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16. Abstract

The Tube Suction Test (TST) was developed in a cooperative effort between the Finnish National Road Administration and the Texas Transportation Institute (TTI) for assessing the moisture susceptibility of granular base materials. The moisture susceptibility ranking is based on the mean surface dielectric value of compacted specimens after a 10-day capillary soak in the laboratory, where the Adek Percometer™ is employed in the test to measure the dielectric values of specimens. Based on promising correlations of test results to important engineering properties of aggregates, this project was initiated by the Texas Department of Transportation (TxDOT) to conduct an interlaboratory study aimed at developing a standard test procedure and a precision statement for the TST.

The project involved six TxDOT district laboratories geographically distributed across the state. The repeatability limits computed from data obtained in this project compared well with those repeatability limits calculated from data collected in earlier research, which were also used to demonstrate that the repeatability limits are proportional to the final dielectric value. The reproducibility limits obtained in this project exceeded the repeatability limits by factors as high as four and were the motivation for further testing. Relative humidity was shown to have major impacts on the final dielectric values of specimens tested in the TST, and the protocol was subsequently revised to require capillary soaking inside a closed ice chest. However, inconsistencies between different Percometer™ devices may also have been the source of the poor reproducibility observed in the study. This report provides background information about the development of the TST, presents the details of the interlaboratory study, summarizes findings, and offers recommendations for further work.

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INTERLABORATORY STUDY OF THE TUBE SUCTION TEST

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Transportation Institute (TTI), the Texas Department of Transportation (TxDOT), or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. Trade names were used solely for information and not for product endorsement. The engineer in charge of the project was Tom Scullion, P.E. #62683.

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The authors wish to acknowledge Mrs. Caroline Herrera, project director, and Mr. Mike Arellano of TxDOT for providing recommendations for specific improvements to the Tube Suction Test (TST) protocol. Mr. Stephen Sebesta and Mr. Marvin Zeig of TTI assisted in exploratory laboratory efforts necessary to develop the revised procedure presented in this report. Dr. Pat Harris and Mr. Lee Gustavus of TTI also provided valuable assistance. In addition, meaningful suggestions were given by various TxDOT engineers and technicians at the Atlanta, Bryan, Fort Worth, Odessa, Waco, and Wichita Falls district laboratories.

TxDOT and FHWA are acknowledged for providing funds to conduct this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

PROJECT DESCRIPTION

The Tube Suction Test (TST) was developed in a cooperative effort between the Finnish National Road Administration and the Texas Transportation Institute (TTI) for assessing the moisture susceptibility of granular base materials (*1*). The moisture susceptibility ranking is based on the mean surface dielectric value of compacted specimens after a 10-day capillary soak in the laboratory, where the Adek Percometer™ is employed in the test to measure the dielectric values of the specimens. Aggregates whose final dielectric values in the TST are less than 10 are expected to provide superior performance as base materials, whereas those with dielectric values above 16 are expected to provide poor performance. Aggregates having final dielectric values between 10 and 16 are expected to be marginally moisture susceptible.

Based on promising correlations of TST results to the engineering behavior of aggregates, the Texas Department of Transportation (TxDOT) purchased several Percometer™ devices and distributed them to various district laboratories for immediate use. This project was then initiated to conduct an interlaboratory study aimed at developing a standard test procedure and a precision statement for the TST. Because accepted reference values for TST results obtained from various materials are not available, a bias statement cannot be developed for this test.

Two aggregate base materials were identified for utilization in the project, and personnel at six TxDOT district laboratories agreed to participate. These included the Atlanta, Bryan, Fort Worth, Odessa, Waco, and Wichita Falls districts. TTI personnel developed a training program and traveled to each of the participating laboratories to present both the theoretical and practical aspects of the test. The training included a detailed review of the test protocol, instructions for measuring dielectric values using the Percometer™, and hands-on practice making measurements and analyzing the results.

At the conclusion of each training session, participants at each district laboratory were supplied with samples of two granular base materials, Colorado Materials and Hanson aggregates. A spreadsheet program developed for the purpose of analyzing collected data was also provided to district personnel to ensure uniform reporting of test results. After the testing was completed, copies of the test data sheets were forwarded to TTI for statistical analyses.

The following chapters provide background information about the development of the TST, discuss the results of the interlaboratory study, summarize project findings, and offer recommendations for further work. A revised TST protocol is also given in the appendix.

CHAPTER 2. BACKGROUND

TEST DEVELOPMENT

TxDOT originally funded research on the relationship between electrical and strength properties of aggregate base materials to assist in utilizing ground-penetrating radar (GPR) for non-destructive evaluation of pavements (*2*). In that project, dielectric values of 11 aggregates of known field performance were compared with strength properties at different moisture contents and densities. Strength was measured with resilient modulus testing and in terms of the California Bearing Ratio (CBR) using a dynamic cone penetrometer (DCP). Researchers also investigated the dielectric properties of frozen specimens.

Because dielectric values for three-phase mixtures of aggregate particles, water, and air are most sensitive to the volumetric percentage of unbound water in the aggregate matrix, and because water directly affects the mechanical properties of soil and aggregate materials, researchers were able to readily identify correlations between the electrical and strength properties of aggregates included in the project. Relative changes in resilient modulus values, variations in CBR values measured with DCP, and differences in unfrozen water contents qualitatively inferred from electrical properties of frozen specimens were used to classify the aggregates into three categories based on dielectric value.

The researchers reported increasing amounts of unfrozen water and descending trends in CBR and resilient modulus with increasing dielectric values. The amount of unfrozen water inferred in frozen specimens increased markedly for samples with dielectric values greater than 10 before freezing. For poorly performing aggregates, especially those with dielectric values above 16, results showed decreases in resilient modulus of up to 75 percent from the dry to the wet states, where the latter was the equilibrium moisture content achieved after subjection to capillary rise conditions (*3*). On the other hand, good aggregates did not imbibe substantial amounts of water in capillary soaking and so did not experience significant strength loss.

Based on these findings, researchers developed an early version of the TST in a second TxDOT project (*4*). In that research, the dielectric values of soaked specimens were correlated with Texas triaxial strength values and compared with mineral components identified in the aggregate fines. The effect of stabilizers on improving the moisture resistance of specimens was also investigated. General findings of this project were that logical trends existed between dielectric values in the TST and the physical and chemical properties of the tested aggregates, the TST was adequately repeatable, and the test was sufficiently sensitive to the addition of additives known to improve the properties of the fines fraction of the aggregate matrix. The project resulted in the recommendation of the TST as a supplement to Item 247, Flexible Base, of *TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*. With the objective of ultimately incorporating the test into standard TxDOT specifications, TTI researchers reduced the height of TST specimens from almost 300 mm (12 in) to about 200 mm (8 in) to be more consistent with existing TxDOT sample preparation techniques.

After this modification, two additional projects were performed at TTI to evaluate the ability of the TST to assess the moisture susceptibility of aggregate base materials proposed for use in cold-regions pavements. A preliminary study investigating both unconfined compressive strength and frost heave showed that materials with higher dielectric values at the end of the TST exhibited lower strengths and experienced greater frost heave after subjection to capillary soaking than materials with lower dielectric values (*5*). A subsequent effort then evaluated 35 specimens representing 10 aggregate base materials from Indiana, Minnesota, Pennsylvania, Texas, and Virginia (*6*). The results provided convincing evidence that the TST can be used as a viable tool for specifying premier aggregate base materials in cold climates. Materials ranked as "good" in the TST imbibed significantly less water and experienced significantly less frost heave upon freezing than high-dielectric specimens. These good performers were characterized by lower fines contents and lower porosity, on average, than specimens with higher dielectric values. The findings suggest that aggregate base materials with dielectric values less than 10 in the TST may be confidently ranked as neither moisture nor frost susceptible.

A Finnish study further demonstrated that low-dielectric specimens have higher void ratios and experience significantly less permanent deformation than samples with higher dielectric values in the TST (*7*). In summary, the final dielectric value achieved by specimens in the TST generally corresponds to the void ratio, CBR, unconfined compressive strength, resilient modulus, permanent deformation, freezing characteristics, and frost heave behavior of aggregates. Based on these promising correlations of test results to engineering parameters, TxDOT funded this project to conduct an interlaboratory study aimed at developing a standard test procedure and a precision statement for the TST.

CHAPTER 3. INTERLABORATORY STUDY

OVERVIEW

The interlaboratory study, or "round robin," conducted in this project followed the American Society for Testing and Materials (ASTM) E 691 designation, "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method." A precision statement allows potential users of the test method to assess its usefulness in prescribed applications and offers guidelines about the type of variability that can be expected among test results when the method is employed in one or more reasonably competent laboratories (*8*). The greater the dispersion or scatter of the test results, the poorer the precision.

Two measurements that serve to express precision in the evaluation of a test method are "repeatability" and "reproducibility." Repeatability addresses variability between independent test results obtained within a single laboratory by a single operator, and reproducibility addresses variability among single test results obtained in different laboratories (*8*). Due to the fact that repeatability testing tends to produce nominal variability and reproducibility testing tends to produce appreciable variability, the precision boundaries for a test can be clearly established in an interlaboratory study. Data collected from the study can be used to compute the repeatability and reproducibility limits to determine the statistical validity of the test method.

In this project, data from six participating laboratories were analyzed, which is the minimum number recommended by ASTM E 691. These included the Atlanta, Bryan, Fort Worth, Odessa, and Wichita Falls Districts together with TTI. The Waco District assisted with additional testing after completion of the interlaboratory study. In conjunction with training sessions held at each of the listed TxDOT district laboratories, samples of two different granular base materials were provided to district personnel for evaluation using the TST. The aggregates were procured in bulk by TTI and each separated by sieving into various size fractions to enable preparation of replicate batches for distribution to the districts. Each batch of an aggregate contained sufficient material for constructing three TST specimens. The materials included Colorado Materials and Hanson aggregates, whose gradations are presented in Figure 1. Moisture-density testing at TTI according to TxDOT Test Method Tex-113-E yielded the optimum moisture content and maximum dry density information given in Figure 2. Based on the chart, the optimum moisture contents for the Colorado Materials and Hanson aggregates were determined to be 7.6 percent and 7.3 percent, respectively. The associated maximum dry densities were 2138 kg/m^3 (133.5 lbs/cf) and 2156 kg/m^3 (134.6 lbs/cf), respectively.

Data collection forms were also supplied to each laboratory to ensure uniform reporting of test reports. Upon completion, copies of the forms were returned to TTI for statistical analyses.

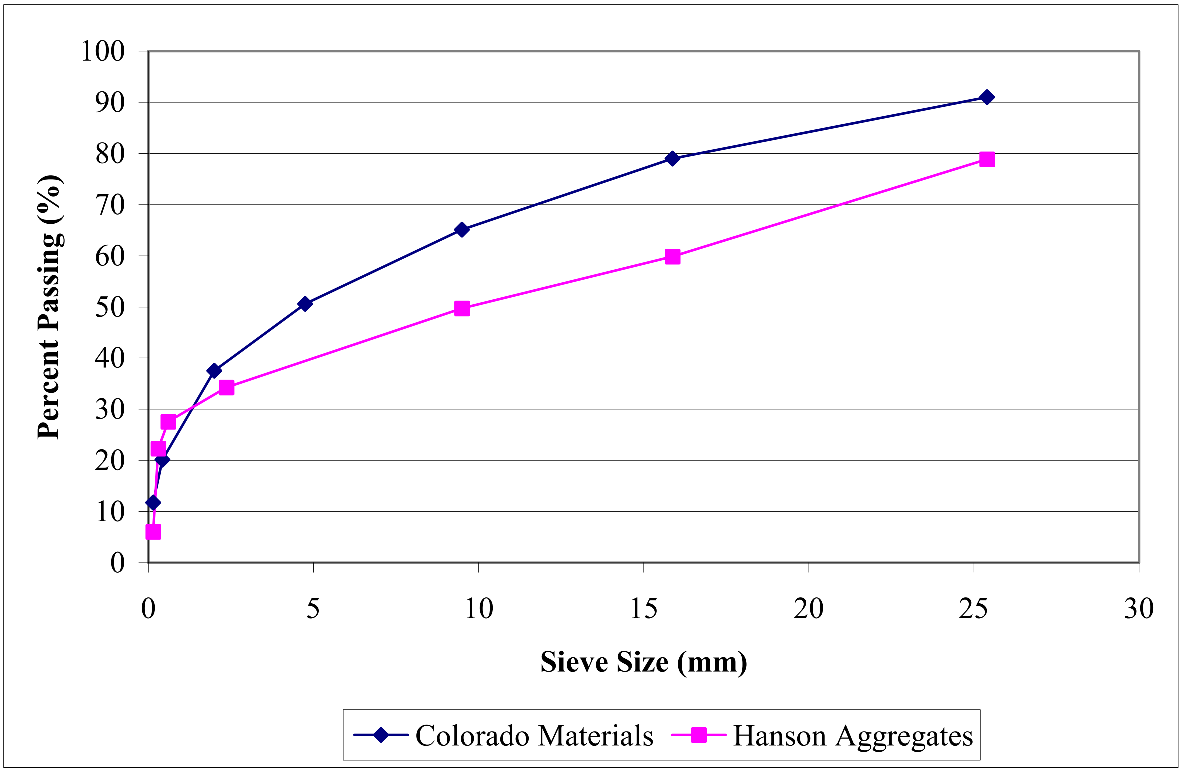

Figure 1. Sieve Analyses.

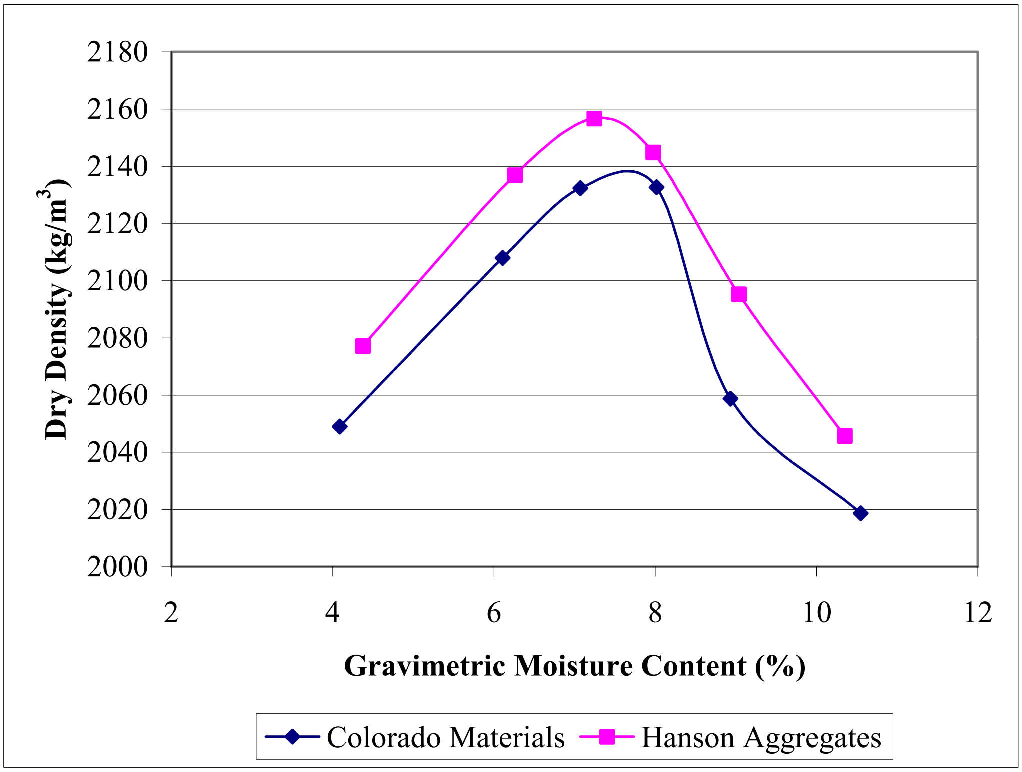

Figure 2. Moisture-Density Relationships.

TEST RESULTS

Summaries of TST results for the Colorado Materials and Hanson aggregates are given in Tables 1 and 2, respectively. The results include reports of actual moisture contents used for compaction, specimen heights and densities, water contents at the beginning and end of capillary soaking, initial and final dielectric values, and the length of the capillary soaking time. Moisture contents used for compaction were within 5 percent and 7 percent, respectively, of the optimum moisture contents for the Colorado Materials and Hanson aggregates. The requirement that the specimen heights should be 203.2 mm (8.0 in) with an allowable variation of 6.4 mm (0.25 in) was met in every case. Relative densities were never less than 97 percent and frequently approached 102 percent. Initial water contents were typically between 3 and 4 percent and corresponded to initial dielectric values between 5 and 8. The Atlanta District did not report the final water contents, but the range in this parameter for the other laboratories was about 6.5 percent to 7.5 percent for the Colorado Materials and about 5.5 percent to almost 7.5 percent for the Hanson aggregates. Final dielectric values exhibited the largest variability among the reported parameters, ranging from about 12 to 20 for both aggregates.

Table 1. Interlaboratory Test Results for Colorado Materials.

Property	Specimen	Laboratory					
		Atlanta	Bryan	Fort Worth	Odessa	TTI	Wichita Falls
Compaction Water (%)	1	7.3	7.4	7.8	7.6	7.4	7.3
	2	7.2	7.4	7.8	7.9	7.4	7.4
	3	7.2	7.5	7.7	7.6	7.4	7.4
	Mean	7.23	7.43	7.77	7.70	7.40	7.37
	Std. Dev.	0.06	0.06	0.06	0.17	0.00	0.06
Specimen Height (mm)*	1	200.7	202.7	203.2	202.7	199.4	200.4
	2	200.2	203.2	203.2	202.7	203.5	203.7
	3	200.4	204.7	203.2	201.9	197.4	204.0
	Mean	200.41	203.54	203.20	202.44	200.07	202.69
	Std. Dev.	0.25	1.06	0.00	0.44	3.10	1.98
Relative Density (%)	1	101.3	101.8	98.7	99.8	101.5	101.3
	2	101.5	101.7	97.3	99.6	102.5	101.8
	3	101.4	101.0	97.4	100.2	101.0	101.6
	Mean	101.40	101.50	97.80	99.87	101.67	101.57
	Std. Dev.	0.10	0.44	0.78	0.31	0.76	0.25
Initial Water Content (%)	1	2.9	3.6	3.0	3.4	3.7	3.4
	2	2.8	3.6	3.1	3.8	3.4	3.5
	3	2.5	3.6	3.1	3.6	3.5	3.4
	Mean	2.73	3.60	3.07	3.60	3.53	3.43
	Std. Dev.	0.21	0.00	0.06	0.20	0.15	0.06
Initial Dielectric Value	1	6.1	6.2	5.6	6.3	7.1	5.1
	2	6.6	7.3	5.6	6.3	6.7	5.7
	3	6.4	5.9	5.6	6.4	6.4	5.2
	Mean	6.37	6.47	5.60	6.33	6.73	5.33
	Std. Dev.	0.25	0.74	0.00	0.06	0.35	0.32
Final Water Content (%)	1	NA	7.2	6.7	7.5	6.4	7.1
	2	NA	7.2	6.6	7.8	6.3	7.0
	3	NA	7.2	6.5	7.5	6.7	7.0
	Mean	NA	7.20	6.60	7.60	6.47	7.03
	Std. Dev.	NA	0.00	0.10	0.17	0.21	0.06
Final Dielectric Value	1	14.5	17.8	13.8	16.8	18.7	13.6
	2	13.6	19.2	14.1	16.9	20.0	14.1
	3	14.4	18.4	13.8	17.8	19.5	12.4
	Mean	14.17	18.47	13.90	17.17	19.40	13.37
	Std. Dev.	0.49	0.70	0.17	0.55	0.66	0.87
Capillary Soak Time (hr)		240.0	215.8	240.3	239.6	246.9	240.0

*25.4 mm = 1 in

Table 2. Interlaboratory Test Results for Hanson Aggregates.

Property	Specimen	Laboratory					
		Atlanta	Bryan	Fort Worth	Odessa	TTI	Wichita Falls
Compaction Water (%)	1	6.8	7.0	7.7	7.9	7.4	7.4
	2	6.9	7.2	7.8	7.4	7.0	7.1
	3	6.8	7.3	7.8	7.3	7.5	7.1
	Mean	6.83	7.17	7.77	7.53	7.30	7.20
	Std. Dev.	0.06	0.15	0.06	0.32	0.26	0.17
Specimen Height (mm)*	1	198.4	201.9	203.2	202.7	204.5	202.7
	2	198.6	202.2	203.2	204.0	203.5	202.7
	3	197.6	204.5	203.2	200.2	202.9	202.7
	Mean	198.20	202.86	203.20	202.27	203.62	202.69
	Std. Dev.	0.53	1.40	0.00	1.94	0.78	0.00
Relative Density (%)	1	102.4	101.9	96.9	99.1	101.0	102.0
	2	102.3	101.7	96.9	98.4	102.5	101.9
	3	102.8	100.7	97.5	100.9	100.7	101.6
	Mean	102.50	101.43	97.10	99.47	101.40	101.83
	Std. Dev.	0.26	0.64	0.35	1.29	0.96	0.21
Initial Water Content (%)	1	3.0	3.9	3.6	3.8	3.7	4.0
	2	3.0	3.8	3.6	3.6	3.4	3.8
	3	3.0	3.8	3.6	3.5	3.9	3.7
	Mean	3.00	3.83	3.60	3.63	3.67	3.83
	Std. Dev.	0.00	0.06	0.00	0.15	0.25	0.15
Initial Dielectric Value	1	7.4	7.7	5.6	7.0	6.1	5.9
	2	7.4	7.6	6.2	6.7	6.8	6.0
	3	7.8	6.9	5.5	6.7	7.4	5.2
	Mean	7.53	7.40	5.77	6.80	6.77	5.70
	Std. Dev.	0.23	0.44	0.38	0.17	0.65	0.44
Final Water Content (%)	1	NA	6.5	6.0	7.4	5.6	6.0
	2	NA	6.7	6.0	7.8	5.0	6.1
	3	NA	6.8	6.0	6.7	5.8	6.2
	Mean	NA	6.67	6.00	7.30	5.47	6.10
	Std. Dev.	NA	0.15	0.00	0.56	0.42	0.10
Final Dielectric Value	1	15.4	19.1	12.0	17.2	11.4	12.1
	2	14.6	19.8	13.8	18.4	11.6	13.6
	3	15.6	16.8	11.7	16.0	13.5	10.5
	Mean	15.20	18.57	12.50	17.20	12.17	12.07
	Std. Dev.	0.53	1.57	1.14	1.20	1.16	1.55
Capillary Soak Time (hr)		240.0	215.8	240.3	239.6	246.9	240.0

*25.4 mm = 1 in

DATA ANALYSIS

Because the final dielectric value is the property used in the TST for assessing the moisture susceptibility of aggregates, the final dielectric values obtained in the interlaboratory study were subjected to the statistical analyses outlined in ASTM E 691. These analyses are designed to determine whether the data are adequately consistent to form the basis for a test method precision statement and to obtain the precision statistics on which the precision statement can be based. Because the procedure recommended for estimating the precision statistics is a one-way analysis of variance (ANOVA), the presence of outliers in the data can invalidate the method by violating assumptions of data distribution required in ANOVA techniques. For this reason, the analysis must first examine consistency of the data.

To facilitate the calculations, the final dielectric values reported by each laboratory were arranged into a convenient format shown in Tables 3 and 4 for the Colorado Materials and Hanson aggregates, respectively. Following the three columns of original data, the mean value $\bar{x}$, or cell average, and the standard deviation s are calculated for each laboratory. The parameter d is the difference between the cell average for each laboratory and the grand average of all the cell averages. The parameter h, which is the between-laboratory consistency statistic, is the ratio of d to the standard deviation of the cell averages, and k, which is the within-laboratory consistency statistic, is the ratio of s to the repeatability standard deviation. The repeatability standard deviation is simply the geometric mean of the individual s values. Specific equations for computing each of these values are given in ASTM E 691.

Table 3. Final Dielectric Values for Colorado Materials.

Laboratory	Final Dielectric Value, x			$\bar{x}$	s	d	h	k
	1	2	3					
Atlanta	13.6	14.4	14.5	14.167	0.493	-1.911	-0.74	0.80
Bryan	17.8	18.4	19.2	18.467	0.702	2.389	0.92	1.14
Fort Worth	13.8	13.8	14.1	13.900	0.173	-2.178	-0.84	0.28
Odessa	16.8	16.9	17.8	17.167	0.551	1.089	0.42	0.90
TTI	18.7	19.5	20.0	19.400	0.656	3.322	1.28	1.07
Wichita Falls	12.4	13.6	14.1	13.367	0.874	-2.711	-1.04	1.42

Table 4. Final Dielectric Values for Hanson Aggregates.

Laboratory	Final Dielectric Value, x			$\bar{x}$	s	d	h	k
	1	2	3					
Atlanta	14.6	15.4	15.6	15.200	0.529	0.583	0.21	0.43
Bryan	16.8	19.1	19.8	18.567	1.570	3.950	1.40	1.27
Fort Worth	11.7	12.0	13.8	12.500	1.136	-2.117	-0.75	0.92
Odessa	16.0	17.2	18.4	17.200	1.200	2.583	0.92	0.97
TTI	11.4	11.6	13.5	12.167	1.159	-2.450	-0.87	0.93
Wichita Falls	10.5	12.1	13.6	12.067	1.550	-2.550	-0.91	1.25

The bar graphs shown in Figures 3 through 6 were then prepared using the values calculated for h and k for each material. In the figures, Colorado Materials and Hanson aggregates are designated as "A" and "B," respectively, while the laboratories are numbered from one to six in the order they appear in Tables 3 and 4. The data are grouped by laboratory in Figures 3 and 4 and by material in Figures 5 and 6. Critical values of h and k were then determined at the 0.5 percent significance level. The critical value of h depends on the number of laboratories participating in the study, which was six in this project, while the critical value of k depends on both the number of laboratories and the number of replicate test results per laboratory per material, which was three in this case. A table given in ASTM E 691 gave critical values of 1.92 and 1.98 for h and k, respectively.

Because the absolute values of all of the h and k values in the figures are less than the critical values, the data may be considered free of outliers. Furthermore, the patterns in the h graphs do not suggest unusual inconsistencies between laboratories. That is, in Figure 3, some laboratories have one negative and one positive value, and the number of laboratories having two negative values is equal to the number of laboratories having two positive values. Figure 4 shows that some laboratories produced results consistently higher or lower than the grand average, but others produced results that were sometimes higher and sometimes lower than the grand average depending on the material. Such balancing is appropriate and expected in consistent experimental data.

There is also insufficient evidence in the k graphs to suggest any unusual inconsistencies between laboratories. Laboratories labeled as 1 and 3 in Figures 5 and 6 do have rather low k values for testing of one of the materials in each case, but not both. Very small k values suggest an unusually low within-laboratory variability that may indicate a measurement problem.

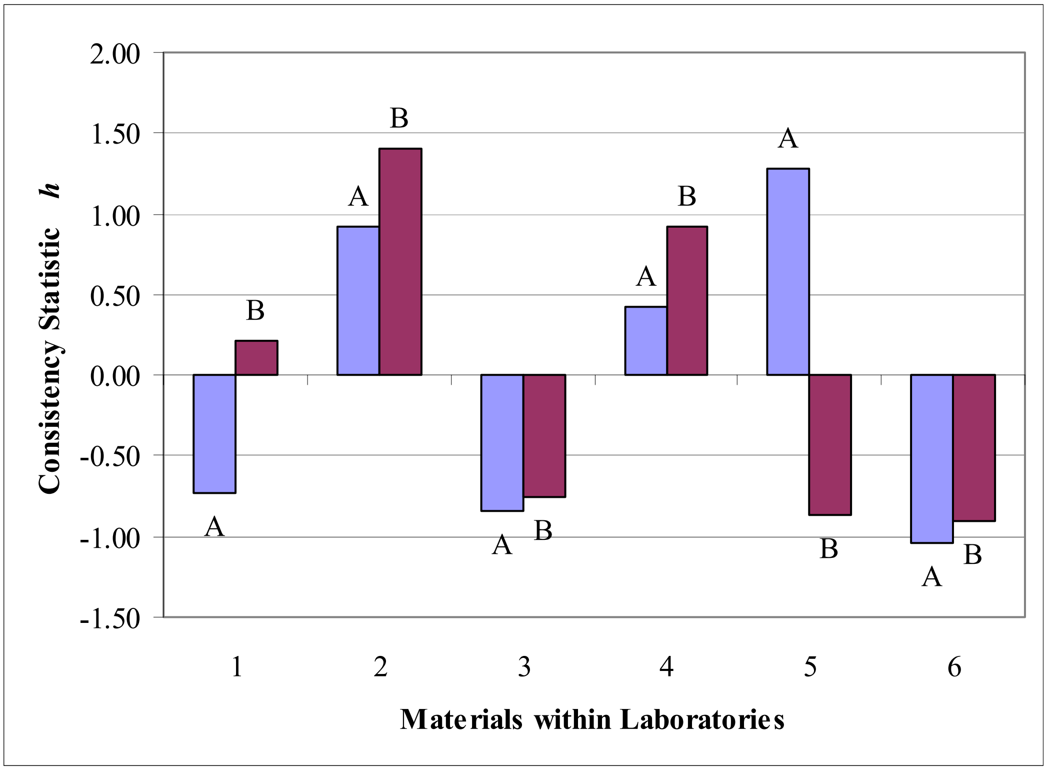

Figure 3. Consistency Statistic *h* for Materials within Laboratories.
A = Colorado Materials, B = Hanson Aggregate

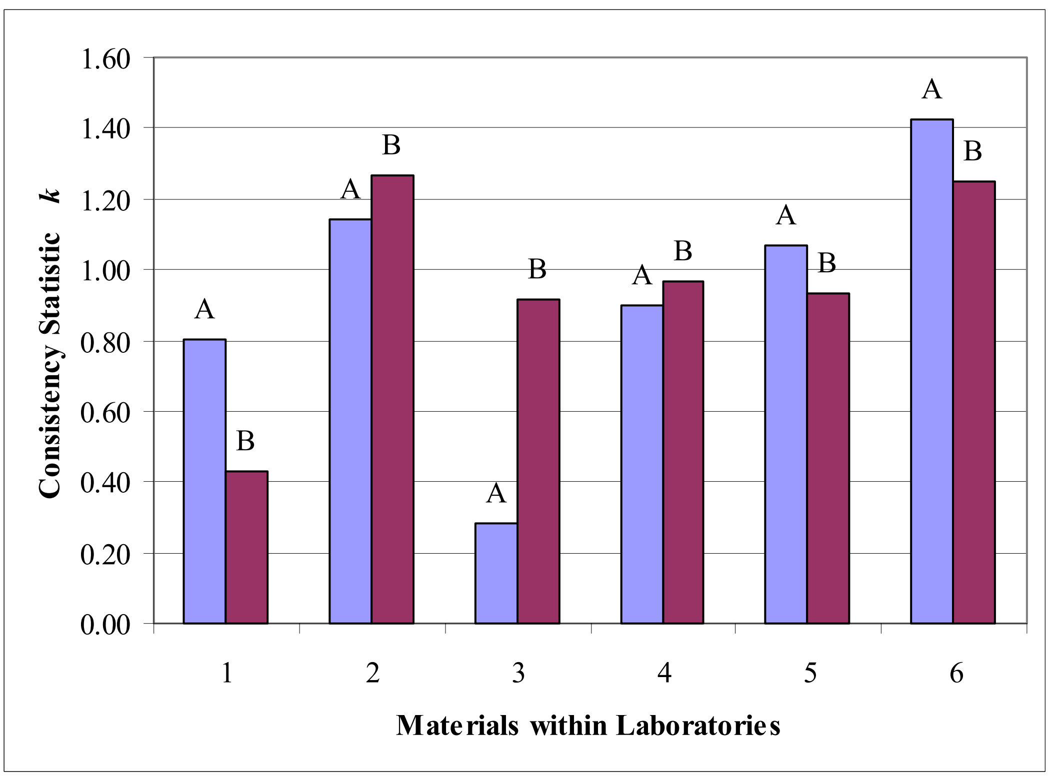

Figure 4. Consistency Statistic *k* for Materials within Laboratories.
A = Colorado Materials, B = Hanson Aggregate

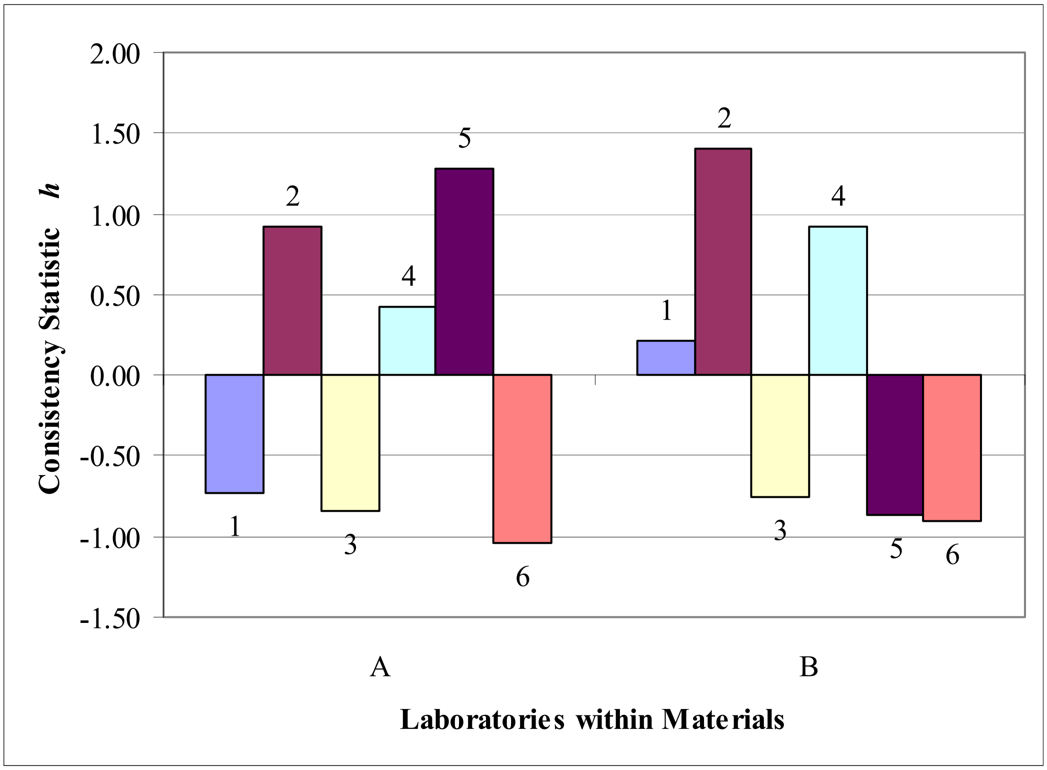

Figure 5. Consistency Statistic *h* for Laboratories within Materials.
A = Colorado Materials, B = Hanson Aggregate

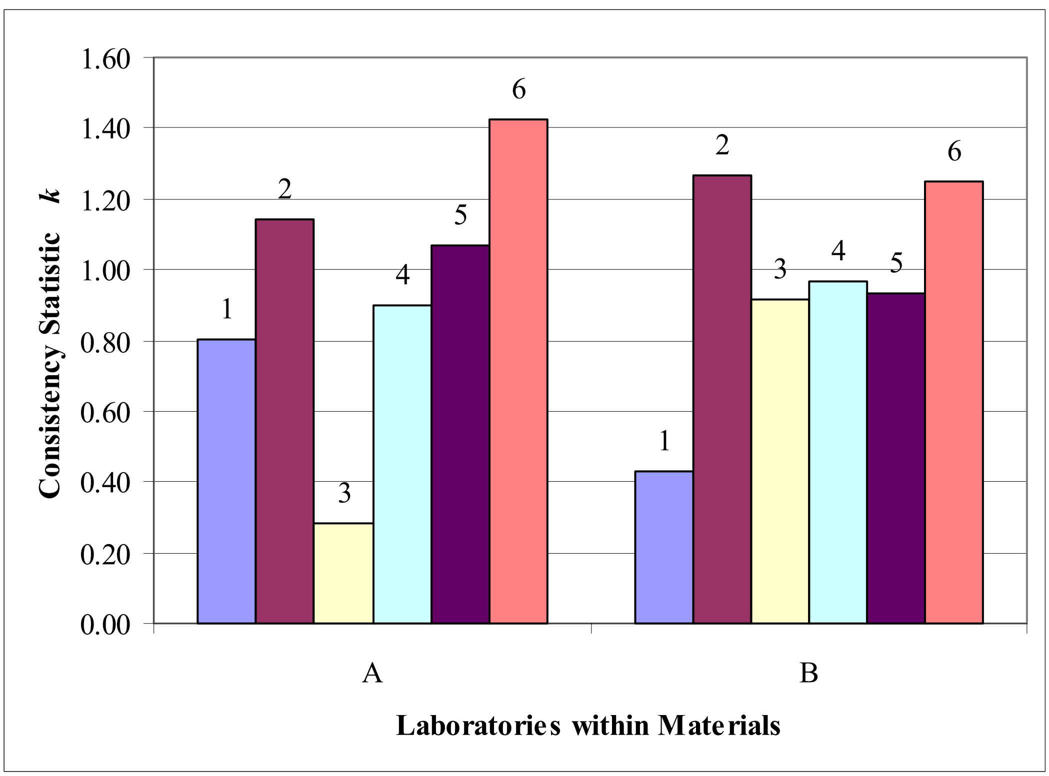

Figure 6. Consistency Statistic *k* for Laboratories within Materials.
A = Colorado Materials, B = Hanson Aggregate

Together with the typical patterns observed in the h plots, the absence of marked discrepancies between k values suggests the absence of unusual data that would have required additional investigation and possible exclusion from the statistical analyses. Therefore, according to recommendations in ASTM E 691, the data are adequately consistent for precision statistics to be calculated.

Based on equations given in ASTM E 691, the repeatability standard deviations for the Colorado Materials and Hanson aggregates were determined to be 0.614 and 1.24, respectively, and the reproducibility standard deviations were determined to be 2.643 and 2.991, respectively. The 95 percent repeatability and reproducibility limits were calculated by multiplying the respective standard deviations by a factor of 2.8. Thus, the repeatability limits for the Colorado Materials and Hanson aggregates were computed to be 1.719 and 3.472, respectively, and the reproducibility limits were computed to be 7.400 and 8.375, respectively. This suggests that for the Colorado Materials, for example, 95 percent of all pairs of final dielectric values for the same material tested within a given laboratory can be expected to differ in absolute value by less than 1.719, while 95 percent of all pairs of test results from laboratories similar to those that participated in this study can be expected to differ in absolute value by less than 7.400.

Previous research conducted at TTI evaluated the repeatability standard deviations of three materials across a range of dielectric values to determine whether the repeatability limit was a function of the final dielectric value *(9)*. The data presented in Table 5 include 10 replicate specimens for each type of aggregate. The repeatability standard deviation for each aggregate is equal in this case to the value of s given in the table and is in fact proportional to the final dielectric value. Thus, repeatability limits for final dielectric values of about 6, 20, and 28 are 0.585, 3.758, and 4.595, respectively, again calculated using the multiplicative factor of 2.8.

Considering that the mean dielectric values of the Colorado Materials and Hanson aggregates used in the interlaboratory study conducted in this project were both about 15, their repeatability limits are consistent with the earlier work. Consequently, based on the findings of that previous project, these repeatability limits do not diminish the ability to confidently discriminate among the three categories of moisture susceptibility rankings utilized in the TST. However, the reproducibility limits do diminish the ability to confidently discriminate among the three categories of moisture susceptibility. The reproducibility limits are greater than the repeatability limits by factors as high as four.

Table 5. Repeatability Data for Other Aggregates (9).

Material	Final Dielectric Value, x										$\bar{x}$	s
	1	2	3	4	5	6	7	8	9	10		
Gravel	5.5	5.6	5.6	5.8	5.8	5.9	5.9	6.0	6.0	6.2	5.815	0.209
Limestone	17.6	18.7	18.7	19.2	19.9	20.0	20.6	20.8	21.1	22.1	19.863	1.342
Caliche	24.7	27.1	27.1	27.3	27.4	27.8	28.1	28.6	29.6	30.8	27.843	1.641

ADDITIONAL TESTING

The excessive reproducibility limits generated in the interlaboratory study were considered to be unacceptable for statewide implementation of the TST, so further testing was undertaken to investigate possible reasons for increased variability of the between-laboratory test results compared to the within-laboratory test results. Natural variation across geographic regions pointed to relative humidity as a potentially influential factor in the TST. Initial testing at TTI had been completed at approximately 50 percent relative humidity, so additional specimens of Colorado Materials and Hanson aggregates were prepared for testing at lower and higher relative humidity values. Computer-controlled environmental chambers maintained at 25 and 80 percent relative humidity were utilized for this purpose.

Except for testing at the designated levels of relative humidity, all other TST procedures were followed exactly as performed in the interlaboratory study. Data presented in Table 6 show that similar water contents were used for compaction as in the previous TTI testing, specimen heights and densities were comparable, and initial water contents and initial dielectric values were approximately the same. However, the final water contents and final dielectric values for the tests conducted at 25 percent relative humidity were markedly lower than the same measurements resulting from testing at 50 percent relative humidity, which were in turn lower than those resulting from testing at 80 percent humidity. The effects of relative humidity on final dielectric values observed in this additional testing are summarized in Figure 7.

The evaporation rate of water across the surfaces of TST specimens is greater at lower levels of relative humidity than at higher levels, causing a reduced surface moisture content at equilibrium in conditions of lower relative humidity. Therefore, with reduced moisture levels within the upper 25 mm of the specimen, the dielectric value also declines. Variations in the relative humidity produced variations in final dielectric values from about 12 to 20, the same range of variation observed in the data collected in the interlaboratory study. However, because

Table 6. Test Results at Different Relative Humidity Levels.

Property	Specimen	Colorado Materials		Hanson Aggregates	
Relative Humidity (%)		25	80	25	80
Compaction Water (%)	1	7.3	7.4	7.1	7.2
	2	7.4	7.5	7.2	7.2
	3	7.6	7.5	7.3	7.2
	Mean	7.43	7.47	7.20	7.20
	Std. Dev.	0.15	0.06	0.10	0.00
Specimen Height (mm)	1	201.9	206.0	200.9	200.9
	2	201.2	202.9	200.2	203.2
	3	205.2	205.7	201.2	202.2
	Mean	202.78	204.89	200.74	202.10
	Std. Dev.	2.16	1.69	0.53	1.15
Relative Density (%)	1	99.1	98.7	101.0	101.0
	2	99.6	99.9	100.9	100.0
	3	98.9	98.7	100.6	100.3
	Mean	99.20	99.10	100.83	100.43
	Std. Dev.	0.36	0.69	0.21	0.51
Initial Water Content (%)	1	3.0	3.3	3.1	3.4
	2	3.1	3.2	3.5	3.6
	3	3.3	3.2	3.4	3.4
	Mean	3.13	3.23	3.33	3.47
	Std. Dev.	0.15	0.06	0.21	0.12
Initial Dielectric Value	1	5.9	7.0	6.2	7.2
	2	5.8	6.7	6.6	7.1
	3	6.0	7.3	7.1	6.9
	Mean	5.90	7.00	6.63	7.07
	Std. Dev.	0.10	0.30	0.45	0.15
Final Water Content (%)	1	6.3	7.4	5.3	6.0
	2	6.2	6.5	5.5	6.3
	3	6.3	6.7	5.2	6.1
	Mean	6.27	6.87	5.33	6.13
	Std. Dev.	0.06	0.47	0.15	0.15
Final Dielectric Value	1	11.8	21.2	10.4	19.6
	2	11.8	17.0	10.0	21.1
	3	11.2	21.5	9.4	20.2
	Mean	11.60	19.90	9.93	20.30
	Std. Dev.	0.35	2.52	0.50	0.75
Capillary Soak Time (hr)		261.0	237.4	260.0	237.4

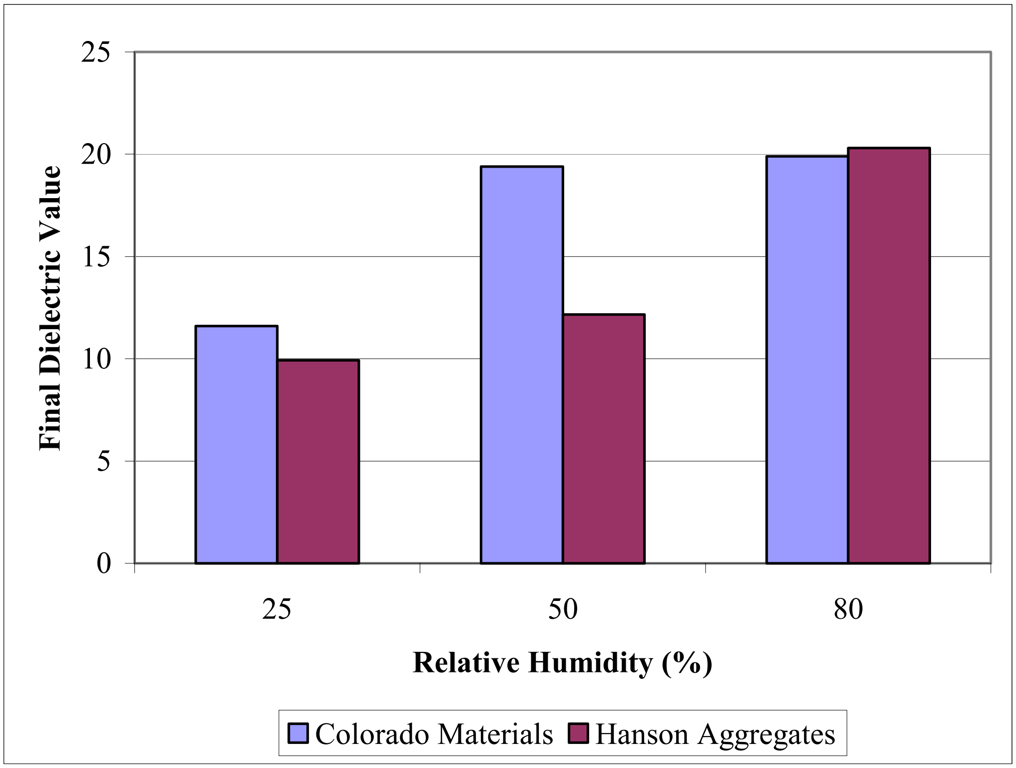

Figure 7. Relative Humidity Effects.

representative relative humidity levels were not readily available for each laboratory, the original data could not be corrected based on this finding.

Nonetheless, to mitigate the effects of relative humidity and, secondarily, temperature fluctuations that may also influence TST results, the test protocol was revised to require capillary soaking inside a closed ice chest. The evaporation of water added in the bottom of the ice chest to create a shallow bath was expected to consistently bring the relative humidity inside the ice chest close to 100 percent, and the insulation was expected to prevent temperature fluctuations that could otherwise cause excessive condensation on the lid inside the ice chest and lead to water dripping onto the specimen surfaces.

For comparative purposes, TxDOT personnel at the Waco District were trained on the revised protocol and provided with samples of Colorado Materials and Hanson aggregates identical to the batches utilized in earlier testing. TTI also repeated the testing using the same materials, but with the capillary soaking conducted inside large ice chests. As expected, a minimal amount of condensation formed on the inside of the ice chest lid, indicating a 100 percent relative humidity condition, but none dripped onto the specimen surfaces. Table 7

Table 7. Test Results Obtained Using Revised Protocol.

Property	Specimen	Colorado Materials		Hanson Aggregates	
		TTI	Waco	TTI	Waco
Compaction Water (%)	1	7.5	7.4	7.3	7.2
	2	7.4	7.5	7.4	7.3
	3	7.4	7.5	7.3	7.3
	Mean	7.43	7.47	7.33	7.27
	Std. Dev.	0.06	0.06	0.06	0.06
Specimen Height (mm)	1	201.6	202.9	202.4	199.5
	2	198.8	203.0	202.4	201.9
	3	202.4	203.6	202.0	201.4
	Mean	200.95	203.17	202.27	200.94
	Std. Dev.	1.88	0.41	0.23	1.30
Relative Density (%)	1	100.0	99.9	99.5	101.2
	2	100.1	99.8	100.0	100.2
	3	99.7	99.5	100.3	100.4
	Mean	99.93	99.73	99.93	100.60
	Std. Dev.	0.21	0.21	0.40	0.53
Initial Water Content (%)	1	3.7	2.8	3.8	3.3
	2	3.7	2.9	3.9	3.3
	3	3.8	3.2	4.0	3.7
	Mean	3.73	2.97	3.90	3.43
	Std. Dev.	0.06	0.21	0.10	0.23
Initial Dielectric Value	1	6.4	6.5	6.6	6.9
	2	6.8	6.3	7.0	7.0
	3	6.5	6.1	6.6	7.0
	Mean	6.57	6.30	6.73	6.97
	Std. Dev.	0.21	0.20	0.23	0.06
Final Water Content (%)	1	6.6	7.1	6.6	6.3
	2	7.4	7.1	6.4	6.9
	3	7.3	7.2	5.4	6.7
	Mean	7.10	7.13	6.13	6.63
	Std. Dev.	0.44	0.06	0.64	0.31
Final Dielectric Value	1	17.3	15.5	18.6	15.6
	2	18.6	15.2	19.0	15.7
	3	17.1	14.7	16.4	15.1
	Mean	17.67	15.13	18.00	15.47
	Std. Dev.	0.81	0.40	1.40	0.32
Capillary Soak Time (hr)		236.8	240.2	236.8	240.2

compares the data reported by the two agencies. Even though the average final water contents obtained by the tested specimens were practically equivalent for both types of aggregates, the dielectric values were still clearly different.

After completion of the testing, the Percometer™ utilized by Waco district personnel was delivered to TTI for inspection. A series of samples were prepared at various moisture levels to allow a comparison of the two devices over a range of dielectric values in the same location and in the same environmental conditions. Figure 8 shows that for dielectric values higher than about 10, the Percometer™ utilized by TTI provided consistently higher readings than those provided by the Percometer™ used at the Waco District laboratory for testing the same specimens. This observation explains the differences in final dielectric values reported in Table 7 by showing that the discrepancy in results may have been entirely attributable to hardware inconsistencies. This conclusion suggests that variations in results collected earlier during the interlaboratory study may also have been affected by inconsistencies between different Percometer™ devices available at each location.

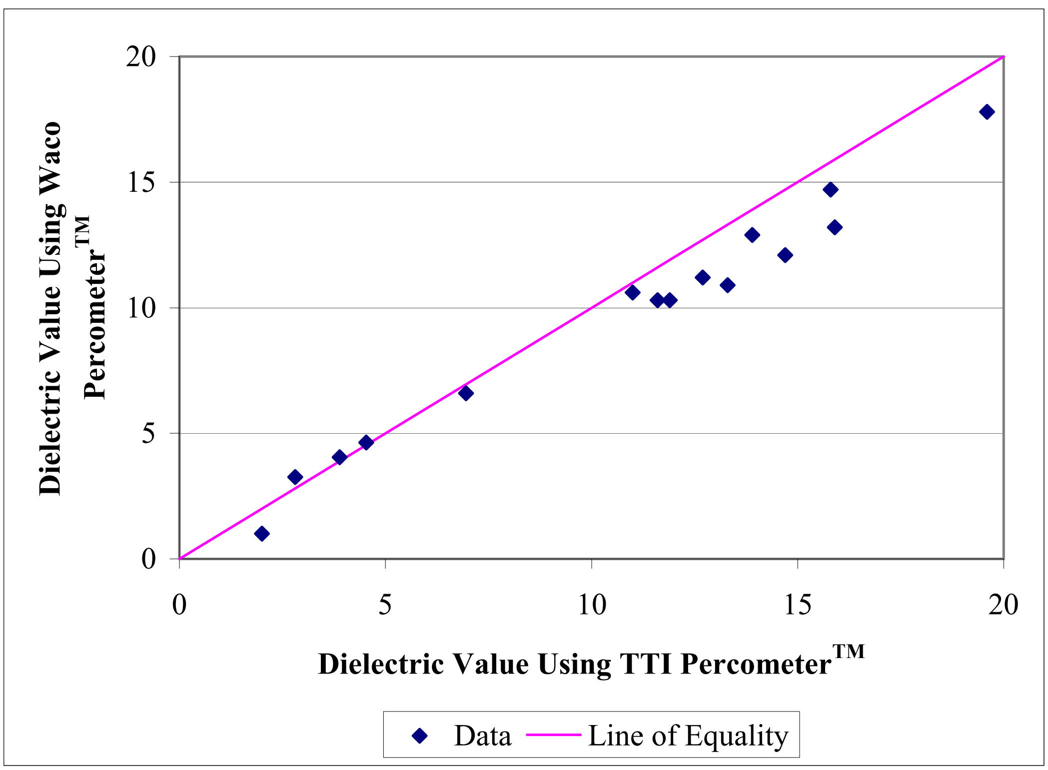

Figure 8. Comparison of Percometer™ Devices.

Inspections of several other Percometer™ instruments revealed that many had experienced wire fatigue in the cable at the side connection attaching the probe to the computer unit and had subsequently required repair. While standard soldering techniques had been employed in each case, the manufacturer explained that the dielectric probe calibration would indeed be affected by any wire breaks or repairs in the probe cable and could possibly generate errors even greater than the variations observed in the interlaboratory test conducted as part of this project. As a result of the discovery of this flaw in the hardware, the manufacturer indicated that the next release of the Percometer™ would be reconfigured to allow calibration to occur inside the probe rather than inside the computer unit, thus eliminating the possibility that any wire breaks could influence the electronic feedback required for calibration upon each use of the device.

SURVEY RESULTS

As part of the training sessions conducted at participating TxDOT laboratories, a brief questionnaire was provided to solicit information about the anticipated uses of the TST envisioned by TxDOT personnel. In total, 34 surveys were completed. Table 8 indicates that more than two-thirds of the participants expressed an interest in using the TST to evaluate the need for aggregate stabilization. The wide range of other expected applications demonstrates the potential benefits of this test to the fields of materials characterization and pavement engineering.

Table 8. Survey Results.

Anticipated Uses for Tube Suction Test	Percent of Survey Respondents (%)
Evaluating Need for Stabilization	68
Research	62
Forensic Investigations	41
Determining Stabilizer Contents	41
Pit Characterization	26
Stockpile Characterization	21
Assessing Effects of Blends	18
Quality Assurance Testing	15

CHAPTER 4. CONCLUSION

SUMMARY

The TST was jointly developed by the Finnish National Road Administration and TTI for assessing the moisture susceptibility of granular base materials. Based on promising correlations of test results to important engineering properties of aggregates, TxDOT initiated this project to conduct an interlaboratory study aimed at developing a standard test procedure and a precision statement for the TST. Two aggregate base materials, Colorado Materials and Hanson aggregates, were selected for a "round robin," which ultimately involved six TxDOT district laboratories geographically distributed across the state. These included Atlanta, Bryan, Fort Worth, Odessa, Waco, and Wichita Falls. TTI personnel developed a training program to present the details of the test protocol, explain the use of the Percometer™, and offer hands-on practice at making measurements and analyzing results. A spreadsheet program written for the purpose of analyzing collected data was also provided to personnel at each district to ensure uniform reporting of test results. After completion of the testing, statistical analyses of the test results were performed by TTI researchers for documentation in this report.

The interlaboratory study conducted in this project followed the ASTM E 691 designation in the development of a precision statement for the TST. Consistency statistics were considered in the identification of possible outliers and potentially invalid data, and repeatability and reproducibility limits computed from data collected in the study were compared against repeatability limits calculated from previous testing. Additional testing was performed to investigate the potential effects of relative humidity on TST results, as well as possible inconsistencies between different Percometer™ devices.

FINDINGS

The interlaboratory study was designed primarily to evaluate the repeatability and reproducibility limits of final dielectric values in the TST, but data related to specimen preparation indicate that the various laboratories were successful in reasonably replicating specimens of aggregate base material, including specimen dimensions and densities. Repeatability limits computed from data obtained in the interlaboratory study compared well to those repeatability limits calculated from data collected in earlier research, which were also utilized to demonstrate that the repeatability limits are proportional to the final dielectric value. The reproducibility limits calculated in this project exceeded the repeatability limits by factors as high as four and were considered unacceptable for statewide implementation of the TST. The wide range of variation was thought to dramatically diminish the ability of the test to discriminate among the three categories of moisture susceptibility rankings utilized in the TST and was the motivation for pursuing further testing.

Relative humidity was shown to have major impacts on the final dielectric values of specimens tested in the TST, and the protocol was subsequently revised to require capillary soaking inside a closed ice chest. The evaporation of water from the shallow bath in the bottom of the ice chest consistently maintains the relative humidity inside the ice chest at close to 100 percent, and the insulation prevents temperature fluctuations that could otherwise cause excessive condensation on the lid inside the ice chest and lead to water dripping onto the specimen surfaces.

Inconsistencies between two of the Percometer™ devices were identified through side-by-side comparisons of the units at the same location and in the same environmental conditions. Inspections of other Percometer™ instruments suggest that some of the between-laboratory variation observed in data collected during the interlaboratory study may have been attributable to such hardware inconsistencies between different devices. A poorly designed connector leading to repeated wire fatigue in the cable connecting the probe to the computer unit was subsequently acknowledged by the manufacturer to be the probable source of the dielectric measurement errors.

RECOMMENDATION FOR CONTINUED EFFORTS

A brief survey conducted during the training sessions held as part of the interlaboratory study suggested that among several promising applications of the TST to materials characterization and pavement engineering, the majority of the participants expressed an interest in using the test to evaluate the need for stabilization of aggregate base materials. Based on the apparent level of interest in the test, TxDOT should continue plans for statewide implementation of the TST. However, the Percometer™ probes currently owned by TxDOT must be properly repaired or replaced to ensure consistent dielectric measurements between different units. At that time, another interlaboratory study should be conducted to determine a more accurate reproducibility limit for inclusion in a precision statement for the test. The development of a calibration block having a constant dielectric value between 15 and 20 would also benefit TxDOT personnel at individual laboratories to confirm that the Percometer™ units are functioning properly.

RECOMMENDATION FOR ACCEPTANCE CRITERIA

This project focused on developing precision statistics for the TST. Although issues regarding the reproducibility of the test need to be resolved, currently no evidence exists to indicate a change in the acceptance criteria is needed. The interpretation of TST results is as follows:

Final dielectric < 10:	Good
Final dielectric between 10 and 16:	Marginal
Final dielectric > 16:	Poor

RECOMMENDATION FOR INCLUSION OF TST IN SPECIFICATION

Because of the success of the TST in discriminating between good and poor aggregate base materials, this report recommends inclusion of the TST among the requirements for flexible base listed in Item 247, Flexible Base, of *TxDOT Standard Specification for Construction and Maintenance of Highways, Streets, and Bridges*. This report proposes the creation of a new "premium" grade of aggregate, which would include all of the requirements listed for the existing Grade 1 specification, as well as a dielectric value less than 10 in the TST. The engineer in charge would determine whether specification of a premium base material was warranted for a particular project. Further discussion with TxDOT personnel is needed on this topic after the TST protocol is standardized.

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APPENDIX:

REVISED TUBE SUCTION TEST PROTOCOL

TUBE SUCTION TEST

This test method evaluates the moisture susceptibility of granular base materials used in pavements.

Significance and Use

The selection of base materials with adequate resistance to damage under traffic and environmental loading is important in maximizing the life of a pavement. Moisture ingress is a primary catalyst for pavement damage, and moisture susceptibility, or the degree to which moisture ingress degrades the engineering properties of aggregates, plays a key role in the performance of these materials in the field.

Research studies demonstrate that moisture susceptibility is related to the matric and osmotic suction properties of aggregates. Matric suction is mainly responsible for the capillary phenomenon in aggregate layers, and osmotic suction is the suction potential resulting from salts present in the pore water of an aggregate matrix.

The Tube Suction Test (TST) rates the resistance of aggregates to moisture damage as good, marginal, or poor. This moisture susceptibility ranking is based on the final surface dielectric values of compacted specimens after a 10-day capillary soak in the laboratory. The Adek Percometer™, a 50 MHz dielectric probe, is employed in the test to measure the dielectric values of specimens.

The dielectric value of a three-phase system comprised of aggregate particles, air, and water depends on the volumetric percentages and dielectric values of each constituent. The dielectric value of dry aggregate particles generally varies from 4 to 6, and the dielectric value of air is 1. The dielectric value of water depends on its state of bonding in the aggregate matrix. Tightly bound, or adsorbed, water has a dielectric value of about 3 or 4, but the dielectric value of unbound water is substantially higher at 81. Unbound water can migrate within the pavement structure to balance changes in suction caused by chemical contaminations, changes in the pore structure, or fluctuations in the water content.

For materials with high suction potential and sufficient permeability, substantial amounts of unbound water rise within the aggregate matrix during soaking and lead to higher dielectric values in the test. Conversely, non-moisture-susceptible materials maintain a strong moisture gradient throughout the test, with little moisture reaching the surface, and have lower dielectric values at the end of testing. Beneficiation techniques such as stabilization, blending, or reducing the fines content should be considered for effectively reducing the moisture susceptibility of poorly performing aggregates.

Apparatus

- Apparatus outlined in Test Method Tex-101-E, Part II
- Apparatus outlined in Test Method Tex-103-E, Part I
- Apparatus outlined in Test Method Tex-113-E
- Triaxial cells, lightweight stainless steel cylinders
- Cylindrical plastic molds with inside diameter of 152.4 mm (6 in.) and minimum height of 50.8 mm (2 in.)
- Power drill with 1.5 mm (1/16 in.) drill bit
- Drying oven maintained at 60 ± 5 °C (140 ± 9 °F)
- Flat-bottomed plastic pan, wide and shallow, for soaking specimens
- Adek Percometer™
- Ice chest for enclosing at least three triaxial cells

Materials

- Distilled water

Sample Preparation

Prepare the sample as in Test Method Tex-101-E, Part II.

Test Record Forms

Record sample preparation and testing data on the Tube Suction Test Data Collection Form (Figure A1). After tests are completed, summarize results on the Tube Suction Test Data Analysis Report (Figure A2).

PROCEDURE

Step	Action
1	Use Test Method Tex-113-E for determining the optimum moisture content (OMC) and maximum dry density (MDD) of the material for molding the test specimens.
2	Obtain three cylindrical plastic molds. At approximately 6 mm (1/4 in.) above the outside bottom of each mold, drill 1.5 mm (1/16 in.) diameter holes around the circumference of the mold at a horizontal spacing of 12.5 mm (1/2 in.). This equates to 38 or 39 holes around the mold base. Also drill one 1.5 mm (1/16 in.) diameter hole in each quadrant of the bottom of the mold about 50 mm (2 in.) from the center. Trim the cylinder as necessary to a height of 50 mm (2 in.) to create a reusable plastic base cap. Make two vertical cuts in each base cap, equally spaced around the circumference as shown in Figure A3, to enable easier installation and removal. Place a 152.4 mm (6 in.) diameter circle of filter paper or paper towel in the bottom of each cap. Weigh the caps to the nearest 1 g (0.0022 lb.) and record as W_{CAP}.
3	Obtain a representative sample of prepared material in sufficient quantity to prepare three specimens. Bring the material to OMC using distilled water.
4	Compact three specimens at optimum moisture and maximum dry density according to Test Method Tex-113-E. The specimens should be 152.4 mm (6 in.) in diameter and 203.2 ± 6.4 mm (8 ± 0.25 in.) in height and should be wetted, mixed, molded, and finished as nearly identical as possible. The surface of each specimen should be made as smooth as possible after compaction. Remove or reposition any coarse aggregate protruding from the specimen surface and fill any large voids as necessary. Application of fines across the whole specimen surface should be avoided, however.
5	After removal of specimens from the compaction sleeve, install a base cap on the bottom of each specimen so that as little air as possible exists between the bottom of the specimen and the cap. Weigh three clean, dry triaxial cells to the nearest 1 g (0.0022 lb.), and record as W_{CELL}. Slide the triaxial cell down over the specimen so that only the lower 25 mm (1 in.) of the base cap remains exposed. Weigh the specimen with the base cap and triaxial cell to the nearest 1 g (0.0022 lb.) and record as W_{OMC}.
6	Place the specimens in an oven maintained at 60 ± 5 °C (140 ± 9 °F) for 48 ± 4 hours.
7	Remove the specimens from the drying oven and weigh each specimen with base cap and triaxial cell to the nearest 1 g (0.0022 lb.) and record as W_{DRY}. Use the Adek Percometer™ to take six initial dielectric readings on each specimen surface as shown in Figure A4. Five should be equally spaced around the perimeter of the specimen, and the sixth should be in the center. Press down on the probe with a force of 4.5 ± 1.4 kg (10 ± 3 lb.) to ensure adequate contact of the probe on the specimen surface. This pattern should be followed each time dielectric values are measured.
8	Place the samples inside an ice chest on a level surface in a laboratory room maintained at 25 ± 5 °C (77 ± 9 °F) and fill the ice chest with distilled water to a depth of 12.5 ± 3.2 mm (1/2 ± 1/8 in.). The water bath should be maintained at this depth throughout the testing. Avoid splashing the specimen surfaces with water during the test. Close the ice chest lid.
9	Take six dielectric readings on each specimen surface once a day for 10 days. If the water content is to be monitored through time, the sample weight should be recorded daily to the nearest 1 g (0.0022 lb.) and recorded as W_{WET} at each time interval. Wipe the bottom of the mold dry before weighing. Close the ice chest lid after taking measurements.
10	The test is completed when the elapsed time exceeds 240 hours. Measure and record final surface dielectric values and weights. If triaxial strength testing is desired in this soaked condition, carefully remove the base cap and perform the test.
11	Determine the final moisture content of each specimen according to Test Method Tex-103-E, Part I, but use the entire sample in the procedure. Wash all aggregate particles from the base cap and interior of the triaxial cell, as well as from any porous stones used in triaxial testing, into the drying pan. Record the weight of the oven-dry aggregate particles as W_S.

Aggregate ______________________ Technician ______________________

Source ______________________ Year ________ Lab. No. ________

Specimen Preparation		Measurement	0	1	2	3	4	5	6	7	8	9	10
OMC, %		Date, mm/dd											
MDD, kg/m^3 (pcf)		Time, hr:min											

Specimen No.		W_{WET}, g (lb.)												
Specimen Testing		Dielectric Value	1											
W_{CAP}, g (lb.)			2											
W_{CELL}, g (lb.)			3											
W_{OMC}, g (lb.)			4											
W_{DRY}, g (lb.)			5											
W_S, g (lb.)			6											

Specimen No.		W_{WET}, g (lb.)												
Specimen Testing		Dielectric Value	1											
W_{CAP}, g (lb.)			2											
W_{CELL}, g (lb.)			3											
W_{OMC}, g (lb.)			4											
W_{DRY}, g (lb.)			5											
W_S, g (lb.)			6											

Specimen No.		W_{WET}, g (lb.)												
Specimen Testing		Dielectric Value	1											
W_{CAP}, g (lb.)			2											
W_{CELL}, g (lb.)			3											
W_{OMC}, g (lb.)			4											
W_{DRY}, g (lb.)			5											
W_S, g (lb.)			6											

Figure A1. Tube Suction Test Data Collection Form.

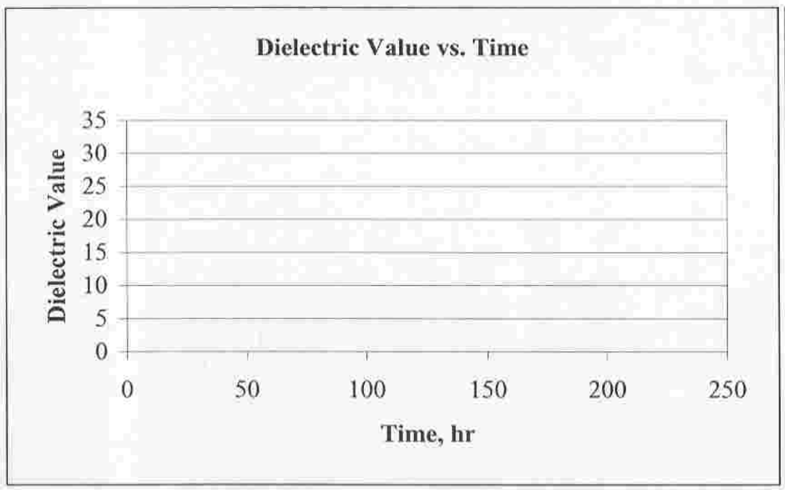
Aggregate ______________________ Technician ______________________

Source ______________________ Year __________ Lab. No. __________

Measurement	0	1	2	3	4	5	6	7	8	9	10
Total Time, hr											
Specimen No.	Average Dielectric Value										
Specimen No.	Gravimetric Water Content During Soaking, %										

Average Final Dielectric Value	
Moisture Susceptibility Ranking	

Average Final Gravimetric Water Content, %	
Average Water Loss in Drying, % of OMC	



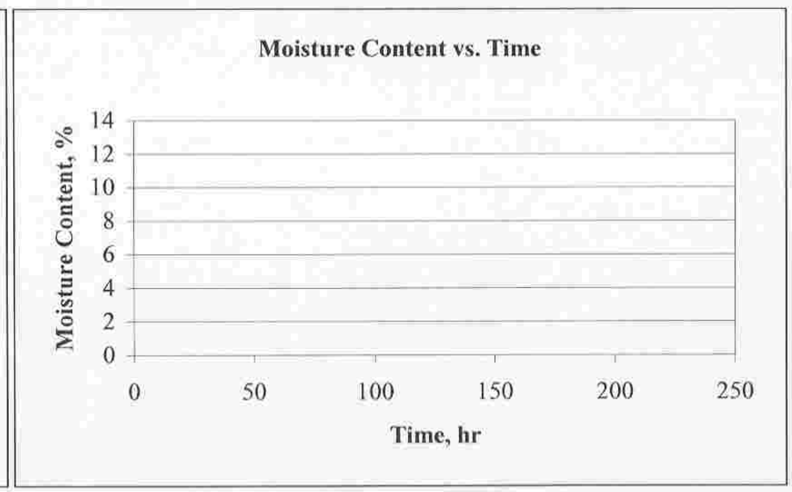


Figure A2. Tube Suction Test Data Analysis Report.

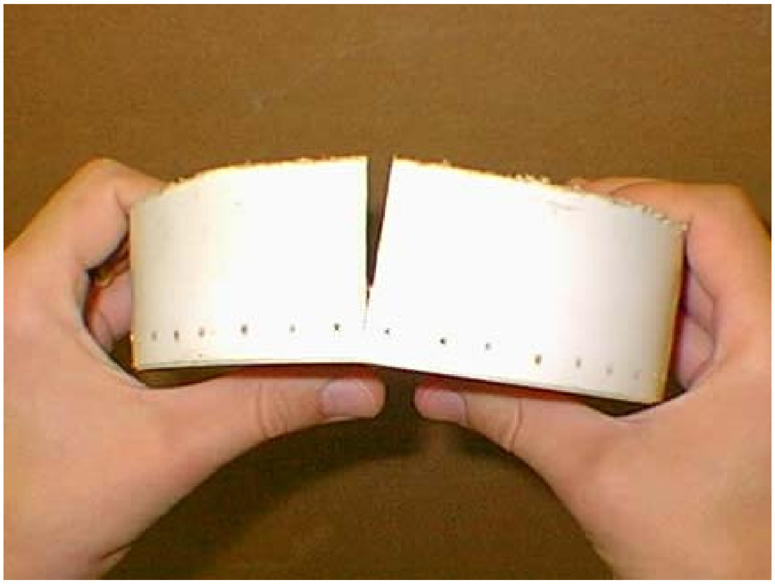


Figure A3. Finished Base Cap.

Figure A4. Using the Adek Percometer™.

Calculations

- Calculate the actual gravimetric moisture content (M_{OMC}, %) of each specimen just after compaction at the optimum moisture content,

$$M_{OMC} = 100\ (W_{OMC} - W_{CAP} - W_{CELL} - W_S)\ /\ W_S$$

Where:

W_{OMC} = weight of specimen with base cap and triaxial cell just after compaction, g (lb.)
W_{CAP} = weight of plastic base cap, g (lb.)
W_{CELL} = weight of clean, dry triaxial cell, g (lb.)
W_S = weight of oven-dry aggregate particles, g (lb.)

- Calculate the gravimetric moisture content (M_{DRY}, %) of each specimen just after the two-day drying period,

$$M_{DRY} = 100\,(W_{DRY} - W_{CAP} - W_{CELL} - W_S) / W_S$$

Where:

W_{DRY} = weight of specimen with base cap and triaxial cell after two-day drying period, g (lb.)
W_{CAP} = weight of plastic base cap, g (lb.)
W_{CELL} = weight of clean, dry triaxial cell, g (lb.)
W_S = weight of oven-dry aggregate particles, g (lb.)

- Calculate the percentage of water loss (P_{LOSS}, % of OMC) for each specimen during the two-day drying period,

$$P_{LOSS} = 10000\,(\,(W_{OMC} - W_{DRY}) / W_S) / M_{OMC}$$

Where:

W_{OMC} = weight of specimen with base cap and triaxial cell just after compaction, g (lb.)
W_{DRY} = weight of specimen with base cap and triaxial cell after two-day drying period, g (lb.)
W_S = weight of oven-dry aggregate particles, g (lb.)
M_{OMC} = gravimetric moisture content just after compaction, %

- Calculate the average percentage of water loss for the three specimens.

- Calculate the gravimetric moisture content (M_{WET}, %) of each specimen at each time interval during the soaking period,

$$M_{WET} = 100\,(W_{WET} - W_{CAP} - W_{CELL} - W_S) / W_S$$

Where:

W_{WET} = weight of specimen with base cap and triaxial mold at time of interest during soaking period, g (lb.)
W_{CAP} = weight of plastic base cap, g (lb.)

W_{CELL} = weight of clean, dry triaxial cell, g (lb.)
W_S = weight of oven-dry aggregate particles, g (lb.)

- Calculate the average gravimetric water content of the three specimens at the end of the soaking period.

- For each specimen at each time interval, discard the highest and lowest dielectric readings. Calculate the average dielectric value from the remaining four readings for plotting against time.

- Calculate the average final mean dielectric value of the three specimens to determine an overall moisture susceptibility ranking. Aggregates with final dielectric values less than 10 are expected to provide good performance, while those with dielectric values above 16 are expected to provide poor performance as base materials. Aggregates having final dielectric values between 10 and 16 are expected to be marginally moisture susceptible.

Graphs

- Plot the dielectric-time curve for each specimen.

- Plot the moisture-time curve for each specimen if requested.

Test Report

Report the average final dielectric value after soaking and the corresponding moisture susceptibility ranking of good, marginal, or poor.

Also, report the average final gravimetric water content of the specimens after soaking and the average percentage of water loss with respect to OMC during the two-day drying period. The former is indicative of the water content this aggregate may attain in the field given the availability of water, and the latter, if less than 50 percent, suggests that special construction considerations may be required in moist conditions to avoid trapping water in the pavement.