mixtures

6.2 AUSTRALIAN MODIFIED MIXTURES STUDY

OSU was contracted to evaluate three different mixtures from an airport project in Australia for water sensitivity. The specimens (4 in. diameter by 4 in. height) were received and then tested using the ECS. ECS summary data and information on mixture types are included in Appendix H. All three mixtures included different types of additives, and two specimens of each mixture were tested.

The results show that SBS modified asphalt did not improve the mixtures' water sensitivity characteristics as shown in Figure 6.4. Mixtures that included class 320 asphalt, and, either lime filler or fly ash, exhibited good water resistance characteristics. Lime and fly ash have been used before as antistripping agents to minimize water damage. However, it has been observed by researchers (Dalter and Gilmore, 1983), who studied the affects of additives on stripping, that in a few instances an additive can be counterproductive, i.e., additives can change the asphalt cement characteristics and lead to stripping.

6.3 CONDITIONING CYCLE DURATION STUDY

The original ECS protocol has established a six-hour cycle duration, and a three-hour cooling time (back to 25 C). However, the ECS procedure required that the laboratory technician come at non-business hours to collect data. Therefore, the cycle duration had to be altered; and one cycle data collection had to be eliminated. The cycle duration was cut by one hour and the data collection after the second cycle was eliminated. In this way the laboratory technician could start the ECS test in the morning, collect data after the first cycle late in the afternoon, then come back the following morning and collect data after the third cycle. Following this schedule, the ECS test could be done within twenty-four hours, and the it was not necessary for the technician to come at night.

Two open graded mixtures were used to investigate the effect of changing the cycle duration; each mixture was tested in three, five, and six hours cycles see Appendix I. The three-hour cycle was added to see if extremely short cycle duration would affect the ECS evaluation. The results indicate that cycle duration is not critical, and that mixture B had the same performance regardless of the cycle duration as shown in Figure 6.5. Mixture C had similar performances for three and six-hour cycles; but the five-hour cycle exhibited more water damage (see Figure 6.6). The visual stripping rate of mixture B was 20 percent for all the specimens regardless of the cycle duration. The visual stripping rate for mixture C was 10 percent for the three-hour cycle, and 20 percent for the five and six hour cycles, respectively.

These results confirm the hypothesis that temperature cycling is more critical than cycle duration, i.e., four six-hour cycles are more severe than two twelve-hour cycles (Terrel and Al-Swailmi, 1992). Also, the results based on five-hour cycles are not different from six-hour cycle duration results. However, it might be feasible to shorten the cycle to three hours instead of five hours, although two mixtures of the same air voids percentage are not enough to make a conclusive decision.

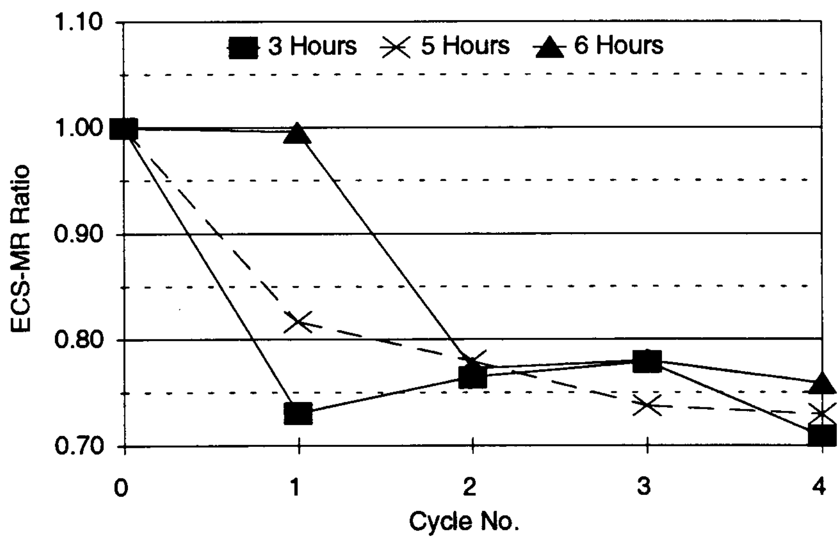


Figure 6.5 **Effect of Cycle Duration on ECS Evaluation of Mixture B**

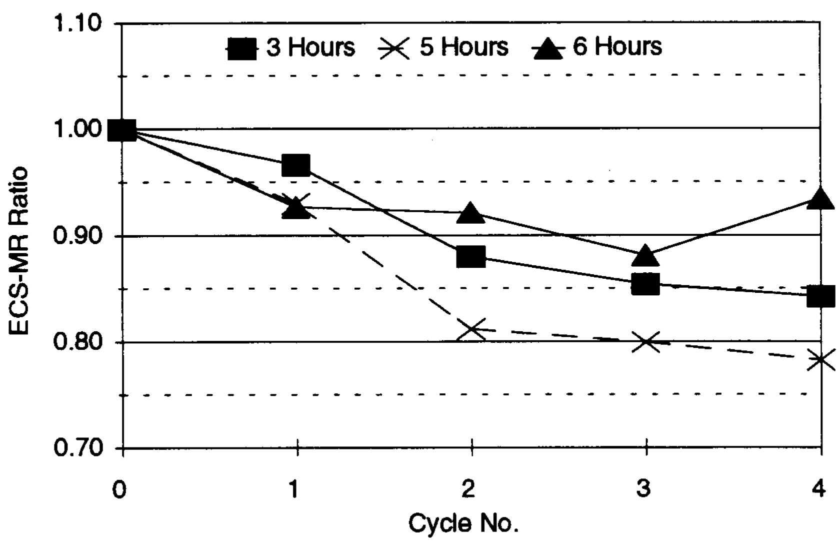


Figure 6.6 **Effect of Cycle Duration on ECS Evaluation of Mixture C**

7.0 CONCLUSIONS AND RECOMMENDATIONS

As stated in Chapter One, the major objectives of the research were to evaluate asphalt concrete mixtures in the ECS for water sensitivity and perform a comparative analysis between the of ECS evaluation and other test evaluations. The work presented in this study included the following:

1) Evaluate 32 SHRP asphalt-aggregate mixtures for water damage using the Environmental Conditioning System, and rank the asphalt and aggregate types based on performance in water sensitivity test,

2) Relate the ECS ranking of the asphalt and aggregate types to OSU and SWK/UN (University of Nottingham, UK) wheel tracking test results, and Net Adsorption Test (NAT) results, and

3) Evaluate open-graded asphalt mixtures from the Washington Department of Transportation (WSDOT) and the Oregon Department of Transportation (ODOT) for water sensitivity using the ECS,

4) Evaluate modified asphalt-aggregate mixtures from Australia for water sensitivity using the ECS, and

5) Evaluate the ECS conditioning cycle duration.

The work presented here included testing of forty-seven different asphalt-aggregate mixtures for water sensitivity. The forty-seven mixtures were replicated and more than one hundred and twenty specimens were tested in the ECS. Based on the research performed, the following conclusions, recommendations for implementation, and recommendations for future research appear warranted.

7.1 CONCLUSIONS

The testing results and analysis presented herein appears to warrant the following conclusions:

1) Performance ranking of mixtures by asphalt type or by aggregate type alone cannot be made for the ECS test results due to the significant interaction between asphalt and aggregate types. The term statistically significant is used here to indicate that the independent variable affects the results represented by the dependent variable. Statistical analyses of ECS results have showed that there is significant differences among the ranking of the 32 SHRP asphalt-aggrgeate mixtures based on water damage potential.

2) The ECS test results have indicated that ECS performance ranking after one cycle is not statistically significant and does not correlate with ranking after three cycles.

3) The results show that the ECS test program has similar rankings to the NAT and SWK/UN test program, while good agreement exists between SWK/UN wheel tracking results and the NAT test program net adsorption results. However, poor agreement exists between the OSU wheel tracking results and those of the other two tests. The significant differences between the results of the two wheel tracking tests may be attributed to the significant differences in testing methods, test apparatus, specimen size, specimen environment during testing, etc.

4) It would appear that the OSU wheel tracking test may not be appropriate for evaluating aggregate type as it pertains to water sensitivity, and comparison of conditioned to unconditioned specimens is required to assess the water damage.

5) Each test program had different asphalt types performance rankings, thus there was no agreement between any test program on the rankings. Asphalt types appear to be more sensitive to test methods than aggregates.

6) The statistical analysis shows the stripping results and initial water permeability to be significant, based on 0.05 significance level, thus the initial water permeability has an effect on the final results of the ECS.

7) Although statistical analyses have indicated that the stripping results is statistically significant to ECS results after three cycles, individual mixtures ranking comparisons based on visual stripping and other tests' rankings do not show good correlations, demonstrating the inconsistency of the stripping evaluation. The visual stripping appears to be very subjective and sometimes is not indicative of water damage potential.

8) Analysis of ECS results and materials properties indicated that of the asphalt properties the softening point was the only significant variable from the list of the variables in Table 3.5. The significant aggregate properties included two major elements in the aggregates' composition (SiO_2, and Al_2O_3) and zeta potential. These aggregate properties have been reported before as properties that relate to aggregates stripping. However, note that the model R^2 is very low comparing to models where only asphalt and aggregate types were used as variables.

The following conclusions are based on the ECS test results of open-graded mixtures only, and should not confused with the conclusions above which are based on ECS evaluation of the SHRP mixtures.

1) Evaluation of WSDOT open-graded mixtures has demonstrated that mixtures with higher initial water permeability or higher air voids tends to lose more strength (ECS-M_R).

2) The WSDOT test program had limited number of specimens and ECS tested specimens were made of three cores glued together. This method of specimen fabrication is believed to be the reason behind the discrepancies between the

ECS results. Therefore, conclusive conclusions regarding the water damage potential of the WSDOT mixtures can not made from these results.

3) Evaluation of ODOT open-graded mixtures shows that six mixtures have passed the criteria of 75 % and one mixture was marginal. However, only one mixture passed the IRS evaluation, and another mixture marginally passed. This confirms that IRS test is very severe "torture test," and perhaps the test is not suitable for water sensitivity evaluation of open-graded mixtures, or the IRS criteria is very high.

4) The ECS test indicates that mixtures water damage potential was minimized when antistripping additive was used.

5) The results indicate that cycle duration is not critical, and mixture performance after three, five, or six hours of ECS conditioning is the same. Mixtures that were tested for three-hour cycles have exhibited water damage.

7.2 RECOMMENDATIONS FOR IMPLEMENTATION

In this research, the ECS has demonstrated its sensitivity in the evaluation of different asphalt-aggregate mixtures. The following recommendations are based on the SHRP test programs which was extensive and included enormous database. Although the ECS does not separate the different failure mechanisms, it evaluates the physical behavioral changes of the mixture which can be due to water damage. The ECS can be used to evaluate asphalt-aggregate mixtures for water sensitivity, and to evaluate antistripping agents.

Prior to specimen fabrication, the materials selected should be evaluated for compatibility between asphalt and aggregate using net adsorption test. If the asphalt aggregate combination exhibit stripping, then the mixture needed to be modified by either changing the materials or using antistripping additives. For mixtures that pass the NAT test, specimens can be fabricated at three different voids levels (optimum, and above and below optimum). Preparing three different air voids specimens eliminates the problem of having to prepare the specimen at certain air voids percent. By testing the mixture at different air voids levels, one can evaluate the mixture sensitivity at different voids levels.

After the specimens preparation, the specimens can be tested in the ECS for the different climate conditions. For mixtures that will be constructed in areas where there are hot climates, three hot cycles (5 hours each, and 3 hours cooling) should be used. For mixtures that will be constructed in areas where there will be freezing climates, three hot and one freeze cycle should be used. One ECS test will take one day for hot climates and one and one half day for cold climates.

Time management is very important in scheduling the ECS test, since the lab technician will work only during business hours. The ECS preparation which includes air permeability measurements, dry ECS-M_R testing, preconditioning, and water permeability measurements takes about one hour, so the technician will have to start by 8 am. The first hot cycle will start at 9 am, and by 5 pm the operator can test for ECS-M_R and water permeability for the first cycle reading.

Next, the ECS is set to run the second and third hot cycles in sequence, thus skipping the second cycle data. The following day the technician can collect data for the third cycle, thus the test will be done for hot climates. For cold climates, the ECS is set for one freeze cycle, and finished by 4 pm. Finally, the specimen is split open and visual stripping is assessed. The ECS-M_R data versus the cycle number should be plotted similar to Figure 7.1 shown, then the figure should be analyzed.

After the first cycle, the ECS-M_R ratio would slightly decrease (less than 0.1 ECS-M_R) for water sensitive mixtures, rapidly decrease for water sensitive mixtures combined with mixture failure, or slightly increase for water resistant mixtures combined with strain hardening. Between the first and third cycles, several actions can happen;

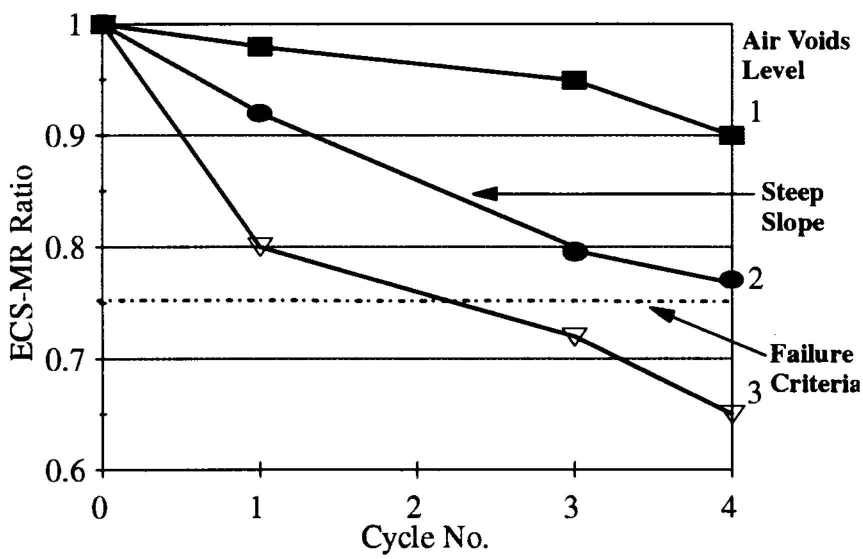


Figure 7.1 ECS Criteria Concept - Water Sensitivity Evaluation

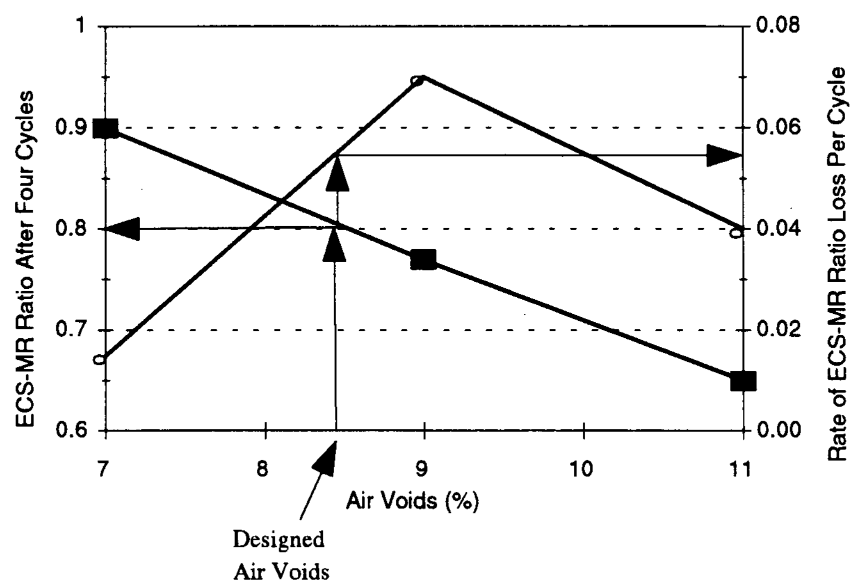


Figure 7.2 ECS Criteria Concept- Design Based on Air Voids

the good mixtures (water resistant) will stay the same without losing much stiffness in these two cycles, but the poor mixtures will sharply lose stiffness, regardless of the ECS-M_R ratio after one cycle.

There are two important parameters in the results of the ECS test: the slope between the first and third cycles, and the final ECS-M_R ratio. For mixtures which have ECS-M_R ratios below prescribed criteria at the end of test, the mixture has "failed." For mixtures which have ECS-M_R ratios higher than the prescribed criteria, the slope of the line between the first and third cycles should be investigated. If the slope is below 0.05, this indicates that the stiffness loss is very gradual, and probably the mixture will pass the prescribed criteria even if the test is extended. However, if the slope is higher than 0.05, this indicates that the mixture might be marginal and lose more strength after one or more cycles, thus failing the test and criteria.

Figure 7.2 shows three mixtures at different air voids levels and with different ECS performance. For a designed air voids of 8.5 %, the ECS performance can be interpreted from the results of the three air voids levels. The mixtures' ECS performance indicates ECS-M_R ratio of 0.80 which indicates the mixture has passed the criteria for water sensitivity. However, the slope of the line between first and third cycles is about 0.055 ECS-M_R ratio per cycle, thus after two more cycles the mixture is expected to reach below 0.75 ECS-M_R ratio and fail.

Criteria for specification guidelines are not yet established, because the ECS results have not been correlated with field performance. However, the following limits might be acceptable for now, based on SHRP mixtures:

ECS-M_R Ratio, minimum	0.75
ECS-M_R ratio per cycle, between first and third cycles	0.05
Visual Stripping, maximum	30 %

7.3 RECOMMENDATIONS FOR FUTURE RESEARCH

From the results of this research, it was evident that some of the test procedures used were not appropriate for evaluating water sensitivity of mixtures. Therefore, several recommendations for improved comparisons to be made in future research are as follows:

1) The ECS should be used to evaluate specific pairs, i.e., asphalt-aggregate combinations only, and should use at least three conditioning cycles.

2) If water sensitivity is important in the OSU wheel tracker tests, both dry and wet conditioned specimens should be tested. This approach will provide a ratio of wet to dry rutting (and possibly other failures), similar to that for the ECS.

3) An improved method of water conditioning needs to be developed for the large beam specimens used in the OSU wheel tracker. The method used in this project was slow and cumbersome, and the thoroughness of wetting and/or conditioning was uncertain. Also, the specimen should be subjected to water conditioning throughout the test, and not just wrapped in plastic and tested. For water damage to start, the specimen should be wetted, and saturation levels should be maintained throughout the test.

4) The ECS conditioning cycle duration should be investigated further, since the results indicated the short cycles are feasible and water damage is sustained by bad asphalt-aggregate mixtures. If the cycle were shortened to three hours, the duration of full cold climates mixture evaluation would be one day, instead of one day and a half.

5) The mixtures' performance, based on the ECS-M_R, should be correlated with field performance to develop failure/pass criteria. This criterion is as important as the test itself, and is vital to the success and survival of the test evaluation. The major problem with existing water sensitivity tests is the lack of good

correlation between laboratory evaluation and field performance, thus the test could be meaningless. Also, the criteria should include other failure mechanisms and distresses that are not subjected by ECS test. The ECS-M_R ratio evaluates only the water sensitivity of the mixture, but the same mixture in the field experiences a combination of rutting, aging, and maybe fatigue. Therefore, the criteria should take these mechanisms into consideration.

6) An improved method of visual stripping evaluation that is less subjective and more consistent with water damage failure mechanisms should be developed. The use of electronic scanners could be adopted and developed in stripping tests. Both unconditioned and conditioned specimens should be scanned to eliminate any problems, such as uncoated aggregates caused in mixing procedure. Any broken aggregate in the conditioned specimen can be colored black to eliminate it from possible inclusion in the stripping evaluation. The scanned image can be imported into a computer program in which a color tone is translated into a factor and multiplied by the sum of the area. This can be done for each color tone. Finally, the summation of color tones by area would translate into a value by which the unconditioned to conditioned ratio could be determined. This should be a good scientific method of evaluating stripping, and with today's computer technology, it is feasible.

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APPENDICES

APPENDIX A

SAMPLE PREPARATION

Standard Practice for

PREPARATION OF TEST SPECIMENS OF BITUMINOUS MIXTURES

BY MEANS OF ROLLING WHEEL COMPACTOR

AASHTO DESIGNATION: T ###-YY

(ASTM DESIGNATION: D ####-YY)

*This document is the draft of a test method being developed by researchers at Oregon State University for the Strategic Highway Research Program (**SHRP**). The information contained herein is considered interim in nature and future revisions are expected. It is also recognized that this document may lack details with respect to the test equipment (schematics, dimensions, etc.); more details will be provided after the test procedure is finalized. This version represents the state of the test procedure as of **July 12, 1993***

*The test method is in a format similar to the test methods contained in the American Association of State Highway and Transportation Officials' (AASHTO) standard specifications. At the conclusion of **SHRP**, selected test methods will be submitted to AASHTO for adoption into its standard specifications.*

1. SCOPE

1.1 This method describes the mixing and compaction procedures to produce large slab specimens (approximately 101.6mm H x 762 mm W x 762 mm L) of bituminous concrete in the laboratory by means of a mechanical rolling wheel compactor. It also describes the procedure for determining the air void content of the specimens obtained.

2. APPLICABLE DOCUMENTS

2.1 *AASHTO Test Methods:*

T 11-85	Amount of Material Finer than 75-m Sieve in Aggregate
T 27-84	Sieve Analysis of Fine and Coarse Aggregates
T 246-81	Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus

2.2 *ASTM Test Methods:*

C 117-90	Materials Finer than 75-m (No. 200) Sieve in Mineral Aggregates by Washing
C 136-84a	Sieve Analysis of Fine and Coarse Aggregates
D 1561-81a	Preparation of Bituminous Mix Test Specimens by Means of California Kneading Compactor
D 2041-78	Test Method for Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures
D 2493-91	Standard Viscosity Temperature Chart for Asphalts

3. APPARATUS

3.1 *Rolling Wheel Compactor* - A mechanical, self-propelled rolling wheel compactor with forward/reverse control such as that shown in Figure 1 for compaction of asphalt concrete mixtures. It must weigh a minimum of 1,000 kg and possess the capability of increasing the weight to 1,500 kg. The load applied must be in the static mode.

3.2 *Mold* - A mold to hold the bituminous mix as shown in Figure 2. The mold is composed of one lift 101.6 mm (4 in.) thick.

3.3 *Ovens* - Forced-draft electric ovens of sufficient size, capable of maintaining a uniform temperature between 100 ± 3C to 200 ± 3C (212 ± 37.4F to 392 ± 37.4F). It is preferable to have ovens with a capacity of 28 to 42 dm^3 (1.0 to 1.5 ft^3) for asphalts and 700 to 850 dm^3 (25 to 30 ft^3)for aggregates.

3.4 *Specimen Mixing Apparatus* - Suitable mechanized mixing equipment is required for mixing the aggregate and the bituminous material. It must be capable of maintaining the bituminous mixture at the selected mixing temperature, and allow the aggregate to be uniformly and completely coated with asphalt during the mixing period (approximately 4 minutes). It is preferable to have a mixer with a capacity of 70 to 85 dm^3 (2.5 to 3 ft^3). A conventional concrete mixer fitted with infrared propane heaters has been found to be suitable.

3.5 *Coring and Saw Cutting Equipment* - Mechanized coring and saw cutting equipment capable of coring 101.6 mm to 203.2 mm (4 to 8 in.) diameter specimens and beams of different sizes from an asphalt concrete slab. It is preferable to dry-cut the cores and beams.

3.6 *Balance* - Two balances are required; one with a capacity of 5 kg or more and sensitive to 1.0 g or less, and the other with a capacity between 45 to 120 kg, and sensitive to 0.5 kg or less.

3.7 *Miscellaneous Apparatus*:

3.7.1 Digital thermometers with thermocouple probe

3.7.2 Spatulas, trowels, scoops, spades, rakes

3.7.3 Heat resistant gloves

3.7.4 Metal pans

3.7.5 Socket wrench, sockets, screw drivers, crescent wrench

3.7.6 Lubricant for mold (eg. PAM cooking oil or equivalent)

3.7.7 Tape measure

3.7.8 Parafilm (manufactured by American National Can Co., Greenwich, CT)

4. MATERIAL PREPARATION

4.1 *Aggregate* - Aggregate to be used for specimen preparation should be prepared in accordance with AASHTO T-11 and T-27. After the aggregate has dried to a constant weight, remove the aggregate from the oven, and cool to room temperature. Then sieve into the separate size fractions necessary for accurately recombining into test mixtures conforming with specified grading requirements.

4.2 *Determine material quantities* - Calculate the quantity of material required to achieve the desired air void content. These calculations are shown in Section 7.

4.3 *Mixing Temperature* - Set the oven to the mixing temperature. For mixes employing unmodified asphalt cements, the temperature of the aggregate and the asphalt at the time mixing begins shall be in accordance with the temperatures specified in AASHTO T 246-82 or ASTM D 1561-81a. Alternatively, for either an unmodified or modified asphalt, the mixing temperatures can be estimated from a Bitumen Test Data Chart (Figure 3). The temperature selected should correspond to a viscosity of 170 ± 20 cS (based on the original asphalt properties). The procedure utilizing the BTDC is the recommended procedure.

4.4 *Heating the asphalt cement* - For asphalts supplied in 5 gal. (19 l) epoxy coated containers, it must first be heated to 135C (275F) in a forced draft oven. The container should be loosely covered with a metal lid. This first heating is to subdivide the 5 gal. (19 l) sample into smaller containers for subsequent use. After approximately 1.5 h, remove the sample from the oven, and stir with a large spatula or metal rod. The sample should be stirred every half hour to ensure uniform heating. Typically, a 5 gal. (19 l) sample will require approximately 5 h for the entire heating cycle.

Note 1: - Watch for signs of blue smoke from the asphalt. This would indicate overheating. If a noticeable quantity of smoke is observed, then the oven temperature should be reduced by 10 to 15F.

Place paper or newsprint on the floor in a well-ventilated area. Place empty and clean 1 liter containers on the paper in a sequence convenient for pouring the hot asphalt. Different sized containers may also be used. It is important that the containers be properly labelled with self-adhesive labels or a diamond-tipped pencil prior to pouring.

Remove the 5 gal. (19 l) container from the oven and stir the asphalt for approximately 1 minute. Fill all the containers on the floor, taking care that the labels on the containers are not obliterated. After filling, close all containers tightly, and allow to cool to room temperature, then store at a temperature of 10C (50F). Closing the containers prior tocooling will produce a vacuum seal.

4.5 Prior to mixing, set the oven to the mixing temperature as determined in Section 4.3. Place a sufficient number of 1 liter cans (with a total weight greater than that calculated in Section 7.8) of asphalt in the oven at least 2 hours prior to mixing. Monitor the temperature of the asphalt periodically. When the temperature approaches the mixing temperature, transfer the asphalt into a large pot (e.g. a 12 qt. stock pot) and at the same time weigh the amount of asphalt added to the pot. Transfer enough asphalt to equal the amount calculated in Section 7.8 plus an extra 80 g (to account for the quantity retained in the pot after asphalt has been added to the aggregate). Then place the pot in the oven and continue to monitor the temperature periodically.

Note 2: - This constitutes the second heating of the asphalt. Any asphalts that have been heated more than twice must be discarded.

4.6 *Mixing* - Preheat the mixer approximately 1 hour prior to mixing. Place coarse aggregate in the mixer followed by the fine aggregate and then the asphalt. Mix for approximately 4 minutes to ensure uniform coating of the aggregate.

4.7 *Short Term Aging* - After mixing, remove the mixture from the mixer and place it in metal pans. Place the mixture in an oven set at a temperature of 135 ± 1C (275F) for 4 h ± 1 min. Stir the mixture once an hour.

5. COMPACTION

5.1 Assemble the mold as shown in the schematic illustrated in Figure 2. Preheat the mold with a "tent" equipped with infrared heat lamps (see Figure 4).

5.2 Check the oil and fuel levels in the rolling wheel compactor and refill if necessary. Start the compactor and allow it to warm up. Spray a mild soapy solution on the rollers.

5.3 Apply sparingly a light oil (e.g. PAM cooking oil) to the base and sides of the mold.

5.4 Remove a pan of mixture from the oven and place it in the center of the mold. Level the mixture using a rake while at the same time avoiding any segregation of the mixture (i.e. avoid any tumbling of the coarse aggregate). Repeat this process until the mold is filled with the required quantity of material to achieve the target air void content. This should be all of the pre-weighed material. Tamp the mixture to achieve as level a surface as possible.

5.5 Monitor the temperature of the mixture at the surface, at mid-depth, and at the bottom in various locations. Allow the mixture to cool until the coolest temperature corresponds to the pre-established compaction temperature.

Note 3: The field compaction temperature should be used. As general guide, the compaction temperature to be used for most typical asphalt cements (AC-5 to AC-30) should correspond to an equiviscous temperature of 280 ± 30 cS (based on original binder properties) as described in Section 4.3. If necessary, the mixture should be placed in an oven until it reaches a uniform temperature.

Note 4: Lower compaction temperatures in the range between 240 to 280F (115C to 138C) may be necessary depending on the compactibility of the mixtures used under the rolling wheel compactor.

5.6 Compact the mixture until the rollers bear down on the compaction stops (steel channels with depths equal to slab thickness inserted in the mold as shown in Figure 2). When compacting, each pass of the roller must extend from the ramp to the platform in a continuous motion, with no stops on the mixture. After the first few passes, it may be necessary to scrape bituminous mixture off the rollers and reshape the mixture.

5.7 When compaction is complete, let the slab cool overnight (typically 15 to 16 hours) before removing the mold. If the slab is still warm to the touch, do not remove the mold. Do *not* place any weights on top of the slab.

5.8 After the slab is completely cooled, remove the slab from the mold together with the removable base of the mold (constructed of particle board) before placing on a pallet jack.

5.9 The slab should then be dry cored and sawn into the desired specimen shapes as soon as possible. Note that the specimens should not be taken from the outside edges (2 to 2.5 in (5 to 6.3 cm)) of the slab. This is approximately 2 to 2.5 times the nominal top size of the aggregate used. Store approximately 3 kg of the wasted mix for the determination of the theoretical maximum specific gravity as described in Section 6.

6. CALCULATE THE AIR VOID CONTENT

6.1 Weigh the dry, unwrapped, room temperature stabilized specimen and record this as *Mass in Air*, A.

6.2 Wrap the specimen in parafilm so that it is completely watertight with no air bubbles between the parafilm and the specimen. Use the minimum amount of parafilm necessary. Weigh the specimen in air and record this as *Mass in Air with Parafilm*, B.

6.3 Weigh the wrapped specimen suspended in water at 25C (77F), taking the reading as soon as the balance stabilizes. Record this as the *Mass in Water with Parafilm*, C.

6.4 Determine the specific gravity of parafilm at 25C (77F) or assume a value of 0.9. Record this as D.

6.5 Calculate the bulk specific gravity of the specimen as follows:

$$G_{mb} = [\frac{A}{B-C-(\frac{B-A}{D})}] \quad (1)$$

where:

A	=	Mass of dry uncoated specimen in air, g
B	=	Mass of parafilm coated specimen in air, g
C	=	Mass of parafilm coated specimen in water, g
D	=	Specific gravity of parafilm at 25C (77F)

6.6 Determine the theoretical maximum specific gravity, G_{mm}, in accordance with ASTM D 2041.

6.7 Calculate the air void content as follows:

$$\text{Air Voids} = [1-\{\frac{G_{mb}}{G_{mm}}\}] * 100\ \% \quad (2)$$

7. CALCULATE THE QUANTITY OF BITUMINOUS MIX REQUIRED

7.1 Measure the dimensions (height, length and width) of the compaction mold that will contain the compacted slab. Record this as H, L and W in dm.

7.2 Determine the volume (V) of the mold in units of dm^3.

7.3 Determine the maximum specific gravity of the bituminous mix at the desired asphalt content in accordance with ASTM D 2041. Record this as G_{mm}.

7.4 Determine target bulk specific gravity for compacted slab based on the target air voids content:

$$G_{mb} = G_{mm}[1 - \frac{\%AV}{100}] \quad (3)$$

where:

G_{mb} = target bulk specific gravity of the compacted slab

%AV = target air voids of the compacted slab

7.5 Determine the unit mass (density) of the compacted slab:

$$\rho = G_{mb}\rho_w \quad (4)$$

where:

ρ = unit mass of the compacted slab, kg/m^3

ρ_w = unit mass of water, kg/m^3

7.6 Determine the mass, M (kg) of the compacted slab:

$$M = \rho V$$

7.7 Determine the mass of the aggregate required for compaction as shown below in Equations 5 and 6. Equation 5 uses the asphalt content based on the dry mass of the aggregate, whereas Equation 6 uses the asphalt content based on total mass of the mixture.

$$M_{aggr} = [\frac{M}{1+\frac{\%AC}{100}}] \quad (5)$$

$$M_{aggr} = M[\frac{\%AC}{100}] \quad (6)$$

where:

M_{aggr} = total mass of aggregate, kg

%AC = asphalt content

7.8 Determine the mass of asphalt binder required for compaction as shown in Equations 7 and 8 below. Equation 7 uses the asphalt content based on the dry mass of the aggregate, whereas Equation 8 uses the asphalt content based on total mass of the mixture.

$$M_{AC} = M_{aggr}\left[\frac{\%AC}{100}\right] \tag{7}$$

$$M_{AC} = M\left[\frac{\%AC}{100}\right] \tag{8}$$

where:

M_{AC} = mass of asphalt binder, kg

8. REPORT

8.1 The report shall include the following information:

8.1.1 *Bituminous Mixture Description* - bitumen type, bitumen content, aggregate type, aggregate gradation, and air void percentage.

8.1.2 Mix and compaction temperatures, C.

8.1.3 Mass of specimen in air, g (A)

8.1.4 Mass of specimen in air with parafilm, g (B)

8.1.5 Mass of specimen in water with parafilm, g (C)

8.1.6 Specific gravity of parafilm (D)

8.1.7 Bulk specific gravity, G_{mb}

8.1.8 Maximum Specific gravity, G_{mm}

8.1.9 Air void content of specimen, %

8.1.10 Dimensions of mold, dm

8.1.11 Volume of mold, dm^3

8.1.12 Unit mass of compacted slab, kg/dm^3

8.1.13 Mass of mix required for compaction, kg

8.1.14 Mass of aggregate required for compaction, M_{aggr} (kg)

8.1.15 Weight of asphalt required for compaction, M_{AC} (kg)

8.1.16 Time of mixing, min

8.1.17 Time of compaction, min

9. PRECISION

9.1 A precision statement has not yet been developed for this test method.

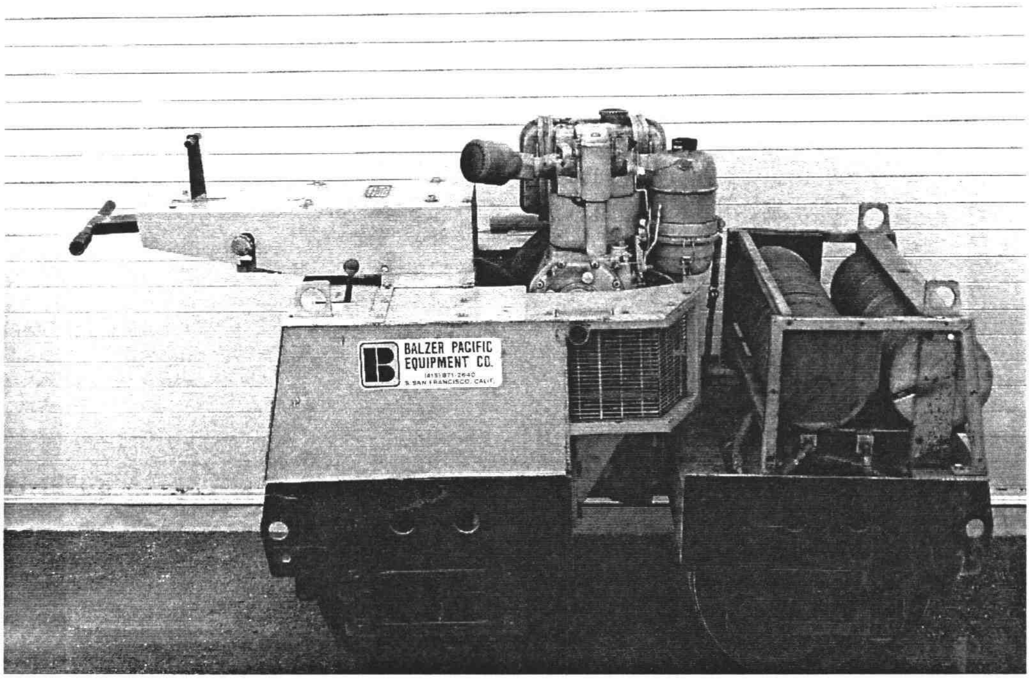


Figure A1 Rolling Wheel Compactor

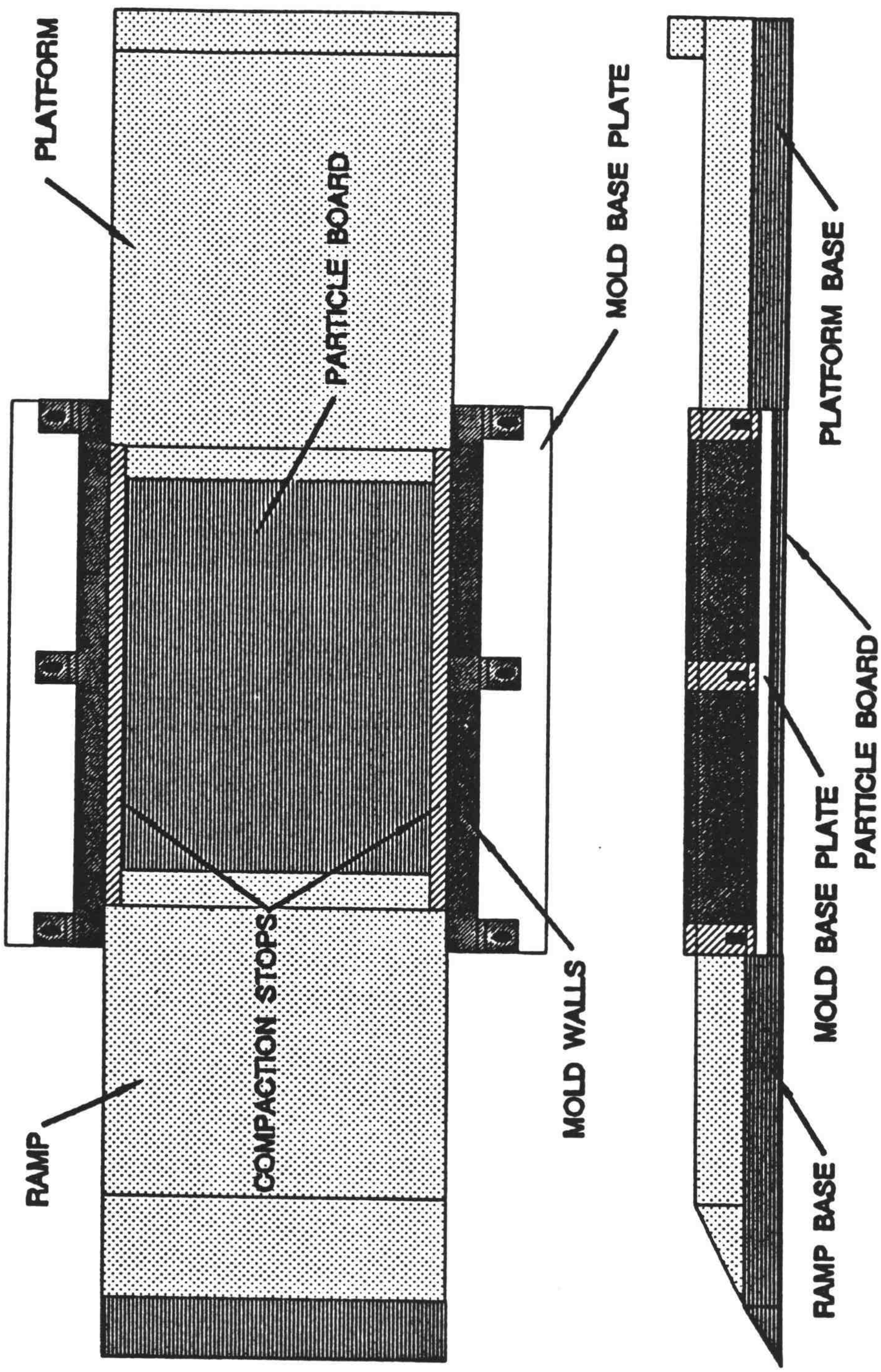


Figure A2 Schematic of Mold for Slab

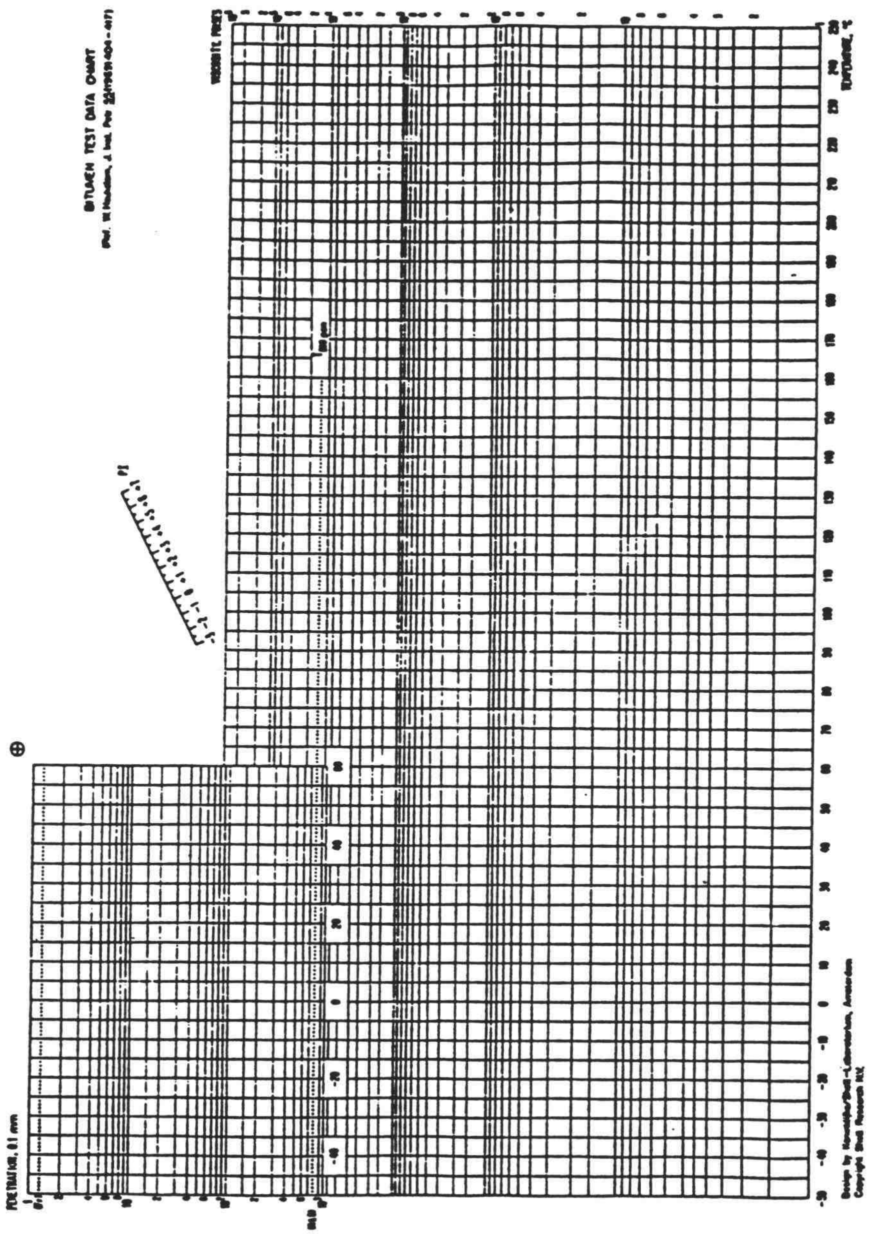


Figure A3 Bitumen Test Data Chart

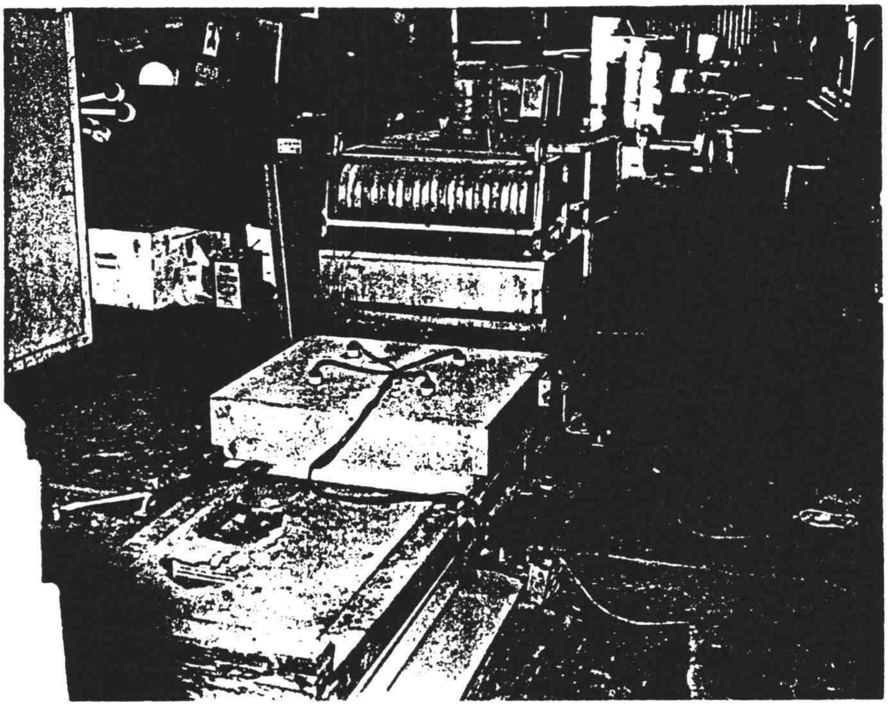


Figure A4 Preheating the Mold

APPENDIX B

TEST PROCEDURES

STANDARD METHOD OF TEST FOR

DETERMINING THE WATER SENSITIVITY CHARACTERISTICS OF COMPACTED ASPHALT CONCRETE MIXTURES SUBJECTED TO HOT AND COLD CLIMATIC CONDITIONS

AASHTO DESIGNATION: T ###-YY

(ASTM DESIGNATION: D ####-YY)

This document is the draft of a test method being developed by researchers at Oregon State University for the Strategic Highway Research Program ***(SHRP)****. The information contained herein is considered interim in nature and future revisions are expected. It is also recognized that this document may lack details with respect to the test equipment (schematics, dimensions, etc.); more details will be provided after the test procedure is finalized. This version represents the state of the test procedure as of* ***July 12, 1993***

The test method is in a format similar to the test methods contained in the American Association of State Highway and Transportation Officials' (AASHTO) standard specifications. At the conclusion of ***SHRP****, selected test methods will be submitted to AASHTO for adoption into its standard specifications.*

1. SCOPE

1.1 This method determines the water sensitivity or stripping characteristics of compacted asphalt concrete mixtures under warm and cold climatic conditions.

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

1.3 The values stated in SI units are to be regarded as the standard. The values in parentheses are for information only.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Documents:*

M ### Specification for Performance Graded Asphalt Binders

R 11 Practice for Indicating Which Places of Figures are to be Considered Significant in Specifying Limiting Values

T 2 Method for Sampling Aggregates

T 40 Method for Sampling Bituminous Materials

T 27 Method for Sieve Analysis of Fine and Coarse Aggregates

T 164 Method for Quantitative Extraction of Bitumen from Paving Mixtures

T 167 Method for Compressive Strength of Bituminous Mixtures

T 168 Method of Sampling Bituminous Paving Mixtures

T 247 Method for Preparation of Test Specimens of Bituminous Mixtures by Means of California Kneading Compactor

T ### Practice for Preparation of Asphalt Concrete Specimens by Means of the Rolling Wheel Compactor

T ### Practice for Short Term Aging of Asphalt Concrete Mixtures

2.2 *ASTM Documents:*

D 8 Standard Definitions of Terms Relating to Materials for Roads and Pavements

D 3549 Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens

3. TERMINOLOGY

3.1 Definitions for many terms common to asphalt are found in the following documents:

3.1.1 Standard Definitions D 8

3.1.2 Performance Graded Asphalt Binder M ###

4. SUMMARY OF PRACTICE

4.1 Compacted asphalt concrete test specimens are subjected to a water and temperature conditioning process. The water sensitivity characteristics of the compacted mixtures are determined based upon measurements of percent stripping, the ECS modulus, and the coefficients of permeability for air and water flow.

5. SIGNIFICANCE AND USE

5.1 The measured water sensitivity characteristics may be used to evaluate or characterize asphalt concrete mixtures.

5.2 The water sensitivity characteristics of asphalt concrete mixtures can be used to determine its suitability for use as a highway paving material. This information may also be used to compare and select various asphalt binders, asphalt modifiers, asphalt concrete mixtures, asphalt concrete additives and asphalt concrete aggregates.

6. APPARATUS

6.1 *Environmental Conditioning System (ECS)* - Any closed-loop computer controlled test system which meets the minimum requirements outlined in Table 1. The ECS must be capable of increasing the temperature within an asphalt concrete specimen to 100C and decreasing it to -20C within 2 hours. It must be capable of pulling air and distilled water through a specimen at specified vacuum levels. The ECS must be capable of applying axial load pulses (220 ± 5 N (50 ± 1 lbf) static and 6700 ± 25 N (1506 ± 5 lbf) dynamic) 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 must also be capable of measuring axial deformations and be equipped with computer software which can compute axial compressive stress and recoverable axial strain at various load cycles. In addition, the ECS must be capable of applying stresses sufficient to obtain deformations between 50 to 100 μstrain in compacted asphalt concrete specimens. The ECS is illustrated in Figures 1, 2 and 3.

6.2 *Testing Machine* - a pneumatic or hydraulic testing machine that meets the requirements outlined in 4.3 of T 167.

6.3 *Specimen End Platens* - two aluminum end platens which are 102 ± 2 mm in diameter by 51 ± 2 mm thick. Each end platen will have a drainage hole at its center that is 4.8 ± 0.5 mm in diameter and one side of each end platen will be patterned with grooves as shown in Fig. 4. In addition, the platen must have a groove around its perimeter at mid height which is of sufficient width and depth to hold the O-rings described in 6.6.2.

6.4 *Perforated Teflon Disks* - As shown in Figure 5. The perforations must coincide with the grooving pattern in the specimen end platens.

6.5 *Yoke and Spacer Assembly* - Used for mounting 2 vertical linear variable transducers (LVDTs) on the test specimen as shown in Figure 2. Spacers should not be more than 51 mm for a 102 mm specimen.

6.6 *Miscellaneous Apparatus :*

6.6.1 150 mm (6 in.) of 100 mm (4 in.) diameter rubber membrane

6.6.2 Two 102 mm (4 in.) O-Rings

6.6.3 Caulking gun for applying silicone sealant

Table B1 Minimum Test System Requirements

Measurement and Control Parameters	Range	Resolution	Accuracy
Load (compression)	0 to 4400 N	0.5%	± 1%
Axial Deformation	0 to 6.35 mm	0.0001 mm	± 0.0001 mm
Chamber Temperature	-20 to +100C	0.5C	± 0.5C
Vacuum Pressure	0 to 635 mm Hg	25 mm Hg	± 25 mm Hg
Air Flow	20 to 20 000 cm^3/min	5%	± 3%
Water Flow	0 to 2525 cm^3/min	2 cm^3/min	± 1 cm^3/min
Water Reserve Temperature	25 ± 3C	0.5C	± 0.5C

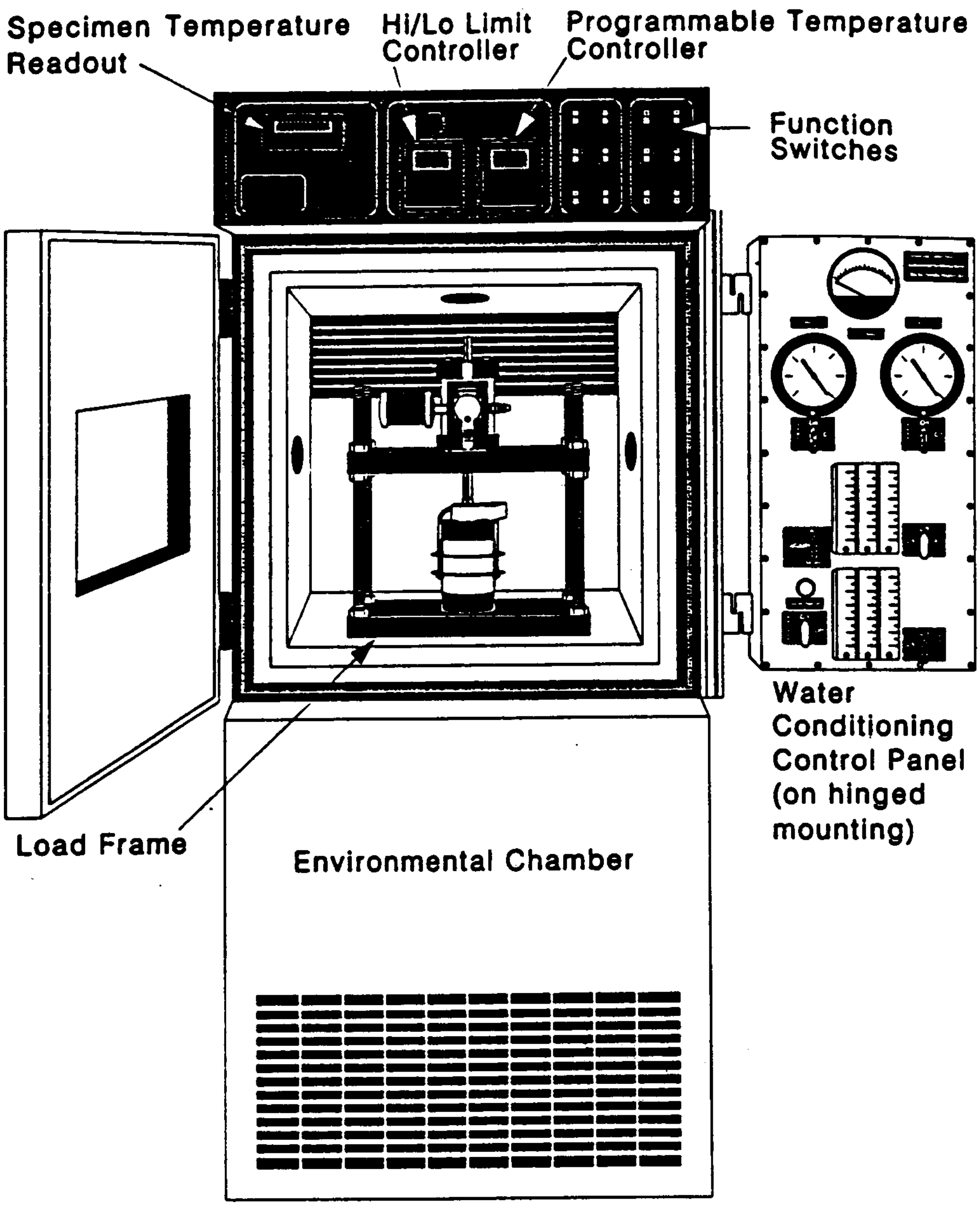


Figure B1 Environmental Conditioning System (Front View)

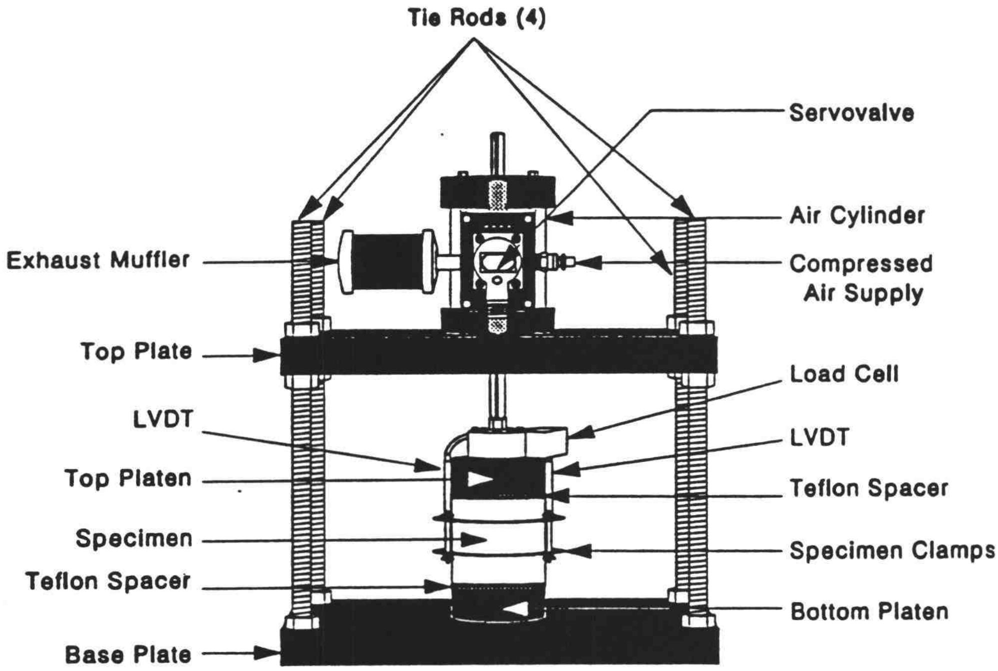


Figure B2 Load Frame with Specimen

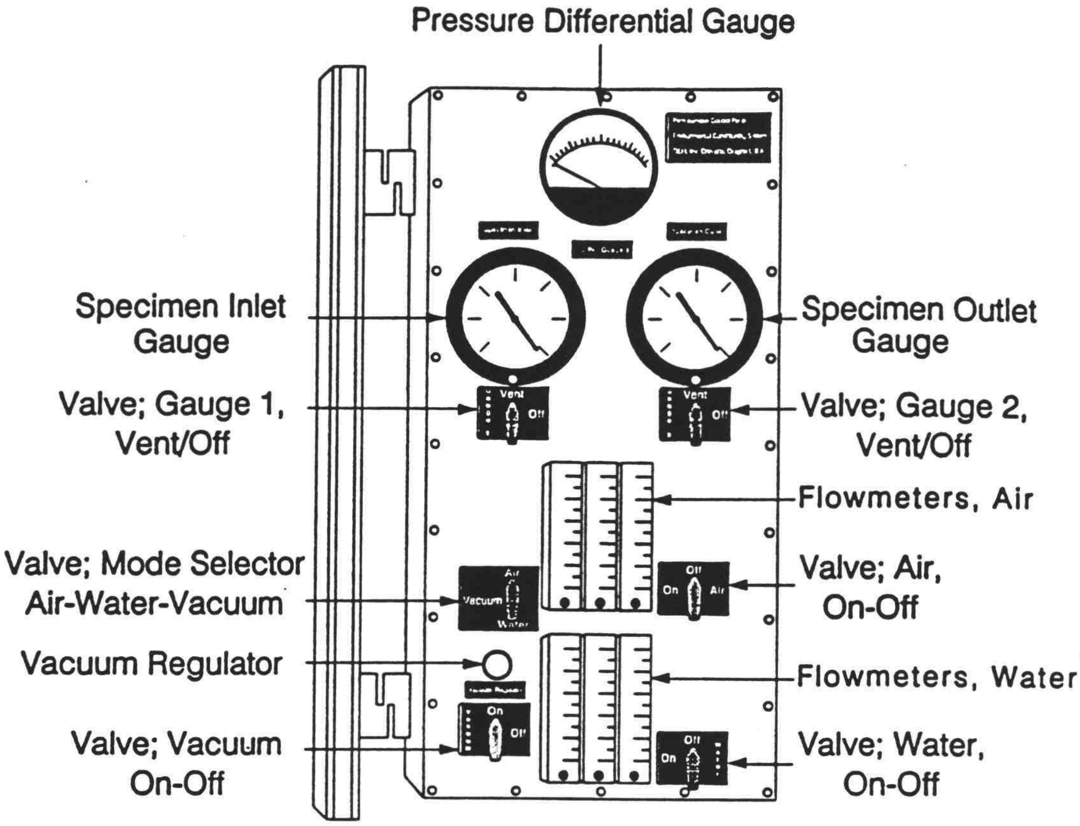


Figure B3 **Control Panel**

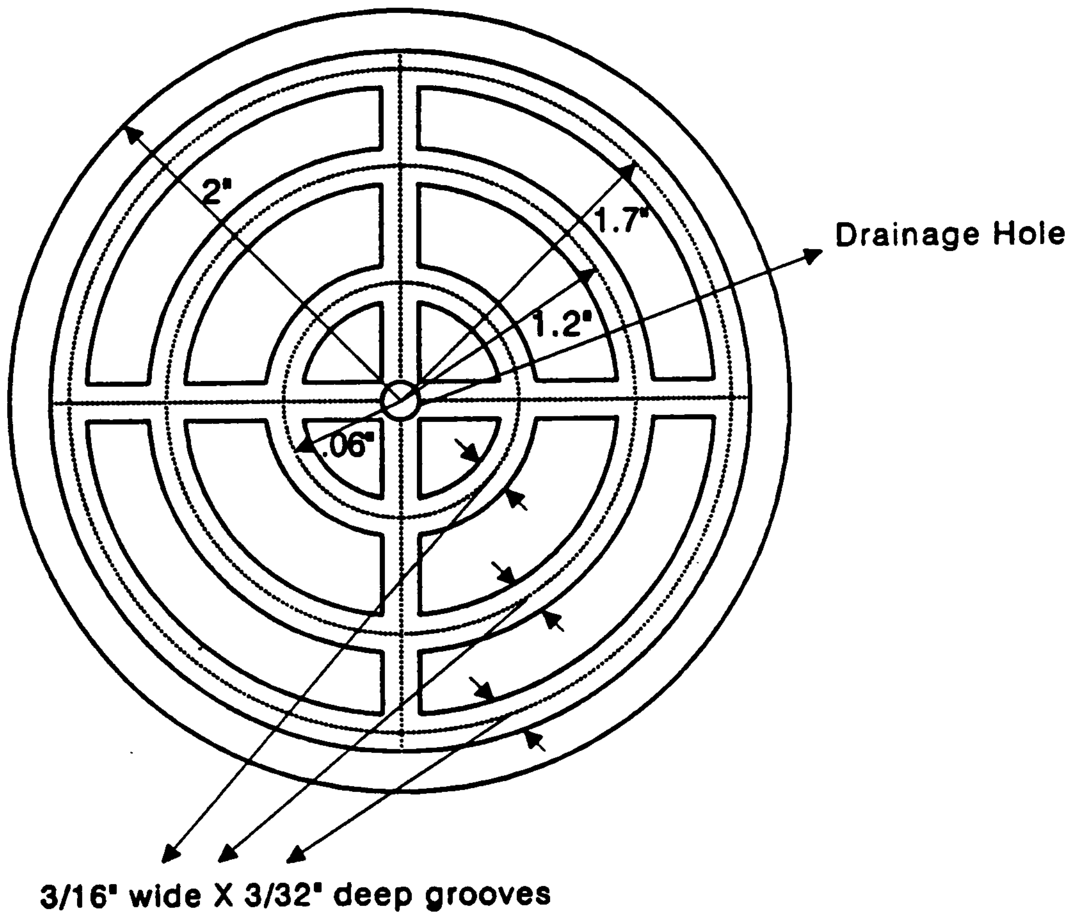


Figure B4 **Groove Pattern for End Platens**

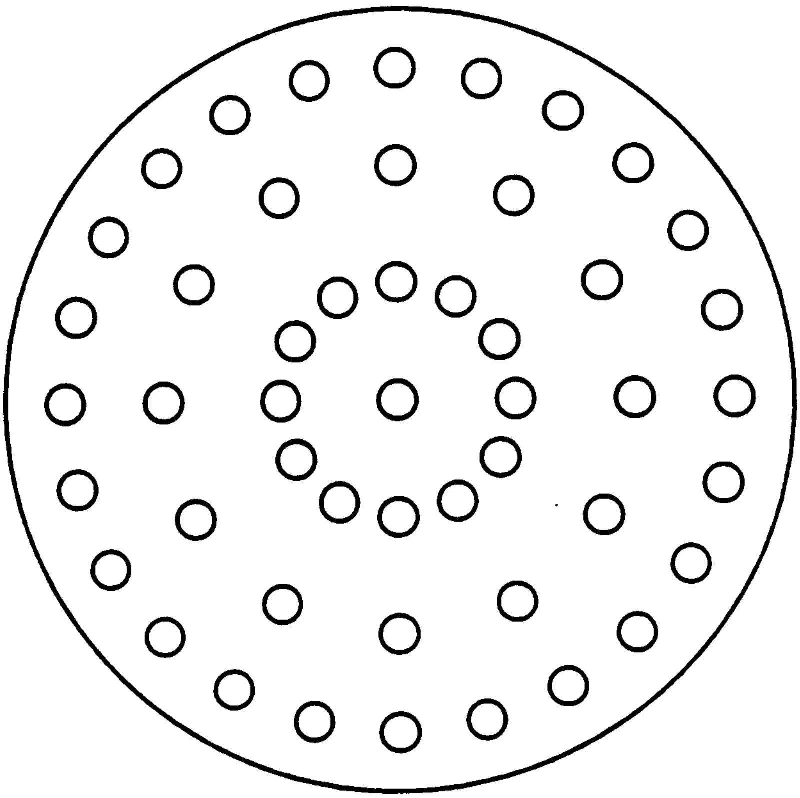


Figure B5 Perforated Teflon Disks

6.6.4 Calipers capable of measuring 150 ± 1 mm

6.6.5 Steel Spatula

6.6.6 Vacuum Source

6.6.7 Distilled Water Source

7. MATERIALS

7.1 The following materials are required:

7.1.1 Clear silicone sealant

7.1.2 Compressed air

8. SAMPLING

8.1 Asphalt binder shall be sampled in accordance with T 40.

8.2 Aggregate shall be sampled in accordance with T 2.

8.3 Asphalt concrete mixtures shall be sampled in accordance with T 168.

8.4 Compacted roadway test specimens from a newly laid pavement may be sampled and tested if the cores meet the dimension requirements specified in 9.4, however, the top and bottom of the cores must not sustain cut surfaces.

9. SPECIMEN PREPARATION

9.1 Prepare an asphalt concrete mixture sample in accordance with T ###, Preparation of Test Specimens of Bituminous Mixtures by Means of Laboratory Kneading Compaction or T ###, Preparation of Test Specimens of Bituminous Mixtures by Means of Rolling Wheel Compactor.

NOTE 1 - Plant mixed asphalt concrete samples are not to be subjected to short term aging as described in T ###.

NOTE 2 - The top and bottom of a specimen cored from a slab must not sustain cut surfaces.

9.2 Determine the air void content of the specimen in accordance with T ### or T ###.

9.3 Measure the diameter and height of the specimen at three locations as described in D 3549. Record the average measurement as the diameter and height of the specimen within ± 1 mm.

9.4 Place the specimen inside the 150 mm long rubber membrane, centering the specimen within the membrane so that there is a 25 mm extension at each end. Inject a continuous line of silicone cement around the specimen at mid height between the membrane and the specimen. Inject sufficient silicone to ensure that the entire surface area of the specimen will be sealed. Use a spatula to smooth and spread the silicone to a thin uniform layer. Allow the specimen to stand at room temperature, overnight or longer, until the silicone is dry.

10. PROCEDURE

10.1 *Test Set-Up*

10.1.1 Place a perforated teflon disk on top of the grooved surface of the bottom end platen inside the load frame.

10.1.2 Place the specimen vertically on top of the teflon disk and bottom end platen.

NOTE 3 - Field cores shall be positioned such that the top of the specimen corresponds with the top of the pavement.

10.1.3 Place a perforated teflon disk on top of the specimen and place the top end platen on top of the disk, with the grooved surface facing the disk and specimen.

10.1.4 Seal the rubber membrane around the specimen platen assembly by placing an O-ring in each groove of the end platens, over the rubber membrane.

10.1.5 To ensure that the system is airtight, close the system to the water and air supplies by selecting vacuum with the Water-Vacuum-Air valve. Open the vacuum valve and adjust the vacuum regulator until the specimen inlet and outlet pressures read 510 ± 25 mm Hg (20 ± 1 in. Hg). Close the vacuum valve. Close the bypass valve so that any air in the specimen is removed. Monitor the specimen inlet and outlet pressure gages for 5 min. If both gage readings remain constant throughout the 5 min, the system is airtight and testing may continue. If either gage reading decreases, the system is not airtight and adjustments must be made to the system prior to continuing testing.

10.1.6 Attach the yoke with the spacers and the LVDTs to the specimen.

10.2 *Coefficient of Permeability For Air Flow*

10.2.1 Set and establish the temperature of the environmental control chamber to 25 ± 0.5C.

10.2.2 Open the vacuum valve and select air from the Water-Vacuum-Air valve. Turn the air valve on. Apply the lowest differential pressure possible (typically 6 to 7 kPa) by adjusting the vacuum regulator. Record the air flow through the test specimen. Record the pressure differential reading.

10.2.3 Repeat 10.2.2 for three additional differential pressures. The pressures selected will vary depending upon the void content of the specimen being tested. Specimens with low air voids will require higher pressures. A constant interval between the differential pressures must be selected (e.g. 20, 30, 40, and 50 kPa (3, 4.4, 5.8, and 7.3 psi)). Any range of pressures may be selected that provides measurable flows on the air flow meters and which results in a range of air flows which are within + 10% of the air flow for the 4 pressures selected.

10.2.4 Calculate the coefficient of permeability for air flow of the test specimen as described in 11.2.1 for each of the pressures applied in 10.2.2 and 10.2.3. Calculate and report the average of the four results.

10.2.5 Close the vacuum valve.

10.3 *ECS Modulus Test*

10.3.1 Maintain the temperature of the environmental chamber at 25 ± 0.5C. Remove the spacers from the yoke.

10.3.2 Apply a static load of 130 ± 25 N (30 ± 5 lbf) and an axial compressive repeated load of approximately 2200 N (494 lbf) to the test specimen. The repeated load should be in a haversine wave form with a load duration of 0.1 s and a rest period of 0.9 s between load pulses.

10.3.3 Adjust the specimen and/or yoke assembly until the readings from the two LVDTs are within 15% of each other.

10.3.4 If the strain is less than 50 μstrain, increase the magnitude of the repeated load until a strain level between 50 and 100 μstrain is reached. If the strain is more than 100 μstrain, decrease the repeated load until a strain level between 50 and 100 μstrain is reached. Record the final loads applied and utilize the same loading levels ± 25 N for subsequent ECS modulus testing after conditioning is applied to the specimen as described in 10.7.

NOTE 4 - Typically, a load of 4000 N (9000 lbf) may be required to achieve a strain level of 100 μstrain.

10.3.5 Measure the peak axial load and recoverable vertical deformations for the load interval from the last 5 cycles. Record the peak axial load and recoverable vertical deformations at each load cycle for the last five load cycles applied. Calculate the ECS moduli as outlined in 11.3.3 and 11.3.4.

NOTE 5 - Do not exceed 250 load cycles when performing the ECS modulus test as this will damage the specimen.

10.3.6 Remove the load from the specimen after the last load cycle. Close the valves of the inlet and outlet gages.

10.4 *Vacuum Conditioning*

10.4.1 Open the bypass valve.

10.4.2 Open the vacuum valve and close the bypass valve. Apply a vacuum of 510 ± 25 mm Hg (20 ± 1 in. Hg) for 10 ± 1 min.

10.4.3 Open the bypass valve. Close the vacuum valve.

10.5 *Wetting*

10.5.1 Maintain the temperature of the environmental chamber at 25 ± 0.5C. Establish the temperature of the distilled water source at 25 ± 3C. Open the bypass valve.

10.5.2 Select water from the Vacuum-Water-Air valve. Turn on the vacuum valve and adjust the vacuum regulator until a level of 510 ± 25 mm Hg is measured at the specimen outlet gage.

10.5.3 Wait about 1 min or until the distilled water has been drawn into the tubing and the system. Close the bypass valve and allow the distilled water to be pulled through the test specimen for 30 ± 1 min.

10.6 *Coefficient of Permeability For Water Flow*

10.6.1 Set the vacuum level to approximately 40 kPa (5.8 psi) differential pressure by adjusting the vacuum regulator. Record the water flow through the test specimen. Record the pressure differential reading.

10.6.2 Repeat 10.6.1 for three additional pressures. The pressures selected will vary depending on the void content of the specimen being tested. Specimens with low air voids will require higher pressures. The pressures may range from 20 to 40 kPa (3 to 6 psi) differential pressure. A constant interval between the pressures must be selected (e.g. 20, 30, 40, and 50 kPa (3, 4.4, 5.8, and 7.3 psi)). Any range of pressures may be selected that provide measurable flow on the water flow meter and which results in a range of water flows which are within + 10% of the water flow for the 4 pressures selected.

10.6.3 Calculate the coefficient of permeability for water flow as described in 11.5.1 for each pressure. Calculate and report the average result.

10.7 *Water Conditioning*

10.7.1 Conduct water conditioning for either the warm or cold climate conditions as described in 10.7.2 or 10.7.3, respectively. Figure 6 summarizes the procedure described in 10.7.2 and 10.7.3.

10.7.2 *Warm Climate Conditioning*

10.7.2.1 Open the vacuum valve and set the vacuum pressure to 254 ± 25 mm Hg (10 ± 1 in. Hg) at the specimen outlet gage. Set the water flow to 4 ± 1 cm^3/min. Close the bypass valve.

10.7.2.2 Set the temperature of the environmental cabinet to 60 ± 0.5C for 6 hr ± 5 min. followed by a temperature of 25 ± 0.5 C for at least 2 hours (but not more than 6 hours).

10.7.2.3 Apply an axial compressive load of 90 ± 5 N static (20 ± 1 lbf) and 900 ± 25 N (202 ± 5 lbf) dynamic to the test specimen, in a haversine wave form with a load duration of 0.1 s and a rest period of 0.9 s between load pulses. Continuous application of the load is to occur throughout the hot conditioning period (i.e., 6 hours at 60 C)

NOTE 6 - For open-graded mixes, the loads may need to be reduced to avoid damage to specimen.

10.7.2.4 After 6 h, terminate the load applications.

CONDITIONING FACTOR	WETTING *	CONDITIONING STAGE			
		CYCLE-1	CYCLE-2	CYCLE-3	CYCLE-4
Vacuum Level (mm. Hg):	510	250	250	250	250
Repeated Loading	NO	YES	YES	YES	NO
Ambient Temp. (C) **	25	60	60	60	-18
Duration (hr.)	0.5	6	6	6	6

Conditioning Procedure for Warm Climate (WETTING through CYCLE-3)

Conditioning Procedure for Cold Climate (WETTING through CYCLE-4)

* WETTING: Wetting the specimen prior to the conditioning cycles

** Inside the Environmental Cabinet

Notes:

1. The conditioning procedure for a warm climate is wet then 3 hot cycles
2. The conditioning procedure for a cold climate is wet then 3 hot cycles plus one cold cycle

Figure B6 Conditioning Cycles for Warm and Cold Climates

10.7.2.5 After 8 h or more (no more that 12 hours), close the vacuum valve, open the bypass valve and open the system to atmospheric pressure. Continue to maintain the temperature setting of the environmental chamber at 25 ± 0.5C. Determine the ECS moduli as described in 10.3.2 to 10.3.6.

NOTE 7 - If excessive deformation (>5%) of the specimen is experienced after a conditioning cycle, terminate further conditioning. Record all information collected as specified in 12.1. Conduct the stripping evaluation as described in 10.8. Note in data recorded that failure of the specimen was encountered during conditioning.

10.7.2.6 Continue to maintain temperature setting of the environmental chamber at 25 ± 0.5C and determine the coefficient of permeability for water flow as described in 10.6.

10.7.2.7 Apply a second hot conditioning cycle by repeating 10.7.2.1 to 10.7.2.6.

10.7.2.8 Apply a third hot conditioning cycle by repeating 10.7.2.1 to 10.7.2.6.

10.7.3 *Cold Climate Conditioning*

10.7.3.1 Complete the three hot conditioning cycles as described in 10.7.2.

10.7.3.2 Turn the vacuum valve on and set the vacuum pressure to 250 ± 25 mm Hg (10 ± 1 in. Hg) at the outlet gage and set the water flow to 4 ± 1 cm^3/min. Terminate the loads applied. Check that the bypass valve is closed.

10.7.3.3 Set the temperature of the environmental chamber to -18 ± 0.5C for 6 hours ± 5 min followed by a temperature of 25 ± 0.5C for at least 2 h (no more than 6 hours).

10.7.3.4 After 8 h or more (not more than 12 hours), close the vacuum valve, open the bypass valve and open the system to atmospheric pressure. Continue to maintain the temperature setting of the environmental chamber at 25 ± 0.5C. Determine the ECS modulus as described in 10.3.2 to 10.3.6.

10.7.3.5 Continue to maintain the temperature setting of the environmental chamber at 25 ± 0.5C and determine the coefficient of permeability for water flow as described in 10.6.

10.8 *Stripping and Binder Migration Evaluation*

10.8.1 At the conclusion of the last conditioning cycle, remove the specimen from the environmental chamber. Remove the membrane from the specimen and place the specimen in a diametral position between two bearing plates of a loading jack on a mechanical or hydraulic testing machine.

10.8.2 Apply a load sufficient to induce a vertical crack in the specimen.

10.8.3 Remove the test specimen and pull the two halves apart.

10.8.4 Estimate the percentage of stripping which has occurred by making a relative comparison to the standard patterns of stripping shown in Fig. 7.

10.8.5 Estimate the level of binder migration which has occurred by making a relative comparison to the standards shown in Figure 8.

11. CALCULATIONS

11.1 Calculate the following:

11.1.1 *Cross Sectional Area (m^2):*

$$A = \frac{\pi d^2}{40000} \qquad (1)$$

where:

d = Average diameter of the test specimen, in cm

π = 3.14159

11.2 After conducting the air permeability testing outlined in 10.2, calculate the following:

11.2.1 *Coefficient of Permeability for Air Flow (cm/s)*

$$k_a = \frac{QH}{\Delta hA} \quad (2)$$

where:

k_a = coefficient of permeability for air flow, cm/s

Q = flow rate of air at mean pressure across specimen, cm^3/s

H = average height of the test specimen, cm

Δh = difference in piezometric head across the specimen, cm

A = cross sectional area of the specimen, cm^2

NOTE 8 : Equation 2 is only applicable for test specimens which are 102 ± 2 mm in diameter and for air supply testing temperatures which are 25 ± 30C. It is also only applicable for the units above.

11.3 After applying each of the last five load cycles as specified in 10.3.5, calculate the following:

11.3.1 *Peak Stress (kPa) per load cycle:*

$$\sigma_{i\text{-}n} = \{\frac{V_{i\text{-}n}}{A}\} \quad (3)$$

where:

$V_{i\text{-}n}$ = peak load applied by the vertical actuator over a load cycle, in N

i = number of conditioning cycles applied (i.e. 0, 1,...4)

n =number of load cycles applied (i.e. 1, 2,...5)

11.3.2 *Recoverable Axial Strain (mm/mm) per load cycle:*

$$\varepsilon_{i\text{-}n} = \frac{\sigma_{ri\text{-}n}}{h} \quad (4)$$

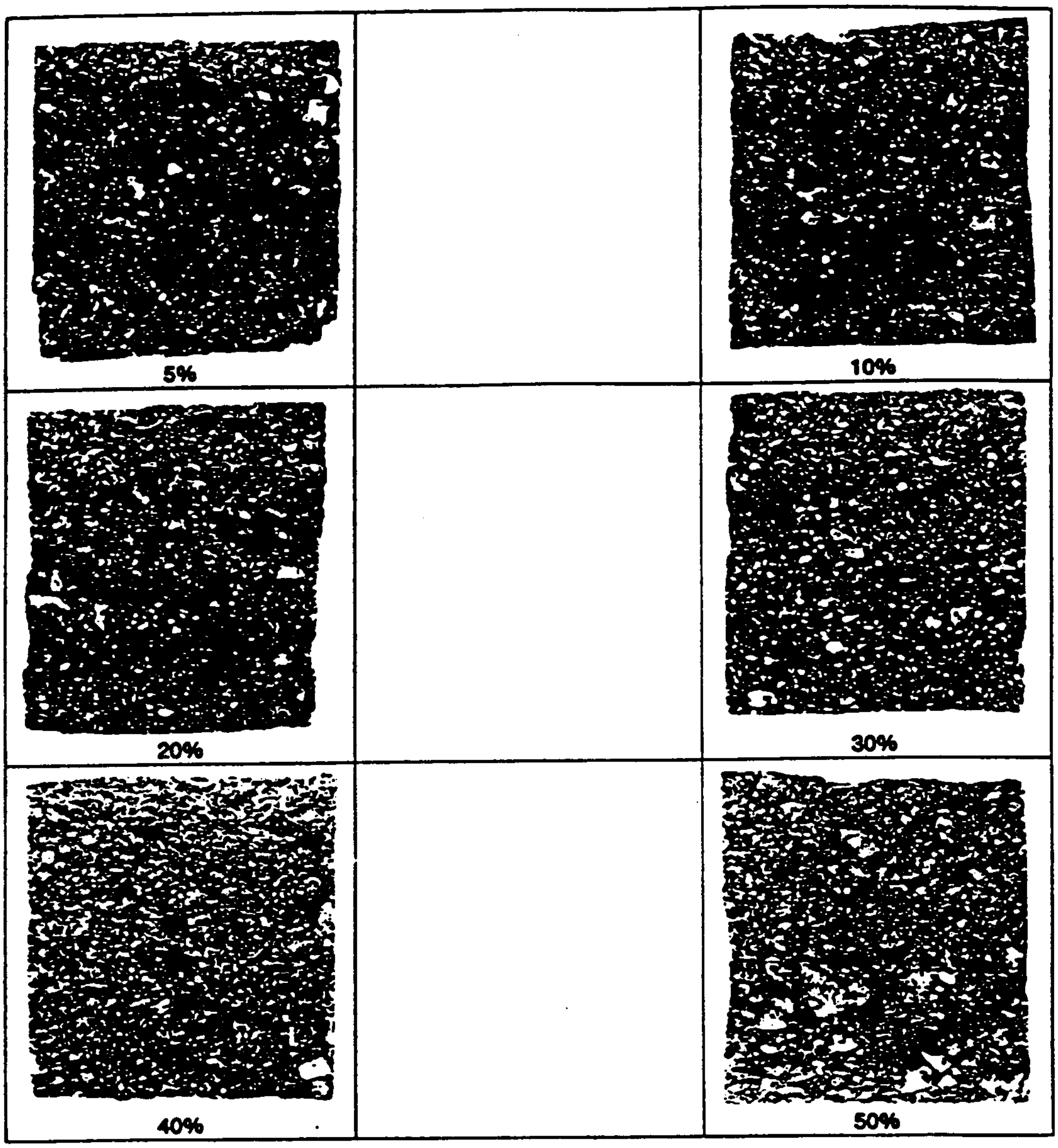


Figure B7 Stripping Rate Standards

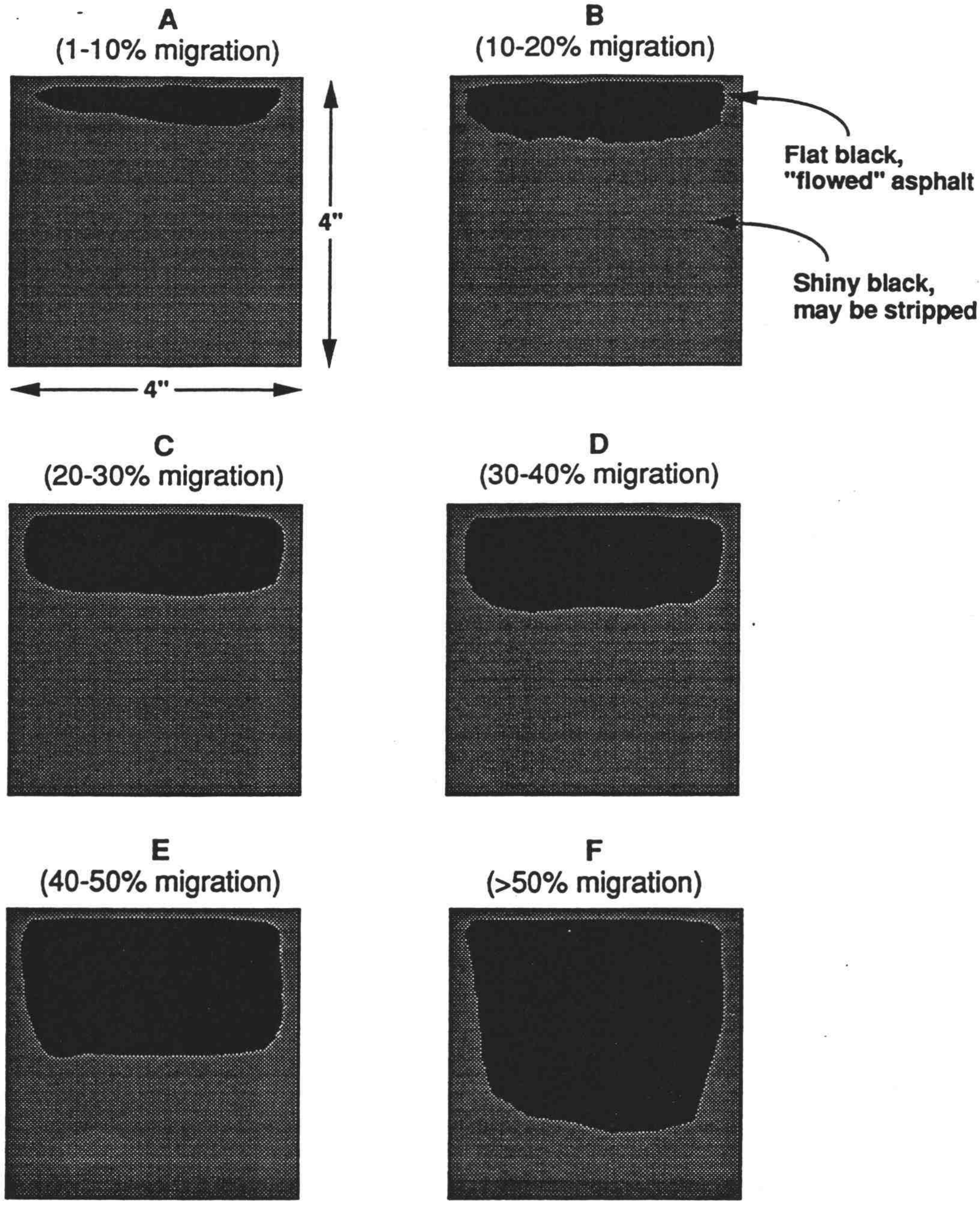


Figure B8 Binder Migration Standards

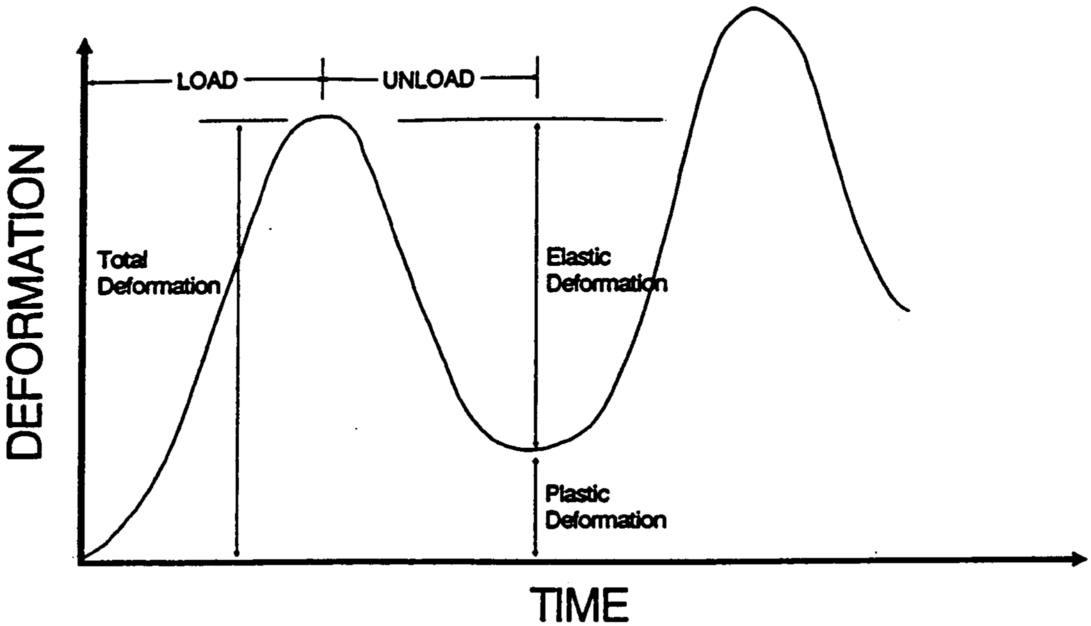


Figure B9 Illustration of Specimen Deformation Resulting from Application of Load Cycles

where:

σ_{ri-n} = peak recoverable vertical deformation over a load cycle, in mm

h = gage length, the distance over which deformations are measured (i.e. distance between yoke rings), in mm

NOTE 9 - The recoverable deformation is the portion of the total deformation that disappears (or is recovered) upon unloading the specimen as shown in Figure 9.

11.3.3 *ECS Modulus (kPa) per load cycle:*

$$M_{i-n} = [\frac{\sigma_{i-n}}{\varepsilon_{i-n}}] \quad (5)$$

11.4 After calculating ECS modulus for the last five load cycles as described in 11.3.5, calculate the following:

11.4.1 *Average ECS Modulus (kPa) per conditioning cycle:*

$$M_{Ai} = \frac{\sum_{n=1}^{5} (M_{i-n})}{\Delta n} \quad (6)$$

where:

Δn = the number of load cycle included in M_{Ai} calculation (for last five load cycles, $n = 5$)

11.5 After conducting the water permeability testing outlined in 10.6, calculate the following:

11.5.1 *Coefficient of Permeability For Water Flow (cm/s):*

$$k_w = \frac{Q\,H}{\Delta h\,A} \quad (7)$$

where:

k_w = coefficient of permeability for water flow, cm/s

Q = flow rate of water at pressure across specimen, in cm^3/s

ΔH = average height of the test specimen, cm

h = difference in piezometric head across the specimen, cm

A = cross sectional area of the specimen, cm^2

NOTE 10: Equation 7 is only applicable for test specimens which are 102 ± 2 mm in diameter and for water supply testing temperatures which are 25 ± 30C. It is also only applicable for the units above.

11.6 After completing each conditioning cycle (i), compute the following:

11.6.1 *ECS Modulus Ratio:*

$$MR_i = \left[\frac{M_{Ai}}{M_{A0}} \right] \tag{8}$$

where:

M_{A0} = initial ECS modulus, in kPa

12. REPORT

12.1. Report the following information:

12.1.1 *Asphalt Binder Grade*

12.1.2 *Asphalt Binder Content* - in % to the nearest 0.1%

12.1.3 *Aggregate Type and Gradation*

12.1.4 *Mixing and Compaction Conditions* - the following information as applicable:

12.1.4.1 *Plant Mixing Temperature* - in C to the nearest 1C

12.1.4.2 *Laboratory Mixing Temperature* - in C to the nearest 1C

12.1.4.3 *Laboratory Compaction Temperature* - in C to the nearest 1C

12.1.4.4 *Laboratory Compaction Method*

12.1.4.5 *Compacted Specimen Height* - in cm to the nearest 0.10 cm

12.1.4.6 *Compacted Specimen Diameter* - in cm to the nearest 0.10 cm

12.1.4.7 *Compacted Specimen Area* - in m^2 to the nearest 0.0002 m^2

12.1.4.8 *Compacted Specimen Density* - in kg/m^2 to the nearest 1 kg/m^2

12.1.4.9 *Compacted Specimen Air Voids* - in % to the nearest 0.1%

12.1.5 *Coefficient of Permeability for Air Flow* - a table listing of the following results for each differential pressure applied:

12.1.5.1 *Chamber Testing Temperature* - in C to the nearest 0.5C

12.1.5.2 *Differential Pressure* - kPa to the nearest 1 kPa

12.1.5.3 *Air Flow* - in cm^3/min to the nearest 2 cm^3/min

12.1.5.4 *Coefficient of Permeability For Air Flow* - in cm/s to the nearest 2 cm/s

12.1.6 *Average Coefficient of Permeability for Air Flow* - in cm/s to the nearest 2 cm/s

12.1.7 *ECS Modulus Results* - a table listing the following results for each load cycle (last five cycles) prior to any conditioning cycles and after each conditioning cycle:

12.1.7.1 *Chamber Testing Temperature* - in C to the nearest 0.5C

12.1.7.2 *Static Load Applied* - in N to the nearest 5 N

12.1.7.3 *Dynamic Load Applied* - in N to the nearest 5 N

12.1.7.4 *Peak Stress* - in kPa to the nearest 0.1 kPa

12.1.7.5 *Recoverable Axial Strain* - in mm/mm to the nearest 10^{-6} mm/mm

12.1.7.6 *ECS Modulus* - in kPa to the nearest 5 kPa

12.1.8 *Initial ECS Modulus* - in kPa to the nearest 5 kPa

12.1.9 *Coefficient of Permeability for Water Flow* - a table listing the following results for each differential pressure applied prior to applying any condition cycles and after each conditioning cycle is applied:

12.1.9.1 *Chamber Testing Temperature* - in C to the nearest 0.5C

12.1.9.1 *Water Temperature* - in C to the nearest 0.5C

12.1.9.2 *Differential Pressure* - in kPa to the nearest 1 kPa

12.1.9.3 *Water Flow* - in cm^3/min to the nearest 2 cm^3/min

12.1.9.4 *Coefficient of Permeability for Water Flow* - in cm/s to the nearest 10^{-4} cm/s

12.1.10 *Initial Average Coefficient of Permeability for Water Flow* - in cm/s to the nearest 10^{-4} cm/s

12.1.11 *Average Coefficient of Permeability for Water Flow after Each Conditioning Cycle Applied* - in cm/s to the nearest 10^{-4} cm/s

12.1.12 *Water Conditioning Results* - a table listing the following results for each conditioning cycle:

12.1.12.1 *Average ECS Modulus* - in kPa to the nearest 5 kPa

12.1.12.2 *ECS Modulus Ratio*

12.1.13 *Stripping Rate* - in percent to the nearest 5 percent

12.1.14 *Binder Migration* - single letter designation

13. PRECISION

13.1 Data to support a precision statement for this test method are not available.

13.2 Since there is no accepted reference value, the bias for this test method cannot be determined.

14. KEY WORDS

14.1 Asphalt concrete, bituminous paving mixtures, water sensitivity, stripping potential, ECS modulus, permeability.

STANDARD METHOD OF TEST FOR

ASPHALT PAVEMENT RUTTING TEST WITH THE OSU WHEEL TRACKER

AASHTO DESIGNATION: T ###-YY

(ASTM DESIGNATION: D ####-YY)

*This document is the draft of a test method being developed by researchers at Oregon State University for the Strategic Highway Research Program **(SHRP)**. The information contained herein is considered interim in nature and future revisions are expected. It is also recognized that this document may lack details with respect to the test equipment (schematics, dimensions, etc.); more details will be provided after the test procedure is finalized. This version represents the state of the test procedure as of* ***July 12, 1993***

The test method is in a format similar to the test methods contained in the American Association of State Highway and Transportation Officials' (AASHTO) standard specifications. At the conclusion of ***SHRP****, selected test methods will be submitted to AASHTO for adoption into its standard specifications.*

1. SCOPE

1.1 This method determines the rutting susceptibility of water and temperature conditioned asphalt concrete beam specimens. The amount of rutting is used a measure of the performance of the mixture in terms of water sensitivity.

2. APPLICABLE DOCUMENTS

2.1 *AASHTO Test Methods:*

T ### Practice for Preparation of Asphalt Concrete Specimens by Means of the Rolling Wheel Compactor

2.2 *ASTM Test Methods:*

D 8 Standard Definitions of Terms Relating to Materials for Roads and Pavements

D 3549 Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens

3. SUMMARY OF PRACTICE

3.1 Compacted asphalt concrete test specimens are subjected a water and temperature conditioning process. The water sensitivity characteristics of the compacted mixtures are determined based upon measurements of percent stripping, binder migration and the amount of rutting.

4. APPARATUS

4.1 *LCPC Rutting Tester* - Also known as the OSU Wheel Tracker, described in Table 1.

4.2 *Specimen Conditioning System* - A system capable of pulling a vacuum of 25 in. Hg (635 mm) through the beam specimen.

4.3 *Hot Water Bath* - A hot water bath capable of holding two 20 x 7.5 x 4 in. (508 x 190.5 x 101.6 mm) specimen containers. The bath will be capable of maintaining a temperature of 140F ± 9F (60C ± 5C).

4.4 *Temperature Controlled Cabinet* - A hot water bath capable of holding two 20 x 7.5 x 4 in. (508 x 190.5 x 101.6 mm) specimen containers. The cabinet will be capable of maintaining a temperature of -0.4F ± 9F (-18C ± 5C).

4.5 *Miscellaneous Apparatus:*

4.5.1 Specimens Holders

4.5.2 Compressed Air Source

4.5.3 Vacuum Source

5. MATERIALS

5.1 The following materials are required:

5.1.1 Clear silicone sealant

5.1.2 Latex rubber sheeting

6. SPECIMEN PREPARATION

6.1 Prepare two asphalt concrete mixture specimens in accordance with T ### "Standard Practice for Preparation of Test Specimens of Bituminous Mixtures by Means of Rolling Wheel Compactor."

6.2 Determine the air void content of the specimens in accordance with Section 6 of T ###.

6.3 Place an 1 in. band of latex rubber sheeting around the circumference of each beam specimen at mid-height, using silicon rubber sealant. Allow to cure overnight (24 hours).

6.4 *Vacuum Conditioning*

6.4.1 Verify the dry weight of specimen and air void content of the specimen were determined in accordance with T ####.

6.4.2 Place the beam specimen on the bottom platen of the vacuum conditioning apparatus.

6.4.3 Place the top platen of the vacuum conditioning system on the specimen.

6.4.4 Fit the latex rubber membrane of the vacuum conditioning up over the specimen and top platen. Secure with appropriate clamping ring.

6.4.5 Set vacuum level to 23 in. Hg (584 mm). Allow specimen to draw water for 30 minutes.

6.4.6 Remove the specimen from the vacuum apparatus.

6.4.7 Weight the specimen and determine the degree of saturation.

6.4.8 If the saturation level is less than 60 percent, repeat steps 6.4.2 through 6.4.7 until the saturation level exceeds 60 percent, but not more than three additional times. The total conditioning time is not to exceed two hours.

6.4.9 Repeat steps 6.4.1 through 6.4.8 with companion specimen.

6.4.10 Place each specimen in a specimen holder and fill the holder with distilled water to cover the specimen.

6.4.11 Place the specimens in their holders in the hot water bath set at 60C (140F). Allow the specimens to condition for six hours.

6.4.12 Remove the specimens from the hot water bath and allow the specimens to cool to 25C (140F) for ten hours. Refill the specimen holder with distilled water as necessary.

6.4.13 Place the specimens into the 60C (140F) hot water bath again. Allow the specimens to condition for six hours.

6.4.14 Remove the specimens from the hot water bath and place in the cold cabinet. Allow the specimens to cool to -20C (-4F) for eight hours.

6.4.15 Remove the specimens from the cold cabinet and place in the 60 C (140 F) hot water bath. Allow the specimen to condition for ten hours.

6.4.16 Remove the specimen from the hot water bath and allow the specimen to cool to 25 C (140 F) for ten hours.

6.4.17 Wrap the specimen in plastic wrap to avoid moisture loss. The specimen are now ready to test in the OSU wheel tracker. The testing should take place immediately.

7. TEST PROCEDURE

7.1 Lubricate the platens of the OSU wheel tracker with a spray lubricant such as Pam.

7.2 Place 19 x 6-1/2 in. (482.6 x 165.1 mm) teflon sheet on the platen.

7.3 Place the asphalt concrete beam in the rutting tester, on the teflon sheet. Do not rip the plastic wrap.

7.4 Place the rutting tester mold over the specimen and teflon sheet. Do not rip the plastic wrap.

7.5 Place thin expanded foam sheets between the specimen and the walls of the mold on all four sides of the specimen. The foam sheets will be cut to the side dimensions of the beam specimen.

7.6 Bolt the mold to the platen of the OSU wheel tracker.

7.7 Repeat steps 7.1 through 7.6 to place the other beam on the opposite side of the OSU wheel tracker.

7.8 Close the doors of the OSU wheel tracker.

7.9 Connect the OSU wheel tracker to power and compressed air.

7.10 Power on the fan/temperature controller and adjust the set point temperature to 104F (40C). Allow the actual temperature to reach the set point temperature before proceeding further.

7.11 Remove the plastic wrap from the top of the specimen. Using a 15/64-in. bit, drill a hole 2-in deep each beam in the outer front corner. Insert the temperature probe in the hole. Manually move the carriage to ensure the tire does not make contact with the temperature probe.

7.12 When the actual temperature reaches the set point temperature check the pressure in each tire. Ensure that each tire is pressured to 100 psi.

7.13 Spread the top of the specimen with chalk dust to prevent sticking between the tire and specimen surface.

7.14 *Precondition the test specimens as follows:*

7.14.1 With the pressure switches in the off (arret) position, set each piston pressure to 50 psi.

7.14.2 Set the counter to 25. The counter value is the number of cycles the carriage will travel: one cycle equals two wheel passes; thus, a counter value of 25 cycles equals 50 wheel passes.

7.14.3 Set the pressure switches in the on (marche) position and ensure the pressure for each piston reads 50 psi. If not, adjust the pressure to 50 psi. NOTE: When adjusting the pressure, always bring the pressure up to the set point pressure, never reduce the pressure to the set point pressure.

7.14.4 Start the carriage in motion by pressing the on (marche) push button.

7.14.5 Immediately after 50 wheel passes have been applied to the test specimens (when the carriage stops), release the pressure of each piston by turning the pressure switches to the off (arret) position.

7.15 Take measurements of the test specimen using the finger apparatus and software.

7.16 With the pressure switches still in the off (arret) position, adjust the pressure for each piston to 90 psi. Set the counter to apply the number of wheel passes for the next data set, as shown by the software. Wait for the actual temperature to reach the set point temperature before proceeding further.

7.17 When the actual temperature reaches the set point temperature, load the test specimens by turning the pressure switches to the on (marche) position. Ensure each piston pressure is 90 psi. If not, adjust the pressure to 90 psi. NOTE: When adjusting the pressure, always bring the pressure up to the set point pressure; never reduce the pressure to the set point pressure.

7.18 Start the carriage in motion by pressing the on (marche) push button.

7.19 Immediately after the wheel passes have been applied (when the carriage stops) release the pressure to each piston by turning the pressure switch to the off (arret) position.

7.20 Take measurements of the test specimen using the finger apparatus and software.

7.21 Repeat Steps 7.16 though 7.20 for all data sets given in the software package.

7.22 At the completion of the test, leave the doors to the rutting tester open and allow the test specimens to cool to room temperature. Once cooled, remove the test specimens and store them for photographing and coring.

7.23 Take a photographic record of the specimen.

7.24 Dry core three cores from the specimen into three cores. The cores will be laterally centered in the wheel path, and one core will be taken from the direct center of the length of the wheel path. No cores should be taken from the end of the wheel path where the OSU wheel tracker tire changes direction.

8. DATA ANALYSIS

Analysis of the data obtained from the rutting tester should consist of the following as a minimum:

8.1 *Calculation of the average rut depth versus number of wheel passes* - This accomplished by taking the average gage reading of data set *i+1* minus the average reading of data set *i*. That is,

$$\text{rut depth} = \frac{P12_i+P13_i+P14_i+P22_i+P23_i+P24_i+P32_i+P33_i+P34_i}{9}$$

$$-\frac{P12_0+P13_0+P14_0+P22_0+P23_0+P24_0+P32_0+P33_0+P34_0}{9}$$

where:

PXY = gage reading at position XY.

8.2 *Calculate the average shove (on each side of the rut) versus number of wheel passes* - This is accomplished by taking the average of the finger readings after certain wheel passes, minus the average of the finger readings for zero wheel passes. That is,

$$\text{shove}_{left} = \frac{P11_i+P21_i+P31_i}{3} - \frac{P11_0+P21_0+P31_0}{3}$$

and

$$\text{shove}_{right} = \frac{P15_i+P25_i+P35_i}{3} - \frac{P15_0+P25_0+P35_0}{3}$$

where:

PXY = gage reading at position XY.

8.3 *Plot the average rut depth and the average shove (both sides) versus number of wheel passes.*

Method of Test for

EFFECT OF WATER ON COHESION OF COMPACTED BITUMINUOS MIXTURES

(Modified AASHTO T 165)

(OSHD Test Method 308C-86)

1.1 Scope

This method of test is intended to measure the loss of cohesion resulting from the action of water on compacted bituminous mixtures. A numerical index of retained cohesion is obtained by comparing the compressive strength of freshly molded and cured specimens with the compressive strength of duplicate specimens that have been immersed in water under prescribed condition. Results will be evaluated by the criteria in OSHD Standard Specifications Section 402 and 403 which require the wet strength to be a minimum of 75% of the dry strength.

2.1 Apparatus

A manually or automatically controlled water bath shall be provided for bringing the imersed specimens to temperature of 25 ± 1 C (77 ± 1.8 F) for the compression test. Any convenvient pan or tank may be used provided it is of suffieent size to permit total immersion of the specimens. The water used for the wet storage of the specimens shall be either distilled or otherwise treated to eliminate electrolytes and the bath sall be emptied, cleaned, and refined with fresh water for each series of tests.

3.1 Test Specimens

The "B" specimens, which were prepared during the companion OSHD TM307, will be used. The "B" specimens would have been placed in water bath at 60 ± 1 C (140 ± 1.8 F) for a period of 24 hours.

4.1 Procedure

1. Optain the specimens from the water they have been immersed for 24 hours at 60 ± 1C (140 ± 1.8 F). Transfer them to the second water bath maintained at 25 ± 1C (77 ± 1.8F), and store them for 2 hours.

2. Test the specimens in axial compression without lateral support at a uniform rate of vertical deformation of 1.3 mm (0.05 in.) per minute per 25 mm (1 in.) of height; 5.1 mm (0.2 in.) per minute for specimens 100 mm (4 in.) in height.

6.1 Calculation

The numerical index of resistance of bitumenous mixtures to the detrimental effect of water shall be expressed as the percent of the original strength that is retained after the immersion period. It shall be calculated as follows:

$$\text{Index of Retained Strength} = \frac{S_2}{S_1} \times 100$$

Where:

S_1= Compressive strength of dry specimens, and

S_2= Compressive strength of immersed specimens

APPENDIX C

SHRP MIXTURES TEST DATA

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
FJ_RE001.ECS	AAF-1	RJ	8.4	July-10-91	0	473.0	1.00	Very Low	N/A	3.96	3.05	
FJ_RE001.ECS	AAF-1	RJ	8.4	July-10-91	6	470.2	0.99	Very Low	N/A	Not Meas	Not Meas	
FJ_RE001.ECS	AAF-1	RJ	8.4	July-10-91	12	468.0	0.99	Very Low	N/A	Not Meas	Not Meas	
FJ_RE001.ECS	AAF-1	RJ	8.4	July-10-91	18	453.1	0.96	Very Low	N/A	Not Meas	Not Meas	
FJ_RE001.ECS	AAF-1	RJ	8.4	July-10-91	24	403.6	0.85	Very Low	N/A	Not Meas	Not Meas	10
CJ_RE007.ECS	AAC-1	RJ	6.4	July-17-91	0	220.0	1.00	3.81	1.00	11.93	9.81	
CJ_RE007.ECS	AAC-1	RJ	6.4	July-17-91	6	189.0	0.86	2.91	0.76	Not Meas	Not Meas	
CJ_RE007.ECS	AAC-1	RJ	6.4	July-17-91	12	174.0	0.79	1.08	0.28	Not Meas	Not Meas	
CJ_RE007.ECS	AAC-1	RJ	6.4	July-17-91	18	164.5	0.75	0.13	0.04	Not Meas	Not Meas	
CJ_RE007.ECS	AAC-1	RJ	6.4	July-17-91	24	164.0	0.75	0.10	0.03	Not Meas	Not Meas	5
MJ_RE006.ECS	AAM-1	RJ	8.2	July-19-91	0	318.0	1.00	2.13	1.00	5.47	4.02	
MJ_RE006.ECS	AAM-1	RJ	8.2	July-19-91	6	278.7	0.88	1.98	0.93	Not Meas	Not Meas	
MJ_RE006.ECS	AAM-1	RJ	8.2	July-19-91	12	262.8	0.83	1.72	0.81	Not Meas	Not Meas	
MJ_RE006.ECS	AAM-1	RJ	8.2	July-19-91	18	251.7	0.79	0.96	0.45	Not Meas	Not Meas	
MJ_RE006.ECS	AAM-1	RJ	8.2	July-19-91	24	242.1	0.76	0.53	0.25	Not Meas	Not Meas	10
KJ_RE003.ECS	AAK-1	RJ	8.7	July-21-91	0	255.0	1.00	3.65	1.00	9.46	6.39	
KJ_RE003.ECS	AAK-1	RJ	8.7	July-21-91	6	218.2	0.86	3.48	0.95	Not Meas	Not Meas	
KJ_RE003.ECS	AAK-1	RJ	8.7	July-21-91	12	213.4	0.84	3.54	0.97	Not Meas	Not Meas	
KJ_RE003.ECS	AAK-1	RJ	8.7	July-21-91	18	204.7	0.80	3.30	0.90	Not Meas	Not Meas	
KJ_RE003.ECS	AAK-1	RJ	8.7	July-21-91	24	212.6	0.83	3.30	0.90	Not Meas	Not Meas	5
KJ_RE001.ECS	AAK-1	RJ	8.2	July-21-91	0	275.0	1.00	4.87	1.00	11.48	8.69	
KJ_RE001.ECS	AAK-1	RJ	8.2	July-21-91	6	219.0	0.80	3.93	0.81	Not Meas	Not Meas	
KJ_RE001.ECS	AAK-1	RJ	8.2	July-21-91	12	215.0	0.78	3.14	0.64	Not Meas	Not Meas	
KJ_RE001.ECS	AAK-1	RJ	8.2	July-21-91	18	201.5	0.73	3.07	0.63	Not Meas	Not Meas	
KJ_RE001.ECS	AAK-1	RJ	8.2	July-21-91	24	213.4	0.78	3.44	0.71	Not Meas	Not Meas	5
BJ_RE005.ECS	AAB-1	RJ	8.2	July-24-91	0	210.0	1.00	5.04	1.00	14.77	13.81	
BJ_RE005.ECS	AAB-1	RJ	8.2	July-24-91	6	197.5	0.94	1.91	0.38	Not Meas	Not Meas	
BJ_RE005.ECS	AAB-1	RJ	8.2	July-24-91	12	190.3	0.91	0.93	0.18	Not Meas	Not Meas	
BJ_RE005.ECS	AAB-1	RJ	8.2	July-24-91	18	189.5	0.90	0.10	0.02	Not Meas	Not Meas	
BJ_RE005.ECS	AAB-1	RJ	8.2	July-24-91	24	177.6	0.85	0.10	0.02	Not Meas	Not Meas	5

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
DJ_RE009.ECS	AAD-1	RJ	7.5	July-24-91	0	215.0	1.00	3.39	1.00	6.90	5.45	
DJ_RE009.ECS	AAD-1	RJ	7.5	July-24-91	6	174.4	0.81	2.75	0.81	Not Meas	Not Meas	
DJ_RE009.ECS	AAD-1	RJ	7.5	July-24-91	12	172.0	0.80	0.12	0.04	Not Meas	Not Meas	
DJ_RE009.ECS	AAD-1	RJ	7.5	July-24-91	18	160.9	0.75	0.07	0.02	Not Meas	Not Meas	
DJ_RE009.ECS	AAD-1	RJ	7.5	July-24-91	24	157.7	0.73	0.05	0.02	Not Meas	Not Meas	10
AJ_RE008.ECS	AAA-1	RJ	8.3	July-27-91	0	155.0	1.00	2.28	1.00	15.84	11.94	
AJ_RE008.ECS	AAA-1	RJ	8.3	July-27-91	6	137.8	0.89	2.42	1.06	Not Meas	Not Meas	
AJ_RE008.ECS	AAA-1	RJ	8.3	July-27-91	12	136.2	0.88	1.77	0.78	Not Meas	Not Meas	
AJ_RE008.ECS	AAA-1	RJ	8.3	July-27-91	18	135.0	0.87	0.59	0.26	Not Meas	Not Meas	
AJ_RE008.ECS	AAA-1	RJ	8.3	July-27-91	24	133.0	0.86	0.11	0.05	Not Meas	Not Meas	5
FJ_RE003.ECS	AAF-1	RJ	8.1	July-27-91	0	550.0	1.00	0.08	1.00	3.19	2.85	
FJ_RE003.ECS	AAF-1	RJ	8.1	July-27-91	6	547.5	1.00	Very low	N/A	Not Meas	Not Meas	
FJ_RE003.ECS	AAF-1	RJ	8.1	July-27-91	12	502.5	0.91	Very low	N/A	Not Meas	Not Meas	
FJ_RE003.ECS	AAF-1	RJ	8.1	July-27-91	18	473.9	0.86	Very low	N/A	Not Meas	Not Meas	
FJ_RE003.ECS	AAF-1	RJ	8.1	July-27-91	24	438.8	0.80	Very low	N/A	Not Meas	Not Meas	10
GJ_RE004.ECS	AAG-1	RJ	9.4	July-29-91	0	440.0	1.00	7.72	1.00	14.15	13.68	
GJ_RE004.ECS	AAG-1	RJ	9.4	July-29-91	6	350.4	0.80	4.73	0.61	Not Meas	Not Meas	
GJ_RE004.ECS	AAG-1	RJ	9.4	July-29-91	12	298.7	0.68	4.58	0.59	Not Meas	Not Meas	
GJ_RE004.ECS	AAG-1	RJ	9.4	July-29-91	18	297.9	0.68	4.10	0.53	Not Meas	Not Meas	
GJ_RE004.ECS	AAG-1	RJ	9.4	July-29-91	24	297.1	0.68	3.89	0.50	Not Meas	Not Meas	10
AJ_RE007.ECS	AAA-1	RJ	8.1	July-29-91	0	136.0	1.00	1.89	1.00	11.56	8.51	
AJ_RE007.ECS	AAA-1	RJ	8.1	July-29-91	6	133.0	0.98	0.10	0.05	Not Meas	Not Meas	
AJ_RE007.ECS	AAA-1	RJ	8.1	July-29-91	12	122.6	0.90	0.10	0.05	Not Meas	Not Meas	
AJ_RE007.ECS	AAA-1	RJ	8.1	July-29-91	18	122.0	0.90	0.09	0.05	Not Meas	Not Meas	
AJ_RE007.ECS	AAA-1	RJ	8.1	July-29-91	24	120.3	0.88	0.04	0.02	Not Meas	Not Meas	10
AD_RE007.ECS	AAA-1	RD	8.0	July-31-91	0	195.0	1.00	2.20	1.00	3.53	1.44	
AD_RE007.ECS	AAA-1	RD	8.0	July-31-91	6	190.7	0.98	4.36	1.98	Not Meas	Not Meas	
AD_RE007.ECS	AAA-1	RD	8.0	July-31-91	12	190.0	0.97	3.19	1.45	Not Meas	Not Meas	
AD_RE007.ECS	AAA-1	RD	8.0	July-31-91	18	185.0	0.95	2.92	1.33	Not Meas	Not Meas	
AD_RE007.ECS	AAA-1	RD	8.0	July-31-91	24	180.5	0.93	2.90	1.32	Not Meas	Not Meas	10

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
CD_RE000.ECS	AAC-1	RD	8.6	July-31-91	0	245.0	1.00	10.53	1.00	12.60	11.52	
CD_RE000.ECS	AAC-1	RD	8.6	July-31-91	6	240.0	0.98	7.34	0.70	Not Meas	Not Meas	
CD_RE000.ECS	AAC-1	RD	8.6	July-31-91	12	227.0	0.93	7.01	0.67	Not Meas	Not Meas	
CD_RE000.ECS	AAC-1	RD	8.6	July-31-91	18	215.4	0.88	6.92	0.66	Not Meas	Not Meas	
CD_RE000.ECS	AAC-1	RD	8.6	July-31-91	24	214.6	0.88	6.92	0.66	Not Meas	Not Meas	5
DD_RE001.ECS	AAD-1	RD	9.2	Aug-5-91	0	218.0	1.00	8.57	1.00	13.97	12.38	
DD_RE001.ECS	AAD-1	RD	9.2	Aug-5-91	6	216.0	0.99	5.46	0.64	Not Meas	Not Meas	
DD_RE001.ECS	AAD-1	RD	9.2	Aug-5-91	12	192.0	0.88	3.19	0.37	Not Meas	Not Meas	
DD_RE001.ECS	AAD-1	RD	9.2	Aug-5-91	18	178.8	0.82	4.36	0.51	Not Meas	Not Meas	
DD_RE001.ECS	AAD-1	RD	9.2	Aug-5-91	24	178.8	0.82	4.26	0.50	Not Meas	Not Meas	10
AD_RE006.ECS	AAA-1	RD	8.1	Aug-10-91	0	177.0	1.00	2.89	1.00	4.46	1.44	
AD_RE006.ECS	AAA-1	RD	8.1	Aug-10-91	6	175.0	0.99	3.36	1.16	Not Meas	Not Meas	
AD_RE006.ECS	AAA-1	RD	8.1	Aug-10-91	12	165.2	0.93	3.27	1.13	Not Meas	Not Meas	
AD_RE006.ECS	AAA-1	RD	8.1	Aug-10-91	18	164.3	0.93	3.27	1.13	Not Meas	Not Meas	
AD_RE006.ECS	AAA-1	RD	8.1	Aug-10-91	24	165.2	0.93	3.27	1.13	Not Meas	Not Meas	10
DD_RE000.ECS	AAD-1	RD	8.8	Aug-10-91	0	195.0	1.00	5.82	1.00	8.03	7.74	
DD_RE000.ECS	AAD-1	RD	8.8	Aug-10-91	6	187.0	0.96	5.36	0.92	Not Meas	Not Meas	
DD_RE000.ECS	AAD-1	RD	8.8	Aug-10-91	12	173.7	0.89	5.20	0.89	Not Meas	Not Meas	
DD_RE000.ECS	AAD-1	RD	8.8	Aug-10-91	18	170.0	0.87	5.20	0.89	Not Meas	Not Meas	
DD_RE000.ECS	AAD-1	RD	8.8	Aug-10-91	24	170.3	0.87	5.20	0.89	Not Meas	Not Meas	10
GD_RE000.ECS	AAG-1	RD	8.0	Aug-12-91	0	510.0	1.00	3.24	1.00	5.53	3.83	
GD_RE000.ECS	AAG-1	RD	8.0	Aug-12-91	6	440.0	0.86	2.32	0.72	Not Meas	Not Meas	
GD_RE000.ECS	AAG-1	RD	8.0	Aug-12-91	12	430.0	0.84	1.60	0.49	Not Meas	Not Meas	
GD_RE000.ECS	AAG-1	RD	8.0	Aug-12-91	18	408.7	0.80	1.55	0.48	Not Meas	Not Meas	
GD_RE000.ECS	AAG-1	RD	8.0	Aug-12-91	24	466.8	0.92	1.50	0.46	Not Meas	Not Meas	20
BD_RE000.ECS	AAB-1	RD	7.2	Aug-12-91	0	280.0	1.00	4.08	1.00	6.69	3.42	
BD_RE000.ECS	AAB-1	RD	7.2	Aug-12-91	6	259.0	0.93	3.85	0.94	Not Meas	Not Meas	
BD_RE000.ECS	AAB-1	RD	7.2	Aug-12-91	12	234.2	0.84	2.83	0.69	Not Meas	Not Meas	
BD_RE000.ECS	AAB-1	RD	7.2	Aug-12-91	18	215.4	0.77	2.83	0.69	Not Meas	Not Meas	
BD_RE000.ECS	AAB-1	RD	7.2	Aug-12-91	24	214.0	0.76	2.03	0.50	Not Meas	Not Meas	5

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
GD_RE002.ECS	AAG-1	RD	7.7	Aug-15-91	0	540.0	1.00	0.05	1.00	3.82	1.82	
GD_RE002.ECS	AAG-1	RD	7.7	Aug-15-91	6	530.0	0.98	0.19	3.73	Not Meas	Not Meas	
GD_RE002.ECS	AAG-1	RD	7.7	Aug-15-91	12	490.5	0.91	0.09	1.82	Not Meas	Not Meas	
GD_RE002.ECS	AAG-1	RD	7.7	Aug-15-91	18	481.1	0.89	0.09	1.82	Not Meas	Not Meas	
GD_RE002.ECS	AAG-1	RD	7.7	Aug-15-91	24	502.4	0.93	0.09	1.82	Not Meas	Not Meas	10
FD_RE002.ECS	AAF-1	RD	9.6	Aug-15-91	0	560.0	1.00	4.99	1.00	5.58	2.28	
FD_RE002.ECS	AAF-1	RD	9.6	Aug-15-91	6	545.0	0.97	5.95	1.19	Not Meas	Not Meas	
FD_RE002.ECS	AAF-1	RD	9.6	Aug-15-91	12	489.6	0.87	5.76	1.15	Not Meas	Not Meas	
FD_RE002.ECS	AAF-1	RD	9.6	Aug-15-91	18	457.7	0.82	5.33	1.07	Not Meas	Not Meas	
FD_RE002.ECS	AAF-1	RD	9.6	Aug-15-91	24	450.0	0.80	5.28	1.06	Not Meas	Not Meas	10
GJ_RE006.ECS	AAG-1	RJ	8.1	Oct-6-91	0	265.0	1.00	3.97	1.00	19.08	17.53	
GJ_RE006.ECS	AAG-1	RJ	8.1	Oct-6-91	6	254.8	0.96	0.72	0.18	Not Meas	Not Meas	
GJ_RE006.ECS	AAG-1	RJ	8.1	Oct-6-91	12	231.0	0.87	0.12	0.03	Not Meas	Not Meas	
GJ_RE006.ECS	AAG-1	RJ	8.1	Oct-6-91	18	175.2	0.66	0.07	0.02	Not Meas	Not Meas	
GJ_RE006.ECS	AAG-1	RJ	8.1	Oct-6-91	24	184.0	0.69	0.07	0.02	Not Meas	Not Meas	10
GH_RE003.ECS	AAG-1	RH	6.8	Nov-10-91	0	640.0	1.00	0.05	1.00	3.32	0.03	
GH_RE003.ECS	AAG-1	RH	6.8	Nov-10-91	6	553.5	0.86	2.52	48.46	Not Meas	Not Meas	
GH_RE003.ECS	AAG-1	RH	6.8	Nov-10-91	12	545.0	0.85	0.13	2.40	Not Meas	Not Meas	
GH_RE003.ECS	AAG-1	RH	6.8	Nov-10-91	18	540.7	0.84	0.09	1.69	Not Meas	Not Meas	
GH_RE003.ECS	AAG-1	RH	6.8	Nov-10-91	24	553.5	0.86	0.05	0.88	Not Meas	Not Meas	10
KD_RE007.ECS	AAK-1	RD	8.7	Nov-14-91	0	293.0	1.00	2.71	1.00	4.85	2.41	
KD_RE007.ECS	AAK-1	RD	8.7	Nov-14-91	6	274.2	0.94	3.48	1.28	Not Meas	Not Meas	
KD_RE007.ECS	AAK-1	RD	8.7	Nov-14-91	12	269.1	0.92	3.58	1.32	Not Meas	Not Meas	
KD_RE007.ECS	AAK-1	RD	8.7	Nov-14-91	18	281.0	0.96	3.73	1.38	Not Meas	Not Meas	
KD_RE007.ECS	AAK-1	RD	8.7	Nov-14-91	24	280.0	0.96	3.73	1.38	Not Meas	Not Meas	5
AH_RE009.ECS	AAA-1	RH	7.5	Nov-14-91	0	135.0	1.00	6.03	1.00	7.91	7.49	
AH_RE009.ECS	AAA-1	RH	7.5	Nov-14-91	6	128.0	0.95	4.41	0.73	Not Meas	Not Meas	
AH_RE009.ECS	AAA-1	RH	7.5	Nov-14-91	12	125.0	0.93	4.41	0.73	Not Meas	Not Meas	
AH_RE009.ECS	AAA-1	RH	7.5	Nov-14-91	18	130.0	0.96	2.75	0.46	Not Meas	Not Meas	
AH_RE009.ECS	AAA-1	RH	7.5	Nov-14-91	24	128.0	0.95	3.40	0.56	Not Meas	Not Meas	5

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
KD_RE006.ECS	AAK-1	RD	8.1	Nov-16-91	0	287.0	1.00	2.13	1.00	3.97	2.62	
KD_RE006.ECS	AAK-1	RD	8.1	Nov-16-91	6	275.0	0.96	3.32	1.56	Not Meas	Not Meas	
KD_RE006.ECS	AAK-1	RD	8.1	Nov-16-91	12	273.0	0.95	3.32	1.56	Not Meas	Not Meas	
KD_RE006.ECS	AAK-1	RD	8.1	Nov-16-91	18	258.9	0.90	3.12	1.46	Not Meas	Not Meas	
KD_RE006.ECS	AAK-1	RD	8.1	Nov-16-91	24	272.5	0.95	3.12	1.46	Not Meas	Not Meas	5
GH_RE002.ECS	AAG-1	RH	5.9	Nov-16-91	0	610.0	1.00	0.05	1.00	2.05	0.03	
GH_RE002.ECS	AAG-1	RH	5.9	Nov-16-91	6	580.0	0.95	2.13	42.60	Not Meas	Not Meas	
GH_RE002.ECS	AAG-1	RH	5.9	Nov-16-91	12	566.0	0.93	0.13	2.54	Not Meas	Not Meas	
GH_RE002.ECS	AAG-1	RH	5.9	Nov-16-91	18	566.0	0.93	0.09	1.78	Not Meas	Not Meas	
GH_RE002.ECS	AAG-1	RH	5.9	Nov-16-91	24	549.2	0.90	0.08	1.68	Not Meas	Not Meas	10
FH_RE000.ECS	AAF-1	RH	7.6	Oct-8-91	0	454.0	1.00	0.16	1.00	1.68	0.99	
FH_RE000.ECS	AAF-1	RH	7.6	Oct-8-91	6	388.3	0.86	2.69	17.13	Not Meas	Not Meas	
FH_RE000.ECS	AAF-1	RH	7.6	Oct-8-91	12	387.5	0.85	2.26	14.39	Not Meas	Not Meas	
FH_RE000.ECS	AAF-1	RH	7.6	Oct-8-91	18	383.3	0.84	2.12	13.50	Not Meas	Not Meas	
FH_RE000.ECS	AAF-1	RH	7.6	Oct-8-91	24	383.0	0.84	2.12	13.50	Not Meas	Not Meas	10
MH_RE003.ECS	AAM-1	RH	7.1	Nov-17-91	0	430.0	1.00	0.00	N/A	0.29	0.00	
MH_RE003.ECS	AAM-1	RH	7.1	Nov-17-91	6	365.0	0.85	4.37	1.00	Not Meas	Not Meas	
MH_RE003.ECS	AAM-1	RH	7.1	Nov-17-91	12	344.6	0.80	0.12	0.03	Not Meas	Not Meas	
MH_RE003.ECS	AAM-1	RH	7.1	Nov-17-91	18	374.9	0.87	2.83	0.65	Not Meas	Not Meas	
MH_RE003.ECS	AAM-1	RH	7.1	Nov-17-91	24	368.3	0.86	2.73	0.62	Not Meas	Not Meas	10
AH_RE011.ECS	AAA-1	RH	8.4	Nov-17-91	0	118.0	1.00	5.66	1.00	7.72	7.50	
AH_RE011.ECS	AAA-1	RH	8.4	Nov-17-91	6	110.3	0.93	4.83	0.85	Not Meas	Not Meas	
AH_RE011.ECS	AAA-1	RH	8.4	Nov-17-91	12	102.3	0.87	4.16	0.73	Not Meas	Not Meas	
AH_RE011.ECS	AAA-1	RH	8.4	Nov-17-91	18	110.5	0.94	4.16	0.73	Not Meas	Not Meas	
AH_RE011.ECS	AAA-1	RH	8.4	Nov-17-91	24	109.4	0.93	4.16	0.73	Not Meas	Not Meas	10
BJ_RE006.ECS	AAB-1	RJ	8.5	Nov-20-91	0	465.0	1.00	4.03	1.00	13.71	13.20	
BJ_RE006.ECS	AAB-1	RJ	8.5	Nov-20-91	6	460.0	0.99	1.41	0.35	Not Meas	Not Meas	
BJ_RE006.ECS	AAB-1	RJ	8.5	Nov-20-91	12	382.0	0.82	0.15	0.04	Not Meas	Not Meas	
BJ_RE006.ECS	AAB-1	RJ	8.5	Nov-20-91	18	373.8	0.80	0.17	0.04	Not Meas	Not Meas	
BJ_RE006.ECS	AAB-1	RJ	8.5	Nov-20-91	24	368.6	0.79	0.15	0.04	Not Meas	Not Meas	20

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
FJ_RE000.ECS	AAF-1	RJ	9.1	Nov-20-91	0	256.0	1.00	5.54	1.00	12.16	11.15	
FJ_RE000.ECS	AAF-1	RJ	9.1	Nov-20-91	6	254.2	0.99	2.64	0.48	Not Meas	Not Meas	
FJ_RE000.ECS	AAF-1	RJ	9.1	Nov-20-91	12	248.6	0.97	2.13	0.38	Not Meas	Not Meas	
FJ_RE000.ECS	AAF-1	RJ	9.1	Nov-20-91	18	228.7	0.89	0.93	0.17	Not Meas	Not Meas	
FJ_RE000.ECS	AAF-1	RJ	9.1	Nov-20-91	24	222.7	0.87	0.13	0.02	Not Meas	Not Meas	30
BD_RE001.ECS	AAB-1	RD	6.8	Nov-28-91	0	300.0	1.00	0.00	N/A	2.19	0.00	
BD_RE001.ECS	AAB-1	RD	6.8	Nov-28-91	6	283.5	0.95	3.92	1.00	Not Meas	Not Meas	
BD_RE001.ECS	AAB-1	RD	6.8	Nov-28-91	12	281.8	0.94	2.58	0.66	Not Meas	Not Meas	
BD_RE001.ECS	AAB-1	RD	6.8	Nov-28-91	18	293.8	0.98	1.98	0.51	Not Meas	Not Meas	
BD_RE001.ECS	AAB-1	RD	6.8	Nov-28-91	24	268.2	0.89	0.86	0.22	Not Meas	Not Meas	5
MD_RE001.ECS	AAM-1	RD	10.1	Nov-28-91	0	285.0	1.00	2.70	1.00	4.84	3.10	
MD_RE001.ECS	AAM-1	RD	10.1	Nov-28-91	6	283.5	0.99	3.35	1.24	Not Meas	Not Meas	
MD_RE001.ECS	AAM-1	RD	10.1	Nov-28-91	12	269.4	0.95	2.79	1.03	Not Meas	Not Meas	
MD_RE001.ECS	AAM-1	RD	10.1	Nov-28-91	18	269.0	0.94	3.16	1.17	Not Meas	Not Meas	
MD_RE001.ECS	AAM-1	RD	10.1	Nov-28-91	24	247.0	0.87	3.16	1.17	Not Meas	Not Meas	5
AD_RE009.ECS	AAA-1	RD	8.2	Nov-25-91	0	190.0	1.00	0.67	1.00	3.12	1.95	
AD_RE009.ECS	AAA-1	RD	8.2	Nov-25-91	6	184.3	0.97	2.48	3.70	Not Meas	Not Meas	
AD_RE009.ECS	AAA-1	RD	8.2	Nov-25-91	12	182.0	0.96	2.48	3.70	Not Meas	Not Meas	
AD_RE009.ECS	AAA-1	RD	8.2	Nov-25-91	18	180.0	0.95	2.20	3.28	Not Meas	Not Meas	
AD_RE009.ECS	AAA-1	RD	8.2	Nov-25-91	24	178.8	0.94	2.00	2.99	Not Meas	Not Meas	5
MC_RE002.ECS	AAM-1	RC	9.7	Nov-25-91	0	235.0	1.00	13.18	1.00	16.04	13.86	
MC_RE002.ECS	AAM-1	RC	9.7	Nov-25-91	6	223.2	0.95	8.58	0.65	Not Meas	Not Meas	
MC_RE002.ECS	AAM-1	RC	9.7	Nov-25-91	12	210.0	0.89	7.09	0.54	Not Meas	Not Meas	
MC_RE002.ECS	AAM-1	RC	9.7	Nov-25-91	18	210.0	0.89	5.94	0.45	Not Meas	Not Meas	
MC_RE002.ECS	AAM-1	RC	9.7	Nov-25-91	24	204.2	0.87	5.76	0.44	Not Meas	Not Meas	10
KC_RE003.ECS	AAK-1	RC	9.4	Dec-3-91	0	250.0	1.00	8.93	1.00	17.05	11.49	
KC_RE003.ECS	AAK-1	RC	9.4	Dec-3-91	6	215.5	0.86	5.12	0.57	Not Meas	Not Meas	
KC_RE003.ECS	AAK-1	RC	9.4	Dec-3-91	12	216.0	0.86	4.57	0.51	Not Meas	Not Meas	
KC_RE003.ECS	AAK-1	RC	9.4	Dec-3-91	18	212.0	0.85	4.48	0.50	Not Meas	Not Meas	
KC_RE003.ECS	AAK-1	RC	9.4	Dec-3-91	24	209.0	0.84	4.22	0.47	Not Meas	Not Meas	20

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
MJ_RE0008.ECS	AAM-1	RJ	9.0	Dec-3-91	0	280.0	1.00	2.73	1.00	12.32	10.27	
MJ_RE0008.ECS	AAM-1	RJ	9.0	Dec-3-91	6	266.9	0.95	2.30	0.84	Not Meas	Not Meas	
MJ_RE0008.ECS	AAM-1	RJ	9.0	Dec-3-91	12	258.6	0.92	2.30	0.84	Not Meas	Not Meas	
MJ_RE0008.ECS	AAM-1	RJ	9.0	Dec-3-91	18	240.0	0.86	2.24	0.82	Not Meas	Not Meas	
MJ_RE0008.ECS	AAM-1	RJ	9.0	Dec-3-91	24	226.0	0.81	1.20	0.44	Not Meas	Not Meas	20
DH_RE004.ECS	AAD-1	RH	7.6	Dec-21-91	0	172.0	1.00	0.00	N/A	0.68	0.00	
DH_RE004.ECS	AAD-1	RH	7.6	Dec-21-91	6	162.0	0.94	0.17	1.00	Not Meas	Not Meas	
DH_RE004.ECS	AAD-1	RH	7.6	Dec-21-91	12	161.0	0.94	0.17	0.99	Not Meas	Not Meas	
DH_RE004.ECS	AAD-1	RH	7.6	Dec-21-91	18	152.0	0.88	0.16	0.89	Not Meas	Not Meas	
DH_RE004.ECS	AAD-1	RH	7.6	Dec-21-91	24	150.0	0.87	0.14	0.81	Not Meas	Not Meas	10
KH_RE000.ECS	AAK-1	RH	8.4	Dec-19-91	0	248.0	1.00	3.27	1.00	1.94	1.72	
KH_RE000.ECS	AAK-1	RH	8.4	Dec-19-91	6	210.0	0.85	3.56	1.09	Not Meas	Not Meas	
KH_RE000.ECS	AAK-1	RH	8.4	Dec-19-91	12	208.0	0.84	3.39	1.04	Not Meas	Not Meas	
KH_RE000.ECS	AAK-1	RH	8.4	Dec-19-91	18	202.0	0.81	2.69	0.82	Not Meas	Not Meas	
KH_RE000.ECS	AAK-1	RH	8.4	Dec-19-91	24	198.0	0.80	2.38	0.73	Not Meas	Not Meas	20
BH_RE004.ECS	AAB-1	RH	7.4	Dec-19-91	0	250.0	1.00	0.11	1.00	1.44	1.10	
BH_RE004.ECS	AAB-1	RH	7.4	Dec-19-91	6	250.0	1.00	2.11	19.01	Not Meas	Not Meas	
BH_RE004.ECS	AAB-1	RH	7.4	Dec-19-91	12	232.0	0.93	2.11	19.01	Not Meas	Not Meas	
BH_RE004.ECS	AAB-1	RH	7.4	Dec-19-91	18	232.0	0.93	2.11	19.01	Not Meas	Not Meas	
BH_RE004.ECS	AAB-1	RH	7.4	Dec-19-91	24	222.0	0.89	1.77	15.95	Not Meas	Not Meas	10
FH_RE003.ECS	AAF-1	RH	6.9	Dec-13-91	0	675.0	1.00	0.00	N/A	0.00	0.00	
FH_RE003.ECS	AAF-1	RH	6.9	Dec-13-91	6	555.0	0.82	0.13	1.00	Not Meas	Not Meas	
FH_RE003.ECS	AAF-1	RH	6.9	Dec-13-91	12	475.0	0.70	0.17	1.36	Not Meas	Not Meas	
FH_RE003.ECS	AAF-1	RH	6.9	Dec-13-91	18	510.0	0.76	0.19	1.49	Not Meas	Not Meas	
FH_RE003.ECS	AAF-1	RH	6.9	Dec-13-91	24	505.0	0.75	0.16	1.29	Not Meas	Not Meas	10
CD_RE002.ECS	AAC-1	RD	8.6	Dec-13-91	0	285.0	1.00	9.33	1.00	12.31	11.40	
CD_RE002.ECS	AAC-1	RD	8.6	Dec-13-91	6	270.0	0.95	7.09	0.76	Not Meas	Not Meas	
CD_RE002.ECS	AAC-1	RD	8.6	Dec-13-91	12	270.0	0.95	6.48	0.69	Not Meas	Not Meas	
CD_RE002.ECS	AAC-1	RD	8.6	Dec-13-91	18	265.0	0.93	5.96	0.64	Not Meas	Not Meas	
CD_RE002.ECS	AAC-1	RD	8.6	Dec-13-91	24	255.0	0.89	5.96	0.64	Not Meas	Not Meas	5

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
CH_RE003.ECS	AAC-1	RH	7.0	Dec-31-91	0	230.0	1.00	0.00	N/A	0.31	0.00	
CH_RE003.ECS	AAC-1	RH	7.0	Dec-31-91	6	240.0	1.04	0.13	1.00	Not Meas	Not Meas	
CH_RE003.ECS	AAC-1	RH	7.0	Dec-31-91	12	275.0	1.20	0.11	0.83	Not Meas	Not Meas	
CH_RE003.ECS	AAC-1	RH	7.0	Dec-31-91	18	260.0	1.13	0.06	0.49	Not Meas	Not Meas	
CH_RE003.ECS	AAC-1	RH	7.0	Dec-31-91	24	260.0	1.13	0.05	0.42	Not Meas	Not Meas	10
MH_RE001.ECS	AAM-1	RH	6.8	Dec-31-91	0	400.0	1.00	0.00	N/A	0.22	0.00	
MH_RE001.ECS	AAM-1	RH	6.8	Dec-31-91	6	327.0	0.82	0.20	1.00	Not Meas	Not Meas	
MH_RE001.ECS	AAM-1	RH	6.8	Dec-31-91	12	300.0	0.75	0.16	0.80	Not Meas	Not Meas	
MH_RE001.ECS	AAM-1	RH	6.8	Dec-31-91	18	299.0	0.75	0.16	0.80	Not Meas	Not Meas	
MH_RE001.ECS	AAM-1	RH	6.8	Dec-31-91	24	286.0	0.72	0.15	0.77	Not Meas	Not Meas	10
AC_RE000.ECS	AAA-1	RC	8.3	Jan-2-92	0	220.0	1.00	3.55	1.00	7.60	6.82	
AC_RE000.ECS	AAA-1	RC	8.3	Jan-2-92	6	210.0	0.95	2.72	0.77	Not Meas	Not Meas	
AC_RE000.ECS	AAA-1	RC	8.3	Jan-2-92	12	210.0	0.95	2.26	0.64	Not Meas	Not Meas	
AC_RE000.ECS	AAA-1	RC	8.3	Jan-2-92	18	199.0	0.90	2.22	0.63	Not Meas	Not Meas	
AC_RE000.ECS	AAA-1	RC	8.3	Jan-2-92	24	183.0	0.83	2.22	0.63	Not Meas	Not Meas	20
BC_RE002.ECS	AAB-1	RC	9.2	Jan-2-92	0	255.0	1.00	5.42	1.00	10.81	7.87	
BC_RE002.ECS	AAB-1	RC	9.2	Jan-2-92	6	245.0	0.96	4.09	0.75	Not Meas	Not Meas	
BC_RE002.ECS	AAB-1	RC	9.2	Jan-2-92	12	242.0	0.95	3.44	0.63	Not Meas	Not Meas	
BC_RE002.ECS	AAB-1	RC	9.2	Jan-2-92	18	239.0	0.94	3.44	0.63	Not Meas	Not Meas	
BC_RE002.ECS	AAB-1	RC	9.2	Jan-2-92	24	215.0	0.84	3.14	0.58	Not Meas	Not Meas	10
DC_RE006.ECS	AAD-1	RC	9.2	Jan-4-92	0	230.0	1.00	3.72	1.00	5.01	3.23	
DC_RE006.ECS	AAD-1	RC	9.2	Jan-4-92	6	195.0	0.85	3.91	1.05	Not Meas	Not Meas	
DC_RE006.ECS	AAD-1	RC	9.2	Jan-4-92	12	179.0	0.78	3.60	0.97	Not Meas	Not Meas	
DC_RE006.ECS	AAD-1	RC	9.2	Jan-4-92	18	178.0	0.77	3.29	0.88	Not Meas	Not Meas	
DC_RE006.ECS	AAD-1	RC	9.2	Jan-4-92	24	174.0	0.76	3.15	0.85	Not Meas	Not Meas	10
DC_RE007.ECS	AAD-1	RC	8.7	Jan-4-92	0	246.0	1.00	0.03	1.00	2.42	0.26	
DC_RE007.ECS	AAD-1	RC	8.7	Jan-4-92	6	209.0	0.85	0.15	4.93	Not Meas	Not Meas	
DC_RE007.ECS	AAD-1	RC	8.7	Jan-4-92	12	206.0	0.84	0.13	4.23	Not Meas	Not Meas	
DC_RE007.ECS	AAD-1	RC	8.7	Jan-4-92	18	194.0	0.79	0.12	3.93	Not Meas	Not Meas	
DC_RE007.ECS	AAD-1	RC	8.7	Jan-4-92	24	188.0	0.76	0.12	3.83	Not Meas	Not Meas	10

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
CC_RE000.ECS	AAC-1	RC	9.0	Jan-6-92	0	335.0	1.00	4.92	1.00	8.50	7.41	
CC_RE000.ECS	AAC-1	RC	9.0	Jan-6-92	6	275.0	0.82	4.20	0.85	Not Meas	Not Meas	
CC_RE000.ECS	AAC-1	RC	9.0	Jan-6-92	12	270.0	0.81	3.63	0.74	Not Meas	Not Meas	
CC_RE000.ECS	AAC-1	RC	9.0	Jan-6-92	18	270.0	0.81	3.20	0.65	Not Meas	Not Meas	
CC_RE000.ECS	AAC-1	RC	9.0	Jan-6-92	24	250.0	0.75	2.67	0.54	Not Meas	Not Meas	20
CC_RE001.ECS	AAC-1	RC	9.0	Jan-6-92	0	275.0	1.00	5.00	1.00	9.26	8.43	
CC_RE001.ECS	AAC-1	RC	9.0	Jan-6-92	6	250.0	0.91	3.17	0.63	Not Meas	Not Meas	
CC_RE001.ECS	AAC-1	RC	9.0	Jan-6-92	12	240.0	0.87	2.77	0.55	Not Meas	Not Meas	
CC_RE001.ECS	AAC-1	RC	9.0	Jan-6-92	18	233.0	0.85	2.21	0.44	Not Meas	Not Meas	
CC_RE001.ECS	AAC-1	RC	9.0	Jan-6-92	24	207.0	0.75	1.89	0.38	Not Meas	Not Meas	20
KC_RE002.ECS	AAK-1	RC	9.2	Jan-20-92	0	280.0	1.00	5.89	1.00	13.04	10.66	
KC_RE002.ECS	AAK-1	RC	9.2	Jan-20-92	6	260.5	0.93	4.23	0.72	Not Meas	Not Meas	
KC_RE002.ECS	AAK-1	RC	9.2	Jan-20-92	12	255.5	0.91	3.47	0.59	Not Meas	Not Meas	
KC_RE002.ECS	AAK-1	RC	9.2	Jan-20-92	18	250.0	0.89	2.80	0.48	Not Meas	Not Meas	
KC_RE002.ECS	AAK-1	RC	9.2	Jan-20-92	24	235.0	0.84	2.55	0.43	Not Meas	Not Meas	10
FC_RE003.ECS	AAF-1	RC	8.3	Jan-20-92	0	490.0	1.00	2.24	1.00	5.03	4.18	
FC_RE003.ECS	AAF-1	RC	8.3	Jan-20-92	6	470.0	0.96	0.70	0.31	Not Meas	Not Meas	
FC_RE003.ECS	AAF-1	RC	8.3	Jan-20-92	12	458.0	0.93	0.11	0.05	Not Meas	Not Meas	
FC_RE003.ECS	AAF-1	RC	8.3	Jan-20-92	18	385.0	0.79	0.08	0.04	Not Meas	Not Meas	
FC_RE003.ECS	AAF-1	RC	8.3	Jan-20-92	24	374.0	0.76	0.04	0.02	Not Meas	Not Meas	20
GC_RE008.ECS	AAG-1	RC	10.1	Jan-23-92	0	410.0	1.00	10.31	1.00	14.57	12.89	
GC_RE008.ECS	AAG-1	RC	10.1	Jan-23-92	6	398.0	0.97	5.42	0.53	Not Meas	Not Meas	
GC_RE008.ECS	AAG-1	RC	10.1	Jan-23-92	12	378.0	0.92	4.36	0.42	Not Meas	Not Meas	
GC_RE008.ECS	AAG-1	RC	10.1	Jan-23-92	18	373.0	0.91	3.68	0.36	Not Meas	Not Meas	
GC_RE008.ECS	AAG-1	RC	10.1	Jan-23-92	24	326.0	0.80	2.31	0.22	Not Meas	Not Meas	20
GC_RE009.ECS	AAG-1	RC	10.4	Jan-23-92	0	315.0	1.00	7.63	1.00	14.43	13.79	
GC_RE009.ECS	AAG-1	RC	10.4	Jan-23-92	6	310.0	0.98	4.56	0.60	Not Meas	Not Meas	
GC_RE009.ECS	AAG-1	RC	10.4	Jan-23-92	12	299.0	0.95	3.87	0.51	Not Meas	Not Meas	
GC_RE009.ECS	AAG-1	RC	10.4	Jan-23-92	18	270.0	0.86	3.25	0.43	Not Meas	Not Meas	
GC_RE009.ECS	AAG-1	RC	10.4	Jan-23-92	24	258.0	0.82	2.22	0.29	Not Meas	Not Meas	20

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
FC_RE001.ECS	AAF-1	RC	9.0	Jan-26-92	0	481.0	1.00	9.42	1.00	15.04	11.6	
FC_RE001.ECS	AAF-1	RC	9.0	Jan-26-92	6	466.0	0.97	4.35	0.46	Not Meas	Not Meas	
FC_RE001.ECS	AAF-1	RC	9.0	Jan-26-92	12	388.0	0.81	4.16	0.44	Not Meas	Not Meas	
FC_RE001.ECS	AAF-1	RC	9.0	Jan-26-92	18	385.0	0.80	3.54	0.38	Not Meas	Not Meas	
FC_RE001.ECS	AAF-1	RC	9.0	Jan-26-92	24	375.0	0.78	3.21	0.34	Not Meas	Not Meas	20
MC_RE003.ECS	AAM-1	RC	10.5	Jan-26-92	0	275.0	1.00	6.02	1.00	22.94	11.42	
MC_RE003.ECS	AAM-1	RC	10.5	Jan-26-92	6	267.0	0.97	3.24	0.54	Not Meas	Not Meas	
MC_RE003.ECS	AAM-1	RC	10.5	Jan-26-92	12	262.0	0.95	2.73	0.45	Not Meas	Not Meas	
MC_RE003.ECS	AAM-1	RC	10.5	Jan-26-92	18	261.0	0.95	2.41	0.40	Not Meas	Not Meas	
MC_RE003.ECS	AAM-1	RC	10.5	Jan-26-92	24	248.0	0.90	2.27	0.38	Not Meas	Not Meas	10
DJ_RE007.ECS	AAD-1	RJ	7.5	Feb-4-92	0	155.0	1.00	4.08	1.00	7.10	5.61	
DJ_RE007.ECS	AAD-1	RJ	7.5	Feb-4-92	6	141.0	0.91	0.97	0.24	Not Meas	Not Meas	
DJ_RE007.ECS	AAD-1	RJ	7.5	Feb-4-92	12	124.0	0.80	0.14	0.03	Not Meas	Not Meas	
DJ_RE007.ECS	AAD-1	RJ	7.5	Feb-4-92	18	130.0	0.84	0.14	0.03	Not Meas	Not Meas	
DJ_RE007.ECS	AAD-1	RJ	7.5	Feb-4-92	24	120.0	0.77	0.10	0.02	Not Meas	Not Meas	10
BC_RE000.ECS	AAB-1	RC	9.5	Feb-6-92	0	250.0	1.00	3.93	1.00	8.28	6.5	
BC_RE000.ECS	AAB-1	RC	9.5	Feb-6-92	6	246.0	0.98	2.97	0.76	Not Meas	Not Meas	
BC_RE000.ECS	AAB-1	RC	9.5	Feb-6-92	12	214.0	0.86	2.11	0.54	Not Meas	Not Meas	
BC_RE000.ECS	AAB-1	RC	9.5	Feb-6-92	18	213.0	0.85	2.07	0.53	Not Meas	Not Meas	
BC_RE000.ECS	AAB-1	RC	9.5	Feb-6-92	24	198.0	0.79	1.78	0.45	Not Meas	Not Meas	10
AC_RE001.ECS	AAA-1	RC	9.0	Feb-6-92	0	160.0	1.00	5.27	1.00	8.91	7.34	
AC_RE001.ECS	AAA-1	RC	9.0	Feb-6-92	6	158.0	0.99	4.44	0.84	Not Meas	Not Meas	
AC_RE001.ECS	AAA-1	RC	9.0	Feb-6-92	12	150.0	0.94	3.52	0.67	Not Meas	Not Meas	
AC_RE001.ECS	AAA-1	RC	9.0	Feb-6-92	18	146.0	0.91	3.52	0.67	Not Meas	Not Meas	
AC_RE001.ECS	AAA-1	RC	9.0	Feb-6-92	24	142.0	0.89	2.89	0.55	Not Meas	Not Meas	10
BH_RE005.ECS	AAB-1	RH	9.1	Feb-8-92	0	210.0	1.00	0.00	N/A	0.26	0	
BH_RE005.ECS	AAB-1	RH	9.1	Feb-8-92	6	203.0	0.97	2.89	1.00	Not Meas	Not Meas	
BH_RE005.ECS	AAB-1	RH	9.1	Feb-8-92	12	185.0	0.88	2.07	0.72	Not Meas	Not Meas	
BH_RE005.ECS	AAB-1	RH	9.1	Feb-8-92	18	193.0	0.92	2.07	0.72	Not Meas	Not Meas	
BH_RE005.ECS	AAB-1	RH	9.1	Feb-8-92	24	195.0	0.93	1.81	0.63	Not Meas	Not Meas	10

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
CH_RE002.ECS	AAC-1	RH	6.8	Feb-10-92	0	231.0	1.00	0.00	N/A	0.27	0	
CH_RE002.ECS	AAC-1	RH	6.8	Feb-10-92	6	264.0	1.14	0.10	1.00	Not Meas	Not Meas	
CH_RE002.ECS	AAC-1	RH	6.8	Feb-10-92	12	264.0	1.14	0.06	0.62	Not Meas	Not Meas	
CH_RE002.ECS	AAC-1	RH	6.8	Feb-10-92	18	259.0	1.12	0.08	0.77	Not Meas	Not Meas	
CH_RE002.ECS	AAC-1	RH	6.8	Feb-10-92	24	259.0	1.12	0.07	0.75	Not Meas	Not Meas	10
GD_RE006.ECS	AAG-1	RD	8.8	Feb-10-92	0	534.0	1.00	0.08	1.00	0.92	0.38	
GD_RE006.ECS	AAG-1	RD	8.8	Feb-10-92	6	505.0	0.95	4.57	60.93	Not Meas	Not Meas	
GD_RE006.ECS	AAG-1	RD	8.8	Feb-10-92	12	500.0	0.94	4.86	64.80	Not Meas	Not Meas	
GD_RE006.ECS	AAG-1	RD	8.8	Feb-10-92	18	495.0	0.93	4.87	64.93	Not Meas	Not Meas	
GD_RE006.ECS	AAG-1	RD	8.8	Feb-10-92	24	495.0	0.93	4.83	64.40	Not Meas	Not Meas	5
BD_RE005.ECS	AAB-1	RD	8.8	Feb-12-92	0	275.0	1.00	5.53	1.00	5.85	3.94	
BD_RE005.ECS	AAB-1	RD	8.8	Feb-12-92	6	266.0	0.97	5.53	1.00	Not Meas	Not Meas	
BD_RE005.ECS	AAB-1	RD	8.8	Feb-12-92	12	256.0	0.93	5.43	0.98	Not Meas	Not Meas	
BD_RE005.ECS	AAB-1	RD	8.8	Feb-12-92	18	268.0	0.97	5.09	0.92	Not Meas	Not Meas	
BD_RE005.ECS	AAB-1	RD	8.8	Feb-12-92	24	255.0	0.93	5.09	0.92	Not Meas	Not Meas	5
FD_RE003.ECS	AAF-1	RD	9.7	Feb-12-92	0	580.0	1.00	3.76	1.00	6.19	2.17	
FD_RE003.ECS	AAF-1	RD	9.7	Feb-12-92	6	550.0	0.95	5.65	1.50	Not Meas	Not Meas	
FD_RE003.ECS	AAF-1	RD	9.7	Feb-12-92	12	540.0	0.93	5.28	1.40	Not Meas	Not Meas	
FD_RE003.ECS	AAF-1	RD	9.7	Feb-12-92	18	540.0	0.93	5.09	1.35	Not Meas	Not Meas	
FD_RE003.ECS	AAF-1	RD	9.7	Feb-12-92	24	530.0	0.91	4.79	1.27	Not Meas	Not Meas	10
MD_RE003.ECS	AAM-1	RD	10.4	Feb-14-92	0	430.0	1.00	0.19	1.00	3.69	2.05	
MD_RE003.ECS	AAM-1	RD	10.4	Feb-14-92	6	402.0	0.93	2.76	14.76	Not Meas	Not Meas	
MD_RE003.ECS	AAM-1	RD	10.4	Feb-14-92	12	380.0	0.88	2.31	12.35	Not Meas	Not Meas	
MD_RE003.ECS	AAM-1	RD	10.4	Feb-14-92	18	364.0	0.85	2.46	13.16	Not Meas	Not Meas	
MD_RE003.ECS	AAM-1	RD	10.4	Feb-14-92	24	390.0	0.91	2.46	13.16	Not Meas	Not Meas	5
CJ_RE012.ECS	AAC-1	RJ	8.0	Feb-14-92	0	380.0	1.00	4.76	1.00	3.17	7.21	
CJ_RE012.ECS	AAC-1	RJ	8.0	Feb-14-92	6	294.0	0.77	4.99	1.05	Not Meas	Not Meas	
CJ_RE012.ECS	AAC-1	RJ	8.0	Feb-14-92	12	265.0	0.70	4.99	1.05	Not Meas	Not Meas	
CJ_RE012.ECS	AAC-1	RJ	8.0	Feb-14-92	18	260.0	0.68	4.69	0.99	Not Meas	Not Meas	
CJ_RE012.ECS	AAC-1	RJ	8.0	Feb-14-92	24	254.0	0.67	4.40	0.92	Not Meas	Not Meas	10

Table C1: Summary Data of 32 SHRP Mixtures- ECS

Specimen ID	Asphalt Code	Aggr. Code	Air Voids (%)	Date Tested	Cond Time (hr)	ECS Mr (ksi)	ECS Mr Ratio	Water Perm (E-3 cm/s)	Retained Perm Ratio	Air Perml (E-5 cm/s)	Air Perml (E-5 cm/s)	Stripping Rate
DH_RE005.ECS	AAD-1	RH	6.9	Mar-24-92	0	230.0	1.00	0.00	N/A	0.18	0	
DH_RE005.ECS	AAD-1	RH	6.9	Mar-24-92	6	222.0	0.97	2.68	1.00	Not Meas	Not Meas	
DH_RE005.ECS	AAD-1	RH	6.9	Mar-24-92	12	220.0	0.96	3.59	1.34	Not Meas	Not Meas	
DH_RE005.ECS	AAD-1	RH	6.9	Mar-24-92	18	219.0	0.95	2.72	1.01	Not Meas	Not Meas	
DH_RE005.ECS	AAD-1	RH	6.9	Mar-24-92	24	218.0	0.95	3.07	1.15	Not Meas	Not Meas	5
KH_RE003.ECS	AAK-1	RH	7.6	Mar-24-92	0	481.0	1.00	0.09	1.00	1.56	1.42	
KH_RE003.ECS	AAK-1	RH	7.6	Mar-24-92	6	403.0	0.84	1.73	18.40	Not Meas	Not Meas	
KH_RE003.ECS	AAK-1	RH	7.6	Mar-24-92	12	394.0	0.82	1.98	21.06	Not Meas	Not Meas	
KH_RE003.ECS	AAK-1	RH	7.6	Mar-24-92	18	373.0	0.78	1.75	18.62	Not Meas	Not Meas	
KH_RE003.ECS	AAK-1	RH	7.6	Mar-24-92	24	370.0	0.77	1.65	17.55	Not Meas	Not Meas	10
FD_RE000.ECS	AAF-1	RD	9.9	Mar-28-92	0	640.0	1.00	5.69	1.00	6.43	5.89	
FD_RE000.ECS	AAF-1	RD	9.9	Mar-28-92	6	510.0	0.80	6.16	1.08	Not Meas	Not Meas	
FD_RE000.ECS	AAF-1	RD	9.9	Mar-28-92	12	494.0	0.77	5.69	1.00	Not Meas	Not Meas	
FD_RE000.ECS	AAF-1	RD	9.9	Mar-28-92	18	488.0	0.76	5.69	1.00	Not Meas	Not Meas	
FD_RE000.ECS	AAF-1	RD	9.9	Mar-28-92	24	500.0	0.78	5.69	1.00	Not Meas	Not Meas	10
MH_RE004.ECS	AAM-1	RH	7.7	Mar-28-92	0	485.0	1.00	2.35	1.00	7.57	2.67	
MH_RE004.ECS	AAM-1	RH	7.7	Mar-28-92	6	362.0	0.75	3.54	1.51	Not Meas	Not Meas	
MH_RE004.ECS	AAM-1	RH	7.7	Mar-28-92	12	350.0	0.72	2.83	1.20	Not Meas	Not Meas	
MH_RE004.ECS	AAM-1	RH	7.7	Mar-28-92	18	348.0	0.72	2.73	1.16	Not Meas	Not Meas	
MH_RE004.ECS	AAM-1	RH	7.7	Mar-28-92	24	345.0	0.71	2.59	1.10	Not Meas	Not Meas	10

Table C2: Summary Data of 32 SHRP Mixtures- SWK

Spec Ref	Agg Code	Asph Code	Slab Void Content (%)	Spec Void Content (%)	Saturation (%)	Time (hr) to Deformation (mm)					Time (hr) to Deformation (mm)					Time to Failure (hr)
						1	2	3	4	5	6	7	8	9	10	
00000RW1	RC	AAA	7.0	8.4	64.8	0.5	64.0	*	*	*	*	*	*	*	*	Pass
00000RW0	RC	AAA	8.6	11.5	84.7	0.5	0.5	1.0	2.0	3.0	4.5	5.5	7.0	8.0	8.5	5
10000RW1	RC	AAB	8.9	12.4	72.9	0.5	26.0	56.0	62.0	78.0	87.0	91.0	*	*	*	58
01000RW0	RC	AAC	8.0	11.7	69.0	0.5	1.0	3.0	5.5	10.5	16.5	24.0	24.5	25.0	25.5	24
11000RW0	RC	AAD	8.8	11.4	95.8	0.5	10.0	*	*	*	*	*	*	*	*	Pass
00100RW1	RC	AAF	9.0	10.9	90.0	0.5	3.0	26.0	54.0	70.0	98.0	163.0	164.0	165.0	165.0	165
10100RW5	RC	AAG	9.2	12.8	70.0	3.0	8.5	10.0	10.0	10.0	10.0	10.0	10.5	10.5	11.0	10
01100RW2	RC	AAK	8.8	9.2	59.4	6.0	*	*	*	*	*	*	*	*	*	Pass
01100RW3	RC	AAK	8.2	9.4	66.0	2.0	*	*	*	*	*	*	*	*	*	Pass
11100RW0	RC	AAM	8.9	12.1	75.4	0.5	13.0	*	*	*	*	*	*	*	*	Pass
00010RW1	RD	AAA	9.0	8.5	51.9	20.0	*	*	*	*	*	*	*	*	*	Pass
00010RW0	RD	AAA	6.3	4.3	30.5	30.0	*	*	*	*	*	*	*	*	*	Pass
10010RW3	RD	AAB	9.1	8.9	67.9	1.0	*	*	*	*	*	*	*	*	*	Pass
01010RW1	RD	AAC	7.0	11.1	65.4	0.5	1.5	5.0	5.5	6.0	6.0	6.5	6.5	7.0	7.5	6
11010RW0	RD	AAD	8.7	8.0	51.4	*	*	*	*	*	*	*	*	*	*	Pass
11010RW1	RD	AAD	8.7	7.6	54.4	0.5	3.0	*	*	*	*	*	*	*	*	Pass
00110RW1	RD	AAF	8.9	8.2	42.4	*	*	*	*	*	*	*	*	*	*	Pass
10110RW1	RD	AAG	7.0	6.0	73.3	13.0	*	*	*	*	*	*	*	*	*	Pass
10110RW0	RD	AAG	7.0	5.8	42.9	0.5	6.0	*	*	*	*	*	*	*	*	Pass
01110RW3	RD	AAK	8.9	8.4	55.5	*	*	*	*	*	*	*	*	*	*	Pass
01110RW1	RD	AAK	6.4	7.6	35.7	20.0	*	*	*	*	*	*	*	*	*	Pass
11110RW0	RD	AAM	9.0	10.2	49.4	0.5	6.0	*	*	*	*	*	*	*	*	Pass
00001RW5	RH	AAA	8.0	9.0	77.3	0.5	24.0	*	*	*	*	*	*	*	*	Pass
10001RW5	RH	AAB	10.4	12.1	64.2	4.0	89.0	*	*	*	*	*	*	*	*	Pass
01001RW0	RH	AAC	7.5	9.2	24.3	2.0	47.0	49.5	50.0	51.0	52.0	54.0	55.0	55.5	56.5	54
11001RW0	RH	AAD	7.9	10.8	55.6	0.5	49.0	55.0	56.0	56.5	56.5	57.0	57.5	57.5	58.0	56
11001RW3	RH	AAD	9.9	12.4	81.1	0.5	5.0	12.5	13.5	13..5	14.0	15.5	15.5	16.0	16.5	14
00101RW1	RH	AAF	8.1	9.8	39.1	0.5	11.5	13.0	14.0	14.0	14.0	14.0	14.5	14.5	15.0	13
10101RW5	RH	AAG	7.9	10.6	44.4	3.0	55.0	81.0	86.0	86.5	89.0	93.0	94.0	95.0	95.5	90
10101RW4	RH	AAG	9.5	12.3	74.3	7.0	21.5	24.0	25.5	26.0	26.0	26.0	26.0	26.5	27.0	26
01101RW0	RH	AAK	8.4	9.3	92.0	5.0	*	*	*	*	*	*	*	*	*	Pass
11101RW0	RH	AAM	7.0	8.1	76.3	0.5	13.0	*	*	*	*	*	*	*	*	Pass
00011RW0	RJ	AAA	9.3	10.6	58.4	4.0	7.0	9.0	10.0	10.5	11.0	11.0	11.0	11.0	11.5	10.0
00011RW1	RJ	AAA	7.9	8.3	50.3	0.5	4.0	16.0	19.0	20.0	21.0	21.5	21.5	22.0	22.0	20.0

Table C2: Summary Data of 32 SHRP Mixtures- SWK

Spec Ref	Agg Code	Asph Code	Slab Void Content (%)	Spec Void Content (%)	Saturation (%)	Time (hr) to Deformation (mm) 1	2	3	4	5	Time (hr) to Deformation (mm) 6	7	8	9	10	Time to Failure (hr)
10011RW0	RJ	AAB	11.7	14.0	82.5	0.5	2.0	3.0	3.0	3.5	3.5	3.5	3.5	4.0	4.0	3.0
01011RW0	RJ	AAC	12.8	9.2	74.3	0.5	2.0	3.0	4.0	5.5	8.0	8.5	9.0	9.0	9.5	9.5
11011RW0	RJ	AAD	7.1	8.4	41.9	3.0	7.5	9.0	9.5	10.5	12.0	13.0	15.0	17.0	17.0	17.0
00111RW0	RJ	AAF	8.0	8.2	38.4	1.5	2.0	2.5	3.5	5.0	6.0	6.0	6.0	6.5	6.5	2.0
10111RW0	RJ	AAG	9.9	9.7	75.0	1.5	5.0	6.5	7.0	7.5	8.0	9.0	9.5	9.5	9.5	6.0
01111RW3	RJ	AAK	9.5	11.6	84.4	1.0	28.0	36.5	38.5	41.5	43.0	44.5	46.0	47.0	47.5	45.0
01111RW1	RJ	AAK	9.9	11.2	83.0	0.5	1.0	4.0	6.0	10.5	15.0	15.0	15.0	15.5	16.0	15
11111RW0	RJ	AAM	11.0	11.7	63.6	0.5	6.0	57.0	61.0	64.5	66.0	67.0	67.0	67.0	67.0	67.0

Table C3: Summary Data of 32 SHRP Mixtures- OSU Wheel Tracker

SAMPLE ID	ASPH ID	AGG ID	ASPH CONT. %	DATE OF TEST	Gmb	Gmm	Air Voids (%)	Sat. (%)	Stripping Rate	Rut 200	Depth, 500	mm, 1000	at 2000	wheel 5000	passes 10000
00000RR0	AAA1	RC	6.25	09/30/91	2.221	2.391	7.1	33	25	1.79	3.48	4.98	6.48	9.43	18.00
00000RR1	AAA1	RC	6.25	09/30/91	2.205	2.391	7.8	55	40	2.97	5.11	7.23	9.63	14.8	*
10000RR0	AAB1	RC	6.25	10/14/91	2.224	2.388	6.9	63	5	1.54	2.36	3.77	4.69	6.8	10.31
10000RR1	AAB1	RC	6.25	10/14/91	2.224	2.388	6.9	73	2.5	1.55	2.66	4.02	5.74	8.49	11.35
01000RR0	AAC1	RC	6.25	11/26/91	2.217	2.401	7.7	64	*	1.95	3.44	4.61	6.26	12.43	*
01000RR1	AAC1	RC	6.25	11/26/91	2.214	2.401	7.8	59	30	2.33	3.85	5.37	7.51	12.15	24.00
11000RR0	AAD1	RC	6.25	10/13/91	2.190	2.381	8.0	65	0	2.35	3.28	5.05	5.42	6.94	9.47
11000RR1	AAD1	RC	6.25	10/13/91	2.205	2.381	7.4	60	30	2.02	3.55	4.94	5.76	7.01	10.26
00100RR0	AAF1	RC	6.25	10/15/91	2.207	2.388	7.6	92	5	2.39	3.32	4.51	6.13	8.20	10.80
00100RR1	AAF1	RC	6.25	10/15/91	2.204	2.388	7.7	66	17.5	2.06	3.07	4.52	6.50	8.35	10.64
10100RR6	AAG1	RC	6.25	11/30/91	2.231	2.422	7.9	72	0	1.98	3.00	4.09	5.06	6.65	9.82
01100RR0	AAK1	RC	6.25	10/08/91	2.196	2.382	7.8	79	5	1.30	1.90	2.19	3.57	4.52	8.45
01100RR1	AAK1	RC	6.25	10/08/91	2.169	2.382	8.9	61	5	1.30	2.44	3.26	5.39	7.58	11.89
11100RR0	AAM1	RC	6.25	10/08/91	2.191	2.373	7.7	73	0	1.80	2.93	4.02	5.28	7.05	9.18
11100RR1	AAM1	RC	6.25	10/08/91	2.182	2.373	8.0	47	5	2.36	3.38	4.93	6.02	8.04	9.88
00010RR2	AAA1	RD	4.5	08/29/91	2.333	2.541	8.2	52	*	0.51	1.26	2.11	3.72	5.35	6.31
00010RR3	AAA1	RD	4.5	10/22/91	2.338	2.541	8.0	60	5	1.56	2.17	2.33	3.64	5.11	6.00
10010RR2	AAB1	RD	4.5	10/22/91	2.310	2.529	8.7	45	15	1.07	1.60	2.62	3.79	5.77	6.69
10010RR3	AAB1	RD	4.5	10/29/91	2.316	2.529	8.4	52	17.5	0.41	1.72	2.72	3.75	5.58	6.99
01010RR2	AAC1	RD	4.5	11/25/91	2.300	2.525	8.9	40	5	1.22	2.47	3.12	4.35	5.91	7.16
11010RR0	AAD1	RD	4.5	09/08/91	2.334	2.549	8.4	57	*	0.87	1.88	2.82	4.37	6.05	7.20
11010RR1	AAD1	RD	4.5	08/30/91	2.331	2.549	8.6	56	*	0.67	1.44	2.25	3.77	5.89	7.16
00110RR0	AAF1	RD	4.5	08/30/91	2.321	2.552	9.0	56	*	0.19	1.34	2.00	3.19	4.51	5.72
00110RR1	AAF1	RD	4.5	09/14/91	2.332	2.552	8.6	49	10	0.75	1.50	2.27	3.46	5.41	6.90
10110RR2	AAG1	RD	4.5	11/05/91	2.321	2.542	8.7	61	5	0.53	1.32	2.36	3.58	6.61	8.60
10110RR3	AAG1	RD	4.5	11/05/91	2.323	2.542	8.6	61	0	0.70	1.72	2.50	4.40	7.54	10.35
01110RR2	AAK1	RD	4.5	09/06/91	2.336	2.542	8.1	51	*	0.13	0.56	0.87	1.67	3.42	4.82
01110RR3	AAK1	RD	4.5	09/14/91	2.314	2.542	9.0	63	5	0.65	1.29	1.76	2.57	3.97	4.99
11110RR1	AAM1	RD	4.5	09/01/91	2.329	2.549	8.6	44	*	1.04	1.58	2.17	3.32	4.56	5.19
00001RR4	AAA1	RH	5.2	09/14/91	2.292	2.496	8.2	54	0	1.22	1.47	2.15	3.92	5.25	7.12
00001RR5	AAA1	RH	5.2	10/22/91	2.309	2.496	7.5	63	12.5	0.92	2.50	3.90	7.11	9.02	10.52
10001RR3	AAB1	RH	5.2	09/14/91	2.295	2.515	8.8	42	10	0.63	1.31	1.90	3.41	5.87	7.88
01001RR1	AAC1	RH	5.2	09/26/91	2.332	2.505	6.9	44	7.5	1.66	2.23	3.43	4.91	8.62	10.98
01001RR3	AAC1	RH	5.2	10/27/91	2.342	2.515	6.9	32	5	0.72	1.21	1.83	2.50	4.18	6.37
11001RR0	AAD1	RH	5.2	09/22/91	2.328	2.519	7.6	46	15	0.81	1.50	2.01	3.10	5.08	6.85
11001RR1	AAD1	RH	5.2	09/22/91	2.322	2.519	7.8	56	5	0.75	1.34	2.51	4.22	6.42	8.17

Table C3: Summary Data of 32 SHRP Mixtures- OSU Wheel Tracker

SAMPLE ID	ASPH ID	AGG ID	ASPH CONT. %	DATE OF TEST	Gmb	Gmm	Air Voids (%)	Sat. (%)	Stripping Rate	Rut 200	Depth, 500	mm, 1000	at 2000	wheel 5000	passes 10000
00101RR0	AAF1	RH	5.2	09/14/91	2.298	2.518	8.7	40	30	0.64	1.26	1.46	2.59	4.97	7.67
00101RR1	AAF1	RH	5.2	10/23/91	2.304	2.518	8.5	57	0	0.96	1.98	1.79	3.81	6.19	8.24
10101RR4	AAG1	RH	5.2	10/24/91	2.296	2.514	8.7	65	45	1.59	2.79	3.60	4.63	6.21	7.52
10101RR5	AAG1	RH	5.2	10/24/91	2.295	2.514	8.7	61	35	0.85	1.74	2.52	3.81	5.96	7.88
01101RR0	AAK1	RH	5.2	09/21/91	2.300	2.519	8.7	43	7.5	0.42	0.89	1.17	2.25	3.29	5.17
01101RR1	AAK1	RH	5.2	09/21/91	2.297	2.519	8.8	46	7.5	0.52	0.98	0.92	2.16	4.69	6.97
11101RR0	AAM1	RH	5.2	10/21/91	2.308	2.500	7.7	71	5	1.29	1.81	2.17	3.08	4.86	6.56
11101RR1	AAM1	RH	5.2	10/21/91	2.308	2.500	7.7	38	2.5	0.61	0.86	1.27	2.16	3.97	5.98
00011RR2	AAA1	RJ	5.0	10/27/91	2.262	2.469	8.4	53	*	0.89	1.52	1.78	2.34	3.43	4.49
00011RR3	AAA1	RJ	5.0	10/27/91	2.262	2.469	8.4	55	*	0.65	1.58	2.52	4.42	6.62	8.30
10011RR2	AAB1	RJ	5.0	8/29/91	2.270	2.458	7.7	80	5.0	0.64	1.14	2.21	3.22	3.91	4.43
10011RR3	AAB1	RJ	5.0	10/23/91	2.270	2.458	7.7	55	*	0.34	0.93	1.78	2.79	3.97	5.41
01011RR7	AAC1	RJ	5.0	9/06/91	2.213	2.433	9.0	63	25.0	0.75	2.18	3.16	4.43	6.91	8.79
11011RR0	AAD1	RJ	5.0	11/18/91	2.268	2.444	7.2	57	7.5	0.69	1.31	1.76	2.63	3.84	6.40
11011RR1	AAD1	RJ	5.0	10/24/91	2.262	2.444	7.4	66	*	0.62	1.20	1.65	2.36	3.64	4.66
00111RR0	AAF1	RJ	5.0	8/25/91	2.279	2.479	8.1	57	*	0.65	1.50	1.76	2.43	3.90	5.47
00111RR1	AAF1	RJ	5.0	10/24/91	2.280	2.479	8.0	41	*	0.55	1.31	1.78	2.75	4.60	6.99
10111RR4	AAG1	RJ	5.0	8/25/91	2.239	2.445	8.4	53	70.0	1.11	2.43	3.14	4.36	5.81	8.65
01111RR0	AAK1	RJ	5.0	12/06/91	2.292	2.471	7.2	47	*	0.24	1.07	1.46	2.59	3.51	4.32
01111RR1	AAK1	RJ	5.0	8/22/91	2.296	2.471	7.1	50	*	0.68	1.26	1.71	2.37	3.27	4.32
11111RR3	AAM1	RJ	5.0	8/22/91	2.243	2.471	9.2	54	*	0.59	0.95	1.28	1.96	2.59	2.65

APPENDIX D

ECS FIGURES

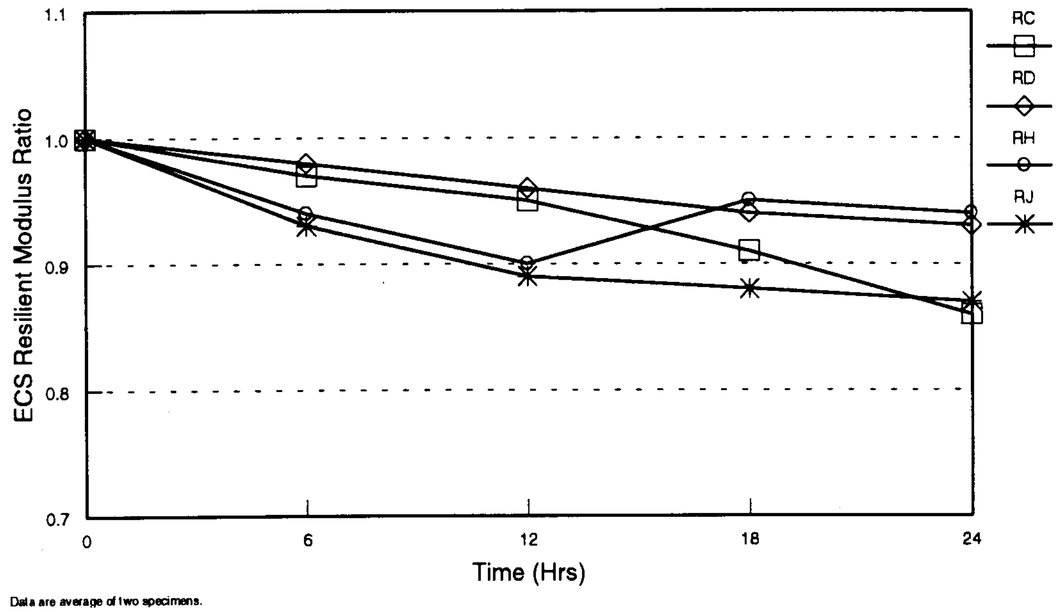


Figure D1: **The Effect Of ECS Conditioning on Asphalt AAA-1 Mixtures**

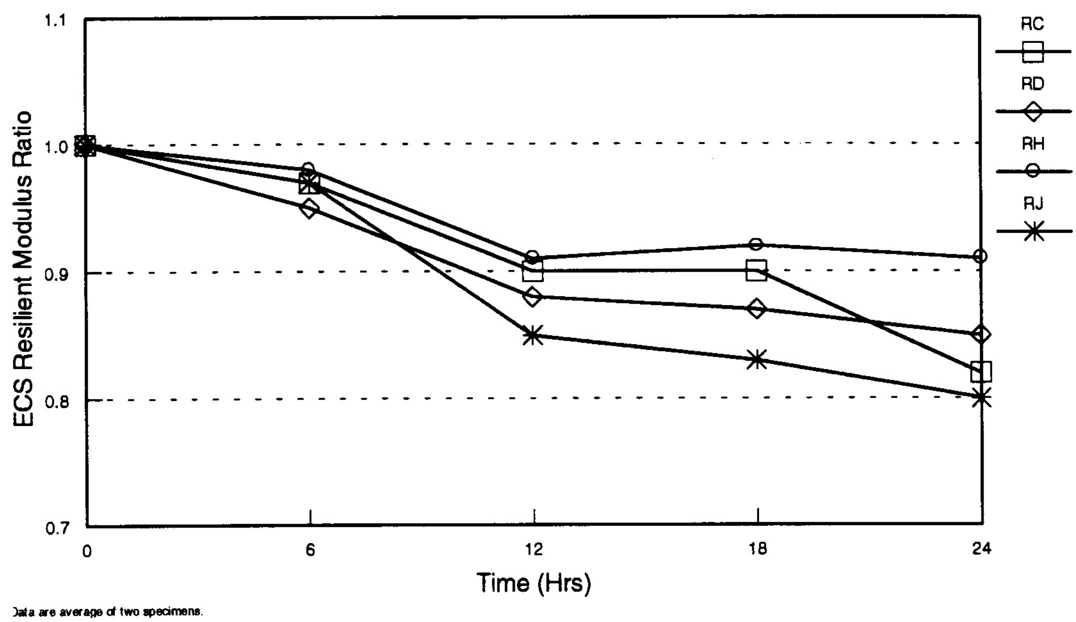


Figure D2: **The Effect Of ECS Conditioning on Asphalt AAB-1 Mixtures**

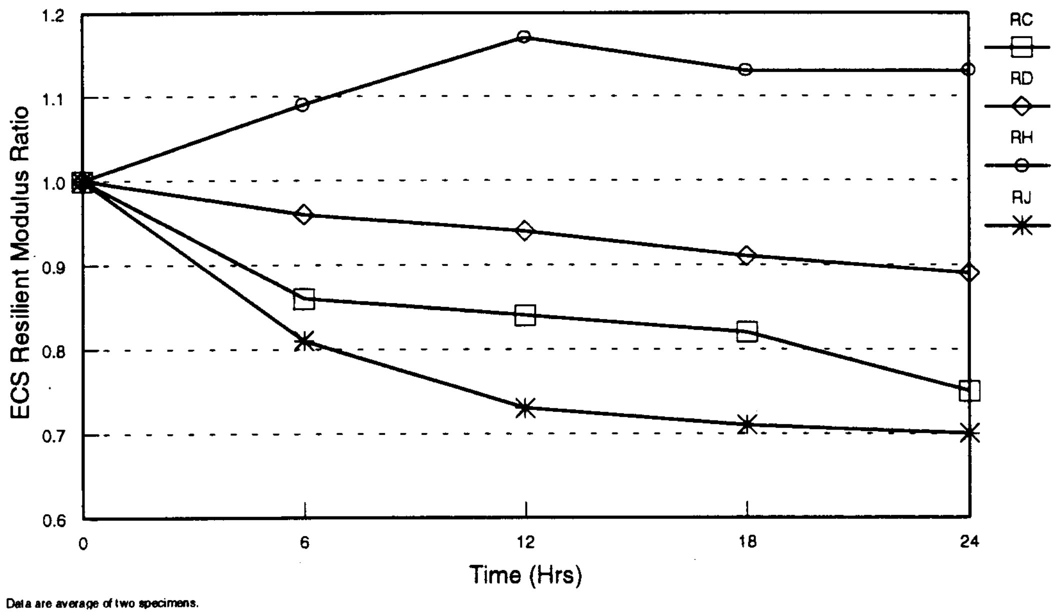


Figure D3: **The Effect Of ECS Conditioning on Asphalt AAC-1 Mixtures**

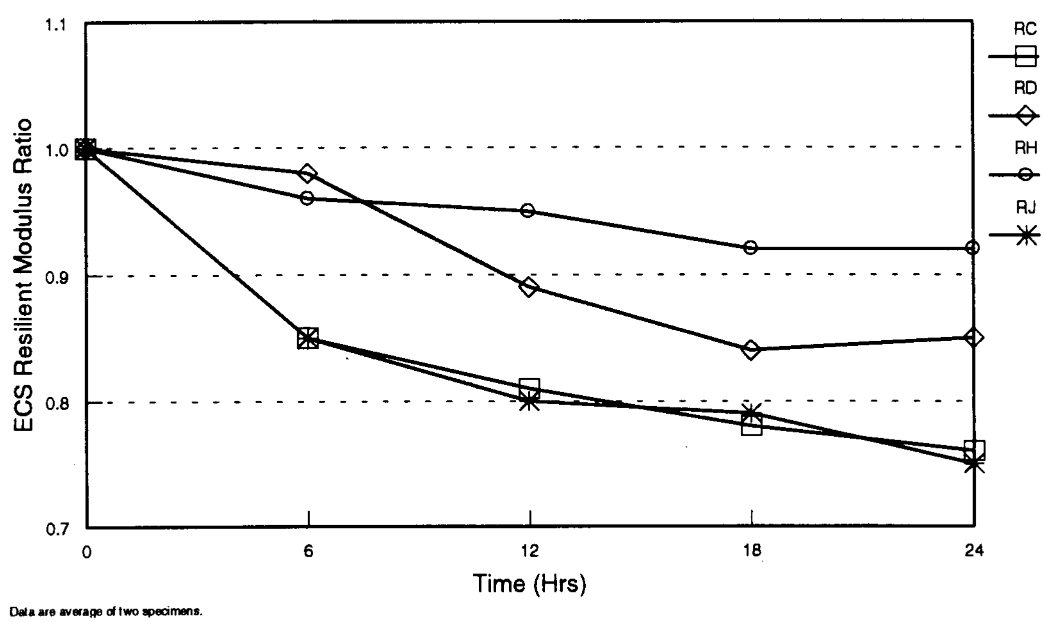


Figure D4: **The Effect Of ECS Conditioning on Asphalt AAD-1 Mixtures**

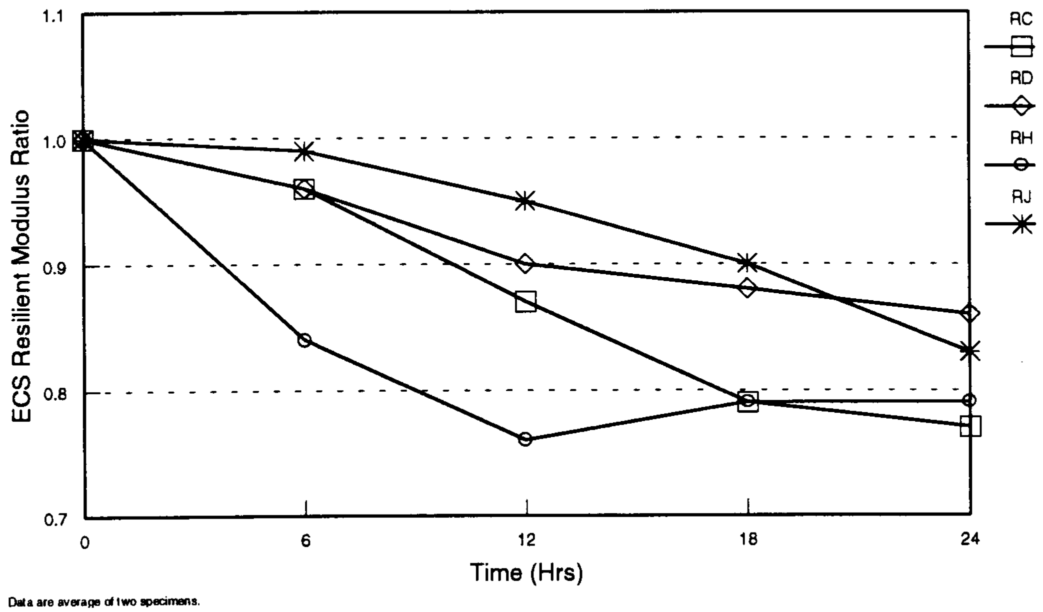


Figure D5: **The Effect Of ECS Conditioning on Asphalt AAF-1 Mixtures**

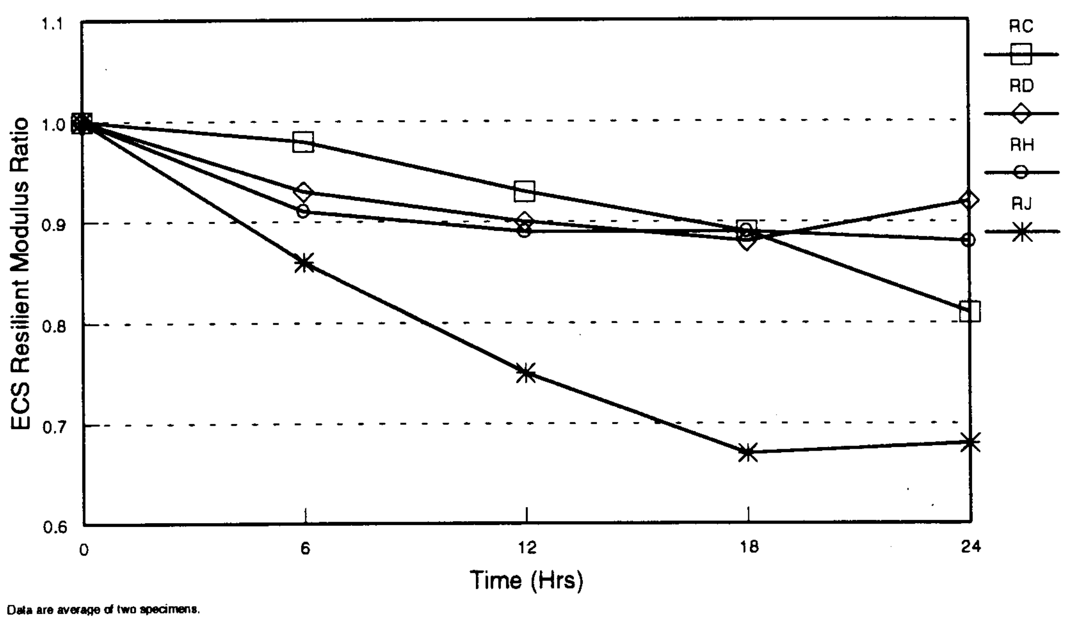
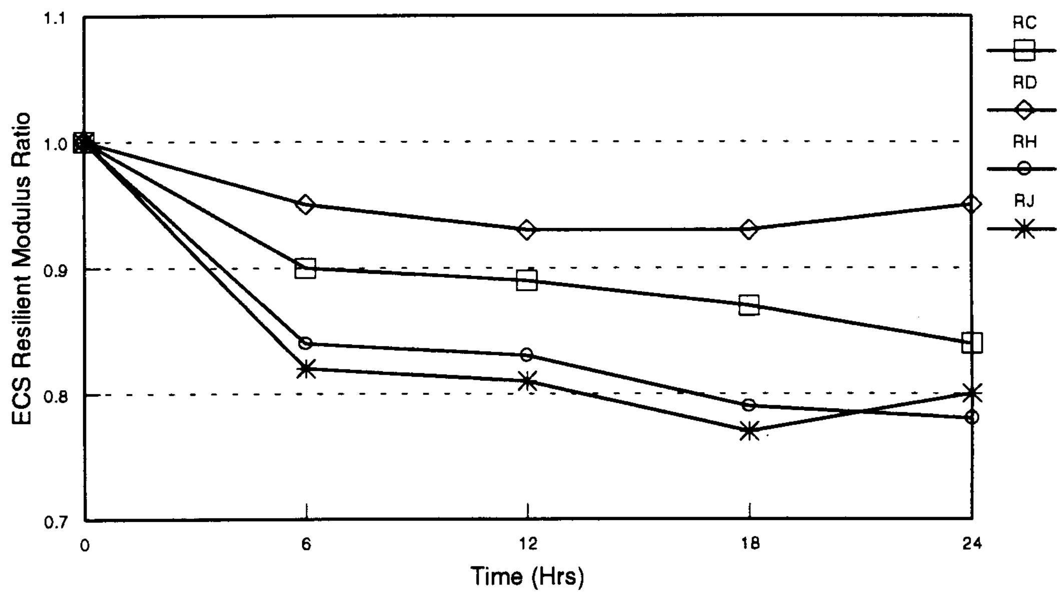
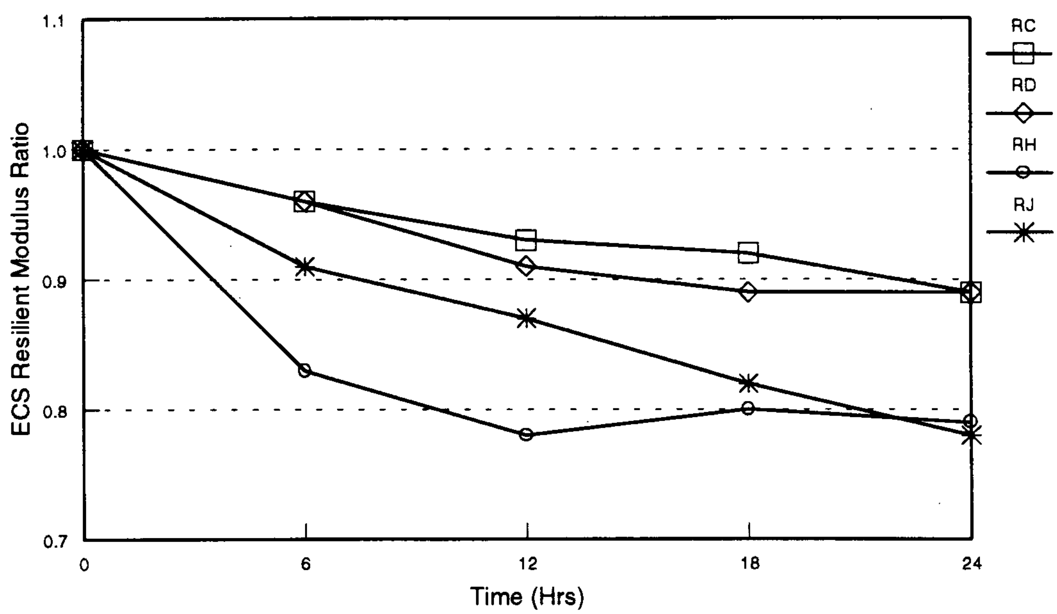


Figure D6: **The Effect Of ECS Conditioning on Asphalt AAG-1 Mixtures**



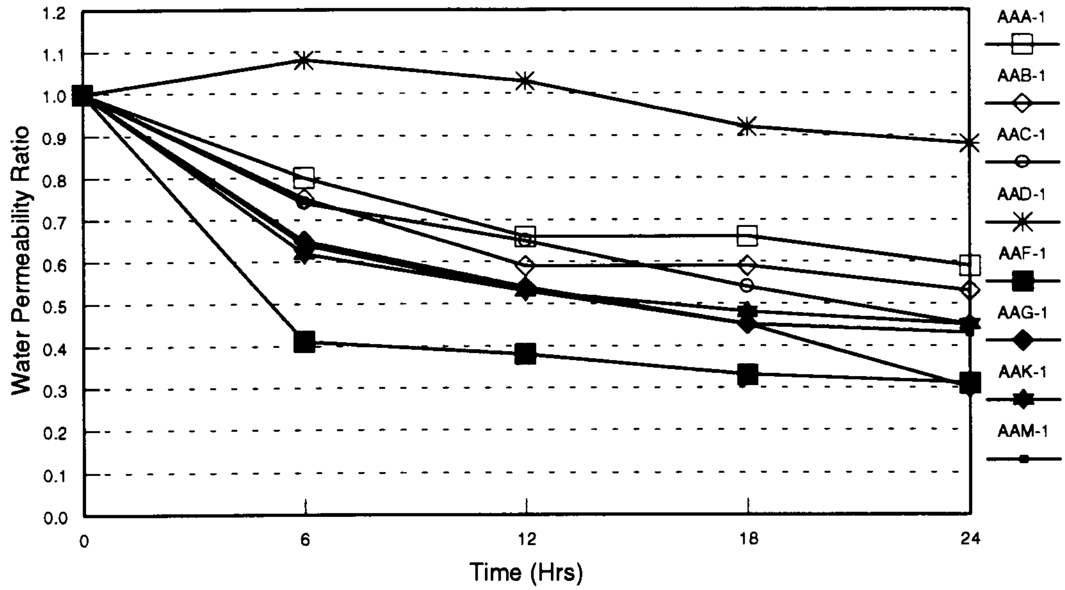
Data are average of two specimens.

Figure D7: **The Effect Of ECS Conditioning on Asphalt AAK-1 Mixtures**



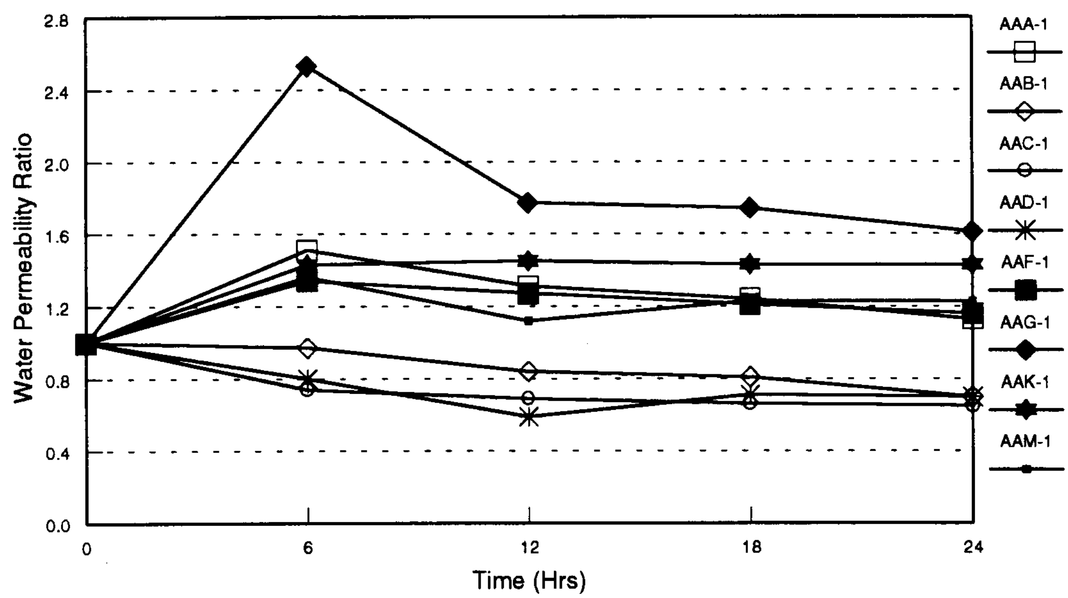
Data are average of two specimens.

Figure D8: **The Effect Of ECS Conditioning on Asphalt AAM-1 Mixtures**



Data are average of two specimens.

Figure D9: **The Effect Of ECS on Water Permeability of Aggregate RC Mixtures**



Data are average of two specimens.

Figure D10: **The Effect Of ECS on Water Permeability of Aggregate RD Mixtures**

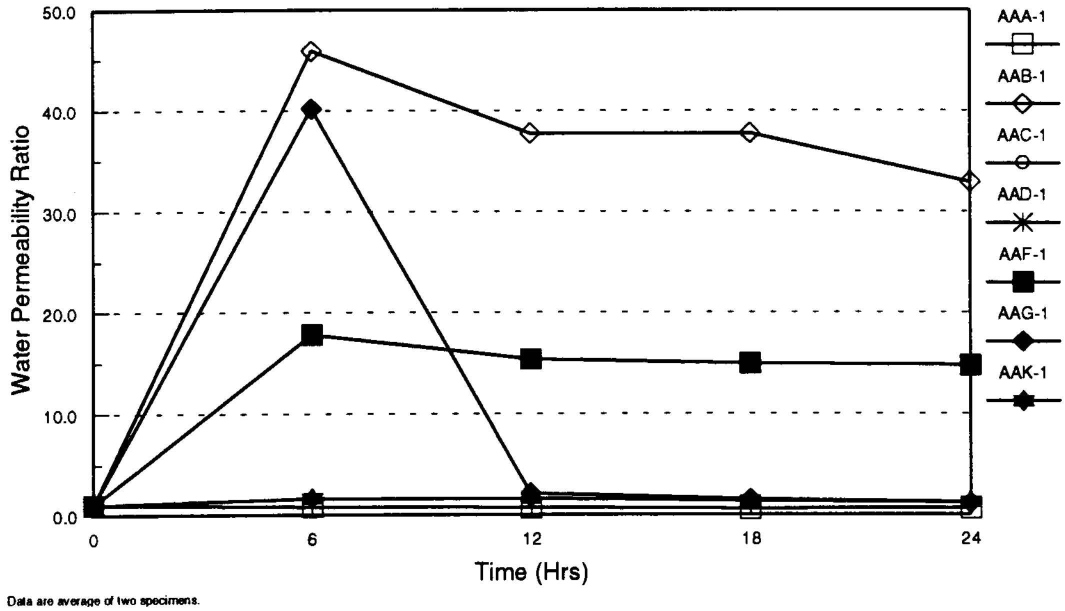


Figure D11: **The Effect Of ECS on Water Permeability of Aggregate RH Mixtures**

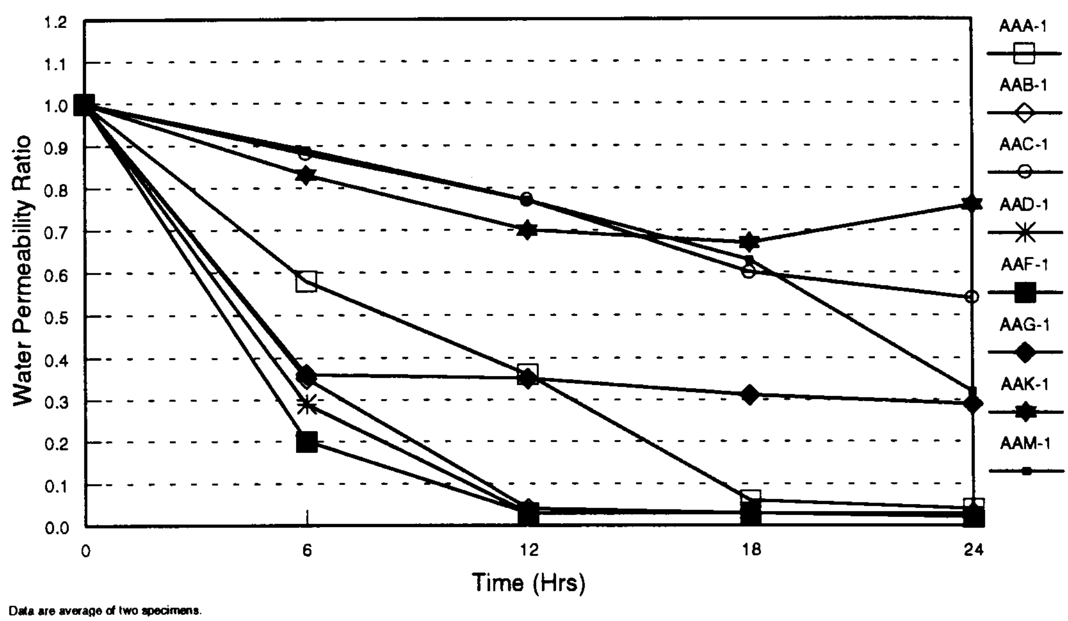


Figure D12: **The Effect Of ECS on Water Permeability of Aggregate RJ Mixtures**

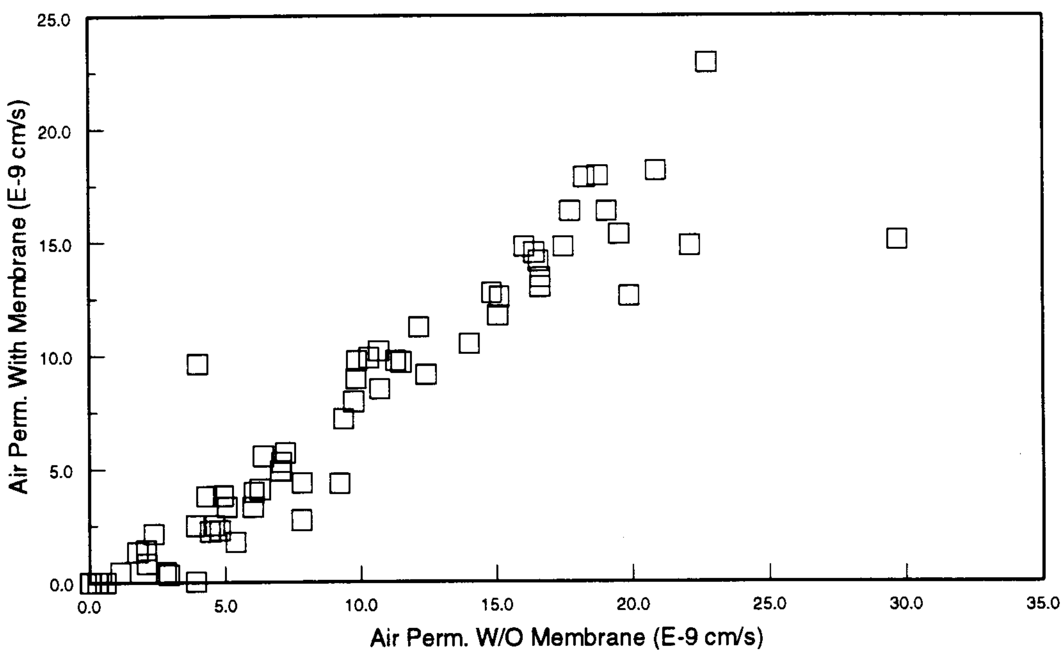


Figure D13: **Effect of Latex Membrane on Air Permeability**

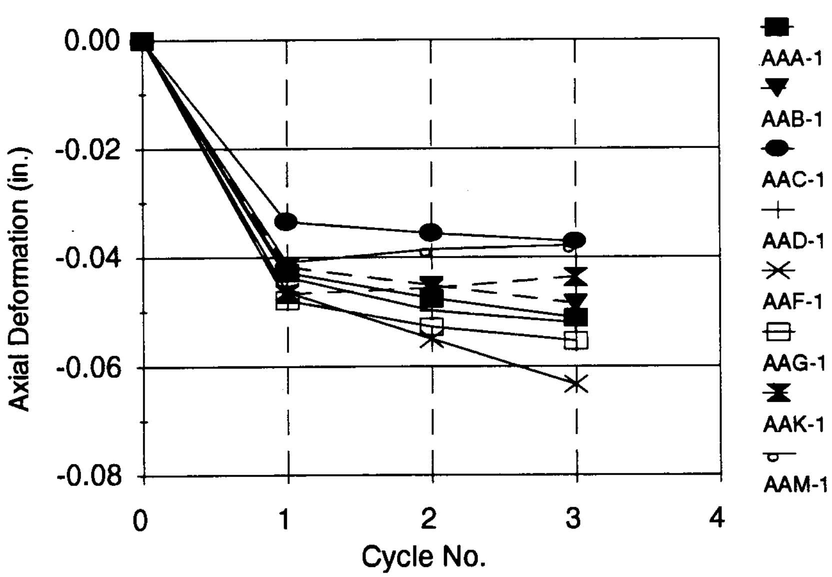


Figure D14: **Axial Deformation For Aggregate RC Mixtures**

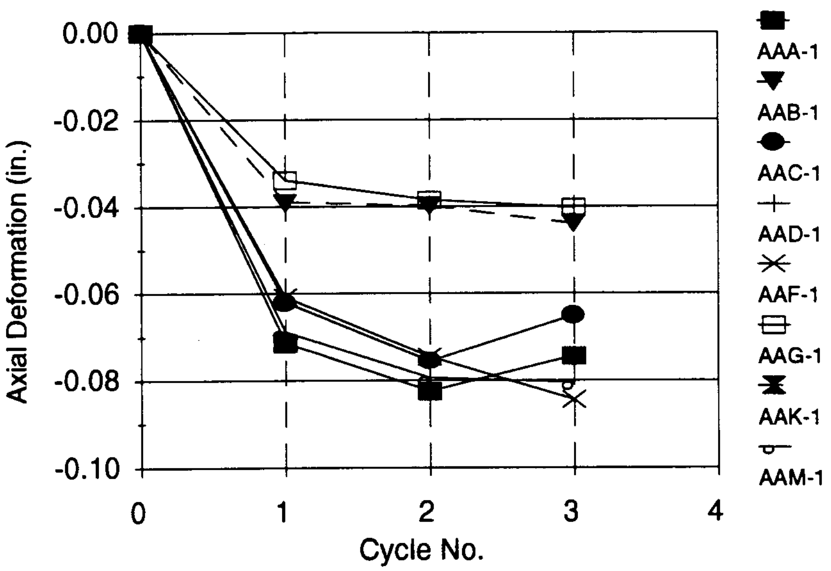


Figure D15: Axial Deformation For Aggregate RD Mixtures

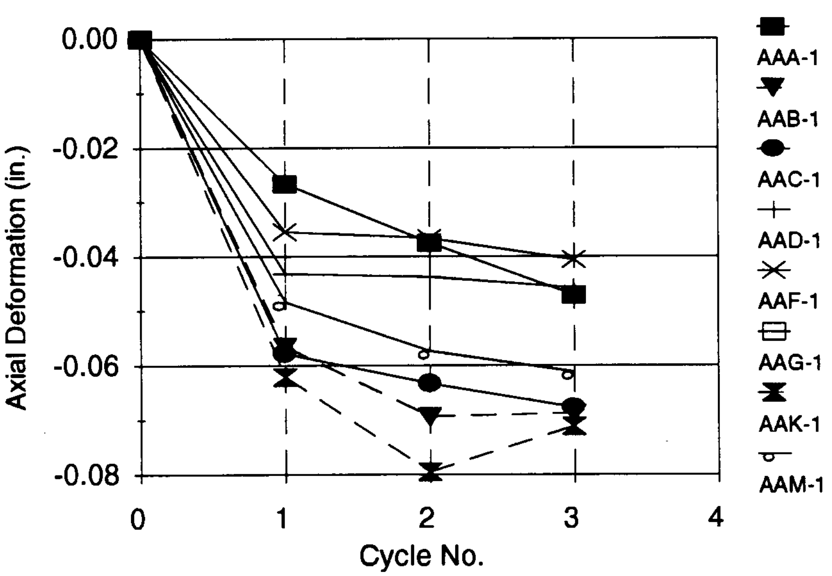


Figure D16: Axial Deformation For Aggregate RH Mixtures

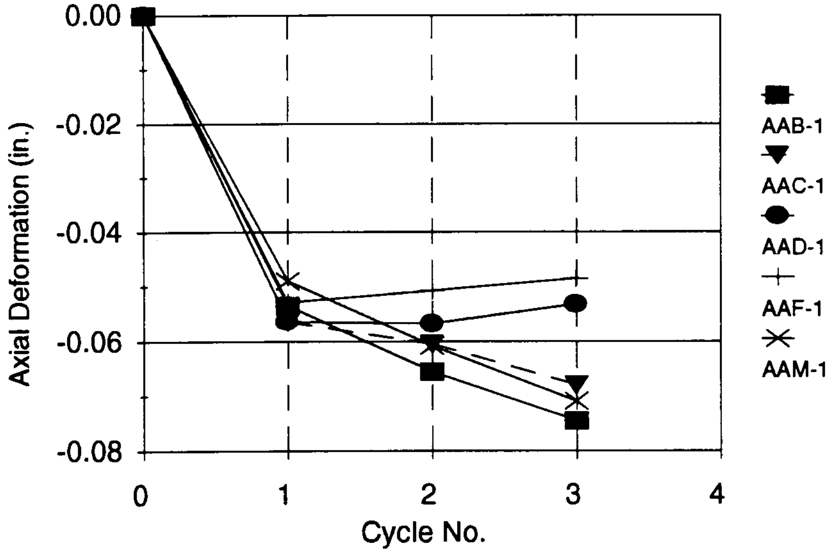


Figure D17: Axial Deformation For Aggregate RJ Mixtures

APPENDIX E

STATISTICAL ANALYSIS

SAS

General Linear Models Procedure
Class Level Information

Class	Levels	Values
AGR	4	RC RD RH RJ
ASPH	8	AAA-1 AAB-1 AAC-1 AAD-1 AAF-1 AAG-1 AAK-1 AAM-1

Number of observations in data set = 64

NOTE: Due to missing values, only 57 observations can be used in this analysis.

Dependent Variable: MRR3

Source	DF	Sum of Squares	F Value	Pr > F
Model	44	0.41597783	4.28	0.0046
Error	12	0.02652743		
Corrected Total	56	0.44250526		

R-Square	C.V.	MRR3 Mean
0.940052	5.420675	0.86736842

Source	DF	Type I SS	F Value	Pr > F
AGR	3	0.05601138	8.45	0.0028
ASPH	7	0.06221613	4.02	0.0170
RUT5	1	0.01817991	8.22	0.0141
SAT	1	0.01233958	5.58	0.0359
AV1	1	0.00081614	0.37	0.5548
AV2	1	0.00085310	0.39	0.5461
AV3	1	0.00672776	3.04	0.1066
STRIP1	1	0.00530597	2.40	0.1473
STRIP2	1	0.04367742	19.76	0.0008
STRIP3	1	0.01031656	4.67	0.0517

MRAVG	1	0.00253286	1.15	0.3055
MR0	1	0.02026768	9.17	0.0105
WP0	1	0.01869657	8.46	0.0131
WP3	1	0.00408178	1.85	0.1992
WP4	1	0.00239006	1.08	0.3189
AGR*ASPH	21	0.15156495	3.26	0.0193

Source	DF	Type III SS	F Value	Pr > F
AGR	3	0.01142323	1.72	0.2154
ASPH	7	0.01359869	0.88	0.5502
RUT5	1	0.00031995	0.14	0.7103
SAT	1	0.00051904	0.23	0.6367
AV1	1	0.00745897	3.37	0.0911
AV2	1	0.00039665	0.18	0.6794
AV3	1	0.00061038	0.28	0.6088
STRIP1	1	0.00035982	0.16	0.6937
STRIP2	1	0.00000541	0.00	0.9613
STRIP3	1	0.00226854	1.03	0.3310
MRAVG	1	0.00009925	0.04	0.8358
MR0	1	0.00129707	0.59	0.4585
WP0	1	0.00113202	0.51	0.4879
WP3	1	0.00399456	1.81	0.2037
WP4	1	0.00510237	2.31	0.1546
AGR*ASPH	21	0.15156495	3.26	0.0193

AGR	MRR3 LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
RC	0.93108402	1	.	0.3893	0.5089	0.1009
RD	0.85277395	2	0.3893	.	0.6704	0.1989
RH	0.87831909	3	0.5089	0.6704	.	0.1010
RJ	0.78671416	4	0.1009	0.1989	0.1010	.

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

ASPH	MRR3 LSMEAN	LSMEAN Number
AAA-1	0.87835254	1
AAB-1	0.88635172	2
AAC-1	0.88007092	3
AAD-1	0.81022660	4
AAF-1	0.87205706	5
AAG-1	0.86831583	6
AAK-1	0.81586656	7
AAM-1	0.88654121	8

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

SAS

General Linear Models Procedure
Class Level Information

Class	Levels	Values
AGR	4	RC RD RH RJ
ASPH	8	AAA-1 AAB-1 AAC-1 AAD-1 AAF-1 AAG-1 AAK-1 AAM-1

Number of observations in data set = 64

NOTE: Due to missing values, only 57 observations can be used in this analysis.

Dependent Variable: MRR3

Source	DF	Sum of Squares	F Value	Pr > F
Model	14	0.14386167	1.45	0.1755
Error	42	0.29864359		
Corrected Total	56	0.44250526		

R-Square	C.V.	MRR3 Mean
0.325107	9.721837	0.86736842

Source	DF	Type I SS	F Value	Pr > F
AGR	3	0.05601138	2.63	0.0628
ASPH	7	0.06221613	1.25	0.2982
SAT	1	0.01297159	1.82	0.1840
AV1	1	0.00174256	0.25	0.6232
AV2	1	0.00003056	0.00	0.9480
STRIP3	1	0.01088946	1.53	0.2228

Source	DF	Type III SS	F Value	Pr > F
AGR	3	0.04629976	2.17	0.1057
ASPH	7	0.02917070	0.59	0.7633
SAT	1	0.01492347	2.10	0.1548
AV1	1	0.00001837	0.00	0.9597
AV2	1	0.00107390	0.15	0.6995
STRIP3	1	0.01088946	1.53	0.2228

AGR MRR3 Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

AGR	LSMEAN	i/j	1	2	3	4
RC	0.88362635	1	.	0.9962	0.9922	0.0729
RD	0.88385166	2	0.9962	.	0.9970	0.0704
RH	0.88400139	3	0.9922	0.9970	.	0.0485
RJ	0.81536454	4	0.0729	0.0704	0.0485	.

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

ASPH	MRR3 LSMEAN	LSMEAN Number
AAA-1	0.90543460	1
AAB-1	0.88307798	2
AAC-1	0.89845620	3
AAD-1	0.83125648	4
AAF-1	0.85927403	5
AAG-1	0.85164788	6
AAK-1	0.83865622	7
AAM-1	0.86588447	8

General Linear Models Procedure
Class Level Information

Class	Levels	Values
AGR	4	RC RD RH RJ
ASPH	8	AAA-1 AAB-1 AAC-1 AAD-1 AAF-1 AAG-1 AAK-1 AAM-1

Number of observations in data set = 64

NOTE: Due to missing values, only 57 observations can be used in this analysis.

Dependent Variable: RUT5

Source	DF	Sum of Squares	F Value	Pr > F
Model	45	291.08230549	4.49	0.0051
Error	11	15.86339276		
Corrected Total	56	306.94569825		

R-Square	C.V.	RUT5 Mean
0.948319	19.66572	6.10649123

Source	DF	Type I SS	F Value	Pr > F
AGR	3	132.90673180	30.72	0.0001
ASPH	7	86.35029195	8.55	0.0011
SAT	1	0.03873242	0.03	0.8728
AV1	1	0.88628313	0.61	0.4496
AV2	1	5.93496362	4.12	0.0674
AV3	1	1.54616899	1.07	0.3227

STRIP1	1	11.79789715	8.18	0.0155
STRIP2	1	1.01275247	0.70	0.4199
STRIP3	1	0.95566626	0.66	0.4329
MRAVG	1	1.36416386	0.95	0.3517
MR0	1	1.37049257	0.95	0.3506
MRR1	1	1.15180824	0.80	0.3906
MRR3	1	0.70314017	0.49	0.4995
MRR4	1	1.18026969	0.82	0.3850
NAT	1	0.16020646	0.11	0.7452
WP0	1	1.64597062	1.14	0.3083
AGR*ASPH	21	42.07676611	1.39	0.2919

Source	DF	Type III SS	F Value	Pr > F
AGR	3	9.16404542	2.12	0.1559
ASPH	7	45.60827083	4.52	0.0133
SAT	1	4.15300150	2.88	0.1178
AV1	1	0.00582846	0.00	0.9505
AV2	1	3.56487717	2.47	0.1442
AV3	1	0.33332116	0.23	0.6401
STRIP1	1	0.00826674	0.01	0.9410
STRIP2	1	4.93073372	3.42	0.0915
STRIP3	1	0.57866420	0.40	0.5394
MRAVG	1	1.73583367	1.20	0.2960
MR0	1	1.18223253	0.82	0.3846
MRR1	1	0.00064154	0.00	0.9836
MRR3	1	0.08006510	0.06	0.8181
MRR4	1	0.12247084	0.08	0.7762
NAT	1	0.29908857	0.21	0.6577
WP0	1	2.65978584	1.84	0.2016
AGR*ASPH	21	42.07676611	1.39	0.2919

AGR RUT5 Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

LSMEAN i/j 1 2 3 4

RC	8.90782848	1	.	0.0649	0.3870	0.2063
RD	5.42290755	2	0.0649	.	0.6306	0.5814
RH	6.42065712	3	0.3870	0.6306	.	0.2861
RJ	3.30392413	4	0.2063	0.5814	0.2861	.

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

ASPH	RUT5 LSMEAN	LSMEAN Number
AAA-1	10.6538076	1
AAB-1	6.5508270	2
AAC-1	9.5045090	3
AAD-1	6.2828786	4
AAF-1	2.2520230	5
AAG-1	3.8187703	6
AAK-1	4.7944975	7
AAM-1	4.2533215	8

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

General Linear Models Procedure
Class Level Information

Class	Levels	Values
AGR	4	RC RD RH RJ
ASPH	8	AAA-1 AAB-1 AAC-1 AAD-1 AAF-1 AAG-1 AAK-1 AAM-1

Number of observations in data set = 64

NOTE: Due to missing values, only 57 observations can be used in this analysis.

Dependent Variable: RUT5

Source	DF	Sum of Squares	F Value	Pr > F
Model	15	235.20518965	8.96	0.0001
Error	41	71.74050859		
Corrected Total	56	306.94569825		

R-Square	C.V.	RUT5 Mean
0.766276	21.66200	6.10649123

Source	DF	Type I SS	F Value	Pr > F
AGR	3	132.90673180	25.32	0.0001
ASPH	7	86.35029195	7.05	0.0001
SAT	1	0.03873242	0.02	0.8825
AV2	1	6.82120086	3.90	0.0551
STRIP2	1	6.74971139	3.86	0.0563
MRAVG	1	0.48304699	0.28	0.6021
WP0	1	1.85547424	1.06	0.3092

Source	DF	Type III SS	F Value	Pr > F
AGR	3	78.61820772	14.98	0.0001
ASPH	7	68.02445253	5.55	0.0002
SAT	1	0.43262100	0.25	0.6217
AV2	1	7.69252044	4.40	0.0422
STRIP2	1	6.48779841	3.71	0.0611
MRAVG	1	0.23828795	0.14	0.7140
WP0	1	1.85547424	1.06	0.3092

General Linear Models Procedure

Least Squares Means

AGR	RUT5 LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
RC	8.73066381	1	.	0.0002	0.0002	0.0001
RD	5.49901444	2	0.0002	.	0.7549	0.1231
RH	5.72218601	3	0.0002	0.7549	.	0.0212
RJ	4.37017134	4	0.0001	0.1231	0.0212	.

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

ASPH	RUT5 LSMEAN	LSMEAN Number
AAA-1	8.15690724	1
AAB-1	5.93227331	2
AAC-1	8.39471690	3
AAD-1	5.48526831	4
AAF-1	5.06727445	5
AAG-1	6.16096036	6
AAK-1	4.42611493	7
AAM-1	5.02055569	8

General Linear Models Procedure
Class Level Information

Class	Levels	Values
AGGR	4	RC RD RH RJ
ASPH	8	AAA-1 AAB-1 AAC-1 AAD-1 AAF-1 AAG-1 AAK-1 AAM-1

Dependent Variable: NAT

R-Square	C.V.	NAT Mean
0.885339	4.993908	71.56957895

Source	DF	Type III SS	F Value	Pr > F
AGGR	3	3725.34358657	97.21	0.0001
ASPH	7	1112.55152394	12.44	0.0001
AGGR*ASPH	21	1327.79603647	4.95	0.0001

AGGR	NAT LSMEAN	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
RC	77.4916667	1	.	0.1886	0.0001	0.0001
RD	76.0991667	2	0.1886	.	0.0001	0.0001
RH	71.3916667	3	0.0001	0.0001	.	0.0001
RJ	61.5291667	4	0.0001	0.0001	0.0001	.

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

ASPH	NAT LSMEAN LSMEAN	LSMEAN Number
AAA-1	73.6875000	1
AAB-1	72.1991667	2
AAC-1	73.1975000	3
AAD-1	75.4866667	4
AAF-1	70.9641667	5
AAG-1	67.6266667	6
AAK-1	74.9500000	7
AAM-1	64.9116667	8

General Linear Models Procedure
Class Level Information

Class	Levels	Values
AGGR	4	RC RD RH RJ
ASPH	8	AAA-1 AAB-1 AAC-1 AAD-1 AAF-1 AAG-1 AAK-1 AAM-1

Number of observations in data set = 96
Dependent Variable: NAT

Source	DF	Sum of Squares	F Value	Pr > F
Model	31	6214.00111649	15.69	0.0001
Error	63	804.78266667		
Corrected Total	94	7018.78378316		

R-Square	C.V.	NAT Mean
0.885339	4.993908	71.56957895

Source	DF	Type I SS	F Value	Pr > F
AGGR	3	3724.14748968	97.18	0.0001
ASPH	7	1162.05759034	13.00	0.0001
AGGR*ASPH	21	1327.79603647	4.95	0.0001

Source	DF	Type III SS	F Value	Pr > F
AGGR	3	3725.34358657	97.21	0.0001
ASPH	7	1112.55152394	12.44	0.0001
AGGR*ASPH	21	1327.79603647	4.95	0.0001

Student-Newman-Keuls test for variable: NAT

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 63 MSE= 12.77433
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 23.74194

Number of Means	2	3	4
Critical Range	2.072976	2.4899759	2.7375156

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	AGGR
A	77.492	24	RC
A			
A	76.053	23	RD
B	71.392	24	RH
C	61.529	24	RJ

General Linear Models Procedure

Student-Newman-Keuls test for variable: NAT

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 63 MSE= 12.77433
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 11.86517

Number of Means	2	3	4	5
Critical Range	2.9323471	3.5222181	3.8723777	4.1209009

Number of Means	6	7	8
Critical Range	4.3130018	4.4692193	4.60033

Means with the same letter are not significantly different.

SNK Grouping		Mean	N	ASPH
	A	75.487	12	AAD-1
	A			
B	A	74.950	12	AAK-1
B	A			
B	A	73.688	12	AAA-1
B	A			
B	A	73.198	12	AAC-1
B	A			
B	A	72.199	12	AAB-1
B				
B		70.964	12	AAF-1
	C	66.759	11	AAG-1
	C			
	C	64.912	12	AAM-1

--------------------------- CYCLE=2 ---------------------------

General Linear Models Procedure
Class Level Information

Class	Levels	Values
MIX	8	A B C D E F G H

Number of observations in by group = 16

Dependent Variable: MR

Source	DF	Sum of Squares	F Value	Pr > F
Model	8	81054.2193750	15.64	0.0008
Error	7	4535.3700000		
Corrected Total	15	85589.5893750		

R-Square	C.V.	MR Mean
0.947010	13.12108	193.99375000

Source	DF	Type I SS	F Value	Pr > F
MIX	7	77399.0943750	17.07	0.0007
STRIP	1	3655.1250000	5.64	0.0492

Source	DF	Type III SS	F Value	Pr > F
MIX	7	78624.2193750	17.34	0.0006
STRIP	1	3655.1250000	5.64	0.0492

General Linear Models Procedure
Least Squares Means

MIX	MR LSMEAN	LSMEAN Number
A	284.750000	1
B	134.250000	2
C	193.750000	3
D	330.500000	4
E	56.350000	5
F	187.250000	6
G	240.450000	7
H	124.650000	8

-------------------------- CYCLE=3 --------------------------

General Linear Models Procedure
Class Level Information

Class	Levels	Values
MIX	8	A B C D E F G H

Number of observations in by group = 16

Dependent Variable: MR

Source	DF	Sum of Squares	F Value	Pr > F
Model	8	75469.4243750	31.48	0.0001
Error	7	2097.4550000		
Corrected Total	15	77566.8793750		

R-Square	C.V.	MR Mean
0.972959	8.990170	192.54375000

Source	DF	Type I SS	F Value	Pr > F
MIX	7	72427.4243750	34.53	0.0001
STRIP	1	3042.0000000	10.15	0.0154

Source	DF	Type III SS	F Value	Pr > F
MIX	7	70250.1413750	33.49	0.0001
STRIP	1	3042.0000000	10.15	0.0154

General Linear Models Procedure
Least Squares Means

MIX	MR LSMEAN	LSMEAN Number
A	282.500000	1
B	133.000000	2
C	200.700000	3
D	305.550000	4
E	67.650000	5
F	211.000000	6
G	212.900000	7
H	127.050000	8

--------------------------- CYCLE=4 ----------------------------

General Linear Models Procedure
Class Level Information

Class	Levels	Values
MIX	8	A B C D E F G H

General Linear Models Procedure

Dependent Variable: MR

Source	DF	Sum of Squares	F Value	Pr > F
Model	8	84160.8743750	31.38	0.0001
Error	7	2347.0150000		
Corrected Total	15	86507.8893750		

R-Square	C.V.	MR Mean
0.972869	9.327705	196.30625000

Source	DF	Type I SS	F Value	Pr > F
MIX	7	80548.3743750	34.32	0.0001
STRIP	1	3612.5000000	10.77	0.0134

Source	DF	Type III SS	F Value	Pr > F
MIX	7	81470.4473750	34.71	0.0001
STRIP	1	3612.5000000	10.77	0.0134

General Linear Models Procedure
Least Squares Means

MIX	MR LSMEAN	LSMEAN Number
A	290.500000	1
B	128.500000	2
C	177.000000	3
D	339.550000	4
E	58.500000	5
F	212.500000	6
G	221.150000	7
H	142.750000	8

APPENDIX F

OREGON DEPARTMENT OF TRANSPORTATION PROJECT

1.0 INTRODUCTION

This report presents the results of ECS evaluation of the open graded mixtures. Open-graded mixtures have been used for many years, in surface and base courses. Porous mixtures have reduced splash and spray during wet weather, thus improving safety. The states' highway agencies have not been able to accurately predict water damage potential of open graded mixtures with conventional test methods. Conventional water sensitivity tests have not been able to detect the potential for water damage. Existing water sensitivity evaluation tests are thought to be conservative, thus requiring additives for mixtures to pass the test and which is costly.

Open-graded mixtures were evaluated in the ECS for water sensitivity and results were compared to conventional water sensitivity test (Indirect Retained Strength). Also, the open-graded mixtures' results were used to evaluate the ECS capabilities to evaluate different mixture types.

The objective of this study was to evaluate the open graded mixtures and develop an improved evaluation procedure and guidelines for water sensitivity. Specific objectives include:

1) Evaluate the selected projects that have experienced water damage;
2) Compare the results of the ECS test with ODOT conventional evaluation method; and
3) Recommend modification to existing procedures if needed.

2.0 PROJECTS EVALUATED

Table F1 shows a summary of the specimens that have been evaluated for water sensitivity, and two specimens were tested in the ECS from each project. Specimens measuring 4 in. (102 mm) dia. by 4 in. (102 mm) height were received from ODOT. There were few mixtures that included antistripping additive and others did not. The mixtures had different aggregate sources and asphalt sources.

Table F1 Summary of ODOT Projects

Specimen ID.	Job Name	Rock Source	Asphalt Source	Additives
A-03	Myrtle Point Power	Wahl's Pit 8-108-3	PBA-5	None
A-02	Myrtle Point Power	Wahl's Pit 8-108-3	PBA-5	None
B-02	Pacific Hwy Gat	Eugene S&G 20-45-3	PBA-5	Lime 1.0% & PBS 0.5%
B-08	Pacific Hwy Gat	Eugene S&G 20-45-3	PBA-5	Lime 1.0% & PBS 0.5%
C-01	Santiam River Bridge	Hilory Pit 24-2-2	Albina PBA-5	Lime 1.0% & Pavebond 0.5%
C-03	Santiam River Bridge	Hilory Pit 24-2-2	Albina PBA-5	Lime 1.0% & Pavebond 0.5%
D-01	Young Bay Br	Naselle Rock #WA-02S-2	McCall PBA-5	Lime 1.0% & Pavebond 0.5%
D-03	Young Bay Br	Naselle Rock #WA-02S-2	McCall PBA-5	Lime 1.0% & Pavebond 0.5%
E-03	Eastside Bypass	Stokel/Horseridge Pit	Albina PBA-5	Lime 1.0% & PBS 0.5%
E-04	Eastside Bypass	Stokel/Horseridge Pit	Albina PBA-5	Lime 1.0% & PBS 0.5%
F-02	Butte Falls Rd	140 Pit 15-192-3/ Kirkland	Witco PBA-6	Lime 1.0% & PBS 0.5%
F-06	Butte Falls Rd	140 Pit 15-192-3/ Kirkland	Witco PBA-6	Lime 1.0% & PBS 0.5%
G-1	Santiam River Bridge	Hilory Pit 24-2-2	Albina PBA-5	None
G-2	Santiam River Bridge	Hilory Pit 24-2-2	Albina PBA-5	None
H-1	Umatilla-Mcnary	30-001-5	Koch PBA-6	None
H-2	Umatilla-Mcnary	30-001-5	Koch PBA-6	None

3.0 Procedures

First, the gravimetric data were obtained for the core specimen. The specimen was then encapsulated in a latex membrane with silicon. In the test, the air permeability and dry (unconditioned) ECS-M_R are determined prior to introduction of water. The ECS test procedure summarized in Table 2.3 was followed in this study. The test was modified and repeated loading through the first three cycles was excluded, because of the high air voids and mixtures' susceptibility to permanent deformation.

4.0 RESULTS

Table F2 shows a summary of the specimens that have been tested through ECS; two specimens have been tested from each mixture. Each mixture represents a project that has been selected for ECS evaluation for water damage. The selection of the two specimens to test in ECS was based on air voids and diametral resilient modulus test results. The two selected specimens best represented the other specimens in the group regarding air voids versus diametral resilient modulus. For example, specimens that fell outside the trends of air voids versus diametral M_R were not selected (see Figure F1). This method is good for eliminating specimens that might have unusual performances and do not represent the other specimens of the same group.

Table F2 includes results from ECS-M_R and water permeability (if permeable) initially and after the second, third, and fourth cycles. Also, the stripping rate at the end of the test is shown. The results of the IRS test (Index of Retained Strength) that was performed at the ODOT laboratory are also included. The IRS test represents a ratio of the mixtures' unconditioned compressive strength to their conditioned compressive strength, while lower values indicate water damage sensitive mixtures.

At room temperature (25 C) the open graded specimens can easily deform, and the asphalt film can flow to the bottom of the specimens. For these reasons, all the specimens that were received at OSU were placed in a 15 C temperature chamber to minimize these problems until two hours prior to testing when they were moved to a 25

Table F2: Summary of ODOT Open-graded Mixtures

Specimen ID	Air Voids (%)	Initial Air Permeability E-5 cm/s	Diam. MR (Ksi)	Cycle No.	ECS-MR (Ksi)	Retained ECS-MR Ratio	Water Permeability E-3 cm/s	Stripping Rate	IRS (%)
A-03	12.8	Impermeable	145.5	0	162.0	1.00	0.68	5	56.3
A-03	12.8	Impermeable	145.5	1	184.0	1.14	1.07	5	56.3
A-03	12.8	Impermeable	145.5	2	174.0	1.07	1.01	5	56.3
A-03	12.8	Impermeable	145.5	3	184.0	1.14	0.66	5	56.3
A-03	12.8	Impermeable	145.5	4	184.0	1.14	0.77	5	56.3
A-02	12.4	1.29	142.0	0	209.0	1.00	0.33	5	56.3
A-02	12.4	1.29	142.0	1	224.5	1.07	0.69	5	56.3
A-02	12.4	1.29	142.0	2	224.5	1.07	0.48	5	56.3
A-02	12.4	1.29	142.0	3	225.0	1.08	0.49	5	56.3
A-02	12.4	1.29	142.0	4	227.0	1.09	0.51	5	56.3
B-02	13.7	Impermeable	169.0	0	188.0	1.00	0.00	20	58.5
B-02	13.7	Impermeable	169.0	1	166.0	0.88	0.52	20	58.5
B-02	13.7	Impermeable	169.0	2	167.0	0.89	0.37	20	58.5
B-02	13.7	Impermeable	169.0	3	167.0	0.89	0.37	20	58.5
B-02	13.7	Impermeable	169.0	4	167.0	0.89	0.33	20	58.5
B-08	13.3	Impermeable	174.0	0	240.0	1.00	0.00	20	58.5
B-08	13.3	Impermeable	174.0	1	196.0	0.82	0.66	20	58.5
B-08	13.3	Impermeable	174.0	2	187.0	0.78	0.59	20	58.5
B-08	13.3	Impermeable	174.0	3	177.0	0.74	0.57	20	58.5
B-08	13.3	Impermeable	174.0	4	175.0	0.73	0.56	20	58.5
C-01	12.6	Impermeable	188.0	0	217.8	1.00	0.00	20	72.0
C-01	12.6	Impermeable	188.0	2	224.0	1.03	0.17	20	72.0
C-01	12.6	Impermeable	188.0	3	234.3	1.08	0.36	20	72.0
C-01	12.6	Impermeable	188.0	4	199.0	0.91	0.31	20	72.0
C-03	12.0	Impermeable	173.0	0	306.6	1.00	0.00	20	72.0
C-03	12.0	Impermeable	173.0	2	249.0	0.81	0.71	20	72.0
C-03	12.0	Impermeable	173.0	3	245.1	0.80	0.68	20	72.0
C-03	12.0	Impermeable	173.0	4	240.0	0.78	0.65	20	72.0
D-01	8.5	Impermeable	207.0	0	328.5	1.00	0.00	10	81.0
D-01	8.5	Impermeable	207.0	2	315.0	0.96	0.33	10	81.0
D-01	8.5	Impermeable	207.0	3	267.6	0.81	0.34	10	81.0
D-01	8.5	Impermeable	207.0	4	302.1	0.92	0.36	10	81.0

Table F2: Summary of ODOT Open-graded Mixtures (Continued)

Specimen ID	Air Voids (%)	Initial Air Permeability E-5 cm/s	Diam. MR (Ksi)	Cycle No.	ECS-MR (Ksi)	Retained ECS-MR Ratio	Water Permeability E-3 cm/s	Stripping Rate	IRS (%)
D-03	9.0	Impermeable	187.0	0	279.1	1.00	0.00	10	81.0
D-03	9.0	Impermeable	187.0	2	260.5	0.93	0.45	10	81.0
D-03	9.0	Impermeable	187.0	3	265.5	0.95	0.64	10	81.0
D-03	9.0	Impermeable	187.0	4	292.0	1.05	0.62	10	81.0
E-03	13.9	Impermeable	63.5	0	120.9	1.00	0.00	20	64.0
E-03	13.9	Impermeable	63.5	2	114.2	0.94	0.25	20	64.0
E-03	13.9	Impermeable	63.5	3	117.0	0.97	0.24	20	64.0
E-03	13.9	Impermeable	63.5	4	115.0	0.95	0.26	20	64.0
E-04	13.7	Impermeable	69.0	0	72.3	1.00	0.00	20	64.0
E-04	13.7	Impermeable	69.0	2	84.0	1.16	0.52	20	64.0
E-04	13.7	Impermeable	69.0	3	96.3	1.33	0.50	20	64.0
E-04	13.7	Impermeable	69.0	4	87.0	1.20	0.48	20	64.0
F-02	13.9	5.1	228.5	0	432.2	1.00	1.20	30	52.0
F-02	13.9	5.1	228.5	2	315.5	0.73	1.30	30	52.0
F-02	13.9	5.1	228.5	3	328.0	0.76	1.10	30	52.0
F-02	13.9	5.1	228.5	4	340.0	0.79	1.09	30	52.0
F-06	13.6	2.6	230.5	0	334.0	1.00	0.70	20	52.0
F-06	13.6	2.6	230.5	2	230.0	0.69	1.57	20	52.0
F-06	13.6	2.6	230.5	3	250.0	0.75	1.31	20	52.0
F-06	13.6	2.6	230.5	4	255.0	0.76	1.39	20	52.0
H-01	13.4	Impermeable	N/A	0	111.3	1.00	0.00	10	77.0
H-01	13.4	Impermeable	N/A	2	101.8	0.91	0.38	10	77.0
H-01	13.4	Impermeable	N/A	3	109.6	0.98	0.20	10	77.0
H-01	13.4	Impermeable	N/A	4	107.3	0.96	0.18	10	77.0
H-03	13.6	Impermeable	N/A	0	70.5	1.00	0.00	10	77.0
H-03	13.6	Impermeable	N/A	2	62.0	0.88	0.44	10	77.0
H-03	13.6	Impermeable	N/A	3	66.5	0.94	0.38	10	77.0
H-03	13.6	Impermeable	N/A	4	93.2	1.32	0.38	10	77.0
G-01	11.6	Impermeable	186.5	0	220.3	1.00	0.00	10	50.0
G-01	11.6	Impermeable	186.5	2	195.0	0.89	0.42	10	50.0
G-01	11.6	Impermeable	186.5	3	175.2	0.80	0.44	10	50.0
G-01	11.6	Impermeable	186.5	4	180.6	0.82	0.59	10	50.0

Table F2: Summary of ODOT Open-graded Mixtures (Continued)

Specimen ID	Air Voids (%)	Initial Air Permeability E-5 cm/s	Diam. MR (Ksi)	Cycle No.	ECS-MR (Ksi)	Retained ECS-MR Ratio	Water Permeability E-3 cm/s	Stripping Rate	IRS (%)
G-02	11.4	Impermeable	192.0	0	229.3	1.00	0.00	10	50.0
G-02	11.4	Impermeable	192.0	2	200.4	0.87	0.52	10	50.0
G-02	11.4	Impermeable	192.0	3	172.6	0.75	0.52	10	50.0
G-02	11.4	Impermeable	192.0	4	176.7	0.77	0.51	10	50.0

C chamber. However, between the time when the specimens were prepared and the time the specimens were received at OSU, the asphalt flowed down the voids and clogged some of the channels, thus causing impermeablity.

Figure F2 shows the results of the ECS conditioning on one specimen from each mixture of the Oregon open graded mixtures. All the mixtures that have experienced water damage are represented by loss in strength (ECS-M_R), except for mixture A. Mixture A did not have any additives and did not show any visual stripping. The mixture could have densified and gained the ten percent (10 %) in strength (ECS-M_R). All the other seven mixtures have shown water sensitivity, especially mixtures B and F.

Figure F3 shows ECS results represented by ECS-M_R ratios after four cycles, visual stripping rates, and IRS results. The results shown are the average of the two specimens. For a seventy percent (70 %) IRS failure criterion, all mixtures have failed the IRS test except for two, and one mixture is marginal. The results indicate that the IRS test is a conservative test. On the other hand, the ECS test would have passed all the mixtures with mixtures F and G being only marginal. Also, stripping of the mixtures was somewhat consistent with IRS results, except for mixture A. Mixtures that showed higher stripping rates (or water damage) have shown lower IRS values.

Figure F4 shows results of mixture C, which includes 1.0 % lime and 0.5 % PBS, and mixture G, which is the same mix as C but without the additives. The ECS test indicates that the mixture improved when the additives were used, and the ECS-M_R ratio was 0.85 instead of 0.80. In the IRS test performed by ODOT, mixture G failed (50 %), and mixture C marginally passed (72 %).

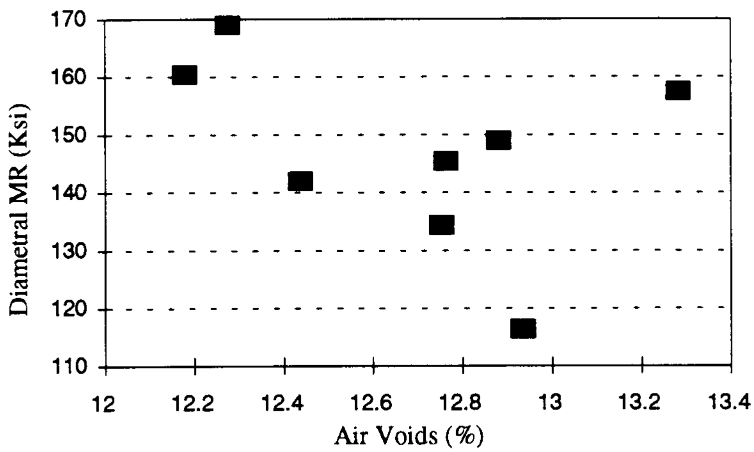


Figure F1: Plot of Diametral M_R and Air Voids Results for Mixture A

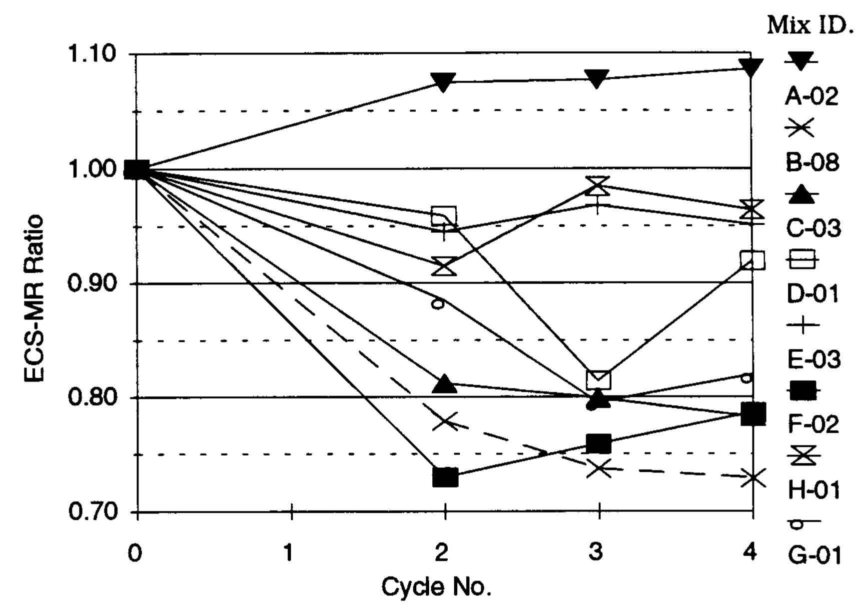


Figure F2: Summary of Open-graded Mixtures Results

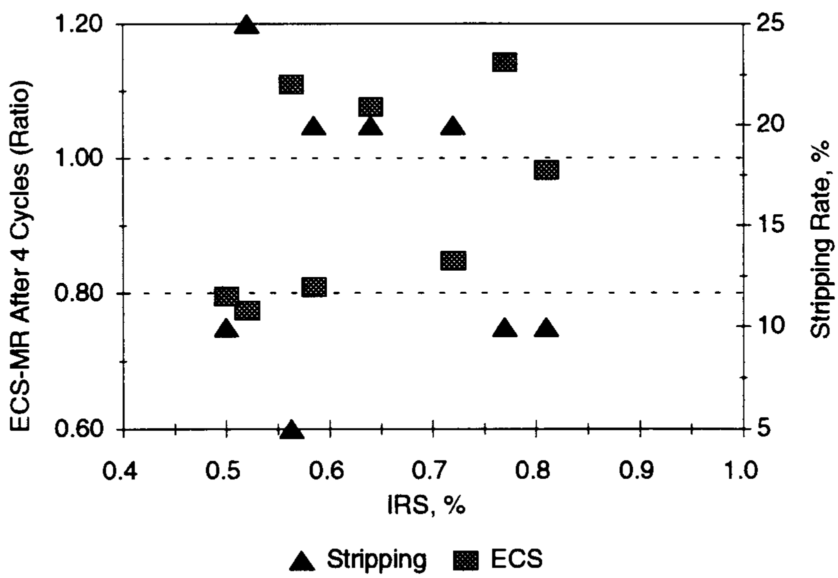


Figure F3: Comparisons Between ECS-M_R, Stripping, and IRS Results

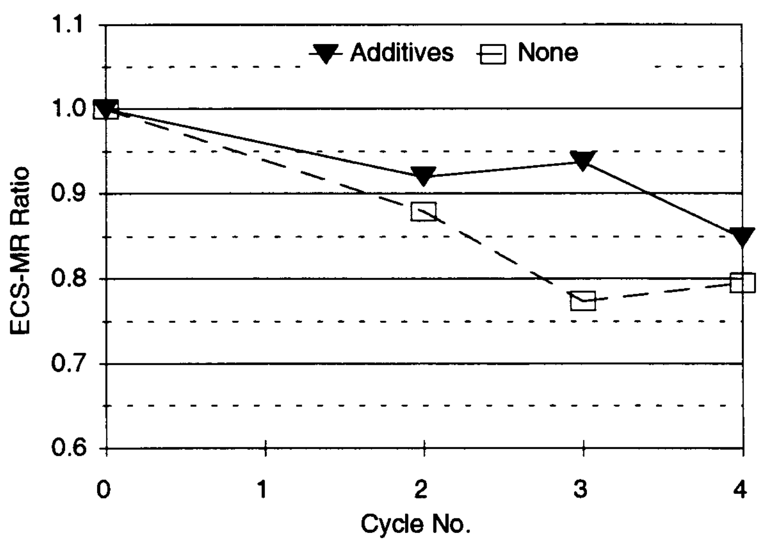


Figure F4: Effect of Additive on Mixture Performance in ECS

The ODOT open-graded mixtures performed well in the ECS in terms of water sensitivity. In the ECS evaluation, six mixtures passed the criteria of 75 % (established for the IRS test by ODOT), and one mixture was marginal (mixture G), as shown in Figure F5. However, only one mixture passed (D) the IRS evaluation, while another mixture (H) marginally passed. This confirms that IRS test is either a very severe test or the passing criteria is conservative, hence the test is not suitable for water sensitivity evaluation of open graded mixtures.

5.0 ANALYSIS AND CONCLUSIONS

The analysis of the ECS test results employed a General Linear Model (GLM) procedure to investigate the significance of the effect of all the different variables and their interactions on the ECS-M_R ratio (the dependent variable). GLM procedure uses the method of least squares to fit general linear models, i.e., testing each variable in a given model reveals how significant the variable (or its interaction with other variables) is to the model. GLM procedure can analyze classification variables which have discrete levels as well as continuous variables. Also, GLM can create output data of the dependent variable (ECS-M_R) based on the prescribed model, i.e., the original ECS-M_R data will be changed to show the effects of the different variables in the model.

The analysis was unsuccessful to show correlations between the different variables, and the only significant variable was the mixture type as shown in Table F3. The reason for the unsuccessful outcome was that the mixtures were very different from each other, and mix type alone explains the difference in the ECS results.

Finally, the IRS test evaluation would suggest that these mixtures would fail very prematurely after construction. However, most of these projects have been in service for more than two years without any visible distress or failures. The IRS evaluation would require that additives would have to be used with all mixtures that failed the test, which is very expensive alternative.

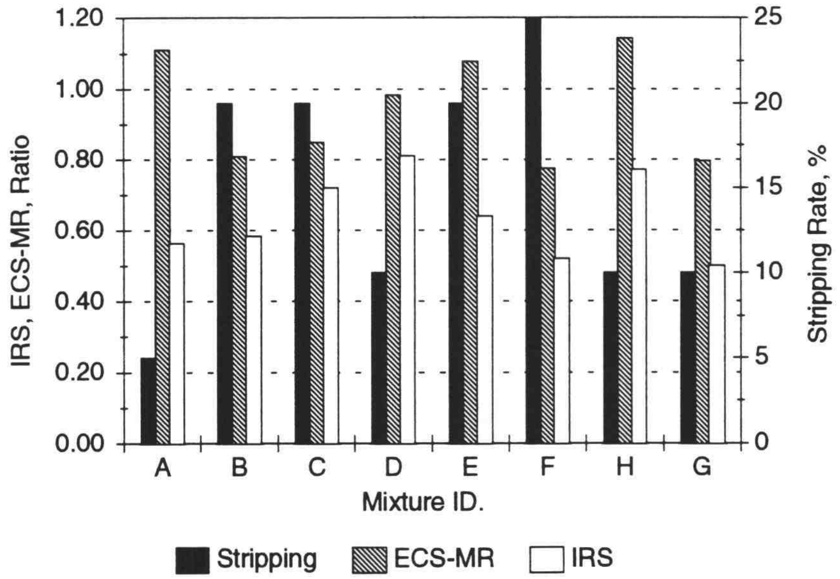


Figure F5: Comparisons of ECS and IRS Performance Ranking

Table F3 GLM Analysis of the Open-graded Mixtures Study

Class Variables	Levels	Values		
MIX	8	A, B, C, D, E, F, G, and H		
Cycle No. 3				
Model: $R^2 = 0.70$, CV = 13.74, ECS-M_R ratio mean = 0.92				
Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
MIX	7	0.30	2.69	0.09
Cycle No. 4				
Model: $R^2 = 0.72$, CV = 13.40, ECS-M_R ratio mean = 0.94				
Source of Error	Degree of Freedom	Type III Sum of Squares	F Values	Probability of $F > F_{critical}$
MIX	7	0.33	2.95	0.08

The following attachments are mix design and materials properties for the open-graded mixtures from ODOT projects. Each attachments lists the aggregate gradation, and wet sieve analysis. Also, Job-Mix Formula test data are included, i.e., percent asphalt, stability, percent voids, maximum specific gravity, index retained strength, and index retained modulus.

PRELIMINARY BITUMINOUS MIXTURE DESIGN

MATERIALS SECTION

PROJECT: MYRTLE POINT S.C.L. - POWERS JCT.		LAB NO. 9205970	
		EA/SUB JOB/ACTIVITY: C11110	DATA SHEET NO.: AB 69194-96
PRIME CONTRACTOR: RACELIN-YEAGER EXCAVATING & TRUCKING INC.		FED. AID NO.: F-14 (40)	
PAVING CONTRACTOR:	MIX TYPE CLASS: "F" a/c	DATE RECEIVED: 4-17-92	DATE REPORTED: 7-9-92
REGION ENGINEER: BOB ALDRICH	PROJECT MANAGER: F.D.MORRISON 8011	TEST NO.: 301 / VAR.: V	LAB CHARGES: $ 950.00

AGGREGATE GRADATION: Source— Wahl's Pit #8-108-3 Type— Gravel

Aggregate Size	3/4 - 1/4	1/4 - 10	10 - 0				Combined ~~Dry Sieve~~	Agg. Grad. Extracted
% Comb.	81	10	9				Wet sieve	
1"	100						100	
3/4	91						93	
1/2	58						66	
3/8	35	100					47	
1/4	10	89	100				26	
10	3	8	92				11	
40	3	4	36				6	
200 (Dry)	--	--	--				--	
200 (Wet)	1.5	2.7	11.7				2.5	
No. Ave.								
Lime Treat (%)							P200/AC = 0.4	

NUCLEAR GAUGE DATA

Calibration Number: 5970
Mix ID: 1110 "F" PBA-5
Number of Samples: 4
Count Time per Sample: 16
Fit Coeff= 0.997
Calibration Date: 6/16/92
Background Count: 2471
Weight: 6580
Calibration Constants:
A1: -12.682818
A2: 6.093182
A3: -4.004573

JOB MIX FORMULA TEST DATA:

Percent Asphalt (total mix)	4.0	4.5	5.0	5.5	6.0	7.0
Asphalt Film	dry	dry-suf	suff.	suff-thk	thick	thick
Sp. Gr. @ 1st Comp. ~~(T-246)~~ geometric voids	2.070		2.107		2.129	2.134
Percent Voids @ 1st Comp.	16.7		14.1		12.4	
Stability @ 1st Comp. (T-247)						
Sp. Gr. @ 2nd Comp.						
Percent Voids @ 2nd Comp.						
Stability @ 2nd Comp.						
Max. Sp. Gr. (T-209)	2.486	2.467	2.453	2.434	2.431	
Index Ret. Str. (T-165)	72		67		68	77 **
Index Ret. Mr. (TM315)						
asphalt draindown *	0	0	10%	20%	50%	95%

JOB MIX FORMULA:

CALCULATED JOB MIX FORMULA PROPERTIES

Aggregate Sieve Size	JMF Gradation	Paving Course	Asphalt Content % By Wt. of Total Mixture	Sp Gr. @ 1st Comp	Sp Gr. @ 2nd Comp	Max Sp Gr T-209	Design Voids 1st Comp	Design Voids 2nd Comp
1"	100	Wearing	6.2	2.130	--	2.429est.	12.3 est.	
3/4	93	Base						
1/2	66							
3/8	47	Shoulder						
1/4	26	Asphalt Lab No. 92-5326					237	245
10	11	Brand— McCall			Mix Placement Temp.—		~~288~~ °F—	~~297~~ °F
40	6	Grade— PBA-5			Mixing Temp.—		~~307~~ °F—	~~316~~ °F
200	2.5	Additive—					253	262

AGGREGATE TEST DATA:

92-3335 CA: LAR = 17.2%; Na2SO4 = 1.4%; Degrade = 1.0", 18.4%; Friables = 0.1%; Dust=.12%
92-3336 FA: " = -- ; " = 2.5%; " = 0.8", 16.6%; " = 0.3%; SE = 72
92-3337 FA: " = -- : " = 2.5%; " = 0.8", 16.6%; " = 1.0%; SE = 72

Const.	COMMENTS: * draindown @ 6.5% asphalt = 90%, target draindown is
FHWA	between 60 and 90%.
Reg. Engr.	
Res. Engr.	** IRS test @ 7.0% asphalt run with 0.5% Pavebond Spec.

Oregon Department of Transportation
HIGHWAY DIVISION

ASPHALT LABORATORY RECORD

OREGON STATE HIGHWAY DIVISION,
MATERIALS SECTION, 800 AIRPORT RD., SALEM OR 97310

ASPHALT BRAND AND TYPE	MCCALL PBA-5
LABORATORY REPORT NUMBER	9205326
PROJECT	MYRTLE POINT S.C.L. - POWERS JCT.
DATA SHEET NO.	NONE
HIGHWAY	COOS BAY - ROSEBURG
COUNTY	COOS
EXP. ACCOUNT. SUB JOB	C11110
CONTRACTOR	BRACELIN - YEAGER
F.A. PROJECT NUMBER	F 14(40)
BID ITEM NUMBER	
PROJECT MANAGER	F.D.MORRISON 8011
AGENCY ORG. UNIT	8011
DATE RECEIVED	5-28-92
DATE REPORTED	6-2-92
SUBMITTED BY	MCCALL OIL CO.
AGENCY ORG. UNIT	
TEST NO.	416A
VAR	
LAB CHARGE	344.00
SOURCE OF MATERIAL	MCCALL OIL CO. PORTLAND, OR.
QUANTITY REPRESENTED	8 qts.
SAMPLED AT	PORTLAND
SAMPLED BY	UNK.
TO BE USED	"F"a/c
DATE SAMPLED	5-27-92

SAMPLE NO. 92-12 COMPLETE **TEST RESULTS** **DATE TESTED:** 5-30-92

PAVING ASPHALT

T 73	Flash Point, closed cup		°F
T 44	Solubility in CHCL:CCL2	99.99	%
T 49	Penetration at 77F/39.2		cm/100
	Penetration ratio 39.2/77F		
T201	Viscosity, Kinematic 275 F	460 ~~598~~	C.S.
T202	Viscosity, Absolute 140 F	2680	P.
T240	Paving Asphalt RTF (c) Residue		
T 47	Loss on heating	~~0.77~~ .59	%
T201	Viscosity, Kinematic 275 F	746	C.S.
T202	Viscosity Absolute 140 F, 30cm Hg., Vac.	7270	P.
	Viscosity Ratio Res./Orig.	2.7	
T 49	Penetration at 77 F/39.2 F	37 / 18	cm/100
	% of orig. penetration		%
T 51	Ductility at 77 F	100+	cm
	Ductility at 45 F	12	cm

Liquid Asphalt

T 48	Flash point, open cup	575	°F
T201	Viscosity, Kinematic at 140 F		C.S.
T 78	Distillation (% of total distillate to 680 F)		
	To 374 F		%
	To 437 F		%
	To 500 F		%
	To 600 F		%
	Residue from distillation to 680 F Volume by difference		%
	Water		%

Liquid Asphalt Residue

T 49	Penetration at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm.
T202	Viscosity ABS at 140 F		P.

Emulsified Asphalt

T 59	Viscosity, S.F. at ____ F		sec.
T 59	Sieve Test		%
T 59	Residue by distillation to 500 F		%
T 59	Oil distillate in		%
T 49	Penetration of Res. at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm

Modified Abson Recovery of Asphalt

T170	Modified Abson Recovery of Asphalt		
T201	Viscosity, Kinematic 275 F		C.S.
T202	Viscosity, Absolute 140 F, 30cm Hg. Vac.		P.
T 49	Penetration of Res. at 77 F		cm/100
	"C" value		

T49 PENETRATION of RESIDUE @ 39.2F
100 g. 5 sec. 5 cm/100

DISTRIBUTION ONLY

X FILES
X F.D. MORRISON
X RAS 3
X BRACELIN-YEAGER EXCAVATING & TRUCKING, INC.
X OPERATIONS
X MCCALL OIL CO.
X BIT
X FHWA

RECOMMENDATION:
Material as represented by this sample does, ~~does not~~ comply with specifications.

The Oregon Department of Transportation
Highway Division

PAGE 1 OF 2

PRELIMINARY BITUMINOUS MIXTURE DESIGN
MATERIAL SECTION

PROJECT: PACIFIC HIGHWAY WEST - GATEWAY ST.	EA / SUB JOB / ACTIVITY: C11194		DATA SHEET NO.: AB 53112,14,17	LABORATORY NO.: 9213599
CONTRACTOR: EUGENE SAND & GRAVEL	FED AID NO.: STATE PRES 92			
PAVING CONTRACTOR:	MIX TYPE CLASS: "F"	DATE RECEIVED: 7-11-92	DATE REPORTED: 10-30-92	
REGION ENGINEER: BOB ALDRICH	PROJECT MANAGER: LARRY LINDLEY 8020	TEST NO.: 301	VAR.: X	LAB CHARGES: $1500.00 *

AGGREGATE GRADATION: SOURCE- EUGENE S & G #20-45-3 TYPE: GRAVEL

AGGREGATE SIZE	3/4 - 1/2	1/2 - 1/4	1/4 - 0		COMBINED WET SIEVE	AGG. GRAD. EXTRACTED	NONE REPORTED	
% COMB.	36	45	19				CALIBRATION NUMBER	
1"	100				100		MIX ID	
3/4	77	100			92		NUMBER OF SAMPLES	
1/2	11	93			65		COUNT TIME PER SAMPLE	
3/8	4	60	100		47		FIT COEFF =	
1/4	2	13	96		25		CALIBRATION DATE	
4	2	4	83		18		BACKGROUND COUNT:	
10	2	2	46		10		BASE WEIGHT:	
40	2	2	20		5		CALIBRATION CONSTANTS - A1:	
200(WET)	1	2	9		3		A2:	
							A3:	
NO. AVE.								
LIME TREAT % =					P200/AC =		VMA=	

JOB MIX FORMULA TEST DATA:

PERCENT ASPHALT (TOTAL MIX)	4.5	5.0	5.5	6.0	6.5
ASPHALT FILM	DRY-SUFF	SUFF	SUFF-THICK	THICK	THK-THK
SPECIFIC GRAVITY @ 1ST COMP. (T-166)					
PERCENT VOIDS @ 1ST COMP.					
STABILITY @ 1ST COMP. (T-246)					
SPECIFIC GRAVITY @ 2ND COMP.					
PERCENT VOIDS @ 2ND COMP.					
STABILITY @ 2ND COMP					
MAXIMUM SPECIFIC GRAVITY (T-209)					
INDEX RET. STR. (T-165)	**	**	**	**	**
INDEX RET. Mr. (TM315)					
PERCENT DRAINDOWN	55	60	75	85	95

JOB MIX FORMULA: / CALCULATED JOB MIX FORMULA PROPERTIES

AGGREGATE SIEVE SIZE	JMF GRADATION	PAVING COURSE	ASPHALT CONTENT % BY Wt. OF TOTAL MIXTURE	Sp. Gr. @ 1ST COMP.	Sp. Gr. @ 2ND COMP.	MAX Sp. Gr.	DESIGN VOIDS 1ST COMP.	DESIGN VOIDS 2ND COMP.
1"		WEARING						
3/4		BASE						
1/2								
3/8		SHOULDER						
1/4		Asphalt LAB NO.						
10		BRAND-	CHEVRON	MIXING TEMP.-				
40		GRADE-	PBA-5	PLACEMENT TEMP.-				
200		ADDITIVE-						

AGGREGATE TEST DATA:

92-7619 & 07620 CA - LAR=15.1;DEG=0.6",14.1;SSL=5.1;DUST=0.26;SPG=2.61

92-07621 FA - SSL=6.8;DEG=0.4",8.4;SPG=2.55;SE=72

These are supplemental charges for extra IRS testing. AK

Distribution		Comments
2X Files		COMMENTS ** DUE TO THE NUMBER OF TESTS CONDUCTED, I.R.S RESULTS ARE ON ATTACHED SHEET.
X CONST.		* CHARGES REDUCED FORM THE NORMAL RATE
X FHWA		
Res. Engr.		
X Proj. Engr.	LARRY LINDLEY	
X Dist. Engr.	RAS 3	
Region Geo.		
X Contractor	EUGENE SAND & GRAVEL	

Oregon Department of Transportation
HIGHWAY DIVISION

ASPHALT LABORATORY RECORD

OREGON STATE HIGHWAY DIVISION,
MATERIALS SECTION, 800 AIRPORT RD., SALEM OR 97310

PAGE 1 OF 2

ASPHALT BRAND AND TYPE: CHEVRON PBA-5		LABORATORY REPORT NUMBER: 9709354	
PROJECT: PACIFIC HIGHWAY WEST-GATEWAY STREET		DATA SHEET NO.: NONE	
HIGHWAY: BELTLINE	COUNTY: LANE	EXP. ACCOUNT, SUB JOB: C11194	
CONTRACTOR: EUGENE SAND & GRAVEL	F.A. PROJECT NUMBER:	BID ITEM NUMBER:	
PROJECT MANAGER: LARRY LINDLEY	AGENCY ORG. UNIT: 8020	DATE RECEIVED: 8-11-92	DATE REPORTED: 8-17-92
SUBMITTED BY: CHEVRON OIL CO.	AGENCY ORG. UNIT:	TEST NO.: 416A	VAR / LAB CHARGE: 344.00
SOURCE OF MATERIAL: CHEVRON OIL CO.PORTLAND, OR.	QUANTITY REPRESENTED: 12 qts.		
SAMPLED AT: PORTLAND / SAMPLED BY: UNK.	TO BE USED: "F"(SD)		DATE SAMPLED: 8-11-92

SAMPLE NO. COMPLETE — TEST RESULTS — DATE TESTED: 8-12-92

PAVING ASPHALT

T 73	Flash Point, closed cup		°F
T 44	Solubility in CHCL:CCL2	99.99	%
T 49	Penetration at 77F/39.2		cm/100
	Penetration ratio 39.2/77F		
T201	Viscosity, Kinematic 275 F	440	C.S.
T202	Viscosity, Absolute 140 F	2670	P.
T240	Paving Asphalt RTF (c) Residue		
T 47	Loss on heating	.72	%
T201	Viscosity, Kinematic 275 F	727	C.S.
T202	Viscosity Absolute 140 F, 30cm Hg., Vac.	6510	P.
	Viscosity Ratio Res./Orig.	2.4	
T 49	Penetration at 77 F/39.2 F	42/20	cm/100
	% of orig. penetration		%
T 51	Ductility at 77 F	105+	cm
	Ductility at 45 F	23+	cm

Liquid Asphalt

T 48	Flash point, open cup	590	°F
T201	Viscosity, Kinematic at 140 F		C.S.
T 78	Distillation (% of total distillate to 680 F)		
	To 374 F		%
	To 437 F		%
	To 500 F		%
	To 600 F		%
	Residue from distillation to 680 F Volume by difference		%
	Water		%

Liquid Asphalt Residue

T 49	Penetration at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm.
T202	Viscosity ABS at 140 F		P.

Emulsified Asphalt

T 59	Viscosity, S.F. at ___ F		sec.
T 59	Sieve Test		%
T 59	Residue by distillation to 500 F		%
T 59	Oil distillate in		%
T 49	Penetration of Res. at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm

T170 Modified Abson Recovery of Asphalt

T201	Viscosity, Kinematic 275 F		C.S.
T202	Viscosity, Absolute 140 F, 30cm Hg. Vac.		P.
T 49	Penetration of Res. at 77 F		cm/100
	"C" value		

T49 Penetration of Residue @ 39.2F 100 g. 5 sec. 7 cm/100

DISTRIBUTION ONLY
X FILES
X OPERATIONS
X FHWA
X LARRY LINDLEY
X RAS 3
X EUGENE SAND AND GRAVEL
X CHEVRON OIL CO.
X BIT

RECOMMENDATION:
Material as represented by this sample does ~~does not~~ comply with specifications

PRELIMINARY BITUMINOUS MIXTURE DESIGN

MATERIALS SECTION

PAGE 2 of #3

LAB NO. 92C6813

PROJECT: YOUNGS BAY BR.-WARRENTON & HAMBURG AVE.
EA/SUB JOB/ACTIVITY: C11162
DATA SHEET NO.: AB 45467-69
PRIME CONTRACTOR: JEWIT PACIFIC CO.
FED. AID NO.: NH-2-6(15) & F-1(49)
PAVING CONTRACTOR:
MIX TYPE CLASS: "F" (SD)
DATE RECEIVED: 6-23-92
DATE REPORTED: 8-14-92
REGION ENGINEER: KEN STONEMAN
PROJECT MANAGER: TOM FALLS 8034
TEST NO.: 301M / 319
VAR.:
LAB CHARGES: $1650.00 / $ 367.00

AGGREGATE GRADATION: Source— Naselle #WA-025-2 Type— Quarry

Aggregate Size	3/4-1/2	1/2-1/4	1/4-0	Sand			Combined Dry Sieve / Wet Sieve	Agg. Grad. Extracted
% Comb.	29	44	22	5				
1"	100						100	
¾	63	100					89	
½	8.8	83					66	
⅜	4.4	27.6	100				40	
¼	2.4	4.0	82	100			26	
10	2.2	3.2	37	98			15	
40	2.0	2.4	16	32			7	
200 (Dry)	--	--	--	--			--	
200 (Wet)	1.6	1.8	9.0	1.9			3.3	
No. Ave.								
Lime Treat (%)							P200/AC =	

JOB MIX FORMULA TEST DATA:

Percent Asphalt (total mix)	5.0	5.5	6.0	6.5	7.0
Asphalt Film					
Sp. Gr. @ 1st Comp. T-166		2.267	2.291	2.305	
Percent Voids @ 1st Comp.					
Stability @ 1st Comp. (T-247)					
Sp. Gr. @ 2nd Comp.					
Percent Voids @ 2nd Comp.					
Stability @ 2nd Comp.					
Max. Sp. Gr. (T-209)					
Index Ret. Str. (T-165)		61	73	79	
Index Ret. Mr. (TM315)					
% DRAINDOWN	40	65	85	90	95

JOB MIX FORMULA:

Aggregate Sieve Size	JMF Gradation	Paving Course	Asphalt Content % By Wt. of Total Mixture	Sp Gr. @ 1st Comp	Sp Gr. @ 2nd Comp	Max Sp Gr T-209	Design Voids 1st Comp	Design Voids 2nd Comp
1"	100	Wearing	6.5	2.305				
¾	89	Base						
½	66							
⅜	40	Shoulder						
¼	26	Asphalt Lab No. 92-08547						
10	15	Brand— McCall						
40	7	Grade— PBA-5						
200	3.3	Additive— 0.5% PAVEBOND SPECIAL						

(CALCULATED JOB MIX FORMULA PROPERTIES)

Mix Placement Temp.— 235 °F— 243 °F

Mixing Temp.— 252 °F— 260 °F

AGGREGATE TEST DATA:

92-06270 & 06271 CA - LAR=12.8; NaSO4=4.9;DEG=0.4",10.0;SpG=2.80;Clay=0.28

92-06272 & 06273 FA - " =14.8;" =1.2",17.5; " =2.73; SE=46

Calibration Number: 6813
Mix ID: 11162
Number of Samples: 4
Count Time per Sample: 16
Fit Coeff= 0.999
Calibration Date: 7/28/92
Background Count: 2463
Weight: 6200
Calibration Constants:
A1: -14.781233
A2: 8.505826
A3: -7.478206

Const.
FHWA
Reg. Engr.
Res. Engr.
Dist. Engr.
Region Geo.
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Oregon Department of Transportation
HIGHWAY DIVISION

ASPHALT LABORATORY RECORD

OREGON STATE HIGHWAY DIVISION,
MATERIALS SECTION, 800 AIRPORT RD., SALEM OR 97310

Page 1 of 2

McCALL PBA-5
ASPHALT BRAND AND TYPE

LABORATORY REPORT NUMBER: 08547				
PROJECT: YOUNGS BAY BRIDGE - WARRENTON/ASTORIA HWY. SECTION		DATA SHEET NO.: NONE		
HIGHWAY: OREGON COAST & LOWER COLUMBIA RIVER	COUNTY: CLATSOP	EXP. ACCOUNT, SUB JOB: C11162		
CONTRACTOR: KIEWIT PACIFIC CO.	F.A. PROJECT NUMBER: NH-2-6(15) & F-1(49)	BID ITEM NUMBER:		
PROJECT MANAGER: TOM FALLS	AGENCY ORG. UNIT: 8034	DATE RECEIVED: 7-30-92		DATE REPORTED: 08-04-92
SUBMITTED BY: McCALL	AGENCY ORG. UNIT:	TEST NO.: 416A	VAR:	LAB CHARGE: 344.00
SOURCE OF MATERIAL: McCALL CO.	QUANTITY REPRESENTED: 12 qts.			
SAMPLED AT: PORTLAND, OR. / SAMPLED BY: McCALL	TO BE USED: "A"C"F" a/c			DATE SAMPLED: 7-29-92

SAMPLE NO. COMPLETE — TEST RESULTS — DATE TESTED: 8-3-92

PAVING ASPHALT

Test	Description	Result	Unit
T 73	Flash Point, closed cup		°F
T 44	Solubility in CHCL:CCL2	99.99	%
T 49	Penetration at 77F/39.2		cm/100
	Penetration ratio 39.2/77F		
T201	Viscosity, Kinematic 275 F	426	C.S.
T202	Viscosity, Absolute 140 F	2370	P.
T240	**Paving Asphalt RTF (c) Residue**		
T 47	Loss on heating	.57	%
T201	Viscosity, Kinematic 275 F	666	C.S.
T202	Viscosity Absolute 140 F, 30cm Hg., Vac.	6220	P.
	Viscosity Ratio Res./Orig.	2.6	
T 49	Penetration at 77 F/39.2 F	40/19	cm/100
	% of orig. penetration		%
T 51	Ductility at 77 F	100+	cm
	Ductility at 45 F	15	cm

Liquid Asphalt

Test	Description	Result	Unit
T 48	Flash point, open cup	575	°F
T201	Viscosity, Kinematic at 140 F		C.S.
T 78	Distillation (% of total distillate to 680 F)		
	To 374 F		%
	To 437 F		%
	To 500 F		%
	To 600 F		%
	Residue from distillation to 680 F Volume by difference		%
	Water		%

Liquid Asphalt Residue

Test	Description	Result	Unit
T 49	Penetration at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm
T202	Viscosity ABS at 140 F		P.

Emulsified Asphalt

Test	Description	Result	Unit
T 59	Viscosity, S.F. at ___ F		sec.
T 59	Sieve Test		%
T 59	Residue by distillation to 500 F		%
T 59	Oil distillate in		%
T 49	Penetration of Res. at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm

Modified Abson Recovery of Asphalt

Test	Description	Result	Unit
T170	Modified Abson Recovery of Asphalt		
T201	Viscosity, Kinematic 275 F		C.S.
T202	Viscosity, Absolute 140 F, 30cm Hg. Vac.		P.
T 49	Penetration of Res. at 77 F		cm/100
	"C" value		

T49 Penetration of Residue @ 39.2F 100 g. 5 sec. [redacted] 4 cm/100

DISTRIBUTION ONLY
- X FILES
- X RAS 2
- X TOM FALLS
- X KIEWIT PACIFIC
- X McCALL OIL
- X OPERATIONS
- X FHWA
- X BIT

RECOMMENDATION:
Material as represented by this sample does, [redacted] comply with specifications

PRELIMINARY BITUMINOUS MIXTURE DESIGN

MATERIALS SECTION

PROJECT: M.P. 4.0-CROWFOOT ROAD		LAB NO. 9?05974	
PRIME CONTRACTOR: LTM		EA/SUB JOB/ACTIVITY: 15 - MISC	DATA SHEET NO. AB 60427-29
PAVING CONTRACTOR:	MIX TYPE CLASS: "F" a/c	FED. AID NO. ———	
REGION ENGINEER: JIM GIX	PROJECT MANAGER: DALE PETRASEK (Jackson Co.)	DATE RECEIVED: 5-11-92	DATE REPORTED:

TEST NO.	VAR.	LAB CHARGES
301M	X	$ 50.00
319	X	$ 67.00

AGGREGATE GRADATION: Source— LTM QUARRY COUNTY SOURCE   Type— QUARRY

Aggregate Size	3/4-1/4	1/4-10	10-0				Combined Dry-Sieve WET SIEVE	Agg. Grad. Extracted
% Comb.	83	7	10					
1"	100						100	
¾	90						92	
½	57						64	
⅜	33	100					46	
¼	9	82					26	
10	0.2	3	83				11	
40	0.2	1	30				4	
200 (Dry)	0.1	3.0	11.2				—	
200 (Wet)							2.1	
No. Ave.	11	11	11					
Lime Treat (%)							P200/AC = 0.4	

JOB MIX FORMULA TEST DATA:

Percent Asphalt (total mix)	5.0	5.5	6.0	6.5	7.0
Asphalt Film	Suf-Thk	Thick	Thick	Thk-Thk	Thk,Thk!!
Sp. Gr. @ 1st Comp. (T-246)					
Percent Voids @ 1st Comp.					
Stability @ 1st Comp. (T-247)					
Sp. Gr. @ 2nd Comp.					
Percent Voids @ 2nd Comp.					
Stability @ 2nd Comp.					
Max. Sp. Gr. (T-209)		2.486			
Index Ret. Str. (T-165)	67		89		79
Index Ret. Mr. (TM315)					
Geometrically measured gravitys	2.116	2.127	2.137		2.142

JOB MIX FORMULA:

Aggregate Sieve Size	JMF Gradation	Paving Course	Asphalt Content % By Wt. of Total Mixture
1"	100	Wearing	5.5
¾	92	Base	
½	64		
⅜	46	Shoulder	
¼	26	Asphalt Lab No. 92-04016	
10	11	Brand— Witco	
40	4	Grade— PBA-5	
200	2.1	Additive—	

CALCULATED JOB MIX FORMULA PROPERTIES

Sp Gr. @ 1st Comp	Sp Gr. @ 2nd Comp	Max Sp Gr T-209	Design Voids 1st Comp	Design Voids 2nd Comp
		2.486		

Mix Placement Temp.— 230 °F— 238 °F

Mixing Temp.— 245 °F— 253 °F

AGGREGATE TEST DATA:

Calibration Number: 5974
Mix ID: 15.4
Number of Samples: 4
Count Time per Sample: 16
Fit Coeff= 0.999
Calibration Date: 6/19/92
Background Count: 2470
Weight: 6500
Calibration Constants:
A1: -28.112749
A2: 15.219207
A3: -16.169669

Const.
FHWA
Reg. Engr.
Res. Engr.
Dist. Engr.
Region Geo.
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Engineer of Materials

MB0028 59

Oregon Department of Transportation
HIGHWAY DIVISION

ASPHALT LABORATORY RECORD

OREGON STATE HIGHWAY DIVISION,
MATERIALS SECTION, 800 AIRPORT RD., SALEM OR 97310

PAGE 1 of 2

ASPHALT BRAND AND TYPE	WITCO PBA-5
LABORATORY REPORT NUMBER	9204016
PROJECT	JACKSON CO. BUTTE FALLS RD.
DATA SHEET NO.	NONE
HIGHWAY	BUTTE FALLS RD.
COUNTY	JACKSON
EXP. ACCOUNT. SUB JOB	15MISC. / CONTR.#238
CONTRACTOR	UNK.
F.A. PROJECT NUMBER	
BID ITEM NUMBER	
PROJECT MANAGER	UNK.
AGENCY ORG. UNIT	COUNTY
DATE RECEIVED	5-4-92
DATE REPORTED	5-8-92
SUBMITTED BY	WITCO CORP.
AGENCY ORG. UNIT	
TEST NO.	416A
VAR	
LAB CHARGE	344.00
SOURCE OF MATERIAL	WITCO CORP. OILDALE CA.
QUANTITY REPRESENTED	8 qts.
SAMPLED AT	OILDALE
SAMPLED BY	UNK.
TO BE USED	"F"a/c
DATE SAMPLED	4-29-92

SAMPLE NO. 92-2 COMPLETE **TEST RESULTS** **DATE TESTED:** 5-7-92

PAVING ASPHALT

T 73	Flash Point, closed cup		°F
T 44	Solubility in CHCL:CCL2	99.68	%
T 49	Penetration at 77F/39.2		cm/100
	Penetration ratio 39.2/77F		
T201	Viscosity, Kinematic 275 F	335	C.S.
T202	Viscosity, Absolute 140 F	2610	P.
T240	**Paving Asphalt RTF (c) Residue**		
T 47	Loss on heating	.17	%
T201	Viscosity, Kinematic 275 F	443	C.S.
T202	Viscosity Absolute 140 F, 30cm Hg., Vac.	5040	P.
	Viscosity Ratio Res./Orig.	1.9	
T 49	Penetration at 77 F/39.2 F	34/17	cm/100
	% of orig. penetration		%
T 51	Ductility at 77 F	100+	cm
	Ductility at 45 F	16	cm

Liquid Asphalt

T 48	Flash point, open cup	590	°F
T201	Viscosity, Kinematic at 140 F		C.S.
T 78	Distillation (% of total distillate to 680 F)		
	To 374 F		%
	To 437 F		%
	To 500 F		%
	To 600 F		%
	Residue from distillation to 680 F Volume by difference		%
	Water		%

Liquid Asphalt Residue

T 49	Penetration at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm.
T202	Viscosity ABS at 140 F		P.

Emulsified Asphalt

T 59	Viscosity, S.F. at ____ F		sec.
T 59	Sieve Test		%
T 59	Residue by distillation to 500 F		%
T 59	Oil distillate in		%
T 49	Penetration of Res. at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm

T170	**Modified Abson Recovery of Asphalt**		
T201	Viscosity, Kinematic 275 F		C.S.
T202	Viscosity, Absolute 140 F, 30cm Hg. Vac.		P.
T 49	Penetration of Res. at 77 F		cm/100
	"C" value		

T49 PENETRATION of RESIDUE @ 39.2F
100 g. 5 sec. 4 cm/100

DISTRIBUTION ONLY
X FILES
2X JACKSON COUNTY PUBLIC WORKS
X WITCO CORP.

RECOMMENDATION:
Material as represented by this sample does, ~~does not~~ comply with specifications

PRELIMINARY BITUMINOUS MIXTURE DESIGN

MATERIALS SECTION

PROJECT: SANTIAM RIVER (SOUTHBOUND) BRIDGE		LAB NO.: ?01077	
PRIME CONTRACTOR: HAMILTON CONST. CO.		EA /SUB JOB/ACTIVITY: C11038	DATA SHEET NO.: AB50162-64
PAVING CONTRACTOR:	MIX TYPE CLASS: "F" a/c	FED. AID NO.: FHWA	
REGION ENGINEER: KEN STONEMAN	PROJECT MANAGER: LEE FRANKLIN 8054	DATE RECEIVED: 2/06/92	DATE REPORTED: 05-12-92
		TEST NO.: 301 / 319	VAR.: X; LAB CHARGES: $950.00 / $367.00

AGGREGATE GRADATION: Source— Hilroy Pit 24-2-2 Type— Gravel

Aggregate Size	3/4 - 1/4	1/4 - 10	10 -0	LIME			Combined Dry Sieve	Agg. Grad. Extracted
% Comb.	84	0	15	1	–		Wet sieve	
1"	100						100	
¾	89						91	
½	60						67	
⅜	31						42	
¼	9		100				24	
10	3		69				14	
40	1		26				6	
200 (Dry)	--		--				--	
200 (Wet)	1.0		11.0	1.0			3.5	
No. Ave.	*		*					
Lime Treat (%)	0.4		2.0				P200/AC = 0.6	

JOB MIX FORMULA TEST DATA:

Percent Asphalt (total mix)	4.0	4.5	5.0	5.5	6.0
Asphalt Film	dry-suff	suff	thick	thick	thick +
Sp. Gr. @ 1st Comp. ~~(T-246)~~ (geometric)	2.117		2.137		2.173
~~Percent Voids @ 1st Comp.~~ Asphalt draindown	none	slight	moderate	moder.	extensive
~~Stability @ 1st Comp. (T-247)~~ % voids	15.1		13.1		11.5
Sp. Gr. @ 2nd Comp.					
Percent Voids @ 2nd Comp.					
Stability @ 2nd Comp.					
Max. Sp. Gr. (T-209)	2.491	2.480	2.459	2.460	2.456
Index Ret. Str. (T-165)	72		80		73
Index Ret. Mr. (TM315)					
Index of Retained Strength w/ 0.5% Pavebond Spec.	95		88		108

JOB MIX FORMULA:

Aggregate Sieve Size	JMF Gradation	Paving Course	Asphalt Content % By Wt. of Total Mixture	Sp Gr. @ 1st Comp	Sp Gr. @ 2nd Comp	Max Sp Gr T-209	Design Voids 1st Comp	Design Voids 2nd Comp
1"	100	Wearing	6.0	2.173	--	2.456	11.5	--
¾	91	Base						
½	67							
⅜	42	Shoulder						
¼	24	Asphalt Lab No. 92-1285						
10	14	Brand— Chevron		Mix Placement Temp.— 236 °F— 245 °F				
40	6	Grade— PBA-5		Mixing Temp.— 253 °F— 261 °F				
200	3.5	Additive— addition of 0.5% Pavebond Special						

(CALCULATED JOB MIX FORMULA PROPERTIES)

AGGREGATE TEST DATA:

92-1073 CA: LAR = 15.0%; Na2SO4 = 1.1%; Degrade = 0.6", 18.0%; Friables = 0.2%; Dust=0.20%
92-1074 FA: ; " = 2.0%; " = 0.4", 9.2%; " = 0.5%; SE = 82
92-1075 FA: ; " = 2.0%; " = 0.4", 9.2%; " = 0.5%; SE = 82

Distribution	COMMENTS:
Const.	* contractor proposed crushing targets.
FHWA	Spec. Grav. = CA 2.64, FA 2.62
Reg. Engr.	
Res. Engr.	
Dist. Engr.	
Region Geo.	
Files	

Oregon Department of Transportation
HIGHWAY DIVISION

ASPHALT LABORATORY RECORD

OREGON STATE HIGHWAY DIVISION,
MATERIALS SECTION, 800 AIRPORT RD., SALEM OR 97310

PAGE 1 OF 2

LABORATORY REPORT NUMBER: ?01285

ASPHALT BRAND AND TYPE: CHEVRON PBA-5

PROJECT	SANTIAM RIVER (SOUTHBOUND) BRIDGE
DATA SHEET NO.	NONE
HIGHWAY	PACIFIC
COUNTY	MARION & LINN
EXP. ACCOUNT. SUB JOB	C11038
CONTRACTOR	HAMILTON CONSTRUCTION CO.
F.A. PROJECT NUMBER	
BID ITEM NUMBER	
PROJECT MANAGER	LEE FRANKLIN
AGENCY ORG. UNIT	8054
DATE RECEIVED	2-14-92
DATE REPORTED	2-19-92
SUBMITTED BY	CHEVRON OIL CO.
AGENCY ORG. UNIT	
TEST NO.	416A
VAR	
LAB CHARGE	344.00
SOURCE OF MATERIAL	CHERON OIL CO. PORTLAND, OR.
QUANTITY REPRESENTED	12 qts.
SAMPLED AT	PORTLAND
SAMPLED BY	UNK.
TO BE USED	"F" a/c
DATE SAMPLED	2-11-92

SAMPLE NO. 92-3 COMPLETE **TEST RESULTS** **DATE TESTED:** 2-18-92

PAVING ASPHALT

T 73	Flash Point, closed cup		°F
T 44	Solubility in CHCL:CCL2	99.99	%
T 49	Penetration at 77F/39.2		cm/100
	Penetration ratio 39.2/77F		
T201	Viscosity, Kinematic 275 F	442	C.S.
T202	Viscosity, Absolute 140 F	2670	P.
T240	**Paving Asphalt RTF (c) Residue**		
T 47	Loss on heating	0.37	%
T201	Viscosity, Kinematic 275 F	650	C.S.
T202	Viscosity Absolute 140 F, 30cm Hg., Vac.	6250	P.
	Viscosity Ratio Res./Orig.	4.0	
T 49	Penetration at 77 F/39.2 F	40/18	cm/100
	% of orig. penetration		%
T 51	Ductility at 77 F	100+	cm
	Ductility at 45 F	16	cm

Liquid Asphalt

T 48	Flash point, open cup	500	°F
T201	Viscosity, Kinematic at 140 F		C.S.
T 78	Distillation (% of total distillate to 680 F)		
	To 374 F		%
	To 437 F		%
	To 500 F		%
	To 600 F		%
	Residue from distillation to 680 F Volume by difference		%
	Water		%

Liquid Asphalt Residue

T 49	Penetration at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm.
T202	Viscosity ABS at 140 F		P.

Emulsified Asphalt

T 59	Viscosity, S.F. at ___ F		sec.
T 59	Sieve Test		%
T 59	Residue by distillation to 500 F		%
T 59	Oil distillate in		%
T 49	Penetration of Res. at 77 F		cm/100
T 44	Solubility in CHCL:CCL2		%
T 51	Ductility at 77 F		cm

T170	**Modified Abson Recovery of Asphalt**		
T201	Viscosity, Kinematic 275 F		C.S.
T202	Viscosity, Absolute 140 F, 30cm Hg. Vac.		P.
T 49	Penetration of Res. at 77 F		cm/100
	"C" value		

T49 Penetration of Residue @ 39.2 F 4cm/100
5sec 100g

DISTRIBUTION ONLY
- x FILES
- X OPERATIONS
- X LEE FRANKLIN
- X RAS 2
- X HAMILTON CONSTR. CO.
- X BIT
- X CHEVRON OIL
- X FHWA

RECOMMENDATION:
Material as represented by this sample does, ~~does not~~ comply with specifications.

APPENDIX G

WASHINGTON DEPARTMENT OF TRANSPORTATION PROJECT

1.0 INTRODUCTION

The purpose of this project was to evaluate cores from the open graded rubber asphalt mixture placed on I-5 near Centralia, Washington. The testing program included moisture sensitivity evaluation using the Environmental Conditioning System (ECS), and resistance to permanent deformation using the shear test device at UCB.

There were four sets of ten cores taken from different areas throughout the project. All of the cores were taken from the left shoulder one foot left of the fog line. The following is a brief description of the sets:

1) Cores 1-10 were taken in the area where PBA-6 asphalt was used, and air temperature was between 60 and 70 F when it was paved. This section of the project was compacted with a vibratory roller.
2) Cores 11-20 were taken in the area where PBA-6GR asphalt was used and air temperature was between 50 and 60 F when it was paved. This section of the project was compacted with a static roller.
3) Cores 21-30 were taken in the area where PBA-6GR asphalt was used and air temperature was between 60 and 70 F when it was paved. This section of the project was compacted with a static roller.
4) Cores 31-40 were taken in the area where PBA-6GR asphalt was used and air temperature was between 60 and 65 F when it was paved. This section of the project was compacted with a vibratory roller.

When the cores were received at OSU, each core was sawed from both ends. The cores were cut to eliminate error caused by end effects; about 1/8 in. was cut from each end. A dry saw was used with CO_2 as coolant, because wetting the core can affect the permeability and gravimetric tests. For the air permeability test the specimen must be dry, water in voids can hinder the air flow through the specimen, thus giving wrong air flow values and air permeability results.

2.0 PROCEDURES

The cores gravimetric data (specific gravities) were determined using the parafilm method, and air voids were calculated. Based on air voids results for each set, three cores were chosen from the same set with similar air voids. The three cores were stacked on top of each other and glued using epoxy resin, the objective of which was to obtain a 4 in. (102 mm) high specimen that could be tested in the ECS. For each mixture, two specimens were tested in the ECS. The ECS test included three hot cycles and one freeze cycle. Repeated loading was not applied in the hot cycles, due to specimens susceptibility to permanent deformation.

3.0 RESULTS

Table G1 shows the summary of ECS test results. The table includes air voids based on average air voids of the three cores that were glued together to produce each specimen. Also, the air permeability, ECS-M_R, water permeability after each conditioning cycle, and stripping rate results are included. Specimen number WA_A are from cores numbered 1-10, WA_B are from cores 11-20, WA_C from cores 21-30, and WA_D from cores 31-40. Two specimens were tested from each set of cores, or a total of eight specimens.

Figure G1 shows the air voids plot for each set of mixes, where mixtures A, B, C, and D consist of cores 1-10, 11-20, 21-30, and 31-40, respectively. The figure shows that cores which came from mixes A and D had the highest air voids, and that mixes B and C had the lower air voids. The cores that came from the section that was compacted by vibratory roller had the higher air voids. The cores that came from the section that was compacted by static roller had the lower air voids.

Table G1 Summary Data of WSDOT Open-graded Mixtures

Specimen ID	Air Voids (%)	Initial Air Permeability E-5 cm/s	Cycle No.	ECS-MR (Ksi)	Retained ECS-MR Ratio	Water Permeability E-3 cm/s	Stripping Rate
WA_A1	15.4	4.73	0	76.9	1.00	3.00	
WA_A1	15.4	4.73	2	68.7	0.89	2.70	
WA_A1	15.4	4.73	3	66.2	0.86	2.67	
WA_A1	15.4	4.73	4	68.2	0.89	2.55	5
WA_A2	16.0	3.96	0	48.2	1.00	2.43	
WA_A2	16.0	3.96	2	44.7	0.93	2.23	
WA_A2	16.0	3.96	3	45.6	0.95	2.21	
WA_A2	16.0	3.96	4	44.9	0.93	2.13	5
WA_B4	11.9	Impermeable	0	118.7	1.00	0.35	
WA_B4	11.9	Impermeable	2	102.0	0.86	1.10	
WA_B4	11.9	Impermeable	3	93.7	0.79	0.79	
WA_B4	11.9	Impermeable	4	95.0	0.80	0.75	5
WA_B6	14.5	Impermeable	0	76.9	1.00	0.89	
WA_B6	14.5	Impermeable	2	70.9	0.92	1.02	
WA_B6	14.5	Impermeable	3	70.8	0.92	1.24	
WA_B6	14.5	Impermeable	4	69.3	0.90	1.10	5
WA_C7	11.7	Impermeable	0	98.0	1.00	0.73	
WA_C7	11.7	Impermeable	2	93.8	0.96	0.94	
WA_C7	11.7	Impermeable	3	90.3	0.92	0.97	
WA_C7	11.7	Impermeable	4	92.1	0.94	1.06	5
WA_C8	13.3	Impermeable	0	40.3	1.00	0.49	
WA_C8	13.3	Impermeable	2	43.3	1.07	0.68	
WA_C8	13.3	Impermeable	3	46.2	1.15	0.68	
WA_C8	13.3	Impermeable	4	54.7	1.36	0.62	5
WA_D10	13.5	Impermeable	0	156.0	1.00	0.68	
WA_D10	13.5	Impermeable	2	103.5	0.66	0.63	
WA_D10	13.5	Impermeable	3	105.0	0.67	0.60	
WA_D10	13.5	Impermeable	4	124	0.79	0.60	5
WA_D11	14.8	2.53	0	63.0	1.00	1.74	
WA_D11	14.8	2.53	2	67.0	1.06	1.37	
WA_D11	14.8	2.53	3	41.6	0.66	1.37	
WA_D11	14.8	2.53	4	48.1	0.76	1.30	5

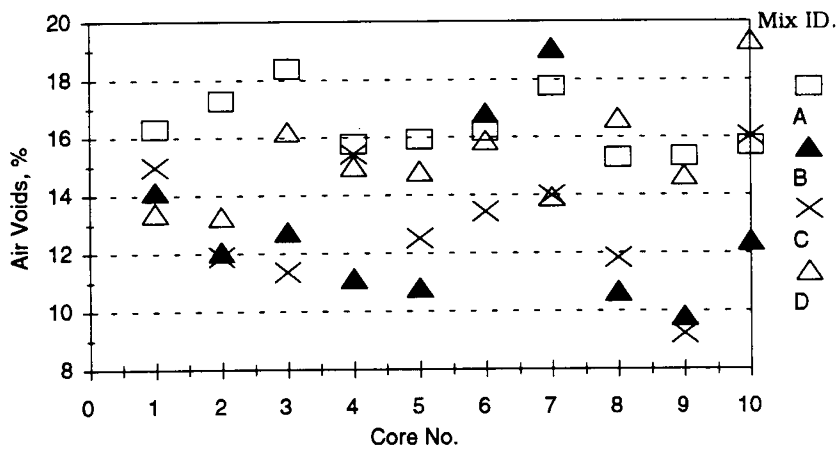

Figure G1 Comparisons Between ECS and IRS Results

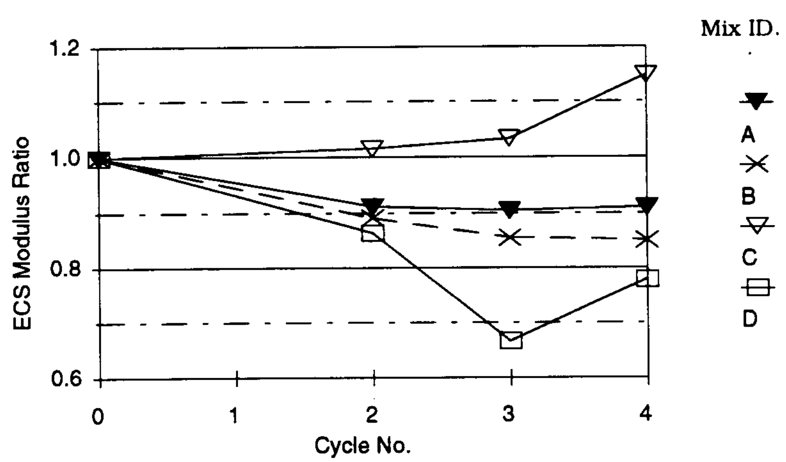

Figure G2 Effect of Additive on Mixture Performance in ECS

Figure G2 shows the ECS conditioning effects on the different mixes. Mixture D exhibited susceptibility to water damage; at the end of the test, the average ECS-M_R ratio was 0.78 for the two specimens. The other three mixes did not show the same decrease in ECS-M_R . One specimen of mix B indicated lower strength after the ECS test, but there was no noticeable stripping present after the ECS test.

Figure G3 shows the effect of air voids and initial water permeability on the final ECS-M_R ratio, regardless of the mix type. The figure shows that specimens with higher initial water permeability will tend to lose more strength. Also, specimens with higher air voids are more susceptible to water damage. The water penetrates the specimens with higher permeability more easily than specimens with lower permeability, hence the water can initiate water damage if the mix is susceptible to water damage.

4.0 CONCLUSIONS

In conclusion, the WSDOT test program had limited number of specimens and ECS tested specimens were made of three cores glued together, this lead to variability in the test data. Statistical analysis was not possible because of the high variability in the data. This method of specimen fabrication is believed to be the reason behind the discrepancies between the ECS results. Therefore, conclusive conclusions regarding the water damage potential of the WSDOT mixtures can not made from these results.

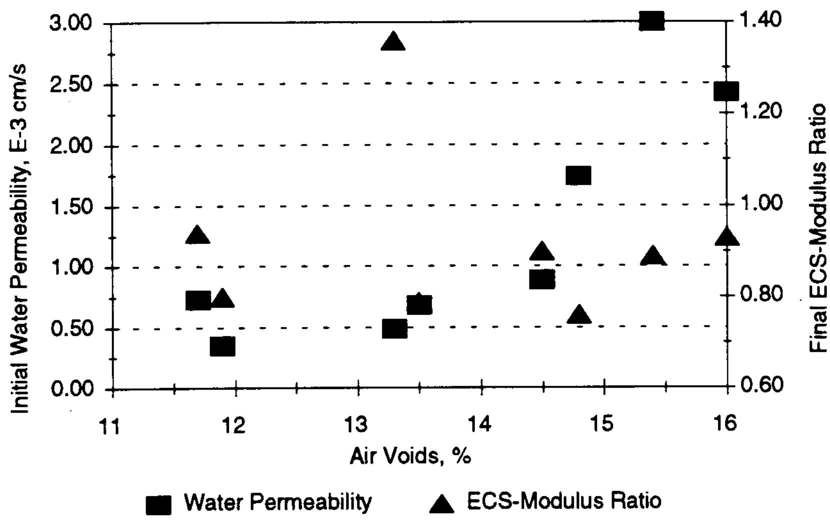

Figure G3 Relationship Between Air Voids and Permeability to ECS Results

APPENDIX H

SUMMARY DATA OF AUSTRALIAN PROJECT

Table H1: Summary of ECS Data for Australian Modified Mixtures

Specimen No.	Mixture Type	Diam. MR (Ksi)	Air Voids (%)	Cycle No.	ECS-MR (Ksi)	Retained ECS-MR Ratio	Water Permeability E-3 cm/s	Water Permeability Ratio
92/22/1	Class 320 Binder Fly Ash fill	284.2	12.0	0	420.0	1.00	3.01	1.00
92/22/1	Class 320 Binder Fly Ash fill	284.2	12.0	1	406.0	0.97	3.25	1.08
92/22/1	Class 320 Binder Fly Ash fill	284.2	12.0	2	379.0	0.90	2.92	0.97
92/22/1	Class 320 Binder Fly Ash fill	284.2	12.0	3	445.0	1.06	2.92	0.97
92/22/1	Class 320 Binder Fly Ash fill	284.2	12.0	4	455.0	1.08	2.89	0.96
92/22/9	Class 320 Binder Fly Ash fill	407.5	10.0	0	409.0	1.00	4.15	1.00
92/22/9	Class 320 Binder Fly Ash fill	407.5	10.0	1	344.0	0.84	4.05	0.98
92/22/9	Class 320 Binder Fly Ash fill	407.5	10.0	2	364.0	0.89	3.80	0.92
92/22/9	Class 320 Binder Fly Ash fill	407.5	10.0	3	360.0	0.88	3.70	0.89
92/22/9	Class 320 Binder Fly Ash fill	407.5	10.0	4	374.0	0.91	3.38	0.81
92/23/11	Class 320 Lime filler	350.5	10.2	0	587.0	1.00	0.10	1.00
92/23/11	Class 320 Lime filler	350.5	10.2	1	610.0	1.04	2.62	26.20
92/23/11	Class 320 Lime filler	350.5	10.2	2	568.0	0.97	2.23	22.30
92/23/11	Class 320 Lime filler	350.5	10.2	3	562.0	0.96	2.23	22.30
92/23/11	Class 320 Lime filler	350.5	10.2	4	560.0	0.95	2.23	22.30
92/23/20	Class 320 Lime filler	379.5	10.8	0	388.0	1.00	3.00	1.00
92/23/20	Class 320 Lime filler	379.5	10.8	1	354.0	0.91	4.34	1.45
92/23/20	Class 320 Lime filler	379.5	10.8	2	364.0	0.94	4.05	1.35
92/23/20	Class 320 Lime filler	379.5	10.8	3	370.0	0.95	4.05	1.35
92/23/20	Class 320 Lime filler	379.5	10.8	4	405.0	1.04	4.05	1.35
92/24/7	SBS modified binder Fly Ash	276.0	10.0	0	462.0	1.00	6.14	1.00
92/24/7	SBS modified binder Fly Ash	276.0	10.0	1	316.0	0.68	4.32	0.70
92/24/7	SBS modified binder Fly Ash	276.0	10.0	2	348.0	0.75	4.32	0.70
92/24/7	SBS modified binder Fly Ash	276.0	10.0	3	365.0	0.79	4.16	0.68
92/24/7	SBS modified binder Fly Ash	276.0	10.0	4	350.0	0.76	4.16	0.68
92/24/8	SBS modified binder Fly Ash	318.0	9.6	0	450.0	1.00	4.49	1.00
92/24/8	SBS modified binder Fly Ash	318.0	9.6	1	272.0	0.60	3.57	0.80
92/24/8	SBS modified binder Fly Ash	318.0	9.6	2	292.0	0.65	4.07	0.91
92/24/8	SBS modified binder Fly Ash	318.0	9.6	3	330.0	0.73	3.39	0.76
92/24/8	SBS modified binder Fly Ash	318.0	9.6	4	314.0	0.70	3.39	0.76

APPENDIX I

SUMMARY DATA OF CYCLE DURATION STUDY

Table I1: Summary of ECS Data for Cycle Duration Study

Specimen ID	Cycle Duration (Hrs)	Air Voids (%)	Diam. MR (Ksi)	Cycle No.	ECS-MR (Ksi)	Retained ECS-MR Ratio	Stripping Rate
B-01	3	13.7	174	0	280	1.00	20
B-01	3	13.7	174	1	205	0.73	20
B-01	3	13.7	174	2	214	0.76	20
B-01	3	13.7	174	3	218	0.78	20
B-01	3	13.7	174	4	199	0.71	20
B-06	3	13.4	164	0	186	1.00	20
B-06	3	13.4	164	1	163	0.88	20
B-06	3	13.4	164	2	155	0.84	20
B-06	3	13.4	164	3	153	0.82	20
B-06	3	13.4	164	4	169	0.91	20
B-02	5	13.7	169	0	188	1.00	20
B-02	5	13.7	169	1	166	0.88	20
B-02	5	13.7	169	2	167	0.89	20
B-02	5	13.7	169	3	167	0.89	20
B-02	5	13.7	169	4	167	0.89	20
B-08	5	13.3	174	0	240	1.00	20
B-08	5	13.3	174	1	196	0.82	20
B-08	5	13.3	174	2	187	0.78	20
B-08	5	13.3	174	3	177	0.74	20
B-08	5	13.3	174	4	175	0.73	20
B-07	6	13.7	165	0	255	1.00	20
B-07	6	13.7	165	1	254	1.00	20
B-07	6	13.7	165	2	197	0.77	20
B-07	6	13.7	165	3	199	0.78	20
B-07	6	13.7	165	4	194	0.76	20
C7	3	12.1	196	0	224	1.00	10
C7	3	12.1	196	1	224	1.00	10
C7	3	12.1	196	2	196	0.88	10
C7	3	12.1	196	3	191	0.85	10
C7	3	12.1	196	4	190	0.85	10
C4	3	12.0	175	0	250	1.00	10
C4	3	12.0	175	1	242	0.97	10
C4	3	12.0	175	2	220	0.88	10
C4	3	12.0	175	3	214	0.85	10
C4	3	12.0	175	4	211	0.84	10
C-01	5	12.6	188	0	218	1.00	20
C-01	5	12.6	188	1	220	1.01	20
C-01	5	12.6	188	2	224	1.03	20
C-01	5	12.6	188	3	234	1.08	20
C-01	5	12.6	188	4	199	0.91	20
C-03	5	12.0	173	0	307	1.00	20
C-03	5	12.0	173	1	285	0.93	20
C-03	5	12.0	173	2	249	0.81	20
C-03	5	12.0	173	3	245	0.80	20
C-03	5	12.0	173	4	240	0.78	20
C-06	6	12.5	189	0	307	1.00	20
C-06	6	12.5	189	1	285	0.93	20
C-06	6	12.5	189	2	283	0.92	20
C-06	6	12.5	189	3	271	0.88	20
C-06	6	12.5	189	4	287	0.93	20