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EVALUATION OF ANTI-STRIPPING AGENTS USING THE ASPHALT PAVEMENT ANALYZER

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June 2001

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16 Abstract

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Preliminary indications reveal that loaded wheel rut testers, such as the Asphalt Pavement Analyzer (APA), have the potential to detect moisture susceptible mixtures. To date no standard test methodology has been developed. The objective of this project was to evaluate the effects of sample preconditioning on APA rut depths and to further evaluate the APA's suitability for predicting moisture susceptible mixtures.

Eight different mixes from seven project sites were evaluated with the APA. Samples were tested at 40°C using four different preconditioning procedures: dry, soaked, saturated, and saturated with a freeze cycle. The results were compared with TSR values, methylene blue values and sand equivalent.

The APA was able to identify every mix with a failing TSR. In addition, the APA identified one mix containing a large percentage of chert, an aggregate with a history of moisture susceptibility, as failing when the TSR indicated a passing result. Additionally, the results indicate that the harsher preconditioning of saturation and saturation with a freeze cycle did not result in increased wet rut depths. Using only dry and soaked conditioning appears to be adequate.

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Final Report

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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Moisture damage of asphalt mixes, better known as stripping, is a major distress affecting pavement performance. AASHTO T 283 (KT-56) has been used by many agencies over the past decade to detect moisture susceptible pavements through the determination of a tensile strength ratio (TSR). Results from AASHTO T283 (KT-56) have been inconsistent. As a result there has been increased interest in finding an alternative test method.

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Eight different mixes from seven project sites were evaluated with the APA. Samples were tested at 40°C using four different preconditioning procedures: dry, soaked, saturated, and saturated with a freeze cycle. The results were compared with TSR values, methylene blue value and sand equivalent.

The APA was able identify every mix with a failing TSR. In addition, the APA identified one mix containing a large percentage of chert, an aggregate with a history of moisture susceptibility, as failing when the TSR indicated a passing result. Additionally, the results indicate that the harsher preconditioning of saturation and saturation with a freeze cycle did not result in increased wet rut depths. Using only dry and soaked conditioning appears to be adequate.

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CHAPTER I

INTRODUCTION

BACKGROUND

Stripping occurs when the adhesive bond between asphalt and aggregates is loosened or weakened by the action of moisture. The damaging effects that can result include rutting and cracking due to shear forces. Although the phenomenon of stripping has been acknowledged for over 50 years, being able to predict the moisture susceptibility of aggregates has not been adequately solved.

Part of the Strategic Highway Research Program (SHRP) was focused on determining a test method to evaluate the moisture damage potential of aggregates. This research was not completely successful. Under a SHRP contract, Oregon State University developed the Environmental Conditioning System (ECS). This method has exhibited potential for being a good predictor of moisture susceptibility, but follow-up evaluation and research has determined that refinement is needed in order to improve the ability of the procedure to identify problem mixes (1, 2). The recommendations from SHRP were to continue using AASHTO T 283, *Resistance of Compacted Bituminous Mixture to Moisture Induced Damage*. As a result, many agencies have adopted or continued to use AASHTO T 283. However, this test method has shortcomings. For example, reproducibility of the test was a problem in this research project. The original scope of the project called for asphalt mixtures from sites that significantly failed the

Kansas Test Method KT-56, *Resistance of Compacted Bituminous Mixture to Moisture Induced Damage* (AASHTO T 283), as well as mixtures that marginally passed and easily passed. From field lab results, it was thought that appropriate sites with failing material had been located. However, after the Kansas Department of Transportation's (DOT) Materials and Research Laboratory tested the mixtures, none of the sites had significantly failing test results. Additionally, Aschenbrener (1), in his research that included mixes with known field performance, found that AASHTO T 283 did not identify mixtures that had marginal performance problems. Finally, this test method is also time intensive (3 to 4 days to complete). Thus, a test method that can accurately predict stripping potential and take hours rather than days to complete would be attractive to highway agencies and contractors alike.

Research by the Colorado DOT (3), the Georgia DOT (4), and the Indiana DOT (5) has shown that loaded wheel testing devices can be used to identify moisture sensitive mixes. Because rutting is one of the symptoms of stripping, developing a test method with these devices is a logical approach. Additionally, the loaded wheel device used in this study, the Asphalt Pavement Analyzer (APA), has the ability to test samples while they are submerged in water providing a more direct simulation of water-asphalt interaction.

OBJECTIVE

The objective of this research project was to evaluate the effects of sample preconditioning on APA rut depths. It was conjectured that the freezing and/or saturation conditioning parameters of KT-56 (AASHTO T 283) would not have a significant effect on the rut depth ranking of the samples. If, instead, a quick and simple two-hour soak conditioning could be employed that yielded similar rut depth results, one hurdle towards developing a quicker test method for predicting moisture susceptibility would have been crossed. The tensile strength ratios (TSR), methylene blue values (MBV), and sand equivalents (SE) of the samples were also evaluated and compared with APA rut depths to determine if any relationships existed. Additionally, the overall viability of using of the APA in predicting moisture susceptible mixes was evaluated. The intent was to discern if the APA exhibited any potential for helping to predict moisture susceptibility. The results indicated, as others have found, that there is potential for using the APA to predict moisture susceptibility. In Chapter IV a test method is put forward that makes use of the APA as well as the MBV test.

SCOPE

The research project was a laboratory study of eight asphalt mixes from seven project sites in Kansas. The only criteria used to select the project sites/mixes was that before the addition of any additives at least two mixes should easily pass KT-56 (AASHTO T 283), at least two mixes should be marginal, and two or three mixes should fail KT-56 (AASHTO T 283). However, due to reproducibility problem of the KT-56 (AASHTO T 283) test mentioned above and the fact that the Kansas DOT attempts to avoid designing mixes which are moisture susceptible, only mixes that passed or were marginal were a part of the study.

Cylindrical samples of the eight asphalt mix designs were made and compacted to 7 ±1% air voids with the Superpave Gyratory Compacter (SGC). The samples were tested in the APA (up to 8000 cycles) with various preconditioning and additives as explained in further detail in Chapter III. The rut depths were recorded in a database and evaluated using the SAS Institute's JMP Software program (6). This statistical software program provided an analysis of variance (ANOVA), correlations, and significant difference determinations among groups.

CHAPTER II

LITERATURE REVIEW

BACKGROUND

Stripping in asphalt pavement (more appropriately called moisture-induced damage) is a major problem in the United States and throughout the world. As an indication of the scope of the problem, a search of the Transportation Research Information System (TRIS) revealed 601 reports with stripping as the main topic. Unfortunately, this large volume of research has yet to result in a foolproof test method to predict the moisture susceptibility of asphalt mixes. In fact, Roberts, et al. (7), noted that no test method has gained wide acceptance because of their low reliability and lack of satisfactory relationship between laboratory and field conditions.

Stripping is not a straight-forward phenomenon, but rather a complex problem which depends upon many variables, such as the type of asphalt, the type of aggregates, the environment, the mix permeability, and the amount and type of traffic. However, the one factor that is common to all cases of stripping is the presence of water (7). Water can contribute to early pavement failures by affecting the integrity of an asphalt mix. In previous research, R.L. Terrel (8) has fittingly outlined three mechanisms by which water can degrade a mix: 1) loss of cohesion (strength) and stiffness of the asphalt film; 2) failure of the adhesion (bond) between the aggregate and the asphalt, which we refer to as stripping; and 3) fracture or degradation of aggregates due to freeze/thaw cycling. This project focused on the second mechanism, stripping.

A review of the literature has shown that the following factors appear to affect adhesion between asphalt and aggregates (7, 8, 9):

1. Surface tension of the asphalt cement and aggregate.
2. Chemical composition of the asphalt and aggregate.
3. Asphalt viscosity.
4. Surface texture of the aggregate.
5. Aggregate porosity.
6. Aggregate cleanliness.
7. Aggregate moisture content and temperature at the time of mixing with asphalt cement.

Terrel and Hicks (8, 9) provide an excellent discussion of the four theories of adhesion that have been developed using the above factors. The four theories are as follows:

Mechanical Adhesion. In general, the rougher and more absorptive (porous) the aggregate the greater the adhesion will be.

Chemical Reaction. The chemical reaction of aggregates and asphalt is recognized as a possible mechanism for adhesion. Some researchers have noted that better adhesion can be achieved with basic aggregates than with acidic aggregates. However, this result is not universal.

Surface Energy. The affinity an aggregate has towards liquids such as asphalt and water is related to surface energy and viscosity. Liquids with low viscosity and low surface tension will be relatively good wetting agents. This explains why water is a better wetting agent than asphalt.

Molecular Orientation. This theory suggests that molecules of a liquid substance will align themselves with unsatisfied electric charges on an aggregate surface. Thus, because water molecules are entirely dipolar and only some asphalt molecules are dipolar, aggregates have a preference for water over asphalt.

Numerous tests such as AASHTO T 283, the Environmental Conditioning System (ECS), the Boiling Water Test (ASTM D 3625), and the Immersion Compression Test (AASHTO T 165 and T 167) have been developed in an attempt to predict the moisture susceptibility of asphalt mixes. In general, these tests contain a conditioning phase and an evaluation phase. In the conditioning phase, the asphalt sample is conditioned to represent harsh environmental conditions such as temperature extremes and high water saturation levels. In the evaluation phase, generally some strength characteristic is measured such as tensile strength.

As mentioned previously, none of these tests have very satisfactory predictive capabilities. Additionally, some of them are very time consuming. As a result there continues to be interest in developing a better test method.

ENVIRONMENTAL CONDITIONING SYSTEM

The ECS was developed as part of the SHRP research (10). The system tests cylindrical samples (100 mm in diameter by 100 mm in height) subjected to water conditioning, temperature cycling, and repeated loading. The temperature conditioning is dependent upon the climatic region. For warm climates, three hot cycles are used, and for cold climates a freeze cycle is added. Table 1 contains a summary of the ECS test procedures that were included in SHRP report A-417 (10). The ECS procedure evaluates the test samples for three criteria: ECS modulus ratio, coefficient of permeability, and visual evaluation of stripping. The ECS modulus ratio is the ratio of the resilient modulus after the temperature and load cycles conditioning to the

Table 1. Summary of the ECS Test Procedure.

Step	Description
1	Prepare test specimens as per SHRP protocol.
2	Determine the geometric and volumetric properties of the specimen. Determine the triaxial and diametral modulus using a closed-loop, hydraulic, or pneumatic test system.
3	Encapsulate specimen in silicon sealant and latex rubber membrane, allow to cure overnight (24 hrs.).
4	Place the specimen in the ECS load frame, between two perforated teflon discs, and determine air permeability.
5	Determine unconditioned (dry) triaxial resilient modulus.
6	Vacuum condition specimen (subject to vacuum of 51 cm Hg for 10 minutes).
7	Wet specimen by pulling distilled water through specimen for 30 minutes using a 51 cm Hg vacuum.
8	Determine unconditioned water permeability.
9	Heat the specimen to 60°C for six hours, under repeated loading. This is a hot cycle.
10	Cool the specimen to 25°C for at least four hours. Measure triaxial resilient modulus and water permeability.
11	Repeat steps 9 and 10 for two more hot cycles.
12	Cool the specimen to -18°C for 6 hours, without repeated loading. This is a freeze cycle.
13	Heat the specimen to 25°C for at least 4 hours and measure the triaxial resilient modulus and water permeability.
14	Split the specimen and perform a visual evaluation of stripping.
15	Plot the triaxial resilient modulus and water permeability ratios.

unconditioned resilient modulus. The specification requires the ECS modulus ratio to be 0.70 or greater after the final conditioning. The slope of the ECS modulus ratio plotted after each temperature cycle is used as a secondary criterion for determining moisture susceptibility. For instance, if the ECS modulus ratio is greater than 0.70, but the slope of the ECS modulus ratio between cycles 1 and 3 is downward, the mixture may be moisture sensitive and still in need of an anti-strip agent (10).

Although the ECS test has shown some potential, it has yet to be fully validated. In research completed by Aschenbrener, et al. (1), the ECS did not adequately identify mixes that were moisture susceptible. Additionally, a study completed by the University of Texas at El Paso (11) found that the ECS conditioning process was not severe enough and the precision of the resilient modulus test was poor. Both of these factors led to inaccurate results. In addition to the above disadvantages, the ECS also takes several days to complete. However, if the ECS conditioning procedures are improved along with the precision of the resilient modulus test, the test may become more attractive and reliable. Its major advantage is the consideration of all the major elements needed (loading, voids, water, and temperature cycles) for stripping to occur.

AASHTO T 283

The AASHTO T 283 test, which is titled "Resistance of Compacted Bituminous Mixture to Moisture Induced Damage," is the test method that was recommended by SHRP for testing moisture sensitivity and it is the most common used moisture sensitivity test by departments of transportation across the U.S. A summary of this method is as follows (12):

"Test specimens for each set of mix conditions, such as plain asphalt, asphalt with anti-stripping agent, and aggregate treated with lime, are tested. Each set of specimens is divided into subsets. One subset is tested in dry condition for indirect tensile strength. The other subset is subjected to vacuum saturation, an optional freeze cycle, followed by a freeze and a warm water cycle before being tested for indirect tensile strength. Numerical indices of retained indirect tensile strength properties are computed from the test data obtained on the two subsets: dry and conditioned."

The saturation level for AASHTO T 283 has a specified range of 55 to 80 percent and the limit on air voids is 6 to 8 percent. The Kansas DOT uses KT-56, which has a required saturation level of 55 to 65 percent. KDOT requires a minimum TSR of 0.80, using KT-56, for mix design approval.

For lack of a more definitive test and because of its use in Kansas, KT-56 was used to select and rank moisture susceptible mixes in this research project. Research by Aschenbrener, et al. (1) has indicated that AASHTO T 283 can predict the performance of very moisture resistant mixes and mixes which are extremely susceptible to moisture damage, but the test cannot successfully identify mixes that are marginally susceptible to moisture damage. Another disadvantage to this test is that it takes several days to complete.

BOILING WATER TEST

The "Boiling Water Test," or ASTM D 3625, is another test that has had some success in identifying moisture susceptible mixes. There are some highway agencies, such as the Texas DOT, that use a form of the Boiling Water Test (13). The test involves a visual determination of the extent of asphalt stripping after a mix has been immersed in boiling water for a specified amount of time. After the mix is removed from the boiling water, it is allowed to dry before a visual determination of the percent asphalt retained takes place. Generally, 95 percent retained asphalt is specified for a passing test.

An advantage of the Boiling Water Test is that it is relatively quick and easy to perform. However, the results are based upon subjective opinion (the visual determination), and the results do not consider the permeability or gradation of the mix. In addition, Aschenbrener, et al. (1) found the test to be overly severe when a 95 percent retained asphalt criteria was applied. It is also interesting to note that Kennedy and Ping (13) found the Boiling Water Test to favor anti-strip liquids over hydrated lime whereas for AASHTO T 283, they found the reverse was true; hydrated lime was favored over the anti-strip liquids.

IMMERSION COMPRESSION TEST

The Immersion-Compression (IC) Test, AASHTO T 165 and T 167 (14), is used by several highway agencies, such as Arizona, New Mexico, Idaho, and FHWA's Federal Lands Division, to test for moisture susceptibility. In this test a minimum of six 101.6 mm (4 inch) diameter by 101.6 mm (4 inch) height cylindrical samples are compacted to 6 - 7 percent air voids (depending upon agency research and preference), and then the samples are separated into two even groups. One group of samples is immediately tested for compressive strength. The other group of duplicate samples is immersed in water for 24 hours at 60°C (an alternate procedure allows for a four-day immersion at 49°C). After the samples are removed from immersion, they are brought to room temperature and tested for compressive strength. An index of retained compressive strength is then calculated by dividing the compressive strength of the immersed or conditioned samples by the compressive strength of the unconditioned (control) samples. Generally, agencies specify a minimum retained strength of 70 percent. The IC test is considered a relatively mild test for moisture sensitivity (9). This may explain why agencies with large networks of low volume roads prefer this test.

SUPPLEMENTAL TESTS

In addition to performing tests on the asphalt mixtures, some highway agencies are considering supplementing mix test results with results from aggregate tests that can determine the amount of detrimental fines. The two aggregate tests being most widely considered are the Sand Equivalent (SE) and the Methylene Blue Value (MBV) tests.

Sand Equivalent Test

There have been studies completed that show the SE value to correlate with the moisture susceptibility of a mix (15). The specific purpose of the SE test (AASHTO T 176 and KT-55) is to determine the amount of dust and clay-like material in the fine aggregate of an asphalt mixture. In the test (12), aggregate passing the 4.75-mm sieve is placed in a graduated cylinder with water and a flocculating agent. The mixture is agitated and then allowed to settle. During the agitation process the dust and clay material separate from the sand allowing for the fine material to settle in a segregated fashion. The SE value then simply becomes the height of the sand material divided by the height of the total material times 100. The minimum specified SE value varies from agency to agency and is sometimes based upon traffic. However, the most common minimum value is 45 (15). The Kansas DOT specifies the minimum SE value (KT-55) on a project-by-project basis and, due to the relatively low traffic volumes on most of their roads, the Kansas DOT requires a minimum SE value of 40 in most cases.

The advantages of the SE test are that it is quick, easy, and inexpensive to perform. However, the MBV test in recent research has been shown to have better correlation coefficients to field performance and TSR values (3, 15).

Methylene Blue Value

The MBV test was developed by the French and is recommended by the International Slurry Surfacing Association (ISSA) as a procedure to measure the amount of potentially harmful fine material present in an aggregate. More specifically, the MBV test quantifies the amount of harmful clays (smectite group), organic matter, and iron hydroxides in the fine aggregates (3). The complete test procedure is described in Technical Bulletin 145 of the ISSA under the title "Determination of Methylene Blue Adsorption Value of Mineral Aggregate Fillers and Fines" (16). The test is performed on only the material passing the 0.075-mm sieve. Three separate 10-g samples of the fine aggregate (minus 0.075 mm material) are each mixed with 30 g of distilled water in a beaker. A solution of methylene blue and distilled water is made and then titrated stepwise in 0.5 ml increments into the beakers containing the aggregate suspension. The aggregate in the beakers is stirred in order to keep a continuous suspension and to thoroughly mix in the methylene blue solution. After each increment of methylene blue solution, a small drop of the aggregate suspension is placed on a piece of filter paper. Initially, a well-defined circle of methylene blue-stained dust is formed on the filter paper and is surrounded with an outer ring or corona of clear water. Additional increments of 0.5 ml methylene blue solution are added to the aggregate suspension until a permanent, light blue coloration or "halo" is observed in the ring of clear water on the filter paper. The MBV is then reported as milligrams of methylene blue solution per gram of fine aggregate. The higher the MBV, the higher the quantity of harmful fines in the aggregate.

Just as with the SE test, the MBV test is quick, easy, and inexpensive to perform. Additionally, Kandhel, et al. (15), determined that the MBV test is the aggregate test that is best related to stripping in asphalt mixtures. One minor disadvantage of this test is that it has yet to be accepted as a standard by AASHTO or ASTM.

Loaded Wheel Testers

A relatively recent application that is showing more and more promise for accurately determining moisture susceptibility of asphalt mixtures is the use of loaded wheel testers and the deformation (rut) data they generate. Loaded wheel testers can simulate deterioration due to traffic loadings and test samples under water. Thus, the loaded wheel testers have all the necessary elements to test for moisture sensitivity: loading, water, temperature extremes, and air voids. Back in 1971, R.P. Lottman (17) recognized the effect that traffic had on accelerating moisture damage. In fact, his study indicated that heavy traffic volume appeared to have a larger impact on stripping than climatic extremes of temperature and precipitation. One problem with applying the loaded wheel testers is the difficulty in discerning between rutting due to plastic flow (unstable mix) and that due to the loss of the adhesive bond (stripping) between the aggregate and asphalt. However, research completed by Terrel (8) has indicated that adhesion is more sensitive to repeated loading (as in the ECS procedure) than to the stiffness/stability of the mix. One approach for discerning between rutting due to instability and rutting due to stripping has been to plot rut depths versus load cycles and then attempt to identify an inflection point.

Three previous studies involving loaded wheel testers and moisture susceptibility were found during the literature review. The Colorado DOT funded a study that compared the results of four stripping tests to mixes of known field performance. The four tests evaluated in that study were the AASHTO T 283, ECS, Boiling Water Test (ASTM D 3625), and the Hamburg Wheel-Tracking Test (1). The study found that after some modification and calibration of the City of Hamburg Germany's specification to Colorado conditions, the results from this wheel-tracking device compared very favorably to the known performance of pavements in Colorado.

The Indiana Department of Transportation sponsored a study involving a loaded wheel tester. For the study (5), Purdue University developed a wheel-tracking device, which they called the PURWheel. The PURWheel and corresponding test method were developed with the concept of creating conditions associated with stripping such as moisture, high temperatures, and traffic loading. The results of this study indicated that the PURWheel had the ability to evaluate both stripping and rutting potential of asphalt mixes.

A third study, sponsored by the Georgia DOT, evaluated the use of the Asphalt Pavement Analyzer (APA) in determining stripping potential. In this study (4), the load cycles from the APA that corresponded to a 5 mm and 7.5 mm rut depth failure criteria were compared and correlated with the TSR from AASHTO T 283 and the equivalent

Georgia DOT test method (GDT-66). One of the conclusions of this study was that it is viable and feasible to use the APA to predict the moisture susceptibility of HMA.

It is evident that other researchers have had success with using loaded wheel testers to determine moisture susceptible mixes. However, researchers have yet to develop a validated and widely accepted test method. This studies attempts to build upon the past research and provide another piece in the development of a test method.

CHAPTER III

PLAN OF STUDY

MATERIALS

The initial intent of the study was to have a range of mixes that could be classified as good, fair, and poor based on the TSR from KT-56 (18) (AASHTO T 283) without any anti-stripping agent being applied. More specifically, the intent was to have two mixes that easily passed KT-56 with a TSR greater than 0.90 (good), two mixes with TSRs in the 0.70-0.85 range (fair), and two mixes with TSRs less than 0.70 (poor). However, in the end, eight different mixes from seven project sites in Kansas were evaluated. Of the eight mixes, two had TSRs greater than 0.90 and six mixes had TSRs between 0.70 and 0.85.

There were two main factors that inhibited the finding of mixes with a TSR below 0.70. The first being the Kansas DOT avoids building projects, whenever possible, with aggregates known to be moisture susceptible. The second factor was the reproducibility of the KT-56 (AASHTO T 283) test. Mixes were identified for testing from District test results. Samples of the aggregates, asphalt cement, anti-strip agent and field mix were then obtained. The KT-56 test procedure was repeated on the sampled materials by the Research section of the Bureau of Materials and Research. The test results were not always reproduced/validated by the Bureau of Materials and Research laboratory. The addition of mixes with low TSRs within the testing plan, less than 0.70, would have been beneficial because it was expected that the APA would definitively single out these mixes. However, as will be shown later in the analysis section, the APA was still able to discern differences between the mixes sampled.

Aggregates and asphalt cement were obtained from each project and samples were compacted at the optimum asphalt content to 7 percent (± 1%) voids total mix (VTM) using a Superpave Gyratory Compactor (SGC). The asphalt cement was either a PG 58-22 or a PG 58-28. Seven of the eight mixes were surface mixes and one was a base mix. Two mixes were Superpave mixes (mix designation S). The Kansas DOT made all of the samples, except for Site 7. The University of Kansas made the Site 7 samples. Table 2 shows the mix designation of the eight mixes and the respective project location and number.

Table 2. Project Locations and Mix Designations.

Location	Project Number	County	Mix Designation	PG Grade	Average VTM(%)
Site 1	96-87 K4459-01	Sedgwick	SM-1T	58-22	7.0
Site 2	27-38 K6555-01	Hamilton	BM-2A	58-28	6.7
Site 3	70 K1803-04	Osage	BM-2	58-22	6.8
Site 4	25-77 K6486	Rawlins	BM-2A	58-28	6.7
Site 5	83-55 K5388-01	Logan	SM-2C	58-28	7.4
Site 6A	24-62 K6977-01	Mitchell	BM-1	58-22	6.6
Site 6B	24-62 K6977-01	Mitchell	BM-1	58-22	6.7
Site 7	36-58 K6955-01	Marshall	BM-1	58-22	7.0

The performance of the asphalt mixes with different additives was an important component of this study. Table 3 shows a summary of the additives evaluated. For Sites 1 through 5, samples were made with four different additives: 1) no additive, 2) with 1% hydrated lime, 3) with various anti-strip liquids, and 4) with the field mix

(FM), which in most cases contained an anti-strip liquid. Sites 6A and 6B samples were made with no additive and with anti-strip liquids. Site 7 samples were made with no additive, with 1% hydrated lime, and with the field mix. In the cases where 1% hydrated lime was added to a mix, the mass of the hydrated lime was included in the total batch mass in accordance with the addendum to KT-56 for "Including Lime as an Antistripping Agent" (18).

Table 3. Additives Tested

Site #	No Additive	1% Hydrated Lime	Anti-Strip Liquids	Field Mix
1	X	X	X	X
2	X	X	X	X
3	X	X	X	X
4	X	X	X	X
5	X	X	X	X
6A	X		X	
6B	X		X	
7	X	X		X

The coarse aggregates in the mixes were blends of either crushed stone, crushed gravel or chat. The fine aggregates in the mixes were natural sand and sand-gravel (SSG) and crushed stone screenings (CS-2). The aggregate blends, producers, and anti-strip additives for each site are listed in Table 4.

ASPHALT PAVEMENT ANALYZER (APA)

The APA is a loaded-wheel test that holds six SGC compacted cylindrical samples (approximately 150 mm x 75 mm) for testing simultaneously. There is no universally accepted test method for performing the APA test. Testing followed the proposed specifications of the Asphalt Pavement Analyzer User Group (19) and Georgia DOT

Table 4. Aggregate Blends and Producers by Site.

DESIGNATION		PRODUCER	BLEND
	Site #1 – SM-1T, *No Additive*		
CS-1A	(Crushed Stone)	Martin-Marietta Moline	22%
CH-1	(Chat)	Bingham	14%
CH-2	(Chat Screenings)	Bingham	48%
SSG	(Natural Sand–Gravel)	Ritchie Sand	16%
	Site #2 – BM-2A, Additive: 0.5% Unichem 8162		
CG-1	(Crushed Gravel)	Eastern Colorado Agg.	13%
CG-5	(Crushed Gravel)	Eastern Colorado Agg.	52%
SSG-1	(Natural Sand-Gravel)	Eastern Colorado Agg.	9%
SSG-2	(Natural Sand-Gravel)	Huber Sand Co.	26%
	Site #3 – BM-2, Additive: 0.5% Ad-Here		
CS-1	(Crushed Stone)	Martin-Marietta Franklin Co.	33%
CS-1A	(Crushed Stone)	Martin-Marietta Franklin Co.	25%
CS-2	(Screenings)	Martin-Marietta Franklin Co.	22%
SSG	(Natural Sand-Gravel)	Penny's Concrete	20%
	Site #4 – BM-2A, Additive: 0.25% Unichem 8162		
CG-1	(Crushed Gravel)	Eastern Colorado Agg.	21%
CG-5	(Crushed Gravel)	Eastern Colorado Agg.	44%
SSG-1	(Natural Sand-Gravel)	Allied, Inc.	35%
	Site #5 – SM-2C, *No Additive*		
CG-1	(Crushed Gravel)	Carder Inc. (Colo.)	22%
CG-2	(Crushed Gravel)	Carder Inc. (Colo.)	33%
CG-3	(Crushed Gravel)	Carder Inc. (Colo.)	29%
SSG-1	(Natural Sand-Gravel)	Huber Sand Co.	10%
	Site #6A – BM-1, Additive: 0.75% Kling Beta 2700		
CS-1	(Crushed Stone)	Hamm Quarries	20%
CS-2	(Screenings)	Hamm Quarries	24%
CS-2A	(Screenings)	Hamm Quarries	31%
SSG	(Natural Sand-Gravel)	Alsop Sand Co.	25%
	Site #6B – BM-1, Additive: 0.75% Kling Beta 2700		
CS-1	(Crushed Stone)	Hamm Quarries	15%
CS-2	(Screenings)	Hamm Quarries	35%
SSG	(Natural Sand-Gravel)	Alsop Sand Co.	40%
SSG-1	(Natural Sand-Gravel)	Alsop Sand Co.	10%
	Site #7 – BM-1, Additive: 0.5% Kling Beta 2700		
CS-1	(Crushed Stone)	Hamm Quarries	19%
CS-2	(Screenings)	Hamm Quarries	22%
CG	(Crushed Gravel)	Blue River Sand	37%
SSG	(Natural Sand-Gravel)	Blue River Sand	22%

Test Method GDT-115, *Method of Test for Determining Rutting Susceptibility Using the Loaded Wheel Tester, Method B (test under water)* (20). GDT-115 Method B recommends AASHTO T 283 preconditioning of samples prior to testing under water. In the APA, rutting is attained in samples by cycling 0.44 kN loaded wheels on rubber hoses that have air pressures of 690 kPa. After an initial zero-reading is made, the APA can be set to cycle as many times as desired. For this study, rut depth measurements were obtained at 500, 1000, 2000, 4000, and 8000 cycles.

The air and water bath temperatures of the APA can be controlled. Air temperatures and water bath temperatures of 40°C were used in this study. Higher test temperatures have been used in other research. However, two of the mixtures in the study were suspected of having high rutting potential and it was thought that rutting would be further exacerbated by KT-56 (AASHTO T 283) conditioning (e.g. vacuum saturation and freezing). It was anticipated that a test temperature above 40°C would lead to rutting above 10 mm after 8000 cycles in some of the samples. Once APA rut depth measurements exceed 10 mm, the loaded wheel can be partially supported by the sample mold, reducing the accuracy of the measurement (21).

When originally developed by the Georgia DOT, a 40°C test temperature was recommended with a 7.5 mm rut depth acceptance limit for determining rutting susceptibility of asphalt mixes (22). However, in recent years test temperatures have risen above 50°C with some users testing at the high pavement performance grade (PG) temperature (21).

TEST PLAN

The test plan encompassed three phases. The primary focus of the study was phase 1 where the objective was to determine the effect of KT-56 (AASHTO T 283) preconditioning on wet and dry rut depths using the APA. In phase 2, the objective was to evaluate the applicability of the APA in predicting moisture susceptibility of asphalt mixes. In phase 3, the objective was to perform an evaluation of liquid anti-strip agents used in Kansas by simple comparisons of APA rut depth data.

Phase 1

Preconditioning

Generally, two samples from each project site and at each preconditioning state were tested in the APA. Four preconditioning states were tested. The first preconditioning state was accomplished by placing the samples in the APA at a chamber temperature of 40°C for four hours prior to running the APA. This is referred to as the ***40°C dry*** condition state. The second preconditioning state was accomplished by soaking the samples in a 40°C water bath for two hours prior to running the APA. In this condition state the samples were tested in the APA while submerged in 40°C water. This condition state is referred to as ***40°C soak***. In the third preconditioning state the samples were vacuum saturated in accordance with KT-56 (AASHTO T 283) and then placed in a 60°C water bath for 24 hours. Next, the samples were placed in the APA water bath at 40°C for two hours and then tested in the APA while submerged in 40°C water. This condition state is referred to as ***40°C saturated***. In the fourth preconditioning state the samples were again vacuum saturated as in the third state, but the freeze cycle of KT-56 (AASHTO T 283) was added. As in the previous two condition states, the samples were placed in the APA water bath for two hours at a temperature of 40°C and then tested submerged in the APA in 40°C water. This condition state is referred to as ***40° C freeze***.

In Phase 1, only samples without additives were evaluated. The purpose was to determine the effect, if any, that the preconditioning states had on the wet and dry APA rut depths. Table 5 shows a summary of the test matrix for phase 1 testing.

Table 5. Test Matrix – Phase 1 Testing.

Site	APA 0.44 kN load, 690 kPa pressure, 8000 cycles			
	Dry 40°C	Soak 40°C	Saturate 40°C	Freeze 40°C
	Number of Samples			
#1	2	2	2	2
#2	1*	2	2	2
#3	2	2	2	2
#4	2	2	2	2
#5	2	2	2	2
#6A	2	2	2	2
#6B	2	2	2	1*
#7	2	2	2	2

*Replicate sample removed due to inconsistent rut depth measurements.

Phase 2

In Phase 2 the objective was to evaluate the applicability of using the APA to predict moisture susceptible mixes. In this phase, APA wet and dry rut depth testing was performed on samples containing hydrated lime and anti-strip liquids. The data from phase 1, containing no additives, were evaluated along with the phase 2 results. Additionally, TSR values, MBVs, S.E. values, and rut ratios for the eight sites were compared to determine if any correlation among these tests existed.

Preconditioning

As discussed in the data analysis section, the results from phase 1 indicated that the 40°C saturated and 40°C freeze condition states did not significantly effect the wet rut depths. Thus, in phase 2 the analysis was performed on the rut depth data from the 40°C dry and 40°C soak preconditioned samples.

Additives

Sites 1 through 5 and Site 7 had samples with 1% hydrated lime added. The lime was incorporated into the mix according to Kansas Test Method KT-56, *Resistance of Compacted Bituminous Mixture to Moisture Induced Damage* (18). In this process the lime is included as part of the total batch mass. The aggregate and hydrated lime is placed in a mixing bowl and water is added to reach a moisture level 3% above the saturated surface dry (SSD) condition. The aggregate and lime mix is thoroughly stirred and then placed in an oven to dry to a constant mass. After pre-heating the asphalt, the required amount is added to the batch and mixed until the aggregate is thoroughly coated. The mixture is then aged and compacted.

Samples from Sites 1 through 6B had various anti-strip liquids incorporated into the mix. In the preparation of these samples the anti-strip liquid was added to the asphalt before mixing with the aggregate. Then the batch was mixed, aged, and compacted.

Field mix (FM) material was acquired from Sites 1 through 5 and Site 7. SGC samples were made with this material by reheating and compacting to 7 percent VTM (±1%). No short-term oven aging was performed on these samples. All FM's contained an anti-strip liquid except Sites 1 and 5. Table 6 below contains a summary of the anti-strip agents incorporated into the samples of the eight project sites. For the most part, two samples were tested for each of the conditioning states, 40°C dry and 40°C soaked.

Table 6. Anti-Strip Agents in Samples – Phase 2 Testing.

Site	APA 0.44 kN load, 690 kPa pressure, 8000 cycles									
	Lime	FM	UltraPave	MorLife	Unichem	Adhere	PBS	Kling-Beta		
								2700	3024	2912
#1	X	X	X	X						
#2	X	X	X		X					
#3	X	X				X	X			
#4	X	X	X		X					
#5	X	X				X		X		
#6A									X	X
#6B								X	X	
#7	X	X								

TSR, Methylene Blue, and Sand Equivalent Testing

The Kansas DOT provided KT-56 TSR values, MBVs, and the SE values for the eight sites (Note: MBVs were not available for Site 7). The tests were performed on samples that did not have any additives (i.e. lime or anti-strip liquids).

Phase 3

The objective of phase 3 was to compare the performance of commonly used anti-strip agents. The APA rut depth results from phase 1 and 2 were used for this phase. The primary focus of this study was the completion of phase 1, therefore available resources did not allow for making and testing additional samples to complete a statistically valid analysis for phase 3. For this phase, simple comparisons of APA rut depths were made on samples containing anti-strip agents. This was performed on a site-by-site basis to prevent mix design (i.e. stability) from being an influence factor.

CHAPTER IV

RESULTS and ANALYSIS

RESULTS

The Kansas DOT completed the MBV tests, the SE tests, and KT-56 (AASHTO T 283) tests on samples from each site. The results are listed in Table 7 below.

Table 7. Material Test Results.

Site and Project Number	TSR (%)	Methylene Blue Value (mg/g)	Sand Equivalent (%)
Site 1, 96-87 K4459-01	82.5	5.5	78.0
Site 2, 27-38 K6555-01	73.5	14.0	79.5
Site 3, 70 K1803-04	84.5	6.5	69.5
Site 4, 25-77 K6486	98.2	29.0	77.0
Site 5, 83-55 K5388-01	92.5	19.5	77.5
Site 6A, 24-62 K6977-01	83.1	8.0	68.0
Site 6B, 24-62 K6977-01	77.2	10.0	61.5
Site 7, 36-58 K6955-01	74.8	*	76.0

*Values not available

The APA rut depth measurements with load cycle for each sample are listed in the appendix. The average maximum rut depths at 8,000 load cycles for the phase 1 samples are shown in Figure 1. During this phase all of the samples were tested without any anti-strip agents in order to determine the effect of the four preconditioning states. The average maximum rut depths for the 40°C freeze conditioning were lower than the 40°C soak conditioning for all eight sites, and the rut depths for the 40°C saturated conditioning were lower than the 40°C soak conditioning for all sites except Site 2.

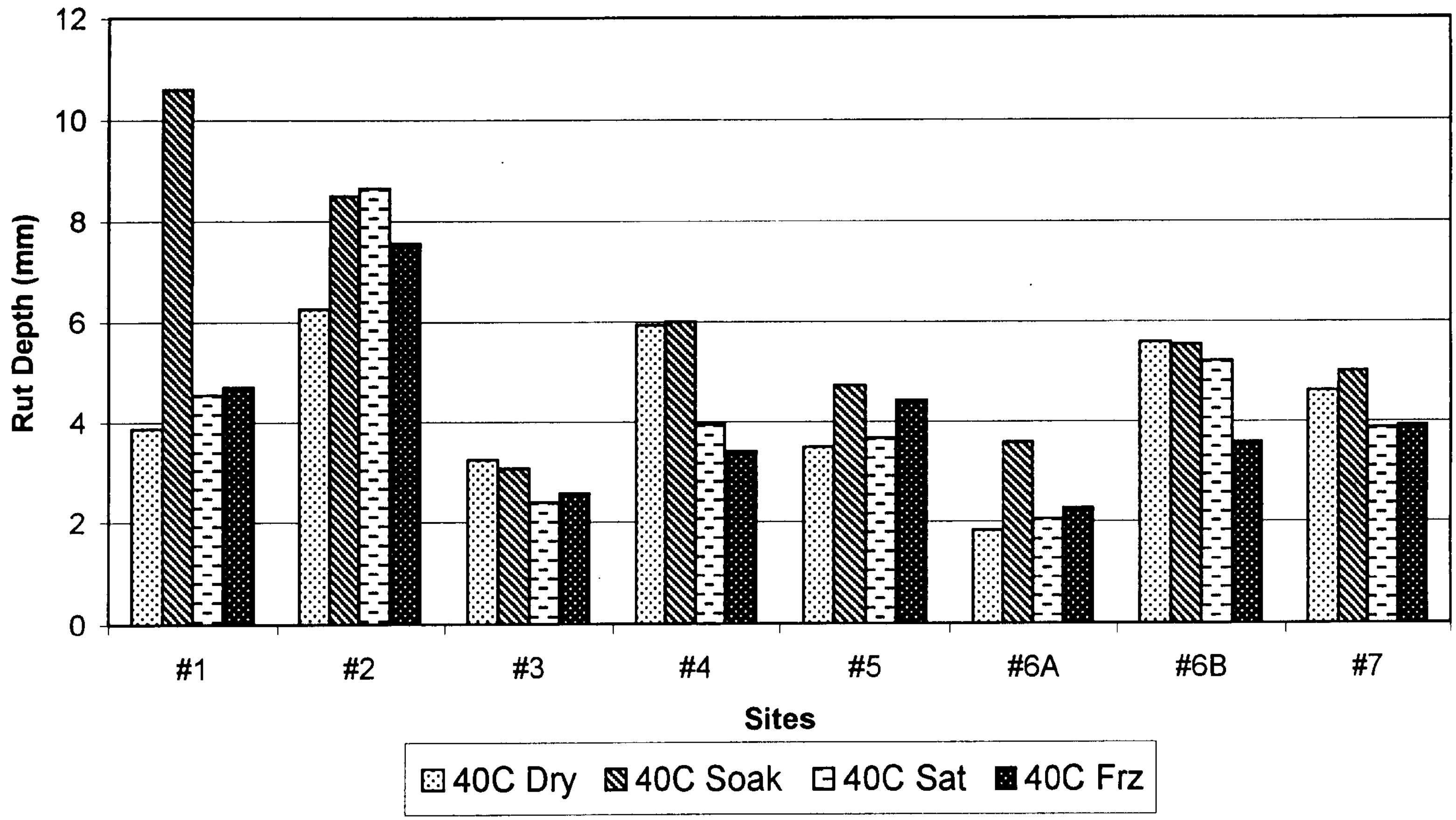

Figure 1. Phase 1 Rut Depth Averages

The results from phase 2 (the average rut depth for samples with and without anti-strip agents) and the results from phase 3 (the performance by site of the anti-strip liquids) are shown in their respective sections.

DATA ANALYSIS

After the testing in the APA was complete, the rutting data was entered in a spreadsheet and was analyzed. As mentioned previously, the major focus of this study was phase 1 and in this phase the rut depths at 8000 cycles were the crucial data elements. This rut depth data was analyzed using a two-way analysis of variance (ANOVA) in which rut depth was the response variable (or Y variable) and project site and preconditioning state were the two effects (or X variables). Additionally, two multiple comparison procedures, the Tukey-Kramer and Student's t methods, were used to determine the statistically significant differences between the various groups.

The Tukey-Kramer method is an adjustment of the Student's t method. The Tukey-Kramer method can be a very exact multiple comparison test if the sample sizes are the same, but it is known to be conservative if the sample sizes are different (23). In this study a few observations/samples were lost due to experimental mishaps and replacement samples were not available. However, as long as the balance between samples is fairly well maintained, it is still satisfactory to employ the Tukey method (24). When using the Student's t method, the chance of a Type I error occurring, declaring something significant that is not, increases as the number of comparisons increases. The Tukey-Kramer method avoids Type I errors by better controlling the overall error rate and this translates into larger least significant differences (LSD) being computed (23). Both the Student's t and Tukey-Kramer methods were employed in an attempt to draw the most appropriate conclusions.

The phase 2 data analysis involved simple comparisons of test results using bar charts, plots of rut depths versus load cycles, and determination of the slope of the rutting curves. Comparisons of TSR values, MBVs, S.E. values, rut depths, and rut ratios were completed. Rut ratio is defined by the following equation:

$$\text{Rut ratio} = \frac{\text{Rut Depth at Condition State X}}{\text{Rut Depth at Dry } 40^{\circ}\text{C}} \qquad [1]$$

As discussed earlier, the phase 3 analysis involved simple comparisons of rut depth data for samples with anti strip agents.

PHASE 1

A two-way ANOVA was performed on the rut depth data using the four preconditioning states. The results, shown in Table 8 below, clearly show that the rut depth variation was due to the effects of the whole model as opposed to chance. The F ratio for the whole model was 25.42 and the probability of a greater F value occurring, if the variation of the rut depth resulted from chance alone, was less than 0.0001 (Prob.>F). The results also showed that the full factorial of effects, project site, preconditioning, and project site×conditioning all had significant effects upon the variation of the rut depth.

Table 8. Analysis of Variance Results.

Source	Degrees Freedom	Sum Squares	Mean Square	F Ratio	Prob. >F
Site	7	160.58	22.94	74.0	0.0001
Preconditioning	3	30.90	10.30	33.2	0.0001
Site * Preconditioning	21	55.13	2.62	8.4	0.0001
Error	30	9.39	0.31		
Total	61	256.00			

The Tukey-Kramer and Student's t multiple comparison procedures were completed on the means of the main effects of site and preconditioning state. Multiple comparison procedures compare the actual difference between group means with the difference that would be significantly different (23). The difference needed for statistical significance is called the least significant difference (LSD). The results of this comparison test on the sites are shown in Table 9. The results indicate that among the eight sites there are four groupings (A thru D) where significantly different rut depths exist. This indicates that there is a sufficient spread in the rutting performance of the mixes.

Table 9. Comparison of Group Means by Site, Tukey-Kramer Test.

Grouping*	Mean Rut Depth (mm)	Site
A	7.95	Site 2
A & B	5.93	Site 1
B	5.17	Site 6B
B & C	4.83	Site 4
B, C, & D	4.36	Site 7
B, C, & D	4.08	Site 5
C & D	2.83	Site 3
D	2.44	Site 6A

* Means with the same letter not significantly different.

As shown in Table 10, the results of the comparison procedures on the conditioning states clearly indicated that the means of the 40°C dry, 40°C saturated, and 40°C freeze condition states were not significantly different. This result was somewhat unexpected. It means that the KT-56 (AASHTO T 283) preconditioning had little effect upon the rutting results. The 40°C soak preconditioning had the greatest rut depth followed by the 40°C saturated, then 40°C dry, and then 40°C freeze, which had the least amount of rutting.

Table 10. Means for One-way ANOVA – Phase 1

Preconditioning	# of Observations	Mean	Std. Error	Grouping*
40°C Dry	15	4.23	0.50567	A
40°C Freeze	15	4.09	0.50567	B
40°C Saturate	16	4.29	0.48961	B
40°C Soak	16	5.88	0.48961	B

*Means with the same letter are not significantly different.

Figure 2 shows the results of the multiple comparison tests using comparison circles. The Tukey-Kramer procedure, at a 95% confidence limit (alpha = 0.05), indicated that the 40°C soak conditioning was borderline significantly different from the other three conditioning states. However, the Student's t test, also at a 95% confidence limit, showed that the 40°C soak conditioning was significantly different. The F test on the four conditioning states also indicated that there was a significant difference (Prob >F = 0.042). Consequently, it can be concluded that the 40°C soak conditioning state had rut depths that were significantly different than the other three conditioning states at a 95% confidence limit.

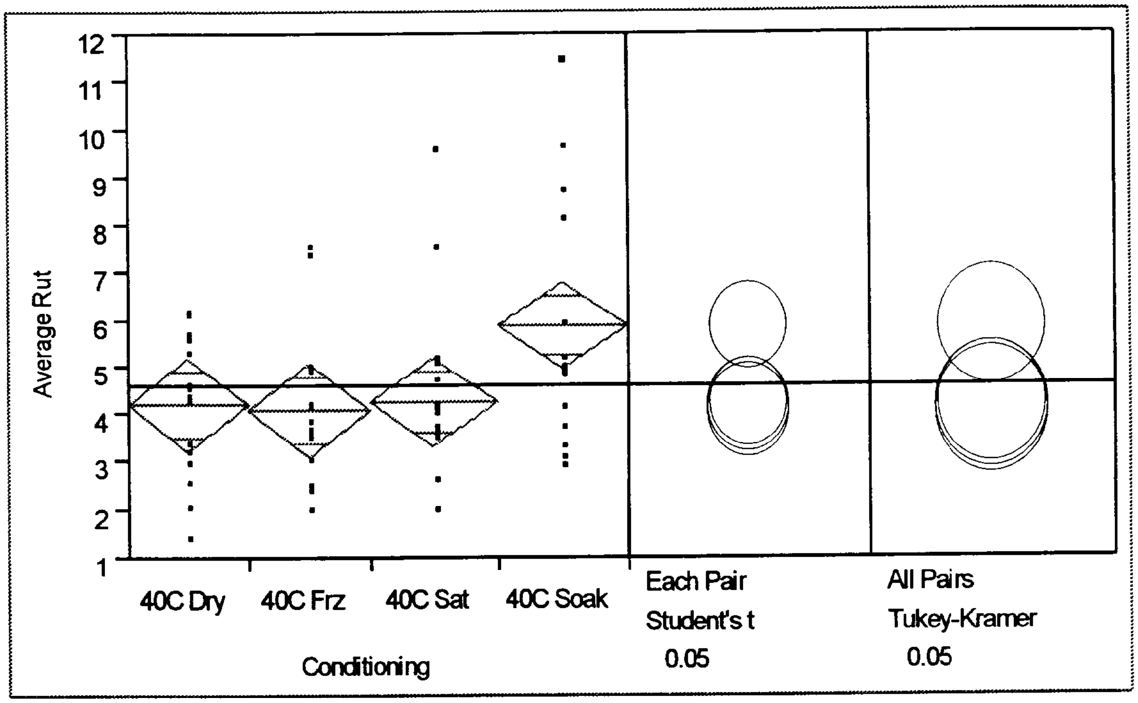

Figure 2. Comparison of Group Means – Phase 1

Looking at the rut depth results by individual sites (Figure 1) gave additional support to the above comparison results. The rut depths for the soak conditioning were greater than the freeze conditioning on all eight sites and they were greater than the saturated conditioning for seven of the eight sites.

Because the KT-56 (AASHTO T 283) preconditioned samples had smaller rut depths than samples that were just soaked, the percent saturation of the samples were evaluated on the available samples. The saturation levels of the vacuum saturated samples were compared to the percent saturation of the soaked samples. The average percent saturation of nine individual 40°C soaked samples was 6.5% with a range of saturation from 4.6% to 9.3%. The vacuum saturated samples had an average saturation of 64%. With this large difference in saturation levels, one hypothesis for the difference in rutting may be due to increased pore water pressure in the vacuum saturated samples. The measured percent saturation is an average percent saturation of the sample and would not be uniform throughout the sample. The inner pores of the sample would have lower saturation levels with the outer pores nearing 100% saturation. With the external pores near complete saturation, pore water pressures could develop that act as a resistance to the wheel load. It could also be possible that the saturation level of KT-56 (AASHTO T 283) is not high enough to sufficiently condition/damage the sample. Aschenbrener, et al. (1), indicated that by using a 90% saturation level it was possible to accurately identify mixtures that were marginally susceptible to moisture damage. According to the TSRs in this study, most of the mixtures were in the marginal range of moisture susceptibility.

Another potential hypothesis was that the differences in the age of the samples when APA testing was completed could have added some bias to the study because oxidation and aging increases the stiffness of the asphalt binder. However, most of the samples within each site were tested within 30 days of each other. There were two sites where samples with KT-56 (AASHTO T 283) preconditioning were tested 77 days and 103 days, respectively, after the samples with soaked preconditioning were tested. On the other hand, there was one site when samples with KT-56 (AASHTO T 283) preconditioning were tested 31 days before samples with soaked conditioning were tested. Thus, this hypothesis can be discounted. Additionally, significant differences in rheology and stiffness of asphalts are generally discussed in terms of years, not months.

A recent study funded by the Southeast Asphalt User/Producer Group (21) discussed factors that may contribute to variability in the APA rutting test, but the study did not include specimen age. The study investigated the following six factors:

1. Air void contents of the test specimens.
2. The test temperature.
3. Specimen preheating time.
4. Wheel load.
5. Hose pressure.
6. Specimen compaction method.

The User/Producer Group study suggested that the allowable range for air void content of ± 1% should be reduced to ± 0.5%. The air void contents of the samples tested were 7% ± 1%. As a result this could have led to some variability in the results. However, factors 2 through 6 were the same for all samples, and most of the samples had air void ranges of ± 0.5%. Thus, the air void content variability was probably not a significant factor in the results or trends of this study.

The results from phase 1 indicate that the saturated and freeze preconditioning from KT-56 (AASHTO T 283) does not adversely affect APA wet rut depths. In fact, it is possible that pore water pressure was created during the wet rut testing due to the vacuum saturated preconditioning of the samples and this pore pressure could have provided some resistance to rutting. Conversely, the soaked preconditioning did exhibit significantly greater rut depths than the other three preconditioning states. Thus, testing samples with dry and soak conditioning may be all that is necessary for developing a test method for predicting moisture susceptibility with the APA.

PHASE 2

In phase 2 the objective was to evaluate the applicability of using the APA to predict moisture susceptibility of asphalt mixes. In addition to using the rut depth data from phase 1, rut depths from samples with hydrated lime and liquid anti strip agents added to the mix were included. Rut depth data from field mixes were also evaluated. Due to the results from phase 1, only APA rut depths from samples with dry and soak conditioning were evaluated.

Correlation and Threshold Analysis

A correlation analysis was performed with the TSR values, MBVs, S.E. values, and the rut depth data from phase 1. As discussed previously, the TSR value generated by AASHTO T 283 (KT-56) is the current SHRP recommended measure for moisture susceptibility. In Europe, the MBV and S.E. tests are widely used to evaluate moisture susceptibility and some agencies in the USA are now using or considering these tests (3). Therefore, the MBV and S.E. test results were included in the correlation analysis. The rut ratio, as defined by equation [1], was also included. It was postulated that the rut ratio, which is the increase in rut depth from the dry conditioning state to the soaked conditioning state, might be an indication of moisture susceptibility.

Table 11 presents the results of the six different test measures and ranks the sites (1 thru 8) from best to worst for each of the particular measures. The ranking is shown in parentheses below the value of the test result.

Table 11. Comparison and Ranking of Test Results.

Measure	Results by Project Site*							
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6A	Site 6B	Site 7
TSR (%) (w/o additive)	82.5 (5)	73.5 (8)	84.5 (3)	98.2 (1)	92.5 (2)	83.1 (4)	77.2 (6)	74.7 (7)
MBV (mg/g)	5.5 (1)	14.5 (5)	6.5 (2)	29.0 (7)	19.5 (6)	8.0 (3)	10.0 (4)	N/A
S.E. (%)	78.0 (2)	79.5 (1)	69.5 (6)	77.0 (4)	77.5 (3)	68.0 (7)	61.5 (8)	76.0 (5)
Dry Rut Depth (mm)	3.88 (4)	6.25 (8)	3.25 (2)	5.93 (7)	3.50 (3)	1.83 (1)	5.58 (6)	4.63 (5)
Soak Rut Depth (mm)	10.6 (8)	8.5 (7)	3.1 (1)	6.0 (6)	4.7 (3)	3.6 (2)	5.5 (5)	5.0 (4)
Rut Depth Ratio	2.70 (8)	1.36 (6)	0.95 (1)	1.01 (3)	1.35 (5)	1.97 (7)	0.99 (2)	1.08 (4)

*The number in parentheses represents the ranking of the site with the particular test.

As is evident from Table 11, the APA rut depth results were not able to rank the sites in the same order as the TSR from KT-56 (AASHTO T 283). However, KT-56 (AASHTO T 283) is not infallible either. Figure 3 shows the soaked and dry maximum rut depths and their corresponding TSRs. All sites with TSR values less than 80% had soaked rut depths greater than 5.00 mm. Two sites with TSR values above 80%, Sites 1 (TSR = 82.5) and 4 (TSR = 98.2), had soaked rut depths greater than 5.00 mm as well. Site 4 was unstable with a dry rut depth of 5.93 mm and should not be used. Site 1 had a TSR of 82%, but a wet rut depth of 10.6 mm and a rut depth ratio of 2.7, indicating moisture damage potential. Site 1 contained 62% chat, which is a waste product of nearly pure chert from the lead and zinc mines of the tri-state region of Missouri, Kansas and Oklahoma. Chert is a highly siliceous aggregate with a history of moisture sensitivity. The APA indicated the high moisture damage potential for this mix, whereas KT-56 (AASHTO T 283) indicates the mix is acceptable. A threshold

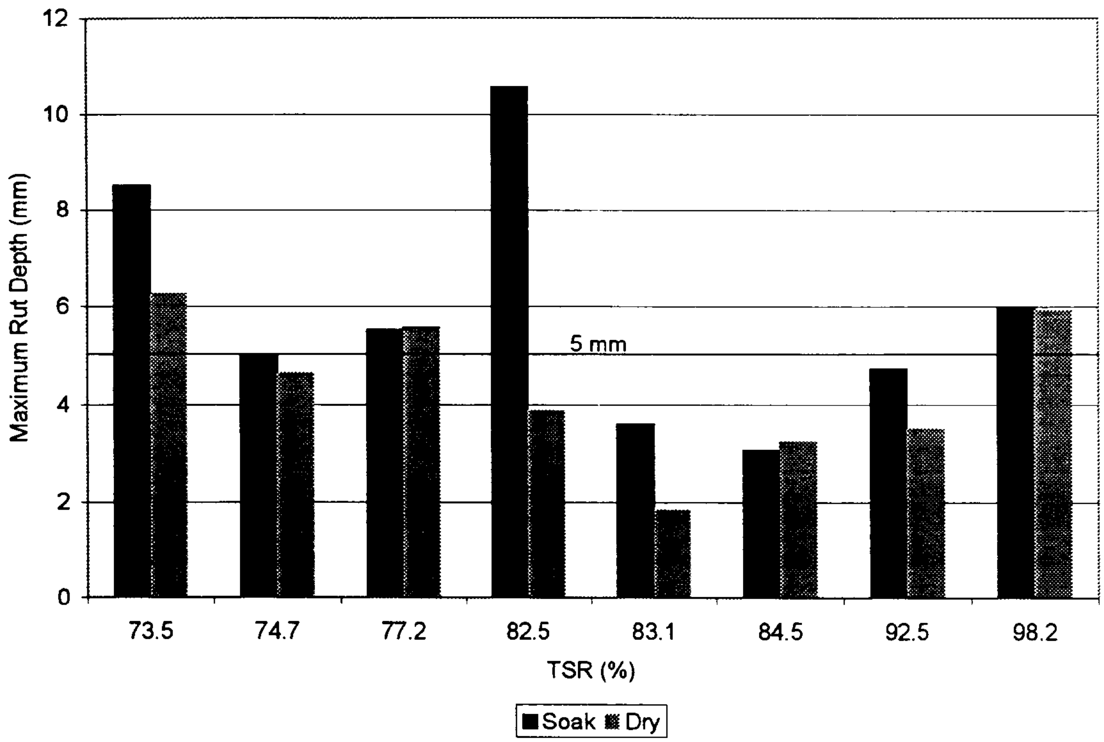

Figure 3. APA Rut Depths vs. TSR

value of 5.00 mm for 40°C soaked preconditioning seems to differentiate between mixes with low TSR's (< 80%) and mix instability from those with satisfactory TSRs.

Table 12 contains the correlation coefficients between the six moisture sensitivity measures. The correlation coefficients are a measure, on a scale of −1 to 1, of how close two variables (such as test methods) are to being linearly related. The coefficients listed in Table 12 are poor, generally less than 0.5. It is important to note that a negative coefficient means the two variables are closer to being inversely related than linearly related. An inverse relationship is appropriate in cases where one variable with an increasing value indicates improved performance and another variable with decreasing value indicates improved performance. For instance, as soak rut depths increase the TSR values should decrease. From reviewing the coefficients of Table 12, it becomes apparent that there are no significant correlations between the test methods. In many cases, the relationship between two variables has the wrong sign from the expected trend (i.e. TSR versus MBV). The correlation between the 40°C soak rut depth and the rut ratio was the only pair with a coefficient above 0.5 with the appropriate sign.

Table 12. Results of Correlation Analysis*

TEST	TSR	MBV	SE	40°C Dry	40°C Soak	Rut Ratio
TSR	1.000	0.704	0.197	-0.145	-0.209	-0.064
MBV	0.704	1.000	0.421	0.495	-0.057	-0.462
SE	0.197	0.421	1.000	0.232	0.524	0.252
40°C Dry	-0.145	0.495	0.232	1.000	0.450	-0.428
40°C Soak	-0.209	-0.057	0.524	0.450	1.000	0.594
Rut Ratio	-0.064	-0.462	0.252	-0.428	0.594	1.000

*TSR values from Site 7 were not available.

The MBV test measures the amount of potentially detrimental fines in the aggregate. Other researchers have found good correlation between MBVs, TSRs, and actual pavement performance (3, 15). Aschenbrener and Zamora (3) developed the relationship shown in Table 13 between MBVs and pavement performance.

The MBV results in this study did not compare favorably with the TSR values. As shown in Table 11, Sites 4 and 5 had the highest TSR values, but these sites also had the two highest MBVs, both in the failing range. The MBV results also did not

Table 13. Relationship of MBV and Anticipated Pavement Performance (3).

MBV (mg/g)	Expected Performance
1 – 10	Excellent
11 – 15	Marginally Acceptable
16 – 20	Problems or Possible Failure
20+	Failure

correlate with the 40°C soak rut depths. The comparisons of the SE values also did not produce any valuable trends. Of the three sites that had TSRs below 80%, all of them had passing SE values. In fact, all of the sites had SE values that easily passed the clay content criteria. The minimum SE value is usually dependent upon traffic and generally varies from 40 to 50.

Additive Comparisons

The phase 2 analysis also compared and evaluated the APA rut depths from samples with lime, anti-strip liquids, and samples made from the field mixes, to the results of the APA rut depths from phase 1. Again, an ANOVA and multiple comparison procedures were performed on the data. The results indicated that the APA was able to detect the influence of liquid anti-strip agents. A three-way ANOVA with site, additive, and preconditioning as the effect variables was completed on Sites 1 to 5 (the only sites where samples with lime and liquid anti-strip were available). Table 14 shows the results of the ANOVA and they indicate that the full factorial of effects all had significant effects on measured rut depths.

Table 14. Phase 2 ANOVA, Sites 1 through 5

Source	DF	Sum of Squares	F Ratio	Prob>F
Site	4	146.33	78.80	<.0001
Additive	2	43.46	46.80	<.0001
Site*Additive	8	43.30	11.66	<.0001
Preconditioning	1	31.58	68.01	<.0001
Site*Preconditioning	4	56.49	30.42	<.0001
Additive*Preconditioning	2	10.76	11.59	<.0001
Site*Additive*Preconditioning	8	30.01	8.08	<.0001
Error	46	21.36		
Total	75	382.29		

Multiple comparison procedures were completed on the additives of hydrated lime, liquid anti-strip and no additive to determine which means were significantly different. The results for the Tukey-Kramer and Student's t test are shown in Tables 15 and 16 and Figure 4. The mean rutting for the samples with liquid anti-strip was 3.84 mm while the means for samples with and without hydrated lime was 5.13 mm and 5.53 mm, respectively. The Student's t and Tukey-Kramer procedures both showed that the samples with anti-strip liquid had significantly different means than the samples without lime.

Unexpectedly, the Tukey-Kramer and Student's t results indicated that there was not a significant difference in rut depths between samples with hydrated lime added and those without. The average rut depth for samples with lime was 5.13 mm and the average rut depth for samples without lime was 5.53 mm. The samples, essentially, were behaving as if no lime had been added. Because lime is a proven anti-strip agent, the APA is either unsuitable for predicting moisture susceptibility or there is some other

Table 15. Comparisons for Each Pair Using Student's t

Abs(Dif)-LSD*	w/o Lime	Lime	Anti-strip liquids
w/o Lime	-1.34101	-0.95585	0.53296
Lime	-0.95585	-1.37776	0.10791
Anti-strip liquids	0.53296	0.10791	-0.93600

*Positive values show pairs of means that are significantly different.

Table 16. Comparisons for All Pairs Using Tukey-Kramer

Abs(Dif)-LSD*	w/o Lime	Lime	Anti-strip liquids
w/o Lime	-1.60978	-1.22833	0.30120
Lime	-1.22833	-1.65389	-0.12815
Anti-strip liquids	0.30120	-0.12815	-1.12360

*Positive values show pairs of means that are significantly different.

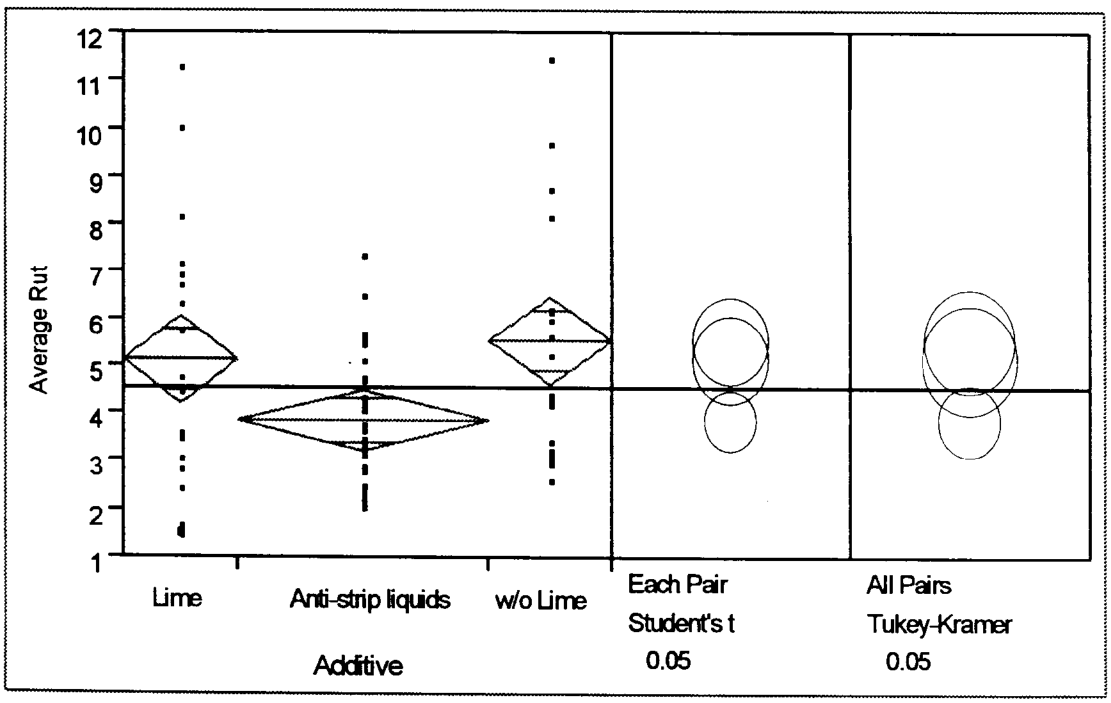

Figure 4. Comparison of Group Means – by Additive

interaction occurring that makes the samples with lime undetectable. It is well documented that hydrated lime mixed with asphalt will generally reduce oxidation and decrease the viscosity of the asphalt (25). This "reduced stiffness" possibly offset the effect of improved aggregate-asphalt bonding. However, the result that lime was not distinguishable is probably related more to the fact that all of the mixes, according to the TSRs, were in the fair to good range of KT-56 (AASHTO T 283).

Despite the lack of discernment between samples with and without lime, the APA was able to differentiate between the rut depths from the field mixes (FM), most of which had an anti-strip liquid added, and those samples with and without lime. As shown in Table 17, the FM samples exhibited the smallest amount of rutting as compared to samples with and without lime, and samples with liquid anti-strip. This result was expected because plant produced asphalt is known to be stiffer than laboratory produced mix. The average rut depth for the FM samples was 2.51 mm, which was significantly different from samples with and without lime, according to both the Tukey-Kramer and Student's t procedures.

Table 17. APA Rut Depth Means for the Additives

Additive	Number of Observations	Mean (mm)
w/o Lime	19	5.53
Lime	18	5.13
Anti-strip liquids	39	3.84
FM	18	2.51

In summary, the APA was able to distinguish samples with anti-strip liquid and samples made from the field mix. However, it is puzzling that the APA could not distinguish the effect of lime being added to the mix. The age of the hydrated lime used to make the samples is unknown. If the hydrated lime was old then the lime could have carbonated and would be non-reactive.

A recent study by Lesueur and Little (26) indicated that in order for hydrated lime to be an effective additive, it must be compatible with the compositional and elemental characteristics of the bitumen. Additionally, other research has shown that mixing lime with asphalt will result in decreased viscosity and improved age hardening characteristics (25). Thus, numerous extraneous factors could have effected the rutting of the samples with lime.

Mixture Evaluation

The next step in the phase 2 analysis was to evaluate rut depths by site and to evaluate the rate of increase of rutting as the number of cycles increased for the conditioning states of dry and soak and all four additives (lime, without lime, anti-strip liquids, and field mix). Figures 4 to 11 are bar charts that differentiate the rut depths by conditioning and additives on a site-by-site basis. At 40°C, a soaked rut depth of 5.0 mm was previously identified as a threshold value for low TSR and a 5.0 mm maximum dry rut depth has been used as a criteria for strength/stability. These rut depth criteria were used to evaluate the eight sites from this research project.

Site 1: The APA indicates this mix is susceptible to moisture damage (Figure 5). The rut depth for dry conditioning is below 5.0 mm. However, the rut depths of the soak conditioning increased by 6.7 mm to 10.6 mm for a rut ratio of 2.7. Thus, according to the above criteria, this mix has a potential to strip.

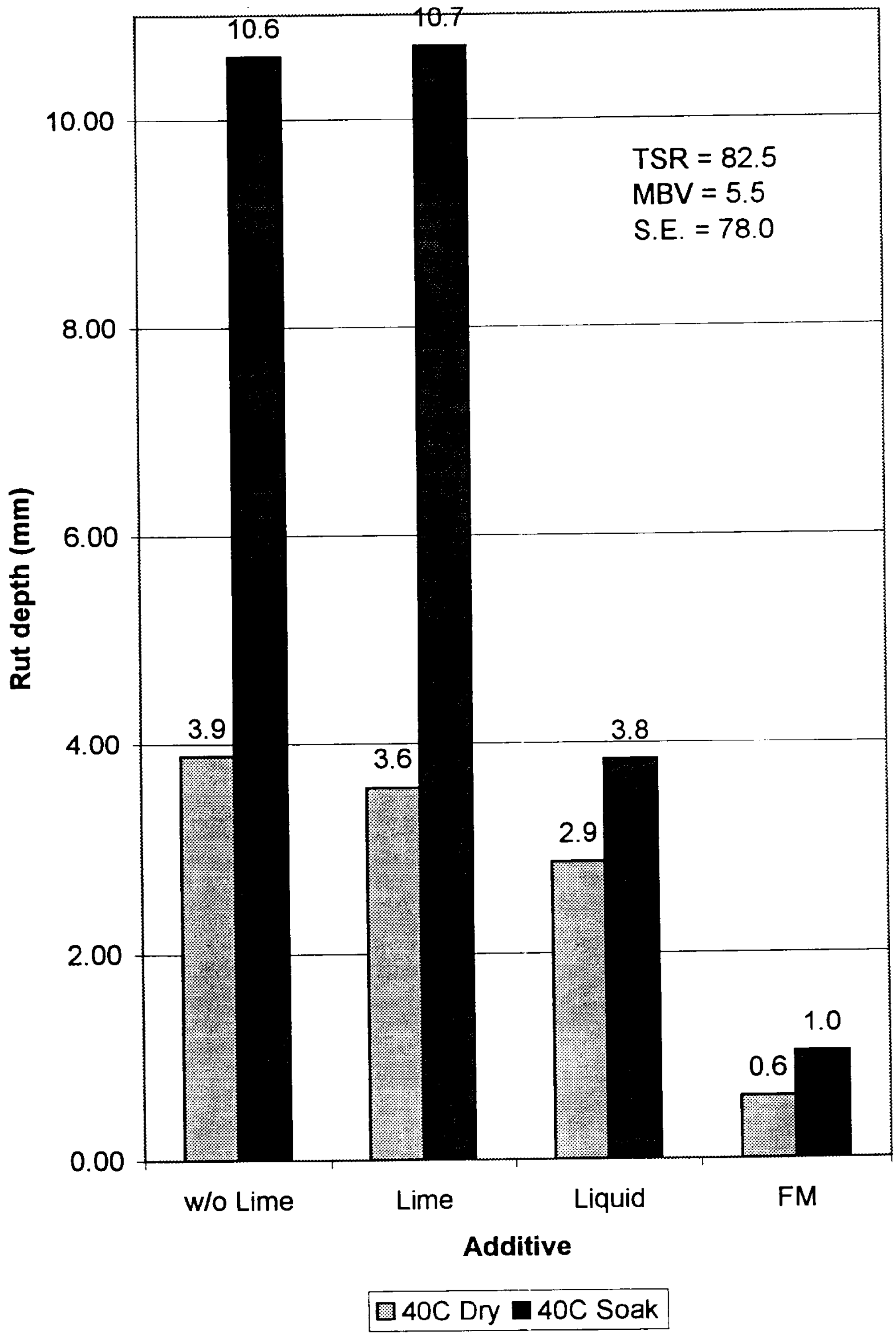

Figure 5. Rut Depth Comparison – Site 1

Additional support for this conclusion comes from the APA test results on samples that had anti-strip liquid added to the mix. The rut depths of the soak conditioning with these samples were notably reduced. As shown in Table 2, the aggregate in this mix consisted of 62% mine chat from northeastern Oklahoma. This is an exceptionally hard aggregate of nearly pure chert, which has a known history of moisture susceptibility. KT-56 (AASHTO T 283) indicated this mix was acceptable with a TSR of 82.5%.

Site 2: As shown in Figure 6, the soaked rut depth was 8.5 mm indicating a moisture susceptible mix. KT-56 (AASHTO T 283) confirms this with a TSR of 79.5 %. The rut depth for dry conditioning was 6.25 mm, which indicates that this mix is unstable as well. The increase in rut depth from the dry to the soak condition was 2.25 mm. Although this increase is not as predominant as in Site 1, it still would indicate that this mix is susceptible to stripping. The MBV of 14.5 also supports this conclusion.

Site 3: Figure 7 shows the rut depth results from Site 3. The rut depth for dry conditioning was 3.25 mm and the rut depth for soak conditioning shows little to no change from the dry condition. The APA indicates the mix should perform well. The TSR and MBV indicate no potential for moisture damage.

Site 4: Figure 8 shows the results for Site 4. The rut depth for dry conditioning was 5.93 mm, which indicates that this mix is unstable. The soaked rut depth

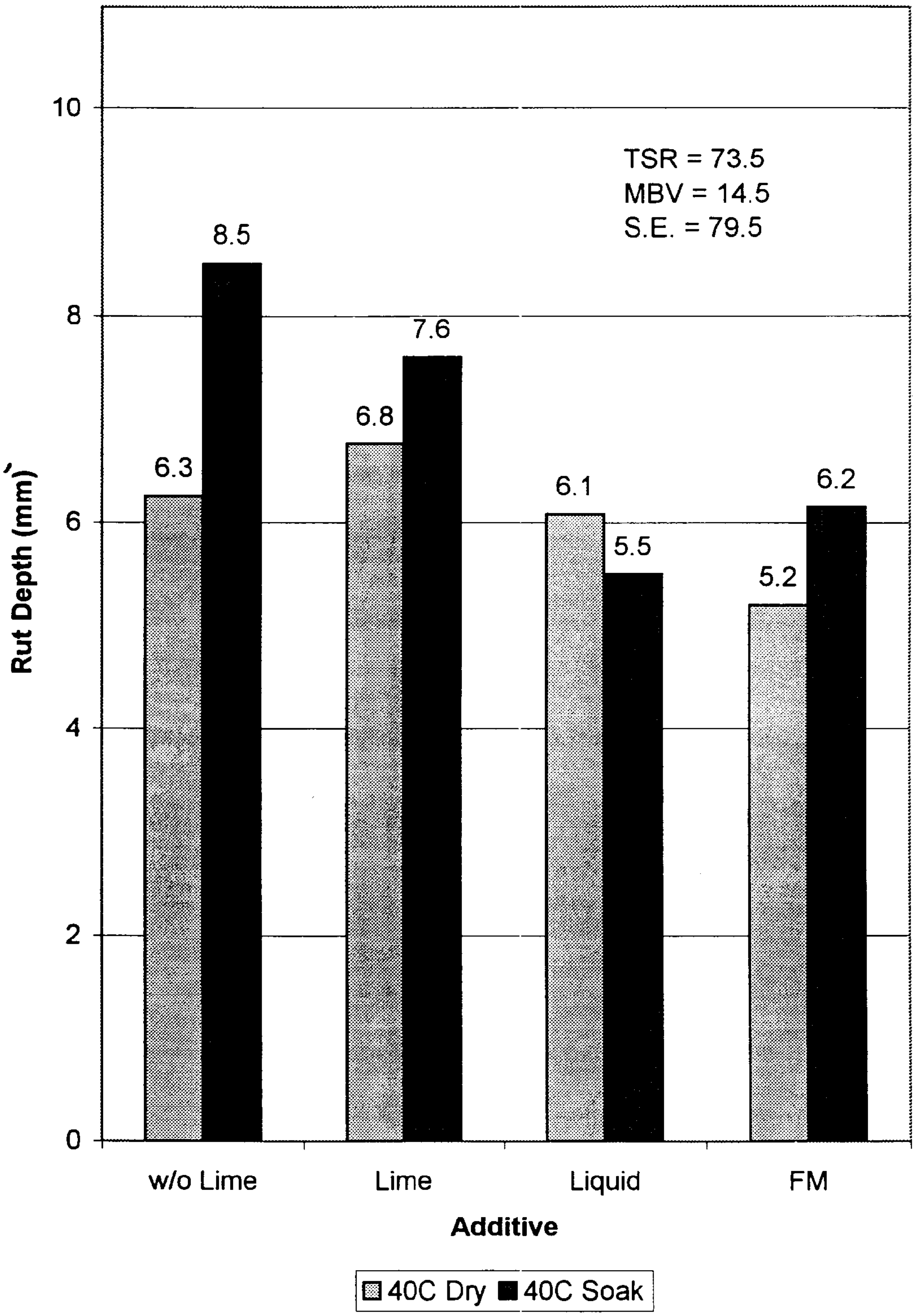

Figure 6. Rut Depth Comparison – Site 2.

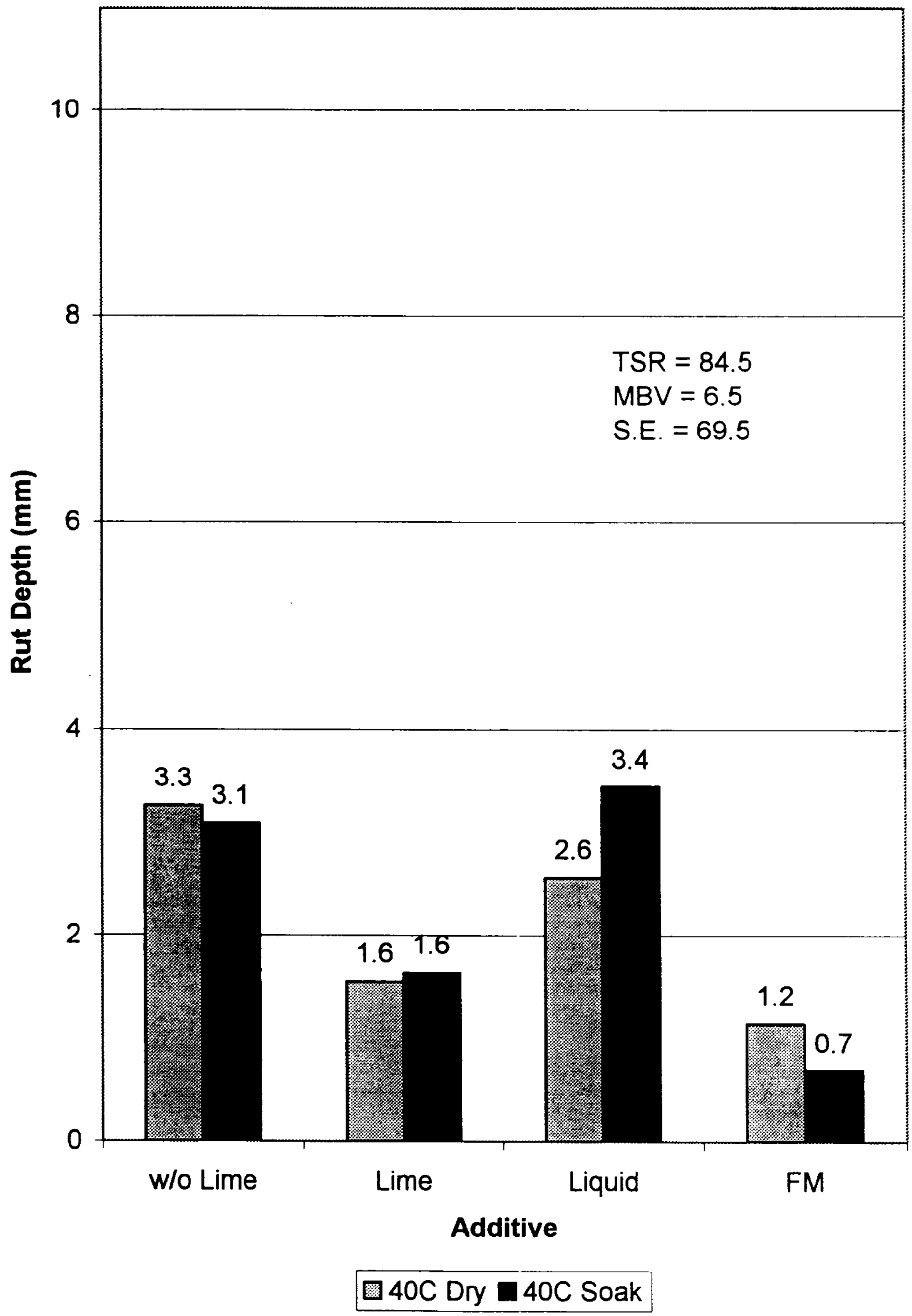

Figure 7. Rut Depth Comparison – Site 3.

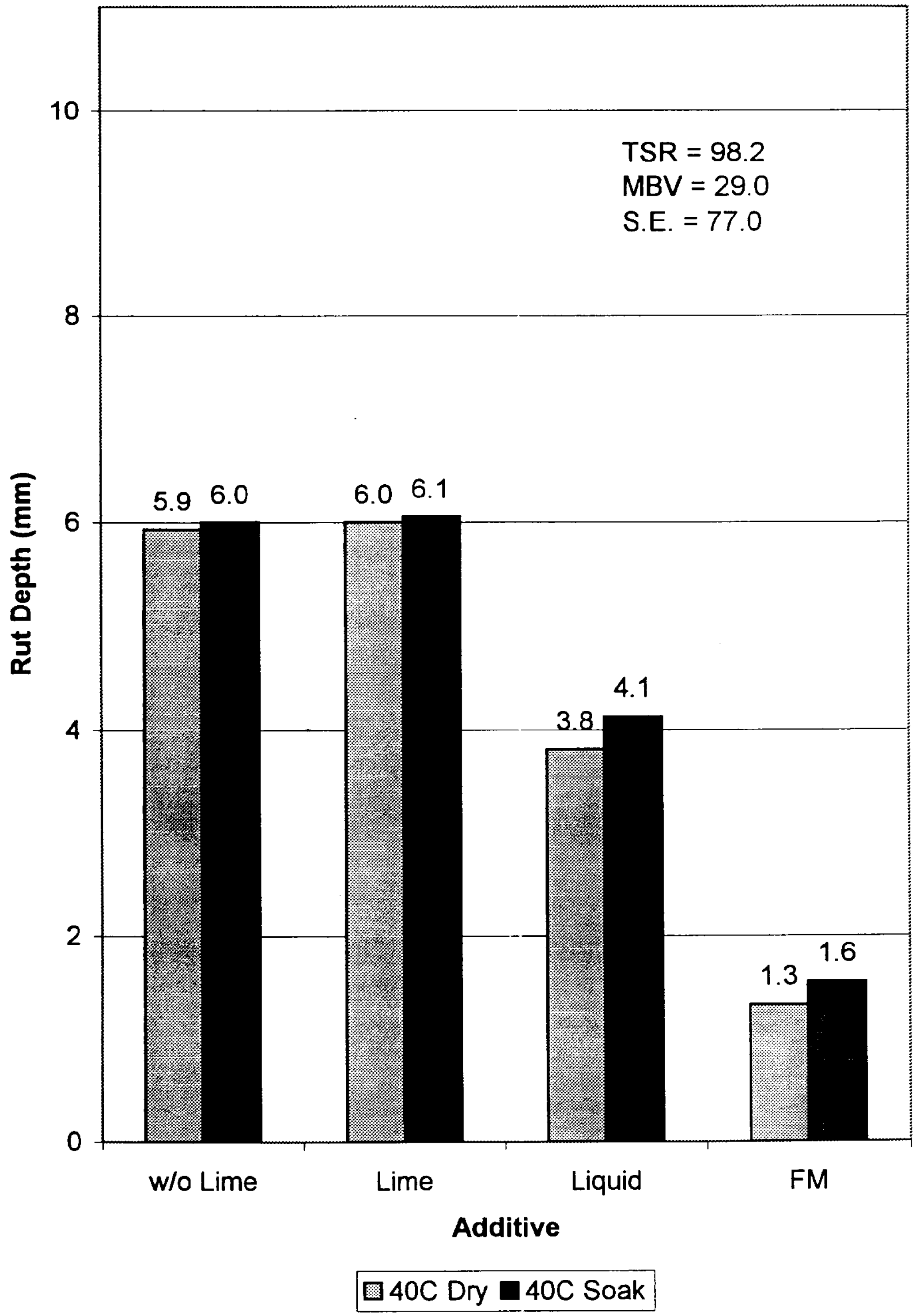

Figure 8. Rut Depth Comparison – Site 4.

was above 5.0 mm, indicating a moisture susceptible mix. However, there was no increase in the rut depth with the soak conditioning compared to the dry. This lack of an increase in rutting could be an indication that the aggregates are not prone to moisture damage. The KT-56 (AASHTOT 283) data indicates this mix is not susceptible to moisture damage. The MBV is in the failure range according to Aschenbrenner (3). The liquid anti-strip reduced the rut depths to the acceptable range, which could indicate the mix is prone to moisture damage. The APA indicated this fact as well.

<u>Site 5</u>: The results from Site 5 are shown in Figure 9. The rut depth for dry conditioning was 3.50 mm. The rut depth for soak conditioning did increase 1.23 mm, but this was still slightly below the threshold value of 5.00 mm. The results from KT-56 (AASHTO T 283) indicate this mix would not be prone to moisture damage. The MBV for this site was 19.5, which, according to Aschenbrener (3) in Table 13, would indicate failure. The APA data agrees more closely with the MBV, indicating a marginally acceptable mix.

<u>Site 6A</u>: As shown in Figure 10, this mix should perform satisfactorily. The rut depth for dry conditioning was 1.83 mm, which is excellent. The rut depth of the soaked conditioning increased to 3.60 mm, which is nearly a 100% increase (rut ratio = 1.97) but is still well below the threshold of 5.0 mm. The KT-56 (AASHTO T 283) TSR value was acceptable as well. As far as stripping potential, this could be a borderline site. The soak conditioning rut depths were

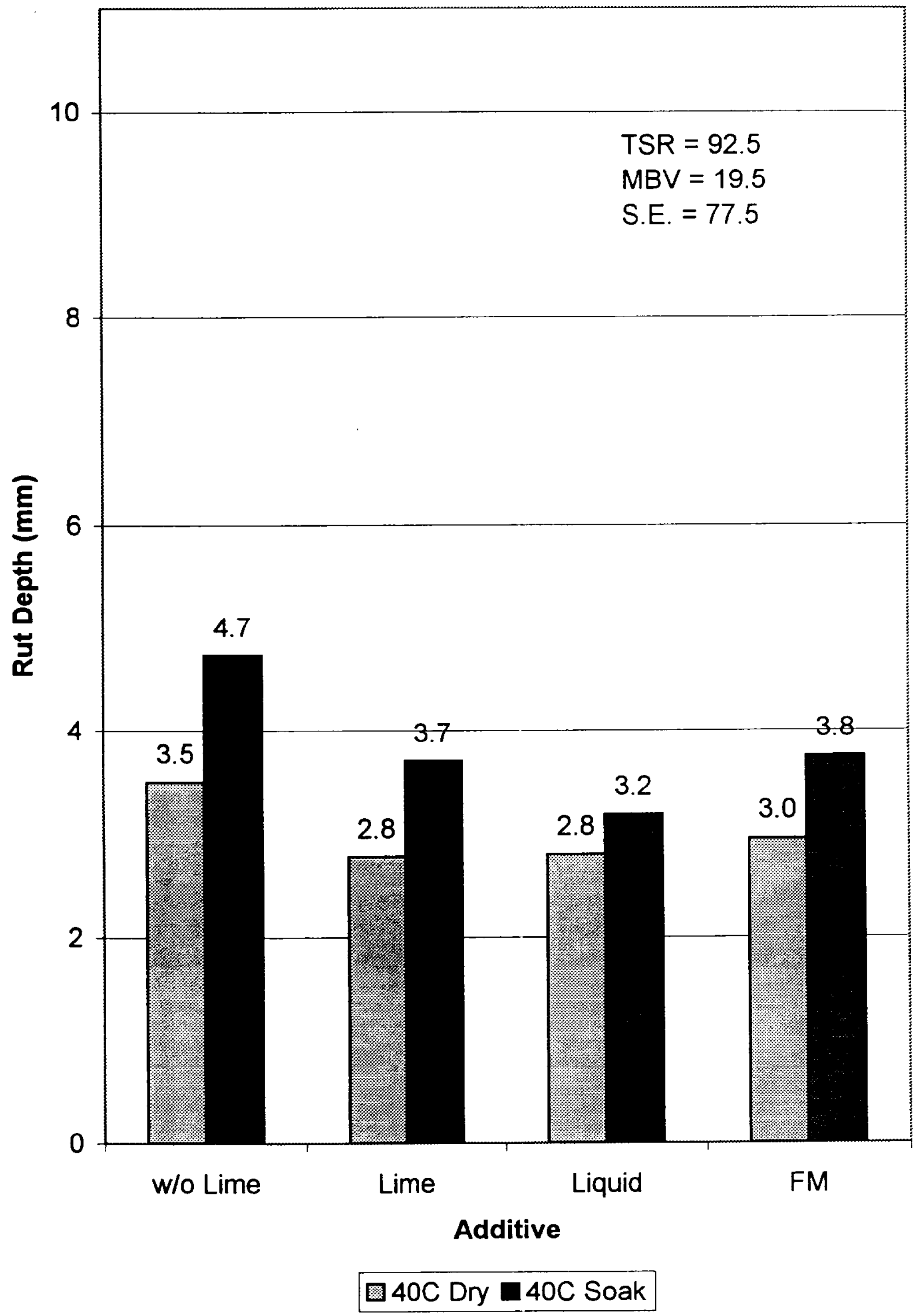

Figure 9. Rut Depth Comparison – Site 5.

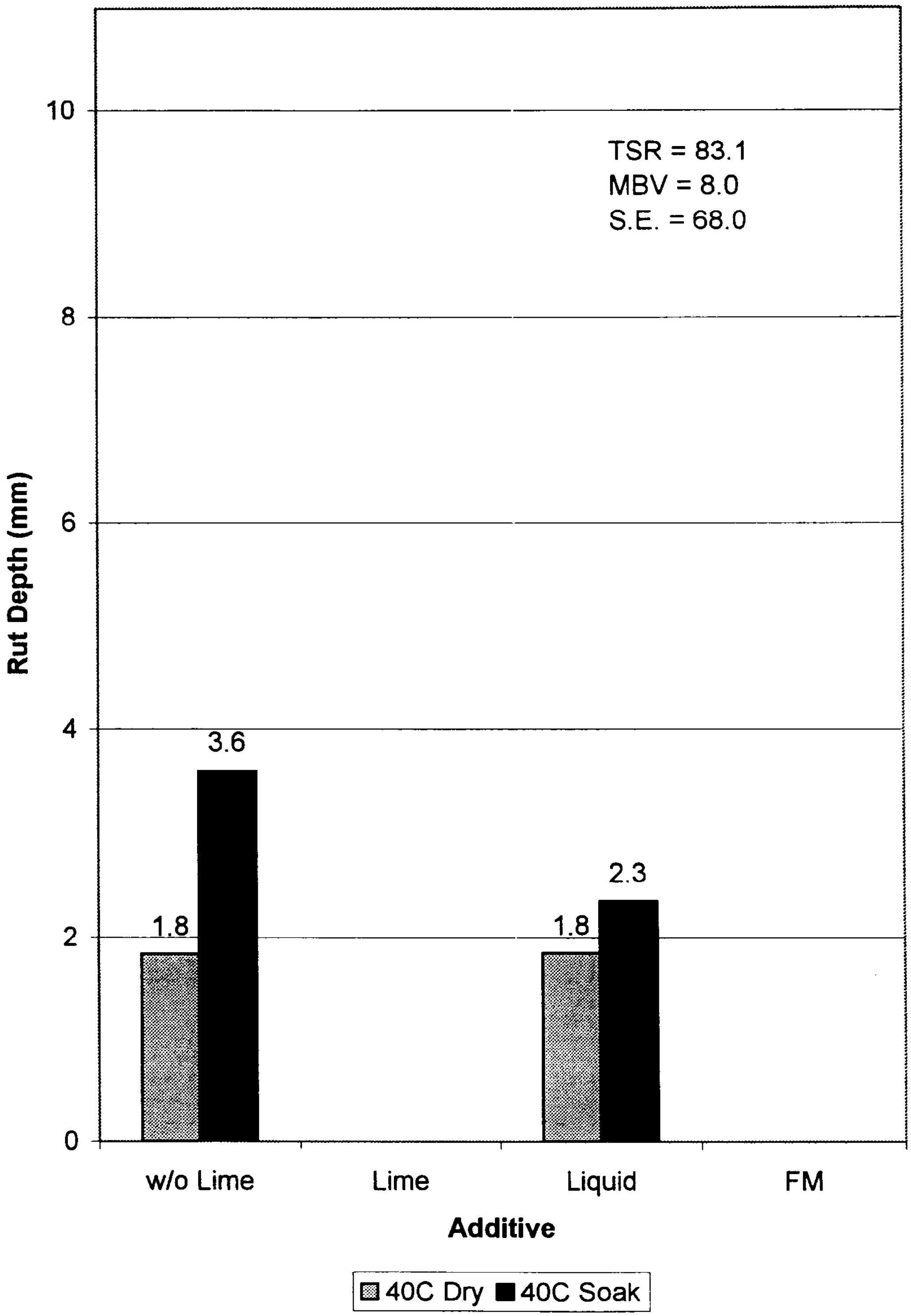

Figure 10. Rut Depth Comparison – Site 6A.

lowered with the use of a liquid anti-strip agent. Thus, one could be conservative and require an anti-strip agent for this site. However, the MBV for this site was 8.0, which according to Aschenbrener (3), indicates satisfactory performance (Table 13). Samples of field mix and samples with hydrated lime were not available for Site 6A.

Site 6B: Figure 11 shows the results from Site 6B. The dry conditioning rut depth was 5.58 mm which, as in Site 2 and Site 4, indicated the potential for a stability/strength problem. The rut depth for the soak conditioning, however, did not increase. The MBV was 10, which according to Aschenbrenner (3), is between the good and fair range. The KT-56 (AASHTO T 283) results indicate this as a moisture susceptible mix. The liquid anti-strip had limited success in lowering the soaked rut depth. Hydrated lime and field mix samples were not available. Using the established APA criteria, this mix would be identified as moisture susceptible, agreeing with the TSR results.

Site 7: The results from the APA testing for Site 7 are shown in Figure 12. The dry conditioning rut depth was 4.63 mm and the rut depth for the soak conditioning increased to 5.00 mm. Thus, according to the threshold values, this mix should be prone to moisture damage. The KT-56 (AASHTO T 283) TSR values indicate the potential for moisture damage as well. The MBV values for this site were not available. It is worth noting that this is the only site where the field mix rut depths were not lower than the laboratory compacted samples.

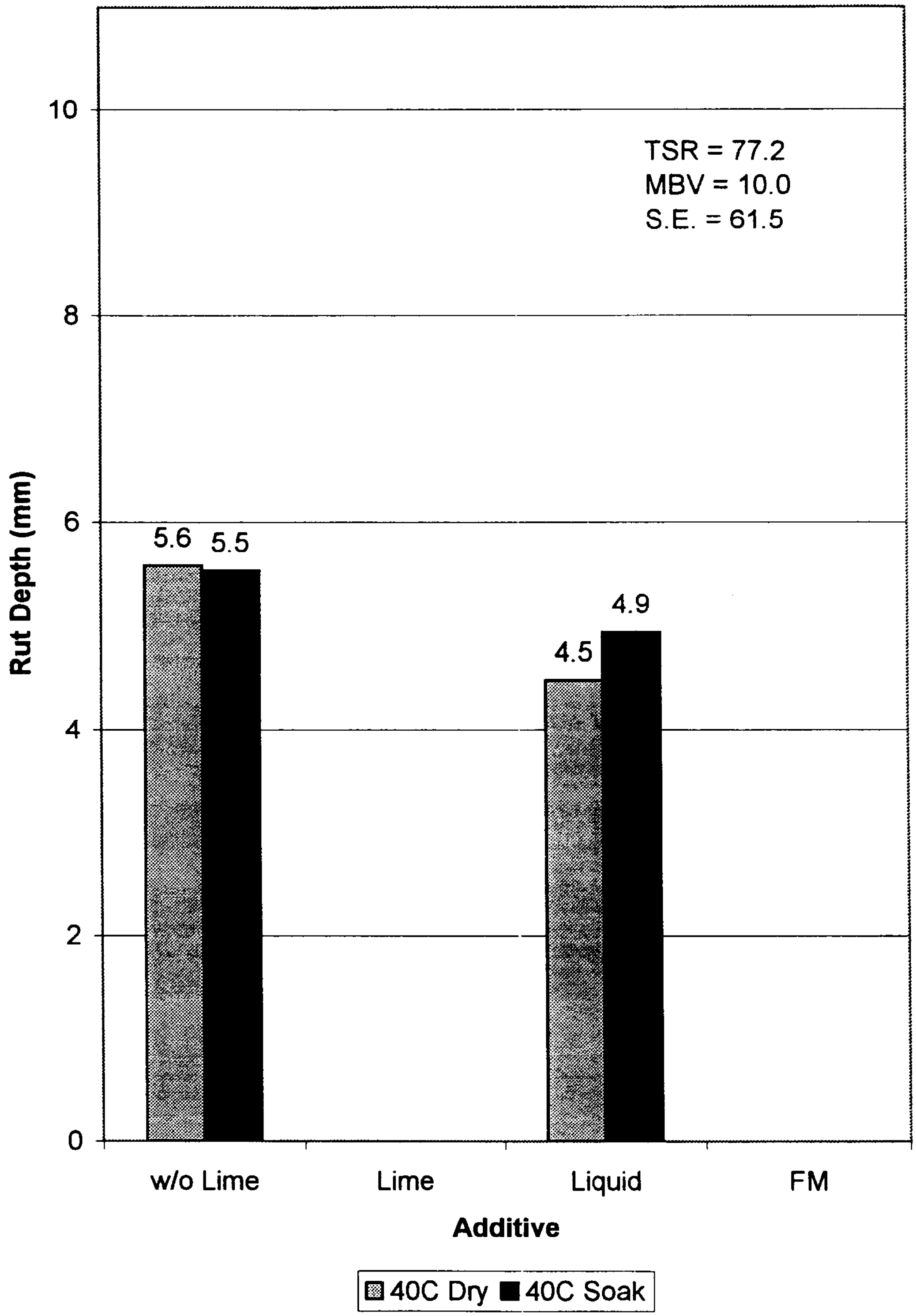

Figure 11. Rut Depth Comparison – Site 6B.

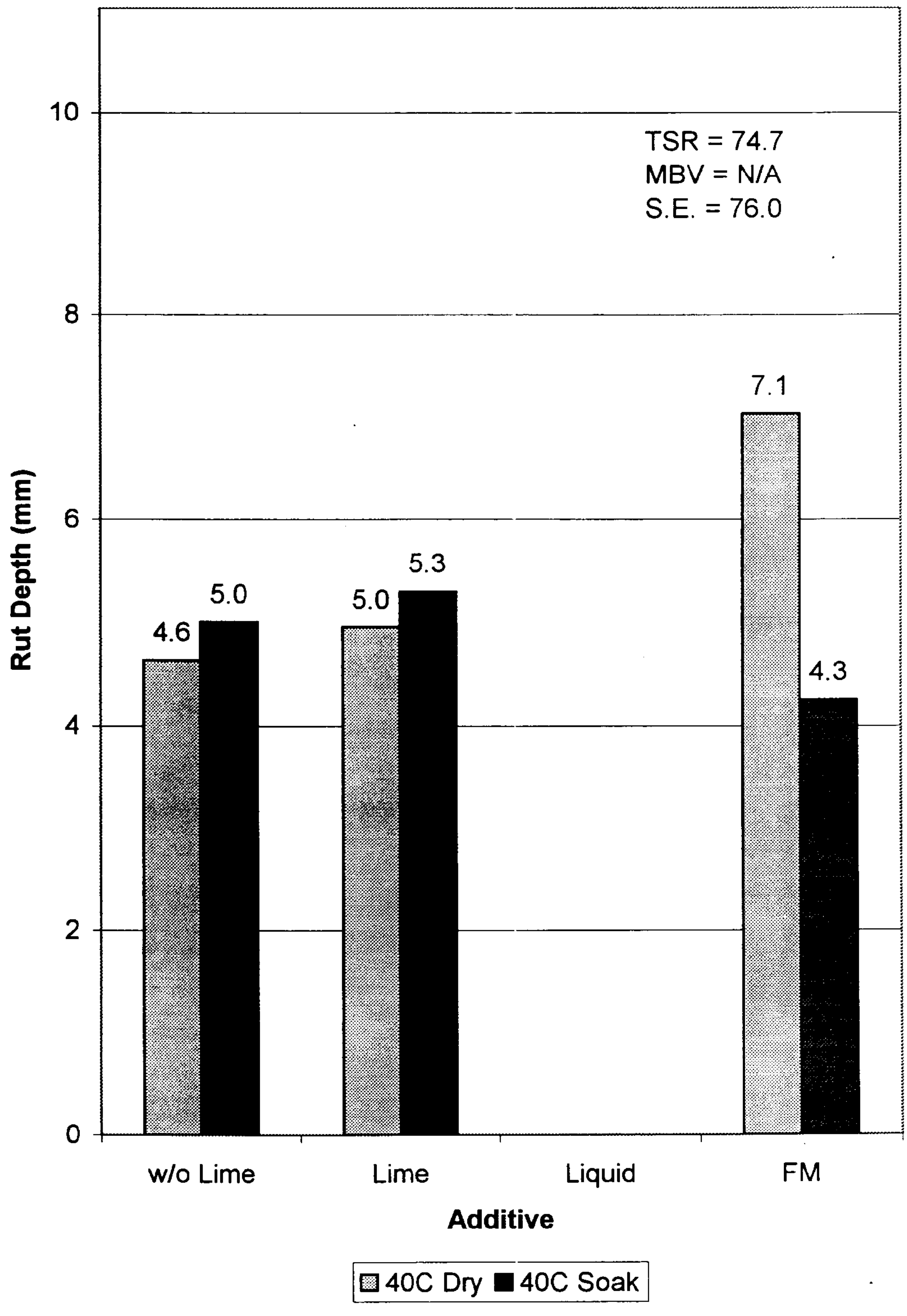

Figure 12. Rut Depth Comparison – Site 7.

The above test method/criteria needs to be evaluated on a different data set to confirm the findings. The 5.0 mm maximum rut depth for the soaked condition identified each site with a KT-56 (AASHTO T 283) TSR below 80%. Additionally, the APA method agreed with Aschenbrenner's (3) MBV test results on five of the eight sites. The MBV test has been shown to have a correlation to the moisture susceptibility of a mix (3, 15).

Thus, as suggested by some researchers, any potential test procedure for determining the moisture susceptibility of mixes that is more reliable than AASHTO T 283 (KT-56) may have to incorporate two or three tests, such as the APA and/or MBV test. An extra benefit of this approach is that loaded-wheel testing also provides an indication of the rut resistance or stability of a mix. Thus, performance and moisture susceptibility could be evaluated using one set of test results.

PHASE 3

In phase 3 the objective was to evaluate the relative performance, based on APA rut depths, of liquid anti-strip agents used in Kansas. To prevent factors such as aggregate type and the grade of asphalt from influencing the results, APA rut depths were only compared on samples from the same site. Secondly, rarely did a single site contain samples with more than one anti-strip liquid or was the same anti-strip liquid used on each site. Therefore, only simple comparisons of APA rut depths were available, as shown in Figures 13 to 20. In these figures the rut depth of samples with anti-strip liquids, without anti-strip liquids (e.g. w/o lime), and the field mix (FM) samples are plotted side-by-side. If the FM contained an anti-strip liquid, it is noted in parentheses. The figures show only the rut depth data at the 40°C soak conditioning. It was postulated that if the anti-strip liquids are providing protection against stripping, the rut depths for samples containing anti-strip liquids should be significantly smaller than samples without anti-strip liquids.

Indeed, as expected, the samples with liquid anti-strip had smaller rut depths than samples without any additive in nearly every case. The one exception that occurred was on Site 3. On Site 3, the samples with liquid anti-strip had a slightly higher rut depth than the samples without any additives.

To summarize, the results shown in Figures 13-20 indicate that, in general, the liquid anti-strip products are performing satisfactory. That is, they show a reduction in rut depth. As discussed in the Phase 2 analysis, there was a clear trend of the liquid anti-strip additives reducing the APA rut depths and the statistical analysis confirmed it. However, many of the rut depth improvements were only minor, 1.5 mm or less. It is noteworthy that none of the liquid anti-strip products stood out in performance. Within each site the paired anti-strip liquids had similar APA rut depth results. From the data it appears that most of the anti-strip liquids have equitable performance. More replicate testing would be necessary to validate these performance trends for specific liquid anti-strip agents. Comparisons with field performance would also be beneficial.

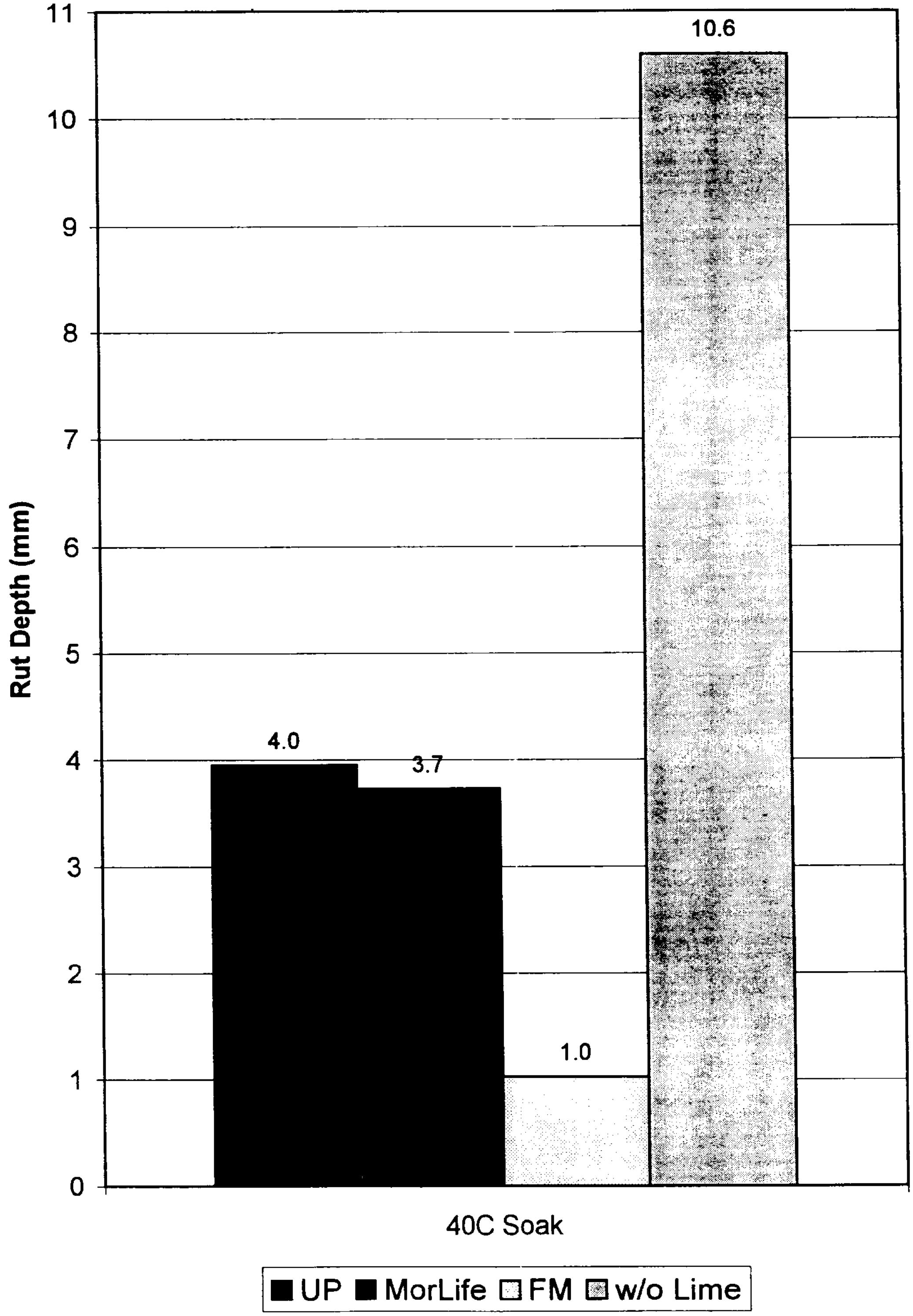

Figure 13. Anti-Strip Liquids Comparison – Site 1.

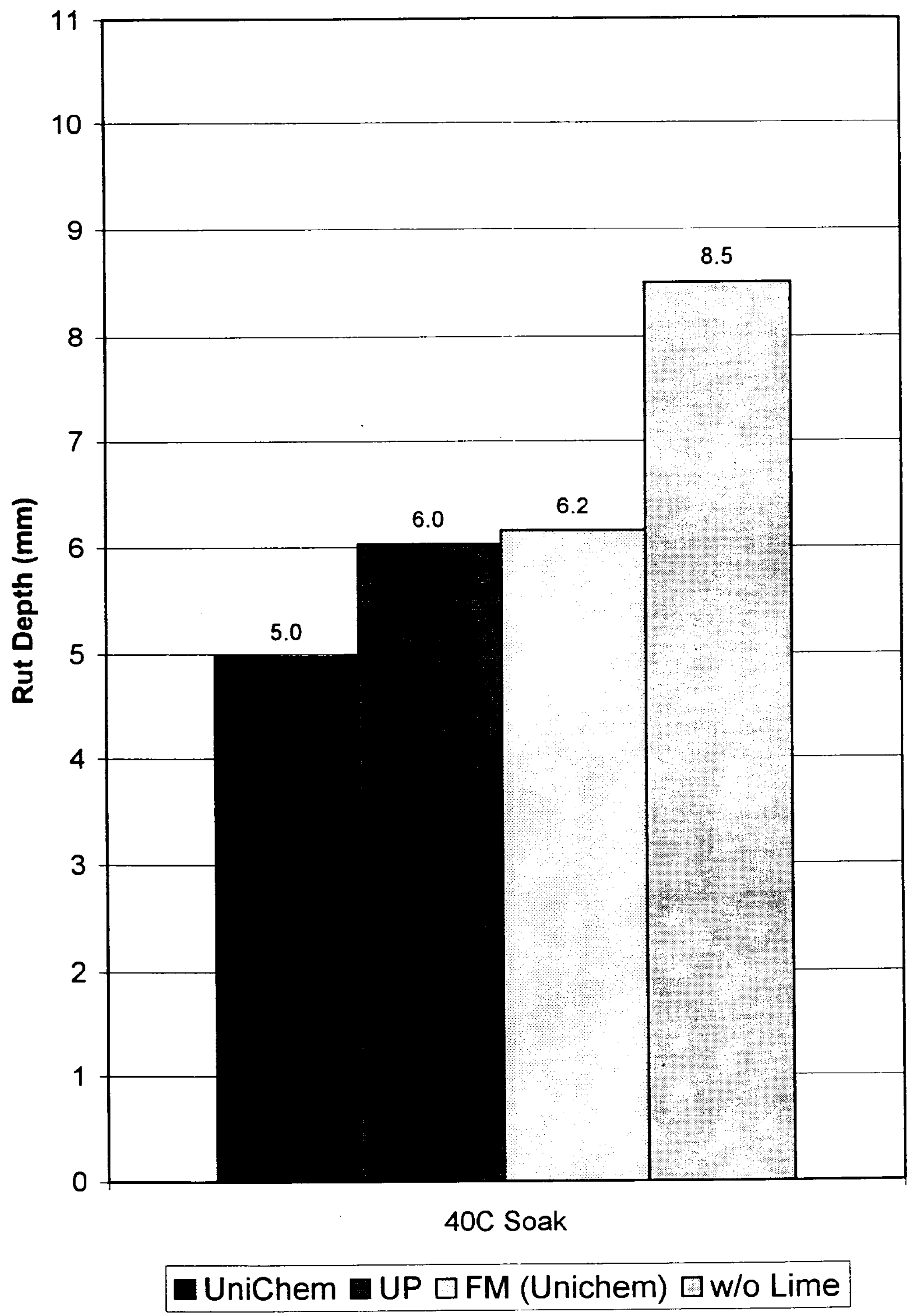

Figure 14. Anti-Strip Liquids Comparison – Site 2.

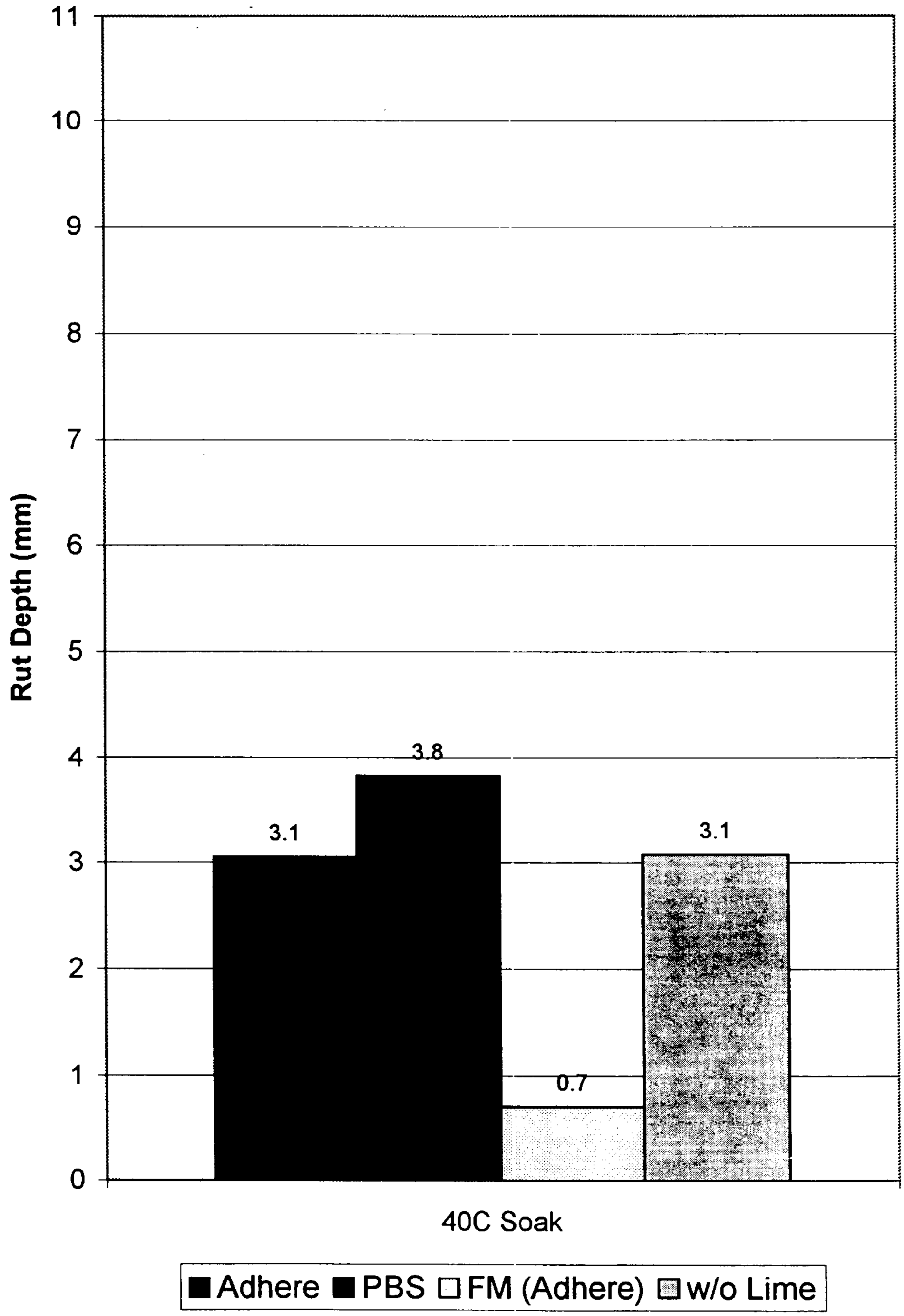

Figure 15. Anti-Strip Liquids Comparison – Site 3.

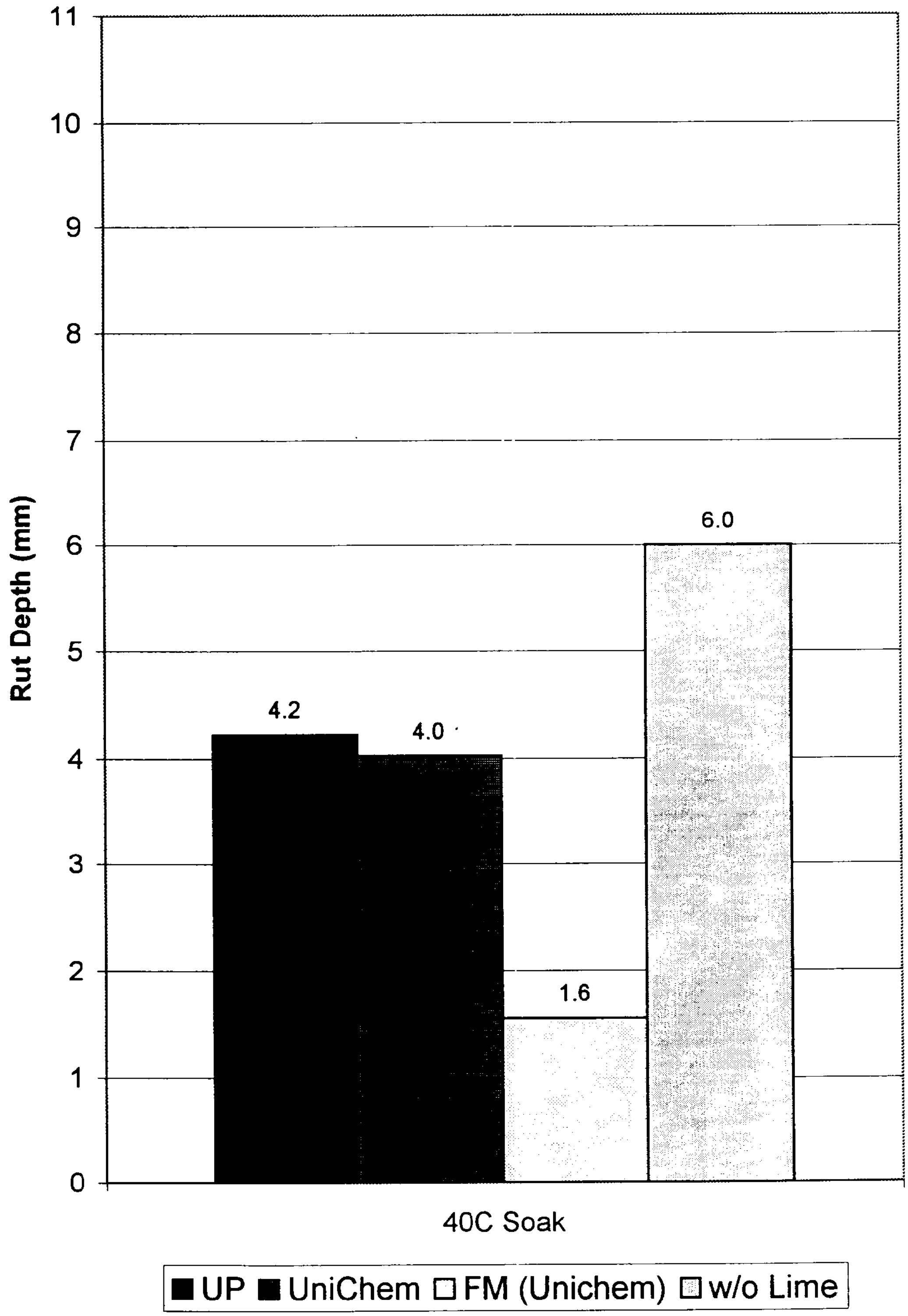

Figure 16. Anti-Strip Liquids Comparison – Site 4.

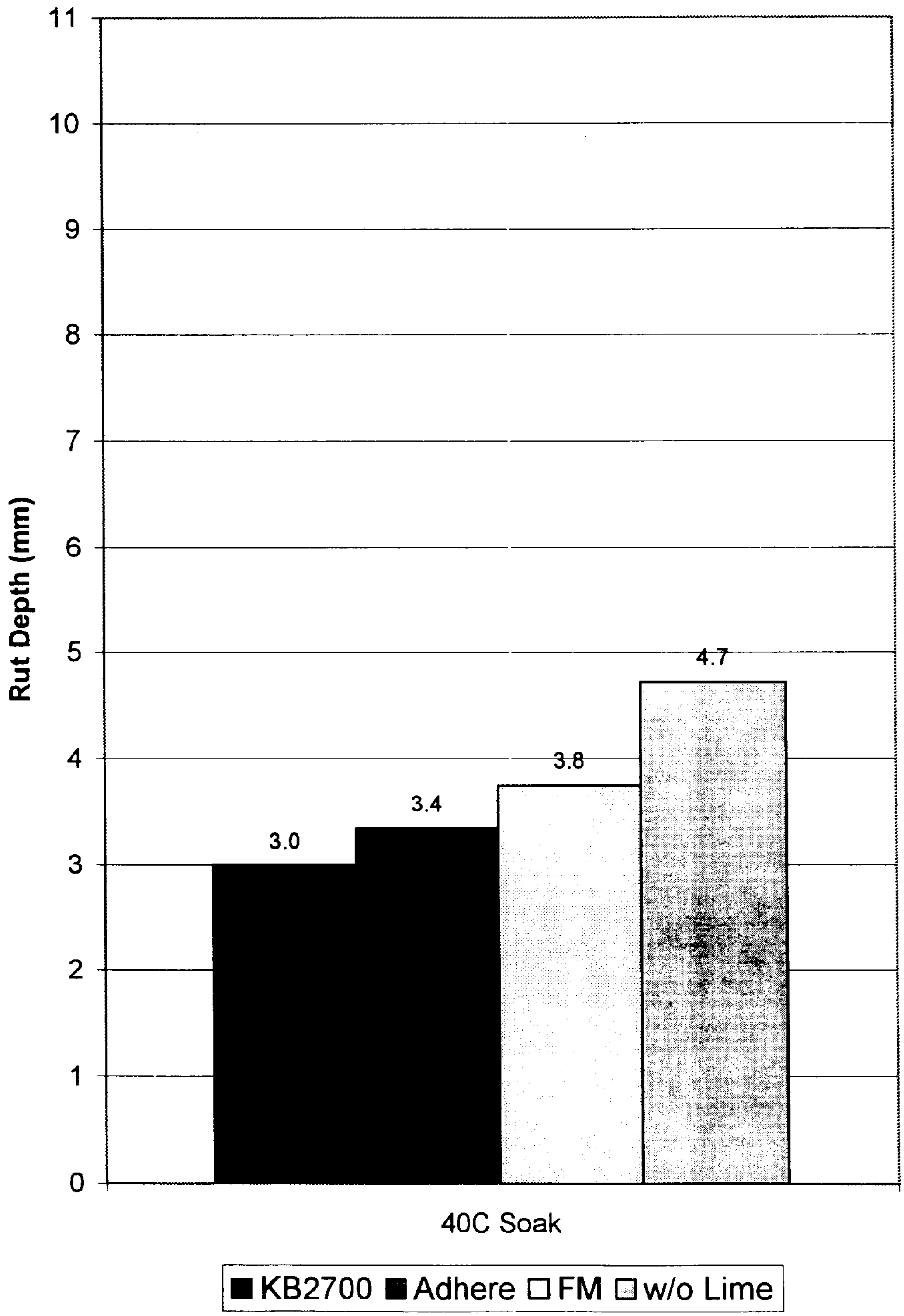

Figure 17. Anti-Strip Liquids Comparison – Site 5.

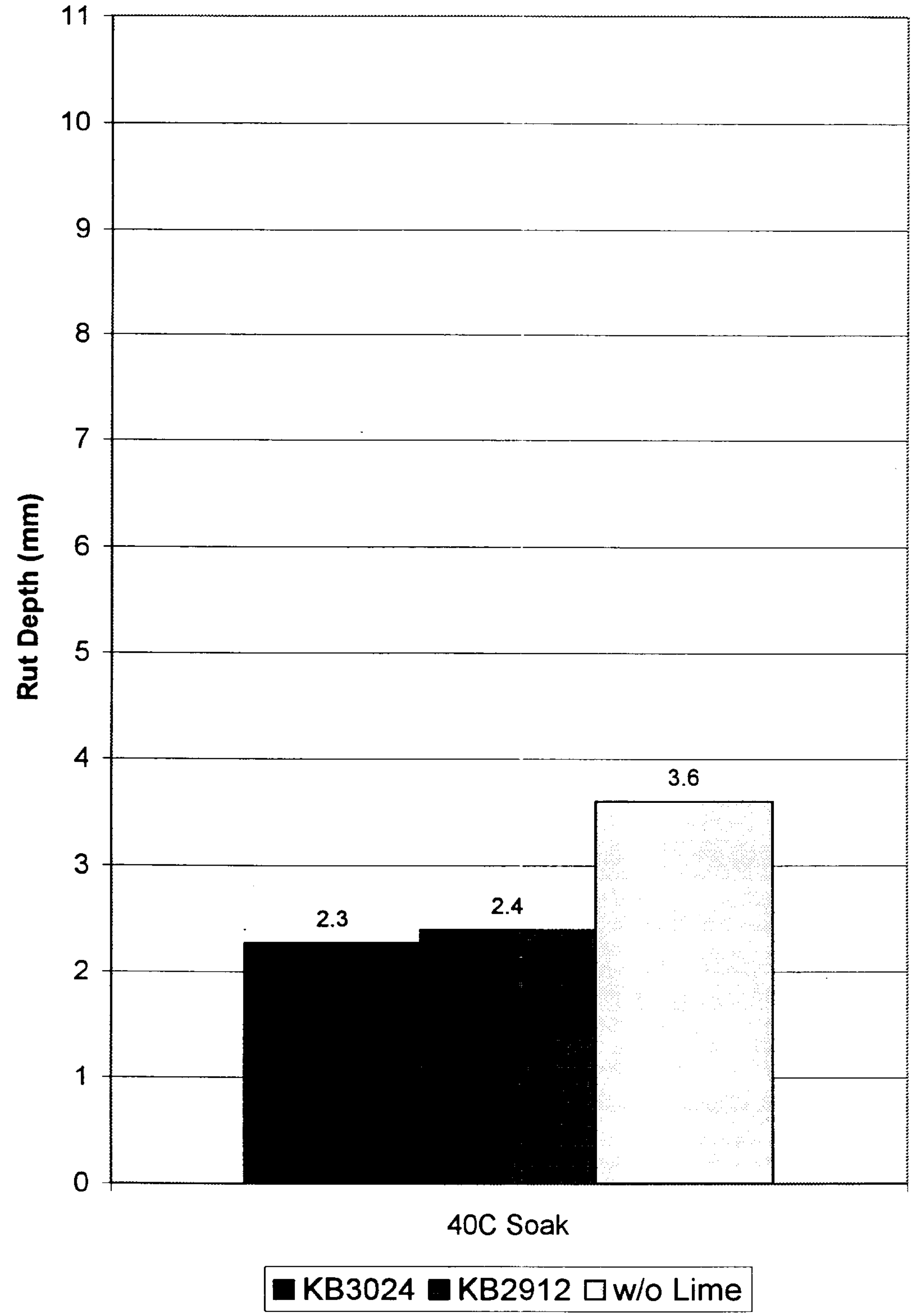

Figure 18. Anti-Strip Liquids Comparison – 6A.

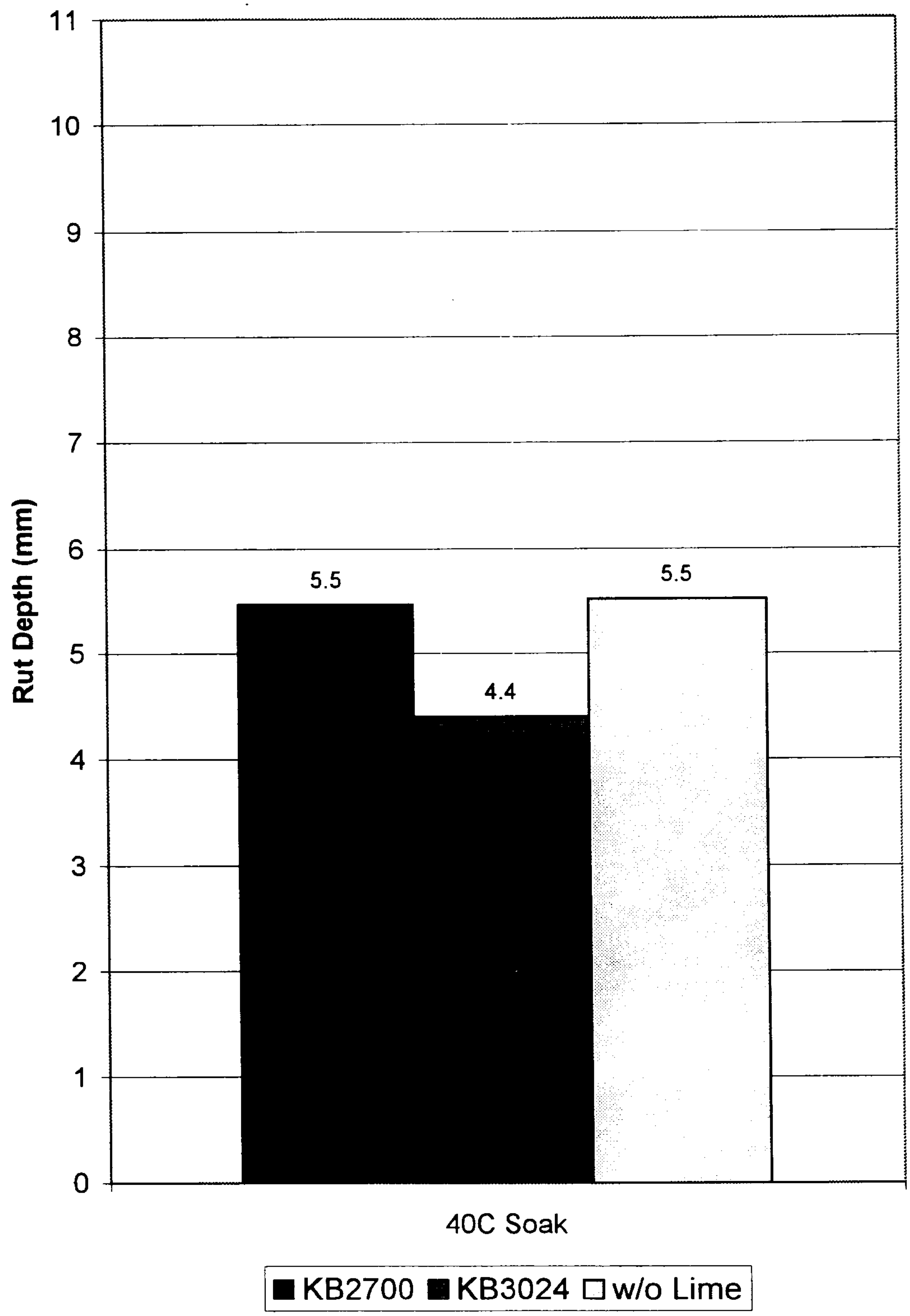

Figure 19. Anti-Strip Liquids Comparison – Site 6B.

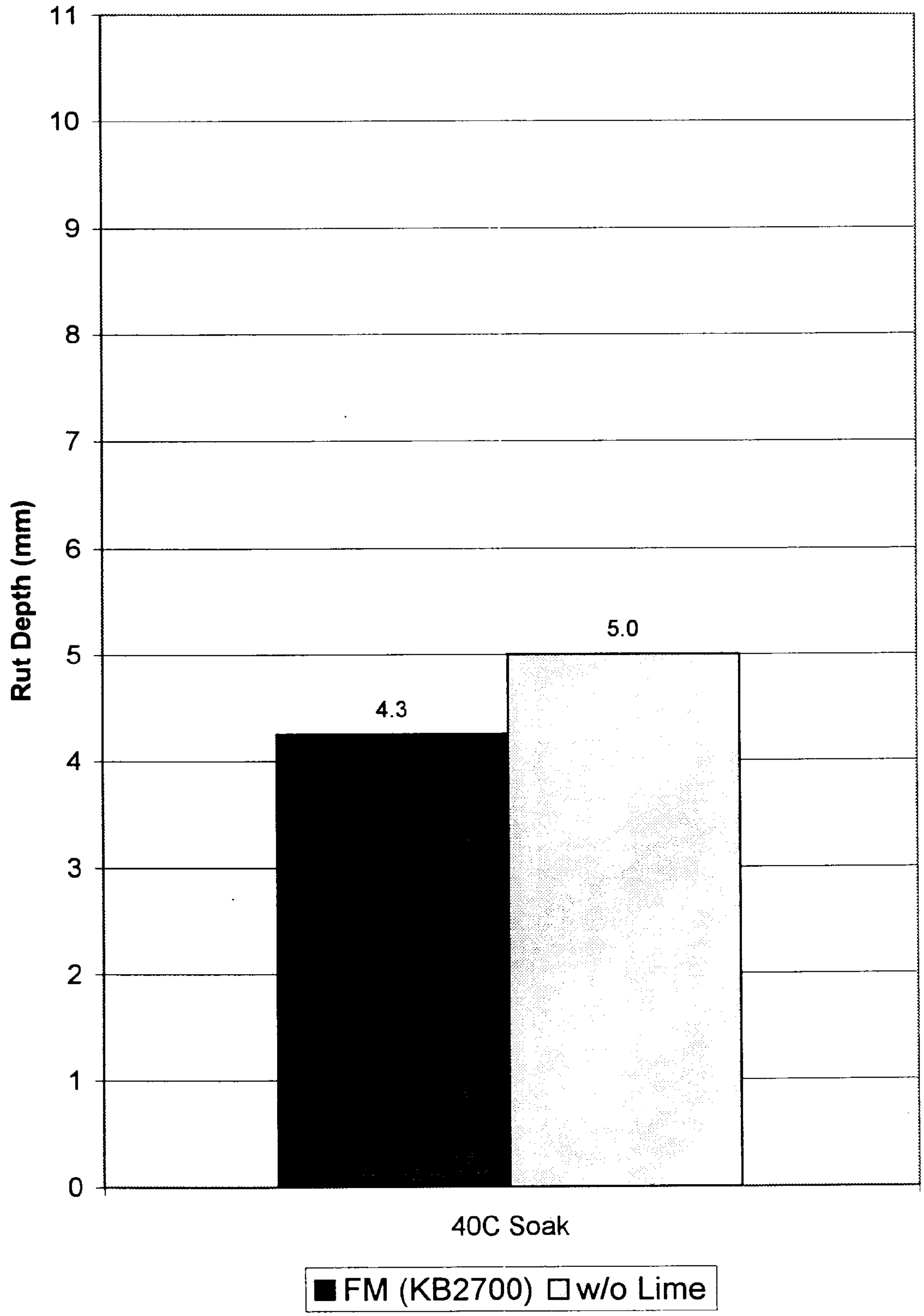

Figure 20. Anti-Strip Liquid Comparison – Site 7.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. The APA rut depths of the 40°C soak conditioning were significantly greater than the other conditioned rut depths. The effect of the KT-56 (AASHTO T 283) sample preconditioning did not yield significant differences in measured rut depths. Therefore, the preconditioning by saturation and the optional freeze cycle of KT-56 (AASHTO T 283) are not necessary to evaluate moisture susceptibility of asphalt mixes. The saturated conditioning, performed in accordance with KT-56 (AASHTO T 283), resulted in saturation levels 50% to 60% higher than that measured in the soaked samples. It is possible that the higher saturation levels resulted in pore water pressure being developed during the cyclic loading. This pore water pressure could help support the load resulting in reduced rut depths when compared to the soaked samples.
2. All sites with TSR values below 80% had rut depths of at least 5.0 mm for the 40°C soak conditioning. In addition, the APA indicated the site containing chert (Site 1), a known stripping aggregate, as failing (> 0.5 mm rut depth). KT-56 (AASHTO T 283) indicated a passing result with a TSR greater than 80%. One other site had a soaked rut depth above 5.0 mm, the site with the highest TSR value (98.2%). This site had a soak conditioning rut depth of 6.0 mm and a dry rut depth of 5.9 mm. The

rutting for this site may have been due to the instability of the mix as opposed to stripping as evidenced by the similar rut depths for the two sample conditionings. Any potential test method may need to consider the increase in rut depth from the dry to the soaked condition, especially for marginally stable mixtures. Additional information can be gained from other tests such as the methylene blue value results and the effects of anti-strip agents on soaked rut depths.

3. The trends in this study indicate that a large increase in rut depths from the dry conditioning to the soak conditioning is an indication that the mix is moisture susceptible. The determination of the exact amount of increase and whether it should be on a percentage or numeric basis was beyond the scope of this study.
4. The APA did not detect the effect of lime in the mix, except on Site 3. The statistical analysis indicated there was no significant difference in rut depths between samples with and without lime. If the lime was old it may have been carbonated and non-reactive. It is also possible on some sites that the lime was not compatible with the asphalt binder and aggregate mix, or maybe the softening effect that lime has on an asphalt binder offset the improved resistance to moisture damage in the APA results.
5. The APA did detect the effect of the anti-strip liquids in the mixes. However, no conclusive trends, good or bad, were found between the specific anti-strip products. Generally, the liquids appear to have equitable performance.
6. The sand equivalent test results, rut depth ratio results, methylene blue results, and the rut depth results did not correlate with TSR.

RECOMMENDATIONS

1. The Asphalt Pavement Analyzer (APA) should be used as another tool to evaluate the moisture sensitivity of asphalt mixtures. The APA might be most useful for evaluating new anti-strip agents and as a referee test when conflicting KT-56 results arise.
2. The sample conditioning of KT-56 (AASHTO T 283) did not significantly affect the APA rut depths. Therefore, a simple wet soak to bring the samples to test temperature is all the conditioning required for performing a moisture sensitivity test.
3. Based on the results of this study, the following test procedure is recommended for evaluating the moisture susceptibility of asphalt mixtures using the APA.

   The test should follow the recommendations of the APA Users Group (19). Determine the APA rut depths at 8000 cycles with a chamber temperature of 40°C for six samples with dry and soak conditioning. If the soaked rut depth is above 5.0 mm and the average increase in rut depth from the dry conditioning to the soak conditioning is greater than 2.00 mm, the mix is probably moisture sensitive and in need of an anti-strip additive. For cases that are suspect or borderline, the methlylene blue test can be used to supplement the APA data. If it is determined that an anti-strip additive is necessary, the procedure should be re-run to verify that the additive significantly reduces the rut depth of the soak conditioning to within 2.0 mm of the dry condition.
4. It is recommended that a future research project validate the threshold value of 5.0 mm at 40°C for soaked conditioning for moisture susceptibility. The question of

whether the rut depth increase should be evaluated and reported by a percent increase or quantitatively or both should also be further researched. By reviewing the mix properties, TSR values, and MBVs of this study, a 2.0-mm increase in rut depth from samples with dry and soak conditioning appears to be a threshold value that provides some correlation. It is also recommended that the performance of the eight sites be evaluated in the future to validate the trends of this study.

5. It is recommended that any future research in this area include mixes with very low TSR values (below 70%) and additional aggregates known to have stripping problems. If the APA is a valid tool for determining moisture susceptibility, it must be able to clearly distinguish these mixes.
6. Follow-up research with moisture susceptibility and the APA should consider using a higher testing temperature, such as 50°C. For the most part, rut depths on samples in this study were well below 10 mm (variability/repeatability can be a problem when rut depths exceed 10 mm), and thus an increase in temperature is probably warranted. The increased temperature may help the APA to better distinguish moisture susceptible mixes.

IMPLEMENTATION

The results from this research project allow two forms of implementation. The first avenue of implementation could be as an additional test method to evaluate the moisture sensitivity of asphalt mixtures. Because the APA is not readily available in Kansas or at KDOT, the procedure may not be suitable at this time for routine testing. The APA may best be utilized as a referee test when conflicting KT-56 (AASHTO T 283) test results occur.

The second method of implementation could be as a tool to evaluate the performance of anti-strip agents. This would require the identification of several "standard" aggregates of known moisture damage potential. Standard aggregate blends providing known APA performance would be established with aggregates of good, marginal, and poor moisture damage resistance. A standard asphalt cement would be required as well. Anti-strip agents could be evaluated by comparing their performance to the standard mixes as well as to the threshold limit of 5.0 mm in the soaked condition. This would allow a relative comparison of anti-strip agents as well as a comparison to a minimum performance level and remove aggregate shape and gradation as a factor in the recorded soaked rut depth.

Both implementation plans could be implemented through the Bureau of Materials and Research. The first implementation plan would simply require notification of all interested parties of the availability of the APA. The University of Kansas would cooperate with this venture. A procedure similar to the agreement for rutting testing would be a good model to follow.

Implementation of the plan for evaluating anti-strip agents would require establishing standard mixes of known APA performance for use in evaluating anti-strip agents. The University of Kansas with input and direction of the Bureau of Materials and Research could implement the evaluation procedure. The assistance of KDOT would be required to identify the "standard" aggregates and asphalt cements. Assistance from KDOT would be required in developing the "standard" mix gradations and determining optimum asphalt content. The actual work could be performed at the University of Kansas. After the development of "standard evaluation mixes," the mixes would need to be evaluated to establish baseline performance data. Again, the University of Kansas could perform this evaluation. A suitable source of funding for implementation could come from the K-TRAN research program or other appropriate funding sources. The University of Kansas would perform evaluations on a continuing basis as a part of the funding agreement.

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APPENDIX

Table A-1. APA Rut Depth Data for Samples With and Without Lime.

Cycles	Site #	Additive	Average Rut Depth (mm)			
			40C Dry	40C Soak	40C Sat.	40C Freeze
0	Site 1	w/o Lime	0.00	0.00	0.00	0.00
500	Site 1	w/o Lime	2.15	3.60	1.00	1.10
1000	Site 1	w/o Lime	*	*	1.45	1.80
2000	Site 1	w/o Lime	2.65	6.20	2.50	3.00
4000	Site 1	w/o Lime	3.50	8.30	3.55	4.15
6000	Site 1	w/o Lime	3.95	10.10	4.35	4.55
8000	Site 1	w/o Lime	4.45	11.50	4.80	5.10
0	Site 1	w/o Lime	0.00	0.00	0.00	0.00
500	Site 1	w/o Lime	1.75	2.95	0.80	1.10
1000	Site 1	w/o Lime	*	*	1.30	1.70
2000	Site 1	w/o Lime	2.15	5.20	2.05	2.60
4000	Site 1	w/o Lime	2.65	6.95	3.05	3.40
6000	Site 1	w/o Lime	2.95	8.40	3.95	4.00
8000	Site 1	w/o Lime	3.30	9.70	4.30	4.30
0	Site 1	Lime	0.00	0.00	0.00	0.00
500	Site 1	Lime	0.75	2.85	1.60	1.20
1000	Site 1	Lime	*	*	2.45	2.25
2000	Site 1	Lime	2.10	5.20	3.20	3.05
4000	Site 1	Lime	3.20	7.35	4.15	4.00
6000	Site 1	Lime	3.55	*	4.55	4.65
8000	Site 1	Lime	3.65	11.35	5.15	5.15
0	Site 1	Lime	0.00	0.00	0.00	0.00
500	Site 1	Lime	0.60	2.80	0.90	1.20
1000	Site 1	Lime	*	*	1.45	1.90
2000	Site 1	Lime	1.80	5.25	2.25	2.80
4000	Site 1	Lime	2.65	6.70	3.10	3.70
6000	Site 1	Lime	3.15	*	3.75	4.25
8000	Site 1	Lime	3.50	10.05	4.05	4.70

* Reading Not Available.

Table A-1 (Con't.). APA Rut Depth Data for Samples With and Without Lime.

			Average Rut Depth (mm)			
Cycles	Site #	Additive	40C Dry	40C Soak	40C Sat.	40C Freeze
0	Site 2	w/o Lime	0.00	0.00	0.00	0.00
500	Site 2	w/o Lime	1.85	2.05	2.85	1.95
1000	Site 2	w/o Lime	*	*	4.20	3.50
2000	Site 2	w/o Lime	3.80	4.90	5.15	4.60
4000	Site 2	w/o Lime	4.90	6.45	7.10	6.00
6000	Site 2	w/o Lime	5.65	7.50	7.75	6.50
8000	Site 2	w/o Lime	6.25	8.20	9.65	7.45
0	Site 2	w/o Lime	N/T	0.00	0.00	0.00
500	Site 2	w/o Lime	N/T	2.20	2.70	2.00
1000	Site 2	w/o Lime	N/T	*	3.90	3.35
2000	Site 2	w/o Lime	N/T	5.25	5.30	4.60
4000	Site 2	w/o Lime	N/T	6.85	6.15	5.80
6000	Site 2	w/o Lime	N/T	8.10	6.00	6.85
8000	Site 2	w/o Lime	N/T	8.80	7.65	7.65
0	Site 2	Lime	0.00	0.00	0.00	0.00
500	Site 2	Lime	2.35	2.35	2.95	2.80
1000	Site 2	Lime	*		4.45	4.50
2000	Site 2	Lime	4.40	4.85	5.70	5.70
4000	Site 2	Lime	5.45	6.30	7.00	6.90
6000	Site 2	Lime	6.30	7.40	7.70	7.70
8000	Site 2	Lime	6.75	8.20	9.90	8.10
0	Site 2	Lime	N/T	0.00	0.00	0.00
500	Site 2	Lime	N/T	2.10	3.00	1.90
1000	Site 2	Lime	N/T	*	4.25	3.50
2000	Site 2	Lime	N/T	4.25	5.35	4.60
4000	Site 2	Lime	N/T	5.55	6.75	5.60
6000	Site 2	Lime	N/T	6.35	7.85	6.05
8000	Site 2	Lime	N/T	7.00	8.35	6.50

*Reading Not Available.
N/T = Sample Not Tested.

Table A-1 (Con't.). APA Rut Depth Data for Samples With and Without Lime.

			Average Rut Depth (mm)			
Cycles	Site #	Additive	40C Dry	40C Soak	40C Sat.	40C Freeze
0	Site 3	w/o Lime	0.00	0.00	0.00	0.00
500	Site 3	w/o Lime	0.60	0.80	0.45	0.40
1000	Site 3	w/o Lime	0.85	1.00	0.70	0.60
2000	Site 3	w/o Lime	1.10	1.50	1.00	0.95
4000	Site 3	w/o Lime	1.65	2.20	1.35	1.45
6000	Site 3	w/o Lime	2.50	2.75	1.70	2.10
8000	Site 3	w/o Lime	3.45	3.15	2.10	2.60
0	Site 3	w/o Lime	0.00	0.00	0.00	0.00
500	Site 3	w/o Lime	0.45	0.50	0.70	0.55
1000	Site 3	w/o Lime	0.70	0.65	1.00	0.80
2000	Site 3	w/o Lime	0.90	1.10	1.60	1.15
4000	Site 3	w/o Lime	1.65	1.95	2.25	1.75
6000	Site 3	w/o Lime	2.35	2.50	2.55	2.25
8000	Site 3	w/o Lime	3.05	3.00	2.70	2.55
0	Site 3	Lime	0.00	0.00	0.00	0.00
500	Site 3	Lime	0.55	0.30	0.50	0.35
1000	Site 3	Lime	0.80	0.30	0.80	0.60
2000	Site 3	Lime	0.85	0.55	1.05	0.90
4000	Site 3	Lime	1.05	1.15	1.55	1.25
6000	Site 3	Lime	1.35	1.50	1.85	1.70
8000	Site 3	Lime	1.55	1.75	2.10	2.10
0	Site 3	Lime	0.00	0.00	0.00	0.00
500	Site 3	Lime	0.30	0.25	0.55	0.50
1000	Site 3	Lime	0.45	0.35	0.75	0.65
2000	Site 3	Lime	0.50	0.55	1.15	0.90
4000	Site 3	Lime	*	0.75	1.50	1.40
6000	Site 3	Lime	*	1.20	1.90	1.70
8000	Site 3	Lime	*	1.50	2.30	2.05

* Reading Not Available.

Table A-1 (Con't.). APA Rut Depth Data for Samples With and Without Lime.

Cycles	Site #	Additive	Average Rut Depth (mm) 40C Dry	40C Soak	40C Sat.	40C Freeze
0	Site 4	w/o Lime	0.00	0.00	0.00	0.00
500	Site 4	w/o Lime	0.70	1.05	0.70	0.70
1000	Site 4	w/o Lime	1.05	1.75	1.20	1.00
2000	Site 4	w/o Lime	1.75	3.05	1.85	1.70
4000	Site 4	w/o Lime	3.40	5.10	2.85	2.60
6000	Site 4	w/o Lime	4.70	*	3.35	3.30
8000	Site 4	w/o Lime	5.65	6.00	3.80	3.75
0	Site 4	w/o Lime	0.00	0.00	0.00	0.00
500	Site 4	w/o Lime	0.60	0.90	0.90	0.65
1000	Site 4	w/o Lime	0.95	1.60	1.40	0.95
2000	Site 4	w/o Lime	1.60	2.80	2.10	1.45
4000	Site 4	w/o Lime	3.55	5.05	2.95	1.95
6000	Site 4	w/o Lime	5.20	*	3.55	2.75
8000	Site 4	w/o Lime	6.20	6.00	4.10	3.10
0	Site 4	Lime	0.00	0.00	0.00	0.00
500	Site 4	Lime	0.45	1.00	0.75	0.75
1000	Site 4	Lime	0.80	1.75	1.20	1.20
2000	Site 4	Lime	1.10	2.95	1.95	1.95
4000	Site 4	Lime	1.95	5.10	3.55	3.10
6000	Site 4	Lime	3.55	*	4.05	3.90
8000	Site 4	Lime	4.80	5.75	4.55	4.35
0	Site 4	Lime	0.00	0.00	0.00	0.00
500	Site 4	Lime	1.00	0.95	0.75	0.65
1000	Site 4	Lime	1.60	1.55	1.30	1.05
2000	Site 4	Lime	2.70	2.75	2.15	1.70
4000	Site 4	Lime	4.70	5.30	3.40	2.75
6000	Site 4	Lime	5.75	*	4.25	3.60
8000	Site 4	Lime	7.20	6.35	4.70	4.15

* Reading Not Available.

Table A-1 (Con't.). APA Rut Depth Data for Samples With and Without Lime.

Cycles	Site #	Additive	Average Rut Depth (mm) 40C Dry	40C Soak	40C Sat.	40C Freeze
0	Site 5	w/o Lime	0.00	0.00	0.00	0.00
500	Site 5	w/o Lime	0.65	1.55	1.25	1.20
1000	Site 5	w/o Lime	0.90	2.05	1.80	1.90
2000	Site 5	w/o Lime	1.45	2.75	2.40	2.45
4000	Site 5	w/o Lime	2.80	3.45	2.95	2.90
6000	Site 5	w/o Lime	3.60	3.90	3.40	*
8000	Site 5	w/o Lime	4.35	4.20	3.65	3.90
0	Site 5	w/o Lime	0.00	0.00	0.00	0.00
500	Site 5	w/o Lime	0.40	1.45	1.10	1.55
1000	Site 5	w/o Lime	0.75	2.35	1.85	2.25
2000	Site 5	w/o Lime	1.15	3.20	2.60	2.85
4000	Site 5	w/o Lime	2.10	4.10	3.10	3.75
6000	Site 5	w/o Lime	2.40	4.75	3.35	*
8000	Site 5	w/o Lime	2.65	5.25	3.70	4.95
0	Site 5	Lime	0.00	0.00	0.00	0.00
500	Site 5	Lime	0.65	0.75	1.05	0.70
1000	Site 5	Lime	0.70	1.05	1.35	1.00
2000	Site 5	Lime	0.95	1.60	2.00	1.65
4000	Site 5	Lime	1.95	2.40	2.75	2.60
6000	Site 5	Lime	2.60	2.70	3.25	*
8000	Site 5	Lime	3.10	2.90	3.45	3.65
0	Site 5	Lime	0.00	0.00	0.00	0.00
500	Site 5	Lime	0.65	1.15	0.90	0.75
1000	Site 5	Lime	1.05	1.70	1.20	1.35
2000	Site 5	Lime	1.25	2.70	1.80	2.05
4000	Site 5	Lime	1.90	3.45	2.50	2.85
6000	Site 5	Lime	2.45	4.05	2.95	*
8000	Site 5	Lime	2.45	4.50	3.35	3.45

* Reading Not Available

Table A-1 (Con't.). APA Rut Depth Data for Samples With and Without Lime.

Cycles	Site #	Additive	Average Rut Depth (mm)			
			40C Dry	40C Soak	40C Sat.	40C Freeze
0	Site 6A	w/o Lime	0.00	0.00	0.00	0.00
500	Site 6A	w/o Lime	0.75	0.45	0.90	0.85
1000	Site 6A	w/o Lime	1.00	0.70	1.15	1.20
2000	Site 6A	w/o Lime	0.85	1.45	1.40	1.55
4000	Site 6A	w/o Lime	1.10	2.55	1.90	2.10
8000	Site 6A	w/o Lime	2.15	3.40	2.05	2.50
0	Site 6A	w/o Lime	0.00	0.00	0.00	0.00
500	Site 6A	w/o Lime	0.65	0.50	0.65	0.70
1000	Site 6A	w/o Lime	0.70	0.90	1.00	0.90
2000	Site 6A	w/o Lime	0.05	1.45	1.40	1.00
4000	Site 6A	w/o Lime	0.50	2.65	1.70	1.70
8000	Site 6A	w/o Lime	1.50	3.80	2.05	2.05
0	Site 6B	w/o Lime	0.00	0.00	0.00	0.00
500	Site 6B	w/o Lime	0.95	1.30	1.70	0.95
1000	Site 6B	w/o Lime	1.90	2.15	2.55	1.35
2000	Site 6B	w/o Lime	3.20	3.20	3.20	1.90
4000	Site 6B	w/o Lime	4.30	4.50	4.30	2.65
8000	Site 6B	w/o Lime	5.75	6.00	5.15	3.60
0	Site 6B	w/o Lime	0.00	0.00	0.00	N/T
500	Site 6B	w/o Lime	0.60	0.85	1.65	N/T
1000	Site 6B	w/o Lime	1.30	1.55	2.40	N/T
2000	Site 6B	w/o Lime	2.55	2.45	2.90	N/T
4000	Site 6B	w/o Lime	3.85	3.70	4.55	N/T
8000	Site 6B	w/o Lime	5.40	5.05	5.25	N/T

* Reading Not Available.
N/T = Sample Not Tested.

Table A-1 (Con't.). APA Rut Depth Data for Samples With and Without Lime.

Cycles	Site #	Additive	Average Rut Depth (mm) 40C Dry	40C Soak	40C Sat.	40C Freeze
0	Site 7	w/o Lime	0.00	0.00	0.00	0.00
500	Site 7	w/o Lime	0.60	1.20	0.90	1.25
1000	Site 7	w/o Lime	1.30	1.85	1.45	1.85
2000	Site 7	w/o Lime	2.20	3.20	2.05	2.55
4000	Site 7	w/o Lime	3.55	4.20	3.10	3.30
8000	Site 7	w/o Lime	4.65	5.10	4.15	4.20
0	Site 7	w/o Lime	0.00	0.00	0.00	0.00
500	Site 7	w/o Lime	0.65	1.05	0.95	0.95
1000	Site 7	w/o Lime	1.25	1.75	1.50	1.35
2000	Site 7	w/o Lime	2.00	3.15	1.85	2.00
4000	Site 7	w/o Lime	3.60	4.10	2.90	2.95
8000	Site 7	w/o Lime	4.60	4.90	3.60	3.65
0	Site 7	Lime	0.00	0.00	0.00	0.00
500	Site 7	Lime	1.60	1.25	1.95	1.20
1000	Site 7	Lime	1.90	1.90	2.65	2.00
2000	Site 7	Lime	2.90	3.15	3.25	2.80
4000	Site 7	Lime	3.75	4.35	4.10	3.40
8000	Site 7	Lime	5.05	5.80	5.05	4.60
0	Site 7	Lime	0.00	0.00	0.00	0.00
500	Site 7	Lime	1.35	1.10	1.45	1.00
1000	Site 7	Lime	2.10	1.65	2.20	1.75
2000	Site 7	Lime	2.90	2.30	3.00	2.60
4000	Site 7	Lime	3.95	3.55	3.65	3.35
8000	Site 7	Lime	4.85	4.80	4.55	4.45

Table A-2. APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 1	4	UP	40C Dry	0.0
500	Site 1	4	UP	40C Dry	0.9
1000	Site 1	4	UP	40C Dry	1.4
2000	Site 1	4	UP	40C Dry	2.0
4000	Site 1	4	UP	40C Dry	2.6
8000	Site 1	4	UP	40C Dry	3.4
0	Site 1	3	UP	40C Dry	0.0
500	Site 1	3	UP	40C Dry	0.5
1000	Site 1	3	UP	40C Dry	0.9
2000	Site 1	3	UP	40C Dry	1.2
4000	Site 1	3	UP	40C Dry	1.8
8000	Site 1	3	UP	40C Dry	2.3
0	Site 1	A	MorLife	40C Dry	0.0
500	Site 1	A	MorLife	40C Dry	0.6
1000	Site 1	A	MorLife	40C Dry	0.9
2000	Site 1	A	MorLife	40C Dry	1.2
4000	Site 1	A	MorLife	40C Dry	1.8
8000	Site 1	A	MorLife	40C Dry	2.6
0	Site 1	F	MorLife	40C Dry	0.0
500	Site 1	F	MorLife	40C Dry	0.5
1000	Site 1	F	MorLife	40C Dry	0.8
2000	Site 1	F	MorLife	40C Dry	1.2
4000	Site 1	F	MorLife	40C Dry	1.9
8000	Site 1	F	MorLife	40C Dry	3.3
0	Site 1	8	FM	40C Dry	0.0
500	Site 1	8	FM	40C Dry	0.3
1000	Site 1	8	FM	40C Dry	0.3
2000	Site 1	8	FM	40C Dry	0.3
4000	Site 1	8	FM	40C Dry	0.3
8000	Site 1	8	FM	40C Dry	0.3
0	Site 1	7	FM	40C Dry	0.0
500	Site 1	7	FM	40C Dry	0.3
1000	Site 1	7	FM	40C Dry	0.0
2000	Site 1	7	FM	40C Dry	0.2
4000	Site 1	7	FM	40C Dry	0.5
8000	Site 1	7	FM	40C Dry	0.6

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 1	5	FM	40C Soak	9.8
500	Site 1	5	FM	40C Soak	0.3
1000	Site 1	5	FM	40C Soak	0.5
2000	Site 1	5	FM	40C Soak	0.5
4000	Site 1	5	FM	40C Soak	0.8
8000	Site 1	5	FM	40C Soak	1.1
0	Site 1	6	FM	40C Soak	0.0
500	Site 1	6	FM	40C Soak	0.3
1000	Site 1	6	FM	40C Soak	0.6
2000	Site 1	6	FM	40C Soak	0.8
4000	Site 1	6	FM	40C Soak	0.9
8000	Site 1	6	FM	40C Soak	1.0
0	Site 1	B	MorLife	40C Soak	0.0
500	Site 1	B	MorLife	40C Soak	0.9
1000	Site 1	B	MorLife	40C Soak	1.4
2000	Site 1	B	MorLife	40C Soak	2.0
4000	Site 1	B	MorLife	40C Soak	2.9
8000	Site 1	B	MorLife	40C Soak	3.8
0	Site 1	C	MorLife	40C Soak	0.0
500	Site 1	C	MorLife	40C Soak	0.9
1000	Site 1	C	MorLife	40C Soak	1.4
2000	Site 1	C	MorLife	40C Soak	1.9
4000	Site 1	C	MorLife	40C Soak	2.7
8000	Site 1	C	MorLife	40C Soak	3.7
0	Site 1	5	UP	40C Soak	0.0
500	Site 1	5	UP	40C Soak	1.0
1000	Site 1	5	UP	40C Soak	1.6
2000	Site 1	5	UP	40C Soak	2.3
4000	Site 1	5	UP	40C Soak	3.3
8000	Site 1	5	UP	40C Soak	4.1
0	Site 1	6	UP	40C Soak	0.0
500	Site 1	6	UP	40C Soak	0.6
1000	Site 1	6	UP	40C Soak	1.1
2000	Site 1	6	UP	40C Soak	2.1
4000	Site 1	6	UP	40C Soak	3.0
8000	Site 1	6	UP	40C Soak	3.8

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 2	1	FM	40C Dry	0.0
500	Site 2	1	FM	40C Dry	0.8
1000	Site 2	1	FM	40C Dry	1.8
2000	Site 2	1	FM	40C Dry	2.6
4000	Site 2	1	FM	40C Dry	3.6
8000	Site 2	1	FM	40C Dry	4.8
0	Site 2	2	FM	40C Dry	0.0
500	Site 2	2	FM	40C Dry	1.1
1000	Site 2	2	FM	40C Dry	2.3
2000	Site 2	2	FM	40C Dry	3.2
4000	Site 2	2	FM	40C Dry	4.3
8000	Site 2	2	FM	40C Dry	5.7
0	Site 2	6	UniChem	40C Dry	0.0
500	Site 2	6	UniChem	40C Dry	1.9
1000	Site 2	6	UniChem	40C Dry	3.1
2000	Site 2	6	UniChem	40C Dry	4.3
4000	Site 2	6	UniChem	40C Dry	5.7
8000	Site 2	6	UniChem	40C Dry	7.4
0	Site 2	7	UniChem	40C Dry	0.0
500	Site 2	7	UniChem	40C Dry	1.2
1000	Site 2	7	UniChem	40C Dry	2.1
2000	Site 2	7	UniChem	40C Dry	3.2
4000	Site 2	7	UniChem	40C Dry	4.3
8000	Site 2	7	UniChem	40C Dry	5.7
0	Site 2	8	UP	40C Dry	0.0
500	Site 2	8	UP	40C Dry	1.2
1000	Site 2	8	UP	40C Dry	2.3
2000	Site 2	8	UP	40C Dry	3.3
4000	Site 2	8	UP	40C Dry	4.7
8000	Site 2	8	UP	40C Dry	5.7
0	Site 2	9	UP	40C Dry	0.0
500	Site 2	9	UP	40C Dry	1.0
1000	Site 2	9	UP	40C Dry	2.1
2000	Site 2	9	UP	40C Dry	2.7
4000	Site 2	9	UP	40C Dry	4.6
8000	Site 2	9	UP	40C Dry	5.6

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 2	4	UniChem	40C Soak	0.0
500	Site 2	4	UniChem	40C Soak	1.5
1000	Site 2	4	UniChem	40C Soak	2.3
2000	Site 2	4	UniChem	40C Soak	3.2
4000	Site 2	4	UniChem	40C Soak	4.0
8000	Site 2	4	UniChem	40C Soak	4.8
0	Site 2	5	UniChem	40C Soak	0.0
500	Site 2	5	UniChem	40C Soak	1.7
1000	Site 2	5	UniChem	40C Soak	2.3
2000	Site 2	5	UniChem	40C Soak	3.3
4000	Site 2	5	UniChem	40C Soak	4.4
8000	Site 2	5	UniChem	40C Soak	5.2
0	Site 2	4	UP	40C Soak	0.0
500	Site 2	4	UP	40C Soak	3.1
1000	Site 2	4	UP	40C Soak	3.0
2000	Site 2	4	UP	40C Soak	4.0
4000	Site 2	4	UP	40C Soak	5.3
8000	Site 2	4	UP	40C Soak	6.6
0	Site 2	5	UP	40C Soak	0.0
500	Site 2	5	UP	40C Soak	1.3
1000	Site 2	5	UP	40C Soak	2.2
2000	Site 2	5	UP	40C Soak	3.2
4000	Site 2	5	UP	40C Soak	4.3
8000	Site 2	5	UP	40C Soak	5.5
0	Site 2	4	FM	40C Soak	0.0
500	Site 2	4	FM	40C Soak	1.9
1000	Site 2	4	FM	40C Soak	2.8
2000	Site 2	4	FM	40C Soak	4.2
4000	Site 2	4	FM	40C Soak	5.2
8000	Site 2	4	FM	40C Soak	6.3
0	Site 2	3	FM	40C Soak	0.0
500	Site 2	3	FM	40C Soak	1.5
1000	Site 2	3	FM	40C Soak	2.3
2000	Site 2	3	FM	40C Soak	3.8
4000	Site 2	3	FM	40C Soak	4.9
8000	Site 2	3	FM	40C Soak	6.0

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 3	3	Adhere	40C Dry	0.0
500	Site 3	3	Adhere	40C Dry	0.4
1000	Site 3	3	Adhere	40C Dry	0.7
2000	Site 3	3	Adhere	40C Dry	1.2
4000	Site 3	3	Adhere	40C Dry	1.8
8000	Site 3	3	Adhere	40C Dry	2.6
0	Site 3	4	Adhere	40C Dry	0.0
500	Site 3	4	Adhere	40C Dry	0.3
1000	Site 3	4	Adhere	40C Dry	0.5
2000	Site 3	4	Adhere	40C Dry	0.8
4000	Site 3	4	Adhere	40C Dry	1.4
8000	Site 3	4	Adhere	40C Dry	2.1
0	Site 3	1	PBS	40C Dry	0.0
500	Site 3	1	PBS	40C Dry	0.5
1000	Site 3	1	PBS	40C Dry	0.7
2000	Site 3	1	PBS	40C Dry	1.4
4000	Site 3	1	PBS	40C Dry	2.5
8000	Site 3	1	PBS	40C Dry	3.5
0	Site 3	2	PBS	40C Dry	0.0
500	Site 3	2	PBS	40C Dry	0.4
1000	Site 3	2	PBS	40C Dry	0.5
2000	Site 3	2	PBS	40C Dry	0.9
4000	Site 3	2	PBS	40C Dry	1.2
8000	Site 3	2	PBS	40C Dry	2.2
0	Site 3	1	FM	40C Dry	0.0
500	Site 3	1	FM	40C Dry	0.4
1000	Site 3	1	FM	40C Dry	0.5
2000	Site 3	1	FM	40C Dry	0.7
4000	Site 3	1	FM	40C Dry	1.1
8000	Site 3	1	FM	40C Dry	1.8
0	Site 3	2	FM	40C Dry	0.0
500	Site 3	2	FM	40C Dry	0.0
1000	Site 3	2	FM	40C Dry	0.0
2000	Site 3	2	FM	40C Dry	0.0
4000	Site 3	2	FM	40C Dry	0.3
8000	Site 3	2	FM	40C Dry	0.5

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 3	3	FM	40C Soak	0.0
500	Site 3	3	FM	40C Soak	0.2
1000	Site 3	3	FM	40C Soak	0.4
2000	Site 3	3	FM	40C Soak	0.5
4000	Site 3	3	FM	40C Soak	0.6
8000	Site 3	3	FM	40C Soak	0.7
0	Site 3	4	FM	40C Soak	0.0
500	Site 3	4	FM	40C Soak	0.2
1000	Site 3	4	FM	40C Soak	0.3
2000	Site 3	4	FM	40C Soak	0.5
4000	Site 3	4	FM	40C Soak	0.6
8000	Site 3	4	FM	40C Soak	0.8
0	Site 3	1	Adhere	40C Soak	0.0
500	Site 3	1	Adhere	40C Soak	0.4
1000	Site 3	1	Adhere	40C Soak	0.9
2000	Site 3	1	Adhere	40C Soak	1.7
4000	Site 3	1	Adhere	40C Soak	2.3
8000	Site 3	1	Adhere	40C Soak	2.9
0	Site 3	2	Adhere	40C Soak	0.0
500	Site 3	2	Adhere	40C Soak	0.9
1000	Site 3	2	Adhere	40C Soak	1.2
2000	Site 3	2	Adhere	40C Soak	1.6
4000	Site 3	2	Adhere	40C Soak	2.1
8000	Site 3	2	Adhere	40C Soak	3.2
0	Site 3	4	PBS	40C Soak	0.0
500	Site 3	4	PBS	40C Soak	0.9
1000	Site 3	4	PBS	40C Soak	1.3
2000	Site 3	4	PBS	40C Soak	2.2
4000	Site 3	4	PBS	40C Soak	3.4
8000	Site 3	4	PBS	40C Soak	4.2
0	Site 3	3	PBS	40C Soak	0.0
500	Site 3	3	PBS	40C Soak	0.6
1000	Site 3	3	PBS	40C Soak	0.9
2000	Site 3	3	PBS	40C Soak	1.5
4000	Site 3	3	PBS	40C Soak	2.5
8000	Site 3	3	PBS	40C Soak	3.5

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 4	1	UP	40C Dry	0.0
500	Site 4	1	UP	40C Dry	0.4
1000	Site 4	1	UP	40C Dry	0.7
2000	Site 4	1	UP	40C Dry	1.1
4000	Site 4	1	UP	40C Dry	1.8
8000	Site 4	1	UP	40C Dry	3.2
0	Site 4	2	UP	40C Dry	0.0
500	Site 4	2	UP	40C Dry	0.4
1000	Site 4	2	UP	40C Dry	0.7
2000	Site 4	2	UP	40C Dry	1.0
4000	Site 4	2	UP	40C Dry	1.7
8000	Site 4	2	UP	40C Dry	3.0
0	Site 4	8	UniChem	40C Dry	0.0
500	Site 4	8	UniChem	40C Dry	0.5
1000	Site 4	8	UniChem	40C Dry	1.0
2000	Site 4	8	UniChem	40C Dry	1.7
4000	Site 4	8	UniChem	40C Dry	3.1
8000	Site 4	8	UniChem	40C Dry	4.4
0	Site 4	7	UniChem	40C Dry	0.0
500	Site 4	7	UniChem	40C Dry	0.7
1000	Site 4	7	UniChem	40C Dry	1.0
2000	Site 4	7	UniChem	40C Dry	1.7
4000	Site 4	7	UniChem	40C Dry	3.2
8000	Site 4	7	UniChem	40C Dry	4.8
0	Site 4	B	FM	40C Dry	0.0
500	Site 4	B	FM	40C Dry	0.2
1000	Site 4	B	FM	40C Dry	0.3
2000	Site 4	B	FM	40C Dry	0.5
4000	Site 4	B	FM	40C Dry	0.9
8000	Site 4	B	FM	40C Dry	1.7
0	Site 4	A	FM	40C Dry	0.0
500	Site 4	A	FM	40C Dry	0.1
1000	Site 4	A	FM	40C Dry	0.3
2000	Site 4	A	FM	40C Dry	0.4
4000	Site 4	A	FM	40C Dry	0.6
8000	Site 4	A	FM	40C Dry	1.0

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 4	D	FM	40C Soak	0.0
500	Site 4	D	FM	40C Soak	0.3
1000	Site 4	D	FM	40C Soak	0.4
2000	Site 4	D	FM	40C Soak	0.5
4000	Site 4	D	FM	40C Soak	0.6
8000	Site 4	D	FM	40C Soak	1.4
0	Site 4	C	FM	40C Soak	0.0
500	Site 4	C	FM	40C Soak	0.5
1000	Site 4	C	FM	40C Soak	0.6
2000	Site 4	C	FM	40C Soak	0.7
4000	Site 4	C	FM	40C Soak	*
8000	Site 4	C	FM	40C Soak	1.7
0	Site 4	5	UniChem	40C Soak	0.0
500	Site 4	5	UniChem	40C Soak	0.9
1000	Site 4	5	UniChem	40C Soak	1.2
2000	Site 4	5	UniChem	40C Soak	1.8
4000	Site 4	5	UniChem	40C Soak	2.8
8000	Site 4	5	UniChem	40C Soak	3.7
0	Site 4	6	UniChem	40C Soak	0.0
500	Site 4	6	UniChem	40C Soak	0.8
1000	Site 4	6	UniChem	40C Soak	1.7
2000	Site 4	6	UniChem	40C Soak	1.9
4000	Site 4	6	UniChem	40C Soak	3.4
8000	Site 4	6	UniChem	40C Soak	4.4
0	Site 4	4	UP	40C Soak	0.0
500	Site 4	4	UP	40C Soak	0.8
1000	Site 4	4	UP	40C Soak	1.4
2000	Site 4	4	UP	40C Soak	1.9
4000	Site 4	4	UP	40C Soak	3.1
8000	Site 4	4	UP	40C Soak	4.2
0	Site 4	3	UP	40C Soak	0.0
500	Site 4	3	UP	40C Soak	0.9
1000	Site 4	3	UP	40C Soak	1.3
2000	Site 4	3	UP	40C Soak	1.8
4000	Site 4	3	UP	40C Soak	3.0
8000	Site 4	3	UP	40C Soak	4.3

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 5	2	Klg-Beta	40C Dry	0.0
500	Site 5	2	Klg-Beta	40C Dry	1.3
1000	Site 5	2	Klg-Beta	40C Dry	1.5
2000	Site 5	2	Klg-Beta	40C Dry	1.7
4000	Site 5	2	Klg-Beta	40C Dry	1.8
8000	Site 5	2	Klg-Beta	40C Dry	2.4
0	Site 5	1	Klg-Beta	40C Dry	0.0
500	Site 5	1	Klg-Beta	40C Dry	1.2
1000	Site 5	1	Klg-Beta	40C Dry	1.5
2000	Site 5	1	Klg-Beta	40C Dry	1.9
4000	Site 5	1	Klg-Beta	40C Dry	2.0
8000	Site 5	1	Klg-Beta	40C Dry	2.6
0	Site 5	3	Adhere	40C Dry	0.0
500	Site 5	3	Adhere	40C Dry	0.6
1000	Site 5	3	Adhere	40C Dry	1.2
2000	Site 5	3	Adhere	40C Dry	1.9
4000	Site 5	3	Adhere	40C Dry	2.5
8000	Site 5	3	Adhere	40C Dry	3.5
0	Site 5	3	FM	40C Dry	0.0
500	Site 5	3	FM	40C Dry	0.8
1000	Site 5	3	FM	40C Dry	1.2
2000	Site 5	3	FM	40C Dry	1.7
4000	Site 5	3	FM	40C Dry	2.1
8000	Site 5	3	FM	40C Dry	3.0
0	Site 5	1	Adhere	40C Soak	0.0
500	Site 5	1	Adhere	40C Soak	0.7
1000	Site 5	1	Adhere	40C Soak	1.5
2000	Site 5	1	Adhere	40C Soak	1.9
4000	Site 5	1	Adhere	40C Soak	2.6
8000	Site 5	1	Adhere	40C Soak	3.3
0	Site 5	2	Adhere	40C Soak	0.0
500	Site 5	2	Adhere	40C Soak	0.9
1000	Site 5	2	Adhere	40C Soak	1.3
2000	Site 5	2	Adhere	40C Soak	1.8
4000	Site 5	2	Adhere	40C Soak	2.6
8000	Site 5	2	Adhere	40C Soak	3.5

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 5	3	Klg-Beta	40C Soak	0.0
500	Site 5	3	Klg-Beta	40C Soak	0.7
1000	Site 5	3	Klg-Beta	40C Soak	1.4
2000	Site 5	3	Klg-Beta	40C Soak	1.9
4000	Site 5	3	Klg-Beta	40C Soak	2.6
8000	Site 5	3	Klg-Beta	40C Soak	3.2
0	Site 5	4	Klg-Beta	40C Soak	0.0
500	Site 5	4	Klg-Beta	40C Soak	0.9
1000	Site 5	4	Klg-Beta	40C Soak	1.2
2000	Site 5	4	Klg-Beta	40C Soak	1.7
4000	Site 5	4	Klg-Beta	40C Soak	2.3
8000	Site 5	4	Klg-Beta	40C Soak	2.9
0	Site 5	1	FM	40C Soak	0.0
500	Site 5	1	FM	40C Soak	0.5
1000	Site 5	1	FM	40C Soak	1.5
2000	Site 5	1	FM	40C Soak	2.1
4000	Site 5	1	FM	40C Soak	2.9
8000	Site 5	1	FM	40C Soak	3.8
0	Site 5	2	FM	40C Soak	0.0
500	Site 5	2	FM	40C Soak	0.8
1000	Site 5	2	FM	40C Soak	1.3
2000	Site 5	2	FM	40C Soak	2.7
4000	Site 5	2	FM	40C Soak	2.9
8000	Site 5	2	FM	40C Soak	3.7
0	Site 6A	17	3024	40C Dry	0.0
500	Site 6A	17	3024	40C Dry	0.5
1000	Site 6A	17	3024	40C Dry	0.8
2000	Site 6A	17	3024	40C Dry	1.1
4000	Site 6A	17	3024	40C Dry	1.7
8000	Site 6A	17	3024	40C Dry	2.4
0	Site 6A	18	3024	40C Dry	0.0
500	Site 6A	18	3024	40C Dry	0.4
1000	Site 6A	18	3024	40C Dry	0.6
2000	Site 6A	18	3024	40C Dry	0.7
4000	Site 6A	18	3024	40C Dry	0.9
8000	Site 6A	18	3024	40C Dry	1.4

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 6A	12	2912	40C Dry	0.0
500	Site 6A	12	2912	40C Dry	0.4
1000	Site 6A	12	2912	40C Dry	0.6
2000	Site 6A	12	2912	40C Dry	0.9
4000	Site 6A	12	2912	40C Dry	1.2
8000	Site 6A	12	2912	40C Dry	1.8
0	Site 6A	11	2912	40C Dry	0.0
500	Site 6A	11	2912	40C Dry	0.3
1000	Site 6A	11	2912	40C Dry	0.5
2000	Site 6A	11	2912	40C Dry	0.7
4000	Site 6A	11	2912	40C Dry	1.1
8000	Site 6A	11	2912	40C Dry	1.8
0	Site 6A	16	3024	40C Soak	0.0
500	Site 6A	16	3024	40C Soak	0.5
1000	Site 6A	16	3024	40C Soak	0.7
2000	Site 6A	16	3024	40C Soak	1.0
4000	Site 6A	16	3024	40C Soak	1.7
8000	Site 6A	16	3024	40C Soak	2.6
0	Site 6A	15	3024	40C Soak	0.0
500	Site 6A	15	3024	40C Soak	0.4
1000	Site 6A	15	3024	40C Soak	0.6
2000	Site 6A	15	3024	40C Soak	0.7
4000	Site 6A	15	3024	40C Soak	1.2
8000	Site 6A	15	3024	40C Soak	2.0
0	Site 6A	13	2912	40C Soak	0.0
500	Site 6A	13	2912	40C Soak	0.7
1000	Site 6A	13	2912	40C Soak	1.0
2000	Site 6A	13	2912	40C Soak	1.4
4000	Site 6A	13	2912	40C Soak	2.0
8000	Site 6A	13	2912	40C Soak	2.5
0	Site 6A	14	2912	40C Soak	0.0
500	Site 6A	14	2912	40C Soak	0.6
1000	Site 6A	14	2912	40C Soak	0.8
2000	Site 6A	14	2912	40C Soak	1.2
4000	Site 6A	14	2912	40C Soak	1.7
8000	Site 6A	14	2912	40C Soak	2.4

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 6A	M	2700	40C Dry	0.0
500	Site 6A	M	2700	40C Dry	0.9
1000	Site 6A	M	2700	40C Dry	1.5
2000	Site 6A	M	2700	40C Dry	2.6
4000	Site 6A	M	2700	40C Dry	3.8
8000	Site 6A	M	2700	40C Dry	5.0
0	Site 6A	L	2700	40C Dry	0.0
500	Site 6A	L	2700	40C Dry	0.6
1000	Site 6A	L	2700	40C Dry	1.2
2000	Site 6A	L	2700	40C Dry	2.1
4000	Site 6A	L	2700	40C Dry	3.1
8000	Site 6A	L	2700	40C Dry	4.6
0	Site 6A	O	3024	40C Dry	0.0
500	Site 6A	O	3024	40C Dry	0.6
1000	Site 6A	O	3024	40C Dry	1.2
2000	Site 6A	O	3024	40C Dry	2.0
4000	Site 6A	O	3024	40C Dry	2.8
8000	Site 6A	O	3024	40C Dry	4.0
0	Site 6A	N	3024	40C Dry	0.0
500	Site 6A	N	3024	40C Dry	0.7
1000	Site 6A	N	3024	40C Dry	1.3
2000	Site 6A	N	3024	40C Dry	2.0
4000	Site 6A	N	3024	40C Dry	3.2
8000	Site 6A	N	3024	40C Dry	4.3
0	Site 6A	Q	3024	40C Soak	0.0
500	Site 6A	Q	3024	40C Soak	1.2
1000	Site 6A	Q	3024	40C Soak	1.8
2000	Site 6A	Q	3024	40C Soak	2.6
4000	Site 6A	Q	3024	40C Soak	3.7
8000	Site 6A	Q	3024	40C Soak	4.5
0	Site 6A	P	3024	40C Soak	0.0
500	Site 6A	P	3024	40C Soak	1.2
1000	Site 6A	P	3024	40C Soak	1.9
2000	Site 6A	P	3024	40C Soak	2.7
4000	Site 6A	P	3024	40C Soak	3.7
8000	Site 6A	P	3024	40C Soak	4.4

Table A-2 (Con't.). APA Rut Depths for Samples With Anti-Strip Agents.

Cycles	Site #	Sample	Additive	Conditioning	Average Rut Depth (mm)
0	Site 6A	J	2700	40C Soak	0.0
500	Site 6A	J	2700	40C Soak	1.1
1000	Site 6A	J	2700	40C Soak	1.9
2000	Site 6A	J	2700	40C Soak	3.1
4000	Site 6A	J	2700	40C Soak	4.5
8000	Site 6A	J	2700	40C Soak	5.1
0	Site 6A	K	2700	40C Soak	0.0
500	Site 6A	K	2700	40C Soak	1.3
1000	Site 6A	K	2700	40C Soak	2.4
2000	Site 6A	K	2700	40C Soak	3.5
4000	Site 6A	K	2700	40C Soak	5.0
8000	Site 6A	K	2700	40C Soak	5.9
0	Site 7	3	FM	40C Dry	0.0
500	Site 7	3	FM	40C Dry	2.3
1000	Site 7	3	FM	40C Dry	3.6
2000	Site 7	3	FM	40C Dry	4.5
4000	Site 7	3	FM	40C Dry	5.5
8000	Site 7	3	FM	40C Dry	7.1
0	Site 7	4	FM	40C Dry	0.0
500	Site 7	4	FM	40C Dry	2.4
1000	Site 7	4	FM	40C Dry	3.6
2000	Site 7	4	FM	40C Dry	4.6
4000	Site 7	4	FM	40C Dry	5.7
8000	Site 7	4	FM	40C Dry	7.1
0	Site 7	1	FM	40C Soak	0.0
500	Site 7	1	FM	40C Soak	0.8
1000	Site 7	1	FM	40C Soak	1.4
2000	Site 7	1	FM	40C Soak	2.5
4000	Site 7	1	FM	40C Soak	3.5
8000	Site 7	1	FM	40C Soak	4.2
0	Site 7	2	FM	40C Soak	0.0
500	Site 7	2	FM	40C Soak	0.9
1000	Site 7	2	FM	40C Soak	1.5
2000	Site 7	2	FM	40C Soak	2.4
4000	Site 7	2	FM	40C Soak	3.5
8000	Site 7	2	FM	40C Soak	4.3

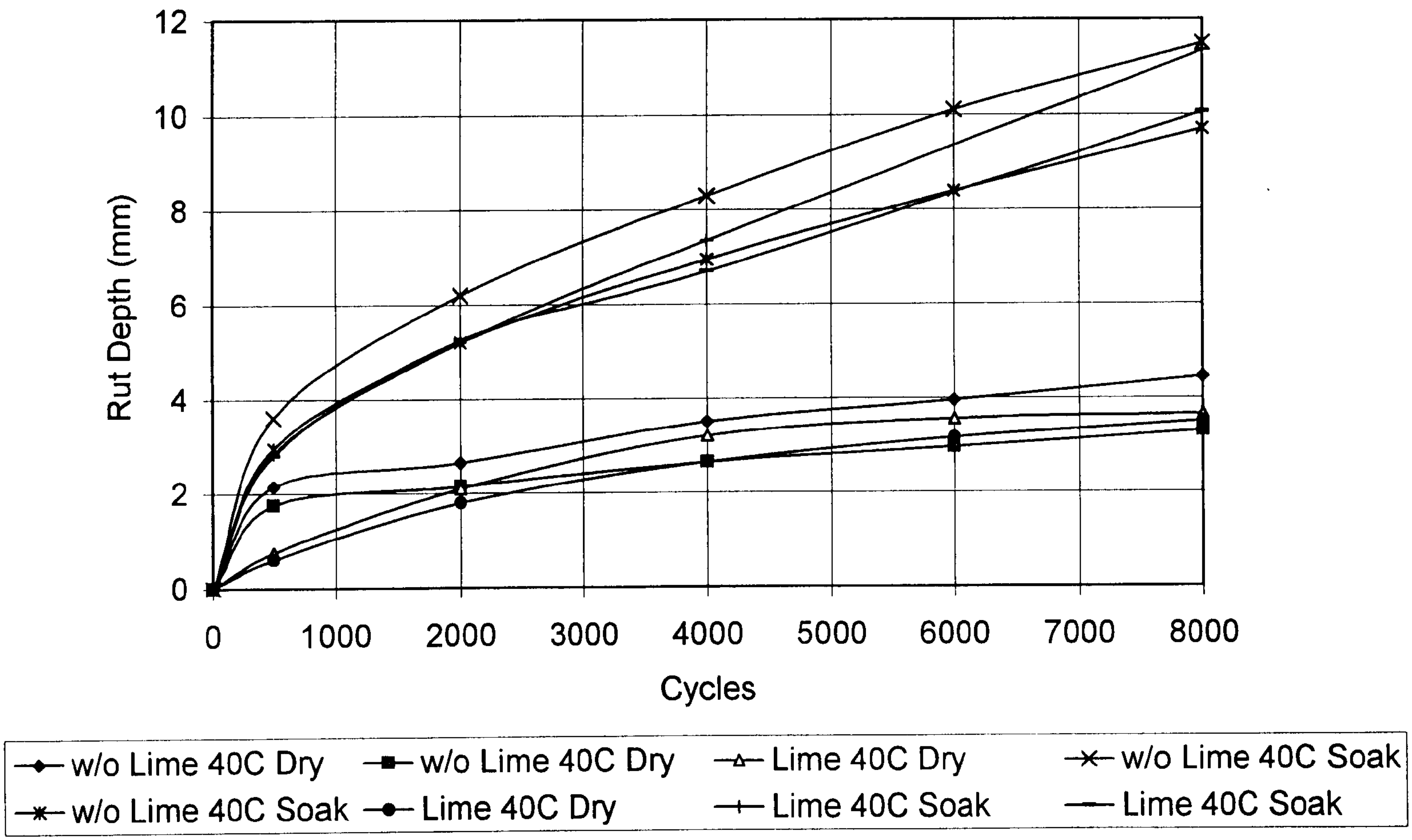

Figure A-1. Site 1 : Rutting Curves.

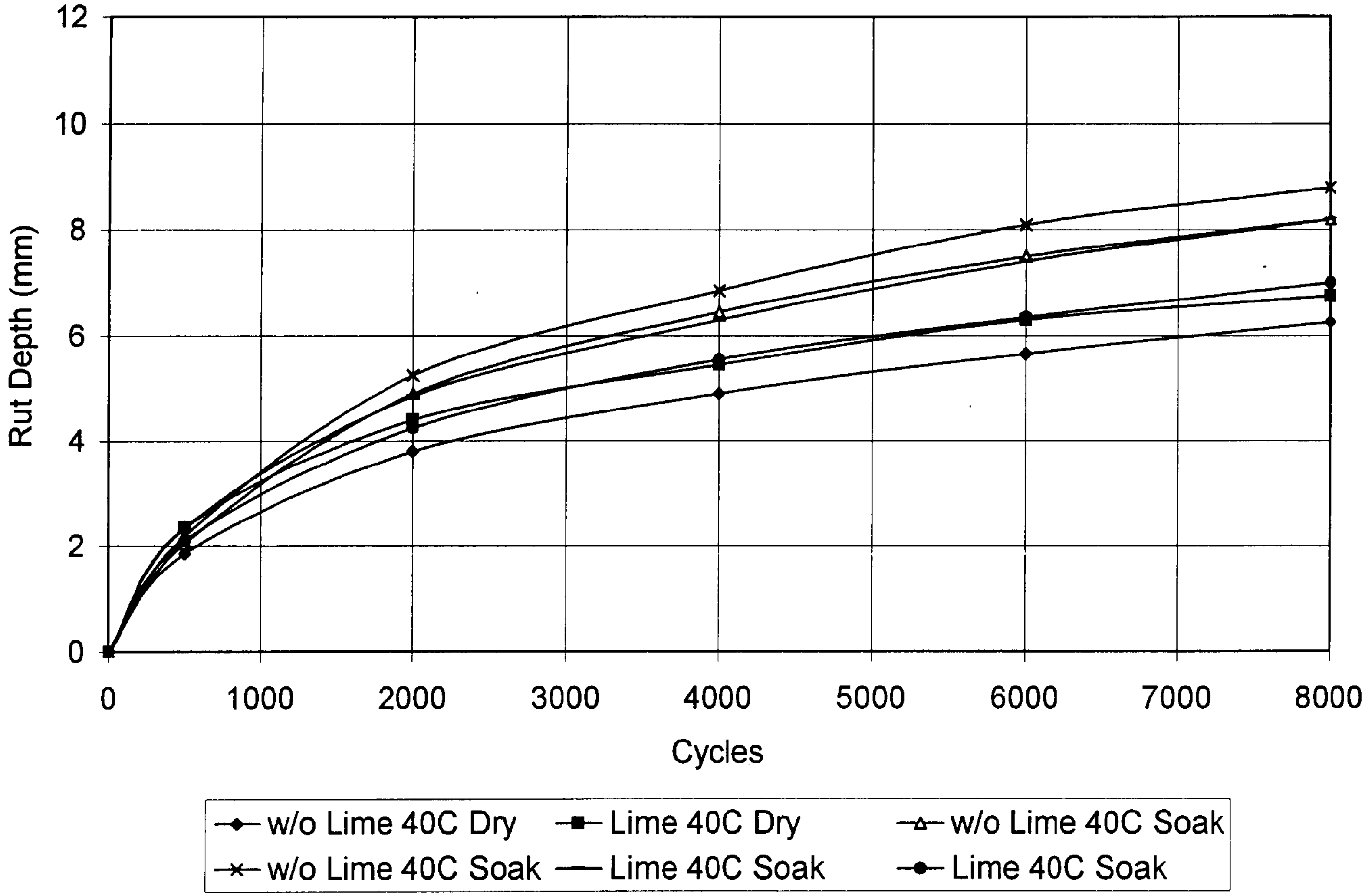

Figure A-2. Site 2 : Rutting Curves.

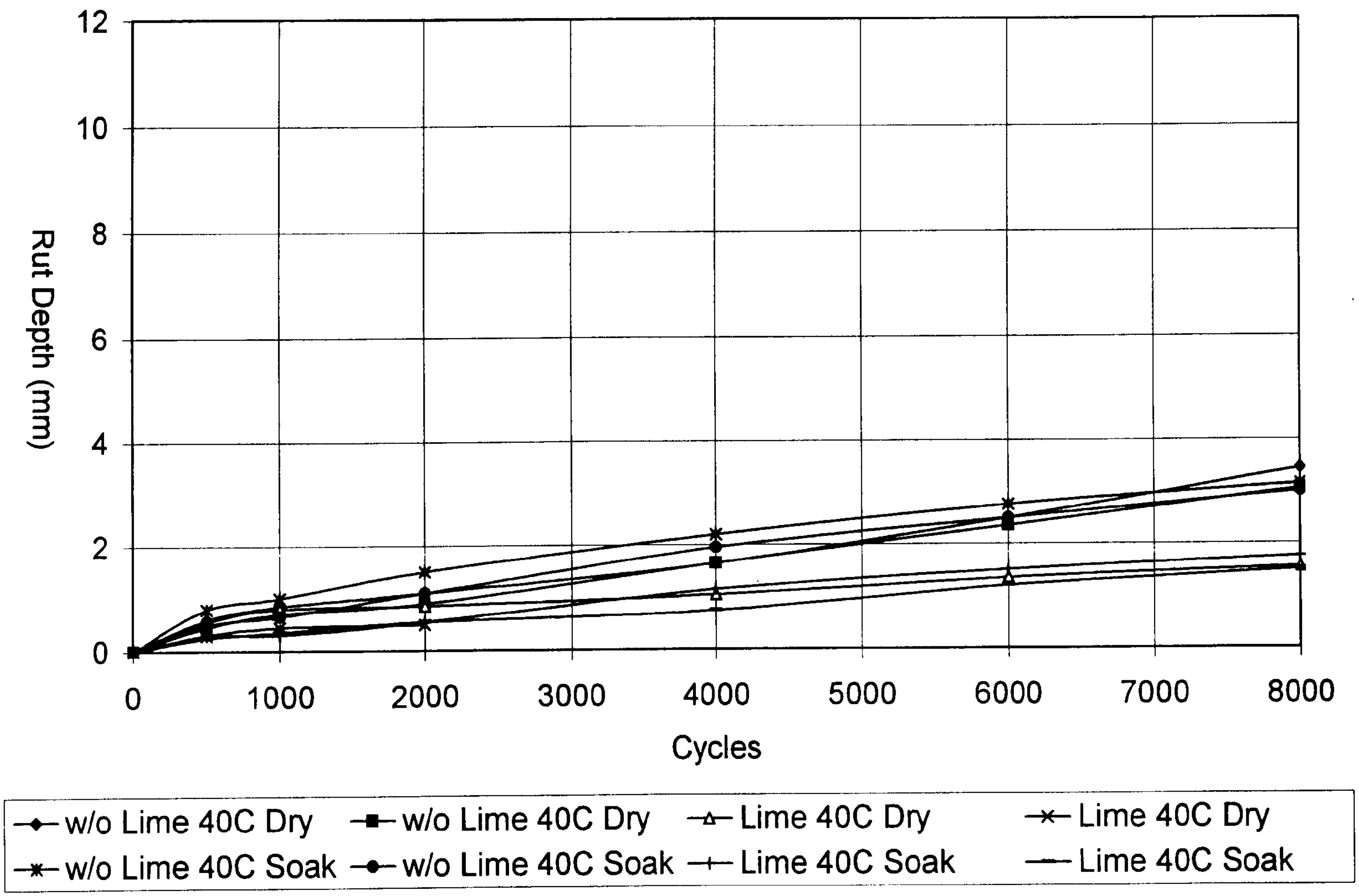

Figure A-3. Site 3 : Rutting Curves.

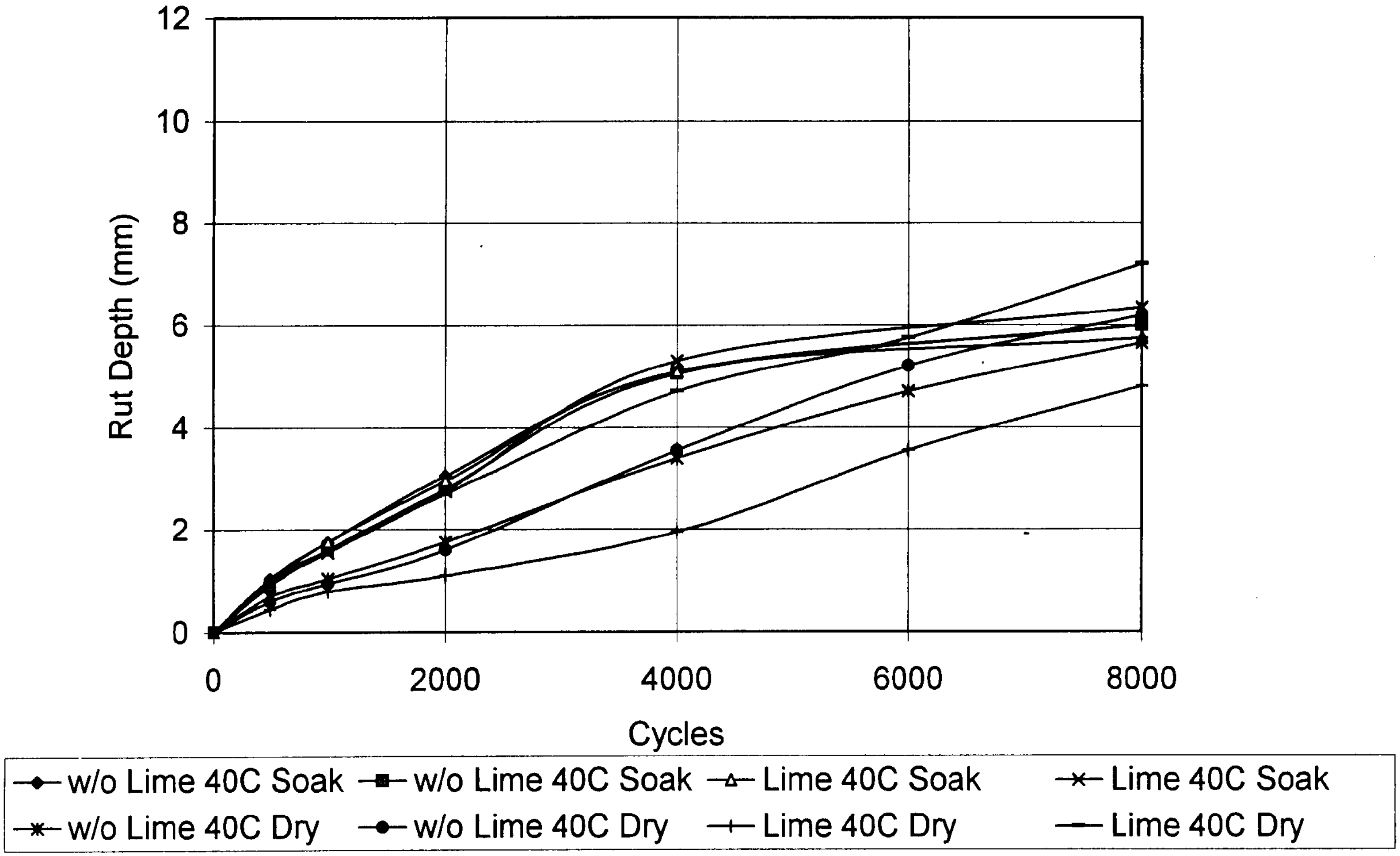

Figure A-4. Site 4 : Rutting Curves.

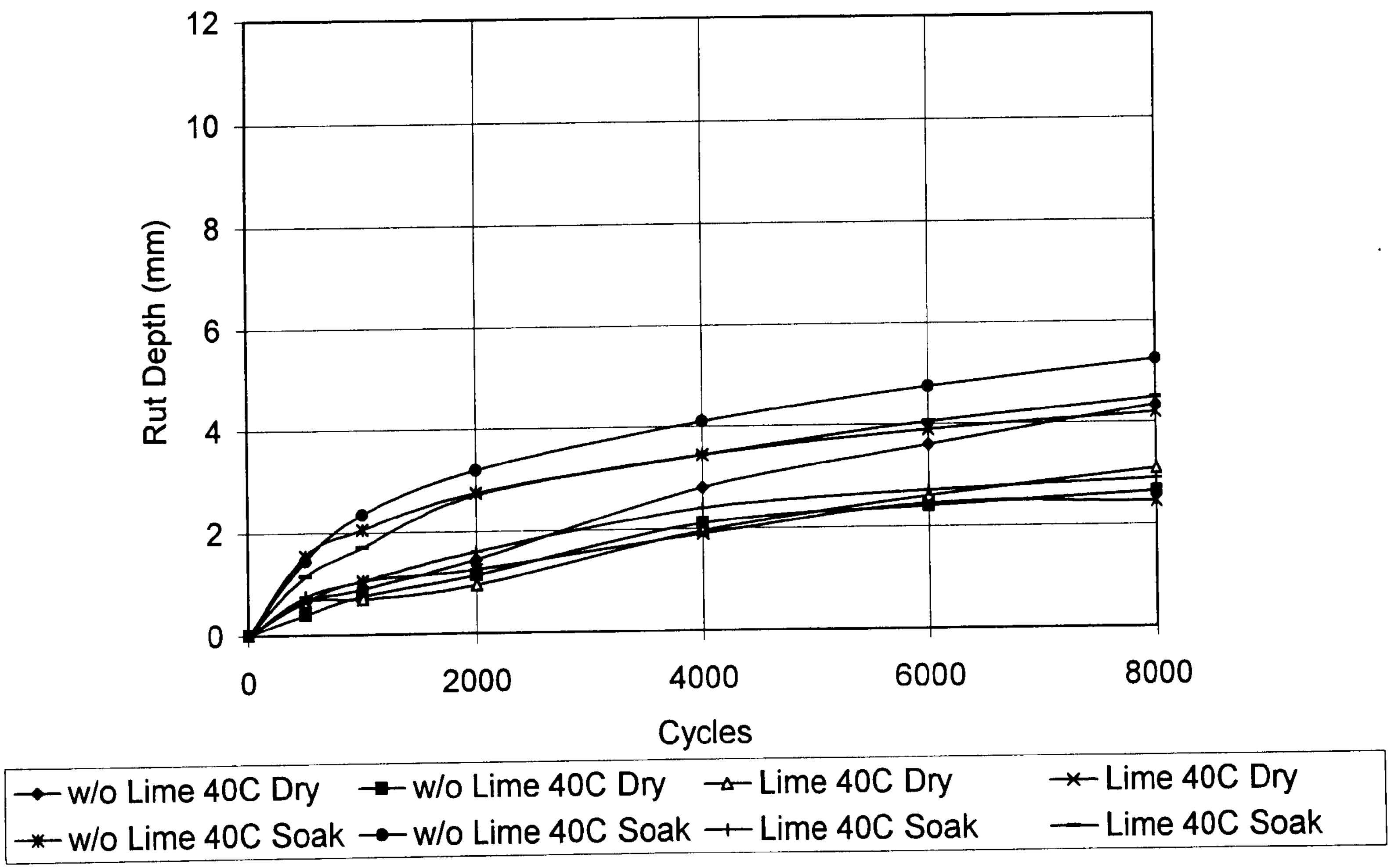

Figure A-5. Site 5 : Rutting Curves.

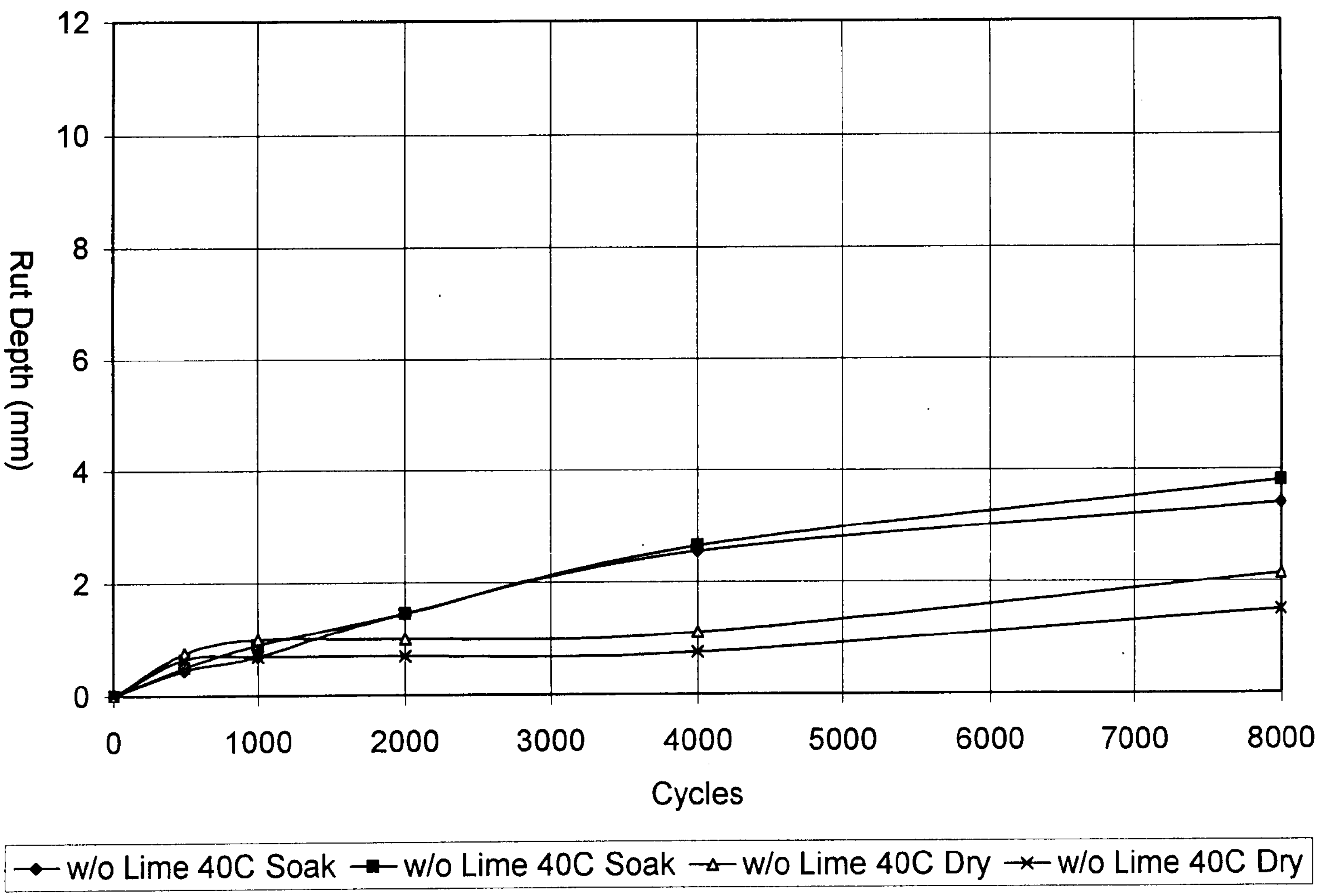

Figure A-6. Site 6A : Rutting Curves.

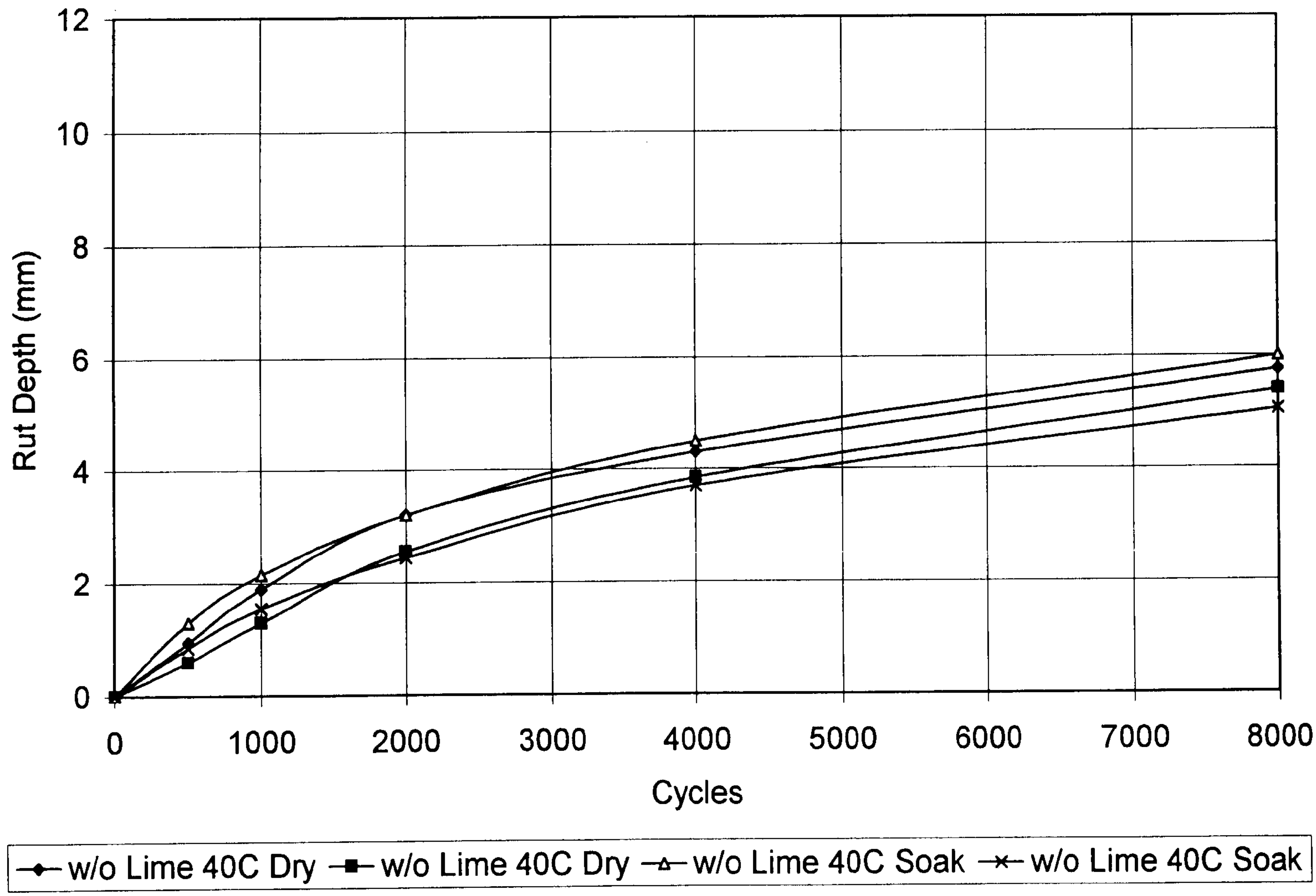

Figure A-7. Site 6B : Rutting Curves.

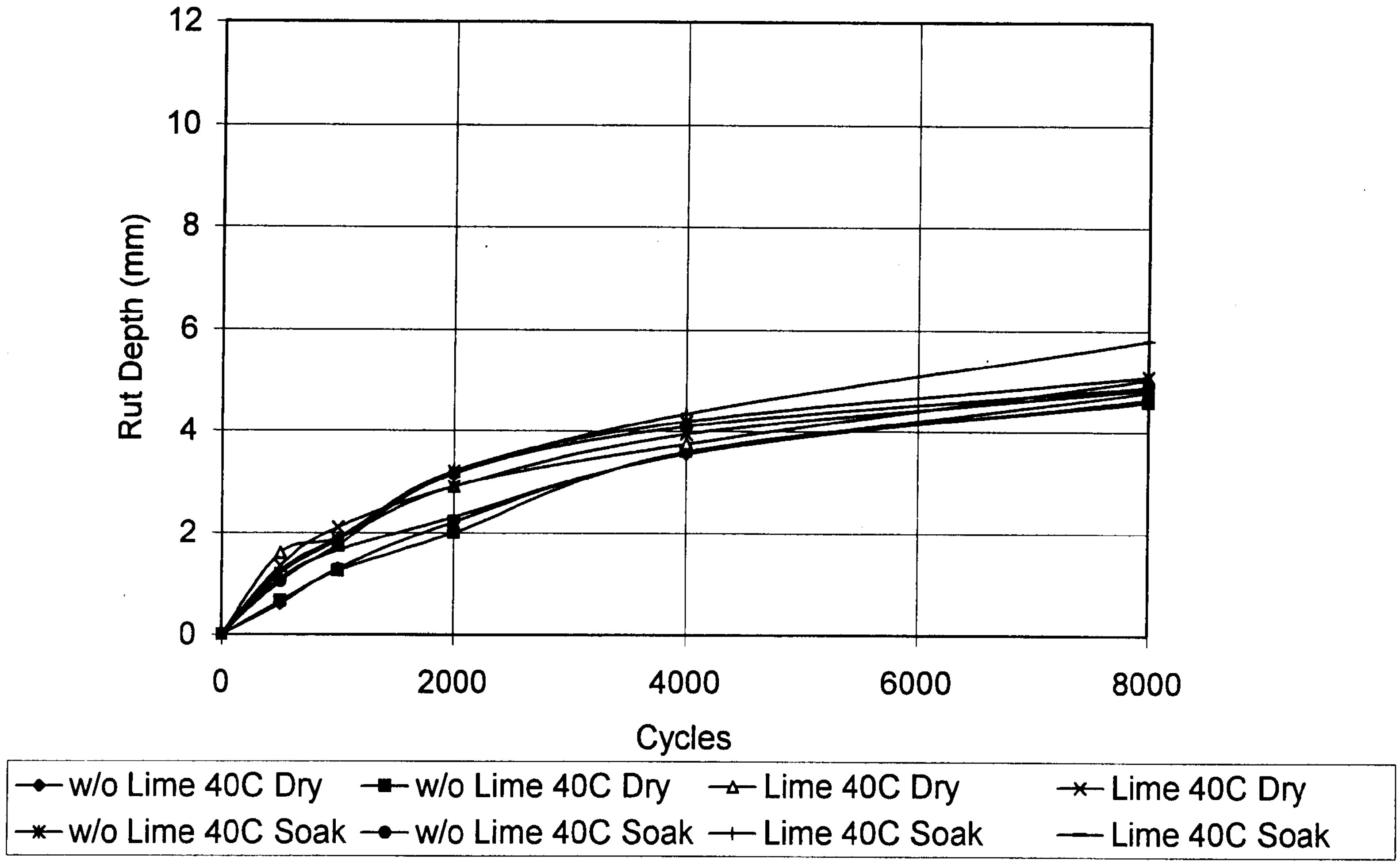

Figure A-8. Site 7 : Rutting Curves.

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AND
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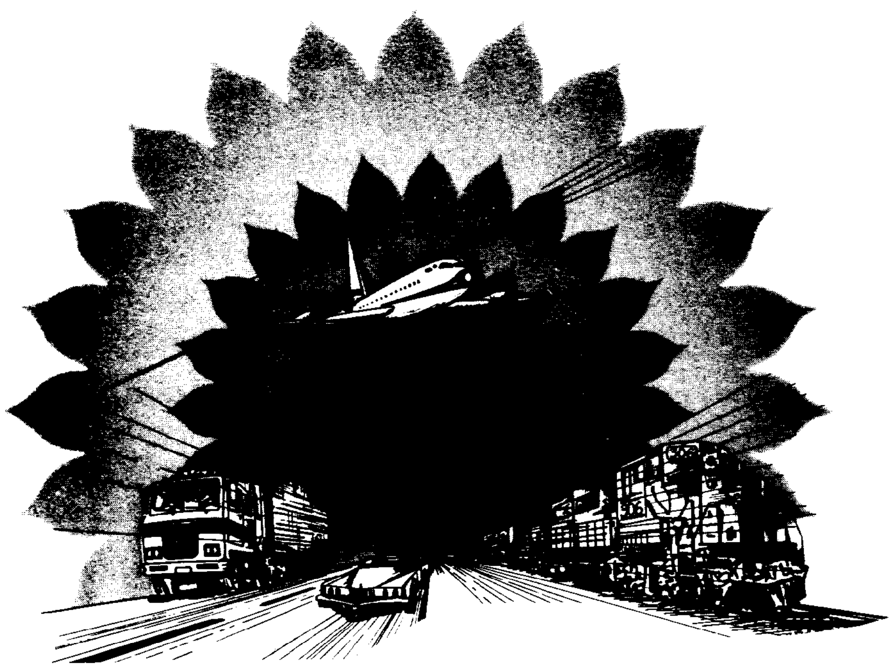

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:

KANSAS DEPARTMENT OF TRANSPORTATION

THE KANSAS STATE UNIVERSITY

THE UNIVERSITY OF KANSAS