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16. Abstract

Preliminary work has been completed in an attempt to devise a satisfactory test program to identify water susceptible asphalt paving mixtures. Two different water treatment methods have been applied to one asphalt-aggregate. Five different antistripping additives were evaluated by comparison to control specimens containing no additive. Common laboratory tests were employed to evaluate mixture strength, stiffness and stability before and after exposure to moisture.

Tensile strength of mixtures appears to be the best measure of water susceptibility. Resilient modulus shows much potential as a predictor of moisture susceptible mixtures.

Generally, hydrated lime added to the aggregate as a slurry seems to offer the best protection from moisture damage.

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DEVELOPMENTAL WORK ON A TEST PROCEDURE TO IDENTIFY WATER SUSCEPTIBLE ASPHALT MIXTURES

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Economic Asphalt Treated Bases
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PREFACE

This report describes preliminary work undertaken to develop a simple laboratory test procedure to evaluate the water susceptibility of asphalt paving mixtures. One asphalt mixture was combined with several antistripping additives and exposed to moisture using two different techniques. Several common tests were conducted to quantify any changes in mixture strength and stability.

This is the first in a series of reports from Study 2-9-80-287 entitled "Desirable Asphalt Properties". The study, sponsored by the State Department of Highways and Public Transportation in cooperation with the Federal Highway Administration, is a comprehensive program to investigate methods of altering asphalt properties to improve performance and to develop test methods that define desirable asphalt properties.

DISCLAIMER

IMPLEMENTATION STATEMENT

Either of the two methods employed to expose the asphalt mixture to moisture caused degradation of the specimen structural capacity. Further, all of the antistripping additives utilized in this study imparted greater resistance to moisture damage to the asphalt mixture tested.

The simplicity of identifying and reducing moisture damage of asphalt paving mixtures has been demonstrated. Recommendations have been made to commence testing of all mixtures for water susceptibility and consider the incorporation of an appropriate anti-stripping additive, when required. This is based on current information that suggests an increase in water susceptibility of asphalt-aggregate mixtures in recent years.

TABLE OF CONTENTS

INTRODUCTION

A recent telephone survey of some 25 state highway materials engineers was conducted to determine the nature of changes in asphalt properties, if any, and how they affect short term pavement performance (1). Although no statistics have been computed, the single most severe and most often occurring asphalt problem mentioned in this survey was water susceptibility. Most of the engineers mentioning water susceptibility as a problem indicated that its occurrence had increased in recent years. Let it be quickly added that water susceptibility of asphalt paving mixtures is not always (and probably not even usually) the fault of the asphalt, but many times is related to the quality of the aggregate or the incompatibility of the two.

Water susceptibility of asphalt paving mixtures will be defined for the purposes of this study as the reduction of structural capacity resulting from moisture-induced damage. Problems associated with water-damage are various and often not easily detected by visual observation. Nevertheless, moisture may cause rapid deterioration of asphaltic concrete pavements as a result of loss of mechanical properties. Pavement serviceability can be significantly reduced because of increased deflections and higher tensile stresses and strains which lead to surface cracking and rutting.

Test procedures used to determine the water susceptibility of asphalt cement mixtures have been, for the most part, subjective in nature and strongly dependent on the judgement of the individuals making the evaluation. Several research efforts have been directed toward establishing a laboratory test procedure that will enable the engineer to predict the moisture susceptibility of asphaltic concrete pavements based on mechanical performance of representative specimens (2, 3, 4, 5). Some promising results have been obtained.

The primary purpose of this study was to utilize standard test methods of the Texas State Department of Highways and Public Transportation (SDHPT) as well as certain non-standard tests and determine their suitability in a simple procedure for establishing water susceptibility of laboratory prepared specimens. A secondary objective was to compare the effectiveness of several commonly used antistripping additives.

This limited study was conducted in two phases. In the first phase, a total of 54 specimens with relatively low air voids were tested. The second phase consisted of a similar test program with specimens containing significantly higher air voids. Only one aggregate, a siliceous subrounded gravel, and one asphalt were used to fabricate the test specimens. All specimens were compacted using the gyratory molding press. Tests included Hveem and Marshall stabilities, resilient modulus and splitting tensile tests before and after two different moisture treatment procedures, namely, the Lottman procedure (4) and a simple vacuum saturation plus seven-day soak procedure.

Of the tests conducted, tensile strength appears to offer the most promise in predicting moisture susceptibility of asphalt paving mixtures. The Lottman procedure may predict long term performance whereas the seven-day soak procedure gives an indication of short term performance. Hydrated lime in the paving mixtures gave better protection against moisture damage than any of the liquid additives utilized in this study.

The resilient modulus test is simple, nondestructive and relatively inexpensive. One of the most encouraging outcomes of this work is the demonstrated potential of the resilient modulus test to identify moisture susceptibility of mixtures.

DESCRIPTION OF EXPERIMENTAL PROGRAM

MATERIALS

Aggregate

The aggregate used throughout this test program was a subrounded siliceous river gravel which has been selected as a Texas A&M University laboratory standard aggregate (6). Standard sieves were used to separate the aggregate into fractions sized from 3/4 in. to minus No. 200 mesh. Then the various aggregate sizes were recombined according to the ASTM D3515-77 5A dense grading specification.

Asphalt

The asphalt cement, also a laboratory standard material (6), was produced by vacuum reduction by the American Petrofina Company at their Mt. Pleasant, Texas, refinery in 1976 and labeled AC-10. It does not, however, meet Texas specifications for AC-10. A description of these materials is given in Appendix A.

Additives

Antistripping additives utilized in this research study included hydrated lime and three commercially available liquid additives.

One and one-half percent lime was added to the aggregate prior to mixing with asphalt using two different techniques: 1) dry and 2) wet, form of a slurry.

One percent (by weight of asphalt) of the liquid additives was added to the asphalt cement prior to mixing with the aggregate.

PREPARATION OF TEST SPECIMENS

Asphalt cement and aggregate were combined at 300°F (150°C) and blended in a mechanical mixer. Optimum asphalt content for this aggregate and gradation had been previously determined to be 3.8 percent by weight of dry aggregate (6), which was used throughout this test program. Compaction of the test specimens was conducted at 250°F (121°C) in accordance with Texas SDHPT Test Method TEX-206-F, Part II, "Motorized Gyratory - Shear Molding Press Operating Procedure".

The first set of test specimens was determined to have an average air void content of about 2 percent, which was not considered to be realistic. Therefore, the molding procedure was modified to exert less compactive effort and a second set of specimens was produced containing 7 to 8 percent air voids. Air void content of this latter set of specimens is more realistic when compared to a newly placed pavement. Each set of specimens was subjected to a similar testing program.

Specimen preparation and testing will be discussed in two phases. Phase I involves the specimens containing about 2 percent air voids while Phase II involves those containing 7 to 8 percent air voids.

Nine specimens containing each additive and nine specimens with no additive (control specimens) were fabricated using the aforementioned procedures. A total of 54 specimens were prepared for each phase of the project. These 4-in. diameter specimens were approximately 2-in. in height and weighed approximately 1,000 grams.

TESTING PROCEDURES

Figure 1 gives the basic outline of the laboratory testing program. When the specimens were sufficiently cool, the bulk specific gravity of each specimen was determined in accordance with ASTM D2726. After one week of curing at room temperature, the resilient modulus, M_R, was determined for each specimen at 77°F (25°C) using the Mark III Resilient Modulus Device developed by Schmidt (7).

Phase I

Following the M_R tests, three specimens of each type (total of 18) were randomly selected and subjected to the splitting tensile test (indirect tension) (8) at 77°F (25°C) and a deformation rate of 2 inches per minute. Hveem stability of the remaining six specimens of each type was determined in accordance with SDHPT Test Method TEX-208-F and the Resistance (R-value) was obtained at 140°F (60°C) using the Texas Cell Calibration and California Test Method, Calif. 301-F Part V (a modification of ASTM D2844-69). These six specimens were then divided into two groups (three specimens of each type in each group) and subjected to two different moisture treatment procedures: 1) A modified Lottman procedure (2, 4) involving vacuum saturation of the specimens then eighteen freeze-thaw cycles followed by resilient modulus test, Hveem tests, and splitting tensile tests (Figure 2); and 2) the Texas A&M University vacuum saturation and 7-day soak procedure centered around the resilient modulus test before, during and after vacuum saturation and soaking in water at 77°F (25°C) for 7 days; then, after drying the

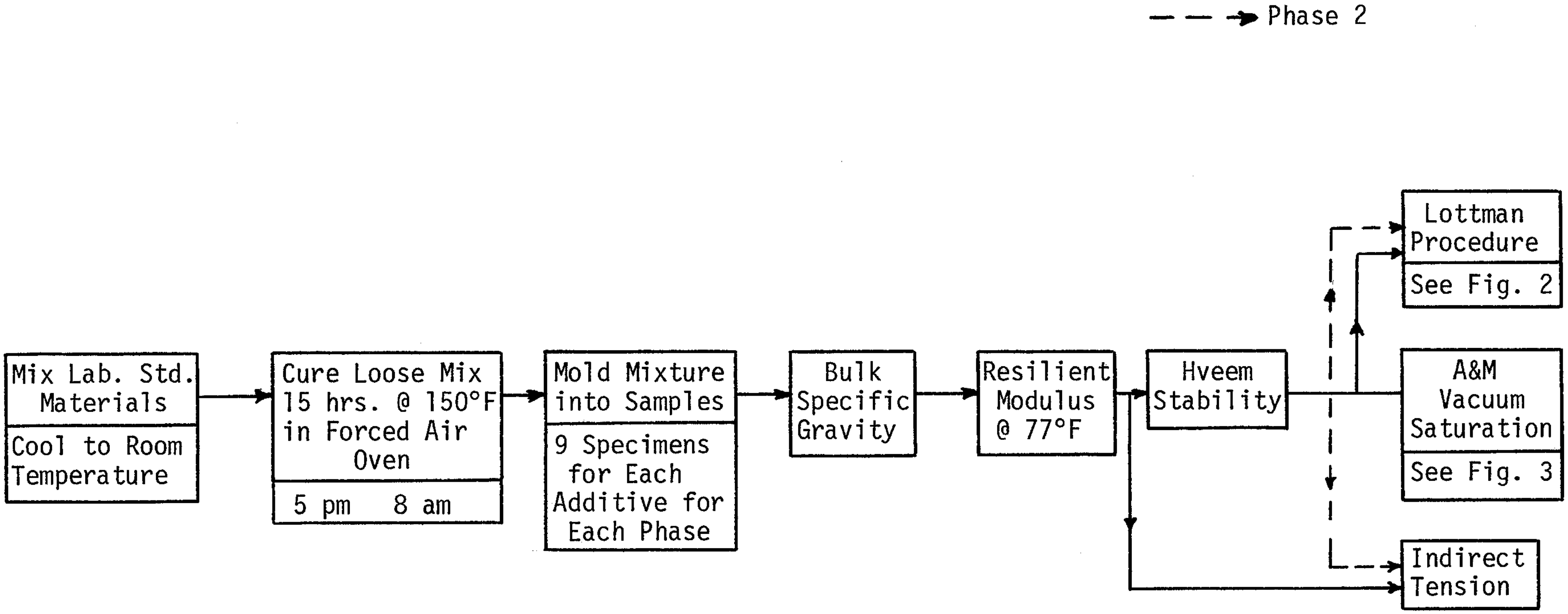

Figure 1. Test Program for Moisture Damage Evaluation in Phase I.

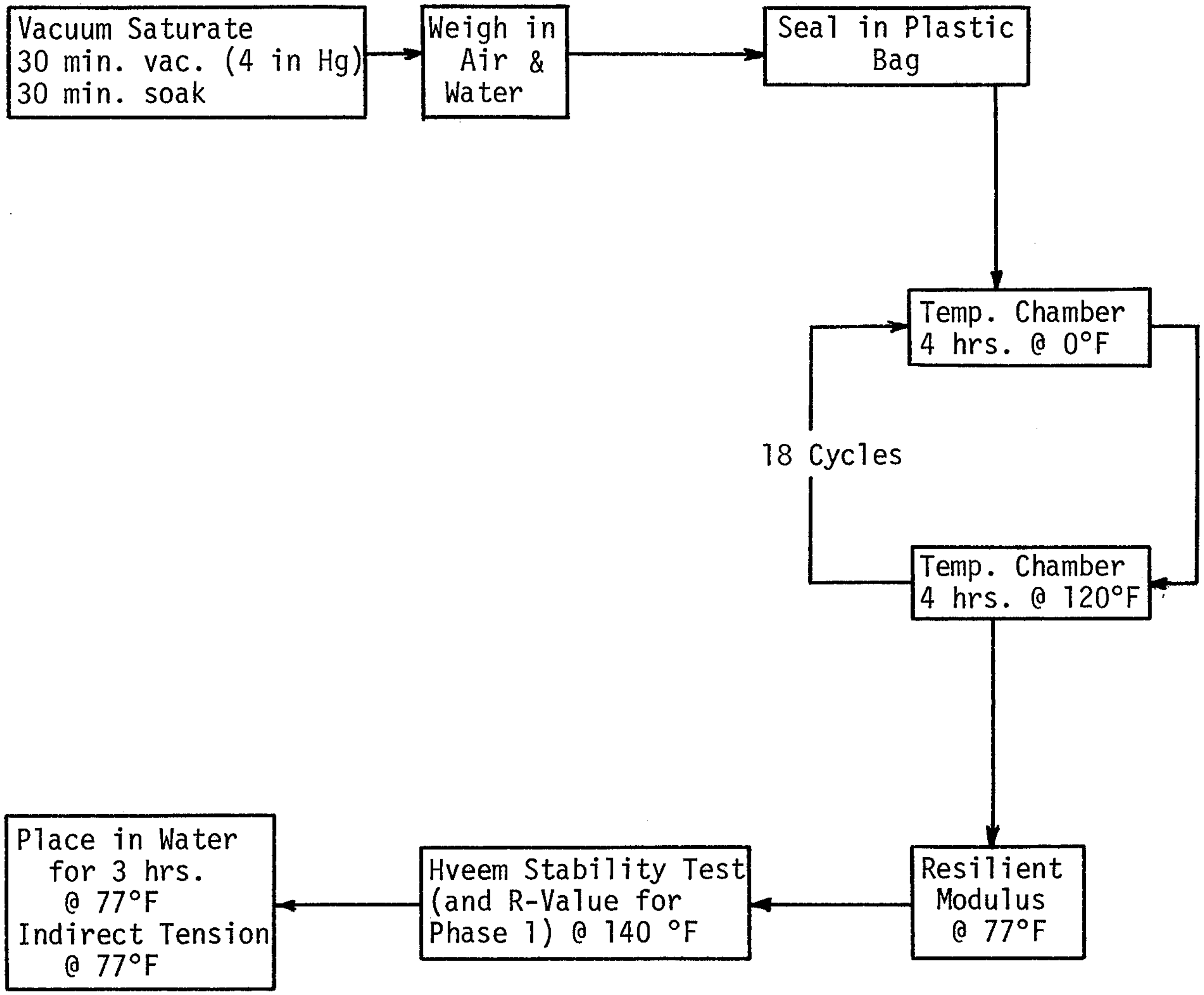

Figure 2. Lottman Moisture Treatment Procedure.

samples to constant weight (which required 9 additional days at 100°F (38°C) resilient modulus, Hveem stability and tensile properties of the specimens were determined (Figure 3).

Phase II

After the original resilient modulus determination, all 54 samples were subjected to the Hveem stability test as in Phase I. However, the R-value determination was eliminated. Specimens were randomly divided into 3 groups of 18 (3 of each type) and tested as shown in Figures 1, 2 and 3. It should be noted that in Phase II the specimens subjected to the vacuum saturation and 7-day soak treatment were not dried to constant weight after the soaking period. The drying procedure used in Phase I resulted in significant gains in strength and stiffness of the specimens which caused problems in analysis of the data.

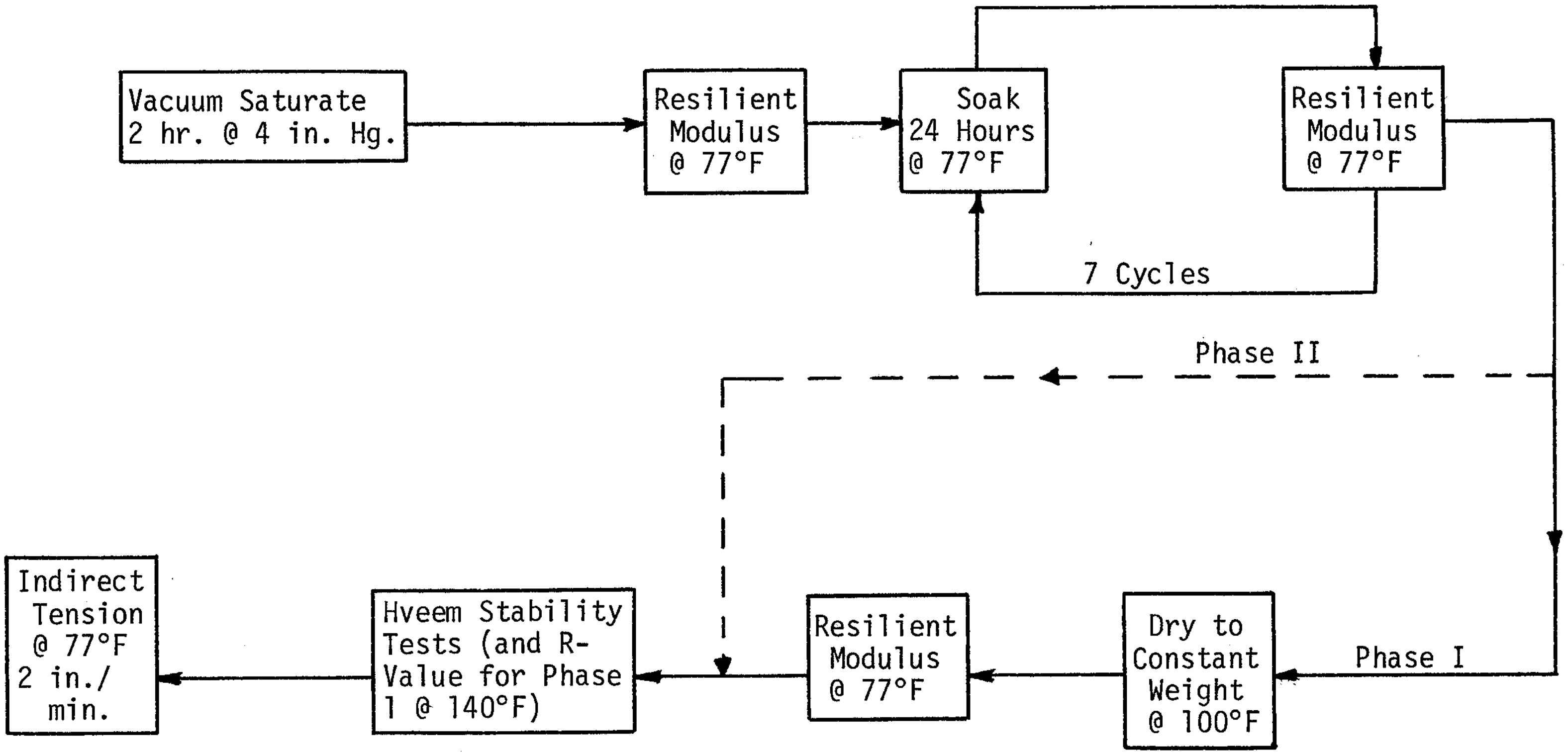

Figure 3. Texas A&M Vacuum Saturation and Seven-Day Soak Procedure.

DISCUSSION OF TEST RESULTS

GENERAL

Statistical summaries (means, standard deviations, and coefficients of variation) of the data collected in this experimental program are presented in Tables B1 through B6, Appendix B, and the mean values are plotted in Figures 4 through 12. The magnitude of those values measuring structural capacity were shown to be significantly higher for the specimens with 2 percent air voids (Phase I) than their counterpart with 8 percent air voids (Phase II).

Moisture damage indexes, defined as the ratio of like values before and after moisture treatment, are given in Tables B7 and B8 for Phase I and Phase II, respectively. These values are measures of water susceptibility of the mixtures and can be used to compare the sensitivity of the different tests to structural damage of the specimens caused by moisture.

Generally, all the additives tested reduced the damage caused by exposure of the specimens to moisture. Hydrated lime, particularly when added in the form of a slurry, produced the best results.

TEST RESULTS PRIOR TO MOISTURE TREATMENT

Tables B1 and B2 contain data from tests conducted prior to any type of moisture treatment for Phases I and II, respectively. The bulk specific gravities and air void contents indicate excellent uniformity among the specimens within each phase. As expected, the magnitude of the values of the different tests were significantly higher for the specimens having the lower air void contents (Phase I).

The resilient modulus was noticeably greater for those specimens containing lime than for any of the others. This was probably caused by the action of the lime as a mineral filler (increasing effective viscosity of the asphalt) and possibly as a promoter of stronger bonds between aggregates and asphalt. Further, Schmidt (9) postulates that lime appears to form a separate, vert friable, crystalline lime-mortar bond between aggregate particles which seems to be synergistic with the binding action of asphalt. In general, resilient modulus of those specimens containing the liquid antistripping additives appeared to be somewhat higher than that of the control specimens, except for specimens containing Additive B in Phase II, which was only slightly lower.

Results from Hveem tests show the control specimens have the highest stabilities and the specimens containing lime slurry have the lowest stabilities. Hveem stability of the specimens in the original condition in Phase II were found to be erroneous and, unfortunately, were eliminated from the data set. The R-values obtained from the samples in Phase I were mutually similar in magnitude and, again, the control and lime slurry specimens revealed the highest and lowest values, respectively.

It appears that the initial tensile strength and tensile modulus are generally greatest for those specimens containing lime and Additive C and lowest for those containing Additives A and B and the control specimens (Tables B1 and B2). This relationship corresponds remarkably well with the data from the resilient modulus test.

TEST RESULTS AFTER MOISTURE TREATMENTS

Tables B3 and B4 give simple statistics of the test results after the Lottman procedure for Phases I and II, respectively. Tables B5 and B6 give similar values after the Texas A&M vacuum saturation and 7-day soak procedure.

Ratios, sometimes called moisture damage indexes, were computed by dividing each given value after moisture treatment by its corresponding original value prior to moisture treatment for example:

$$\text{Resilient Modulus Ratio} = \frac{M_R \text{ after moisture treatment}}{\text{Original } M_R \text{ of specimen}}$$

Several of these ratios are presented in Table B7 for Phase I and Table B8 for Phase II. Obviously, the larger the ratio the better the comparative performance of that particular mixture.

Graphical representation of the values obtained for the resilient moduli during the 7-day soak period and after the Lottman procedure is shown in Figures 4 (Phase I) and 5 (Phase II). All the specimens, after being soaked for 7 days, exhibited a decrease in resilient modulus. The control specimens showed the greatest decrease and the lime treated samples the least decrease. Figure 4 shows that after drying the specimens resilient modulus showed a significant rebound by the specimens containing lime, but those containing the three liquid antistripping agents showed little or no rebound and the control specimens actually showed a decrease in resilient modulus.

The Lottman moisture treatment caused a sharp drop in resilient modulus of specimens in Phase I (air void content of 2 percent); again, the control specimens were the most severely affected. In Phase II (8 percent voids), the Lottman procedure affected differently the resilient moduli of the various specimen types. Specimens containing lime and Additive A showed a surprising increase while the rest showed a decrease, with the control specimens most severely affected.

According to these results, the addition of lime, whether dry or in the form of slurry, significantly increases the stiffness of this asphalt concrete mixture both before and after moisture treatment which is probably due to its action as a mineral filler. The three commercially available additives did not appreciably affect the stiffness of the original specimens; however, specimens containing these liquid additives did retain resilient moduli better than the control specimens.

As expected, with 2 percent air voids, decreases in resilient moduli were greater after specimens were subjected to the Lottman treatment rather than after 7-day soak moisture treatment. It is interesting to note that with 8 percent air voids and use of additives, the 7-day soak treatment appears more detrimental to the resilient modulus than the Lottman procedure which is inconsistent with other test results reported herein. However, the results of the resilient moduli after the Lottman procedure are generally consistent with other test results. Resilient modulus of asphalt paving mixtures are very sensitive to small changes in temperature in the 77°F (25°C) temperature range. A difference of only 3 or 4°F could account for these abnormal values.

Results from the Hveem stability tests are very consistent within each phase but show different effects due to the two moisture treatment procedures between the two phases of the program. In Phase I, the stability decreased after being subjected to either treatment (Figure 6) and the ratios of before and after moisture treatment are lower for the specimens exposed to the 7-day soak procedure than for those exposed to the Lottman treatment. (The reader is reminded that those specimens subjected to the 7-day soak procedure were dryed to constant weight prior to Hveem testing whereas those subjected to the Lottman procedure were tested in the saturated condition.) For Phase II no initial values of Hveem stability are available but should be considered to be approximately thirty-five, as shown in Figure 7. The Hveem stability test (Figure 7) shows no consistent difference between specimens exposed to the two different moisture treatments. Neither are the Hveem results consistent with results from resilient modulus and indirect tension tests. For example, those specimens containing lime are shown to have the lowest retained Hveem stabilities, whereas, they always exhibited the highest retained resilient modulus and tensile properties. Since Hveem stability is related to interparticle shear resistance of the aggregates and apparently not dependent on the asphalt-aggregate bond, it is considered by the authors as unacceptable for identifying water susceptible asphalt paving mixtures.

The Resistance, R-values, (Figure 8) which were determined only in Phase I, are characterized by a lack of contrast between the initial values as well as those after the two moisture treatment procedures. Due to this lack of contrast the R-value is not considered to be a good estimator of water susceptibility.

Tensile properties are directly affected by the quality of the bond between aggregate and asphalt cement. Comparative tensile strength, measured here by the indirect method (splitting tensile test), would appear to be an excellent method to determine the water susceptibility of asphalt concrete mixtures. Acceptable criteria for retained tensile strength after a moisture treatment procedure have been set forth by R. P. Lottman (2). He claims a tensile strength ratio of 0.70 or higher indicates acceptable water susceptibility of an asphalt concrete mixture.

Applying this criterion to the test results, it is observed that the control specimens, in both phases, as well as samples containing Additive C in Phase I and Additive B in Phase II, are unacceptable (Tables 7 and 8). However, ratios can be misleading, in some cases, where the original values of strength and/or stiffness are significantly increased by the additive. Therefore, retained values of tensile strength and stiffness should be compared to the corresponding values of the control specimens in addition to observation of the ratios.

The tensile strength ratios obtained from specimens subjected to the 7-day soak procedure are in most cases greater than one. It should be remembered that all samples that were exposed to the 7-day soak treatment in Phase I were dried to constant weight before their tensile strength was measured and this drying process took nine days at 100°F (38°C). Results from this phase indicate the effectiveness of the additives in promiting healing in a weakened asphalt concrete mixture upon removal of the absorbed water (Figure 9, Table B7).

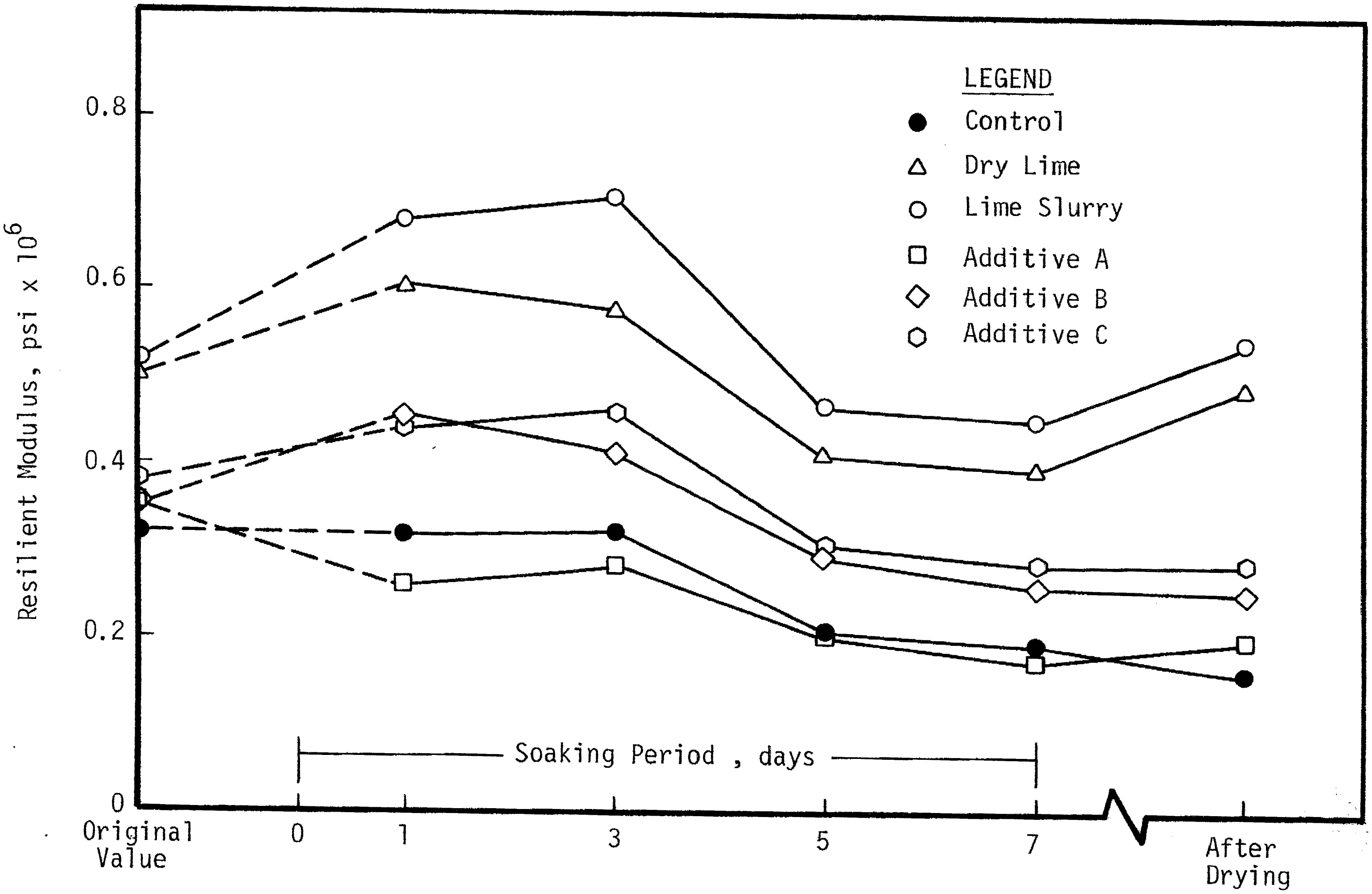

Figure 4. Resilient Modulus @ 77°F Before and After Moisture Treatments (Phase I).

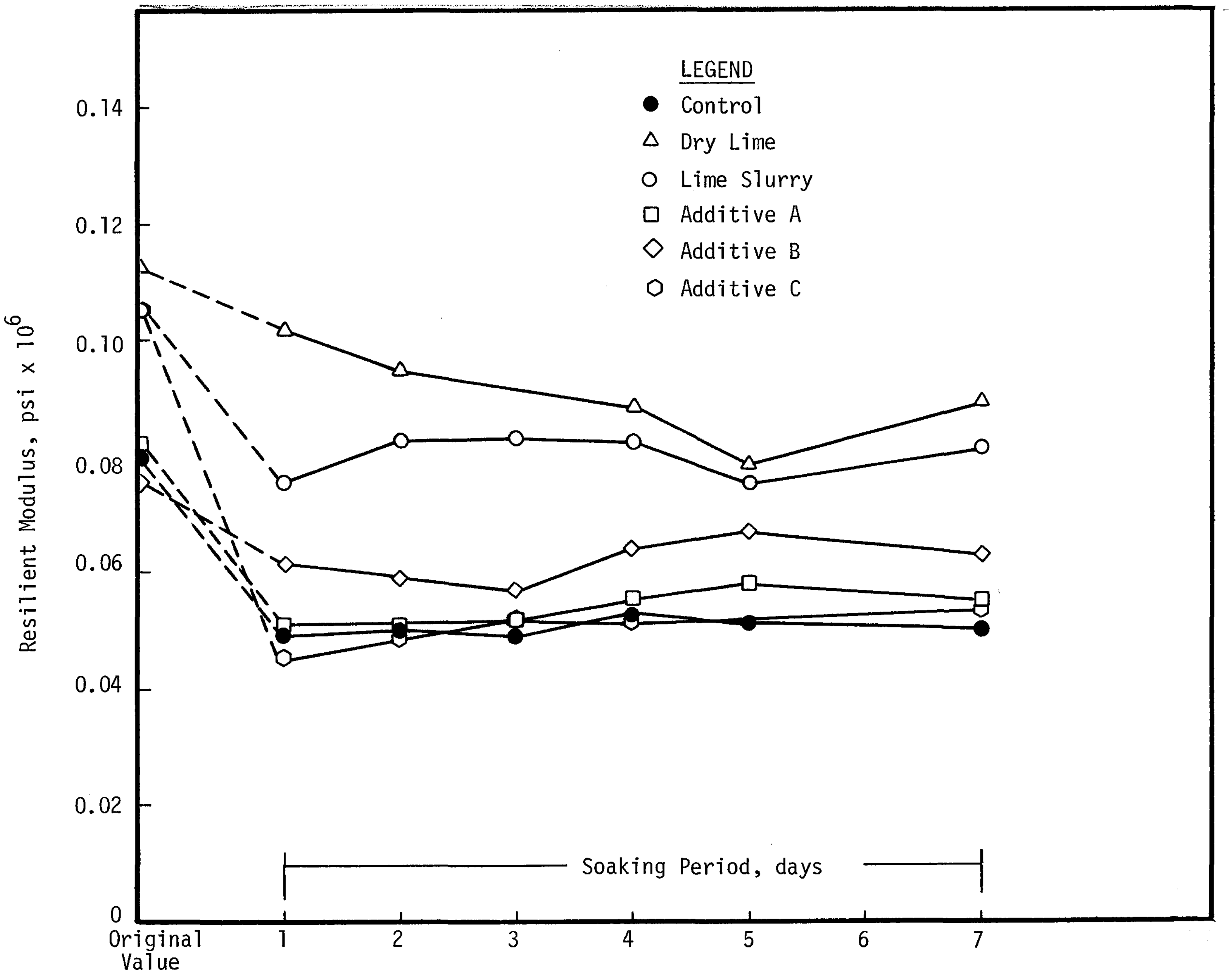

Figure 5 . Resilient Modulus @ 77°F Before and After Moisture Treatments (Phase II).
* Average Value for All Nine Specimens
** Three Specimens Different from Those Tested for M_R

In Phase II, the increase in tensile strength after the 7-day soak procedure (Figure 10) may have resulted from a temperature differential effected by cooling of the specimens due to evaporation of moisture from their surfaces just prior to and during testing, that is, assuming the soak procedure did not appreciably affect the tensile strength of the specimens. This effect may also be responsible for the increase in tensile strength of certain specimens after the Lottman procedure, assuming the lime slurry and Additive A afforded good protection from moisture damage.

Mean values of the secant moduli derived from the splitting tensile tests are plotted in Figures 11 and 12 for Phases I and II, respectively. As anticipated, the results are similar to those established by the tensile strength results, that is, ratios of before and after moisture exposure obtained from specimens subjected to the Lottman procedure are smaller than those obtained from samples exposed to the 7-day soak treatment (Tables 7 and 8). In fact, specimens containing antistripping additives, in Phase I, exhibited a very significant increase in secant modulus resulting from the exceptional gain in strength of the mixtures while drying.

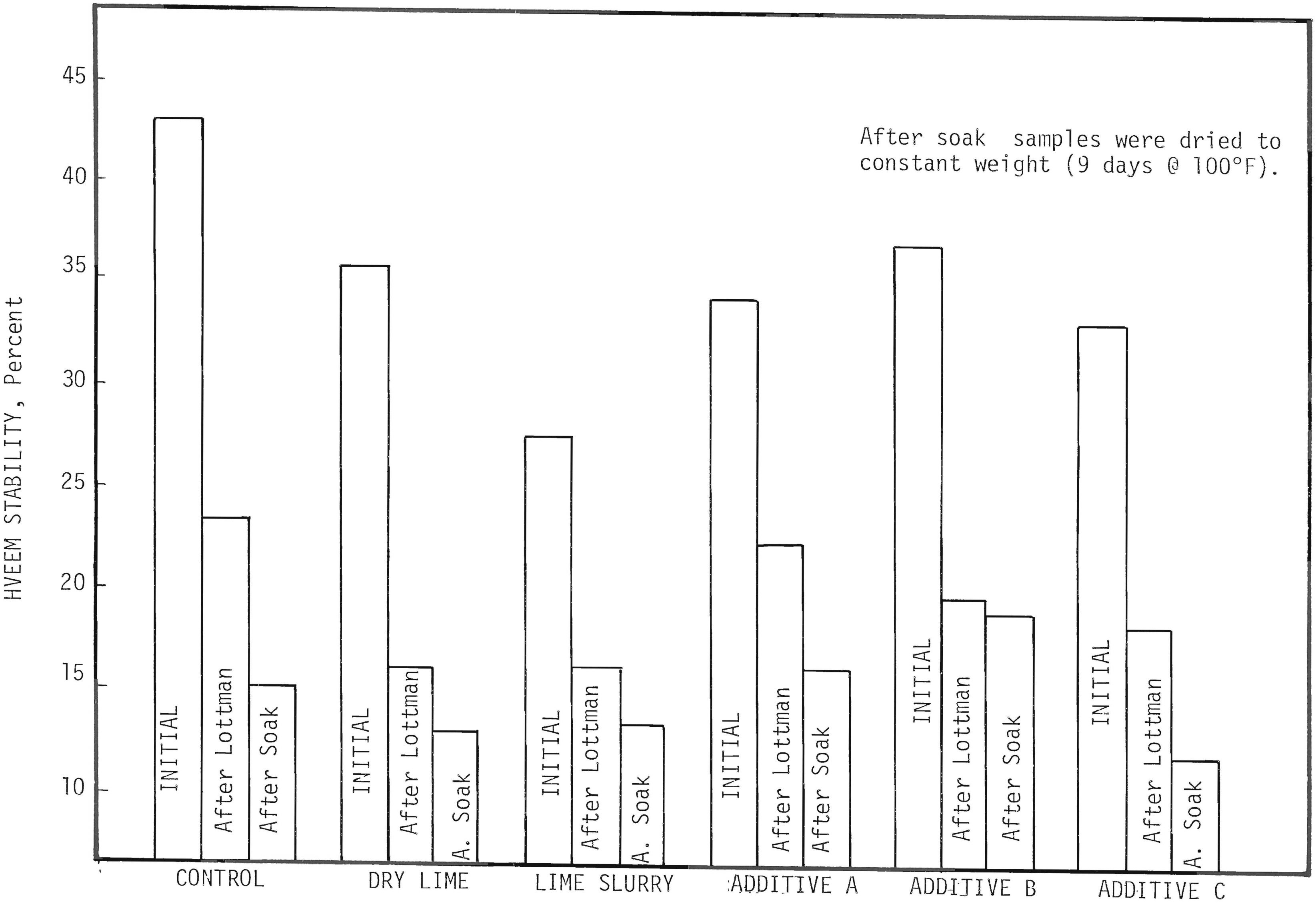

Figure 6. Hveem Stability Before and After Moisture Treatment (Phase I)
(Values after soak were obtained after drying specimens to constant weight)

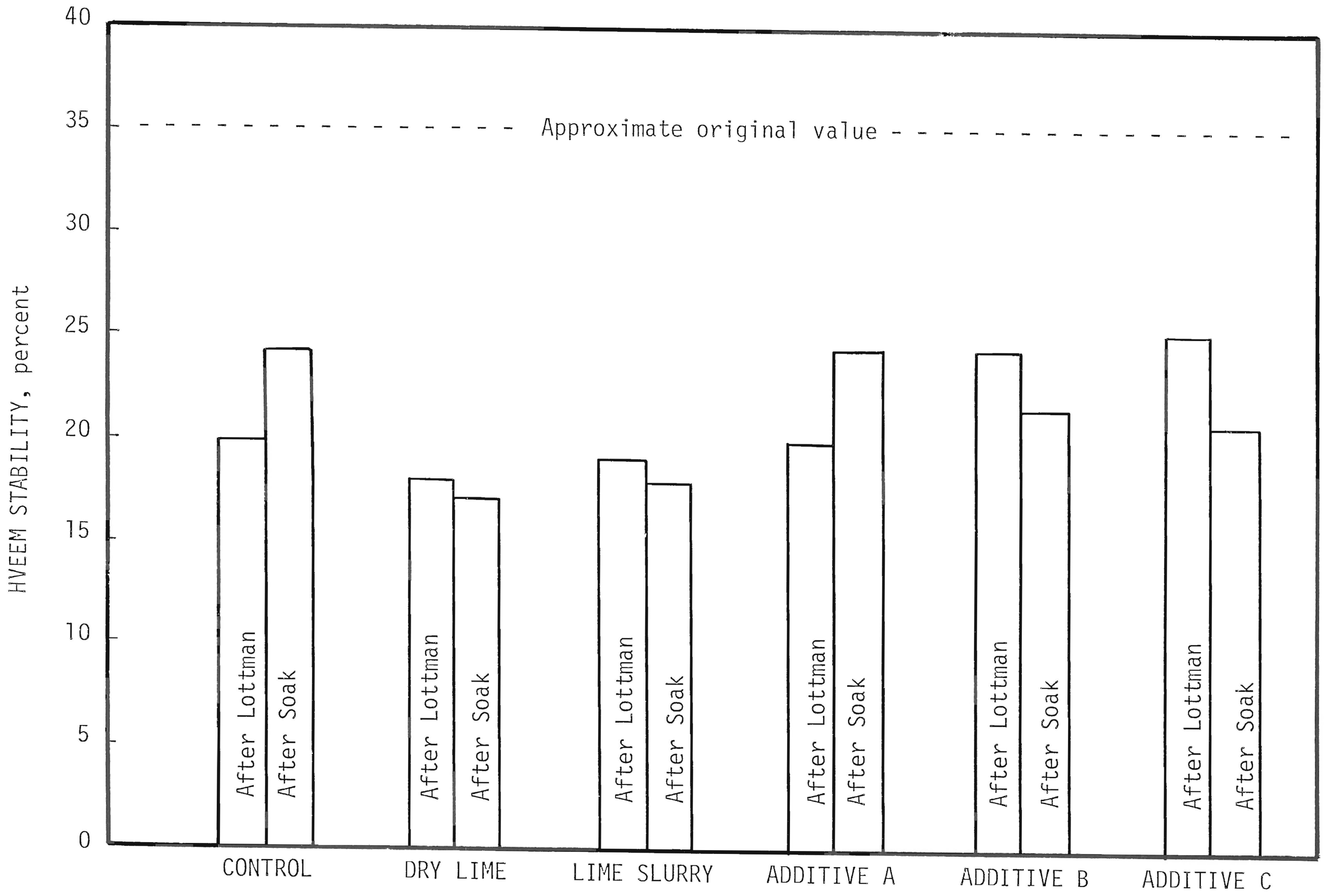

Figure 7. Hveem Stability Before and After Moisture Treatment (Phase II) (Stability of original specimens unavailable.)

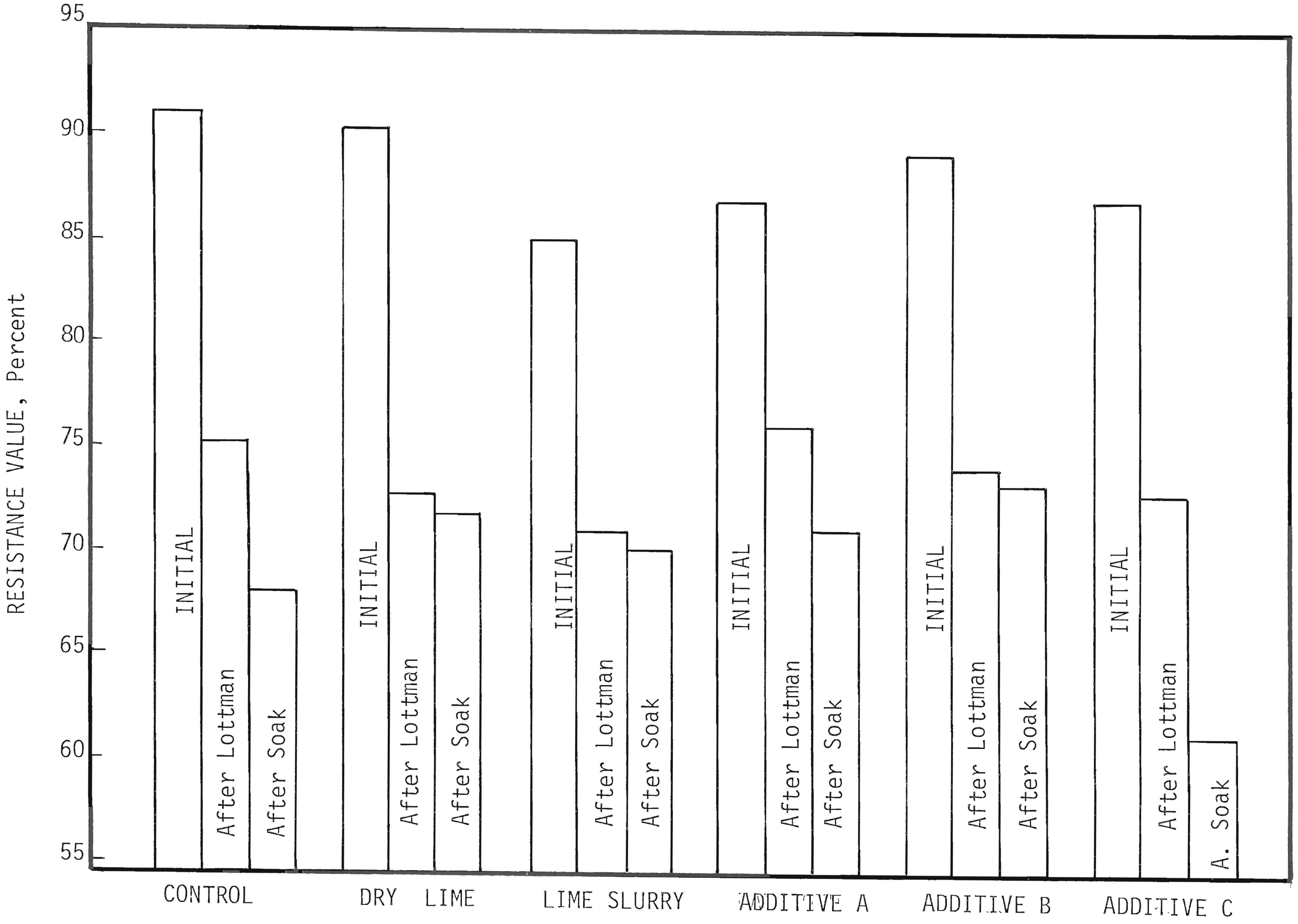

Figure 8. Resistance (R-Value) Before and After Moisture Treatment (Phase I)
(Values after soak were obtained after drying specimens to constant weight)

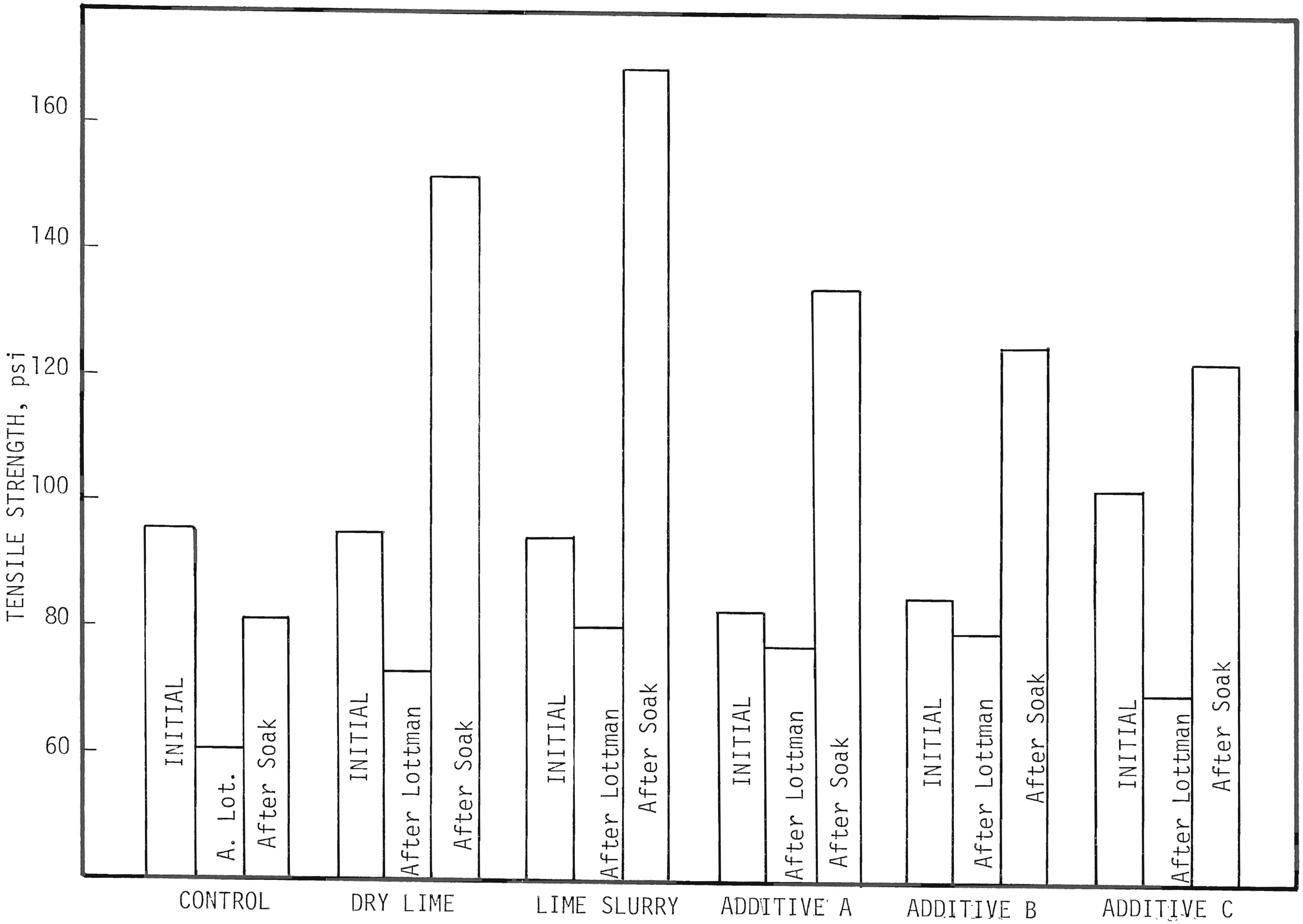

Figure 9. Tensile Strength Before and After Moisture Treatment (from Splitting Tensile Test)(Phase I)
(Values after soak were obtianed after drying specimens to constant weight)

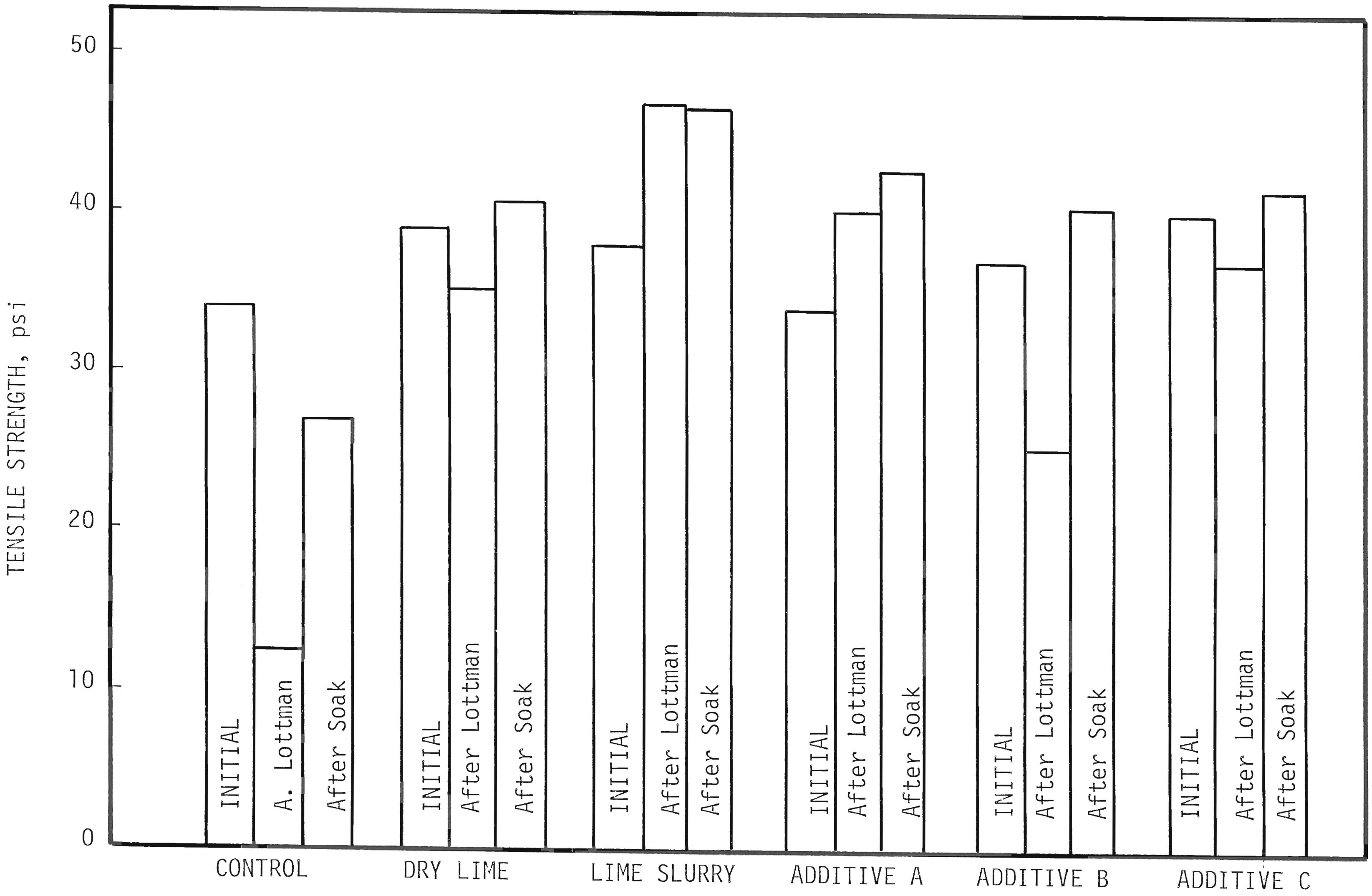

Figure 10. Tensile Strength Before and After Moisture Treatment (Phase II).

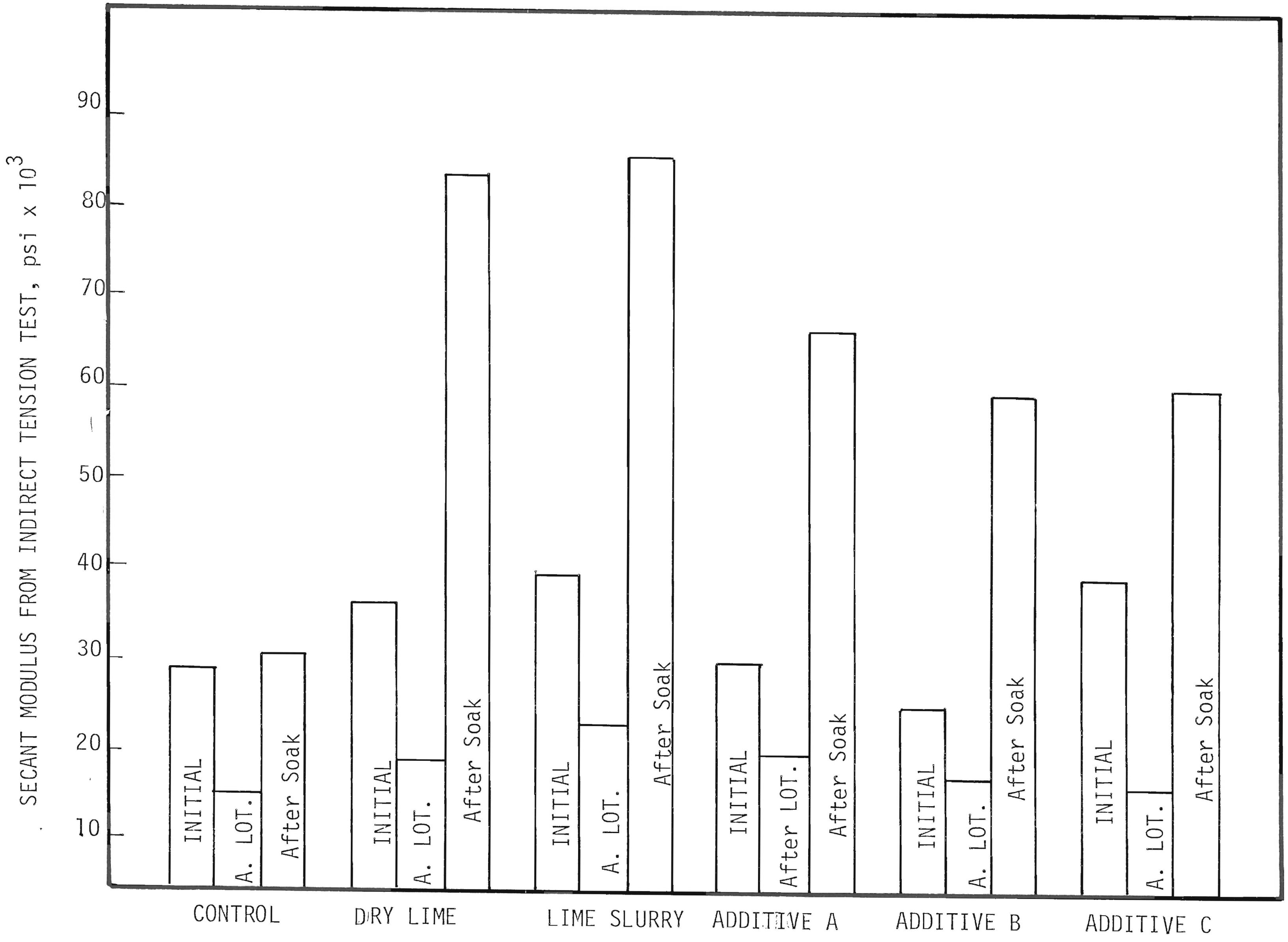

Figure 11. Secant Moduli Before and After Moisture Treatment (from Splitting Tensile Test)(Phase I)
(Values after soak are large due to the drying to constant weight procedure)

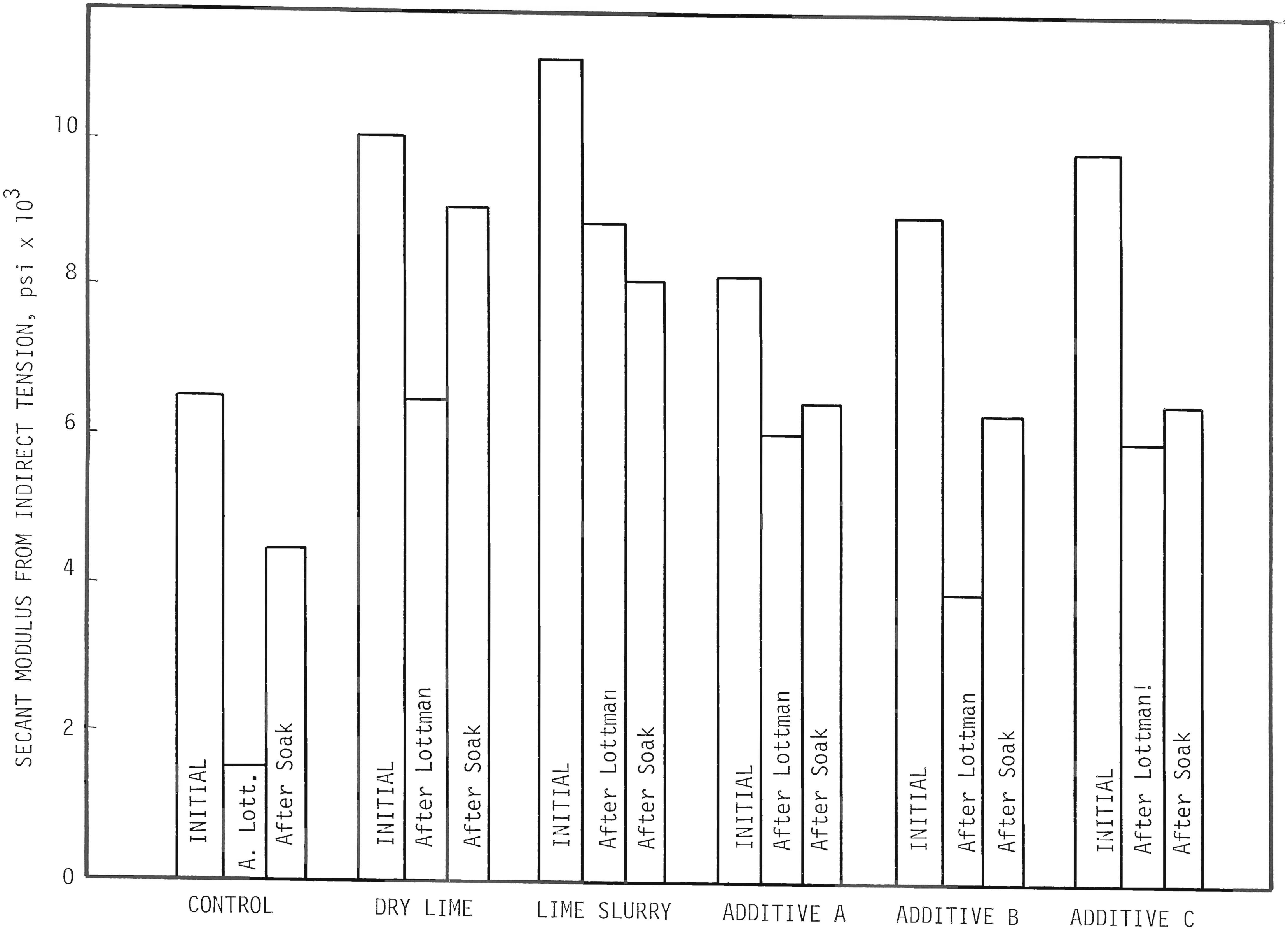

Figure 12. Secant Moduli Before and After Moisture Treatment (from Splitting Tensile Test)(Phase II)

SIGNIFICANCE OF TESTS AND RESULTS

The main objective of this study was to evaluate test methods that could delineate water susceptibility of bituminous mixtures and effects of adding antistripping agents on mixture performance.

Appraisal of moisture susceptibility of a mixture will allow the engineer, among other things, to provide a better mix design by analyzing the results obtained when different asphalt-aggregate combinations and additives are used. Monitoring of pavements by comparing actual deterioration with predicted moisture damage may yield information that can be valuable in maintenance or rehabilitation programs.

It has been verified by earlier research (3) that voids have a significant effect on the degree of moisture-induced damage, specifically stripping, in a mix. The greater the voids percentage, the greater the potential for stripping. In the present study this anticipated difference is not evident. The initial properties measured were of much higher quality for the specimens that contained only 2 percent voids than for the corresponding specimens that contained 8 percent voids. The ratios of parameters before and after moisture treatment do not, however, show significant and consistent differences between the two phases of the project.

Laboratory moisture treatments are intended to simulate field conditions that will be imposed on the pavement during its service life. It is evident that the Lottman procedure is a more severe treatment than the 7-day soak procedure and one could assume that the latter will simulate short-term damage whereas the Lottman will simulate long-term damage.

In this test program, the splitting tensile test (indirect tension) was performed at a rate of vertical deformation of 2 in./min. @ 77°F (5 cm/min. @ 25°C) as opposed to either 0.065 in./min. @ 55°F (0.165 cm/min. @ 13°C) or 0.15 in./min. @ 73°F (0.381 cm/min. @ 23°C) as recommended by Lottman (4). However, a study done by Maupin (3), in which similar samples were tested at deformation rates of 0.065 in./min. @ 55°F and 2 in./min. @ 77°F, showed that there was no significant difference in the test methods and were also equivalent in their ability to predict stripping.

The non-destructive feature of the resilient modulus test makes it a desirable alternative for predicting moisture damage and, although there were some unexpected results, it appears to have the potential to provide useful information when evaluating water susceptibility of asphaltic mixtures.

In general, the use of antistripping additives improved the resistance of asphalt paving mixtures to damage by moisture. Hydrated lime, particularly when added in the form of a slurry, provided better protection than any other of the additives. Hydrated lime added while dry to the asphalt mixture performed about as well as the liquid antistripping agents. All of the additives improved the resistance of the asphalt specimens to damage by water.

CONCLUSIONS

The following conclusions have ensued from analysis of the test results produced in this research study:

1. The Lottman moisture treatment procedure appears to yield more reliable results for prediction of moisture susceptibility in the field than the 7-day soak procedure. Tensile properties of asphalt paving mixtures appear to be quite sensitive to damage by moisture. Since "biscuit" specimens are easily produced by most materials laboratories, the splitting tensile test lends itself quite well to evaluating moisture damage.

2. Resilient modulus tests show a great deal of potential for predicting moisture susceptible asphalt mixtures in the laboratory. Determination of the resilient modulus prior to destruction of the specimen by the splitting tensile test will provide valuable information and should be performed.

3. Testing of specimens after drying to constant weight (having previously been saturated) can give confusing results. However, this method is realistic and can show the unique ability of certain anti-stripping additives to promote "healing" upon drying of an asphalt mixture having been exposed to moisture.

4. Hveem stability is unacceptable for predicting moisture susceptibility of asphalt paving mixtures.

5. The addition of hydrated lime, particularly when applied to the aggregate in the form of a slurry, appears to provide superior protection from moisture.

RECOMMENDATIONS

The primary emphasis of this study involved the development of a simple, inexpensive test to identify paving mixtures that are susceptible to damage by water. According to comments by about one-half the state highway materials engineers across the United States, water susceptibility of asphalt pavements is a serious problem that has increased in frequency and intensity in recent years. (More marginal aggregates being used, properties of asphalts changing.)

This test program was very limited and even introductory in nature. Certain tests have been shown to reveal damage by moisture while others have been shown to be relatively ineffective. The knowledge developed in this research study and that drawn from published information provides a base on which to build in order to establish a realistic and effective method to identify water susceptible mixtures before they reach the field. In addition, the ability of certain antistripping additives to reduce the adverse effects of moisture has been demonstrated.

Based on published research, it is reasonable to assume that some antistripping additives may be incompatible with certain asphalt-aggregate mixtures (10, 11, 12). Thus, testing is necessary to confirm the benefits of selected antistripping additives in a given mixture.

Therefore, the following recommendations are proposed:

1. Test all asphalt paving mixtures to determine their susceptibility to damage by moisture, particularly those suspected of having this problem.

2. If a mixture is water susceptible, continue testing to verify

the suitability of the selected antistripping additive. Do not assume that any antistripping additive will perform adequately with a given asphalt paving mixture.

3. Continue building on the foundation established by this limited study.

   a. A realistic test program might include repetitive loading of test specimens while under water in the saturated condition to simulate the action of traffic; then test to assess relative damage.

   b. An abbreviated program might involve saturation and soaking of specimens in warm water, say, 140°F, for a relatively short duration, say, one to three days.

   c. Tests should be conducted using a fine inert material, such as silica flour, in place of hydrated lime to determine the comparative stiffening effects due entirely to action as a mineral filler.

   d. This work should culminate with a controlled field experiment to determine cost-benefits of selected antistripping additives.

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APPENDIX A

Properties of Asphalts and Aggregates

Table A1. Properties of Laboratory Standard Asphalt Cement.

Characteristic Measured	Measurement
Viscosity, 77°F (25°C) poise	5.8×10^5
Viscosity, 140°F (60°C) poise	1580
Viscosity, 275°F (135°C) poise	3.8
Penetration, 77°F (25°C), dmm (100 gm, 5 sec)	118
Penetration, 39°F (4°C), dmm (200 gm, 60 sec)	26
Softening Point (R & B), °F (°C)	107 (42)
Penetration Index	-1.4
Specific Gravity @ 77°F (25°C)	1.02
Ductility @ 77°F (25°C), cm	150+
Solubility ($CH Cl:CCl_2$), Percent	99.99
Flash Point, °F (°C)	615 (324)
Fire Point, °F (°C)	697 (370)
Spot Test	Neg.
Thin Film Oven Test	
Penetration of Residue @ 77°F	68
Ductility of Residue @ 77°F	150+
Viscosity of Residue @ 140°F	3050
Loss on Heating	Neg.
Hardening Index (Due to Actinic Light)	1.9
Vanadium Content, ppm	3.4

Table A2. Physical Properties of Rounded Gravel.

Physical Property	Test Designation	Aggregate Grading	Test Results
Bulk Specific Gravity	ASTM C 127 AASHTO T 85	Coarse Material*	2.621
Bulk Specific Gravity (SSD)			2.640
Apparent Specific Gravity			2.672
Absorption, percent			0.72
Bulk Specific Gravity	ASTM C 218 AASHTO T 84	Fine Material**	2.551
Bulk Specific Gravity (SSD)			2.597
Apparent Specific Gravity			2.675
Absorption, percent			1.8
Bulk Specific Gravity	ASTM C 127 & C 128 AASHTO T 84 & T 85	Project Design Gradation	2.580
Apparent Specific Gravity			2.671
Absorption, percent			1.3
Abrasion Resistance, percent loss	ASTM C 131 AASHTO T 96	Grading C	19
Compacted Unit Weight, pcf	ASTM C 29 AASHTO T 19	Project Design Gradation	129
Surface Capacity, percent by wt. dry aggregate	Centifuge Kerosene Equivalent	Fine Material**	3.0
Surface Capacity, percent oil retained by wt. agg.	Oil Equivalent	-3/8 inch to + No. 4	1.8
Estimated Optimum Asphalt Content, percent by wt. dry aggregate	C.K.E. and Oil Equivalent	Project Design Gradation	4.7

*Material retained on No. 4 sieve from Project Design Gradation.

**Material passing No. 4 sieve from Project Design Gradation.

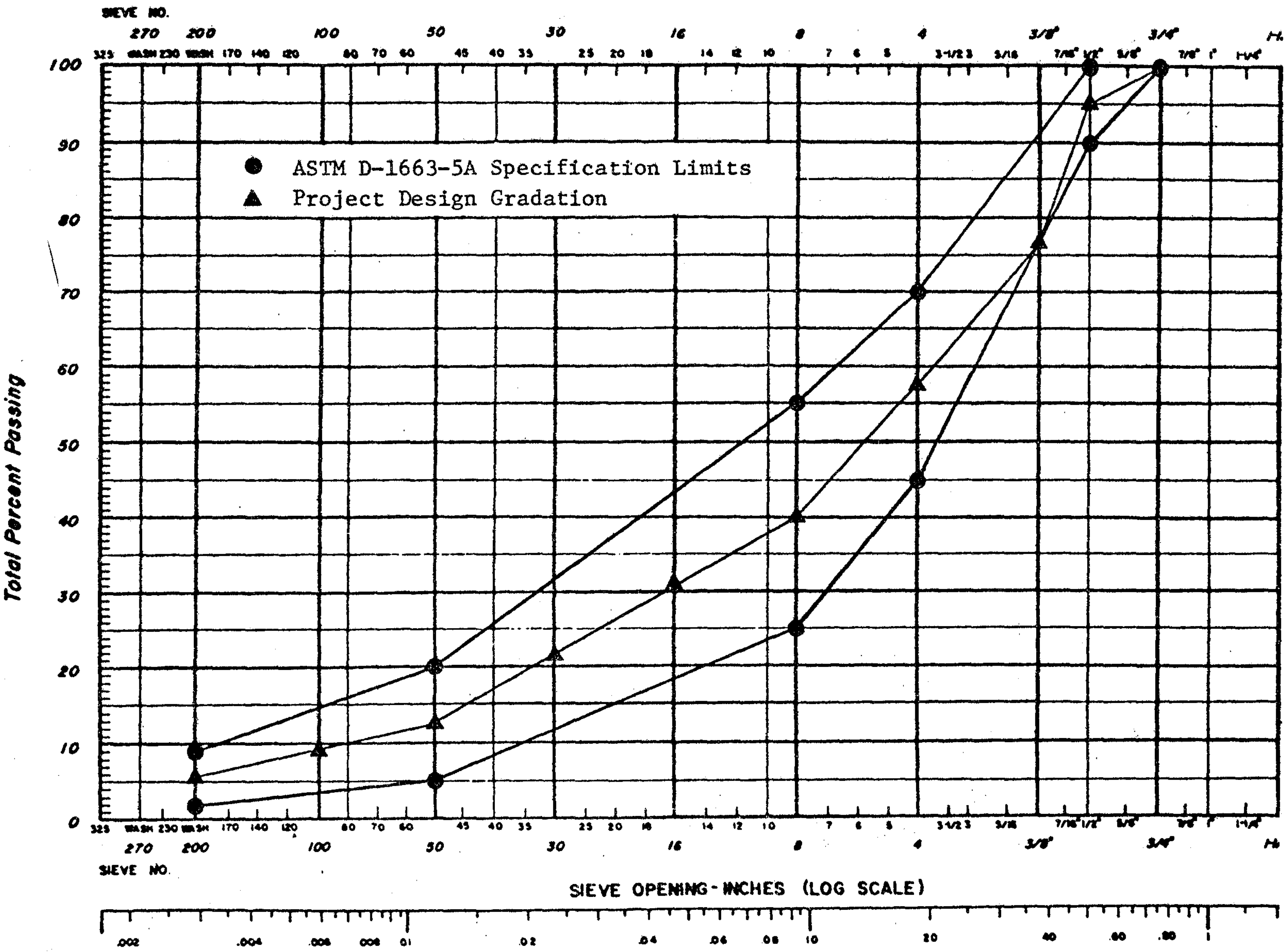

Figure A1. ASTM D-1663 - Aggregate Gradation 5A Specification and Project Gradation Design.

APPENDIX B

Tabulated Test Data

Table B1. Statistical Summary of Test Results Prior to Water Treatment - Phase I (Initial Properties).

Specimen Type	Statistic	Bulk Specific Gravity*	Air Voids,* percent	Resilient Modulus* @ 77°F, psi	Hveem Tests		Splitting Tensile Test		
					Stability,** percent	Resistance Value**	Tensile Strength,*** psi	Strain @ Failure,*** in/in	Secant Modulus*** psi
Control	Mean	2.43	2.2	325,000	43	91	96	0.0034	28,600
	Std. Dev.	0.009	0.35	40,000	3.4	1.5	12.0	0.00029	5,000
	Coef. Var. %	0.4	16	12	8	2	13	9	18
Dry Lime	Mean	2.44	1.7	499,000	36	90	95	0.0026	37,000
	Std. Dev.	0.011	0.42	52,000	4.5	1.5	14.6	0.00023	5,800
	Coef. Var. %	0.4	25	10	13	2	15	9	16
Lime Slurry	Mean	2.46	1.2	520,000	28	85	94	0.0024	39,800
	Std. Dev.	0.007	0.25	88,000	4.1	2.7	13.1	0.00031	5,300
	Coef. Var. %	0.3	20	17	5	3	14	13	13
Liquid Additive A	Mean	2.44	2.0	352,000	34	87	83	0.0029	29,000
	Std. Dev.	0.007	0.29	25,000	4.5	3.3	18.6	0.00024	8,400
	Coef. Var. %	0.3	14	7	13	4	22	8	29
Liquid Additive B	Mean	2.44	2.0	353,000	37	89	85	0.0034	25,400
	Std. Dev.	0.009	0.26	14,000	2.5	1.2	8.7	0.00045	3,100
	Coef. Var. %	0.4	14	4	7	1	10	13	12
Liquid Additive C	Mean	2.44	1.9	377,000	33	87	103	0.0027	40,400
	Std. Dev.	0.010	0.32	80,000	1.8	0.8	10.1	0.00079	11,000
	Coef. Var. %	0.4	17	21	5	1	10	29	27

*Means represent 9 specimens

**Means represent 6 specimens

***Means represent 3 specimens

Table B2. Statistical Summary of Test Results Prior to Treatment - Phase II (Initial Properties).

Specimen Type	Statistic	Bulk Specific Gravity*	Air Voids,* percent	Resilient Modulus (M_R)* @ 77°F, psi	Splitting Tensile Test**		
					Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi
Control	Mean	2.29	7.8	80,000	34	0.0053	6,500
	Std. Dev.	0.007	0.30	11,000	7.0	0.0006	1,300
	Coef. Var. %	0.3	4	13	20	11	20
Dry Lime	Mean	2.29	7.9	107,000	39	0.0040	10,100
	Std. Dev.	0.012	0.48	8,000	2.8	0.0003	700
	Coef. Var. %	0.5	6	7	7	8	7
Lime Slurry	Mean	2.30	7.5	107,000	38	0.0035	11,100
	Std. Dev.	0.009	0.37	8,000	1.0	0.0004	1,300
	Coef. Var. %	0.4	5	8	3	11	11
Liquid Additive A	Mean	2.30	7.6	83,000	34	0.0042	8,200
	Std. Dev.	0.011	0.44	8,000	1.7	0.0008	1,300
	Coef. Var. %	0.5	6	9	5.0	19	16
Liquid Additive B	Mean	2.29	8.0	76,000	37	0.0041	9,000
	Std. Dev.	0.009	0.39	8,000	2.9	0.00005	600
	Coef. Var. %	0.4	5	10	8	1	7
Liquid Additive C	Mean	2.31	6.9	107,000	40	0.0041	9,900
	Std. Dev.	0.002	0.08	9,000	0.6	0.0003	800
	Coef. Var. %	0.1	1	8	2	7	9

*Means represent 9 specimens

**Means represent 3 specimens

Table B3. Statistical Results After Lottman Procedure* (Phase I).

Specimen Type	Statistic	Bulk Specific Gravity	Resilient Modulus psi	Hveem Tests		Splitting Tensile Test		
				Stability, percent	Resistance Value, percent	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi
Control	Mean	2.45	110,000	23	75	61	0.0031	15,300
	Std. Dev.	0.005	470	2.6	3.3	8.0	0.00111	1,020
	Coef. Var. %	0.2	0.4	11	4	13	36	7
Dry Lime	Mean	2.46	196,000	16	73	73	0.0039	18,700
	Std. Dev.	0.008	5,400	3.6	3.3	4.0	0.00012	1,040
	Coef. Var. %	0.3	3	22	5	5	3	6
Lime Slurry	Mean	2.47	256,000	16	71	80	0.0034	23,400
	Std. Dev.	0.008	27,900	2.5	2.5	3.5	0.00032	2,270
	Coef. Var. %	0.3	11	15	3	4	9	10
Liquid Additive A	Mean	2.46	177,000	22	76	77	0.0035	20,800
	Std. Dev.	0.0	11,000	2.5	2.0	6.5	0.00046	3,600
	Coef. Var. %	0	6	11	3	8	13	17
Liquid Additive B	Mean	2.46	175,000	20	74	79	0.0044	18,500
	Std. Dev.	0.0	34,000	1.5	1.0	9.6	0.00061	4.500
	Coef. Var. %	0	19	7.8	1	12	14	24
Liquid Additive C	Mean	2.46	171,000	18	73	70	0.0042	16,800
	Std. Dev.	0.0	20,000	4.9	5.7	5.6	0.00017	1,600
	Coef. Var. %	0	12	27	8	8	4	10

*Each mean represents 3 specimens.

Table B4. Statistical Test Results After Lottman Procedure* (Phase II).

Specimen Type	Statistic	Resilient Modulus, (M_R) psi	Hveem Stability, percent	Splitting Tensile Test		
				Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi
Control	Mean Std. Dev. Coef. Var. %	46,500 23,000 49	20 4.0 20	12.4 4.4 35	0.0080 0.0005 6	1,500 450 29
Dry Lime	Mean Std. Dev. Coef. Var. %	134,000 12,000 9	18 2.1 12	35.3 3.0 9	0.0055 0.0007 13	6,500 1,350 21
Lime Slurry	Mean Std. Dev. Coef. Var. %	153,000 5,500 4	19 2.6 14	46.7 1.6 4	0.0053 0.0008 16	8,900 1,600 18
Liquid Additive A	Mean Std. Dev. Coef. Var. %	104,000 11,300 11	20 2.3 12	40.2 2.1 5	0.0066 0.0003 4	6,100 500 8
Liquid Additive B	Mean Std. Dev. Coef. Var. %	66,000 14,000 21	24 2.6 11	25.3 3.9 16	0.0067 0.0012 18	3,900 1,200 30
Liquid Additive C	Mean Std. Dev. Coef. Var. %	89,000 5,600 6	25 0.6 2	36.8 2.4 7	0.0064 0.0002 3	6,000 500 8

*Each mean represents 3 specimens

Table B5. Statistical Results During and After 7-Day Soak* (Phase I).

Specimen Type	Statistic	Resilient Modulus x 10^3 psi					Hveem Tests on undried Day-7 specimens		Splitting Tensile Test on undried Day-7 specimens		
		Day-1	Day-3	Day-5	Day-7	After** Drying	Stability, percent	R-Value, percent	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi x 10
Control	Mean	320	321	208	196	160	15	68	82	0.0034	30,700
	Std. Dev.	24	30	5	12	13	3.6	5.1	32.7	0.0017	15,800
	Coef. Var. %	8	9	2	6	8	24	8	40	49	52
Dry Lime	Mean	661	626	408	395	489	15	72	152	0.0017	83,400
	Std. Dev.	45	106	56	49	73	3.5	4.9	2.1	0.00026	15,200
	Coef. Var. %	7	17	14	12	15	24	7	1	16	18
Lime Slurry	Mean	682	708	465	452	541	13	70	168	0.0016	108,200
	Std. Dev.	76	38	48	57	58	6.2	6.4	14.8	0.00025	26,700
	Coef. Var. %	11	5	10	13	11	46	9	9	16	25
Liquid Additive A	Mean	261	281	202	174	197	16	71	134	0.0020	67,000
	Std. Dev.	67	75	56	49	45	7.9	8.7	8.2	0.00025	11,200
	Coef. Var. %	26	27	28	28	23	50	12	6	12	17
Liquid Additive B	Mean	456	414	292	259	255	19	73	125	0.0021	60,100
	Std. Dev.	26	27	36	34	21	6.2	5.9	10.7	0.00019	9,900
	Coef. Var. %	6	7	12	13	8	33	8	9	9	16
Liquid Additive C	Mean	455	460	301	283	283	12	61	123	0.0020	61,100
	Std. Dev.	55	36	38	35	40	13.1	18.2	28.6	0.00039	9,600
	Coef. Var. %	12	8	13	12	14	109	30	23	19	16

*Each mean represents 3 specimens

**These specimens were tested after drying to constant weight which required 9 additional days at 100°F.

Table B6. Statistical Test Results During and After 7-Day Soak* (Phase II).

Specimen Type	Statistic	Resilient Modulus (M_R), psi						Hveem Stability, percent	Splitting Tensile Test		
		Day-1	Day-2	Day-3	Day-4	Day-5	Day-7		Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi
Control	Mean	49,000	50,500	48,400	53,100	51,300	50,500	24	40.5	0.0060	6,700
	Std. Dev.	9,200	1,600	700	3,150	7,100	2,000	4.9	19.1	0.0001	3,100
	Coef. Var. %	19	3	1	6	14	4	20	47	1	46
Dry Lime	Mean	101,400	94,800	78,000	88,700	78,300	89,400	17	40.7	0.0045	9,100
	Std. Dev.	23,700	12,900	7,300	12,400	6,500	9,500	0.7	4.2	0.0002	440
	Coef. Var. %	23	14	9	14	8	11	4	10	5	5
Lime Slurry	Mean	75,600	83,100	82,700	82,400	75,500	82,100	18	46.5	0.0057	8,100
	Std. Dev.	10,500	16,000	8,500	2,400	2,300	2,500	-	3.4	0.0005	260
	Coef. Var. %	14	19	10	3	3	3	-	7	9	3
Liquid Additive A	Mean	51,600	51,500	52,100	55,600	58,100	55,100	24	42.7	0.0066	6,500
	Std. Dev.	900	4,500	2,900	3,600	3,700	2,800	2.3	5.3	0.0002	1,030
	Coef. Var. %	2	9	6	7	6	5	10	12	3	16
Liquid Additive B	Mean	61,100	59,000	56,300	64,300	66,900	63,800	22	40.3	0.0064	6,350
	Std. Dev.	11,900	13,500	6,100	7,000	12,700	11,700	1.5	0.9	0.0005	420
	Coef. Var. %	19	23	11	11	19	18	7	2	8	7
Liquid Additive C	Mean	45,200	48,600	51,900	51,900	63,000	54,800	21	41.6	0.0064	6,500
	Std. Dev.	2,400	5,400	350	10,100	2,200	900	1.4	3.9	0.0005	120
	Coef. Var. %	5	11	1	19	4	2	7	9	8	2

*Each mean represents 3 specimens

Table B7. Ratios of "Before" and "After" Moisture Test Results (Phase I).

Specimen Type	Resilient Modulus Ratio (M_R)			Hveem Stability Ratio		Resistance Value Ratio		Split-Tensile Strength Ratio		Split-Tensile Modulus Ratio	
	Lottman	7-Day Soak*	7-Day Soak**	Lottman	7-Day Soak	Lottman	7-Day Soak	Lottman	7-Day Soak	Lottman	7-Day Soak
Control	0.34	0.60	0.49	0.54	0.35	0.83	0.75	0.64	0.85	0.54	1.07
Dry Lime	0.42	0.79	0.98	0.45	0.44	0.80	0.88	0.77	1.60	0.51	2.25
Lime Slurry	0.46	0.87	1.04	0.58	0.48	0.83	0.82	0.85	1.47	0.59	2.72
Additive A	0.49	0.49	0.57	0.65	0.47	0.88	0.82	0.93	1.61	0.72	2.31
Additive B	0.49	0.73	0.72	0.53	0.51	0.83	0.82	0.93	1.78	0.73	2.37
Additive C	0.45	0.75	0.75	0.55	0.36	0.83	0.70	0.68	1.19	0.42	1.51

*Ratio before specimens dryed to constant weight, i.e., saturated specimens.

**Ratio after specimens dryed to constant weight.

Table B8. Ratios of "Before" and "After" Moisture Test Results (Phase II).

Specimen Type	Resilient Modulus Ratio		Split Tensile Strength Rato		Split-Tensile Modulus Ratio	
	Lottman	7-Day Soak	Lottman	7-Day Soak	Lottman	7-Day Soak
Control	0.58	0.63	0.36	1.19	0.23	1.03
Dry Lime	1.25	0.84	0.91	1.04	0.64	0.90
Lime Slurry	1.43	0.77	1.23	1.22	0.88	0.73
Additive A	1.25	0.66	1.18	1.26	0.74	0.79
Additive B	0.87	0.84	0.68	1.09	0.43	0.71
Additive C	0.83	0.51	0.92	1.04	0.61	0.66