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ENVIRONMENTAL EFFECTS IN PAVEMENT MIX AND STRUCTURAL DESIGN SYSTEMS

CALIBRATION AND VALIDATION OF THE ICM VERSION 2.6

PRELIMINARY DRAFT
FINAL REPORT
PART 2

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W.N. Houston, M.W. Mirza, and C.E. Zapata
Arizona State University
Fulton School of Engineering
Department of Civil and Environmental Engineering

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

This report documents and presents the results of the NCHRP 9-23 Project titled *Environmental Effects in Pavement Mix and Structural Design Systems.* The objectives of this research project were to: (1) Validate the Version 2.6 of the ICM (EICM) developed in NCHRP Project 1-37A with data from the Long Term Pavement Performance Seasonal Monitoring Program (LTPP SMP) and other field experiments; (2) Develop practical guidelines for selecting EICM input data sets; (3) Verify the estimated period or rate of aging simulated by the current Superpave binder and hot mix asphalt (HMA) conditioning procedures – AASHTO provisional practices PP1-98 and PP2-99 – with data from LTPP Specific Pavement Studies (SPS) and other field experiments; and (4) Revise the current conditioning procedures as necessary for their use with the materials characterization test and model under development in NCHRP 9-19 project for the Superpave performance model system.

The last two objectives were accomplished and summarized in PART 1 of this report, submitted to the review panel in September 2005. The first two objectives are summarized in this report (PART 2). The variables required to run and validate the EICM are identified, as well as the variables needed to select the pavement sections for the analysis. A statistically-based experiment design for the calibration and validation of the Integrated Climatic Model (ICM) version 2.6 is presented. To evaluate the models currently implemented, a site investigation of thirty LTPP sections was completed and the results of the laboratory testing are presented. Finally, the calibration and validation of the individual EICM models is presented.

Results of the statistical analysis of the current model showed that all the models and particular the *Suction model* were in need of improvement and calibration. The individual models were calibrated with the best dataset available gathered from the sites visited and from the LTPP database and therefore, they will perform better than the currently 2004 EICM version 2.6 adopted models. Individual validation of the models showed improvement in all predictions.

The individual models developed as part of this project are considered to comprise the state of the art material found in the literature as well as a very substantial database derived form site visits and laboratory testing as a part of the NCHRP 9-23 project. However, there is of course, still room for improvement if the databases are extended and more information becomes available. Further research should include completion of the sensitivity study relative to moisture content predictions. The ongoing effort to improve and polish the models has been taken over by NCHRP 1-40D project entitled *Technical Assistance Project to NCHRP in the M-E Pavement Analysis System Developed under NCHRP 1-37A.* Based on ongoing studies on sensitivity of the models, deficiencies and continuous feedback received by the research team, future work planned under the 1-40D project will handle some of the model limitations the research team has found as of today (end of 2004).

SUMMARY

This report documents and presents the results of the NCHRP 9-23 Project titled *Environmental Effects in Pavement Mix and Structural Design Systems.* The Enhanced Integrated Climatic Model (EICM) was subjected to evaluation and calibration under this project. The EICM is a one-dimensional coupled heat and moisture flow model initially developed for the FHWA and adopted in the *Mechanistic-Empirical Pavement Design Guide* (MEPDG) developed under NCHRP 1-37A project. The model is intended to predict or simulate the changes in behavior and characteristics of pavement and unbound materials in conjunction with environmental conditions over several years of operation. The research work presented in this report was intended to evaluate and calibrate the ICM version 2.6 (currently known as EICM) moisture predictive capabilities.

The equilibrium moisture condition in the EICM version 2.6 is currently based on a suction model that depends on the water table depth and on a SWCC model that is functionally dependent on simple soil properties. Findings by the team in charge of the NCHRP 9-23 project, indicated that the sources of error in the prediction of moisture content were primarily derived from the *Suction model* currently implemented. Further analysis and research indicated that a much more accurate approach exists for suction computations through the use of specific models developed in the NCHRP 9-23 project and presented in this report. The new model eliminates the use of the water table depth as the basis for the prediction and incorporates an approach based on the Thornthwaite Moisture Index (*TMI*). To some significant degree, this index balances lateral infiltration and evaporation for a particular region. While the recommended *TMI* methodology (new *Suction models*) has an empirical component; it has been found that the new model significantly improves the prediction of the equilibrium moisture for the granular bases, which helps to alleviate the stated concerns of the team of independent reviewers of the MEPDG.

The NCHRP 9-23 team did not have the time and resources to investigate one important aspect of moisture movement not currently addressed in the EICM. One major hypothesis formulated by the research team is that the primary source of water reaching the base course is a result of nighttime condensation of water vapor coming in laterally from the shoulders and or underlying layers. The process is hysteretic and difficult to reverse and any buildup of water in the base course is then pulled into the subgrade, more or less at steady state. Moisture movements in response to temperature and solute gradients were not directly addressed in this study. Further research is needed to better understand these effects. A detailed list of the tasks that should be accomplished is presented in Chapter 7.

The report has been divided into two parts. PART 1 presents the conclusions for the asphalt aging study based on the work done under Tasks 2 and 7. PART 2 contains the

findings for the moisture study, which comprises the work done under Tasks 4 and 5. PART 1 has already been submitted for panel review. PART 2 is presented herein.

The report is organized into 8 major chapters, which describe the general study approach adopted and the research findings: Chapter 1 presents the experimental design for calibration and validation of the EICM models. The parameters needed to run the models are presented and the selection process of the sections chosen for site investigation is presented. Chapter 2 presents details of the field investigation. Chapter 3 summarizes the parameters required to run the EICM from the different databases used in the analysis and Chapter 4 summarizes the laboratory testing results on the material collected from the site investigation. Chapter 5 presents the statistical analysis to evaluate the EICM models and Chapter 6 presents the calibration of the new models proposed in this study and individual validation of the models. Chapter 7 presents the recommendations for future research work and Chapter 8 present the summary and conclusions of the study.

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT

The satisfactory design of a pavement mix and structural configuration for a layered pavement system requires the execution of numerous challenging tasks and must usually be done in an iterative mode. Two important aspects of this process are the use of a computational model to quantify environmental effects for the design period and the translation of changes in temperature and moisture contents into changes in moduli and other physical properties, including aging effects.

The Enhanced Integrated Climatic Model (EICM) was subjected to evaluation and calibration under this project. The EICM is a one-dimensional coupled heat and moisture flow model initially developed for the FHWA and adopted in the ***Mechanistic-Empirical*** *Pavement Design Guide* (MEPDG) developed under NCHRP 1-37A project. The model is intended to predict or simulate the changes in behavior and characteristics of pavement and unbound materials in conjunction with environmental conditions over several years of operation. The research work presented in this report was intended to evaluate and calibrate the ICM version 2.6 (currently known as EICM) moisture predictive capabilities.

Environmental conditions play a significant role in the change of pavement material properties and hence the pavement response. This was also observed by several research studies including the work done under SHRP A-005 and SHRP A-002 studies.

The SHRP A-005 study clearly showed the environmental effect on the age hardening characteristics of asphalt binders (AAPT 1995 – "Development of Global Aging System for Short and Long Term Aging of Asphalt Cements). The importance of climatic conditions on the age hardening characteristics of the asphalt mixes was illustrated. Other factors considered were the volumetric properties (air voids), and the depth below the pavement surface. Furthermore, the model developed takes into account the temperature susceptibility of the binder.

In addition to the work done under SHRP A-005, work under SHRP A-002 resulted in the development of two provisional test methods to study the age hardening properties of asphalt binders (AASHTO Designation: PP1-98, Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel, PAV) and for the mixes (AASHTO Designation: PP2-99, Standard Practice for Mixture Conditioning of Hot Mix Asphalt, HMA). These two provisional procedures are associated with certain limitations and work was needed to verify the guidelines presented in these provisional protocols.

The research done under the NCHRP 9-23 project evaluated the protocols for aging, PP1-98 and PP2-99, to find if they correctly simulated changes in mechanical properties, such as moduli, and if these changes occurred in periods of time which corresponded to those of the natural-aged prototype asphalt mixes.

CURRENT KNOWLEDGE

Enhanced Integrated Climatic Model

The earlier versions of the EICM were comprised of three major components:

1. The Infiltration and Drainage Model (ID Model) developed at the Texas A&M University;
2. The Climatic-Materials-Structural Model (CMS Model) developed at the University of Illinois; and,
3. The Cold Regions Research and Engineering Laboratory (CRREL) Frost Heave and Thaw Settlement Model (CRREL Model) developed at the United States Army CRREL.

The EICM output includes temperature, moisture content, and freeze/thaw depths throughout the entire pavement profile, and can be applied to either asphalt concrete (AC) or Portland cement concrete (PCC) pavements. Modifications to the EICM have spanned the last decade (Lytton et al. 1990, Larson and Dempsey 1997). In July 1999, the latest available version of the ICM was Version 2.1, as developed by Larson and Dempsey at the University of Illinois. Version 2.1 was nominated for use in the Superpave performance model and the ***Mechanistic-Empirical Pavement Design Guide***. The Advanced Pavement research team at Arizona State University headed by Dr. M. Witczak initiated a series of checks on the predictive accuracy of the ICM Version 2.1 for ten LTPP SMP sites in 1999. The agreements between predicted and TDR measured moisture contents were judged unsatisfactory and the ASU research team was commissioned to develop a set of modifications to the ICM, aimed at increasing its predictive accuracy. Initially, the ASU team developed the following modifications:

1. Use of new functional fits for the soil-water characteristics curves (SWCCs);
2. Use of new relationships between the SWCCs and material index properties;
3. Use of new hydraulic conductivity functions for saturated (k_{sat}) and unsaturated (k_{unsat}) materials; and
4. Employment of equilibrium moisture content as an input value.

One of the subsequent findings that was not fully anticipated was that the seasonal variations in moisture were relatively small compared to the changes in moisture from the initial placement condition to the "equilibrium" or an average moisture achieved after a few years. In consideration of these findings, the question arose as to whether it was appropriate to input the equilibrium moisture in the general case, because, for example, these equilibrium moisture contents would typically not be known for new pavement construction where instrumentation is unavailable. Thus, it was ultimately concluded that the ICM should, in fact, be required to predict the equilibrium moisture contents. However, the emphasis for this first study was on predicting seasonal oscillations about the equilibrium or mean moisture contents. It was later found that, as stated above, these

seasonal oscillations were typically fairly minor, in the absence of open cracks in the pavement.

A major goal of the NCHRP 9-23 project was to evaluate if the improvements to the model (called EICM after ASU modifications) were adequate and if further improvements would be necessary. The decisions on how to make any needed improvement were based on the results of sampling and testing at the LTPP sites. The recommendations made from the moisture study part are included in this report. The asphalt aging study part has been finalized and it is currently under reviw by the NCHRP technical panel.

Moisture Content Changes

Moisture content changes that occur after construction of the pavement section fall into one of three categories:

1. Increase or decrease from the initial condition (typically near optimum) to the equilibrium or *average* condition,
2. Seasonal fluctuation about the average or normal moisture condition due to infiltration of rainfall through cracks in the bound layer(s) and due to fluctuations in groundwater table in the absence of freeze/thaw, and
3. Variations in moisture content due to freeze/thaw.

Recent studies (Witczak et al. 2000) have shown that the effect on resilient moduli, M_R, due to categories 1 and 3 can be quite significant. However, category 2 results, i.e., seasonal changes in moisture in the absence of freeze/thaw, were found to produce typically insignificant changes in M_R. As a consequence of this finding, it was tentatively decided for the *Mechanistic-Empirical Pavement Design Guide* to assume that there are no cracks in newly-constructed pavements and that the groundwater table (GWT) does not fluctuate during the design period. After making these simplifying assumptions, the role of the EICM with respect to moisture content was the prediction of changes under categories 1 and 3.

To validate the changes that lead to the new EICM version, the research team of the NCHRP Project 1-37A carried out a limited validation study (Witczak et al. 2000) with data from ten Long Term Pavement Performance – Seasonal Monitoring Program (LTPP SMP) sections. However, the comparison between the EICM-predicted and the TDR-measured moisture contents was made in this study before the finding that seasonal changes in moisture content in the absence of freeze/thaw produced negligible changes in M_R had been made. Therefore, the comparisons were repeated as a part of the NCHRP Project 9-23, which was directed at the full data set from all the LTPP SMP sections. In this project, the emphasis was placed on prediction of the changes from the initial condition to the equilibrium condition.

It is apparent that the prediction of moisture content alone is not a justifiable end. It is the effect of moisture changes on the mechanical properties of the pavement layers, such as M_R, that is of primary interest. Therefore, in order to decide if a given level of predictive accuracy on moisture content is acceptable or not, it is necessary to translate a typical error in moisture content into a typical error in modulus or another mechanical property.

Effects of Temperature

Temperature serves as the link between the environmental effects on unbound layers and bound layers. Temperature changes directly control freezing and thawing, which in turn produces dramatic changes in the M_R of unbound layers. Moduli of bound layers, particularly asphaltic layers, are likewise directly controlled by temperature, which also controls thermal cracking of the pavement. Furthermore, temperature and time couple to produce aging effects. Thus, temperature is a key variable in all of these processes which control the response of pavement sections to traffic loads, and the EICM is to be required to predict temperature.

RESEARCH OBJECTIVES

The objectives of this research project were to:

1. Validate the Version 2.6 of the ICM (EICM) developed in NCHRP Project 1-37A with data from the Long Term Pavement Performance Seasonal Monitoring Program (LTPP SMP) and other field experiments.
2. Verify the estimated period or rate of aging simulated by the current Superpave binder and hot mix asphalt (HMA) conditioning procedures – AASHTO provisional practices PP1-98 and PP2-99 – with data from LTPP Specific Pavement Studies (SPS) and other field experiments.
3. Revise the current conditioning procedures as necessary for their use with the materials characterization test and model under development in NCHRP 9-19 project for the Superpave performance model system.

RESEARCH APPROACH

To accomplish the objectives described above, the NCHRP Project 9-23 was divided into three phases. The tasks within each phase are shown below.

PHASE I

- Task 1: Experiment Design for the Calibration and Validation of the Version 2.6 of the ICM
- Task 2: Literature Review on the Development and Validation of the Superpave Mix Conditioning Procedures
- Task 3: Preparation of the Interim Report Presenting the Results of Phase I

PHASE II

- Task 4: Validation of the EICM with the Full LTPP SMP Data Set
- Task 5: Sensitivity Analysis of the Fully Validated EICM
- Task 6: Preparation of the Interim Report Presenting the Results of Phase II

PHASE III

- Task 7: Experiments to Verify the Estimates of Rate of Aging Simulated by AASHTO PP1-98 and PP2-99 Test Procedures
- Task 8: Preparation of Final Report

Task 1: Experiment Design for Calibration and Validation of the ICM Version 2.6

Task 1 required the preparation of a detailed, statistically based experiment design for the calibration and validation of the version 2.6 of the ICM. The experiment design began with the identification of the material and climatic input data needed for thorough analyses.

Task 2: Literature Review on the Development and Validation of the Superpave Mix Conditioning Procedures

This task included a critical review of the development of the Superpave mix conditioning procedures PP1-98 and PP2-99 that were developed to study the age hardening characteristics of the asphalt mixes.

Task 3: Preparation of the Interim Report Presenting the Results of Tasks 1 and 2

An interim report that documented the research performed in Phase I and included details of the work planned for Phases II and III was prepared and submitted to the NCHRP panel.

Task 4: Validation of the EICM with the LTPP SMP Data Set

Task 4 required the execution of the experiment developed under Task 1. This encompassed the evaluation, calibration and validation of the EICM with the LTPP SMP data set and other data sets as may be found useful. This validation was an iterative process. The EICM was used in its current form for prediction, for the first iteration. Given that the predictive accuracy had room for improvement, then all available information and research findings available to date were used to develop a list of modifications to the EICM. These modifications were made and comparative runs were repeated until acceptable accuracy was achieved.

Task 5: Sensitivity Analysis of the Validated EICM

This task was to include a sensitivity analysis of the fully validated EICM. After the EICM predictions were made to be as accurate overall as was practical, a sensitivity analysis of the output variables to the input variables was to be completed. This quantification was to involve varying the input variables through a multi-factor designed experiment over their reasonable ranges and mapping the corresponding output variable

ranges. This sensitivity analysis is important because rational decisions needed to be made relative to the time and money that should be spent in maximizing the quality of the input data. An informed basis is needed for deciding which input variables could be selected from a range of default values versus those inputs which should be project-specific or based on actual tests on materials from the project. Because it was not possible to complete the programming and full implementation of the new NCHRP 9-23 model into the EICM, it was necessary to check and verify the new models against field-measured data using spreadsheet computations of the predicted moisture contents. Because the sensitivity analysis is still considered important it was recommended to be completed under the NCHRP 1-40D project.

Task 6: Preparation of the Interim Report Presenting the Results of Phase II

An interim report that documented the research performed in Phase II was planned in Task 6. Given the delay in the research schedule, the Interim Report was not submitted to the NCHRP panel, and instead, was delivered as part of the preliminary draft of the final report.

Task 7: Experiments to Verify the Estimates of Rate of Aging Simulated by AASHTO PP1-98 and PP2-99 Test Procedures

The objective of this task was to conduct laboratory testing on the binders and field mixes to verify PP1-98 and PP2-99 test procedures.

Task 8: Preparation of Final Report

The final report will summarize the findings and conclusions drawn during the study. The present document is the preliminary draft report. The final report will be submitted to the NCHRP panel once the reviw and recommendations from the panel are incorporated.

ORGANIZATION OF THE REPORT

The report was divided into two parts. PART 1 presents the conclusions for the aging study and the work done under Tasks 2 and 7. PART 2 contains the findings for the moisture study, which comprises the work done under Tasks 4 and 5. PART 2 is presented in the following document. PART 1 was already submitted and it is currently under reviw.

PART II

CALIBRATION AND VALIDATION OF THE ICM VERSION 2.6 (EICM)

CHAPTER 1

EXPERIMENT DESIGN FOR CALIBRATION AND VALIDATION OF THE ICM VERSION 2.6 (EICM)

INTRODUCTION

Task 1 involved the preparation of a detailed statistically based experiment design for the calibration and validation of the EICM. The experiment design began with the identification of the data needed for a thorough analysis. The variables that were identified fall into three categories:

1. Parameters required to run the EICM
2. Data required for validation of the EICM
3. Data required to select pavement sections for analysis

The recognition of the parameters required to run and validate the EICM was important during the experiment design as pavement sections without these parameters were eliminated from consideration. Variables required for running the EICM included location, pavement profile, asphalt or Portland cement concrete material properties, compacted material properties, and in-situ material properties. The variable required for validation of the EICM was the measured moisture content.

Additional variables were needed to aid in the selection of appropriate pavement sections. Parameters such as location, climatic condition, and in-situ material properties allowed for better statistical distributions. Examination of pavement cracking data ensured that the pavement sections included did not have excessive water flow through the pavement.

The experiment design was divided into two parts. One part included pavement sections that were analyzed and results compared to previously measured values extracted from available databases. The other part included pavement sections that were analyzed and results compared to direct, in-situ measurements. These sites were visited during the course of the project to obtain these direct measurements.

PARAMETERS NEEDED FOR THE CALIBRATION AND VALIDATION OF THE EICM

Input Parameters Needed to Run and Evaluate the EICM

A relatively large number of input parameters were needed to run the EICM. The set of parameters required for input depends on the accuracy desired in the pavement analysis. In the Mechanistic-Empirical Pavement Design Guide – MEPDG (NCHRP 1-37A *Design Guide for New and Rehabilitated Pavement Structures* project), three hierarchical levels of analysis have been defined. Level 1 is the most accurate and Levels 2 and 3 are more approximate. Level 1 requires that a complete set of measured variables be input by the

user. Levels 2 and 3 require less data from direct measurements. The EICM internally generates values for missing data by using correlations with input data. Obviously, some data must be input for each unbound layer. In some cases, this input data can be only index properties such as gradation and plasticity. In the tables that follow, parameters that can either be input by the user or internally generated by the EICM are shown in bold. The parameters not shown in bold are always internal to the EICM and are never required to be input by the user.

Table 1 describes the input parameters for model initialization and the climatic/boundary conditions. No distinction relative to level is made for these inputs as they are required at all levels.

Site latitude, longitude, and elevation define the climatic conditions. These parameters are necessary to trigger the climatic module, which has an available database of nearly 800 weather stations throughout the continental Unites States and Canada from the National Climatic Data Center (NCDC). The users may select the station or stations they consider to be the most representative of the site. Each weather station file contains approximately 4 years of hourly climatic data. This data is needed by the EICM for several calculations. The climatic information available from each station includes:

1. Hourly air temperature
2. Hourly precipitation
3. Hourly wind speed
4. Hourly percentage sunshine
5. Hourly relative humidity

The air temperature is required by the heat balance equation for calculations of long wave radiation emitted by the air and for the convective heat transfer from surface to air. In addition to the heat calculations, the temperature data is used to define the freeze/thaw periods within the analysis period.

Heat fluxes resulting from precipitation and infiltration into the pavement structure have not been considered in formulating the surface heat flux boundary conditions. The role of the precipitation under these circumstances is not entirely clear, and methods to incorporate it in the energy balance have not been attempted. However, precipitation is needed to compute the amount of snow: the precipitation that falls during a month when the mean temperature is less than the freezing temperature of water is assumed to fall as snow.

Wind speed is required in the computations of the convection heat transfer coefficient at the pavement surface. The percentage sunshine is needed for the calculations of heat balance at the surface of the pavement.

The groundwater table (GWT) depth is intended to be the best estimate of the annual average depth and should be determined from profile characterization borings prior to design. As part of the NCHRP 9-23 study it was found that material index properties and climatic conditions as reflected by the Thornthwaite Moisture Index (TMI) provided a much better indication of suction than did the GWT depth. Thus, the importance of GWT depth diminished.

The layer thicknesses should correspond to layers that are more or less homogeneous (same material properties within).

Table 2 covers the required asphalt concrete or Portland cement concrete material input properties.

As indicated under the options for determination, direct measurements of the parameters shown on Table 2 are recommended for Levels 1 and 2. Use of default values is acceptable for any of the three levels, in case the whole set has not been determined by direct measurements.

Thermal conductivity, *K*, is the quantity of heat that flows normally across a surface of unit area per unit of time and per unit of temperature gradient normal to the surface. The moisture content has an influence upon the thermal conductivity of asphalt concrete or Portland cement concrete. If the moisture content is small, the differences between the unfrozen, freezing and frozen thermal conductivity are small. Only when the moisture content is high (e.g., greater than 10%) does the thermal conductivity vary substantially. The EICM does not vary the thermal conductivity with varying moisture content of the asphalt layers as it does with the unbound layers.

The heat or thermal capacity is the actual amount of heat energy, *Q*, necessary to change the temperature of a unit mass by one degree.

The surface short wave absorptivity of the pavement depends on pavement composition, color and texture. The surface short wave absorptivity directly correlates with the amount of available solar energy that is absorbed by the pavement surface. Generally the lighter and more reflective the surface is, the lower the short wave absorptivity will be.

Table 3 describes the input parameters for compacted unbound materials. For Levels 1 and 2, it is required to provide carefully measured values of maximum dry unit weight (g_{dmax}), optimum moisture content (w_{opt}) and specific gravity of the solids (G_s) for each appropriate layer. From these three properties, all other mass-volume parameters can be precisely computed. If the user cannot provide all three of these values, it is then recommended to drop to Level 3. Level 3 requires measurement of only index properties from the grain size distribution curve, Plasticity Index (*PI*) and percent passing the #200 sieve (P_{200}).

The soil-water characteristic curve (SWCC) is defined as the variation of water storage capacity within the macro and micro pores of a soil, with respect to suction (Fredlund et al. 1995). This relationship is generally plotted as the variation of the water content (gravimetric, volumetric, or degree of saturation) with soil suction. Several mathematical equations have been proposed to represent the SWCC and some studies have been conducted on comparing the different equations available (Leong & Rahardjo 1996, Zapata 1999). The EICM made use of the equation proposed by Fredlund and Xing in 1994 (Fredlund & Xing 1994), which has shown good agreement with an extended database.

Due to the difficulties that arise when the soil suction is directly measured, only Level 1 analysis requires input of parameters from direct measurement of the SWCC. For Levels 2 and 3 analyses, the results of recent studies on the SWCC were introduced into the EICM. In these studies, the fitting parameters of the Fredlund and Xing equation were correlated with soil index properties (Zapata 1999). Therefore, for Levels 2 and 3 analyses the user is required to input simple soil index properties that are internally correlated with the SWCC parameters.

Table 4 describes the input parameters for natural, in-situ layers, which lie below the compacted layers. No distinction is made for Levels 1, 2, and 3. The properties of these lower layers are important to the response to load, but not as important as those of the overlying compacted layers. Therefore, more approximate algorithms are acceptable for the in-situ materials, and it is recommended that only PI, P_{200}, P_4, and D_{60} be measured for the in-situ layers.

Variables Needed for the Validation of the EICM

The variables needed to validate the EICM include:

1. Temperature distribution throughout the pavement profile with time,
2. Moisture content measurements throughout the pavement profile with time,
3. Frost penetration,
4. California Bearing Ratio (CBR) (This is a desirable value, for purposes of improving existing correlations, but not a necessary value.)

Temperature is an important factor affecting the asphalt stiffness and consequently the dynamic modulus of asphalt concrete mixes. Because the modulus of the asphalt layers within the pavement structure affect the overall pavement response, it is important to properly account for the temperature as a function of time and depth. The EICM model provides a frequency distribution of the pavement temperature as a function of time and depth.

Moisture content measurements throughout the pavement profile were likewise needed to compare with the EICM predicted moisture content predictions. Moisture content is an important parameter which is required to compute a set of time and position varying

adjustment factors for the resilient modulus M_R, which account for the effects of environmental parameters and conditions such as moisture content changes, freezing, thawing, and recovery from thawing. This unbound material layer adjustment factor, denoted F_{env}, varies with position within the pavement structure and with time throughout the analysis period. The F_{env} factor is a coefficient that is multiplied by the resilient modulus at optimum conditions (M_{Ropt}) to obtain M_R as a function of position and time. The values of M_{Ropt} and thus M_R, are not provided by the MEPDG version of the ICM but are calculated in other components of the MEPDG software.

Finally the CBR values were needed for calibration of some of the correlations that are internal to the EICM.

Variables Needed for Site Selection

In selecting sites for analysis, more data were required to run the EICM and to validate the results. Additional variables were needed to ensure acceptable statistical representation. These variables included:

1. Location
2. Climatic conditions
    a. Mean annual air temperature
    b. Annual precipitation
3. Frost penetration depth
4. Subgrade material properties
    a. Gradation
    b. Plasticity
5. Pavement cracking

Although latitude, longitude and elevation are needed to run the EICM, the location referred to here is much more general. The state or province of each prospective site was determined in an effort to insure a good geographical distribution (which also ensures a good statistical representation).

A good distribution over the different climatic zones was also important to this phase of the project. Mean annual air temperature and annual precipitation data were used as indicators of climatic zones. Both variables were averaged over a ten-year period (1987-1996) to obtain an unbiased estimate. Frost penetration is, of course, related to climatic conditions, but was considered separately given its relationship with the type of soil.

A variety of subgrade materials was also desired. Therefore, the subgrade gradation, specifically the percent passing the #200 sieve, was determined for each site. For fine-grained subgrades, plasticity was also examined.

Pavement cracking was considered as cracks allow water flow into the pavement structure. Such flow adds to the moisture content in a way for which the EICM cannot

precisely compensate. Using pavement sections with excessive cracking would thus bias the calibration of the EICM.

Cracking information was based on a 500-ft section length. It was considered that moderate and high severity longitudinal, transverse, and fatigue (alligator) cracking contributed the most to infiltration of water through the pavement section profile. It was also assumed that longitudinal and fatigue cracking was mostly present in the wheel path, which can be considered approximately 2.5 feet wide. For two wheel paths, the area subjected to cracking within a section would be 500 ft x 2.5 ft x 2 = 2500 ft^2 = 232.3 m^2

Fatigue cracking is measured in units of area, but longitudinal and transverse cracking is measured in units of length. In order to determine a total cracking percentage, the longitudinal and transverse cracking information were converted to an equivalent area by multiplying the length of cracking by 1 ft (0.3048 m), assuming that the cracking affects 6 inches on each site of the crack. In order to combine moderate and high severity cracking data into the total cracking percentage, moderate cracking data were given a weighting factor of 0.5. A section was eliminated if more than 25% of the area subjected to cracking was moderately or severely cracked.

Note that cracking was considered for the time period in which moisture content measurements were made. However, in determining which sites would be visited for direct measurement, the most recent cracking data available were used.

AVAILABLE DATABASES

After the variables were identified, the research team proceeded to determine the databases available for use in the project. The search was focused in the following databases:

1. Long Term Pavement Performance (LTPP) Database
2. MnRoad
3. WesTrack
4. Arizona Department of Transportation (ADOT) Database

LTPP Database

The LTPP program is a 20-year investigation of pavement performance. It was initiated in 1987 as a part of the Strategic Highway Research Program (SHRP), and has been managed by the FHWA since 1992. Data characterizing the pavement structure, materials, and performance are being collected for test sections on in-service highways throughout the United States and Canada. Within LTPP, the Seasonal Monitoring Program (SMP) involves a more intensive level of data collection targeted at advancing our understanding of temporal variations in the pavement structure.

MnRoad

MnRoad is an experimental test track built by the Minnesota Department of Transportation. The track consists of forty 500-ft sections built from 1992 to 1994. MnRoad is located along I-94, 40 miles northwest of Minneapolis-St. Paul and was loaded with actual highway traffic. Some of the objectives of this study were to evaluate the effects of heavy vehicles on pavements, seasonal changes in paving materials, and improving the design and performance of low-volume roads.

WesTrack

WesTrack is an experimental road test funded by the FHWA. WesTrack is located in western Nevada and began construction in 1995. WesTrack opened to traffic in 1996 and is trafficked by a driverless loaded truck system. It consists of 26 asphalt pavement sections. The objective of the WesTrack experiment is to evaluate the effect of variations in binder content, gradation and density of the Superpave Mix Design System.

ADOT Database

The Arizona Department of Transportation, in cooperation with the FHWA, monitored 37 sites in Arizona over a period of 5 years in the late 1970's. Temperature, moisture, and deflection data were gathered in addition to material property data. However, either temperature or moisture content measurements were recorded for any particular site. The objective of the study was to quantify environmental factors and their relation to structural characteristics.

SELECTION OF THE SECTIONS FOR ANALYSIS

Once the necessary variables were identified, the next step was to select sections for the experimental design. These sections were divided into two groups: those that were analyzed in the office and compared to recorded data in the available databases, and those to be visited for direct in-situ measurements.

Table 5 lists all the sites in this study and indicates to which group the site belongs. Figure 1 presents a map showing the locations of all the sites.

Selection of Sites to be Compared to Previously Recorded Data

Preliminary sites were selected using the variables discussed above. Fifty-four (54) sections from the LTPP database meet these criteria and were included in this study. Sites at MnRoad and WesTrack were also identified for possible use. Two (2) sites from each site were included in this study. Several of the sites used in the ADOT study also met the criteria. Two (2) of these sites were also analyzed. In total, 60 sites were analyzed and compared to previously recorded data. These sixty sites were representative of the available data, which met all the criteria discussed above.

The distribution of these sites with respect to the selection criteria is shown on Figure 2. These sites are located in 31 different states and two Canadian provinces. Twenty-three

(23) sites are located in areas with high mean annual air temperature, *Maat* (defined as greater than 15ºC), and 37 sites are located in areas with low *Maat*. Nineteen (19) sites are located in areas with periods of significant soil freezing. Thirty-two (32) sites are in areas with high mean annual precipitation (defined as greater than 800 mm per year) and 28 are in areas with low mean annual precipitation.

Subgrade conditions also enjoy a good distribution. Thirty-four (34) sites have coarse-grained subgrades (defined as less than 50% passing the #200 sieve). Twenty-six (26) sites have fine-grained subgrades. Of these 26 sites, 13 have high plasticity index, *PI* (defined as greater than 20) and 13 have low *PI*.

Thirty-nine (39) of these sites are asphalt concrete (AC) pavements and 21 are Portland cement concrete (PCC).

Selection of Sites Visited and Compared to Directly Measured Values

Thirty sites (30) were selected to be visited. Twenty (20) of these sites were used to validate the recorded data found in the databases. Based on the criteria above, 10 new sites were chosen to provide additional data where needed. Figure 3 shows the distribution of these sites with respect to the selection criteria.

The 20 validation sites were chosen from amongst the 60 sites to be compared to historical data. These sites were not chosen randomly, but from the experimental design shown on Figure 2. First, the original 60 sites were examined with regard to the dates of the historical data. Only sites where data collection concluded in 1998 or later were considered for a site visit. Next, the most recent cracking data were examined to best determine the present condition of the pavement. A total cracking percentage was calculated as described previously and only sites with less than 25% cracking were considered for a site visit.

From the remaining sections, selection was completed in order to represent the original distribution. In particular, the percentages of low and high *Maat*, low and high precipitation, frozen soil and non-frozen soil, coarse and fine subgrade, high and low plasticity index, and asphalt and Portland cement concrete in the validation sections were kept as close as possible to those of the original 60 sections.

Based on the conditions described above, the 10 new sections were chosen to provide additional data where needed. Since the original 60 have a rather large proportion of PCC sections (35%), all the 10 new sections selected were AC pavements.

Table 1
Input Parameters for Model Initialization and Climatic/Boundary Conditions Required for Levels 1, 2, and 3

Parameter	Description/Application
• **Base/subgrade construction completion date** • **Design period**	Input parameters required for model initialization and for controlling the length of the analysis period.
• **Site latitude** • **Site longitude** • **Site elevation**	Input parameters needed to define climatic conditions.
• **Groundwater table depth**	Input parameter needed as a boundary condition.
• **Layer thickness**	Needed to define the pavement system profile. It is required to input the thickness for every layer to be considered.

Table 2
Input Parameters Required for AC and PCC Material Properties

Level	Required Properties	Options for Determination
1	• **Thermal conductivity** • **Heat capacity** • **Surface short wave absorptivity**	Direct measurements are recommended at this level. However, default property values are available for user convenience.
2	Same as Level 1	Direct measurements or default values can be combined and used.
3	Same as Level 1	Default values are available.

Table 3
Input Parameters Required for Compacted Material Properties

Level	Required Parameters	Options for Determination
1	• **Specific Gravity**	Direct measurement required.
	• **Saturated Hydraulic Conductivity**	Direct measurement required.
	• **Maximum Dry Unit Weight**	Direct measurement required.
	• **Dry Thermal Conductivity**	Direct measurement is recommended at this level. However, default values are available for user convenience in case the property is not determined by direct measurements.
	• **Dry Heat Capacity**	Direct measurement is recommended at this level. However, default values are available for user convenience in case the property is not determined by direct measurements.
	• **Plasticity Index**	Direct measurement required.
	• **% Passing #200** • **% Passing #4** • **Diameter D_{60}**	Direct measurement required.
	• **Optimum Gravimetric Water Content**	Direct measurement required.
	• **Soil-Water Characteristic Curve Parameters**	Direct measurement required.
2	• **Specific Gravity**	Direct measurement required.
	• **Saturated Hydraulic Conductivity**	Direct measurement required.
	• **Maximum Dry Unit Weight**	Direct measurement required.
	• **Dry Thermal Conductivity** • **Heat Capacity**	Direct measurements or default values can be combined and used.
	• **Plasticity Index**	Direct measurement required.
	• **% Passing #200** • **% Passing #4** • **Diameter D_{60}**	Direct measurement required.
	• **Optimum Gravimetric Water Content**	Direct measurement required.

Table 3 – Cont'd

Level	Required Parameters	Options for Determination
3	• Specific Gravity	Direct measurement not required.
	• Saturated Hydraulic Conductivity	Direct measurement not required.
	• Maximum Dry Unit Weight	Direct measurement not required.
	• Dry Thermal Conductivity • Heat Capacity	Default values available
	• **Plasticity Index**	Direct measurement required.
	• **% Passing #200** • **% Passing #4** • **Diameter D_{60}**	Direct measurement required.
	• Optimum Volumetric Water Content	Direct measurement not required.

Table 4
Input Parameters Required for Natural, In-Situ Material Properties for Levels 1, 2, and 3

Required Properties	Options for Determination
• Specific Gravity	Direct measurement not required.
• Saturated Hydraulic Conductivity	Direct measurement not required.
• Maximum Dry Unit Weight	Direct measurement not required.
• Dry Thermal Conductivity • Heat Capacity	Direct measurements or default values can be combined and used.
• **Plasticity Index**	Direct measurement required
• **% Passing #200** • **% Passing #4** • **Diameter D_{60}**	Direct measurement required
• Optimum Gravimetric Water Content	Not required.

Table 5
List of Selected Sites

Section ID	State	Originating Project	To be Visited	To be Compared to Historical Data
010101	AL	LTPP	Y	Y
010102	AL	LTPP	N	Y
040113	AZ	LTPP	N	Y
040114	AZ	LTPP	N	Y
040215	AZ	LTPP	Y	Y
041024	AZ	LTPP	N	N
052042	AR	LTPP	Y	N
063042	CA	LTPP	N	Y
081053	CO	LTPP	Y	Y
091803	CT	LTPP	Y	Y
100102	DE	LTPP	Y	Y
120107	FL	LTPP	N	N
131005	GA	LTPP	N	Y
131031	GA	LTPP	N	Y
133019	GA	LTPP	Y	Y
161010	ID	LTPP	Y	Y
161021	ID	LTPP	N	N
183002	IN	LTPP	N	Y
204054	KS	LTPP	Y	Y
220118	LA	LTPP	Y	N
231026	ME	LTPP	N	Y
241634	MD	LTPP	N	Y
271018	MN	LTPP	N	N
274040	MN	LTPP	N	Y
281016	MS	LTPP	Y	Y
308129	MT	LTPP	N	Y
310114	NE	LTPP	Y	Y
313018	NE	LTPP	N	Y
320101	NV	LTPP	N	Y
320204	NV	LTPP	Y	Y
331001	NH	LTPP	N	Y
350105	NM	LTPP	Y	N
351112	NM	LTPP	Y	Y
360801	NY	LTPP	N	Y
364018	NY	LTPP	Y	Y
370201	NC	LTPP	N	Y
370205	NC	LTPP	Y	Y
370208	NC	LTPP	N	Y
370212	NC	LTPP	N	Y

Table 5 - Cont'd

Section ID	State	Originating Project	To be Visited	To be Compared to Historical Data
371028	NC	LTPP	N	Y
390204	OH	LTPP	Y	Y
404165	OK	LTPP	N	Y
421606	PA	LTPP	N	Y
469187	SD	LTPP	N	Y
481060	TX	LTPP	Y	Y
481068	TX	LTPP	N	Y
481077	TX	LTPP	Y	Y
481122	TX	LTPP	N	Y
483739	TX	LTPP	N	Y
484142	TX	LTPP	N	Y
484143	TX	LTPP	N	Y
491001	UT	LTPP	N	Y
493011	UT	LTPP	N	Y
501002	VT	LTPP	N	Y
510113	VA	LTPP	N	Y
510114	VA	LTPP	Y	Y
533813	WA	LTPP	N	Y
561007	WY	LTPP	N	Y
831801	Manitoba	LTPP	N	Y
833802	Manitoba	LTPP	N	Y
871622	Ontario	LTPP	N	N
893015	Quebec	LTPP	N	Y
501681	VT	LTPP	Y	N
420603	PA	LTPP	Y	N
416011	OR	LTPP	Y	N
473101	TN	LTPP	BACKUP	N
562020	WY	LTPP	Y	N
562019	WY	LTPP	BACKUP	N
307066	MT	LTPP	Y	N
537322	WA	LTPP	BACKUP	N
531007	WA	LTPP	Y	N
MnRd1	MN	MnRd	Y	Y
MnRd2	MN	MnRd	N	Y
Wstk1	NV	WesTrack	Y	Y
Wstk2	NV	WesTrack	N	Y
ADOT1	AZ	ADOT	N	Y
ADOT14	AZ	ADOT	N	Y
087035	CO	LTPP	Y	N

Figure 1
Map of Sites Selected to Validate the EICM

					Pavement type			
					AC		PCC	
					GWT depth			
					Deep	Shallow	Deep	Shallow
High Maat > 15°C	High Precipitation > 800 mm	Frozen	Coarse Sg					
			Fine Sg	High PI				
				Low PI				
		No freeze	Coarse Sg		1	3		1
			Fine Sg	High PI		3	4	1
				Low PI				1
	Low Precipitation < 800 mm	Frozen	Coarse Sg					
			Fine Sg	High PI				
				Low PI				
		No freeze	Coarse Sg		4	1	1	
			Fine Sg	High PI				
				Low PI	1	1		1
Low Maat < 15°C	High Precipitation > 800 mm	Frozen	Coarse Sg			4		2
			Fine Sg	High PI				
				Low PI				
		No freeze	Coarse Sg			4		2
			Fine Sg	High PI				1
				Low PI	2	1		2
	Low Precipitation < 800 mm	Frozen	Coarse Sg		1	3		2
			Fine Sg	High PI		2		1
				Low PI		3		1
		No freeze	Coarse Sg			4	1	
			Fine Sg	High PI		1		
				Low PI				

Figure 2
Matrix to Select Sites with Recorded Data

					Pavement type			
					AC		PCC	
					GWT depth			
					Deep	Shallow	Deep	Shallow
High Maat > 15°C	High Precipitation > 800 mm	Frozen	Coarse Sg					
			Fine Sg	High PI				
				Low PI				
		No freeze	Coarse Sg		1	1		
			Fine Sg	High PI	1	1	1	
				Low PI		1		1
	Low Precipitation < 800 mm	Frozen	Coarse Sg					
			Fine Sg	High PI				
				Low PI				
		No freeze	Coarse Sg		1		1	
			Fine Sg	High PI	1			
				Low PI		1		
Low Maat < 15°C	High Precipitation > 800 mm	Frozen	Coarse Sg		1	1		1
			Fine Sg	High PI				
				Low PI				
		No freeze	Coarse Sg		1	1		
			Fine Sg	High PI	1			1
				Low PI	1			1
	Low Precipitation < 800 mm	Frozen	Coarse Sg		1	1		
			Fine Sg	High PI		1		
				Low PI	1	1		
		No freeze	Coarse Sg			1	1	
			Fine Sg	High PI	1	1		
				Low PI	1			

Figure 3
Matrix to Select Sites to be Visited

CHAPTER 2

SITE INVESTIGATION

As shown in Chapter 1, the sites originally selected for visiting included 28 LTPP sites, MnRoad test facility, and WesTrack test facility for a total of 30 sites.

An ASU graduate student, assisted by a faculty member or a graduate assistant, performed the fieldwork. The 30 sites selected were visited as originally planned, but due to the rain and very shallow groundwater encountered at the site located in Delaware, Ohio, no sampling was performed for the reason that data from saturated layers would have produced only trivial data for the analyses. Out of 29 sites, 18 were sites with TDR instrumentation.

The LTPP sites were identified by a section identification number, which contains a two-digit State code and a four-digit site code as shown in Table 6.

In general, three locations, three feet apart, located along the center of the outer lane of the highway were cored and soil samples were collected representing each unbound layer beneath the pavement. At the 18 LTPP SMP sites, the three locations were cored near the TDR instrumentation hole just outside the respective test section, in the transition zone located either at the start or end of the section. At non-SMP sites there was no TDR instrumentation and, therefore, sampling was performed in one of the two transition zones approximately 8 to 10 feet from the section. Due to reconstruction, resurfacing, or decommissioning of the SMP program, several sites did not have or physically showed the location of the TDR instrumentation. In such cases, the former TDR location was located from the data obtained from LTPP database. LTPP database provided the coordinates of the TDR with respect to the section and the outer edge of the lane.

Typically, three sand cone tests and samples from the granular base and six tube samples from the subgrade were obtained from each site. In addition, a tube sample or a grab sample was collected from the side of the highway away from the shoulder. If cracks were present in the pavement, one of the three locations (or a fourth location) was chosen next to a crack. A typical layout of a site including the sample locations is shown in Figure 4.

TRAFFIC CONTROL

The test sections were located on various types of highways: interstate freeways, four-lane divided highways, and two-lane undivided highways. At each site, traffic controls were required in order to carry out the fieldwork. The four LTPP regional consultants, Nichols Consulting Engineers, Fugro-BRE, Inc., Stantec, and ERES Consultants, provided the necessary services regarding arranging traffic controls at each site, and some assistance at many of the sites. The schedule of fieldwork was provided to the liaison officer assigned by each consultant and the liaison officer contacted the respective agencies at least two weeks in advance to make the arrangements. Traffic controls were

typically arranged for two days per site from 8:00 AM to 5:00 PM on weekdays excluding holidays. Reduced hours were available at some of the sites due to heavy traffic conditions. The schedule of site visits is shown on the trip calendar in Figure 5.

TRANSPORTATION

Transportation between ASU in Tempe, Arizona and sites visited required considerable planning due to the distance and travel time. A large U-Haul trailer towed by an ASU full-size pickup truck was used for transportation. The amount of storage space available in the truck and the trailer restricted the number of sites per trip to a maximum of six. Geographical location of the sites often made more than three or four sites per trip impractical. Thus, eight trips were scheduled as shown on Figure 5.

The collected samples were transported to ASU and stored in the Geotechnical laboratory after each trip. Three to five days available between the trips were used to organize the samples and assign a testing plan for each site. The laboratory personnel assigned to the project carried out the testing according to the plan while the other trips were in progress. However, due to the enormous volume of lab testing entailed, the lab testing continued long after the field trips were completed.

A map of the United States showing the grouping of sites with respect to the 8 trips is presented in Figure 6.

FIELD EQUIPMENT AND SUPPLIES

The field equipment needed for the project was either manufactured at the ASU workshop or purchased from outside vendors. The main pieces of equipment included: a coring machine capable of coring 10-inch diameter holes in asphalt and concrete (see Figure 7), a gasoline operated generator, a modified Sand Cone apparatus (see Figure 8), hand sampling equipment for thin-walled tube sampling, and numerous coring and sampling supplies. Table 7 describes the equipment used in the field.

The rest of the tools required for the project included: a jackhammer, sledgehammer, post-hole digger, shovels, spoons, brushes, small power drill, wheelbarrow, steel tape, 100-foot tape, wood rulers, extension cords, tool kit (with pipe wrenches, tee-wrenches, screw drivers, sockets, trimming tools), crowbars, steel and wood wedges, calculator, engineering scale, and a camera.

The supplies required for the project included: cement, 10”-diameter pre-cast concrete plugs (Note: cold patch trademarked QPR was used on the first two trips), sand for Sand Cone apparatus, non-shrinking grout, ready-mix, accelerator for cement, cement coloring, water, gray tape, masking tape, plastic bags, plastic containers for Sand Cone samples, 5-gallon plastic buckets, plastic bins for sample storage, paper towel, ropes, wood sheets, tarps, rags, and safety gear such as gloves, ear-plugs, rain gear, yellow jackets, steel-toe boots, and hard hats.

The ASU field crew traveled to the sites carrying the tools and supplies required to complete the sampling and testing tasks. Some of the readily available supplies were replenished from hardware stores as the trip progressed.

FIELD SAMPLING AND TESTING

This task consisted of several subtasks carried out during one or two days at the field at each site. The subtasks included gathering initial site information, coring the pavement, performing Sand Cone tests on the granular base, collecting tube samples from the subgrade, collecting a side sample, backfilling the holes, and patching the pavement. The following sections describe each task in detail. A summary of the sampling procedure and an example data sheet are presented in Appendix A.

Gathering Initial Site Information

After arriving at the site on morning of the first day, the test section was observed to find the TDR instrumentation hole if the site was an SMP site. For non-SMP sites, one of the transition zones of the test section was selected to perform the sampling and testing. If the TDR location was not visible, it was located with the help of the weather instrumentation post located on the side of the road and the coordinates of the instrumentation hole obtained from the LTPP database. The traffic control measures were checked to ensure the selected sampling locations were well enclosed and the fieldwork could be performed throughout the day without any traffic interference.

A site description was recorded on a field data sheet with a sketch of the site details. The site information included: site identification, exact site location, name of the highway, pavement type (AC or PCC), pavement condition (cracking and rutting), condition of the shoulders, median and sides (grassy or gravelly slopes) side drainage features, general topography in the site vicinity, special features such as hills, water ponds, water in the side drains, vegetation, and land use. Photographs were taken showing the site identification signs, general site vicinity, sampling locations on the pavement, and any special features. Also, included in the site description were the weather conditions: temperature, sky, and wind. Detailed information gathered from each site is presented in Appendix A.

Pavement Coring

As illustrated in Figure 4, the pavement was cored at least in three locations along the centerline of the outer lane. The coring locations were marked on the pavement approximately three feet apart. Depending on the pavement type, AC or PCC, the appropriate 10-inch diameter-coring bit was mounted on the coring device and the coring device was firmly bolted to the pavement by means of four bolts. The four bolt-holes were pre-drilled using a hammer-action drill. The coring operation required water supplied to the cutting edge through a hole on the top of the coring bit. Water was supplied with a hose connected either to a spray bottle or an elevated bucket of water. During the coring, the wastewater was continuously removed with a shop-vac.

Prior to drilling the first hole, a random location on the pavement, at least ten feet away from the actual sampling locations, was drilled with a 2-inch-diameter coring bit to assess the thickness of the bound layer at the site. With this information, the sample locations were cored with the 10-inch core bit to a depth such that one inch of the pavement was left intact and then the coring bit was retracted. This action was carefully executed to prevent the contamination of the unbound layers beneath the pavement with drilling water. The water in the cut was removed using the shop-vac attached with a tube with a flattened end. The cut cylinder was detached at its base by driving flat steel wedges into the crack. The removed asphalt cores were labeled and stored in 5-gallon plastic buckets for transportation back to ASU for testing. The remaining inch of material in the bottom of the hole was removed using a jackhammer. A typical photograph of a site illustrating the coring in progress is shown in Figure 9.

The coring procedure was repeated for the other two holes. If a treated base was encountered, it was removed using the jackhammer. The time taken to core one hole on an AC pavement was about 20 to 30 minutes depending on the pavement thickness. However, it took several hours to core a hole on PCC pavements, which always resulted in carrying the fieldwork over to a second day.

Sand Cone Tests on Granular Base

Granular base materials do not permit tube sampling and, therefore, Sand Cone tests were performed on granular base layers to determine the in situ moisture content and the dry density. Once coring exposed the granular base layer, less than one inch of the base material was removed and a leveled surface was prepared inside the hole. The specially prepared cylindrical base plate was placed on the leveled surface and the cylinder was secured in place by driving wood wedges around it. A 6-inch diameter, 7 to 8-inch deep hole was excavated within the base plate and all the material removed from the hole was carefully collected in a plastic container preventing any loss of moisture due to evaporation. The container was tightly sealed, weighed, labeled, and stored in a plastic tub for transporting. The pre-weighed Sand Cone apparatus filled with sand was placed on the base plate covering the excavated hole and the sand was allowed to run into the hole by opening the valve on the neck of the Sand Cone apparatus. This part of the testing was performed with no or very little traffic to avoid ground vibrations affecting the flow and density of sand. Once the sand flow stopped the valve was closed and the final weight of the apparatus was recorded. The difference between the initial and final weights gave the amount of sand in the funnel and the hole.

The Sand Cone was calibrated in the laboratory prior to the fieldwork using the same sand used in the field. Sand from the same source was used throughout the project. The calibration included determining the volume of sand required to fill the funnel and the density of sand when allowed to free-fall from the apparatus. These values were used in the dry density computations. The weight of soil removed from the hole provided the in situ moist weight and the amount of sand in the hole and density of sand were used to calculate volume of the hole. The moist density was obtained using the moist weight and volume of the hole. The sample was oven dried in the laboratory to obtain the dry weight and hence the dry density.

Once the Sand Cone test was completed, the hole was cleaned free of sand, widened, and deepened until the subgrade was exposed. The procedure was repeated at each hole. A figure illustrating the typical sampling process is shown in Figure 10.

Tube Sampling

Most of the subgrade materials found at the 29 sites were cohesive soils that permitted tube sampling. However, a few sites containing granular subgrades required Sand Cone testing even on the subgrades.

Once the subgrade was exposed, sample tubes were driven into the subgrade to collect the material. Two types of tubes were used: 1.8-inch diameter by 6-inch long and 2.8-inch diameter by 12-inch long. The small 1.8-inch diameter tubes were driven to a depth of 4 inches while the large 2.8-inch diameter tubes were typically driven to a depth of 8 inches. A sliding hammer pounding on the end of the sample pipes was used to drive the tubes into the soil. Two slotted wood plates placed on the pavement against the pipes maintained the verticality of the sampling rods during the driving. The starting depth of the sample was recorded. The sample tube was retracted from the ground by extracting the tube and the pipes with a jack.

Each tube used in sampling had been stamped for identification, and the weight, height, and internal diameter had been previously recorded. The retrieved sample was separated from the sampling rod and moved to the sample processing area, which was the tailgate of the truck. The sample was carefully trimmed to have smooth flat surfaces on both ends and the distance to the soil surface from each edge of the tube was measured. Ten locations along the perimeter of the tube were measured on each side to obtain these two distances, ΔL_1 and ΔL_2. With ΔL_1, ΔL_2, and the length of the tube, the length of the sample was determined for volume calculations. The tube containing the trimmed sample was weighed, capped with plastic lids on both sides, taped, labeled, and stored in a plastic tub for transportation. In this way, all data needed for the calculation of the moist density was gathered in the field.

Side Samples and Disturbed Samples

A sample was collected from the side of the road at each site to allow comparison of the conditions of uncovered soil with the covered material. Often the side soils were fine-grained permitting tube samples. However, there were few occasions where Sand Cone procedure was required on the side due to the presence of granular material.

A representative disturbed sample was collected for index testing from around each Sand Cone hole and around each tube sample. These samples were collected into plastic bags, labeled, and placed in a plastic tub for transportation. The samples collected at each site are listed in Table 8.

Backfilling and Patching the Pavement

Following the sample collection, the holes were backfilled with the left over soil excavated from holes mixed with sand, gravel, and a small amount of cement. The mixture was filled into the hole in 6-inch lifts and compacted with the compaction device. The hole was filled according to this manner up to the bottom level of the pavement. In the case of AC pavements, the core was taken as a sample and the patching required a suitable material. A cold patch trademarked QPR was used for this purpose for the first two trips. Three-inch lifts of QPR were compacted in the hole until the patching was flushed with the pavement surface. For all subsequent trips the top 7" of the bound layer was patched with a pre-cast concrete plug dyed black for AC pavement. In the case of PCC pavements, the cored concrete cylinder was put back into the hole. All the concrete plugs were secured in the hole by grouting the crack with specially prepared cement slurry. The cement slurry was prepared by mixing non-shrinking cement grout with an accelerator. The patching required only 20 to 30 minutes of hardening before the road was ready for traffic.

SAMPLE IDENTIFICATION

In general, the test sections or the sites were identified by the six-digit section identification adopted by the LTPP program. However, an abbreviated site identification number was used when labeling the samples. The abbreviated site number was derived from the trip number and the site number within the trip. For example, the second site in the third trip was identified as 3-2. The abbreviated site number along with the hole number and the depth of the sample written with hyphenations uniquely identified the samples. For example, a sample collected from Site 3-2, Hole 1, at a depth of 25 inches was labeled as 3-2-1-25. The abbreviated site identification numbers are shown on Table 9 along with the main site information.

MOISTURE CONTENT NEAR CRACKS

When cracks were present on the pavement, soil samples were obtained from the unbound layers near a crack by coring one of the holes about two inches away from a selected crack. There were 12 sites that contained such samples near cracks. The moisture contents of the samples near cracks were compared with the average moisture content of the samples obtained from the other holes, which were located away from the crack. The comparison indicted that the average difference in moisture contents was +0.38% with a minimum of –1.72% and a maximum of +2.61%. The standard deviation of this difference was 0.81. The positive sign indicates the moisture near the crack was higher that the moisture away from the crack.

It was apparent from this comparison that the moisture content near the cracks was not significantly higher. Therefore, it appeared that the cracks were not providing avenues for water penetration, perhaps because they were typically filled with dust and fine particles.

Table 6
Sites Selected for Visiting

No.	Section ID	State	City	TDR Instrumentation
1	010101	Alabama (AL)	Opelika	Y
2	040113	Arizona (AZ)	Chloride	Y
3	040215	Arizona (AZ)	Buckeye	Y
4	052042	Arkansas (AR)	Crossett	N
5	063042	California (CA)	Thornton	Y
6	081053	Colorado (CO)	Delta	Y
7	087035	Colorado (CO)	Aurora	N
8	091803	Connecticut (CT)	Groton	Y
9	204054	Kansas (KS)	Abilene	Y
10	220118	Louisiana (LA)	Moss Bluff	N
11	281802	Mississippi (MS)	Collins	Y
12	307066	Montana (MT)	Big Timber	N
13	310114	Nebraska (NE)	Hebron	Y
14	320204	Nevada (NV)	Battle Mountain	Y
15	350105	New Mexico (NM)	Rincon	N
16	364018	New York (NY)	Otego	Y
17	370205	North Carolina (NC)	Lexington	Y
18	390204	Ohio (OH)	Delaware	Y
19	416011	Oregon (OR)	Harrisburg	N
20	420603	Pennsylvania (PA)	Milesburg	N
21	473101	Tennessee (TN)	Auburntown	N
22	481060	Texas (TX)	Vidaurri	Y
23	481077	Texas (TX)	Estelline	Y
24	484143	Texas (TX)	Beaumont	Y
25	501681	Vermont (VT)	Charlotte	Y
26	537322	Washington (WA)	Pullman	N
27	562019	Wyoming (WY)	Gillette	N
28	562020	Wyoming (WY)	Sheridan	N
29	MnRoad	Minnesota (MN)	Albertville	Y
30	WesTrack	Nevada (NV)	Silver Springs	Y

Table 7
List of Field Equipment

Item	Use/Description
Coring Device	Core Bore Drilling Machine™, Model M1capable of coring 10” holes through asphalt and concrete pavements (See Figure 7). Due to wet drilling, the top several inches of the pavement was drilled with the drilling machine and the last inch was removed manually to prevent moisture contamination.
Coring Bits	10” diameter diamond coring bits for drilling through asphalt and concrete.
Generator	Generac™ 7000-watt portable AC generator powered the coring machine and other power tools.
Sprayer	3.5-gallon pump-up sprayer for supplying water for the coring machine.
Shop-Vac	For cleaning waste (cooling water + cuttings) generated during coring.
50-Gallon Container	Used to transport water that was needed for coring.
Modified Sand Cone	Fitted with a narrow acrylic bottle (5.5” diameter), which can be lowered into 10” diameter holes. The base plate was modified as a cylinder to fit in circular holes (See Figure 8).
Hand Sampling Equipment	Consisted of 1.8” and 2.8” diameter stainless steel sampling tubes ($A_r \approx$ 10-15%), two sampling heads, extension pipes, a sliding hammer, slotted wood plates to guide the pipes, and a jack.
Compaction Device	A steel rod with a cylindrical base. With the help of the compaction device, the holes were backfilled and compacted with sand and gravel mixed with excavated soil after the sampling and the asphalt pavement was patched with a cold patch for the first two trips. For all subsequent trips the top 7” of the bound layer was patched with a precast concrete plug dyed black for AC pavement. For PCC pavement the 10” plug removed was put back in the hole. All concrete plugs were set in quick-set non-shrink grout.
Electronic Balance	Capable of measuring maximum of 20 kg with an accuracy of 0.1 g.

Table 8
Samples Collected from Sites Visited

#	Section	General Location	Highway	Layer Information[1]	AC Cores	Sand Cone Tests	Tube Samples
1	010101	Opelika, AL	US-280, WB	7.5" AC; 7.5" GB; Clayey SG	4	4	6
2	040113	Chloride, AZ	US-93, NB	4.5" AC; 7.5" GB; Granular SG	4	9	0
3	040215	Buckeye, AZ	I-10, EB	11" PCC; 7" GB; Granular SG	—	6	1
4	052042	Crossette, AR	US-82, WB	7" AC; 7" TB; 1.5" GB; Clayey SG	4	0	9
5	063042	Thornton, CA	I-5, SB	8.5" PCC; 4.5" TB; 8" Comp. SG; Clayey/Silty SG	—	0	10
6	081053	Delta, CO	US-50, NB	7" AC; 6" GB; 30" SB; Clayey SG	3	6	5
7	087035	Aurora, CO	I-70, EB	6" AC; 8.5" PCC; 4.5" GB; 29.5" SB; Clayey SG	3	3	8
8	091803	Groton, CT	ST-117, NB	9" AC; 12" GB; Rocky SG	3	6	0
9	204054	Junction City, KS	I-70, WB	9.5" PCC; 4" TB; 2.5" GB; Clayey SG	—	0	6
10	220118	Moss Bluff, LA	US-171, NB	10.5" AC; 4" & 8.5" TBs; Clayey SG	3	0	7
11	281016	Collins, MS	ST-35, WB	9.5" AC; 33" GB; Clayey SG	3	1	10
12	307066	Big Timber, MT	I-90, WB	10.5" AC; 3" GB; 15.5" SB; Clayey SG	3	5	6
13	310114	Hebron, NE	US-81, SB	7" AC; 12" GB; Clayey SG	3	3	7
14	320204	Battle Mountain, NV	I-80, EB	11.5" PCC; 6.5" GB; 20.5" SB; TB; Unknown SG	—	6	0
15	350105	Rincon, NM	I-25, NB	10" AC; 3" GB; Clayey SG	3	0	6
16	364018	Otego, NY	I-88, EB	9.3" PCC; Granular SG	—	6	0
17	370205	Lexington, NC	US-52, SB	8.5" PCC; 7.5" CTB; Clayey SG	—	0	7
18	416011	Harrisburg, OR	I-5, SB	13" AC; 12"+ GB; GWT @ 25"; Unknown SG	2	1	0
19	420603	Milesburg, PA	I-80, WB	4" AC; 10.5" PCC; 8" GB; 29.5" SB; Rocky SG	3	7	0
20	473101	Auburntown, TN	ST-96, EB	5.5" AC; 7" open graded AC; 4" CTB; Clayey SG	3	0	7
21	481060	Vidaurri, TX	US-77, NB	7”"AC; 10" TB; 7" GB; Clayey SG	3	3	7
22	481077	Estelline, TX	US-287, SB	2" AC; 12" TB; 12" GB; Granular SG	3	4	6

Table 8 – Cont'd
Samples Collected from Sites Visited

#	Section	General Location	Highway	Layer Information[1]	AC Cores	Sand Cone Tests	Tube Samples
23	484143	Beaumont, TX	US-90, EB	10.5" PCC; 4" TB; 10" Compacted SB; Clayey SG	—	1	5
24	501681	Charlotte, VT	US-7, NB	7" AC; 3.5" TB; 21.5" GB; 12" SB; Clayey/Silty SG	3	4	7
25	537322	Pullman, WA	US-195, NB	10" AC; 9" GB; Clayey SG	3	3	7
26	562019	Gillette, WY	ST-59, SB	8" AC; 11" CTB; 11" SB; Clayey SG	4	0	8
27	562020	Sheridan, WY	I-90, WB	7" AC; 12.5" CTB; Clayey SG	3	0	7
28	MnRoad	Albertville, MN	I-94, WB	8.5" AC; Compacted Clayey SG	13	0	9
29	WesTrack	Silver Springs, NV	Test Loop	6" AC; 11.5" GB; 12" Eng. Fill; 6" Compacted Clayey SG	8	6	14

[1] AC = Asphalt concrete; GB = Granular base; SG = Subgrade; PCC = Portland cement concrete; CTB = Cement treated base; TB = Treated base; SB = Subbase

Table 9
Summary of Site Information

No.	Section ID	Abbr ID	City	State	Date of field Work		Highway	Latitude North	Longitude West	Elev. (ft)	Pave Type	TDR	Cracks
1	010101	1-3	Opelika	AL	Nov 7	2001	US-280 WB	32.6061	85.2512	151	AC	Yes	None
2	040113	2-3	Chloride	AZ	Dec 3,4	2001	US-93 NB	35.3920	114.2550	3580	AC	Yes	Severe
3	040215	4-1	Buckeye	AZ	Dec 18,19	2001	I-10 EB	33.4570	112.7400	1100	PCC	Yes	None
4	052042	1-5	Crossett	AR	Nov 15	2001	US-82 WB	33.1342	91.8384	140	AC	No	Minor
5	063042	8-3	Thornton	CA	Jun10,11,12	2001	I-5 SB	38.2389	121.4403	11	PCC	Yes	Mod
6	081053	7-5	Delta	CO	May 22	2002	US-50 NB	38.6979	108.0263	5140	AC	Yes	None
7	087035	7-4	Aurora	CO	May 20	2002	I-70 EB	39.7431	104.7378	5500	AC/PCC	No	Mod
8	091803	6-1	Groton	CT	Apr 16	2002	ST-117 NB	41.3950	72.0270	165	AC	Yes	Minor
9	204054	5-3	Abilene	KS	Apr 1,2	2002	I-70 WB	38.9670	97.0910	1190	PCC	Yes	Mod
10	220118	3-1	Moss Bluff	LA	Dec 10	2001	US-171 NB	30.3342	93.1983	27	AC	No	None
11	281802	1-4	Collins	MS	Nov 13	2001	ST-35 WB	33.1342	89.4200	1549	AC	Yes	None
12	307066	7-1	Big Timber	MT	May 13	2002	I-90 WB	45.8134	110.0024	4072	AC	No	Mod
13	310114	5-4	Hebron	NE	Apr 3	2002	US-81 SB	40.0710	97.6239	1611	AC	Yes	Mod
14	320204	8-2	Battle Mtn	NV	June 5	2002	I-80 EB	40.7210	117.0380	4550	PCC	Yes	Mod
15	350105	1-1	Rincon	NM	Oct 29	2001	I-25 NB	32.6783	107.0707	4117	AC	No	None
16	364018	6-3	Otego	NY	Apr 22	2002	I-88 EB	42.3780	75.1920	1070	PCC	Yes	Mod
17	370205	5-1	Lexington	NC	Mar 25, 26	2002	US-52 SB	35.8700	80.2660	742	PCC	Yes	Mod
18	416011	2-2	Harrisburg	OR	Nov 30	2001	I-5 SB	44.2946	123.0612	323	AC	No	None
19	420603	6-4	Milesburg	PA	Apr 24	2002	I-80 WB	40.9745	77.7914	1360	AC/PCC	No	None
20	473101	5-2	Auburntown	TN	Mar 28	2002	ST-96 EB	35.9412	86.1223	770	AC	No	None
21	481060	3-3	Vidaurri	TX	Dec 13	2001	US-71 NB	28.5098	97.0583	78	AC	Yes	None
22	481077	1-2	Estelline	TX	Nov 1,2	2001	US-287 SB	34.5387	100.4352	1835	AC	Yes	None
23	484143	3-2	Beaumont	TX	Dec 11,12	2001	US-90 EB	28.5098	94.3710	42	PCC	Yes	None
24	501681	6-2	Charlotte	VT	Apr 18	2002	US-7 NB	44.3081	73.2456	255	AC	Yes	Mod
25	537322	8-1	Pullman	WA	Jun 3	2002	US-195 NB	46.7299	117.2235	2545	AC	No	None
26	562019	7-3	Gillette	WY	May 16	2002	ST-59 SB	44.1652	105.4460	4577	AC	No	Minor
27	562020	7-2	Sherdan	WY	May 14	2002	I-90 WB	44.9386	107.1974	4022	AC	No	Minor
28	MnRd	6-5	Albertville	MN	May 2,3	2002	I-94 WB	45.2400	93.6500	-	AC	Yes	Severe
29	WesTr	2-1	Silver Springs	NV	Nov 26, 27	2001	Test Loop	39.4200	119.2200	-	AC	Yes	Minor

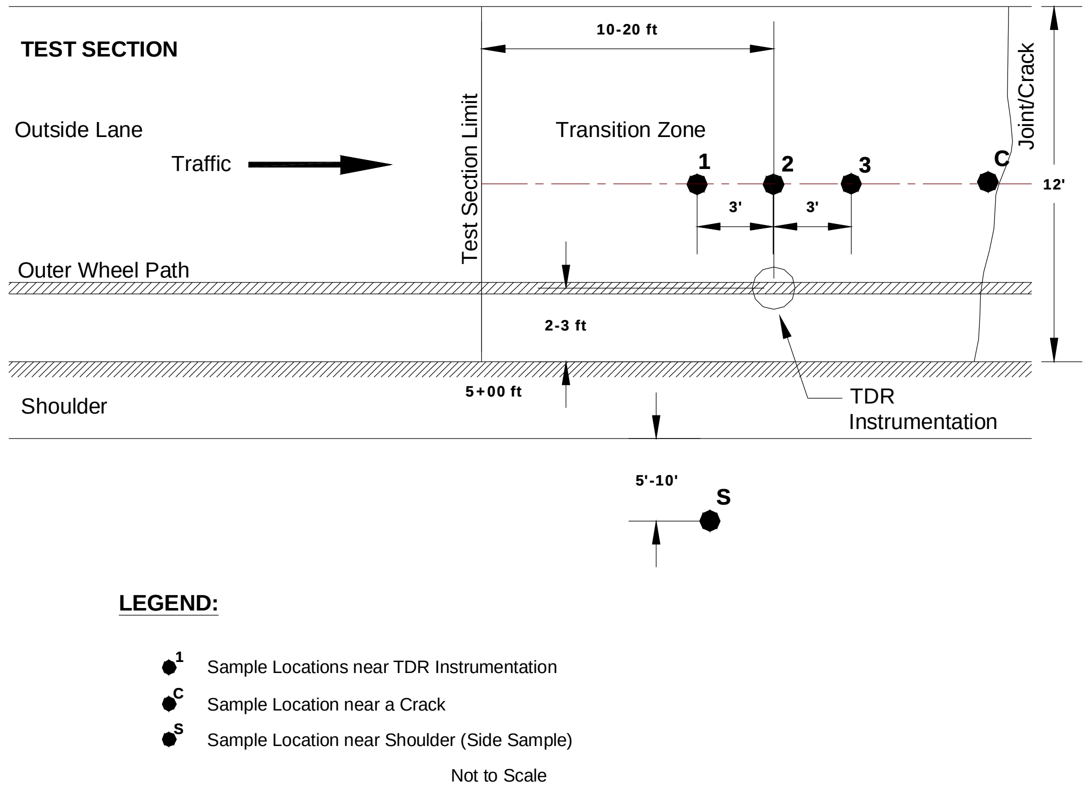
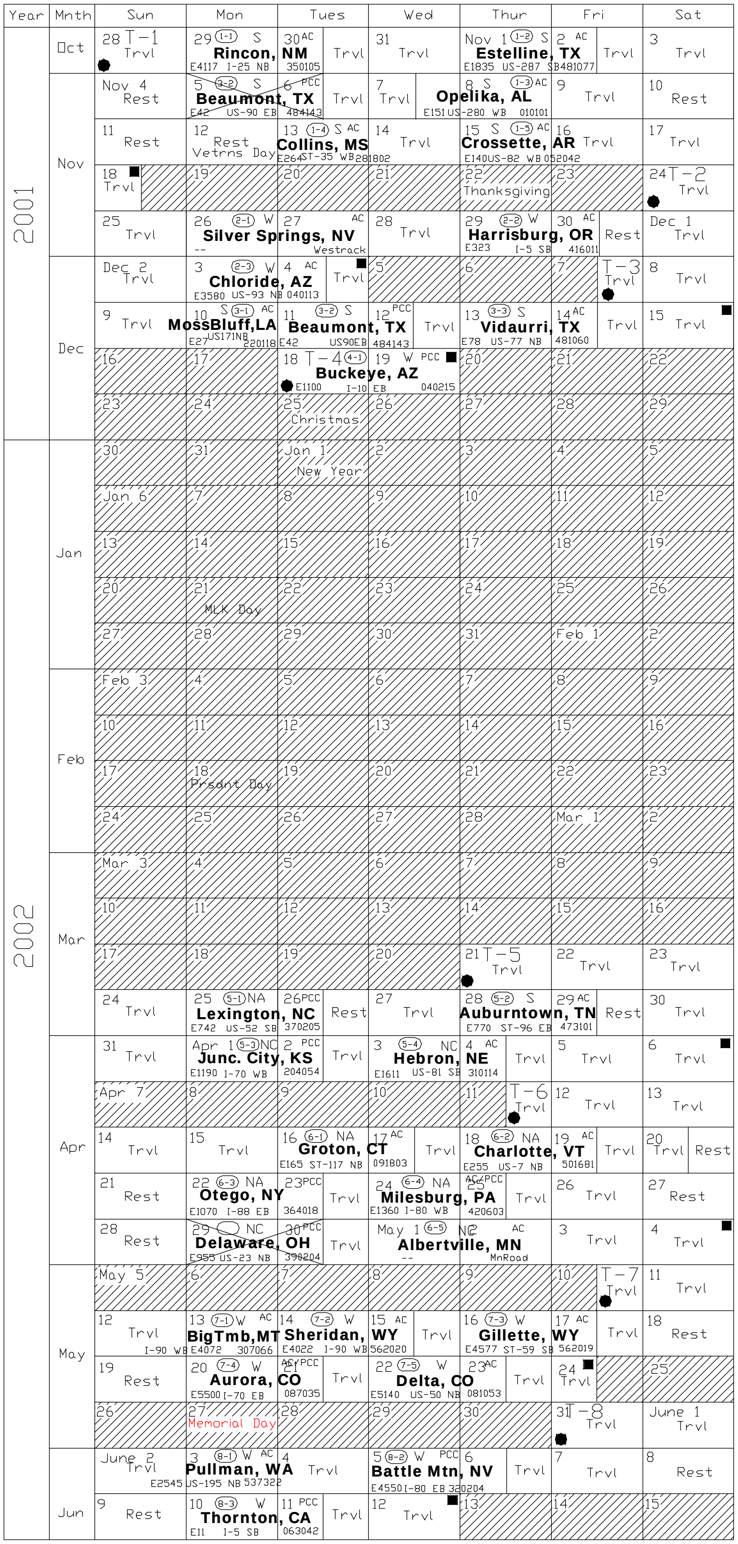


Figure 4
Typical Sample Location Layout

Trip Calendar



LEGEND:

●	Start of Trip
■	End of Trip
Trvl	Travel Time
Rest	Stop Over
(hatched)	Home
PCC	Portland Cement Concrete
AC	Asphalt Concrete
040215	Section ID
E1100	Elevation = 1100 (TYP)
S	South Region
W	Western Region
NA	North-Atlantic Region
NC	North-Central Region
(5-2)	Abbreviated Site Number
US-287 SB	Route US 287 South Bound (TYP)

Trip	Dates
T-1	Oct 28 to Nov 18
T-2	Nov 24 to Dec 4
T-3	Dec 7 to Dec 15
T-4	Dec 18 & Dec 19
T-5	Mar 21 to Apr 6
T-6	Apr 11 to May 6
T-7	May 10 to May 25
T-8	May 31 to Jun 12

Figure 5
Trip Calendar

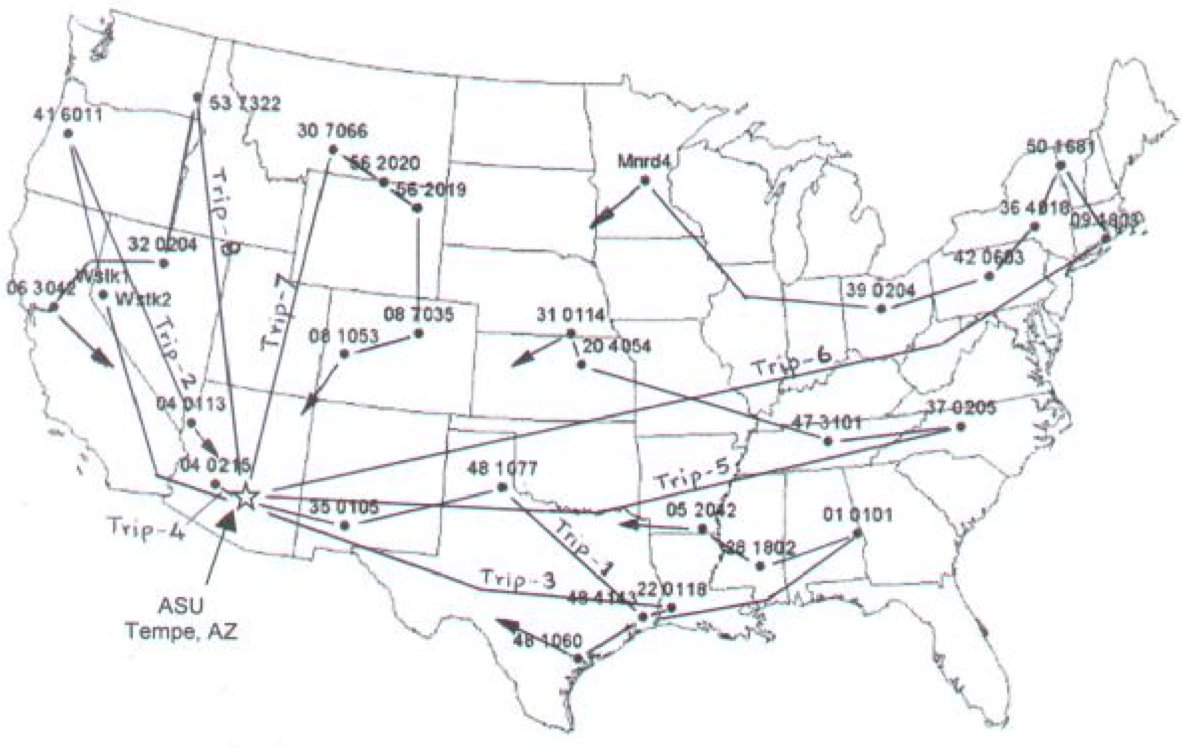


Figure 6
Trip Routes

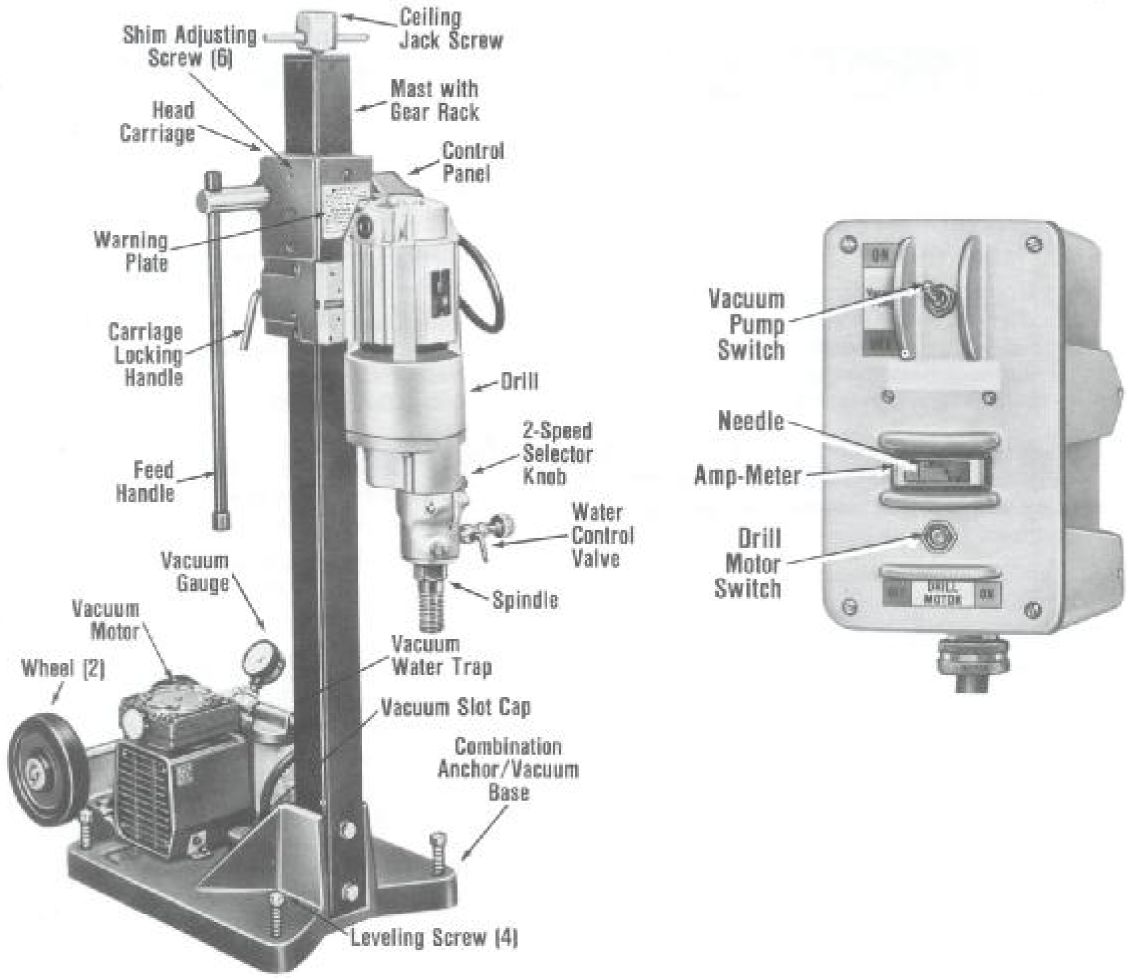


Figure 7
Core Bore Drilling Machine™

Figure 8
Modified Sand Cone Apparatus

Figure 9
Coring Operation in Groton, Connecticut

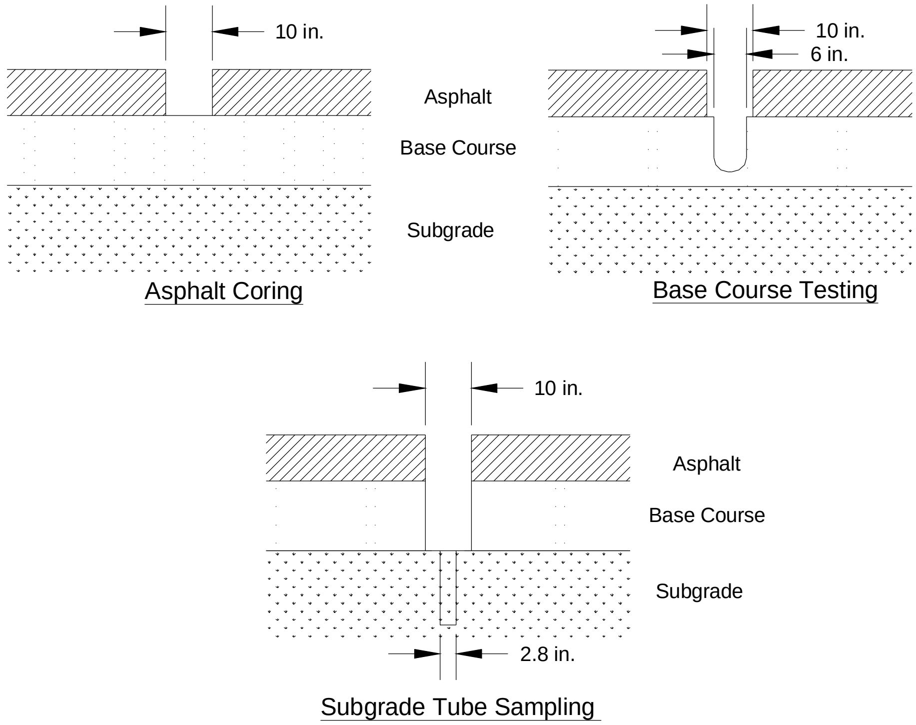


Figure 10
Sampling Process

CHAPTER 3
DATA COLLECTED FROM EXISTING DATABASES

INTRODUCTION

Once the necessary variables needed to run the EICM were identified, the next step was to select sections for the experimental design. These sections were divided into two groups: those that were analyzed in the office and compared to recorded data in the available databases, and those to be visited for direct in-situ measurements. The sites to be visited were identified in Chapter 2. In this Chapter, the data collected for the office analysis is presented.

The search was focused in the following databases:

1. Long Term Pavement Performance (LTPP) Database
2. MnRoad
3. WesTrack
4. Arizona Department of Transportation (ADOT) Database

For sites where adequate data existed, needed parameters for the preliminary runs of the EICM were extracted from the databases. These parameters included: a) parameters required to run the EICM; and b) data required for validation of the EICM.

PARAMETERS REQUIRED TO RUN THE EICM

Parameters required to run the EICM are summarized below. The list presented is based on the nomenclature used by LTPP, which includes particular Section Identification numbers and State codes.

Analysis Conditions

- Section
- State Code
- SHRP Identification Number
- State
- Project Type
- Pavement Type
- Construction Number
- Unbound Layers Preparation Completion Date
- Asphalt Construction Completion Date
- Traffic Opening Date
- Date of Another Event
- Event
- TDR/Thermistor Installation Date
- Design Period
- Sites Already Visited
- Lab ID

Pavement Lane Properties

- Pavement Type
- Lane Width
- Pavement Slope
- Thermal Conductivity
- Heat Capacity
- Surface Short Wave Absorptivity

Environmental/Climatic

- Latitude (degrees and minutes)
- Longitude (degrees and minutes)
- Elevation
- Groundwater Table Depth

Pavement Structure

- Layer Number
- Layer Type
- Layer Description
- Representative Thickness
- Material Description
- Bedrock Information

Atterberg Limits

- State Code and SHRP ID Number
- Construction Number
- Layer Number and Layer Type
- Liquid Limit, Plastic Limit, and Plasticity Index
- Source of Information

Gradation Parameters

- State Code and SHRP ID Number
- Layer Number and Layer Type
- Percent Passing #200 Sieve
- Percent Passing #4 Sieve
- Diameter D_{60}

Optimum Moisture Content and Maximum Dry Unit Weight

- State Code and SHRP ID Number
- Layer Number and Layer Type
- Optimum Moisture Content
- Maximum Dry Unit Weight
- Source of Information

Unbound Materials Gradation

- State Code and SHRP ID Number
- Layer Number and Layer Type
- Test Number
- Test Date
- Gradation Analysis from Passing 3" Sieve to Passing ½" Sieve
- Gradation Analysis from Passing 3/8" to Passing #200 Sieve
- Hydrometer Analysis
- Percentage > 2 mm
- Percentage of Coarse Sand
- Percentage of Fine Sand
- Percentage of Silt
- Percentage of Clay
- Source of Information

Unbound Materials Classification

- AASHTO Soil Classification (Test 1 and Test 2 when applicable)
- Unified Soil Classification (Test 1 and Test 2 when applicable)
- Dry Thermal Conductivity
- Heat Capacity

PARAMETERS REQUIRED TO VALIDATE THE EICM

The variables required to validate the EICM include the moisture content measurements throughout the pavement profile with time. Time Domain Reflectometry (TDR) measurements were collected for the sites selected.

LTPP DATABASE

Parameters Required to Run the EICM

The data required to run the EICM and presented above was extracted. The information presented includes data for a total of 67 test sections from the LTPP SMP database. Fifty-five (55) out of the 67 sections were used for the ***Stage IV runs*** calibration analysis described in Chapter 5; whereas, 28 sites were used for the ***Stage II and III runs***. These 28 sites were visited to gather field information needed to complete the ***Stage I runs*** calibration analysis. The input data and sources of information needed are tabulated and presented in Tables 10 to 24. TDR data can be found in the LTPP database and it is not presented in this report due to its large size.

Missing Data

In the collection of the LTPP data, several pieces of information were missing. The information that was not available in the database was requested from the LTPP regions and the DOTs. In some cases, reasonable assumptions were used to complete the database. This section is intended to describe either the sources or the assumptions needed to complete the data set for those parameters for which it was not possible to get the complete information from the LTPP database.

Unbound Layers Preparation Completion Date

This information was not found in the LTPP database in many of the cases. It was assumed to be 2 months prior to the Asphalt Construction Completion date.

Design Period

The design period was chosen based on the time the TDR and thermistor information available in the database.

Pavement Slope

A value of 1.5% was assumed for all of the sections.

Dry Thermal Conductivity

Reasonable values of thermal conductivity for AC pavements range from 0.44 to 0.81 BTU/hr-ft-^{o}F. A default value of 0.67 BTU/hr-ft-^{o}F was assumed for all of the sections. For PCC pavements, the values range between 0.47 and 0.67 BTU/hr-ft-^{o}F. A value of 0.57 BTU/hr-ft-^{o}F was assumed.

The dry thermal conductivity of the unbound materials is not available in the database. The values shown in Table 24 are the default values used by the EICM, and they are a function of the AASHTO soil classification. The dry thermal conductivity is not an input option anymore due to changes to the software in the past year. However, this parameter was needed to run the current version of the EICM.

The following references were used to obtain the thermal conductivity default values: Tye (1969), Larsen (1982), Yaws (1997), and Farouki (1982). In addition to the mentioned references, the team followed the recommendations found in the ICM User's Manual for considering the values to be close enough to the ones found while reviewing the references.

Heat Capacity

Reasonable values of heat capacity for AC pavements range from 0.22 to 0.40 BTU/lb-^{o}F. A default value of 0.22 BTU/hr-ft-^{o}F was assumed for all of the sections. For PCC pavements, the values range between 0.15 and 0.25 BTU/lb-^{o}F. A value of 0.15 BTU/lb-^{o}F was assumed.

The heat capacity of the soil was not available in the database. A recommended value of 0.18 BTU/lb-^{o}F is used in the EICM for every material type (Robertson & Hemingway 1995). As with the dry thermal conductivity, the heat capacity is not an input parameter anymore, but it is needed to run the current version of the EICM model.

Surface Short Wave Absorptivity

Reasonable values of surface short wave absorptivity for weathered asphalt (gray) range from 0.80 to 0.90. A default value of 0.85 was assumed for all of the AC sections. For

PCC pavements, the values range between 0.70 and 0.90. A value of 0.80 was assumed (Moats 1994).

Groundwater Table Depth

Information not found on the LTPP database was extracted from the Inter-team technical report presented by Von Quintus (2001) - Tables B-1, B-2, and B-3 as part of the NCHRP project 1-37A. The data shown in this report was gathered from Soil Conservation Service reports and maps. Additional data was gathered from the US Geological Survey records, state DOTs, and LTPP boring logs and comments. The agencies contacted, private environmental consultants, and visited number of Internet websites to inquire/search the required information are summarized in Table 25.

Out of the various sources included in Table 25, the NWIS website generated quick groundwater levels with just the longitude and latitude information of the site. The generated groundwater level data was considered adequate when the wells identified in the search were reasonably close to the site and the data was recently recorded. However, for some sites, the available data could not be considered recent and/or the distance between the site and the wells were too large. In such cases, we contacted environmental consultants in the area for some guidance. These consultants either provided their in-house data, if available, or directed us to the appropriate state agencies. The state agencies typically provided the groundwater data through their homepages. For example, the Texas Water Development Board (TWDB) maintained a good groundwater database for the entire state on their website. On the other hand, the Arizona Department of Water Resources (ADWR) provided the groundwater data via fax messages.

There were several sites for which the groundwater table depth information was still missing. The boring log information in the LTPP database was revisited and the groundwater table was assumed to be at the bottom of the borehole, given that this is the most conservative assumption. Some of the sites are believed to have a deep groundwater table; this situation should not strongly impact the prediction of moisture content variations at shallow depths.

Layer Type

In all cases, the subgrade (SS) was reported to be an uncompacted layer; therefore the top 12 inches of the subgrade was assumed to be compacted material. This compacted "sublayer" was not included in the pavement structure shown in Table 16.

Bedrock Information

In most of the cases, records of depth to bedrock were not found in the LTPP database. In order to complete this information, the following sources were used:

1. Inter-team technical report presented by Harold Von Quintus on March 2001 (Tables B-1, B-2, and B-3) with data from the Soil Conservation Service reports and maps as part of the NCHRP project 1-37A (Von Quintus 2001).
2. Data available from the US Geological Survey and state DOTs.

3. State DOTs records.
4. LTPP boring log information and comments.

Lime Treated or Cement Aggregate Material

There are several sections that have either lime treated soil or cement-aggregate material. EICM is currently incapable of dealing with these types of materials. Furthermore, there is no data available in the LTPP for these layers. These sections can be run by making assumptions such as plasticity reduction and gradation changes.

MINNESOTA ROAD RESEARCH PROJECT (MNROAD) DATA

The main objective of this section is to summarize mix design data, material properties, pavement structure data, and construction information, as well as moisture content and temperature profiles data for the MnRoad test sections selected for the research work in the NCHRP 9-23 project.

For the office verification of the EICM two sections were selected, namely cell 4 and 21 from the Mainline road. The general layout of the Mainline road of the MnRoad Project and pavement cross sections of the test sites are presented in Figure 11.

MnRoad Research Project

The Minnesota Department of Transportation (MnDOT), constructed forty, 500-foot long asphalt, concrete and gravel-surfaced pavement test sections (known as test cells) from 1992 to 1994. The site, known as MnRoad consists of 3 miles of two-lane interstate I-94 (known as Mainline cells) as well as 2.5 miles of closed loop low volume test track (known as low volume cells). The I-94 traffic, an estimated 14,000 vehicles per day (15% trucks), generally uses the Mainline facility where 23 heavily instrumented test cells are subjected to live traffic loads. The low volume facility with 17 test cells is subjected to controlled loading by a single vehicle circling the two-lane test track. The Mainline portion is divided into two parts, referred to as the 5-Year Mainline (5 years design life) and 10-Year Mainline (10 years design life) (U. of Minnesota 1997).

Environmental Conditions

MnRoad Test Road is located parallel to I-94 in Otsego approximately 40 miles northwest of the Minneapolis-St. Paul metropolitan area (Latitude: 45°3’; Longitude: 93°17’). The Mean Annual Air Temperature (MAAT) at MnRoad is 46.2°F. Based on historic temperature data, freeze-thaw data and rainfall distributions obtained at the MnRoad test site, the yearly temperature, freeze-thaw and rainfall were divided for five distinct seasons. Table 26 presents the start time and duration of each season for the three climatic regions (NE, CEN and SE).

Table 27 presents maximum fluctuations of daily pavement temperature reported at MnRoad flexible pavement sections.

Figure 12 and Figure 13 present the results of water table level below pavement surface for cell 4 and cell 21, respectively. The average water table level for cell 4 is 9.40 ft

below pavement surface and the average water table for cell 21 is 14.88 ft below pavement surface.

Instrumentation packages developed by the SHRP LTPP program for measurement of moisture, temperature, and frost penetration in pavement sections were placed at MnRoad. Moisture content was recorded by using Time Domain Reflectometry (TDR) probes. Data was recorded at 2-week intervals. Table 28 displays the data collected from 1994 to 1998. Figure 14 and Figure 15 show the TDR locations along with the NCHRP 9-23 core locations for cells 4 and 21, respectively. In addition to moisture measurements, pavement temperature was measured with temperature probes and electrical resistivity probes were installed to measure frost penetration.

Pavement Structure

The general layout of the Mainline Test Road and pavement cross-sections for the two cells evaluated in the NCHRP 9-23 Project is shown in Figure 11. Table 29 presents information about the pavement structure: type of pavement layers, thickness and dates of construction start and end.

One of the sections designed for the 5-year life was selected for this experiment. Test cell 4 is a full depth pavement structure in the 5-Year Mainline with a total thickness of 8-inches of bituminous materials placed over the graded and compacted subgrade. The section selected within the 10-year design life portion of the MnRoad project was cell 21. This cell has a total AC layer thickness of about 8 inches and a granular base layer of 23 inches of the Class-5 SB material.

Material Properties

Table 30 presents a summary of the main characteristics of the mix design.

Aggregates

The combined aggregate gradation was held constant for all the MnRoad asphalt concrete mixtures and for all test cells. Three stockpiles of aggregates were used. The majority of the mix was comprised of two stockpiles obtained from Buffalo Bituminous Crow River pit in Buffalo, Minnesota. Both of these aggregates were partially crushed river gravel. The third stockpile was obtained from Meridian, Inc in St. Cloud, Minnesota and was a 100% crushed granite. The physical properties, stockpile gradations, and blending percentages used to prepare the mix design materials and the adjusted percentages used for construction are shown in Table 31.

The blending percentages used in construction were different than those used for preparation of the laboratory-prepared mix design materials. The original gradation blend was selected during the mix design work completed by the Minnesota Department of Transportation prior to construction. Re-sampling of the stockpiles just before the start of the construction showed that the gradation blends needed adjustment due to increased and erratic fines content. The construction stockpiles were eventually reworked so that a

consistent gradation was achieved during construction and no further blending adjustment.

Asphalt Cement

The Koch Refinery in Rosemount, Minnesota supplied two grades of binder, a 120/150-Penetration grade and AC-20 Viscosity grade. Only the 120/150 Pen grade was used for the 5-Year Mainline (cell 4). Test cell 21 (in the 10-Year Mainline) was constructed with the 120/150-Pen grade asphalt. Binder properties results extracted from MnRoad Report 97-06 (U. of Minnesota 1997) are presented in Table 32.

Granular Materials

Four different aggregate gradations were used as base and subbase materials in the construction of the MnRoad project. These materials are referred to as Class 3 SB, Class 4 SB, Class 5 SB and Class 6 SB, and are labeled "special" due to the fact that they were used for MnRoad exclusively. Class 5 SB was used in cell 21, which was classified by the Minnesota Department of Transportation as sandy gravel with approximately 5.7% fines. Cell 4 did not include a granular base. In-situ gradation test results are presented in Table 33 and Figure 16 for the different aggregates used at MnRoad.

Proctor tests, conducted by the Minnesota Department of Transportation were used to determine the materials maximum dry density and optimum moisture content. These tests show that the materials have the following characteristics:

- Class 3 SB: the least dense material, of the materials tested, with maximum dry density of about 127.9 pounds per cubic foot.
- Class 4 SB: the highest optimum water content at approximately 10% of the total dry weight.
- Class 5 SB: the densest of the four materials tested with a maximum dry density of approximately 132.7 pounds per cubic foot.
- Class 6 SB: the lowest optimum water content at approximately 6.8%.

Proctor test results are presented in Table 34.

Dynamic Cone Penetrometer (DCP) results are indicative of the shear strength (CBR) of granular materials. Laboratory tests were conducted on cylindrical specimens (9-inch diameter and 15-inch in height). The calibrated lower rod was driven into the material using a 17.6-pound anvil on the upper rod. The rod penetration after each anvil blow was recorded as inches/blow. This was recorded as the penetration rate (PR). CBR was estimated from PR using following equation:

$$\mathrm{Log}_{10}\,(\mathrm{CBR}) = 0.84 - 1.26 * \mathrm{Log}_{10}\,(\mathrm{PR})$$

Table 35 presents the results from DCP testing for the Class 5 SB material at different moisture and density levels.

Subgrade Soils

There is only one type of subgrade soil in the Mainline flexible pavement sections. The native soil at the site is primarily silty clay and the existing topography had no more than 10 to 13 feet of relief prior to construction. The embankments for the Mainline track range in height between 0.3 to 10 feet and are constructed on cuts ranging from 0.7 to 2 feet. MnDOT performed laboratory testing on the cohesive soil and collected subgrade samples at various stages of construction for laboratory testing. Gradation data is shown in Table 36 for cells 4 and 21.

Samples were obtained using bulk bag samples (disturbed). The samples were collected after subgrade completion and before placement of subbase/base layers. The samples were from depths ranging 1 foot to 6 feet under the right outer wheel path at various stations. All bag samples were taken from beneath the centerline of the roadway, near the center of each cell. Table 37 presents the results of soil analysis on bag samples. According to AASHTO classification the subgrade was classified as an A-6 soil (silty clay with more than 35% passing the 200 sieve, LL-40 maximum, and PI-11 minimum).

Tests conducted on the soils prior to construction indicated an average design Resistance Value (R) equal to 12.

Construction Data

The base material for the 5-Year Mainline were placed and compacted during the spring and summer of 1992. The first lift of the test cell 4 was placed on September 24, 1992. The third and fourth lifts for cell 4 were placed on September 25, and September 28, 1992, respectively. Sensors within the asphalt concrete were installed in each test cell about one month after construction.

Cell 21, part of the 10-year design life portion of the MnRoad was constructed in July 1993. The first and second lifts of cell 21 were placed on the second and third days of construction. Table 38 presents information about test cells construction including section length, completion of construction date, and opening for traffic date.

Maintenance Activities

In 1998 some of the cells on the Mainline were sealed and some others with similar distress were left unsealed. Route and seal technique was done using Crafco 522 sealant (extra low modulus). In 1999 some crack sealing was done on the Mainline cells to review the effects sealant had on the inflow of moisture from the cracked surface above. On April 24-25, 2000, several MnRoad test cells were sealed on the Mainline according to the recommendations of the MnRoad staff. A Clean and Seal method was used (air blown and then sealed). Table 39 presents a summary of the maintenance activities done on MnRoad Mainline on cells 4 and 21.

Traffic Characterization

The MnRoad project is located on one of the highest truck volume routes (I-94) in the state of Minnesota. The design average daily traffic for this portion is 24,000 vehicles

with 3,200 of these classified as heavy commercial vehicles. The traffic characterization in the project is performed using a Weight-In-Motion (WIM) system. A weight-in-motion system is located at the beginning of the facility to monitor axle weights. WIM consists of four platforms in a sealed frame, four loop detectors, and a microcomputer.

The equivalent single axle loads (ESALs) were calculated from the WIM data. ESAL calculations were performed for each cell in both the driving and passing lane. The ESALs in the passing lane are 25 percent of the accumulated ESALs in the driving lane for all cells. Table 40 shows the accumulated annual number of ESAL on cells 4 and 21 through October 2001.

WESTRACK DATA

The main objective of this section is to summarize the material properties, pavement structure data, and construction information, as well as moisture content and temperature profiles data for the WesTrack test sections selected for the research work in the NCHRP 9-23.

Three test sections from WesTrack were selected for the office verification of the Enhanced Integrated Climatic Model (EICM). The chosen sections are section 12, sections 15, and sections 25. The general layout of the WesTrack Project showing the selected sections is presented in Figure 17.

The information presented was extracted mostly from the NCHRP Report 455, *Recommended Performance-Related Specification for Hot-Mix Asphalt Construction: Results of the WesTrack Project* (Epps et al. 2002).

WesTrack Research Project

WesTrack is an experimental test road facility constructed at the Nevada Automotive Test Center (NATC) near Fallon, Nevada, under the Federal Highway Administration (FHWA) project "Accelerated Field Test of Performance-Related Specifications for Hot-Mix Asphalt Construction". WesTrack was constructed as a 2.9 km oval loop consisting of twenty-six 70-m-long experimental sections on the two tangents. Construction was completed in October 1995. Traffic was carried out between March 1996 and February 1999.

The experimental variables were asphalt content, in-place air void content, and aggregate gradation. The research efforts considered two primary types of HMA pavement distress: (1) permanent deformation or rutting, and (2) fatigue cracking on the wheelpath area.

Environmental Conditions

The site of the test track is located 28 miles east of Carson City. The main proving ground area is intersected by the Carson River and Nevada State Rout 2B (Fort Churchill Road). The WesTrack location has an annual precipitation of less than 100 mm per year and no annual subgrade soil freeze-thaw conditions are expected. The yearly average

daytime temperature is 69°F and humidity is typically below 20 to 30 percent. Extreme daytime high temperatures of 104°F and low temperatures of –4°F can be expected.

An LTPP-type weather station was installed at WesTrack near the vehicle and staging and maintenance area. The equipment was used in the SHRP LTPP program to monitor climate at the Specific Pavement Studies (SPS) test sites. The equipment records the following information every hour:

- Air temperature
- Relative humidity
- Wind speed
- Wind directions
- Solar radiation
- Precipitation (water equivalent).

Besides the data collected at the site, two weather stations from the National Climatic Data Center are closed by: Fallon, NV located about 27 mi. from the site (Latitude: 39° 25'; Longitude: 118° 42') and the Cannon International Airport station located in Reno, NV about 30 mi. away from the NATC facility (Latitude: 39° 29'; Longitude: 119° 46'). The elevation at WesTrack site is approximately 4,100 ft.

Instrumentation packages developed by the SHRP LTPP program for measurement of moisture, temperature, and frost penetration in pavement sections were placed at the edge of the test lane for section 12 and section 25. The following sensors were placed at each of these locations:

- 10 Time Domain Reflectometer (TDR) probes.
- 18 probes to measure pavement surface temperature.
- 35 electrical resistivity probes to measure frost penetration.

Data from the temperature and resistivity probes were continuously recorded, while data from TDR probes were recorded at approximately 2-week intervals. Readings were monitored continuously at 0.5 in. intervals in the pavement. Table 41 presents the TDR data recorded. Temperature data is also available but it is not included in this report due to its length.

A piezometer/observation well was installed near the SHRP seasonal instrumentation packages on the south tangent (near section 12) and on the north tangent (near section 25) to monitor the elevation of the groundwater table. The recorded data is shown in Figure 18 and the tabulated data is presented in Table 42.

The average water table depth for the south tangent was found to be about 10.8 ft. below the pavement surface and approximately 11.2 ft for the north tangent. The relative high water table was attributed to the high water flow in the Carson River, which resulted from the wet winter of 1994-95 in the Sierra Nevada Mountains.

Pavement Structure

The total length of WesTrack is 2.8 km (1.76 miles). The selected track length is summarized as follows:

- Two tangents **x** 13 sections **x** 70 m (230 ft) per section
- Four spiral transitions **x** 46 m (150 ft) per transition
- Two alignment transitions **x** 15 m (50 ft) per transition
- Two horizontal curves **x** 398.5 m (1307 ft) per curve

The layout and plan view of the test track are shown in Figure 17. Because of the flat profile of the natural ground, vertical curves were not needed. With a 2% cross-slope, the 11-m (36-ft) track cross section consists of the following elements as described from the outside of the track toward the inside of the track:

- Outside shoulder 1.8 m (6 ft) gravel and 1.2 m (4 ft) HMA.
- Test lane 3.7 m (12 ft).
- Trial lane 3.7 m (12 ft).
- Inside shoulder 0.6 m of gravel (2 ft).

A single thickness of HMA was selected. The final structural section for the tangent or test sections is as follows:

• HMA	150 mm	6 in.
• Base course	300 mm	12 in.
• Engineered fill	460 mm	18 in.
• Subgrade-compacted	150 mm	6 in.
• Natural subgrade		

The as-built thickness of the HMA placed during the original construction was measured at four different locations.

Table 43 presents an average final thickness for the selected sections. Thickness variations between sections are in part a result of the differences in gradation, asphalt binder content, and target in-place air voids.

Based on information from boring logs from subsurface investigation on February 23, 1995, a rigid layer or bedrock was not found at 21 ft of depth.

Material Properties

Mix Designs

Three different mixtures designs were used at WesTrack: fine, fine-plus, and coarse. All three mixtures were prepared with the partially crushed gravel from Granite Construction's Dayton pit.

Three levels of in-place air voids were selected: low, medium, and high. The medium level was selected at 8%. A low value of 4% and a high value of 12% were selected to represent expected extremes in in-place air voids.

The experimental plan considering the above-mentioned variables and the design asphalt content is shown in Table 44 for the original 26 sections constructed at WesTrack. The selected sections for the NCHRP 9-23 project are presented in bold.

Hydrated lime was used on the sections constructed. The hydrated lime in the mixtures placed at WesTrack ranged from 1.3 to 1.5 % by dry weight of total aggregate.

Aggregates

Based on the mixture design results, a single aggregate source was used for the test sections during the original construction of the test track. The aggregate selected was partially crushed, water-deposited gravel from near Dayton, Nevada.

The gradations of the three mixtures used for original construction on WesTrack are designated as fine, fine-plus, and coarse. Percentages of aggregate used during original construction are shown in Table 45.

Asphalt Cement

Because of the limited size of the project, a single asphalt binder was selected. The binder selected was a PG 64-22.

Base Course Materials

The base course material used in the track was a blend of four different aggregate stockpiles generated by crushing rock obtained from a quarry at the site. The average gradation of the two lifts of base course is shown in Table 46. A summary of the moisture and density data collected during construction is presented in Table 47. Table 48 and Table 49 contain Atterberg Limits, CBR values, and R-values collected on specific sections of the tangents for each of the two lifts.

Cone Penetrometer values were also obtained during construction. The data were converted to CBR values by use of the U.S. Army Corps of Engineers' software and Livneh. The calculated CBR values based on the U.S. Army Corps of Engineers' conversion method are shown in Table 50 for the sections 15 and 25. The CBR values obtained using the Livneh's equation, are also available in Epps et al. (2002).

FWD data were used to calculate modulus values for the base course. These data are presented in Table 51 for sections 15 and 25. Additionally, laboratory tests were performed to define the resilient modulus of the base course. Laboratory-determined resilient modulus values for section 25 are shown in Table 52.

Engineered Fill

The compaction conditions of the engineered fill are summarized in Table 53. Table 54 shows the average relative density data collected during construction for the original sections.

Table 55 contains Atterberg Limits, California Bearing Ratio (CBR) values, R-values, and soil classification information collected on the selected sections of the tangents. Lift 3 was pulverized, mixed, and re-compacted and has been identified as lift 4. Therefore, the actual data of importance are those associated with lifts 1, 2, and 4.

Assignment of resilient modulus values for the engineered fill was made based upon the laboratory-based resilient modulus testing carried out on selected soil samples. The modulus of the engineered fill was found to be relatively insensitive to the modulus of the underlying soil. The average value was about 9,300 psi for the tangent sections. The state-of-stress associated with this value was on the order of 1 psi confining pressure and 4 psi deviator stress.

Subgrade Soils

Consistent with the depositional process of the Carson River, the soils at the site consisted of varying proportions of blends of fine-grained clays, sands, and silts. In situ moisture contents ranged from 4 to 22 %. The optimum moisture content and maximum dry density (based on AASHTO T 99) were in the range of 16 to 20 % and 1,600 to 1,746 kg/m^3 (100 to 109 pcf), respectively.

A subsurface investigation was performed on February 23, 1995. A drill rig was used and the boring log is presented in Figure 19. Table 54 shows the average relative density data collected during construction for the original sections.

Falling-Weight Reflectometer (FWD) data was used to back-calculate the resilient modulus of the subgrade soil. Table 56 shows the mean and the standard deviation for three different sets of data taking between October 1994 and April 1995. These data are considered representative of back-calculated moduli for the 2.5-m (8-ft) soil layer above the water table. As can be seen, the data suggested that seasonal variations such as moisture content and level of groundwater table could have a significant impact on soil properties (Epps 2002).

Research conducted at the UNR on the effects of seasonal variations within the state has shown that, for state highways near WesTrack site, the natural soil moduli vary from 70 to 102 % of the summer moduli. The normalized range is shown in Table 57.

Based on this information and the average back-calculated moduli shown in Table 56, monthly resilient modulus values for the natural soil were estimated. These values are shown in Table 58.

During construction, FWD data were used to calculate modulus values for the engineered fill and subgrade soil. These data are presented in Table 51 by section number and date

of testing for the subgrade soil. Laboratory tests were also performed to define the resilient modulus of the subgrade. Laboratory-determined resilient modulus values are shown in Table 52.

Construction Data

Table 59 shows the schedule of the WesTrack construction activities relative to the other WesTrack activities. The construction activity schedule for placement of the subgrade, engineered fill, and base course is shown in Table 60 whereas, the HMA construction schedule for the test lane of the original construction sections is shown in Table 61.

Maintenance Activities

Pavement rehabilitation and maintenance activities were carried out during the trafficking of WesTrack. These activities were initiated when a section reached a "failed" condition or the track become unsafe for the operation of the truck. Failure at WesTrack was defined as rut depths of approximately 1 in. or fatigue cracking in excess of 50% of the wheel-path, for the purposes of rehabilitation and maintenance operations.

Table 62 contains a listing of maintenance and rehabilitation activities performed at the WesTrack selected sections.

ARIZONA DEPARTMENT OF TRANSPORTATION DATA

The main objective of this section is to summarize the material properties, pavement structure data, performance, and construction information, as well as moisture content and temperature profiles data for the Arizona Department of Transportation (ADOT) test sections selected for the research work in the NCHRP 9-23.

Two test sites from ADOT were selected for the office calibration of the Enhanced Integrated Climatic Model (EICM). The chosen sections are Site 1 and Site14.

Site 1 is located in Avondale, between Buckeye and 91st Avenue. Its construction was completed in 1936. In December 1956 the road was widened; also new subgrade and subbase layers were constructed. Section 14 is located in Flagstaff, between I 17 and MP 337. It was completed in August 1960.

The information presented in this report was extracted from the FHWA/AZ Report 80/157, *Environmental Factor Determination from In-Place Temperature and Moisture Measurements under Arizona Pavements.* September 1980 (Way 1980).

Environmental Conditions

The ADOT site 1 is located 33° 26.15' latitude North, 112° 15.3' longitude West, and has an elevation of 994 ft. Its subgrade consists of alluvial sediments with caliche. The site has an annual precipitation between 130 to 300 mm per year and no annual subgrade soil freeze-thaw conditions are expected. The yearly average daytime temperature is above

70°F and humidity is typically between 26 to 35 percent. Extreme daytime high temperatures above 120°F and low temperatures between 11 to 20°F can be expected.

The ADOT site 14 is located 35° 8' latitude North, 111° 41.1' longitude West, and has an elevation of 9,658 ft. Its subgrade consists of Kalbab limestone. The site has an annual precipitation between 500 to 750 mm per year. On average, 183 cm of snow per year is expected in this area, and the subgrade soil freeze-thaw conditions can occur up to 20 times a year. The yearly average daytime temperature is 50° F and humidity is typically between 46 to 55 percent. Extreme daytime high temperatures above 96°F and low temperatures between -19 to -10°F can be expected.

Instrumentation packages for measurement of moisture, and temperature were placed at the edge of the side lane for site 1 and 14. The following sensors were placed at each of these locations:

- Four TDR to measure moisture.
- Six thermistors to measure pavement temperature.

Data from the thermistor probes were recorded monthly, while data from the TDR probes were recorded in uneven periods ranging from few days to one year. Table 63 presents the temperature data, and Table 64 includes the TDR data. The depth of the thermistors is quantified from the top of the pavement surface.

The ground water table was not monitored at the sites during the time of the experiments. Therefore an approximate ground water depth was determined using USGS data. The average water table for site 1 was found to be about 68.1 ft below the pavement surface. The data was collected 0.067 miles away from the test location. The ground water table for site 14 was determined to be about 1002 ft below the pavement surface. The data was collected at two locations, 0.164 and 0.180 miles away from the test site. The information is presented in Figure 20 and Table 65.

Pavement Structure

Site 1 was originally built as a two-lane road which consisted of three layers: subgrade, concrete and asphaltic concrete. In the following years the road was widened to five lanes with 2 % crown. New subbase and asphaltic layers were placed on top of the original pavement, which is illustrated in Figure 21. The pavement structure data for sites 1 and 14 are given in Table 66.

Material Properties

Mix Designs

Two sets of data are available for the ADOT sites. The first set of experiments was performed during construction, while the second one in 1977. The obtained data is presented in Table 67. The results indicate that the percent of air voids decreases with time due to compaction. The asphalt characteristics are given in Table 68.

Asphalt Cement

Gradation data of the asphalt cement used at the ADOT sites are given in Table 69.

Base Course Materials

Gradation data of the base course materials used at the ADOT sites are given in Table 70. A summary of the moisture and density data collected during construction is presented in Table 71. Table 72 contains Atterberg Limits, and soil classification. CBR, FWD and R-values for base course were unavailable.

Subbase

Gradation data of the subbase or engineered fill used at the ADOT sites are given in Table 73. A summary of the moisture and density data collected during construction is presented in Table 74. Table 75 contains Atterberg Limits, and soil classification. CBR, FWD, resilient modulus and R-values for the engineered fill were unavailable.

Subgrade Soils

Gradation data of the subgrade soil used at the ADOT sites are given in Table 76. A summary of the available moisture and density data collected during construction is presented in Table 77. Table 78 contains Atterberg Limits, and soil classification. CBR, FWD, resilient modulus and R-values for the subgrade soils were unavailable.

Construction Data

Table 66 shows the schedule of the ADOT site 1 and 14 construction activities.

Maintenance Activities

Pavement rehabilitation and maintenance activities were carried out when site reached "failed" condition or the road became unsafe for the operation of truck. Table 79 contains a listing of maintenance and rehabilitation activities at both sites 1 and 14.

Table 10
Analysis Conditions I – LTPP Data

Section	State Code	SHRP ID	State	Project Type	Pavement Type	Construction Number	Unbound Layers Preparation Completion Date	Source
01 0101	1	0101	AL	SPS-1,SMP	AC	1	8/26/1992	SPS1_UNBOUND_AGG_BASE
01 0102	1	0102	AL	SPS-1,SMP	AC	1	1/1/1993	Assumed
04 0113	4	0113	AZ	SPS-1,SMP	AC	1	6/29/1993	SPS1_UNBOUND_AGG_BASE
04 0114	4	0114	AZ	SPS-1,SMP	AC	1	6/17/1993	SPS1_UNBOUND_AGG_BASE
04 0215	4	0215	AZ	SPS-2,SMP	PCC	1	8/13/1993	SPS2_UNBOUND_AGG_BASE
05 2042	5	2042	AR	GPS-2,GPS-6S	AC	1, 2	10/1/1972	Assumed
06 3042	6	3042	CA	GPS-3,SMP	PCC	1	-----	Not needed for PCC sections
08 1053	8	1053	CO	GPS-1,SMP	AC	1	12/1/1983	Assumed
08 7035	8	7035	CO	GPS-7A,GPS-7S	PCC	1, 2		
09 1803	9	1803	CT	GPS-1,SMP	AC	1, 2, 3	5/1/1985	Assumed
						3		
10 0102	10	0102	DE	SPS-1,SMP	AC	1, 2	7/6/1995	SPS1_UNBOUND_AGG_BASE
13 1005	13	1005	GA	GPS-1,SMP	AC	1	4/1/1986	Assumed
13 1031	13	1031	GA	GPS-1,GPS-6S	AC	1, 2	4/1/1981	Assumed
13 3019	13	3019	GA	GPS-3,SMP	PCC	1	-----	Not needed for PCC sections
16 1010	16	1010	ID	GPS-1,SMP	AC	1	8/1/1969	Assumed
18 3002	18	3002	IN	GPS-3,SMP	PCC	1	-----	Not needed for PCC sections
20 4054	20	4054	KS	GPS-4,SMP	PCC	1	-----	Not needed for PCC sections
22 0118	22	0118	LA	SPS-1,SMP	AC	1	5/6/1996	SPS1_UNBOUND_AGG_BASE
23 1026	23	1026	ME	GPS-1,GPS-6B,SMP	AC	1, 2	-----	Not needed for Rehab sections
24 1634	24	1634	MD	GPS-2,GPS-6C	AC	1, 2	4/1/1976	Assumed
27 4040	27	4040	MN	GPS-4,SMP	PCC	1	-----	Not needed for PCC sections
28 1016	28	1016	MS	GPS-2,SMP	AC	1	9/1/1986	Assumed
28 1802	28	1802	MS	GPS-2,SMP	AC	1	4/1/1982	Assumed
30 7066	30	7066	MT	GPS-1,GPS-6B,SMP	AC	1, 2	-----	
30 8129	30	8129	MT	GPS-1,SMP	AC	1	4/1/1988	Assumed
31 0114	31	0114	NE	SPS-1,SMP	AC	1	5/1/1995	Assumed
31 3018	31	3018	NE	GPS-3,SMP	PCC	1	-----	

Table 10 – Cont'd
Analysis Conditions I – LTPP Data

Section	State Code	SHRP ID	State	Project Type	Pavement Type	Construction Number	Unbound Layers Preparation Completion Date	Source
32 0101	32	0101	NV	SPS-1,SMP	AC	1	7/19/1995	SPS1_UNBOUND_AGG_BASE
32 0204	32	0204	NV	SPS-2,SMP	PCC	1	6/28/1995	SPS2_UNBOUND_AGG_BASE
33 1001	33	1001	NH	GPS-1,SMP	AC	1	11/1/1980	Assumed
35 0105	35	0105	NM	SPS-1,SMP	AC	1	10/17/1995	SPS1_UNBOUND_AGG_BASE
35 1112	35	1112	NM	GPS-1,SMP	AC	1	4/1/1984	Assumed
36 0801	36	0801	NY	SPS-8,SMP	AC	1	8/9/1994	SPS8_UNBOUND_AGG_BASE
36 4018	36	4018	NY	GPS-4,SMP	PCC	1, 2, 3, 4, 5	-----	
						3		
						4		
						5		
37 0201	37	0201	NC	GPS-2,SMP	PCC	1	11/12/1993	SPS2_UNBOUND_AGG_BASE
37 0205	37	0205	NC	GPS-2,SMP	PCC	1	7/1/1993	SPS2_SUBGRADE_PREP
37 0208	37	0208	NC	GPS-2,SMP	PCC	1	6/24/1993	SPS2_SUBGRADE_PREP
37 0212	37	0212	NC	GPS-2,SMP	PCC	1	6/29/1993	SPS2_SUBGRADE_PREP
37 1028	37	1028	NC	GPS-1,SMP	AC	1	3/1/1982	Assumed
39 0204	39	0204	OH	SPS-2,SMP	PCC	1	8/16/1995	SPS2_UNBOUND_AGG_BASE
40 4165	40	4165	OK	GPS-2,SMP	AC	1	4/1/1984	Assumed
41 6011	41	6011	OR	GPS-6A,GPS-6S	AC	1	4/1/1961	Assumed
						2		
						3		
						4		
42 0603	42	0603	PA	SPS-6	AC	1		
						2		
42 1606	42	1606	PA	GPS-4,SMP	PCC	1	-----	
46 9187	46	9187	SD	GPS-1,SMP	AC	1	3/1/1989	Assumed
						2		

Table 10 – Cont'd
Analysis Conditions I – LTPP Data

Section	State Code	SHRP ID	State	Project Type	Pavement Type	Construction Number	Unbound Layers Preparation Completion Date	Source
						3		
47 3101	47	3101	TN	GPS-2,GPS-6B,SMP	AC	1		
						2		
48 1060	48	1060	TX	GPS-1,SMP	AC	1	1/1/1986	
48 1068	48	1068	TX	GPS-1,SMP	AC	1	9/1/1985	
						2		
						3		
						4		
48 1077	48	1077	TX	GPS-1,SMP	AC	1	11/1/1981	Assumed
						2		
48 1122	48	1122	TX	GPS-1,SMP	AC	1	12/1/1973	Assumed
48 3739	48	3739	TX	GPS-1,SMP	AC	1	3/1/1982	
						2		
						3		
48 4142	48	4142	TX	GPS-4,SMP	PCC	1	-----	
48 4143	48	4143	TX	GPS-4,SMP	PCC	1	-----	
49 1001	49	1001	UT	GPS-1,SMP	AC	1	9/1/1980	
						2		
49 3011	49	3011	UT	GPS-3,SMP	PCC	1	-----	
50 1002	50	1002	VT	GPS-1,SMP	AC	1	6/1/1984	Assumed
50 1681	50	1681	VT	GPS-2,GPS-6B,SMP	AC	1	7/1/1963	Assumed
						2		
						3		
51 0113	51	0113	VA	SPS-1,SMP	AC	1	8/22/1995	SPS1_UNBOUND_AGG_BASE
51 0114	51	0114	VA	SPS-1,SMP	AC	1	8/29/1995	SPS1_UNBOUND_AGG_BASE

Table 10 – Cont'd
Analysis Conditions I – LTPP Data

Section	State Code	SHRP ID	State	Project Type	Pavement Type	Construction Number	Unbound Layers Preparation Completion Date	Source
53 1007	53	1007	WA	GPS-1,GPS-6B,SMP	AC	1		
ELIMINATED						2		
						3		
53 3813	53	3813	WA	GPS-3,SMP	PCC	1	-----	
53 7322	53	7322	WA	GPS-6A	AC	1		
						2		
						3		
56 1007	56	1007	WY	GPS-1,SMP	AC	1	5/1/1980	Assumed
						2		
56 2019	56	2019	WY	GPS-2,SMP	AC	1		
						2		
						3		
56 2020	56	2020	WY	GPS-2,SMP	AC	1		
83 1801	83	1801	Manitoba	GPS-1,SMP	AC	1	11/1/1983	Assumed
83 3802	83	3802	Manitoba	GPS-3,SMP	PCC	1	-----	
						2		
89 3015	89	3015	Quebec	GPS-3,SMP	PCC	1	-----	
						2		
						3		
						4		
ADOT1	ADOT1		AZ	ADOT	AC			
ADOT14	ADOT14		AZ	ADOT	AC			
Mnrd 4	---	---	MN	MnRd	AC	1	8/10/1992	General Info (March 2002)
						2		
Mnrd 21	---	---	MN	MnRd	AC	1	6/2/1992	General Info (March 2002)
						2		
Wstk 12	---	---	NV	WesTrack	AC	1	8/1/1995	Table 75 - NCHRP Report 455
Wstk 15	---	---	NV	WesTrack	AC	1	8/1/1995	Table 75 - NCHRP Report 455

Table 10 – Cont'd
Analysis Conditions I – LTPP Data

Section	State Code	SHRP ID	State	Project Type	Pavement Type	Construction Number	Unbound Layers Preparation Completion Date	Source
Wstk 25	**---**	**---**	NV	WesTrack	AC	1	8/1/1995	Table 75 - NCHRP Report 455

Notes
1 Assumed to be the same as Section 370212, for which data was found
Bold sections are used for Office Calibration; Shaded sections are used for Field Calibration

Office Calibration	61	
Field Calibration	29	
1-37A Sections	12	
Total	67	LTPP
	6	Others

Table 11
Analysis Conditions II – LTPP Data

Section	Construction Number	Unbound Layers Preparation Completion Date	Source	Asphalt Construction Completion Date	Source	Traffic Opening Date	Source
01 0101	1	8/26/1992	SPS1_UNBOUND_AGG_BASE	12/14/1992	SPS1_PMA_CONSTRUCTION	3/1/1993	SPS_ID
01 0102	1	1/1/1993	Assumed	3/1/1993		3/1/1993	SPS_ID
04 0113	1	6/29/1993	SPS1_UNBOUND_AGG_BASE	8/1/1993		8/1/1993	SPS_ID
04 0114	1	6/17/1993	SPS1_UNBOUND_AGG_BASE	8/1/1993		8/1/1993	SPS_ID
04 0215	1	8/13/1993	SPS2_UNBOUND_AGG_BASE	10/1/1993		10/1/1993	SPS_ID
05 2042	1, 2	10/1/1972	Assumed	12/1/1972		12/1/1972	INV_AGE
06 3042	1	-----	Not needed for PCC sections	6/1/1979		6/1/1979	INV_AGE
08 1053	1	12/1/1983	Assumed	2/1/1984		11/1/1984	INV_AGE
08 7035	1, 2			8/1/1965		8/1/1965	INV_AGE
09 1803	1, 2, 3	5/1/1985	Assumed	7/1/1985		7/1/1985	INV_AGE
	3						
10 0102	1, 2	7/6/1995	SPS1_UNBOUND_AGG_BASE	9/16/1995	SPS1_PMA_CONSTRUCTION	5/1/1996	SPS_ID
13 1005	1	4/1/1986	Assumed	6/1/1986		6/1/1986	INV_AGE
13 1031	1, 2	4/1/1981	Assumed	6/1/1981		6/1/1981	INV_AGE
13 3019	1	-----	Not needed for PCC sections	12/1/1981		12/1/1981	INV_AGE
16 1010	1	8/1/1969	Assumed	10/1/1969		10/1/1969	INV_AGE
18 3002	1	-----	Not needed for PCC sections	8/1/1976		8/1/1976	INV_AGE
20 4054	1	-----	Not needed for PCC sections	10/1/1985		11/1/1985	INV_AGE
22 0118	1	5/6/1996	SPS1_UNBOUND_AGG_BASE	6/20/1997	SPS1_PMA_PLACEMENT_DATA	7/1/1997	SPS_ID
23 1026	1, 2	-----	Not needed for Rehab sections	7/1/1973		8/1/1973	INV_AGE
24 1634	1, 2	4/1/1976	Assumed	6/1/1976		6/1/1976	INV_AGE
27 4040	1	-----	Not needed for PCC sections	10/1/1979		10/1/1979	INV_AGE
28 1016	1	9/1/1986	Assumed	11/1/1986		11/1/1986	INV_AGE
28 1802	1	4/1/1982	Assumed	6/1/1982		6/1/1982	INV_AGE
30 7066	1, 2	-----		9/1/1982		9/1/1982	INV_AGE
30 8129	1	4/1/1988	Assumed	6/1/1988		6/1/1988	INV_AGE
31 0114	1	5/1/1995	Assumed	7/1/1995		8/1/1995	SPS_ID
31 3018	1	-----		5/1/1985		7/1/1985	INV_AGE

Table 11 – Cont'd
Analysis Conditions II – LTPP Data

Section	Construction Number	Unbound Layers Preparation Completion Date	Source	Asphalt Construction Completion Date	Source	Traffic Opening Date	Source
32 0101	1	7/19/1995	SPS1_UNBOUND_AGG_BASE	8/1/1995		9/1/1995	SPS_ID
32 0204	1	6/28/1995	SPS2_UNBOUND_AGG_BASE	8/1/1995		9/1/1995	SPS_ID
33 1001	1	11/1/1980	Assumed	1/1/1981		9/1/1981	INV_AGE
35 0105	1	10/17/1995	SPS1_UNBOUND_AGG_BASE	11/1/1995		11/1/1995	SPS_ID
35 1112	1	4/1/1984	Assumed	6/1/1984		6/1/1984	INV_AGE
36 0801	1	8/9/1994	SPS8_UNBOUND_AGG_BASE	8/12/1994	SPS8_PMA_CONSTRUCTION	9/1/1994	SPS_ID
36 4018	1, 2, 3, 4, 5	-----		6/1/1974		8/1/1975	INV_AGE
	3						
	4						
	5						
37 0201	1	11/12/1993	SPS2_UNBOUND_AGG_BASE	7/1/1994		7/1/1994	SPS_ID
37 0205	1	7/1/1993	SPS2_SUBGRADE_PREP	9/3/1993	1	7/1/1994	SPS_ID
37 0208	1	6/24/1993	SPS2_SUBGRADE_PREP	9/3/1993	1	7/1/1994	SPS_ID
37 0212	1	6/29/1993	SPS2_SUBGRADE_PREP	9/3/1993	SPS2_PMA_CONSTRUCTION	7/1/1994	SPS_ID
37 1028	1	3/1/1982	Assumed	5/1/1982		5/1/1982	INV_AGE
39 0204	1	8/16/1995	SPS2_UNBOUND_AGG_BASE	9/1/1996		10/1/1996	SPS_ID
40 4165	1	4/1/1984	Assumed	6/1/1984		6/1/1984	INV_AGE
41 6011	1	4/1/1961	Assumed	6/1/1961		6/1/1961	INV_AGE
	2						
	3						
	4						
42 0603	1			1/1/1987		1/1/1987	EXPERIMENT_SECTION
	2						
42 1606	1	-----		9/1/1977		11/1/1977	INV_AGE
46 9187	1	3/1/1989	Assumed	5/1/1989		5/1/1989	INV_AGE
	2						
	3						

Table 11 – Cont'd
Analysis Conditions II – LTPP Data

Section	Construction Number	Unbound Layers Preparation Completion Date	Source	Asphalt Construction Completion Date	Source	Traffic Opening Date	Source
47 3101	1			1/1/1980		1/1/1980	INV_AGE
	2						
48 1060	1	1/1/1986		3/1/1986		3/1/1986	INV_AGE
48 1068	1	9/1/1985		11/1/1985		3/1/1987	INV_AGE
	2						
	3						
	4						
48 1077	1	11/1/1981	Assumed	1/1/1982		1/1/1982	INV_AGE
	2						
48 1122	1	12/1/1973	Assumed	2/1/1974		2/1/1974	INV_AGE
48 3739	1	3/1/1982		5/1/1982		5/1/1982	INV_AGE
	2						
	3						
48 4142	1	-----		9/1/1976		5/1/1977	INV_AGE
48 4143	1	-----		10/1/1970		12/1/1970	INV_AGE
49 1001	1	9/1/1980		11/1/1980		11/1/1980	INV_AGE
	2						
49 3011	1	-----		5/1/1986		5/1/1986	INV_AGE
50 1002	1	6/1/1984	Assumed	8/1/1984		11/1/1984	INV_AGE
50 1681	1	7/1/1963	Assumed	9/1/1963		11/1/1963	INV_AGE
	2						
	3						
51 0113	1	8/22/1995	SPS1_UNBOUND_AGG_BASE	9/26/1995	SPS1_PMA_CONSTRUCTION	7/1/1996	SPS_ID
51 0114	1	8/29/1995	SPS1_UNBOUND_AGG_BASE	11/28/1995	SPS1_PMA_PLACEMENT_DATA	7/1/1996	SPS_ID
53 1007	1			9/1/1983		10/1/1983	INV_AGE
ELIMINATED	2						
	3						
53 3813	1	-----		8/1/1966		9/1/1966	INV_AGE

Table 11 – Cont'd
Analysis Conditions II – LTPP Data

Section	Construction Number	Unbound Layers Preparation Completion Date	Source	Asphalt Construction Completion Date	Source	Traffic Opening Date	Source
53 7322	1			9/1/1973		9/1/1973	INV_AGE
	2						
	3						
56 1007	1	5/1/1980	Assumed	7/1/1980		7/1/1980	INV_AGE
	2						
56 2019	1			7/1/1985		7/1/1985	INV_AGE
	2						
	3						
56 2020	1			7/1/1985		7/1/1985	INV_AGE
83 1801	1	11/1/1983	Assumed	1/1/1984		1/1/1984	INV_AGE
83 3802	1	-----		9/1/1985		10/1/1985	INV_AGE
	2						
89 3015	1	-----		9/1/1984		9/1/1984	INV_AGE
	2						
	3						
	4						
ADOT1							
ADOT14							
Mnrd 4	1	8/10/1992	General Info (March 2002)	9/28/1992	Cell layers - General Info (March 2002)	7/15/1994	MnRoad Loading - ESALS
	2						
Mnrd 21	1	6/2/1992	General Info (March 2002)	7/29/1993	Cell layers - General Info (March 2002)	7/15/1994	MnRoad Loading - ESALS
	2						
Wstk 12	1	8/1/1995	Table 75 - NCHRP Report 455	10/1/1995	Table 75 - NCHRP Report 455	3/1/1996	Table 75 - NCHRP Report 455
Wstk 15	1	8/1/1995	Table 75 - NCHRP Report 455	10/1/1995	Table 75 - NCHRP Report 455	3/1/1996	Table 75 - NCHRP Report 455
Wstk 25	1	8/1/1995	Table 75 - NCHRP Report 455	10/1/1995	Table 75 - NCHRP Report 455	3/1/1996	Table 75 - NCHRP

Table 12
Analysis Conditions III – LTPP Data

Section	Construction Number	Date of Another Event	Event	Source
01 0101	1			
01 0102	1			
04 0113	1			
04 0114	1			
04 0215	1			
05 2042	1, 2	10/1/1993	Mill off AC and overlay with AC	EXPERIMENT_SECTION
06 3042	1			
08 1053	1			
08 7035	1, 2			
09 1803	1, 2, 3	1/18/1995	Cracks Sealed	MNT_ASPHALT_CRACK_SEAL
	3	7/25/1996	Cracks Sealed	MNT_ASPHALT_CRACK_SEAL
10 0102	1, 2	9/23/1996	AC Full Depth Patch; grinding surface	MNT_ASPHALT_PATCH; MNT_IMP
13 1005	1			
13 1031	1, 2	5/31/1997	Mill off AC and overlay with AC	EXPERIMENT_SECTION
13 3019	1			
16 1010	1			
18 3002	1			
20 4054	1			
22 0118	1			
23 1026	1, 2	9/27/1996	AC Overlay	RHB_PMA_CONSTRUCTION
24 1634	1, 2	6/3/1998	AC Overlay	RHB_PMA_CONSTRUCTION
27 4040	1			
28 1016	1			
28 1802	1			
30 7066	1, 2	9/13/1991	AC Overlay	RHB_PMA_CONSTRUCTION
30 8129	1			
31 0114	1			
31 3018	1			
32 0101	1			

Table 12 – Cont'd
Analysis Conditions III – LTPP Data

Section	Construction Number	Date of Another Event	Event	Source
32 0204	1			
33 1001	1			
35 0105	1			
35 1112	1			
36 0801	1			
36 4018	1, 2, 3, 4, 5	7/7/1993	AC shoulder restoration; Longitudinal subdrains	
	3	9/9/1993	Transverse joint sealing; Lane-shoulder long. Joint sealing	MNT_PCC_JOINT_RESEAL; MNT_IMP
	4	7/12/1994	Transverse joint sealing; Lane-shoulder long. Joint sealing	MNT_PCC_JOINT_RESEAL; MNT_IMP
	5	9/30/1999	Partial depth patching of PCC pavement other than at joint	MNT_PCC_PART_DEPTH; MNT_IMP
37 0201	1			
37 0205	1			
37 0208	1			
37 0212	1			
37 1028	1			
39 0204	1			
40 4165	1			
41 6011	1			
	2	6/9/1992	Mechanical premix patch	MNT_ASPHALT_PATCH
	3	7/29/1993	AC Overlay	RHB_PMA_CONSTRUCTION
	4	5/10/1996	Mill off AC and overlay with AC	EXPERIMENT_SECTION
42 0603	1			
	2	8/19/1992	Partial depth patching of PCC pavement other than at joint	MNT_IMP; SPS6_PCC_FULL_DEPTH; SPS6_PCC_PART_DEPTH
42 1606	1			
46 9187	1			
	2	6/19/1991	Cracks Sealing	MNT_ASPHALT_CRACK_SEAL
	3	8/6/1992	AC Surface Sealed - Aggregate seal coat	MNT_ASPHALT_SEAL
47 3101	1			
	2	9/1/1995	Mill off AC and overlay with AC	EXPERIMENT_SECTION

Table 12 – Cont'd
Analysis Conditions III – LTPP Data

Section	Construction Number	Date of Another Event	Event	Source
48 1060	1			
48 1068	1			
	2	10/15/1992	AC Surface Sealed - Fog seal coat	MNT_ASPHALT_SEAL
	3	8/15/1993	AC Surface Sealed - Tack coat	MNT_ASPHALT_SEAL
	4	7/28/1999	AC Surface Sealed - Aggregate seal coat	MNT_ASPHALT_SEAL
48 1077	1			
	2	11/17/1992	AC Surface Sealed - Fog seal coat	MNT_ASPHALT_SEAL
48 1122	1			
48 3739	1			
	2	9/26/1994	AC Surface Sealed - Aggregate seal coat	MNT_ASPHALT_SEAL
	3	2/7/1995	AC Surface Sealed - Fog seal coat	MNT_ASPHALT_SEAL
48 4142	1			
48 4143	1			
49 1001	1			
	2	9/4/1996	AC Surface Sealed - Aggregate seal coat	MNT_ASPHALT_SEAL
49 3011	1			
50 1002	1			
50 1681	1			
	2	9/9/1991	AC Overlay	RHB_PMA_CONSTRUCTION
	3	7/29/1999	Cracks Sealing	MNT_ASPHALT_CRACK_SEAL
51 0113	1			
51 0114	1			
53 1007	1			
ELIMINATED	2	6/25/1991	AC Overlay	RHB_PMA_CONSTRUCTION
	3	6/15/1995	AC Surface Sealed - Aggregate seal coat	MNT_ASPHALT_SEAL
53 3813	1			
53 7322	1			
	2	5/5/1998	Patch pot holes	MNT_ASPHALT_PATCH
	3	6/9/1999	AC Overlay	RHB_PMA_CONSTRUCTION

Table 12 – Cont'd
Analysis Conditions III – LTPP Data

Section	Construction Number	Date of Another Event	Event	Source
56 1007	1			
	2	4/2/1998	AC Surface Sealed - Aggregate seal coat	MNT_IMP
56 2019	1			
	2	9/26/1996	AC Overlay	RHB_PMA_CONSTRUCTION
	3	8/30/1997	AC Surface Sealed - Aggregate seal coat	MNT_ASPHALT_SEAL
56 2020	1			
83 1801	1			
83 3802	1			
	2	9/1/2000	AC Overlay	EXPERIMENT_SECTION
89 3015	1			
	2	9/3/1992	Partial depth patching of PCC pavement other than at joint	MNT_PCC_PART_DEPTH; MNT_IMP
	3	9/6/1994	Partial depth patching of PCC pavement other than at joint	MNT_PCC_PART_DEPTH; MNT_IMP
	4	7/21/1999	Crack sealing, partial depth patching of PCC pavements at joints	MNT_PCC_CRACK_SEAL; MNT_PCC_PART_DEPTH; MNT_IMP
ADOT1				
ADOT14				
Mnrd 4	1			
	2	4/24/2000	400 ft of sealant applied	MnRoad Sealing History
Mnrd 21	1			
	2	4/24/2000	450 ft of sealant applied	MnRoad Sealing History
Wstk 12	1	-	----------------	----------------
Wstk 15	1	-	----------------	----------------
Wstk 25	1			
		6/1/1997	Replaced by Section 55	NCHRP Report 455
		10/1/1997	Mill sections with rutting and roughness (25 mm) – wheelpaths.	NCHRP Report 455

Table 13
Analysis Conditions IV – LTPP Data

Section	Construction Number	TDR / Thermistor Installation Date	Source	TDR / Thermistor Last Reading	Source	Design Period (years)	Site Visited	Lab ID
01 0101	1	7/24/1995	SMP_GRAV_MOIST	11/17/1998	SMP_TDR_AUTO	10	X	1-3
01 0102	1	7/24/1995	Assumed	11/17/1998	Assumed	6		
04 0113	1	8/15/1995	SMP_GRAV_MOIST	11/17/1998	SMP_TDR_AUTO	6	X	2-3
04 0114	1	8/16/1995	SMP_GRAV_MOIST	5/20/1998	SMP_TDR_AUTO	5		
04 0215	1	8/24/1995	SMP_LAYOUT_INFO	11/20/1998	SMP_TDR_AUTO	6	X	4-1
05 2042	1, 2	----------------	----	12/1/2001	Field Visit	30	X	1-5
06 3042	1	7/12/1995	SMP_GRAV_MOIST	11/24/1998	SMP_TDR_AUTO	23	X	
08 1053	1	7/1/1993	SMP_GRAV_MOIST	9/26/1997	SMP_TDR_AUTO	14	X	
08 7035	1, 2	----------------	----------------	----------------	----------------	37	X	
09 1803	1, 2, 3	7/24/1996	SMP_GRAV_MOIST	10/16/1997	SMP_TDR_AUTO	17	X	
	3					----		
10 0102	1, 2	10/4/1995	SMP_GRAV_MOIST	1/27/2000	SMP_TDR_AUTO	5		
13 1005	1	8/7/1995	SMP_GRAV_MOIST	11/18/1998	SMP_TDR_AUTO	13		
13 1031	1, 2	8/2/1995	SMP_GRAV_MOIST	8/7/2000	SMP_TDR_AUTO	20		
13 3019	1	7/31/1995	SMP_LAYOUT_INFO	8/8/2000	SMP_TDR_AUTO	20		
16 1010	1	9/30/1993	SMP_GRAV_MOIST	6/26/1997	SMP_TDR_AUTO	28		
18 3002	1	9/7/1995	SMP_GRAV_MOIST	9/28/1998	SMP_TDR_AUTO	23		
20 4054	1	8/24/1995	SMP_GRAV_MOIST	11/19/1998	SMP_TDR_AUTO	15	X	
22 0118	1	----------------	----------------	12/1/2001	Field Visit	6	X	3-1
23 1026	1, 2	9/15/1993	SMP_GRAV_MOIST	10/21/1997	SMP_TDR_AUTO	25		
24 1634	1, 2	5/11/1995	SMP_GRAV_MOIST	4/8/1998	SMP_TDR_AUTO	25		
27 4040	1	9/21/1993	SMP_GRAV_MOIST	9/9/1997	SMP_TDR_AUTO	20		
28 1016	1	10/19/1996	SMP_GRAV_MOIST	10/19/1996	SMP_TDR_AUTO	11		
28 1802	1	7/20/1995	SMP_GRAV_MOIST	11/13/1998	SMP_TDR_AUTO	20	X	1-4
30 7066	1, 2	----------------	----------------	----------------	----------------	20	X	
30 8129	1	8/12/1992	SMP_GRAV_MOIST	10/1/1997	SMP_TDR_AUTO	10		
31 0114	1	8/7/1995	SMP_GRAV_MOIST	10/27/2000	SMP_TDR_AUTO	7	X	
31 3018	1	8/10/1995	SMP_GRAV_MOIST	2/7/2001	SMP_TDR_AUTO	16		
32 0101	1	10/8/1996	SMP_GRAV_MOIST	3/15/2001	SMP_TDR_AUTO	8		

Table 13 – Cont'd
Analysis Conditions IV – LTPP Data

Section	Construction Number	TDR / Thermistor Installation Date	Source	TDR / Thermistor Last Reading	Source	Design Period (years)	Site Visited	Lab ID
32 0204	1	10/9/1996	SMP_GRAV_MOIST	9/9/1997	SMP_TDR_AUTO	8	X	
33 1001	1	10/14/1993	SMP_GRAV_MOIST	10/22/1997	SMP_TDR_AUTO	22		
35 0105	1	----------------	----------------	12/1/2001	Field Visit	7	X	1-1
35 1112	1	4/5/1994	SMP_GRAV_MOIST	7/12/2000	SMP_TDR_AUTO	20		
36 0801	1	8/22/1995	SMP_GRAV_MOIST	1/31/2001	SMP_TDR_AUTO	10		
36 4018	1, 2, 3, 4, 5	10/27/1993	SMP_GRAV_MOIST	10/14/1997	SMP_TDR_AUTO	30	X	
	3					----		
	4					----		
	5					----		
37 0201	1	10/18/1993	SMP_GRAV_MOIST	10/15/1998	SMP_TDR_AUTO	10		
37 0205	1	10/18/1993	SMP_GRAV_MOIST	9/24/1998	SMP_TDR_AUTO	10	X	
37 0208	1	10/17/1993	SMP_GRAV_MOIST	9/24/1998	SMP_TDR_AUTO	10		
37 0212	1	10/17/1993	SMP_GRAV_MOIST	9/24/1998	SMP_TDR_AUTO	10		
37 1028	1	5/17/1995	SMP_GRAV_MOIST	10/20/1998	SMP_TDR_AUTO	22		
39 0204	1	7/20/1995	SMP_GRAV_MOIST	10/14/1999	SMP_TDR_AUTO	4		
40 4165	1	3/29/1994	SMP_GRAV_MOIST	9/11/1997	SMP_TDR_AUTO	20		
41 6011	1	----------------	----------------	12/1/2001	Field Visit	41	X	2-2
	2					----		
	3					----		
	4					----		
42 0603	1	----------------	----------------	----------------	----------------	15	X	
	2					----		
42 1606	1	8/9/1995	SMP_GRAV_MOIST	9/14/2000	SMP_TDR_AUTO	26		
46 9187	1	7/18/1994	SMP_GRAV_MOIST	9/23/1997	SMP_TDR_AUTO	14		
	2					----		
	3					----		
47 3101	1	----------------	----------------	----------------	----------------	22	X	
	2					----		
48 1060	1	11/30/1993	SMP_GRAV_MOIST	9/30/1997	SMP_TDR_AUTO	17	X	3-3

Table 13 – Cont'd
Analysis Conditions IV – LTPP Data

Section	Construction Number	TDR / Thermistor Installation Date	Source	TDR / Thermistor Last Reading	Source	Design Period (years)	Site Visited	Lab ID
48 1068	1	7/27/1999	SMP_GRAV_MOIST	12/17/1999	SMP_TDR_AUTO	18		
	2					----		
	3					----		
	4					----		
48 1077	1	10/25/1993	SMP_GRAV_MOIST	9/16/1997	SMP_TDR_AUTO	20	X	1-2
	2					----		
48 1122	1	11/22/1993	SMP_GRAV_MOIST	9/29/1997	SMP_TDR_AUTO	30		
48 3739	1	12/6/1993	SMP_GRAV_MOIST	7/18/2000	SMP_TDR_AUTO	20		
	2					----		
	3					----		
48 4142	1	11/8/1993	SMP_GRAV_MOIST	9/26/1997	SMP_TDR_AUTO	26		
48 4143	1	11/17/1993	SMP_GRAV_MOIST	9/25/1997	SMP_TDR_AUTO	32	X	3-2
49 1001	1	8/5/1993	SMP_GRAV_MOIST	9/24/1997	SMP_TDR_AUTO	22		
	2					----		
49 3011	1	8/3/1993	SMP_GRAV_MOIST	9/22/1997	SMP_TDR_AUTO	18		
50 1002	1	10/6/1993	SMP_GRAV_MOIST	1/31/2001	SMP_TDR_AUTO	18		
50 1681	1	----------------	----------------	----------------	----------------	39	X	
	2					----		
	3					----		
51 0113	1	10/23/1995	SMP_GRAV_MOIST	10/14/1998	SMP_TDR_AUTO	8		
51 0114	1	10/23/1995	SMP_GRAV_MOIST	10/13/1998	SMP_TDR_AUTO	8		
53 1007	1	----------------	----------------	----------------	----------------			
ELIMINATED	2							
	3							
53 3813	1	7/18/1995	SMP_GRAV_MOIST	12/9/1998	SMP_TDR_AUTO	36		
53 7322	1	----------------	----------------	----------------	----------------	29	X	
	2					----		
	3					----		

Table 13 – Cont'd
Analysis Conditions IV – LTPP Data

Section	Construction Number	TDR / Thermistor Installation Date	Source	TDR / Thermistor Last Reading	Source	Design Period (years)	Site Visited	Lab ID
56 1007	1	8/10/1993	SMP_GRAV_MOIST	9/30/1997	SMP_TDR_AUTO	22		
	2					----		
56 2019	1	----------------	----------------	----------------	----------------	17	X	
	2					----		
	3					----		
56 2020	1	----------------	----------------	----------------	----------------	17	X	
83 1801	1	10/12/1993	SMP_GRAV_MOIST	3/14/2001	SMP_TDR_AUTO	20		
83 3802	1	10/14/1993	SMP_GRAV_MOIST	9/15/1997	SMP_TDR_AUTO	18		
	2					----		
89 3015	1	9/29/1993	SMP_GRAV_MOIST	4/27/2000	SMP_TDR_AUTO	19		
	2					----		
	3					----		
	4					----		
ADOT1								
ADOT14								
Mnrd 4	1	9/26/1994 - 1/1/1993	TDR_Cell4	2/26/1998 - 5/13/2002	TDR_Cell4	10	X	
	2							
Mnrd 21	1	7/15/1993 - 3/28/1994	TDR_Cell21	2/26/1998 - 5/13/2002	TDR_Cell21	10		
	2							
Wstk 12	1	10/28/1996	Ed Harrigan - WesTrack Database	4/15/1998	Ed Harrigan - WesTrack Database	10	X	2-1
Wstk 15	1	----------------	----------------	----------------	----------------	10	X	2-1
Wstk 25	1	10/28/1996	Ed Harrigan - WesTrack Database	4/15/1998	Ed Harrigan - WesTrack Database	10		

Table 14
Pavement Lane Properties – LTPP Data

Section	State Code	SHRP ID	Pavement Type	Lane Width (ft)	Pavement Slope[1] (%)	Initial IRI[2] (in/mile)	Thermal Conductivity[3] (BTU/hr-ft-oF)	Heat Capacity[4] (BTU/lb-oF)	Surface Short Wave Absorptivity
01 0101	1	0101	AC	12	1.5	63	0.67	0.22	0.85
01 0102	1	0102	AC	12	1.5	63	0.67	0.22	0.85
04 0113	4	0113	AC	12	1.5	63	0.67	0.22	0.85
04 0114	4	0114	AC	12	1.5	63	0.67	0.22	0.85
04 0215	4	0215	PCC	12	1.5	63	0.57	0.15	0.8
05 2042	5	2042	CTB				0.57	0.15	0.8
			AC	12	1.5	63	0.67	0.22	0.85
06 3042	6	3042	CTB				0.57	0.15	0.8
			PCC	12	1.5	63	0.57	0.15	0.8
08 1053	8	1053	AC	12	1.5	63	0.67	0.22	0.85
08 7035	8	7035	PCC	12	1.5	63	0.57	0.15	0.8
09 1803	9	1803	AC	11	1.5	63	0.67	0.22	0.85
10 0102	10	0102	AC	12	1.5	63	0.67	0.22	0.85
13 1005	13	1005	AC	12	1.5	63	0.67	0.22	0.85
13 1031	13	1031	AC	12	1.5	63	0.67	0.22	0.85
13 3019	13	3019	PCC	12	1.5	63	0.57	0.15	0.8
16 1010	16	1010	AC	15	1.5	63	0.67	0.23	0.85
18 3002	18	3002	PCC	12	1.5	63	1.25	0.28	0.85
20 4054	20	4054	PCC	12	1.5	63	1.25	0.28	0.85
22 0118	22	0118	AC	12	1.5	63	0.67	0.23	0.85
23 1026	23	1026	AC	12	1.5	63	0.67	0.23	0.85
24 1634	24	1634	AC	12	1.5	63	0.67	0.23	0.85
27 4040	27	4040	PCC	12	1.5	63	1.25	0.28	0.85
28 1016	28	1016	AC	12	1.5	63	0.67	0.23	0.85
28 1802	28	1802	AC	12	1.5	63	0.67	0.23	0.85
30 7066	30	7066	AC	12	1.5	63	0.67	0.23	0.85
30 8129	30	8129	AC	12	1.5	63	0.67	0.23	0.85
31 0114	31	0114	AC	12	1.5	63	0.67	0.23	0.85
31 3018	31	3018	PCC	12	1.5	63	1.25	0.28	0.85

Table 14 – Cont'd
Pavement Lane Properties – LTPP Data

Section	State Code	SHRP ID	Pavement Type	Lane Width (ft)	Pavement Slope[1] (%)	Initial IRI[2] (in/mile)	Thermal Conductivity[3] (BTU/hr-ft-oF)	Heat Capacity[4] (BTU/lb-oF)	Surface Short Wave Absorptivity
32 0101	32	0101	AC	12	1.5	63	0.67	0.23	0.85
32 0204	32	0204	PCC	12	1.5	63	1.25	0.28	0.85
33 1001	33	1001	AC	12	1.5	63	0.67	0.23	0.85
35 0105	35	0105	AC	12	1.5	63	0.67	0.23	0.85
35 1112	35	1112	AC	12	1.5	63	0.67	0.23	0.85
36 0801	36	0801	AC	12	1.5	63	0.67	0.23	0.85
36 4018	36	4018	PCC	12	1.5	63	1.25	0.28	0.85
37 0201	37	0201	PCC	12	1.5	63	1.25	0.28	0.85
37 0205	37	0205	PCC	12	1.5	63	1.25	0.28	0.85
37 0208	37	0208	PCC	12	1.5	63	1.25	0.28	0.85
37 0212	37	0212	PCC	12	1.5	63	1.25	0.28	0.85
37 1028	37	1028	AC	12	1.5	63	0.67	0.23	0.85
39 0204	39	0204	PCC	12	1.5	63	1.25	0.28	0.85
40 4165	40	4165	AC	12	1.5	63	0.67	0.23	0.85
41 6011	41	6011	AC	12	1.5	63	0.67	0.23	0.85
42 0603	42	0603	AC	12	1.5	63	0.67	0.23	0.85
42 1606	42	1606	PCC	12	1.5	63	1.25	0.28	0.85
46 9187	46	9187	AC	12	1.5	63	0.67	0.23	0.85
47 3101	47	3101	AC	12	1.5	63	0.67	0.23	0.85
48 1060	48	1060	AC	12	1.5	63	0.67	0.23	0.85
48 1068	48	1068	AC	12	1.5	63	0.67	0.23	0.85
48 1077	48	1077	AC	12	1.5	63	0.67	0.23	0.85
48 1122	48	1122	AC	12	1.5	63	0.67	0.23	0.85
48 3739	48	3739	AC	12	1.5	63	0.67	0.23	0.85
48 4142	48	4142	PCC	12	1.5	63	1.25	0.28	0.85
48 4143	48	4143	PCC	12	1.5	63	1.25	0.28	0.85
49 1001	49	1001	AC	12	1.5	63	0.67	0.23	0.85
49 3011	49	3011	PCC	12	1.5	63	1.25	0.28	0.85
50 1002	50	1002	AC	12	1.5	63	0.67	0.23	0.85
50 1681	50	1681	AC	12	1.5	63	0.67	0.23	0.85

Table 14 – Cont'd
Pavement Lane Properties – LTPP Data

Section	State Code	SHRP ID	Pavement Type	Lane Width (ft)	Pavement Slope1 (%)	Initial IRI2 (in/mile)	Thermal Conductivity3 (BTU/hr-ft-oF)	Heat Capacity4 (BTU/lb-oF)	Surface Short Wave Absorptivity
51 0113	51	0113	AC	12	1.5	63	0.67	0.23	0.85
51 0114	51	0114	AC	12	1.5	63	0.67	0.23	0.85
53 1007	53	1007	AC	12	1.5	63	0.67	0.23	0.85
53 3813	53	3813	PCC	12	1.5	63	1.25	0.28	0.85
53 7322	53	7322	AC	12	1.5	63	0.67	0.23	0.85
56 1007	56	1007	AC	12	1.5	63	0.67	0.23	0.85
56 2019	56	2019	AC	12	1.5	63	0.67	0.23	0.85
56 2020	56	2020	AC	12	1.5	63	0.67	0.23	0.85
83 1801	83	1801	AC	12	1.5	63	0.67	0.23	0.85
83 3802	83	3802	PCC	12	1.5	63	1.25	0.28	0.85
89 3015	89	3015	PCC	12	1.5	63	1.25	0.28	0.85
ADOT1	ADOT1		AC			63	0.67	0.23	0.85
ADOT14	ADOT14		AC			63	0.67	0.23	0.85
Mnrd 4	---	---	AC	12	1.5	63	0.67	0.23	0.85
Mnrd 21	---	---	AC	12	1.5	63	0.67	0.23	0.85
Wstk 12	---	---	AC	12	2	63	0.67	0.23	0.85
Wstk 15	---	---	AC	12	2	63	0.67	0.23	0.85
Wstk 25	---	---	AC	12	2	63	0.67	0.23	0.85

Notes
[1] Assumed
[2] IRI: International Roughness Index
[3] Assumed a value of 0.67 for AC and 0.57 for PCC
[4] Assumed a value of 0.22 for AC and 0.15 for PCC

Table 15
Environmental/Climatic – LTPP Data

Section	Latitude (degrees)	Latitude (minutes)	Longitude (degrees)	Longitude (minutes)	Elevation (ft)	Groundwater Table Depth[1] (ft)	Source of Information
01 0101	32	36	85	15	151	25.50	water.usgs.gov/nwis/gwlevels
01 0102	32	36	85	15	151	25.50	water.usgs.gov/nwis/gwlevels
04 0113	35	23	114	15	3580	52.00	water.usgs.gov/nwis/gwlevels
04 0114	35	23	114	15	3580	52.00	water.usgs.gov/nwis/gwlevels
04 0215	33	27	112	44	1100	86	water.usgs.gov/nwis/gwlevels
05 2042	33	8	91	50	140	2.0	Harold Von Quintus Report
06 3042	38	14	121	26	11	9.5	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
08 1053	38	41	108	1	5140	7.8	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
08 7035	39	44	104	44	5500	30.0	water.usgs.gov/nwis/gwlevels
09 1803	41	23	72	1	165	6.4	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
10 0102	38	47	75	26	47	7.5	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
13 1005	32	36	83	42	452	5.9	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
13 1031	34	24	84	0	120	6.4	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
13 3019	34	22	83	43	1042	3.1	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
16 1010	43	40	112	7	4775	11.5	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
18 3002	40	35	87	22	831	6.8	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
20 4054	38	58	97	5	1190	12.5	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
22 0118	30	20	93	11	27	12.3	Harold Von Quintus Report
23 1026	44	34	70	17	486	6.9	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
24 1634	38	22	75	15	39	7.6	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
27 4040	47	18	93	43	1305	5.8	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
28 1016	33	3	89	34	399	15.6	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
28 1802	31	42	89	25	264	8.5	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
30 7066	45	48	110	0	4072	70	water.usgs.gov/nwis/gwlevels
30 8129	46	18	109	8	4440	9.8	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
31 0114	40	4	97	37	1611	13.6	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
31 3018	40	40	99	2	2134	11.4	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
32 0101	40	41	117	0	4550	15.0	LTPP Boring Log
32 0204	40	43	117	2	4550	62.0	water.usgs.gov/nwis/gwlevels
33 1001	43	13	71	30	252	13.1	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN

Table 15 – Cont'd
Environmental/Climatic – LTPP Data

Section	Latitude (degrees)	Latitude (minutes)	Longitude (degrees)	Longitude (minutes)	Elevation (ft)	Groundwater Table Depth[1] (ft)	Source of Information
35 0105	32	40	107	4	4117	11.16	water.usgs.gov/nwis/gwlevels
35 1112	32	37	103	31	3760	>20	Harold Von Quintus Report
36 0801	43	21	77	55	250	5.1	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
36 4018	42	22	75	11	1070	12.6	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
37 0201	35	52	80	15	741	40.0	water.usgs.gov/nwis/gwlevels
37 0205	35	52	80	15	741	40.0	water.usgs.gov/nwis/gwlevels
37 0208	35	52	80	15	741	40.0	water.usgs.gov/nwis/gwlevels
37 0212	35	52	80	15	741	40.0	water.usgs.gov/nwis/gwlevels
37 1028	36	31	76	21	20	7.9	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
39 0204	40	23	83	3	955	7.9	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
40 4165	36	23	98	17	1319	8.1	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
41 6011	44	17	123	3	323	5.0	water.usgs.gov/nwis/gwlevels
42 0603	40	58	77	47	1360	20.0	water.usgs.gov/nwis/gwlevels
42 1606	40	13	78	28	1400	78.0	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
46 9187	44	46	102	3	2360	76.1	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
47 3101	35	56	86	7	770	5.5	water.usgs.gov/nwis/gwlevels
48 1060	28	30	97	3	78	>11	Harold Von Quintus Report
48 1068	33	30	95	35	445	12.0	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
48 1077	34	32	100	26	1835	10.9	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
48 1122	29	14	98	15	470	50	water.usgs.gov/nwis/gwlevels
48 3739	26	59	97	47	36	10.8	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
48 4142	31	1	93	58	363	13.1	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
48 4143	30	2	94	22	42	9.6	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
49 1001	37	16	109	35	4384	14.6	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
49 3011	39	40	111	51	5105	14.8	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
50 1002	44	7	73	10	283	4.2	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
50 1681	44	18	73	14	255	10.0	water.usgs.gov/nwis/gwlevels
51 0113	36	39	79	21	643	49.0	water.usgs.gov/nwis/gwlevels
51 0114	36	39	79	21	643	49.0	water.usgs.gov/nwis/gwlevels
53 1007	46	2	119	36	903		

Table 15 – Cont'd
Environmental/Climatic – LTPP Data

Section	Latitude (degrees)	Latitude (minutes)	Longitude (degrees)	Longitude (minutes)	Elevation (ft)	Groundwater Table Depth[1] (ft)	Source of Information
53 3813	45	34	122	27	440	13.4	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
53 7322	46	43	117	13	2545	25.0	water.usgs.gov/nwis/gwlevels
56 1007	44	30	108	55	5204	4.1	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
56 2019	44	9	105	26	4577	58.0	water.usgs.gov/nwis/gwlevels
56 2020	44	56	107	11	4022	250.0	water.usgs.gov/nwis/gwlevels
83 1801	49	46	100	32	1400	8.4	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
83 3802	49	37	97	8	773	7.5	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
89 3015	46	28	72	21	104	7.4	LTPP Dbase: SMP_WATERTAB_DEPTH_MAN
ADOT1							
ADOT14							
Mnrd 4	45	3	93	17	944.22	5.3	Water_table_elevations_cel 4_ and_21
Mnrd 21	45	3	93	17	966.95	11.5	Water_table_elevations_cel 4_ and_21
Wstk 12	39	25	119	13	4100	10.8	Ed Harrigan - Nichols Database
Wstk 15	39	25	119	13	4100	10.7	NCHRP Report 455, Figure 23
Wstk 25	39	25	119	13	4100	11.2	Ed Harrigan - Nichols Database

[1] Average from pavement surface to be used in Level 3 analysis

Table 16
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
1	**0101**	1	1	SS	Subgrade	
1	**0101**	1	2	GB	Base Layer	7.9
1	**0101**	1	3	AC	AC Layer Below Surface - Binder Course	6.2
1	**0101**	1	4	AC	Original Surface Layer	1.3
1	**0102**	1	1	SS	Subgrade	
1	**0102**	1	2	GB	Base Layer	11.9
1	**0102**	1	3	AC	AC Layer Below Surface - Binder Course	2.9
1	**0102**	1	4	AC	Original Surface Layer	1.3
4	**0113**	1	1	SS	Subgrade	600
4	**0113**	1	2	GB	Base Layer	7.5
4	**0113**	1	3	AC	Original Surface Layer	4.5
4	**0114**	1	1	SS	Subgrade	600
4	**0114**	1	2	GB	Base Layer	12
4	**0114**	1	3	AC	Original Surface Layer	6.8
4	**0215**	1	1	SS	Subgrade	
4	**0215**	1	2	GB	Base Layer	6.1
4	**0215**	1	3	PC	Original Surface Layer	11.3
5	**2042**	1	1	SS	Subgrade	100
5	**2042**	1	2	CTB	Base Layer	6.6
5	**2042**	1	3	AC	AC Layer Below Surface - Binder Course	3.2
5	**2042**	1	4	AC	Original Surface Layer	2
5	**2042**	2	1	SS	Subgrade	100
5	**2042**	2	2	CTB	Base Layer	6.6
5	**2042**	2	3	AC	AC Layer Below Surface - Binder Course	3.2
5	**2042**	2	4	AC	Original Surface Layer	2
6	**3042**	1	1	SS	Subgrade	
6	**3042**	1	2	GS	Subbase Layer	5.8
6	**3042**	1	3	CTB	Base Layer	4.5
6	**3042**	1	4	PC	Original Surface Layer	8.8

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
8	**1053**	1	1	SS	Subgrade	
8	**1053**	1	2	GS	Subbase Layer	23.5
8	**1053**	1	3	GB	Base Layer	5.4
8	**1053**	1	4	AC	Original Surface Layer	4.6
8	**7035**	1	1	SS	Subgrade	
8	**7035**	1	2	GS	Subbase Layer	8.3
8	**7035**	1	3	GB	Base Layer	3.3
8	**7035**	1	4	PC	Original Surface Layer	8.4
8	**7035**	1	5	AC	Overlay	4.8
8	**7035**	2	1	SS	Subgrade	
8	**7035**	2	2	GS	Subbase Layer	8.3
8	**7035**	2	3	GB	Base Layer	3.3
8	**7035**	2	4	PC	Original Surface Layer	8.4
8	**7035**	2	5	AC	Overlay	3.5
8	**7035**	2	6	AC	Overlay	1.5
9	**1803**	1	1	SS	Subgrade	5
9	**1803**	1	2	GB	Base Layer	12
9	**1803**	1	3	AC	AC Layer Below Surface - Binder Course	4.3
9	**1803**	1	4	AC	Original Surface Layer	3.1
9	**1803**	2	1	SS	Subgrade	5
9	**1803**	2	2	GB	Base Layer	12
9	**1803**	2	3	AC	AC Layer Below Surface - Binder Course	4.3
9	**1803**	2	4	AC	Original Surface Layer	3.1
9	**1803**	3	1	SS	Subgrade	**65**
9	**1803**	3	2	GB	Base Layer	12
9	**1803**	3	3	AC	AC Layer Below Surface - Binder Course	4.1
9	**1803**	3	4	AC	Original Surface Layer	3

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
10	**0102**	1	1	SS	Subgrade	
10	**0102**	1	2	GS	Subbase Layer	39
10	**0102**	1	3	GB	Base Layer	11.8
10	**0102**	1	4	AC	AC Layer Below Surface - Binder Course	2.7
10	**0102**	1	5	AC	Original Surface Layer	1.4
10	**0102**	1	6	AC	Friction Course	1
10	**0102**	2	1	SS	Subgrade	
10	**0102**	2	2	GS	Subbase Layer	39
10	**0102**	2	3	GB	Base Layer	11.8
10	**0102**	2	4	AC	AC Layer Below Surface - Binder Course	2.7
10	**0102**	2	5	AC	Original Surface Layer	1.4
10	**0102**	2	6	AC	Friction Course	1
13	**1005**	1	1	SS	Subgrade	
13	**1005**	1	2	GB	Base Layer	9.1
13	**1005**	1	3	AC	AC Layer Below Surface - Binder Course	4
13	**1005**	1	4	AC	AC Layer Below Surface - Binder Course	2.2
13	**1005**	1	5	AC	Original Surface Layer	1.5
13	**1031**	1	1	SS	Subgrade	600
13	**1031**	1	2	GB	Base Layer	8.8
13	**1031**	1	3	AC	AC Layer Below Surface - Binder Course	8.1
13	**1031**	1	4	AC	Original Surface Layer	2.4
13	**1031**	1	5	AC	Friction Course	0.6
13	**1031**	2	1	SS	Subgrade	600
13	**1031**	2	2	GB	Base Layer	8.8
13	**1031**	2	3	AC	AC Layer Below Surface - Binder Course	8.3
13	**1031**	2	4	AC	Original Surface Layer	2.4
13	**1031**	2	5	AC	Friction Course	0
13	**1031**	2	6	AC	Overlay	0.8
13	**3019**	1	1	SS	Subgrade	
13	**3019**	1	2	GB	Base Layer	7.2
13	**3019**	1	3	PC	Original Surface Layer	9.1

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
16	**1010**	1	1	SS	Subgrade	
16	**1010**	1	2	GB	Base Layer	5.4
16	**1010**	1	3	AC	AC Layer Below Surface - Binder Course	5.7
16	**1010**	1	4	AC	Original Surface Layer	5
16	**1010**	1	5	AC	Seal Coat	0.2
18	**3002**	1	1	SS	Subgrade	
18	**3002**	1	2	GB	Base Layer	5.5
18	**3002**	1	3	PC	Original Surface Layer	9.5
20	**4054**	1	1	SS	Subgrade	
20	**4054**	1	2	CTB	Base Layer	3.4
20	**4054**	1	3	PC	Original Surface Layer	9.5
22	**0118**	1	1	SS	Subgrade	
22	**0118**	1	2	GS	Subbase Layer	18
22	**0118**	1	3	GB	Base Layer	4.1
22	**0118**	1	4	ATB	Base Layer	7
22	**0118**	1	5	AC	AC Layer Below Surface - Binder Course	2.7
22	**0118**	1	6	AC	Original Surface Layer	1.7
23	**1026**	1	1	SS	Subgrade	42
23	**1026**	1	2	GB	Base Layer	17.6
23	**1026**	1	3	AC	AC Layer Below Surface - Binder Course	5.4
23	**1026**	1	4	AC	Original Surface Layer	1
23	**1026**	2	1	SS	Subgrade	42
23	**1026**	2	2	GB	Base Layer	17.6
23	**1026**	2	3	AC	AC Layer Below Surface - Binder Course	6.2
23	**1026**	2	4	AC	Original Surface Layer	1.2
23	**1026**	2	5	AC	Embankment Layer	1
23	**1026**	2	6	AC	Overlay	1.6

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
24	**1634**	1	1	SS	Subgrade	
24	**1634**	1	2	GS	Subbase Layer	13
24	**1634**	1	3	ATB	Base Layer	4.8
24	**1634**	1	4	AC	Original Surface Layer	3.6
24	**1634**	2	1	SS	Subgrade	
24	**1634**	2	2	GS	Subbase Layer	13
24	**1634**	2	3	ATB	Base Layer	4.8
24	**1634**	2	4	AC	Original Surface Layer	3.6
24	**1634**	2	5	AC	Overlay	1.7
24	**1634**	2	6	AC	Overlay	1.5
27	**4040**	1	1	SS	Subgrade	
27	**4040**	1	2	GB	Base Layer	6
27	**4040**	1	3	PC	Original Surface Layer	8.1
28	**1016**	1	1	SS	Subgrade	
28	**1016**	1	2	GS	Subbase Layer	19.5
28	**1016**	1	3	ATB	Base Layer	5.7
28	**1016**	1	4	AC	AC Layer Below Surface - Binder Course	1.4
28	**1016**	1	5	AC	Original Surface Layer	0.8
28	**1802**	1	1	SS	Subgrade	
28	**1802**	1	2	GS	Subbase Layer	2
28	**1802**	1	3	ATB	Base Layer	4.7
28	**1802**	1	4	AC	AC Layer Below Surface - Binder Course	1.9
28	**1802**	1	5	AC	Original Surface Layer	1.3
30	**7066**	1	1	SS	Subgrade	

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
30	**7066**	1	2	GS	Subbase Layer	15.9
30	**7066**	1	3	GB	Base Layer	3
30	**7066**	1	4	AC	Original Surface Layer	4.9
30	**7066**	1	5	AC	Friction Course	0.5
30	**7066**	2	1	SS	Subgrade	
30	**7066**	2	2	GS	Subbase Layer	15.9
30	**7066**	2	3	GB	Base Layer	3
30	**7066**	2	4	AC	Original Surface Layer	4.9
30	**7066**	2	5	AC	Friction Course	0
30	**7066**	2	6	AC	Overlay	1.7
30	**8129**	1	1	SS	Subgrade	7.6
30	**8129**	1	2	GB	Base Layer	22.8
30	**8129**	1	3	AC	Original Surface Layer	3
30	**8129**	1	4	AC	Seal Coat	0.2
31	**0114**	1	1	SS	Subgrade	600
31	**0114**	1	2	GS	Embankment Layer	24
31	**0114**	1	3	GB	Base Layer	12
31	**0114**	1	4	AC	Original Surface Layer	6.7
31	**3018**	1	1	SS	Subgrade	
31	**3018**	1	2	CTB	Base Layer	5.6
31	**3018**	1	3	PC	Original Surface Layer	11.9
32	**0101**	1	1	SS	Subgrade	
32	**0101**	1	2	TS	Subbase Layer	12
32	**0101**	1	3	GS	Subbase Layer	22.8
32	**0101**	1	4	GB	Base Layer	8.5
32	**0101**	1	5	AC	Original Surface Layer	7.2
32	**0204**	1	1	SS	Subgrade	
32	**0204**	1	2	TS	Subbase Layer	12
32	**0204**	1	3	GS	Subbase Layer	20.5
32	**0204**	1	4	GB	Base Layer	6.2
32	**0204**	1	5	PC	Original Surface Layer	11.8

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
33	**1001**	1	1	SS	Subgrade	41.9
33	**1001**	1	2	GS	Subbase Layer	14.4
33	**1001**	1	3	GB	Base Layer	19.3
33	**1001**	1	4	AC	AC Layer Below Surface - Binder Course	7.2
33	**1001**	1	5	AC	Original Surface Layer	1.2
35	**0105**	1	1	SS	Subgrade	
35	**0105**	1	2	GB	Base Layer	3.7
35	**0105**	1	3	ATB	Base Layer	4
35	**0105**	1	4	AC	Original Surface Layer	5.3
35	**0105**	1	5	AC	Friction Course	0.6
35	**1112**	1	1	SS	Subgrade	
35	**1112**	1	2	GB	Base Layer	6
35	**1112**	1	3	AC	Original Surface Layer	5.5
35	**1112**	1	4	AC	Friction Course	0.8
36	**0801**	1	1	SS	Subgrade	168
36	**0801**	1	2	GB	Base Layer	8.4
36	**0801**	1	3	AC	AC Layer Below Surface - Binder Course	3.6
36	**0801**	1	4	AC	Original Surface Layer	1.3
36	**4018**	1	1	SS	Subgrade	80.6
36	**4018**	1	2	PC	Original Surface Layer	9.4
36	**4018**	2	1	SS	Subgrade	80.6
36	**4018**	2	2	PC	Original Surface Layer	9.4
36	**4018**	3	1	SS	Subgrade	80.6
36	**4018**	3	2	PC	Original Surface Layer	9.4
36	**4018**	4	1	SS	Subgrade	80.6
36	**4018**	4	2	PC	Original Surface Layer	9.4
36	**4018**	5	1	SS	Subgrade	80.6
36	**4018**	5	2	PC	Original Surface Layer	9.4

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
37	**0201**	1	1	SS	Subgrade	
37	**0201**	1	2	LTS	Subbase Layer	8
37	**0201**	1	3	GB	Base Layer	9.3
37	**0201**	1	4	PC	Original Surface Layer	9
37	**0205**	1	1	SS	Subgrade	
37	**0205**	1	2	LTS	Subbase Layer	8
37	**0205**	1	3	CTB	Base Layer	6.5
37	**0205**	1	4	PC	Original Surface Layer	8
37	**0208**	1	1	SS	Subgrade	
37	**0208**	1	2	LTS	Subbase Layer	8
37	**0208**	1	3	CTB	Base Layer	5.9
37	**0208**	1	4	PC	Original Surface Layer	11.2
37	**0212**	1	1	SS	Subgrade	
37	**0212**	1	2	LTS	Subbase Layer	8
37	**0212**	1	3	GB	Base Layer	3.8
37	**0212**	1	4	ATB	Base Layer	4.3
37	**0212**	1	5	PC	Original Surface Layer	10.9
37	**1028**	1	1	SS	Subgrade	38.6
37	**1028**	1	2	AC	Base Layer	7.8
37	**1028**	1	3	AC	Original Surface Layer	1.6
39	**0204**	1	1	SS	Subgrade	
39	**0204**	1	2	GS	Embankment Layer	16
39	**0204**	1	3	GB	Base Layer	5.8
39	**0204**	1	4	PC	Original Surface Layer	11.1
40	**4165**	1	1	SS	Subgrade	
40	**4165**	1	2	ATB	Base Layer	5.4
40	**4165**	1	3	AC	Original Surface Layer	2.7

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
41	**6011**	1	1	SS	Subgrade	
41	**6011**	1	2	GS	Subbase Layer	18
41	**6011**	1	3	GB	Base Layer	3.5
41	**6011**	1	4	AC	Original Surface Layer	6.1
41	**6011**	1	5	AC	Overlay	3.8
41	**6011**	1	6	AC	Overlay	1.7
41	**6011**	1	7	AC	Overlay	1.3
41	**6011**	2	1	SS	Subgrade	
41	**6011**	2	2	GS	Subbase Layer	18
41	**6011**	2	3	GB	Base Layer	3.5
41	**6011**	2	4	AC	Original Surface Layer	6.1
41	**6011**	2	5	AC	Overlay	3.8
41	**6011**	2	6	AC	Overlay	1.7
41	**6011**	2	7	AC	Overlay	1.3
41	**6011**	3	1	SS	Subgrade	
41	**6011**	3	2	GS	Subbase Layer	18
41	**6011**	3	3	GB	Base Layer	3.5
41	**6011**	3	4	AC	Original Surface Layer	6.1
41	**6011**	3	5	AC	Overlay	3.8
41	**6011**	3	6	AC	Overlay	1
41	**6011**	3	7	AC	Overlay	0
41	**6011**	3	8	AC	Overlay	2
41	**6011**	4	1	SS	Subgrade	
41	**6011**	4	2	GS	Subbase Layer	18
41	**6011**	4	3	GB	Base Layer	3.5
41	**6011**	4	4	AC	Original Surface Layer	6.1
41	**6011**	4	5	AC	Overlay	3.8
41	**6011**	4	6	AC	Overlay	1
41	**6011**	4	7	AC	Overlay	0
41	**6011**	4	8	AC	Overlay	2

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
42	**0603**	1	1	SS	Subgrade	
42	**0603**	1	2	GB	Base Layer	10
42	**0603**	1	3	PC	Original Surface Layer	10.1
42	**0603**	2	1	SS	Subgrade	
42	**0603**	2	2	GB	Base Layer	10
42	**0603**	2	3	PC	Original Surface Layer	10.1
42	**0603**	2	4	AC	AC Layer Below Surface - Binder Course	2.4
42	**0603**	2	5	AC	Overlay	1.8
42	**1606**	1	1	SS	Subgrade	204
42	**1606**	1	2	GB	Base Layer	7.8
42	**1606**	1	3	PC	Original Surface Layer	9.9
46	**9187**	1	1	SS	Subgrade	198
46	**9187**	1	2	GS	Subbase Layer	3
46	**9187**	1	3	GB	Base Layer	6
46	**9187**	1	4	AC	AC Layer Below Surface - Binder Course	3.3
46	**9187**	1	5	AC	Original Surface Layer	2.2
46	**9187**	2	1	SS	Subgrade	198
46	**9187**	2	2	GS	Subbase Layer	3
46	**9187**	2	3	GB	Base Layer	6
46	**9187**	2	4	AC	AC Layer Below Surface - Binder Course	3.3
46	**9187**	2	5	AC	Original Surface Layer	2.2
46	**9187**	3	1	SS	Subgrade	198
46	**9187**	3	2	GS	Subbase Layer	3
46	**9187**	3	3	GB	Base Layer	6
46	**9187**	3	4	AC	AC Layer Below Surface - Binder Course	3.3
46	**9187**	3	5	AC	Original Surface Layer	2.2
46	**9187**	3	6	AC	Seal Coat	0.4

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
47	**3101**	1	1	SS	Subgrade	144
47	**3101**	1	2	GS	Subbase Layer	5.5
47	**3101**	1	3	ATB	Base Layer	3.3
47	**3101**	1	4	AC	AC Layer Below Surface - Binder Course	2.1
47	**3101**	1	5	AC	Original Surface Layer	3.5
47	**3101**	1	6	AC	Seal Coat	0.6
47	**3101**	2	1	SS	Subgrade	144
47	**3101**	2	2	GS	Subbase Layer	5.5
47	**3101**	2	3	ATB	Base Layer	3.3
47	**3101**	2	4	AC	AC Layer Below Surface - Binder Course	2.1
47	**3101**	2	5	AC	Original Surface Layer	3.5
47	**3101**	2	6	AC	Seal Coat	0.6
48	**1060**	1	1	SS	Subgrade	600
48	**1060**	1	2	TS	Subbase Layer	6
48	**1060**	1	3	GB	Base Layer	12.3
48	**1060**	1	4	AC	AC Layer Below Surface - Binder Course	5.8
48	**1060**	1	5	AC	Original Surface Layer	1.7
48	**1068**	1	1	SS	Subgrade	454
48	**1068**	1	2	TS	Subbase Layer	8
48	**1068**	1	3	GB	Base Layer	6
48	**1068**	1	4	AC	AC Layer Below Surface - Binder Course	7.8
48	**1068**	1	5	AC	Original Surface Layer	3.1

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
48	**1068**	2	1	SS	Subgrade	454
48	**1068**	2	2	TS	Subbase Layer	8
48	**1068**	2	3	GB	Base Layer	6
48	**1068**	2	4	AC	AC Layer Below Surface - Binder Course	7.8
48	**1068**	2	5	AC	Original Surface Layer	3.1
48	**1068**	2	6	AC	Seal Coat	0.5
48	**1068**	3	1	SS	Subgrade	454
48	**1068**	3	2	TS	Subbase Layer	8
48	**1068**	3	3	GB	Base Layer	6
48	**1068**	3	4	AC	AC Layer Below Surface - Binder Course	7.8
48	**1068**	3	5	AC	Original Surface Layer	3.1
48	**1068**	3	6	AC	Seal Coat	0.1
48	**1068**	3	7	AC	Seal Coat	0.1
48	**1068**	4	1	SS	Subgrade	454
48	**1068**	4	2	TS	Subbase Layer	8
48	**1068**	4	3	GB	Base Layer	6
48	**1068**	4	4	AC	AC Layer Below Surface - Binder Course	7.8
48	**1068**	4	5	AC	Original Surface Layer	3.1
48	**1068**	4	6	AC	Seal Coat	0.1
48	**1068**	4	7	AC	Seal Coat	0.1
48	**1068**	4	8	AC	Seal Coat	0.5
48	**1077**	1	1	SS	Subgrade	
48	**1077**	1	2	GB	Base Layer	10.4
48	**1077**	1	3	AC	AC Layer Below Surface - Binder Course	3.7
48	**1077**	1	4	AC	Original Surface Layer	1.4

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
48	**1077**	2	1	SS	Subgrade	
48	**1077**	2	2	GB	Base Layer	10.4
48	**1077**	2	3	AC	AC Layer Below Surface - Binder Course	3.7
48	**1077**	2	4	AC	Original Surface Layer	1.4
48	**1077**	2	5	AC	Seal Coat	0.1
48	**1122**	1	1	SS	Subgrade	
48	**1122**	1	2	GS	Subbase Layer	8.4
48	**1122**	1	3	GB	Base Layer	15.6
48	**1122**	1	4	AC	AC Layer Below Surface - Binder Course	1.6
48	**1122**	1	5	AC	Original Surface Layer	1.4
48	**1122**	1	6	AC	Seal Coat	0.4
48	**3739**	1	1	SS	Subgrade	
48	**3739**	1	2	TS	Subbase Layer	7.4
48	**3739**	1	3	GB	Base Layer	11.4
48	**3739**	1	4	AC	Original Surface Layer	1.5
48	**3739**	1	5	AC	Seal Coat	0.3
48	**3739**	2	1	SS	Subgrade	
48	**3739**	2	2	TS	Subbase Layer	7.4
48	**3739**	2	3	GB	Base Layer	11.4
48	**3739**	2	4	AC	Original Surface Layer	1.5
48	**3739**	2	5	AC	Seal Coat	0.3
48	**3739**	2	6	AC	Seal Coat	0.3
48	**3739**	3	1	SS	Subgrade	
48	**3739**	3	2	TS	Subbase Layer	7.4
48	**3739**	3	3	GB	Base Layer	11.4
48	**3739**	3	4	AC	Original Surface Layer	1.4
48	**3739**	3	5	AC	Seal Coat	0.3
48	**3739**	3	6	AC	Seal Coat	0.2
48	**3739**	3	7	AC	Seal Coat	0

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
48	**4142**	1	1	SS	Subgrade	
48	**4142**	1	2	GS	Subbase Layer	3.75
48	**4142**	1	3	ATB	Base Layer	7.6
48	**4142**	1	4	PC	Original Surface Layer	9.6
48	**4143**	1	1	SS	Subgrade	
48	**4143**	1	2	TS	Subbase Layer	5.5
48	**4143**	1	3	CTB	Base Layer	4.3
48	**4143**	1	4	PC	Original Surface Layer	10.4
49	**1001**	1	1	SS	Subgrade	40.9
49	**1001**	1	2	GB	Base Layer	5.8
49	**1001**	1	3	AC	Original Surface Layer	5.1
49	**1001**	1	4	AC	Seal Coat	0.4
49	**1001**	2	1	SS	Subgrade	40.9
49	**1001**	2	2	GB	Base Layer	5.8
49	**1001**	2	3	AC	Original Surface Layer	5.1
49	**1001**	2	4	AC	Seal Coat	0.4
49	**1001**	2	5	AC	Seal Coat	0.4
49	**3011**	1	1	SS	Subgrade	
49	**3011**	1	2	GS	Subbase Layer	3.2
49	**3011**	1	3	CTB	Base Layer	4
49	**3011**	1	4	PC	Original Surface Layer	10.2
50	**1002**	1	1	SS	Subgrade	
50	**1002**	1	2	GB	Base Layer	25.8
50	**1002**	1	3	AC	AC Layer Below Surface - Binder Course	5.5
50	**1002**	1	4	AC	Original Surface Layer	3
50	**1681**	1	1	SS	Subgrade	
50	**1681**	1	2	GS	Subbase Layer	12
50	**1681**	1	3	GS	Subbase Layer	21.6
50	**1681**	1	4	ATB	Base Layer	3.4
50	**1681**	1	5	AC	Original Surface Layer	2.4

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
50	**1681**	2	1	SS	Subgrade	
50	**1681**	2	2	GS	Subbase Layer	12
50	**1681**	2	3	GS	Subbase Layer	21.6
50	**1681**	2	4	ATB	Base Layer	3.4
50	**1681**	2	5	AC	Original Surface Layer	2.4
50	**1681**	2	6	AC	Overlay	4.5
50	**1681**	3	1	SS	Subgrade	
50	**1681**	3	2	GS	Subbase Layer	12
50	**1681**	3	3	GS	Subbase Layer	21.6
50	**1681**	3	4	ATB	Base Layer	3.4
50	**1681**	3	5	AC	Original Surface Layer	2.4
50	**1681**	3	6	AC	Overlay	4.5
51	**0113**	1	1	SS	Subgrade	
51	**0113**	1	2	CTS	Subbase Layer	6
51	**0113**	1	3	GB	Base Layer	7.9
51	**0113**	1	4	AC	AC Layer Below Surface - Binder Course	2.3
51	**0113**	1	5	AC	Original Surface Layer	1.7
51	**0114**	1	1	SS	Subgrade	
51	**0114**	1	2	CTS	Subbase Layer	6
51	**0114**	1	3	GB	Base Layer	11.9
51	**0114**	1	4	AC	AC Layer Below Surface - Binder Course	3.8
51	**0114**	1	5	AC	Original Surface Layer	3.4
53	**1007**	1	1	SS	Subgrade	
53	**1007**	1	2	GB	Base Layer	13
53	**1007**	1	3	AC	Original Surface Layer	2.4

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
53	**1007**	2	1	SS	Subgrade	
53	**1007**	2	2	GB	Base Layer	13
53	**1007**	2	3	AC	Original Surface Layer	2.4
53	**1007**	2	4	AC	Overlay	4
53	**1007**	3	1	SS	Subgrade	
53	**1007**	3	2	GB	Base Layer	13
53	**1007**	3	3	AC	Original Surface Layer	2.4
53	**1007**	3	4	AC	Overlay	4
53	**3813**	1	1	SS	Subgrade	72
53	**3813**	1	2	GS	Subbase Layer	12.7
53	**3813**	1	3	GS	Subbase Layer	18.6
53	**3813**	1	4	GS	Subbase Layer	7.4
53	**3813**	1	5	GB	Base Layer	1.5
53	**3813**	1	6	PC	Original Surface Layer	8
53	**7322**	1	1	SS	Subgrade	
53	**7322**	1	2	GB	Base Layer	9.6
53	**7322**	1	3	AC	AC Layer Below Surface - Binder Course	2.7
53	**7322**	1	4	AC	Original Surface Layer	4.7
53	**7322**	1	5	AC	Overlay	2.2
53	**7322**	2	1	SS	Subgrade	
53	**7322**	2	2	GB	Base Layer	9.6
53	**7322**	2	3	AC	AC Layer Below Surface - Binder Course	2.7
53	**7322**	2	4	AC	Original Surface Layer	4.7
53	**7322**	2	5	AC	Overlay	2.2

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
53	**7322**	3	1	SS	Subgrade	
53	**7322**	3	2	GB	Base Layer	9.6
53	**7322**	3	3	AC	AC Layer Below Surface - Binder Course	2.7
53	**7322**	3	4	AC	Original Surface Layer	5
53	**7322**	3	5	AC	Overlay	2.3
53	**7322**	3	6	AC	Overlay	1.8
56	**1007**	1	1	SS	Subgrade	
56	**1007**	1	2	GB	Base Layer	6.2
56	**1007**	1	3	AC	Original Surface Layer	2.8
56	**1007**	2	1	SS	Subgrade	
56	**1007**	2	2	GB	Base Layer	6.2
56	**1007**	2	3	AC	Original Surface Layer	2.8
56	**2019**	1	1	SS	Subgrade	
56	**2019**	1	2	GS	Subbase Layer	17
56	**2019**	1	3	GS	Subbase Layer	14.4
56	**2019**	1	4	CTB	Base Layer	10.6
56	**2019**	1	5	AC	Original Surface Layer	3.4
56	**2019**	1	6	AC	Friction Course	0.8
56	**2019**	2	1	SS	Subgrade	
56	**2019**	2	2	GS	Subbase Layer	17
56	**2019**	2	3	GS	Subbase Layer	14.4
56	**2019**	2	4	CTB	Base Layer	10.6
56	**2019**	2	5	AC	Original Surface Layer	3.4
56	**2019**	2	6	AC	Friction Course	0.8
56	**2019**	2	7	AC	AC Layer Below Surface - Binder Course	1.2
56	**2019**	2	8	AC	Overlay	1.5

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
56	**2019**	3	1	SS	Subgrade	
56	**2019**	3	2	GS	Subbase Layer	17
56	**2019**	3	3	GS	Subbase Layer	14.4
56	**2019**	3	4	CTB	Base Layer	10.6
56	**2019**	3	5	AC	Original Surface Layer	3.4
56	**2019**	3	6	AC	Friction Course	0.8
56	**2019**	3	7	AC	AC Layer Below Surface - Binder Course	1.2
56	**2019**	3	8	AC	Overlay	1.5
56	**2019**	3	9	AC	Seal Coat	0.1
56	**2020**	1	1	SS	Subgrade	600
56	**2020**	1	2	CTB	Base Layer	12.6
56	**2020**	1	3	AC	Original Surface Layer	4.2
56	**2020**	1	4	AC	Friction Course	0.8
83	**1801**	1	1	SS	Subgrade	
83	**1801**	1	2	GS	Subbase Layer	13.2
83	**1801**	1	3	GB	Base Layer	5.6
83	**1801**	1	4	AC	AC Layer Below Surface - Binder Course	2.2
83	**1801**	1	5	AC	Original Surface Layer	2.2
83	**3802**	1	1	SS	Subgrade	
83	**3802**	1	2	TS	Treated Subbase	5.8
83	**3802**	1	3	GB	Granular Base	4.8
83	**3802**	1	4	PC	Original Surface Layer	9.8
83	**3802**	2	1	SS	Subgrade	
83	**3802**	2	2	TS	Treated Subbase	5.8
83	**3802**	2	3	GB	Granular Base	4.8
83	**3802**	2	4	PC	Original Surface Layer	9.8
83	**3802**	2	5	AC	Overlay	3.9

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
89	**3015**	1	1	SS	Subgrade	
89	**3015**	1	2	GB	Base Layer	13.3
89	**3015**	1	3	PC	Original Surface Layer	8.2
89	**3015**	2	1	SS	Subgrade	
89	**3015**	2	2	GB	Base Layer	13.3
89	**3015**	2	3	PC	Original Surface Layer	8.2
89	**3015**	3	1	SS	Subgrade	
89	**3015**	3	2	GB	Base Layer	13.3
89	**3015**	3	3	PC	Original Surface Layer	8.2
89	**3015**	4	1	SS	Subgrade	
89	**3015**	4	2	GB	Base Layer	13.3
89	**3015**	4	3	PC	Original Surface Layer	8.2
ADOT1	---					
ADOT14	---					
Mnrd 4	---	1	1	SS	Subgrade	
		1	2	AC	Original Surface Layer	9.07
Mnrd 21	---	1	1	SS	Subgrade	
		1	2	GB	Base Layer	22.99
		1	3	AC	Original Surface Layer	15.51
Wstk 12	---		1	SS	Natural subgrade	
			2	SS	Compacted subgrade	6
			3	GS	Engineering fill	18
			4	GB	Base course	12
			5	AC	HMA	6.57
Wstk 15	---		1	SS	Natural subgrade	
			2	SS	Compacted subgrade	6
			3	GS	Engineering fill	18
			4	GB	Base course	12
			5	AC	HMA	6.1

Table 16 – Cont'd
Pavement Structure I – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Layer Description	Representative Thickness (in)
Wstk 25	---		1	SS	Natural subgrade	
			2	SS	Compacted subgrade	6
			3	GS	Engineering fill	18
			4	GB	Base course	12
			5	AC	HMA	6.46

Table 17
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
1	**0101**	1	1	SS	Sandy Silt	> 20' (Harold VonQuintus report)
1	**0101**	1	2	GB	Crushed Stone	
1	**0101**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
1	**0101**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
1	**0102**	1	1	SS	Lean Clay with Sand	> 20' (Harold VonQuintus report)
1	**0102**	1	2	GB	Crushed Stone	
1	**0102**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
1	**0102**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
4	**0113**	1	1	SS	Well-Graded Sand with Silt and Gravel	50'. (Harold VonQuintus report)
4	**0113**	1	2	GB	Crushed Gravel	
4	**0113**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
4	**0114**	1	1	SS	Silty Sand with Gravel	50'. (Harold VonQuintus report)
4	**0114**	1	2	GB	Crushed Gravel	
4	**0114**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
4	**0215**	1	1	SS	Silty Sand with Gravel	Infinite (assumed)
4	**0215**	1	2	GB	Crushed Gravel	
4	**0215**	1	3	PC	Portland Cement Concrete - JPCP	
5	**2042**	1	1	SS	Sandy Silt	100" (Harold VonQuintus report)
5	**2042**	1	2	CTB	Cement Aggregate Mixture	
5	**2042**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
5	**2042**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
5	**2042**	2	1	SS	Sandy Silt	
5	**2042**	2	2	CTB	Cement Aggregate Mixture	
5	**2042**	2	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
5	**2042**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
6	**3042**	1	1	SS	Sandy Lean Clay	Infinite (assumed)
6	**3042**	1	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
6	**3042**	1	3	CTB	Cement Aggregate Mixture	
6	**3042**	1	4	PC	Portland Cement Concrete - JPCP	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
8	**1053**	1	1	SS	Lean Organic Clay	Infinite (Harold VonQuintus report)
8	**1053**	1	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
8	**1053**	1	3	GB	Crushed Gravel	
8	**1053**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
8	**7035**	1	1	SS	Lean Clay with Sand	
8	**7035**	1	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
8	**7035**	1	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
8	**7035**	1	4	PC	Portland Cement Concrete - JPCP	
8	**7035**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
8	**7035**	2	1	SS	Lean Clay with Sand	
8	**7035**	2	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
8	**7035**	2	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
8	**7035**	2	4	PC	Portland Cement Concrete - JPCP	
8	**7035**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
8	**7035**	2	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
9	**1803**	1	1	SS	Well-Graded Sand with Silt and Gravel	2' from surface (TST_SAMPLE_LOG)
9	**1803**	1	2	GB	Gravel - Uncrushed	Infinite (Harold VonQuintus report)
9	**1803**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
9	**1803**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
9	**1803**	2	1	SS	Well-Graded Sand with Silt and Gravel	2' from surface (TST_SAMPLE_LOG)
9	**1803**	2	2	GB	Gravel - Uncrushed	Infinite (Harold VonQuintus report)
9	**1803**	2	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
9	**1803**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
9	**1803**	3	1	SS	Well-Graded Sand with Silt and Gravel	2' from surface (TST_SAMPLE_LOG)
9	**1803**	3	2	GB	Gravel - Uncrushed	Infinite (Harold VonQuintus report)
9	**1803**	3	3	AC	Hot Mixed, Hot laid AC, Dense Graded	**7' assumed (from TDR depths)**
9	**1803**	3	4	AC	Hot Mixed, Hot laid AC, Dense Graded	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
10	**0102**	1	1	SS	Poorly Graded Sand	
10	**0102**	1	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
10	**0102**	1	3	GB	Crushed Stone	
10	**0102**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
10	**0102**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
10	**0102**	1	6	AC	Hot Mixed, Hot Laid, Open Graded	
10	**0102**	2	1	SS	Poorly Graded Sand	
10	**0102**	2	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
10	**0102**	2	3	GB	Crushed Stone	
10	**0102**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
10	**0102**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
10	**0102**	2	6	AC	Hot Mixed, Hot Laid, Open Graded	
13	**1005**	1	1	SS	Clayey Sand	
13	**1005**	1	2	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
13	**1005**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
13	**1005**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
13	**1005**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
13	**1031**	1	1	SS	Silty Sand	50' (Harold VonQuintus report)
13	**1031**	1	2	GB	Fine Grained Soils	
13	**1031**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
13	**1031**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
13	**1031**	1	5	AC	Hot Mixed, Hot Laid, Open Graded	
13	**1031**	2	1	SS	Silty Sand	50' (Harold VonQuintus report)
13	**1031**	2	2	GB	Fine Grained Soils	
13	**1031**	2	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
13	**1031**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
13	**1031**	2	5	AC	Hot Mixed, Hot Laid, Open Graded	
13	**1031**	2	6	AC	Hot Mixed, Hot laid AC, Dense Graded	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
13	**3019**	1	1	SS	Sandy Lean Clay	Infinite (assumed)
13	**3019**	1	2	GB	Crushed Stone	
13	**3019**	1	3	PC	Portland Cement Concrete - JPCP	
16	**1010**	1	1	SS	Silty Sand	Infinite (assumed)
16	**1010**	1	2	GB	Crushed Gravel	
16	**1010**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
16	**1010**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
16	**1010**	1	5	AC	Chip Seal	
18	**3002**	1	1	SS	Sandy Lean Clay	Infinite (assumed)
18	**3002**	1	2	GB	Crushed Stone	
18	**3002**	1	3	PC	Portland Cement Concrete - JPCP	
20	**4054**	1	1	SS	Lean Organic Clay	Infinite (assumed)
20	**4054**	1	2	CTB	Econocrete	
20	**4054**	1	3	PC	Portland Cement Concrete - JRCP	
22	**0118**	1	1	SS	Lean Organic Clay	> 20' (Harold VonQuintus report)
22	**0118**	1	2	GS	Fine Grained Soils	
22	**0118**	1	3	GB	Crushed Stone	
22	**0118**	1	4	ATB	HMAC	
22	**0118**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
22	**0118**	1	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
23	**1026**	1	1	SS	Silty Sand with Gravel	5.5', 2.3' (TST_SAMPLE_LOG)
23	**1026**	1	2	GB	Gravel - Uncrushed	
23	**1026**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
23	**1026**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
23	**1026**	2	1	SS	Silty Sand with Gravel	5.5', 2.3' (TST_SAMPLE_LOG)
23	**1026**	2	2	GB	Gravel - Uncrushed	
23	**1026**	2	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
23	**1026**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
23	**1026**	2	5	AC	Dense Graded Asphalt Concrete Interlayer	
23	**1026**	2	6	AC	Hot Mixed, Hot laid AC, Dense Graded	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
24	**1634**	1	1	SS	Silt	
24	**1634**	1	2	GS	Fine Grained Soils	
24	**1634**	1	3	ATB	Sand Asphalt	
24	**1634**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
24	**1634**	2	1	SS	Silt	
24	**1634**	2	2	GS	Fine Grained Soils	
24	**1634**	2	3	ATB	Sand Asphalt	
24	**1634**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
24	**1634**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
24	**1634**	2	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
27	**4040**	1	1	SS	Lean Clay with Sand	
27	**4040**	1	2	GB	Gravel - Uncrushed	
27	**4040**	1	3	PC	Portland Cement Concrete - JRCP	
28	**1016**	1	1	SS	Silty Sand	
28	**1016**	1	2	GS	Fine Grained Soils	
28	**1016**	1	3	ATB	HMAC	
28	**1016**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
28	**1016**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
28	**1802**	1	1	SS	Poorly Graded Sand	
28	**1802**	1	2	GS	Fine Grained Soils	
28	**1802**	1	3	ATB	HMAC	
28	**1802**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
28	**1802**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
30	**7066**	1	1	SS	Sandy Clay with Gravel	
30	**7066**	1	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
30	**7066**	1	3	GB	Crushed Gravel	
30	**7066**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
30	**7066**	1	5	AC	Hot Mixed, Hot Laid, Open Graded	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
30	**7066**	2	1	SS	Sandy Clay with Gravel	
30	**7066**	2	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
30	**7066**	2	3	GB	Crushed Gravel	
30	**7066**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
30	**7066**	2	5	AC	Hot Mixed, Hot Laid, Open Graded	
30	**7066**	2	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
30	**8129**	1	1	SS	Gravelly Lean Clay with Sand	Refusal at 33.6" (TST_SAMPLE_LOG)
30	**8129**	1	2	GB	Crushed Gravel	Infinite (Harold VonQuintus report)
30	**8129**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	Note: Bedrock considered semi-infinite - TDR info.
30	**8129**	1	4	AC	Chip Seal	
31	**0114**	1	1	SS	Silty Clay	50' (Harold VonQuintus report)
31	**0114**	1	2	GS	Silty Clay	Note: Bedrock considered semi-infinite
31	**0114**	1	3	GB	Crushed Stone	
31	**0114**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
31	**3018**	1	1	SS	Poorly Graded Sand	Infinite (assumed)
31	**3018**	1	2	CTB	Soil Cement	
31	**3018**	1	3	PC	Portland Cement Concrete - JPCP	
32	**0101**	1	1	SS	Silty Sand	> 20' (Harold VonQuintus report)
32	**0101**	1	2	TS	Lime Treated Soil	Infinite (assumed)
32	**0101**	1	3	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
32	**0101**	1	4	GB	Crushed Gravel	
32	**0101**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
32	**0204**	1	1	SS	Sandy Silt	
32	**0204**	1	2	TS	Lime Treated Soil	
32	**0204**	1	3	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
32	**0204**	1	4	GB	Crushed Gravel	
32	**0204**	1	5	PC	Portland Cement Concrete - JPCP	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
33	**1001**	1	1	SS	Poorly Graded Sand with Silt	Refusal at 84" (TST_SAMPLE_LOG)
33	**1001**	1	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
33	**1001**	1	3	GB	Gravel - Uncrushed	
33	**1001**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
33	**1001**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
35	**0105**	1	1	SS	Fat Inorganic Clay	> 60" Calcareous (harold VonQuintus report)
35	**0105**	1	2	GB	Crushed Stone	
35	**0105**	1	3	ATB	HMAC	
35	**0105**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
35	**0105**	1	5	AC	Hot Mixed, Hot Laid, Open Graded	
35	**1112**	1	1	SS	Poorly Graded Sand	Infinite (Harold VonQuintus report)
35	**1112**	1	2	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
35	**1112**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
35	**1112**	1	4	AC	Hot Mixed, Hot Laid, Open Graded	
36	**0801**	1	1	SS	Silty Sand	BR = 15.1 ft.
36	**0801**	1	2	GB	Crushed Gravel	Note: Assumed infinite layer if bedrock deeper than 15 ft.
36	**0801**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
36	**0801**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
36	**4018**	1	1	SS	Silty Gravel with Sand	Refusal at 60" (TST_SAMPLE_LOG)
36	**4018**	1	2	PC	Portland Cement Concrete - JRCP	
36	**4018**	2	1	SS	Silty Gravel with Sand	Refusal at 60" (TST_SAMPLE_LOG)
36	**4018**	2	2	PC	Portland Cement Concrete - JRCP	
36	**4018**	3	1	SS	Silty Gravel with Sand	Refusal at 60" (TST_SAMPLE_LOG)
36	**4018**	3	2	PC	Portland Cement Concrete - JRCP	
36	**4018**	4	1	SS	Silty Gravel with Sand	Refusal at 60" (TST_SAMPLE_LOG)
36	**4018**	4	2	PC	Portland Cement Concrete - JRCP	
36	**4018**	5	1	SS	Silty Gravel with Sand	Refusal at 60" (TST_SAMPLE_LOG)
36	**4018**	5	2	PC	Portland Cement Concrete - JRCP	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
37	**0201**	1	1	SS	Clay	Infinite (assumed)
37	**0201**	1	2	LTS	Lime Treated Soil	
37	**0201**	1	3	GB	Crushed Stone	
37	**0201**	1	4	PC	Portland Cement Concrete - JPCP	
37	**0205**	1	1	SS	Clay	Infinite (assumed)
37	**0205**	1	2	LTS	Lime Treated Soil	
37	**0205**	1	3	CTB	Lean Concrete	
37	**0205**	1	4	PC	Portland Cement Concrete - JPCP	
37	**0208**	1	1	SS	Sandy Silt	Infinite (assumed)
37	**0208**	1	2	LTS	Lime Treated Soil	
37	**0208**	1	3	CTB	Lean Concrete	
37	**0208**	1	4	PC	Portland Cement Concrete - JPCP	
37	**0212**	1	1	SS	Sandy Silt	Infinite (assumed)
37	**0212**	1	2	LTS	Lime Treated Soil	
37	**0212**	1	3	GB	Crushed Stone	
37	**0212**	1	4	ATB	Open Graded, Hot Laid, Central Plant Mix	
37	**0212**	1	5	PC	Portland Cement Concrete - JPCP	
37	**1028**	1	1	SS	Poorly Graded Sand with Silt	Refusal at 48" (TST_SAMPLE_LOG)
37	**1028**	1	2	AC	HMAC	Note: Bedrock considered semi-infinite - TDR info.
37	**1028**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
39	**0204**	1	1	SS	Silty Clay	
39	**0204**	1	2	GS	Silty Clay	
39	**0204**	1	3	GB	Crushed Stone	
39	**0204**	1	4	PC	Portland Cement Concrete - JPCP	
40	**4165**	1	1	SS	Silty Sand	Infinite (Harold VonQuintus report)
40	**4165**	1	2	ATB	HMAC	
40	**4165**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
41	**6011**	1	1	SS	Gravelly Fat Clay	
41	**6011**	1	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
41	**6011**	1	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
41	**6011**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	1	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	1	7	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	2	1	SS	Gravelly Fat Clay	
41	**6011**	2	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
41	**6011**	2	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
41	**6011**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	2	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	2	7	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	3	1	SS	Gravelly Fat Clay	
41	**6011**	3	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
41	**6011**	3	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
41	**6011**	3	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	3	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	3	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	3	7	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	3	8	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	4	1	SS	Gravelly Fat Clay	
41	**6011**	4	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
41	**6011**	4	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
41	**6011**	4	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	4	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	4	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	4	7	AC	Hot Mixed, Hot laid AC, Dense Graded	
41	**6011**	4	8	AC	Hot Mixed, Hot laid AC, Dense Graded	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
42	**0603**	1	1	SS	Silt	
42	**0603**	1	2	GB	Crushed Stone	
42	**0603**	1	3	PC	Portland Cement Concrete - JRCP	
42	**0603**	2	1	SS	Silt	
42	**0603**	2	2	GB	Crushed Stone	
42	**0603**	2	3	PC	Portland Cement Concrete - JRCP	
42	**0603**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
42	**0603**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
42	**1606**	1	1	SS	Gravelly Lean Clay with Sand	5", 18.5", 61.2" from surface (TST_SAMPLE_LOG)
42	**1606**	1	2	GB	Crushed Gravel	Note: Assumed infinite layer if bedrock deeper than 15 ft.
42	**1606**	1	3	PC	Portland Cement Concrete - JRCP	
46	**9187**	1	1	SS	Lean Organic Clay	BR = 17.7 ft.
46	**9187**	1	2	GS	Gravel - Uncrushed	Note: Assumed infinite layer if bedrock deeper than 15 ft.
46	**9187**	1	3	GB	Gravel - Uncrushed	
46	**9187**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
46	**9187**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
46	**9187**	2	1	SS	Lean Organic Clay	
46	**9187**	2	2	GS	Gravel - Uncrushed	
46	**9187**	2	3	GB	Gravel - Uncrushed	
46	**9187**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
46	**9187**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
46	**9187**	3	1	SS	Lean Organic Clay	
46	**9187**	3	2	GS	Gravel - Uncrushed	
46	**9187**	3	3	GB	Gravel - Uncrushed	
46	**9187**	3	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
46	**9187**	3	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
46	**9187**	3	6	AC	Chip Seal	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
47	**3101**	1	1	SS	Fat Clay with Sand	12' below surface (INV_DEPTH_TO_RIGID)
47	**3101**	1	2	GS	Crushed Stone	
47	**3101**	1	3	ATB	HMAC	
47	**3101**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
47	**3101**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
47	**3101**	1	6	AC	Chip Seal	
47	**3101**	2	1	SS	Fat Clay with Sand	12' below surface (INV_DEPTH_TO_RIGID)
47	**3101**	2	2	GS	Crushed Stone	
47	**3101**	2	3	ATB	HMAC	
47	**3101**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
47	**3101**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
47	**3101**	2	6	AC	Chip Seal	
48	**1060**	1	1	SS	Silty Sand	50'. (Harold VonQuintus report)
48	**1060**	1	2	TS	Lime Treated Soil	
48	**1060**	1	3	GB	Crushed Stone	
48	**1060**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1060**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1068**	1	1	SS	Sandy Lean Clay	40' below suface (INV_DEPTH_TO_RIGID)
48	**1068**	1	2	TS	Lime Treated Soil	
48	**1068**	1	3	GB	Crushed Stone	
48	**1068**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1068**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1068**	2	1	SS	Sandy Lean Clay	40' below suface (INV_DEPTH_TO_RIGID)
48	**1068**	2	2	TS	Lime Treated Soil	
48	**1068**	2	3	GB	Crushed Stone	
48	**1068**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1068**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1068**	2	6	AC	Fog Seal	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
48	**1068**	3	1	SS	Sandy Lean Clay	40' below suface (INV_DEPTH_TO_RIGID)
48	**1068**	3	2	TS	Lime Treated Soil	
48	**1068**	3	3	GB	Crushed Stone	
48	**1068**	3	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1068**	3	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1068**	3	6	AC	Fog Seal	
48	**1068**	3	7	AC	Fog Seal	
48	**1068**	4	1	SS	Sandy Lean Clay	40' below suface (INV_DEPTH_TO_RIGID)
48	**1068**	4	2	TS	Lime Treated Soil	
48	**1068**	4	3	GB	Crushed Stone	
48	**1068**	4	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1068**	4	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1068**	4	6	AC	Fog Seal	
48	**1068**	4	7	AC	Fog Seal	
48	**1068**	4	8	AC	Chip Seal	
48	**1077**	1	1	SS	Sandy Silt	Infinite (Harold VonQuintus report)
48	**1077**	1	2	GB	Crushed Stone	
48	**1077**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1077**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1077**	2	1	SS	Sandy Silt	Infinite (Harold VonQuintus report)
48	**1077**	2	2	GB	Crushed Stone	
48	**1077**	2	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1077**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1077**	2	5	AC	Fog Seal	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
48	**1122**	1	1	SS	Clayey Sand	Infinite (assumed)
48	**1122**	1	2	GS	Fine Grained Soils	
48	**1122**	1	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
48	**1122**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1122**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**1122**	1	6	AC	Chip Seal	
48	**3739**	1	1	SS	Poorly Graded Sand	Infinite (assumed)
48	**3739**	1	2	TS	Lime Treated Soil	
48	**3739**	1	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
48	**3739**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**3739**	1	5	AC	Chip Seal	
48	**3739**	2	1	SS	Poorly Graded Sand	
48	**3739**	2	2	TS	Lime Treated Soil	
48	**3739**	2	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
48	**3739**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**3739**	2	5	AC	Chip Seal	
48	**3739**	2	6	AC	Chip Seal	
48	**3739**	3	1	SS	Poorly Graded Sand	
48	**3739**	3	2	TS	Lime Treated Soil	
48	**3739**	3	3	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
48	**3739**	3	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
48	**3739**	3	5	AC	Chip Seal	
48	**3739**	3	6	AC	Chip Seal	
48	**3739**	3	7	AC	Fog Seal	
48	**4142**	1	1	SS	Clayey Sand	Infinite (assumed)
48	**4142**	1	2	GS	Fine Grained Soils	
48	**4142**	1	3	ATB	Sand Asphalt	
48	**4142**	1	4	PC	Portland Cement Concrete - JRCP	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
48	**4143**	1	1	SS	Lean Organic Clay	Infinite (assumed)
48	**4143**	1	2	TS	Lime Treated Soil	
48	**4143**	1	3	CTB	Cement Aggregate Mixture	
48	**4143**	1	4	PC	Portland Cement Concrete - JRCP	
49	**1001**	1	1	SS	Silty Sand	Refusal at 52.2" avg (TST_SAMPLE_LOG)
49	**1001**	1	2	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	Note: Bedrock considered semi-infinite - TDR info.
49	**1001**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
49	**1001**	1	4	AC	Chip Seal	
49	**1001**	2	1	SS	Silty Sand	Refusal at 52.2" avg (TST_SAMPLE_LOG)
49	**1001**	2	2	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
49	**1001**	2	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
49	**1001**	2	4	AC	Chip Seal	
49	**1001**	2	5	AC	Chip Seal	
49	**3011**	1	1	SS	Clayey Gravel with Sand	Infinite (assumed)
49	**3011**	1	2	GS	Crushed Gravel	
49	**3011**	1	3	CTB	Cement Aggregate Mixture	
49	**3011**	1	4	PC	Portland Cement Concrete - JPCP	
50	**1002**	1	1	SS	Poorly Graded Gravel with Silt and Sand	Infinite (Harold VonQuintus report)
50	**1002**	1	2	GB	Crushed Gravel	
50	**1002**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
50	**1002**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
50	**1681**	1	1	SS	Clayey Gravel with Sand	
50	**1681**	1	2	GS	Sand	
50	**1681**	1	3	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
50	**1681**	1	4	ATB	Asphalt Treated Mixture	
50	**1681**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
50	**1681**	2	1	SS	Clayey Gravel with Sand	
50	**1681**	2	2	GS	Sand	
50	**1681**	2	3	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
50	**1681**	2	4	ATB	Asphalt Treated Mixture	
50	**1681**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
50	**1681**	2	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
50	**1681**	3	1	SS	Clayey Gravel with Sand	
50	**1681**	3	2	GS	Sand	
50	**1681**	3	3	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
50	**1681**	3	4	ATB	Asphalt Treated Mixture	
50	**1681**	3	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
50	**1681**	3	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
51	**0113**	1	1	SS	Silt	> 20' (Harold VonQuintus report)
51	**0113**	1	2	CTS	Cement Treated Soil	> 78" hard rock fragments (HVQ report)
51	**0113**	1	3	GB	Crushed Stone	
51	**0113**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
51	**0113**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
51	**0114**	1	1	SS	Sandy Silty Clay with Gravel	> 20' (Harold VonQuintus report)
51	**0114**	1	2	CTS	Cement Treated Soil	> 78" hard rock fragments (HVQ report)
51	**0114**	1	3	GB	Crushed Stone	
51	**0114**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
51	**0114**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**1007**	1	1	SS	Silt with Sand	
53	**1007**	1	2	GB	Crushed Gravel	
53	**1007**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**1007**	2	1	SS	Silt with Sand	
53	**1007**	2	2	GB	Crushed Gravel	
53	**1007**	2	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**1007**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
53	**1007**	3	1	SS	Silt with Sand	
53	**1007**	3	2	GB	Crushed Gravel	
53	**1007**	3	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**1007**	3	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**3813**	1	1	SS	Silty Sand	Refusal at 30" (TST_SAMPLE_LOG)
53	**3813**	1	2	GS	Soil-Aggregate Mixture - Predominantly Fine-Grained	
53	**3813**	1	3	GS	Soil-Aggregate Mixture - Predominantly Fine-Grained	
53	**3813**	1	4	GS	Crushed Gravel	
53	**3813**	1	5	GB	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
53	**3813**	1	6	PC	Portland Cement Concrete - JPCP	
53	**7322**	1	1	SS	Lean Organic Clay	
53	**7322**	1	2	GB	Crushed Gravel	
53	**7322**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**7322**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**7322**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**7322**	2	1	SS	Lean Organic Clay	
53	**7322**	2	2	GB	Crushed Gravel	
53	**7322**	2	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**7322**	2	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**7322**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**7322**	3	1	SS	Lean Organic Clay	
53	**7322**	3	2	GB	Crushed Gravel	
53	**7322**	3	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**7322**	3	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**7322**	3	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
53	**7322**	3	6	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**1007**	1	1	SS	Silty Sand with Gravel	Infinite (Harold VonQuintus report)
56	**1007**	1	2	GB	Crushed Gravel	
56	**1007**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
56	**1007**	2	1	SS	Silty Sand with Gravel	Infinite (Harold VonQuintus report)
56	**1007**	2	2	GB	Crushed Gravel	
56	**1007**	2	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**2019**	1	1	SS	Silty Gravel with Sand	
56	**2019**	1	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
56	**2019**	1	3	GS	Soil-Aggregate Mixture - Predominantly Fine-Grained	
56	**2019**	1	4	CTB	Cement Aggregate Mixture	
56	**2019**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**2019**	1	6	AC	Hot Mixed, Hot Laid, Open Graded	
56	**2019**	2	1	SS	Silty Gravel with Sand	
56	**2019**	2	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
56	**2019**	2	3	GS	Soil-Aggregate Mixture - Predominantly Fine-Grained	
56	**2019**	2	4	CTB	Cement Aggregate Mixture	
56	**2019**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**2019**	2	6	AC	Hot Mixed, Hot Laid, Open Graded	
56	**2019**	2	7	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**2019**	2	8	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**2019**	3	1	SS	Silty Gravel with Sand	
56	**2019**	3	2	GS	Soil-Aggregate Mixture - Predominantly Coarse-Grained	
56	**2019**	3	3	GS	Soil-Aggregate Mixture - Predominantly Fine-Grained	
56	**2019**	3	4	CTB	Cement Aggregate Mixture	
56	**2019**	3	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**2019**	3	6	AC	Hot Mixed, Hot Laid, Open Graded	
56	**2019**	3	7	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**2019**	3	8	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**2019**	3	9	AC	Chip Seal	

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
56	**2020**	1	1	SS	Clayey Gravel with Sand	50' (Harold VonQuintus report)
56	**2020**	1	2	CTB	Cement Aggregate Mixture	
56	**2020**	1	3	AC	Hot Mixed, Hot laid AC, Dense Graded	
56	**2020**	1	4	AC	Hot Mixed, Hot Laid, Open Graded	
83	**1801**	1	1	SS	Silty Sand	Infinite (assumed)
83	**1801**	1	2	GS	Gravel - Uncrushed	
83	**1801**	1	3	GB	Crushed Gravel	
83	**1801**	1	4	AC	Hot Mixed, Hot laid AC, Dense Graded	
83	**1801**	1	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
83	**3802**	1	1	SS	Fat Inorganic Clay	Infinite (assumed)
83	**3802**	1	2	TS	Lime Treated Soil	
83	**3802**	1	3	GB	Crushed Stone	
83	**3802**	1	4	PC	Portland Cement Concrete - JPCP	
83	**3802**	2	1	SS	Fat Inorganic Clay	
83	**3802**	2	2	TS	Lime Treated Soil	
83	**3802**	2	3	GB	Crushed Stone	
83	**3802**	2	4	PC	Portland Cement Concrete - JPCP	
83	**3802**	2	5	AC	Hot Mixed, Hot laid AC, Dense Graded	
89	**3015**	1	1	SS	Poorly Graded Sand	Infinite (assumed)
89	**3015**	1	2	GB	Crushed Stone	
89	**3015**	1	3	PC	Portland Cement Concrete - JPCP	
89	**3015**	2	1	SS	Poorly Graded Sand	
89	**3015**	2	2	GB	Crushed Stone	
89	**3015**	2	3	PC	Portland Cement Concrete - JPCP	
89	**3015**	3	1	SS	Poorly Graded Sand	
89	**3015**	3	2	GB	Crushed Stone	
89	**3015**	3	3	PC	Portland Cement Concrete - JPCP	
89	**3015**	4	1	SS	Poorly Graded Sand	
89	**3015**	4	2	GB	Crushed Stone	
89	**3015**	4	3	PC	Portland Cement Concrete - JPCP	
ADOT1	**---**					

Table 17 – Cont'd
Pavement Structure II – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Material Description	Bedrock Information
ADOT14	---					
Mnrd 4	---	1	1	SS	Clay Subgrade (R-Value=12)	> 100 ft. MnRoad geology unit map.
		1	2	AC	Hot Mix Asphalt Surface	
Mnrd 21	---	1	1	SS	Clay Subgrade (R-Value=12)	> 100 ft. MnRoad geology unit map.
		1	2	GB	Class-5 Special Base	
		1	3	AC	Hot Mix Asphalt Surface	
Wstk 12	---		1	SS		Infinite (assumed)
			2	SS	-------	
			3	GS	-------	
			4	GB	-------	
			5	AC	-------	
Wstk 15	---		1	SS		Infinite (assumed)
			2	SS	-------	
			3	GS	-------	
			4	GB	-------	
			5	AC	-------	
Wstk 25	---		1	SS		Infinite (assumed)
			2	SS	-------	
			3	GS	-------	
			4	GB	-------	
			5	AC	-------	

Table 18
Atterberg Limits – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Liquid Limit (LL) Test 1	Plastic Limit (PL) Test 1	Plasticity Index (PI) Test 1	Liquid Limit (LL) Test 2	Plastic Limit (PL) Test 2	Plasticity Index (PI) Test 2	Source
1	**0101**	1	1	SS	49	35	14	----	----	----	LTPP table TST_UG04_SS03
1	**0101**	1	2	GB			NP	----	----	----	Assumed
1	**0102**	1	1	SS	48	33	15	----	----	----	LTPP table TST_UG04_SS03
1	**0102**	1	2	GB			NP	----	----	----	Assumed
4	**0113**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
4	**0113**	1	2	GB	21	NP	NP	----	----	----	Design Guide Database
4	**0114**	1	1	SS	24	17	7	----	----	----	LTPP table TST_UG04_SS03
4	**0114**	1	2	GB	21	NP	NP	----	----	----	Design Guide Database
4	**0215**	1	1	SS	22	19	3	----	----	----	TST_UG04_SS03 - 040216
4	**0215**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
5	**2042**	1	1	SS	20	18.5	1.5	----	----	----	LTPP table TST_UG04_SS03
6	**3042**	1	1	SS	30	20.5	9.5	----	----	----	LTPP table TST_UG04_SS03
6	**3042**	1	2	GS	28	24	4	----	----	----	LTPP table TST_UG04_SS03
8	**1053**	1	1	SS	40	18	22	----	----	----	LTPP table TST_UG04_SS03
8	**1053**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
8	**1053**	1	3	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
8	**7035**	1	1	SS	35.5	12.5	23	----	----	----	LTPP table TST_UG04_SS03
8	**7035**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
8	**7035**	1	3	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
9	**1803**	1	1	SS	----	----	NP	----	----	----	Design Guide Database
9	**1803**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
10	**0102**	1	1	SS	24	17	7	----	----	----	TST_UG04_SS03 - 100103
10	**0102**	1	2	GS	----	----	NP	----	----	----	Assumed
10	**0102**	1	3	GB	----	----	NP	----	----	----	Assumed
13	**1005**	1	1	SS	27	15	12	19	18	1	LTPP table TST_UG04_SS03
13	**1005**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
13	**1031**	1	1	SS	31	23	8	----	----	----	LTPP table TST_UG04_SS03

Table 18 – Cont'd
Atterberg Limits– LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Liquid Limit (LL) Test 1	Plastic Limit (PL) Test 1	Plasticity Index (PI) Test 1	Liquid Limit (LL) Test 2	Plastic Limit (PL) Test 2	Plasticity Index (PI) Test 2	Source
13	**1031**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
13	**3019**	1	1	SS	34	27	7	32	19	13	LTPP table TST_UG04_SS03
13	**3019**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
16	**1010**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
16	**1010**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
18	**3002**	1	1	SS	30.5	16.5	14	----	----	----	LTPP table TST_UG04_SS03
18	**3002**	1	2	GB	----	----	NP	----			LTPP table TST_UG04_SS03
20	**4054**	1	1	SS	39	20	19	46	20	26	LTPP table TST_UG04_SS03
22	**0118**	1	1	SS	44	18	26	----	----	----	LTPP table TST_UG04_SS03
22	**0118**	1	2	GS	23	19	4	----	----	----	LTPP table TST_UG04_SS03
22	**0118**	1	3	GB	----	----	NP	----	----	----	Assumed
23	**1026**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
23	**1026**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
24	**1634**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
24	**1634**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
27	**4040**	1	1	SS	39	19	20	32	18	14	LTPP table TST_UG04_SS03
27	**4040**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
28	**1016**	1	1	SS	19.5	17	2.5	----	----	----	LTPP table TST_UG04_SS03
28	**1016**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
28	**1802**	1	1	SS	18	15	3	----	----	NP	LTPP table TST_UG04_SS03
28	**1802**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
30	**7066**	1	1	SS	32	13.5	18.5	----	----	----	LTPP table TST_UG04_SS03
30	**7066**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
30	**7066**	1	3	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
30	**8129**	1	1	SS	31	14.5	16.5	----	----	----	LTPP table TST_UG04_SS03
30	**8129**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03

Table 18 – Cont'd
Atterberg Limits– LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Liquid Limit (LL) Test 1	Plastic Limit (PL) Test 1	Plasticity Index (PI) Test 1	Liquid Limit (LL) Test 2	Plastic Limit (PL) Test 2	Plasticity Index (PI) Test 2	Source
31	**0114**	1	1	SS	41	17	24	----	----	----	TST_UG04_SS03 - 310115
31	**0114**	1	2	GS	51	18	33	----	----	----	TST_UG04_SS03 - 310115
31	**0114**	1	3	GB	----	----	NP	----	----	----	Assumed
31	**3018**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
32	**0101**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
32	**0101**	1	2	TS	----	----	NP	----	----	----	Assumed
32	**0101**	1	3	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
32	**0101**	1	4	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
32	**0204**	1	1	SS				----	----	----	
32	**0204**	1	2	TS				----	----	----	
32	**0204**	1	3	GS				----	----	----	
32	**0204**	1	4	GB				----	----	----	
33	**1001**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
33	**1001**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
33	**1001**	1	3	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
35	**0105**	1	1	SS	58	27	31	----	----	----	LTPP table TST_UG04_SS03
35	**0105**	1	2	GB	----	----	NP	----	----	----	Design Guide Database
35	**1112**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
35	**1112**	1	2	GB	23.5	18	5.5	----	----	----	LTPP table TST_UG04_SS03
36	**0801**	1	1	SS	23	16	7	----	----	NP, NP[b]	LTPP table TST_UG04_SS03
36	**0801**	1	2	GB	----	----	NP[a]	----	----	----	
36	**4018**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
37	**0201**	1	1	SS	61	30	31	----	----	----	LTPP table TST_UG04_SS03
37	**0201**	1	2	LTS	NA	NA	27	----	----	----	Estimated based on 3 % lime added
37	**0201**	1	3	GB	18	----	NP	----	----	----	LTPP table TST_UG04_SS03
37	**0205**	1	1	SS	64	41	22	----	----	----	TST_UG04_SS03 - 370208
37	**0205**	1	2	LTS	NA	NA	18	----	----	----	Estimated based on 3 % lime added

Table 18 – Cont'd
Atterberg Limits– LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Liquid Limit (LL) Test 1	Plastic Limit (PL) Test 1	Plasticity Index (PI) Test 1	Liquid Limit (LL) Test 2	Plastic Limit (PL) Test 2	Plasticity Index (PI) Test 2	Source
37	**0208**	1	1	SS	64	41	22	----	----	----	LTPP table TST_UG04_SS03
37	**0208**	1	2	LTS	NA	NA	17.5	----	----	----	Estimated based on 3.6 % lime added
37	**0212**	1	1	SS	48	26	22	----	----	----	LTPP table TST_UG04_SS03
37	**0212**	1	2	LTS	NA	NA	18	----	----	----	Estimated based on 3 % lime added
37	**0212**	1	3	GB	----	----	NP	----	----	----	TST_UG04_SS03 - 370204
37	**1028**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
39	**0204**	1	1	SS				----	----	----	
39	**0204**	1	2	GS				----	----	----	
39	**0204**	1	3	GB				----	----	----	
40	**4165**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
41	**6011**	1	1	SS	58	23	35	65	21	44	LTPP table TST_UG04_SS03
41	**6011**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
41	**6011**	1	3	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
42	**0603**	1	1	SS	23	16	7	----	----	----	LTPP table TST_UG04_SS03
42	**0603**	1	2	GB	----	----	NP[a]	----	----	----	
42	**1606**	1	1	SS	29	19	10	34	18	16	LTPP table TST_UG04_SS03
42	**1606**	1	2	GB	20	14.5	5.5	----	----	----	LTPP table TST_UG04_SS03
46	**9187**	1	1	SS	51	19	32	44	20	24	LTPP table TST_UG04_SS03
46	**9187**	1	2	GS	21.5	18.5	3	----	----	----	LTPP table TST_UG04_SS03
46	**9187**	1	3	GB	----	----	NP[a]	----	----	----	
47	**3101**	1	1	SS	52.5	26	26.5	----	----	----	LTPP table TST_UG04_SS03
47	**3101**	1	2	GS	19	13	6	----	----	----	LTPP table TST_UG04_SS03
48	**1060**	1	1	SS	19	18	1	22	15	7	LTPP table TST_UG04_SS03
48	**1060**	1	2	LTS	22	21	1	----	----	----	INV_UNBOUND
48	**1060**	1	3	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03

Table 18 – Cont'd
Atterberg Limits– LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Liquid Limit (LL) Test 1	Plastic Limit (PL) Test 1	Plasticity Index (PI) Test 1	Liquid Limit (LL) Test 2	Plastic Limit (PL) Test 2	Plasticity Index (PI) Test 2	Source
48	**1068**	1	1	SS	43	18	25	33	18	15	LTPP table TST_UG04_SS03
48	**1068**	1	2	LTS	60	23	37	29	21	8	Estimated based on 6 % lime added
48	**1068**	1	3	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
48	**1077**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
48	**1077**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
48	**1122**	1	1	SS	26	14	12	----	----	NP	LTPP table TST_UG04_SS03
48	**1122**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
48	**1122**	1	3	GB	16	14.5	1.5	----	----	----	LTPP table TST_UG04_SS03
48	**3739**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
48	**3739**	1	2	LTS	21	20	1	----	----	----	INV_UNBOUND
48	**3739**	1	3	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
48	**4142**	1	1	SS	21	14	7	36	20	19	LTPP table TST_UG04_SS03
48	**4142**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
48	**4143**	1	1	SS	41	18	23	----	----	----	LTPP table TST_UG04_SS03
48	**4143**	1	2	LTS	38	19.5	18.5	----	----	----	Estimated based on 4 % lime added
49	**1001**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
49	**1001**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
49	**3011**	1	1	SS	21	14	7	----	----	----	LTPP table TST_UG04_SS03
49	**3011**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
50	**1002**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
50	**1002**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
50	**1681**	1	1	SS	26.5	18	8.5	----	----	----	LTPP table TST_UG04_SS03
50	**1681**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
50	**1681**	1	3	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
51	**0113**	1	1	SS	31	26	5	----	----	----	TST_UG04_SS03 - 510115
51	**0113**	1	3	GB	----	----	NP	----	----	----	Assumed
51	**0114**	1	1	SS	31	26	5	----	----	----	TST_UG04_SS03 - 510115

Table 18 – Cont'd
Atterberg Limits– LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Liquid Limit (LL) Test 1	Plastic Limit (PL) Test 1	Plasticity Index (PI) Test 1	Liquid Limit (LL) Test 2	Plastic Limit (PL) Test 2	Plasticity Index (PI) Test 2	Source
51	**0114**	1	3	GB	----	----	NP	----	----	----	Assumed
53	**1007**	1	1	SS	21	----	NP	----	----	----	LTPP table TST_UG04_SS03
53	**1007**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
53	**3813**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
53	**3813**	1	2	GS	26	20	6	----	----	----	LTPP table TST_UG04_SS03
53	**3813**	1	3	GS	26	18	8	----	----	NP	LTPP table TST_UG04_SS03
53	**3813**	1	4	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
53	**3813**	1	5	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
53	**7322**	1	1	SS	33	17.5	15.5	----	----	----	LTPP table TST_UG04_SS03
53	**7322**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
56	**1007**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
56	**1007**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
56	**2019**	1	1	SS	34	16	18	----	----	NP	LTPP table TST_UG04_SS03
56	**2019**	1	2	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
56	**2019**	1	3	GS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
56	**2020**	1	1	SS	34	12	22	26	14	12	LTPP table TST_UG04_SS03
83	**1801**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
83	**1801**	1	2	GS	28.5	17.5	11	----	----	----	LTPP table TST_UG04_SS03
83	**1801**	1	3	GB	21	17	4	----	----	----	LTPP table TST_UG04_SS03
83	**3802**	1	1	SS	69	33	36	79	32	47	LTPP table TST_UG04_SS03
83	**3802**		2	LTS	40	35	5	----	----	----	INV_UNBOUND
83	**3802**		3	GB	NA	NA	NP	----	----	----	Estimated
89	**3015**	1	1	SS	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
89	**3015**	1	2	GB	----	----	NP	----	----	----	LTPP table TST_UG04_SS03
MnRoad 4	---	1	1	SS	32.5	18.3	14.2	30.6	20.0	10.6	Sample 1: 0 offset at 14.75"; Sample 2: -9.8' offset at 32.75"
MnRoad 21	---	1	1	SS	35.7	19.9	15.8	34.6	20.6	14.0	Sample 1: 0 offset at 36.75"; Sample 2: -9.8' offset at 30.75"
			2	GB	----	----	NP	----	----	----	

Table 18 – Cont'd
Atterberg Limits– LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Layer Type	Liquid Limit (LL) Test 1	Plastic Limit (PL) Test 1	Plasticity Index (PI) Test 1	Liquid Limit (LL) Test 2	Plastic Limit (PL) Test 2	Plasticity Index (PI) Test 2	Source
Wstk 12	---		1	SS	44	19	25	----	----	----	Assumed same as compacted subgrade
			2	SS	44	19	25	----	----	----	Assumed same as Section 13
			3	GS	47	15	32	34	15	19	NCHRP Report 455
			4	GB	----	----	NP	----	----	----	NCHRP Report 455
Wstk 15	---		1	SS	33	20	13	----	----	----	Assumed same as compacted subgrade
			2	SS	33	20	13	----	----	----	Assumed same as Section 16
			3	GS	48	20	28	42	19	23	NCHRP Report 455
			4	GB	----	----	NP	----	----	----	NCHRP Report 455
Wstk 25	---		1	SS	42	20	22				Assumed same as compacted subgrade
			2	SS	42	20	22				NCHRP Report 455
			3	GS	47	22	25				NCHRP Report 455
			4	GB	----	----	NP	----	----	----	NCHRP Report 455

Notes:
[a] Estimated
[b] Test No. 3
[c] Same result from Test 2 and Test 3
[d] Not available in the LTPP database. Values shown are default available within the EICM program
[e] Recommended value used by EICM
Shaded cell indicates data not available at present

Table 19
Gradation Parameters – LTPP Data

State Code	SHRP ID	Layer No.	% Passing #200 Sieve Test 1	% Passing #200 Sieve Test 2, 3	% Passing #200 Sieve Average	% Passing #4 Sieve Test 1	% Passing #4 Sieve Test 2, 3	% Passing #4 Sieve Average	Diameter D_{60} (mm) Test 1	Diameter D_{60} (mm) Test 2	Diameter D_{60} (mm) Average
1	**0101**	1	68.00	----		99.10	----		0.0463	----	
1	**0101**	2	12.00	----		46.60	----		8.5900	----	
1	**0102**	1	68[a]	----		99.1[a]	----		0.046[a]	----	
1	**0102**	2	12.00	----		46.60	----		8.5900	----	
4	**0113**	1	8.80	----		77.00	----		2.2850	----	
4	**0113**	2	10.17	----		42.83	----		5.7739	----	
4	**0114**	1	19.10	----		64.00	----		3.7196	----	
4	**0114**	2	10.17	----		42.83	----		5.7739	----	
4	**0215**	1	25.60	----		83.00	----		0.7726	----	
4	**0215**	2	8.00	----		54.00	----		7.0000	----	
5	**2042**	1	78.50	68.90	73.70	98.00	93.00	95.50	0.0380	0.0420	0.0400
6	**3042**	1	70.70	58.30	64.50	98.00	100.00	99.00	0.0329	0.0707	0.0518
6	**3042**	2	45.20	----		94.00	----		0.1615	----	
8	**1053**	1	91.80	----		97.00	----		0.0000	----	
8	**1053**	2	9.40	7.60	8.50	42.00	38.00	40.00	14.0661	20.0000	17.0331
8	**1053**	3	8.90	6.90	7.90	47.00	48.00	47.50	7.7380	7.3003	7.5192
8	**7035**	1	72.30	76.00	74.15	100.00	99.00	99.50	0.0407	0.0371	0.039
8	**7035**	2	13.30	----		99.00	----		0.3937	----	
8	**7035**	3	12.70	21.80	17.25	81.00	69.00	75.00	0.8495	2.0000	1.425
9	**1803**	1	12.60	----		90.00	----		0.5371	----	
9	**1803**	2	9.60	5.80	7.70	63.00	49.00		3.6073	10.0000	
10	**0102**	1	26.80	----		100.00	----		0.2852	----	
10	**0102**	2	13.60	----		100.00	----		0.3341	----	
10	**0102**	3	6.00	----		49.00	----		6.6320	----	
13	**1005**	1	38.40	36.00		93.00	100.00		0.1598	0.1483	
13	**1005**	2	7.80	8.90		44.00	48.00		9.8276	8.7932	
13	**1031**	1	44.80	42.60		98.00	88.00		0.1720	0.2491	
13	**1031**	2	21.50	10.70		94.00	93.00		1.2500	0.6758	
13	**3019**	1	56.80	63.00		93.00	94.00		0.0900	0.0583	
13	**3019**	2	10.90	25.60		41.00	36.00		12.3262	14.6519	

Table 19 – Cont'd
Gradation Parameters– LTPP Data

State Code	SHRP ID	Layer No.	% Passing #200 Sieve Test 1	% Passing #200 Sieve Test 2, 3	% Passing #200 Sieve Average	% Passing #4 Sieve Test 1	% Passing #4 Sieve Test 2, 3	% Passing #4 Sieve Average	Diameter D_{60} (mm) Test 1	Diameter D_{60} (mm) Test 2	Diameter D_{60} (mm) Average
16	**1010**	1	8.30	13.10		92.00	97.00		0.7069	0.3511	
16	**1010**	2	7.80	8.20		46.00	46.00		7.8929	7.5619	
18	**3002**	1	62.00	72.80	67.40	94.00	98.00	96.00	0.0522	0.0222	0.0372
18	**3002**	2	3.00	4.10	3.55	27.00	37.00	32.00	14.2122	10.6650	12.4386
20	**4054**	1	87.20	95.90	91.55	97.00	99.00		0.0187	0.0166	
22	**0118**	1	96.50	----		100.00	----		0.00000000	----	
22	**0118**	2	91.30	----		98.90	----		0.0356	----	
22	**0118**	3		----			----			----	
23	**1026**	1	11.20	12.60		60.00	90.00		4.3000	0.4990	
23	**1026**	2	4.00	0.20		32.00	9.00		45.2199	74.0331	Used max. allowed: 25 mm for both runs
24	**1634**	1	97.90	99.00	98.45	99.00	100.00	99.50	0.0000	0.0000	Used min. allowed of 0.001 mm
24	**1634**	2	98.90	98.90	98.90	100.00	100.00	100.00	0.0000	0.0000	Used min. allowed of 0.001 mm
27	**4040**	1	79.40	72.70	76.05	96.00	98.00	97.00	0.0124	0.0265	0.0195
27	**4040**	2	14.00	14.00	14.00	68.00	68.00	68.00	2.0000	2.0000	2.0000
28	**1016**	1	34.40	25.70	30.05	99.00	92.00	95.50	0.1653	0.2588	0.2121
28	**1016**	2	21.40	11.50	16.45	99.00	100.00	99.50	0.1770	0.2374	0.2072
28	**1802**	1	1.70	6.80	4.25	100.00	100.00		0.3692	0.3930	0.3811
28	**1802**	2	17.40	18.10	17.75	99.00	90.00	94.50	0.3429	0.3600	0.3515
30	**7066**	1	56.30	54.70	55.50	91.00	90.00		0.1120	0.1000	
30	**7066**	2	11.70	8.40	10.05	42.00	42.00		9.5184	11.6797	
30	**7066**	3	10.10	----		63.00	----		4.2322	----	
30	**8129**	1	55.20	60.30	57.75	85.00	84.00	84.50	0.1000	0.0750	0.088
30	**8129**	2	6.80	7.50	7.15	35.00	43.00	39.00	9.1454	8.2428	8.69

Table 19 – Cont'd
Gradation Parameters– LTPP Data

State Code	SHRP ID	Layer No.	% Passing #200 Sieve Test 1	% Passing #200 Sieve Test 2, 3	% Passing #200 Sieve Average	% Passing #4 Sieve Test 1	% Passing #4 Sieve Test 2, 3	% Passing #4 Sieve Average	Diameter D_{60} (mm) Test 1	Diameter D_{60} (mm) Test 2	Diameter D_{60} (mm) Average
31	**0114**	1	96.7	----		100	----		0.0169	----	
31	**0114**	2	97.8	----		100	----		0.0113	----	
31	**0114**	3	6.9	----		74	----		2.5426	----	
31	**3018**	1	4.50	4.80	4.65	91.00	91.00	91.00	0.9436	0.8544	0.899
32	**0101**	1	24.20	----		100.00	----		0.2842	----	
32	**0101**	2	24.20	----		100.00	----		0.2842	----	
32	**0101**	3	11.40	----		48.00	----		8.5133	----	
32	**0101**	4	12.40	----		46.00	----		9.5819	----	
32	**0204**	1		----			----			----	
32	**0204**	2		----			----			----	
32	**0204**	3		----			----			----	
32	**0204**	4		----			----			----	
33	**1001**	1	14.80	7.90		95.00	98.00		0.3000	0.3553	
33	**1001**	2	8.00	4.90	6.45	75.00	69.00	72.00	1.4621	2.0000	1.731
33	**1001**	3	4.50	4.60	4.55	44.00	42.00	43.00	13.0000	13.2070	13.104
35	**0105**	1	86.40	----		98.50	----		0.0078	----	
35	**0105**	2	4.70	----		54.30	----		5.1031	----	
35	**1112**	1	3.60	2.70	3.15	99.00	100.00	99.50	0.1553	0.1773	0.166
35	**1112**	2	14.70	18.90	16.80	67.00	73.00	70.00	2.2724	1.7344	2.003
36	**0801**	1	21.90	31.6; 28.7	30.15	88.00	80; 97	88.50	0.2500	0.2; 0.1962	0.1981
36	**0801**	2	8.10	----		30.10	----		16.8533	----	
36	**4018**	1	21.40	15.90	18.65	68.00	64.00	66.00	3.1699	3.8852	3.528
37	**0201**	1	70.30	----		100.00	----		0.0200	----	
37	**0201**	2	70.30	----		100.00	----		0.0200	----	
37	**0201**	3	8.80	----		51.00	----		8.0000	----	
37	**0205**	1	61.80	----		99.00	----		0.0617	----	
37	**0205**	2	61.80	----		99.00	----		0.0617	----	
37	**0208**	1	70.70	----		100.00	----		0.0250	----	
37	**0208**	2	70.70	----		100.00	----		0.0250	----	

Table 19 – Cont'd
Gradation Parameters– LTPP Data

State Code	SHRP ID	Layer No.	% Passing #200 Sieve Test 1	% Passing #200 Sieve Test 2, 3	% Passing #200 Sieve Average	% Passing #4 Sieve Test 1	% Passing #4 Sieve Test 2, 3	% Passing #4 Sieve Average	Diameter D_{60} (mm) Test 1	Diameter D_{60} (mm) Test 2	Diameter D_{60} (mm) Average
37	**0212**	1	67.30	----		100.00	----		0.0423	----	
37	**0212**	2	67.30	----		100.00	----		0.0423	----	
37	**0212**	3	6.20	----		45.90	----		9.2366	----	
37	**1028**	1	8.50	8.80	8.65	100.00	100.00	100.00	0.2028	0.1921	0.197
39	**0204**	1		----			----			----	
39	**0204**	2		----			----			----	
39	**0204**	3		----			----			----	
40	**4165**	1	28.20	30.00	29.10	100.00	100.00	100.00	0.1910	0.1740	0.183
41	**6011**	1	62.60	64.20		88.00	69.00		0.0500	0.0200	
41	**6011**	2	5.40	----		31.00	----		13.8385	----	
41	**6011**	3	3.40	3.50		20.00	56.00		14.9269	5.1624	
42	**0603**	1	33.40	----		63.00	----		3.7000	----	
42	**0603**	2	6.60	----		34.00	----		11.8612	----	
42	**1606**	1	43.70	50.80		80.00	77.00		0.3500	0.3000	
42	**1606**	2	5.30	10.20		16.00	37.00		17.1264	12.1796	
46	**9187**	1	85.70	64.00	74.85	100.00	93.00	96.50	0.0259	0.0600	0.043
46	**9187**	2	7.40	10.20	8.80	50.00	59.00	54.50	6.7474	5.0000	5.874
46	**9187**	3	6	----		54	----		6.3000	----	
47	**3101**	1	74.50	80.70	77.60	93.00	98.00		0.0140	0.0115	
47	**3101**	2	16.20	9.90	13.05	49.00	48.00		7.5567	7.4487	
48	**1060**	1	30.70	37.20	33.95	100.00	97.00		0.2764	0.2301	
48	**1060**	2	24.4[a]	----		48.00	----		9.1964	----	
48	**1060**	3	7.10	2.80	4.95	52.00	40.00	46.00	6.4772	14.0000	10.239
48	**1068**	1	94.00	54.00		100.00	100.00		0.0144	0.1552	
48	**1068**	2	94.00	54.00		100.00	100.00		0.0144	0.1552	
48	**1068**	3	12.20	12.00	12.10	38.00	43.00	40.50	10.2346	8.9271	9.581
48	**1077**	1	51.80	73.60	62.70	94.00	97.00	95.50	0.1038	0.0567	0.0803
48	**1077**	2	9.30	7.00	8.15	41.00	49.00	45.00	12.0954	9.0000	10.548

Table 19 – Cont'd
Gradation Parameters– LTPP Data

State Code	SHRP ID	Layer No.	% Passing #200 Sieve Test 1	% Passing #200 Sieve Test 2, 3	% Passing #200 Sieve Average	% Passing #4 Sieve Test 1	% Passing #4 Sieve Test 2, 3	% Passing #4 Sieve Average	Diameter D_{60} (mm) Test 1	Diameter D_{60} (mm) Test 2	Diameter D_{60} (mm) Average
48	**1122**	1	6.50	32.10		99.00	99.00		0.3220	0.3226	
48	**1122**	2	27.90	18.70	23.30	96.00	96.00	96.00	0.2793	0.3810	0.330
48	**1122**	3	21.70	22.90	22.30	57.00	53.00	55.00	5.2945	6.6909	5.993
48	**3739**	1	6.20	4.30	5.25	99.00	100.00	99.50	0.1731	0.1725	0.173
48	**3739**	2	11.00	----		41.00	----		11.7374	----	
48	**3739**	3	9.30	4.80		66.00	61.00		3.3000	4.3489	
48	**4142**	1	5.50	42.90		100.00	100.00		0.1737	0.1389	
48	**4142**	2	11.20	11.80	11.50	100.00	97.00	98.50	0.3764	0.4814	0.429
48	**4143**	1	91.20	89.10	90.15	100.00	100.00	100.00	0.0178	0.0223	0.02
48	**4143**	2	91.20	----		100.00	----		0.0178	----	
49	**1001**	1	14.10	26.80	20.45	97.00	100.00	98.50	0.2102	0.1425	0.176
49	**1001**	2	12.60	8.60		63.00	49.00		4.0000	9.0000	
49	**3011**	1	36.40	35.00		72.00	70.00		0.5500	0.7300	
49	**3011**	2	13.60	14.00	13.80	42.00	44.00	43.00	9.7237	9.6250	9.674
50	**1002**	1	6.90	----		48.00	----		7.7356	----	
50	**1002**	2	3.40	2.70	3.05	15.00	20.00	17.50	25.6352	21.0688	23.352
50	**1681**	1	32.30	25.00	28.65	85.00	51.00		0.7662	13.0000	
50	**1681**	2	10.70	8.40	9.55	75.00	89.00		1.9988	0.7778	
50	**1681**	3	5.60	4.00	4.80	61.00	55.00		4.4153	6.2335	
51	**0113**	1	37.90	----		96.00	----		0.1993	----	
51	**0113**	3	11.00	----		51.20	----		6.5095	----	
51	**0114**	1	37.90	----		96.00	----		0.1993	----	
51	**0114**	3	11.00	----		51.20	----		6.5095	----	
53	**1007**	1	68.40	71.70		95.00	98.00		0.0580	0.0548	
53	**1007**	2	7.50	9.10		55.00	56.00		5.2950	5.1722	
53	**3813**	1	31.00	22.50	26.75	85.00	98.00	91.50	0.3801	0.2081	0.294
53	**3813**	2	57.90	----		96.00	----		0.0760	----	
53	**3813**	3	44.10	32.70		83.00	83.00		0.1300	0.5000	
53	**3813**	4	11.40	10.80	11.10	45.00	38.00	41.50	8.4716	11.9604	10.216
53	**3813**	5	17.50	12.90		66.00	58.00		3.6914	4.7837	

Table 19 – Cont'd
Gradation Parameters– LTPP Data

State Code	SHRP ID	Layer No.	% Passing #200 Sieve Test 1	% Passing #200 Sieve Test 2, 3	% Passing #200 Sieve Average	% Passing #4 Sieve Test 1	% Passing #4 Sieve Test 2, 3	% Passing #4 Sieve Average	Diameter D_{60} (mm) Test 1	Diameter D_{60} (mm) Test 2	Diameter D_{60} (mm) Average
53	**7322**	1	82.40	96.90	89.65	87.00	100.00		0.0287	0.0216	
53	**7322**	2	7.00	4.50	5.75	46.00	59.00		6.8184	5.0000	
56	**1007**	1	24.30	23.00	23.65	88.00	75.00	81.50	0.2000	0.2200	0.210
56	**1007**	2	9.80	8.60	9.20	51.00	54.00	52.50	6.6623	5.6233	6.143
56	**2019**	1	14.50	18.50	16.50	89.00	62.00		0.3300	4.0000	
56	**2019**	2	8.70	----		70.00	----		3.1425	----	
56	**2019**	3	32.20	15.10	23.65	97.00	98.00		0.4921	0.3070	
56	**2020**	1	13.50	12.20	12.85	30.00	38.00		8.6101	9.8184	
83	**1801**	1	21.90	28.80	25.35	100.00	100.00	100.00	0.1533	0.2167	0.185
83	**1801**	2	10.50	10.10	10.30	57.00	61.00	59.00	6.0000	4.0000	5.000
83	**1801**	3	10.90	9.60	10.25	62.00	59.00	60.50	3.9448	5.0000	4.472
83	**3802**	1	90.60	92.50	91.55	98.00	100.00	99.00	0.0025	0.0008	0.0017
83	**3802**	2	90.60	----		98.00	----		0.0025	----	
83	**3802**	3	9.80	10.50		64.00	66.00		3.8957	3.5992	
89	**3015**	1	3.80	2.00	2.90	92.00	91.00	91.50	0.2875	0.2699	0.279
89	**3015**	2	3.70	4.70	4.20	41.00	48.00	44.50	12.7437	8.6291	10.686
MnRoad 4	---	1	58.30	62.00	60.15	----	----	97.80	----	----	0.00628
MnRoad 21	---	1	----	----		----	----	98.65	----	----	0.00630
		2	5.70	---		69.00	---		2.8000	---	
Wstk 12	---	1	73.80		Report 455 - Fig. 22						
		2	73.80								
		3									
		4	9.20	---	---	37.50	---	---	10.0000	---	---
Wstk 15	---	1	31.20		Report 455 - Fig. 22						
		2	31.20								
		3									
		4	9.20	---	---	37.50	---	---	10.0000	---	---

Table 19 – Cont'd
Gradation Parameters– LTPP Data

State Code	SHRP ID	Layer No.	% Passing #200 Sieve Test 1	% Passing #200 Sieve Test 2, 3	% Passing #200 Sieve Average	% Passing #4 Sieve Test 1	% Passing #4 Sieve Test 2, 3	% Passing #4 Sieve Average	Diameter D_{60} (mm) Test 1	Diameter D_{60} (mm) Test 2	Diameter D_{60} (mm) Average
Wstk 25	---	1 2 3 4	9.20	---	---	37.50	---	---	10.0000	---	---

Table 20
Optimum Moisture Content and Maximum Dry Unit Weight – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Optimum Moisture Content (%) Test 1	Optimum Moisture Content (%) Test 2	Maximum Dry Unit Weight (pcf) Test 1	Maximum Dry Unit Weight (pcf) Test 2	Source
1	**0101**	1	1	----	20		104	TST_UG05_SS05
1	**0101**	1	2	NA	----	132.88		SMP_TDR_MOISTURE_SUPPORT
1	**0102**	1	1	NA	----			Assumed same subgrade as Section 010101
1	**0102**	1	2	NA	----			
4	**0113**	1	1	----	10		126	TST_UG05_SS05
4	**0113**	1	2	NA	----	140.55		SMP_TDR_MOISTURE_SUPPORT
4	**0114**	1	1	----	8		133	TST_UG05_SS05
4	**0114**	1	2	NA	----			
4	**0215**	1	1	NA	----	100.44		SMP_TDR_MOISTURE_SUPPORT
4	**0215**	1	2	----	6		143	TST_UG05_SS05
5	**2042**	1	1	12	11	117	118	TST_UG05_SS05
6	**3042**	1	1	20	17	108	111	TST_UG05_SS05
6	**3042**	1	2	20	17	105	112	TST_UG05_SS05
8	**1053**	1	1	----	20	----	100	TST_UG05_SS05
8	**1053**	1	2	6	8	134	133	TST_UG05_SS05
8	**1053**	1	3	6	7	137	138	TST_UG05_SS05
8	**7035**	1	1	18	18	108	105	TST_UG05_SS05
8	**7035**	1	2	9	----	122	----	TST_UG05_SS05
8	**7035**	1	3	7	8	130	134	TST_UG05_SS05
9	**1803**	1	1	12.4	----	122	----	INV_SUBGRADE
9	**1803**	1	2	7	5	138	136	TST_UG05_SS05
10	**0102**	1	1	10	----	122	----	TST_UG05_SS05
10	**0102**	1	2	----	9	----	119	TST_UG05_SS05
10	**0102**	1	3	----	6	----	147	TST_UG05_SS05
13	**1005**	1	1	13	10	117	128	TST_UG05_SS05
13	**1005**	1	2	8	7	136	137	TST_UG05_SS05
13	**1031**	1	1	13	13	119	116	TST_UG05_SS05
13	**1031**	1	2	6	6	141	136	TST_UG05_SS05

Table 20 – Cont'd
Optimum Moisture Content and Maximum Dry Unit Weight – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Optimum Moisture Content (%) Test 1	Optimum Moisture Content (%) Test 2	Maximum Dry Unit Weight (pcf) Test 1	Maximum Dry Unit Weight (pcf) Test 2	Source
13	**3019**	1	1	14	15	118	115	TST_UG05_SS05
13	**3019**	1	2	7	6	135	140	TST_UG05_SS05
16	**1010**	1	1	10	12	113	114	TST_UG05_SS05
16	**1010**	1	2	5	5	138	142	TST_UG05_SS05
18	**3002**	1	1	12	13	117	116	TST_UG05_SS05
18	**3002**	1	2	6	8	141	140	TST_UG05_SS05
20	**4054**	1	1	20	----	103	----	TST_UG05_SS05
22	**0118**	1	1	----	15	----	109	TST_UG05_SS05
22	**0118**	1	2	----	11	----	116	TST_UG05_SS05
22	**0118**	1	3	NA	----		----	
23	**1026**	1	1	8	10	133	120	TST_UG05_SS05
23	**1026**	1	2	6	7	137	139	TST_UG05_SS05
24	**1634**	1	1	4	12	109	102	TST_UG05_SS05
24	**1634**	1	2	7	8	130	128	TST_UG05_SS05
27	**4040**	1	1	16	----	114	----	TST_UG05_SS05
27	**4040**	1	2	6	6	141	140	TST_UG05_SS05
28	**1016**	1	1	13	10	119	126	TST_UG05_SS05
28	**1016**	1	2	11	12	122	112	TST_UG05_SS05
28	**1802**	1	1	10	10	124	122	TST_UG05_SS05
28	**1802**	1	2	7	7	129	133	TST_UG05_SS05
30	**7066**	1	1	11	11	118	118	TST_UG05_SS05
30	**7066**	1	2	6	5	144	142	TST_UG05_SS05
30	**7066**	1	3	7	----	140	----	TST_UG05_SS05
30	**8129**	1	1	10	11	120	117	TST_UG05_SS05
30	**8129**	1	2	7	6	139	138	TST_UG05_SS05
31	**0114**	1	1	NA	----	NA	----	
31	**0114**	1	2	NA	----	NA	----	
31	**0114**	1	3	NA	----	NA	----	

Table 20 – Cont'd
Optimum Moisture Content and Maximum Dry Unit Weight – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Optimum Moisture Content (%) Test 1	Optimum Moisture Content (%) Test 2	Maximum Dry Unit Weight (pcf) Test 1	Maximum Dry Unit Weight (pcf) Test 2	Source
31	**3018**	1	1	10	7	120	119	TST_UG05_SS05
32	**0101**	1	1	----	10	----	123	TST_UG05_SS05
32	**0101**	1	2	----	10	----	123	Assumed same as Layer 1
32	**0101**	1	3		8		131	TST_UG05_SS05
32	**0101**	1	4		6		139	TST_UG05_SS05
32	**0204**	1	1	15		113.942315		TST_UG07_SS07_A
32	**0204**	1	2	NA				
32	**0204**	1	3	NA				
32	**0204**	1	4	NA				
33	**1001**	1	1	11	13	116	114	TST_UG05_SS05
33	**1001**	1	2	7	6	129	128	TST_UG05_SS05
33	**1001**	1	3	7	7	136	138	TST_UG05_SS05
35	**0105**	1	1		22		98.3	TST_UG05_SS05
35	**0105**	1	2	NA				
35	**1112**	1	1	13	12	106	106	TST_UG05_SS05
35	**1112**	1	2	12	8	119	123	TST_UG05_SS05
36	**0801**	1	1		10		121	TST_UG05_SS05
36	**0801**	1	2		5		151	TST_UG05_SS05
36	**4018**	1	1	6	6	139	140	TST_UG05_SS05
37	**0201**	1	1	22		101		TST_UG05_SS05
37	**0201**	1	2	22		101		Assumed same as Layer 1
37	**0201**	1	3	NA		NA		
37	**0205**	1	1	NA		89.96		SMP_TDR_MOISTURE_SUPPORT
37	**0205**	1	2	NA		89.96		Assumed same as Layer 1
37	**0208**	1	1	30		88		TST_UG05_SS05
37	**0208**	1	2	30		88		Assumed same as Layer 1

Table 20 – Cont'd
Optimum Moisture Content and Maximum Dry Unit Weight – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Optimum Moisture Content (%) Test 1	Optimum Moisture Content (%) Test 2	Maximum Dry Unit Weight (pcf) Test 1	Maximum Dry Unit Weight (pcf) Test 2	Source
37	**0212**	1	1	19		104.5		TST_UG05_SS05
37	**0212**	1	2	19		104.5		Assumed same as Layer 1
37	**0212**	1	3	NA				
37	**1028**	1	1	13	13	108	110	TST_UG05_SS05
39	**0204**	1	1	8		134.9325099		TST_UG07_SS07_A
39	**0204**	1	2	NA				
39	**0204**	1	3	NA				
40	**4165**	1	1	11	11	121	122	TST_UG05_SS05
41	**6011**	1	1	19	17	100	95	TST_UG05_SS05
41	**6011**	1	2	8		139		TST_UG05_SS05
41	**6011**	1	3	9	8	135	136	TST_UG05_SS05
42	**0603**	1	1		8[B]		135[b]	TST_UG05_SS05
42	**0603**	1	2		6[b]		144[b]	TST_UG05_SS05
42	**1606**	1	1	12	11	117	120	TST_UG05_SS05
42	**1606**	1	2	6	5	145	143	TST_UG05_SS05
46	**9187**	1	1	17	17	102	108	TST_UG05_SS05
46	**9187**	1	2	6	6	137	138	TST_UG05_SS05
46	**9187**	1	3	NA		132.88		SMP_TDR_MOISTURE_SUPPORT
47	**3101**	1	1	19	24	107	98	TST_UG05_SS05
47	**3101**	1	2	6	5	144	147	TST_UG05_SS05
48	**1060**	1	1	13	13	117	110	TST_UG05_SS05
48	**1060**	1	2	18		106		INV_UNBOUND
48	**1060**	1	3	8	8	133	132	TST_UG05_SS05
48	**1068**	1	1	19	20	105	102	TST_UG05_SS05
48	**1068**	1	2	14.4	----	104	----	INV_UNBOUND; Gradation assumed same as Layer 1
48	**1068**	1	3	6	7	136	136	TST_UG05_SS05

Table 20 – Cont'd
Optimum Moisture Content and Maximum Dry Unit Weight – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Optimum Moisture Content (%) Test 1	Optimum Moisture Content (%) Test 2	Maximum Dry Unit Weight (pcf) Test 1	Maximum Dry Unit Weight (pcf) Test 2	Source
48	**1077**	1	1	10	11	119	114	TST_UG05_SS05
48	**1077**	1	2	5	5	140	139	TST_UG05_SS05
48	**1122**	1	1	8	12	116	118	TST_UG05_SS05
48	**1122**	1	2	11	11	123	121	TST_UG05_SS05
48	**1122**	1	3	6	7	137	138	TST_UG05_SS05
48	**3739**	1	1	10	14	103	104	TST_UG05_SS05
48	**3739**	1	2	16.4		109		INV_UNBOUND
48	**3739**	1	3	18	19	108	104	TST_UG05_SS05
48	**4142**	1	1	13	18	120	107	TST_UG05_SS05
48	**4142**	1	2	8	8	120	120	TST_UG05_SS05
48	**4143**	1	1	15	15	108	109	TST_UG05_SS05
48	**4143**	1	2	NA	----	NA	----	Assumed same as Layer 1
49	**1001**	1	1	12	12	114	116	TST_UG05_SS05
49	**1001**	1	2	5	6	134	138	TST_UG05_SS05
49	**3011**	1	1	11	10	125	125	TST_UG05_SS05
49	**3011**	1	2	5	5	140	140	TST_UG05_SS05
50	**1002**	1	1	7		137		TST_UG05_SS05
50	**1002**	1	2	6	7	144	143	TST_UG05_SS05
50	**1681**	1	1	11	9	124	124	TST_UG05_SS05
50	**1681**	1	2	6	8	135	136	TST_UG05_SS05
50	**1681**	1	3	9	6	125	137	TST_UG05_SS05
51	**0113**	1	1	NA	----	84.84	----	SMP_TDR_MOISTURE_SUPPORT
51	**0113**	1	3	NA	----	132.88	----	SMP_TDR_MOISTURE_SUPPORT
51	**0114**	1	1	NA	----	116.04	----	SMP_TDR_MOISTURE_SUPPORT
51	**0114**	1	3	NA	----	132.88	----	SMP_TDR_MOISTURE_SUPPORT
53	**1007**	1	1	13	14	115	114	TST_UG05_SS05
53	**1007**	1	2	9	9	137	138	TST_UG05_SS05

Table 20 – Cont'd
Optimum Moisture Content and Maximum Dry Unit Weight – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Optimum Moisture Content (%) Test 1	Optimum Moisture Content (%) Test 2	Maximum Dry Unit Weight (pcf) Test 1	Maximum Dry Unit Weight (pcf) Test 2	Source
53	**3813**	1	1	16	16	113	115	TST_UG05_SS05
53	**3813**	1	2	14		118		TST_UG05_SS05
53	**3813**	1	3	10	12	124	125	TST_UG05_SS05
53	**3813**	1	4	8	6	140	141	TST_UG05_SS05
53	**3813**	1	5	7	10	139	140	TST_UG05_SS05
53	**7322**	1	1	17	18	106	106	TST_UG05_SS05
53	**7322**	1	2	9	8	143	142	TST_UG05_SS05
56	**1007**	1	1	12	12	121	122	TST_UG05_SS05
56	**1007**	1	2	6	6	140	140	TST_UG05_SS05
56	**2019**	1	1	14	14	110	114	TST_UG05_SS05
56	**2019**	1	2	7		127		TST_UG05_SS05
56	**2019**	1	3	9	12	124	117	TST_UG05_SS05
56	**2020**	1	1	12	13	124	126	TST_UG05_SS05
83	**1801**	1	1	12	10	106	110	TST_UG05_SS05
83	**1801**	1	2	8	8	136	135	TST_UG05_SS05
83	**1801**	1	3	8	7	137	138	TST_UG05_SS05
83	**3802**	1	1	18	22	92	87	TST_UG05_SS05
83	**3802**		2	NA	----	NA	----	Assumed same as Layer 1
83	**3802**		3	6	6	141	141	TST_UG05_SS05
89	**3015**	1	1	12	12	110	110	TST_UG05_SS05
89	**3015**	1	2	7	6	136	137	TST_UG05_SS05
MnRoad 4	**---**	1	1	16.2	---	110.4	---	
MnRoad 21	**---**	1	1	17.3	---	109.2	---	
			2	7.9	---	135.3	---	Sample 1: 0 offset at 14"

Table 20 – Cont'd
Optimum Moisture Content and Maximum Dry Unit Weight – LTPP Data

State Code	SHRP ID	Construction No.	Layer No.	Optimum Moisture Content (%) Test 1	Optimum Moisture Content (%) Test 2	Maximum Dry Unit Weight (pcf) Test 1	Maximum Dry Unit Weight (pcf) Test 2	Source
Wstk 12	---		1					
			2	15	---	113	---	
			3	15	---	113	---	
			4	7		133.5		
Wstk 15	---		1					
			2	13	---	118.5	---	
			3	13	---	118.5	---	
			4	7		133.5		
Wstk 25	---		1					
			2	13	---	118.5	---	
			3	13	---	118.5	---	
			4	7		133.5		

Table 21
Unbound Materials Gradation I – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3" Passing	2" Passing	1 1/2" Passing	1" Passing	7/8" Passing	3/4" Passing	5/8" Passing	1/2" Passing
1	**0101**	1	SS		4/8/1997	100	100	100	100		100		99.6
1	**0101**	2	GB		2/21/1997	100	100	100	96.7		87		71.8
1	**0102**	1	SS										
1	**0102**	2	GB		2/21/1997	100	100	100	96.7		87		71.8
4	**0113**	1	SS		12/24/1993	100	100	98	96		93		89
4	**0113**	2	GB								93		
4	**0114**	1	SS		12/23/1993	100	96	94	85		82		77
4	**0114**	2	GB								93		
4	**0215**	1	SS		12/27/1993	100	100	100	100		99		97
4	**0215**	2	GB		12/13/1993	100	100	100	100		94		72
5	**2042**	1	SS	1	8/21/1991	100	100	100	100		100		99
				2	8/21/1991	100	100	100	100		99		97
5	**2042**	2	CTB										
6	**3042**	1	SS	1	6/25/1991	100	100	100	100		100		100
				2	6/25/1991	100	100	100	100		100		100
6	**3042**	2	GS		4/24/1991	100	100	100	100		100		100
8	**1053**	1	SS		1/24/1991	100	100	100	100		100		100
8	**1053**	2	GS	1	1/24/1991	100	77	77	72		65		57
				2	1/24/1991	100	81	73	65		57		49
8	**1053**	3	GB	1	1/24/1991	100	100	100	100		98		78
				2	1/24/1991	100	100	100	100		100		81
8	**7035**	1	SS	1	2/26/1991	100	100	100	100		100		100
				2	2/26/1991	100	100	100	100		100		100
8	**7035**	2	GS		1/21/1991	100	100	100	100		100		100
8	**7035**	3	GB	1	1/21/1991	100	100	100	100		100		96
				2	1/21/1991	100	100	100	100		100		95
9	**1803**	1	SS				99				95		
9	**1803**	2	GB	1	12/14/1990	97	97	93	86		82		76
				2	12/14/1990	92	89	85	76		71		63

Table 21 – Cont'd
Unbound Materials Gradation I – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3" Passing	2" Passing	1 1/2" Passing	1" Passing	7/8" Passing	3/4" Passing	5/8" Passing	1/2" Passing
10	**0102**	1	SS		11/18/1996	100	100	100	100		100		100
10	**0102**	2	GS		11/27/1998	100	100	100	100		100		100
10	**0102**	3	GB		6/15/1996			100	98		91		79
13	**1005**	1	SS	1	6/27/1990	100	100	100	100		99		98
				2	6/27/1990	100	100	100	100		100		100
13	**1005**	2	GB	1	6/27/1990	100	100	100	96		84		66
				2	6/27/1990	100	100	100	94		83		68
13	**1031**	1	SS	1	7/2/1991	100	100	100	100		100		99
				2	8/6/1990	100	100	99	97		94		91
13	**1031**	2	GB	1	7/2/1991	100	100	100	99		98		96
				2	7/2/1991	100	100	100	99		97		95
13	**3019**	1	SS	1	6/12/1991	100	100	100	100		99		98
				2	6/12/1991	100	100	100	100		99		97
13	**3019**	2	GB	1	6/12/1991	100	100	100	94		78		59
				2	6/12/1991	100	100	100	94		77		55
16	**1010**	1	SS	1	6/14/1990	100	100	100	100		100		99
				2	6/14/1990	100	100	100	100		100		100
16	**1010**	2	GB	1	6/14/1990	100	100	100	100		100		83
				2	6/14/1990	100	100	100	100		100		87
18	**3002**	1	SS	1	1/2/1991	100	100	100	100		99		96
				2	12/19/1990	100	100	100	100		100		99
18	**3002**	2	GB	1	12/5/1990	100	100	100	98		83		51
				2	12/5/1990	100	100	100	99		91		67
20	**4054**	1	SS	1	4/19/1990	100	100	100	100		100		99
				2	4/19/1990	100	100	100	100		100		100
22	**0118**	1	SS		10/17/1996	100	100	100	100		100		100
22	**0118**	2	GS		4/2/1997	100	100	100	100		100		100
22	**0118**	3	GB										
23	**1026**	1	SS	1	10/17/1990	94	89	85	78		74		69
				2	10/19/1990	100	100	99	97		97		95

Table 21 – Cont'd
Unbound Materials Gradation I – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3" Passing	2" Passing	1 1/2" Passing	1" Passing	7/8" Passing	3/4" Passing	5/8" Passing	1/2" Passing
23	**1026**	2	GB	1	10/25/1990	71	61	59	50		45		41
				2	10/25/1990	62	47	32	26		22		17
24	**1634**	1	SS	1	7/19/1990	100	100	100	100		100		100
				2	7/19/1990	100	100	100	100		100		100
24	**1634**	2	GS	1	7/23/1990	100	100	100	100		100		100
				2	7/24/1990	100	100	100	100		100		100
27	**4040**	1	SS	1	2/12/1990	100	100	100	100		99		97
				2	2/12/1990	100	100	100	100		99		99
27	**4040**	2	GB	1	1/15/1990	100	100	100	100		94		84
				2	1/15/1990	100	100	100	100		94		84
28	**1016**	1	SS	1	7/2/1991	100	100	100	100		100		100
				2	7/2/1991	100	100	100	99		97		96
28	**1016**	2	GS	1	7/2/1991	100	100	100	100		100		100
				2	7/2/1991	100	100	100	100		100		100
28	**1802**	1	SS	1	7/12/1991	100	100	100	100		100		100
				2	7/12/1991	100	100	100	100		100		100
28	**1802**	2	GS	1	7/12/1991	100	100	100	100		100		100
				2	7/12/1991	100	100	100	100		99		96
30	**7066**	1	SS	1	7/11/1990	100	100	100	98		97		96
				2	7/11/1990	100	98	98	96		94		93
30	**7066**	2	GS	1	6/18/1990	100	100	100	96		86		69
				2	6/18/1990	100	100	100	87		75		60
30	**7066**	3	GB		6/18/1990	100	100	100	100		100		93
30	**8129**	1	SS	1	8/23/1990	100	100	100	98		97		94
				2	8/23/1990	100	100	100	99		97		93
30	**8129**	2	GB	1	7/25/1990	100	100	100	100		97		77
				2	7/19/1990	100	100	100	100		95		76
31	**0114**	1	SS	2	6/19/1996	100	100	100	100		100		100
31	**0114**	2	GS	2	6/19/1996	100	100	100	100		100		100
31	**0114**	3	GB	2	12/19/1995			100	100		100		91

Table 21 – Cont'd
Unbound Materials Gradation I – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3" Passing	2" Passing	1 1/2" Passing	1" Passing	7/8" Passing	3/4" Passing	5/8" Passing	1/2" Passing
31	**3018**	1	SS	1	5/2/1990	100	100	100	100		100		99
				2	5/2/1990	100	100	100	100		100		98
32	**0101**	1	SS		5/6/1996	100	100	100	100		100		100
32	**0101**	2	TS		5/6/1996	100	100	100	100		100		100
32	**0101**	3	GS		3/19/1996	100	94	88	81		77		66
32	**0101**	4	GB		2/12/1996	100	100	100	96		85		67
32	**0204**	1	SS										
32	**0204**	2	TS										
32	**0204**	3	GS										
32	**0204**	4	GB										
33	**1001**	1	SS	1	9/19/1990	100	100	100	99		99		98
				2	9/19/1990	100	100	100	100		100		99
33	**1001**	2	GS	1	9/18/1990	100	100	97	93		89		85
				2	9/18/1990	100	97	93	88		84		79
33	**1001**	3	GB	1	9/19/1990	100	100	100	77		68		59
				2	9/18/1990	100	99	93	75		67		57
35	**0105**	1	SS		4/9/1997	100	100	100	100		100		99.2
35	**0105**	2	GB			100	100	100	100		98.1		
35	**1112**	1	SS	1	9/17/1991	100	100	100	100		100		100
				2	9/17/1991	100	100	100	100		100		100
35	**1112**	2	GB	1	9/17/1991	100	100	100	98		95		89
				2	9/17/1991	100	100	99	97		95		90
36	**0801**	1	SS	1	7/27/1994	100	100	100	100		93		92
				2	8/25/1994	100	100	91	87		86		85
				3	8/25/1994	100	100	100	100		100		100
36	**0801**	2	GB		2/12/1997	100	100	94	75.9		63.2		49.1
36	**4018**	1	SS	1	12/3/1990	100	100	99	94		90		84
				2	11/29/1990	100	99	99	96		91		84
37	**0201**	1	SS		11/29/1993	100	100	100	100		100		100
37	**0201**	2	LTS		11/29/1993	100	100	100	100		100		100
37	**0201**	3	GB		11/30/1993	100	100	100	98		87		73

Table 21 – Cont'd
Unbound Materials Gradation I – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3" Passing	2" Passing	1 1/2" Passing	1" Passing	7/8" Passing	3/4" Passing	5/8" Passing	1/2" Passing
37	**0205**	1	SS		11/29/1993	100	100	100	100		100		100
37	**0205**	2	LTS		11/29/1993	100	100	100	100		100		100
37	**0208**	1	SS		11/29/1993	100	100	100	100		100		100
37	**0208**	2	LTS		11/29/1993	100	100	100	100		100		100
37	**0212**	1	SS		1/20/1997	100	100	100	100		100		100
37	**0212**	2	LTS		1/20/1997	100	100	100	100		100		100
37	**0212**	3	GB		1/16/1997	100	100	100	90.4		79.2		64.9
37	**1028**	1	SS	1	9/27/1989	100	100	100	100		100		100
				2	9/27/1989	100	100	100	100		100		100
39	**0204**	1	SS										
39	**0204**	2	GS										
39	**0204**	3	GB										
40	**4165**	1	SS	1	4/29/1991	100	100	100	100		100		100
				2	4/29/1991	100	100	100	100		100		100
41	**6011**	1	SS	1	5/23/1991	100	100	100	100		100		99
				2	5/23/1991	100	100	100	100		100		100
41	**6011**	2	GS		3/25/1991	100	100	100	88		75		54
41	**6011**	3	GB	1	3/25/1991	100	100	100	86		76		49
				2	3/25/1991	100	100	100	100		98		85
42	**0603**	1	SS		4/10/1997	100	100	97	93		88		79
42	**0603**	2	GB		4/7/1997	100	100	99	91		79		60
42	**1606**	1	SS	1	2/4/1991	100	100	100	99		95		90
				2	2/4/1991	100	98	97	94		89		85
42	**1606**	2	GB	1	2/7/1991	100	100	100	96		70		39
				2	2/4/1991	100	100	100	97		81		60
46	**9187**	1	SS	1	7/12/1990	100	100	100	100		100		100
				2	7/12/1990	100	100	100	100		100		98
46	**9187**	2	GS	1	4/20/1990	100	100	98	93		86		74
				2	4/20/1990	100	100	100	98		94		85
46	**9187**	3	GB				100	100	100	100	99.5	94.5	84

Table 21 – Cont'd
Unbound Materials Gradation I – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3" Passing	2" Passing	1 1/2" Passing	1" Passing	7/8" Passing	3/4" Passing	5/8" Passing	1/2" Passing
47	**3101**	1	SS	1	9/5/1991	100	100	100	100		100		98
				2	9/5/1991	100	100	100	100		100		99
47	**3101**	2	GS	1	9/5/1991	100	100	100	100		95		78
				2	9/5/1991	100	100	100	99		94		75
48	**1060**	1	SS	1	4/29/1991	100	100	100	100		100		100
				2	4/29/1991	100	100	100	100		99		99
48	**1060**	2	TS							82		73	
48	**1060**	3	GB	1	4/29/1991	100	100	98	92		85		73
				2	4/29/1991	100	99	93	79		68		56
48	**1068**	1	SS	1	8/23/1991	100	100	100	100		100		100
				2	8/23/1991	100	100	100	100		100		100
48	**1068**	2	TS										
48	**1068**	3	GB	1	8/23/1991	100	100	100	95		86		68
				2	8/23/1991	100	100	100	95		87		72
48	**1077**	1	SS	1	12/18/1990	100	100	100	98		97		96
				2	12/18/1990	100	100	100	100		99		99
48	**1077**	2	GB	1	12/18/1990	100	100	100	86		74		60
				2	12/18/1990	100	100	100	91		82		69
48	**1122**	1	SS	1	12/18/1990	100	100	100	100		100		100
				2	12/18/1990	100	100	100	100		100		100
48	**1122**	2	GS	1	12/18/1990	100	100	99	99		99		98
				2	12/18/1990	100	99	99	99		98		97
48	**1122**	3	GB	1	12/18/1990	100	100	100	98		93		83
				2	12/18/1990	100	99	99	94		88		77
48	**3739**	1	SS	1	11/28/1990	100	100	100	100		100		100
				2	11/28/1990	100	100	100	100		100		100
48	**3739**	2	TS									100	65
48	**3739**	3	GB	1	6/26/1991	100	100	100	99		95		88
				2	6/26/1991	100	100	100	97		93		84
48	**4142**	1	SS	1	7/22/1991	100	100	100	100		100		100
				2	7/22/1991	100	100	100	100		100		100

Table 21 – Cont'd
Unbound Materials Gradation I – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3" Passing	2" Passing	1 1/2" Passing	1" Passing	7/8" Passing	3/4" Passing	5/8" Passing	1/2" Passing
48	**4142**	2	GS	1	7/22/1991	100	100	100	100		100		100
				2	7/22/1991	100	100	100	100		100		99
48	**4143**	1	SS	1	4/15/1991	100	100	100	100		100		100
				2	4/15/1991	100	100	100	100		100		100
48	**4143**	2	TS										
49	**1001**	1	SS	1	11/2/1989	100	100	100	100		100		100
				2	11/2/1989	100	100	100	100		100		100
49	**1001**	2	GB	1	10/24/1989	100	100	100	100		99		86
				2	10/24/1989	100	100	100	100		97		76
49	**3011**	1	SS	1	12/20/1989	100	100	99	95		90		84
				2	12/20/1989	100	99	98	93		90		82
49	**3011**	2	GS	1	12/6/1989	100	100	100	100		93		72
				2	12/6/1989	100	100	100	100		90		70
50	**1002**	1	SS		2/14/1991	94	92	88	80		76		70
50	**1002**	2	GB	1	2/14/1991	100	93	83	56		45		31
				2	2/14/1991	100	92	81	64		54		42
50	**1681**	1	SS	1	10/31/1990	100	100	100	99		98		96
				2	10/31/1990	84	77	72	67		64		59
50	**1681**	2	GS	1	11/5/1990	100	98	97	96		95		91
				2	11/2/1990	100	100	100	99		99		97
50	**1681**	3	GS	1	11/5/1990	100	99	96	92		86		79
				2	11/2/1990	100	95	88	83		77		71
51	**0113**	1	SS		4/23/1997	100	100	100	100		100		98
51	**0113**	3	GB		10/28/1996	100	100	100	100		90.8		82.6
51	**0114**	1	SS		4/23/1997	100	100	100	100		100		98
51	**0114**	3	GB		10/28/1996	100	100	100	100		90.8		82.6
53	**1007**	1	SS	1	4/4/1991	100	100	100	100		100		99
				2	4/3/1991	100	100	100	100		100		100
53	**1007**	2	GB	1	2/15/1991	100	100	100	100		95		86
				2	2/15/1991	100	100	100	100		95		87

Table 21 – Cont'd
Unbound Materials Gradation I – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3" Passing	2" Passing	1 1/2" Passing	1" Passing	7/8" Passing	3/4" Passing	5/8" Passing	1/2" Passing
53	**3813**	1	SS	1	4/25/1991	100	100	100	99		97		94
				2	4/25/1991	100	100	100	100		100		100
53	**3813**	2	GS		3/19/1991	100	100	100	99		98		98
53	**3813**	3	GS	1	3/20/1991	100	100	100	100		98		95
				2	3/20/1991	100	100	100	97		95		92
53	**3813**	4	GS	1	3/19/1991	100	100	99	89		84		72
				2	3/19/1991	100	100	92	82		73		62
53	**3813**	5	GB	1	3/20/1991	100	100	100	100		99		97
				2	3/20/1991	100	100	100	100		97		93
53	**7322**	1	SS	1	4/3/1991	100	100	100	100		100		93
				2	4/3/1991	100	100	100	100		100		100
53	**7322**	2	GB	1	2/11/1991	100	100	100	100		95		86
				2	2/11/1991	100	100	100	100		99		93
56	**1007**	1	SS	1	11/30/1990	100	100	100	100		100		98
				2	12/31/1990	100	100	100	99		97		91
56	**1007**	2	GB	1	11/27/1990	100	100	100	100		98		81
				2	11/27/1990	100	100	100	100		98		84
56	**2019**	1	SS	1	1/31/1991	100	100	100	100		100		100
				2	1/23/1991	100	90	86	84		81		75
56	**2019**	2	GS		1/15/1991	100	100	100	100		100		97
56	**2019**	3	GS	1	1/15/1991	100	100	100	100		98		98
				2	1/15/1991	100	100	100	100		100		100
56	**2020**	1	SS	1	11/30/1990	100	100	97	95		92		82
				2	12/31/1990	100	100	100	92		81		69
83	**1801**	1	SS	1	10/28/1991	100	100	100	100		100		100
				2	10/28/1991	100	100	100	100		100		100
83	**1801**	2	GS	1	7/31/1991	100	100	100	91		85		74
				2	7/31/1991	100	100	100	93		85		77
83	**1801**	3	GB	1	7/31/1991	100	100	100	100		100		85
				2	7/31/1991	100	100	100	100		100		86

Table 21 – Cont'd
Unbound Materials Gradation I – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3" Passing	2" Passing	1 1/2" Passing	1" Passing	7/8" Passing	3/4" Passing	5/8" Passing	1/2" Passing
83	**3802**	1	SS	1	11/25/1991	100	100	100	100		100		100
				2	11/25/1991	100	100	100	100		100		100
		2	LTS										
83	**3802**	3	GB	1	7/30/1991	100	100	100	100		100		88
				2	7/30/1991	100	100	100	100		100		91
89	**3015**	1	SS	1	8/6/1991	100	100	97	97		96		95
				2	8/6/1991	100	100	100	99		97		95
89	**3015**	2	GB	1	8/7/1991	100	96	90	76		67		58
				2	8/6/1991	100	99	88	80		74		66
MnRoad 4	**---**	1	SS										
MnRoad 21	**---**	1	SS										
		2	GB			100	100	100	100		96		

Table 22
Unbound Materials Gradation II – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3/8" Passing	#4 Passing	#10 Passing	#40 Passing	#80 Passing	#200 Passing	Hydrometer 0.02 mm	Hydrometer 0.002 mm	Hydrometer 0.001 mm
1	**0101**	1	SS		4/8/1997	99.6	99.1	97.8	89.6	82.1	68	46.1	23	
1	**0101**	2	GB		2/21/1997	63	46.6	34.1	24.2	18.6	12			
1	**0102**	1	SS											
1	**0102**	2	GB		2/21/1997	63	46.6	34.1	24.2	18.6	12			
4	**0113**	1	SS		12/24/1993	86	77	58	22	11	8.8	5.7	2.7	2.3
4	**0113**	2	GB			71.2	57.2				10.2			
4	**0114**	1	SS		12/23/1993	74	64	51	31	24	19.1	12.3	7.7	7.2
4	**0114**	2	GB			71.2	57.2				10.2			
4	**0215**	1	SS		12/27/1993	93	83	75	49	35	25.6	13.5	6.9	6
4	**0215**	2	GB		12/13/1993	64	54	48	26	14	8			
5	**2042**	1	SS	1	8/21/1991	99	98	96	93	89	78.5	42.5	16.4	0
				2	8/21/1991	96	93	90	85	80	68.9	29	14.6	0
5	**2042**	2	CTB											
6	**3042**	1	SS	1	6/25/1991	98	98	98	95	86	70.7	53.2	34.7	21.6
				2	6/25/1991	100	100	100	97	83	58.3	39.3	16	14.5
6	**3042**	2	GS		4/24/1991	100	94	87	76	63	45.2			
8	**1053**	1	SS		1/24/1991	100	97	97	96	94	91.8			
8	**1053**	2	GS	1	1/24/1991	52	42	33	21	14	9.4			
				2	1/24/1991	46	38	32	16	11	7.6			
8	**1053**	3	GB	1	1/24/1991	66	47	35	22	14	8.9			
				2	1/24/1991	66	48	36	21	11	6.9			
8	**7035**	1	SS	1	2/26/1991	100	100	100	91	80	72.3	48.2	38.9	33.4
				2	2/26/1991	100	99	98	92	83	76	47.2	29.1	26.6
8	**7035**	2	GS		1/21/1991	100	99	99	64	25	13.3			
8	**7035**	3	GB	1	1/21/1991	90	81	75	48	22	12.7			
				2	1/21/1991	84	69	59	39	28	21.8			
9	**1803**	1	SS				90	84			12.6			
9	**1803**	2	GB	1	12/14/1990	71	63	52	33	18	9.6			
				2	12/14/1990	58	49	40	22	11	5.8			

Table 22 – Cont'd
Unbound Materials Gradation II – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3/8" Passing	#4 Passing	#10 Passing	#40 Passing	#80 Passing	#200 Passing	Hydrometer 0.02 mm	Hydrometer 0.002 mm	Hydrometer 0.001 mm
10	**0102**	1	SS		11/18/1996	100	100	99	74	43	26.8	16.8	5.2	
10	**0102**	2	GS		11/27/1998	100	100	100	79	27	13.6	10	5.6	
10	**0102**	3	GB		6/15/1996	71	49	32	17	9	6			
13	**1005**	1	SS	1	6/27/1990	97	93	89	81	68	38.4	32	23.9	22.8
				2	6/27/1990	100	100	100	95	79	36	27.3	19.1	18.6
13	**1005**	2	GB	1	6/27/1990	59	44	36	27	17	7.8			
				2	6/27/1990	61	48	41	30	18	8.9			
13	**1031**	1	SS	1	7/2/1991	99	98	93	75	61	44.8	30.3	14.9	0
				2	8/6/1990	90	88	84	69	56	42.6	31	18	15
13	**1031**	2	GB	1	7/2/1991	95	94	66	52	37	21.5			
				2	7/2/1991	94	93	78	48	29	10.7			
13	**3019**	1	SS	1	6/12/1991	97	93	86	75	69	56.8	33.5	17.9	
				2	6/12/1991	96	94	90	83	77	63	44	28.4	
13	**3019**	2	GB	1	6/12/1991	52	41	34	26	17	10.9			
				2	6/12/1991	47	36	33	31	28	25.6			
16	**1010**	1	SS	1	6/14/1990	97	92	78	48	19	8.3			
				2	6/14/1990	99	97	88	66	38	13.1			
16	**1010**	2	GB	1	6/14/1990	65	46	34	23	14	7.8			
				2	6/14/1990	68	46	34	25	16	8.2			
18	**3002**	1	SS	1	1/2/1991	95	94	92	86	72	62	51.3	27.4	
				2	12/19/1990	99	98	97	93	80	72.8	61.6	33.6	
18	**3002**	2	GB	1	12/5/1990	41	27	22	20	10	3			
				2	12/5/1990	55	37	30	27	13	4.1			
20	**4054**	1	SS	1	4/19/1990	99	97	96	94	89	87.2	58.1	33.4	
				2	4/19/1990	100	99	99	98	97	95.9	64.1	37.6	
22	**0118**	1	SS		10/17/1996	100	100	100	99	99	96.5			
22	**0118**	2	GS		4/2/1997	99.3	98.9	98.5	97.6	97.3	91.3	33.6	8.7	
22	**0118**	3	GB											
23	**1026**	1	SS	1	10/17/1990	66	60	54	36	23	11.2			
				2	10/19/1990	93	90	84	58	32	12.6			

Table 22 – Cont'd
Unbound Materials Gradation II – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3/8" Passing	#4 Passing	#10 Passing	#40 Passing	#80 Passing	#200 Passing	Hydrometer 0.02 mm	Hydrometer 0.002 mm	Hydrometer 0.001 mm
23	**1026**	2	GB	1	10/25/1990	38	32	26	13	7	4			
				2	10/25/1990	14	9	5	2	1	0.2			
24	**1634**	1	SS	1	7/19/1990	100	99	98	98	98	97.9			
				2	7/19/1990	100	100	100	99	99	99			
24	**1634**	2	GS	1	7/23/1990	100	100	99	99	99	98.9			
				2	7/24/1990	100	100	99	99	99	98.9			
27	**4040**	1	SS	1	2/12/1990	97	96	94	89	84	79.4	69.2	33.2	25.6
				2	2/12/1990	99	98	95	88	78	72.7	58.3	23.8	17.3
27	**4040**	2	GB	1	1/15/1990	78	68	59	30	19	14			
				2	1/15/1990	78	68	59	30	19	14			
28	**1016**	1	SS	1	7/2/1991	99	99	99	97	66	34.4	28.5	18.9	
				2	7/2/1991	94	92	91	85	46	25.7	22.5	14.8	
28	**1016**	2	GS	1	7/2/1991	99	99	99	98	60	21.4			
				2	7/2/1991	100	100	100	97	34	11.5			
28	**1802**	1	SS	1	7/12/1991	100	100	98	70	11	1.7			
				2	7/12/1991	100	100	96	64	21	6.8			
28	**1802**	2	GS	1	7/12/1991	100	99	97	79	28	17.4			
				2	7/12/1991	94	90	86	64	27	18.1			
30	**7066**	1	SS	1	7/11/1990	95	91	85	77	66	56.3	38	23.2	20.7
				2	7/11/1990	92	90	87	81	69	54.7	42.6	26	22.9
30	**7066**	2	GS	1	6/18/1990	61	42	30	22	16	11.7			
				2	6/18/1990	54	42	30	20	12	8.4			
30	**7066**	3	GB		6/18/1990	85	63	40	22	14	10.1			
30	**8129**	1	SS	1	8/23/1990	92	85	77	72	66	55.2	37.6	22.7	20.1
				2	8/23/1990	90	84	79	76	72	60.3	39.4	21.1	17.6
30	**8129**	2	GB	1	7/25/1990	63	35	20	15	10	6.8			
				2	7/19/1990	66	43	29	21	12	7.5			
31	**0114**	1	SS	2	6/19/1996	100	100	99	98	98	96.7	65.3	27.6	
31	**0114**	2	GS	2	6/19/1996	100	100	100	99	98	97.8	73.7	39.5	
31	**0114**	3	GB	2	12/19/1995	87	74	54	23	10	6.9			

Table 22 – Cont'd
Unbound Materials Gradation II – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3/8" Passing	#4 Passing	#10 Passing	#40 Passing	#80 Passing	#200 Passing	Hydrometer 0.02 mm	Hydrometer 0.002 mm	Hydrometer 0.001 mm
31	**3018**	1	SS	1	5/2/1990	97	91	78	35	13	4.5	1.4	0.6	
				2	5/2/1990	97	91	80	38	14	4.8	0.7	0.3	
32	**0101**	1	SS		5/6/1996	100	100	98	76	42	24.2	15.3	6.6	
32	**0101**	2	TS		5/6/1996	100	100	98	76	42	24.2	15.3	6.6	
32	**0101**	3	GS		3/19/1996	60	48	38	24	17	11.4	7.5	3.3	
32	**0101**	4	GB		2/12/1996	59	46	37	24	17	12.4			
32	**0204**	1	SS											
32	**0204**	2	TS											
32	**0204**	3	GS											
32	**0204**	4	GB											
33	**1001**	1	SS	1	9/19/1990	97	95	93	74	40	14.8	7.8	4	3.7
				2	9/19/1990	99	98	96	70	26	7.9	6.6	3.4	3.3
33	**1001**	2	GS	1	9/18/1990	81	75	68	37	17	8			
				2	9/18/1990	76	69	60	24	10	4.9			
33	**1001**	3	GB	1	9/19/1990	52	44	37	16	8	4.5			
				2	9/18/1990	50	42	35	16	9	4.6			
35	**0105**	1	SS		4/9/1997	98.8	98.5	98.1	96.9	94.3	86.4	72.4	45.3	
35	**0105**	2	GB				54.3	35.2			4.7			
35	**1112**	1	SS	1	9/17/1991	100	99	99	96	70	3.6			
				2	9/17/1991	100	100	99	94	60	2.7			
35	**1112**	2	GB	1	9/17/1991	83	67	59	49	36	14.7			
				2	9/17/1991	86	73	61	48	38	18.9			
36	**0801**	1	SS	1	7/27/1994	90	88	86	76	43	21.9	5.2	4.8	
				2	8/25/1994	83	80	77	72	56	31.6	19.9	8.7	8.4
				3	8/25/1994	99	97	95	86	56	28.7	14	6.4	5.6
36	**0801**	2	GB		2/12/1997	42.6	30.1	20.6	12.2	10.2	8.1			
36	**4018**	1	SS	1	12/3/1990	79	68	54	32	26	21.4			
				2	11/29/1990	77	64	49	25	19	15.9			
37	**0201**	1	SS		11/29/1993	100	100	99	86	78	70.3	59.7	35.3	34.2
37	**0201**	2	LTS		11/29/1993	100	100	99	86	78	70.3	59.7	35.3	34.2
37	**0201**	3	GB		11/30/1993	64	51	33	16	12	8.8			

Table 22 – Cont'd
Unbound Materials Gradation II – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3/8" Passing	#4 Passing	#10 Passing	#40 Passing	#80 Passing	#200 Passing	Hydrometer 0.02 mm	Hydrometer 0.002 mm	Hydrometer 0.001 mm
37	**0205**	1	SS		11/29/1993	100	99	96	84	75	61.8			
37	**0205**	2	LTS		11/29/1993	100	99	96	84	75	61.8			
37	**0208**	1	SS		11/29/1993	100	100	100	99	93	70.7	56.3	28.1	23.9
37	**0208**	2	LTS		11/29/1993	100	100	100	99	93	70.7	56.3	28.1	23.9
37	**0212**	1	SS		1/20/1997	100	100	99	90	81	67.3	50.9	25.8	
37	**0212**	2	LTS		1/20/1997	100	100	99	90	81	67.3	50.9	25.8	
37	**0212**	3	GB		1/16/1997	59.9	45.9	27.7	12.2	8.6	6.2			
37	**1028**	1	SS	1	9/27/1989	100	100	100	94	50	8.5	8.1	4.4	4
				2	9/27/1989	100	100	99	93	55	8.8	8.4	6	5
39	**0204**	1	SS											
39	**0204**	2	GS											
39	**0204**	3	GB											
40	**4165**	1	SS	1	4/29/1991	100	100	100	92	56	28.2	13	9	0
				2	4/29/1991	100	100	100	95	61	30	14	11.7	0
41	**6011**	1	SS	1	5/23/1991	97	88	83	74	67	62.6	53.7	35.5	32.5
				2	5/23/1991	97	69	68	67	66	64.2	60.8	37	32.4
41	**6011**	2	GS		3/25/1991	45	31	23	13	7	5.4			
41	**6011**	3	GB	1	3/25/1991	38	20	14	8	5	3.4			
				2	3/25/1991	75	56	35	12	6	3.5			
42	**0603**	1	SS		4/10/1997	75	63	52	42	38	33.4	20.6	6.8	
42	**0603**	2	GB		4/7/1997	52	34	22	11	8	6.6			
42	**1606**	1	SS	1	2/4/1991	86	80	73	63	50	43.7	35	22.3	19.1
				2	2/4/1991	81	77	73	64	55	50.8			
42	**1606**	2	GB	1	2/7/1991	26	16	12	8	6	5.3			
				2	2/4/1991	50	37	26	15	12	10.2			
46	**9187**	1	SS	1	7/12/1990	100	100	99	98	97	85.7	54.9	35.4	
				2	7/12/1990	97	93	87	77	73	64	39.4	23.4	
46	**9187**	2	GS	1	4/20/1990	68	50	38	19	12	7.4			
				2	4/20/1990	78	59	45	23	15	10.2			
46	**9187**	3	GB			71.5	54	40.5	20	11.5	6			

Table 22 – Cont'd
Unbound Materials Gradation II – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3/8" Passing	#4 Passing	#10 Passing	#40 Passing	#80 Passing	#200 Passing	Hydrometer 0.02 mm	Hydrometer 0.002 mm	Hydrometer 0.001 mm
47	**3101**	1	SS	1	9/5/1991	96	93	89	81	78	74.5	63	40.7	
				2	9/5/1991	99	98	96	91	88	80.7	65	44	
47	**3101**	2	GS	1	9/5/1991	67	49	39	23	19	16.2			
				2	9/5/1991	67	48	33	16	12	9.9			
48	**1060**	1	SS	1	4/29/1991	100	100	97	79	46	30.7	25	17	0
				2	4/29/1991	98	97	95	83	53	37.2	32.5	22	0
48	**1060**	2	TS			60	48	41	28		24.4			
48	**1060**	3	GB	1	4/29/1991	66	52	43	25	14	7.1			
				2	4/29/1991	50	40	32	16	6	2.8			
48	**1068**	1	SS	1	8/23/1991	100	100	98	97	96	94	66	38.9	0
				2	8/23/1991	100	100	88	71	61	54	45	25.9	0
48	**1068**	2	TS				71							
48	**1068**	3	GB	1	8/23/1991	59	38	31	24	21	12.2			
				2	8/23/1991	63	43	34	26	21	12			
48	**1077**	1	SS	1	12/18/1990	95	94	93	87	76	51.8	15	10	0
				2	12/18/1990	98	97	97	94	90	73.6	23	12.5	0
48	**1077**	2	GB	1	12/18/1990	53	41	35	23	14	9.3			
				2	12/18/1990	61	49	42	25	12	7			
48	**1122**	1	SS	1	12/18/1990	99	99	97	75	29	6.5	6	6	0
				2	12/18/1990	99	99	98	72	46	32.1	26.3	24.5	0
48	**1122**	2	GS	1	12/18/1990	98	96	91	72	46	27.9			
				2	12/18/1990	97	96	96	64	34	18.7			
48	**1122**	3	GB	1	12/18/1990	75	57	47	32	27	21.7			
				2	12/18/1990	69	53	43	31	27	22.9			
48	**3739**	1	SS	1	11/28/1990	100	99	99	98	72	6.2	4.3	4.3	0
				2	11/28/1990	100	100	100	99	68	4.3	3	3	0
48	**3739**	2	TS				41		18					
48	**3739**	3	GB	1	6/26/1991	82	66	53	34	23	9.3			
				2	6/26/1991	76	61	43	20	13	4.8			
48	**4142**	1	SS	1	7/22/1991	100	100	100	99	62	5.5			
				2	7/22/1991	100	100	99	95	86	42.9	39.6	30.6	

Table 22 – Cont'd
Unbound Materials Gradation II – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3/8" Passing	#4 Passing	#10 Passing	#40 Passing	#80 Passing	#200 Passing	Hydrometer 0.02 mm	Hydrometer 0.002 mm	Hydrometer 0.001 mm
48	**4142**	2	GS	1	7/22/1991	100	100	98	71	20	11.2			
				2	7/22/1991	99	97	95	55	19	11.8			
48	**4143**	1	SS	1	4/15/1991	100	100	99	98	97	91.2	62	37	
				2	4/15/1991	100	100	99	96	96	89.1	57	34	
48	**4143**	2	TS											
49	**1001**	1	SS	1	11/2/1989	99	97	96	91	50	14.1	7.5	3.9	3.1
				2	11/2/1989	100	100	100	99	80	26.8	13.7	8.3	7.2
49	**1001**	2	GB	1	10/24/1989	74	63	56	49	32	12.6			
				2	10/24/1989	62	49	39	27	17	8.6			
49	**3011**	1	SS	1	12/20/1989	80	72	66	58	47	36.4	19.5	10.8	8.5
				2	12/20/1989	78	70	65	55	45	35	20.4	10.7	8.3
49	**3011**	2	GS	1	12/6/1989	59	42	32	25	19	13.6			
				2	12/6/1989	60	44	33	26	19	14			
50	**1002**	1	SS		2/14/1991	62	48	38	17	10	6.9	6.4	2.6	2.1
50	**1002**	2	GB	1	2/14/1991	24	15	10	5	4	3.4			
				2	2/14/1991	34	20	10	4	3	2.7			
50	**1681**	1	SS	1	10/31/1990	92	85	74	51	38	32.3	28	12.2	11.1
				2	10/31/1990	56	51	44	35	29	25	22.5	13	12.9
50	**1681**	2	GS	1	11/5/1990	86	75	61	29	15	10.7			
				2	11/2/1990	94	89	79	45	18	8.4			
50	**1681**	3	GS	1	11/5/1990	74	61	44	17	9	5.6			
				2	11/2/1990	67	55	39	19	9	4			
51	**0113**	1	SS		4/23/1997	98	96	91	74	60	37.9	18.7	8.8	
51	**0113**	3	GB		10/28/1996	71	51.2	35	21.5	16.9	11			
51	**0114**	1	SS		4/23/1997	98	96	91	74	60	37.9	18.7	8.8	
51	**0114**	3	GB		10/28/1996	71	51.2	35	21.5	16.9	11			
53	**1007**	1	SS	1	4/4/1991	96	95	93	87	80	68.4	27.8	7.1	6
				2	4/3/1991	99	98	97	92	84	71.7	29.9	6.8	5.3
53	**1007**	2	GB	1	2/15/1991	79	55	35	15	11	7.5			
				2	2/15/1991	79	56	37	18	13	9.1			

Table 22 – Cont'd
Unbound Materials Gradation II – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3/8" Passing	#4 Passing	#10 Passing	#40 Passing	#80 Passing	#200 Passing	Hydrometer 0.02 mm	Hydrometer 0.002 mm	Hydrometer 0.001 mm
53	**3813**	1	SS	1	4/25/1991	92	85	79	62	50	31	16.2	4.4	3.2
				2	4/25/1991	100	98	95	86	53	22.5	11.3	3	1.4
53	**3813**	2	GS		3/19/1991	97	96	95	91	85	57.9			
53	**3813**	3	GS	1	3/20/1991	92	83	78	70	63	44.1			
				2	3/20/1991	90	83	76	58	46	32.7			
53	**3813**	4	GS	1	3/19/1991	64	45	29	17	14	11.4			
				2	3/19/1991	54	38	28	17	14	10.8			
53	**3813**	5	GB	1	3/20/1991	88	66	48	28	23	17.5			
				2	3/20/1991	85	58	39	20	16	12.9			
53	**7322**	1	SS	1	4/3/1991	89	87	86	84	84	82.4	47.7	21.4	19.6
				2	4/3/1991	100	100	100	99	98	96.9	57.5	26.6	24.7
53	**7322**	2	GB	1	2/11/1991	72	46	27	12	9	7			
				2	2/11/1991	85	59	33	8	5	4.5			
56	**1007**	1	SS	1	11/30/1990	96	88	84	78	52	24.3	17.9	11.3	11.2
				2	12/31/1990	87	75	74	71	50	23	17.3	11.2	10
56	**1007**	2	GB	1	11/27/1990	70	51	40	28	18	9.8			
				2	11/27/1990	74	54	41	26	16	8.6			
56	**2019**	1	SS	1	1/31/1991	99	89	88	68	32	14.5			
				2	1/23/1991	71	62	56	47	29	18.5	12.3	6.1	5.2
56	**2019**	2	GS		1/15/1991	91	70	48	24	14	8.7			
56	**2019**	3	GS	1	1/15/1991	97	97	80	59	43	32.2			
				2	1/15/1991	100	98	98	80	31	15.1			
56	**2020**	1	SS	1	11/30/1990	70	30	24	20	18	13.5	12.4	7.3	7
				2	12/31/1990	61	38	29	20	16	12.2	11.7	8.1	7.3
83	**1801**	1	SS	1	10/28/1991	100	100	100	99	75	21.9	10.9	6.2	
				2	10/28/1991	100	100	99	93	49	28.8	16.9	9.6	
83	**1801**	2	GS	1	7/31/1991	69	57	47	17	12	10.5			
				2	7/31/1991	73	61	54	23	12	10.1			
83	**1801**	3	GB	1	7/31/1991	78	62	48	23	12	10.9			
				2	7/31/1991	77	59	47	22	11	9.6			

Table 22 – Cont'd
Unbound Materials Gradation II – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	Test Date	3/8" Passing	#4 Passing	#10 Passing	#40 Passing	#80 Passing	#200 Passing	Hydrometer 0.02 mm	Hydrometer 0.002 mm	Hydrometer 0.001 mm
83	**3802**	1	SS	1	11/25/1991	99	98	97	95	94	90.6	79.6	57.6	
				2	11/25/1991	100	100	100	99	97	92.5	89.1	68.8	
		2	LTS											
83	**3802**	3	GB	1	7/30/1991	80	64	45	19	11	9.8			
				2	7/30/1991	84	66	46	15	11	10.5			
89	**3015**	1	SS	1	8/6/1991	94	92	90	84	25	3.8	3.1	0.6	0.5
				2	8/6/1991	93	91	89	84	29	2			
89	**3015**	2	GB	1	8/7/1991	51	41	33	18	7	3.7			
				2	8/6/1991	59	48	39	22	9	4.7			
MnRoad 4	**---**	1	SS											
MnRoad 21	**---**	1	SS											
		2	GB			81	69	54	20		5.7			

Table 23
Unbound Materials Gradation III – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	% > 2 mm	% Coarse Sand	% Fine Sand	% Silt	% Clay	% Colloids	Source
1	**0101**	1	SS		2.2	8.1	22.9	43.8	23		TST_SS02_UG03
1	**0101**	2	GB								TST_SS01_UG01_UG02
1	**0102**	1	SS								
1	**0102**	2	GB								TST_SS01_UG01_UG02
4	**0113**	1	SS		42	36	13	6.1	2.7	2.3	TST_SS02_UG03
4	**0113**	2	GB								BRE-Cal 2002 Guide
4	**0114**	1	SS		49	20	13	11.3	7.7	7.2	TST_SS02_UG03
4	**0114**	2	GB								BRE-Cal 2002 Guide
4	**0215**	1	SS		25	26	23	18.8	6.9	6	TST_SS02_UG03-040216
4	**0215**	2	GB								TST_SS01_UG01_UG02
5	**2042**	1	SS	1	4	3	15	62.1	16.4	0	TST_SS02_UG03
				2	10	5	16	54.3	14.6	0	TST_SS02_UG03
5	**2042**	2	CTB								
6	**3042**	1	SS	1	2	3	24	46	24.7	21.6	TST_SS02_UG03
				2	0	3	39	42.3	16	14.5	TST_SS02_UG03
6	**3042**	2	GS								TST_SS01_UG01_UG02
8	**1053**	1	SS								TST_SS01_UG01_UG02
8	**1053**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
8	**1053**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
8	**7035**	1	SS	1	0	9	18	38.9	33.4	33.4	TST_SS02_UG03
				2	2	6	16	46.9	29.1	26.6	TST_SS02_UG03
8	**7035**	2	GS								TST_SS01_UG01_UG02
8	**7035**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
9	**1803**	1	SS								Cheryl Richter-Cal ICM
9	**1803**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02

Table 23 – Cont'd
Unbound Materials Gradation III – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	% > 2 mm	% Coarse Sand	% Fine Sand	% Silt	% Clay	% Colloids	Source
10	**0102**	1	SS		1	21	51	21.6	5.2		TST_SS02_UG03
10	**0102**	2	GS		0	17	70	7.2	5.6		TST_SS02_UG03
10	**0102**	3	GB								TST_AG04 - 100103
13	**1005**	1	SS	1	11	8	42	14.5	23.9	22.8	TST_SS02_UG03
				2	0	5	59	16.9	19.1	18.6	TST_SS02_UG03
13	**1005**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
13	**1031**	1	SS	1	7	18	30	29.9	14.9	0	TST_SS02_UG03
				2	16	15	27	24	18	15	TST_SS02_UG03
13	**1031**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
13	**3019**	1	SS	1	14	11	18	38.9	17.9		TST_SS02_UG03
				2	10	7	20	34.6	28.4		TST_SS02_UG03
13	**3019**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
16	**1010**	1	SS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
16	**1010**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
18	**3002**	1	SS	1	8	4	21	39.6	27.4		TST_SS02_UG03
				2	3	4	20	39.1	33.6		TST_SS02_UG03
18	**3002**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
20	**4054**	1	SS	1	4	2	9	51.1	33.4		TST_SS02_UG03
				2	1	1	3	57.8	37.6		TST_SS02_UG03
22	**0118**	1	SS								TST_SS01_UG01_UG02
22	**0118**	2	GS		1.5	0.9	5.4	83.5	8.7		TST_SS02_UG03
22	**0118**	3	GB								
23	**1026**	1	SS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02

Table 23 – Cont'd
Unbound Materials Gradation III – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	% > 2 mm	% Coarse Sand	% Fine Sand	% Silt	% Clay	% Colloids	Source
23	**1026**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
24	**1634**	1	SS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
24	**1634**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
27	**4040**	1	SS	1	6	5	9	46.5	33.2	25.6	TST_SS02_UG03
				2	5	6	17	48.5	23.8	17.3	TST_SS02_UG03
27	**4040**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
28	**1016**	1	SS	1	1	2	63	15.5	18.9		TST_SS02_UG03
				2	9	6	59	10.9	14.8		TST_SS02_UG03
28	**1016**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
28	**1802**	1	SS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
28	**1802**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
30	**7066**	1	SS	1	15	8	21	30.3	26	22.9	TST_SS02_UG03
				2	13	6	26	31.5	23.2	20.7	TST_SS02_UG03
30	**7066**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
30	**7066**	3	GB								TST_SS01_UG01_UG02
30	**8129**	1	SS	1	23	5	17	32.5	22.7	20.1	TST_SS02_UG03
				2	21	3	16	39.2	21.1	17.6	TST_SS02_UG03
30	**8129**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
31	**0114**	1	SS	2	1	0	1	70.5	27.6		TST_SS02_UG03-310115
31	**0114**	2	GS	2	0	0	1	59.8	39.5		TST_SS02_UG03-310115
31	**0114**	3	GB	2							TST_AG04

Table 23 – Cont'd
Unbound Materials Gradation III – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	% > 2 mm	% Coarse Sand	% Fine Sand	% Silt	% Clay	% Colloids	Source
31	**3018**	1	SS	1	22	29	42	6.4	0.6		TST_SS02_UG03
				2	20	37	38	4.2	0.3		TST_SS02_UG03
32	**0101**	1	SS		2	18	54	18.8	6.6		TST_SS02_UG03
32	**0101**	2	TS		2	18	54	18.8	6.6		Assumed same as Layer 1
32	**0101**	3	GS		62	14	13	7.2	3.3		TST_SS02_UG03
32	**0101**	4	GB								TST_SS01_UG01_UG02
32	**0204**	1	SS								
32	**0204**	2	TS								
32	**0204**	3	GS								
32	**0204**	4	GB								
33	**1001**	1	SS	1	7	19	59	10.9	4	3.7	TST_SS02_UG03
				2	5	25	62	4.5	3.4	3.3	TST_SS02_UG03
33	**1001**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
33	**1001**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
35	**0105**	1	SS		1.9	1.2	12.5	39.2	45.3		TST_SS02_UG03
35	**0105**	2	GB								BRE-Cal 2002 Guide
35	**1112**	1	SS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
35	**1112**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
36	**0801**	1	SS	1	12	2	64	17.1	4.8		TST_SS01_UG01_UG02
				2	23	5	40	22.9	8.7	8.4	TST_SS02_UG03
				3	5	9	57	22.3	6.4	5.6	TST_SS02_UG03
36	**0801**	2	GB								TST_SS01_UG01_UG02
36	**4018**	1	SS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
37	**0201**	1	SS		2	15	16	33.7	35.3	34.2	TST_SS02_UG03
37	**0201**	2	LTS		2	15	16	33.7	35.3	34.2	Assumed same as Layer 1
37	**0201**	3	GB								TST_SS01_UG01_UG02-Layer 2

Table 23 – Cont'd
Unbound Materials Gradation III – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	% > 2 mm	% Coarse Sand	% Fine Sand	% Silt	% Clay	% Colloids	Source
37	**0205**	1	SS								TST_SS01_UG01_UG02-370206
37	**0205**	2	LTS								Assumed same as Layer 1
37	**0208**	1	SS		0	1	21	50	28.1	23.9	TST_SS02_UG03
37	**0208**	2	LTS		0	1	21	50	28.1	23.9	Assumed same as Layer 1
37	**0212**	1	SS		1	7	23	43.7	25.8		TST_SS02_UG03
37	**0212**	2	LTS		1	7	23	43.7	25.8		Assumed same as Layer 1
37	**0212**	3	GB								TST_SS01_UG01_UG02-370204-Layer 2
37	**1028**	1	SS	1	0	6	86	4.1	4.4	4	TST_SS02_UG03
				2	0	6	84	2.8	6	5	TST_SS02_UG03
39	**0204**	1	SS								
39	**0204**	2	GS								
39	**0204**	3	GB								
40	**4165**	1	SS	1	0	8	64	19.2	9	0	TST_SS02_UG03
				2	0	5	65	18.3	11.7	0	TST_SS02_UG03
41	**6011**	1	SS	1	17	9	11	27.1	35.5	32.5	TST_SS02_UG03
				2	32	1	3	27.2	37.2	32.4	TST_SS02_UG03
41	**6011**	2	GS								TST_SS01_UG01_UG02
41	**6011**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
42	**0603**	1	SS		48	10	9	26.6	6.8		TST_SS02_UG03
42	**0603**	2	GB								TST_SS01_UG01_UG02
42	**1606**	1	SS	1	27	10	19	21.5	22.3	19.1	TST_SS02_UG03
				2							TST_SS01_UG01_UG02
42	**1606**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
46	**9187**	1	SS	1	1	1	11	51.5	35.4		TST_SS02_UG03
				2	13	13	10	40.4	23.4		TST_SS02_UG03
46	**9187**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
46	**9187**	3	GB								INV_GRADATION

Table 23 – Cont'd
Unbound Materials Gradation III – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	% > 2 mm	% Coarse Sand	% Fine Sand	% Silt	% Clay	% Colloids	Source
47	**3101**	1	SS	1	11	8	7	33.8	40.7		TST_SS02_UG03
				2	4	5	10	36.7	44		TST_SS02_UG03
47	**3101**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
48	**1060**	1	SS	1	3	18	48	13.7	17	0	TST_SS02_UG03
				2	5	12	46	15.2	22	0	TST_SS02_UG03
48	**1060**	2	TS								BRE-Cal 2002 Guide
48	**1060**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
48	**1068**	1	SS	1	2	1	3	55.1	38.9	0	TST_SS02_UG03
				2	12	17	17	28.1	25.9	0	TST_SS02_UG03
48	**1068**	2	TS								
48	**1068**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
48	**1077**	1	SS	1	7	6	35	41.8	10	0	TST_SS02_UG03
				2	3	3	20	61.1	12.5	0	TST_SS02_UG03
48	**1077**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
48	**1122**	1	SS	1	3	22	69	0.5	6	0	TST_SS02_UG03
				2	2	26	40	7.6	24.5	0	TST_SS02_UG03
48	**1122**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
48	**1122**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
48	**3739**	1	SS	1	1	1	92	1.9	4.3	0	TST_SS02_UG03
				2	0	0	96	1.3	3	0	TST_SS02_UG03
48	**3739**	2	TS								INV_GRADATION
48	**3739**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
48	**4142**	1	SS	1	0	38	57				TST_SS02_UG03
				2	1	4	52	12.3	30.6		TST_SS02_UG03

Table 23 – Cont'd
Unbound Materials Gradation III – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	% > 2 mm	% Coarse Sand	% Fine Sand	% Silt	% Clay	% Colloids	Source
48	**4142**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
48	**4143**	1	SS	1	1	1	7	54.2	37		TST_SS02_UG03
				2	1	3	7	55.1	34		TST_SS02_UG03
48	**4143**	2	TS								
49	**1001**	1	SS	1	4	5	77	10.2	3.9	3.1	TST_SS02_UG03
				2	0	2	72	18.5	8.3	7.2	TST_SS02_UG03
49	**1001**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
49	**3011**	1	SS	1	34	8	22	25.6	10.8	8.5	TST_SS02_UG03
				2	35	10	20	24.4	10.7	8.3	TST_SS02_UG03
49	**3011**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
50	**1002**	1	SS		62	21	10	4.3	2.6	2.1	TST_SS02_UG03
50	**1002**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
50	**1681**	1	SS	1	26	23	19	20.1	12.2	11.1	TST_SS02_UG03
				2	56	10	10	12.1	13	12.9	TST_SS02_UG03
50	**1681**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
50	**1681**	3	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
51	**0113**	1	SS		9	18	38	26.4	8.8		TST_SS02_UG03-510115
51	**0113**	3	GB								TST_SS01_UG01_UG02-510117
51	**0114**	1	SS		9	18	38	26.4	8.8		TST_SS02_UG03-510115
51	**0114**	3	GB								TST_SS01_UG01_UG02-510117
53	**1007**	1	SS	1	7	6	19	61.3	7.1	6	TST_SS02_UG03
				2	3	5	20	64.9	6.8	5.3	TST_SS02_UG03
53	**1007**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02

Table 23 – Cont'd
Unbound Materials Gradation III – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	% > 2 mm	% Coarse Sand	% Fine Sand	% Silt	% Clay	% Colloids	Source
53	**3813**	1	SS	1	21	17	31	26.6	4.4	3.3	TST_SS02_UG03
				2	5	9	64	19.5	3	1.4	TST_SS02_UG03
53	**3813**	2	GS								TST_SS01_UG01_UG02
53	**3813**	3	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
53	**3813**	4	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
53	**3813**	5	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
53	**7322**	1	SS	1	14	2	2	61	21.4	19.6	TST_SS02_UG03
				2	0	1	2	70.3	26.6	24.7	TST_SS02_UG03
53	**7322**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
56	**1007**	1	SS	1	15	5	55	13.3	11.3	11.2	TST_SS02_UG03
				2	26	3	48	11.8	11.2	10	TST_SS02_UG03
56	**1007**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
56	**2019**	1	SS	1	12	11	22	38.9	15.9	13	TST_SS02_UG03
				2	44	9	28	12.4	6.1	5.2	TST_SS02_UG03
56	**2019**	2	GS								TST_SS01_UG01_UG02
56	**2019**	3	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
56	**2020**	1	SS	1	76	4	6	6.2	7.3	7	TST_SS02_UG03
				2	71	9	8	4.1	8.1	7.3	TST_SS02_UG03
83	**1801**	1	SS	1	0	0	81	12.6	6.2		TST_SS02_UG03
				2	1	1	77	11	9.6		TST_SS02_UG03
83	**1801**	2	GS	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
83	**1801**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02

Table 23 – Cont'd
Unbound Materials Gradation III – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	Test No.	% > 2 mm	% Coarse Sand	% Fine Sand	% Silt	% Clay	% Colloids	Source
83	**3802**	1	SS	1	3	3	7	29.7	57.6		TST_SS02_UG03
				2	0	0	7	24.7	68.6		TST_SS02_UG03
		2	LTS								
83	**3802**	3	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
89	**3015**	1	SS	1	10	7	80	3.2	0.6	0.5	TST_SS02_UG03
				2							TST_SS01_UG01_UG02
89	**3015**	2	GB	1							TST_SS01_UG01_UG02
				2							TST_SS01_UG01_UG02
MnRoad 4	**---**	1	SS								
MnRoad 21	**---**	1	SS								
		2	GB								MnROAD Aggregate Profile

Table 24
Unbound Materials Classification – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	AASHTO Soil Classification	Unified Soil Classification	AASHTO Soil Classification Test 2	Unified Soil Classification Test 2	Dry Thermal Conductivity (BTU/hr-ft-°F)[d]	Heat Capacity (BTU/lb-°F)[e]
1	**0101**	1	SS	A-7-5	ML	----	----	0.13	0.18
1	**0101**	2	GB	A-1-a	GM	----	----	0.30	0.18
1	**0102**	1	SS	A-7-5	ML	----	----	0.13	0.18
1	**0102**	2	GB	A-1-a	GM	----	----	0.30	0.18
4	**0113**	1	SS	A-1-b	SW-SM	----	----	0.27	0.18
4	**0113**	2	GB	A-1-a	SP-SM	----	----	0.30	0.18
4	**0114**	1	SS	A-2-4	SC	----	----	0.23	0.18
4	**0114**	2	GB	A-1-a	SP-SM	----	----	0.30	0.18
4	**0215**	1	SS	A-2-4	GM	----	----	0.23	0.18
4	**0215**	2	GB	A-1-a	GP-GM	----	----	0.30	0.18
5	**2042**	1	SS	A-4	ML	A-4	ML	0.22	0.18
6	**3042**	1	SS	A-4	CL	A-4	CL	0.22	0.18
6	**3042**	2	GS	A-4	SM	----	----	0.22	0.18
8	**1053**	1	SS	A-6	CL	----	----	0.18	0.18
8	**1053**	2	GS	A-1-a	GW-GM	A-1-a	GP-GM	0.30	0.18
8	**1053**	3	GB	A-1-a	GW-GM	A-1-a	GP-GM	0.30	0.18
8	**7035**	1	SS	A-6	CL	A-6	CL	0.18	0.18
8	**7035**	2	GS	A-2-4	SM	----	----	0.23	0.18
8	**7035**	3	GB	A-1-b	SM	A-1-b	SM	0.27	0.18
9	**1803**	1	SS	A-2-4	SM	----	----	0.23	0.18
9	**1803**	2	GB	A-1-b	SP-SM	A-1-a	GP-GM	0.27	0.18
10	**0102**	1	SS	A-2-4	SC	----	----	0.23	0.18
10	**0102**	2	GS	A-2-4	SM	----	----	0.23	0.18
10	**0102**	3	GB	A-1-a	GP-GM	----	----	0.30	0.18
13	**1005**	1	SS	A-6	SC	A-4	SM	0.18	0.18
13	**1005**	2	GB	A-1-a	GP-GM	A-1-b	GP-GM	0.30	0.18
13	**1031**	1	SS	A-4	SM	A-4	SM	0.22	0.18
13	**1031**	2	GB	A-2-4	SM	A-1-b	SP-SM	0.23	0.18

Table 24 – Cont'd
Unbound Materials Classification – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	AASHTO Soil Classification	Unified Soil Classification	AASHTO Soil Classification Test 2	Unified Soil Classification Test 2	Dry Thermal Conductivity (BTU/hr-ft-°F)[d]	Heat Capacity (BTU/lb-°F)[e]
13	**3019**	1	SS	A-4	ML	A-6	CL	0.22	0.18
13	**3019**	2	GB	A-1-a	GP-GM	A-2-4	GM	0.30	0.18
16	**1010**	1	SS	A-1-b	SP-SM	A-2-4	SM	0.27	0.18
16	**1010**	2	GB	A-1-a	GW-GM	A-1-a	GW-GM	0.30	0.18
18	**3002**	1	SS	A-6	CL	A-6	CL	0.18	0.18
18	**3002**	2	GB	A-1-a	GP	A-1-a	GW	0.30	0.18
20	**4054**	1	SS	A-6	CL	A-7-6	CL	0.18	0.18
22	**0118**	1	SS	A-7-6	CL	----	----	0.12	0.18
22	**0118**	2	GS	A-4	CL-ML	----	----	0.22	0.18
22	**0118**	3	GB			----	----	FALSE	0.18
23	**1026**	1	SS	A-1-b	SP-SM	A-2-4	SP	0.27	0.18
23	**1026**	2	GB	A-1-a	GP	A-1-a	GW	0.30	0.18
24	**1634**	1	SS	A-4	CL	A-4	CL	0.22	0.18
24	**1634**	2	GS	A-4	CL	A-4	CL	0.22	0.18
27	**4040**	1	SS	A-6	CL	A-6	CL	0.18	0.18
27	**4040**	2	GB	A-1-b	SM	A-1-b	SM	0.27	0.18
28	**1016**	1	SS	A-2-4	SM	A-2-4	SM	0.23	0.18
28	**1016**	2	GS	A-2-4	SM	A-2-4	SP-SM	0.23	0.18
28	**1802**	1	SS	A-2-4	SP	A-3	SP-SM	0.23	0.18
28	**1802**	2	GS	A-2-4	SM	A-2-4	SM	0.23	0.18
30	**7066**	1	SS	A-6	CL	A-6	CL	0.18	0.18
30	**7066**	2	GS	A-1-a	GP-GM	A-1-a	GW-GM	0.30	0.18
30	**7066**	3	GB	A-1-a	SW-SM	----	----	0.30	0.18
30	**8129**	1	SS	A-6	CL	A-6	CL	0.18	0.18
30	**8129**	2	GB	A-1-a	GP-GM	A-1-a	GP-GM	0.30	0.18
31	**0114**	1	SS	A-7-6	CL	----	----	0.12	0.18
31	**0114**	2	GS	A-7-6	CH	----	----	0.12	0.18
31	**0114**	3	GB	A-3	SW-SM	----	----	0.30	0.18

Table 24 – Cont'd
Unbound Materials Classification – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	AASHTO Soil Classification	Unified Soil Classification	AASHTO Soil Classification Test 2	Unified Soil Classification Test 2	Dry Thermal Conductivity (BTU/hr-ft-°F)[d]	Heat Capacity (BTU/lb-°F)[e]
31	**3018**	1	SS	A-1-b	SW	A-1-b	SP	0.27	0.18
32	**0101**	1	SS	A-2-4	SM	----	----	0.23	0.18
32	**0101**	2	TS	A-2-4	SM	----	----	0.23	0.18
32	**0101**	3	GS	A-1-a	GW-GM	----	----	0.30	0.18
32	**0101**	4	GB	A-1-a	GW-GM	----	----	0.30	0.18
32	**0204**	1	SS			----	----	FALSE	0.18
32	**0204**	2	TS			----	----	FALSE	0.18
32	**0204**	3	GS			----	----	FALSE	0.18
32	**0204**	4	GB			----	----	FALSE	0.18
33	**1001**	1	SS	A-2-4	SM	A-3	SP-SM	0.23	0.18
33	**1001**	2	GS	A-1-b	SP-SM	A-1-b	SW	0.27	0.18
33	**1001**	3	GB	A-1-a	GP	A-1-a	GP	0.30	0.18
35	**0105**	1	SS	A-7-6	CH	----	----	0.12	0.18
35	**0105**	2	GB	A-1-a	SW	----	----	0.30	0.18
35	**1112**	1	SS	A-3	SP	A-3	SP	0.30	0.18
35	**1112**	2	GB	A-1-b	SC-SM	A-1-b	SC-SM	0.27	0.18
36	**0801**	1	SS	A-2-4	SC-SM	A-2-4[c]	SM[c]	0.23	0.18
36	**0801**	2	GB	A-1-a	GP-GM	----	----	0.30	0.18
36	**4018**	1	SS	A-1-b	SM	A-1-b	SM	0.27	0.18
37	**0201**	1	SS	A-7-5	CH	----	----	0.13	0.18
37	**0201**	2	LTS	A-7-5	CH	----	----	0.13	0.18
37	**0201**	3	GB	A-1-a	GW-GM	----	----	0.30	0.18
37	**0205**	1	SS	A-7-5	MH	----	----	0.13	0.18
37	**0205**	2	LTS	A-7-5	MH	----	----	0.13	0.18
37	**0208**	1	SS	A-7-5	MH	----	----	0.13	0.18
37	**0208**	2	LTS	A-7-5	MH	----	----	0.13	0.18

Table 24 – Cont'd
Unbound Materials Classification – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	AASHTO Soil Classification	Unified Soil Classification	AASHTO Soil Classification Test 2	Unified Soil Classification Test 2	Dry Thermal Conductivity (BTU/hr-ft-°F)[d]	Heat Capacity (BTU/lb-°F)[e]
37	**0212**	1	SS	A-7-6	CL	----	----	0.12	0.18
37	**0212**	2	LTS	A-7-6	CL	----	----	0.12	0.18
37	**0212**	3	GB	A-1-a	GP-GM	----	----	0.30	0.18
37	**1028**	1	SS	A-3	SP-SM	A-3	SP-SM	0.30	0.18
39	**0204**	1	SS			----	----	FALSE	0.18
39	**0204**	2	GS			----	----	FALSE	0.18
39	**0204**	3	GB			----	----	FALSE	0.18
40	**4165**	1	SS	A-2-4	SM	A-2-4	SM	0.23	0.18
41	**6011**	1	SS	A-7-6	CH	A-7-6	CH	0.12	0.18
41	**6011**	2	GS	A-1-a	GP-GM	----	----	0.30	0.18
41	**6011**	3	GB	A-1-a	GP	A-1-a	GW	0.30	0.18
42	**0603**	1	SS	A-2-4	GC-GM	----	----	0.23	0.18
42	**0603**	2	GB	A-1-a	GP-GM	----	----	0.30	0.18
42	**1606**	1	SS	A-4	SC	A-6	CL	0.22	0.18
42	**1606**	2	GB	A-1-a	GP-GC	A-1-a	GP-GC	0.30	0.18
46	**9187**	1	SS	A-7-6	CH	A-7-6	CL	0.12	0.18
46	**9187**	2	GS	A-1-a	GW-GM	A-1-a	SW-SM	0.30	0.18
46	**9187**	3	GB	A-1-a	SP-SM	----	----	0.30	0.18
47	**3101**	1	SS	A-7-6	CH	A-7-6	CH	0.12	0.18
47	**3101**	2	GS	A-1-b	GC-GM	A-1-a	GC-GM	0.27	0.18
48	**1060**	1	SS	A-2-4	SM	A-4	SC-SM	0.23	0.18
48	**1060**	2	LTS	A-2-7	GC	----	----	0.20	0.18
48	**1060**	3	GB	A-1-a	GP-GM	A-1-a	GP	0.30	0.18
48	**1068**	1	SS	A-7-6	CL	A-6	CL	0.12	0.18
48	**1068**	2	LTS	A-7-6	CH	A-4	CL	0.12	0.18
48	**1068**	3	GB	A-1-a	GP-GM	A-1-a	GW-GM	0.30	0.18
48	**1077**	1	SS	A-4	ML	A-4	ML	0.22	0.18
48	**1077**	2	GB	A-1-a	GP-GM	A-1-a	GP-GM	0.30	0.18

Table 24 – Cont'd
Unbound Materials Classification – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	AASHTO Soil Classification	Unified Soil Classification	AASHTO Soil Classification Test 2	Unified Soil Classification Test 2	Dry Thermal Conductivity (BTU/hr-ft-°F)[d]	Heat Capacity (BTU/lb-°F)[e]
48	**1122**	1	SS	A-2-6	SP-SC	A-2-4	SM	0.22	0.18
48	**1122**	2	GS	A-2-4	SM	A-2-4	SM	0.23	0.18
48	**1122**	3	GB	A-1-b	GM	A-1-b	GM	0.27	0.18
48	**3739**	1	SS	A-3	SP-SM	A-3	SP	0.30	0.18
48	**3739**	2	LTS	A-1-a	GP-GM	----	----	0.30	0.18
48	**3739**	3	GB	A-1-b	SP-SM	A-1-a	SW	0.27	0.18
48	**4142**	1	SS	A-2-4	SP-SC	A-6	SC	0.23	0.18
48	**4142**	2	GS	A-2-4	SW-SM	A-2-4	SW-SM	0.23	0.18
48	**4143**	1	SS	A-7-6	CL	A-7-6	CL	0.12	0.18
48	**4143**	2	LTS	A-6	CL	----	----	0.18	0.18
49	**1001**	1	SS	A-2-4	SM	A-2-4	SM	0.23	0.18
49	**1001**	2	GB	A-1-b	SM	A-1-a	GP-GM	0.27	0.18
49	**3011**	1	SS	A-4	SM	A-2-4	SM	0.22	0.18
49	**3011**	2	GS	A-1-a	GP-GM	A-1-a	GP-GM	0.30	0.18
50	**1002**	1	SS	A-1-a	GW-GM	----	----	0.30	0.18
50	**1002**	2	GB	A-1-a	GP	A-1-a	GW	0.30	0.18
50	**1681**	1	SS	A-2-4	SC	A-1-b	GC	0.23	0.18
50	**1681**	2	GS	A-1-b	SW-SM	A-1-b	SP-SM	0.27	0.18
50	**1681**	3	GS	A-1-a	SW-SM	A-1-a	SP	0.30	0.18
51	**0113**	1	SS	A-4	SM	----	----	0.22	0.18
51	**0113**	3	GB	A-1-a	GP-GM	----	----	0.30	0.18
51	**0114**	1	SS	A-4	SM	----	----	0.22	0.18
51	**0114**	3	GB	A-1-a	GP-GM	----	----	0.30	0.18
53	**1007**	1	SS	A-4	ML	A-4	ML	0.22	0.18
53	**1007**	2	GB	A-1-a	SP-SM	A-1-a	SP-SM	0.30	0.18

Table 24 – Cont'd
Unbound Materials Classification – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	AASHTO Soil Classification	Unified Soil Classification	AASHTO Soil Classification Test 2	Unified Soil Classification Test 2	Dry Thermal Conductivity (BTU/hr-ft-°F)[d]	Heat Capacity (BTU/lb-°F)[e]
53	**3813**	1	SS	A-2-4	SM	A-2-4	SM	0.23	0.18
53	**3813**	2	GS	A-4	CL-ML	----	----	0.22	0.18
53	**3813**	3	GS	A-4	SC	A-2-4	SM	0.22	0.18
53	**3813**	4	GS	A-1-a	GP-GM	A-1-a	GP-GM	0.30	0.18
53	**3813**	5	GB	A-1-b	SM	A-1-a	SM	0.27	0.18
53	**7322**	1	SS	A-6	CL	A-6	CL	0.18	0.18
53	**7322**	2	GB	A-1-a	GP-GM	A-1-a	SW	0.30	0.18
56	**1007**	1	SS	A-2-4	SM	A-2-4	SM	0.23	0.18
56	**1007**	2	GB	A-1-a	GP-GM	A-1-a	GP-GM	0.30	0.18
56	**2019**	1	SS	A-2-6	SC	A-1-b	SM	0.22	0.18
56	**2019**	2	GS	A-1-a	SW-SM	----	----	0.30	0.18
56	**2019**	3	GS	A-2-4	SM	A-2-4	SM	0.23	0.18
56	**2020**	1	SS	A-2-6	GC	A-2-6	GC	0.22	0.18
83	**1801**	1	SS	A-2-4	SM	A-2-4	SM	0.23	0.18
83	**1801**	2	GS	A-2-6	SP-SC	A-2-6	SP-SC	0.22	0.18
83	**1801**	3	GB	A-1-a	SW-SM	A-1-a	SP-SM	0.30	0.18
83	**3802**	1	SS	A-7-5	CH	A-7-5	CH	0.13	0.18
83	**3802**	2	LTS	A-4	ML	----	----	0.22	0.18
83	**3802**	3	GB	A-3	SP-SM	A-2-4	SP-SM	0.30	0.18
89	**3015**	1	SS	A-3	SP	A-3	SP	0.30	0.18
89	**3015**	2	GB	A-1-a	GP	A-1-a	GP	0.30	0.18
MnRoad 4	**---**	1	SS	A-6	ML	A-6	ML	0.18	0.18
MnRoad 21	**---**	1	SS	A-6	ML	A-6	ML	0.18	0.18
		2	GB	A-1-b	SW-SM	---	---	0.27	0.18
Wstk 12	**---**	1	SS						
		2	SS						
		3	GS	A-7-6		A-6			
		4	GB						

Table 24 – Cont'd
Unbound Materials Classification – LTPP Data

State Code	SHRP ID	Layer No.	Layer Type	AASHTO Soil Classification	Unified Soil Classification	AASHTO Soil Classification Test 2	Unified Soil Classification Test 2	Dry Thermal Conductivity (BTU/hr-ft-°F)[d]	Heat Capacity (BTU/lb-°F)[e]
Wstk 15	**---**	1	SS						
		2	SS						
		3	GS	A-7-6		A-7-6			
		4	GB						
Wstk 25	**---**	1	SS						
		2	SS	A-7-6					
		3	GS						
		4	GB						

Table 25
Sources Contacted During Groundwater Table Data Search

State/ Province	Agency/Consultant	Location	Contact Information
Federal	The United States Geological Survey (USGS)	Virginia	703-648-5035 Bill Alley, National Groundwater Project Coordinator
	USGS National Water Information System (NWIS)	Website	water.usgs.gov/nwis/gwlevels
Alabama (AL)	Alabama Department of Environmental Management (ADEM)	Website	www.adem.state.al.us
Arizona (AZ)	Arizona Department of Water Resources (ADWR)	Phoenix	602-417-2485, 602-417-2488 (fx) Carlane Stephan, ADWR Bookstore
Louisiana (LA)	Louisiana Department of Transportation and Development (LDOTD)	Baton Rouge	225-379-1434 Water Resources Division
	LDOTD	Website	www.dotd.state.la.us
	CH2MHill	New Orleans	504-593-9421 Mr. Tom Johnson
Minnesota (MN)	Minnesota Pollution Control Agency (MPCA)	Duluth	218/723-4929 Multimedia Integration Mr. Andrew Streitz andrew.streitz@pca.state.mn.us
	Minnesota Department of Natural Resources (MDNR)	Website	www.dnr.state.mn.us
	Peterson Environmental Consulting, Inc.	Duluth	218-728-1228
North Carolina (NC)	North Carolina Dep. of Environmental & Natural resources (NCDENR)	Raleigh	919-7156182 Division of Water Quality Mr. Ted Mew
	NCDENR	Website	www.enr.state.nc.us
	Woodward Clyde Consultants	Raleigh	919-850-9511
New Mexico (NM)	New Mexico Env. Department (NMED)	Santa Fe	505-827-6140 Mr. Curt Frischkorn Pollution Prevention
	CERL Environmental Consultants, Inc.	Santa Fe	505-988-4143
	New Mexico Office of the State Engineer (NMOSE)	Website	www.ose.state.nm.us
South Dakota (SD)	Dakota Environmental Consultants	Huron	Mr. Jim Hyans
Texas (TX)	Texas Water Development Board (TWDB)	Website	www.twdb.state.tx.us
	Applied Earth Sciences, Inc.	Houston	713-981-7140
Virginia (VA)	Virginia Department of Environmental Quality (Virginia DEQ)	Richmond	800-592-5482
	Virginia DEQ	Website	www.deq.state.va.us
	Geotechnical & Environmental Services, Inc.	Staunton	540-248-0610

Table 26
Duration of Seasons

	Season 1	Season 2	Season 3	Season 4	Season 5
	Winter	**Early Spring**	**Late Spring**	**Summer**	**Fall**
Begins	FI > 194°F- days	TI > 59°F- days	4 weeks after Season 2	3-day T_{AVG} > 61°F	3-day T_{AVG} < 61°F
NE	114	28	46	91	86
CEN	96	28	47	108	86
SE	90	28	49	108	90

*FI – Freezing Index; TI – Thawing Index

Table 27
Daily Pavement Temperature Fluctuations

Pavement Type	Max. Daily Change (F)	Date	Max. Temp. (F)	Min. Temp. (F)	Duration from Max. to Min. (hours)
Thin HMA (5 inch)	59.1	6/5/2000	104.3	45.2	9.75
Thick HMA (8 inch)	63	4/21/2000	92.1	29.1	9.00
Air Temp. Change	34.4	4/21/2000	61.6	27.2	9.25
Max. Air Temp. Change	42.9	9/28/2000	79.6	36.7	10.50

Table 28
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)	Section	Date	TDR Number	Volumetric Moisture Content (%)
4	11/22/1994	1	0.348	21	7/15/1993	1	0.135
	12/21/1994	1	0.200		3/2/1994	1	0.051
	1/5/1995	1	0.172		3/22/1994	1	0.095
	1/20/1995	1	0.185		4/5/1994	1	0.100
	1/25/1995	1	0.173		4/11/1994	1	0.094
	1/31/1995	1	0.185		4/18/1994	1	0.099
	2/23/1995	1	0.197		4/26/1994	1	0.093
	2/28/1995	1	0.182		9/27/1994	1	0.101
	3/30/1995	1	0.324		12/21/1994	1	0.055
	4/13/1995	1	0.319		1/5/1995	1	0.050
	4/20/1995	1	0.366		1/20/1995	1	0.050
	5/23/1995	1	0.397		1/25/1995	1	0.053
	6/23/1995	1	0.387		2/28/1995	1	0.035
	11/6/1995	1	0.364		3/30/1995	1	0.123
	11/15/1995	1	0.335		4/13/1995	1	0.123
	12/15/1995	1	0.176		5/23/1995	1	0.113
	12/28/1995	1	0.183		6/12/1995	1	0.113
	1/10/1996	1	0.174		6/22/1995	1	0.106
	3/1/1996	1	0.176		7/14/1995	1	0.112
	3/12/1996	1	0.182		8/15/1995	1	0.112
	3/20/1996	1	0.349		9/1/1995	1	0.111
	4/1/1996	1	0.310		9/13/1995	1	0.109
	6/11/1996	1	0.363		10/16/1995	1	0.105
	8/1/1996	1	0.363		11/15/1995	1	0.102
	8/12/1996	1	0.360		12/15/1995	1	0.052
	8/27/1996	1	0.347		12/28/1995	1	0.054
	9/13/1996	1	0.337		1/10/1996	1	0.050
	10/1/1996	1	0.318		3/1/1996	1	0.053
	10/14/1996	1	0.322		3/12/1996	1	0.083
	10/31/1996	1	0.295		3/19/1996	1	0.101
	11/20/1996	1	0.283		5/2/1996	1	0.107
	1/3/1997	1	0.169		5/13/1996	1	0.113
	2/1/1997	1	0.180		5/30/1996	1	0.113
	2/12/1997	1	0.165		6/11/1996	1	0.120
	3/4/1997	1	0.180		7/2/1996	1	0.124
	3/20/1997	1	0.202		7/16/1996	1	0.127
	3/24/1997	1	0.335		8/1/1996	1	0.121
	4/1/1997	1	0.339		8/12/1996	1	0.121
	4/11/1997	1	0.313		8/27/1996	1	0.119
	4/15/1997	1	0.319		9/13/1996	1	0.124
	4/29/1997	1	0.330		9/30/1996	1	0.116

Table 28 – Cont'd
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)
4	5/6/1997	1	0.330
	5/20/1997	1	0.253
	7/2/1997	1	0.267
	7/8/1997	1	0.257
	7/29/1997	1	0.390
	8/8/1997	1	0.388
	8/15/1997	1	0.274
	8/20/1997	1	0.259
	9/4/1997	1	0.363
	9/10/1997	1	0.377
	9/18/1997	1	0.356
	9/24/1997	1	0.348
	10/1/1997	1	0.339
	10/8/1997	1	0.353
	10/15/1997	1	0.331
	10/29/1997	1	0.316
	11/5/1997	1	0.304
	11/12/1997	1	0.300
	11/20/1997	1	0.295
	12/10/1997	1	0.298
	12/19/1997	1	0.296
	2/10/1998	1	0.185
	2/26/1998	1	0.335
	11/22/1994	2	0.347
	12/21/1994	2	0.191
	1/5/1995	2	0.155
	1/20/1995	2	0.171
	1/25/1995	2	0.158
	1/31/1995	2	0.184
	2/23/1995	2	0.193
	2/28/1995	2	0.176
	3/30/1995	2	0.309
	4/13/1995	2	0.307
	4/20/1995	2	0.371
	6/23/1995	2	0.397
	11/6/1995	2	0.345
	11/15/1995	2	0.343
	12/15/1995	2	0.169
	12/28/1995	2	0.169
	1/10/1996	2	0.167
	3/1/1996	2	0.158
	3/12/1996	2	0.196
	3/20/1996	2	0.337
21	10/14/1996	1	0.116
	10/31/1996	1	0.115
	11/20/1996	1	0.108
	1/3/1997	1	0.075
	2/12/1997	1	0.071
	3/20/1997	1	0.122
	3/24/1997	1	0.113
	4/1/1997	1	0.117
	4/11/1997	1	0.121
	4/15/1997	1	0.120
	4/29/1997	1	0.117
	5/6/1997	1	0.112
	5/21/1997	1	0.119
	7/2/1997	1	0.111
	7/8/1997	1	0.107
	7/17/1997	1	0.119
	7/29/1997	1	0.122
	8/8/1997	1	0.123
	8/15/1997	1	0.110
	8/20/1997	1	0.108
	9/4/1997	1	0.125
	9/10/1997	1	0.125
	9/18/1997	1	0.115
	9/24/1997	1	0.115
	10/1/1997	1	0.119
	10/8/1997	1	0.118
	10/15/1997	1	0.118
	11/12/1997	1	0.111
	12/19/1997	1	0.112
	1/29/1998	1	0.071
	2/10/1998	1	0.087
	2/26/1998	1	0.117
	7/15/1993	2	0.142
	3/2/1994	2	0.052
	3/22/1994	2	0.107
	4/5/1994	2	0.105
	4/11/1994	2	0.111
	4/18/1994	2	0.111
	4/26/1994	2	0.111
	9/27/1994	2	0.117
	12/21/1994	2	0.063
	1/5/1995	2	0.053
	1/20/1995	2	0.053

Table 28 – Cont'd
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)	Section	Date	TDR Number	Volumetric Moisture Content (%)
4	4/1/1996	2	0.313	21	1/25/1995	2	0.052
	6/11/1996	2	0.359		2/23/1995	2	0.065
	8/1/1996	2	0.372		2/28/1995	2	0.042
	8/12/1996	2	0.360		3/30/1995	2	0.125
	8/27/1996	2	0.359		4/13/1995	2	0.127
	9/13/1996	2	0.335		5/23/1995	2	0.121
	10/1/1996	2	0.319		6/12/1995	2	0.124
	10/14/1996	2	0.325		6/22/1995	2	0.113
	10/31/1996	2	0.298		7/14/1995	2	0.130
	11/20/1996	2	0.284		7/24/1995	2	0.125
	1/3/1997	2	0.176		8/15/1995	2	0.130
	2/1/1997	2	0.223		9/1/1995	2	0.130
	2/12/1997	2	0.164		9/13/1995	2	0.128
	3/4/1997	2	0.223		10/16/1995	2	0.119
	3/20/1997	2	0.305		11/15/1995	2	0.117
	3/24/1997	2	0.312		12/15/1995	2	0.053
	4/1/1997	2	0.316		12/28/1995	2	0.052
	4/11/1997	2	0.300		1/10/1996	2	0.054
	4/15/1997	2	0.304		3/1/1996	2	0.053
	4/29/1997	2	0.320		3/12/1996	2	0.064
	5/6/1997	2	0.317		3/19/1996	2	0.116
	5/20/1997	2	0.257		5/2/1996	2	0.125
	7/2/1997	2	0.275		5/13/1996	2	0.132
	7/8/1997	2	0.263		5/30/1996	2	0.134
	8/15/1997	2	0.272		6/11/1996	2	0.126
	8/20/1997	2	0.273		7/2/1996	2	0.140
	9/4/1997	2	0.373		7/16/1996	2	0.141
	9/10/1997	2	0.373		8/1/1996	2	0.124
	9/18/1997	2	0.383		8/12/1996	2	0.125
	9/24/1997	2	0.362		8/27/1996	2	0.127
	10/1/1997	2	0.342		9/13/1996	2	0.124
	10/8/1997	2	0.367		9/30/1996	2	0.122
	10/15/1997	2	0.330		10/14/1996	2	0.122
	10/29/1997	2	0.304		10/31/1996	2	0.119
	11/5/1997	2	0.302		11/20/1996	2	0.115
	11/12/1997	2	0.299		1/3/1997	2	0.069
	11/20/1997	2	0.287		2/12/1997	2	0.064
	12/10/1997	2	0.293		3/20/1997	2	0.137
	12/19/1997	2	0.294		3/24/1997	2	0.126
	2/10/1998	2	0.198		4/1/1997	2	0.126
	2/26/1998	2	0.309		4/11/1997	2	0.124
	11/22/1994	3	0.374		4/15/1997	2	0.124
	12/21/1994	3	0.296		4/29/1997	2	0.126

Table 28 – Cont'd
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)
4	1/5/1995	3	0.219
	1/20/1995	3	0.212
	1/25/1995	3	0.207
	1/31/1995	3	0.204
	2/23/1995	3	0.206
	2/28/1995	3	0.200
	3/30/1995	3	0.340
	4/13/1995	3	0.316
	4/20/1995	3	0.397
	11/15/1995	3	0.377
	12/15/1995	3	0.213
	12/28/1995	3	0.224
	1/10/1996	3	0.200
	3/1/1996	3	0.205
	3/12/1996	3	0.193
	3/20/1996	3	0.255
	4/1/1996	3	0.251
	6/11/1996	3	0.382
	8/1/1996	3	0.384
	8/12/1996	3	0.383
	8/27/1996	3	0.381
	9/13/1996	3	0.368
	10/1/1996	3	0.343
	10/14/1996	3	0.341
	10/31/1996	3	0.320
	11/20/1996	3	0.300
	1/3/1997	3	0.187
	2/1/1997	3	0.198
	2/12/1997	3	0.182
	3/4/1997	3	0.198
	3/20/1997	3	0.210
	3/24/1997	3	0.334
	4/1/1997	3	0.333
	4/11/1997	3	0.314
	4/15/1997	3	0.330
	4/29/1997	3	0.333
	5/6/1997	3	0.341
	5/20/1997	3	0.251
	7/2/1997	3	0.267
	7/8/1997	3	0.262
	7/17/1997	3	0.383
	8/15/1997	3	0.266
	8/20/1997	3	0.270
	9/4/1997	3	0.393

Section	Date	TDR Number	Volumetric Moisture Content (%)
21	5/6/1997	2	0.126
	5/21/1997	2	0.127
	7/2/1997	2	0.123
	7/8/1997	2	0.119
	7/17/1997	2	0.132
	7/29/1997	2	0.135
	8/8/1997	2	0.135
	8/15/1997	2	0.125
	8/20/1997	2	0.124
	9/4/1997	2	0.133
	9/10/1997	2	0.134
	9/18/1997	2	0.129
	9/24/1997	2	0.131
	10/1/1997	2	0.128
	10/8/1997	2	0.133
	10/15/1997	2	0.131
	11/12/1997	2	0.123
	12/19/1997	2	0.118
	1/29/1998	2	0.072
	2/10/1998	2	0.080
	2/26/1998	2	0.127
	7/15/1993	3	0.166
	3/2/1994	3	0.058
	3/22/1994	3	0.133
	4/5/1994	3	0.129
	4/11/1994	3	0.133
	4/18/1994	3	0.140
	4/26/1994	3	0.129
	9/27/1994	3	0.135
	12/21/1994	3	0.073
	1/5/1995	3	0.057
	1/20/1995	3	0.056
	1/25/1995	3	0.061
	2/28/1995	3	0.045
	3/30/1995	3	0.143
	4/13/1995	3	0.143
	5/23/1995	3	0.135
	6/22/1995	3	0.127
	7/14/1995	3	0.141
	7/24/1995	3	0.138
	8/15/1995	3	0.141
	9/1/1995	3	0.138
	9/13/1995	3	0.141
	10/16/1995	3	0.137

Table 28 – Cont'd
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)
4	9/10/1997	3	0.377
	9/18/1997	3	0.379
	9/24/1997	3	0.390
	10/1/1997	3	0.368
	10/8/1997	3	0.371
	10/15/1997	3	0.355
	10/29/1997	3	0.330
	11/5/1997	3	0.328
	11/12/1997	3	0.320
	11/20/1997	3	0.309
	12/10/1997	3	0.312
	12/19/1997	3	0.313
	2/10/1998	3	0.211
	2/26/1998	3	0.348
	11/22/1994	4	0.392
	12/21/1994	4	0.346
	1/5/1995	4	0.337
	1/20/1995	4	0.310
	1/25/1995	4	0.229
	1/31/1995	4	0.205
	2/28/1995	4	0.217
	3/30/1995	4	0.333
	4/13/1995	4	0.327
	12/15/1995	4	0.352
	12/28/1995	4	0.323
	1/10/1996	4	0.222
	3/1/1996	4	0.214
	3/12/1996	4	0.184
	3/20/1996	4	0.227
	4/1/1996	4	0.213
	6/11/1996	4	0.383
	8/1/1996	4	0.383
	8/12/1996	4	0.386
	8/27/1996	4	0.395
	9/13/1996	4	0.393
	10/1/1996	4	0.369
	10/14/1996	4	0.357
	10/31/1996	4	0.347
	11/20/1996	4	0.321
	1/3/1997	4	0.194
	2/1/1997	4	0.204
	2/12/1997	4	0.186
	3/4/1997	4	0.204
21	11/15/1995	3	0.128
	12/15/1995	3	0.054
	12/28/1995	3	0.058
	1/10/1996	3	0.057
	3/1/1996	3	0.058
	3/12/1996	3	0.053
	3/19/1996	3	0.120
	5/2/1996	3	0.140
	5/13/1996	3	0.145
	5/30/1996	3	0.146
	6/11/1996	3	0.140
	7/2/1996	3	0.158
	7/16/1996	3	0.173
	8/1/1996	3	0.141
	8/12/1996	3	0.143
	8/27/1996	3	0.140
	9/13/1996	3	0.140
	9/30/1996	3	0.136
	10/14/1996	3	0.133
	10/31/1996	3	0.134
	11/20/1996	3	0.128
	1/3/1997	3	0.065
	2/12/1997	3	0.062
	3/20/1997	3	0.110
	3/24/1997	3	0.165
	4/1/1997	3	0.154
	4/11/1997	3	0.148
	4/15/1997	3	0.150
	4/29/1997	3	0.150
	5/6/1997	3	0.156
	5/21/1997	3	0.157
	7/2/1997	3	0.154
	7/8/1997	3	0.157
	7/17/1997	3	0.164
	7/29/1997	3	0.175
	8/8/1997	3	0.167
	8/15/1997	3	0.151
	8/20/1997	3	0.157
	9/4/1997	3	0.170
	9/10/1997	3	0.167
	9/18/1997	3	0.168
	9/24/1997	3	0.165
	10/1/1997	3	0.163

Table 28 – Cont'd
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)	Section	Date	TDR Number	Volumetric Moisture Content (%)
4	3/20/1997	4	0.211	21	10/8/1997	3	0.163
	3/24/1997	4	0.195		10/15/1997	3	0.163
	4/1/1997	4	0.328		11/12/1997	3	0.153
	4/11/1997	4	0.333		12/19/1997	3	0.141
	4/15/1997	4	0.328		1/29/1998	3	0.076
	4/29/1997	4	0.342		2/10/1998	3	0.082
	5/6/1997	4	0.353		2/26/1998	3	0.151
	5/20/1997	4	0.237		2/10/1998	3	0.080
	7/2/1997	4	0.263		2/26/1998	3	0.127
	7/8/1997	4	0.275		7/15/1993	4	0.320
	8/8/1997	4	0.390		3/2/1994	4	0.206
	8/15/1997	4	0.273		3/22/1994	4	0.341
	8/20/1997	4	0.267		4/5/1994	4	0.340
	9/24/1997	4	0.379		4/11/1994	4	0.341
	10/1/1997	4	0.391		4/18/1994	4	0.381
	10/8/1997	4	0.378		4/26/1994	4	0.392
	10/15/1997	4	0.380		12/21/1994	4	0.331
	10/29/1997	4	0.364		1/5/1995	4	0.302
	11/5/1997	4	0.352		1/20/1995	4	0.227
	11/12/1997	4	0.354		1/25/1995	4	0.212
	11/20/1997	4	0.335		2/3/1995	4	0.041
	12/10/1997	4	0.339		2/23/1995	4	0.216
	12/19/1997	4	0.340		2/28/1995	4	0.232
	2/10/1998	4	0.285		3/30/1995	4	0.328
	2/26/1998	4	0.349		4/13/1995	4	0.328
	9/26/1994	5	0.213		11/15/1995	4	0.387
	11/22/1994	5	0.184		12/15/1995	4	0.261
	12/21/1994	5	0.168		12/28/1995	4	0.263
	1/5/1995	5	0.166		1/10/1996	4	0.227
	1/20/1995	5	0.168		3/1/1996	4	0.228
	1/25/1995	5	0.145		3/12/1996	4	0.229
	1/31/1995	5	0.156		3/19/1996	4	0.162
	2/23/1995	5	0.142		6/11/1996	4	0.392
	2/28/1995	5	0.157		9/30/1996	4	0.390
	3/30/1995	5	0.162		10/14/1996	4	0.391
	4/13/1995	5	0.195		10/31/1996	4	0.365
	4/20/1995	5	0.196		11/20/1996	4	0.333
	5/10/1995	5	0.204		1/3/1997	4	0.200
	5/23/1995	5	0.220		2/12/1997	4	0.211
	6/12/1995	5	0.229		3/20/1997	4	0.228
	6/23/1995	5	0.226		3/24/1997	4	0.328
	7/14/1995	5	0.259		4/1/1997	4	0.325
	7/24/1995	5	0.259		4/11/1997	4	0.337
	8/15/1995	5	0.223		4/15/1997	4	0.339

Table 28 – Cont'd
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)
4	9/1/1995	5	0.238
	9/13/1995	5	0.212
	10/16/1995	5	0.192
	11/6/1995	5	0.218
	11/15/1995	5	0.182
	12/15/1995	5	0.171
	12/28/1995	5	0.169
	1/10/1996	5	0.161
	3/1/1996	5	0.121
	3/12/1996	5	0.116
	3/20/1996	5	0.120
	4/1/1996	5	0.189
	5/2/1996	5	0.226
	5/13/1996	5	0.231
	5/30/1996	5	0.277
	6/11/1996	5	0.242
	7/2/1996	5	0.305
	7/16/1996	5	0.299
	8/1/1996	5	0.221
	8/12/1996	5	0.224
	8/27/1996	5	0.192
	9/13/1996	5	0.174
	10/1/1996	5	0.167
	10/14/1996	5	0.159
	10/31/1996	5	0.161
	11/20/1996	5	0.151
	1/3/1997	5	0.138
	4/1/1997	5	0.165
	4/11/1997	5	0.185
	4/15/1997	5	0.180
	4/29/1997	5	0.194
	5/6/1997	5	0.264
	5/20/1997	5	0.219
	7/2/1997	5	0.212
	7/8/1997	5	0.210
	7/17/1997	5	0.216
	7/29/1997	5	0.224
	8/8/1997	5	0.220
	8/15/1997	5	0.216
	8/20/1997	5	0.218
	9/4/1997	5	0.256
	9/10/1997	5	0.250

Section	Date	TDR Number	Volumetric Moisture Content (%)
21	4/29/1997	4	0.375
	7/2/1997	4	0.258
	7/8/1997	4	0.248
	8/15/1997	4	0.253
	8/20/1997	4	0.259
	11/20/1997	4	0.382
	12/10/1997	4	0.364
	12/19/1997	4	0.375
	1/29/1998	4	0.253
	2/10/1998	4	0.257
	2/26/1998	4	0.378
	7/15/1993	5	0.276
	3/2/1994	5	0.173
	3/22/1994	5	0.198
	4/5/1994	5	0.330
	4/11/1994	5	0.340
	4/18/1994	5	0.363
	4/26/1994	5	0.379
	12/21/1994	5	0.323
	1/5/1995	5	0.305
	1/20/1995	5	0.293
	1/25/1995	5	0.288
	2/3/1995	5	0.035
	2/23/1995	5	0.191
	2/28/1995	5	0.209
	3/30/1995	5	0.318
	4/13/1995	5	0.327
	6/22/1995	5	0.339
	11/15/1995	5	0.345
	12/15/1995	5	0.302
	12/28/1995	5	0.282
	1/10/1996	5	0.225
	3/1/1996	5	0.186
	3/12/1996	5	0.177
	3/19/1996	5	0.195
	5/2/1996	5	0.387
	6/11/1996	5	0.317
	8/1/1996	5	0.375
	8/12/1996	5	0.379
	8/27/1996	5	0.374
	9/13/1996	5	0.373
	9/30/1996	5	0.363

Table 28 – Cont'd
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)
4	9/18/1997	5	0.246
	9/24/1997	5	0.213
	10/1/1997	5	0.205
	10/8/1997	5	0.188
	10/15/1997	5	0.174
	10/29/1997	5	0.174
	11/5/1997	5	0.168
	11/12/1997	5	0.171
	11/20/1997	5	0.166
	12/10/1997	5	0.164
	12/19/1997	5	0.167
21	10/14/1996	5	0.349
	10/31/1996	5	0.334
	11/20/1996	5	0.309
	1/3/1997	5	0.189
	2/12/1997	5	0.164
	3/20/1997	5	0.185
	3/24/1997	5	0.189
	4/1/1997	5	0.255
	4/11/1997	5	0.299
	4/15/1997	5	0.291
	4/29/1997	5	0.311
	5/6/1997	5	0.320
	5/21/1997	5	0.337
	7/2/1997	5	0.254
	7/8/1997	5	0.252
	8/15/1997	5	0.273
	8/20/1997	5	0.245
	12/10/1997	5	0.373
	12/19/1997	5	0.371
	1/29/1998	5	0.281
	2/10/1998	5	0.306
	2/26/1998	5	0.376
	7/15/1993	6	0.320
	3/2/1994	6	0.212
	3/22/1994	6	0.235
	4/5/1994	6	0.244
	4/11/1994	6	0.353
	4/18/1994	6	0.371
	4/26/1994	6	0.382
	12/21/1994	6	0.353
	1/5/1995	6	0.326
	1/20/1995	6	0.333
	1/25/1995	6	0.321
	2/3/1995	6	0.071
	2/23/1995	6	0.301
	2/28/1995	6	0.307
	3/30/1995	6	0.296
	4/13/1995	6	0.309
	6/22/1995	6	0.349
	11/15/1995	6	0.393
	12/15/1995	6	0.359
	12/28/1995	6	0.347

Table 28 – Cont'd
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)
21	1/10/1996	6	0.334
	3/1/1996	6	0.217
	3/12/1996	6	0.216
	3/19/1996	6	0.225
	5/2/1996	6	0.383
	6/11/1996	6	0.314
	8/1/1996	6	0.342
	8/12/1996	6	0.344
	8/27/1996	6	0.351
	9/13/1996	6	0.353
	9/30/1996	6	0.336
	10/14/1996	6	0.328
	10/31/1996	6	0.325
	11/20/1996	6	0.309
	1/3/1997	6	0.281
	2/12/1997	6	0.203
	3/20/1997	6	0.224
	3/24/1997	6	0.276
	4/1/1997	6	0.253
	4/11/1997	6	0.299
	4/15/1997	6	0.293
	5/6/1997	6	0.315
	5/21/1997	6	0.318
	7/2/1997	6	0.260
	7/8/1997	6	0.252
	7/17/1997	6	0.380
	8/15/1997	6	0.261
	8/20/1997	6	0.256
	11/20/1997	6	0.368
	12/10/1997	6	0.355
	12/19/1997	6	0.354
	1/29/1998	6	0.315
	2/10/1998	6	0.296
	2/26/1998	6	0.331
	7/15/1993	7	0.264
	3/2/1994	7	0.253
	3/22/1994	7	0.268
	4/5/1994	7	0.249
	4/11/1994	7	0.248
	4/18/1994	7	0.270
	4/26/1994	7	0.275
	9/27/1994	7	0.313
	12/21/1994	7	0.284

Section	Date	TDR Number	Volumetric Moisture Content (%)
21	1/5/1995	7	0.272
	1/20/1995	7	0.265
	1/25/1995	7	0.264
	2/3/1995	7	0.093
	2/23/1995	7	0.264
	2/28/1995	7	0.268
	3/30/1995	7	0.216
	4/13/1995	7	0.219
	5/23/1995	7	0.288
	6/22/1995	7	0.255
	7/14/1995	7	0.314
	7/24/1995	7	0.316
	8/15/1995	7	0.321
	9/1/1995	7	0.328
	9/13/1995	7	0.323
	10/16/1995	7	0.335
	11/15/1995	7	0.298
	12/15/1995	7	0.290
	12/28/1995	7	0.274
	1/10/1996	7	0.284
	3/1/1996	7	0.268
	3/12/1996	7	0.268
	3/19/1996	7	0.268
	5/2/1996	7	0.277
	5/13/1996	7	0.292
	5/30/1996	7	0.300
	6/11/1996	7	0.245
	7/2/1996	7	0.309
	7/16/1996	7	0.330
	8/1/1996	7	0.258
	8/12/1996	7	0.256
	8/27/1996	7	0.260
	9/13/1996	7	0.264
	9/30/1996	7	0.254
	10/14/1996	7	0.257
	10/31/1996	7	0.254
	11/20/1996	7	0.251
	1/3/1997	7	0.246
	2/12/1997	7	0.244
	3/20/1997	7	0.241
	3/24/1997	7	0.246
	4/1/1997	7	0.242
	4/11/1997	7	0.242
	4/15/1997	7	0.246

Table 28 – Cont'd
Moisture Data from TDR Probes – MnRoad Data

Section	Date	TDR Number	Volumetric Moisture Content (%)
21	4/29/1997	7	0.246
	5/6/1997	7	0.245
	5/21/1997	7	0.244
	7/2/1997	7	0.244
	7/8/1997	7	0.240
	7/17/1997	7	0.264
	7/29/1997	7	0.269
	8/15/1997	7	0.247
	8/20/1997	7	0.250
	9/4/1997	7	0.267
	9/10/1997	7	0.264
	9/18/1997	7	0.266
	9/24/1997	7	0.272
	10/1/1997	7	0.266
	10/8/1997	7	0.268
	10/15/1997	7	0.264
	10/29/1997	7	0.258
	11/5/1997	7	0.259
	11/12/1997	7	0.255
	11/20/1997	7	0.254
	12/10/1997	7	0.253
	12/19/1997	7	0.250
	1/29/1998	7	0.246
	2/10/1998	7	0.249

Table 29
Pavement Structure – MnRoad Data

Section	Layer Number	Layer Type	Thickness (in)	Construction Start	Construction End
4	1	Hot Mix Asphalt	1.5	09/28/92	09/28/92
	2	Hot Mix Asphalt	1.8	09/25/92	09/25/92
	3	Hot Mix Asphalt	2.3	09/24/92	09/24/92
	4	Hot Mix Asphalt	2.4	09/23/92	09/23/92
	5	Clay Subgrade		08/10/92	08/10/92
21	1	Hot Mix Asphalt	1.4	07/29/93	07/29/93
	2	Hot Mix Asphalt	2.1	07/28/93	07/28/93
	3	Hot Mix Asphalt	1.8	07/21/93	07/21/93
	4	Hot Mix Asphalt	1.4	07/20/93	07/20/93
	5	Class-5 Special Base	23.0	06/25/92	06/28/93
	6	Clay Subgrade		06/02/92	06/02/92

Table 30
Asphalt Concrete Mix Design and Material Properties

Section	Mix Design Method	Design Period (years)	Binder Type	Superpave Binder Grade	Design AC (%)	Aggregate Type
04	Superpave	5	120/150	58-28	5.6	MnRoad
21	Marshall50Blow	10	120/150	58-28	6.1	MnRoad

Table 31
Aggregate Properties for MnRoad Asphalt Concrete Test Cells

Property	Crow River Fines	Crow River Coarse	CA-50	Combined Gradation (Job Mix Formula)
Blending Percentages (%)				
Mix Design	74	16	10	100
Construction	66	24	10	100
Bulk Specific Gravity	2.73	2.66	2.62	2.708 (Mix) 2.702 (Field) 2.619 (ASU) [1]
Percent Crushed (%)	-	61.2	100	-
Cumulative Percent Passing (%)				
19 mm (3/4 in)	100	100	100	100
12.5 mm (1/2 in)	100	75	80	92
9.0 mm (3/8 in)	99	53	37	82
4.75 mm (No.4)	94	19	4	67
2.0 mm (No.10)	82	11	-	57
1.0 mm (No.20)	63	8	-	-
0.45 mm (No.40)	39	6	-	27
0.25 mm (No.80)	10	4	-	-
0.125 mm (No.100)	8	3	-	-
0.075 mm (No.200)	4.9	2.4	-	4

[1] Data determined during NCHRP 9-19 Phase I Project (Pellinen 2001).

Table 32
Asphalt Cements Properties

Property	Koch 120/150 Penetration Grade	Koch AC-20
Test on Original Binder		
Viscosity, 140F, Poise	846	1,987
Viscosity, 275F, Poise	271	397
Penetration, 77F, 0.1mm	130	76
Ductility, 77F, 5cm/min	120+	120+
Flash Point, F min	605 min	NA
Test on Residue from Thin Film Oven Test		
Viscosity, 140F, Poise	1,880	4,662
Viscosity, 275F, Poise	439	579
Penetration, 77F, 0.1mm	71	45
Ductility, 77F, 5cm/min	120+	120+

Table 33
In-Situ Gradation Results for the Granular Materials

Material	Gradation (% Passing)									
	1"	3/4"	3/8"	No.4	No.10	No.20	No.40	No.60	No.100	No.200
Class-3 SB	100	99.5	97.7	90.5	79.6	61.9	39.6	26.2	18.3	13.2
Class-4 SB	100	98	91	80	67	46	28	-	11	7.3
Class-5 SB	100	96	81	69	54	34	20	-	8	5.7
Class-6 SB	100	97.7	69.7	46	27.8	15.1	10.4	8.1	6.3	4.7

Table 34
Proctor Test Results for Granular Materials – MnRoad Data

Material	Class 3 SB	Class 4 SB	Class 5 SB	Class 6 SB
Max. Dry Density, pcf	127.9	126	132.7	128.7
Opt. Moisture Cont., %	8.8	10	8.1	6.8

Table 35
Dynamic Cone Penetrometer Test Results for Granular Materials - MnRoad

Material	Moisture Content (%)	Dry Density (pcf)	Penetration Rate (inch/blow)	CBR (%)
Class-5 SB	6.4	129.0	0.78	9
Class-5 SB	7.6	139.0	0.67	11
Class-5 SB	8.4	138.0	1.03	7

Table 36
Subgrade Soil Gradations - MnRoad

Section	**04**	**21**
Material Group	**Silty-Clay**	**Silty-Clay**
Passing #4	97.8	98.7
Passing #10	96.1	97.0
Passing #20	92.0	93.1
Passing #40	86.9	89.0
Passing #60	79.7	81.2
Passing #100	71.1	71.5
Passing #200	61.6	60.4

Table 37
Results of Soil Analysis from Bag Samples - MnRoad

Section	Station	Depth (in)	Liquid Limit (%)	Plasticity Index (%)	OMC (%)	Density (pcf)	R-value @ 240 psi
04	112280	26.77	32.5	14.2	16.2	110.37	13.1
21	123060	48.7	35.7	15.7	17.3	109.19	13.7

Table 38
Construction Data - MnRoad

Section	Section Length [ft]	Completion Date	Traffic Opening Date
04	495.46	09/29/92	07/15/94
21	500	08/05/93	07/20/94

Table 39
Maintenance Activities - MnRoad

Section	Date	Work Done	Passing Lane	Driving Lane
04	04/24/00	Clean and Seal	~400 ft of 3723 sealant	~400 ft of 3719 sealant
21	04/24/00	Clean and Seal	~450 ft of 3719 sealant	~450 ft of 3723 sealant

Table 40
Accumulated ESALs on MnRoad Cells 4 and 21

Section	Lane	Year							
		1994	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
04	Driving Lane	247,474	805,718	1,295,078	1,658,775	2,207,873	2,789,315	3,407,488	3,825,260
	Passing Lane	53,255	187,101	311,285	400,958	533,850	691,294	857,429	970,399
21	Driving Lane	232,332	757,056	1,216,838	1,557,651	2,078,825	2,627,004	3,215,591	3,612,758
	Passing Lane	49,007	173,031	288,503	371,603	495,711	642,813	798,259	903,860

Table 41
Moisture Data from TDR Probes – WesTrack Data

Section	Date	TDR Number	Volumetric Moisture Content (%)	Section	Date	TDR Number	Volumetric Moisture Content (%)
12	11/22/1996	1	44	15	10/28/1996	1	24
	12/11/1996	1	46		11/11/1996	1	29
	3/31/1997	1	9		11/22/1996	1	40
	4/14/1997	1	7		12/11/1996	1	36
	4/29/1997	1	6		12/19/1996	1	31
	5/16/1997	1	7		2/19/1997	1	31
	12/16/1997	1	11		3/4/1997	1	33
	1/13/1998	1	11		3/17/1997	1	31
	1/27/1998	1	11		3/31/1997	1	31
	2/11/1998	1	17		4/14/1997	1	30
	3/5/1998	1	11		4/29/1997	1	29
	3/26/1998	1	13		5/16/1997	1	31
	4/15/1998	1	15		7/15/1997	1	32
	10/28/1996	2	42		8/5/1997	1	24
	11/11/1996	2	28		8/19/1997	1	9
	11/22/1996	2	43		9/2/1997	1	9
	12/11/1996	2	42		9/16/1997	1	9
	12/19/1996	2	42		10/28/1997	1	9
	2/19/1997	2	18		12/16/1997	1	9
	3/4/1997	2	22		12/30/1997	1	9
	3/17/1997	2	18		1/13/1998	1	9
	3/31/1997	2	17		1/27/1998	1	9
	4/14/1997	2	17		2/11/1998	1	11
	4/29/1997	2	17		3/5/1998	1	11
	5/16/1997	2	16		4/15/1998	1	15
	7/15/1997	2	17		10/28/1996	2	38
	8/5/1997	2	16		11/11/1996	2	39
	8/19/1997	2	16		11/22/1996	2	47
	9/2/1997	2	17		12/11/1996	2	47
	9/16/1997	2	15		12/19/1996	2	39
	11/18/1997	2	17		2/19/1997	2	41
	12/2/1997	2	16		3/4/1997	2	43
	12/16/1997	2	20		3/17/1997	2	41
	12/30/1997	2	17		3/31/1997	2	41
	1/13/1998	2	18		4/14/1997	2	40
	1/27/1998	2	17		4/29/1997	2	41
	2/11/1998	2	42		5/16/1997	2	43

Table 41 – Cont'd
Moisture Data from TDR Probes – WesTrack Data

Section	Date	TDR Number	Volumetric Moisture Content (%)		Section	Date	TDR Number	Volumetric Moisture Content (%)
12	3/5/1998	2	19		15	7/15/1997	2	44
	3/26/1998	2	43			8/5/1997	2	39
	4/15/1998	2	30			8/19/1997	2	26
	10/28/1996	3	46			9/2/1997	2	20
	11/11/1996	3	44			9/16/1997	2	19
	11/22/1996	3	45			10/28/1997	2	18
	12/11/1996	3	45			12/16/1997	2	17
	12/19/1996	3	44			12/30/1997	2	17
	2/19/1997	3	37			1/13/1998	2	18
	3/4/1997	3	42			1/27/1998	2	20
	3/17/1997	3	36			2/11/1998	2	26
	3/31/1997	3	35			3/5/1998	2	26
	4/14/1997	3	33			4/15/1998	2	30
	4/29/1997	3	33			10/28/1996	3	40
	5/16/1997	3	33			11/11/1996	3	42
	7/15/1997	3	36			11/22/1996	3	47
	8/5/1997	3	33			12/11/1996	3	46
	8/19/1997	3	35			12/19/1996	3	43
	9/2/1997	3	34			2/19/1997	3	43
	9/16/1997	3	32			3/4/1997	3	46
	11/18/1997	3	32			3/17/1997	3	43
	12/2/1997	3	29			3/31/1997	3	43
	12/16/1997	3	42			4/14/1997	3	42
	12/30/1997	3	33			4/29/1997	3	43
	1/13/1998	3	31			5/16/1997	3	45
	1/27/1998	3	36			7/15/1997	3	47
	2/11/1998	3	45			8/5/1997	3	40
	3/5/1998	3	38			8/19/1997	3	30
	3/26/1998	3	44			9/2/1997	3	27
	4/15/1998	3	35			9/16/1997	3	22
	10/28/1996	4	46			10/28/1997	3	22
	11/11/1996	4	44			12/2/1997	3	24
	11/22/1996	4	42			12/16/1997	3	25
	12/11/1996	4	41			12/30/1997	3	23
	12/19/1996	4	42			1/13/1998	3	24
	2/19/1997	4	37			1/27/1998	3	26
	3/4/1997	4	37			2/11/1998	3	31
	3/17/1997	4	36			3/5/1998	3	29
	3/31/1997	4	37			3/26/1998	3	101

Table 41 – Cont'd
Moisture Data from TDR Probes – WesTrack Data

Section	Date	TDR Number	Volumetric Moisture Content (%)		Section	Date	TDR Number	Volumetric Moisture Content (%)
	4/14/1997	4	35			4/15/1998	3	35
	4/29/1997	4	38			10/28/1996	4	38
	5/16/1997	4	39			11/11/1996	4	40
	7/15/1997	4	42			11/22/1996	4	48
	8/5/1997	4	43			12/11/1996	4	44
12	8/19/1997	4	43		15	12/19/1996	4	41
	9/2/1997	4	42			2/19/1997	4	41
	9/16/1997	4	42			3/4/1997	4	43
	11/18/1997	4	36			3/17/1997	4	41
	12/2/1997	4	34			3/31/1997	4	41
	12/16/1997	4	46			4/14/1997	4	39
	12/30/1997	4	33			4/29/1997	4	40
	1/13/1998	4	32			5/16/1997	4	41
	1/27/1998	4	36			7/15/1997	4	43
	2/11/1998	4	43			8/5/1997	4	35
	3/5/1998	4	39			8/19/1997	4	22
	3/26/1998	4	44			9/2/1997	4	41
	4/15/1998	4	38			9/16/1997	4	26
	10/28/1996	5	41			10/28/1997	4	28
	11/11/1996	5	37			12/2/1997	4	29
	11/22/1996	5	37			12/16/1997	4	29
	12/11/1996	5	35			12/30/1997	4	28
	12/19/1996	5	33			1/13/1998	4	28
	2/19/1997	5	32			1/27/1998	4	32
	3/4/1997	5	32			2/11/1998	4	37
	3/17/1997	5	32			3/5/1998	4	34
	3/31/1997	5	32			4/15/1998	4	38
	4/14/1997	5	31			10/28/1996	5	25
	4/29/1997	5	32			11/22/1996	5	32
	5/16/1997	5	33			12/11/1996	5	32
	7/15/1997	5	35			12/19/1996	5	29
	8/5/1997	5	36			2/19/1997	5	28
	8/19/1997	5	36			3/4/1997	5	30
	9/2/1997	5	36			3/17/1997	5	27
	9/16/1997	5	37			3/31/1997	5	28
	11/18/1997	5	34			4/14/1997	5	26
	12/2/1997	5	30			4/29/1997	5	27
	12/16/1997	5	37			5/16/1997	5	27
	12/30/1997	5	30			7/15/1997	5	29

Table 41 – Cont'd
Moisture Data from TDR Probes – WesTrack Data

Section	Date	TDR Number	Volumetric Moisture Content (%)	Section	Date	TDR Number	Volumetric Moisture Content (%)
	1/13/1998	5	29		8/5/1997	5	28
	1/27/1998	5	32		8/19/1997	5	26
	2/11/1998	5	35		9/2/1997	5	29
	3/5/1998	5	33		9/16/1997	5	25
	3/26/1998	5	35		10/28/1997	5	23
	4/15/1998	5	30		12/2/1997	5	23
	10/28/1996	6	42		12/16/1997	5	22
	11/11/1996	6	47		12/30/1997	5	22
	11/22/1996	6	41		1/13/1998	5	22
	12/11/1996	6	40		1/27/1998	5	25
12	12/19/1996	6	40	15	2/11/1998	5	27
	2/19/1997	6	35		3/5/1998	5	25
	3/4/1997	6	33		3/26/1998	5	36
	3/17/1997	6	35		4/15/1998	5	30
	3/31/1997	6	36		10/28/1996	6	22
	4/14/1997	6	36		11/11/1996	6	22
	4/29/1997	6	38		11/22/1996	6	29
	5/16/1997	6	40		12/11/1996	6	28
	7/15/1997	6	45		12/19/1996	6	25
	8/5/1997	6	43		2/19/1997	6	25
	8/19/1997	6	46		3/4/1997	6	26
	9/2/1997	6	44		3/17/1997	6	24
	9/16/1997	6	45		3/31/1997	6	23
	11/18/1997	6	34		4/14/1997	6	22
	12/2/1997	6	32		4/29/1997	6	23
	12/16/1997	6	40		5/16/1997	6	22
	12/30/1997	6	32		7/15/1997	6	24
	1/13/1998	6	30		8/5/1997	6	23
	1/27/1998	6	32		8/19/1997	6	23
	2/11/1998	6	37		9/2/1997	6	26
	3/5/1998	6	35		9/16/1997	6	23
	3/26/1998	6	38		10/28/1997	6	22
	4/15/1998	6	27		12/2/1997	6	21
	10/28/1996	7	21		12/16/1997	6	20
	11/11/1996	7	22		12/30/1997	6	20
	11/22/1996	7	22		1/13/1998	6	21
	12/11/1996	7	21		1/27/1998	6	23
	12/19/1996	7	22		2/11/1998	6	24
	2/19/1997	7	22		3/5/1998	6	23

Table 41 – Cont'd
Moisture Data from TDR Probes – WesTrack Data

Section	Date	TDR Number	Volumetric Moisture Content (%)	Section	Date	TDR Number	Volumetric Moisture Content (%)
	3/4/1997	7	22		3/26/1998	6	35
	3/17/1997	7	22		4/15/1998	6	27
	3/31/1997	7	22		10/28/1996	7	21
	4/14/1997	7	22		11/11/1996	7	22
	4/29/1997	7	23		11/22/1996	7	31
	5/16/1997	7	24		12/11/1996	7	28
	7/15/1997	7	25		12/19/1996	7	26
	8/5/1997	7	25		2/19/1997	7	24
	8/19/1997	7	25		3/4/1997	7	26
	9/2/1997	7	27		3/17/1997	7	24
	9/16/1997	7	26		3/31/1997	7	23
	11/18/1997	7	22		4/14/1997	7	23
	12/2/1997	7	22		4/29/1997	7	22
	12/16/1997	7	26		5/16/1997	7	22
	12/30/1997	7	22		7/15/1997	7	23
12	1/13/1998	7	21	15	8/5/1997	7	23
	1/27/1998	7	21		8/19/1997	7	23
	2/11/1998	7	22		9/2/1997	7	26
	3/5/1998	7	23		9/16/1997	7	24
	3/26/1998	7	23		10/28/1997	7	22
	4/15/1998	7	28		12/2/1997	7	21
	10/28/1996	8	22		12/16/1997	7	21
	11/11/1996	8	19		12/30/1997	7	20
	11/22/1996	8	18		1/13/1998	7	20
	12/11/1996	8	19		1/27/1998	7	24
	12/19/1996	8	18		2/11/1998	7	24
	2/19/1997	8	21		3/5/1998	7	22
	3/4/1997	8	20		3/26/1998	7	34
	3/17/1997	8	20		4/15/1998	7	28
	3/31/1997	8	21		10/28/1996	8	15
	4/14/1997	8	22		11/11/1996	8	16
	4/29/1997	8	22		11/22/1996	8	22
	5/16/1997	8	22		12/11/1996	8	20
	7/15/1997	8	23		12/19/1996	8	21
	8/5/1997	8	23		2/19/1997	8	17
	8/19/1997	8	23		3/4/1997	8	20
	9/2/1997	8	23		3/17/1997	8	17
	9/16/1997	8	23		3/31/1997	8	16
	11/18/1997	8	22		4/14/1997	8	15

Table 41 – Cont'd
Moisture Data from TDR Probes – WesTrack Data

Section	Date	TDR Number	Volumetric Moisture Content (%)
	12/2/1997	8	20
	12/16/1997	8	23
	12/30/1997	8	22
	1/13/1998	8	20
	1/27/1998	8	20
	2/11/1998	8	20
	3/5/1998	8	23
	3/26/1998	8	22
	4/15/1998	8	19
	10/28/1996	9	11
	11/11/1996	9	11
	11/22/1996	9	11
	12/11/1996	9	11
	12/19/1996	9	11
	2/19/1997	9	14
	3/4/1997	9	13
	3/17/1997	9	13
	3/31/1997	9	13
	4/14/1997	9	13
	4/29/1997	9	13
12	5/16/1997	9	13
	7/15/1997	9	14
	8/5/1997	9	13
	8/19/1997	9	13
	9/2/1997	9	14
	9/16/1997	9	13
	11/18/1997	9	12
	12/2/1997	9	12
	12/16/1997	9	15
	12/30/1997	9	13
	1/13/1998	9	12
	1/27/1998	9	12
	2/11/1998	9	12
	3/5/1998	9	12
	3/26/1998	9	12
	4/15/1998	9	12
	10/28/1996	10	12
	11/11/1996	10	12
	11/22/1996	10	12

Section	Date	TDR Number	Volumetric Moisture Content (%)
	4/29/1997	8	16
	5/16/1997	8	16
	7/15/1997	8	18
	8/5/1997	8	18
	8/19/1997	8	18
	9/2/1997	8	21
	9/16/1997	8	18
	10/28/1997	8	15
	12/2/1997	8	21
	12/16/1997	8	15
	12/30/1997	8	16
	1/13/1998	8	14
	1/27/1998	8	17
	2/11/1998	8	18
	3/5/1998	8	15
	3/26/1998	8	30
	4/15/1998	8	19
	10/28/1996	9	9
	11/11/1996	9	8
	11/22/1996	9	7
15	12/11/1996	9	8
	12/19/1996	9	8
	2/19/1997	9	10
	3/4/1997	9	10
	3/17/1997	9	10
	3/31/1997	9	10
	4/14/1997	9	9
	4/29/1997	9	10
	5/16/1997	9	10
	7/15/1997	9	11
	8/5/1997	9	11
	8/19/1997	9	12
	9/2/1997	9	12
	9/16/1997	9	12
	10/28/1997	9	12
	12/2/1997	9	11
	12/16/1997	9	11
	12/30/1997	9	11
	1/13/1998	9	10

Table 41 – Cont'd
Moisture Data from TDR Probes – WesTrack Data

Section	Date	TDR Number	Volumetric Moisture Content (%)
	12/11/1996	10	11
	12/19/1996	10	11
	2/19/1997	10	14
	3/4/1997	10	14
	3/17/1997	10	14
	3/31/1997	10	14
	4/14/1997	10	14
	4/29/1997	10	14
	5/16/1997	10	14
	7/15/1997	10	14
	8/5/1997	10	14
	8/19/1997	10	14
	9/2/1997	10	14
	9/16/1997	10	14
	11/18/1997	10	13
	12/2/1997	10	13
	12/16/1997	10	13
	12/30/1997	10	13
	1/13/1998	10	12
	1/27/1998	10	12
	2/11/1998	10	12
	3/5/1998	10	12
	3/26/1998	10	12
	4/15/1998	10	22

Section	Date	TDR Number	Volumetric Moisture Content (%)
	1/27/1998	9	11
	2/11/1998	9	10
	3/5/1998	9	11
	3/26/1998	9	35
	4/15/1998	9	12
	10/28/1996	10	14
	11/11/1996	10	14
	11/22/1996	10	13
	12/11/1996	10	12
	12/19/1996	10	12
	2/19/1997	10	13
	3/4/1997	10	13
	3/17/1997	10	13
	3/31/1997	10	12
	4/14/1997	10	13
	4/29/1997	10	13
	5/16/1997	10	14
	7/15/1997	10	9
	8/5/1997	10	17
	8/19/1997	10	16
	9/2/1997	10	17
	9/16/1997	10	17
	10/28/1997	10	16
	12/2/1997	10	14
	12/16/1997	10	15
15	12/30/1997	10	14
	1/13/1998	10	14
	1/27/1998	10	15
	2/11/1998	10	15
	3/5/1998	10	14
	3/26/1998	10	43
	4/15/1998	10	22

Table 42
Groundwater Table Depth Recorded at WesTrack

Location	Reading Date	Groundwater Table Depth (m)	Groundwater Table Depth (ft)
South Tangent	3/18/1996	3.08	10.10
	4/16/1996	2.96	9.71
	4/29/1996	2.9	9.51
	5/15/1996	2.72	8.92
	5/20/1996	2.3	7.55
	5/29/1996	2.7	8.86
	6/11/1996	2.72	8.92
	6/24/1996	2.97	9.74
	7/8/1996	3.16	10.37
	7/22/1996	3.39	11.12
	8/5/1996	3.6	11.81
	8/19/1996	3.69	12.11
	9/3/1996	3.74	12.27
	9/18/1996	3.79	12.43
	9/30/1996	3.8	12.47
	10/14/1996	3.8	12.47
	10/28/1996	3.69	12.11
	11/11/1996	3.63	11.91
	11/22/1996	3.64	11.94
	12/9/1996	3.38	11.09
	12/19/1996	3.34	10.96
	1/9/1997	2.58	8.46
	1/30/1997	2.4	7.87
	2/18/1997	2.9	9.51
	3/3/1997	3.05	10.01
	3/17/1997	3.08	10.10
	4/14/1997	3.09	10.14
	4/29/1997	2.8	9.19
	5/16/1997	2.67	8.76
	7/14/1997	3.42	11.22
	8/5/1997	3.6	11.81
	8/19/1997	3.71	12.17
	9/2/1997	3.77	12.37
	9/16/1997	3.77	12.37
	10/27/1997	3.64	11.94
	11/18/1997	3.47	11.38
	12/2/1997	3.56	11.68
	12/16/1997	3.55	11.65
	12/30/1997	3.57	11.71

Table 42 – Cont'd
Groundwater Table Depth Recorded at WesTrack

Location	Reading Date	Groundwater Table Depth (m)	Groundwater Table Depth (ft)
South Tangent	1/13/1998	3.54	11.61
	1/27/1998	3.48	11.42
	2/10/1998	3.46	11.35
	3/4/1998	3.39	11.12
	3/26/1998	3.11	10.20
	4/15/1998	3.25	10.66
	5/7/1998	2.82	9.25
	6/2/1998	2.82	9.25
	9/17/1998	3.52	11.55
	3/9/1999	3.57	11.71
North Tangent	3/18/1996	3.54	11.61
	4/16/1996	3.34	10.96
	4/29/1996	3.16	10.37
	5/15/1996	3.14	10.30
	5/20/1996	3.04	9.97
	5/29/1996	2.39	7.84
	6/11/1996	3.12	10.24
	6/24/1996	3.17	10.40
	7/8/1996	3.22	10.56
	7/22/1996	3.34	10.96
	8/5/1996	3.5	11.48
	8/19/1996	3.59	11.78
	9/3/1996	3.67	12.04
	9/18/1996	3.76	12.34
	9/30/1996	3.67	12.04
	10/14/1996	3.8	12.47
	10/28/1996	3.85	12.63
	11/11/1996	3.85	12.63
	11/22/1996	3.85	12.63
	12/9/1996	3.71	12.17
	12/19/1996	3.74	12.27
	1/9/1997	2.64	8.66
	1/30/1997	2.58	8.46
	2/18/1997	2.79	9.15
	3/3/1997	3.08	10.10
	3/17/1997	3.2	10.50
	4/14/1997	3.06	10.04
	4/29/1997	3.28	10.76
	5/16/1997	2.86	9.38
	7/14/1997	3.19	10.47

Table 42 – Cont'd
Groundwater Table Depth Recorded at WesTrack

Location	Reading Date	Groundwater Table Depth (m)	Groundwater Table Depth (ft)
	8/5/1997	3.47	11.38
	8/19/1997	3.45	11.32
	9/2/1997	3.52	11.55
	9/16/1997	3.57	11.71
	10/27/1997	3.56	11.68
	11/18/1997	3.56	11.68
	12/2/1997	3.67	12.04
	12/16/1997	3.74	12.27
	12/30/1997	3.75	12.30
	1/13/1998	3.78	12.40
	1/27/1998	3.77	12.37
	2/10/1998	3.76	12.34
	3/4/1998	3.74	12.27
	3/26/1998	3.72	12.20
	4/15/1998	3.77	12.37
	5/7/1998	2.97	9.74
	6/2/1998	3.27	10.73
	9/17/1998	3.57	11.71
	3/9/1999	3.32	10.89

Table 43
As-Built Pavement Thickness of WesTrack Original Sections

Section	Average Thickness (m)
12	0.167
15	0.155
25	0.164

Table 44
Experiment Design for Original 26 WesTrack Sections

Design Air Void Content	Aggregate Gradation Designation								
	Fine			Fine Plus			Coarse		
	Design Asphalt Content (%)								
%	Low 4.7	Opt. 5.4	High 6.1	Low 4.7	Opt. 5.4	High 6.1	Low 5.0	Opt. 5.7	High 6.4
4		04	18		**12**	09/12		23	**25**
8	02	01/**15**	14	22	11/19	13	08	05/24	07
12	03/16	17		10	20		26	06	

Table 45
Aggregate Stockpile Percentages During Original Construction

Stockpile	Mixture Designation			
	Fine	Fine-Plus	Coarse	
			Bottom	Top
Dayton ¾-in. 1994	25.0	25.0	39.0	39.0
Dayton ½-in. 1994	25.0	25.0	27.0	
Dayton ½-in. 1995				12.2
Dayton ⅜-in. 1994	10.0	10.0		14.8
Dayton rock dust 1994	13.5	13.5	32.5	32.5
Dayton sand 1994				
Wadsworth sand 1994	25.0	25.0		
Lime	1.5	1.5	1.5	1.5

Table 46
Gradation of Base Course Placed at WesTrack

Sieve Size		Percent Passing
1-in.	**25-mm**	100.0
¾-in.	**19-mm**	93.6
½-in.	**12.5-mm**	73.2
⅜-in.	**9.5-mm**	59.6
No. 4	**4.75-mm**	37.5
No. 8	**2.36-mm**	28.3
No. 16	**1.18-mm**	23.6
No. 40	**0.425-mm**	18.4
No. 100	**0.15-mm**	12.6
No. 200	**0.075-mm**	9.2

Table 47
WesTrack Base Course Moisture Density Data

Tangent	Density (pcf)			Moisture Content (%)		
	Mean	Standard Dev.	PWL	Mean	Standard Dev.	PWL
South	102.24	1.22	84.88	7.49	0.48	78.94
North	103.11	10.7	90.76	7.24	0.46	53.74
Both	102.67	1.15	87.82	7.37	0.47	66.34

Table 48
WesTrack Granular Base Lab Test Data for Lift 1

Section Number	Liquid Limit (AASHTO T 89-93)	Plasticity Index (AASHTO T 90-92)	CBR (AASHTO T 193-92)	R-value (AASHTO T190-93)
15	NA	NP	100	82
25	NA	NP		

Table 49
WesTrack Granular Base Lab Test Data for Lift 2

Section Number	Liquid Limit (AASHTO T 89-93)	Plasticity Index (AASHTO T 90-92)	CBR (AASHTO T 193-92)	R-value (AASHTO T190-93)
12	NA	NP		
15	NA	NP	100	82

Table 50
Base Course and Subgrade CBR Values from U.S. Army Corps of Engineers' Software

Section	CBR Base Course		CBR Subgrade Soil	
	Left Wheelpath	**Right Wheelpath**	**Left Wheelpath**	**Right Wheelpath**
DCP Test – November 11, 1996				
25	74	55	8	9
DCP Test – April 22, 1999				
15	83	98	15	10

Table 51
Back-calculated Moduli for the Base Course and Subgrade Soil in MPa

Section	Base Course Right Wheelpath	Subgrade Soil Right Wheelpath
FWD Testing – October 28, 1996		
25	138	91
FWD Testing – March 10, 1999		
15	177	82

Table 52
Resilient Modulus Testing for Base and Subgrade Soils, in MPa

Section Number	Base Modulus	Subgrade Modulus
25	75	100

Table 53
WesTrack Compaction Data for Engineered Fill

Tangent	Test	Sample 1	Sample 2	Sample 3	Average
North	Optimum water content (%)				13.0
	Maximum dry density (pcf)				118.5
	Water content (%)	13.5	13.0	12.6	
	Dry density (%)	107.4	107.1	107.5	
	Relative Density (%)	90.6	90.4	90.7	
South	Optimum water content (%)				15.0
	Maximum dry density (pcf)				113.0
	Water content (%)	15.5	15.4	14.5	
	Dry density (%)	102.5	101.8	104.3	
	Relative Density (%)	90.7	90.1	92.3	

Table 54
WesTrack Average Relative Density for Subgrade and Engineered Fill

Subgrade Lift	Mean	Standard Deviation	PWL
Lift 1	91.26	1.99	68.39
Lift 2	91.58	1.57	82.42
Lift 3	92.21	1.49	86.88
Lift 4	93.46	1.38	90.44

Table 55
WesTrack Engineered Fill Additional Properties

Section Number	Lift	Liquid Limit	Plasticity Index	CBR	R-value	Classification
25	1	42	22			A-7-6
	2	47	25	4	<5	A-7-6
12	3	47	26			A-7-6
	4	34	19	3	<5	A-6
15	3	48	28	4	<5	A-7-6
	4	42	23			A-7-6

Table 56
Back-calculated Resilient Modulus for Subgrade Soil

Tangent	Resilient Modulus (psi)					
	October 1994		February 1995		April 1995	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
North	16,472	4,340	5,832	3,173	9,959	3,645
South	14,947	4,835	4,769	1,423	3,677	1,229
Combined	15,710	5,300	5,301	2,298	6,818	2,437

Table 57
Normalized Range of Subgrade Soil Resilient Modulus (Epps 2002)

Season	Period	Average % of Summer Months
Winter	January-March	81
Spring	April-June	70
Summer	July-September	100
Fall	October-December	102

Table 58
Estimated Monthly Subgrade Soil Modulus Values for WesTrack Project

Season	Month	Estimated Soil Moduli (psi)
Summer	September	8,300
Fall	October	8,500
	November	8,500
	December	8,500
Winter	January	6,700
	February	6,700
	March	6,700
Spring	April	5,800
	May	5,800
	June	5,800
Summer	July	8,300
	August	8,300

Table 59
WesTrack Activities

Date	Traffic (ESAL x 10^6)		Activity	Comments
	Original Sections	Replacement Sections		
October'94			Project approved	
January'95			Geometric design and experimental design completed.	
May'95			Start construction.	
May-August'95			Fill and subgrade completed.	
August'95			Base course placement completed.	
October'95			HMA placement completed - original construction.	
March'96	-0-		Start of traffic.	
November'96	1.46		Mill and fill 5 rutted sections (50 mm).	Sections 7, 9, 13, 21, and **25**
January'97	1.79		Carson River flood.	
June'97	2.77	-0-	Construction of replacement sections.	Remove sections 5, 6, 7, 8, 9, 13, 21, 24, **25**, and 26. Replace with 35, 36, 37, 38, 39, 43, 51, 54, 55, and 56.
January'98	4.1	1.28	Cold patching.	
March'99	5.0	2.23	Trafficking completed.	

Table 60
Construction Activities – Subgrade and Engineered Fill and Base Course

Date	Activity
May 31, 1995 through June 14, 1995	Place and compact layer 1 of subgrade and engineered fill
June 2, 1995 through June 23, 1995	Place and compact layer 2 of subgrade and engineered fill
June 21, 1995 through July 7, 1995	Place and compact layer 3 of subgrade and engineered fill
August 4, 1995 through August 16, 1995	Place and compact layer 4 of subgrade and engineered fill
August 21, 1995 through August 28, 1995	Place and compact layer 1 of base course
August 29, 1995 through August 31, 1995	Place and compact layer 2 of base course

Table 61
HMA Construction Schedule for Original Construction Test Lanes

Date	Mixture	Lift	Section Numbers
9-20-95	Fine	Bottom	1, 2, 3, 4, 14, **15**, 16, 17, and 18
9-21-95	Fine plus	Bottom	19, 20, 21, 22, 9, 10, 11, **12**, and 13
9-30-95	Coarse	Bottom	5, 6, 7, 8, 23, 24, **25**, and 26
10-2-95	Fine	Top	1, 2, 3, 4, 14, **15**, 16, 17, and 18
10-3-95	Fine plus	Top	19, 20, 21, 22, 9, 10, 11, **12**, and 13
10-4-95	Coarse	Top	5, 6, 7, 8, 23, 24, **25**, and 26

Table 62
Rehabilitation and Maintenance Activities

Date	Activity	Comments
November 1996	Mill and fill fine rutted sections (50 mm).	Sections 7, 9, 13, 21, and **25**
June 1997	Construction of replacement sections.	See Table 59.
January 1998	Cold patching.	

Table 63
Temperature Data for ADOT Sections

Thermo Couple No.	Therm. Depth (in)	Therm. Depth (ft)	Date	Site 1 Temperature (F)	Site 14 Temperature (F)
1	0	0	1/1977	61	27
			2/1977	70	32
			3/1977	77	43
			4/1977	86	45
			5/1977	102	61
			6/1977	113	64
			7/1977	124	74
			8/1977	118	75
			9/1977	111	66
			10/1977	91	43
			11/1977	68	42
			12/1977	64	25
2	3	0.25	1/1977	61	28
			2/1977	71	31
			3/1977	75	43
			4/1977	84	45
			5/1977	101	60
			6/1977	111	65
			7/1977	123	72
			8/1977	117	72
			9/1977	110	65
			10/1977	91	43
			11/1977	67	35
			12/1977	63	26
3	9	0.75	1/1977	59	31
			2/1977	69	32
			3/1977	72	46
			4/1977	85	50
			5/1977	102	62
			6/1977	111	68
			7/1977	118	65
			8/1977	110	67
			9/1977	92	63
			10/1977	85	45
			11/1977	66	39
			12/1977	62	27

Table 63 - Cont'd
Temperature Data for ADOT Sections

Thermo Couple No.	Therm. Depth (in)	Therm. Depth (ft)	Date	Site 1 Temperature (F)	Site 14 Temperature (F)
4	15	1.25	1/1977	58	32
			2/1977	71	33
			3/1977	72	45
			4/1977	84	49
			5/1977	102	63
			6/1977	111	68
			7/1977	116	65
			8/1977	111	67
			9/1977	92	65
			10/1977	86	55
			11/1977	74	44
			12/1977	71	39
5	24	2	1/1977	59	35
			2/1977	72	35
			3/1977	82	51
			4/1977	90	55
			5/1977	96	68
			6/1977	106	73
			7/1977	111	65
			8/1977	105	67
			9/1977	89	67
			10/1977	85	50
			11/1977	77	44
			12/1977	70	33
6	30	2.5	1/1977	61	37
			2/1977	62	39
			3/1977	67	47
			4/1977	76	50
			5/1977	93	56
			6/1977	104	62
			7/1977	105	63
			8/1977	104	64
			9/1977	90	62
			10/1977	86	59
			11/1977	82	48
			12/1977	71	38

Table 64
Moisture Data from TDR Probes

Section	Date	TDR Number	Depth from Asphalt Layer [in]	Volumetric Moisture Content (%)
1	1/1973	1	0-4	0.1
	1/1974	2	5-10	2.2
	3/1975	2	5-10	2
	1/1974	3	11-17	11.1
	1/1974	4	18-36	12.6
14	7/1975	1	0-4	0.3
	12/1975	1		0.3
	3/1976	1		0.6
	6/1975	1		0.3
	8/1977	1		0.8
	4/1978	1		0.7
	7/1975	2	5-10	13.3
	11/1975	2		12.8
	12/1975	2		12.4
	3/1976	2		13.2
	6/1976	2		10
	7/1976	2		12.8
	8/1977	2		15
	4/1978	2		13.4
	7/1975	3	11-17	20.6
	11/1975	3		20.6
	12/1975	3		21.2
	3/1976	3		21.7
	6/1976	3		21.4
	8/1977	3		22.8
	4/1978	3		21
	7/1975	4	18-36	10
	12/1975	4		8.7
	3/1976	4		8.7
	6/1976	4		8.7
	8/1977	4		10.5
	4/1978	4		9.2

Table 65
Groundwater Table Depth Recorded

Location	Reading Date	Groundwater Table Depth (m)	Groundwater Table Depth (ft)
Site 1	1/17/72	25	82
	1/73	25.9	85
	4/73	23.4	76.8
	12/6/76	23.9	78.5
	4/11/77	34.4	113
	2/78	10.1	33
	1/79	21.9	72
	4/11/79	20.4	67
	5/16/79	19.8	65
	12/20/79	19.2	63
	5/12/80	23.2	76
	1/81	17.7	58
	12/22/82	18	59.2
	12/01/84	16.1	52.8
	1/9/86	14.9	49
	11/05/91	17.9	58.7
Site 14	10/19/1992	324	1063
	5/21/1985	286.8	941

Table 66
As-Built Layer Thicknesses of ADOT Original Sections

Site	Date Built	Thickness (in)	Thickness (mm)	Layer
1	11/1977	0.5	12.7	Friction Course
	8/1974	0.5	12.7	Friction Course
	8/1974	1.5	38.1	Asphaltic Concrete
	12/1956	0.3	7.62	Seal Coat
	12/1956	2	50.8	Asphaltic Concrete
	12/1956	4	101.6	Base Layer
	12/1956	8	203.2	Subbase Layer
	1936	2	50.8	Asphaltic Concrete
	1936	6	152.4	Base Layer
	NA	NA	NA	Subgrade
14	1974	0.5	12.7	Friction Course
	9/1966	0.3	7.62	Seal Coat
	9/1966	3.5	88.9	Original Surface Layer
	8/1960	1	25.4	Base Layer
	8/1960	6	152.4	Base Layer
	8/1960	10	254	Subbase Layer
	8/1960	12	304.8	Subgrade

Table 67
Air Voids Data for ADOT Sites

Site	Date Built	% Air Voids	Air Voids at Age = t (%)	Age t (months)	VMA	
					Construction Data	Field Data
1	1956	10	9.1	240	17.6	19.4
	1974	9.6	1.1	24	18.7	12.1
14	1966	13.4	1.8	120	32.5	-

Table 68
Asphaltic Binder Type and Percent of Asphalt in Mix

Site	Date Built	Asphaltic Binder Type	% Asphalt
1	1956	150/200	3.6
	1974	AR4000	11.3
14	1966	120/150	4.5

Table 69
Gradation of Asphaltic Concrete

Sieve Size		Percent Passing		
		Site1, 1956	Site 1, 1974	Site 14,1966
1.5-in.	**38.1-mm**	100	100	100
¾-in.	**19-mm**	89	97	98
⅜-in.	**9.5-mm**	65	58	80
No. 4	**4.75-mm**	56	42	60
No. 8	**2.36-mm**	51	32	46
No. 16	**1.18-mm**	47	25	35
No. 30	**0.595-mm**	36	17	27
No. 50	**.297-mm**	18	10	19
No. 100	**0.15-mm**	6	5	12
No. 200	**0.075-mm**	2	3	7

Table 70
Gradation of Base Course

Sieve Size		Percent Passing		
		Site1, 1956	Site 14, 1960 (BSB)	Site 14,1960 (AB)
1.5-in.	**38.1-mm**	100	100	100
¾-in.	**19-mm**	89	100	100
⅜-in.	**9.5-mm**	68	100	82
No. 4	**4.75-mm**	60	21	53
No. 8	**2.36-mm**	57	6	33
No. 16	**1.18-mm**	52	6	19
No. 30	**0.595-mm**	39	6	13
No. 50	**.297-mm**	21	6	8
No. 100	**0.15-mm**	11	5	5
No. 200	**0.075-mm**	7	3	3

Table 71
Summaries of Base Course Moisture Density Data

Tangent	Mean Density (pcf)			Mean Moisture Content (%)		
	Proctor	Field	of R	Proctor	Field	of R
Site 1	-	136.1	-	-	3.8	-
Site 14	80.3	81.1	85.1	21.7	15.2	15.8

Table 72
Granular Base PI and Soil Classification

Section Number	Liquid Limit	Plasticity Index	AASHTO Classification	USCS Classification
1	NP	NP	A-1-b	SP-SM
14	NP	NP	A-1-a	SP

Table 73
Gradation of Engineered Fill

Sieve Size		Percent Passing	
		Site 1, 1957	Site 14, 1960
1.5-in.	**38.1-mm**	66	100
¾-in.	**19-mm**	51	98
⅜-in.	**9.5-mm**	45	84
No. 4	**4.75-mm**	42	56
No. 8	**2.36-mm**	41	37
No. 16	**1.18-mm**	38	24
No. 30	**0.595-mm**	30	16
No. 50	**.297-mm**	17	10
No. 100	**0.15-mm**	7	6
No. 200	**0.075-mm**	4	3

Table 74
Compaction Data for Engineered Fill

Location	Test	Proctor Test	Field Test	Average
Site 1	Optimum water content (%)	-	2.2	2.2
	Maximum dry density (pcf)	-	136.1	136.1
Site 14	Optimum water content (%)	17.3	17.6	17.45
	Maximum dry density (pcf)	70	78	74

Table 75
Engineered Fill PI and Soil Classification

Section Number	Liquid Limit	Plasticity Index	AASHTO Classification	USCS Classification
1	NP	NP	A-1-a	SP-SM
14	NP	NP	A-1-a	SP

Table 76
Gradation of Subgrade

Sieve Size		Percent Passing	
		Site1, 1957	Site 14, 1960
1.5-in.	**38.1-mm**	100	79
¾-in.	**19-mm**	100	65
⅜-in.	**9.5-mm**	100	54
No. 4	**4.75-mm**	100	44
No. 8	**2.36-mm**	100	39
No. 16	**1.18-mm**	99	34
No. 30	**0.595-mm**	97	30
No. 50	**.297-mm**	93	28
No. 100	**0.15-mm**	84	25
No. 200	**0.075-mm**	74	14

Table 77
Compaction Data for Subgrade

Location	Test	Proctor Test	Field Test	Average
Site 1	Optimum water content (%)	-	-	-
	Maximum dry density (pcf)	-	-	-
Site 14	Optimum water content (%)	11.6	10.6	11.1
	Maximum dry density (pcf)	121.2	119.5	120.35

Table 78
Subgrade PI and Soil Classification

Section Number	Liquid Limit	Plasticity Index	AASHTO Classification	USCS Classification
1	NP	NP	A-6	CL
14	NP	NP	A-1-a	GM

Table 79
Rehabilitation and Maintenance Activities

Site	Date Built	Thickness (in)	Thickness (mm)	Activity
1	11/1977	0.5	12.7	Applying friction course
	8/1974	0.5	12.7	Applying friction course
	8/1974	1.5	38.1	Applying asphaltic concrete
14	1974	0.5	12.7	Applying friction course
	9/1966	0.3	7.62	Applying seal coat

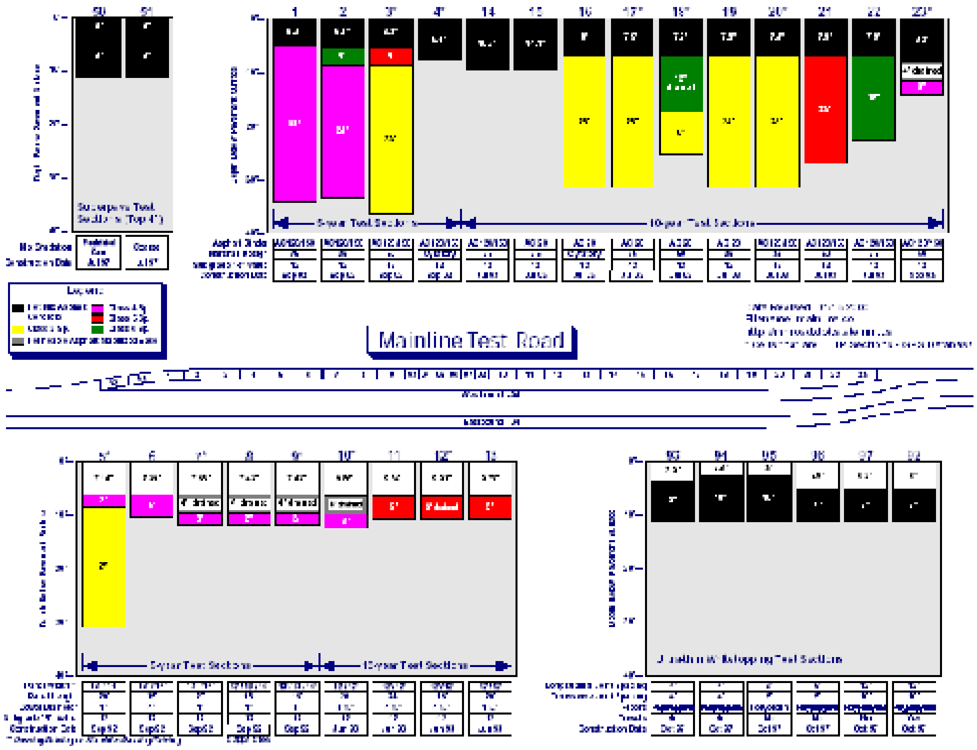


Figure 11
MnRoad Mainline Test Road Layout

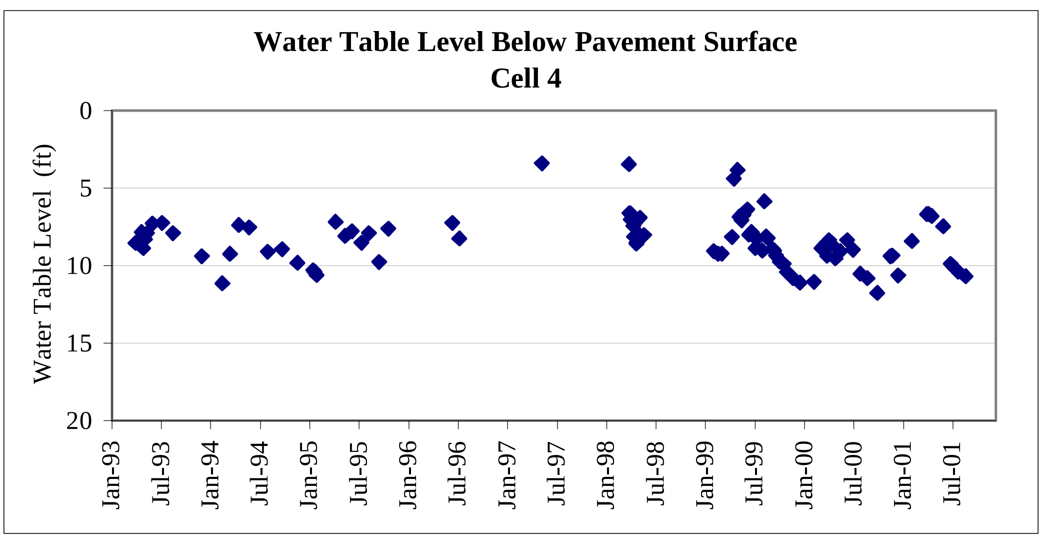


Figure 12
Water Table Level for MnRoad Cell 4

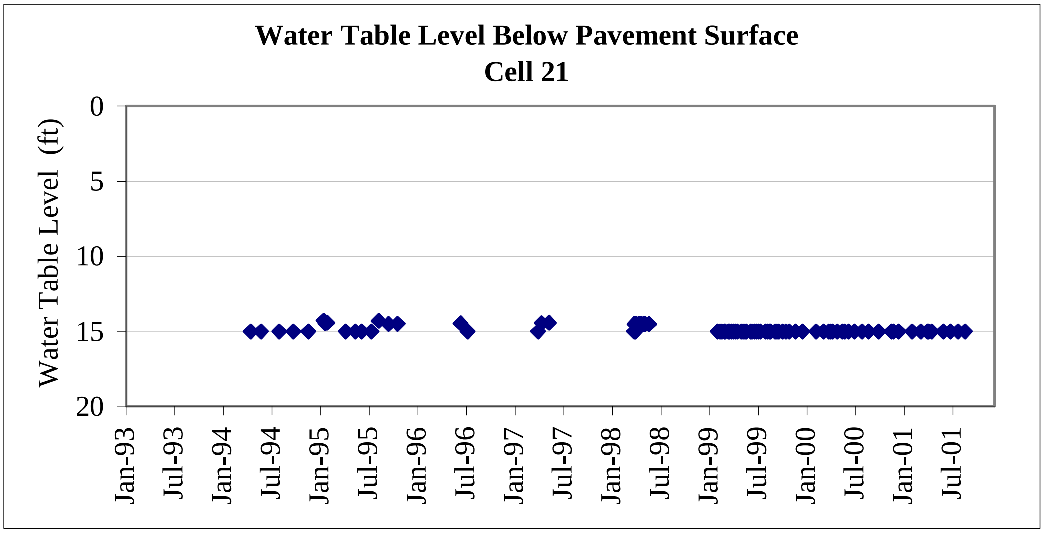


Figure 13
Water Table Level for MnRoad Cell 21

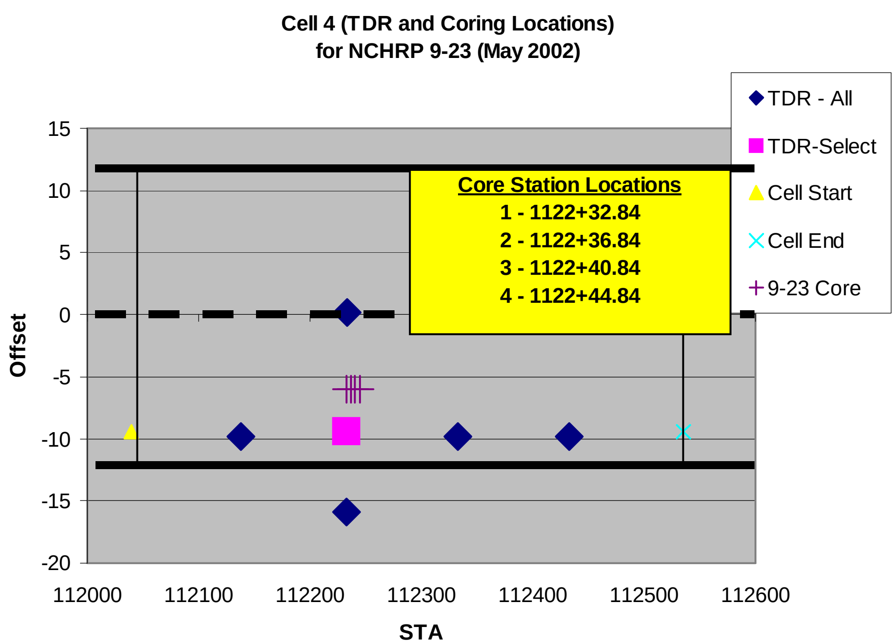


Figure 14
TDR Location for MnRoad Cell 4

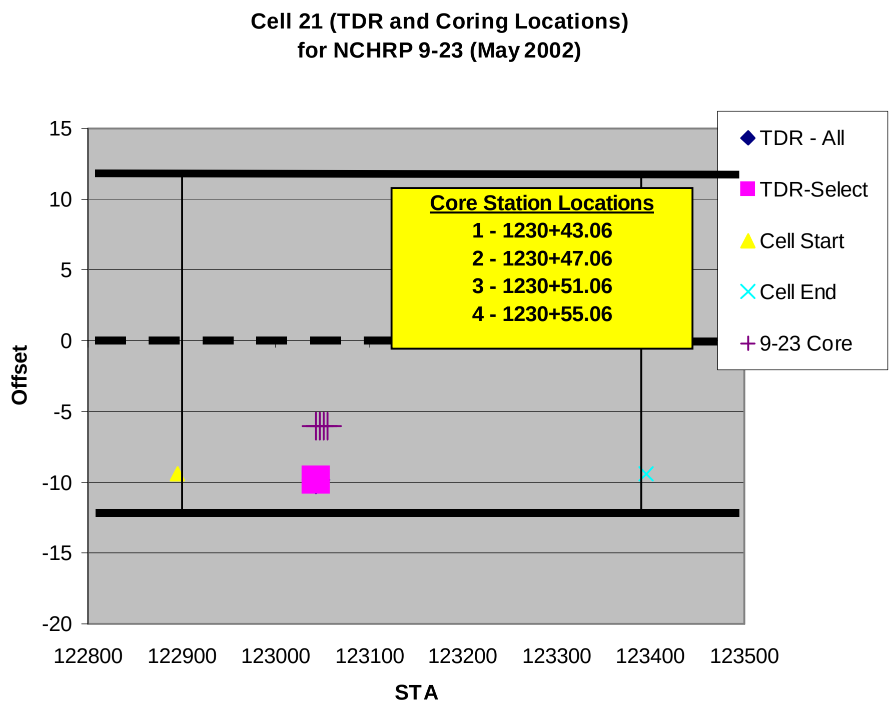


Figure 15
TDR Location for MnRoad Cell 21

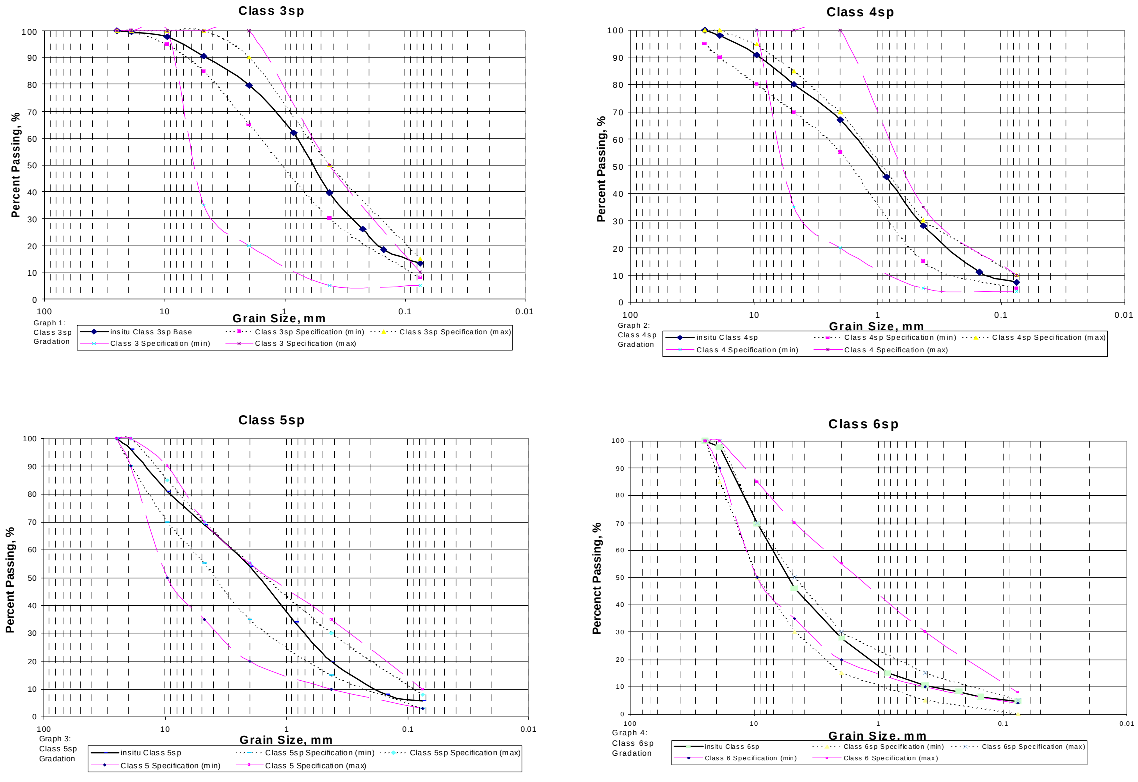


Figure 16
Gradation Curves – MnRoad Data

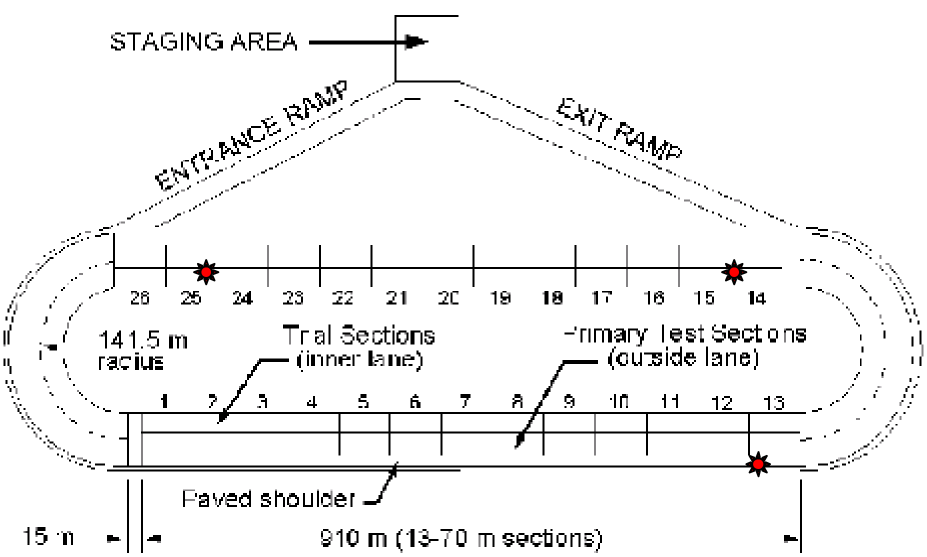


Figure 17
Layout of WesTrack Test Track (not to scale)

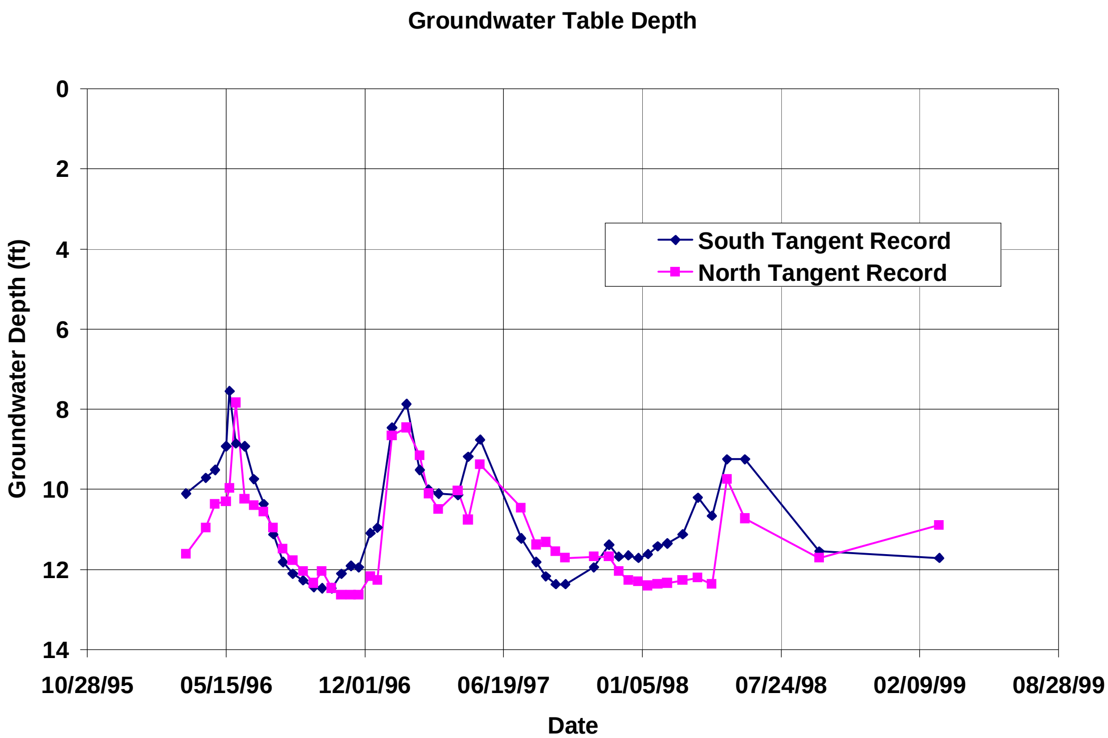


Figure 18
Groundwater Table Depth below Pavement Surface - WesTrack

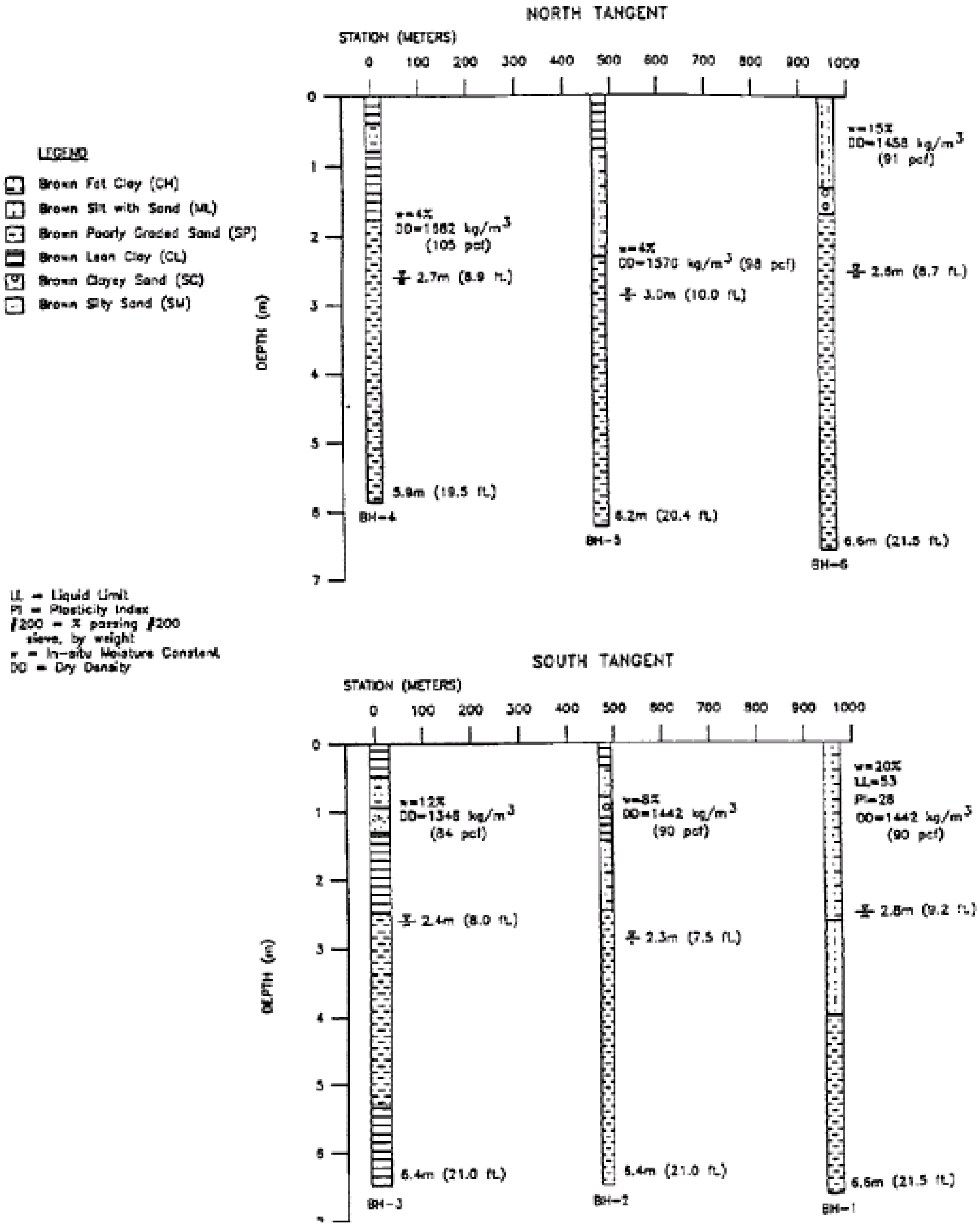


Figure 19 ADOT Subgrade Soil Boring Logs (Way 1980)

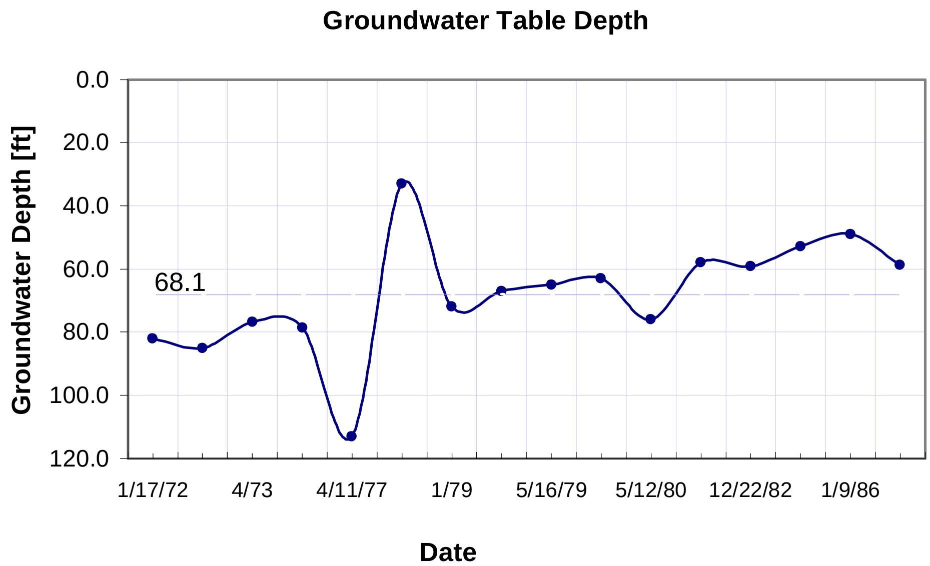


Figure 20
Groundwater Table Depth below Pavement Surface for ADOT Site 1.

Figure 21
ADOT Cross Section of Roadway

CHAPTER 4
LABORATORY TESTING AND TEST RESULTS

INTRODUCTION

The laboratory tests conducted on the soil samples are listed in Table 80. The details of the testing program with results are included in this chapter.

In addition to the tests performed on soil samples, hydraulic conductivity tests were performed on one of the AC cores obtained from each AC pavement site. All the asphalt cores were eventually relinquished to the advanced pavement group at ASU for asphalt testing.

General Notes on Laboratory Testing

The number of tests performed was very large compared to any other testing program performed in the laboratory. Therefore, whenever it was deemed reasonable samples obtained from the same layer were combined before testing for gradation, Atterberg limits, and specific gravity.

The samples collected from the first trip did not contain grab samples around the Sand Cone holes or around the tubes. Therefore, all the tests were carried out on the Sand Cone sample or tube sample itself. Since the Atterberg limits and specific gravity tests should be performed before oven-drying the samples, only partial moisture content determinations were possible in such cases, prior to the completion of all tests. The dry weight of the portion of the sample separated for tests other than moisture determination were totaled at the end and the total dry weight was used to determine the final moisture content. Comparison of the final and partial moisture contents indicated that most of the time the difference was less than 0.5%, which was considered to be negligible. Saturated hydraulic conductivity and SWCC tests on selected undisturbed samples also resulted in partial and final moisture determinations.

Granular base samples were reconstituted using the procedure described later in this chapter for hydraulic conductivity testing and SWCC testing. Only the fraction of sample passing No. 4 sieve was used in the reconstitution procedure.

MOISTURE CONTENT AND DRY DENSITY

The in situ moisture content and dry density of granular bases and subgrades provided valuable data in determining the equilibrium moisture contents beneath the pavements. The moisture contents at the time of the site visit were regarded as the equilibrium moisture content or very close to the equilibrium moisture content since all the pavements were constructed more than five years ago. The seasonal fluctuation could be a factor influencing this assumption. However, based on the TDR moisture content data, the seasonal fluctuation appeared to be significant only in the cold regions where freeze

and thaw conditions could occur. Also, if the groundwater table is within 2 feet of the ground surface, the soil may become fully saturated. The design moisture contents derived from the data obtained in this study are most applicable when the two conditions mentioned above are not likely to occur.

Moisture Content of Sand Cone Samples

Sand Cone samples were collected in plastic containers in the field. The total moist weight of the sample was determined by simply weighing the sample plus the container and subtracting the weight of the container. The moist soil in the container was transferred in to a drying pan and dry weight was obtained after drying the soil in the oven for at least 24 hours at 110 °C. The moist weight and dry weight were used to calculate the moisture content of the sample. Even though care was given to prevent drying of the sample after opening, the preceding procedure leads to an accurate moisture content and dry density determination, even if some accidental drying occurs.

The above procedure used the total sample because a supplemental undisturbed sample collected from around the Sand Cone hole was available for conducting Atterberg Limit and specific gravity tests that required samples in natural state. However, when a supplemental sample was not available, a portion of the Sand Cone sample was separated for other tests. This resulted in determining the moisture content on a partial sample. Once the other tests were completed, the dry weight of the separated sample was obtained and the moisture content of the total sample was computed.

Moisture Content of Tube Samples

The tube samples containing moist soil were weighed in the field and the weight, length, and diameter of each tube were recorded in the data sheet. These measurements and the recess of the trimmed sample from each end provided information to compute the moist density of the sample. The samples were extruded out of the tubes in the laboratory and oven dried for moisture content determination.

If a portion of the sample was required for saturated hydraulic conductivity test and SWCC test, partial moisture content was obtained as described in the previous section. The moisture content based on the total sample was obtained after completing all the tests.

Dry Density

The field measurements of both Sand Cone Samples and tube samples provided the moist densities. Once the moisture content of a sample was determined the dry density was obtained by:

$$\gamma_{dry} = \gamma_{moist} / (1+ w) \qquad (1)$$

Where:

γ_{dry} = dry density
γ_{moist} = moist density
w = moisture content

GRAIN SIZE DISTRIBUTION

Results of the grain size distribution (GSD) or the gradation test were of great importance on developing the moisture prediction models and the modification of the family of SWCCs. In the moisture prediction models, the percent of the material passing the US sieve #200 (P_{200}) was used as one of the two correlation parameters. In the SWCC modifications most of the correlation parameters were derived from the gradation curve: D_{10}, D_{20}, D_{30}, D_{90}, C_c, C_u, and P_{200}.

The GSD of a sample was obtained by minus #200 wash and the sieve analysis of the oven dried sample using a standard set of ASTM sieves. The set of sieves used in the sieve analysis is presented in Table 81. In some instances, samples from the same layer were composited for GSD analysis.

The GSD data for each sample was subjected to curve fitting using SoilVision. SoilVision is a commercially available database designed by SoilVision Systems Ltd, Saskatoon, Canada. This software was primarily designed for handling unsaturated soil properties. It contains a four-parameter curve-fitting feature that is capable of fitting sigmoidal curves to GSD as well as SWCCs. This feature was extensively used in this study. The four parameters associated with the sigmoidal fit are designated a, b, c, and h_r.

When the curve fitting was for GSD, the parameters were designated a_g, b_g, c_g, and h_{rg}, respectively. Once the parameters are known for a given GSD of a soil the equation of the GSD was expressed as, Percent Passing = f (Particle Diameter, a_g, b_g, c_g, h_{rg}):

$$\text{Percent Passing} = \frac{\left[1 - \left\{ \frac{\ln\left(1 + \frac{h_{rg}}{\text{Diameter}}\right)}{\ln\left(1 + \frac{h_{rg}}{1\times 10^{-5}}\right)} \right\}^{7}\right]}{\left[\ln\left[\exp(1) + \left(\frac{a_g}{\text{Diameter}}\right)^{b_g}\right]\right]^{c_g}} \quad (2)$$

This enabled the calculation of D_{10} through D_{90} values for each curve. When the curve fitting was for SWCC, the parameters were designated a_f, b_f, c_f, and h_{rf}, respectively. SWCC curve fitting is discussed in detail later in this chapter.

ATTERBERG LIMITS

Atterberg Limits or in other terms, Liquid Limit (LL) and Plastic Limit (PL), were determined on individual samples as well as composite samples. The plasticity index (PI) was calculated from: PI = LL – PL. The values of LL, PL, and PI were used as correlation parameters in moisture prediction models and SWCC modifications.

SPECIFIC GRAVITY

Specific gravity of individual samples and composite samples were determined using the standard test procedures using 500 ml flasks. Samples were de-aired using vacuum pumps and heating the sample in hot water. Typically, the samples were sieved through No. 4 sieve and the fraction passing No. 4 sieve was used for the test. For granular base materials with gravel, the procedure was modified to use a 1000 ml beaker in place of the 500 ml flask. In this case, the total sample was used without sieving. Each flask and beaker was calibrated prior to the testing.

SATURATED HYDRAULIC CONDUCTIVITY

Selected undisturbed samples from subgrades and reconstituted samples from granular bases were subjected to saturated hydraulic conductivity tests. The samples were selected representing each layer encountered at the sites. Typically, two tests were carried out for a site. The saturated hydraulic conductivity was determined using falling head permeability test method. Samples were tested in 2.8-inch diameter, 12-inch long stainless steel tubes as shown on Figure 22.

The tube containing the sample was placed vertically in a 5-gallon bucket and the tube was filled with water. The initial and final heights of the water levels inside and outside the sample tube along with the elapsed time between readings were recorded. The time taken for the test was dependent on the soil type. Reconstituted granular materials took only a couple of hours while fine-grained samples took several days.

Sample Extrusion

Tube samples selected for hydraulic conductivity tests were carefully extruded leaving about 2 to 3-inch length of soil in the tube. A manually operated hydraulic jack and a steel frame were used in the extrusion process. The extruded soil was used for partial moisture content determination. The tube containing the sample was mounted on the hydraulic conductivity setup as shown in Figure 22.

Calculation of Saturated Hydraulic Conductivity

The hydraulic conductivity was calculated using the following equation:

$$k_{sat} = \frac{aL}{At} \ln\left(\frac{H_i}{H_f}\right) \qquad (3)$$

Where:

k_{sat} = saturated hydraulic conductivity,
a = area of the water surface above the sample,
L = length of the soil sample,
A = area of the soil sample,
t = elapsed time between initial and final readings,
H_i = initial head,
H_f = final head.

Reconstitution of Granular Samples

Granular base samples were reconstituted in 2.8-inch diameter tubes for hydraulic conductivity test. Only the portion of the sample passing No. 4 sieve was used in reconstitution process as described in the procedure below.

Procedure for Reconstituting Granular Samples

1. Determine the dry density (g_d), specific gravity (G_s), and grain size distribution (GSD) of the granular base material.
2. Assume the G_s of the portion of sample retained on No. 4 sieve (Plus No. 4) and the portion of sample passing No. 4 sieve (Minus No. 4) are equal.
3. Assume the Minus No. 4 material predominantly contributes to the voids of the base material layer in the filed. In other words, the contribution of Plus No. 4 material to formation of voids is insignificant.
4. Calculate the mass of Minus No. 4 material (M_{-4}) in 1 cubic feet (ft^3) of soil by $g_d \times P_4$, where P_4 is Percent Passing No. 4 sieve.
5. Calculate the mass of Plus No. 4 material (M_{+4}) in 1 ft^3 of soil by $g_d \times (1 - P_4)$, and then calculate the volume of Plus No. 4 material (V_{+4}) in 1 ft^3 by $M_{+4} / (G_s \times g_w)$.
6. Calculate the volume of Minus No. 4 material (V_{-4}) in 1 ft^3 by $1 - V_{+4}$.
7. Calculate the density of Minus No. 4 material in the filed, $g_{d\,(-4)}$, by M_{-4} / V_{-4}.
8. Calculate the mass of Minus No. 4 material required to fill the desired height of the tube so that the density is $g_{d\,(-4)}$.
9. Weigh the required mass of Minus No. 4 material and compact in the tube in 1-inch lifts maintaining a homogeneous compaction. Mix approximately 3 to 4% of water to the soil sample to facilitate the compaction.

To obtain a representative Minus No. 4 sample from the main sample, the distribution of Minus No. 4 sample between No. 4 and No. 10 sieves, No. 10 and No. 40 sieves, and passing No. 40 sieve was calculated based on the GSD of the total sample. Then the individual masses passing and retaining respective sieves were weighed separately and combined prior to compaction. The same sample reconstitution procedure was used in preparation of granular samples for SWCC testing. The SWCC testing procedure is described later in this chapter.

HYDRAULIC CONDUCTIVITY ON ASPHALT CORES

One of the AC cores from each site was subject to hydraulic conductivity test to determine the infiltration of actual asphalt layers in the field. The AC core was prepared by painting the sides for water proofing and making a mini-dam on the top with silicone. The prepared AC core was placed inside a 5-gallon bucket on a bed of dry sand as shown in Figure 23. The top of the core was filled with water within the mini-dam. The weight of water added was recorded. The water was allowed to permeate through the asphalt for 24 hours maintaining the water level constant. The weight of the bucket and dry sand before and after the test was recorded. The difference between the weight measurements indicated the amount of water passed through the core during the test. The test was started with dry sand and the bucket was tightly closed with a lid to prevent any evaporation. The percentage of water passed through the AC cores was computed.

All together 22 cores were tested in this manner. Out of the 22 tests, 20 tests did not indicate significant water permeation through the asphalt material. The two tests that did show measurable permeation through the cores belong to WesTrack site in Nevada; and Big Timber, Montana.

SOIL-WATER CHARACTERISTIC CURVES

Determination of SWCCs played a very important role in this study. The SWCC describes the relationship between the matric suction and the moisture content for a given soil. One of the main objectives of this research was to improve an existing family of SWCCs by correlating parameters derived from GSD and index properties. A large number of experimentally determined SWCCs were required to accomplish this objective. NCHRP 9-23 project provided over 90 soil samples well distributed over the entire country, which was considered an excellent representation of the soil conditions throughout the continental U.S.A.

Samples were selected for SWCC testing from each of the 29 sites to represent each layer encountered during the sampling. In addition, the samples collected from the side of the highway were selected for SWCC testing. Therefore, each site contributed at least three samples. Finally, a total of 85 SWCCs were generated from 33 granular or non-plastic samples and 52 fine-grained samples. Added to the list of SWCCs were nine fabricated granular samples that increased the total number of SWCCs to 94. The fabricated samples were prepared by mixing 1%, 10%, and 20% of non-plastic fines with fine, medium, and coarse sand samples, respectively. A new suction measurement device was developed as part of this research and the above-mentioned samples were tested using this new device. A detailed description of the new device is given below.

PRESSURE PLATE DEVICES

Background

The measurement of soil suction has never been an easy task for engineers and scientists due to many obstacles. Direct measurements of suction in the field are restricted to 1 bar

due to cavitation. Indirect methods have been adopted, but all methods have inherent restrictions. For example, the gypsum block technique is being used as an indirect method of measuring suction in the field. However, this method is not a highly reliable method due to many sources of error: sensitivity to temperature changes, time required for equilibration, and sensitivity to salt content. On the other hand, pressure plates with high air-entry discs are used for measuring suction in the laboratory and are considered fairly reliable. However, the range of measurements is restricted to 1,500 kPa due to the maximum air-entry value of the discs. Table 82 presents different devices and their capabilities (Ridley and Wray, 1995; Fredlund and Rahardjo, 1989):

In this research, matric suction values of soil samples were measured using a newly developed pressure plate device. High air-entry ceramic discs (rated up to 1,500 kPa) obtained from SoilMoisture Equipment Corp. were used in the device. Approximately 90 soil water characteristic curves (SWCCs) were obtained by testing reconstituted and undisturbed soil samples collected from 29 sites located throughout the United States. A detailed discussion of the device and the procedure used to develop the SWCCs are presented below.

A New Pressure Plate Device

The new device is an improved pressure plate device that measures matric suction of soil. There are new features to this device that enhance the effectiveness compared to the other pressure plates and other devices being used for measuring soil suction in the laboratory. These new features are:

1. Capability of simulating the in situ overburden pressure by applying loads on the sample.
2. Capability of measuring volume of water released or absorbed from the sample during the test that enabled the computation of water content of the sample at any given time.
3. Capability of tracking the height change of the sample that enabled the application of density correction for each data point.
4. Capability of generating any number of data points without dismantling the apparatus, since the water content of the sample corresponding to each applied matric suction can be determined as described in 2 above.
5. Relatively easy sample preparation, setup, and measurements.

Pressure Plate Design

The design of the pressure plate was based on the original design ideas provided to ASU by Prof. D. W. Fredlund. The design was slightly modified by Prof. W. N. Houston at ASU and the design team at Geotechnical Consulting and Testing Systems (GCTS), Tempe, Arizona.

When a soil sample is placed in a pressurized chamber with an air pressure of u_a, the soil sample eventually attains an equilibrium corresponding to the applied pressure by

releasing or absorbing water. The applied pressure u_a is equal to the matric suction since u_w is negligible. If the volume of released or absorbed water is known, that will provide information to compute the moisture change in the sample. One of the design ideas was to direct this water into two graduated tubes through a high air entry disk. This was accomplished by placing the sample on a high air entry disk, which was attached to a base with a recess filled with water. When the high air entry disk is saturated there is a continuous water path between the sample and the recess. The recess is connected to two vertical volume tubes allowing any water entered or absorbed by the sample will increase or decrease the height of water in the tubes. However, air diffusion through the high air entry disk could very slowly introduce diffused air into the recess creating air bubbles. These air bubbles will add an error to the water volume readings. Flushing the air bubbles out of the recess before taking the readings solved this problem. Flushing was carried out by pumping air into one of the volume tubes and pushing water column that expelled the air bubbles out of the system through the second tube. This process was repeated until there were no air bubbles in the system. A diagram of the new pressure plate device is shown in Figure 24.

As shown in Figure 24, the application of overburden pressure was accomplished with a loading rod inserted from the top of the device. The opening for the loading rod on the top of the device is sealed with an o-ring as shown in the Figure. The platen and the loading rod move up or down with the sample as the sample expands or settles. Measurement of platen movement provides the information to compute the volume changes in the sample.

Pressure Plate Device Setup

According to the final design, eight pressure plate devices were manufactured at the ASU workshop. Stainless steel was used to manufacture all parts of the device and three types of o-rings were used in the pressure plate to seal the metal-to-metal contacts. The eight devices were setup in the ASU geotechnical laboratory as shown in Figure 25. Three wood frames were manufactured to install the regulators, pressure gauges, and volume tubes. The pressure plate devices were connected to the regulators through quick-disconnect (QD) valves and Tygon tubing.

Two sources of pressure were used in the SWCC testing procedure. The house-air supplied from a central air compressor provided a maximum of 690 kPa (100 psi). Pressurized nitrogen cylinder was used for achieving pressures beyond 690 kPa up to a maximum of 1400 kPa. The maximum pressure was governed by the air-entry value of the high air entry discs, which were 15 bars (1,500 kPa).

The accessories needed for the SWCC testing included: weights, high air entry discs (ceramic stones), a flushing device, demineralized water, a balance with an accuracy of 0.01 g, brass or similar rings to hold the samples, a Vernier caliper, a conventional oven, glass or plastic plates, tools such as allen-wrenches, screw drivers etc., a compressed air supply, and a nitrogen cylinder.

PREPARATION OF SAMPLES

The tube samples were carefully extruded into 2.42-inch diameter by 1-inch high brass rings with minimum disturbances. Both sides of the sample were trimmed flush with the edges of the ring. The trimmed samples were stored in 5-gallon plastic buckets until the time of testing. The buckets were kept tightly closed and a 1-inch layer of fine sand saturated with water was placed at the bottom of the bucket to keep the samples from drying.

The granular samples were prepared for SWCC testing by reconstituting the material passing No. 4 sieve in 2.42-inch diameter by 1-inch high brass rings. The sample reconstitution procedure was similar to the procedure described above.

Prior to testing, the SWCC samples were saturated by partially submerging in de-mineralized water. The samples were placed on a porous stone lined with filter papers and transferred into a wide container. De-mineralized water was added into the container until the water level was just below (approximately 2 mm) the brim of the ring. It only required several hours to saturate a granular sample. However, the fine-grained subgrade samples, which were comprised of high plastic clays required several days of soaking. The samples were visually observed to get indications that the saturation process was complete. The top surface of the sample became distinctively wet when it reached the maximum possible saturation. The degree of saturation achieved by this method of soaking ranged between 87 and 100%.

SOIL WATER CHARACTERISTIC CURVE TESTING

Following saturation, the sample was removed from the water and placed on a glass plate without the porous stone and the filter paper. The sample was allowed to drain any excess water through the bottom for about 15 to 20 minutes. The drained excess water was mopped out using paper towels without loosing any soil. Covering the sample with an aluminum cup during the draining process prevented any water loss due to evaporation. Any additional water left on the plate and on the out side of the ring was wiped out and the weight of the sample and the glass plate was recorded. The sample was transferred onto a saturated surface dry (SSD) ceramic stone and the weight of the glass plate was recorded. The ceramic stone was submerged in demineralized water overnight and the surface was dried carefully prior to the use. Then the weight of the SSD ceramic stone and the sample was recorded. These measurements provided information to calculate the saturated weight of the sample.

The pressure plate device was prepared by cleaning all three o-rings and surfaces and placing the o-rings in their grooves. The base of the cell was connected to the graduated volume tubes with Tygon tubing through the two QD valves located on the sides of the base. The QD valves were opened, and the ceramic stone ring with the sample was pressed carefully into the well of the base. The o-ring in the well was moistened to facilitate the downward movement of the ceramic stone ring. Once the ceramic stone

ring was in place, the grooved metal platen was placed centered on the sample. Then the inner cylinder and the outer cylinder were placed on the base surrounding the sample. Then the top plate was placed carefully observing the proper placement of the groove over the o-ring on the top of the outer cylinder. The top plate already contained the loading rod inserted through the top screw and top o-ring. A washer was screwed on to the bottom of the rod to prevent the rod escaping from the cell when pressure was applied. The metal platen was attached to the top of the rod to place weights during the test. The top plate was tightly screwed on to the base with four 5-inch long socket-head cap screws that sealed the cell between the top plate and the base.

Four types of ceramic stones available from SoilMoisture Corporation were used during the testing program: 1-bar, 3-bar, 5 bar, and 15-bar. Selection of the ceramic stone was based on the type of soil being tested as shown on Table 83.

Low to medium air pressures up to 690 kPa were regulated through bleeding type Fairchild™ pressure regulators rated for two different pressure ranges: 0 to 30 psi and 0 to 100 psi. The higher pressures applied using nitrogen cylinder was regulated through non-bleeding type Fairchild™ pressure regulators rated 0 to 225 psi. The applied pressure was measured with pressure gauges with 0.25 or 0.50 % full-scale accuracy. Pressure gauges with ranges of 0 to 200 kPa, 0 to 690 kPa, and 0 to 1500 kPa were used in the setup. One of the low range pressure gauges was also connected to a U-tube filled with water to measure very low pressures ranged between 0 and 20 kPa.

The pressure cell containing the sample was then connected to a regulator/gauge setup depending on the anticipated pressure range to be applied. Inserting the Tygon tube coming from the pressure regulator into the QD valve located on the top plate made the connection. Before pressurizing the cell, one of the QD valves on the base was closed and the volume tube located on the same side was filled with demineralized water. When the valve was opened, water flowed into the other volume tube through the grooves on the bottom of the base pushing most of the air bubbles out of the base. Then the system was flushed a few times using a flushing device. A ball pump was used for this purpose. The tip of the pump was inserted in to a volume tube from the top and then air was pumped forcing the water column down making sure the water column did not pass the bottom of the tube or the water rising from the other tube did not spill out from the top. The procedure was repeated changing the sides until no air bubbles appeared inside the tubes. When the water columns stabilized the two initial volume tube readings were recorded with the date and time.

The pressure increments to be applied were pre-determined based on the type of soil being tested. Since the index properties of each soil were determined, it was possible to calculate the D_{60} value or wPI of the soil. The existing family of SWCCs (Zapata 1999) was used to obtain an approximate curve corresponding to the D_{60} or wPI value of the soil. Once the curve was selected, three points of suction values were extracted so that they reasonably span over the degree of saturation range of 20 to 90 %. However, it was

not always possible to maintain a good span with clay samples since the curves extended well beyond the 1,400-kPa limits.

Prior to applying pressure, the screw on the top plate was hand tightened. Now the QD valve on the top plate was opened and the initial pressure was applied to the inside of the cell. The applied pressure exerted an upward thrust on the loading rod and, the o-ring on the plate around the rod created a friction. Applying correct amount of weights on the loading platen compensated the upward thrust and the friction forces. The weights were increased on the loading plate for compensation until the rod would move down only very slowly or move with a light touch. Then additional weights were applied that required to simulate the overburden pressure. The overburden pressure was calculated corresponding to the depth of the sample and the moist density of soil in the field. When the rod was seated on the platen located on the top of the sample the device was checked for air leaks by wetting the locations with o-rings. The distance between the top of the top plate and the bottom of the loading platen (height measurement) was measured using a pair of spring clippers and a Vernier caliper.

The system was left with the applied pressure for equilibration, recording regular volume readings. Two or three readings, typically six hours apart, were recorded per day. Each time the readings were recorded before and after flushing. The equilibration was considered attained and the system was ready to receive the next pressure increment when the volume readings did not change more than one division over a six-hour period with 1 and 3-bar ceramic stones or over a 12-hour period with 5 and 15-bar ceramic stones. Prior to increasing the pressure the height measurement was recorded. Then all the loads were removed and pressure was increased to the second pressure level. The up thrust and the friction were compensated again by placing weights and the overburden load was replaced. The same procedure was repeated for the third pressure point.

At the end of the third pressure increment, the sample was taken out from the cell. In the process, the weights were removed, the pressure was released, and the cell was opened to take the sample out. The moist weight of the sample was recorded and oven dried weight was obtained after drying the sample in an oven for 24 hours. The ceramic stone was removed from the base and the SSD weight was recorded. The difference between the initial and final weights of SSD ceramic stone indicated any amount of water absorbed or released by the ceramic stone during the test. If this amount of water is significant, a correction was applied to the readings.

Typical SWCC Data Points

The main readings obtained from SWCC testing included applied pressure, volume tube readings, and height measurements. The degree of saturation corresponding to applied suction was computed using the water content, dry density, and specific gravity of the sample. A typical SWCC data sheet is shown in Figure 26. A typical calculation sheet is shown in Figure 27 and the corresponding plot of degree of saturation verses matric suction is shown in Figure 28. The best fitting sigmoidal curve obtained from SoilVision

curve fitting that uses Fredlund and Xing equation is shown on the plot along with the experimental data points

SWCC Test Results

Over 90 SWCCs were generated for this project using the new pressure plate devices. The number of tests performed on each category of samples is shown in Table 84. All the SWCCs are presented in Appendix B.

In addition, nine non-plastic fabricated samples were prepared by mixing fine, medium, and coarse sand with 1%, 10%, and 20% non-plastic fines, respectively. Sand and fines were obtained from different sources. The fabricated samples were tested for comparison purposes.

Observations on SWCCs

As the SWCCs were developed using the new apparatus several observations were made regarding the shape of the curves:

1. Data points generated for non-plastic curves were plotted with the existing family of curves. When the soil contained very little or no amount of fines, i.e. P_{200} of less than 2%; the curves appeared to agree with the existing curves. However, when the value of P_{200} was higher, the curves deviated from the family of curves assuming a less steep path.
2. It was observed that the shape of the GSD curve played a role in deciding the shape of the SWCC. In fact, several researchers showed this relation in the past.
3. For plastic soils, the density correction greatly influenced the curve. As the tests progressed, the density increased due to drying of the sample and as a result the void ratio decreased. As void ratio decreased the degree of saturation increased. Therefore, the new data points showed an upward trend deviating from the existing curves.
4. The Fredlund and Xing equation restricted the projection of SWCC to 1,000,000 kPa at zero degree of saturation. However, the new curves associated with high plastic soils seemed to project pass this limiting value.
5. One of the fabricated samples that contained coarse sand and 20% of fines indicated that, towards the end of the test the fine particles traveled to the bottom of the sample through the voids of the gap-graded coarse sand and created a silt barrier prohibiting further movement of water.

LABORATORY TEST RESULTS

The laboratory test results of in situ moisture content, dry density, plasticity index, specific gravity, saturated hydraulic conductivity, and GSD are presented in Table 85.

The abbreviated site number along with the hole number and the depth of the sample written with hyphenations uniquely identified the samples. For example, a sample

collected from Site 3-2, Hole 1, at a depth of 25 inches was labeled as 3-2-1-25. The abbreviated site identification numbers are shown on Table 85 along with the main site information.

The abbreviations used in Table 85 are:

ID	=	identification number
PI	=	plasticity index
G_s	=	specific gravity
k_{sat}	=	saturated hydraulic conductivity
pcf	=	pounds per cubic feet
cm/sec	=	centimeters per second
GB	=	granular base
SS	=	subgrade
Side	=	side of the highway
Med	=	median
CSS	=	compacted subgrade
SB	=	subbase
TB	=	treated base
Fill	=	engineering fill
NP	=	non-plastic

Table 80
Laboratory Tests Performed for NCHRP 9-23 Project

Test	Sample	Number
Moisture Content	All Sand Cone and Tube Samples	257
Dry Density	All Sand Cone and Tube Samples	251
Gradation	Composite Samples Representing Each Layer	144
Atterberg Limits (Liquid Limit and Plastic Limit)	Composite Samples Representing Each Layer	148
Specific Gravity	Composite Samples Representing Each Layer	104
Saturated Hydraulic Conductivity	Selected Granular Base and Subgrade Samples	64
SWCC Testing	Selected Granular Base, Subgrade, and Side Samples	85
Hydraulic Conductivity on AC Cores	Cores from AC Pavements	22

Table 81
Sieve Set Used in Sieve Analysis

Sieve Size or Number	Sieve Size in mm
2.0 in.	50.8
1.5 in.	38.1
1.0 in.	25.4
0.5 in.	12.7
No. 4	4.75
No. 10	2.00
No. 40	0.425
No. 60	0.250
No. 100	0.150
No. 200	0.075

Table 82
Methods for Measuring Total and Matric Suction

Device	Method (property measured)	Suction	Range (kPa)	Principal constraints
Thermocouple psychrometer	Indirect (Rel. Humidity)	Total	100 to 7,500	Affected by temperature fluctuations. Sensitivity deteriorates with time.
Thermistor psychrometer	Indirect (Rel. Humidity)	Total	100 to 10,000	Poor sensitivity in the low suction range. Frequent re-calibration is required.
Transistor psychrometer	Indirect (Rel. Humidity)	Total	100 to 71,000	Frequent re-calibration is required. Specimens must be tested in order of increasing suction to avoid hysteresis.
Filter paper (non-contact)	Indirect (Water content)	Total	400 to 30,000	Calibration is sensitive to the elapsed time of the test.
Filter paper (in-contact)	Indirect (Water content)	Matric	Entire range	Automation of the procedure is impossible.
Suction plate	Direct	Matric	0 to 90	Low range of usefulness.
Pressure plate	Direct	Matric	0 to 1,500	Range of suction limited by the air-entry value of the plate.
Pressure membrane	Direct	Matric	0 to 1,500	Range in suction is limited by the air-entry value of the membrane.
Standard tensiometer	Direct	Matric	0 to 90	Requires daily maintenance. Temperature fluctuations affect readings. Slow to equilibrate in highly plastic soils.
Osmotic tensiometer	Direct	Matric	0 to 1,500	Reference pressure can deteriorate with time. Temperature dependent.
Imperial College tensiometer	Direct	Matric	0 to 1,800	Range in suction is limited by the air-entry value of the ceramic.
Porous block (Gypsum, nylon, fiberglass)	Indirect (Electrical resistance)	Matric	30 to 3,000	Observations need to be corrected by temperature. Blocks are subject to hysteresis. Response to suction can be slow.
Heat dissipation sensors	Indirect (Thermal conductivity)	Matric	0 to 1,500 or the maximum of the calibration.	High failure rate. Very fragile.
Osmotic cell	Indirect (Osmotic press. of solutions)	Matric	Not available	Not available.
Fredlund Device	Thermal conductivity of a ceramic stone	Matric	0 to 10,000±	Calibration curve may be somewhat soil type dependant.

Table 83
Selection of Ceramic Stones

Type of Soil	Rating of Ceramic Stone
Sand	1-bar
Silty Sand, Clayey Sand	3-bar
Sandy Silt, Sandy Clay	5-bar
Clay	15-bar

Table 84
Number of SWCCs

Sample Category	Non-Plastic	Plastic (PI > 0)
Granular Base	16	1
Subbase	5	1
Subgrade	8	26
Side	4	15
Compacted Subgrade	--	7
Fill	--	2
Fabricated	9	--
Total	42	52

Table 85
Laboratory Test Results

No. Sec. ID State	Sample ID	Sample Type	Layer	w	r_d	PI	Gs	ksat	Grain Size Distribution									
									2”	1.5”	1”	0.5”	#4	#10	#40	#60	#100	#200
				(%)	(pcf)	--	--	(cm/sec)	(% Passing)									
1 **010101** **AL**	1-3-1-10	SC	GB	9.64	140.71	NP	2.85	1.21E-04	100	100	97.35	78.55	53.95	38.82	26.93	23.05	19.05	13.43
	1-3-2-9.5	SC	GB	9.18	146.35	NP	2.85	1.21E-04	100	100	97.35	78.55	53.95	38.82	26.93	23.05	19.05	13.43
	1-3-3-8.25	SC	GB	10.27	137.69	NP	2.85	1.21E-04	100	100	97.35	78.55	53.95	38.82	26.93	23.05	19.05	13.43
	1-3-4-7.5	SC	GB	10.12	136.81	NP	2.85	1.21E-04	100	100	97.35	78.55	53.95	38.82	26.93	23.05	19.05	13.43
	1-3-1-15	Tube	SS	23.58	97.37	19	2.76	4.86E-08	100	100	100	100	99.73	98.6	91.38	87.36	82.01	73.65
	1-3-2-15	Tube	SS	22.49	101.44	19	2.76	4.86E-08	100	100	100	98.53	97.40	96.64	89.58	85.48	80.1	71.92
	1-3-3-14.5	Tube	SS	24.23	100.26	19	2.76	4.86E-08	100	100	100	97.79	97.27	96.45	88.94	84.59	79.59	71.25
	1-3-1-23	Tube	SS	18.94	107.02	13	2.77	2.40E-07	100	100	100	100	99.38	98.86	91.95	85.49	78.05	67.24
	1-3-2-23	Tube	SS	20.61	104.07	13	2.77	2.40E-07	100	100	100	100	99.38	98.86	91.95	85.49	78.05	67.24
	1-3-3-23	Tube	SS	18.81	110.16	13	2.77	2.40E-07	100	100	100	100	99.38	98.86	91.95	85.49	78.05	67.24
2 **040113** **AZ**	2-3-1-5.5	SC	GB	3.39	139.35	NP	2.75	3.26E-04	100	100	100	72.01	48.12	36.61	22.22	17.74	14.02	10.23
	2-3-2-5.5	SC	GB	2.97	140.72	NP	2.75	3.26E-04	100	100	100	72.01	48.12	36.61	22.22	17.74	14.02	10.23
	2-3-3-5.5	SC	GB	3.41	138.39	NP	2.75	3.26E-04	100	100	100	81.96	57.58	43.75	26.07	20.59	16.16	11.72
	2-3-C-6.5	SC	GB	3.79	130.80	NP	2.75	3.26E-04	100	100	100	82.32	61.85	46.99	27.19	21.19	16.75	11.92
	2-3-1-13.5	SC	SS	6.92	119.91	NP	2.75	3.92E-04	100	100	100	87.49	70.65	56.55	31.37	23.04	17.71	12.63
	2-3-2-12	SC	SS	6.22	118.92	NP	2.75	3.92E-04	100	100	100	87.49	70.65	56.55	31.37	23.04	17.71	12.63
	2-3-3-12	SC	SS	8.81	108.46	NP	2.75	3.92E-04	100	100	100	96.91	85.16	69.72	39.23	29.85	23.18	17.20
	2-3-S-20	SC	Side	3.36	122.61	NP	2.78	--	100	100	100	83.04	68.53	52.66	21.43	13.15	8.57	5.11
	2-3-M-15	SC	Med	3.13	111.07	8	2.74	--	100	100	100	94.11	86.28	73.61	44.4	26.62	19.76	13.41
3 **040215** **AZ**	4-1-1-11.5	SC	GB	4.67	139.02	NP	2.71	1.22E-03	100	100	100	59.36	37.39	31.03	16.95	11.91	9.07	6.80
	4-1-2-11.5	SC	GB	5.73	132.29	NP	2.71	1.22E-03	100	100	100	75.40	51.97	42.77	23.54	16.92	13.10	9.82
	4-1-3-11.5	SC	GB	5.24	137.43	NP	2.71	1.22E-03	100	100	100	59.25	40.02	33.83	18.19	12.68	9.51	7.31
	4-1-1-18.5	Tube	SS	6.70	126.47	2.5	2.71	2.07E-06	100	100	100	93.45	85.74	74.00	44.30	33.80	27.50	21.60
	4-1-2-18	SC	SS	7.88	125.82	3.0	2.71	2.07E-06	100	100	100	95.08	85.77	74.25	44.71	33.90	27.11	21.57
	4-1-3-18	SC	SS	7.90	128.28	5.2	2.71	2.07E-06	100	100	100	93.98	83.73	73.05	44.08	33.29	26.98	21.13
	4-1-S-12	SC	Side	4.98	116.52	NP	2.78	--	100	100	100	96.41	86.16	76.10	51.57	41.84	34.44	27.00
4 **052042** **AR**	1-5-2-13.5	Grab	GB	--	--	NP	--	--	100	100	100	97.42	89.92	84.91	64.15	32.24	19.7	16.32
	1-5-3-14	Grab	GB	--	--	NP	--	--	--	--	--	--	--	--	--	--	--	--
	1-5-4-13	Grab	GB	19.83	106.14	NP	--	--	100	100	100	97.42	89.92	84.91	64.15	32.24	19.7	16.32
	1-5-1-18.5	Tube	SS	18.16	103.26	7	2.70	7.31E-07	100	100	100	100	100	99.8	99.52	98.57	94.57	84.04
	1-5-2-15	Tube	SS	18.52	106.14	13	2.72	4.80E-07	100	100	100	100	100	99.93	99.71	99.41	98.32	94.29
	1-5-3-15	Tube	SS	17.25	104.91	11	2.72	4.80E-07	100	100	100	100	100	99.88	99.48	98.95	97	90.16
	1-5-4-15.5	Tube	SS	18.27	110.34	8	2.72	4.80E-07	100	100	100	100	100	99.74	99.32	98.62	95.68	86.35
	1-5-1-23	Tube	SS	17.28	105.41	8	2.70	4.08E-08	100	100	100	100	99.54	98.1	96.4	95.74	94.74	91.02
	1-5-2-23	Tube	SS	16.06	90.72	7	2.70	4.08E-08	100	100	100	100	98.48	97.21	95.7	94.93	93.52	88.18
	1-5-3-24	Tube	SS	17.88	109.60	9	2.70	4.08E-08	100	100	100	100	99.96	98.83	97.05	96.06	94.17	89.38
	1-5-4-23.5	Tube	SS	16.62	111.21	6	2.70	4.08E-08	100	100	100	100	96.72	94.46	91.34	89.96	88.54	84.49
	1-5-S-13	Tube	Side	19.83	108.21	8	--	--	100	100	100	100	100	99.91	99.75	98.69	96.52	90.97
5	8-3-1-13	Tube	CSS	18.32	105.70	5.4	2.78	2.62E-06	100	100	100	100	98.95	96.01	88.66	83.40	71.02	58.22
	8-3-2-14	Tube	CSS	19.08	109.20	5.4	2.78	2.62E-06	100	100	100	100	98.95	96.01	88.66	83.40	71.02	58.22

No. Sec. ID State	Sample ID	Sample Type	Layer	w	γ_d	PI	Gs	ksat	Grain Size Distribution									
									2”	1.5”	1”	0.5”	#4	#10	#40	#60	#100	#200
				(%)	(pcf)	--	--	(cm/sec)	(% Passing)									
063042	8-3-3-14	Tube	CSS	19.40	106.80	5.4	2.78	2.62E-06	100	100	100	100	98.95	96.01	88.66	83.40	71.02	58.22
CA	8-3-1-20	Tube	SS	16.32	116.60	9.4	2.77	3.72E-07	100	100	100	100	99.91	99.62	96.17	90.29	70.26	54.15
	8-3-2-20	Tube	SS	16.60	113.40	9.4	2.77	3.72E-07	100	100	100	100	99.91	99.62	96.17	90.29	70.26	54.15
	8-3-3-21	Tube	SS	16.76	112.50	9.4	2.77	3.72E-07	100	100	100	100	99.91	99.62	96.17	90.29	70.26	54.15
	8-3-1-28	Tube	SS	14.17	106.86	0.7	2.80	2.43E-06	100	100	100	99.86	99.66	99.37	91.31	79.13	62.39	46.36
	8-3-2-29	Tube	SS	17.18	108.60	0.7	2.80	2.43E-06	100	100	100	99.86	99.66	99.37	91.31	79.13	62.39	46.36
	8-3-3-29	Tube	SS	18.28	110.70	0.7	2.80	2.43E-06	100	100	100	99.86	99.66	99.37	91.31	79.13	62.39	46.36
	8-3-S-12	Tube	Side	12.97	96.90	4.8	2.75	--	100	100	100	100	99.82	99.28	6.65	92.88	84.43	68.06
	7-5-1-7.5	SC	GB1	3.66	139.78	NP	2.71	3.13E-04	100	100	100	84.30	49.04	35.57	21.33	14.37	10.05	6.99
	7-5-2-7.5	SC	GB1	3.74	140.97	NP	2.71	1.52E-04	100	100	100	84.30	49.04	35.57	21.33	14.37	10.05	6.99
	7-5-3-7.5	SC	GB1	3.63	135.09	NP	2.71	1.52E-04	100	100	100	84.30	49.04	35.57	21.33	14.37	10.05	6.99
	7-5-1-14	SC	GB2	5.93	107.38	NP	2.76	6.14E-03	96.00	79.96	71.56	54.56	39.60	32.64	20.22	15.79	12.57	9.88
6	7-5-2-13.5	SC	GB2	4.09	125.74	NP	2.76	6.14E-03	96.00	80	71.56	54.56	39.60	32.64	20.22	15.79	12.57	9.88
081053	7-5-3-13.5	SC	GB2	5.54	127.67	NP	2.76	6.14E-03	96.00	80	71.56	54.56	39.60	32.64	20.22	15.79	12.57	9.88
CO	7-5-1-43	Tube	SS	23.06	103.10	22.8	2.78	1.07E-07	100	100	100	100	99.21	98.60	97.57	96.98	96.19	94.64
	7-5-3-43	Tube	SS	22.85	103.56	22.8	2.78	1.07E-07	100	100	100	100	99.21	98.60	97.57	96.98	96.19	94.64
	7-5-1-50	Tube	SS	22.85	106.36	22.7	2.81	--	100	100	100	100	99.96	99.78	99.55	99.40	99.16	98.66
	7-5-3-50	Tube	SS	24.07	101.33	22.7	2.81	--	100	100	100	100	99.96	99.78	99.55	99.40	99.16	98.66
	7-5-S-12	Tube	Side	19.34	103.41	18.6	2.82	--	100	100	100	100	99.58	99.40	96.19	92.65	90.17	83.73
	7-4-1-14.5	SC	GB	3.50	125.96	NP	2.73	1.07E-03	100	100	100	91.00	58.68	45.71	24.53	17.00	12.16	7.98
	7-4-2-14.5	SC	GB	3.27	132.02	NP	2.73	7.66E-04	100	100	100	91.00	58.68	45.71	24.53	17.00	12.16	7.98
	7-4-3-14.5	SC	GB	3.17	136.50	NP	2.73	1.07E-03	100	100	100	91.00	58.68	45.71	24.53	17.00	12.16	7.98
	7-4-1-19	Tube	SB	6.71	116.02	NP	2.66	6.15E-05	100	100	100	100	99.96	99.96	60.83	36.88	24.10	16.24
7	7-4-2-19	Tube	SB	6.39	117.36	NP	2.66	6.15E-05	100	100	100	100	99.96	99.96	60.83	36.88	24.10	16.24
	7-4-3-19	Tube	SB	6.82	112.50	NP	2.66	6.15E-05	100	100	100	100	99.96	99.96	60.83	36.88	24.10	16.24
087035	7-4-1-37	Tube	SB	9.73	116.97	NP	2.66	6.15E-05	100	100	100	100	99.99	99.96	63.59	38.33	27.58	17.70
CO	7-4-3-37	Grab	SB	--	--	NP	--	--	100	100	100	100	99.99	99.96	63.59	38.33	27.58	17.70
	7-4-1-48	Tube	SS	19.86	110.88	18.1	2.74	1.41E-07	100	100	100	100	100	99.97	96.85	93.49	91.28	83.35
	7-4-2-48	Tube	SS	20.17	104.77	18.1	2.74	1.41E-07	100	100	100	100	100	99.97	96.85	93.49	91.28	83.35
	7-4-3-48	Tube	SS	19.90	107.07	18.1	2.74	1.41E-07	100	100	100	100	100	99.97	96.85	93.49	91.28	83.35
	7-4-S-15	Tube	Side	14.89	106.42	18.9	2.78	--	100	100	100	100	99.57	99.57	96.30	93.66	91.14	84.60
	6-1-1-11	SC	GB	5.00	142.68	NP	2.80	--	93.00	89.3	83.65	64.29	47.13	35.61	19.93	13.77	9.40	5.85
8	6-1-2-12.5	SC	GB	5.04	143.85	NP	2.80	--	93.00	89.3	83.65	64.29	47.13	35.61	19.93	13.77	9.40	5.85
	6-1-3-10	SC	GB	5.05	129.27	NP	2.80	--	93.00	89.3	83.65	64.29	47.13	35.61	19.93	13.77	9.40	5.85
091803	6-1-1-20	SC	SS	6.42	123.43	NP	2.74	1.54E-04	95.90	83.00	76.81	68.39	59.85	53.5	40.06	33.36	28.13	23.06
CT	6-1-2-21	SC	SS	7.84	129.42	NP	2.74	1.54E-04	95.90	83.00	76.81	68.39	59.85	53.5	40.06	33.36	28.13	23.06
	6-1-S-12	SC	Side	9.80	114.86	NP	2.66	--	86.6	80.6	80.6	71.66	64.93	59.62	45.13	37.33	30.43	23.54
	5-3-2-16.5	Tube	SS	21.13	102.14	24.5	2.76	4.93E-08	100	100	100	98.16	95.50	94.11	91.83	90.44	89.43	88.23
9	5-3-3-16	Tube	SS	22.91	103.60	24.5	2.76	4.93E-08	100	100	100	98.16	95.50	94.11	91.83	90.44	89.43	88.23
	5-3-2-27	Tube	SS	17.12	119.58	21.5	2.80	--	100	100	100	100	97.07	81.00	77.07	74.72	72.78	72.76
204054	5-3-3-22	Tube	SS	21.17	105.12	21.5	2.81	--	100	100	100	100	99.67	98.37	97.17	95.86	94.77	93.36
KS	5-3-S-12	Tube	Side	17.86	110.70	10.4	2.80	--	--	--	--	--	--	--	--	--	--	--
	5-3-S2-8	Tube	Side	20.94	103.96	28.2	2.79	--	100	100	100	100	97.85	97.28	96.42	95.84	94.98	93.91

No. Sec. ID State	Sample ID	Sample Type	Layer	w	γ_d	PI	Gs	ksat	Grain Size Distribution									
									2”	1.5”	1”	0.5”	#4	#10	#40	#60	#100	#200
				(%)	(pcf)	--	--	(cm/sec)	(% Passing)									
10 220118 LA	3-1-1-24	Tube	SS	19.98	92.80	8	2.68	--	100	100	100	100	97.65	96.02	93.92	93.20	92.36	86.97
	3-1-2-24	Tube	SS	14.92	113.80	6	2.68	--	100	100	100	100	98.57	97.52	95.7	95.08	94.12	88.21
	3-1-3-24	Tube	SS	14.96	109.37	6	2.68	--	100	100	100	100	99.74	99.01	97.82	97.38	96.83	89.41
	3-1-1-34	Tube	SS	22.63	102.71	7	2.68	3.70E-07	100	100	100	100	99.52	98.65	97.61	97.31	96.7	91.61
	3-1-2-29	Tube	SS	16.83	107.01	10	2.68	3.70E-07	100	100	100	100	99.41	97.51	95.12	94.44	92.4	86.48
	3-1-3-32	Tube	SS	21.45	105.64	10	2.68	3.70E-07	100	100	100	100	99.60	98.70	97.70	97.40	96.80	91.70
	3-1-S-12	Tube	Side	19.28	108.04	11	2.68	--	100	100	100	100	99.94	99.52	98.87	98.69	98.22	93.44
11 281802 MS	1-4-1-9.5	SC	GB	10.67	129.82	NP	2.67	--	100	100	100	100	99.79	99.5	94.24	62.14	33.91	57.91
	1-4-2-10.5	Tube	GB	10.74	124.52	NP	2.67	2.70E-07	100	100	100	100	99.89	99.52	90.85	63.56	41.86	37.18
	1-4-3-10.5	Tube	GB	9.46	123.90	NP	2.67	2.70E-07	100	100	100	100	99.7	99.35	93.38	66.38	31.7	26.09
	1-4-1-19	Tube	GB	10.00	120.18	NP	2.67	1.59E-05	100	100	100	100	99.76	99.29	91.05	60.64	37.76	32.71
	1-4-3-18	Tube	GB	10.67	124.16	NP	2.67	1.59E-05	100	100	100	100	99.89	99.57	92.09	64.99	43.03	37.78
	1-4-1-27	Tube	GB	7.59	113.09	NP	2.66	1.08E-03	100	100	100	100	99.25	97.79	82.52	42.76	21.15	17.92
	1-4-2-42	Tube	SS	16.07	112.22	4	2.71	4.43E-07	100	100	100	100	99.8	99.16	91.37	72.55	58.62	51.76
	1-4-3-40	Tube	SS	17.29	106.12	4	2.71	4.43E-07	100	100	100	100	99.34	98.2	89.1	69.67	54.41	47.73
	1-4-S-12	Tube	Side	9.32	126.60	4	2.70	--	100	100	100	100	98.85	98.17	87.36	56.65	36.42	31.50
12 307066 MT	7-1-1-10	SC	GB	6.00	144.70	NP	2.76	2.34E-05	100	100	100	91.71	61.79	46.63	28.13	21.40	16.63	11.92
	7-1-2-10.5	SC	GB	5.87	144.14	NP	2.76	2.34E-05	100	100	100	91.71	61.79	46.63	28.13	21.40	16.63	11.92
	7-1-1-13.5	SC	SB	5.36	141.14	NP	2.78	5.90E-05	100	100	88.72	67.36	47.85	37.69	23.97	18.09	13.59	10.40
	7-1-2-13.5	SC	SB	5.33	137.41	NP	2.78	5.90E-05	100	100	88.72	67.36	47.85	37.69	23.97	18.09	13.59	10.40
	7-1-3-13	SC	SB	5.49	138.41	NP	2.78	5.90E-05	100	100	88.72	67.36	47.85	37.69	23.97	18.09	13.59	10.40
	7-1-1-30	Tube	SS	13.21	119.70	16.5	2.75	--	100	100	100	98.64	94.21	91.04	83.62	75.13	64.67	52.32
	7-1-2-29	Tube	SS	14.38	115.06	16.5	2.75	--	100	100	100	98.64	94.21	91.04	83.62	75.13	64.67	52.32
	7-1-3-30	Tube	SS	13.98	115.69	16.5	2.75	--	100	100	100	98.64	94.21	91.04	83.62	75.13	64.67	52.32
	7-1-1-39	Tube	SS	14.52	124.17	--	2.80	--	100	100	100	100	97.81	95.97	94.42	93.19	89.00	80.34
	7-1-3-38	Tube	SS	15.09	104.69	--	2.80	--	100	100	100	100	97.81	95.97	94.42	93.19	89.00	80.34
	7-1-S-15	Tube	Side	22.65	101.76	14.9	2.80	--	100	100	100	99.50	97.79	96.30	89.33	83.26	77.33	69.77
13 310114 NE	5-4-1-9	SC	GB	2.40	141.63	NP	2.69	1.23E-03	100	100	100	79.09	54.45	37.55	14.29	8.80	6.27	5.12
	5-4-2-7.5	SC	GB	2.33	139.25	NP	2.69	1.23E-03	100	100	100	79.09	54.45	37.55	14.29	8.80	6.27	5.12
	5-4-3-7.5	SC	GB	2.38	143.54	NP	2.69	1.23E-03	100	100	100	79.09	54.45	37.55	14.29	8.80	6.27	5.12
	5-4-1-19	Tube	SS	28.50	97.79	29.5	2.80	--	100	100	100	100	99.95	99.63	99.31	99.17	98.92	98.44
	5-4-2-19	Tube	SS	25.19	100.55	29.5	2.80	--	100	100	100	100	99.95	99.63	99.31	99.17	98.92	98.44
	5-4-3-19	Tube	SS	25.13	100.15	29.5	2.80	--	100	100	100	100	99.95	99.63	99.31	99.17	98.92	98.44
	5-4-1-27	Tube	SS	24.73	99.47	22.1	2.74	4.29E-08	100	100	100	100	99.98	99.84	99.62	99.43	99.15	98.59
	5-4-2-25	Tube	SS	23.54	102.38	22.1	2.74	4.29E-08	100	100	100	100	99.98	99.84	99.62	99.43	99.15	98.59
	5-4-3-28	Tube	SS	25.41	101.56	22.1	2.74	4.29E-08	100	100	100	100	99.98	99.84	99.62	99.43	99.15	98.59
	5-4-S-12	Tube	Side	21.28	104.15	23	2.77	--	100	100	100	100	99.92	99.68	99.45	99.27	99.05	98.64
14 320204 NV	8-2-1-12	SC	GB	4.51	145.59	5.6	2.76	1.45E-06	100	100	98.04	75.95	51.43	40.40	24.00	20.00	16.96	13.48
	8-2-2-12	SC	GB	5.23	146.41	5.6	2.76	1.14E-06	100	100	98.04	75.95	51.43	40.40	24.00	20.00	16.96	13.48
	8-2-3-12	SC	GB	5.49	142.02	5.6	2.76	1.45E-06	100	100	98.04	75.95	51.43	40.40	24.00	20.00	16.96	13.48
	8-2-1-19	SC	SB	5.78	125.18	3.1	2.69	6.80E-05	100	100	93.77	77.56	56.11	44.14	28.05	21.85	17.05	13.21
	8-2-2-18	SC	SB	5.83	134.87	3.1	2.69	6.80E-05	100	100	93.77	77.56	56.11	44.14	28.05	21.85	17.05	13.21
	8-2-3-18	SC	SB	6.20	128.66	3.1	2.69	6.80E-05	100	100	93.77	77.56	56.11	44.14	28.05	21.85	17.05	13.21

No. Sec. ID State	Sample ID	Sample Type	Layer	w	γ_d	PI	Gs	ksat	Grain Size Distribution									
									2”	1.5”	1”	0.5”	#4	#10	#40	#60	#100	#200
				(%)	(pcf)	--	--	(cm/sec)	(% Passing)									
	8-2-S-18	Tube	Side	11.78	102.63	2.1	2.72	--	100	100	100	100	99.47	97.88	87.91	78.98	69.94	58.67
15 350105 NM	1-1-1-11	Grab	GB	--	--	NP	2.71	--	100	100	99.9	84.13	50.41	37.44	19.63	10.84	6.88	4.66
	1-1-2-10	Grab	GB	--	--	NP	2.71	--	100	100	99.9	84.13	50.41	37.44	19.63	10.84	6.88	4.66
	1-1-1-13	Tube	SS	22.71	103.69	15	2.74	--	100	100	100	100	99.14	95.68	88.23	85.66	81.69	74.64
	1-1-2-13	Tube	SS	19.08	110.85	16	2.74	--	100	100	100	100	99.14	95.68	88.23	85.66	81.69	74.64
	1-1-3-13	Tube	SS	19.56	106.94	19	2.74	--	100	100	100	100	99.14	95.68	88.23	85.66	81.69	74.64
	1-1-1-22	Tube	SS	23.16	98.42	27	2.75	--	100	100	100	100	100	99.76	97.49	96.11	94.26	90.79
	1-1-2-22	Tube	SS	21.30	100.56	22	2.75	--	100	100	100	100	100	99.76	97.49	96.11	94.26	90.79
	1-1-3-22	Tube	SS	21.64	103.78	18	2.75	--	100	100	100	100	100	99.76	97.49	96.11	94.26	90.79
16 364018 NY	6-3-1-10.5	SC	SS	5.06	144.09	NP	2.74	4.25E-06	100	94.9	85.18	69.94	51.25	36.33	15.70	13.12	11.59	9.76
	6-3-2-10	SC	SS	5.36	135.09	NP	2.74	4.25E-06	100	94.9	85.18	69.94	51.25	36.33	15.70	13.12	11.59	9.76
	6-3-3-10	SC	SS	5.46	143.40	NP	2.74	4.25E-06	100	94.9	85.18	69.94	51.25	36.33	15.70	13.12	11.59	9.76
	6-3-1-19	SC	SS	4.92	141.57	NP	2.76	--	100	89.8	84.27	68.41	46.80	32.80	16.47	13.63	11.73	9.70
	6-3-2-18	SC	SS	5.21	137.50	NP	2.76	--	100	89.8	84.27	68.41	46.80	32.80	16.47	13.63	11.73	9.70
	6-3-S-12	SC	Side	12.29	99.93	NP	2.70	--	100	83.2	78.90	71.01	61.27	53.13	40.96	38.38	35.39	29.96
17 370205 NC	5-1-1-16	Tube	SS	31.76	83.00	9.3	2.72	--	100	100	100	99.71	99.06	91.37	69.11	63.40	58.27	51.33
	5-1-2-16	Tube	SS	31.03	84.96	9.3	2.72	--	100	100	100	99.71	99.06	91.37	69.11	63.40	58.27	51.33
	5-1-3-16	Tube	SS	31.54	85.43	9.3	2.72	--	100	100	100	99.71	99.06	91.37	69.11	63.40	58.27	51.33
	5-1-1-24	Tube	SS	26.85	94.78	12.8	2.73	1.50E-07	100	100	100	100	99.83	95.10	81.57	78.5	75.4	68.61
	5-1-2-24	Tube	SS	29.68	91.61	12.8	2.73	1.50E-07	100	100	100	100	99.83	95.10	81.57	78.5	75.4	68.61
	5-3-3-24	Tube	SS	27.51	94.17	12.8	2.73	1.50E-07	100	100	100	100	99.83	95.10	81.57	78.5	75.4	68.61
	5-1-S-12	Tube	Side	21.61	98.48	10.8	2.76	--	100	100	100	98.92	95.84	91.25	76.76	70.31	63.28	53.85
18 416011 OR	2-2-1-15	SC	GB	7.60	141.55	NP	2.79	--	100	100	97.76	59.83	32.07	22.63	13.93	9.46	6.9	5.09
19 420603 PA	6-4-1-17	SC	GB	3.63	139.76	NP	2.85	6.03E-05	100	100	100	77.92	42.70	26.88	15.97	14.09	12.93	11.69
	6-4-2-17	SC	GB	4.14	140.55	NP	2.85	6.03E-05	100	100	100	77.92	42.70	26.88	15.97	14.09	12.93	11.69
	6-4-3-15.5	SC	GB	3.65	142.37	NP	2.85	6.03E-05	100	100	100	77.92	42.70	26.88	15.97	14.09	12.93	11.69
	6-4-1-23	SC	SS	10.93	124.36	4.7	2.79	1.23E-06	100	100	96.43	87.90	70.12	58.36	46.62	44.23	41.77	38.43
	6-4-2-23	SC	SS	11.06	120.29	4.7	2.79	1.23E-06	100	100	96.43	87.90	70.12	58.36	46.62	44.23	41.77	38.43
	6-4-3-22.5	SC	SS	9.06	122.92	4.7	2.79	1.23E-06	100	100	96.43	87.90	70.12	58.36	46.62	44.23	41.77	38.43
	6-4-S-19	SC	Side	5.33	109.67	3.2	2.80	--	100	94.1	90.85	73.67	50.8	38.22	27.29	25.02	23.22	20.30
20 473101 TN	5-2-1-17	Tube	SS	31.51	93.94	28.5	2.80	5.23E-08	100	100	100	100	92.58	84.37	79.53	78.04	76.88	75.43
	5-2-2-17	Tube	SS	34.01	88.18	28.5	2.80	5.23E-08	100	100	100	100	92.58	84.37	79.53	78.04	76.88	75.43
	5-2-3-20	Tube	SS	36.10	87.29	28.5	2.80	5.23E-08	100	100	100	100	92.58	84.37	79.53	78.04	76.88	75.43
	5-2-1-25	Tube	SS	35.21	87.69	41.9	2.80	--	100	100	100	100	99.75	99.44	96.97	95.72	94.55	93.16
	5-2-2-26	Tube	SS	36.10	89.61	41.9	2.80	--	100	100	100	100	99.75	99.44	96.97	95.72	94.55	93.16
	5-2-3-24	Tube	SS	34.31	88.34	41.9	2.80	--	100	100	100	100	99.75	99.44	96.97	95.72	94.55	93.16
	5-2-S-12	Tube	Side	32.66	87.76	38.1	2.80	--	100	100	100	100	99.89	99.10	94.56	93.03	91.82	90.37
21 481060 TX	3-3-1-7.5	SC	TB	--	--	NP	2.70	2.87E-05	100	100	100	86.09	67.65	51.15	24.00	14.8	9.61	5.26
	3-3-2-17	SC	GB	7.60	111.50	NP	2.70	2.38E-04	100	81.1	78.55	68.07	55.1	46.55	29.74	21.16	16.05	11.94
	3-3-3-17	SC	GB	8.40	117.75	NP	2.70	2.38E-04	100	81.1	78.55	68.07	55.1	46.55	29.74	21.16	16.05	11.94
	3-3-1-24	Tube	SS	18.04	104.53	10.4	2.74	--	100	100	100	100	97.5	95.97	83.73	65.49	54.07	46.70
	3-3-2-23	Tube	SS	20.25	93.79	13.8	2.74	--	100	100	100	100	98.55	96.89	83.13	63.69	50.91	44.70

No. Sec. ID State	Sample ID	Sample Type	Layer	w	γ_d	PI	Gs	ksat	Grain Size Distribution									
									2”	1.5”	1”	0.5”	#4	#10	#40	#60	#100	#200
				(%)	(pcf)	--	--	(cm/sec)	(% Passing)									
	3-3-3-26	Tube	SS	17.83	106.37	12.6	2.74	--	100	100	100	100	69.72	94.41	83.95	74.14	68.12	63.55
	3-3-1-34	Tube	SS	21.18	106.48	21.0	2.71	--	99.20	99.20	99.20	99.20	97.50	96.10	82.20	69.70	64.80	60.30
	3-3-2-32	Tube	SS	20.92	105.08	21.0	2.71	--	100	100	100	100	98.24	96.82	82.87	70.28	65.31	60.74
	3-3-3-34	Tube	SS	21.81	107.24	21.0	2.71	--	99.20	99.20	99.20	99.20	97.50	96.10	82.20	69.70	64.80	60.30
	3-3-S-18	Tube	SS	21.92	82.24	21.3	2.71	--	100	100	100	100	99.08	97.69	87.07	70.02	60.46	53.88
22 481077 TX	1-2-1-5	SC	TB	--	--	NP	2.60	2.48E-05	100	100	96.12	82.82	62.50	46.90	22.90	13.90	7.50	2.90
	1-2-1-16	SC	GB	3.29	133.27	NP	2.63	1.63E-04	100	100	100	71.13	48.99	41.61	25.69	16.38	11.83	8.53
	1-2-2-15	SC	GB	3.63	140.02	NP	2.63	1.63E-04	100	100	100	71.13	48.99	41.61	25.69	16.38	11.83	8.53
	1-2-3-15	SC	GB	3.14	143.71	NP	2.63	1.63E-04	100	100	100	71.13	48.99	41.61	25.69	16.38	11.83	8.53
	1-2-1-22	Tube	SS	9.26	103.81	NP	2.70	1.44E-05	100	100	100	100	99.97	99.93	98.37	95.66	92.75	63.65
	1-2-2-22	Tube	SS	8.84	104.07	NP	2.70	1.44E-05	100	100	100	100	99.97	99.93	98.37	95.66	92.75	63.65
	1-2-3-22	Tube	SS	9.12	103.08	NP	2.70	1.44E-05	100	100	100	100	99.72	99.64	97.92	95.15	92.12	75.26
	1-2-1-31	Tube	SS	11.33	108.29	NP	2.68	--	--	--	--	--	--	--	--	--	--	--
	1-2-2-30.5	Tube	SS	10.28	103.29	NP	2.68	--	--	--	--	--	--	--	--	--	--	--
	1-2-3-31	Tube	SS	12.18	104.10	NP	2.68	--	--	--	--	--	--	--	--	--	--	--
23 484143 TX	3-2-1-15	SC	CSS	25.55	92.33	17.6	2.74	2.73E-05	100	100	100	100	97.36	94.91	92.22	91.46	90.51	85.11
	3-2-1-25	Tube	SS	20.03	109.04	18.2	2.74	3.31E-08	100	100	100	100	98.70	98.23	97.29	97.05	96.46	90.27
	3-2-2-25	Tube	SS	19.31	108.42	20.0	2.74	3.31E-08	100	100	100	100	96.6	95.6	94.6	94.3	93.6	88.1
	3-2-1-35	Tube	SS	19.65	108.56	20.0	2.74	--	100	100	100	100	98.01	96.23	94.21	93.69	93.02	87.09
	3-2-2-36	Tube	SS	20.29	106.42	20.0	2.74	--	100	100	100	100	98.01	96.23	94.21	93.69	93.02	87.09
	3-2-S-12	Tube	Side	19.79	102.24	16.9	2.74	--	100	100	100	96.35	93.47	91.23	89.21	88.73	88.01	81.93
24 501681 VT	6-2-1-11.5	SC	GB	2.99	130.91	NP	2.72	3.97E-04	100	100	85.46	74.22	55.19	39.24	17.44	11.05	6.84	4.23
	6-2-1-20	SC	GB	3.64	130.45	NP	2.72	1.42E-03	100	100	85.46	74.22	55.19	39.24	17.44	11.05	6.84	4.23
	6-2-2-17	SC	GB	3.52	138.94	NP	2.72	1.42E-03	100	100	85.46	74.22	55.19	39.24	17.44	11.05	6.84	4.23
	6-2-3-13	SC	GB	2.85	139.68	NP	2.72	1.42E-03	100	100	85.46	74.22	55.19	39.24	17.44	11.05	6.84	4.23
	6-2-2-35	Tube	SB	8.70	121.93	NP	2.71	--	100	100	100	97.23	91.56	81.91	51.66	32.94	19.22	10.21
	6-2-3-33	Tube	SB	10.07	132.34	NP	2.71	--	100	100	100	97.23	91.56	81.91	51.66	32.94	19.22	10.21
	6-2-1-44	Tube	SS	17.02	113.34	15.8	2.65	1.46E-07	100	100	100	97.69	78.84	64.64	50.27	46.56	43.39	39.96
	6-2-2-44	Tube	SS	10.13	116.84	15.8	2.65	1.46E-07	100	100	100	97.69	78.84	64.64	50.27	46.56	43.39	39.96
	6-2-3-44	Tube	SS	10.50	126.11	15.8	2.65	1.46E-07	100	100	100	97.69	78.84	64.64	50.27	46.56	43.39	39.96
	6-2-S1-15	Tube	Side	55.12	65.25	--	2.79	--	100	100	100	100	98.68	96.6	93.78	92.60	82.74	45.86
	6-2-S2-24	Tube	Side	16.31	--	--	2.78	--	--	--	--	--	--	--	--	--	--	--
25 537322 WA	8-1-1-11	SC	GB	4.84	137.17	NP	2.88	2.50E-04	100	100	100	87.54	54.97	35.05	15.78	12.71	10.52	8.31
	8-1-2-10.5	SC	GB	5.25	137.32	NP	2.88	2.50E-04	100	100	100	87.54	54.97	35.05	15.78	12.71	10.52	8.31
	8-1-3-10	SC	GB	5.06	136.55	NP	2.88	2.50E-04	100	100	100	87.54	54.97	35.05	15.78	12.71	10.52	8.31
	8-1-1-20	Tube	SS	21.32	93.39	13.9	2.73	2.69E-07	100	100	100	100	99.13	98.65	97.37	96.86	96.36	94.54
	8-1-2-22	Tube	SS	22.02	102.52	13.9	2.73	2.69E-07	100	100	100	100	99.13	98.65	97.37	96.86	96.36	94.54
	8-1-3-20	Tube	SS	20.76	106.18	13.9	2.73	2.69E-07	100	100	100	100	99.13	98.65	97.37	96.86	96.36	94.54
	8-1-1-29	Tube	SS	20.58	107.35	12.4	2.79	1.63E-07	100	100	100	100	99.49	99.19	97.92	97.34	96.74	94.78
	8-1-2-31	Tube	SS	21.08	100.44	12.4	2.79	1.63E-07	100	100	100	100	99.49	99.19	97.92	97.34	96.74	94.78
	8-1-3-29	Tube	SS	20.04	108.32	12.4	2.79	1.63E-07	100	100	100	100	99.49	99.19	97.92	97.34	96.74	94.78
	8-1-S-12	Tube	Side	22.58	102.88	28.7	2.80	--	100	100	100	100	95.5	93.33	87.00	79.16	70.36	57.32
26	7-3-1-19.5	Tube	SB	14.87	109.08	NP	2.66	2.01E-06	100	100	100	99.77	98.97	97.76	76.38	50.72	33.23	22.73

No. Sec. ID State	Sample ID	Sample Type	Layer	w	γ_d	PI	Gs	ksat	Grain Size Distribution									
									2"	1.5"	1"	0.5"	#4	#10	#40	#60	#100	#200
				(%)	(pcf)	--	--	(cm/sec)	(% Passing)									
562019 WY	7-3-2-19.5	Tube	SB	14.31	114.01	NP	2.66	2.01E-06	100	100	100	99.77	98.97	97.76	76.38	50.72	33.23	22.73
	7-3-3-19	Tube	SB	13.52	109.96	NP	2.66	2.01E-06	100	100	100	99.77	98.97	97.76	76.38	50.72	33.23	22.73
	7-3-1-30	Tube	SS	17.42	109.86	22.7	2.69	4.45E-08	100	100	100	99.60	96.71	94.30	90.72	88.34	84.39	73.98
	7-3-2-30	Grab	SS	21.05	--	22.7	2.69	4.45E-08	100	100	100	99.60	96.71	94.30	90.72	88.34	84.39	73.98
	7-3-4-30	Tube	SS	20.57	106.37	22.7	2.69	4.45E-08	100	100	100	99.6	96.71	94.30	90.72	88.34	84.39	73.98
	7-3-4-39	Tube	SS	22.33	100.83	--	2.71	--	--	--	--	--	--	--	--	--	--	--
	7-3-4-46	Tube	SS	23.22	96.41	--	2.72	--	--	--	--	--	--	--	--	--	--	--
	7-3-S-16	Tube	Side	17.57	109.29	22.2	2.80	--	100	100	100	98.77	96.43	94.00	87.65	82.22	76.76	71.01
27 562020 WY	7-2-1-20	Tube	SS	14.19	121.39	19.7	2.87	7.03E-08	100	100	100	100	92.19	84.49	77.93	74.44	69.09	58.84
	7-2-2-20.5	Tube	SS	15.17	119.41	19.7	2.87	7.03E-08	100	100	100	100	92.19	84.49	77.93	74.44	69.09	58.84
	7-2-3-21	Tube	SS	14.86	120.65	19.7	2.87	7.03E-08	100	100	100	100	92.19	84.49	77.93	74.44	69.09	58.84
	7-2-1-29	Tube	SS	15.67	121.55	17.2	2.87	5.17E-08	100	100	100	96.4	86.12	74.99	66.38	61.91	56.78	48.14
	7-2-2-30	Tube	SS	14.93	125.20	17.2	2.87	5.17E-08	100	100	100	96.4	86.12	74.99	66.38	61.91	56.78	48.14
	7-2-3-29	Tube	SS	13.40	124.88	17.2	2.87	5.17E-08	100	100	100	96.4	86.12	74.99	66.38	61.91	56.78	48.14
	7-2-S-14	Tube	SS	13.21	127.52	13.4	--	--	100	100	100	98.26	78.26	62.81	53.07	47.89	41.81	35.03
28 MnRoad MN	6-5-1-12	Tube	CSS	13.68	117.94	11.2	2.73	2.37E-07	100	100	100	98.59	96.46	93.05	82.93	72.97	62.28	54.61
	6-5-2-11	Tube	CSS	14.81	116.41	11.2	2.73	2.37E-07	100	100	100	98.59	96.46	93.05	82.93	72.97	62.28	54.61
	6-5-3-9	Tube	CSS	14.98	116.80	11.2	2.73	2.37E-07	100	100	100	98.59	96.46	93.05	82.93	72.97	62.28	54.61
	6-5-4-9	Tube	CSS	14.29	115.82	11.2	2.73	2.37E-07	100	100	100	98.59	96.46	93.05	82.93	72.97	62.28	54.61
	6-5-1-20	Tube	CSS	14.76	116.41	11.4	2.69	--	100	100	100	98.22	95.48	92.25	82.94	74.89	65.54	56.47
	6-5-2-19	Tube	CSS	12.56	114.06	11.4	2.69	--	100	100	100	98.22	95.48	92.25	82.94	74.89	65.54	56.47
	6-5-3-15	Tube	CSS	14.88	116.92	11.4	2.69	--	100	100	100	98.22	95.48	92.25	82.94	74.89	65.54	56.47
	6-5-4-17	Tube	CSS	13.87	118.13	11.4	2.69	--	100	100	100	98.22	95.48	92.25	82.94	74.89	65.54	56.47
	6-5-S-12	Tube	Side	22.41	101.84	14.4	2.70	--	100	100	100	97.19	93.92	90.14	74.67	61.46	48.28	40.22
29 WesTrack **NV**	2-1-1-7	SC	GB	7.42	131.94	NP	2.75	8.02E-05	100	100	100	88.09	51.74	35.81	23.62	20.04	16.71	12.60
	2-1-2-8	SC	GB	7.45	127.87	3	2.75	8.02E-05	100	100	100	84.02	48.22	33.28	21.98	18.79	15.76	12.05
	2-1-3-6.5	SC	GB	6.30	135.27	3.5	2.75	8.02E-05	100	100	100	65.46	33.16	23.73	16.56	14.15	11.94	8.99
	2-1-1-17.5	Tube	Fill	18.79	105.26	20	2.68	2.07E-06	100	100	100	100	99.9	99	90.04	84.39	78.54	67.14
	2-1-2-18	Tube	Fill	17.14	106.78	15	2.68	2.07E-06	100	100	100	100	99.58	98.69	89.35	83.54	77.18	66.23
	2-1-3-18	Tube	Fill	18.87	107.74	8	2.64	2.07E-06	100	100	100	100	99.58	98.69	89.35	83.54	77.18	66.23
	2-1-1-30	Tube	CSS	21.52	97.52	8	2.75	6.15E-08	100	100	100	100	99.70	99.10	93.70	90.30	85.90	74.30
	2-1-2-30	Tube	CSS	18.69	102.71	12	2.75	6.15E-08	100	100	100	100	99.90	99.20	93.00	89.40	84.50	74.00
	2-1-3-30	Tube	CSS	22.71	99.08	15	2.75	6.15E-08	100	100	100	100	100	99.80	96.90	94.80	91.10	80.50
	2-1-1-39	Tube	SS	14.99	111.45	15	2.75	--	100	100	100	100	99.01	97.29	80.36	71.41	63.46	50.75
	2-1-4-8	SC	GB	8.37	127.42	NP	2.76	8.02E-05	100	100	100	84.24	52.55	37.12	23.95	19.67	15.96	11.24
	2-1-5-6.5	SC	GB	6.78	134.52	4	2.76	8.02E-05	100	100	100	74.51	39.34	28.06	19.34	16.46	13.85	10.27
	2-1-6-6.5	SC	GB	6.57	134.86	2	2.76	8.02E-05	100	100	100	72.25	32.27	22.34	14.95	12.29	9.73	6.65
	2-1-4-18	Tube	Fill	22.53	102.49	11	2.64	5.78E-07	100	100	100	100	99.3	98.94	95.05	92.23	88.47	79.07
	2-1-5-18	Tube	Fill	22.11	98.14	17	2.68	5.78E-07	100	100	100	100	99.54	99.15	94.67	91.88	87.99	78.65
	2-1-6-18	Tube	Fill	23.01	102.09	19	2.68	5.78E-07	100	100	100	100	99.90	99.50	95.50	92.70	89.10	79.60
	2-1-4-30	Tube	CSS	22.53	100.81	20	2.72	1.72E-06	100	100	100	100	99.90	99.40	97.00	95.20	91.50	81.10
	2-1-5-30	Tube	CSS	22.19	103.36	20	2.72	1.72E-06	100	100	100	100	99.90	99.40	97.00	95.20	91.50	81.10
	2-1-6-30	Tube	CSS	21.47	103.35	22	2.72	1.72E-06	100	100	100	100	99.91	99.51	96.89	94.89	21.14	82.56

No. Sec. ID State	Sample ID	Sample Type	Layer	w	γ_d	PI	Gs	ksat	Grain Size Distribution									
									2”	1.5”	1”	0.5”	#4	#10	#40	#60	#100	#200
				(%)	(pcf)	--	--	(cm/sec)	(% Passing)									
	2-1-S-12	Tube	Side	11.52	96.75	11	2.69	--	100	100	100	100	99.93	99.69	97.68	96.11	91.93	79.94
1 010101 AL	1-3-1-10	SC	GB	9.64	140.71	NP	2.85	1.21E-04	100	100	97.35	78.55	53.95	38.82	26.93	23.05	19.05	13.43
	1-3-2-9.5	SC	GB	9.18	146.35	NP	2.85	1.21E-04	100	100	97.35	78.55	53.95	38.82	26.93	23.05	19.05	13.43
	1-3-3-8.25	SC	GB	10.27	137.69	NP	2.85	1.21E-04	100	100	97.35	78.55	53.95	38.82	26.93	23.05	19.05	13.43
	1-3-4-7.5	SC	GB	10.12	136.81	NP	2.85	1.21E-04	100	100	97.35	78.55	53.95	38.82	26.93	23.05	19.05	13.43
	1-3-1-15	Tube	SS	23.58	97.37	19	2.76	4.86E-08	100	100	100	100	99.73	98.6	91.38	87.36	82.01	73.65
	1-3-2-15	Tube	SS	22.49	101.44	19	2.76	4.86E-08	100	100	100	98.53	97.40	96.64	89.58	85.48	80.1	71.92
	1-3-3-14.5	Tube	SS	24.23	100.26	19	2.76	4.86E-08	100	100	100	97.79	97.27	96.45	88.94	84.59	79.59	71.25
	1-3-1-23	Tube	SS	18.94	107.02	13	2.77	2.40E-07	100	100	100	100	99.38	98.86	91.95	85.49	78.05	67.24
	1-3-2-23	Tube	SS	20.61	104.07	13	2.77	2.40E-07	100	100	100	100	99.38	98.86	91.95	85.49	78.05	67.24
	1-3-3-23	Tube	SS	18.81	110.16	13	2.77	2.40E-07	100	100	100	100	99.38	98.86	91.95	85.49	78.05	67.24
3 040113 AZ	2-3-1-5.5	SC	GB	3.39	139.35	NP	2.75	3.26E-04	100	100	100	72.01	48.12	36.61	22.22	17.74	14.02	10.23
	2-3-2-5.5	SC	GB	2.97	140.72	NP	2.75	3.26E-04	100	100	100	72.01	48.12	36.61	22.22	17.74	14.02	10.23
	2-3-3-5.5	SC	GB	3.41	138.39	NP	2.75	3.26E-04	100	100	100	81.96	57.58	43.75	26.07	20.59	16.16	11.72
	2-3-C-6.5	SC	GB	3.79	130.80	NP	2.75	3.26E-04	100	100	100	82.32	61.85	46.99	27.19	21.19	16.75	11.92
	2-3-1-13.5	SC	SS	6.92	119.91	NP	2.75	3.92E-04	100	100	100	87.49	70.65	56.55	31.37	23.04	17.71	12.63
	2-3-2-12	SC	SS	6.22	118.92	NP	2.75	3.92E-04	100	100	100	87.49	70.65	56.55	31.37	23.04	17.71	12.63

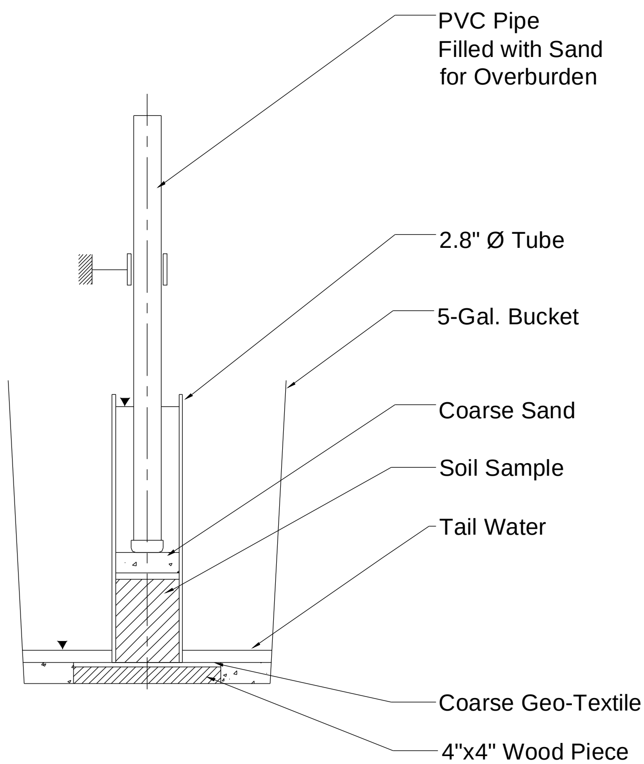


Figure 22
Hydraulic Conductivity Setup

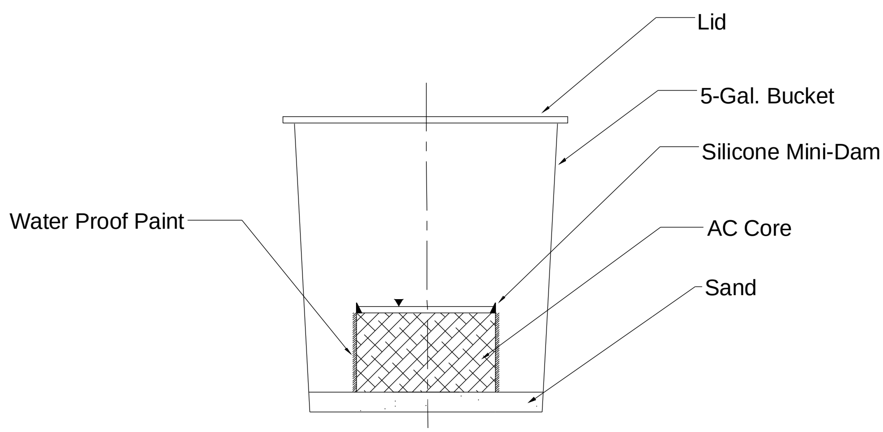


Figure 23
Testing of AC Cores for Hydraulic Conductivity Setup

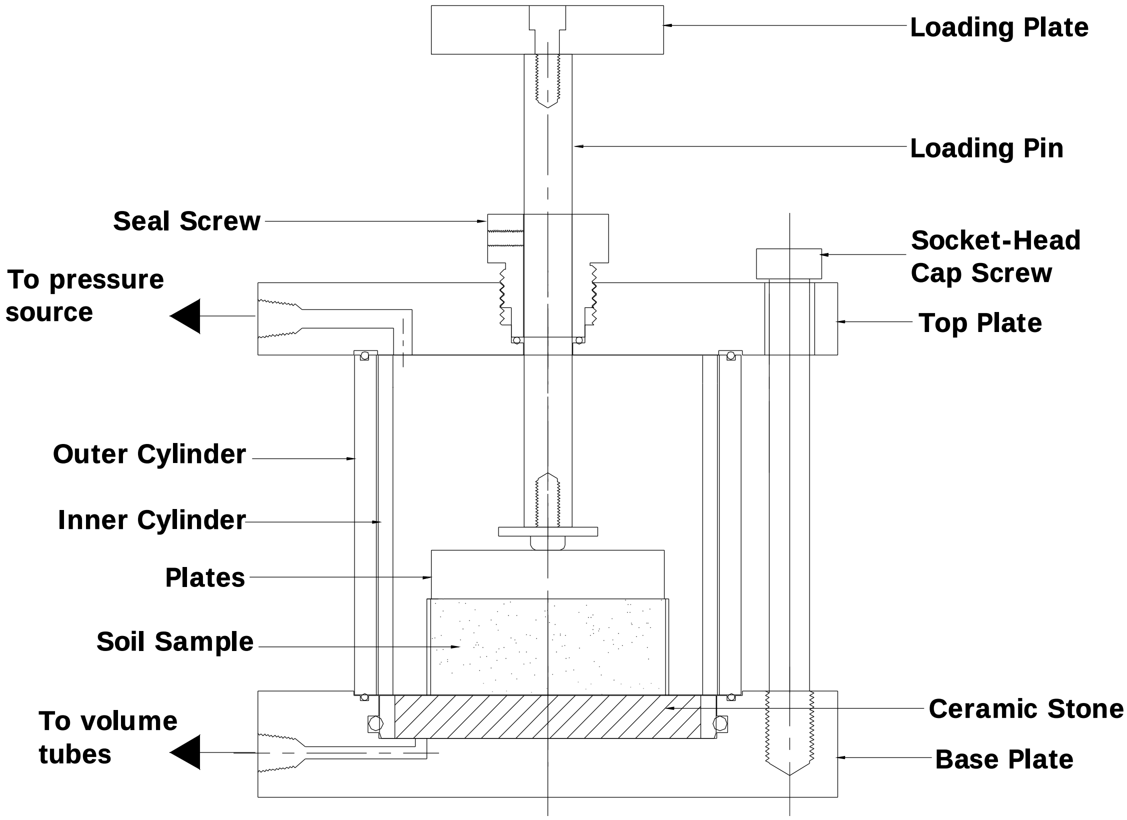


Figure 24
New Pressure Plate Device

Figure 25
New Setup of Pressure Plate Devices at ASU

SWCC Test (Reconstituted Sample)

D_{60}	12.09	Sample ID >	4-1-1-11.5
- No. 200	6.8%	CS ID>	5A
PI	NP	Suction >	4; 30; 500 kPa
wPI	NA	Sta. No. >	1
Gs	2.71	Initials >	YYP

	Date	Time	Suction (kPa)	UT (mm)	Volume Reading L mm	Volume Reading R mm	Height (mm)
1	3/10/2003	10:05	3.9	255	91.0	92.0	62.70
2	3/13/2003	17:25	30		108.0	109.0	62.66
3	3/15/2003	22:45	500		179.0	180.0	62.56
4	3/20/2003	16:40			216.0	216.0	62.60
5							
6							
7							
8							
9							
10							
11							

End of the Test:

Wt. of Wet Sample+Ring+Tare	g	228.90
Wt. of Dry Sample+Ring+Tare	g	222.53
Wt. of Ring	g	44.69
Wt. of Tare	g	51.07
Wt. of Water	g	6.37
Wt. of Dry Soil	g	126.77
Final w.c.	%	5.02
Final Degree of Sat.		0.23

Brass Ring:

ID		RN-4
Weight	g	44.69
Height	mm	25.40
Diameter	mm	61.25
Volume	ft3	0.00264

Ceramic Stone:

Wt. Of SSD CS (initial)	g	198.70
Wt. Of SSD CS (final)	g	198.68

Specimen:

Wt of Dry Specimen	g	126.77
Wt of Glass Plate	g	125.80
Wt. of Sat. Spec.+Ring+GP	g	323.22
Wt. of Sat. Spec.+Ring+CS	g	395.46
Wt. of Sat. Specimen	g	152.07

Overburden:

Density of Overburden	pcf	150
Height of Overburden	in	12
Overburden Pressure	psi	1.042
Diameter of Metal Plate	mm	60.96
Area of Metal Plate	in^2	4.524
Overburden Load	lbs	4.712
Wt. to be applied	g	1859

Compensation Load for Upthrust:

Diam. of Loading Shaft	in	0.5
Area of Loading Shaft	in^2	0.196
Applied pressure	kPa	1.0
Upthrust	lbs	0.028
	g	13

Figure 26
Typical SWCC Data Sheet

Calculation of Degree of Saturation							
Initial amount of water absorbed				25.30	g		
Initial Water content				19.96	%		
initial Dry Density				105.65	pcf		
Initial Degree of Saturation				0.90			
Suction kPa	Water Released g	Water Rlsd from CS g	w.c. pcf	Samp Height mm	Samp. Vol. ft^3	Dry Density pcf	Deg of Sat.
3.93	2.52	0.00	17.97	25.36	0.0026414	105.71	0.81
30.00	13.02	0.00	9.68	25.26	0.00263098	106.13	0.44
500.00	18.43	0.00	5.42	25.30	0.00263515	105.96	0.25

Figure 27
Typical Calculation Sheet for Degree of Saturation

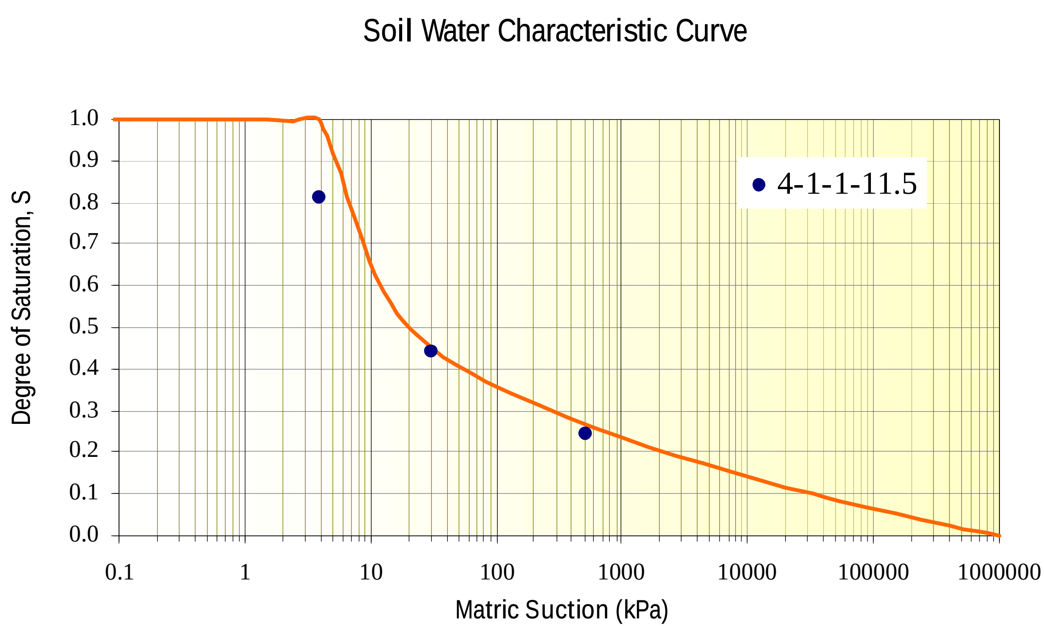


Figure 28
Typical SWCC for a Granular Sample

CHAPTER 5
EVALUATION OF THE ENHANCED INTEGRATED CLIMATIC MODEL

INTRODUCTION

The work plan for Task 4 included the verification and validation of the EICM with the data from the Long Term Pavement Performance, MnRoad, ADOT, and WesTrack sections. The EICM was used in its current form (version 2.6 developed for the NCHRP 1-37A project) for prediction, for the first iteration. The EICM predictive accuracy was judged to be unacceptable and all information and research findings available to date were used to develop modifications to the program. These modifications were made and comparative runs repeated until acceptable accuracy was achieved. Task 4 was broken into the following subtasks:

1. Gather data
2. Run EICM
3. Compare measured and EICM-predicted values
4. Modify the EICM
5. Repeat the EICM runs
6. Continue iterating until acceptable accuracy was achieved.

GATHERING DATA

The data needed to validate the EICM was summarized in Chapter 3. The data received from the LTPP database, MnRoad, WesTrack and ADOT was extracted, assembled, and input into the EICM. These data, along with the field information collected from the 29 LTPP sites visited was used for the validation of the 2.6 version of the EICM.

In addition to the data collected from the 29 LTPP sites visited and 60 sections currently available in the LTPP database, WesTrack reports were reviewed and the data for three sections was extracted. Additional data collected included two MnRoad sections and two more from the Arizona Department of Transportation (ADOT). Appendix C presents a summary of the measured moisture content, the density and the soil-water characteristic curve parameters for each site visited.

EICM RUNS

Stage I Runs

The outcome of the Stage I runs played an important role in the validation of the different models and algorithms built into the EICM to predict the moisture content. The stepwise process adopted allowed for checking of individual models one at a time.

Stage I comprises the EICM runs for the sites visited therefore, directly measured index properties were used to input the EICM program. The input data was obtained from the

laboratory testing done on the samples collected at each site and therefore, it represents our best dataset. It includes the soil-water characteristic curves, saturated hydraulic conductivity, specific gravity, gradation analysis, and the Atterberg limits measured at each sample collected at different depth for every site. The laboratory plan did not include compaction curves and therefore, the optimum water content and the maximum dry density were extracted from the data available from LTPP, MnRoad, and WesTrack databases.

The EICM runs were completed at 5 different levels of input parameters for a total of 150 runs. The statistical analysis is shown later in this chapter.

Stage II Runs

In order to measure the accuracy and the level of confidence on index properties catalogued into the databases, which are key parameters for the models built, a set of runs called the *Stage II* runs was scheduled. For this analysis, the field Percent Passing #200 and the Plasticity Index were replaced by the data from the databases. These runs were aimed at quantifying the errors in moisture content caused by errors in the index properties derived from the databases. The runs at this stage were done for some of the sites visited.

Stage III Runs

Stage III runs comprised those for the sites visited as in Stage I and II runs. However, the input data was derived from the databases only, including the measured water content values. That is, the TDR values reported in the databases were used as the measured values. The added error in going from Stage II to Stage III was due primarily to error in the TDR values themselves.

Stage IV Runs

Stage IV runs comprised all sites, the visited and the office sites, and the input data was derived from the databases only. TDR moisture values were used to compare with the predicted moisture from the EICM version 2.6 output files.

EICM RUNS WITHIN THE MEPDG HIERARCHICAL LEVELS OF ANALYSIS

As currently implemented, three hierarchical levels of analysis have been defined in the MEPDG. The level of analysis determines the set of parameters required for input by the user. For instance, the user will require a lot more input parameters in order to use the MEPDG Level 1. On the other hand, if Level 3 analysis is desired, the user will be inputting less accurate and/or default parameters and in most cases, fewer. The Levels then determine the accuracy of the output based on the accuracy of the input. It is important to note, however, that the internal analysis is the same whether Level 1, 2, or 3 has been selected.

The hierarchical levels concept also applies to the EICM model. A summary of the input required to run the EICM is shown in Table 86, along with the Level of analysis for which it is required. It can be seen that Level 1 analysis could not be validated for the Stage IV due to the lack of information. The LTPP does not contain the following parameters:

- Seasonal values of the groundwater table depth (for several sections)
- Direct measurements of thermal conductivity, heat capacity, specific gravity of solids, saturated hydraulic conductivity (very few available), suction measurements, and surface short wave absorptivity.

It was possible to check Level 2 analysis for some of the sections, but not for all of them. The following parameters could be ascertained for use in Level 2:

- Seasonal variation of the groundwater table depth (some sections)
- Saturated hydraulic conductivity (very few sections)
- Maximum dry unit weight
- Optimum moisture content
- CBR option to estimate the resilient modulus at optimum condition

Level 3 analysis was completed for all the office sites selected. The most important input option to be considered at this level is related to the Infiltration allowed into the pavement structure. Currently, there are four ways to consider infiltration in the EICM model:

a) Negligible: 0% of rainfall allowed to infiltrate the pavement system. EICM assumes 0 ft of cracking.

b) Minor: 10% of rainfall allowed to infiltrate the pavement system. EICM assumes 10 ft of cracks per 100 ft of survey length.

c) Moderate: 50% of rainfall allowed to infiltrate the pavement system. EICM assumes 100 ft of cracks per 100 ft of survey length.

d) Extreme: 100% of rainfall allowed to infiltrate the pavement system. EICM assumes 1,000 ft of cracks per 100 ft of survey length.

Stage IV runs only considered the Negligible infiltration option. No comparisons were made considering Minor, Moderate or Extreme infiltration. The infiltration model developed by the University of Illinois (based on edge drains measurements) considers pavement cracking as the way water flows into the pavement structure. Based on the type of pavement, an infiltration rate is assumed based upon the ratios shown above. After rainfall, water is added to the moisture content of the base coarse in proportion to the amount of rainfall, and the infiltration rate. The NCHRP 1-37A team in charge of the flexible pavement design decided several years ago that this model needed a revision and

hence, the EICM was calibrated based on *no infiltration* due to rainfall. For this reason, the selection of the sections to validate the EICM in the present study was based on pavements for which cracking was reported to be low to none.

As reported in Chapter 2, when cracks were present on the pavement sections visited, soil samples were obtained from the unbound layers near a crack by coring one of the holes about two inches away from a selected crack. There were 12 sites that contained such samples near cracks. The moisture contents of the samples near cracks were compared with the average moisture content of the samples obtained from the other holes, which were located away from the crack. The comparison indicted that the average difference in moisture contents was +0.38% with a minimum of –1.72% and a maximum of +2.61%. The standard deviation of this difference was 0.81. The positive sign indicated that the moisture near the crack was higher that the moisture away from the crack.

It was apparent from this comparison that the moisture content near the cracks was not significantly higher. Therefore, it appeared that the cracks were not providing avenues for water penetration, perhaps because they were typically filled with dust and fine particles.

STATISTICAL ANALYSIS

The data obtained from the EICM runs was submitted to a statistical analysis. The statistical parameters used to draw conclusions were the adjusted coefficient of determination, R^2, and the standard error of the estimate divided by the standard deviation, S_e/S_y. Furthermore, two additional different types of error were measured. The first error was the algebraic mean error, e_{alg}, given by

$$e_{a\lg} = \frac{100\sum_{i=1}^{n}\frac{(y_i - \hat{y}_i)}{y_i}}{n} \quad \text{.......(4)}$$

Where:

y_i = measured moisture content
$\hat{y}_i$ = predicted moisture content
n = number of data points

The second error was the absolute mean error, e_{abs}, given by

$$e_{abs} = \frac{100\left|\sum_{i=1}^{n}\frac{(y_i - \hat{y}_i)}{y_i}\right|}{n} \quad \text{.......(5)}$$

Besides the values of the regression parameters, the adjusted coefficient of determination, R^2, was calculated as a measure of the accuracy of prediction of the model. The value of R^2 is calculated as a function of the ratio Se/Sy as shown in the following equation:

$$R^2 = 1 - \left(\frac{S_e}{S_y} \right)^2 \quad \text{.......(6)}$$

Where:
R^2 = Adjusted coefficient of determination
S_e = Standard error of estimate
S_y = Standard deviation

The formulas used to calculate S_e and Sy are given below:

$$S_e = \sqrt{\frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)^2}{n - p}} \quad \text{.......(7)}$$

$$S_y = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \overline{y})^2}{n - 1}} \quad \text{.......(8)}$$

Where:

y_i = measured moisture content
$\hat{y}_i$ = predicted moisture content
$\overline{y}_i$ = average of y_i
n = number of data points
p = number of unknown parameters

A summary of the possible sources of error is presented in Table 87 for the four stages of analysis.

The possible sources of error will be explained in detail in the following sections.

Stage I Analysis

For Stage I analysis, 89 measured moisture content values were compared to the predicted results. The Stage I runs were considered at 5 different levels of accuracy:

- Stage I-Level 1
- Stage I-Level 2a
- Stage I-Level 2b
- Stage I-Level 2c
- Stage I-Level 3

This step-procedure allowed quantifying the contribution to the error of each of the models built into the EICM to predict the moisture content, considering the input parameters were not sources of error for this Stage (see Table 87). More importantly, this analysis allowed for the calibration of the current version of the EICM moisture prediction.

The Stage I-Level 1 analysis comprised the moisture prediction for the pavement sections visited. The information gathered in the field is considered the best set available therefore; the error found in the prediction was primarily due to the *Suction model* built into the EICM. The *Suction model* refers to the process used to calculate the equilibrium suction, ***h***, in the field. This parameter is calculated by the following equation:

$$h = y \cdot g_{water} \qquad (9)$$

Where:

y = distance from groundwater table

g_{water} = unit weight of water

The Stage I-Level 2a analysis allowed taking a step further into the error analysis. These runs were for the same sites used in Stage I-Level 1 but the soil-water characteristic curve (SWCC) parameters were not input. EICM automatically calculated the SWCC parameters and this process allowed defining the error due to the *SWCC model* built into the program. The *SWCC model* refers to the set of correlations used to calculate the equilibrium moisture content based on soil suction and soil index properties such as Passing #200 (P_{200}), Diameter 60 (D_{60}), and Plasticity Index (*PI*). The *SWCC model* is given by the Fredlund and Xing equation:

$$q_w = C(h) \times \left[\frac{q_{sat}}{\left[\ln\left[EXP(1) + \left(\frac{h}{a_f} \right)^{b_f} \right] \right]^{c_f}} \right] \qquad (10)$$

With:

$$C(h) = \left[1 - \frac{ln\left(1 + \frac{h}{h_r}\right)}{ln\left(1 + \frac{1.45 \times 10^5}{h_r}\right)} \right] \qquad (11)$$

Where:

q_w = Volumetric moisture content, in %

a_f, b_f, c_f, and h_r = SWCC fitting parameters

In the MEPDG current version, the SWCC parameters are correlated with soil index properties using the following equations:

1. For plastic unbound materials ($P_{200}PI$ > 0)

$$a_f = \frac{0.00364(P_{200}PI)^{3.35} + 4(P_{200}PI) + 11}{6.895} \quad \text{(psi)} \qquad (12)$$

$$\frac{b_f}{c_f} = -2.313(P_{200}PI)^{0.14} + 5 \quad \text{(dimensionless)} \qquad (13)$$

$$c_f = 0.0514(P_{200}PI)^{0.465} + 0.5 \quad \text{(dimensionless)} \qquad (14)$$

$$\frac{h_r}{a_f} = 32.44e^{0.0186(P_{200}PI)} \quad \text{(dimensionless)} \qquad (15)$$

2. For granular non-plastic materials ($P_{200}PI$ = 0)

$$a_f = \frac{0.8627(D_{60})^{-0.751}}{6.895} \quad \text{(psi)} \qquad (16)$$

$$\bar{b}_f = 7.5 \quad \text{(dimensionless)} \qquad (17)$$

$$c_f = 0.1772\ln(D_{60}) + 0.7734 \quad \text{(dimensionless)} \qquad (18)$$

$$\frac{h_r}{a_f} = \frac{1}{D_{60} + 9.7e^{-4}} \quad \text{(dimensionless)} \qquad (19)$$

The Stage I-Level 2b analysis allowed defining the error due to the ***k-sat model*** built into the EICM. These runs were for the same sites and data used in Stage I-Level 2a analysis but the saturated hydraulic conductivity was automatically calculated by the EICM. The ***k-sat model*** refers to the set of correlations used to calculate the saturated hydraulic conductivity based on soil index properties such as Passing #200 (P_{200}), Diameter 60 (D_{60}), and Plasticity Index (*PI*). The ***k-sat model*** is defined by the following relationships:

1. For granular non-plastic and very low plastic materials ($0 \le P_{200}PI < 1$)

$$k_{sat} = 118.11 \times 10^{\left[-1.1275(\log D_{60}+2)^2 + 7.2816(\log D_{60}+2) - 11.2891\right]} \quad \text{(ft/hr)} \qquad (20)$$

The above equation is valid for D_{60} less than 20 mm. If D_{60} is greater than 20 mm, the EICM sets D_{60} = 20 mm.

2. For plastic unbound materials ($P_{200}PI \ge 1$)

$$k_{sat} = 118.11 \times 10^{\left[0.0004(P_{200}PI)^2 - 0.0929(P_{200}PI) - 6.56\right]} \text{ (ft/hr)} \quad (21)$$

The Stage I-Level 2c analysis allowed defining the error due to the *Gs model* build into the EICM. The *Gs model* refers to the correlation used to calculate the specific gravity of the solids based on the Passing #200 (P_{200}) and Plasticity Index (PI). These runs were for the same sites and data used in Stage I-Level 2b analysis except that in this case, the specific gravity, G_s, was automatically calculated by the EICM. The *Gs model* is defined by the following relationship:

$$G_s = 0.041(P_{200}PI)^{0.29} + 2.65 \quad (22)$$

The Stage I-Level 3 analysis allowed defining the error due to the *Compaction model* build into the EICM. The *Compaction model* refers to the correlations used to estimate the optimum water content and the dry unit weight of the material for those cases where this information is not available. The relationships are based on the Passing #200 (P_{200}), Diameter 60 (D_{60}), and Plasticity Index (PI). These runs used the same sites and data used in Stage I-Level 2c analysis except that in this case, the compaction parameters were estimated by the EICM. The following steps comprise the *Compaction model*:

3. The model identifies the layer as a compacted base course, compacted subgrade, or natural in-situ subgrade.
4. Calculate the optimum degree of saturation, S_{opt}:

$$S_{opt} = 6.752\,(P_{200}PI)^{0.147} + 78 \quad (23)$$

5. Compute the optimum gravimetric moisture content, w_{opt}:
   e) If $P_{200}PI > 0$ (plastic materials):

$$w_{opt} = 1.3\,(P_{200}PI)^{0.73} + 11 \quad (24)$$

   f) If $P_{200}PI = 0$ (granular, non-plastic materials):

$$w_{opt\,(T99)} = 8.6425\,(D_{60})^{-0.1038} \quad (25)$$

   i. If layer is not a base course

$$w_{opt} = w_{opt\,(T99)} \quad (26)$$

   ii. If layer is a base course

$$Dw_{opt} = 0.0156[w_{opt(T99)}]^2 - 0.1465 w_{opt(T99)} + 0.9 \quad (27)$$

$$w_{opt} = w_{opt\,(T99)} - Dw_{opt} \quad (28)$$

6. Compute $g_{d\,max}$ for compacted materials, $g_{d\,max\,comp}$

$$g_{d\,max\,comp} = \frac{G_s g_{water}}{1+\frac{w_{opt}G_s}{S_{opt}}} \quad \text{.......................(29)}$$

7. Compute $g_{d\,max}$
   g) If layer is a compacted material

$$g_{d\,\max} = g_{d\,\max\,\mathrm{comp}} \quad \text{.......................(30)}$$

   h) If layer is a natural in-situ material

$$g_{d} = 0.90 g_{d\,\max\,\mathrm{comp}} \quad \text{.......................(31)}$$

   EICM uses g_d for $g_{d\,max}$.

8. Compute the volumetric water content, q_{opt}

$$q_{opt} = \frac{w_{opt} g_{d\,\max}}{g_{water}} \quad \text{.......................(32)}$$

The measured versus predicted moisture content results from the Level 1 analysis runs are presented in Table 88. Same results are depicted in Figures 29 through 33. The summary of the statistical analysis is presented in Table 89.

The following observations were made based on the results presented in the previous section. The results represent the accuracy of the pre NCHRP 9-23 model as it is currently implemented.

Predicted water contents were found to be lower than measured water contents, particularly for soils with low Plasticity Index and non-plastic materials, at all stages of the analysis. This conclusion was based on the algebraic error, which showed to be positive for all of the stages of the analysis. Possible explanations to this result are given below:

1. The suction model, which predicts suction by $y\gamma_w$, over predicts suction – the absolute error associated with this model was found to be 31%, which is equivalent to an R^2 of 65%. Note that the R^2 for the Stage I – Level 1 runs, which analyzed the accuracy of the suction model, is 65%). This is considered a substantial error.

2. The SWCC models added some minor error to the overall prediction of moisture content. This error was calculated as the difference of the absolute error found for

Level 1 – Stage 2a runs and the error found for the Level 1 – Stage 1 runs. The absolute error change was found to be 10% (from 31% to 41%), which is equivalent to a change in R^2 statistics from 65% to 58%. Further analysis on the moisture content prediction showed that the error contribution was mostly due to the error found on the prediction for nonplastic granular materials as shown in Figure 34.

3. The inclusion of the ***k-sat*** model in the prediction of moisture content did not add substantial error to the estimate. The R^2 went from 58.2% from the previous run to 57.5%; and the absolute error improved to 36% from 41%. It was noticed that once freezing occurs, nonplastic granular soils dry up, the unsaturated hydraulic conductivity, k_{unsat} tends to zero and water does not have enough time to get back in before freezing occurs again. This phenomenon would explain in part the under-predicted moisture content results.

4. The *Gs model* accuracy analysis was attempted from the Stage I – Level 2c runs. Results showed that the error did not increase when the *Gs model* was used instead of the specific gravity measured in the field. The absolute error was found to be 35.4%, which compares with the error found in the previous run of 35.5%. Of interest, the R^2 went up again to a value of 64%, which indicates less scatter in the overall prediction of moisture content, but not necessarily a better one.

5. Stage I – Level 3 analysis was aimed to check the added error when the compaction model was incorporated into the analysis. Results showed very little deterioration of the prediction as the absolute error went from 35.4% from the previous run to 35.7% in this run. The scatter, as measured by the R^2 statistics, was found to be marginally larger (R^2 of 64% from the previous run to R^2 of 60% for this run).

Based on the results of the Stage I analysis, it was found that the EICM version 2.6 model was under-predicting the moisture content in the unbound materials. It was concluded that the Suction and the SWCC models needed improvement. The prediction of moisture content for the plastic materials was found to be better than the prediction for the granular materials. In addition, it appeared that there were limitations and problems with the modeling of post freezing moisture contents under certain conditions, which could be related to the ***k-sat model*** and a fix for this problem was also pursued.

Note that $y\gamma_w$ may typically over estimate suction because the real suction is being depressed somewhat by a more or less steady influx of water from condensation of vapor (mostly), which is not considered in the current model. Further, the presence of small undetected lenses of perched water, which are believed to be prevalent, would lead to overestimation of the suction.

Stage II Analysis

Stage II analysis made use of the databases available for the sites visited. The material properties available in the different databases were used as input parameters into the EICM program. This process allowed us to recognize the validity of the parameters found in the databases as well as the sensitivity of the models to the most important parameters when used for moisture prediction purposes.

The databases available (LTPP, MnRoad, and WesTrack) provided information on gradation of the material, Atterberg limits, optimum water content, and maximum dry unit weight. Data such as SWCCs, hydraulic conductivity, and specific gravity are rarely catalogued in such databases. On the other hand, compaction data was not part of the laboratory program of this project. This situation left us in the position of checking only the validity of the gradation and Atterberg limits data, which was considered to be fundamental information in the whole prediction process.

From the databases available, 49 points of measured moisture content were extracted. The LTPP and MnRoad databases were used. The information was compared to the predicted data points given by the EICM runs. The predicted moisture content along with the site identification is presented in Table 90. The statistical analysis summary is presented in Table 89.

The results showed that the model under-predicted the moisture content. The measured versus predicted values are shown in Figure 35. The algebraic error went from 8% to 34% for the runs with actual measurements to the runs with data from databases. The R^2 statistics went from 65% to 48% as the scatter increased. The results showed that the EICM models used to predict the moisture content of the unbound material are very sensitive to the gradation and Atterberg limits physical properties of the soil and therefore, it emphasized the need to always input measured gradation and Atterberg Limits into the MEPDG and not to attempt estimating them.

Stage III Analysis

Stage III analysis is similar to Stage II, except that the moisture predictions were compared to the Time Domain Reflectometry (TDR) moisture data from the databases. This step allowed quantifying the errors associated with the TDR data available, which is crucial for future predictive capabilities.

The TDR-measured volumetric moisture contents for LTPP SMP sites were obtained from the LTPP database (LTPP 2003). Typically, TDR instrumentation contained ten probes installed at ten different depths starting from the granular base and reaching well into the subgrade. The depth of each probe was recoded in the database. For comparison, the data from the probes corresponding to the sample depth were extracted from the database. The extracted data were plotted against time. A typical plot depicting the TDR volumetric water content versus time data for the site located in Opelika,

Alabama is shown in Figure 36. Appendix D presents the plots for all of the sections analyzed.

In general, the TDR data indicated that the moisture content fluctuates around an average value with higher moisture contents in the spring season. The fluctuation was prominent for the sites located in cold regions. For the purpose of this study the average moisture content was computed by excluding the unusually low moisture contents recorded during winter months. These unusual readings are the result from frozen water. The TDR probe measures the dielectric constant of the soil water surrounding the probe. The dielectric constant is related to the moisture content. Once the dielectric constant is obtained the moisture content can be computed using functions developed through calibrations for fine-grained and coarse-grained materials. However, the TDR can detect only the unfrozen or free water and when water freezes the readings will erroneously indicate very low values of moisture.

Forty-three data points were used in the comparison shown in Figure 37. The data obtained for each of these points is presented in Table 91. The statistics shown in Table 89 represents the error associated with the TDR measurements as well as the error associated with the use of gradation and Atterberg limits from the databases. The data indicated that the TDR-measured values generally were higher than the field-measured values.

In order to be able to use the TDR data in subsequent analysis, the average TDR-measured moisture contents along with the corresponding field-measured moisture contents for our best 23 sites were compared. The comparison was aimed at obtaining a correction factor for the TDR readings that would allow us to do better comparisons in the future. The 23 sites were the sites found to have a more stable readings history and less data from freeze-thawing cycles. The TDR and field volumetric moisture contents are presented in Table 92. The data, as expected from previous results, indicated that the TDR-measured values generally were higher than the field-measured values. The TDR versus field-measured moisture content plot is shown in Figure 38 along with a fitting curve to the data that served to determine the correction factor. The correction factor is presented in Figure 39 and the corrected data after applying the correction factor is shown in Figure 40.

Stage IV Analysis

Stage IV runs comprised all sites, the visited and the office sites, and the input data was derived from the databases only. TDR moisture values were used to compare with the predicted moisture from the EICM version 2.6 output files. Figure 41 shows the measured versus predicted moisture contents for the Alabama site as an example of the data obtained. The legend to the right indicates the depth of the TDR device in inches. Appendix E shows the complete set of plots of measured versus predicted water content for this Stage runs.

Once the runs were completed, the next step in the analysis was aimed at recognizing the possible sources of error in the measured data obtained from the databases and proceed to eliminate the points that did not fitted into the category of "equilibrium" conditions that was desired for an unbiased estimate. Appendix F shows the plots for the sections with data eliminated. The sources of discrepancies between measured and predicted data recognized were:

1. Frozen water. In this case, the moisture content measured in the field was much lower than that predicted by the EICM.
2. Water content measurements performed during thawing seasons. The measured water content was not at equilibrium and in general was higher than the one predicted by EICM.
3. TDR malfunction. In this case, the recorded data was erratic.

Error analysis was not even necessary to find out that the models needed a revision. The sources of error came from a) errors in the input index values, b) errors in the SWCCs, c) errors in the groundwater table position, d) errors in the material profile, and e) errors in the TDR values themselves.

The systematic scheme used for discovering and quantifying these potential errors showed that all models need a refinement, and particularly the Suction model. The next Chapter deals with the development of improved models based on our extensive field collected database, which allowed for improvement of the prediction capabilities of the EICM version 2.6.

Table 86
Input Required by the EICM by Level of Analysis

Parameter	Application	Level of Analysis		
		1	2	3
Model Initialization				
Base/Subgrade construction date	Required for model initialization	√	√	√
Climatic/Boundary Conditions				
Latitude	To define weather station	√	√	√
Longitude	To define weather station	√	√	√
Elevation	To define weather station	√	√	√
Groundwater Table Depth	Annual average			√
	Seasonal values	√	√	
Pavement Structure				
Layer thickness		√	√	√
Material type		√	√	√
Asphalt Concrete and PCC Materials				
Thermal conductivity	Default value		√	√
	Direct measurement	√		
Heat capacity	Default value		√	√
	Direct measurement	√		
Unbound Materials (Compacted or natural)				
Atterberg limits	Direct measurement	√	√	√
Sieve analysis	Direct measurement	√	√	√
Soil classification	To correlate with resilient modulus			√
Resilient modulus or CBR or R-value or Layer coefficient a_i at optimum condition			√	
k_1, k_2, k_3 values	To calculate the resilient modulus at optimum conditions	√		
Specific gravity of solids	Direct measurement	√	√	
Saturated hydraulic conductivity	Direct measurement	√	√	
Maximum dry unit weight	Direct measurement	√	√	
Optimum moisture content	Direct measurement	√	√	
Dry thermal conductivity	Direct measurement	√	√	
	Default value		√	√
Heat capacity	Direct measurement	√		
	Default value		√	√
Soil-water characteristic curve parameters	From direct suction measurements	√		
Drainage and Surface Properties				
Surface short wave absorptivity	Default value		√	√
	Direct measurement	√		
Infiltration	Choose from Negligible, Minor, Moderate, or Extreme	√	√	√
Drainage path length	Only if infiltration is considered	√	√	√
Pavement cross slope	Only if infiltration is considered	√	√	√

Table 87
Possible Sources of Error

Sources of Error	**Stage I**					**Stage II**	**Stage III**	**Stage IV**
Level of Analysis	**1**	**2a**	**2b**	**2c**	**3**	**1**	**1**	**3**
Suction model	√	√	√	√	√	√	√	√
SWCC model		√	√	√	√			√
k-sat model			√	√	√			√
Gs model				√	√			√
Compaction model					√			√
TDR measurements							√	√
Input parameters:								
SWCC parameters		—	—	—	—			—
Saturated permeability			—	—	—			—
Specific gravity				—	—			—
Optimum water content					—			—
Maximum dry density					—			—
Atterberg limits						√	√	√
Gradation						√	√	√

Table 88
Measured versus Predicted Moisture Content – Stage I Analysis

Section ID	State	Lab ID	Sample Type	Layer	Measured Grav. w (%).	Level 1 EICM Predicted Grav. w (%)	Level 2a EICM Predicted Grav. w (%)	Level 2b EICM Predicted Grav. w (%)	Level 2c EICM Predicted Grav. w (%)	Level 3 EICM Predicted Grav. w (%)
10101	**AL**	1-3-(7.5-10)	Grab (SC)	GB	9.80	5.96	9.51	10.80	7.16	6.67
		1-3-(14.5-15)	Tube	SS	23.43	22.47	24.10	22.91	22.78	22.60
		1-3-(23)	Tube	SS	18.81	20.34	21.81	20.73	20.62	20.45
40113	**AZ**	2-3-(5.5-6.5)	Grab (SC)	GB	3.19	5.10	0.00	0.00	0.00	0.00
		2-3-(12-13.5)	Grab (SC)	SS	7.52	8.23	0.00	0.00	0.00	0.00
40215	**AZ**	4-1-(11.5)	Grab (SC)	GB	5.21	2.75	7.19	7.19	7.19	0.00
		4-1-(18-18.5)	Tube	SS	7.49	14.46	9.99	10.48	10.38	7.18
52042	**AR**	1-5-(13-14)	Grab	GB	19.83	17.52	17.28	15.23	15.76	18.52
		1-5-(18.5)	Tube	SS	18.16	18.01	17.77	15.65	16.20	19.04
		1-5-(15-15.5)	Tube	SS	18.01	17.28	17.05	15.02	15.54	18.26
		1-5-(23-24)	Tube	SS	16.96	17.84	18.14	18.14	18.56	24.72
63042	**CA**	8-3-(13-14)	Tube	Comp SS	18.93	21.07	18.68	18.68	18.62	13.03
		8-3-(20-21)	Tube	SS	16.56	19.68	17.98	17.93	17.60	16.67
		8-3-(28-29)	Tube	SS	16.54	19.46	18.88	18.83	18.48	17.51
81053	**CO**	7-5-(7.5)	Grab (SC)	GB1	3.68	2.70	0.00	0.00	0.00	0.00
		7-5-(13.5-14)	Grab (SC)	GB2	5.19	3.84	0.00	0.00	0.05	0.05
		7-5-(43)	Tube	NatSS	22.96	23.55	24.10	24.28	23.91	23.97
		7-5-(50)	Tube	NatSS	23.46	23.80	24.52	24.52	23.86	27.40
87035	**CO**	7-4-(14.5)	Grab (SC)	GB	3.31	1.66	0.00	2.47	2.47	2.37
		7-4-(19)	Tube	SB	6.64	0.22	1.41	7.69	7.96	8.61
		7-4-(37)	Tube	SB	9.73	0.21	1.39	7.58	7.84	8.48
		7-4-(48)	Tube	SS	19.98	18.91	19.55	19.14	19.14	20.48
91803	**CT**	6-1-(10-12.5)	Grab (SC)	GB	5.03	2.84	0.00	0.00	0.00	0.00
		6-1-(20-21)	Grab (SC)	SS	7.13	6.56	0.00	0.00	0.00	0.00
204054	**KS**	5-3-(16-16.5)	Tube	SS	22.02	20.87	21.90	21.96	21.90	23.72
		5-3-(22)	Tube	SS	21.17	20.42	21.43	21.49	21.43	23.21
		5-3-(27)	Tube	SS	17.12	19.10	20.30	20.51	19.88	22.60

Section ID	State	Lab ID	Sample Type	Layer	Measured Grav. w (%).	Level 1 EICM Predicted Grav. w (%)	Level 2a EICM Predicted Grav. w (%)	Level 2b EICM Predicted Grav. w (%)	Level 2c EICM Predicted Grav. w (%)	Level 3 EICM Predicted Grav. w (%)
220118	**LA**	3-1-(24)	Tube	SS	16.62	13.27	12.97	12.97	13.03	17.48
		3-1-(29)	Tube	SS	16.83	13.06	12.77	12.77	12.83	17.20
		3-1-(32)	Tube	SS	21.45	13.23	12.94	12.94	13.00	17.43
		3-1-(34)	Tube	SS	22.63	20.60	17.68	17.50	17.80	17.98
281802	**MS**	1-4-(9.5-10.5)	Grab (SC)	GB	10.10	7.18	1.46	5.93	5.83	6.08
		1-4-(18-19)	Tube	GB	10.34	7.30	1.48	6.03	5.92	6.18
		1-4-1-27	Tube	GB	7.59	15.06	13.08	13.41	13.30	17.82
		1-4-(40-42)	Tube	SS	16.68	15.60	13.55	13.89	13.78	18.46
307066	**MT**	7-1-(10-10.5)	Grab (SC)	GB	5.94	5.75	0.00	0.00	0.00	4.10
		7-1-(13-13.5)	Grab (SC)	SB	5.39	5.97	0.00	0.00	0.00	4.27
		7-1-(29-30)	Tube	SS	13.86	13.84	11.70	6.73	6.57	12.71
		7-1-(38-39)	Tube	SS	14.52	12.92	13.72	13.72	13.12	18.69
310114	**NE**	5-4-(7.5-9)	Grab (SC)	GB	2.37	4.06	0.00	0.00	0.00	0.00
		5-4-(19)	Tube	SS	26.27	18.69	24.65	24.21	24.21	24.21
		5-4-(25-28)	Tube	SS	24.56	18.39	24.25	23.82	23.82	23.82
320204	**NV**	8-2-(12)	Grab (SC)	GB	5.08	8.02	0.00	0.00	0.00	0.00
		8-2-(18-19)	Grab (SC)	SB	5.94	12.43	0.00	0.00	0.00	0.00
		1-1-(10-13)	Tube	SS	20.45	19.39	23.58	23.87	23.87	20.90
		1-1-(22)	Tube	SS	22.03	19.97	25.04	25.35	25.35	22.20
364018	**NY**	6-3-(10-10.5)	Grab (SC)	SS	5.29	7.58	0.00	0.00	0.00	0.00
		6-3-(18-19)	Grab (SC)	SS	5.07	7.83	0.00	0.00	0.00	0.00
370205	**NC**	5-1-(16)	Tube	SS	31.44	17.21	15.88	15.88	15.81	19.87
		5-1-(24)	Tube	SS	28.01	20.62	21.49	21.49	21.49	20.02
420603	**PA**	6-4-(15-17)	Grab (SC)	GB	3.81	0.18	0.00	3.10	0.00	6.47
		6-4-(22.5-23)	Grab (SC)	ComSS	10.35	0.20	9.07	9.68	8.71	9.01
473101	**TN**	5-2-(17)	Tube	SS	32.76	24.19	25.29	21.72	21.65	20.28
		5-2-(20)	Tube	SS	36.10	25.23	26.38	22.66	22.59	21.16
		5-2-(24-26)	Tube	SS	35.21	24.88	27.98	25.72	25.65	29.32
481060	**TX**	3-3-(17)	Grab (SC)	GB	8.40	8.80	11.34	11.34	10.55	9.64
		3-3-(23-24)	Tube	SS	19.15	20.89	20.51	20.51	20.07	20.89

Section ID	State	Lab ID	Sample Type	Layer	Measured Grav. w (%).	Level 1 EICM Predicted Grav. w (%)	Level 2a EICM Predicted Grav. w (%)	Level 2b EICM Predicted Grav. w (%)	Level 2c EICM Predicted Grav. w (%)	Level 3 EICM Predicted Grav. w (%)
		3-3-(26)	Tube	SS	17.83	19.24	16.19	16.19	16.31	20.12
		3-3-(32-34)	Tube	SS	21.37	19.28	16.22	16.22	16.34	20.16
481077	**TX**	1-2-(15-16)	Grab (SC)	GB	3.29	5.43	2.29	4.26	4.03	2.06
		1-2-(22)	Tube	SS	9.07	13.79	2.95	5.48	5.18	2.65
		1-2-(30.5-31)	Tube	SS	11.26	17.97	3.14	5.69	5.46	3.62
484143	**TX**	3-2-1-15	Grab (SC)	Comp SB	25.55	14.87	17.37	17.37	17.37	22.98
		3-2-(25)	Tube	SS	19.67	17.56	17.79	17.62	17.62	21.06
		3-2-(35-36)	Tube	SS	19.97	19.56	18.52	18.52	18.05	18.75
501681	**VT**	6-2-(11.5)	Grab (SC)	GB	2.99	1.14	0.00	1.33	0.24	0.00
		6-2-(13)	Grab (SC)	GB	2.85	1.12	0.00	3.75	0.45	6.03
		6-2-(17-20)	Grab (SC)	GB	3.58	1.16	0.00	9.31	5.05	8.48
		6-2-(33-35)	Tube	SB	9.39	2.11	0.05	9.77	8.88	10.70
		6-2-(44)	Tube	SS	12.55	10.67	11.56	13.14	14.13	17.55
537322	**WA**	8-1-(10-11)	Grab (SC)	GB	5.05	3.14	0.00	0.09	0.09	0.09
		8-1-(20-22)	Tube	SS	21.37	21.44	20.57	21.13	21.13	22.06
		8-1-(29-31)	Tube	SS	20.57	20.49	19.66	20.19	20.19	21.08
562019	**WY**	7-3-(19-19.5)	Tube	SB	14.23	12.20	1.24	0.17	5.62	0.17
		7-3-(30)	Tube	SS	19.68	14.95	1.39	0.17	8.37	0.17
		7-3-(39)	Tube	SS	22.33	16.03	19.31	17.45	18.07	21.97
		7-3-(46)	Tube	SS	23.22	17.28	20.19	18.25	18.90	22.98
562020	**WY**	7-2-(20-21)	Tube	SS	14.74	0.21	13.67	13.67	12.27	16.68
		7-2-(29-30)	Tube	SS	14.67	10.48	10.23	10.23	9.17	12.90
MnRoad 4	**MN**	6-5-(9-12)	Tube	Comp SS	14.44	17.05	15.13	15.13	15.02	14.32
		6-5-(19-20)	Tube	Comp SS	13.66	17.71	15.11	15.05	15.38	18.36
		6-5-(15-17)	Tube	Comp SS	14.38	16.94	15.03	15.03	14.92	14.23
Wstk 12	**NV**	2-1-(6.5-8)	Grab (SC)	GB	7.06	8.39	4.36	7.53	6.82	6.21
		2-1-(17.5-18)	Tube	Eng. Fill	18.27	14.23	18.97	17.44	18.09	20.08
		2-1-(30)	Tube	Comp SS	20.97	17.32	18.83	18.01	18.08	19.95
		2-1-1-39	Tube	SS	14.99	15.84	15.96	15.96	15.73	15.01
Wstk 15	**NV**	2-1-(6.5-8)	Grab (SC)	GB	7.24	8.44	1.42	7.41	6.89	6.09

Section ID	State	Lab ID	Sample Type	Layer	Measured Grav. w (%).	Level 1 EICM Predicted Grav. w (%)	Level 2a EICM Predicted Grav. w (%)	Level 2b EICM Predicted Grav. w (%)	Level 2c EICM Predicted Grav. w (%)	Level 3 EICM Predicted Grav. w (%)
		2-1-(18)	Tube	Eng. Fill	22.55	15.15	17.38	15.09	14.16	19.85
		2-1-(30)	Tube	Comp SS	22.06	13.21	18.38	16.31	16.38	22.28

Table 89
Statistical Parameters for Runs at Different Stages of Analysis

Analysis	n	Unknown Parameters	Degrees Freedom	S_e	S_y	S_e/S_y	R^2	e_{alg} (%)	e_{abs} (%)
Stage I – Level 1	89	0		4.8216	8.1707	0.590	0.652	8.8	31.1
Stage I – Level 2a	89	4	85	5.2802	8.1707	0.646	0.582	34.1	41.4
Stage I – Level 2b	89	5	84	5.3282	8.1707	0.652	0.575	22.2	35.5
Stage I – Level 2c	89	6	83	4.9299	8.1707	0.603	0.636	26.5	35.4
Stage I – Level 3	89	8	81	5.1756	8.1707	0.633	0.599	16.9	35.7
Stage II	49	0		5.5182	7.6696	0.719	0.482	34.3	42.3
Stage III	43	8	35	7.8344	6.7690	1.157	-0.340	36.5	45.9

Table 90
Measured versus Predicted Moisture Content – Stage II Analysis

Site No.	Section ID	State	Sample ID	Layer	Average Grav. Moisture Content (%)	Predicted Vol. Eq. Moisture Content EICM (%)	Predicted Grav. Eq. Moisture Content EICM (%)
1	**10101**	**AL**	1-3-1-15	SS	23.4	16.4	10.2
			1-3-1-23	SS	18.8	26.0	14.7
2	**40113**	**AZ**	2-3-1-5.5	GB	3.2	0.0	0.0
			2-3-1-13.5	SS	7.5	0.0	0.0
3	**40215**	**AZ**	4-1-1-11.5	GB	5.2	14.2	6.5
			4-1-1-18.5	SS	7.5	11.4	5.6
4	**63042**	**CA**	8-3-1-13	Comp SS	18.9	11.9	6.9
			8-3-1-20	SS	16.6	23.1	12.6
			8-3-1-28	SS	16.5	31.4	18.0
5	**81053**	**CO**	7-5-1-7.5	GB1	3.7	0.1	0.0
			7-5-1-14	GB2	5.2	0.0	0.0
			7-5-1-43	NatSS	23.0	36.4	22.0
			7-5-1-50	NatSS	23.5	43.8	26.3
6	**91803**	**CT**	6-1-1-11	GB	5.0	0.0	0.0
			6-1-1-20	SS	7.1	2.3	1.1
7	**204054**	**KS**	5-3-2-16.5	SS	22.0	29.6	18.0
			5-3-2-27	SS	17.1	34.3	17.9
			5-3-3-22	SS	21.2	29.6	17.6
8	**281802-A**	**MS**	1-4-1-9.5	GB	10.1	1.6	0.8
			1-4-1-19	GB	10.3	20.1	10.3
			1-4-1-27	GB	7.6	26.1	14.4
			1-4-2-42	SS	16.7	26.9	15.4
9	**281802-B**	**MS**	1-4-1-9.5	GB	10.1	1.6	0.8
			1-4-1-19	GB	10.3	1.7	0.9
			1-4-1-27	GB	7.6	2.7	1.5
			1-4-2-42	SS	16.7	3.7	2.1
10	**310114**	**NE**	5-4-1-9	GB	2.4	0.0	0.0
			5-4-1-19	SS	26.3	41.6	26.1
			5-4-1-27	SS	24.6	41.6	25.7
11	**364018**	**NY**	6-3-1-10.5	SS	5.3	0.0	0.0
			6-3-1-19	SS	5.1	0.0	0.0
12	**370205**	**NC**	5-1-1-16	SS	31.4	31.6	23.3
			5-1-1-24	SS	28.0	33.6	22.4
13	**481060 A/B**	**TX**	3-3-2-17	GB	8.4	0.0	0.0
			3-3-1-24	SS	19.1	24.0	15.1
			3-3-3-26	SS	17.8	24.6	14.4
			3-3-1-34	SS	21.4	24.6	14.5
			3-3-2-17	GB	8.4	15.8	8.4
			3-3-1-24	SS	19.1	27.0	17.0

Site No.	Section ID	State	Sample ID	Layer	Average Grav. Moisture Content (%)	Predicted Vol. Eq. Moisture Content EICM (%)	Predicted Grav. Eq. Moisture Content EICM (%)
			3-3-3-26	SS	17.8	29.6	17.4
			3-3-1-34	SS	21.4	29.6	17.4
15	**481077**	**TX**	1-2-1-16	GB	3.3	7.4	3.5
			1-2-1-22	SS	9.1	7.4	4.5
16	**484143**	**TX**	3-2-1-15	Comp SB	25.6	34.4	23.2
			3-2-1-25	SS	19.7	38.8	22.3
			3-2-1-35	SS	20.0	38.8	22.5
17	**MnRoad 4**	**MN**	6-5-1-12	Comp SS	14.4	28.3	15.1
			6-5-1-20	Comp SS	13.7	28.3	15.3
			6-5-3-15	Comp SS	14.4	28.3	15.0

Table 91
Measured versus Predicted Moisture Content – Stage III Analysis

Site No.	Section ID	State	Sample ID	Layer	Average TDR Grav. Moisture Content (%)	Predicted Vol. Eq. Moisture Content EICM (%)	Predicted Grav. Eq. Moisture Content EICM (%)
1	**10101**	**AL**	1-3-1-10	GB	7.67	18.3	8.1
			1-3-1-15	SS	21.75	33.9	21.2
			1-3-1-23	SS	13.59	33.9	19.2
2	**40113**	**AZ**	2-3-1-5.5	GB	8.15	0.0	0.0
			2-3-1-13.5	SS	6.55	0.0	0.0
3	**40215**	**AZ**	4-1-1-11.5	GB	12.42	0.0	0.0
			4-1-1-18.5	SS	13.63	15.3	7.5
4	**52042**	**AR**	1-5-2-13.5	GB	**A**	26.7	15.7
			1-5-1-18.5	SS	**A**	26.7	16.1
			1-5-2-15	SS	**A**	26.7	15.5
			1-5-1-23	SS	**A**	26.7	16.0
5	**63042**	**CA**	8-3-1-13	Comp SS	21.71	20.3	11.8
			8-3-1-20	SS	20.39	31.4	17.2
			8-3-1-28	SS	22.96	31.4	18.0
6	**81053**	**CO**	7-5-1-7.5	GB1	5.96	18.1	8.1
			7-5-1-14	GB2	8.94	6.4	3.3
			7-5-1-43	NatSS	22.85	38.9	23.5
			7-5-1-50	NatSS	19.59	44.4	26.7
7	**87035**	**CO**	7-4-1-14.5	GB	**A**	5.0	2.4
			7-4-1-19	SB	**A**	16.2	8.8
			7-4-1-37	SB	**A**	16.2	8.6
			7-4-1-48	SS	**A**	36.4	21.1
8	**91803**	**CT**	6-1-1-11	GB	8.68	0.0	0.0
			6-1-1-20	SS	12.45	0.0	0.0
9	**204054**	**KS**	5-3-2-16.5	SS	25.17	38.6	23.4
			5-3-2-27	SS	19.93	46.2	24.1
			5-3-3-22	SS	27.96	38.6	22.9
10	**220118**	**LA**	3-1-1-24	SS	**A**	22.3	13.2
			3-1-1-34	SS	**A**	40.4	24.5
			3-1-2-29	SS	**A**	22.3	13.0
			3-1-3-32	SS	**A**	22.3	13.2
11	**281802**	**MS**	1-4-1-9.5	GB	10.11	2.8	1.4
			1-4-1-19	GB	11.50	2.8	1.4
			1-4-1-27	GB	11.90	5.6	3.1
			1-4-2-42	SS	10.69	5.6	3.2
12	**307066**	**MT**	7-1-1-10	GB	**A**	10.8	4.7
			7-1-1-13.5	SB	**A**	10.8	4.8
			7-1-1-30	SS	**A**	14.5	7.7
			7-1-1-39	SS	**A**	34.2	17.2

Site No.	Section ID	State	Sample ID	Layer	Average TDR Grav. Moisture Content	Predicted Vol. Eq. Moisture Content EICM	Predicted Grav. Eq. Moisture Content EICM
					(%)	(%)	(%)
13	**310114**	**NE**	5-4-1-9	GB	7.28	0.0	0.0
			5-4-1-19	SS	24.31	42.0	26.3
			5-4-1-27	SS	23.12	42.0	25.9
15	**350105**	**NM**	1-1-1-13	SS	**A**	41.1	23.9
			1-1-1-22	SS	**A**	41.1	25.4
16	**364018**	**NY**	6-3-1-10.5	SS	10.89	0.0	0.0
			6-3-1-19	SS	15.10	0.0	0.0
17	**370205**	**NC**	5-1-1-16	SS	27.58	31.5	23.3
			5-1-1-24	SS	22.85	33.6	22.4
19	**420603**	**PA**	6-4-1-17	GB	**A**	0.0	0.0
			6-4-1-23	ComSS	**A**	0.0	0.0
20	**473101**	**TN**	5-2-1-17	SS	**A**	33.2	22.8
			5-2-3-20	SS	**A**	33.2	23.7
			5-2-1-25	SS	**A**	33.2	23.4
21	**481060**	**TX**	3-3-2-17	GB	21.89	16.3	8.6
			3-3-1-24	SS	25.86	26.9	16.9
			3-3-3-26	SS	24.11	28.5	16.7
			3-3-1-34	SS	25.39	28.5	16.8
22	**481077**	**TX**	1-2-1-16	GB	7.90	4.4	2.1
			1-2-1-22	SS	9.08	4.4	2.6
			1-2-1-31	SS	11.26	6.1	3.6
23	**484143**	**TX**	3-2-1-15	Comp SB	24.53	36.5	24.7
			3-2-1-25	SS	20.32	39.2	22.5
			3-2-1-35	SS	20.96	45.9	26.6
24	**501681**	**VT**	6-2-1-11.5	GB	**A**	2.0	1.0
			6-2-1-20	GB	**A**	15.5	7.2
			6-2-3-13	GB	**A**	5.7	2.5
			6-2-2-35	SB	**A**	21.8	10.7
			6-2-1-44	SS	**A**	29.8	15.7
25	**537322**	**WA**	8-1-1-11	GB	**A**	0.2	0.1
			8-1-1-20	SS	**A**	0.3	0.2
			8-1-1-29	SS	**A**	36.0	21.3
26	**562019**	**WY**	7-3-1-19.5	SB	**A**	0.2	0.1
			7-3-1-30	SS	**A**	0.3	0.2
			7-3-4-39	SS	**A**	3.6	2.2
			7-3-4-46	SS	**A**	3.6	2.3
27	**562020**	**WY**	7-2-1-20	SS	**A**	21.2	11.0
			7-2-1-29	SS	**A**	19.5	9.8
28	**MnRoad 4**	**MN**	6-5-1-12	Comp SS	18.14	28.2	15.1
			6-5-1-20	Comp SS	17.75	28.2	15.3
			6-5-3-15	Comp SS	17.63	28.2	15.0
A	No TDR data (or site was not visited)						
B	Not enough input data on LTPP to run EICM						

Table 92
TDR and Field Volumetric Moisture Content

Site	Sample ID	Depth (in)	Layer	Field Measured q_w %	TDR-Measured q_w %
AL	1-3-1-15	15	SS	36.79	34.33
AZ1	2-3-2-13	13	SS	11.85	11.49
AZ2	4-1-1-18.5	18.5	SS	13.58	26.10
CA	8-3-3-21	21	SS	30.22	37.10
CA	8-3-1-28	28	SS	24.27	37.56
CO1	7-5-1-43	43	SS	38.10	43.00
CT	6-1-1-20	20	SS	12.70	25.57
KS	5-3-2-16.5	16.5	SS	35.47	39.15
MS	1-4-2-42	42	SS	28.90	20.71
NE	5-4-2-25	25	SS	38.62	41.46
NV	8-2-3-18	18	SB	12.78	21.10
NY	6-3-1-19	19	SS	11.16	18.69
NC	5-1-2-24	24	SS	43.57	36.60
TX1	3-3-2-23	23	SS	30.44	39.81
TX2	1-2-1-22	22	SS	15.41	19.40
TX3	3-2-1-15	15	C SS	37.80	36.47
TX4	3-2-2-25	25	SS	33.55	38.31
TX5	3-2-1-35	35	SS	34.19	39.86
MnR	6-5-3-15	15	C SS	27.88	28.33
MnR	6-5-1-20	20	C SS	27.54	29.76
WTr	2-1-2-18	18	Fill	32.02	37.30
WTr	2-1-2-30	30	C SS	30.76	33.80
MS	1-4-3-18	18	SB	21.23	19.97

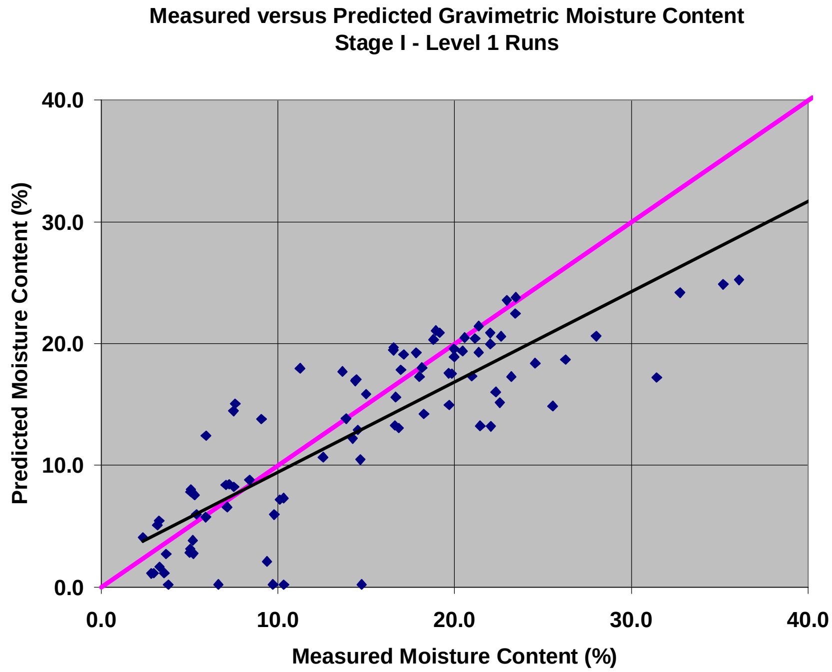


Figure 29
Comparison of Measured and Predicted Moisture Contents – Stage I-Level 1 Runs

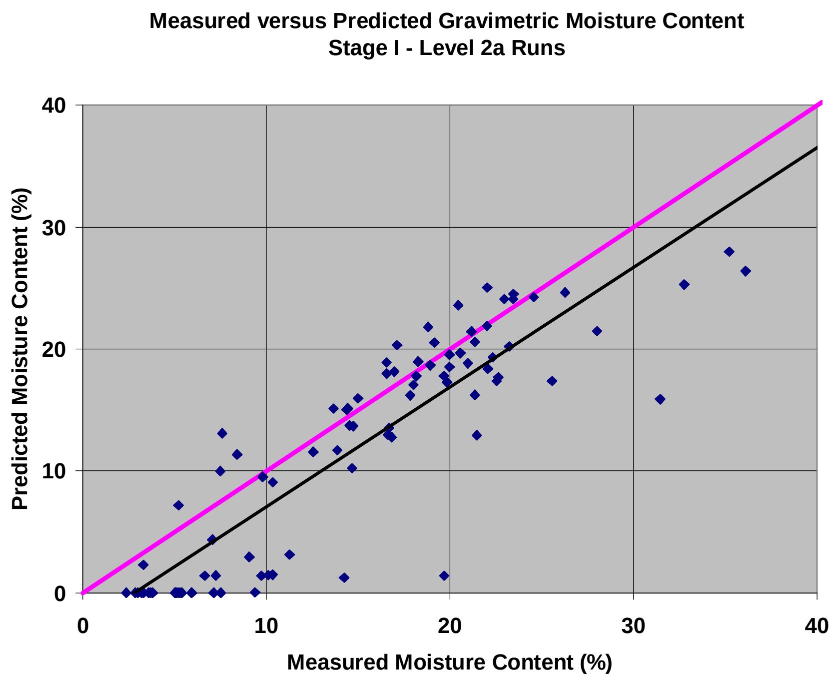


Figure 30
Comparison of Measured and Predicted Moisture Contents – Stage I-Level 2a Runs

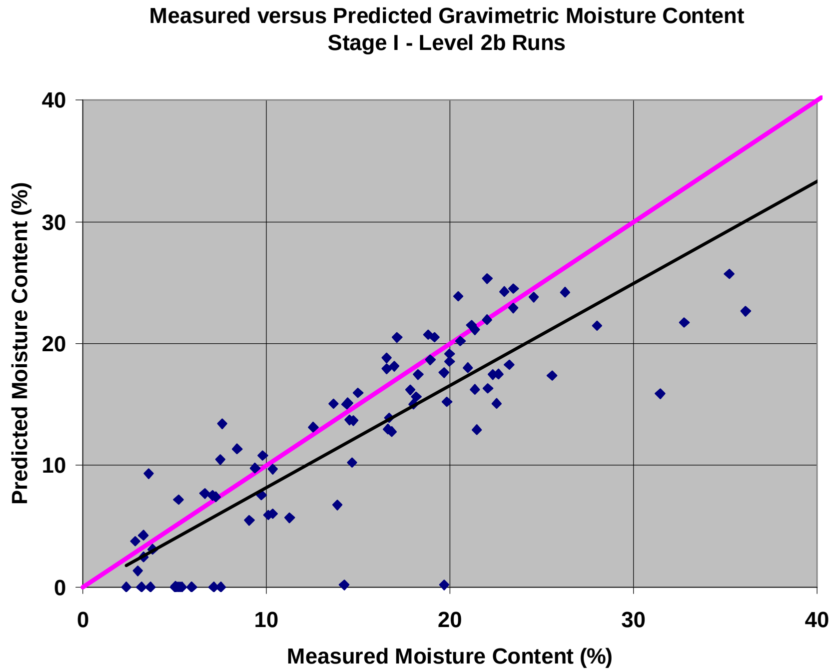


Figure 31
Comparison of Measured and Predicted Moisture Contents – Stage I-Level 2b Runs

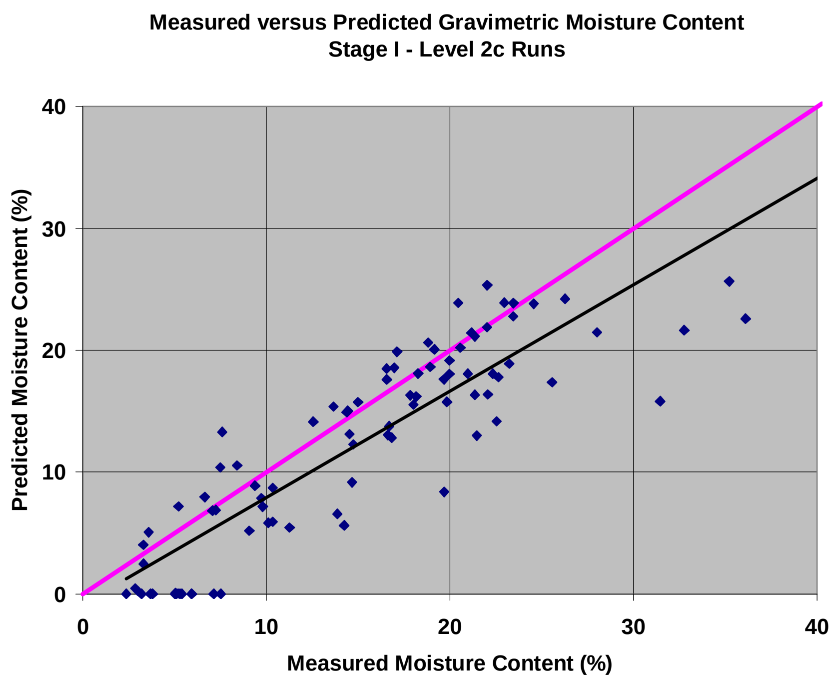


Figure 32
Comparison of Measured and Predicted Moisture Contents – Stage I-Level 2c Runs

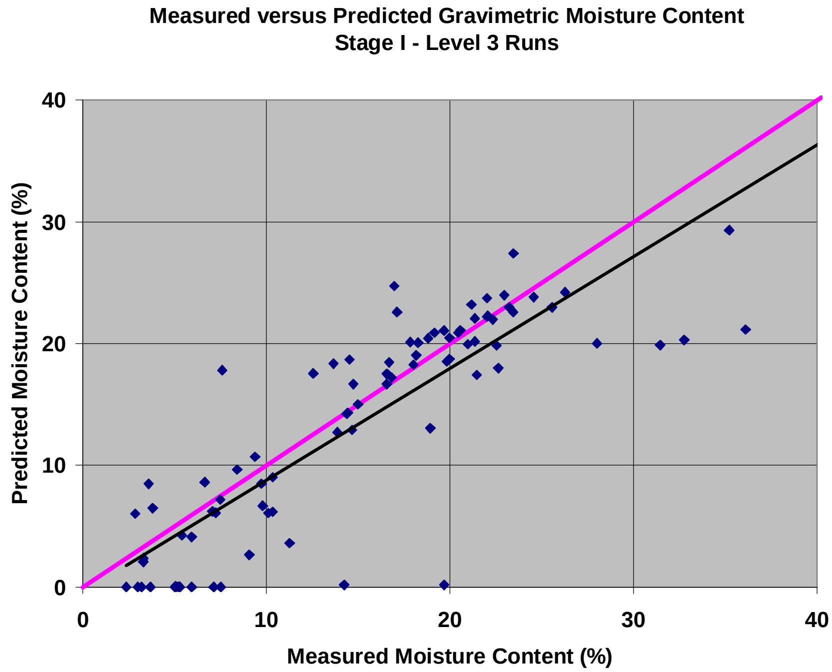


Figure 33
Comparison of Measured and Predicted Moisture Contents – Stage I-Level 3 Runs

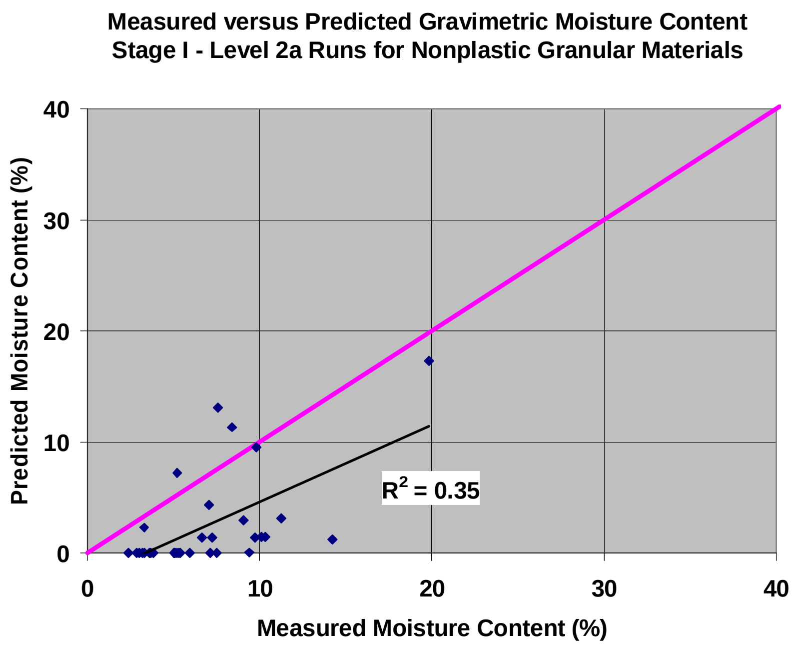


Figure 34
Stage I-Level 2a Runs Subset for Nonplastic Granular Materials

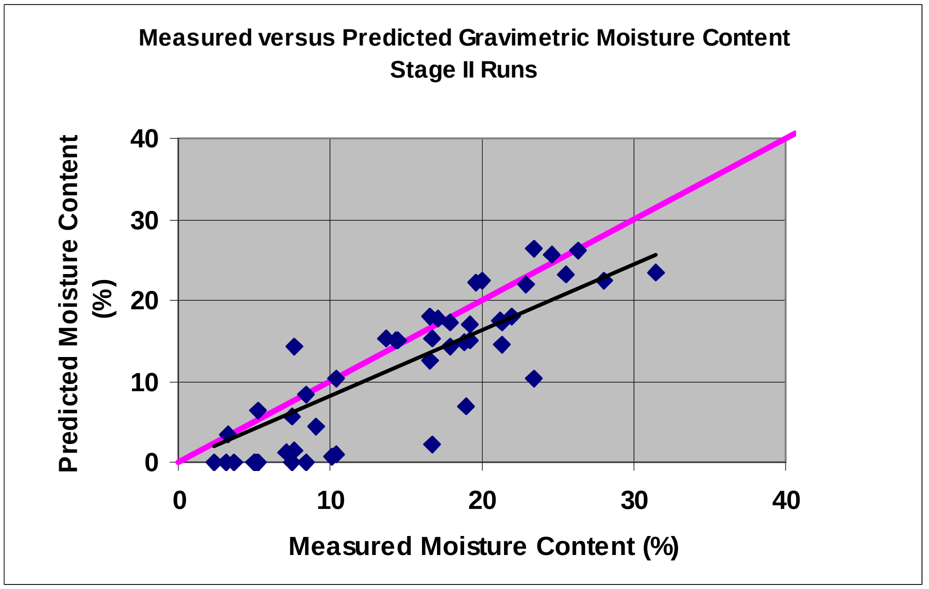


Figure 35
Comparison of Measured and Predicted Moisture Contents - Stage II Runs

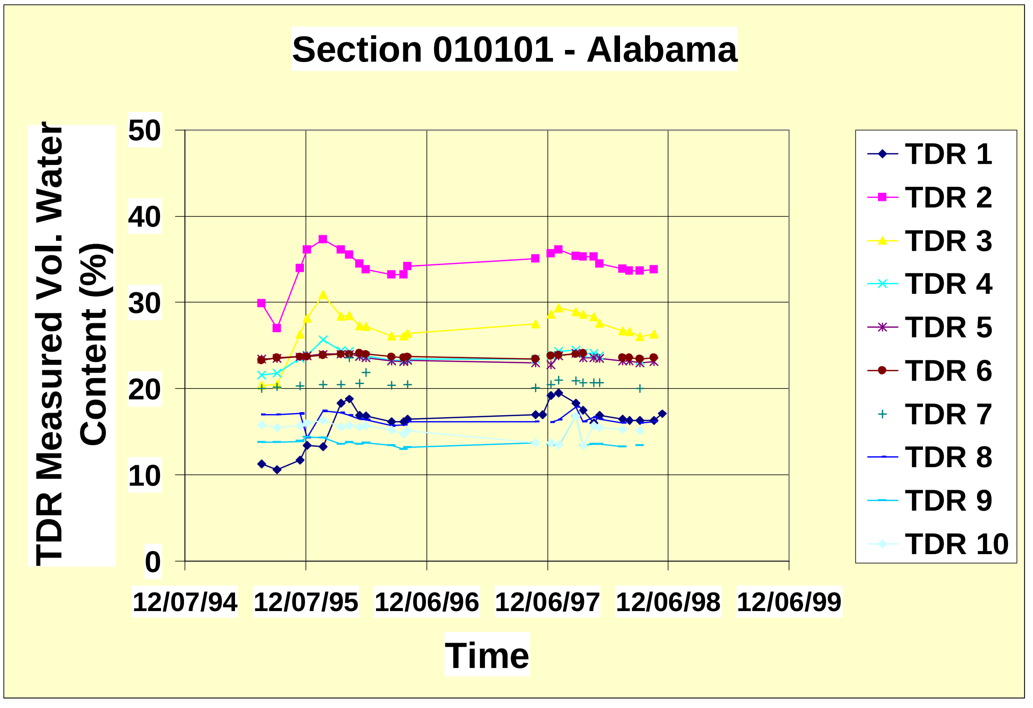


Figure 36
TDR data for Alabama Site

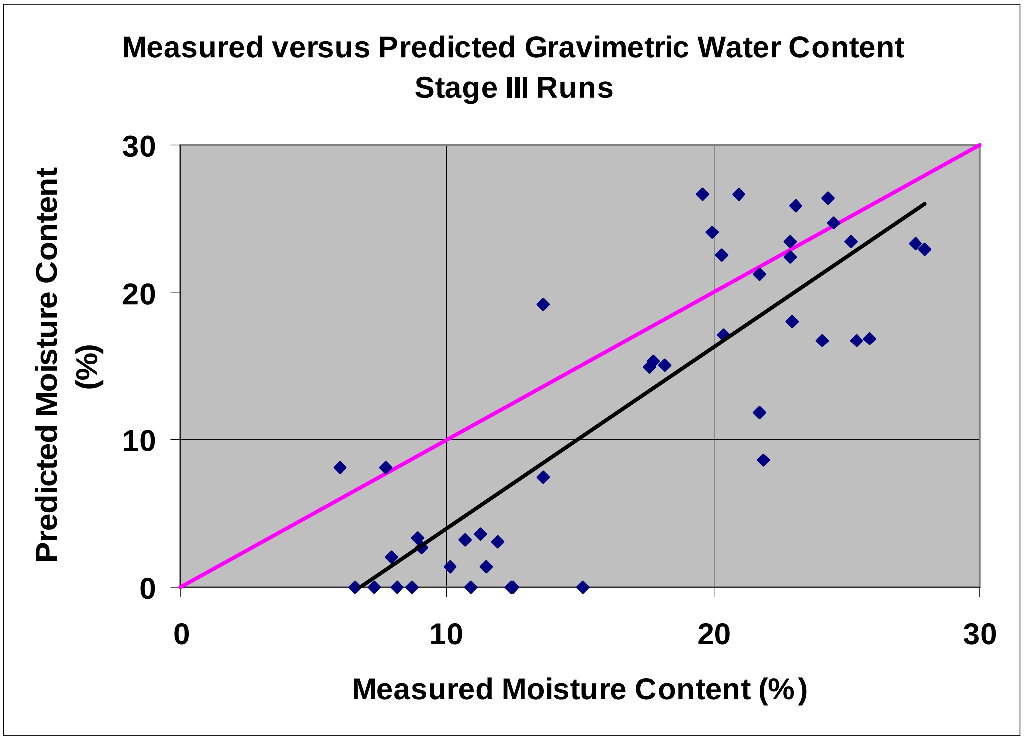


Figure 37
Comparison of Measured and Predicted Moisture Contents - Stage III Runs

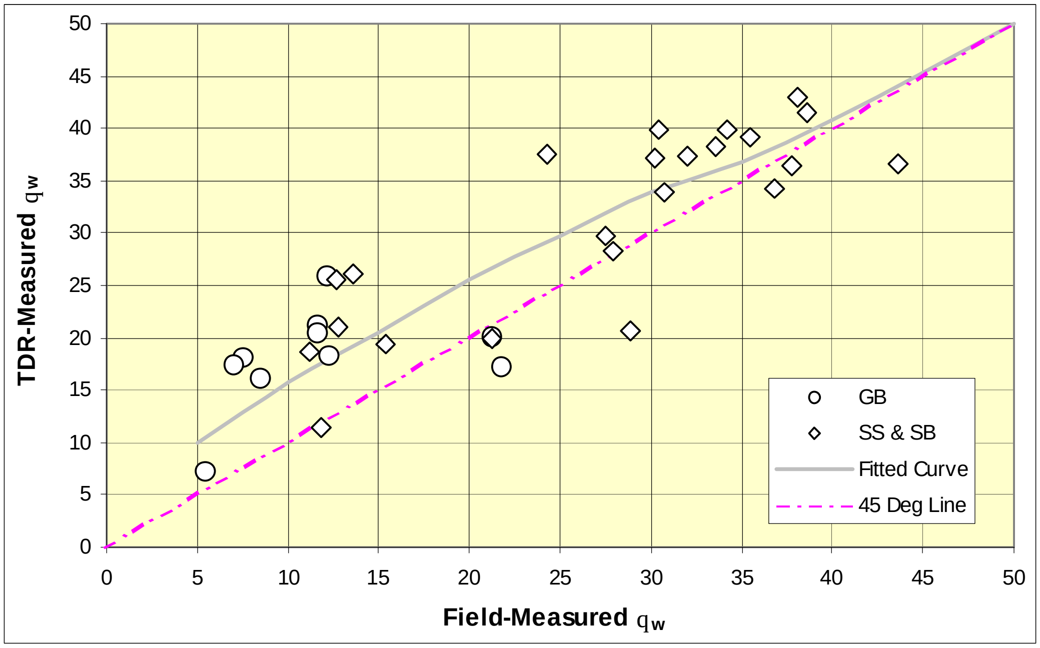


Figure 38
TDR-Measured versus Field-Measured Moisture Content

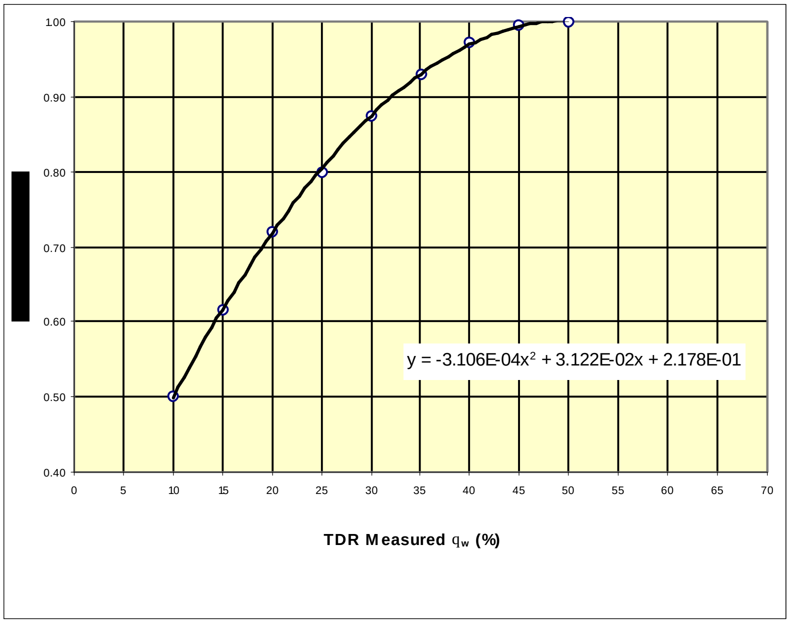


Figure 39
Correction Factor for TDR-Measured Moisture Content

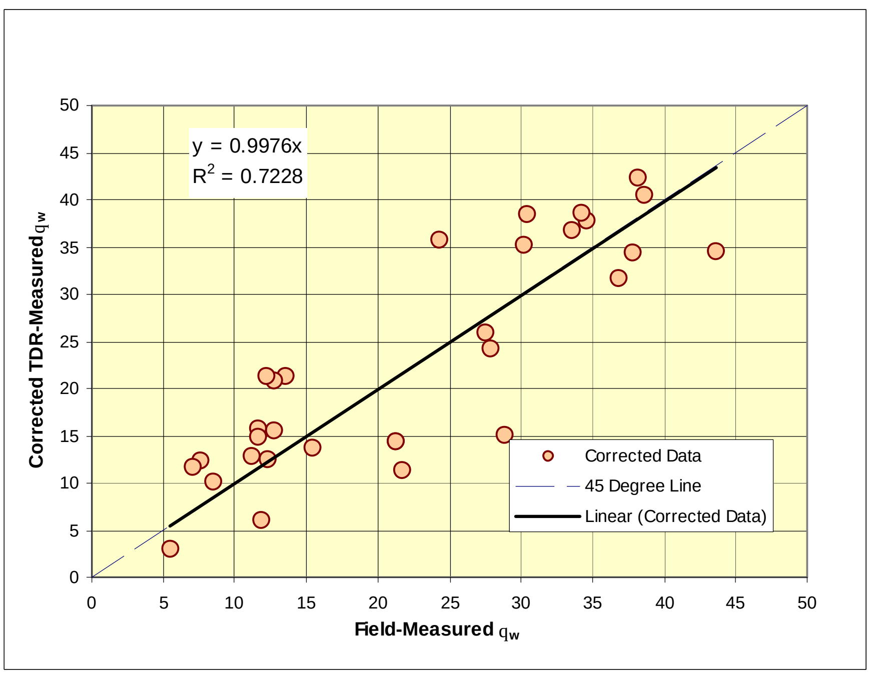


Figure 40
Corrected TDR Data versus Field Measured Data

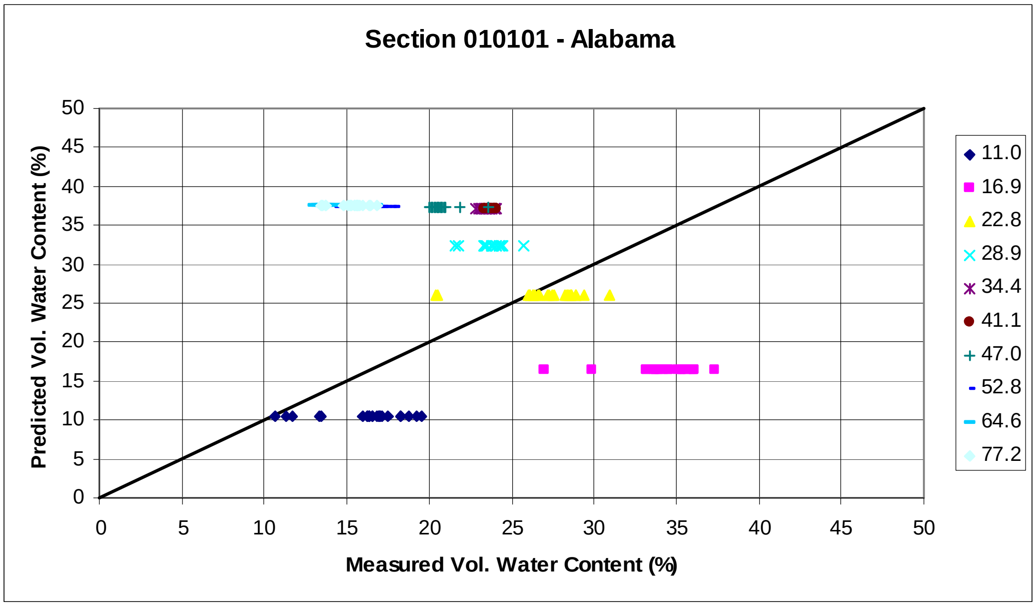


Figure 41
LTPP Section 010101 – Stage IV run

CHAPTER 6

CALIBRATION OF THE ENHANCED INTEGRATED CLIMATIC MODEL

LITERATURE BACKGROUND

Soil Suction and Soil Moisture

The total potential of soil moisture (ϕ) is fundamentally a thermodynamic variable. For isothermal conditions ϕ is identical to the relative free energy of the soil moisture. The retention of moisture in soils and the gradient causing flow of moisture can be expressed quantitatively in terms of relative free energy of soil moisture. For convenience, the free energy is usually quoted as an equivalent potential or suction at the same temperature (Richards 1965). The following equations show the components of total potential:

$$f = z + y \quad (33)$$

Where:

z = gravitational potential

y = total suction = $h_m + h_s$ ....(34)

Where:

h_m = matric suction = $u_a - u_w$

h_s = solute suction or osmotic pressure due to dissolved salts

u_a = pore-air pressure

u_w = pore-water pressure

Substituting $u_a - u_w$ for h_m in Equation 33, and assuming gravitational potential is zero, the total potential can be expressed as:

$$f = y = (u_a - u_w) + h_s \quad (35)$$

In engineering practice it is commonly assumed that we have negligible solute suction or negligible solute suction changes due to change in moisture content (Fredlund & Rahardjo 1993). For those cases, the solute suction can be omitted and Equation 35 can be written in terms of matric suction only.

$$y = u_a - u_w \quad (36)$$

It is common to have applications with pore-air pressure being equal to atmospheric pressure. For such cases $u_a = 0$, and the total potential is simply equals to the negative pore-water pressure u_w.

$$y = -u_w \quad (37)$$

Definitions

Definitions of total, matric, and solute suctions are as follows (Aitchison and Richards 1965):

"Matric or capillary component of free energy—In suction terms, it is the equivalent suction derived from the measurement of the partial pressure of the water vapor in equilibrium with the soil water, relative to the partial pressure of the water vapor in equilibrium with a solution identical in composition with the soil water.

Osmotic (or solute) component of free energy—In suction terms, it is the equivalent suction derived from the measurement of the partial pressure of the water vapor in equilibrium with a solution identical in composition with the soil water, relative to the partial pressure of the water vapor in equilibrium with free pure water.

Total suction or free energy of soil water—In suction terms, it is the equivalent suction derived from the measurement of the partial pressure of the water vapor in equilibrium with the soil water, relative to the partial pressure of the water vapor in equilibrium with free pure water."

Moisture Flow in Unsaturated Soils

The flow of moisture through saturated as well as unsaturated soils is driven by the potential gradient or in other words by hydraulic head gradient. The hydraulic head gradient is comprised of pressure head gradient and elevation head gradient under isothermal conditions, i.e. $d\phi/dx = d(z + \psi)/dx$. The temperature difference under non-isothermal conditions will also contribute to the driving potential of the flow, however, it is not considered in the theory presented here. When the elevation gradient is omitted and the air pressure gradient is zero, in salt free soils, the matric suction gradient is numerically equal to the hydraulic head gradient. Since these conditions are common in nature, matric suction ($h_m = u_a - u_w$) is widely used in flow equations. Matric suction is an independent stress state variable that also affects the hydraulic conductivity of the unsaturated medium.

Darcy's law governs the flow of water in saturated soils:

$$v = -k\frac{\partial f}{\partial x} \qquad (38)$$

Where:

v = velocity of water

k = hydraulic conductivity (a constant for a saturated soil)

$\frac{\partial f}{\partial x}$ = gradient of potential or total head in the x direction

Darcy's law is also applicable to unsaturated soils. In unsaturated soils the presence of two fluids (water and air) results in flows associated with water, water vapor, and air. The hydraulic conductivity, *k*, is no longer a constant and is a function of the water content or the soil suction. Therefore, Darcy's law can be modified as follows:

$$v = -\,k(\theta)\frac{\partial f}{\partial x} \qquad (39)$$

Where:

q = volumetric water content,
k(q) = hydraulic conductivity as a function of *q*.

Note: For convenience, *k* is typically expressed in terms of h_m. The SWCC relates *q* and h_m.

The modified Darcy's law is coupled with the law of continuity to yield the diffusion equation. In three dimensions the diffusion equation reads:

$$\frac{\partial h}{\partial t} = \frac{\partial h}{\partial \theta}\nabla k(\theta)\cdot\nabla f \qquad (40)$$

Where:

h = total suction, or matric suction in salt free soils
t = time

Assuming $\frac{\partial f}{\partial \theta}$ is relatively constant over the range of suction considered, Equation 40 can be reduced to a convenient form as shown below. This form of equation is useful in numerical modeling of unsaturated flow when modeling with finite element methods.

$$\frac{\partial h}{\partial t} = \nabla D \nabla f \qquad (41)$$

Where:

D = diffusivity = *D(h)* = $\frac{\partial h}{\partial \theta}k(h)$
∇ = mathematical operator = $\left(\frac{\partial}{\partial x_1}+\frac{\partial}{\partial x_2}+\frac{\partial}{\partial x_3}\right)$.

Researchers have numerically solved Equation 41 or similar equations in modeling unsaturated flow under covered areas (Barbour et al. 1996; Richards 1965). The value of *D* in the equation is dependent on the soil type, previous moisture, and stress history. The boundary conditions of the equation are functions of environmental factors: temperature, precipitation, evapotranspiration, relative humidity, solar radiation, and wind speed.

Richards (1965) preformed a numerical analysis of subgrade conditions of a road site in Australia using two-dimensional diffusion equation similar to Equation 41. Field measurements of suction and temperatures were made using gypsum blocks and thermistors. Also, the suction values were determined in the laboratory on the samples obtained from the site while installing the instrumentation. The measured values were compared with the computer solution.

Reasonable agreement was obtained especially beneath the pavement. The experiment indicated that vertical moisture movement controlled the moisture profile beneath the centerline of the road; the rate of change of suction under the pavement was extremely slow giving practically stable conditions. In contrast, the edges of the pavement showed much wetter conditions due to excessive infiltration through the shoulders, but seasonal variations appeared to be insignificant.

Another research study conducted by Barbour et al. in 1992 demonstrated a potential mechanism for the wetting of pavement subgrades using a two-dimensional saturated/ unsaturated flow modeling and imposed flux boundary conditions. The following partial differential equation was used in the model:

$$\frac{\partial}{\partial x}\left(k_x(u_w)\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y(u_w)\frac{\partial h}{\partial y}\right)=m_2^w\frac{\partial u_w}{\partial t} \quad \text{...(42)}$$

Where:

t = time

x, y = cartesian coordinate directions,

m_2^w = volumetric modulus representing a change in volume of water with respect to a change in matric suction, $u_a - u_w$.

Figure 42 illustrates the typical pavement section and the surface flux boundary used for the analysis. A steady state seepage analysis was performed applying positive and negative surface fluxes. Positive fluxes represented infiltration into the soil mass due to rain while negative fluxes represented evaporation out of the soil mass. In the same study, two cases where thermal conductivity sensors for measuring field suction were examined. The field evidence and numerical modeling indicated the subgrade beneath the pavement eventually attains an equilibrium moisture content and the equilibrium condition is largely controlled by microclimate and the material used in the shoulder of the highway. It was concluded that microclimate determines the flux boundary conditions. The subgrade was wetted due to lateral flows. However, evaporation did not influence the center of the pavement. It was also concluded that clay or silt containing shoulders prevent moisture infiltration in the subgrade and result in drier and stronger subgrade beneath the pavement. This is due to the fact that fine-grained soils exhibit low infiltration and high evaporation rates. In contrary, granular materials exhibit high infiltration and low evaporation rates that would be detrimental to the subgrade when used in the shoulder.

Moisture Accumulation under Covered Areas

The studies conducted on moisture conditions under covered areas indicated that the moisture content beneath pavements tend to increase over the time, compared to the initial placement values, and eventually reach an equilibrium condition. The two case studies cited in the previous section discussed this phenomenon. Janssen and Dempsey (1981) also observed that, in subgrade soils, there is a tendency of water to move vertically when a water table is present until equilibrium is attained. Basma et al. (1991) presented approximate ranges of equilibrium

moisture contents for different roadbed soils (in Basma and Al-Suleiman 1991) based on Janssen and Dempsey's work as shown in
Table 93. Basma et al. suggested using this table for predicting moisture contents under pavements for design purposes.

Studies conducted in cold regions indicated that seasonal variations of moisture content in granular bases and subgrades occur, especially due to spring thaw conditions. Based on a laboratory testing and field measurements performed in Canada, Eigenbrod and Kennepohl (1996) indicated that under certain temperature conditions in the ground below the pavement, water accumulates because of condensation at the base-pavement interface. If the temperature at the interface was –1 to –2 °C, this temperature was sufficiently high to provide significant quantities of water from condensation, but low enough to permit freezing of the condensed water. The accumulation of condensed water which subsequently freezes may result in oversaturation of the subbase.

Factors Affecting Moisture Conditions under Covered Areas

The earlier studies indicated that many factors affect the moisture conditions under covered areas. Some of these factors were already discussed in the previous section. These factors are illustrated in Figure 43.

In a broad sense, geology and climate are responsible for the soil type in a region, and soil type and vegetation combined with topography are responsible for regional moisture distribution (Coleman 1965).

Most of the studies performed in the past identified soil type and environmental factors as the most influential in controlling the moisture conditions under covered areas (Coleman 1965; De Bruijn 1965; Fredlunad and Rahardjo 1993; Klemunes 1995; Smetten and Gregory 1996). Soil properties such as P_{200}, liquid limit (*LL*), plastic limit (*PL*), plasticity index (*PI*), and hydraulic conductivity vary with the soil type and influence the moisture conditions. The environmental factors controlling the moisture conditions include: ambient temperature, precipitation, atmospheric relative humidity, wind speed, solar radiation and depth to groundwater table (GWT).

In 1965, Aitchison and Richards conducted a broad-scale study of moisture conditions in pavement subgrades in Australia. Measurements of total and matric suction were collected from 17 subgrades located throughout Australia using gypsum blocks and laboratory measurements. The experimental data showed a general agreement between Thonthwaite Moisture Index (***TMI***) and the soil suction in the stable moisture zone beneath the pavement. It was shown that a ***TMI***-suction relationship is suitable for arid or semi-arid regions where annual precipitation does not exceed 10 inches or depth to groundwater is relatively deep. The data obtained by Aitchison and Richards was plotted as shown in Figure 44. The curve in Figure 44 shows the relationship of ***TMI*** and suction, which was presented by Russam and Coleman in 1961.

As stated above, another major factor, which had been long believed to affect the soil moisture conditions is the depth to GWT. Russam and Coleman (1961) concluded that soil suctions are in

static equilibrium with the water table when the depth to GWT is less than 10 to 15 feet or even 20 to 30 feet.

Russam (1965) described three categories of design recommendations for predicting subgrade moisture conditions based on subgrade moisture studies.

1. When the water table is within 20 feet of the surface the soil, suction depends only on the position of ground water table and overburden pressure.
2. When the water table is deeper than 20 feet from the surface and seasonal rainfall exceeds 10 inches, ultimate suction of the subgrade can be estimated from the *TMI* and soil texture. The Plasticity Index can be used as guide to the soil texture and for a given climate the ratio of ultimate moisture content to plastic limit tends to be constant.
3. When the water table is deeper than 20 feet from the surface and the annual rainfall is less than 10 inches the soil suction is controlled by atmospheric humidity.

In this project, the measured suction values from 29 different sites were plotted against the *TMI*. The data points not only followed the general pattern depicted in Figure 44, but also indicated a relationship with the soil properties. The findings were incorporated into the *Suction model* that is to be used in predicting moisture in the granular base and subgrade for pavement design purposes. A detailed discussion of this model is given below.

SUCTION MODEL CALIBRATION

The *Suction model* refers to the process used to calculate the equilibrium suction, *h*, in the field. The EICM currently uses the depth to groundwater table information as an input and computes the suction using the following expression:

$$h = y \cdot g_{water} \quad (43)$$

As shown in Figure 45, the distance from the groundwater table to the point of interest is *y*, and g_{water} is the unit weight of water.

The EICM program originally adopted the Russam and Coleman relationship that relates soil suction to the Thornthwaite Moisture Index (*TMI*) in predicting the moisture content in subgrades (Russam and Coleman, 1961). The Russam and Coleman (R/C) relationship provides only one curve for sand and one for clay, and there is considerable space between for intermediate soil with no guidance. This procedure was later replaced by the yg_w method due to the high variability associated with the original model. As discussed later, the findings of this research indicated that a) R/C relationship is consistent in several ways with the conditions found throughout the United States but additional functional relationships need to be added to account for the effects of varying P_{200} for non-plastic materials and varying *wPI* for plastic materials; and b) the current models incorporated into the MEPDG were underpredicting moisture content particularly for the granular base materials.

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Based on the test results of this project, the R/C relationship has been modified and improved. The suction beneath the pavement was found to be varying not only with the *TMI* but also with the soil type. The values of P_{200} and *wPI* were introduced into the relationship as parameters

describing the soil type. The predictive abilities of the two methods, yg_w and the method proposed in this project, ***TMI-P$_{200}$/wPI*** model, were submitted to an error analysis. The error analysis clearly indicated the superiority of the proposed model over the yg_w method. For instance, the absolute mean error and algebraic mean error for granular bases associated with the proposed method were 9.5% and 2.1% while the same errors associated with yg_w method were 267% and –259%, respectively.

Measurements of Soil Suction beneath Pavements

As described in Chapter 2, the in situ gravimetric water content of granular base materials and subgrade materials were determined for the 29 sites visited for this project. The samples were collected in the field making sure that no water contamination or evaporation could occur that would change the true moisture content. The dry density and the specific gravity of each sample were determined in the laboratory. Selected samples representing granular bases and subgrades at the 29 sites were subjected to SWCC testing (described in Chapter 4). A set of newly developed pressure plate devices with exclusive new features was used in determining the SWCCs. The new devices were equipped with a loading plate to add dead weights for simulating overburden pressure and also to measure the volume change during the test. Most importantly, the moisture content of the sample was computed by measuring the water released or absorbed by the sample without dismantling the apparatus between data points. The relatively easy test procedure and the use of a setup of nine devices enabled obtaining over 90 drying SWCCs in a six-month period.

The granular base materials were reconstituted in 2.42-inch internal diameter and 1-inch high brass rings using only the fraction passing sieve # 4. The reconstitution was performed in such a way that the unit weight of the passing #4 laboratory sample was equivalent to the unit weight of the passing #4 fraction in the field. The unit weight of the passing #4 material in the field was computed based on the assumption that the voids in the retained #4 material are occupied by passing #4 material. In the case of tube samples, SWCC samples were prepared by direct extrusion into brass rings. Therefore, the tube samples were tested in undisturbed condition.

Prior to testing, samples were saturated overnight by placing them in water. Clayey samples required several days of saturation. The degree of saturation achieved after this soaking process ranged between 87% and 100%. During the testing, a normal load equivalent to the in situ overburden pressure was maintained throughout the test.

The SWCC testing produced a curve of degree of saturation versus matric suction for each sample collected. In general, three data points were obtained from each SWCC test and points were plotted as shown schematically in Figure 46. Three sets of data points are presented in Figure 46 to illustrate the nature of SWCCs associated with sand, silt, and clay soils. The data points were fitted with a sigmoid using a commercially available software package trademarked SoilVision®. SoilVision handles unsaturated soil properties. It was developed by SoilVision Systems, Ltd., Saskatoon, Canada (SoilVision 2000).

In addition, soil samples were tested for water content (*w*), dry density ($g_{d\mathrm{ry}}$), Plasticity Index (PI), Grain Size Distribution, specific gravity of solids (G_s), and saturated hydraulic conductivity

(k_{sat}). The test results of *w*, g_{dry}, and G_s along with the unit weight of water, g_w, were used to obtain the in-situ degree of saturation, *S*, for each soil sample.

The laboratory results were presented in Chapter 4. The SWCCs for each sample were included in Appendix B. The following procedure was used to determine the in situ matric suction based on the test results and SWCCs:

1. Compute the degree of saturation, S, using the gravimetric water content, the specific gravity and the dry density of each sample using the following equation:

$$S = \frac{w}{\left(\frac{\gamma_w}{\gamma_d} - \frac{1}{G_s}\right)} \qquad (44)$$

   Given the values of g_d, *w*, and G_s were all measured, the degree of saturation (*S*) from Equation 44 can be referred to as "measured degree of saturation".

2. Use SoilVision® to fit Fredlund and Xing curves to the SWCC data points and obtain a curve passing through the data points.

3. With the measured value of *S*, enter the respective SWCC and read the corresponding matric suction.

The suction values along with degree of saturation values determined using the above procedure are listed in Tables 94, 95 and 96 below and are hereafter referred to as measured suction and measured degree of saturation.

Factors Considered in the Analysis

According to past studies, the suction beneath covered areas is mainly dependent on climatic factors and soil index properties (Coleman 1965; De Bruijn 1965; Fredlund and Rahardjo 1993; Klemunes 1995; Smettem and Gregory 1996; Russam and Coleman 1961; Zapata 1999). This assertion is equivalent to the assertion that it is not mainly dependent n distance above the GWT. Furthermore, the assertion that the suction depends on soil index properties is equivalent to saying that research findings allow for the possibility that two materials at the same elevation (depth) could have different suctions because they have different index properties. Based on these studies, a large number of climatic parameters and soil index properties were subjected to different correlation processes in order to find a most suitable model. Table 97 presents the parameters considered in this study. Most of the climatic parameters were obtained from a database included in a CD-ROM titled Climate Atlas of USA, dated September 2000 issued by National Climatic Data Center (NCDC) of National Oceanic and Atmospheric Administration (NOAA) (Climatic Atlas of USA, 2000). The climatic data was also extracted from the database included in the NCHRP MEPDG Database (NCHRP 137a, 2003). TDR measured volumetric water content data and groundwater information were gathered from the LTPP database (LTPP, 2003). If groundwater information was not available in the LTPP database, the depth to groundwater in the site vicinity was obtained from the United States Geological Survey (USGS) website, waterdata.usgs.gov/nwis/gwlevels, based on the longitude and latitude information of

the site (USGS website, 2003). Some of the groundwater depth information obtained from the USGS website was regarded as of lower quality when the distance between the site and the groundwater well was greater than 0.5 mile.

Analysis of Suction Measurements

The granular bases and subgrades were analyzed separately since they represented two distinct layers with contrasting soil properties. The first analysis was performed for 18 sites consisting of at least a four-inch thick granular base. When the thickness of the granular base was less than four inches, Sand Cone tests were not performed and, therefore, a complete set of data was not available. Of the 11 remaining sites, six sites contained thin granular bases, four sites contained treated bases with no granular base, and at one site the pavement was built on a compacted subgrade.

The measured suction data for the 18 sites was correlated with the parameters shown in Table 97. The suction data of these sites were obtained from SWCCs determined from reconstituted samples, as described earlier. In the correlation process, each set of data was plotted and evaluated for significant trends and the unlikely combinations were eliminated by visual inspection. The remaining plots were subjected to regression curve fitting and analysis. For example, the AMRH versus matric suction plot indicated that suction decreased as AMRH increased as shown in Figure 47. A sigmoid was fitted to the data points because the theoretical relation between the relative humidity of pore-water vapor and the total suction is sigmoidal in shape as indicated by the theoretical curve shown in Figure 47. The theoretical curve was derived from Kelvin's equation, which relates the relative humidity and the soil suction. Despite the trend, a simple error analysis showed the correlation was not adequate to be considered as a predictive model. Similar conclusions were drawn from the correlations found with the rest of the parameters shown in Table 97, except for the *TMI* data.

The plots illustrating other correlations: the number of days with measurable precipitation (*NDMP*), P_{200}, and the depth to groundwater table are shown in Figures 48, 49 and 50, respectively as more examples. All these plots indicated the correlations were not quite sufficient to be used to predict reliable suction values.

Thornthwaite Moisture Index (*TMI*)

The Thornthwaite Moisture Index was found to be the most significant parameter for predicting suction under pavements. Therefore, the calculation of the *TMI* is presented in this Section.

In 1948, Thornthwaite introduced the *TMI* as an index that classified the climate of a given location (McKeen and Johnson 1990). The *TMI* quantifies the aridity or humidity of a soil-climate system by summing the effects of annual precipitation, evapo-traspiration, storage, deficit and runoff. *TMI* is calculated by combining two indices: Aridity Index (I_a) and Humidity Index (I_h).

$$I_a = 100\left(\frac{DF}{PE}\right) \qquad (45)$$

$$I_h = 100\left(\frac{R}{PE}\right) \qquad (46)$$

Where:

DF = moisture deficit
R = moisture surplus or runoff
PE = potential evapotranspiration

TMI for a year *y* is calculated by combining I_a and I_h:

$$TMI_y = \frac{100(R_y) - 60(DF_y)}{(PE_y)} \qquad (47)$$

Where:

R_y = runoff in cm of water for year *y*
DF_y = deficit in cm of water for year *y*
PE_y = potential evapotranspiration in cm of water for year *y*

Note: The factor 60 associated with DF_y in Equation 47 is based on the idea that water can enter a soil profile more easily than it can be extracted.

TMI is calculated as a yearly index by considering the moisture balance carried out from monthly values of precipitation, air temperature, and potential evapotranspiration. Thornthwaite had described three major components in determination of *TMI*:

1. Determination of potential evapotranspiration (*PE*).
2. Computation of moisture balance to determine allocation of water to storage, deficit, or runoff.
3. Computation of annual summations that are used to determine the index value.

Determination of Potential Evapotranspiration

Potential evapotranspiration (*PE*) is the total evaporation and transpiration that would occur from the ground surface if the storage were unlimited. PE is a function of variables such as temperature (air, leaf and ground), relative humidity, wind speed, solar radiation, soil type, and vegetation. *PE* can be calculated using Thornthwaite evapotranspiration equation (Chow, 1964). As shown below, Thornthwaite evapotranspiration equation uses mean monthly temperature and latitude, assuming nominal vegetative cover.

$$h_i = (0.2t_i)^{1.514} \qquad (48)$$

Where:

h_i = heat index for the i^{th} month

t_i = mean monthly temperature in °C

The annual heat index for year *y* (H_y) is calculated from the following equation:

$$H_y = \sum_{i=1}^{12} h_i \quad \text{.......(49)}$$

The unadjusted potential evapotranspiration for the i^{th} month (PE_i) is calculated from:

$$PE_i = 1.6\left(\frac{10t_i}{H_y}\right)^a \quad \text{.......(50)}$$

Where:

$$a = 6.75\times10^{-7}\left(H_y^{\,3}\right) + 7.71\times10^{-5}\left(H_y^{\,2}\right) + 0.017921\left(H_y\right) + 0.49239 \quad \text{.......(51)}$$

The value of PE_i obtained from Equation 50 represents potential evapotranspiration in cm of water per month for a 30-day month of 12-hour days. PE_i is adjusted depending on the latitude and the month of the year as follows:

$$PE_i' = PE_i \frac{D_i N_i}{30} \quad \text{.......(52)}$$

Where:

PE_i' = adjusted potential evapotranspiration
D_i = day length correction based on the latitude (Table 98 and Table 99)
N_i = number of days in the month

Moisture Balance

The following steps are used to calculate the moisture balance using monthly *PE* values.

1. Extract monthly precipitation (P_i) from climatic records.
2. Estimate the initial and maximum water storage corresponding to the soil profile in the region. Storage is the holding capacity of the soil profile in cm of water. The initial storage (S_o) dependent on previous moisture condition and maximum storage (S_{max}) dependant on soil type.
3. For each month, perform monthly moisture balance to obtain *R* and *DF* using the flow chart in Figure 51.

Alternatively, the *TMI* values for a region can be estimated from the contour map shown in Figure 52. Figure 52 was also digitalized to facilitate the incorporation into the MEPDG software.

For the analysis presented herein, the *TMI* value for each site was obtained from the *TMI* contour map shown in Figure 52 (FHWA-RD-90-033, 1990). It was observed that suction decreased as *TMI* increased.

Models Development

In 1961, Russam and Coleman (R/C) presented three curves representing sands, pumice soils, and heavy clays, which demonstrated a similar correlation between *TMI* and subgrade suction (Russam and Coleman, 1961). When the R/C curves were overlaid on the current data plot, the data scattered within a band approximately bounded by the curves corresponding to sand and pumice soils as shown in Figure 53. Based on the test results, the Russam and Coleman relationship was modified and improved. The suction of granular materials beneath the pavement was found to vary not only with the *TMI* but also with the soil type. Within a climatic region, the soil suction tends to increase as the P_{200} increases. For example, the three leftmost data points labeled AZ2, AZ1, and NV in Figure 53 belong to the same climatic region with *TMI* of -45. The P_{200} values of AZ2, AZ1, and NV are 6.8, 10.2, and 13.5 respectively, as shown on the data labels. The examination of the location of other data points on the plot indicated the same trend. Using the values of P_{200} corresponding to each data point, contour lines of P_{200} = 4 through 12 were added to the plot as shown in Figure 54.

Similar to the analysis performed for the granular bases, the subbases and subgrades were grouped and analyzed to find a prospective moisture prediction model. In this case, the SWCCs were determined mostly on undisturbed, fine-grained samples. It was apparent that the P_{200} as well as *PI* of the soil were needed to describe plastic soils. Therefore, the parameter *wPI* was introduced in addition to the parameter P_{200}. The parameter, *wPI,* as discussed in earlier parts of this report, is obtained as the product of P_{200} as a decimal and *PI* as a percentage. The plotted data points are shown in Figure 55. Again the plotted data followed the pattern shown in the Russam and Coleman curves. Now the data points spread towards and even beyond the heavy clay line.

The data on the plot was examined with respect to the P_{200} and *wPI* corresponding to each point. The data showed similar trend as that observed earlier with the granular base materials. The suction values increased with the values of P_{200} and *wPI*. However, in this case more scatter of data was observed. The contour lines drawn on the plot are shown in Figure 56. The curves for P_{200}=10 and P_{200} = 50 are to be used for interpolation.

Error Analysis

The predictive abilities of the two methods, the currently implemented model yg_w and the new methods proposed in this study, *TMI*-P_{200}/*wPI* models, were analyzed by conducting an error analysis. The predicted suction values for each site (h_p) were estimated using the contours and compared with the measured values (h). The absolute mean error (e_{abs}) and algebraic mean error (e_{alg}), were calculated using the equations shown below:

$$e_{abs} = \frac{\sum \left| \frac{(h - h_p)}{h} \right|}{n} 100 \qquad (53)$$

$$e_{alg} = \frac{\sum \frac{(h - h_p)}{h}}{n} 100 \quad (54)$$

Where:

h = measured matric suction
h_p = predicted matric suction
n = number of data points

The algebraic error provided a measure of how well the curve fits were "centered" on the body of data. A small e_{alg} indicates the curves (the prediction model) is well centered and has very little bias. If e_{alg} is not small, bias to the high side or to the low side is indicated and the sign of e_{alg} indicates the direction of the bias. The value of e_{abs} is a measure of the scatter about the "best fit" curve. It is similar to the standard error, S_e, except that the error is not squared and thus less weight is given to points that are well off the curve. Table 100 presents the results of the error analyses for the two models along with the error obtained for the yg_w model discussed earlier.

The relationships between matric suction, ***TMI***, P_{200}, and ***wPI*** are clearly superior to the yg_w model as predictive models.

The literature review indicates that a shallow groundwater table controls the suction under covered areas. Due to this fact, another error analysis was performed using the groundwater table data available. The suction was predicted using yg_w for the sites with the groundwater table at less than 10 feet and $TMI\text{-}P_{200}$ model predicted values were used for other sites. The mixed data was subjected to error analysis that resulted in absolute mean error of 35.6% and algebraic mean error of –8.9%. This second error analysis indicated the $TMI\text{-}P_{200}$ model alone shown in Table 100 above would give slightly better predictions. Based on these results, the $TMI\text{-}P_{200}$ model was selected as the moisture prediction model for granular bases. Accordingly, the influence of the groundwater table on suction was downgraded considerably and the groundwater table was considered dominant only when it was within four feet from the ground surface.

Mathematical Representation of $TMI\text{-}P_{200}$ Granular Base Model

Using a statistically based software program, the five contour lines of the $TMI\text{-}P_{200}$ model corresponding to P_{200} = 4, 6, 8, 10, and 12 were fitted with regression curves and equations were obtained. Later, the curves were extrapolated to include P_{200} values ranging from 0 to 16 (Figure 57). It was determined that P_{200} = 16 should be the maximum limiting value for a granular base. This means that for any granular base with P_{200} > 16, the P_{200} = 16 curve is to be used. It should also be noted that these extrapolations are highly unlikely to be used, given that experience shows that P_{200} is more than 2% and less than 12% for almost all granular bases for pavements.

All the R^2 values were better than 0.99 for these curves. The common equation obtained reads as:

$$h_m = a + e^{[b+g\,(TMI+101)]} \quad (55)$$

Where a, b, g are constants obtained through the regression process and the values are as shown in Table 101.

Mathematical Representation of *TMI-P₂₀₀/wPI* Subgrade Model

Using a statistically based software program, the six contour lines of the ***TMI-P_{200}/wPI*** model corresponding to P_{200} = 10, P_{200} = 50/*wPI* = 0.5, *wPI* = 5, 10, 20, and 50 were fitted with regression curves and equations were obtained. All of the R^2 values were better than 0.99 for these curves. The common equation obtained reads as:

$$h = a\left[e^{\left[\frac{b}{TMI+g}\right]} + d\right] \quad (56)$$

Where a, b, g, and d are constants obtained through the regression process and the values are as shown in Table 102.

If the P_{200} or *wPI* of a soil is between two of the defined curves, the suction value should be obtained for curves above and below the known value, and linear interpolation used to find the desired value.

Summary

There are two models for calculating matric suction, the ***TMI-P_{200}*** model for granular bases, and the ***TMI-P_{200}/wPI*** model for subgrades. The subgrade model consists of 5 curves for plastic materials, with *wPI* ranging from 0.5 to 50. The subgrade model also consists of 2 curves for non-plastic materials (*wPI*=0), which are P_{200} = 0 and P_{200} = 50. By coincidence, the P_{200} = 50% curve and the *wPI* = 0.5 curve are the same curve. The ***TMI-P_{200}*** model can be used for all granular bases. If the value of P_{200} exceeds 16%, then the curve for P_{200} = 16% is to be used.

For a subgrade soil, the *TMI-P_{200}/wPI* model is to be used. If *wPI* > 50%, then the *wPI* = 50% curve is to be used. For values of *wPI* between 0.5 and 50, log linear interpolation is to be used. The suction values for the appropriate *TMI* are to be computed first for the curve above and below the desired *wPI*, and then log linear interpolation is applied.

If *wPI* value is less than 0.5, default to a *wPI* value of 0.5.
If *wPI* = 0, check P_{200}.
If P_{200} for the subgrade is greater or equal to 50%, default to the P_{200} = 50 curve.
If P_{200} is less than 10%, the suction should be calculated using the ***TMI-P_{200}*** (granular base) model.

SWCC MODEL CALIBRATION

Background

The relationship between soil suction and moisture content is commonly known as the soil water characteristic curve (SWCC). This relationship is important to know when modeling unsaturated flow and predicting moisture contents for design purposes. In the SWCC, the soil moisture can be expressed as gravimetric water content, volumetric water content, or degree of saturation. The shape of SWCC is dependent on the soil type. Typical SWCCs for sand, silt, and clay are shown in Figure 58. The amount of fines and the plasticity index of the soil tend to highly influence the SWCC (Zapata 1999).

The most direct way of obtaining the SWCC for a given soil is to measure the suction of a representative sample in the laboratory using filter paper method or pressure plate or any other available method. Several suction-moisture content data pairs are experimentally determined to obtain a complete curve. This process may take several days to a couple of weeks depending on the type of soil being tested. It has been shown that the drying curve may differ from the wetting curve introducing a hysteresis to the characteristics. If the hysteresis is not very significant it may be omitted and a single curve may be used for both drying and wetting cases.

Solute suction does not seem to be sensitive to the changes in the soil water content. As a result, change in the total suction is usually represented by the change in matric suction. Therefore, matric suction measurements are of importance and typically presented in SWCCs (Fredlund and Rahardjo 1993).

Since the determination of SWCCs involves special testing devices and difficult procedures, it is not very widely performed in common engineering practice compared to other well-known tests. For example, the direct shear test is commonly carried out to obtain the soil strength parameters; cohesion and angle of friction for design purposes. Also, consolidation tests are carried out to determine the settlement and expansive characteristics of soils. Yet, determination of soil suction is a very important task in the field of unsaturated soil mechanics. Therefore, many researchers have suggested methods of obtaining the SWCC using grain size distribution (GSD) and other soil properties without direct measurements of the SWCC. These methods can be grouped into three categories (Zapata 1999).

1. Statistical estimation of water contents at selected matric suction values. This process generally requires a regression analysis and a curve fitting procedure.
2. Correlation of soil properties with the fitting parameters of an analytical equation that represents the SWCC.
3. Estimation of SWCC using a physics-based conceptual model.

Comparison of different models can be found in van Genuchten and Leij (1992); Williams and Ahuja (1992); Kern (1995); Nandagiri and Prasad (1997); and Zapata (1999). In this study the second approach was adopted. Researchers that have adopted the second approach include Ghosh (1980); Williams et al. (1983); Ahuja et al. (1985); Rawls et al. (1992); Cresswell and Paydar (1996); Tomasella and Hodnett (1998); and Zapata (1999).

In 1999, Zapata presented a detailed discussion of each method in her PhD dissertation. Zapata developed a family of SWCCs correlating simple soil properties: D_{60} and *wPI*. D_{60} refers to the diameter in mm corresponding to 60 percent passing by weight, *wPI* is the weighted Plasticity Index, *PI* ($wPI = P_{200}$ ´ PI), and P_{200} is the percent passing Number 200 sieve.

The fitting parameters of a sigmoidal curve described by the Fredlund and Xing equation were correlated to D_{60} and *wPI*. The Fredlund and Xing (1994) equation is shown below.

$$\theta_w = C(h) \times \left[\frac{\theta_s}{\left[\ln\left[\exp(1) + \left(\frac{h_s}{a} \right)^b \right] \right]^c} \right] \quad \text{..........(57)}$$

$$C(h) = \left[1 - \frac{\ln\left(1 + \frac{h_s}{h_r}\right)}{\ln\left(1 + \frac{10^6}{h_r}\right)} \right] \quad \text{..........(58)}$$

Where:

a = a soil parameter which is primarily a function of the air entry value of the soil in kPa.
b = a soil parameter which is primarily a function of the rate of water extraction from the soil, once the air entry value has been exceeded.
c = a soil parameter which is primarily a function of the residual water content.
h_r = a soil parameter which is primarily a function of the suction at which the residual water content is reached in kPa.

The SWCC curves determined for this research study (over 90 SWCCs) were also evaluated by correlating various parameters to the fitting parameters used in Equation 57. The correlation parameters included the soil properties: D_{10}, D_{20}, D_{30}, D_{60}, D_{90}, C_c, C_u, *LL, PL, PI,* P_{200}, *wPI,* and the unit surface area of soil. In addition to these parameters, four parameters identified as a_g, b_g, c_g, and h_{rg} were included in the analysis. These four fitting parameters were computed by fitting the GSD of each soil to a sigmoidal curve available in a software package trademarked SoilVision®. SoilVision handles unsaturated soil properties. It was developed by SoilVision Systems, Ltd., Saskatoon, Canada. Based on the results, a new method to obtain SWCCs was developed and it is presented in the next sections.

Existing SWCC Models

The existing family of SWCCs referred in this study as the *SWCC model* was the family of SWCCs developed by Zapata in 1999, as part of her Ph.D. dissertation at ASU. Zapata investigated the uncertainty in SWCC and impacts on unsaturated shear strength predictions. A database containing 180 experimentally obtained SWCCs generated by her and others was

analyzed in developing the family of curves. In the analysis, non-plastic and plastic soils were treated separately and two sets of SWCCs were developed.

The *SWCC model* currently implemented in the EICM version 2.6 is given by the Fredlund and Xing equation:

$$q_w = C(h) \times \left[\frac{q_{sat}}{\left[\ln\left[EXP(1) + \left(\frac{h}{a_f} \right)^{b_f} \right] \right]^{c_f}} \right] \tag{59}$$

with:

$$C(h) = \left[1 - \frac{ln\left(1 + \frac{h}{h_r} \right)}{ln\left(1 + \frac{1.45 \times 10^5}{h_r} \right)} \right] \tag{60}$$

where:

h = Matric suction, in psi
q_w = Volumetric moisture content, in %
a_f, b_f, c_f, and h_r = SWCC fitting parameters

The SWCC parameters were correlated with soil index properties as explained below:

For Granular Non-Plastic Materials (wPI = 0)

The soils with plasticity equal to zero fall into this group. In Zapata's analysis, parameters derived from the grain size distribution (GSD) of each soil were analyzed in search of a correlation with the SWCC. In order to obtain correlation parameters associated with the SWCC, each set of data points was fitted with Fredlund and Xing equation using SoilVision® to generate four fitting parameters: a_f, b_f, c_f, and h_r. The four parameters were correlated with the parameters derived from the respective GSD. In the case of non-plastic soils, D_{60} was selected as the best correlating parameter with a_f, b_f, c_f, and h_r. The correlations are represented by the following equations:

$$a_f = \frac{0.8627(D_{60})^{-0.751}}{6.895} \text{, psi} \tag{61}$$

$$\bar{b}_f = 7.5 \tag{62}$$

$$c_f = 0.1772 \ln(D_{60}) + 0.7734 \tag{63}$$

$$\frac{h_r}{a_f} = \frac{1}{D_{60} + 9.7e^{-4}} \tag{64}$$

These correlations lead to generate a family of curves based on D_{60} values ranging from 0.1 mm to 1.0 mm as shown in Figure 59.

For Plastic Unbound Materials (*wPI *> 0)

The soils that exhibit plasticity fall into this group. In the case of plastic soils, parameters, a_f, b_f, c_f, and h_r showed correlations with the *wPI* value ($P_{200}PI$) as follows:

$$a_f = \frac{0.00364(wPI)^{3.35} + 4(wPI) + 11}{6.895}, \text{ psi} \quad (65)$$

$$\frac{b_f}{c_f} = -2.313(wPI)^{0.14} + 5 \quad (66)$$

$$c_f = 0.0514(wPI)^{0.465} + 0.5 \quad (67)$$

$$\frac{h_r}{a_f} = 32.44e^{0.0186(wPI)} \quad (68)$$

Therefore, another family of curves was generated based on the *wPI* values ranging from 0.1 to 50 as shown in Figure 60.

Both families of curves were combined and presented as one family of curves as shown in Figure 61 below (Zapata et al. 2000). Based on the suggestions by other researchers, all SWCCs were forced through a suction of 10^6 kPa for 0% saturation.

Method Adopted in Developing a New Set of SWCCs

The SWCCs available from other sources used in Zapata's analysis were originated from tests where the volume changes were not taken into consideration. In the past, the SWCCs were determined by testing slurry samples with no volume change tracking. Therefore, no corrections were applied with respect to the volume change in computing the degree of saturation. This leads to errors, especially near the tail end (high suction) of SWCCs for plastic soils. In the case of determining drying SWCCs, the density of the soil sample tends to increase as the test progresses. The density change could be significant when highly plastic compressible soils are involved. Because the degree of saturation increases with the density of the material, the tail end of a SWCC could really be located higher than the position of the uncorrected curve.

The new pressure plate device developed and used in this project provided the necessary data to apply the volume change corrections. The new density of the sample was calculated for each point and used in the computation of degree of saturation and therefore, a new set of SWCCs was obtained that captured the volume-change-correction.

The availability of 180 SWCCs from the previous study was useful even in this study since they were combined into the analysis, statistically enhancing the database. In fact, the previously available180 SWCCs were included, but approximate volume change corrections were applied to each curve associated with plastic soils before pooling the data together as described later.

The method for obtaining the correlations developed in this study was similar to the method used by Zapata in 1999. However, more parameters or parameter combinations were considered.

Correlation Parameters and Curve Fitting Procedure

The procedure followed to find a new set of SWCCs was as follows:

1. The GSD curves for all the soils with SWCCs were developed.
2. Values of D_{10} through D_{90} from the GSD were obtained.
3. *Cc*, *Cu*, P_{200}, *LL*, *PL*, *PI*, *wPI*, and estimated surface area for each soil were found.
4. Possible combinations of the above parameters were obtained. For example, relations such as D_{90}/D_{10}, P_{200} x D_{90}/D_{10}, $(D_{90}D_{60}D_{10})/3$, D_0, and D_{100}. D_0 and D_{100} are estimated by projecting the two extremes of the GSD curve on to Percent Passing = 0 and 100% lines, respectively as shown in Figure 62 were considered in the analysis.
5. SoilVision® software was used to fit Fredlund and Xing equations to the experimental data points of each SWCC and fitting parameters a_f, b_f, c_f, and h_r for nonplastic soils and a_{fh}, b_{fh}, c_{fh}, and h_{rfh} fitting parameters for plastic soils were found.
6. By means of statistical non-linear regression analyses, the best correlations between a_f, b_f, c_f, h_r, a_{fh}, b_{fh}, c_{fh}, h_{rfh} and the soil index parameters were found.
7. The fitting parameters were expressed in terms of best correlating soil index parameters and the values of a_f, b_f, c_f, h_r, a_{fh}, b_{fh}, c_{fh}, and h_{rfh} for each soil using the respective function were found.
8. The parameter-based curves along with the experimental data points for each soil were compared.
9. The new correlations were acceptable if the comparison between the experimental data points and the parameter-based curve showed a good agreement.

Application of Volume Change Correction

The required correction factors were derived based on the SWCC testing results for the samples gathered from the sites visited for this project as follows:

1. A total of 52 new SWCCs, measured on soils that exhibited plasticity were considered.
2. Using the sample height measurement at each data point, the vertical strain of the sample, *e*, corresponding to the matric suction was computed as:

   $$e = DH/Ho \qquad (69)$$

   Where:
   - *DH* = Change in sample height
   - *Ho* = Initial sample height

3. The strain versus matric suction relationship corresponding to 52 samples was plotted and the curves were analyzed to find a trend.
4. Based on the plots, a set of correction curves was developed using *wPI* as the variable soil property. The curves are shown in Figure 63.

5. Three well-spanned data points representing each SWCC to be corrected were selected from the uncorrected curve and the corresponding *e* values were determined using Figure 63 based on suction and *wPI*.
6. The strain values were converted to change in void ratio using:

$$\varepsilon = \frac{\Delta e}{1+e_o} \quad (70)$$

Where:

De = Change in void ratio
e_o = Initial void ratio

7. The change in void ratio, De, was subtracted from e_o to obtain the corrected void ratio e_1.
8. Using the volumetric water content q_w, and g_d of the original data, gravimetric water content, *w*, was back-calculated using the following equation:

$$w = \frac{\theta_w \gamma_w}{\gamma_d} \quad (71)$$

9. The corrected volumetric water content, $q_{w\text{-}corr}$ was calculated for each point:

$$\theta_{w\text{-}corr} = \frac{G_s w}{1 + e} \quad (72)$$

10. A modified Fredlund and Xing curve was fitted to the corrected data points to obtain the four fitting parameters: a_{fh}, b_{fh}, c_{fh}, and h_{rfh}.

Databases Used in SWCC Model Calibration

For the purpose of analysis, the soils with a weighted PI of less than 1.0 were categorized as non-plastic (NP) soils. The Weighted PI (*wPI*), is referred to as the product of P_{200} (expressed as a decimal) and the *PI* of the soil. The soils that exhibited *wPI* greater than or equal to 1.0 were categorized as plastic (*PI*) soils.

A database containing 180 experimentally obtained SWCCs collected from published journal papers was used in Zapata's analyses in developing the family of SWCC curves that is currently implemented in the EICM version 2.6 model of the MEPDG. Of these SWCCs, the best 134 curves were pooled with the 83 curves determined under the NCHRP 9-23 project. The number of soils used in the analysis from each database is summarized in Table 103.

Following a regression analysis, two sets of correlations were derived for non-plastic soils and plastic soils, respectively. The following sections present the set of correlation equations derived for each soil type.

Correlation Equations for Non-Plastic Soils

$$a_f = 1.14a - 0.5 \quad (73)$$

Where:

$$a = -2.79 - 14.1\log(D_{20}) - 1.9\times10^{-6} P_{200}^{4.34} + 7\log(D_{30}) + 0.055 D_{100} \quad (74)$$

$$D_{100} = 10^{\left[\frac{40}{m_1} + \log(D_{60})\right]} \quad (75)$$

$$m_1 = \frac{30}{[\log(D_{90}) - \log(D_{60})]} \quad (76)$$

Note: There may exist some extreme cases where the computed value of a_f is negative, which will lead to erroneous results. Therefore, the value of a_f was limited to 1.0.

$$b_f = 0.936b - 3.8 \quad (77)$$

Where:

$$b = \left\{5.39 - 0.29\ln\left[P_{200}\left(\frac{D_{90}}{D_{10}}\right)\right] + 3D_0^{0.57} + 0.021P_{200}^{1.19}\right\} m_1^{0.1} \quad (78)$$

$$D_0 = 10^{\left[\frac{-30}{m_2} + \log(D_{30})\right]} \quad (79)$$

$$m_2 = \frac{20}{[\log(D_{30}) - \log(D_{10})]} \quad (80)$$

$$c_f = 0.26e^{0.758c} + 1.4D_{10} \quad (81)$$

Where:

$$c = \log\left(m_2^{1.15}\right) - \left(1 - \frac{1}{b_f}\right) \quad (82)$$

$$h_{rf} = 100 \quad (83)$$

Correlation Equations for Plastic Soils

$$a_f = 32.835\{\ln(wPI)\} + 32.438 \quad (84)$$

$$b_f = 1.421(wPI)^{-0.3185} \quad (85)$$

$$c_f = -0.2154\{\ln(wPI)\} + 0.7145 \quad (86)$$

$$h_{rf} = 500 \quad (87)$$

Where:

> wPI = weighed Plasticity index equal to the product of P_{200} (expressed as a decimal) and the *PI*.

Error Analysis

A statistical analysis was performed to find out the error associated with the newly proposed functions. In the error analysis, the field measured *S* was compared with the predicted *S*. The percent mean algebraic error (e_{alg}), the percent mean absolute error (e_{abs}), the sum of the squared error based on measured S (S_e), and the mean squared error based on average measured S (S_y) were computed as follows:

$$e_{alg} = \frac{\sum \left[\frac{\left(S_m - S_p\right)100}{S_m} \right]}{n} \qquad (88)$$

$$e_{abs} = \frac{\sum \left| \frac{\left(S_m - S_p\right)100}{S_m} \right|}{n} \qquad (89)$$

$$S_e = \sqrt{\frac{\sum \left(S_m - S_p\right)^2}{n-p}} \qquad (90)$$

$$S_y = \sqrt{\frac{\sum \left(\bar{S}_m - S_p\right)^2}{n-p}} \qquad (91)$$

Where:

> S_m = measured degree of saturation,
> S_p = predicted degree of saturation,
> $\bar{S}_m$ = average measured degree of saturation,
> n = number of data points,
> p = number of parameters associated with the proposed functions.

The corresponding values of S_e/S_y and the adjusted coefficient of correlation (R^2), $1 - (S_e/S_y)^2$, are presented in Table 104. In addition, the same error analysis was performed for the model developed by Zapata in 1999 for comparison. The results are also presented in the same table.

According to the results obtained, the percent mean algebraic and absolute errors associated with the proposed model for non-plastic soils were found to be 8.6% and 14.8%, respectively. The same errors associated with the Zapata model were found to be 88.5%. Similarly, the percent mean algebraic and absolute errors associated with the proposed model for plastic soils were 0.1% and 9.2%, respectively, while the same errors associated with the Zapata model were 20.4% and 23.9%, respectively. Therefore, the new models provide a far better prediction than the models developed in 1999. The adjusted R^2 values also reflect the predictive capability of the new model. The measured *S* versus predicted *S* plots for non-plastic and plastic soils are shown in Figure 64 and Figure 65, respectively.

G_S MODEL CALIBRATION

Gs Model Currently Implemented into the EICM

The *Gs model* currently implemented into the EICM for Level 3 analysis follows the relationship:

$$G_s = 0.041(wPI)^{0.29} + 2.65 \quad (92)$$

Where:

$$wPI = PI*P_{200}/100 \quad (93)$$

G_s = Specific gravity of solids
P_{200} = Passing sieve #200 [decimal]
PI = Plasticity index [%]

This correlation was developed using 268 soil data points extracted from literature, where plastic and non-plastic soils were analyzed separately. In an effort to find a correlation for the granular soils with no plasticity (NP), G_s was plotted against D_{60}. The plot is presented in Figure 66, where D_{60} is the grain size diameter from the grain size distribution curve at 60% passing. It was evident from the plot that G_s does not depend on D_{60}. This conclusion was confirmed by statistical analysis, which produced a R^2 of 0.14%. It was also found that the measured values of G_s have an average value of 2.65. Therefore, due to the lack of better correlation, G_s was approximated to be 2.65 for the NP soils.

A similar analysis was pursued for the plastic soils. The analysis showed a non-linear relationship between G_s, plasticity index (*PI*) and percent of soil passing sieve # 200 (P_{200}) that is expressed by equations 92 and 93 above. The relationship between G_s and *wPI* is plotted in Figure 67. Statistical analysis performed on this model yielded R^2 value of 0.22%, which means that the predicted G_s values correlated very poorly with the measured G_s. Therefore, it was decided that further analysis should be performed to find a better correlation between G_s and other soil parameters for both plastic and non plastic soils to be used in the Level 3 analysis of the *EICM model*, currently implemented in the MEPDG.

In order to calibrate the currently implemented *Gs model*, a new set of empirical data was gathered from the visited sites. The extended data set was used to calculate G_s values that were

plotted against measured G_s. The results shown in Figure 68 further confirmed that the currently implemented *Gs model* required refining.

New *Gs Model* for Non-Plastic Soils

The extended data set, consisting of 136 points, was used in the currently implemented *Gs model* for non-plastic soils. In order to determine the predicted capability of the model, G_s calculated was plotted against G_s measured in Figure 69 It was determined that the correlation between G_s and D_{60} was not significant. Even though the majority of the soils have measured G_s value of 2.65, the remaining values range from 2.57 to 2.88. As a result, the data set plots as a straight line instead of a point [2.65, 2.65]. This finding was confirmed by statistical analysis that yielded a R^2 value of 0.14%.

The acquisition and further addition of the field or the empirical data into the existing data set allowed for further study of the relationship between G_s and other soil parameters for the non-plastic soils. It was found that G_s depends linearly on gradation when gradation variable, g (defined below) varies within 0.5 and 6. For values of g larger than 6, the specific gravity approaches 2.65. The following equations define the relationship between G_s and gradation that is presented graphically in Figure 70.

$$G_s = -0.0526 * g + 2.9243, \qquad 0.5 < g \leq 6 \qquad (94)$$

$$G_s = 2.65 \qquad g > 6 \qquad (95)$$

$$g = 2.9 - 0.1(P_4/P_{200})^2 + 0.57(P_{40}/P_{200})^2 \qquad (96)$$

Where:

P_{200} = Percent of soil passing sieve # 200
P_{40} = Percent of soil passing sieve # 40
P_4 = Percent of soil passing sieve # 4

Error analysis of equations 94 to 96 revealed that there is a significant correlation between G_s and gradation since R^2 is 74%. The statistical parameters corresponding to the new model are presented in Figure 70. The final number of data points included into the analysis was 103 after removal of outliers.

New *Gs Model* for Plastic Soils

A refined linear correlation was developed for plastic soils assuming G_s is a function of optimal water content (w_{opt}), maximum dry unit weight (g_{d_max}) and *PI* based on the following equation:

$$G_s = 2.4528 + 0.006075\ w_{opt} + 0.001486\ g_{d\_max} + 0.001871\ PI \qquad (97)$$

Sensitivity Analysis of Gs Model for Non-Plastic Soils

The equations developed for the non-plastic soils were subjected to a sensitivity analysis. In the first part of the analysis, two gradation parameters were held constant while the third one was allowed to vary. The gradation variable, g, was then used to calculate the specific gravity which

was plotted against the varying gradation parameter. The results were plotted in Figures 71, 72 and 73.

From Figure 71, it can be seen that P_4 is a significant parameter when P_{40} and P_{200} are small. On the other hand, P_4 does not contribute at much to the result when the remaining gradation parameters are very large. It was found that G_s increases as P_4 increases.

Figure 72 shows that G_s increases as P_{40} decreases. It was found that P_{40} is a significant parameter when P_4 and P_{200} are small. P_{40} contributes to variation in G_s very little when the remaining two parameters are very large.

The variation of G_s with respect to P_{200} was considered in the final stage of sensitivity analysis. Figure 73 shows that G_s increases when P_{200} increases. Furthermore, it was found that P_{200} is a very significant parameter for all considered ranges of P_4 and P_{40}.

Based on the results obtained in the parametric study, it can be concluded that the new proposed model is technically valid and statistically sound.

Sensitivity Analysis of Gs Model for Plastic Soils

The equation for the plastic soils was subjected to a similar sensitivity analysis. In this case, the equation is linear, and influenced by three parameters: *PI*, g_{d_max} and w_{opt}. Therefore, an analysis was performed by holding two of the parameters constant and varying the third one. The results are shown in Figures 74 to 79. In addition, a combined effect was studied by holding g_{d_max} constant, and varying the other two parameters. The results are shown in Figure 80.

Summary

Based on the information presented above, the following conclusions can be drawn:

Improvements to the currently implemented *Gs model* resulted in increased R^2 values for both non-plastic and plastic soils.

For non-plastic soils, the following correlation yielded an R^2 value of 80%:

$$G_s = -0.0526 * g + 2.9243, \qquad 0.5 < g \leq 6 \quad \text{.......} (98)$$

$$G_s = 2.65 \qquad g > 6 \quad \text{.......} (99)$$

$$g = 2.9 - 0.1\left(\frac{P_4}{P_{200}}\right)^2 + 0.57\left(\frac{P_{40}}{P_{200}}\right)^2 \quad \text{.......} (100)$$

It was determined that all three gradation parameters used in the *Gs model* for NP soils were significant, where P_{200} is the most significant of the three for all ranges of P_4 and P_{40} considered. P_4 and P_{40} are significant only when the remaining two parameters are small.

For plastic soils, the following correlation was found:

$$G_s = 2.4528 + 0.006075\, w_{opt} + 0.001486\, g_{d\_max} + 0.001871\, PI \quad (101)$$

The sensitivity analysis yielded expected results as G_s increased when PI, w_{opt} and γ_{d_max} increased, being the PI the most significant parameter in the relationship and γ_{d_max} the least significant. The values found by the relationship vary from 2.65 and 2.85 for most common combination of parameters.

K-SAT MODEL CALIBRATION

k-sat Model Currently Implemented into the EICM Version 2.6

The ***k-sat model*** currently implemented into the EICM is the following:

For non-plastic soils:

$$k_{sat} = 118.11 \cdot 10^{\left(-1.1275(\log D_{60}+2)^2 + 7.2816(\log D_{60}+2) - 11.2891\right)} \quad (102)$$

For plastic soils:

$$k_{sat} = 118.11 \cdot 10^{\left(0.0004(P_{200}PI)^2 - 0.0929(P_{200}PI) - 6.56\right)} \quad \text{for } P_{200} > 50 \text{ and PI} > 4 \quad (103)$$

Where:

k_{sat} = Saturated hydraulic conductivity (ft/hr)
D_{60} = Grain size diameter at 60% passing (mm)
P_{200} = Passing sieve #200 (decimal)
PI = Plasticity index (%)

These correlations were developed with a limited database extracted from literature, where plastic and non-plastic soils were analyzed separately. For non-plastic soils, it was concluded that k_{sat} exclusively depended on D_{60}, where D_{60} is the grain size diameter from the grain size distribution curve at 60% passing. It was also found that for plastic soils, k_{sat} yielded reasonable correlations with plasticity index (*PI*) and P_{200} as defined above.

Validation of the Currently Implemented *k-sat Model*

In order to validate the currently implemented ***k-sat model***, a new set of measured data was gathered from the 29 visited sites. The values of k_{sat} were measured on 27 non-plastic soils and 42 plastic soils. Equations 102 and 103 were applied to the newly acquired data set. The calculated values of k_{sat} were plotted against k_{sat} obtained through laboratory testing. The results are presented in Figure 81 and Figure 82.

The results obtained in Chapter 5 suggested that the currently implemented ***k-sat model*** was in need of improvement.

Development of a New *k-sat Model*

In the development of any new k_{sat} *model*, where k_{sat} is correlated with index properties, it is typically necessary to compromise. As a general rule, the more index properties are used, the better the correlation is. On the other hand, the more index properties required, the more cumbersome is its use and the less likely it is to be used. These trades-off together with the knowledge of the index properties, that practitioners commonly and readily determine, where used to select the appropriate combinations. New k_{sat} models were developed for the plastic and non-plastic soils.

K-sat Model for Plastic Soils

The weighted plasticity index is abbreviated ***wPI*** and defined by ***wPI*** = P_{200}*PI, with P_{200} in decimal and ***PI*** in percentage. Within this report, the product P_{200}*PI is used in lieu of ***wPI*** with the understanding that P_{200} is always in decimal when P_{200} and ***PI*** are presented as a product. Because of past experience with ***wPI***, it was expected to be an important parameter. The percent of clay, $P_{0.002}$, was also expected to be an important parameter, but when it was added, the improvement in the model was marginal to negligible. Because of the added testing burden of acquiring $P_{0.002}$, from laboratory testing, its use was dropped.

The following equation represents the best model for plastic soils. The measured versus predicted hydraulic conductivity data is presented in Figure 83.

$$k_{sat} = 2*10^{(-0.1*P_{200}PI-6)} \qquad \text{[cm/s]} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (104)$$

An R^2 value of - 10 is obviously an extremely poor correlation, but it is much better than the old model, which had an R^2 of -15. These poor correlations are believed to be an inherent result of the fact that k_{sat} ranges over so many orders of magnitude that is unreasonable to expect a good correlation. These results accordingly show that if a fairly good estimate of time rate of water movement through soil is to be obtained, k_{sat} must be measured directly. The correlations with index properties proposed in this report will provide only very crude estimates of k_{sat}.

K-sat Model for Non-Plastic Soils

For the non-plastic soils it was assumed that a full gradation curve down to D_{10} would typically be available. Accordingly, the following parameters were considered to be important and practical to use: D_{10}, D_{60}, D_{60}/D_{10}, and P_{200}. Numerous models were tried with very discouraging, highly negative R^2 values; but finally the following model produced a dramatic increase in R^2_{adj} to 0.82. The measured versus predicted hydraulic conductivity results are shown in Figure 84.

$$k_{sat} = 10^{-6}10^{\left(5.3D_{10}+0.049D_{60}+0.0092\frac{D_{60}}{D_{10}}-0.1P_{200}+1.5\right)} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (105)$$

When the data sets for both plastic and non-plastic soils were combined, there is an apparent improvement in the fit statistics, as shown in Figure 85. The improvement is primarily due to the

expansion of the database where in the low k_{sat} values for plastic soils were combined with the high k_{sat} values of the NP soils. The final R^2_{adj} was found to be 0.83.

These correlations were considered to be about the best that can be achieved with the currently available database. It should also be noted that time-rate of water flow is not often a critical issue in the MEPDG applications of the EICM. For example, after the moisture contents under pavements reach more or less an equilibrium value (at a distance of 2 m (6 ft) or more from the edge of paved shoulders), further variations are fairly minor. There can be some exceptions to this generalization in cases of freezing/frost action.

COMPACTION MODEL CALIBRATION

The last model to be considered for calibration was the *Compaction model*. This model allows the estimation of the optimum water content and the maximum dry unit weight for coarse and fine-grained materials in case the user does not provide the input data.

Based on the results obtained in Chapter 5, where an exhaustive statistical analysis of the currently available models was presented, it was decided that the *Compaction model* was good enough for the prediction and only a minor improvement was needed.

Compaction Model Currently Implemented into the EICM Version 2.6

The relationships are based on the Passing #200 (P_{200}), Diameter 60 (D_{60}), and Plasticity Index (PI). The following steps comprise the *Compaction model*:

1. The model identifies the layer as a compacted base course, compacted subgrade, or natural in-situ subgrade.
2. Calculate the optimum degree of saturation, S_{opt}:

$$S_{opt} = 6.752\,(P_{200}PI)^{0.147} + 78 \quad (106)$$

3. Compute the optimum gravimetric moisture content, w_{opt}:

   a) If $P_{200}PI > 0$ (plastic materials):

$$w_{opt} = 1.3\,(P_{200}PI)^{0.73} + 11 \quad (107)$$

   b) If $P_{200}PI = 0$ (granular, non-plastic materials):

$$w_{opt\,(T99)} = 8.6425\,(D_{60})^{-0.1038} \quad (108)$$

   iii. If layer is not a base course

$$w_{opt} = w_{opt\,(T99)} \quad (109)$$

   iv. If layer is a base course

$$Dw_{opt} = 0.0156[w_{opt(T99)}]^2 - 0.1465w_{opt(T99)} + 0.9 \quad (110)$$

$$w_{opt} = w_{opt\ (T99)} - Dw_{opt} \quad (111)$$

4. Compute $g_{d\ max}$ for compacted materials, $g_{d\ max\ comp}$

$$g_{d\ max\ comp} = \frac{G_s g_{water}}{1 + \frac{w_{opt} G_s}{S_{opt}}} \quad (112)$$

5. Compute $g_{d\ max}$

    a) If layer is a compacted material

$$g_{d\ \max} = g_{d\ \max\ \mathrm{comp}} \quad (113)$$

    b) If layer is a natural in-situ material

$$g_d = 0.90 g_{d\ \max\ \mathrm{comp}} \quad (114)$$

    EICM uses g_d for $g_{d\ max}$.

6. Compute the volumetric water content, q_{opt}

$$q_{opt} = \frac{w_{opt} g_{d\ \max}}{g_{water}} \quad (115)$$

Improvement to the *Compaction Model*

After the analysis performed in Chapter 5, it was decided that the Compaction model currently implemented was good enough and no mayor improvements to the model were needed. However, the analysis highlighted that for natural in-situ materials, the approximation used in Equation 114 could be improved.

The following equation to estimate the unit weight of the in-situ materials was found to be better than the equation previously used:

$$g_d = 0.81944 g_{d\ \max\ \mathrm{comp}} + 18.485 \quad (116)$$

Where:

g = Unit weight of the in-situ material (pcf)

$g_{dmax\ comp}$ = Maximum dry unit weight of the compacted material (pcf)

This equation replaces $g_d = 0.9 g_{d\ \max\ \mathrm{comp}}$

Table 93
Approximate Range for Equilibrium Moisture Content

Type of Road Bed Soil	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	Equilibrium Moisture Content (%)
Coarse Sand	120-135	8-13	10-15
Medium Sand	110-125	10-14	13-17
Fine Sand	105-120	12-16	15-20
Silt	100-120	14-21	20-30
Clay	85-110	16-30	25-35

Table 94
Measured Suction Values for Granular Bases

No.	City	State	Abbr.	Layer Thickness			Sample	w	g_d	G_s	q_w	S	h
			ID	TB	GB	SB/CSS	ID	%	pcf		%	%	kPa
1	Opelika	AL	1-3	--	7.5"	--	1-3-1-10	9.64	140.71	2.85	21.74	100	**0**
2	Chloride	AZ	2-3	--	7.5"	--	2-3-1-5.5	3.39	139.35	2.75	7.57	40	**55**
3	Buckeye	AZ	4-1	--	7.0"	--	4-1-1-11.5	5.73	132.29	2.71	12.15	56	**13**
4	Delta	CO	7-5	--	4.5"	30.0"	7-5-2-7.5	3.74	140.97	2.71	8.45	51	**16**
5	Aurora	CO	7-4	--	7.5"	29.5"	7-4-2-14.5	3.27	132.02	2.73	6.92	31	**28**
6	Groton	CT	6-1	--	12.0"	--	6-1-2-12.5	5.04	143.85	2.80	11.62	66	**7**
7	Collins	MS	1-4	--	33.0"	--	1-4-3-18	10.67	124.16	2.67	21.23	83	**10**
8	Big Timber	MT	7-1	--	3.0"	15.5"	7-1-2-10.5	5.87	144.14	2.76	13.56	83	**21**
9	Hebron	NE	5-4	--	12.0"	--	5-4-1-9	2.40	141.63	2.69	5.45	35	**18**
10	Battle Mtn	NV	8-2	12.0"	6.5"	20.5"	8-2-2-12	5.23	146.41	2.76	12.27	82	**150**
11	Otego	NY	6-3	--	--	--	6-3-2-10	5.36	135.09	2.74	11.60	55	**12**
12	Harrisburg	OR	2-2	--	>12"	--	2-2-1-15	7.60	141.55	2.79	17.24	92	**1**
13	Milesburg	PA	6-4	--	8.0"	--	6-4-2-17	4.14	140.55	2.85	9.32	44	**20**
14	Vidaurri	TX	3-3	10.0"	7.0"	--	3-3-2-17	8.40	117.75	2.70	15.85	53	**50**
15	Estelline	TX	1-2	12.0"	8.0"	--	1-2-1-16	3.29	133.27	2.63	7.03	37	**20**
16	Charlotte	VT	6-2	3.5"	21.5"	12.0"	6-2-1-20	3.64	130.45	2.72	7.61	33	**5**
17	Pullman	WA	8-1	--	9.0"	--	8-1-2-10.5	5.25	137.32	2.88	11.55	49	**17**
18	WesTrack	NV	2-1	--	12.0"	12"/6"	2-1-1-7	7.42	131.94	2.75	15.69	68	**95**

Note: The site located in Opelika, Alabama contained numerous previously cored holes left unpatched on the pavement that may have contributed to the saturation of the granular base. This site was excluded from the analysis.

Table 95
Measured Suction Values for Subgrades and Subbases

No.	City	State	Abbr. ID	Layer	Sample ID	w	g_d	G_s	q_w	S	h
						%	pcf		%	%	kPa
1	Opelika	AL	1-3	SS	1-3-1-15	23.58	97.37	2.76	36.79	85	**45**
2	Chloride	AZ	2-3	SS	2-3-2-13	6.22	118.92	2.75	11.85	39	**50**
3	Buckeye	AZ	4-1	SS	4-1-1-18.5	6.70	126.47	2.71	13.58	54	**80**
4	Crossett	AR	1-5	SS	1-5-1-18.5	18.16	103.26	2.70	30.05	78	**28**
5	Crossett	AR	1-5	SS	1-5-2-23	17.58	107.51	2.70	30.29	84	**40**
6	Thornton	CA	8-3	CSS	8-3-2-14	19.08	109.34	2.78	33.43	70	**600**
7	Thornton	CA	8-3	SS	8-3-3-21	16.76	112.50	2.77	30.22	87	**25**
8	Thornton	CA	8-3	SS	8-3-1-28	14.17	106.86	2.80	24.27	62	**15**
9	Delta	CO	7-5	SS	7-5-1-43	23.06	103.10	2.78	38.10	94	**500**
10	Aurora	CO	7-4	SB	7-4-3-19	6.82	112.50	2.66	12.30	38	**18**
11	Aurora	CO	7-4	SS	7-4-3-48	19.90	107.07	2.74	34.15	91	**170**
12	Groton	CT	6-1	SS	6-1-1-20	6.42	123.43	2.74	12.70	46	**20**
13	Abilene	KS	5-3	SS	5-3-2-16.5	21.79	101.58	2.76	35.47	86	**120**
14	Moss Bluff	LA	3-1	SS	3-1-3-24	15.75	108.62	2.68	27.42	78	**190**
15	Collins	MS	1-4	SB	1-4-3-18	10.67	124.16	2.67	21.23	83	**9**
16	Collins	MS	1-4	SS	1-4-2-42	16.07	112.22	2.71	28.90	86	**15**
17	Big Timber	MT	7-1	SB	7-1-1-13.5	5.36	141.14	2.78	12.12	65	**12**
18	Big Timber	MT	7-1	SS	7-1-1-30	13.21	119.70	2.75	25.34	84	**100**
19	Hebron	NE	5-4	SS	5-4-2-25	23.54	102.38	2.74	38.62	96	**320**
20	Battle Mtn	NV	8-2	SB	8-2-3-18	6.20	128.66	2.69	12.78	55	**70**
21	Rincon	NM	1-1	SS	1-1-1-13	22.71	103.69	2.74	37.74	96	**19**
22	Otego	NY	6-3	SS	6-3-1-19	4.92	141.57	2.76	11.16	63	**4**
23	Lexington	NC	5-1	SS	5-1-2-24	29.68	91.61	2.74	43.57	94	**100**
24	Milesburg	PA	6-4	SS	6-4-3-22.5	10.93	124.36	2.79	21.78	76	**115**
25	Auburntown	TN	5-2	SS	5-2-2-17	34.01	88.18	2.80	48.06	97	**80**
26	Vidaurri	TX	3-3	SS	3-3-2-23	20.25	93.79	2.74	30.44	67	**140**
27	Estelline	TX	1-2	SS	1-2-1-22	9.26	103.81	2.70	15.41	40	**35**
28	Beaumont	TX	3-2	CSS	3-2-1-15	25.55	92.33	2.74	37.80	82	**40**
29	Beaumont	TX	3-2	SS	3-2-2-25	19.31	108.42	2.74	33.55	92	**130**
30	Beaumont	TX	3-2	SS	3-2-1-35	19.65	108.56	2.74	34.19	94	**150**
31	Charlotte	VT	6-2	CSS	6-2-3-33	9.14	133.47	2.71	19.55	93	**3**
32	Charlotte	VT	6-2	CSS	6-2-2-35	8.70	123.47	2.71	17.21	64	**7**
33	Charlotte	VT	6-2	CSS	6-2-3-44	10.50	126.11	2.65	21.22	89	**18**
34	Pullman	WA	8-1	SS	8-1-2-20	22.02	102.52	2.73	36.18	91	**300**
35	Pullman	WA	8-1	SS	8-1-1-29	20.58	107.35	2.79	35.40	92	**245**
36	Gillette	WY	7-3	SB	7-3-2-19.5	14.31	114.01	2.66	26.15	83	**25**
37	Gillette	WY	7-3	SS	7-3-1-30	17.42	109.86	2.69	30.67	89	**500**
38	Sheridan	WY	7-2	SS	7-2-2-20.5	15.17	119.41	2.87	29.03	87	**130**
39	Sheridan	WY	7-2	SS	7-2-1-29	15.67	121.55	2.87	30.52	95	**80**
40	Albertville	MN	6-5	CSS	6-5-3-15	14.88	116.92	2.69	27.88	92	**30**
41	Albertville	MN	6-5	CSS	6-5-1-20	14.76	116.41	2.69	27.54	90	**80**
42	Silver Springs	NV	2-1	Fill	2-1-2-18	19.01	105.10	2.68	32.02	86	**350**
43	Silver Springs	NV	2-1	CSS	2-1-2-30	18.69	102.71	2.75	30.76	77	**300**
44	Silver Springs	NV	2-1	CSS	2-1-4-30	22.53	100.81	2.72	36.40	90	**500**

Table 96
Measured Suction Values of Side Samples

No.	City	State	Abbr. ID	Layer	Sample ID	w	g_d	G_s	q_w	S	h
						%	pcf		%	%	kPa
1	Chloride	AZ	2-3	Side	2-3-S-20	3.36	122.61	2.78	6.60	23	**40**
2	Buckeye	AZ	4-1	Side	4-1-S-12	4.98	116.52	2.78	9.30	28	**600**
3	Thornton	CA	8-3	Side	8-3-S-12	12.97	96.90	2.75	20.14	46	**800**
4	Delta	CO	7-5	Side	7-5-S-12	19.34	103.41	2.82	32.05	78	**2000**
5	Aurora	CO	7-4	Side	7-4-S-15	14.89	106.42	2.78	25.39	66	**200**
6	Groton	CT	6-1	Side	6-1-S-12	9.80	114.86	2.66	18.04	59	**30**
7	Abilene	KS	5-3	Side	5-3-S2-8	20.94	103.96	2.79	34.89	87	**600**
8	Big Timber	MT	7-1	Side	7-1-S-15	22.65	101.76	2.80	36.94	88	**600**
9	Hebron	NE	5-4	Side	5-4-S-12	21.28	104.15	2.77	35.52	89	**1000**
10	Battle Mtn	NV	8-2	Side	8-2-S-18	11.78	102.63	2.72	19.37	49	**200**
11	Otego	NY	6-3	Side	6-3-S-12	12.29	99.93	2.70	19.68	48	**95**
12	Lexington	NC	5-1	Side	5-1-S-12	21.61	98.48	2.77	34.11	79	**2000**
13	Milesburg	PA	6-4	Side	6-4-S-19	5.33	109.67	3.20	9.37	21	**300**
14	Auburntown	TN	5-2	Side	5-2-S-12	32.66	87.76	2.80	45.93	92	**500**
15	Charlotte	VT	6-2	Side	6-2-S1-15	55.12	65.25	2.79	57.64	92	**15**
16	Pullman	WA	8-1	Side	8-1-S-12	22.58	102.88	2.80	37.23	91	**500**
17	Sheridan	WY	7-2	Side	7-2-S-14	22.58	102.88	2.88	37.23	87	**500**
18	Gillette	WY	7-3	Side	7-3-S-16	17.57	109.29	2.80	30.77	82	**800**
19	Albertville	MN	6-5	Side	6-5-S-12	22.41	101.84	2.70	36.57	92	**100**

Table 97
Set of Parameters Considered in Correlations

Parameter	Abbreviation or Symbol	Source
Annual Mean Relative Humidity	AMRH	National Climatic Data Center; MEPDG Database
Quarterly Mean Relative Humidity	QMRH	National Climatic Data Center; MEPDG Database
Quarterly Relative Humidity (One quarter prior to site visit)	QRH	MEPDG Database
Monthly Mean Relative Humidity	MMRH	National Climatic Data Center; MEPDG Database
Monthly Relative Humidity (One month prior to site visit)	MRH	MEPDG Database
Mean Daily Average Temperature	MDAT	National Climatic Data Center; MEPDG Database
Mean Daily Temperature Range	MDTR	National Climatic Data Center; MEPDG Database
Number of Days with Measurable Precipitation	NDMP	National Climatic Data Center; MEPDG Database
Number of Days with Temperature Less Than 32 ºF	NDTL32	National Climatic Data Center; MEPDG Database
Number of Days with Relative Humidity Greater Than 96%	NDRHG96	MEPDG Database
Number of Days with Relative Humidity Greater Than 98%	NDRHG98	MEPDG Database
Annual Mean Dew Point	AMDP	National Climatic Data Center
Annual Mean Precipitation	AMP	National Climatic Data Center
Annual Mean Sunshine	AMSS	National Climatic Data Center
Thornthwaite Moisture Index	TMI	Contour Map (Figure 52)
Passing No. 200 Sieve	P_{200}	Data from this project
Depth to Ground water Table	GWT	LTPP Database; USGS Database
Volumetric Water Content	q_w	LTPP Database

Table 98
Mean Possible Duration of Sunlight - Northern Hemisphere

Northern latitude	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
5	1.02	0.93	1.03	1.02	1.06	1.03	1.06	1.05	1.01	1.03	0.99	1.02
10	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
15	0.97	0.91	1.03	1.04	1.11	1.08	1.12	1.08	1.02	1.01	0.95	0.97
20	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
25	0.93	0.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	0.99	0.91	0.91
26	0.92	0.88	1.03	1.06	1.15	1.15	1.17	1.12	1.02	0.99	0.91	0.91
27	0.92	0.88	1.03	1.07	1.16	1.15	1.18	1.13	1.02	0.99	0.90	0.90
28	0.91	0.88	1.03	1.07	1.16	1.16	1.18	1.13	1.02	0.98	0.90	0.90
29	0.91	0.87	1.03	1.07	1.17	1.16	1.19	1.13	1.03	0.98	0.90	0.89
30	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
31	0.90	0.87	1.03	1.08	1.18	1.18	1.20	1.14	1.03	0.98	0.89	0.88
32	0.89	0.86	1.03	1.08	1.19	1.19	1.21	1.15	1.03	0.98	0.88	0.87
33	0.88	0.86	1.03	1.09	1.19	1.20	1.22	1.15	1.03	0.97	0.88	0.86
34	0.88	0.85	1.03	1.09	1.20	1.20	1.22	1.16	1.03	0.97	0.87	0.86
35	0.87	0.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	0.97	0.86	0.85
36	0.87	0.85	1.03	1.10	1.21	1.22	1.24	1.16	1.03	0.97	0.86	0.84
37	0.86	0.84	1.03	1.10	1.22	1.23	1.25	1.17	1.04	0.97	0.85	0.83
38	0.85	0.84	1.03	1.10	1.23	1.24	1.25	1.17	1.04	0.96	0.84	0.83
39	0.85	0.84	1.03	1.11	1.23	1.24	1.26	1.18	1.04	0.96	0.84	0.82
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
41	0.83	0.83	1.03	1.11	1.25	1.26	1.27	1.19	1.04	0.96	0.82	0.80
42	0.82	0.83	1.03	1.12	1.26	1.27	1.28	1.19	1.04	0.95	0.82	0.79
43	0.81	0.82	1.02	1.12	1.26	1.28	1.29	1.20	1.04	0.95	0.81	0.77
44	0.81	0.82	1.02	1.13	1.27	1.29	1.30	1.20	1.04	0.95	0.80	0.76
45	0.80	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75
46	0.79	0.81	1.02	1.13	1.29	1.31	1.32	1.22	1.04	0.94	0.79	0.74
47	0.77	0.80	1.02	1.14	1.30	1.32	1.33	1.22	1.04	0.93	0.78	0.73
48	0.76	0.80	1.02	1.14	1.31	1.33	1.34	1.23	1.05	0.93	0.77	0.72
49	0.75	0.79	1.02	1.14	1.32	1.34	1.35	1.24	1.05	0.93	0.76	0.71
50	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.73	0.70

Table 99
Mean Possible Duration of Sunlight - Southern Hemisphere

Southern latitude	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5	1.06	0.95	1.04	1.00	1.02	0.99	1.02	1.03	1.00	1.05	1.03	1.06
10	1.08	0.97	1.05	0.99	1.01	0.96	1.00	1.01	1.00	1.06	1.05	1.10
15	1.12	0.98	1.05	0.98	0.98	0.94	0.97	1.00	1.00	1.07	1.07	1.12
20	1.14	1.00	1.05	0.97	0.96	0.91	0.95	0.99	1.00	1.08	1.09	1.15
25	1.17	1.01	1.05	0.96	0.94	0.88	0.93	0.98	1.00	1.10	1.11	1.18
30	1.20	1.03	1.06	0.95	0.92	0.85	0.90	0.96	1.00	1.12	1.14	1.21
35	1.23	1.04	1.06	0.94	0.89	0.82	0.87	0.94	1.00	1.13	1.17	1.25
40	1.27	1.06	1.07	0.93	0.86	0.78	0.84	0.92	1.00	1.15	1.20	1.29
42	1.28	1.07	1.07	0.92	0.85	0.76	0.82	0.92	1.00	1.16	1.22	1.31
44	1.30	1.08	1.07	0.92	0.83	0.74	0.81	0.91	0.99	1.17	1.23	1.33
46	1.32	1.10	1.07	0.91	0.82	0.72	0.79	0.90	0.99	1.17	1.25	1.35
48	1.34	1.11	1.08	0.90	0.80	0.70	0.76	0.89	0.99	1.18	1.27	1.37
50	1.37	1.12	1.08	0.89	0.77	0.67	0.74	0.88	0.99	1.19	1.29	1.41

Table 100
Comparison of Errors Associated with the Proposed Suction Models and yg_w Model

Error Analyzed	TMI-P_{200} Model	TMI-P_{200}/wPI Model	yg_w
Mean Absolute Error	9.5 %	37.7 %	267 %
Mean Algebraic Error	2.1 %	0.07 %	-259 %

Table 101
Regression Constants for the *TMI-P_{200}* Model

P_{200}	*a*	*b*	*g*	R^2
0	3.649	3.338	-0.05046	> 0.99
2	4.196	2.741	-0.03824	> 0.99
4	5.285	3.473	-0.04004	> 0.99
6	6.877	4.402	-0.03726	> 0.99
8	8.621	5.379	-0.03836	> 0.99
10	12.18	6.646	-0.04688	> 0.99
12	15.59	7.599	-0.04904	> 0.99
14	20.202	8.154	-0.05164	> 0.99
16	23.564	8.283	-0.05218	> 0.99

Table 102
Regression Constants for *TMI-P_{200}/wPI* Model

P_{200} or wPI	a	b	g	d	R^2
P_{200} = 10	0.300	419.07	133.45	15.00	> 0.99
P_{200} = 50/ wPI = 0.5 or less	0.300	521.50	137.30	16.00	>0.99
wPI = 5	0.300	663.50	142.50	17.50	>0.99
wPI = 10	0.300	801.00	147.60	25.00	>0.99
wPI = 20	0.300	975.00	152.50	32.00	>0.99
wPI = 50	0.300	1171.20	157.50	27.80	>0.99

Table 103
Information on Databases

Database	Soil Type	No. of SWCCs	Volume Change Correction	Fitting Parameters
NCHRP 9-23	Non-Plastic	36	--	a_f, b_f, c_f, h_{rf}
	Plastic	47	--	a_{fh}, b_{fh}, c_{fh}, h_{rfh}
Zapata's	Non-Plastic	118	--	a_f, b_f, c_f, h_{rf}
	Plastic	16	Yes	a_{fh}, b_{fh}, c_{fh}, h_{rfh}

Table 104
Errors Associated with SWCC Predictions

Parameter	Non-Plastic Soils		Plastic Soils	
	Proposed Model	Zapata	Proposed Model	Zapata
e_{alg}	8.6%	88.5%	0.1%	20.4%
e_{abs}	14.8%	88.5%	9.2%	23.9%
S_e/S_y	0.65	1.01	0.70	0.91
Adjusted R^2	0.58	-0.02	0.51	0.18

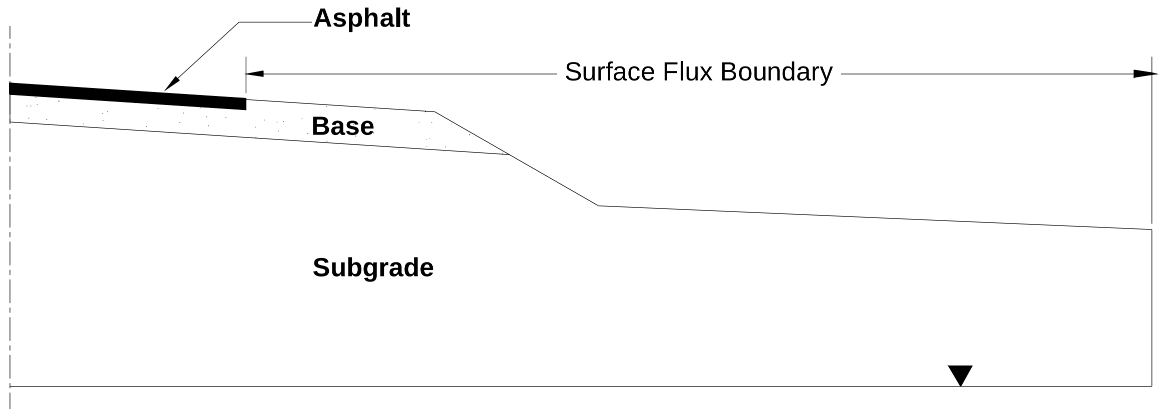


Figure 42
Typical Highway Cross-Section Showing the Surface Boundary Controlled by Microclimatic Conditions (Barbour et al. 1992)

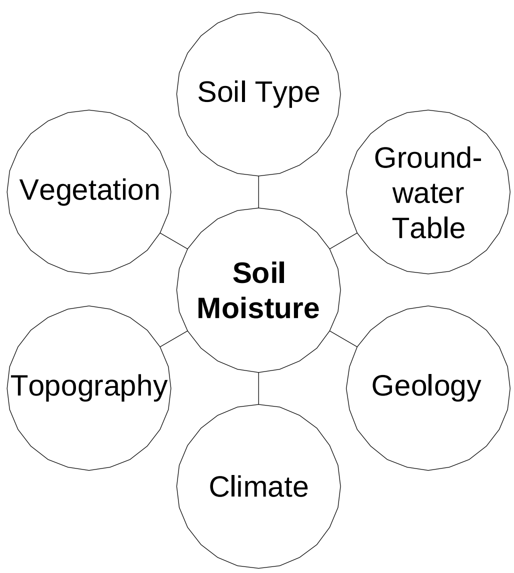
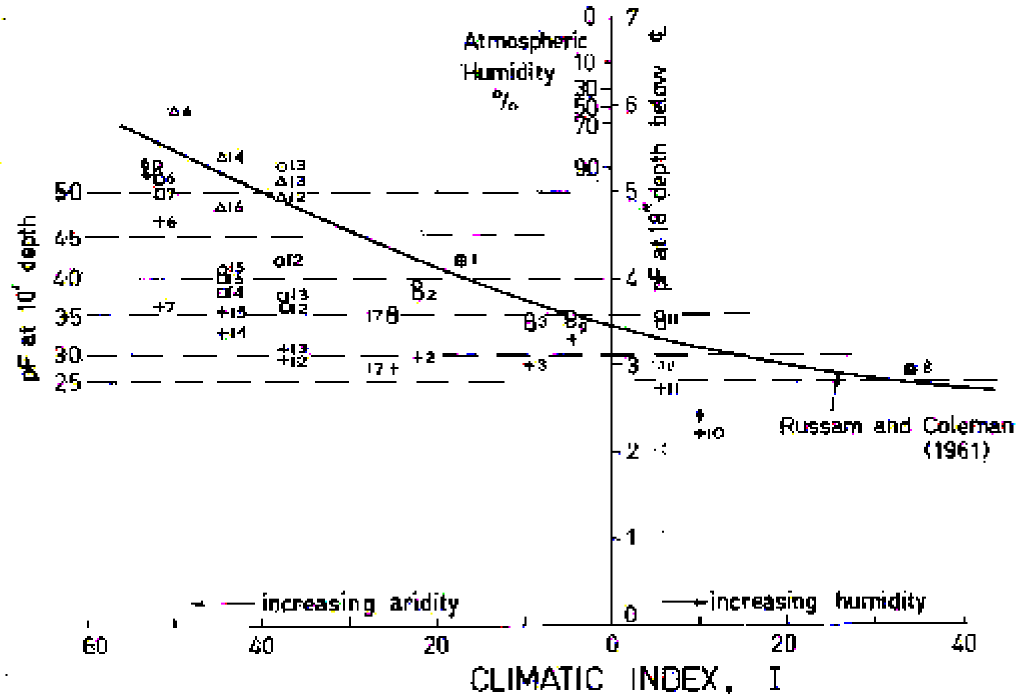


Figure 43
Factors Affecting Moisture Conditions



+ Measured matrix suction—gypsum blocks.
⌶ Total suction from gypsum blocks and total soluble salts.
△ Total suction measured in laboratory.
○ Estimated design total suction based on suction measured at 10-ft depth.

1. Adelaide.
2. Horsham.
3. Bordertown.
4. Alice Springs 62 m.
5. Alice Springs 17 m.
6. Woomera Road.
7. Woomera Aerodrome.
8. Midland Junction.
9. Jondaryan.
10. Gordon.
11. Tullamarine.
12. Nyngan 5½ m.
13. Nyngan 3½ m.
14. Cloncurry 8 m.
15. Cloncurry 3½ m.
16. Winton.
17. Tongala.

Figure 44
Design Curves for Values of Subgrade Suction

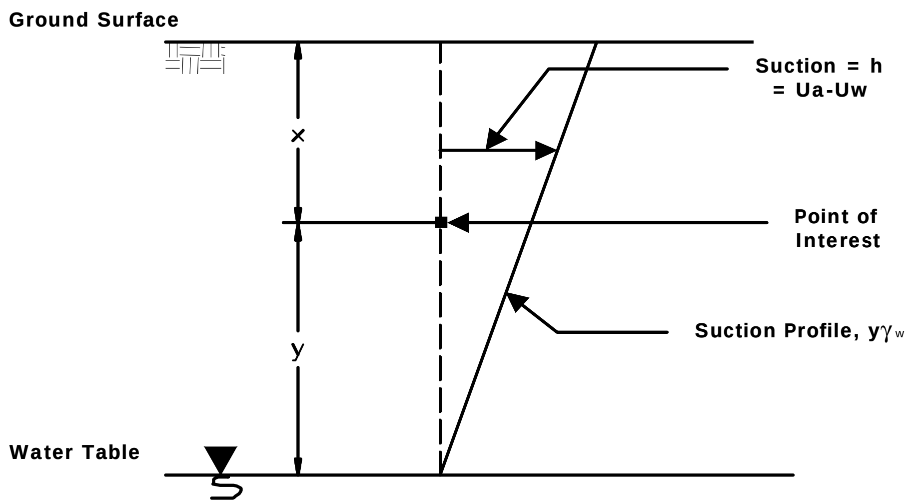


Figure 45
Suction Profile Using *yg_w*

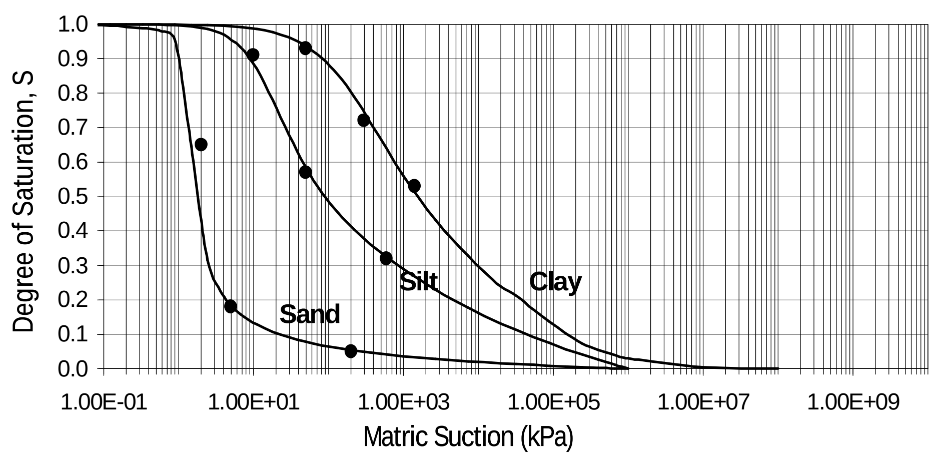


Figure 46
Typical Soil Water Characteristic Curves

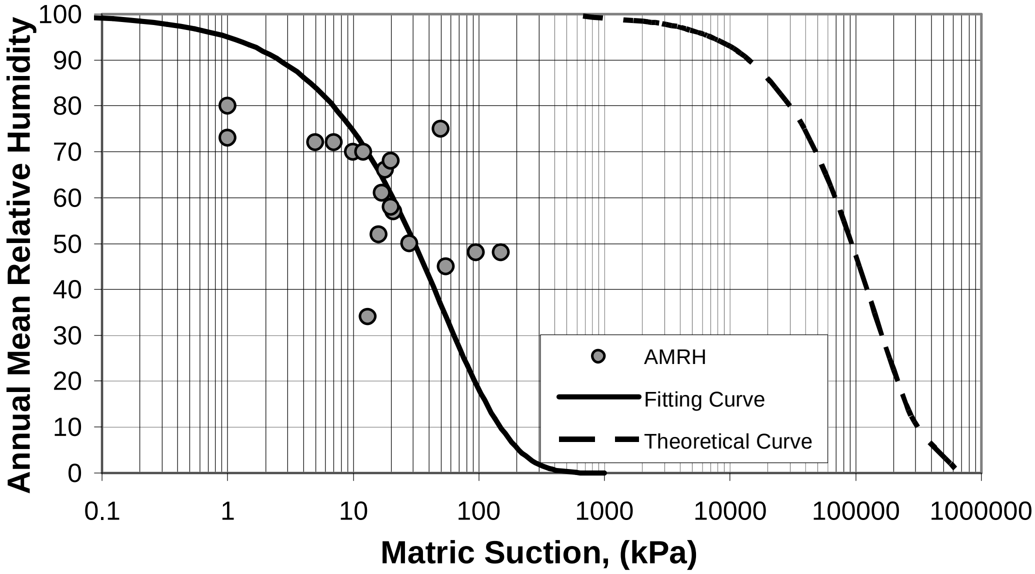


Figure 47
Annual Mean Relative Humidity versus Matric Suction

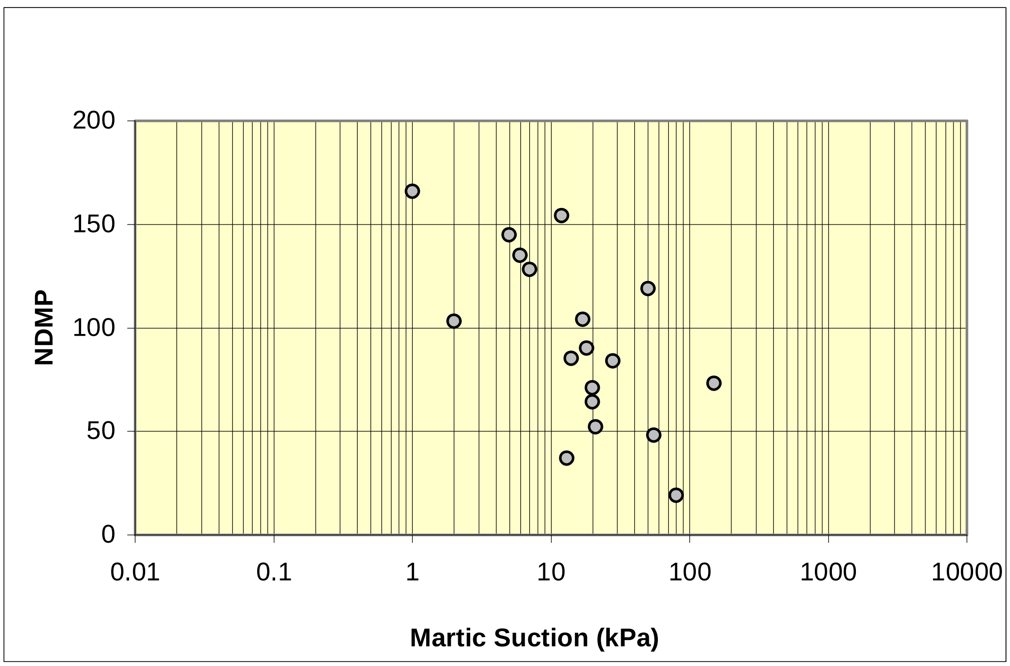


Figure 48
Correlation between NDMP and Matric Suction

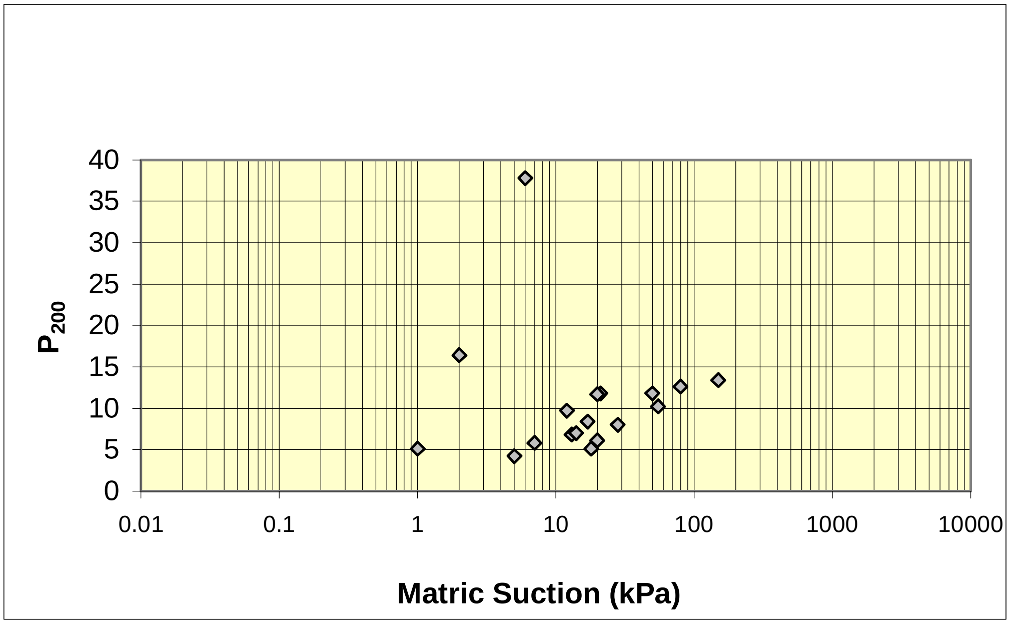


Figure 49
Correlation between P_{200} and Matric Suction

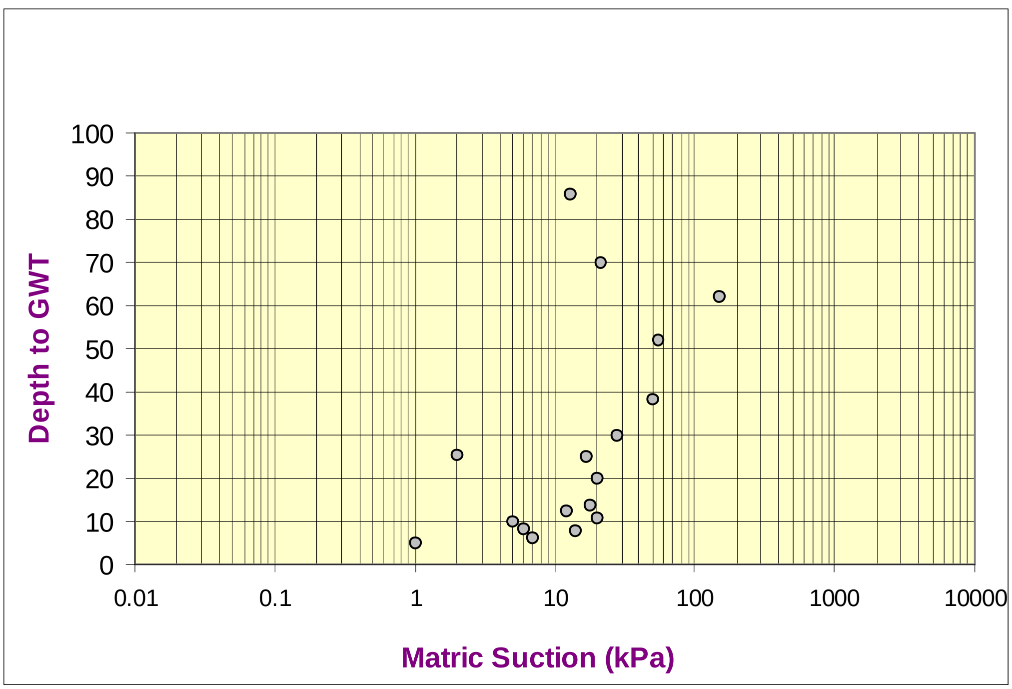


Figure 50
Correlation between Depth to Groundwater Table and Matric Suction

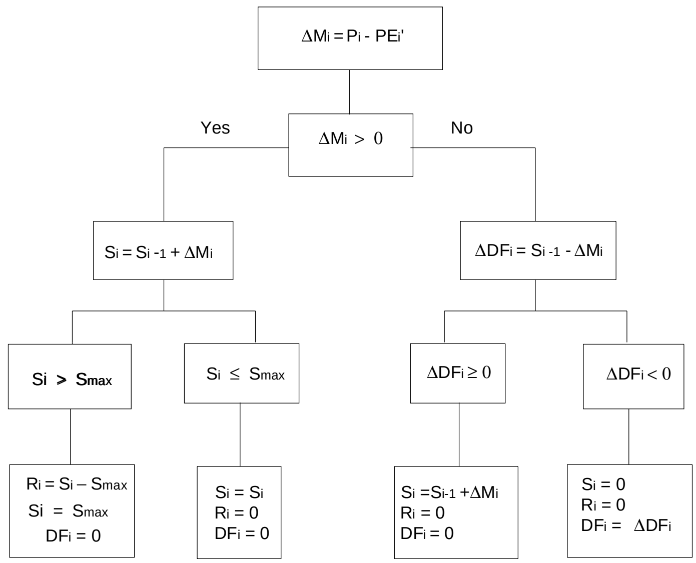


Figure 51
Flow Chart to Calculate Moisture Balance (McKeen and Johnson 1990)

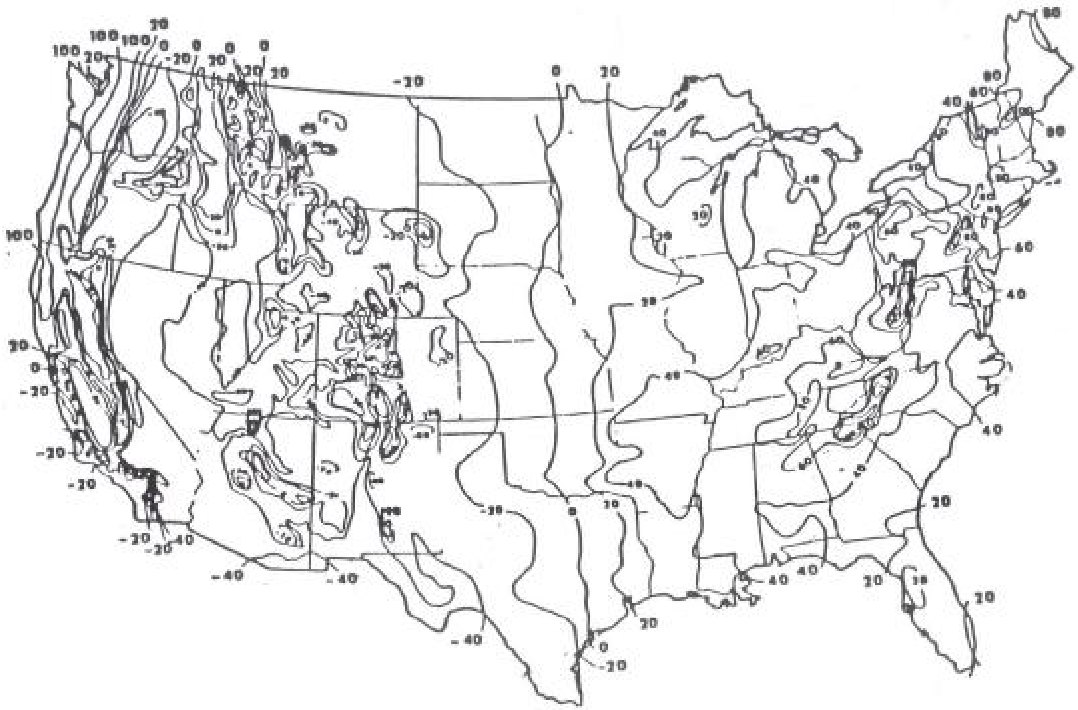


Figure 52
Thornthwaite Moisture Index Contour Map

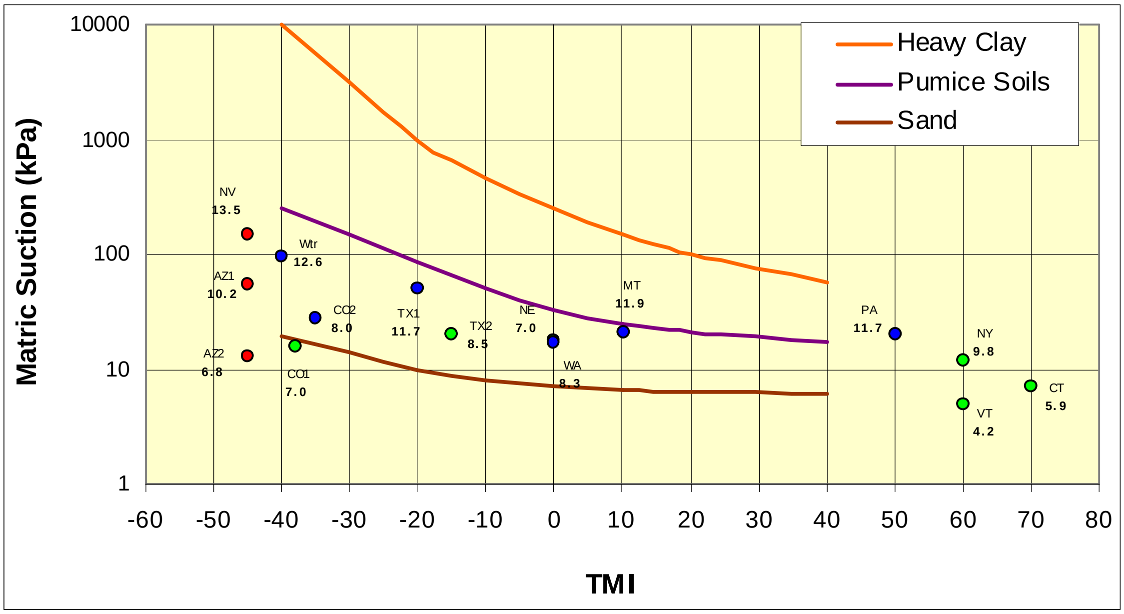


Figure 53
Matric Suction versus *TMI* for Granular Bases.

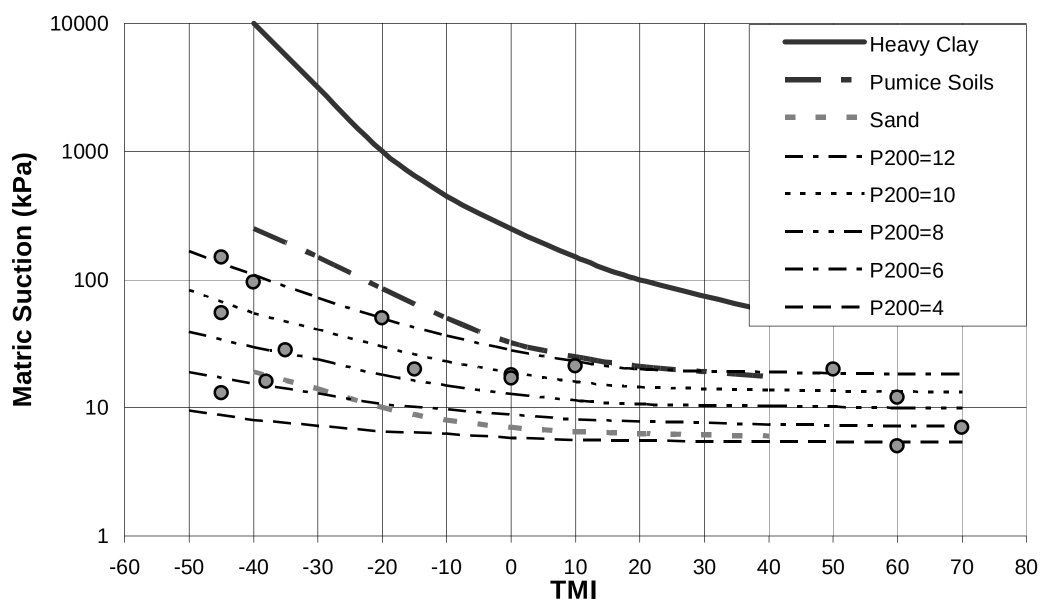


Figure 54
***TMI-P*$_{200}$ Model**

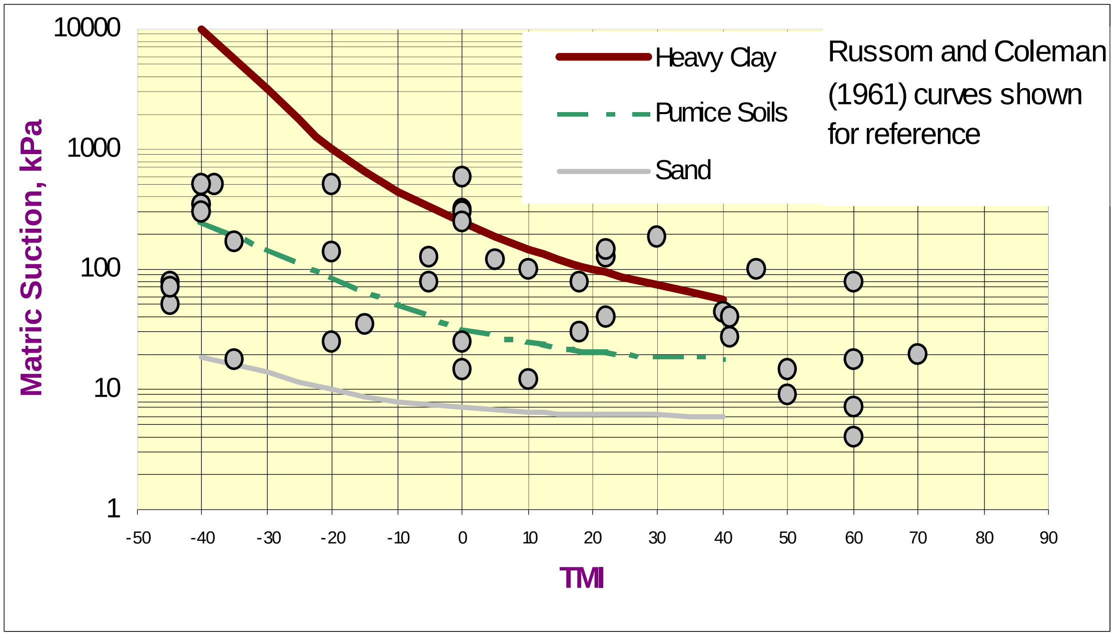


Figure 55
Correlation between Matric Suction and *TMI* for Subbases and Subgrades

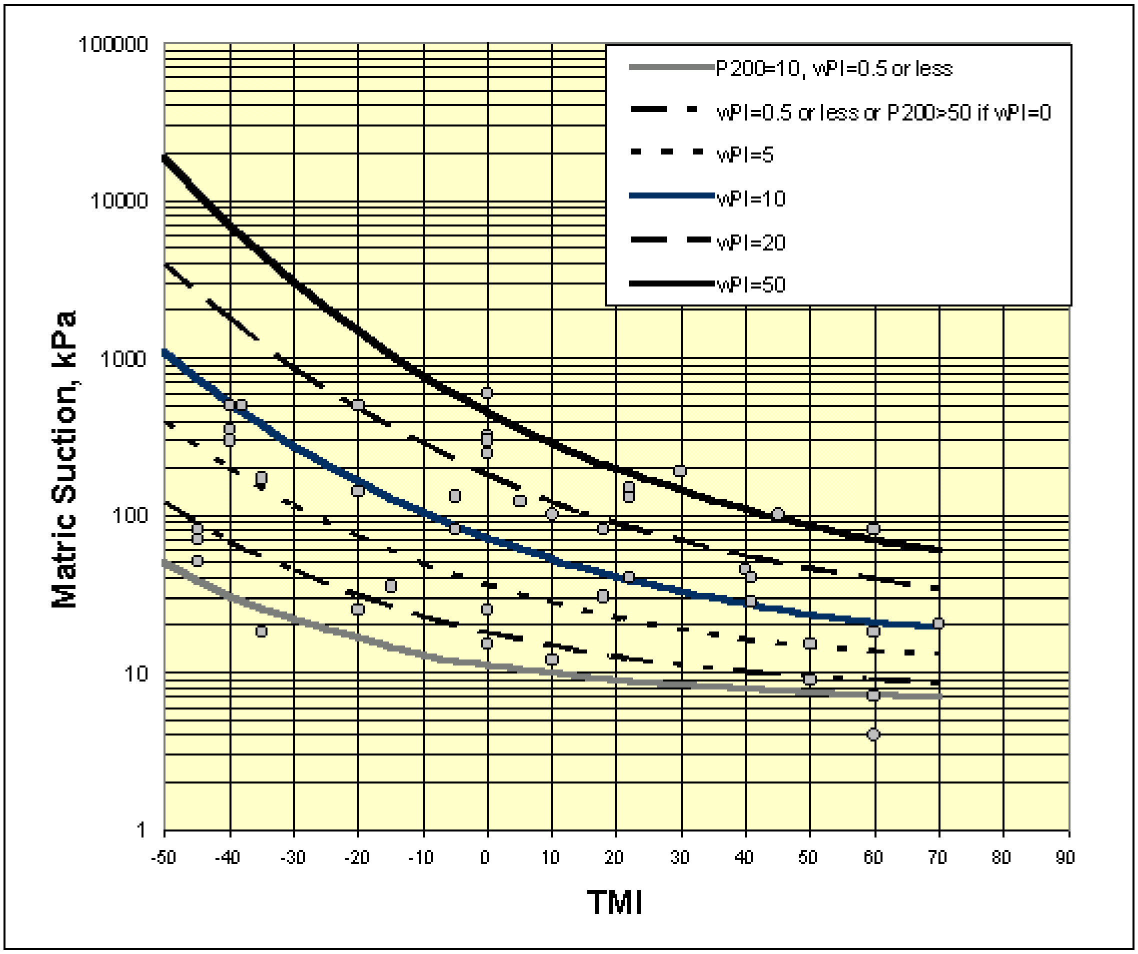


Figure 56
TMI-P_{200}/wPI **Model for Subbase and Subgrade Materials**

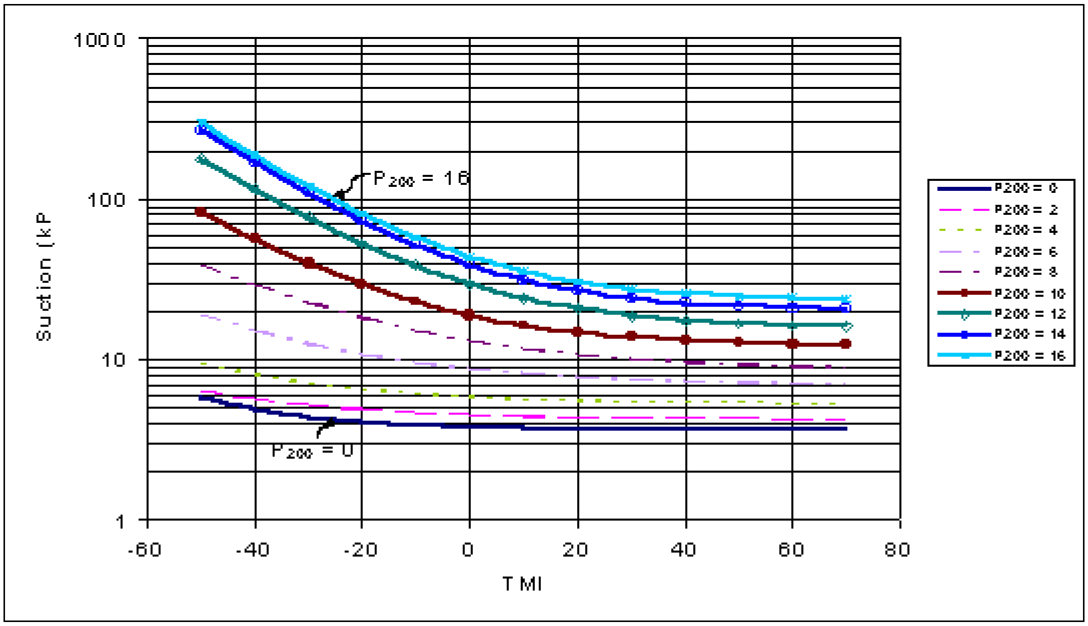


Figure 57

***TMI-P_{200}* Model for Granular Base Materials**

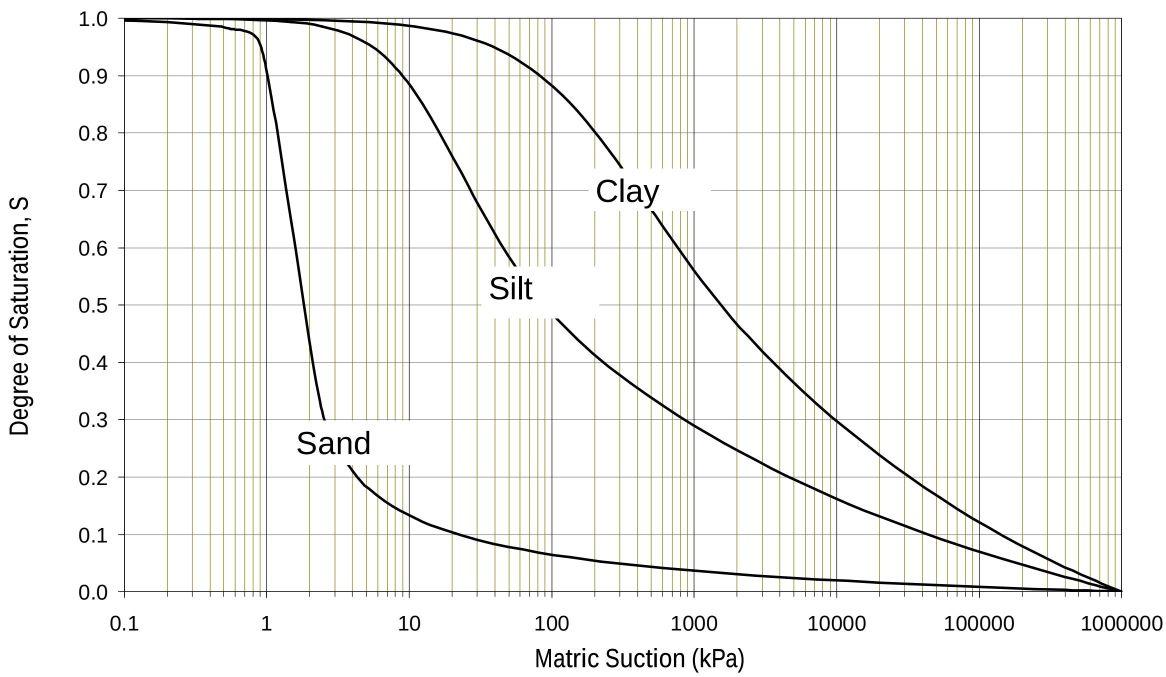


Figure 58

Typical Soil Water Characteristic Curves

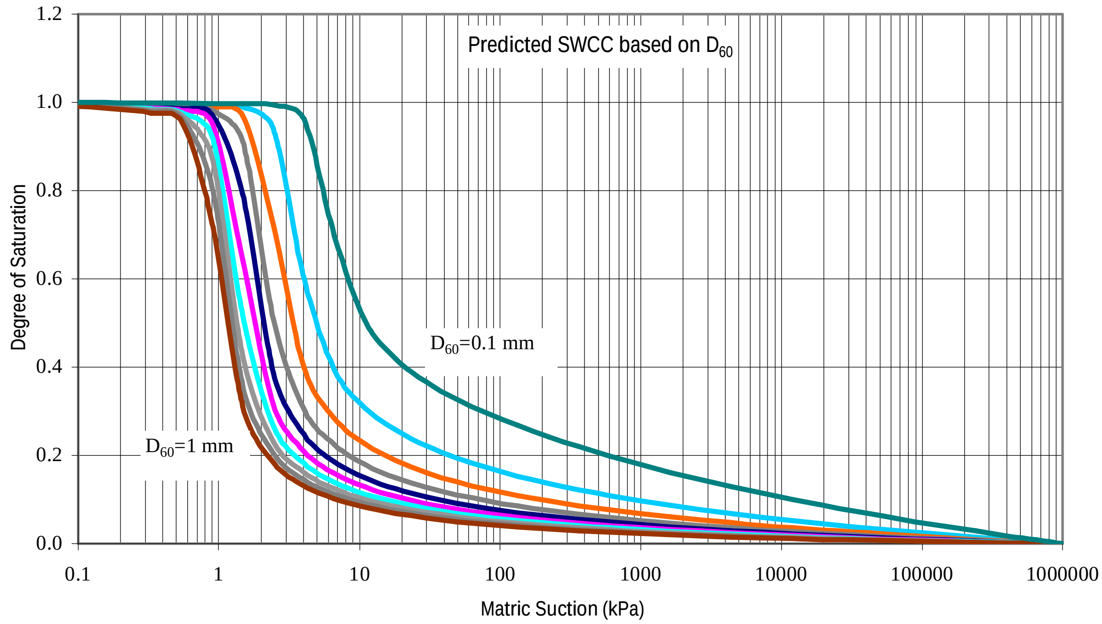


Figure 59
Family of Existing SWCCs for Non-Plastic Soils

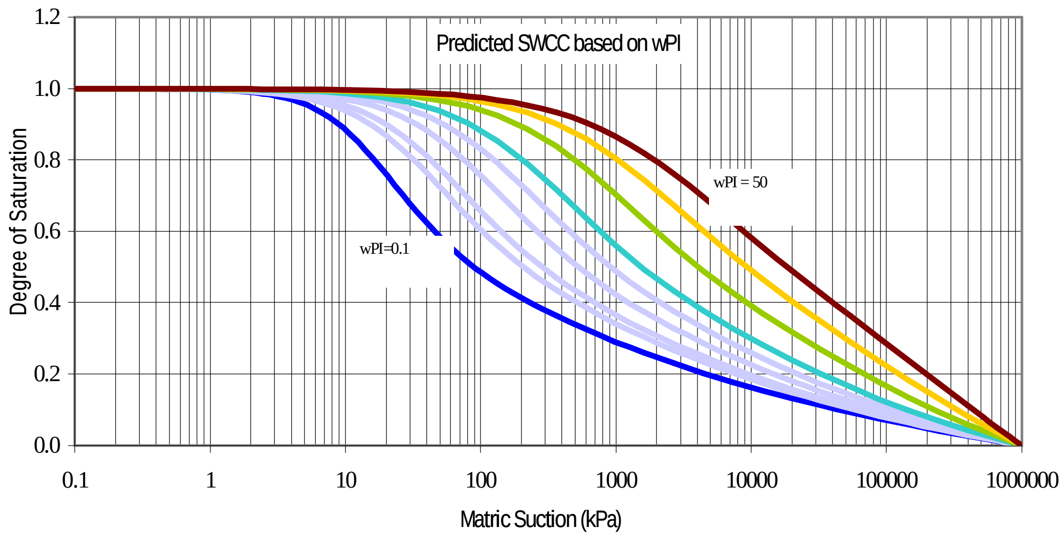


Figure 60
Family of Existing SWCCs for Plastic Soils

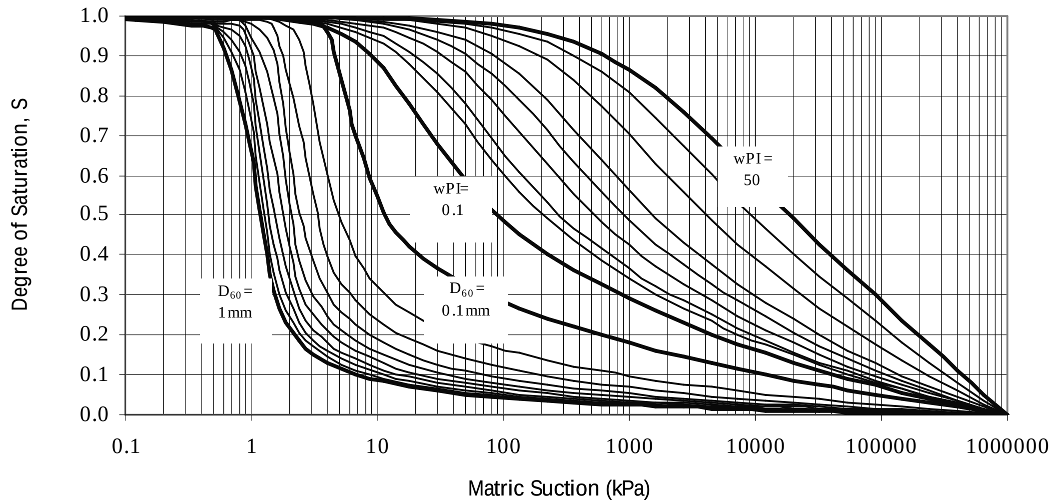


Figure 61
Family of Existing Soil-Water Characteristic Curves

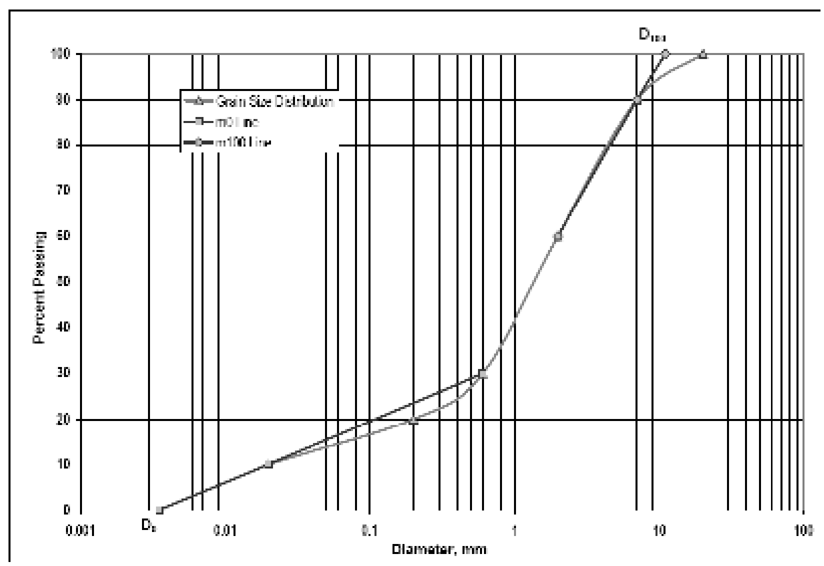


Figure 62
Projection of GSD to obtain D0 and D100

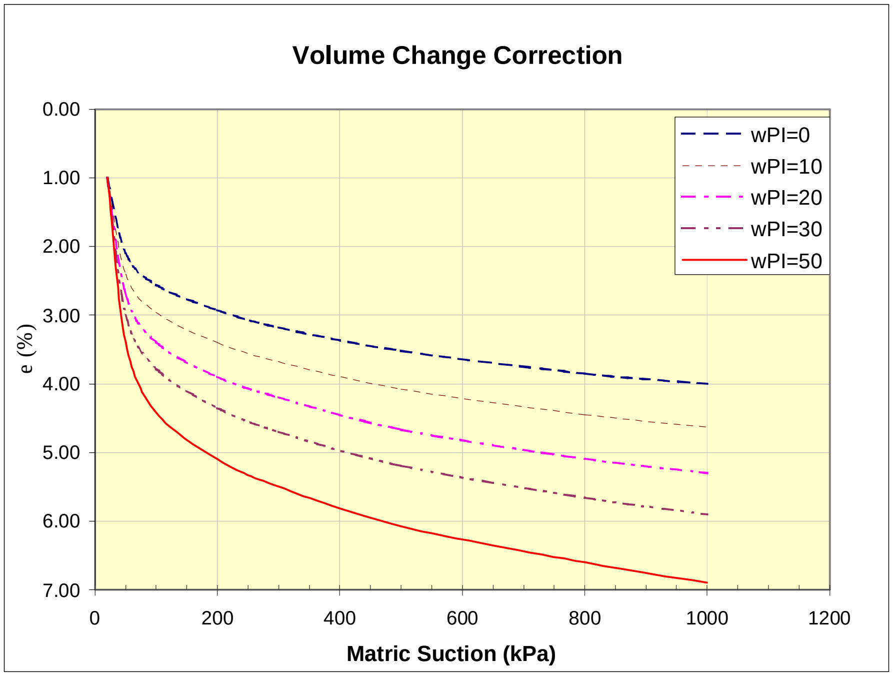


Figure 63
Volume Change Correction Curves

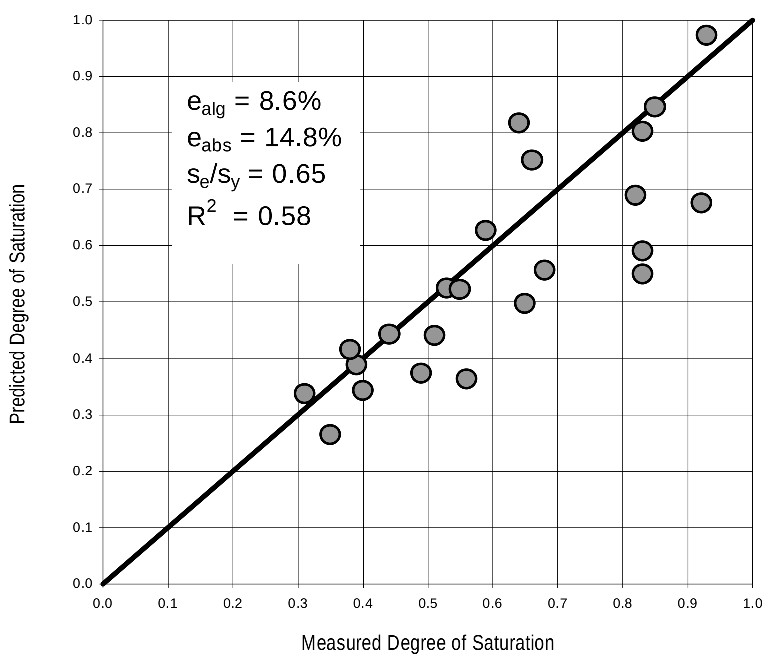


Figure 64
Measured versus Predicted *S* for Non-Plastic Soils

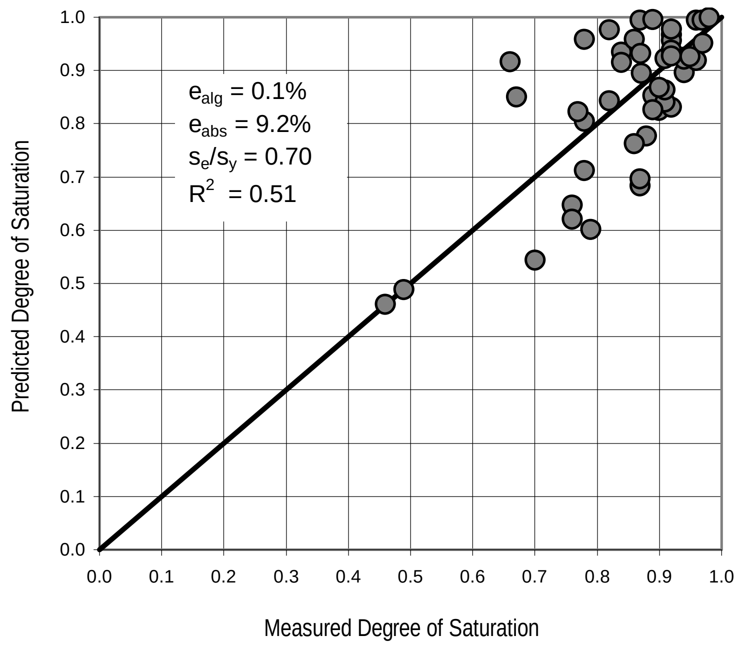


Figure 65
Measured versus Predicted *S* for Plastic Soils

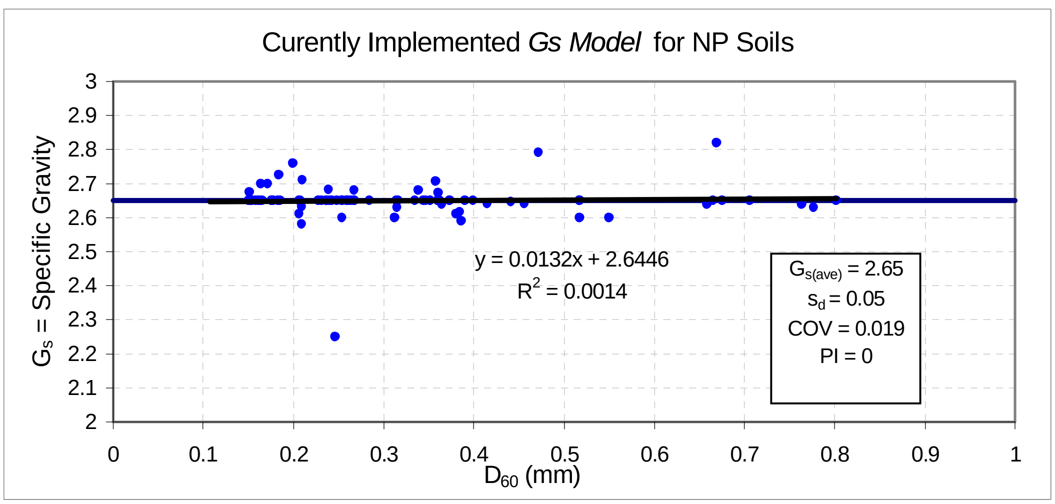


Figure 66
Currently Implemented *Gs Model* for Non Plastic Soils using the Literature Data Set

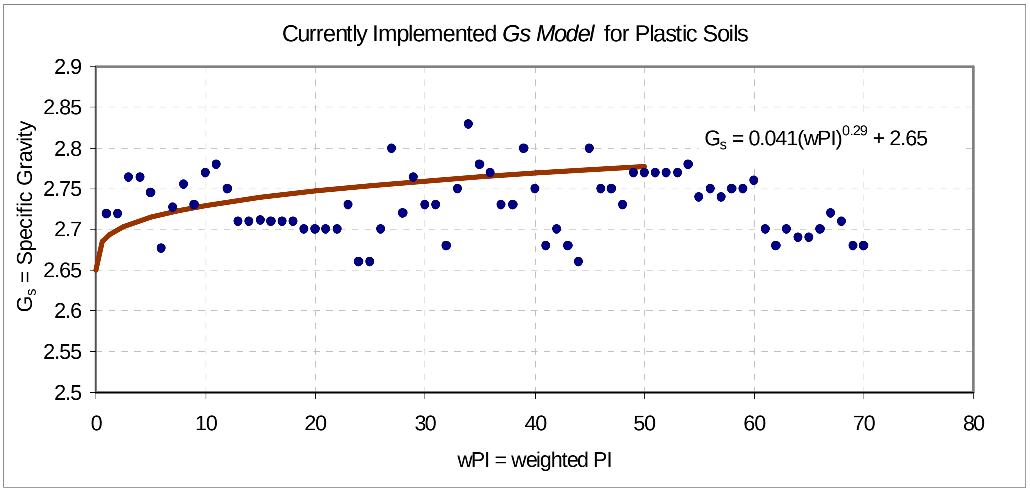


Figure 67
Currently Implemented *Gs Model* for Plastic Soils using the Literature Data Set

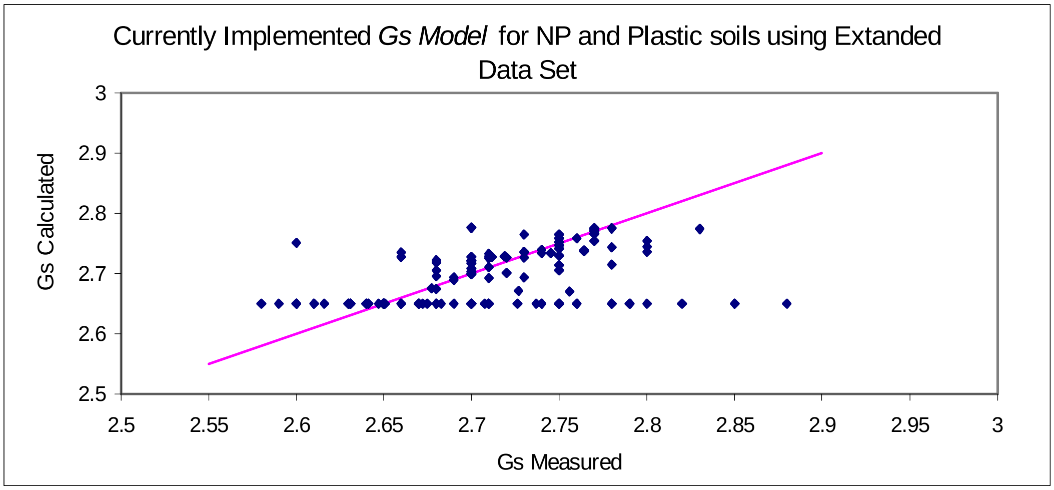


Figure 68
Error Analysis of Currently Implemented *Gs Model* for both NP and Plastic Soils Using the Extended Data Set

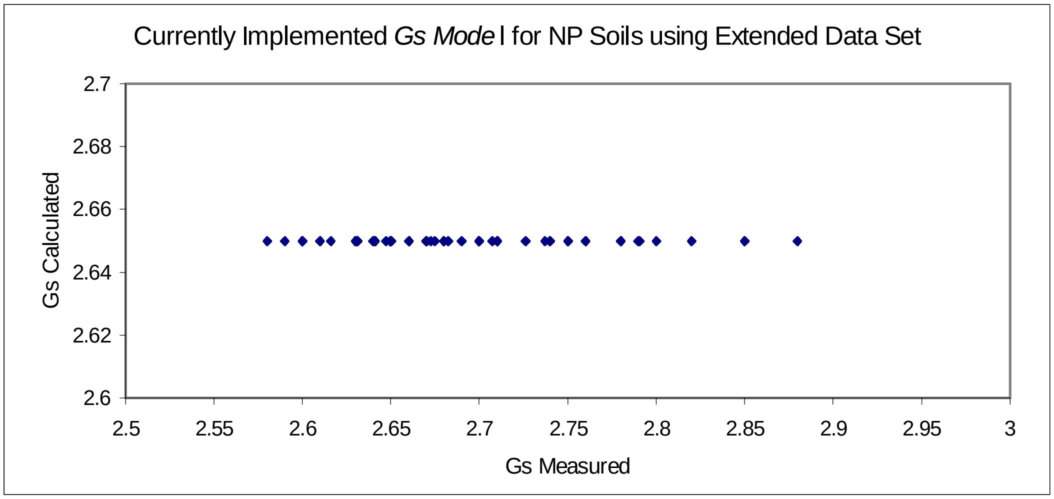


Figure 69
Currently Implemented *Gs Model* for Non Plastic Soils using Complete Data Set

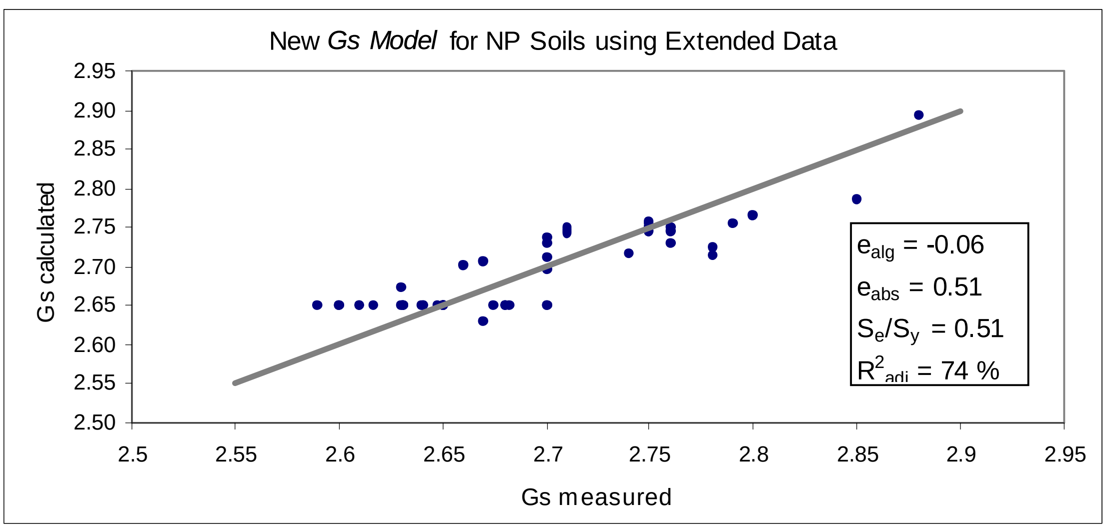


Figure 70
Error Analysis of Final Gs Model for Non Plastic Soils using Complete Data Set

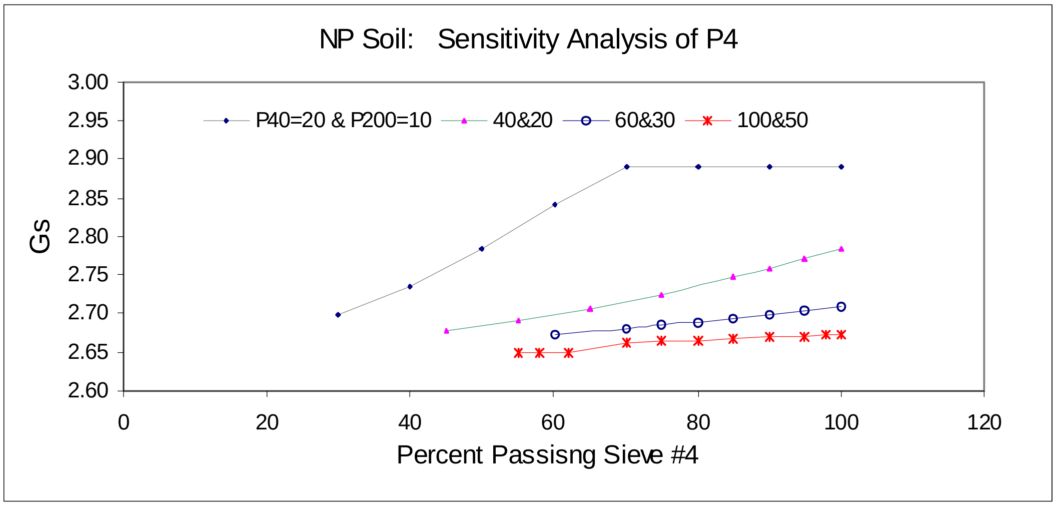


Figure 71
Sensitivity Analysis of P_4 for the Non-Plastic Soils

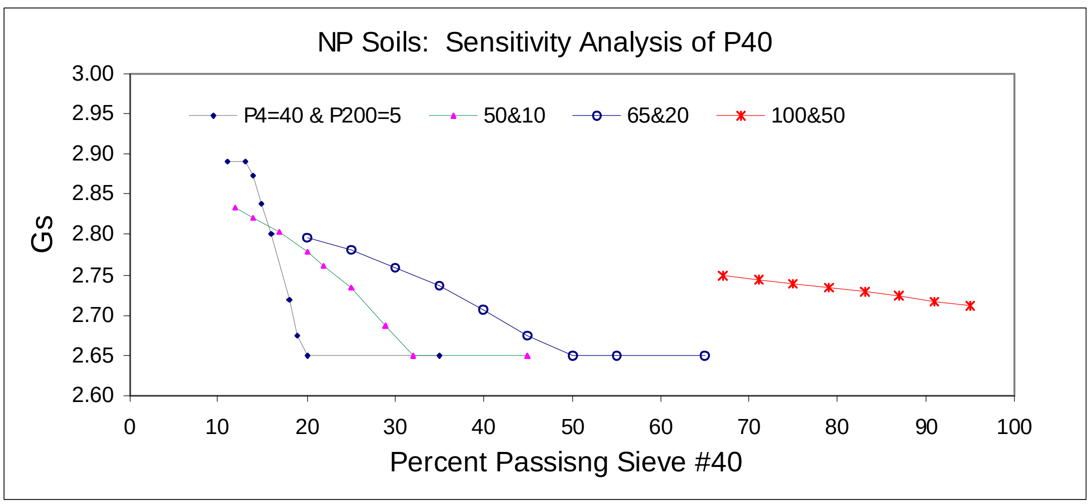


Figure 72
Sensitivity Analysis of P_{40} for the Non-Plastic Soils

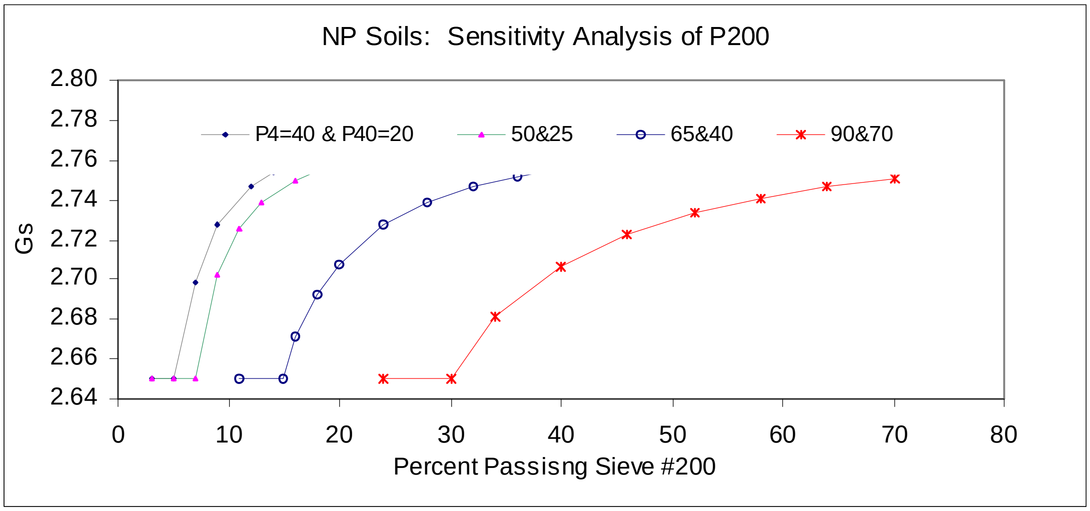


Figure 73
Sensitivity Analysis of *P_{200}* for the Non-Plastic Soils

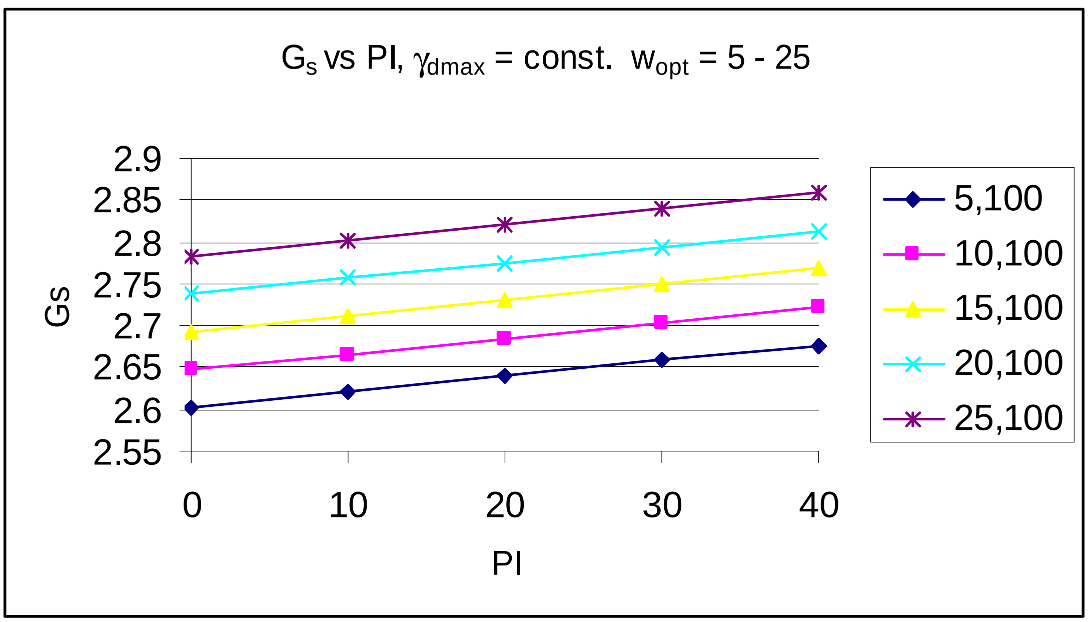


Figure 74
Sensitivity of *Gs Model* when *PI* is Varying and g_{d_max} and w_{opt} are Held Constant

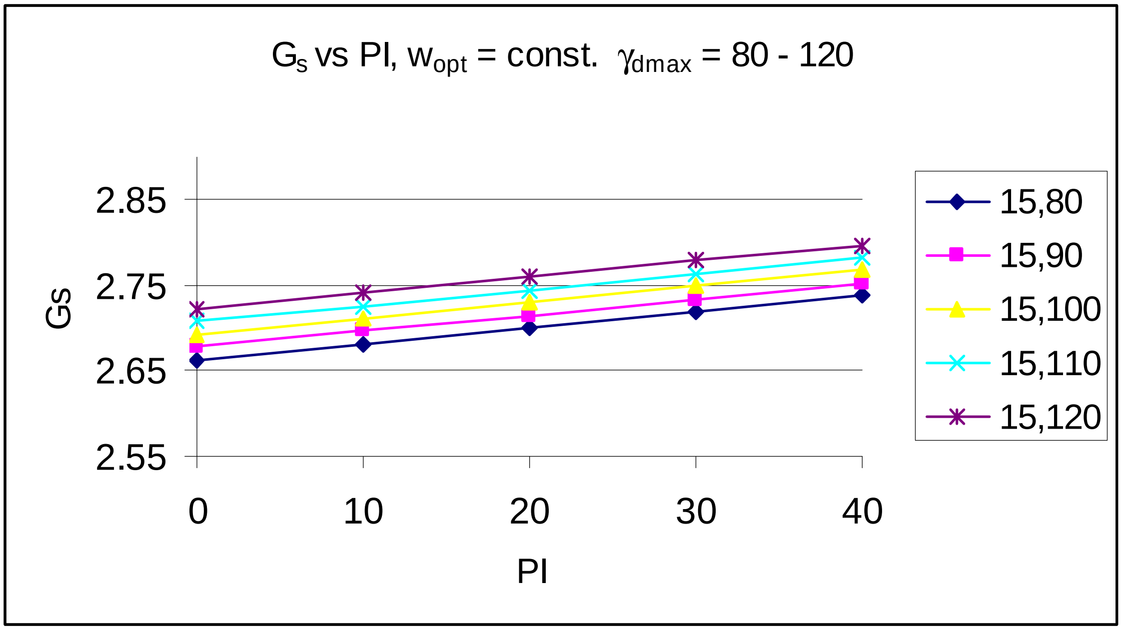


Figure 75
Sensitivity of *Gs Model* when *PI* is Varying and w_{opt} and g_{d_max} are Held Constant

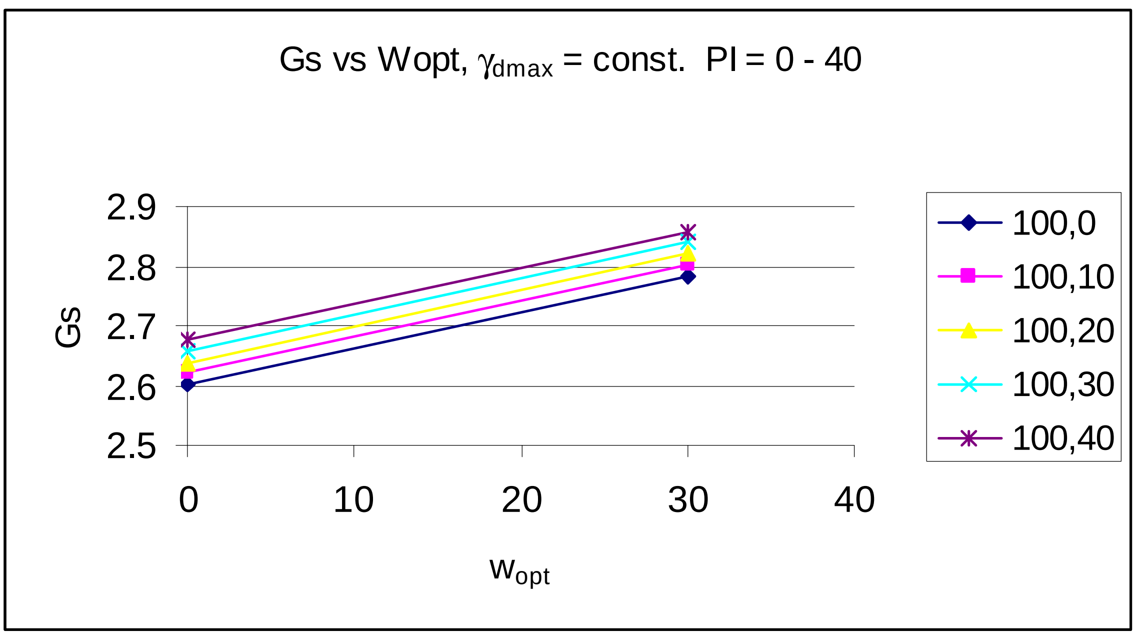


Figure 76
Sensitivity of *Gs Model* when w_{opt} is Varying and g_{d_max} and *PI* are Held Constant

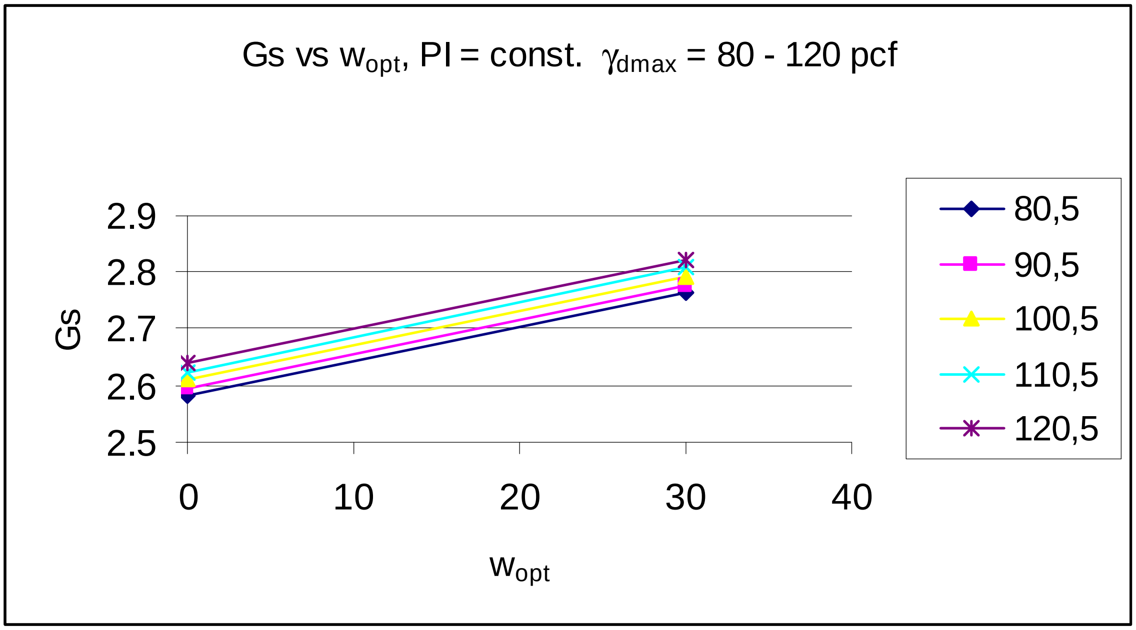


Figure 77
Sensitivity of *Gs Model* when w_{opt} is Varying and γ_{d_max} and *PI* are Held Constant

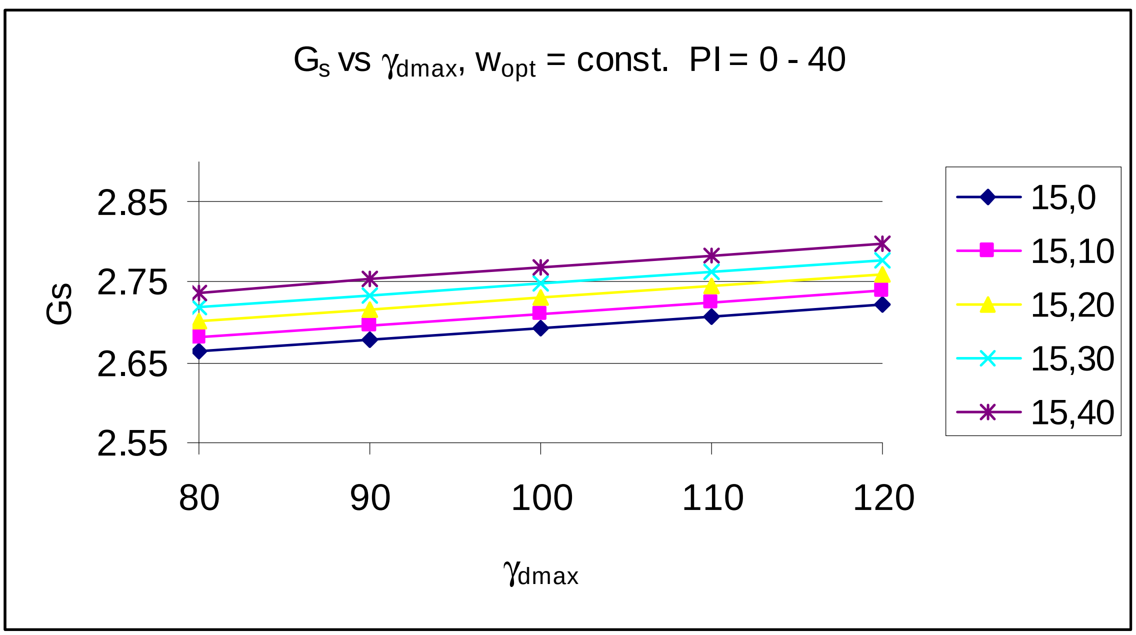


Figure 78
Sensitivity of *Gs Model* when γ_{d_max} is Varying and w_{opt} and *PI* are Held Constant

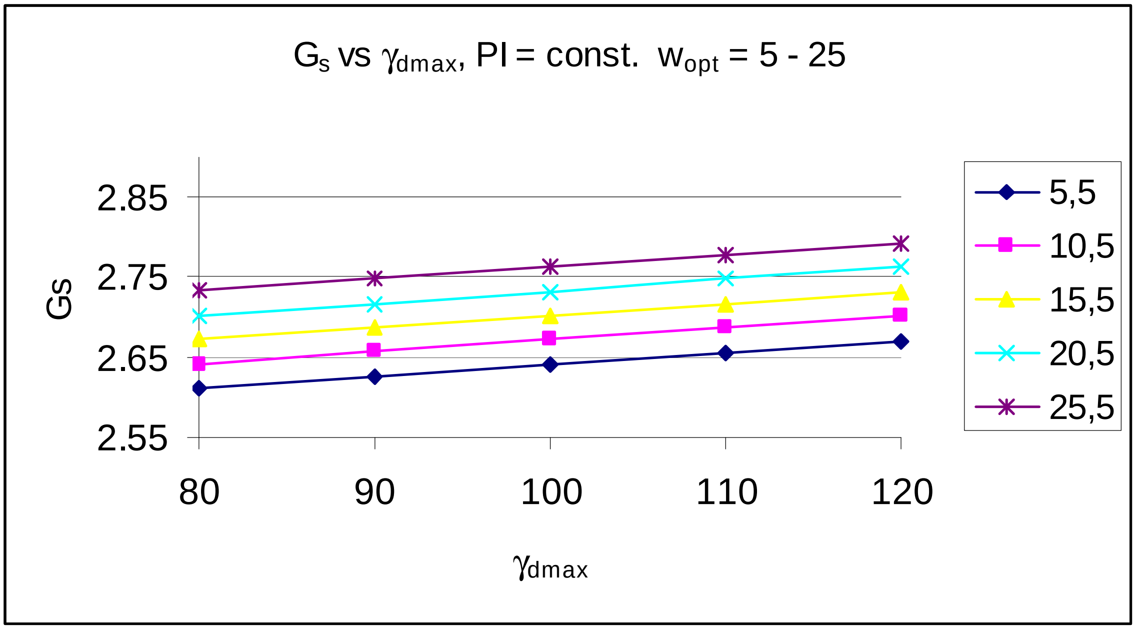


Figure 79
Sensitivity of *Gs Model* when g_{d_max} is Varying and w_{opt} and *PI* is Held Constant

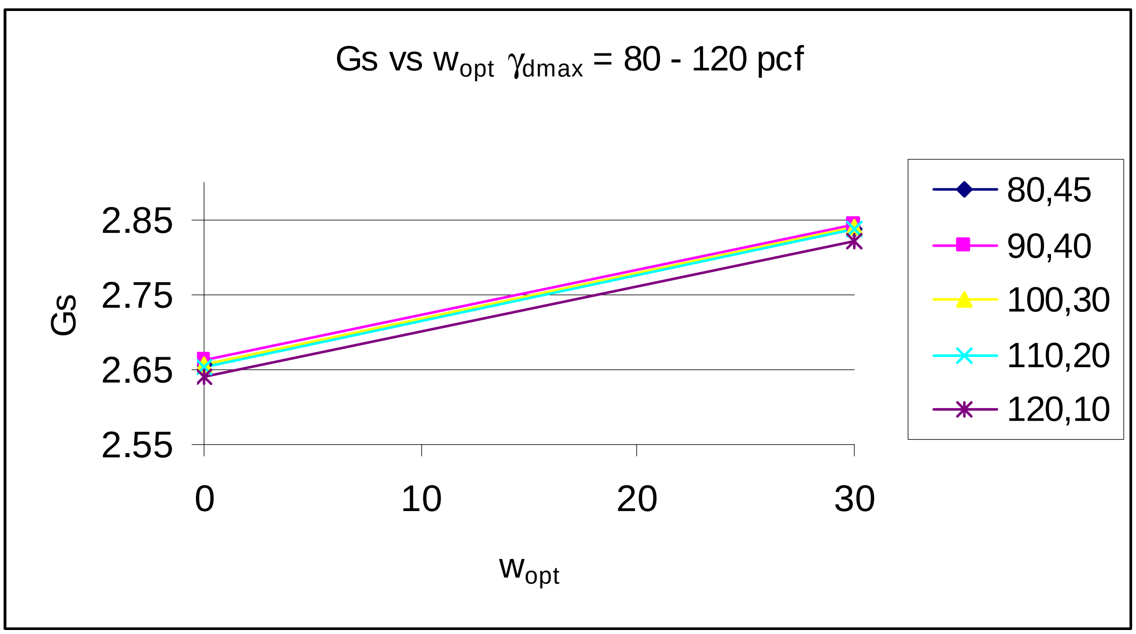


Figure 80
Sensitivity of *Gs Model* when w_{opt} and g_{d_max} are Varying and *PI* is Held Constant

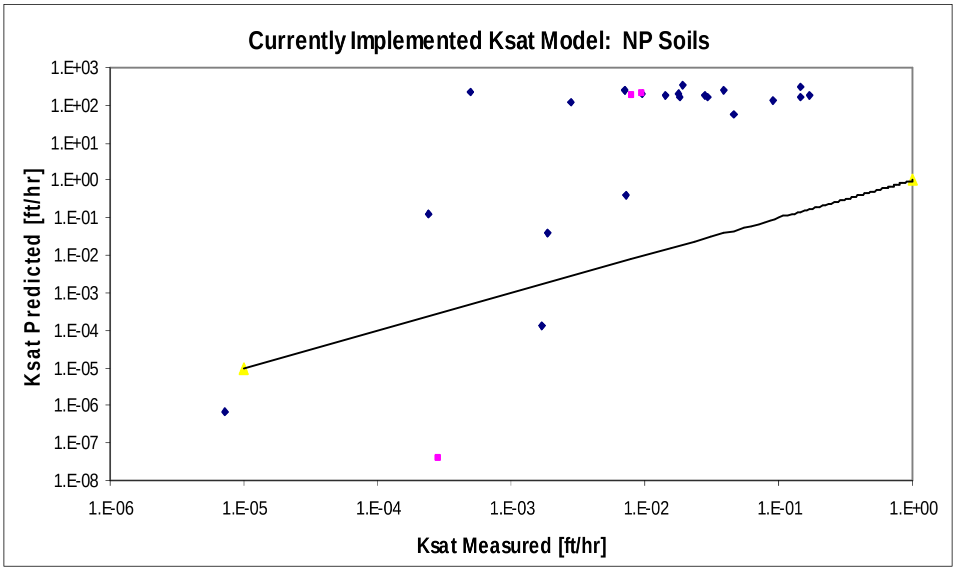


Figure 81
Performance of Currently Implemented *k-sat Model* for Non Plastic Soils Using the New Data Set

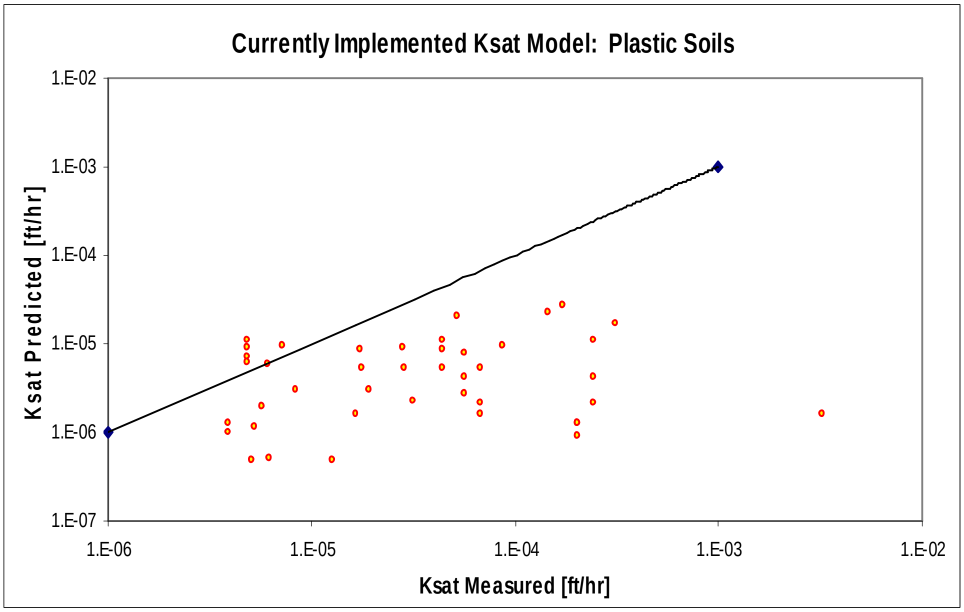


Figure 82
Performance of Currently Implemented *k-sat Model* for Plastic Soils Using the New Data Set

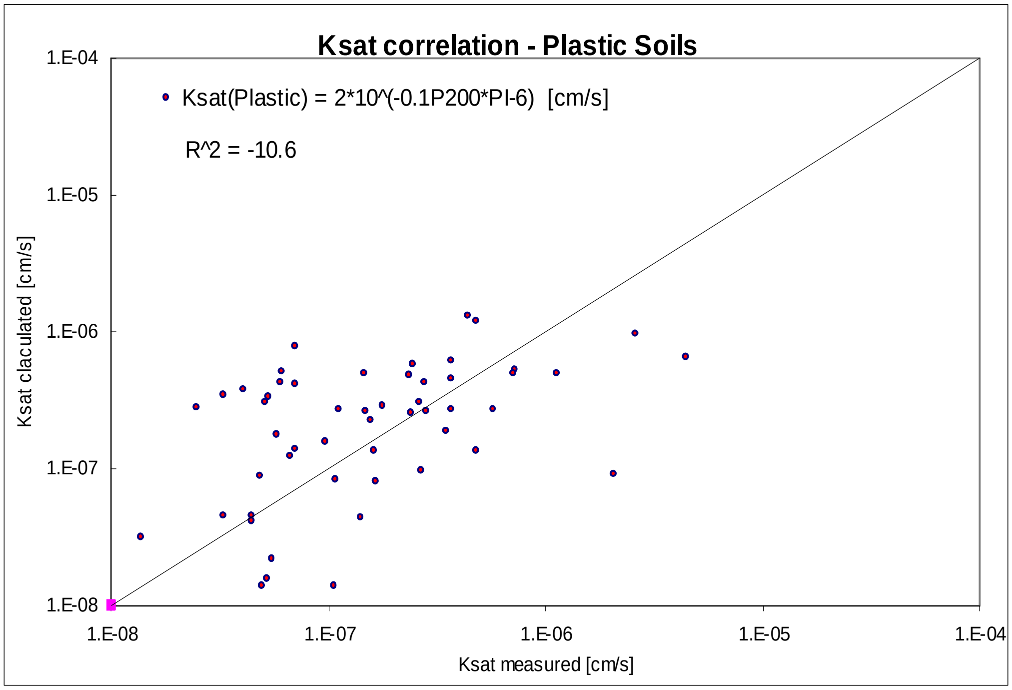


Figure 83
Performance of Improved *k-sat Model* for Plastic Soils Using the New Data Set

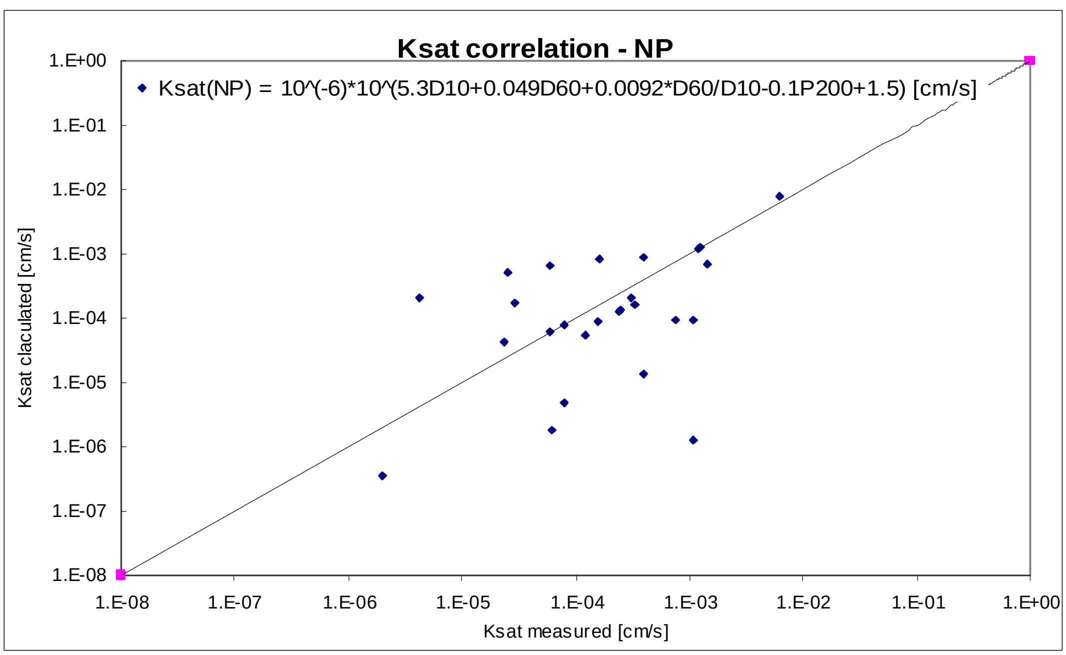


Figure 84
Performance of Improved *k-sat Model* for Non-Plastic Soils Using the New Data Set

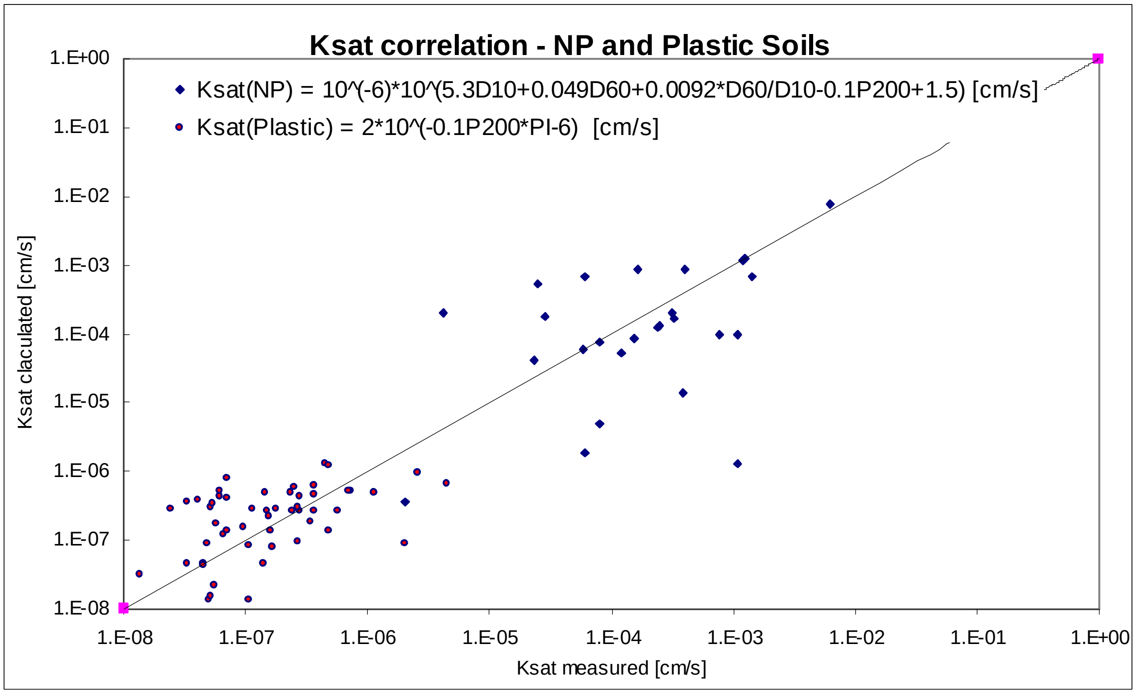


Figure 85

Performance of Improved *k-sat Model* for Plastic and Non-Plastic Soils Using the New Data Set

CHAPTER 7

RECOMMENDATIONS FOR FUTURE RESEARCH

In Chapter 6 the individual models were calibrated with the best dataset available, gathered from the sites visited. As expected, they perform better than the current 2004 EICM version 2.6 models. The next step planned as part of the 9-23 study was to validate the model results. This step required programming of the presented new models in order to check the overall response of moisture content predictions. Unfortunately, this programming was not completed at the due date of this report and for some time afterward it was impossible to validate the response of the models with time due to the complexity of the analysis. However, the models were validated by spreadsheet computations. There are, of course, several outputs of the EICM code which could be produced by the limited scope spreadsheet. Once this programming is complete and full implementation into the computer code is completed, further work should include a validation of the predictive models suggested in this report.

The individual models developed as part of this project are considered to comprise the state of the art material found in the literature, as well as a very substantial database derived form site visits and laboratory testing. However, there is room for improvement if the databases are extended and more information becomes available.

The ongoing effort to improve the models has been taken over by NCHRP 1-40D project entitled *Technical Assistance Project to NCHRP in the M-E Pavement Analysis System Developed under NCHRP 1-37A*. Based on ongoing studies on sensitivity of the models, deficiencies and continuous feedback received by the research team, future work planned under the 1-40D project will handle some of the model limitations the research team has found as of today (end of 2004). The following research work tasks will be evaluated under the 1-40D project:

- Task 5 required a sensitivity analysis of the fully validated EICM. In other words, after the EICM predictions had been made to be as accurate overall as practical, it was intended to quantify the sensitivity of the output variables to the input variables. This quantification involved varying the input variables through a multi-factor designed experiment over their reasonable ranges and mapping the corresponding output variable ranges. The sensitivity analysis was not possible as the models were not programmed due to time limitations. This sensitivity analysis is important because rational decisions need to be made relative to the time and money that should be spent in maximizing the quality of the input data. An informed basis is needed for deciding which input variables can be selected from a range of default values versus those inputs which should be project-specific or based on actual tests on materials from the project.

- The EICM can make predictions far into the future but those predictions are not necessarily valid for the long run, even if they are found to be valid for the short run. Any significant decrease in the quality of EICM long-term predictions (for a 20 to 25 year project life, for example) should be investigated. For the MEPDG the decision has been made to use as climatic input data a 5 to 7-year record and repeat this input as many times as necessary to complete the design project life. The reasonableness of this

decision should checked by securing several very long-term climatic data records, subdividing each full record into subsets, and then statistically characterizing and comparing the subsets.

- Validate the response of the models with time once the complete set of new equations is implemented into the EICM software.

- The *Suction models*, which make use of the Thornthwaite Moisture Index (*TMI*) to estimate suction, were calibrated with *TMI* values from a contour map that is available only for the continental U.S.A. In order to make the model universal, that is for sites within U.S.A., as well as for sites located outside the U.S.A; an attempt should be made to develop an equation or analytical model that estimates the *TMI* based on climatic parameters and Latitude.

- The models developed were subdivided into models that predicted the needed properties for granular, non-plastic materials and models that predicted properties for fine-grained, plastic materials. Some of the models, such as the *Suction model* showed a nice overlapping of the results for both types of soils. Further research should be done to refine the merging of the two models, especially for the *SWCC models*.

- Finally, flow diagrams for the three hierarchical levels of analysis used in the MEPDG are needed to improve the user's knowledge of the internal processes used by the Enhanced Integrated Climatic Model to predict the moisture content variation of the unbound materials under pavements.

It is envisioned that the models improvement will be an ongoing effort once enough feedback have been received and sensitivity analysis have been performed. Additional long term research studies should include:

- Further expansion of the database developed in this study would clarify and enhance the models developed. Even though a sensitivity analysis was done for each one of the models presented, the complete database used to calibrate the Level 1 analysis was limited to thirty sites visited. For Level 3 analysis, the LTPP effort has been a great source of information but unsaturated soil properties are missing. A comprehensive study that includes laboratory testing of the most important unsaturated soil characteristics will allow researchers to re-calibrate and enhance the models, to include new data available and to refine the limits or boundaries of the proposed equations. The development of a national database that includes unsaturated soil properties is strongly encouraged.

- A sensitivity analysis that quantifies the error in moisture content predictions due to errors in the input parameters. The error quantification would allow an evaluation of the corresponding error in the resilient modulus prediction, which is linked to the changes in moisture content. With this analysis, one should be able to estimate the effect of error in moisture content prediction on the pavement design life.

- The definition of a more accurate set of Level 3 default parameters for unbound materials is needed. This can be accomplished if a rigorous sensitivity analysis of the input parameters, as previously explained, can be carried out.

- Revisitation of the resilient modulus models, which utilize total stress and suction directly, thus bypassing SWCCs and moisture content, is strongly recommended. This can be accomplished by using the new suction models to estimate the equilibrium (average) future suction and then use the SWCCs latest version models and known placement conditions to estimate "initial" moduli, which gradually migrate to the equilibrium (average) moduli.

- The NCHRP 9-23 team did not have the time and resources to investigate one important aspect of moisture movement not currently addressed in the EICM. One major hypothesis formulated by the research team is that the primary source of water reaching the base course is a result of nighttime condensation of water vapor coming in laterally from the shoulders and or underlying layers. The process is hysteretic and difficult to reverse and any buildup of water in the base course is then pulled into the subgrade, more or less at steady state. Research on the hysteretic nature of the SWCCs should be part of a future effort to improve the models.

- Neither the moisture movement caused by temperature gradients or by osmotic suction (solute potential due to salts) is considered in the current model. The model is rather simplistic considering the complexity of the phenomenon but includes the most important elements and complies with the objective to incorporate a sound environmental analysis in the pavement design. Through calibration (comparison of measured and predicted moisture contents and model adjustment) some of the errors due to omission of temperature gradients and solute gradients have been compensated for in the current models. However, the research team considers temperature and osmotic suction gradients to be significant and should be a topic for further research.

CHAPTER 8

SUMMARY AND CONCLUSIONS

This report has documented and presented the results of the NCHRP 9-23 Project titled *Environmental Effects in Pavement Mix and Structural Design Systems.* A statistically-based experiment design for the calibration and validation of the Integrated Climatic Model (ICM) version 2.6 was presented. The variables required to run and validate the EICM were identified, as well as the variables needed to select the pavement sections for the analysis.

The Enhanced Integrated Climatic Model (EICM) was subjected to evaluation and calibration under this project. The EICM is a one-dimensional coupled heat and moisture flow model initially developed for the FHWA and adopted in the *Mechanistic-Empirical Pavement Design Guide* (MEPDG) developed under NCHRP 1-37A project. The model is intended to predict or simulate the changes in behavior and characteristics of pavement and unbound materials in conjunction with environmental conditions over several years of operation. The research work presented in this report was intended to evaluate and calibrate the ICM version 2.6 (currently known as EICM) moisture predictive capabilities.

In order to evaluate and calibrate the EICM, 30 sites were selected for field investigation which included 28 LTPP sites, the MnRoad test facility, and the WesTrack test facility. The 30 sites were visited in 8 trips that lasted more than 100 days, covered 40 states, 75 major cities and 40,000 plus miles. An ASU graduate student, assisted by a faculty member or a graduate assistant, performed the fieldwork. In general, three locations, three feet apart, located along the center of the outer lane of the highway were cored and soil samples were collected representing each unbound layer beneath the pavement. At the 18 LTPP SMP sites, the three locations were cored near the TDR instrumentation hole just outside the respective test section, in the transition zone located either at the start or end of the section. At non-SMP sites there was no TDR instrumentation and, therefore, sampling was performed in one of the two transition zones approximately 8 to 10 feet from the section. Typically, three sand cone tests and samples from the granular base and six tube samples from the subgrade were obtained from each site. In addition, a tube sample or a grab sample was collected from the side of the highway away from the shoulder. If cracks were present in the pavement, one of the three locations (or a fourth location) was chosen next to a crack. A total of 84 sand cone tests were performed in-situ. Eighty-four AC cores were brought to the ASU laboratories along with 165 tube samples for asphalt and soil characterization. Details of planning stages and the field testing were presented in Chapters 1 and 2.

The number of tests performed for this project was very large compared to a typical testing program performed in the laboratory. The laboratory program included 257 moisture content determination tests, 251 dry density determinations, 144 grain size distribution curves, 148 Atterberg limits tests, 104 specific gravity tests, 64 saturated hydraulic conductivity tests, and 85 soil-water characteristic curves determinations.

Table 105 presents the mean, maximum, minimum and coefficient of variation of the soil properties for nonplastic and plastic soils. In addition to the tests performed on soil samples, 22 hydraulic conductivity tests were performed on the AC cores obtained from the AC pavement sites. All the asphalt cores were eventually relinquished to the advanced pavement group at ASU for asphalt testing. Details of the laboratory testing program and results were presented in Chapter 4.

In addition to the data collected from field testing, the parameters and information needed to complete the input set to run the Enhanced Integrated Climatic Model as well as parameters to validate the models were extracted from the existing databases. The search was focused in the following databases: Long Term Pavement Performance (LTPP) Database, MnRoad, WesTrack, and Arizona Department of Transportation (ADOT) Database. A summary of each parameter collected from databases was presented in Chapter 3.

The NCHRP 9-23 research team measured hydraulic conductivity for some 22 large cores of bound material from the 30 sites visited. The hydraulic conductivity was found to be far too low to account for any significant water infiltration through the asphalt mix layer. For the 30 sites visited, very few cracks were found. In a few cases where cracks were found, the water content adjacent to the crack was measured and found to be not statistically significantly higher than other locations away from the crack. Furthermore, early in the original NCHRP 1-37A study, the ASU team made some limited attempts to find correlations by plotting TDR water contents versus time under plots of precipitation versus time and groundwater table depth versus time. Absolutely ***no correlations*** were found between the TDR readings and rainfall events nor between TDR readings and fluctuations in the groundwater table. Some modest variations in TDR readings with temperature changes, which possibly reflect some real water content change or possibly a sensitivity of the TDR to temperature, were found.

The equilibrium moisture condition in the EICM version 2.6 is currently based on a suction model that depends on the water table depth and on a SWCC model that is functionally dependent on simple soil properties. Findings by the team in charge of the NCHRP 9-23 project indicated that the sources of error in the prediction of moisture content were primarily derived from the *Suction model* currently implemented. Further analysis and research indicated that a much more accurate approach exists for suction computations through the use of the specific models presented in this report. A detailed statistical analysis is shown in Chapter 5.

The new *Suction model* eliminates the use of the water table depth as the basis for the prediction and incorporates an approach based on the Thornthwaite Moisture Index (*TMI*). To some significant degree, this index balances lateral infiltration and evaporation for a particular region. While the recommended *TMI* methodology (new *Suction models*) has an empirical component; it has been found that the new model significantly improves the prediction of the equilibrium moisture for the granular bases, which helps to alleviate the stated concerns of the team of independent reviewers of the MEPDG.

In addition to the new *Suction model*, new or re-calibrated models such as the soil-water characteristic curve models (*SWCC models*), the specific gravity model (*Gs model*), the saturated hydraulic conductivity model (*Ksat model*), and the *Compaction model* were developed based on

the extensive database gathered from the field. Approximately 50 different models were tested against measured data in the process of development the presented models. Details of the new or re-calibrated models are shown in Chapter 6.

The NCHRP 9-23 research team is aware that the existing Surface Water Infiltration methodology is still available and that it may be possible to arbitrarily increase the base course water content, more or less at will. However, the team feels that this approach is not superior to the methodology presented in this report, which is consistent with actual measured water contents at the 30 sites visited and at other sites that were not visited.

The NCHRP 9-23 team did not have the time and resources to investigate and quantify the effect of temperature fluctuations on moisture movement under the pavement. One major hypothesis formulated by the research team is that the primary source of water reaching the base course is a result of nighttime condensation of water vapor coming in laterally from the shoulders and or underlying layers. The process is hysteretic and difficult to reverse and any buildup of water in the base course is then pulled into the subgrade, more or less at steady state. Further research would be needed to quantify the effect theoretically. However, this effect has already been incorporated empirically in the various models developed as a part of this project. A detailed list of the tasks that should be accomplished under future research was presented in Chapter 7.

Table 105
Summary of Laboratory Results on Unbound Materials

Parameter	Nonplastic soils			Plastic soils		
	Range	Mean	COV (%)	Range	Mean	COV (%)
Moisture content (%)	2 – 20	7	50	3 - 55	19	38
Dry density (pcf)	100 - 146	129	10	65 - 146	108	12
Plasticity Index	NP	NP	--	1 – 42	15	57
Degree of saturation (%)	27 – 100	74	29	16 – 100	81	20
Matric suction (kPa)	3 - 150	28	109	20 - 1100	179	122
Specific gravity	2.60 – 2.88	2.73	2.3	2.64 – 2.87	2.74	1.7
Hydraulic conductivity (ft/hr)	3E-5 – 0.7	7	2	4E-6 – 1E-2	6E-4	340

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