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16. Abstract
The Texas Department of Transportation (TxDOT) currently uses Item 247 "Flexible Base" to specify a pavement foundation course. The goal of this project was to evaluate the current method of base course acceptance and investigate methods to replace materials approval based on stockpile sampling and testing with a mixture design methodology and quality control procedure. Researchers gathered existing information that would assist in defining the types of tests to be used, specification acceptance criteria, and acceptance limits. Researchers then gathered data to identify tests that should be considered for inclusion in the specification and defined property variability of base course materials from nine pits/quarries in Texas. They also conducted other activities concerning precision and bias statement development, production/placement variability, technician certification, laboratory accreditation, and the development of relationships that allow test property parameters to predict pavement performance. The project developed draft flexible base course specifications in a quality control/quality assurance and quality monitoring program format. Researchers recommend an implementation project to determine the accuracy of the developed pavement performance prediction techniques and the suitability of the specification, including the types and limits of the test parameters in the specification.

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DEVELOPMENT OF A SPECIFICATION FOR FLEXIBLE BASE CONSTRUCTION

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

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This project was made possible by the Texas Department of Transportation and the Federal Highway Administration. The Project Director was Caroline Herrera, P.E. Members of the Project Monitoring Committee included: John Bilyeu, Darlene Goehl, Ronald Hatcher, Joe Leidy, Stevan Perez, Chris Reed, and Richard Williamee. The Project Director and Project Monitoring Committee were responsible for review of all specifications and work plans associated with sampling and testing. German Claros was the Project Engineer and provided overall guidance for the project.

A number of graduate and undergraduate students participated in the project. An Industry Working Group, consisting of the following, was responsible for review of all specification documents: Karl Bednarz (TxDOT), Glen Dvorak (TxDOT), Darlene Goehl (TxDOT), Richard Williamee (TxDOT), Brad Bradford (Industry), Harry Bush (Industry), Ted Swiderski (Industry), and Johnny Weisman (Industry). Special thanks to the Texas Associated General Contractors and Thomas Bohuslov for arranging for and facilitating meetings with suppliers and contractors on the Industry Working Group.

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CHAPTER 1. INTRODUCTION

BACKGROUND

The Texas Department of Transportation (TxDOT) currently utilizes Item 247, "Flexible Base," to specify a foundation course of flexible base for use in a pavement structure. This current specification utilizes aggregate gradation, Atterberg Limits, Wet Ball Mill, and compressive strength to define the desired properties of a flexible base material. The specification limits, based on these parameters, are broad in order to accommodate the wide variety of aggregates sources available in Texas.

Material approval is achieved by testing individual stockpiles and ensuring that the material meets the specified requirement for different types and grades of materials, as described in Table 1.1. Since flexible base material contains a wide range of aggregate sizes, stockpiles are easily segregated, non-uniform, and representative samples are difficult to obtain. Variability of properties can be relatively large, depending on the methods used to form the stockpile and the methods of sampling.

Under current specifications, base materials are not allowed to be utilized by the contractors until the materials have been approved in the stockpile, typically, at the point of production or at or near the construction site. A number of days and perhaps months are required to build a stockpile. Since stockpiles are not allowed to be used until testing and acceptance is complete by TxDOT, stockpile space and risk of acceptance by the producer/contractor can become problems.

The number of stockpiles produced by producer/contractors during a construction season is considerable. The number of TxDOT employees available for sampling and testing is limited in many locations in the state, and timely evaluation of flexible base materials can become a problem. Producer/contractors are not presently required to perform process control or quality control tests during the production and stockpiling of these materials. Thus, the risk of producing a material that does not meet the specification, as sampled and tested by TxDOT, is higher than desired.

Research Project 0-6621 (Developing a Mixture Based Specification for Flexible Base) was developed by TxDOT to evaluate the current method of base material acceptance, as required in Item 247, and to investigate methods to replace material approval based on stockpile sampling and testing with a mixture design methodology and quality control procedure. The methodology stated in the Request for Proposal (RFP) indicated that the producer/contractor should provide a design of the flexible base materials that would meet the specification requirements similar to the Job Mix Formula concept used in hot mix asphalt specifications. In addition, the RFP desired the development of protocols to ensure that the materials delivered and placed in the field meet the requirements specified by the contractor in the Job Mix. Relatively simple tests for quality control, quality assurance, and acceptance were also desired by TxDOT. TxDOT expected the research to be completed in two years.

TxDOT envisioned that the project would provide a methodology that would provide a more uniform flexible base material that would meet specification requirements when placed in the field. The methodology would make the testing and acceptance of materials by TxDOT more efficient, reduce manpower requirements for TxDOT, reduce the time of acceptance/rejection of a material, and increase the responsibility of the contractor to produce a consistent, high-quality product.

Based on the information supplied in the RFP and by the Project Monitoring Committee, a scope, objective, and outcomes have been formulated by the Texas A&M Transportation Institute (TTI) research team to guide the project. These are presented below.

SCOPE

The scope of the project is directed to the development of a mixture-based specification for flexible base material utilizing as many current test methods and acceptance criteria as possible without significant changes in the Type and Grade of material, as defined in the current base material specification (Table 1.1). The developed specification should not significantly alter the Equipment, Construction, Method of Measurement and Method of Payment sections of the current specification. Quality control/quality assurance (QC/QA) specification elements should be considered in development of the specification. Stabilized base materials and cold in-place recycling operations would not be considered in this effort.

OBJECTIVES

As stated in the RFP, the main objectives of this project are as follows:

1. Propose modifications to the current specification.
2. Develop criteria for the gradation tolerances from a Job Mix Formula that will not compromise the strength of the material.
3. Develop a quality control procedure to test and accept material in the field in lieu of strength testing materials from individual stockpiles.
4. Identify tests that can be used to establish quality control parameters (including tolerances) and that can be used to compare field materials with approved Job Mix Formula material properties.
5. Identify simple tests along with specification limits to evaluate the durability of aggregates used in flexible base.
6. Develop QC/QA procedures that ensure that the flexible base material utilized on a project matches the approved design.
7. Verify acceptance criteria with flexible base materials that represent the population of aggregates used by TxDOT.

DESIRED OUTCOMES

Desired outcomes for the research, as stated in the RFP, include:

1. Test flexible base materials in the field rather than in stockpiles.
2. Improve the efficiency of testing and acceptance of materials by TxDOT.
3. Reduce TxDOT workforce needs for sampling and testing.

4. Reduce flexible base materials acceptance time.
5. Increase responsibility of the contractor to control the consistency and quality of the material produced.

APPROACH

TTI researchers prepared a proposal to perform the research based on their understanding of the RFP and in particular the Scope, Objective, and Outcomes, as stated above.

A 12-task work plan was proposed, as shown on Figure 1.1. The key features of this work plan were as follows:

1. Early formulation of a draft specification.
2. Utilization of TxDOT's Project Monitoring Committee (PMC) to review and recommend changes to the specification.
3. Formation of an Industry Working Group (IWG) consisting of representatives from TxDOT and producer/contractors to review and recommend changes to the specification.
4. Utilization of existing information, as much as possible, to formulate acceptance criteria and limits for the specification.
5. Performance of research to fill the information gaps in the specification.
6. Perform implementation efforts consisting of certification and accreditation programs, shadow specification field projects, and training/workshops.

The initial efforts were focused toward the development of a QC/QA type of specification for base material. This specification contained the requirement for a Job Mix Formula developed by the producer/contractor, sampling and testing plans for the producer/contractor for quality control purposes, and sampling and testing plans for TxDOT for quality assurance. This type of specification format satisfied many of the objectives and outcomes of the project and satisfied the scope of the research program. Figure 1.2 illustrates the review and revision process. Review and revisions were also made by the Project Director and members of the research staff. Numerous drafts of the QC/QA specification were prepared during the two-year duration of the project.

The specification development was re-directed toward a "Quality Monitoring Program" approach based on an October 15, 2011, meeting of the Industry Working Group. The first draft of this type of specification was supplied to TxDOT in January of 2012.

Research Team

The research team was composed of TxDOT, an Industry Working Group, and Texas A&M Transportation Institute staff as shown on Figure 1.3. Caroline Herrera was the Project Director (PD) and chaired the Project Monitoring Committee, which consisted of the TxDOT Advisors identified on Figure 1.3. The Industry Working Group was co-chaired by Caroline Herrera from TxDOT and Lon Albert from industry. Four TxDOT and four producer/contractors were members of the IWG. The TTI Team was headed by Jon Epps and Stephen Sebesta. Research Engineers included Dr. Lytton, Dr. Luo and Joe Button. Several graduate and undergraduate students as well as technicians and support staff were involved in the research effort for TTI, as shown on Figure 1.3.

Project Monitoring Committee and Industry Working Group Meetings

The Project Monitoring Committee met to initiate the project on October 21, 2010, and held meetings on February 15, 2011, June 9, 2011, and October 7, 2011, to review draft specifications and sampling and test plans. A meeting was held on April 27, 2012, to review the progress of the study. Based on this meeting, a memo was prepared to outline the tasks to be completed by September 1, 2012 (termination of the project), and which tasks would not be completed.

The Industry Working Group met on September 13, 2011, October 26, 2011, and September 26, 2012, to review draft specifications and discuss the status of the project. Minutes are available from all of these meetings.

Specification Drafts

Specification drafts were prepared by the research team and reviewed according to the following schedule:

January 15, 2011	Draft Prepared and Reviewed by PD-QC/QA Format
February 15, 2011	Draft Prepared and Reviewed by PMC-QC/QA Format
March 11, 2011	Draft Prepared Based on February 15, 2011, Meeting of PMC-QC/QA Format
April 1, 2011	Draft Prepared Based on TTI Internal Review-QC/QA Format
June 15, 2011	Draft Prepared Based on June 15, 2011, Meeting of PMC-QC/QA Format
September 10, 2011	Draft Prepared Based on PD and TTI Internal Review-QC/QA Format
October 1, 2011	Draft Prepared Based on IWG Review on September 13, 2011-QC/QA Format
October 15, 2011	Draft Prepared Based on October 7, 2011, Meeting of PMC-QC/QA Format
January 19, 2012	Draft Prepared Based on October 26, 2011, Meeting of IWG-Quality Monitoring Program Format

The last draft of the specification was supplied by the research team on January 19, 2012, in a Quality Monitoring Program format. Review and revision of this specification draft was delayed until the field sampling and testing program, and information from TxDOT historical records and producer/contractors historical records could be obtained and analyzed. These delays resulted in elimination of Task 10.0 (Shadow and Field Projects) and Task 11.0 (Training/Workshops). To date, Task 9.0 (Certification and Accreditation) remains incomplete, as all of the test methods that will be used in the specification have not been finalized.

Table 1.1. Material Requirements.

Property	Test Method	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Master gradation sieve size (cumulative % retained)	Tex-110-E					
2-1/2 in.		–	0	0	As shown on the plans	0
1-3/4 in.		0	0-10	0-10		0-5
7/8 in.		10-35	–	–		10-35
3/8 in.		30-50	–	–		35-65
No. 4		45-65	45-75	45-75		45-75
No. 40		70-85	60-85	50-85		70-90
Liquid Limit, % max.[1]	Tex-104-E	35	40	40	As shown on the plans	35
Plasticity Index, % max.[1]	Tex-106-E	10	12	12	As shown on the plans	10
Plasticity Index, min[1]		As shown on the plans				
Wet ball mill, % max.[2]	Tex-116-E	40	45	–	As shown on the plans	40
Wet ball mill, %max. increase passing the No. 40 sieve		20	20	–	As shown on the plans	20
Classification, max.[3]	Tex-117-E	When shown on the plans	When shown on the plans	–	As shown on the plans	–
Min. compressive strength, psi	Tex-117-E				As shown on the plans	
lateral pressure 0 psi		45	35	–		–
lateral pressure 3 psi		–	–	–		90
lateral pressure 15 psi		175	175	–		175

1. Determine the plastic index in accordance with Tex-107-E (linear shrinkage) when liquid limit is unattainable, as defined in Tex-104-E.
2. When a soundness value is required by the plans, test material in accordance with Tex-411-A.
3. When Classification is required by the plans, a triaxial Classification of 1.0 or less for Grades 1 and 2.3 or less for Grade 2 is required. The Classification requirement for Grade 4 will be as shown on the plans.

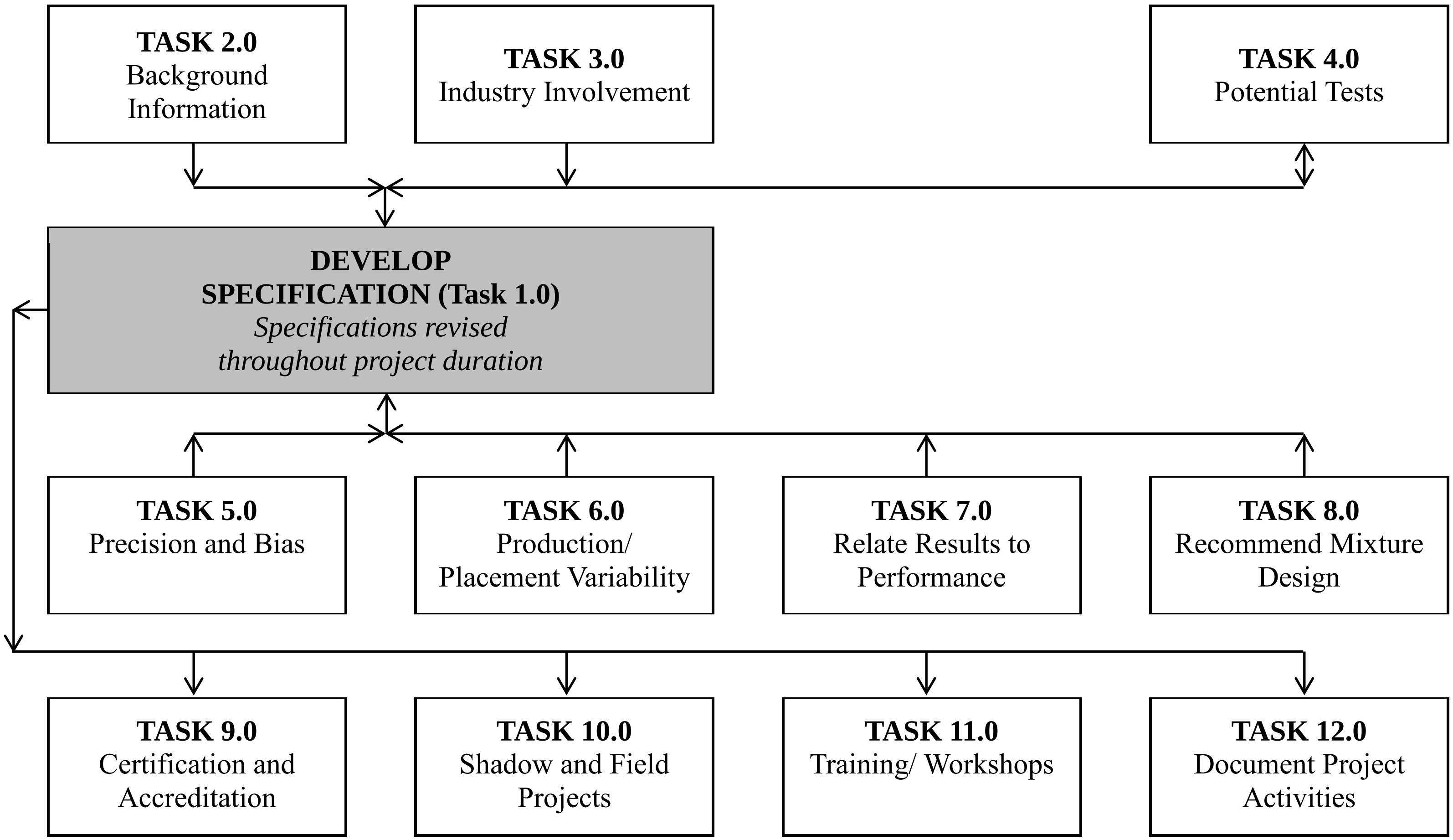

Figure 1.1. Proposal Work Plan.

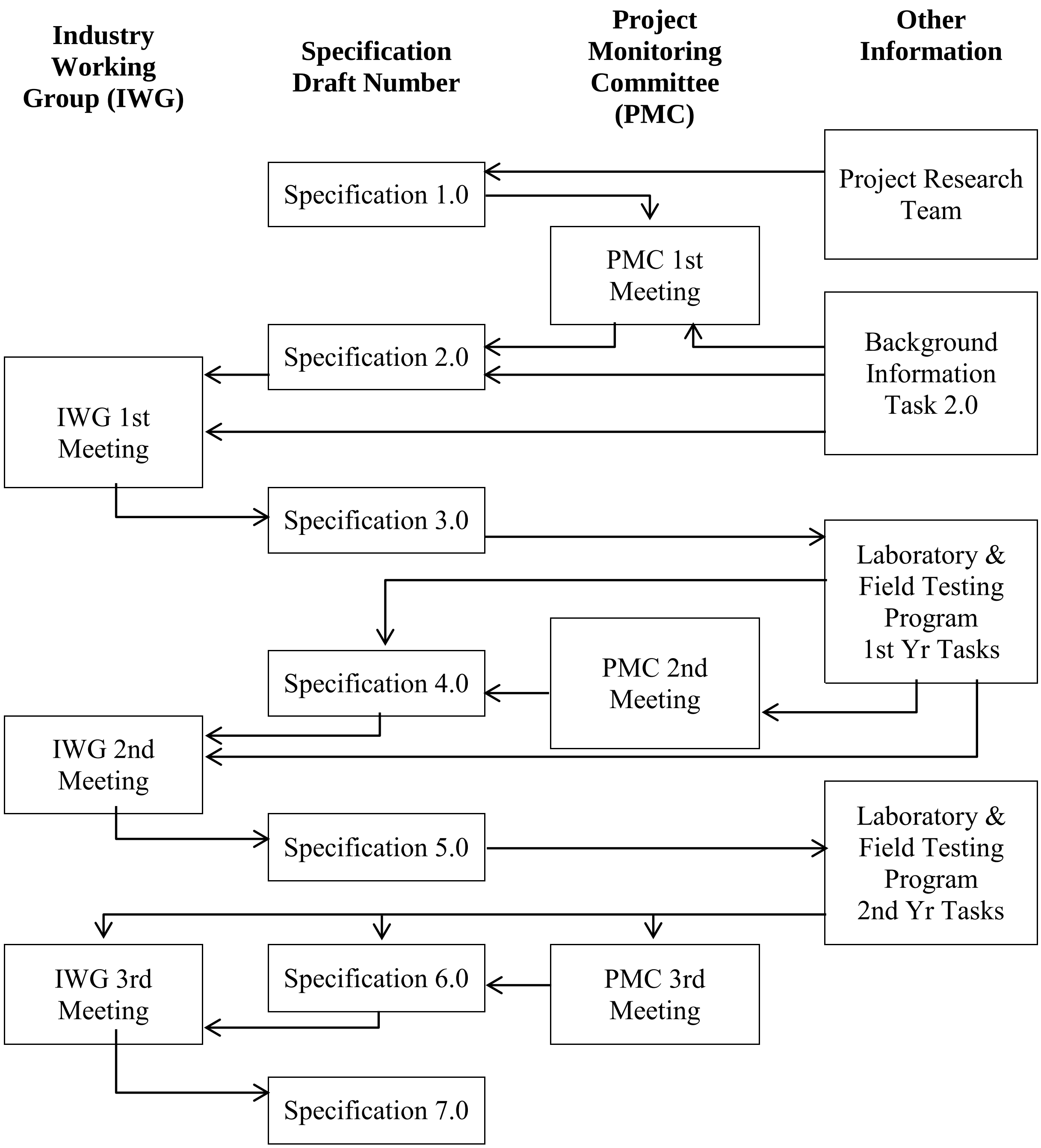

Figure 1.2. Specification Review and Revisions.

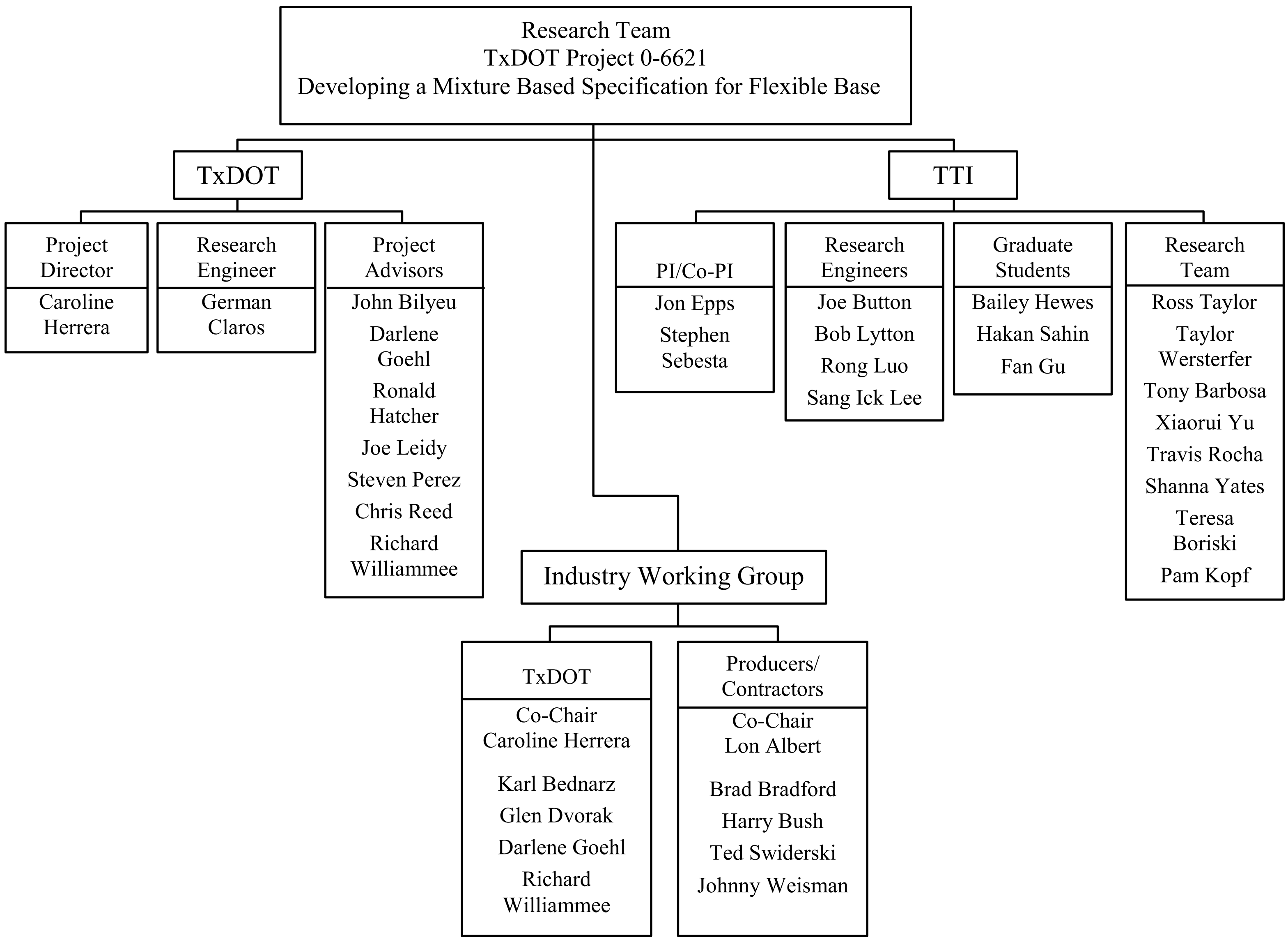

Figure 1.3. Research Team.

REFERENCES

1.1 "Item 247-Flexible Base and Special Provision 247-033 Flexible Base," Standard Specifications for Construction and Maintenance of Highway, Streets and Bridges, Texas Department of Transportation, 2004.

CHAPTER 2. BACKGROUND

INTRODUCTION

Chapter 1 of this report defines the scope, objectives, and desired outcomes of this research project. The main research result is a revised specification for flexible base materials. Figure 1.1 describes the work plan for the project. A 12-task work plan was envisioned. Results of the tasks completed to date are contained in this report. Task 10.0 (Shadow and Field Projects) and Task 11.0 (Training/Workshops) will not be completed as part of this research effort. It is anticipated that a follow-on Inter-Agency Agreement for implementation of the project will perform this effort.

The research project proposed and completed early-on drafts of a specification for this project. The research team established the project schedule in this manner to allow for numerous reviews of the specification by the Project Monitoring Committee and the Industry Working Group. This also allowed for the sampling and laboratory testing program to be directed to develop information needed to define important sections in the specifications.

The remaining sections in this Chapter briefly define the information collected in the various project tasks and identify the Chapters in which the information is contained.

SPECIFICATION DEVELOPMENT (TASK 1)

A draft QC/QA type of specification was developed early in the project. This specification was reviewed several times as described above. During the second year of the project, the specification format was changed to a Quality Monitoring Program concept.

INFORMATION GATHERING (TASK 2)

The intent of this project was to utilize as much information as possible from the literature, TxDOT historical records, industry historical records, and the research team to prepare the specification. Two separate literature reviews were performed in the study. One literature review was initiated at the start of the research effort and the second during the second year of the project. The literature reviews had somewhat different purposes. Historical information was gathered from TxDOT and industry throughout the project. Numerous requests were made for information from these sources.

The initial literature review was focused on available test methods to define the properties of base materials that relate to field performance. The test methods not only need to be related to performance but also have sufficient information on construction QC/QA variability to allow their incorporation into specifications, such that acceptance limits can be established and buyer and seller risks defined.

Literature Review

The first literature review effort summarized information that defines the test methods and acceptance criteria utilized in specifications used in both the United States as well as other countries. Electronic search tools available at the Texas A&M Library as well as the TTI Library were used for this literature search. The research team utilized the following databases:

- Transportation Research Information Service.
- National Technical Information Service.
- Federal Highway Administration.
- National Cooperative Highway Research Program.
- U.S. Army Corps of Engineers.
- Transportation Research Board.
- National Stone Association.

More detailed information on this first part of the project literature review can be located in the first report issued for this project (2.1) as well as Chapter 3 of this report.

The research team conducted the second portion of the literature review to locate information on quality control and quality assurance test result variability associated with flexible base material specifications as well as to define typical properties of flexible base materials produced in Texas. Emphasis was placed on research projects conducted by Texas universities and sponsored by TxDOT. A listing of some of the project reports reviewed included:

Project Number	Brief Title/Research Agency
1781	Minimum Testing Frequencies (UT)
2966	Fly Ash Bases (TTI)
3903	In-place Recycling Base Properties (TTI)
4182	Full Depth Recycling (TTI)
4358	Heavy Duty Aggregate Base (TTI)
4760	Ride Quality of Bases (TTI)
4774	Quality of Flexible Pavement Construction
4954	Crushed PCC Bases (TTI)
5135	Lab Compactor (TTI)
5223	Pulverization of Stabilized Bases (UTEP)
5562	Local Materials (UTEP)
5797	Dual Base Stabilizers (UTEP)
5873	Soil Binder Strength (TTI)
6587	Flexible Base Acceptance Testing

The University of Texas Center for Transportation Research Library and the TTI Library were used extensively for this portion of the library search. Information from this literature review is contained in Chapter 3 of this report.

District Questionnaire and Interviews

The research team developed a brief questionnaire and circulated it to TxDOT districts through their Materials and Pavement Section. Responses were received from 16 of 25 districts. Interviews were conducted in 13 districts. Chapter 3 provides a summary of the findings from the questionnaire and district interviews.

Historical Property Information from TxDOT

Three TxDOT Districts supplied historical property information from 43 different pit/quarries. The information was used to develop typical property information for TxDOT bases as well as provide variability information for a particular pit/quarry over a fairly extended period of time. Chapter 3 summarized this information.

TxDOT Forensic Studies

Several forensic type studies have been conducted by TxDOT. Information from six forensic studies from four districts was supplied to the research team by TxDOT. Chapter 3 summarized this information.

Producer/Contractor Interviews

Interviews were conducted with four producer/contractors. The size of these producers/contractors ranges from very large to reasonably small. Chapter 3 summarized this information.

Historical Property Information from Producer/Contractors

Historical property information was supplied by three of the four producer/contractors visited or three of the nine producer/contractors who supplied base material samples for testing as part of this project. Information supplied was typically collected over several months or years. Chapter 3 summarizes this information.

The information gathered in Task 2 of this project helped defined the following:

- Quantity of flexible base material utilized by TxDOT.
- Performance of flexible base courses in Texas.
- Typical properties of flexible base courses utilized in Texas.
- Typical production variability associated with flexible base materials.
- Water sensitivity of flexible base materials.

SAMPLING AND TESTING PROGRAM (TASK 4)

The information gathering portion of this research project provided data to identify tests that should be considered for inclusion into the specification. These tests included determination of the minus No. 200 sieve fraction, methylene blue test to define the amount and characteristics of the fine fraction in base materials, and resilient modulus to determine the load carrying and permanent deformation characteristics of base materials. The literature also indicated that the resilient modulus may be predicted from typical soil characterization tests and soil water-soil suction curves.

In order to define typical production variability (relatively short term) of base materials supplied on TxDOT projects, nine sources were selected, sampled, and tested. These data are contained in Chapter 5 of this report.

PRECISION AND BIAS (TASK 5)

Test method precision information was obtained from the literature as well as from TxDOT proficiency samples. Limited information was obtained from ASTM and AASHTO standards. The data obtained from the proficiency sample program supplied the best information for TxDOT test procedures used to define the properties of flexible base materials. This information is contained in Chapter 5.

PRODUCTION/PLACEMENT VARIABILITY (TASK 6)

The information gathering task of this project furnished considerable information to describe the variability of test parameters utilized to define quality of base materials. Most of these data were obtained over an extended period of time. The information obtained from the laboratory portion of the project represents shorter term variability information. These data are shown in Chapters 3 and 5.

PERFORMANCE-BASED SPECIFICATION (TASKS 7 AND 8)

Ideal specifications measure materials properties that can be related to performance as directly as possible. A considerable portion of the sampling and laboratory test program has been devoted to establishing relationships of material properties to performance. These results are shown in Chapters 5 and 6.

TECHNICIAN CERTIFICATION AND LABORATORY ACCREDITATION (TASK 9)

Chapter 8 summarized existing national and state technician certification and laboratory accreditation programs.

IMPLEMENTATION (TASK 10 AND 11)

The implementation effort was scheduled to be accomplished in Tasks 10 and 11 of this project. TxDOT projects will be selected and "shadow specifications" will be used on these projects to determine if the proposed specification will operate properly. Training/workshop presentations will be made to all districts. Chapter 9 contains more details on these plans.

REFERENCES

2.1 Epps, J., Sebesta, S., Sahin, H., Button, J., Luo, R., and Lytton, R. "Developing a Mixture Design Specification for Flexible Base Construction." Report No. FHWA/TX-12/0-6621-1, Federal Highway Administration, Report 0-6621-1, Texas Transportation Institute, June, 2011.

CHAPTER 3. LITERATURE/INFORMATION GATHERING

INTRODUCTION

A literature review was conducted as part of this study and reported in Reference 3.1 "Developing a Mixture Design Specification for Flexible Base Construction." The literature review conducted for Reference 3.1 focused on existing specifications and test methods associated with the use of flexible or granular base materials. A second literature review was conducted to primarily define typical properties of flexible base materials used in Texas as well as to define construction variability for construction in Texas as well as construction in the United States. Part of this second literature review was directed toward the research performed under TxDOT contracts at universities in the state of Texas.

Information was also gathered from TxDOT districts and central office as well as aggregate producers and contractors. Specific sources of information are identified and briefly discussed below under the Background Section of this Chapter.

BACKGROUND

In addition to the literature reviews, information was obtained from a number of sources, as listed below:

1. District Questionnaire and Interviews.
2. Historical Property Information from TxDOT.
3. TxDOT Forensic Studies.
4. Producer/Contractor Interviews.
5. Historical Property Information from Producers/Contractors.
6. Specifications.
7. Test Methods.

These efforts are described below.

District Questionnaire and Interviews

A brief and general questionnaire was prepared by the project staff and circulated by TxDOT's Materials and Pavements Section to all districts. Responses were received from 16 of the 25 districts. General information requested included:

1. Quantity of base materials utilized.
2. Type and grade of base materials utilized.
3. Estimate of the amount of premature pavement distress caused by base materials.
4. Suggested specification items that should be considered for revision in the current specification.

Information is summarized below.

Visits were also made to 13 districts to discuss flexible base materials. These visits discussed current specifications, recommended changes to specifications, and premature performance issues. Detailed information was typically not supplied by the districts during these visits. Some districts supplied information to allow for the calculation of typical property data and variability information after the visits.

Historical Property Information from TxDOT

Three TxDOT districts supplied historical property information from 43 different pit/quarries. This information was used to prepare summary tables to define typical base material properties as well as to describe production variability. Information from a given pit/quarry was typically gathered over several months and, in most cases, other several years. Thus, property variability from these data sources is long term rather than short term. A typical sample unit for TxDOT is a stockpile of approximately 25,000 tons that is produced over several days or a few weeks. Information was obtained for four different grades of materials. Information is summarized below.

TxDOT Forensic Studies

Some forensic type studies have been conducted by TxDOT. These studies are typically performed when a pavement has premature distress and the district desires a detailed understanding of the probable causes of this distress. The TxDOT district, central office, and sometimes one or more universities are involved. TxDOT supplied six forensic studies from four districts. This information is summarized below.

Producer/Contractor Interviews

The research team conducted interviews with four producer/contractors. These suppliers represent large aggregate producers as well as a producer/contractor that produces aggregates from “roadside” quarry/pits. Each producer/contractor provided a tour of their production facilities. Topics of discussion included production processes, variability, current specification, and specification items that should be considered for change. Information obtained from these interviews is discussed below.

Historical Property Information from Producers/Contractors

Historical property data was supplied from the files of three of the four producer/contractors interviewed. These data have been analyzed to determine typical properties as well as property variability. Information supplied was typically collected over several months or years and represents long term production variability and not short term production variability.

Information from the literature and the other information gathering efforts identified above were used to describe:

1. Quantity of flexible base materials used by TxDOT.
2. Performance of flexible base courses in Texas.
3. Typical properties of flexible base courses in Texas.
4. Typical production variability associated with flexible base material.
5. Water sensitivity of base materials.
6. Test methods and specifications.

This information is presented below.

QUALITY OF FLEXIBLE BASE MATERIALS USED BY TXDOT

Results from the District Questionnaire and TxDOT central office records were used to provide information that described the quantity of base materials utilized on an annual basis. Table 3.1 shows the quantity of base materials purchased annually by the 16 districts (4.3 million tons or approximately 2.4 million CY) and statewide (approximately 6.7 million tons or 3.7 million CY). Of the 4.3 million tons purchased by the 16 districts, approximately 86 percent was purchased under Construction Contracts, 9 percent purchased under Maintenance Contracts and 5 percent purchased directly by Maintenance Forces (Table 3.1). Statewide data contained on Table 3.1 also indicates that approximately 95 percent of all base materials are purchased under contract. Note that the statewide data shown on Tables 3.1 to 3.3 represent the average of two years (FY 2010 and FY 2011).

The percent of the total base material purchased by these 16 districts (as reported on the questionnaire) and statewide (central office records) by type and grade is shown on Tables 3.2 and 3.3. Based on statewide information, about 40 percent of the total purchases for use on construction projects were for crushed stone base (Type A), 38 percent for crushed stone or crushed portland cement concrete (Type E), and 22 percent "as shown on the plans" (Type E). Grade 4 base or "as shown on the plans" was 62 percent of statewide purchases for construction operations. Grade 2 base (intermediate quality) was purchased 20 percent of the time and a Grade 1 or Grade 5 base (higher quality) was purchased 17 percent of the time under construction contracts. Two percent of the base materials purchased had no strength requirement (Grade 3).

Based on statewide data, a significant percent of the base materials purchased directly by maintenance were crushed materials (Type A, Grade 2) or "as shown on the plans" (Tables 3.2, 3.3). These data contained in Tables 3.2 and 3.3 suggest that the majority of the flexible base material used by TxDOT construction and maintenance operations are crushed stone or mixtures of crushed stone and recycled crushed portland cement concrete that satisfy the requirements of either Grade 1 or Grade 2. Significant quantities of base material are purchased under "as shown on the plans" requirements for both construction and maintenance operations. This designation allows the engineer to designate the requirements for base materials. These requirements may vary from district to district and somewhat from job to job. Maintenance operations use the purchase designation, "as shown on the plans," more frequently than construction purchases.

PERFORMANCE OF FLEXIBLE BASE MATERIALS IN TEXAS

Background

Performance of asphalt and portland cement concrete pavements can be affected by the quality of the flexible base course layer. When flexible bases are utilized under portland cement concrete pavements, the most critical properties are drainage and resistance to pumping under traffic loads. Strength of the flexible base course has importance in portland cement concrete pavements; however, strength of the flexible base material is more important when utilized in an asphalt surfaced pavement.

Flexible base courses must not only have good strength properties at the time of compaction but also they must retain their strength at elevated water contents and over long periods of service. They must not "break down" (change gradation-create fines) during construction and under the action of traffic and environmental elements. Typically, base courses are specified such that frost susceptibility and volume change due to moisture content variations are not problems.

The ability of a flexible base course to be constructed with a reasonable smooth riding surface is important during the construction operation. The smoothness of the pavement surfacing materials is somewhat dependent on the smoothness of the finished flexible base layer. This is particularly important when constructing pavements with surface treatments. Smoothness or grade control is also important for maintaining a consistent thickness of the pavement surfacing material. For example, a base course with poor grade control and smoothness will result in the use of larger quantities of paving material to obtain the minimum thickness required by the specifications.

When revising base course specifications, it is important to have an appreciation of the performance of pavements constructed utilizing materials currently specified. Four sources of information were utilized to help define performance of base courses in Texas. The sources are identified above and were the District Questionnaire and Interviews, TxDOT Forensic Studies, and Supplier/Contractor Interviews. Results from these information sources follow.

District Questionnaire and Interviews

Districts were asked to supply information that describes the number of premature distressed pavements that could be attributed to flexible base material properties and construction on an annual basis ("premature base failures"). This question had a number of interpretations by the districts. Figure 3.1 shows the number of premature distresses reported by the 16 districts responding to the questionnaire. The majority of the problems with flexible bases were reported by the east and north Texas districts. The west Texas districts and the majority of the south Texas districts did not report a significant occurrence. A total of about 400 premature base failures were reported by the 16 districts.

The districts were also requested to supply their view of the causes of premature base failures in terms of design, materials, and construction related issues. Nine districts supplied information for the question. They indicated that the causes are about equally divided between design, materials, and construction. Of the reporting districts, most believed that the cause of premature base failures is likely related to all three factors.

A few districts indicated that the premature base failures were a result of improper construction operations including:

1. Working the materials too dry (inadequate water during compaction).
2. Not removing loose material from surface of base to improve adherence of prime and seal coats.
3. Not having sufficient rollers as required by specification.

Other causes identified by districts include weather conditions, such as drought and excessive rainfall during construction. Failures on pavement widening projects were also noted.

Several districts indicated that some of their highest quality base materials with low Minus No. 200 material and low plastic index provided very good service except on narrow roadways with heavy traffic. These types of base materials need lateral support to be effective (confining pressure). Thus, when tested in the laboratory at low confining pressures, the base materials may fail the specification requirement but have exceptional strength when confined and exceptional strength when wet of optimum. Proper use of these quality materials is a function of pavement geometrics and pavement thickness design.

Nine districts also reported on the location (highway category-IH, US, SH, and FM) of the premature base failures. Sixty-five percent of the premature base failures were located on farm to market (FM) roads, 25 percent on state highways (SH), and 10 percent on United States designated routes. Only 1 of about 400 reported sites was located on an interstate highway (IH) route.

As stated above, several districts were visited and interviews conducted. General comments were provided relative to the performance of flexible base courses in Texas. These comments are summarized below.

1. Premature distress does occur in some base courses.
2. Heavy traffic on FM roads causes a substantial number of edge failures.
3. Pumping of fines from base course through pavement surface is fairly common.

From a structural pavement design point of view, the quality of the base course is more important on relatively thin pavements as compared to thick pavements. In addition, with the recent escalation in energy-related development in the state, more of the FM system is being subjected to a relatively large number of heavy roads. This increase in traffic and loads is causing premature distresses in these pavements.

The districts were asked to recommend revision to the flexible base material specification. A number of suggestions were received and are provided below:

1. Add a requirement for Minus No. 200 material.
2. Add a moisture sensitivity requirement.
3. Eliminate the allowance of crushed portland cement concrete.
4. Require QC/QA type of specification.
5. Require ride quality for bases when surface treatments are utilized as the surface course.
6. Consider provisions that will allow “clean” bases (low P.I., low Minus No. 200 sieve and poor strength at 0 psi confining pressure.
7. Add maximum dielectric constant.
8. Remove the 0 psi confining pressure strength.

TxDOT Forensic Studies

In addition to the general questions asked relative to performance, the districts were asked to supply any forensic type studies that they had performed in the last several years. Several forensic reports have been prepared by districts, and they are summarized on Table 3.4. The types of distress most commonly noted in these forensic analyses are localized failures that occurred shortly after opening to traffic. Specific premature distress was typically rutting and/or fatigue or alligator cracking in the asphalt surface layer (Table 3.4). Pumping of fines from the base course was also noted in one forensic analysis and can be frequently observed after rainfall events on cracked pavements.

Three of the six pavements described in these forensic reports had a flexible base layer between the asphalt mixture surfacing material and a stabilized subbase (either lime or portland cement).

The causes of the distress, as identified by the forensic teams, included:

1. Out of specification gradations (particularly on the No. 40 sieve).
2. High plastic index.
3. Moisture sensitive flexible base material (material that loses strength with an increase in moisture content above optimum.
4. Weak base materials, defined as materials that failed to meet the compressive strength requirement of the specification.
5. Presence of moisture in the base course layer (often in the top layer of the base course).
6. Stiff asphalt mixture (premature aging of the asphalt binder is suggested in several studies).
7. High air voids in the asphalt mixture.
8. Poor bond between the asphalt mixture layers.

Supplier/Contractor Interviews

The supplier/contractor interviews provided little additional information on the types and causes of premature pavement distress associated with the use of flexible base materials. Most supplier/contractors indicated that the amount of premature distress in pavements associated with base course material properties and/or construction operations is minor. In addition, the cost benefit or life-cycle cost analysis supports the continued use of locally produced base materials in Texas. They concluded that this use should continue without substantial changes in property requirements and construction operations.

TYPICAL PROPERTIES OF FLEXIBLE BASE MATERIALS IN TEXAS

Information defining typical properties of base materials produced in Texas was obtained from a literature search directed at research studies conducted by Texas universities and sponsored by TxDOT. This property information is shown on Table 3.5 to 3.9. These data sets from the literature represented a single value for a specific property for a given pit. The databases did not have sufficient data to determine variability by commonly used statistical approaches. Variability data, presented later in the report, contains not only data to describe typical values (mean) but also variability information (standard deviation and coefficient of variation).

Typical property information shown on these tables provides an indication of the capability of the industry to produce materials of these properties considering the constraints of available materials, production equipment, workforce, and economics. It should be evident that the typical property data reported for Texas base materials is a result of current specification limits.

Typical data for specific properties are contained on the following tables.

Table 3.5	Gradation
Table 3.6	Atterberg Limits
Table 3.7	Wet Ball Mill
Table 3.8	Maximum Density/Optimum Water Content
Table 3.9	Compressive Strength

Information is presented for more than 30 quarry/pits from 14 districts. References 3.2 to 3.5 contain these data.

TYPICAL PRODUCTION VARIABILITY ASSOCIATED WITH FLEXIBLE BASE MATERIAL

Introduction

Typical production variability information for base materials was obtained from "Historical property information from TxDOT," "Historical property information from producers/contractors," and a national literature search. Information from these data sources has been summarized and placed in summary tables.

Historical Property Information from TxDOT

Historical property information on more than 40 quarry/pits was supplied by three districts. Sufficient samples were obtained from these pits over a period of time to allow basic statistical calculations to define mean, standard deviation, and coefficient of variation. Data sets were available for calculations to be performed for Grades 1, 2, and 3 base materials. A fourth category was created when the grade could not be defined in the data set (Grade X). Tables 3.10 to 3.14 contain information on Grade 1 materials, Tables 3.15 to 3.19 for Grade 2 materials, Tables 3.20 to 3.24 for Grade 3 materials and Tables 3.25 to 3.29 for Grade X materials. Information is available for gradation, Atterberg Limits, Wet Ball Mill, maximum dry density-optimum moisture content, and compressive strength. Note that Tables 3.22 and 3.27 contain some Wet Ball Mill percent loss and percent increase values that are too high to be realistic. These values were checked with the source values, and it was determined that there must have been a data entry error before the research team received these data.

Historical Property Information from Producers/Contactors

Three producer/contractors supplied data to allow the calculation of variability information from four sources. These data were combined with information from TxDOT and data sets and one reference to produce Tables 3.30 to 3.34. Information is available for gradation, Atterberg Limits, Wet Ball Mill, maximum dry density-optimum moisture content, and compressive strength.

Several comparisons are available as a result of the data set groupings that were used to analyze these data. These comparisons include variability calculations prior to and after 2010. In 2010, some changes were made in the test methods to more explicitly define test procedures and calibration.

Other comparisons available in these data sets include comparisons between commercial laboratories and TxDOT laboratories and comparison between two groups of TxDOT laboratories. The comparisons are discussed below.

Variability before and after 2010

Comparison of data sets prior to and after 2010 contain not only variability resulting from the changes in test methods but also variability resulting from changes from the raw materials, processing operation, test technician, and perhaps the laboratory. A review of Tables 3.30 to 3.34 indicates that some data comparisons reflect a difference in properties while most do not. Assignment of this difference to laboratory test methods is not defensible.

Variability between Laboratories

Information is presented on Tables 3.30 to 3.34 that allows a comparison between commercial and TxDOT laboratories and between two groupings of TxDOT laboratories. Most of the data presented that allows for this comparison contain not only variability resulting from the difference between the two groupings of laboratories but also variability resulting from changes in the raw materials, production operation, and test technician. The few data sets on Tables 3.30 to 3.34 that allow for comparisons between commercial and TxDOT laboratories show little differences between laboratories.

Maximum density-optimum moisture content information shown on Table 3.33 also illustrates little difference between the commercial lab and the TxDOT lab for the one laboratory comparison possible. Comparisons between TxDOT groupings of laboratories also show little difference in properties. These data sets represent much shorter production times than other comparisons shown on these tables.

Table 3.34 contains compressive strength information. Nine comparisons are possible on this table between commercial and TxDOT laboratories. In all cases, the commercial laboratory reported a higher mean strength value. Some of these differences are statistically significant while several others are not significant. The relatively large variability of the strength tests should be considered by the reader when making these comparisons.

These data also allow for a comparison between groups of TxDOT laboratories. TxDOT C laboratory reports a higher mean value than TxDOT D laboratory in 19 of the 22 comparisons that are possible in the data set. Statistically, few of these differences are significant.

National Literature

A search of the national literature was performed to define variability of base materials produced in Texas versus other states. References 3.6 and 3.7 contained summaries of information and are summarized in Tables 3.35 to 3.36. Data are provided for gradation and in-place density and moisture content. Information contained in these tables is from the AASHTO road test, a FHWA study, and other states.

In general, the variability of the gradation information, as represented by the standard deviation, is smaller when compared to the Texas data sets summarized in this report. The cumulative distributions of the standard deviations from the various data sets are contained in Chapter 5.

WATER SENSITIVITY OF BASE MATERIALS

TxDOT supplied information that illustrates the compressive strength behavior of base materials as influenced by the moisture content at the time of testing. The compressive strength information was supplied for 0 psi confining pressures on a wide variety of materials. The samples were prepared as part of the normal process for developing maximum dry density-optimum moisture content curves and tested after compaction at different moisture contents. These data are shown on Figures 3.2 to 3.26.

Strength data is shown for various water contents relative to the optimum moisture content of the base material. Significant losses of strength occur at moisture contents 1 percent above optimum for many materials. The strength and strength loss at 1 percent above optimum is shown on Table 3.37 for those materials with sufficient data to allow for this parameter to be calculated.

TEST METHODS AND SPECIFICATIONS

Specifications for flexible or aggregate base materials have historically been developed to provide initial and long-term strength or load carrying ability, durability, or resistance to long-term property changes caused by traffic and the environment, and the desired permeability. Table 3.38 shows these desired properties and the current TxDOT tests that are utilized to control these properties. The literature review conducted by the research team and reported in Reference 3.1 contains a listing of tests and specifications used by other specifying agencies to control these same properties. Tests used to control these desired flexible base material properties in current specifications are summarized below.

Initial and Long-Term Strength

A number of tests are utilized in the TxDOT specification to control initial and long-term strength. Gradation, particle shape and texture (crushed/not crushed-Type), Atterberg limits, compressive strength/classification, and in-place density all help ensure adequate initial strength of flexible base courses. Other specifying agencies utilize similar and some other tests, as shown in Reference 3.1. Other tests frequently used by other specifying agencies to define initial strength include: gradation with the No. 200 sieve, percent fractured faces, California Bearing Ratio, California "R" value, and resilient modulus.

Tests used by TxDOT to define long-term strength include gradation, Atterberg limits, wet ball mill, sulfate soundness, and compressive strength. Other tests frequently used by other specifying agencies to define long-term strength include sand equivalent and LA abrasion.

Durability

Durability tests are included in specifications to control the ability of the base course to withstand degradation due to traffic loads, volume change, freeze-thaw resistance, wet-dry resistance, and the pumping of fines. The primary tests used by TxDOT to control these properties include wet ball mill for traffic degradation; gradation and Atterberg limits for volume change; gradation, Atterberg limits, and sulfate soundness for freeze-thaw resistance; soundness for resistance to wet-dry cycles; and gradation, wet ball mill, and soundness to control pumping fines. Other tests frequently used by other specifying agencies to define durability include: LA abrasion, micro duval, aggregate freeze-thaw tests, aggregate durability index, and deleterious material tests.

Permeability

Permeability is controlled in the TxDOT specification by controlling the gradation and Atterberg limits. A few states perform permeability tests; however, most states control the minus No. 200 sieve content and Atterberg limits or sand equivalent to ensure that a permeable base material is utilized.

Tests Recommended for Further Evaluation

Based on the literature review conducted for this project and the summary presented above, additional tests should be considered for inclusion in the Texas DOT specification. These tests include the following:

1. Minus No. 200 sieve.
2. Methylene Blue.
3. Index to indicate the loss of strength with an increase in water content.

The inclusion of the minus No. 200 sieve in the specification will help control initial and long-term strength, volume change, freeze-thaw resistance, pumping of fines, and permeability.

The methylene blue test will potentially provide a better estimate of the amount and activity of the fines in flexible base materials. The amount and type of fines control initial and long-term strength, volume change, freeze-thaw resistance, pumping, and permeability.

An index associated with strength testing will define the initial versus long-term strength. Flexible base courses under paved surfaces can increase in water content. Typically, this increase in water content will result in a decrease in strength or load carrying capability. A specification parameter that reflects this potential strength loss with an increase in water content would be beneficial.

The research program described in this report determined the minus No. 200 materials content, methylene blue, and strength index parameters in nine different flexible base materials produced and utilized in Texas. Test results are presented later in this report.

Table 3.1. Flexible Base Material Quantities Purchased Annually by Construction and Maintenance.

Type of Purchase	16 Districts		Statewide	
	Quantity, Tons	Quantity, Percent	Quantity, CY	Quantity, Percent
Construction Contracts	3,725,500	86.0	3,486,405	93.9
Maintenance Contracts	377,000	8.7	--	--
Direct Purchase by Maintenance	229,500	5.3	224,815	6.1
Totals	4,332,000	100	3,711,220	100

Table 3.2. Flexible Base Material Quantities by Type.

Type	Description	16 District Quantities, Percent		Statewide, Percent	
		Construction	Maintenance	Construction	Maintenance
A	Crushed Stone	70.9	79.9	39.6	63.0
B	Crushed or Uncrushed Gravel		0.8	0.1	
C	Crushed Gravel				
D	Crushed Stone or Crushed PCC	29.0	16.9	38.0	
E	As Shown on Plans	0.1	2.4	22.3	37.0
	Total	100.0	100.0	100.0	

Table 3.3. Flexible Base Material Quantities by Grade.

Grade	Description	16 District Quantities, Percent		Statewide, Percent	
		Construction	Maintenance	Construction	Maintenance
1	Low LL/PI, Gradation Control and High Strength	30.4	4.3	5.7	2.8
2	Commonly Used Base Material	31.9	84.2	19.2	23.7
3	No Strength/Wet Ball Mill Requirements	1.0	5.4	2.0	3.3
4	As Shown on Plans	33.3	6.1	61.9	70.2
5	Low LL/PI, Gradation Control and High Strength	3.4		11.3	
	Total	100.0	100.0	100.0	100.0

Table 3.4. Premature Pavement Distress Related to Base Course Quality-Forensic Analysis.

Project	Traffic, 18 Kip Eq.*	Type of Distress	Structural Section				Causes
			Surface	Flex Base	Subbase	Subgrade	
SH -A	6.2	• Localized failures while under construction traffic	2 course surface treatment	24 in.	8 in. cement stabilized subgrade	Geotextile over wet, weak soil	• Out of spec material-No. 40, wet ball mill, strength • Moisture in base • High ground water • Slope backfill low permeability
SH -B	5.0	• Localized distress (6 months) • Base pumping • Fatigue cracking	2 in. asphalt mixture	10 in.	6 in. lime stabilized		• Stiff asphalt mix • Top 6 in. of base in one is weak direction • Moisture sensitive base course
US -A	2.8	• Rutting • Fatigue cracking • Distress in a few weeks	3 in asphalt mixture	9 in	6 in. cement treated subgrade		• Weak and moisture sensitive base course • High P.I. • Stiff asphalt mix
FM -A		• Localized failures					• High fines and high P.I. in base • Weak and moisture sensitive base course
FM -B		• Fatigue cracking a few days after opening to traffic • Rutting	4 in. asphalt mixture	12 in.		Silty clay	• Top layer of base wet and weak • Elevated P.I. • Poor bond between asphalt mixture layers • High air voids in bottom lift of asphalt mixture • Stiff asphalt mixture
IH -A	49.1	• Potholes • Rutting • Distress a few months after construction	6 in. asphalt mixture	14 in.			• Weak and moisture sensitive base • High air voids and high stiffness of asphalt mixture

*one direction, accumulative 20-year equivalent 18-kip axle

Table 3.5. Typical Gradation of Flexible Base Materials in Texas.

Pit/Quarry	District	Material	Ref	Gradation, percent retained						
				1 3/4	1 1/4	7/8	5/8	3/8	No. 4	No. 40
F-03	Abilene	Limestone	10							
F-44	Abilene	Limestone	10	0.0					47.0	80.7
F-14	San Angelo	Limestone	10	0.0	9.0	21.0	31.0	57.0	57.0	80.0
F-13	San Angelo	Limestone	10	0.0					60.7	79.8
F-33	Brownwood	Limestone	10	2.3		21.9	29.6	40.4	51.6	73.7
F-42	Brownwood	Limestone	10	0.0					47.0	80.7
F-38	Pharr	Pit run	10						55.4	72.7
F-04	San Antonio	Aggr/sand	10	0.0	2.7	12.3	24.3	36.1	49.8	71.0
F-10	Tyler	Sand/Igneous Rock	10	0.0					68.1	77.6
F-23	San Antonio	Limestone	10	0.0		20.8		49.1	61.4	78.2
F-12	San Antonio	Limestone	10	0.0		18.5		47.4		78.2
F-45	Beaumont	Limestone	10							
F-46	Corpus Christi	Limestone	10	0.0		18.9		53.8	67.2	81.9
F-16	Waco	Limestone	10						59.7	77.1
F-41	Dallas	Limestone	10	0.0		15.1		43.6	60.2	81.4
F-06	Tyler	Sand/Gravel	10	0.0		22.4		49.4	59.2	76.2
F-22	El Paso	Sand/Gravel	10	0.0		14.0		36.0	49.0	78.0
F-24	El Paso	Limestone	10	0.0					49.0	79.0
F-47	El Paso	Sand/Gravel	10	0.0		15.0		36.0	50.0	79.0
F-36	Lubbock	Reworked	10							
F-05	Abilene	Limestone	18	0.0		19		46.0	62.0	88.0
F-30		Limestone	18	0.0		24.0		50.0	65.0	90.0
F-35	Brownwood	Limestone	18	0.0		18.0		41.0	55.0	81.0
F-34		Limestone	18	0.0		20.0		39.0	53.0	77.0
F-43		Limestone	18	0.0		7.0		31.0	50.0	92.0
F-11	El Paso	Limestone	18	0.0		23.0		40.0	55.0	78.0
F-08	Lubbock	Rhyolite Tuff	18	0.0		21.0		51.0	66.0	88.0
F-09		Rhyolite Tuff	18	0.0		11.0		45.0	66.0	93.0
F-25	San Angelo	Limestone	18	0.0		15.0		38.0	50.0	69.0
F-40		Limestone	18	0.0		24.0		51.0	63.0	82.0

Table 3.6. Typical Atterberg Limit Properties of Flexible Base Materials in Texas.

Pit/Quarry	District	Material	Ref	Plastic Limit, Percent	Liquid Limit, Percent	Plastic Index
F-03	Abilene	Limestone	10	12	22	10
F-44	Abilene	Limestone	10	12	14	2
F-14	San Angelo	Limestone	10	18	26	8
F-13	San Angelo	Limestone	10	13	16	3
F-33	Brownwood	Limestone	10	21	28	7
F-42	Brownwood	Limestone	10	12	14	2
F-38	Pharr	Pit run	10	18	24	6
F-04	San Antonio	Aggr/sand	10	14	17	3
F-10	Tyler	Sand/Igneous Rock	10	22	27	5
F-23	San Antonio	Limestone	10	13	17	4
F-12	San Antonio	Limestone	10	12	16	4
F-45	Beaumont	Limestone	10	15	23	8
F-46	Corpus Christi	Limestone	10			5
F-16	Waco	Limestone	10	15	21	6
F-41	Dallas	Limestone	10	14	21	7
F-06	Tyler	Sand/Gravel	10			3
F-22	El Paso	Sand/Gravel	10			5
F-24	El Paso	Limestone	10			5
F-47	El Paso	Sand/Gravel	10			3
F-36	Lubbock	Reworked	10			
F-05	Abilene	Limestone	18	12	18	6
F-30		Limestone	18	8	16	7
F-35	Brownwood	Limestone	18	15	20	5
F-34		Limestone	18	17	26	9
F-43		Limestone	18	11	15	4
F-11	El Paso	Limestone	18	19	27	8
F-08	Lubbock	Rhyolite Tuff	18	14	34	20
F-09		Rhyolite Tuff	18	18	26	8
F-25	San Angelo	Limestone	18	18	29	11
F-40		Limestone	18	2	7	5
F-01		Granite 1	15			NP
F-02		Granite 2	15			4
F-29		Sandstone	15			6

Table 3.7. Typical Wet Ball Mill Properties of Flexible Base Materials in Texas.

Pit/Quarry	District	Material	Ref	Percent Loss	% Increase in No. 40
F-03	Abilene	Limestone	10		
F-44	Abilene	Limestone	10	33	12
F-14	San Angelo	Limestone	10	34	14
F-13	San Angelo	Limestone	10	31	11
F-33	Brownwood	Limestone	10	48	19
F-42	Brownwood	Limestone	10	33	12
F-38	Pharr	Pit run	10	35	8
F-04	San Antonio	Aggr/sand	10	39	10
F-10	Tyler	Sand/Igneous Rock	10	38	15
F-23	San Antonio	Limestone	10	35	15
F-12	San Antonio	Limestone	10	32	11
F-45	Beaumont	Limestone	10	38	7
F-46	Corpus Christi	Limestone	10	28	5
F-16	Waco	Limestone	10	33	6
F-41	Dallas	Limestone	10	21	5
F-06	Tyler	Sand/Gravel	10	32	7
F-22	El Paso	Sand/Gravel	10	39	18
F-24	El Paso	Limestone	10	27	5
F-47	El Paso	Sand/Gravel	10	37	17
F-36	Lubbock	Reworked	10		
F-01		Granite	15	19.7	5
F-02		Granite	15	20	8
F-29		Sandstone	15	36.5	10

Table 3.8. Typical Maximum Density-Moisture Content Properties of Flexible Base Materials in Texas.

Pit/Quarry	District	Material	Ref	Max Unit Weight, pcf	Optimum Water Content, Percent
F-03	Abilene	Limestone	10	134.1	8.0
F-44	Abilene	Limestone	10	145.1	5.7
F-14	San Angelo	Limestone	10	138.6	7.1
F-13	San Angelo	Limestone	10		
F-33	Brownwood	Limestone	10	127.0	10.5
F-42	Brownwood	Limestone	10	145.1	5.7
F-38	Pharr	Pit run	10	128.7	8.7
F-04	San Antonio	Aggr/sand	10	134.7	6.3
F-10	Tyler	Sand/Igneous Rock	10	136.4	7.5
F-23	San Antonio	Limestone	10	141.8	6.1
F-12	San Antonio	Limestone	10	140.3	6.0
F-45	Beaumont	Limestone	10	129.2	8.7
F-46	Corpus Christi	Limestone	10	127.9	9.4
F-16	Waco	Limestone	10	134.0	7.6
F-41	Dallas	Limestone	10	138.2	5.8
F-06	Tyler	Sand/Gravel	10	141.1	5.4
F-22	El Paso	Sand/Gravel	10	136.5	7.7
F-24	El Paso	Limestone	10	135.0	7.4
F-47	El Paso	Sand/Gravel	10	135.9	6.9
F-36	Lubbock	Reworked	10		
F-05	Abilene	Limestone	18	143.0	7.3
F-30		Limestone	18	138.0	6.2
F-35	Brownwood	Limestone	18	133.0	10.8
F-34		Limestone	18	125.0	13.3
F-43		Limestone	18	142.0	6.6
F-11	El Paso	Limestone	18	143.0	6.4
F-08	Lubbock	Rhyolite Tuff	18	124.0	11.6
F-09		Rhyolite Tuff	18	114.0	10.2
F-25	San Angelo	Limestone	18	122.0	12.7
F-40		Limestone	18	131.0	6.7
F-01		Granite	15	137.4	6.0
F-02		Granite	15	147.0	5.5
F-29		Sandstone	14	138.0	5.5

Table 3.9. Typical Compressive Strength Properties of Flexible Base Materials in Texas.

Pit/Quarry	District	Material	Ref	Compressive Strength, psi	
				0 psi	15 psi
F-03	Abilene	Limestone	10	46.7	206.0
F-44	Abilene	Limestone	10	28.6	191.9
F-14	San Angelo	Limestone	10	45.0	177.0
F-13	San Angelo	Limestone	10		
F-33	Brownwood	Limestone	10	24.7	123.2
F-42	Brownwood	Limestone	10	53.0	193.9
F-38	Pharr	Pit run	10	41.0	
F-04	San Antonio	Aggr/sand	10	47.2	176.2
F-10	Tyler	Sand/Igneous Rock	10	50.9	194.8
F-23	San Antonio	Limestone	10	50.3	244.4
F-12	San Antonio	Limestone	10	70.3	253.8
F-45	Beaumont	Limestone	10	64.2	
F-46	Corpus Christi	Limestone	10	59.0	222.0
F-16	Waco	Limestone	10	27.5	198.3
F-41	Dallas	Limestone	10	43.3	190.1
F-06	Tyler	Sand/Gravel	10	24.7	205.0
F-22	El Paso	Sand/Gravel	10	46.1	147.6
F-24	El Paso	Limestone	10	50.2	142.9
F-47	El Paso	Sand/Gravel	10	46.2	137.9
F-36	Lubbock	Reworked	10		
F-05	Abilene	Limestone	18	54.0	255.0
F-30		Limestone	18	34.0	130.0
F-35	Brownwood	Limestone	18	23.0	117.0
F-34		Limestone	18	29.0	120.0
F-43		Limestone	18	32.0	180.0
F-11	El Paso	Limestone	18	62.0	230.0
F-08	Lubbock	Rhyolite Tuff	18	46.0	198.0
F-09		Rhyolite Tuff	18	42.0	178.0
F-25	San Angelo	Limestone	18	53.0	133.0
F-40		Limestone	18	70.0	166.0
F-01		Granite	15	36.0	218.0
F-02		Granite	15	65.0	213.2
F-29		Sandstone	15	44.0	209.0

Table 3.10A. Gradation Variability Information from TxDOT Districts-Grade 1.

Pit/Quarry	District	Material	2 ½ inch				1 ¾ inch				7/8 inch			
			x	s	n	cv	x	s	n	cv	X	s	n	cv
A-36	Austin	Limestone					0.0	0.0	61	0.0	25.8	3.7	61	14.4
A-28	Austin	Limestone					0.0	0.0	91	0.0	23.0	2.9	90	12.4
A-43	Bryan	Young					0.0	0.0	3	0.0	24.7	5.3	3	21.6
A-06	Waco	Connor-Greenwade												
A-04	Waco	Connor-Cobb												
A-12	Waco	Gibbs-Killeen												
A-16	Waco	Odell Geer-Youngsport												

Table 3.10B. Gradation Variability Information from TxDOT Districts-Grade 1.

Pit/Quarry	District	Material	3/8 inch				No. 40 Sieve			
			X	s	n	Cv	X	S	n	cv
A-36	Austin	Limestone	49.7	4.5	61	9.0	76.4	2.8	61	3.7
A-28	Austin	Limestone	47.5	4.6	90	9.7	77.9	7.3	91	9.4
A-43	Bryan		49.9	7.2	3	14.5	74.3	1.2	3	1.6
A-06	Waco						73.6	4.2	12	5.7
A-04	Waco						78.3	3.0	37	3.9
A-12	Waco						77.9	3.2	17	4.1
A-16	Waco						82.9	2.7	7	3.2

Table 3.11. Atterberg Limit Variability Information from TxDOT Districts-Grade 1.

Pit/Quarry	District	Material	Plastic Limit, Percent				Liquid Limit, Percent				Plastic Index			
			x	s	n	Cv	x	s	n	cv	X	s	n	cv
A-36	Austin	Limestone	16.3	1.2	53	7.4	18.0	3.0	34	16.7	4.7	3.1	59	65.1
A-28	Austin	Limestone	13.4	1.4	88	10.3	17.9	2.2	87	12.0	4.7	2.2	90	47.4
A-43	Bryan										5.7	0.8	3	14.5
A-06	Waco										4.3	1.8	10	40.5
A-04	Waco										5.5	2.1	38	39.2
A-12	Waco										4.5	1.4	17	30.7
A-16	Waco										5.8	2.6	7	45.1

Table 3.12. Wet Ball Mill Variability Information from TxDOT Districts-Grade 1.

Pit/Quarry	District	Material	Percent Loss				% Increase in No. 40			
			x	s	n	cv	x	s	n	cv
A-36	Austin	Limestone	37.3	10.3	54	27.6	13.8	6.6	56	47.4
A-28	Austin	Limestone	32.4	2.7	88	8.5	11.4	1.7	88	15.3
A-43	Bryan		36.3	2.08	3	5.7	11.6	1.7	3	14.6
A-06	Waco		39.2	3.5	11	9.0	14.8	1.8	11	12.0
A-04	Waco		35.7	4.1	38	11.5	14.9	2.3	38	15.7
A-12	Waco		34.6	2.8	17	8.0	12.2	1.6	17	12.8
A-16	Waco		27.3	3.5	7	12.6	11.4	3.5	7	30.7

Table 3.13. Maximum Density-Moisture Content Variability Information from TxDOT Districts-Grade 1.

Pit/Quarry	District	Material	Maximum Unit Weight, pcf				Optimum Water Content, Percent			
			x	s	n	cv	x	s	n	cv
A-36	Austin	Limestone	132.1	2.8	61	20.9	8.4	0.7	61	8.1
A-28	Austin	Limestone	138.7	1.8	90	1.3	6.3	0.4	90	5.9
A-43	Bryan		133.1		1		8.5		1	
A-06	Waco		132.4	1.7	12	1.3	8.5	0.7	12	7.9
A-04	Waco		135.7	1.8	38	1.3	7.6	0.7	37	8.6
A-12	Waco		132.7	2.6	16	1.9	8.3	0.6	16	7.8
A-16	Waco		137.4	1.7	7	1.2	6.9	1.1	7	15.3

Table 3.14. Compressive Strength Variability Information from TxDOT Districts-Grade 1.

Pit/Quarry	District	Material	0 psi Confining Pressure				3 psi Confining Pressure				15 psi Confining Pressure			
			X	s	n	cv	x	s	n	cv	x	s	n	Cv
A-36	Austin	Limestone	46.5	9.9	54	21.4	100.1	17.1	53	17.0	207.8	26.1	54	12.6
A-28	Austin	Limestone	54.4	7.9	53	14.6	107.0	10.4	53	9.7	219.7	14.6	53	6.6
A-43	Bryan		48.5		2		105.2		2		188.9		2	
A-06	Waco		46.6	9.0	13	19.3	103.6	13.8	11	13.3	184.6	22.2	13	12.0
A-04	Waco		51.3		38		104.3	14.9	38	14.3	201.1	22.5	38	11.2
A-12	Waco		51.6	11.8	15	22.8	124.7	23.7	15	19.0	219.0	25.5	14	11.7
A-16	Waco		45.9	10.2	6	22.1	126.9	16.1	6	12.7	237.9	26.2	6	11.0

Table 3.15A. Gradation Variability Information from TxDOT Districts-Grade 2.

Pit/Quarry	District	Material	2 ½ inch				1 ¾ inch				7/8 inch			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
A-29	Austin						0.0	0.0	3	0.0	26.0	1.7	3	6.6
A-26	Austin						2.3	5.3	21	276	27.6	7.6	21	27.5
A-37	Austin						0.0	0.0	7	0.0	16.2	3.0	7	18.2
A-33	Austin						0.1	.26	14	374	23.5	6.8	14	28.8
A-24	Austin						0.0	0.0	59	0.0	22.4	4.1	59	18.2
A-39	Bryan						0.0	0.0	55	0.0	30.9	6.2	55	20.1
A-42	Bryan						0.0	0.0	7	0.0	24.4	9.3	7	38.3
A-38	Bryan						0.0	0.0	4	0.0	37.5	9.1	4	24.2
A-41	Bryan						0.0	0.1	9	29	24.3	7.8	9	32.0
A-40	Bryan						0.0	0.0	3	0.0	31.8	3.6	3	11.2
A-01	Waco													
A-08	Waco													
A-09	Waco													
A-10	Waco													
A-11	Waco													
A-13	Waco													
A-15	Waco													
A-18	Waco													
A-17	Waco													
A-19	Waco													
A-21	Waco													

Table 3.15B. Gradation Variability Information from TxDOT Districts-Grade 2.

Pit/Quarry	District	Material	3/8 inch				No. 40 Sieve			
			x	s	n	cv	x	s	n	cv
A-29	Austin		43.9	2.1	3	4.8	73.1	7.7	3	2.3
A-26	Austin		49.3	4.5	21	9.1	75.6	2.8	21	3.7
A-37	Austin		42.7	4.1	7	9.7	83.4	2.4	7	2.9
A-33	Austin		48.7	6.9	14	14.2	75.6	3.6	14	4.7
A-24	Austin		50.4	4.8	59	9.5	77.9	2.6	59	3.3
A-39	Bryan		53.3	6.5	55	12.2	76.4	10.5	54	13.7
A-42	Bryan		51.2	10.5	7	20.5	75.3	7.5	7	9.9
A-38	Bryan		57.0	6.9	4	12.1	72.2	7.0	4	9.7
A-41	Bryan		49.6	8.1	9	16.4	64.4	24.7	9	38.3
A-40	Bryan		55.8	3.2	3	5.7	74.6	2.5	3	3.4
A-01	Waco						76.4	2.7	28	3.5
A-08	Waco						79.1	3.7	37	4.7
A-09	Waco						78.8	2.4	40	3.0
A-10	Waco						73.8	5.5	16	7.5
A-11	Waco						72.0	2.9	5	4.0
A-13	Waco						80.5	2.8	11	3.5
A-15	Waco						77.7	3.8	6	4.9
A-18	Waco						75.0	1.0	3	1.3
A-17	Waco						81.2	2.9	15	3.6
A-19	Waco						77.4	2.7	31	3.5
A-21	Waco						74.8	4.8	9	6.4

Table 3.16. Atterberg Limit Variability Information from TxDOT Districts-Grade 2.

Pit/Quarry	District	Material	Plastic Limit, Percent				Liquid Limit, Percent				Plastic Index			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
A-29	Austin		15.3	2.5	3	16.4	20.0	2.6	3	13.2	4.7	3.1	3	65.5
A-26	Austin		16.8	1.6	21	9.6	21.7	2.9	19	13.5	5.7	3.3	21	58.1
A-37	Austin		17.5	3.8	6	21.9	16.0	9.1	7	56.9	9.7	4.1	6	42.7
A-33	Austin		17.1	2.2	12	22.6	20.5	2.5	11	12.0	3.7	1.3	14	35.7
A-24	Austin		16.9	1.5	58	8.9	20.3	3.1	55	15.4	5.8	4.1	59	70.3
A-39	Bryan		10.2	3.5	49	33.7	4.4	9.4	41	212	8.0	2.4	51	30.5
A-42	Bryan		10.3	3.0	7	29.0	5.3	8.5	6	159	6.5	2.7	7	41.6
A-38	Bryan		9.5	1.9	4	20.1	4.5	9.0	4	2.0	8.3	2.2	4	25.9
A-41	Bryan		11.8	3.2	6	26.9	11.5	12.6	6	110	8.7	1.4	6	16.2
A-40	Bryan		8.7	2.9	3	33.3								
A-01	Waco										5.1	2.2	28	42.9
A-08	Waco										5.1	1.6	37	31.4
A-09	Waco										6.5	2.6	4	40.7
A-10	Waco										5.9	1.6	16	27.8
A-11	Waco										6.2	1.1	5	17.7
A-13	Waco										3.5	1.2	11	34.8
A-15	Waco										5.1	0.6	6	10.9
A-18	Waco										5.3	0.6	3	10.8
A-17	Waco										4.9	1.3	16	25.8

Table 3.16. Atterberg Limit Variability Information from TxDOT Districts-Grade 2 (Continued).

Pit/Quarry	District	Material	Plastic Limit, Percent				Liquid Limit, Percent				Plastic Index			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
A-19	Waco										5.3	1.7	31	31.7
A-21	Waco										4.9	2.8	9	58.5

Table 3.17. Wet Ball Mill Variability Information from TxDOT Districts-Grade 2.

Pit/Quarry	District	Material	Percent Loss				% Increase in No. 40			
			x	s	n	cv	x	s	n	cv
A-29	Austin		41.0	6.2	3	15.1	14.2	4.8	3	33.7
A-26	Austin		35.2	2.2	17	62.2	11.1	0.8	17	7.7
A-37	Austin		44.7	34.2	6	76.5	14.7	9.4	7	63.9
A-33	Austin		34.6	4.6	13	13.3	10.5	3.0	13	28.6
A-24	Austin		40.2	16.6	58	41.2	15.0	7.0	58	46.7
A-39	Bryan		35.2	2.7	53	7.6	12.9	1.7	52	13.5
A-42	Bryan		37.6	6.3	7	16.8	13.4	2.0	7	14.8
A-38	Bryan		35.2	1.6	3	4.6	10.8	1.3	3	12.3
A-41	Bryan		34.4	4.3	9	12.5	12.1	2.0	9	16.5
A-40	Bryan		38.7	1.2	3	3.0	13.3	1.5	3	11.5
A-01	Waco		40.1	4.3	29	10.6	16.8	2.6	29	15.4
A-08	Waco		33.6	3.6	37	10.8	12.5	1.3	35	10.1
A-09	Waco		33.8	1.3	4	3.7	14.0	0.8	4	5.8
A-10	Waco		38.5	5.1	13	13.3	13.6	6.3	12	46.1
A-11	Waco		38.6	2.7	5	7.0	10.6	0.5	5	5.2
A-13	Waco		36.9	5.2	11	14.1	17.0	2.8	11	16.4
A-15	Waco		33.8	3.9	4	11.4				
A-18	Waco		42.3	1.5	3	3.6	17.7	0.6	3	3.3
A-17	Waco		36.1	3.8	16	10.4	17.3	3.5	16	20.6
A-19	Waco		37.9	3.6	29	9.4	19.4	7.6	29	39.4
A-21	Waco		36.4	4.8	9	13.2	13.0	1.7	9	12.7

Table 3.18. Maximum Density-Moisture Content Variability Information from TxDOT Districts-Grade 2.

Pit/Quarry	District	Material	Maximum Unit Weight, pcf				Optimum Water Content, Percent			
			x	s	n	cv	x	s	n	cv
A-29	Austin		126.3	1.4	3	1.1	9.7	0.3	3	3.6
A-26	Austin		134.5	1.6	17	1.2	7.3	0.5	17	6.2
A-37	Austin		145.5	2.1	7	1.5	5.7	0.3	7	4.7
A-33	Austin		126.5	3.0	14	2.4	9.4	1.2	14	13.2
14-2	Austin		131.2	3.6	59	2.7	8.4	0.8	59	9.3
A-39	Bryan		134.7	1.0	41	0.7	7.2	0.3	41	4.4
A-42	Bryan		134.4	0.6	5	0.5	6.8	0.3	5	3.7
A-38	Bryan		133.0		2		7.3		2	

Table 3.18. Maximum Density-Moisture Content Variability Information from TxDOT Districts-Grade 2 (Continued).

A-41	Bryan		132.0	2.7	6	2.0	8.1	0.8	6	9.8
A-40	Bryan		134.7		2		7.2		2	
A-01	Waco		133.6	4.1	28	3.1	8.4	14.4	28	16.3
A-08	Waco		134.8	1.5	38	1.1	7.5	0.5	38	7.0
A-09	Waco		134.6	0.8	4	0.6	7.8	0.2	4	2.9
A-10	Waco		135.5	1.3	16	0.9	7.1	0.4	16	6.1
A-11	Waco		134.9	1.0	5	0.8	7.3	0.4	5	5.7
A-13	Waco		131.2	3.4	11	2.6	9.1	1.2	11	12.7
A-15	Waco		130.6	2.2	6	1.7	8.0	1.0	6	12.5
A-18	Waco		129.9	2.0	3	1.5	9.2	0.3	3	2.7
A-17	Waco		131.8	1.5	16	1.2	8.5	0.6	16	7.1
A-19	Waco		131.4	2.3	34	1.8	8.7	1.0	34	11.3
A-21	Waco		135.1	1.3	9	1.0	7.3	0.5	9	7.1

Table 3.19. Compressive Strength Variability Information from TxDOT Districts-Grade 2.

Pit/Quarry	District	Material	0 psi Confining Pressure				3 psi Confining Pressure				15 psi Confining Pressure			
			X	s	n	Cv	x	s	n	Cv	x	s	n	Cv
A-29	Austin													
A-26	Austin		49.7	7.2	13	14.5	106.1	7.3	13	6.9	215.2	17.9	13	8.3
A-37	Austin		43.8	19.5	6	44.6	122.3	23.4	6	19.1	228.7	26.0	6	11.4
A-33	Austin		44.7	8.7	14	19.4	99.7	16.6	14	16.7	202.6	26.0	14	12.8
A-24	Austin		46.4	9.6	48	20.7	98.2	13.3	48	13.6	203.9	18.7	48	9.1
A-39	Bryan		47.6	10.6	46	22.2	106.5	21.9	44	20.5	192.6	53.9	46	28.0
A-42	Bryan		41.7	12.8	7	30.7	101.5	12.8	7	12.6	192.3	26.6	7	13.8
A-38	Bryan		45.8	7.7	4	16.9	104.8		2		190.1	17.3	4	9.1
A-41	Bryan		50.4	10.0	7	19.9	118.6	16.1	7	13.5	214.2	18.1	7	8.4
A-40	Bryan		42.0	2.1	3	5.0	102.9	12.3	3	11.9	196.7	11.6	3	5.9
A-01	Waco		38.8	8.7	28	22.6	96.1	12.2	28	12.7	183.9	23.2	28	12.6
A-08	Waco		42.7	10.7	38	25.0	114.2	16.6	38	14.5	201.8	26.7	38	13.2
A-09	Waco		41.2	12.2	4	29.5	116.7	15.0	4	12.8	206.3	24.8	4	12.0
A-10	Waco		35.4	6.6	13	18.5	97.9	9.9	13	10.7	199.1	17.0	13	8.5
A-11	Waco		36.1	16.9	5	46.9	101.2	18.4	5	18.2	217.6	25.7	5	11.8
A-13	Waco		42.5	6.0	11	14.2	109.1	15.2	11	13.9	199.5	22.1	11	11.1
A-15	Waco		40.1	11.0	6	27.5	99.1	22.7	6	22.9	206.2	22.2	6.0	10.8
A-18	Waco		38.7	6.4	3	16.5	106.2	14.1	3	13.2	201.0	22.2	3	11.0
A-17	Waco		35.1	8.8	16	25.2	107.1	14.5	16	13.5	195.2	14.7	16	7.5
A-19	Waco		36.7	10.4	33	28.3	95.2	19.9	33	20.9	181.9	22.1	33	12.2
A-21	Waco		36.3	6.2	9	17.2	110.8	9.4	9	8.5	210.9	22.2	9	10.5

Table 3.20A. Gradation Variability Information from TxDOT Districts-Grade 3.

Pit/Quarry	District	Material	2 ½ inch				1 ¾ inch				7/8 inch			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
A-31	Austin						0.0	0.0	4	0.0	18.5	4.2	4	22.7
A-23	Austin						0.0	0.0	23	0.0	17.5	3.9	23	22.5
A-30	Austin						0.0	0.0	10	0.0	22.6	2.7	10	11.9
A-02	Waco													
A-03	Waco													
A-05	Waco													
A-07	Waco													
A-20	Waco													
A-22	Waco													

Table 3.20B. Gradation Variability Information from TxDOT Districts-Grade 3.

Pit/Quarry	District	Material	3/8 inch				No. 40 Sieve			
			x	s	n	cv	x	s	n	cv
A-31	Austin		48.8	2.5	4	5.1	84.0	5.7	4	6.7
A-23	Austin		45.1	5.1	23	11.4	81.3	4.0	23	5.0
A-30	Austin		49.1	4.7	10	9.6	80.0	1.4	10	1.7
A-02	Waco						76.4	2.0	3	2.6
A-03	Waco						77.3	3.9	25	5.1
A-05	Waco						71.7	1.0	5	1.4
A-07	Waco						78.8	3.6	51	4.6
A-20	Waco						63.0	10.9	6	17.3
A-22	Waco						77.4	3.8	33	4.8

Table 3.21. Atterberg Limit Variability Information from TxDOT Districts-Grade 3.

Pit/Quarry	District	Material	Plastic Limit, Percent				Liquid Limit, Percent				Plastic Index			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
A-31	Austin		17.0	13.8	3	81.5	29.3	4.5	3	15.3	9.7	11.6	3	119.9
A-23	Austin		10.4	4.7	20	45.0	18.0	2.3	15	12.6	12.0	3.0	15	25.0
A-30	Austin		12.8	4.8	10	37.5	19.0	4.8	6	25.4	11.3	5.2	6	46.2
A-02	Waco										5.6	0.8	3	14.4
A-03	Waco										5.1	1.6	25	31.2
A-05	Waco										6.2	1.9	5	31.0
A-07	Waco										5.7	1.4	51	25.1
A-20	Waco										5.5	0.7	6	13.2
A-22	Waco										6.1	1.5	34	25.5

Table 3.22. Wet Ball Mill Variability Information from TxDOT Districts-Grade 3.

Pit/Quarry	District	Material	Percent Loss				% Increase in No. 40			
			x	s	n	cv	x	s	n	cv
A-31	Austin		50.0	35.6	3	71.2	20.8	8.4	4	40.4
A-23	Austin		76.0	29.5	22	38.8	24.4	11.0	22	45.2
A-30	Austin		71.4	27.0	7	37.8	27.2	9.6	10	35.3
A-02	Waco		39.3	3.5	3	8.9	31.7	16.3	3	51.4
A-03	Waco		35.3	5.2	25	14.7	13.1	2.9	25	21.9

Table 3.22. Wet Ball Mill Variability Information from TxDOT Districts-Grade 3 (Continued).

Pit/Quarry	District	Material	Percent Loss				% Increase in No. 40			
			x	s	n	cv	x	s	n	cv
A-05	Waco		44.2	1.3	5	2.9	15.8	1.1	5	6.9
A-07	Waco		34.9	3.9	44	11.2	22.7	12.1	44	53.1
A-20	Waco		46.0	10.0	5	21.7	30.8	19.4	5	62.9
A-22	Waco									

Table 3.23. Maximum Density-Moisture Content Variability Information from TxDOT Districts-Grade 3.

Pit/Quarry	District	Material	Maximum Unit Weight, pcf				Optimum Water Content, Percent			
			x	s	n	cv	x	s	n	Cv
A-31	Austin		123.6	1.8	4	1.5	10.7	0.7	4	6.2
A-23	Austin		148.9	2.1	23	1.4	5.5	0.3	23	5.3
A-31	Austin		138.3	1.1	11	0.8	6.7	0.6	10	8.3
A-02	Waco		132.9	2.4	3	1.8	6.9	1.1	3	15.6
A-03	Waco		135.7	0.9	26	0.7	7.3	0.3	26	3.9
A-05	Waco		130.9	0.5	5	0.4	8.5	0.3	5	3.1
A-07	Waco		131.9	3.2	51	2.4	8.1	1.2	51	14.3
A-20	Waco		135.4	1.8	6	1.3	6.5	1.0	6	16.1
A-22	Waco		135.0	1.1	38	0.8	7.2	0.7	38	9.3

Table 3.24. Compressive Strength Variability Information from TxDOT Districts-Grade 3.

Pit/Quarry	District	Material	0 psi Confining Pressure				3 psi Confining Pressure				15 psi Confining Pressure			
			X	s	n	cv	x	s	n	cv	x	s	n	cv
A-31	Austin		39.8	10.4	4	26.1	103.0	22.2	4	21.5	201.3	12.7	4	6.3
A-23	Austin		43.8	8.8	22	20.1	107.6	13.3	22	12.4	220.7	16.5	22	7.5
A-30	Austin		43.6	9.4	9	21.5	109.3	16.0	9	14.6	213.8	32.3	9	15.1
A-02	Waco		33.5	17.8	3	53.0	96.0	39.3	3	40.9	189.3	13.0	3	6.9
A-03	Waco		38.6	13.2	26	34.3	104.0	22.9	26	22.0	169.1	17.5	26	10.3
A-05	Waco		28.2	2.8	5	9.8	95.7	6.1	5	6.3	180.8	10.8	5	6.0
A-07	Waco		39.7	13.4	46	33.8	98.0	20.8	46	21.2	210.1	31.6	46	15.0
A-20	Waco		51.0	14.5	6	28.5	97.1	21.1	6	21.7	203.6	25.9	6	12.7
A-22	Waco		33.4	12.0	38	35.9	89.2	21.0	38	23.6	185.8	16.9	38	9.1

Table 3.25A. Gradation Variability Information from TxDOT Districts-Grade X.

Pit/Quarry	District	Material	2 ½ inch				1 ¾ inch				7/8 inch			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
A-25	Austin						0.1	0.3	10	316	23.0	4.3	10	18.6
A-27	Austin						0.0	0.0	4	0.0	21.3	4.5	4	21.1
A-35	Austin						0.1	0.3	7	264	23.3	5.9	7	25.4
A-32	Austin						0.8	1.0	4	128	25.0	5.8	4	23.3
A-34	Austin						0.6	0.5	6	91.8	23.6	5.0	6	21.1

Table 3.25B. Gradation Variability Information from TxDOT Districts-Grade X.

Pit/Quarry	District	Material	3/8 inch				No. 40 Sieve			
			x	s	n	cv	x	s	n	cv
A-25	Austin		48.1	4.6	10	9.7	77.4	2.8	10	3.6
A-27	Austin		45.8	6.0	4	13.2	77.3	1.7	4	2.2
A-35	Austin		49.2	5.8	7	11.7	78.9	0.8	7	1.0
A-32	Austin		51.8	6.8	4	13.2	81.3	2.2	4	2.7
A-34	Austin		50.4	5.1	6	10.1	78.0	2.4	6	3.1

Table 3.26. Atterberg Limit Variability Information from TxDOT Districts-Grade X.

Pit/Quarry	District	Material	Plastic Limit, Percent				Liquid Limit, Percent				Plastic Index			
			X	s	n	cv	x	s	n	cv	x	s	n	cv
A-25	Austin		12.9	3.7	10	28.9	21.4	2.4	9	11.2	14.3	2.9	9	20.3
A-27	Austin		10.8	1.0	4	8.9	21.8	0.5	4	23.0	18.3	1.5	4	8.2
A-35	Austin		14.4	2.5	7	17.4	21.0	1.4	6	6.7	15.0	0.6	6	4.2
A-32	Austin		18.3	1.5	4	8.2	20.0	1.4	4	7.1	14.3	0.5	4	3.5
A-34	Austin		13.7	2.2	6	15.8	18.7	1.5	3	8.1	16.0	0.0	3	0.0

Table 3.27. Wet Ball Mill Variability Information from TxDOT Districts-Grade X.

Pit/Quarry	District	Material	Percent Loss				% Increase in No. 40			
			x	s	n	cv	x	s	n	cv
A-25	Austin		77.6	17.6	7	22.6	33.2	8.4	10	25.3
A-30	Austin		86.0	1.4	2	1.6	33.8	2.1	4	6.1
A-35	Austin		85.6	1.3	5	1.6	36.3	2.6	7	7.1
A-32	Austin		87.3	1.5	4	1.7	38.0	2.4	4	6.4
A-34	Austin		86.7	3.1	3	3.5	36.3	3.4	6	9.5

Table 3.28. Maximum Density-Moisture Content Variability Information from TxDOT Districts-Grade X.

Pit/Quarry	District	Material	Maximum Unit Weight, pcf				Optimum Water Content, Percent			
			x	s	n	cv	x	s	n	cv
A-25	Austin		136.3	0.5	10	0.3	7.0	0.2	10	2.6
A-27	Austin		133.5	1.8	4	1.4	8.4	0.5	4	5.6
A-35	Austin		134.1	1.6	7	1.2	8.1	0.7	7	9.2
A-32	Austin		131.6	1.7	4	1.3	8.8	0.3	4	3.7
A-34	Austin		128.5	1.6	6	1.3	8.6	0.7	6	8.1

Table 3.29. Compressive Strength Variability Information from TxDOT Districts-Grade X.

Pit/Quarry	District	Material	0 psi Confining Pressure				3 psi Confining Pressure				15 psi Confining Pressure			
			X	s	n	cv	x	s	n	cv	x	s	n	cv
A-25	Austin		36.9	8.3	10	22.4	94.2	15.6	9	16.6	193.6	16.8	10	8.7
A-27	Austin		42.3	9.8	4	23.1	98.5	13.0	4	13.2	202.8	16.5	4	8.1
A-35	Austin		34.6	5.7	7	16.4	91.1	15.1	7	16.6	193.9	8.0	7	4.1
A-32	Austin		33.8	4.6	4	13.6	92.0	6.7	4	7.3	193.0	15.4	4	8.0
A-34	Austin		49.8	8.3	6	16.7	105.0	9.2	6	8.8	191.3	12.1	6	6.3

Table 3.30A. Gradation Variability Information on Texas Base Materials.

Pit/Quarry	Material	Dates of Tests	Laboratory	2 ½ inch				1 ¾ inch				7/8 inch			
				x	s	n	cv	x	s	n	cv	x	s	n	cv
B-03	City	<2010	Commercial												
		>2010	Commercial												
	State	<2010	Commercial												
			TxDOT-D												
		>2010	Commercial												
B-01	State	>2010	Commercial												
			TxDOT-D												
B-02	State	>2010	Commercial					0.0	0.0	10	0.0	19.6	3.4	10	17.5

Table 3.30B. Gradation Variability Information on Texas Base Materials.

Pit/Quarry	Material	Dates of Tests	Laboratory	3/8 inch				No. 40 Sieve			
				x	s	n	cv	x	s	n	cv
B-03	City	<2010	Commercial					74.4	2.5	109	3.4
		>2010	Commercial					75.0	2.7	26	3.6
	State	<2010	Commercial					76.3	2.1	7	2.8
			TxDOT-D					73.6	3.1	9	4.3
		>2010	Commercial					76.0	1.2	5	1.6
B-01	State	>2010	Commercial					17.9	2.4	7	13.5
			TxDOT-D					21.1	5.0	11	23.7
B-02	State	>2010	Commercial	46.6	4.9	10	10.6	84.5	3.5	10	4.2

Table 3.31. Atterberg Limit Variability Information on Texas Base Materials.

Pit/Quarry	Material	Dates of Tests	Laboratory	Plastic Limit, Percent				Liquid Limit, Percent				Plastic Index			
				x	s	n	cv	x	s	n	cv	x	s	n	cv
B-03	City	<2010	Commercial									5.1	2.5	94	49.3
		>2010	Commercial									2.9	1.6	26	53.8
	State	<2010	Commercial									2.4	1.0	7	40.2
		>2010	Commercial									4.6	1.5	5	33.0
C-01			TxDOT-D												
			TxDOT-C												
B-01	State	>2010	Commercial					18.2	0.8	6	4.1	3.8	1.6	6	41.8
			TxDOT-D					17.3	2.3	11	13.2	4.5	2.2	11	47.6
F-17	State	<2010	TxDOT					20.0	1.7	237	8.8	6.0	1.7	237	31.4
F-18	State	<2010	TxDOT					21.0	1.9	847	9.1	4.0	1.7	847	41.3
F-19	State	<2010	TxDOT					21.0	2.2	1784	10.3	5.0	2.2	1779	46.1
F-20	State	<2010	TxDOT					20.0	2.8	83	13.7	6.0	2.7	133	46.7
B-02	State	>2010	Commercial	12.5	0.1	4	0.8	16.7	0.1	4	0.5	6.0	1.8	9	29.6

Table 3.32. Wet Ball Mill Variability Information on Texas Base Materials.

Pit/Quarry	Material	Dates of Tests	Laboratory	Percent Loss				% Increase in No. 40			
				x	s	n	cv	x	s	n	cv
B-03	City	<2010	Commercial	35.8	3.2	109	8.9				
		>2010	Commercial	35.1	3.2	26	9.0				
	State	<2010	Commercial	33.9	3.6	7	10.6				
		>2010	State	38.1	3.1	7	8.2				
			Commercial	34.9	2.9	5	8.3				
B-01	State	>2010	Commercial	33.7	1.7	7	5.1	12.1	1.5	7	12.1
			TxDOT-D	35.5	4.4	11	12.3	12.6	1.2	11	9.5
F-17	State	<2010	TxDOT	35.0	1.9	99	5.4				
F-18	State	<2010	TxDOT	35.0	3.6	351	10.0				
F-19	State	<2010	TxDOT	36.0	3.5	746	9.7				
F-20	State	<2010	TxDOT	36.0	4.3	23	11.9				
B-02	State	>2010	Commercial	25.8	4.5	10	17.6	10.3	1.2	10	12.1

Table 3.33. Maximum Density-Moisture Content Variability Information on Texas Base Materials.

Pit/Quarry	Material	Dates of Tests	Laboratory	Maximum Unit Weight, pcf				Optimum Water Content, Percent			
				x	s	n	cv	x	s	n	cv
B-03	City	<2010	Commercial	131.3	2.7	109	2.0	8.9	2.5	109	28.3
		>2010	Commercial	132.4	2.1	26	1.6	8.4	0.7	26	8.3
	State	<2010	Commercial	134.0	2.6	7	1.9	7.9	0.6	7	8.1
			State	131.3	2.8	9	2.1	8.6	0.6	9	7.3
		>2010	Commercial	134.5	1.3	5	1.0	7.5	0.6	5	7.8
C-01	State		TxDOT-D	139.3	0.0	3	0.0	6.2	0.0	3	0.0
	State		TxDOT-C	141.1	1.9	3	1.4	6.3	0.1	3	0.9
C-04	State		TxDOT-D	136.6	2.2	10	1.6	7.0	0.5	10	6.8
	State		TxDOT-C	137.7	2.1	12	1.5	7.0	0.4	12	6.0

Table 3.33. Maximum Density-Moisture Content Variability Information on Texas Base Materials (Continued).

Pit/Quarry	Material	Dates of Tests	Laboratory	Maximum Unit Weight, pcf				Optimum Water Content, Percent			
				x	s	n	cv	x	s	n	cv
C-05	State		TxDOT-D	139.9	2.1	23	1.5	6.2	0.4	23	6.7
	State		TxDOT-C	139.8	1.5	24	1.1	6.4	0.5	24	7.4
C-07	State		TxDOT-D	139.0	1.6	3	1.2	5.9	0.2	3	2.9
	State		TxDOT-C	139.4	3.4	3	2.4	5.9	0.0	3	0.0
C-02	State		TxDOT-D	138.6	2.1	28	1.5	6.5	0.3	28	3.9
	State		TxDOT-C	138.9	1.2	29	0.9	6.5	0.3	29	4.8
C-06	State		TxDOT-D	142.4	1.1	4	0.8	5.8	0.2	4	2.6
	State		TxDOT-C	143.2	0.5	4	0.3	5.7	0.1	4	1.0
C-03	State		TxDOT-C	138.0	0.4	4	0.3	6.2	0.2	4	3.3

Table 3.34. Compressive Strength Variability Information on Texas Base Materials.

Pit/Quarry	Material	Dates of Tests	Laboratory	0 psi Confining Pressure				3 psi Confining Pressure				15 psi Confining Pressure			
				x	s	n	cv	x	s	n	cv	x	s	n	cv
B-03	City	<2010	Commercial	48.4	5.5	109	11.4	112.5	7.4	17	6.6	215.3	14.7	109	6.8
		>2010	Commercial	48.0	13.9	26	28.9	113.0	12.5	26	11.1	225.1	16.8	26	7.5
	State	<2010	Commercial	51.4	5.9	7	11.4	118.3	20.3	6	17.2	228.7	12.7	7	5.5
			State	41.2	9.6	9	23.3	93.6	13.4	7	14.3	192.7	28.1	9	14.6
		>2010	Commercial	33.4	6.6	5	19.8	96.4	7.3	5	7.5	209.2	6.7	5	3.2
C-01	State		TxDOT-D	35.6	3.2	3	9.1					250.1	84.2	3	33.7
	State		TxDOT-C	44.1	9.6	3	21.7					215.5	12.8	3	5.9
C-04	State		TxDOT-D	23.5	11.2	10	47.8	77.2	16.9	5	21.8	153.3	35.7	10	23.3
	State		TxDOT-C	27.6	7.2	11	26.1	83.3	18.0	6	21.6	169.9	28.9	12	17.0
C-05	State		TxDOT-D	32.4	7.2	28	22.1	84.1	19.6	8	23.3	185.7	28.1	23	15.1
	State		TxDOT-C	40.9	14.0	29	34.2	83.2	19.4	10	23.4	185.7	26.4	24	14.2
C-07	State		TxDOT-D	28.7	4.1	3	14.3	90.6	13.1	3	14.5	186.6	22.6	3	12.1
	State		TxDOT-C	32.5	2.8	3	8.7	117.8	0/8	2	0.7	208.5	26.3	3	12.6
C-02	State		TxDOT-D	32.4	7.2	28	22.1	110.2	25.3	23	23.0	195.0	33.6	28	17.2
	State		TxDOT-C	40.9	14.0	29	34.2	97.6	15.5	25	15.9	195.2	24.0	29	12.3
C-02	City	<2010	Commercial	48.9	10.8	9	22.2					217.2	20.8	9	9.6
		>2010	Commercial	47.0	7.4	8	15.8	105.1	6.8	8	6.5	212.9	17.4	8	8.2
	State	<2010	Commercial	56.7	2.3	3	4.1	115.3	14.2	3	12.3	232.7	23.1	3	9.9
			TxDOT-D	30.1	4.1	5	13.7					171.8	32.1	4	18.7
			TxDOT-C	35.6	13.2	5	36.9	85.3	13.4	4	15.7	181.2	27.8	5	15.3
		>2010	Commercial	48.7	7.8	7	16.0	111.1	12.5	7	11.3	207.3	14.8	7	7.1
			TxDOT-D	37.4	8.2	27	21.8	95.1	9.8	27	10.3	193.3	15.7	27	8.1
			TxDOT-C	38.5	8.1	8	21.1	96.3	11.0	8	11.4	195.6	12.5	8	6.4
C-06	State		TxDOT-D	39.0	4.2	4	10.8	116.4	9.0	3	7.8	236.8	10.0	4	4.2
	State		TxDOT-C	60.5	11.9	4	19.6	123.6	12.3	3	10.0	244.6	5.3	3	2.2
C-03	State		TxDOT-C	29.8	12.2	4	41.0	81.8	10.1	4	12.4	175.5	19.6	4	11.2
F-05	State	<2010	TxDOT	39.5	11.5	16	28.2								
F-07	State	<2010	TxDOT	41.5	12.5	2	30.1								
F-15	State	<2010	TxDOT	17.7	3.7	3	21.0								
F-21	State	<2010	TxDOT	28.0	7.8	3	27.9								
F-26	State	<2010	TxDOT	39.2	6.2	2	15.7								
F-27	State	<2010	TxDOT	39.7	7.4	6	18.6								
F-28	State	<2010	TxDOT	30.6	6.1	5	20.1								
F-31	State	<2010	TxDOT	31.5	8.9	4	28.1								
F-32	State	<2010	TxDOT	37.5	7.5	3	20.1								
F-37	State	<2010	TxDOT	23.0	10.9	7	47.5								
F-39	State	<2010	TxDOT	26.5	2.5	2	9.4								
F-48	State	<2010	TxDOT	33.7	3.9	3	11.5								

Table 3.35A. Gradation Variability Information for Base Materials-National.

Pit/Quarry	Material	Reference	1 inch				3/4 inch				1/2 inch			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
G-07		20												
G-08		20												
G-09		20												
G-01	Crushed-Plant	21	90.0	3.0	2125	3.4	81.0	3.7	2125	4.5	68.0	3.5	2125	5.2
G-02	Crushed-In Place	21	90.0	3.5	271	3.9	80.0	4.6	271	5.7	68.0	4.7	271	6.9
G-03	Gravel-Plant	21	98.8	1.4	26	1.5					73.0	3.7	26	5.0
G-04	Gravel-In Place	21	98.5	1.6	29	1.6					74.3	4.3	29	5.8
G-17		21		1.9	8532									
G-21	Granite-No Pugmill	21						3.9	106					
G-22	Limestone-No Pugmill	21						1.8	65					
G-23	Limestone-Pugmill	21						0.9	53					
G-24	Limestone-No Pugmill	21												
G-25	Gravel-Pit Run	21												
G-26	Gravel-Pit Run	21												
G-13	Plant-No Pugmill	21		2.2	169							4.2	169	
G-14	In Place-No Pugmill	21		1.8	180							4.3	180	
G-18	Granite	21												
G-19	Limestone	21												
G-20	Trap Rock	21												

Table 3.35B. Gradation Variability Information for Base Materials-National.

Pit/Quarry	Material	Reference	3/8 inch				No. 4				No. 8			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
G-07		20					50.9	3.1	200	6.1				
G-08		20					58.1	2.8	200	4.8				
G-09		20					52.7	5.7	200	10.8				
G-01	Crushed-Plant	21					48.0	2.2	2125	4.7				
G-02	Crushed-In Place	21					50.0	3.6	271	7.1				
G-03	Gravel-Plant	21					46.2	2.0	26	4.2				
G-04	Gravel-In Place	21					48.9	3.4	29	7.0				
G-17		21												
G-21	Granite-No Pugmill	21						3.3	106			3.7	106	
G-22	Limestone-No Pugmill	21						2.3	65			1.7	65	
G-23	Limestone-Pugmill	21						2.8	53			2.0	53	
G-24	Limestone-No Pugmill	21						6.7	163			2.7	163	
G-25	Gravel-Pit Run	21						7.7	25			3.3	25	
G-26	Gravel-Pit Run	21						6.8	22			2.5	22	
G-13	Plant-No Pugmill	21						3.4	169					
G-14	In Place-No Pugmill	21						4.2	180					

Table 3.35B Gradation Variability Information for Base Materials-National (Continued).

G-18	Granite	21						4.3	30					
G-19	Limestone	21						4.5	21					
G-20	Trap Rock	21						4.6	68					

Table 3.35C. Gradation Variability Information for Base Materials-National.

Pit/Quarry	Material	Reference	No. 10				No. 16				No. 30			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
G-07		20									23.8	2.5	200	10.5
G-08		20									27.3	2.3	200	8.4
G-09		20									23.4	2.9	200	12.4
G-01	Crushed-Plant	21	35.0	1.6	2125	4.4								
G-02	Crushed-In Place	21	36.0	2.2	271	6.1								
G-03	Gravel-Plant	21					32.5	1.6	26	4.8				
G-04	Gravel-In Place	21					35.0	2.7	29	7.6				
G-17		21		2.8	8532									
G-21	Granite-No Pugmill	21		3.7	106									
G-22	Limestone-No Pugmill	21		1.6	65									
G-23	Limestone-Pugmill	21		1.7	53									
G-24	Limestone-No Pugmill	21		1.5	163									
G-25	Gravel-Pit Run	21		0.9	25									
G-26	Gravel-Pit Run	21		1.2	22									
G-13	Plant-No Pugmill	21		3.0	169									
G-14	In Place-No Pugmill	21		4.3	180									
G-18	Granite	21		3.4	30									
G-19	Limestone	21		3.0	21									
G-20	Trap Rock	21		3.0	68									

Table 3.35D. Gradation Variability Information for Base Materials-National.

Pit/Quarry	Material	Reference	No. 40				No. 60				No. 100			
			x	s	n	cv	x	s	n	cv	x	s	n	cv
G-07		20												
G-08		20												
G-09		20												
G-01	Crushed-Plant	21	20.0	0.9	2125	4.5					13.5	0.7	2125	5.0
G-02	Crushed-In Place	21	20.0	1.5	271	7.3					14.5	1.0	271	7.0
G-03	Gravel-Plant	21	20.6	1.4	26	6.9					11.4	1.0	26	8.7
G-04	Gravel-In Place	21	22.8	2.3	29	10.2					12.8	1.1	29	8.9
G-17		21												
G-21	Granite-No Pugmill	21						3.1	106					
G-22	Limestone-No Pugmill	21						1.5	65					
G-23	Limestone-Pugmill	21						1.0	53					
G-24	Limestone-No Pugmill	21												

Table 3.35D. Gradation Variability Information for Base Materials-National (Continued).

G-25	Gravel-Pit Run	21												
G-26	Gravel-Pit Run	21												
G-13	Plant-No Pugmill	21												
G-14	In Place-No Pugmill	21												
G-18	Granite	21												
G-19	Limestone	21												
G-20	Trap Rock	21												

Table 3.35E. Gradation Variability Information for Base Materials-National.

Pit/Quarry	Material	Reference	No. 200											
			x	s	n	Cv	x	s	n	cv	x	s	n	cv
G-07		20	6.0	0.7	200	11.7								
G-08		20	7.9	1.1	200	13.9								
G-09		20	4.6	0.95	200	20.7								
G-01	Crushed-Plant	21	10.0	0.6	2125	6.0								
G-02	Crushed-In Place	21	11.5	0.9	271	7.5								
G-03	Gravel-Plant	21	7.6	0.8	26	10.8								
G-04	Gravel-In Place	21	9.1	0.8	29	9.2								
G-17		21		0.9	8532									
G-21	Granite-No Pugmill	21		1.2	106									
G-22	Limestone-No Pugmill	21		1.0	65									
G-23	Limestone-Pugmill	21		0.7	53									
G-24	Limestone-No Pugmill	21												
G-25	Gravel-Pit Run	21												
G-26	Gravel-Pit Run	21												
G-13	Plant-No Pugmill	21		1.0	169									
G-14	In Place-No Pugmill	21		1.3	180									
G-18	Granite	21		1.0	30									
G-19	Limestone	21		1.2	21									
G-20	Trap Rock	21		1.2	68									

Table 3.36. Relative Density/Moisture Content Variability Information for Base Materials-National.

Pit/Quarry	Material	Reference	Relative Density				Moisture Content			
			x	s	n	cv	x	s	n	cv
G-01	Subbase-Flex Pvt	21	102.2	1.6	979	1.6				
G-02	Subbase-Rigid Pvt	21	101.6	1.6	717	1.6				
G-03	Crushed Stone	21	101.5	1.2	115	1.2				
G-04	Gravel	21	103.7	1.3	105	1.3				
G-15		21	98.7	2.9		3.0				
G-16		21	98.7	2.9		2.9				
G-05	Subbase	21	100.7	2.3	100	2.3				
G-06	Base	21	99.2	4.1	96	4.1				
G-10	Subbase	21	89.4	3.3		3.7				
G-11	Subbase	21	91.7	3.1		3.4				
G-12	Subbase	21	93.6	2.2		2.5				

Table 3.37. Moisture Content vs. Unconfined Strength Data.

Quarry/Pit	Sample	Strength at Optimum Moisture Content (psi)	Strength at 1% Above Optimum (psi)	Loss in Strength with Addition of 1% Moisture (Δpsi)	% Strength Loss with Addition of 1% Moisture	Ratio (Strength at 1% Above Optimum/Strength at Optimum)
D-13	NA	36	33	3	8.3	0.917
D-03	NA	39	10	29	74.4	0.256
D-21	NA	31	17	14	45.2	0.548
D-07	NA	48	18	30	62.5	0.375
D-15	A	22	12	10	45.5	0.545
	B	21	11	10	47.6	0.524
	C	36	26	10	27.8	0.722
	D	22	9	13	59.1	0.409
	E	24	12	12	50.0	0.500
D-19	NA	45	29	16	35.6	0.644
D-23	NA	40	6	34	85.0	0.150
D-09	NA	37	28	9	24.3	0.757
D-17	NA	27	12	15	55.6	0.444
D-10	NA	33	12	21	63.6	0.364

Table 3.37. Moisture Content vs. Unconfined Strength Data. (continued)

Quarry/Pit	Sample	Strength at Optimum Moisture Content (psi)	Strength at 1% Above Optimum (psi)	Loss in Strength with Addition of 1% Moisture (Δpsi)	% Strength Loss with Addition of 1% Moisture	Ratio (Strength at 1% Above Optimum/Strength at Optimum)
D-20	NA	40	5	35	87.5	0.125
D-22	A	70	45	25	35.7	0.643
	B	30	15	15	50.0	0.500
	C	20	10	10	50.0	0.500
D-18	A	22	12	10	45.5	0.545
	B	30	21	9	30.0	0.700
D-14	A	31	12	19	61.3	0.387
	B	42	48	-6	-14.3	1.143
D-05	A	34	13	21	61.8	0.382
	B	54	25	29	53.7	0.463
	C	32	16	16	50.0	0.500
	D	36	15	21	58.3	0.417

Table 3.38. Desired Flexible Base Properties and Associated Test Methods.

Property		Gradation (Tex-110-E)	Atterberg Limits (Tex-105, 105, 105, 107-E)	Wet Ball Mill (Tex-116-E)	Soundness (Tex-411-A)	Compressive Strength /Classification (Tex-117-E)	In-place density-moisture content
Load Carrying Ability	Initial	X	X			X	X
	Long Term	X	X	X	X	X	
Durability	Degradation			X	X		
	Volume Change	X	X				
	Freeze-Thaw Resistance	X	X		X		
	Wet-Dry Resistance				X		
	Pumping of Fines	X		X	X		
Permeability		X	X	X	X		X

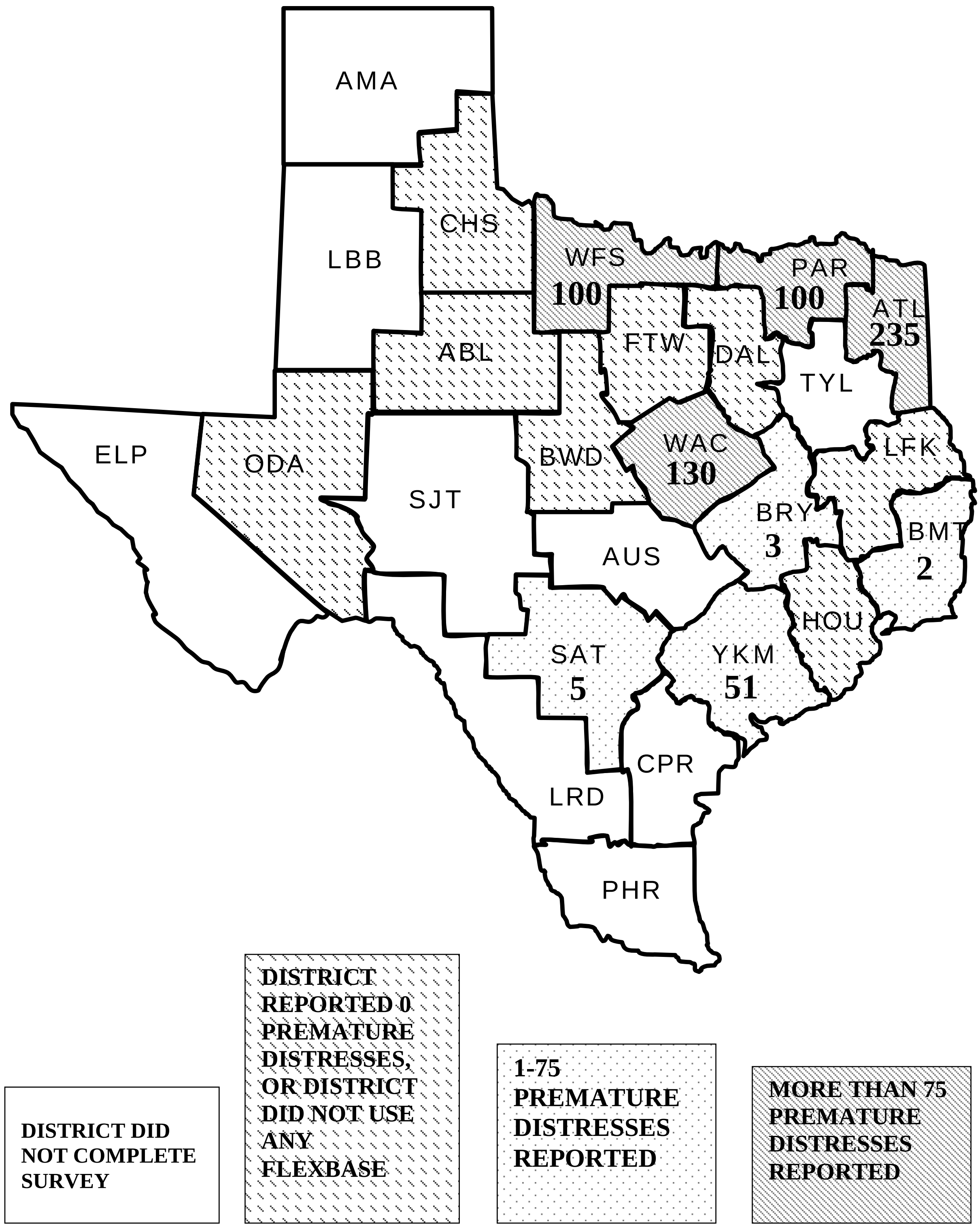

Figure 3.1. Reported Highway (IH, US, SH, and FM Combined) Premature Pavement Distresses Caused by Flexible Base per Year.

Figure 3.2. Pit/Quarry D-08.

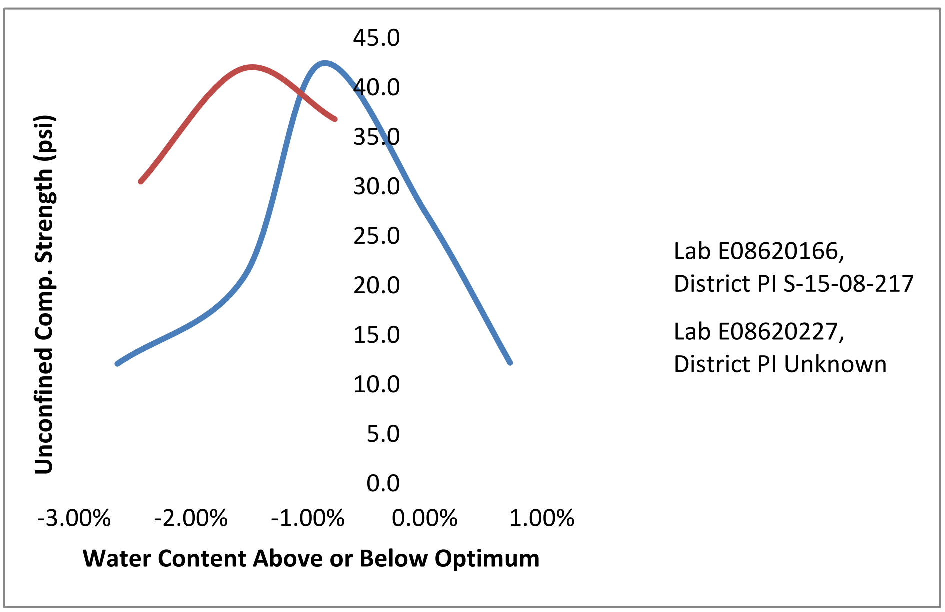

Figure 3.3. Pit/Quarry D-02.

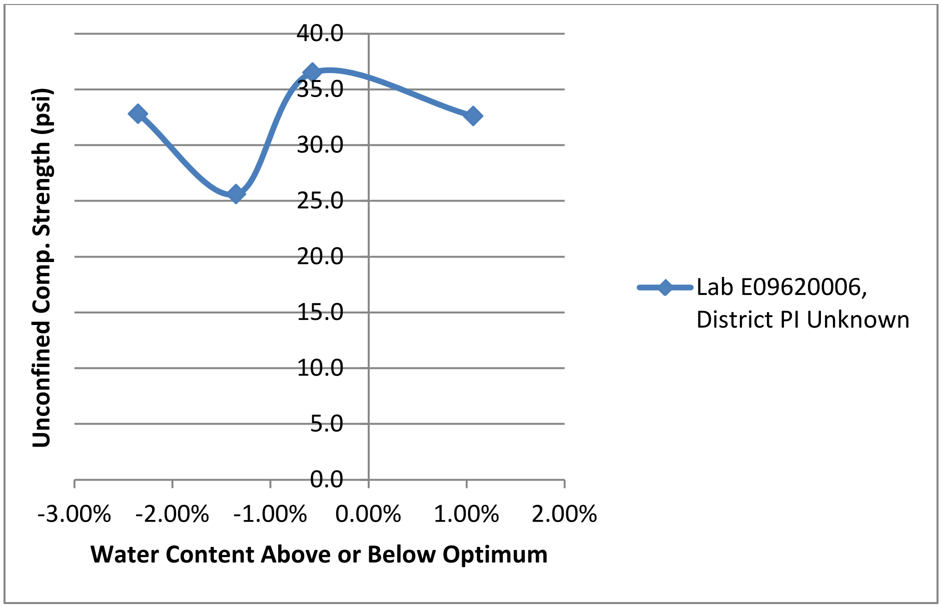

Figure 3.4. Pit/Quarry D-13.

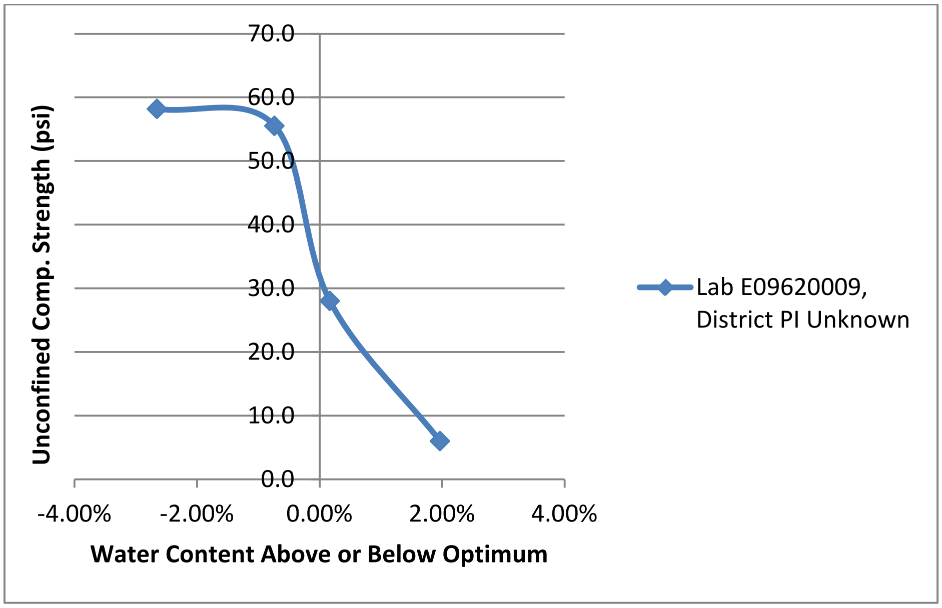

Figure 3.5. Pit/Quarry D-21.

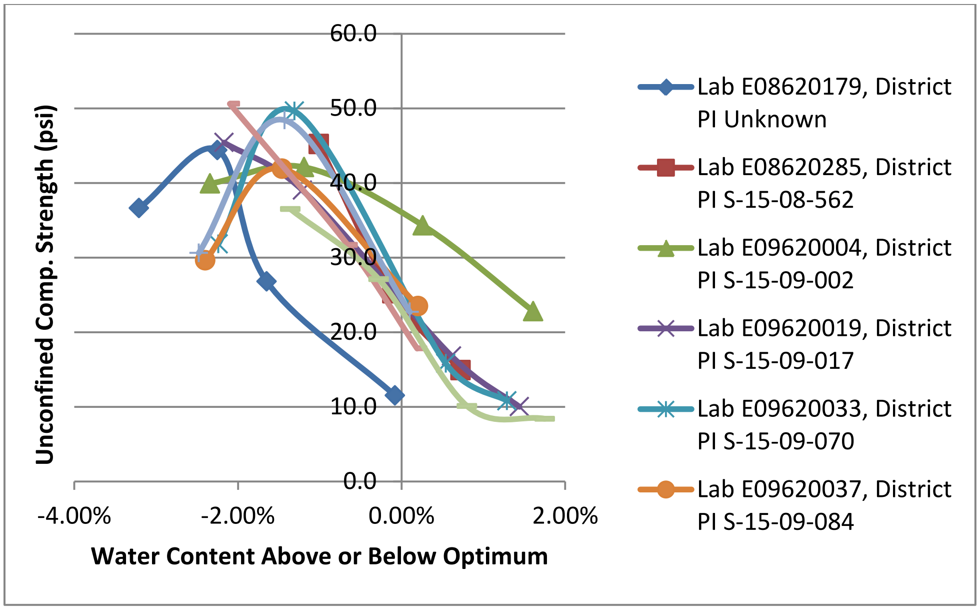

Figure 3.6. Pit/Quarry D-15.

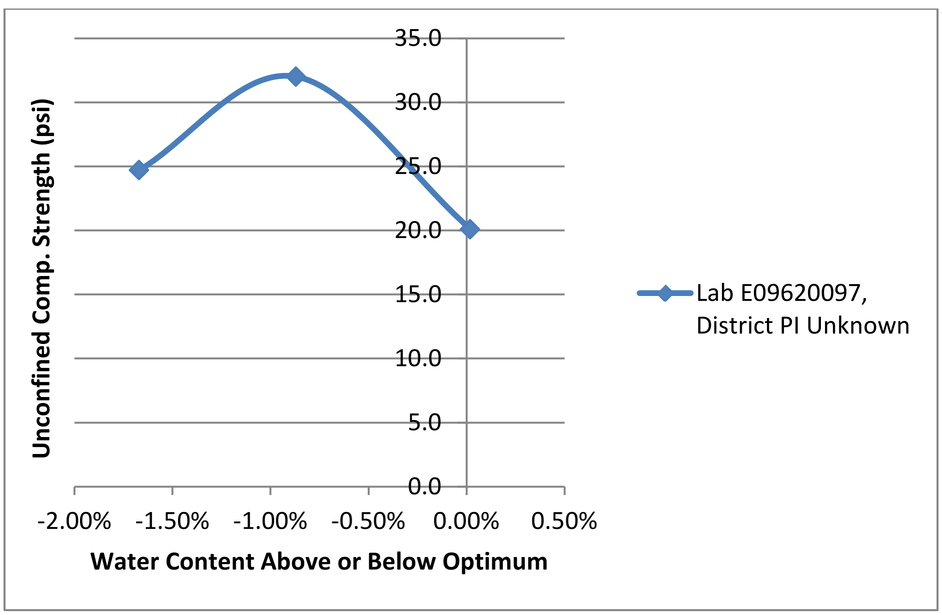

Figure 3.7. Pit/Quarry D-01.

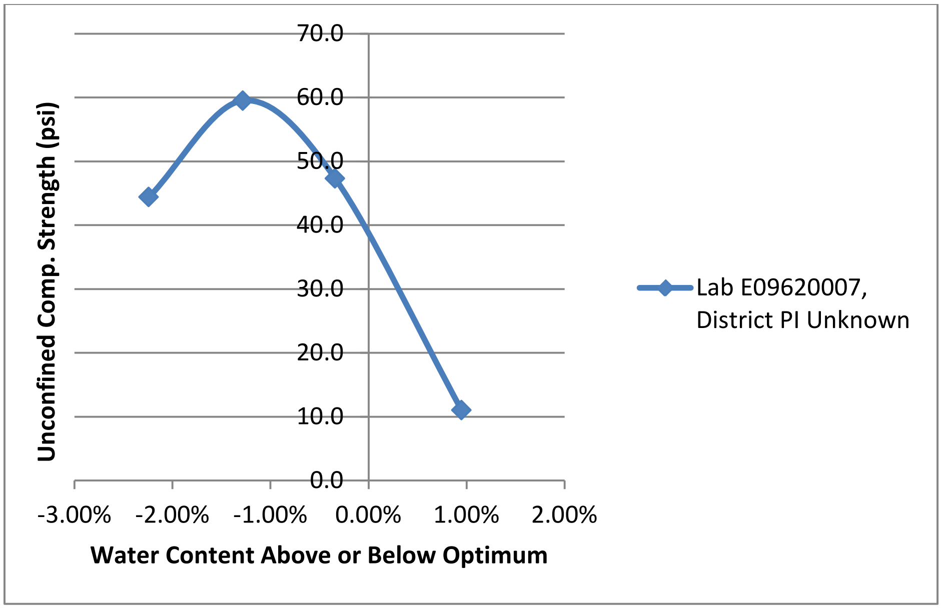

Figure 3.8. Pit/Quarry D-03.

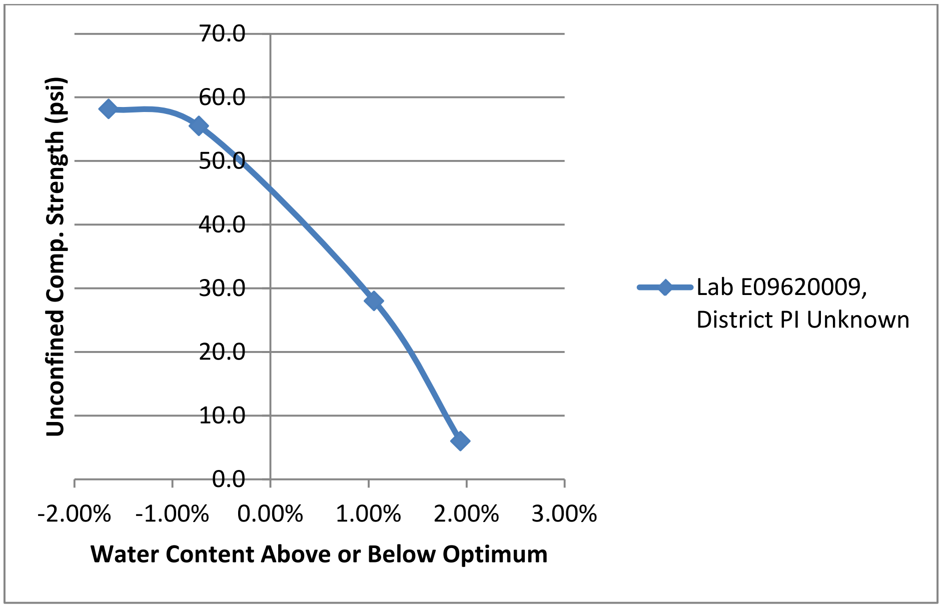

Figure 3.9. Pit/Quarry D-19.

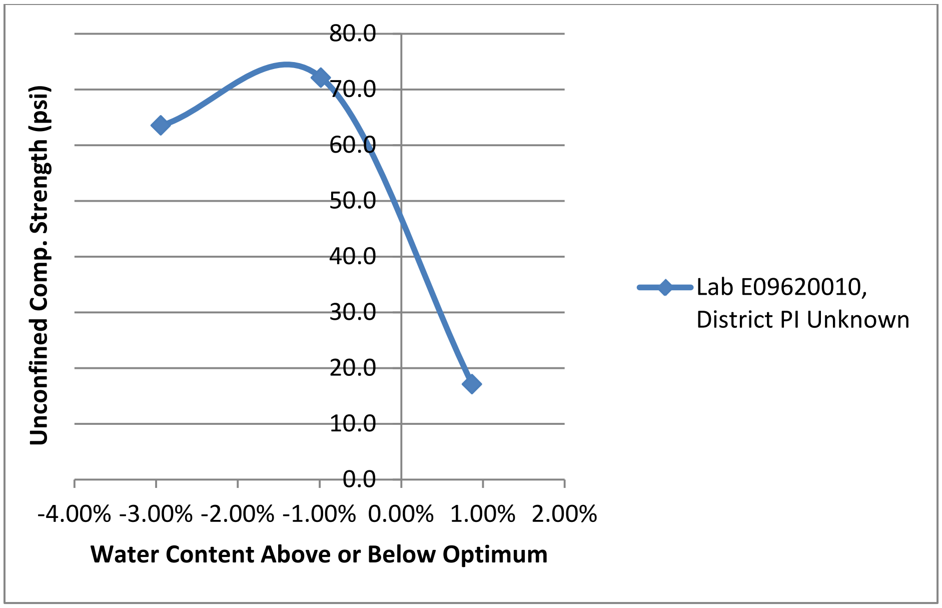

Figure 3.10. Pit/Quarry D-07.

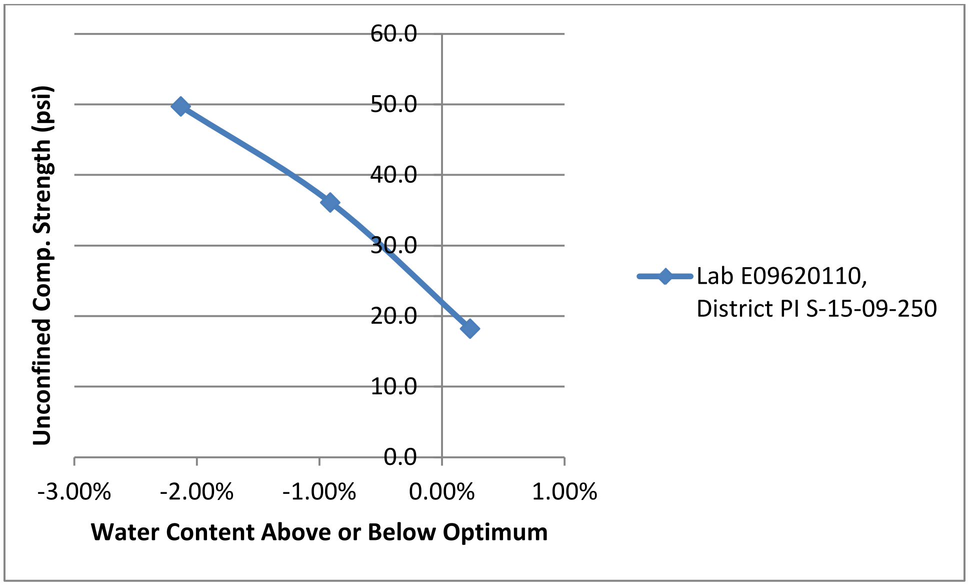

Figure 3.11. Pit/Quarry D-25.

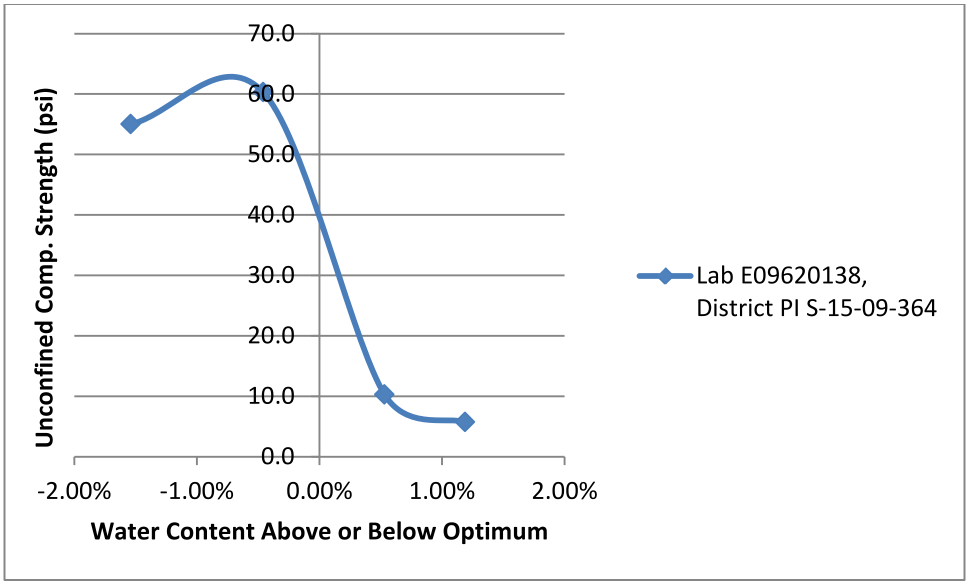

Figure 3.12. Pit/Quarry D-23.

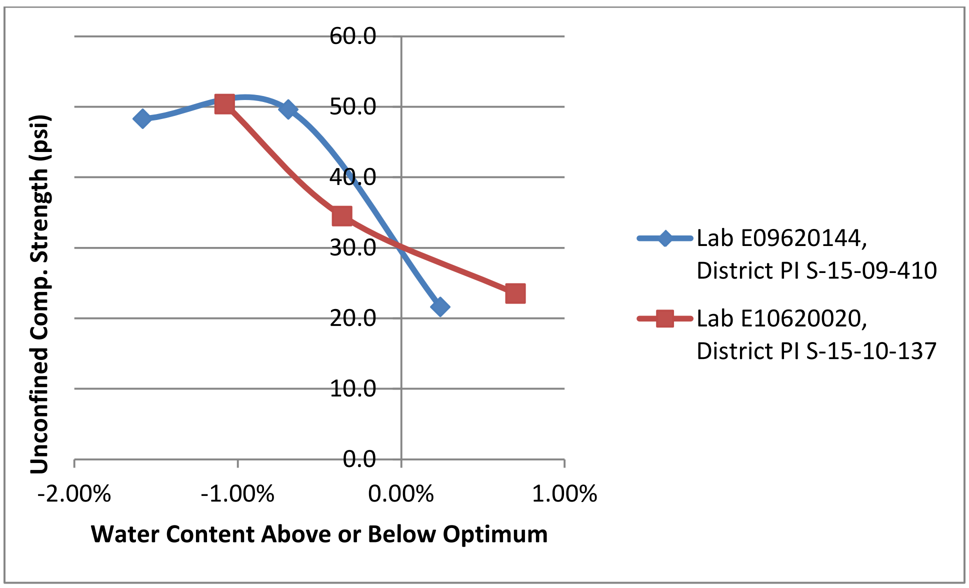

Figure 3.13. Pit/Quarry D-06.

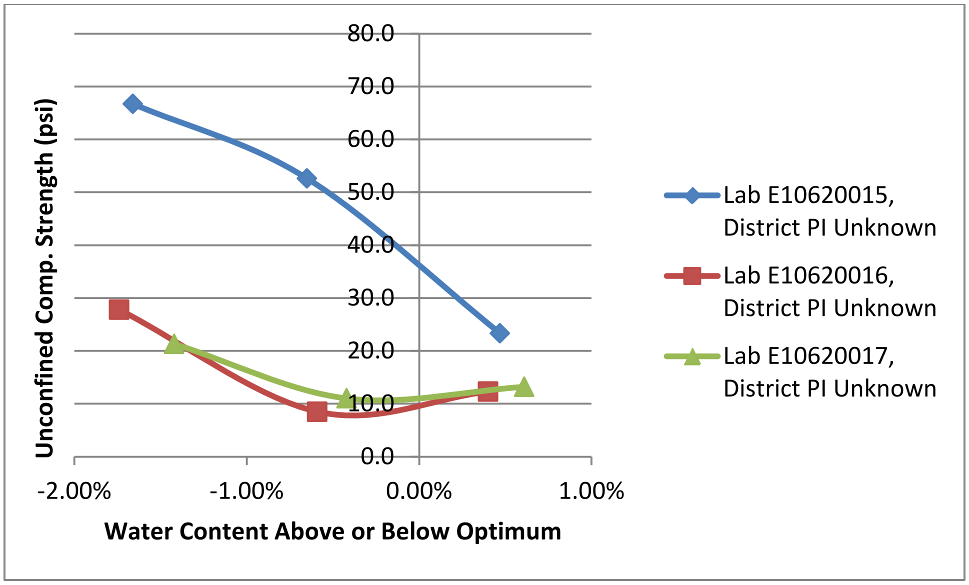

Figure 3.14. Pit/Quarry D-16.

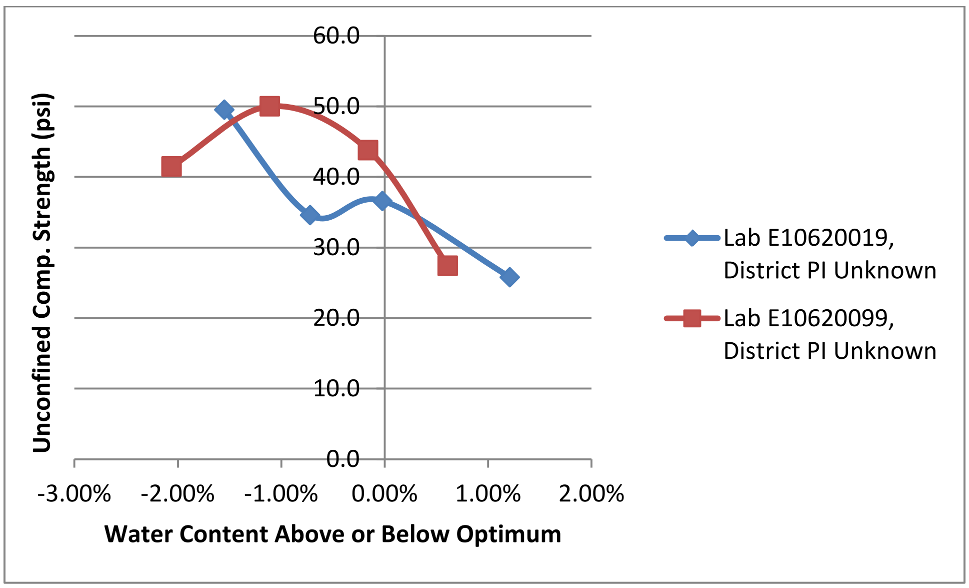

Figure 3.15. Pit/Quarry D-09.

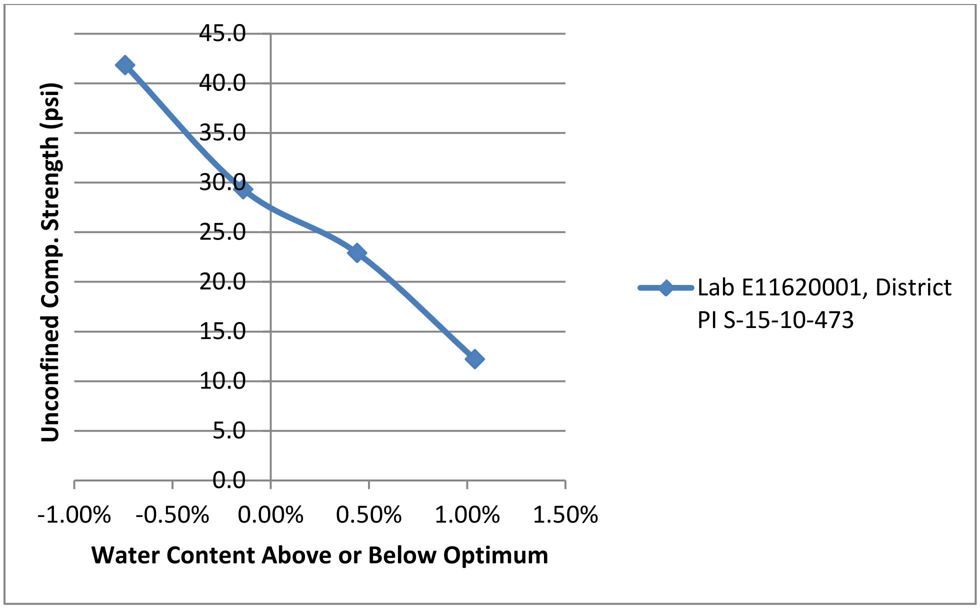

Figure 3.16. Pit/Quarry D-17.

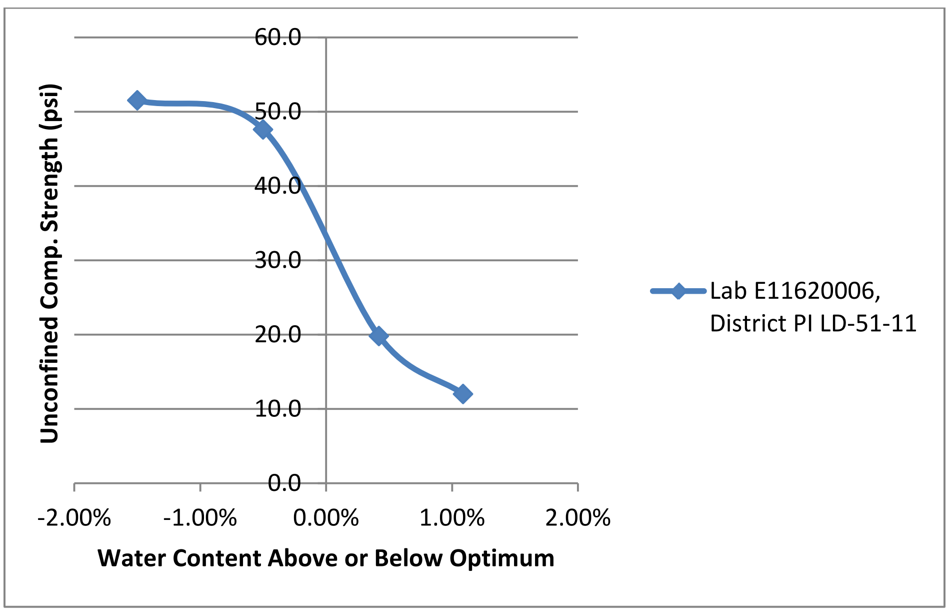

Figure 3.17. Pit/Quarry D-10.

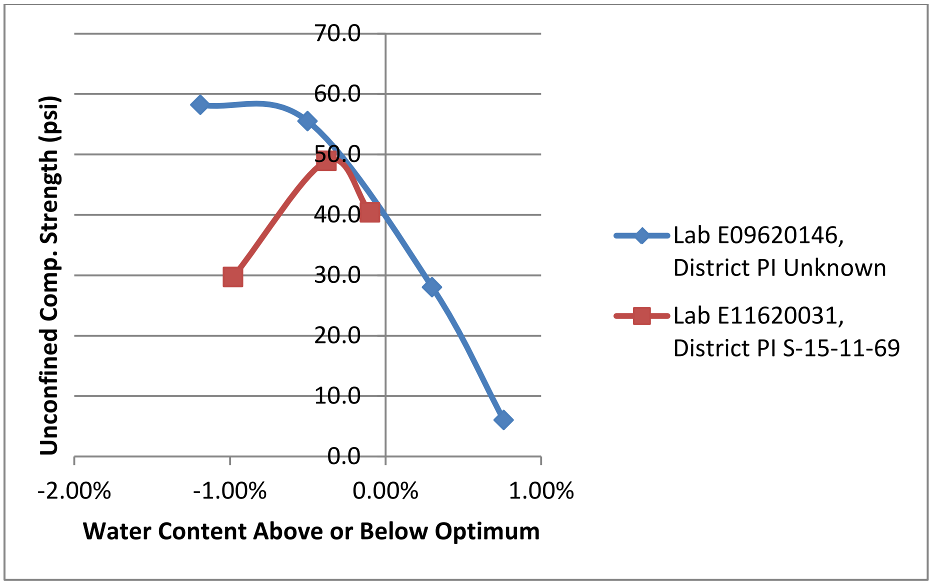

Figure 3.18. Pit/Quarry D-20.

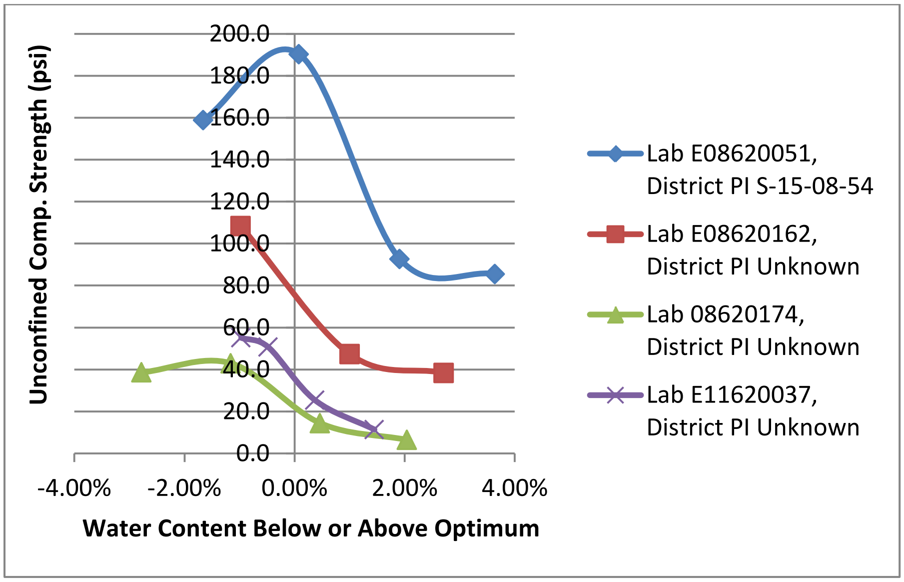

Figure 3.19. Pit/Quarry D-22.

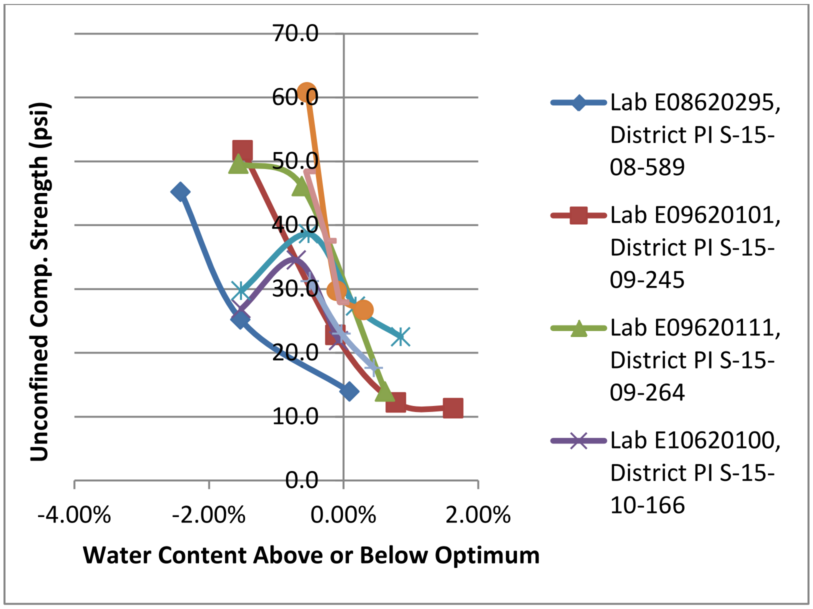

Figure 3.20. Pit/Quarry D-18.

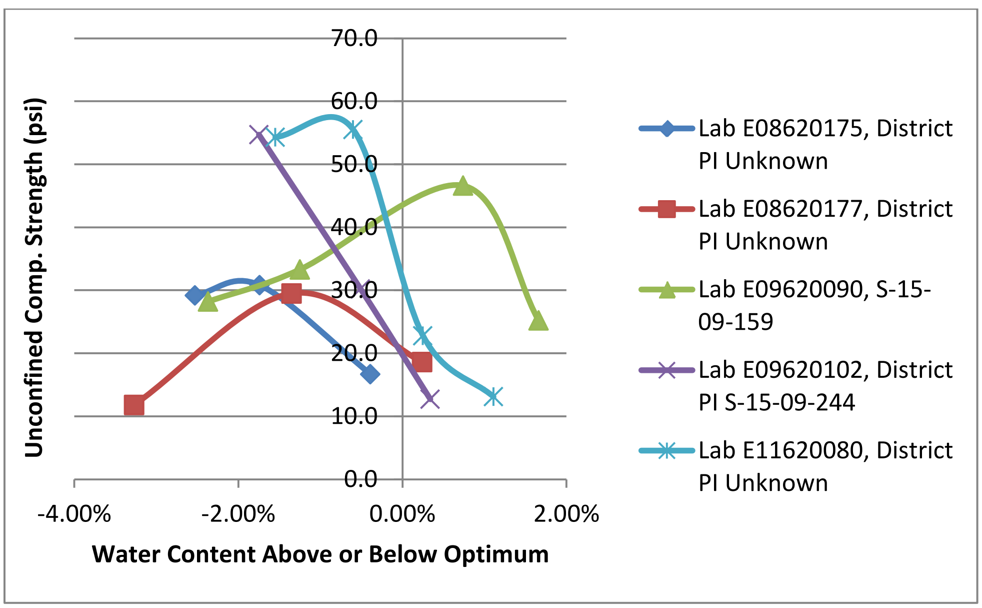

Figure 3.21. Pit/Quarry D-14.

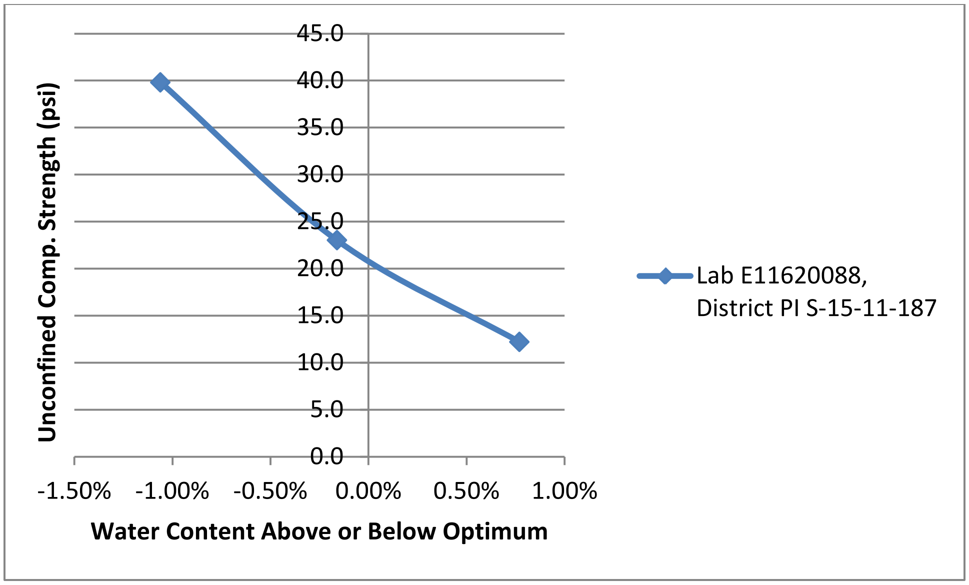

Figure 3.22. Pit/Quarry D-12.

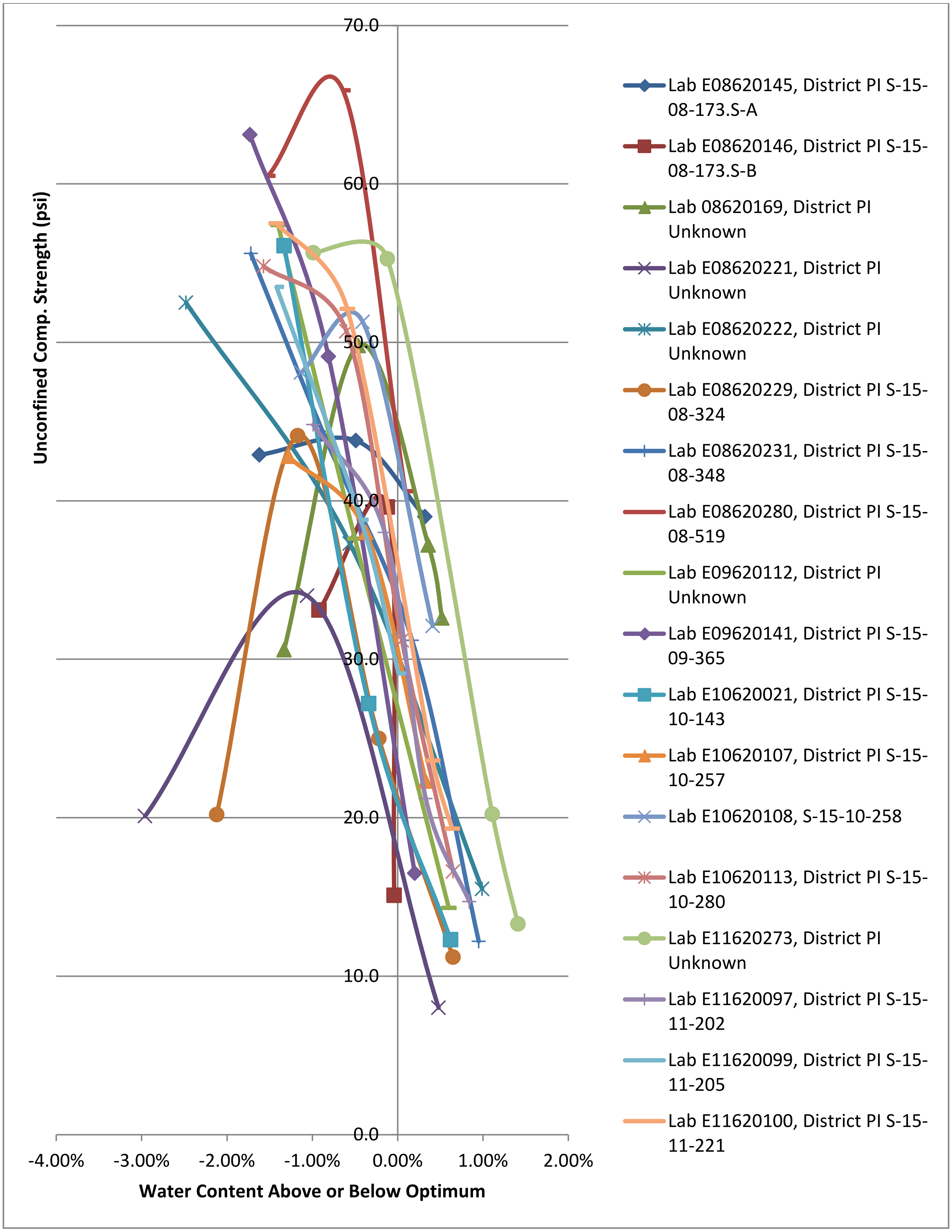

Figure 3.23. Pit/Quarry D-05.

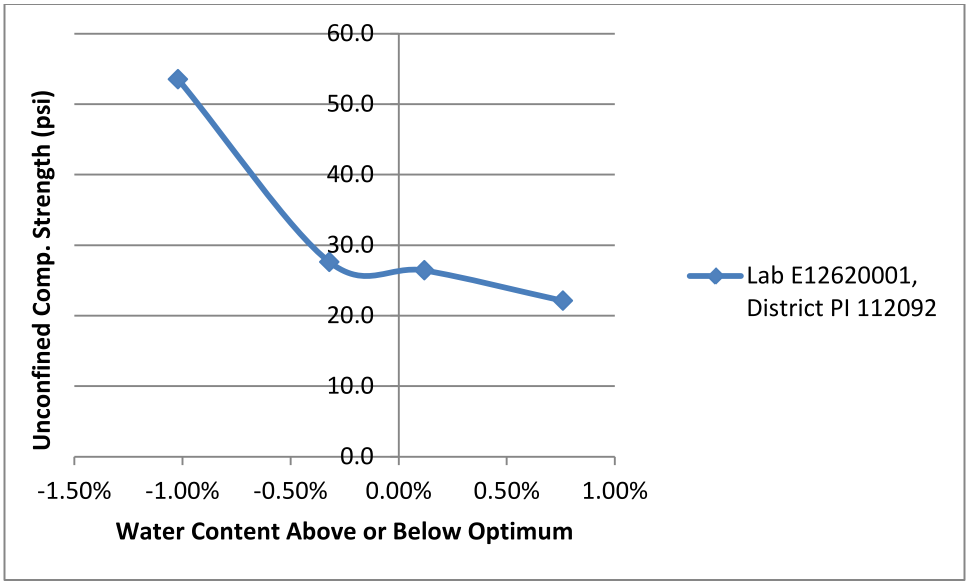

Figure 3.24. Pit/Quarry D-04.

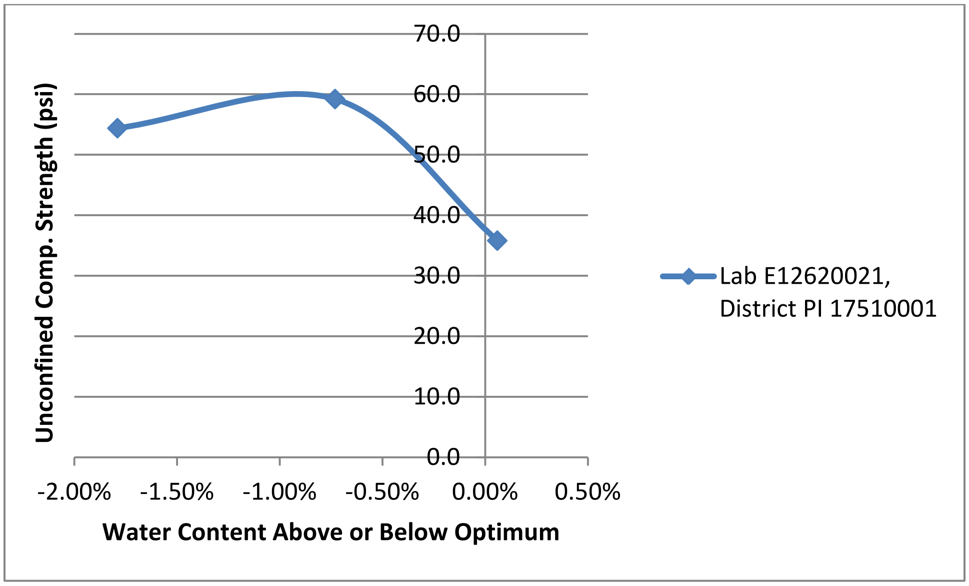

Figure 3.25. Pit/Quarry D-11.

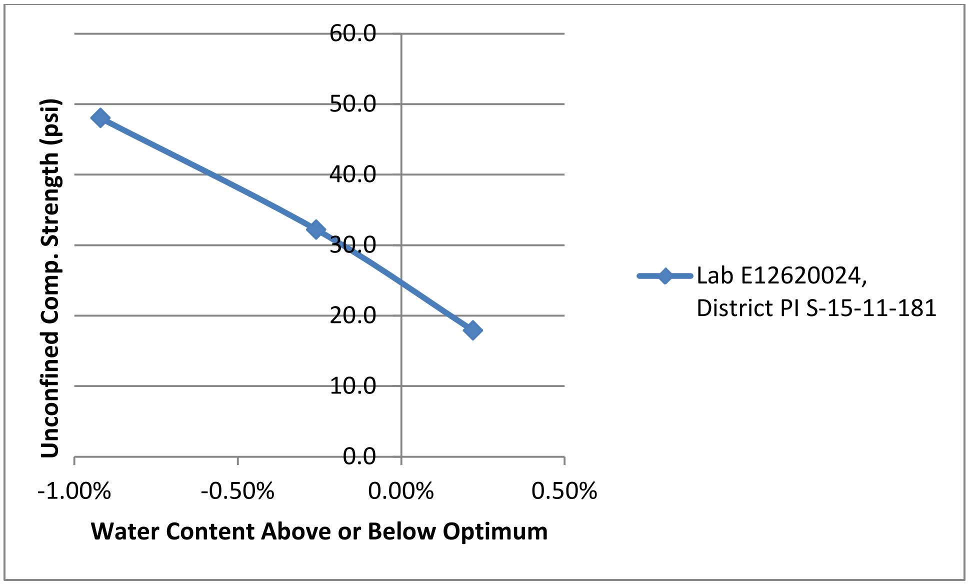

Figure 3.26. Pit/Quarry D-24.

REFERENCES

3.1 Epps, J., Sebesta, S., Sahin, H., Button, J., Luo, R., and Lytton, R. "Developing a Mixture Design Specification for Flexible Base Construction." Report No. FHWA/TX-12/0-6621-1, Federal Highway Administration, Report 0-6621-1, Texas Transportation Institute, June 2011.

3.2 Jayawickrama, P., Merrick, M., and Senadheera, S. "Develop a New Testing and Evaluation Protocol to Assess Flexbase Performance Using Strength of Soil Binder." Report No. 5873-1, Texas Tech University, August 2008.

3.3 Gautam, B., Yan, D., Abdallah, I., and Nazarian, S. "Guidelines for Using Local Materials for Roadway Base and Subbase." Report No. 5562, FHWA-TX-08/05562-1, University of Texas at El Paso, January 2009.

3.4 Scullion, T., Harris, J., Sebesta, S., and Nazarian, S. "Heavy Duty Flexible Bases: Field Performance and Draft Specifications." Report 4358-4, FHWA/TX-06/0-4358-4, Texas Transportation Institute, December 2007.

3.5 Gandara, J., Kancherla, A., Alvarado, G., Nazarian, S., and Scullion, T. "Impact of Aggregate Gradation on Base Material Performance." Report No. 4358-2, University of Texas at El Paso, November 2005.

3.6 McMahon, Halstead, Baker, Granley and Kelly, "Quality Assurance in Highway Construction." Report No. FHWA-TS-8A-038, October 1990.

3.7 Epps, J., Hand, A., and Sebaaly, P. "Subgrade, Base Course and Hot-Mix Asphalt Construction Variability." WesTrack Technical Report UNR-29, July 22, 2000 (also available from NCHRP).

CHAPTER 4. PRECISION AND BIAS OF TEST METHODS

INTRODUCTION

Results from sampling and testing of materials are typically used as part of the acceptance process for construction operations. Sampling and testing procedures are standardized and material property limits are established based on the type and use of the materials by the owner agencies. Variability of properties is evident when materials are sampled and tested during the conduct of a project. This variability is important when establishing specification acceptance limits for construction materials as well as when comparing results from two or more laboratories. For example, laboratory A may be used for quality control, and laboratory B may be used for quality assurance purposes.

When examining process control, quality control, quality assurance, and/or independent assurance test results, it is recognized that variability of these data sets can be caused by a number of factors that are typically summarized into those affecting the sampling process, testing process, and resulting from production and/or placement of the material. This can be conveniently expressed by the following equation.

$$S^2 qc/qa = S^2 sampling + S^2 testing + S^2 material\ production/construction$$

Where:

S^2qc/qa = variance associated with a quality control or quality assurance data set
S^2sampling = variance associated with sampling of the material
S^2testing = variance associated with testing of the material
S^2material production/construction = variance associated with materials production and construction operations

Note that the variance (S^2) is the standard deviation squared where standard deviation is the calculated parameter that is used to express variability.

Quality Control/Quality Assurance Variability

Large and numerous data sets can be made available to define the variability of quality control and quality assurance types of testing for construction projects. Unfortunately, these data sets are difficult to obtain from owner agencies and producer/contractors. Data describing QC/QA types of data sets are included in this report in another section for both Texas base course materials and base courses produced nationally.

The portion of the QC/QA variability associated with the individual components of "sampling," "testing," or "material production/construction" for base materials has not been quantified to the authors' knowledge. One FHWA study (4.1) has quantified component variability for asphalt mixtures in a study conducted over 40 years ago. It is important to note that only variability due to "material production/construction" influences the performance of the pavement in which these materials are used. Variability due to "sampling" and "testing" are part of the data set but do not influence performance, as they are not "changing" the materials properties. Material properties are only influenced by "material production/construction" variability. Unfortunately, for some tests, the "sampling and testing" component of variability is larger than the "materials production/construction" component variability.

Testing Variability

Precision and bias statements contained in many ASTM and AASHTO standard test methods and in some DOT standard test methods can be used to define "testing" variability. Precision statements define both within and between-laboratory variability associated with conducting a test. Depending on how the samples are obtained to form the database from which the precision statement is generated, the variability reported is only associated with testing and not sampling and material production/construction variability.

Test method precision statements recognize that identical materials, when tested within a laboratory or in several laboratories, do not yield identical results. ASTM (4.2) indicates that this variability is unavoidable random errors inherent in every test procedure and that all the factors that influence the outcome of a test cannot all be completely controlled The main factors that influence the magnitude of this variability include the operator, equipment used, calibration of the equipment, and environment (temperature, humidity, air quality). The variability between test results obtained by different operators or with different equipment will usually be greater than that between test results obtained by a single operator using the same equipment. In addition, variability between or among test results taken over a period of time (even with the same operator) will usually be greater than that obtained over a short period of time.

According to ASTM (4.3), precision is usually expressed in terms of two measurement concepts. "Repeatability" and "Reproducibility." "Repeatability" defines variability associated with a single operator in a single laboratory when the testing is performed in a short period of time. "Repeatability" is commonly referred to as "within-laboratory" variability. "Reproducibility" defines variability associated with multiple operators performing tests in separate laboratories over a relatively short period of time. "Reproducibility" is commonly referred to as "between-laboratory" variability. Reproducibility or between-laboratory variability includes the effects of operator, equipment, calibration, and environment, as a minimum.

AASHTO and several state DOTs routinely send out samples of identical materials to laboratories for testing. Usually, more than one sample of an identical material is sent to each laboratory. The samples are tested by the same individual using the same equipment in the same laboratory in a relatively short period of time. Results from these samples are returned to a central location, and statistical analyses are performed to determine if the laboratories are performing the test in a similar manor. This is judged by the closeness of the test results. The proficiency of the laboratory is judged by investigating the results of a "round-robin" type of testing program. These samples are commonly referred to as "proficiency samples" and a "proficiency testing program."

Results from "proficiency testing programs" are sometimes used to develop precision and bias statements for AASHTO, ASTM, and/or state DOT test methods. Three "proficiency testing program" sets of results performed by TxDOT were supplied to the research team. Within-laboratory and between-laboratory precision statements were prepared from these data and are presented below.

TXDOT PROFICIENCY SAMPLES

TxDOT supplied two, nearly identical base materials samples to about 125 TxDOT, producer and commercial laboratories in 2008, 2009, and 2010. Gradation and Atterberg limit information was reported on these samples. These data were utilized to calculate within-laboratory and between-laboratory variability expressed as a standard deviation and within-laboratory and between-laboratory precision statements (repeatability and reproducibility respectively) according to the ASTM E 691 (4.2, 4.3) procedure. These results are shown on Tables 4.1 to 4.10 for various sieve sizes and Atterberg limits. Results are grouped by year and also by who performed the tests (TxDOT or Industry laboratories).

As noted on these tables (Tables 4.1 to 4.10), data for both within-laboratory and between-laboratory standard deviation and "acceptable range of two test results" are provided. The term "acceptable range of two test results" statistically is the "acceptable difference between two results" and has been selected by ASTM (4.3) as the appropriate index of precision in most precision statements. These indexes indicate a maximum acceptable difference between two results obtained on test portions of the same material. The (d2s) index is the difference between two individual test results that would be equaled or exceeded in the long run in only 1 case in 20 in the normal and correct operation of the test method (4.3). These indexes are calculated by multiplying the appropriate standard deviation (1s) by the factor of 2x2^0.5 or 2.83. Thus, "acceptable range of two test results" in Tables 4.1 to 4.13 implies the following:

Within Laboratory - the results of two properly conducted tests by the same operator on the same material sample should not differ by more than the quantity shown.

Between Laboratory - the results two properly conducted tests by two different laboratories (two different operators and two different sets of equipment) should not differ by more than the quantity shown.

If the difference between the two tests is greater than the values indicated, an investigation should be conducted to determine the cause of the difference and the values should not be accepted.

Tables 4.1 to 4.10 allow for comparisons among the three TxDOT Proficiency Sample Test Programs. Both the within- and between- laboratory variability are reasonably consistent for the gradation on the 7/8, 5/8, and 3/8-inch sieves. The within-laboratory variability is also consistent among the three test programs for the No. 4 and No. 40 sieves. More variability is noted among the three samples for the No. 4 and No. 40 sieve for between-laboratory samples (see 2009 sample compared to other sample dates). Variability reported for the TxDOT laboratories is not significantly different than the variability for the industry laboratories.

Atterberg limit information for the two samples with relatively high plastic index (2009 and 2010) has more variability than the sample with relatively low plastic index (2008).

ASTM AND AASHTO TEST METHODS

Precision statements from ASTM and AASHTO test methods (4.4, 4.5) were reviewed and precision statements summarized on Table 4.1 to 4.13, where available. Information was located for gradation, Atterberg Limits, maximum unit weight, and optimum water content as well as methylene blue tests. The ranges of variability for TxDOT data and ASTM/AASHTO data are similar for nearly all tests.

REFERENCES

4.1 Hughes, C. "Variability in Highway Pavement Construction." NCHRP Synthesis Report 232, February 1997.

4.2 "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method-Designation: E 691-11." Annual Book of ASTM

4.3 Standards, ASTM International, 2012. Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials," Annual Book of ASTM Standards, Vol. 04.02-Concrete and Aggregates, ASTM International, 2012.

4.4 Annual Book of ASTM Standards, Vol. 04.02-Concrete and Aggregates, ASTM International, 2012.

4.5 Annual Book of ASTM Standards, Vol. 04.03-Road and Paving Materials; Vehicle-Pavement Systems, ASTM International, 2012.

Table 4.1. Precision and Bias Statement for 7/8-Inch Sieve.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory		Between Laboratories	
					Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT	Tex-110-E	2008	TxDOT	27.8	0.9	2.4	1.8	5.0
			Industry	28.4	1.0	2.9	1.2	3.4
			All	28.2	1.0	2.7	1.5	4.2
		2009	TxDOT	18.1	1.2	3.4	2.7	7.6
			Industry	18.0	1.0	2.7	1.3	3.7
			All	18.0	1.0	2.9	1.8	5.0
		2010	TxDOT	23.8	1.2	3.4	1.8	4.9
			Industry	23.7	1.2	3.4	1.7	4.7
			All	23.7	1.2	3.4	1.7	4.8
ASTM*	C 136		All		1.32, 0.83	3.7, 2.4	1.97, 1.41	5.6, 4
AASHTO**	T 27		All					

*for materials with 20 to 60 percent passing a given sieve, coarse and fine aggregates, respectively
**ASTM and AASHTO provide same precision and bias statement

Table 4.2. Precision and Bias Statement for 5/8-Inch Sieve.

					Within Laboratory		Between Laboratories	
Proficiency Sample	Test Method	Year	Labs	Mean	Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT	Tex-110-E	2008	TxDOT	41.6	1.0	2.8	2.0	5.7
			Industry	42.2	1.3	3.6	1.8	4.9
			All	41.9	1.2	3.3	1.9	5.3
		2009	TxDOT	30.9	0.9	2.6	3.0	8.5
			Industry	31.0	1.0	2.8	1.9	5.5
			All	31.0	1.0	2.8	2.3	6.4
		2010	TxDOT	41.4	1.3	3.6	1.9	5.4
			Industry	41.0	0.9	2.4	1.7	4.8
			All	41.1	1.0	2.8	1.8	5.0
ASTM*	C 136		All		1.32,0.83	3.7,2.4	1.97,1.41	5.6,4.0
AASHTO**	T 27		All					

*for materials with 20 to 60 percent passing a given sieve, coarse and fine aggregate, respectively
**ASTM and AASHTO provide same precision and bias statement

Table 4.3. Precision and Bias Statement for 3/8-Inch Sieve.

					Within Laboratory		Between Laboratories	
Proficiency Sample	Test Method	Year	Labs	Mean	Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT	Tex-110-E	2008	TxDOT	55.0	1.3	3.8	2.6	7.3
			Industry	55.6	1.4	4.0	2.2	6.2
			All	55.4	1.4	3.9	2.4	6.6
		2009	TxDOT	44.3	0.6	1.8	2.5	7.1
			Industry	44.7	0.9	2.5	2.7	7.5
			All	44.6	0.8	2.4	2.6	7.4
		2010	TxDOT	53.9	1.3	3.6	2.3	6.4
			Industry	53.5	0.8	2.3	1.6	4.5
			All	53.6	1.0	2.7	1.8	5.0
ASTM*	C 136		All		1.32,0.83	3.7,2.4	1.97,1.41	5.6,4.0
AASHTO**	T 27		All					

*for materials with 20 to 60 percent passing a given sieve, coarse and fine aggregate, respectively
**ASTM and AASHTO provide same precision and bias statement

Table 4.4. Precision and Bias Statement for No. 4-Inch Sieve.

					Within Laboratory		Between Laboratories	
Proficiency Sample	Test Method	Year	Labs	Mean	Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT	Tex-110-E	2008	TxDOT	66.6	1.0	2.7	2.4	6.8
			Industry	67.1	0.8	2.3	2.1	5.8
			All	66.9	0.9	2.5	2.2	6.2
		2009	TxDOT	54.7	0.6	1.7	4.7	13.2
			Industry	55.1	0.9	2.4	4.0	11.2
			All	55.0	0.8	2.3	4.2	11.7
		2010	TxDOT	61.2	0.8	2.2	3.4	9.6
			Industry	60.7	0.8	2.3	1.7	4.9
			All	60.8	0.8	2.3	2.3	6.4
ASTM*	C 136		All		2.25,0.55	6.4,1.6	2.82,0.77	8.0,2.2
AASHTO**	T 27		All					

*for materials with 60 to 80 percent passing a given sieve, coarse and fine aggregate, respectively
**ASTM and AASHTO provide same precision and bias statement

Table 4.5. Precision and Bias Statement for No. 40 Sieve.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory		Between Laboratories	
					Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT	Tex-110-E	2008	TxDOT	80.6	2.1	5.8	3.9	10.9
			Industry	82.4	2.3	6.5	3.0	8.3
			All	81.7	2.2	6.3	3.5	9.7
		2009	TxDOT	77.1	1.5	4.2	7.3	20.4
			Industry	78.7	1.7	4.8	8.1	22.6
			All	78.3	1.7	4.6	7.9	22.0
		2010	TxDOT	83.0	1.3	3.5	5.5	15.5
			Industry	82.8	1.1	3.0	5.5	15.5
			All	82.9	1.1	3.1	5.5	15.4
ASTM*	C 136		All		2.25,0.55	6.4,1.6	2.82,0.77	8.0,2.2
AASHTO**	T 27		All		1.07	3.0	1.98	5.6

*for materials with 60 to 80 percent passing a given sieve, coarse and fine aggregate, respectively
**ASTM and AASHTO provide same precision and bias statement

Table 4.6. Precision and Bias Statement for No. 200 Sieve.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory		Between Laboratories	
					Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT	Tex-111-E	2008	TxDOT					
			Industry					
			All					
		2009	TxDOT					
			Industry					
			All					
		2010	TxDOT					
			Industry					
			All					
ASTM*	C 117		All		0.1,0.15	0.28,0.43	0.22,0.29	0.62,0.82
AASHTO**	T 88		All		1.19	3.4	2.31	6.5

*coarse and fine aggregates, respectively

Table 4.7. Precision and Bias Statement for Plastic Limit.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory		Between Laboratories	
					Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT	Tex-105-E	2008	TxDOT	15.5	0.7	1.8	1.7	4.8
			Industry	16.1	0.5	1.4	1.4	4.0
			All	15.9	0.6	1.6	1.6	4.4
		2009	TxDOT	18.7	1.2	3.5	4.1	11.5
			Industry	21.5	1.4	4.0	4.5	12.6
			All	20.7	1.4	3.9	4.6	12.7
		2010	TxDOT	25.5	1.0	2.7	6.7	18.9
			Industry	26.1	1.6	4.6	5.3	14.8
			All	26.0	1.5	4.2	5.7	15.9
ASTM*	D 4318		All		0.3	1.0	0.9	3.0
AASHTO**	T 89,90		All			10		18

*silty soil of low plasticity **for soils with plastic limit between 15-32

Table 4.8. Precision and Bias Statement for Liquid Limit.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory Standard Deviation	Within Laboratory Acceptable Range of Two Tests	Between Laboratories Standard Deviation	Between Laboratories Acceptable Range of Two Tests
TxDOT	Tex-104-E	2008	TxDOT	19.0	0.7	1.9	1.2	3.2
			Industry	19.2	0.6	1.8	1.4	4.1
			All	19.1	0.7	1.8	1.3	3.8
		2009	TxDOT	49.1	1.4	4.0	2.6	7.2
			Industry	50.3	1.4	3.9	3.0	8.4
			All	50.0	1.4	3.9	2.9	8.2
		2010	TxDOT	61.4	1.3	3.6	4.2	11.9
			Industry	63.0	1.7	4.6	5.3	14.8
			All	62.6	1.6	4.4	5.1	14.2
ASTM*	D 4318		All		0.5	2	1.3	4
AASHTO**	T 89,90		All			7		13

*silty soil of low plasticity **soils with liquid limit between 21-67

Table 4.9. Precision and Bias Statement for Plastic Index.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory Standard Deviation	Within Laboratory Acceptable Range of Two Tests	Between Laboratories Standard Deviation	Between Laboratories Acceptable Range of Two Tests
TxDOT	Tex-106-E	2008	TxDOT	3.8	0.7	2.0	1.6	4.4
			Industry	3.3	0.7	2.1	1.7	4.6
			All	3.5	0.7	2.1	1.6	4.6
		2009	TxDOT	30.4	1.5	4.3	4.1	11.4
			Industry	28.8	1.4	4.1	5.6	15.7
			All	29.2	1.5	4.1	5.2	14.7
		2010	TxDOT	36.0	1.4	3.9	7.1	19.8
			Industry	36.9	2.0	5.7	6.9	19.4
			All	36.6	1.9	5.3	6.9	19.4
ASTM*	D 4318		All		0.6	2	1.9	5.0
AASHTO	T 89,90		All					

*silty soil of low plasticity

Table 4.10. Precision and Bias Statement for Linear Shrinkage.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory Standard Deviation	Within Laboratory Acceptable Range of Two Tests	Between Laboratories Standard Deviation	Between Laboratories Acceptable Range of Two Tests
TxDOT	Tex-107-E	2008	TxDOT	3.5	0.5	1.4	1.2	3.3
			Industry	3.2	0.5	1.5	2.2	6.1
			All	3.3	0.5	1.5	1.9	5.2
		2009	TxDOT	17.4	1.0	2.9	3.5	9.8
			Industry	19.4	1.5	4.3	5.3	15.0
			All	18.9	1.4	4.0	5.0	14.0
		2010	TxDOT	22.0	0.8	2.2	3.6	10.0
			Industry	23.5	1.2	3.3	6.6	18.5
			All	23.1	1.1	3.1	6.0	16.8
ASTM*			All					
AASHTO**			All					

Table 4.11. Precision and Bias Statement for Maximum Unit Weight.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory		Between Laboratories	
					Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT	Tex-113-E	2008	TxDOT					
			Industry					
			All					
		2009	TxDOT					
			Industry					
			All					
		2010	TxDOT					
			Industry					
			All					
ASTM*	D 1557		All		0.6	1.8	1.6	4.4
AASHTO**			All					

Table 4.12. Precision and Bias Statement for Optimum Water Content.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory		Between Laboratories	
					Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT	Tex-113-E	2008	TxDOT					
			Industry					
			All					
		2009	TxDOT					
			Industry					
			All					
		2010	TxDOT					
			Industry					
			All					
ASTM*	D 1557		All		0.4	1	0.7	2.1
AASHTO**			All					

Table 4.13. Precision and Bias Statement for Methylene Blue.

Proficiency Sample	Test Method	Year	Labs	Mean	Within Laboratory		Between Laboratories	
					Standard Deviation	Acceptable Range of Two Tests	Standard Deviation	Acceptable Range of Two Tests
TxDOT		2008	TxDOT					
			Industry					
			All					
		2009	TxDOT					
			Industry					
			All					
		2010	TxDOT					
			Industry					
			All					
ASTM*	C 837		All			0.25meq/100g		
AASHTO**			All					

CHAPTER 5. SAMPLING AND LABORATORY TESTING PROGRAM FOR EXISTING SPECIFICATION TESTS

To assist in the establishment of reasonable specification tolerances, the research team performed a sampling and laboratory testing program to investigate the typical variability associated with flexible base material production. Nine production operations from around the state were represented in the sampling. Two phases of testing took place. One phase conducted standard methods already in the existing TxDOT specification and served to determine tolerances that are attainable in real-world production. A second testing phase carried out new tests recommended by the research team for better characterization of the materials' expected field performance. Together, the two phases of testing allowed selection of specification tolerances that balance the naturally occurring production variability with the impact of that variability on field performance.

This chapter presents the results from existing specification tests conducted on samples from nine different production operations. Chapter 6 presents the results from the new tests conducted as part of the second phase of testing.

PIT/QUARRY SAMPLING LOCATIONS

The research team arranged for sampling from nine quarries around the state. These quarries were selected in coordination with the project director in attempts to capture the geographic, mineralogical, and production volume diversity of typical sources used for TxDOT projects. Table 5.1 summarizes the sources used in the sampling and testing program.

Table 5.1. Sources of Material for Sampling and Laboratory Testing.

Source	Rock Type	Production Size
E-02	Sandstone	Large
E-01	Limestone	Medium
E-08	Limestone	Large
E-07	Limestone	Large
E-05	Limestone	Large
E-06	Limestone	Large
E-09	Limestone	Medium
E-04	Limestone	Small
E-03	Caliche	Small

SAMPLING PLAN

The TTI research team developed a sampling plan with the goal of capturing daily, weekly, and monthly production variability. Table 5.2 presents the initial sampling plan, which included a total of 28 samples for performing index-type tests and an additional 10 samples to perform both index and performance tests. However, during the course of meetings with the IWG, several producers shared that stockpile production was one aspect of how they controlled production to meet specifications. These producers indicated that stockpile production enabled them to blend material for product adjustment prior to sampling for stockpile acceptance. Most producers also indicated base production typically does not occur daily, making a schedule-based sampling plan more difficult to implement. Based on this feedback, the sampling plan in Table 5.2 was appended, as indicated in Table 5.3. Most producers performed stockpile sampling as indicated in Table 5.3, while sources E01 and E02 sampled based on the month/week schedule presented in Table 5.2.

Table 5.2. Sampling Plan for Laboratory Testing Program.

Month	Week	1	2	3	4	5	Samples/Day
1	1						1
	2						5
	3						3
	4						1
2	1						3
	2						1
	3						1
	4						1
3	1						5
	2						0
	3						1
	4						0
4	1						5
	2						1
	3						1
	4						1

Test Plan A: Index Tests – gradation, Atterberg limits, wet ball mill, methylene blue.

Text Plan A&B: Index and Performance Tests – all of Test Plan A plus moisture-density relationship, compressive strength, aggregate imaging, soil-water characteristic curve, and repeated load triaxial.

Table 5.3. Stockpile Sampling Plan for Laboratory Test Program.

Stockpile	Number of Sample Locations for Test Plan A	Number of Sample Locations for Test Plan B	Total Number of Sample Locations
1	11	3	14
2	5	1	6
3	5	5	10
4	7	1	8

EXISTING SPECIFICATION TEST RESULTS

Tables 5.4 through 5.11 present the summary results for the existing specification tests conducted on the nine sources. The methods employed included:

- Gradation: Tex- 200-F using the 1 ¾, 1 ¼, 7/8, 5/8, 3/8, No. 4, No. 40, and No. 200.
- Liquid Limit: Tex-104-E.
- Plastic Limit: Tex-105-E.
- Calculating the Plasticity Index: Tex-106-E.
- Wet Ball Mill: Tex-116-E.
- Moisture Density Relationship: Tex-113-E.
- Unconfined Compressive Strength: Tex-117-E Part II.

Tables 5.4 through 5.7 present the results from sources sampled by calendar day and contain information relevant to daily, weekly, and monthly variability. Tables 5.8 through 5.11 present the results from sources sampled by stockpile and, therefore, contain information only relevant to stockpile variability. These tables present the mean, standard deviation, number of tests, and coefficient of variation. Although the planned sampling included 4 months of production (or 4 stockpiles, as appropriate to the source), some sources were not able to generate the full spectrum of planned samples during the time frame of this project. The research team thus limited the focus of testing to, at most, production during the first 2 months/stockpiles. Appendix A to this report presents the details of each individual test result.

Table 5.4. Summary of Dry Gradation Results from Sources Sampled by Calendar.

Producer - Month			E-02-1	E-02-1 (Daily)	E-02-1 (Weekly)	E-02-2	E-02-1&2	E-01-1
Tex-110-E (Cumulative % Retained)	1 1/4"	x	6.1	7.1	6.3	10.8	7.2	1.4
		s	2.3	2.8	0.8	1.3	2.9	0.4
		n	13.0	5.0	5.0	4	17	7
		Cv (%)	37.2	39.7	12.8	12.4	40.1	28.5
	7/8"	x	24.0	27.3	21.6	29.3	25.3	9.1
		s	4.7	6.1	1.1	2.5	4.8	2.5
		n	13.0	5	5	4	17	7
		Cv (%)	19.6	22.2	5.1	8.4	19.1	27.7
	5/8"	x	36.5	40.5	32.3	41.9	37.8	18.9
		s	5.5	6.4	1.2	3.6	5.5	4.1
		n	13.0	5	5	4	17	7
		Cv (%)	15.1	15.8	3.8	8.5	14.7	21.8
	3/8"	x	48.9	52.7	44.0	54.6	50.3	35.7
		s	5.5	5.4	0.9	3.3	5.6	6.0
		n	13	5	5	4	17	7
		Cv (%)	11.3	10.2	2.1	6.1	11.1	16.7
	#4	x	62.7	66.1	59.2	69.6	64.3	55.7
		s	4.7	3.9	1.3	3.4	5.2	5.6
		n	13	5	5	4	17	7
		Cv (%)	7.4	5.8	2.1	4.9	8.1	10.0
	#40	x	78.4	79.9	77.5	82.6	79.4	90.1
		s	3.2	1.4	1.3	2.5	3.5	1.5
		n	13	5	5	4	17	7
		Cv (%)	4.1	1.8	1.7	3.1	4.4	1.7

Table 5.5. Summary of Atterberg Limits and Wet Ball Mill Results from Sources Sampled by Calendar.

Producer - Month			E-02- 1	E-02-1 (Daily)	E-02-1 (Weekly)	E-02- 2	E-02-1&2	E-01-1
Tex-104, 105, 106, 116-E	Liquid Limit	x	18.6	19.0	20.0	15.0	18.3	19.3
		s	2.1	1.6	1.0	NA	2.2	1.6
		n	10.0	5.0	3	1	11	7
		Cv (%)	11.1	8.3	5.0	NA	12.3	8.3
	Plastic Limit	x	11.4	12.4	11.7	10.0	11.3	11.0
		s	1.9	1.5	0.6	NA	1.8	0.8
		n	10.0	5	3	1	11	7
		Cv (%)	16.6	12.2	4.9	NA	16.4	7.4
	Plasticity Index	x	7.2	6.6	8.3	5.0	7.0	8.3
		s	1.2	0.9	1.2	NA	1.3	1.3
		n	10	5	3	1	11	7
		Cv (%)	17.1	13.6	13.9	NA	19.2	15.1
	Wet Ball Mill Value	x	34.3	31.2	37.4	NA	34.3	23.8
		s	4.9	4.8	2.4	NA	4.9	1.6
		n	10	5	5	NA	10	5
		Cv (%)	14.2	15.4	6.4	NA	14.2	6.9
	WBM % Increase	x	10.9	11.4	10.4	NA	10.9	6.8
		s	1.4	1.7	0.9	NA	1.4	1.8
		n	10	5	5	NA	10	5
		Cv (%)	12.6	14.7	8.6	NA	12.6	26.3

Table 5.6. Summary of Washed Sieve Analysis Results from Sources Sampled by Calendar.

Producer - Month			E-02-1	E-02-1 (Daily)	E-02-1 (Weekly)	E-02-2	E-02-1&2	E-01-1
Tex-200-F (Cumulative % Retained)	1 1/4"	x	6.3	7.5	5.9	12.7	7.8	1.8
		s	2.3	3.1	0.9	1.6	3.5	0.4
		n	13	5	5	4	17	7
		Cv (%)	36.1	41.6	14.8	12.8	44.5	24.0
	7/8"	x	23.8	26.8	21.7	29.5	25.2	8.6
		s	4.4	5.9	0.7	2.3	4.7	2.5
		n	13	5	5	4	17	7
		Cv (%)	18.7	22.1	3.0	7.8	18.6	29.1
	5/8"	x	36.2	40.4	32.1	42.0	37.6	18.5
		s	5.6	6.3	1.4	3.7	5.7	3.7
		n	13	5	5	4	17	7
		Cv (%)	15.4	15.5	4.4	8.8	15.1	20.0
	3/8"	x	47.8	51.6	42.7	54.0	49.2	33.7
		s	5.4	5.2	0.9	3.4	5.6	5.3
		n	13	5	5	4	17	7
		Cv (%)	11.4	10.0	2.1	6.4	11.4	15.7
	#4	x	60.5	64.4	56.2	68.0	62.2	52.9
		s	5.0	4.0	1.0	3.6	5.6	5.9
		n	13	5	5	4	17	7
		Cv (%)	8.2	6.2	1.8	5.2	9.0	11.1
	#40	x	75.4	78.4	72.9	81.1	76.7	84.1
		s	4.1	1.6	1.6	3.1	4.5	1.8
		n	13	5	5	4	17	7
		Cv (%)	5.4	2.0	2.1	3.8	5.9	2.1
	#200	x	89.9	92.6	87.3	92.7	90.6	89.6
		s	2.8	0.8	0.8	0.7	2.7	1.3
		n	13	5	5	4	17	7
		Cv (%)	3.1	0.9	0.9	0.7	3.0	1.4

Table 5.7. Summary of Moisture-Density and Strength Tests from Sources Sampled by Calendar.

Producer - Month			E-02-1	E-02-2	E-02-1&2	E-01-1
Tex-113, 117-E	Max Density (pcf)	x	136.4	136.3	136.3	142.1
		s	1.1	NA	0.8	1.3
		n	2	1	3	2
		Cv (%)	0.8	NA	0.6	0.9
	Opt. Moisture (%)	x	7.1	7.2	7.1	6.1
		s	0.0	NA	0.1	0.4
		n	2	1	3	2
		Cv (%)	0.0	NA	0.8	5.8
	0psi Strength (psi)	x	25.5	18.2	23.1	35.0
		s	14.9	NA	11.4	2.9
		n	2	1	3	2
		Cv (%)	58.5	NA	49.4	8.3
	3psi Strength (psi)	x	82.7	114.9	93.4	91.8
		s	16.2	NA	21.8	6.7
		n	2	1	3	2
		Cv (%)	19.6	NA	23.4	7.3
	15psi Strength (psi)	x	152.1	271.4	191.9	192.7
		s	105.7	NA	101.7	0.6
		n	2	1	3	2
		Cv (%)	69.5	NA	53.0	0.3

Table 5.8. Summary of Dry Gradation Results from Sources Sampled by Stockpile.

Producer/Pit - Stockpile			E-03-6	E-03-2	E-03-1	E-03-4	E-03-6, 2, 1 &4	E-05-1
Tex-110-E (Cumulative % Retained)	1 1/4"	x	3.9	4.0	5.0	6.0	4.7	6.1
		s	3.4	0.0	3.0	2.5	3.0	1.6
		n	13	2	5	8	28	12
		Cv (%)	86.7	0.0	60.0	41.8	63.5	27.0
	7/8"	x	17.1	18.5	20.0	24.4	19.8	17.5
		s	6.0	0.7	3.1	8.1	6.6	3.4
		n	13	2	5	8	28	12
		Cv (%)	35.0	3.8	15.4	33.1	33.6	19.3
	5/8"	x	28.6	32.0	33.8	38.0	32.5	28.3
		s	9.1	1.4	4.0	11.4	9.5	4.5
		n	13	2	5	8	28	12
		Cv (%)	31.9	4.4	11.7	29.9	29.1	16.0
	3/8"	x	42.5	45.0	48.6	52.8	46.7	43.6
		s	10.3	2.8	5.5	13.9	11.1	5.6
		n	13	2	5	8	28	12
		Cv (%)	24.3	6.3	11.2	26.4	23.7	12.8
	#4	x	55.9	57.0	59.8	63.4	58.8	60.7
		s	9.6	2.8	5.1	15.4	10.8	5.3
		n	13	2	5	8	28	12
		Cv (%)	17.2	5.0	8.6	24.3	18.4	8.7
	#40	x	76.5	77.0	76.6	77.3	76.8	85.5
		s	9.0	5.7	5.6	14.7	9.9	2.3
		n	13	2	5	8	28	12
		Cv (%)	11.7	7.3	7.3	19.0	12.9	2.7

Table 5.8. Summary of Dry Gradation Results from Sources Sampled by Stockpile (Continued).

Producer/Pit - Stockpile			E-04-1	E-04-2	E-04-1&2	E-06-1	E-06-2	E-06-3	E-06-1, 2&3
Tex-110-E (Cumulative % Retained)	1 1/4"	x	3.4	5.4	3.8	4.0	4.5	4.2	4.2
		s	1.0	1.9	1.5	1.3	1.4	NA	1.3
		n	14	4	18	11	6	1	18
		Cv (%)	30.1	35.6	38.6	33.5	30.0	NA	30.7
	7/8"	x	14.6	19.6	15.7	16.3	16.8	16.7	16.5
		s	2.3	4.1	3.4	3.0	3.6	NA	3.0
		n	14	4	18	11	6	1	18
		Cv (%)	16.0	20.8	21.6	18.1	21.3	NA	18.2
	5/8"	x	27.1	32.7	28.4	27.4	26.8	26.7	27.1
		s	3.3	5.7	4.4	4.0	4.7	NA	4.0
		n	14	4	18	11	6	1	18
		Cv (%)	12.0	17.5	15.6	14.7	17.6	NA	14.8
	3/8"	x	44.7	50.1	45.9	39.6	37.4	36.9	38.8
		s	4.3	6.6	5.2	4.4	5.6	NA	4.7
		n	14	4	18	11	6	1	18
		Cv (%)	9.6	13.1	11.3	11.1	14.9	NA	12.1
	#4	x	62.5	65.4	63.1	50.2	46.6	46.4	48.8
		s	4.3	6.2	4.8	3.7	6.1	NA	4.7
		n	14	4	18	11	6	1	18
		Cv (%)	6.9	9.4	7.5	7.4	13.2	NA	9.7
	#40	x	89.9	87.4	89.4	84.3	82.8	86.6	84.0
		s	1.7	3.2	2.3	1.6	2.9	NA	2.2
		n	14	4	18	11	6	1	18
		Cv (%)	1.9	3.7	2.6	1.9	3.6	NA	2.7

Table 5.8. Summary of Dry Gradation Results from Sources Sampled by Stockpile (Continued).

Producer/Pit - Stockpile			E-09-1	E-07-1	E-07-2	E-07-1&2	E-08-1	E-08-2	E-08-1&2
Tex-110-E (Cumulative % Retained)	1 1/4"	x	6.2	5.0	9.7	6.5	2.5	4.8	3.2
		s	1.5	3.3	8.2	5.6	2.2	3.1	2.6
		n	11	13	6	19	13	6	19
		Cv (%)	24.8	65.5	84.5	85.3	86.0	64.8	81.5
	7/8"	x	19.1	17.4	29.8	21.3	11.2	19.7	13.9
		s	3.3	6.2	17.2	11.9	3.8	7.8	6.6
		n	11	13	6	19	13	6	19
		Cv (%)	17.5	35.4	57.6	55.9	34.2	39.8	47.2
	5/8"	x	30.4	29.9	45.8	35.0	21.1	31.9	24.5
		s	4.8	8.2	18.9	14.2	6.9	9.4	9.1
		n	11	13	6	19	13	6	19
		Cv (%)	15.9	27.5	41.1	40.6	32.7	29.6	37.2
	3/8"	x	45.1	43.6	61.1	49.1	34.6	48.1	38.8
		s	5.8	10.8	16.8	15.1	8.9	11.0	11.3
		n	11	13	6	19	13	6	19
		Cv (%)	12.9	24.9	27.4	30.6	25.7	22.8	29.2
	#4	x	63.2	56.3	73.5	61.7	49.1	64.6	54.0
		s	4.3	9.7	13.7	13.5	9.4	9.9	11.8
		n	11	13	6	19	13	6	19
		Cv (%)	6.8	17.3	18.6	21.9	19.1	15.3	21.9
	#40	x	84.1	76.1	86.7	79.5	85.1	90.7	86.9
		s	2.4	6.5	6.9	8.2	6.7	3.0	6.3
		n	11	13	6	19	13	6	19
		Cv (%)	2.8	8.5	8.0	10.3	7.8	3.3	7.2

Table 5.9. Summary of Atterberg Limits and Wet Ball Mill Results from Sources Sampled by Stockpile.

Producer/Pit - Stockpile			E-03-6	E-03-2	E-03-1	E-03-4	E-03-6, 2, 1 &4	E-05-1
Tex-104, 105, 106, 116-E	Liquid Limit	x	27.3	30.0	27.6	30.1	28.3	14.2
		s	2.1	0.0	2.7	3.1	2.7	0.6
		n	14	2	5	8	29	11
		Cv (%)	7.8	0.0	9.8	10.3	9.5	4.3
	Plastic Limit	x	15.1	16.0	18.2	15.9	15.9	11.2
		s	1.7	1.4	1.9	2.2	2.1	0.9
		n	14	2	5	8	29	11
		Cv (%)	11.5	8.8	10.6	14.1	13.3	7.8
	Plasticity Index	x	12.1	14.0	9.4	14.3	12.4	3.0
		s	2.0	1.4	3.8	4.3	3.4	0.8
		n	14	2	5	8	29	11
		Cv (%)	16.7	10.1	40.2	30.2	27.3	25.8
	Wet Ball Mill Value	x	46.7	45.5	39.7	44.3	45.1	27.3
		s	4.5	0.7	0.6	10.4	6.5	3.3
		n	13	2	3	7	25	10
		Cv (%)	9.6	1.6	1.5	23.4	14.4	12.2
	WBM % Increase	x	16.0	17.5	14.3	23.0	17.9	9.5
		s	2.6	0.7	3.8	8.7	5.9	1.0
		n	13	2	3	7	25	10
		Cv (%)	16.3	4.0	26.4	38.0	33.0	10.2

Table 5.9. Summary of Atterberg Limits and Wet Ball Mill Results from Sources Sampled by Stockpile (Continued).

Producer/Pit - Stockpile			E-04-1	E-04-2	E-04-1&2	E-06-1	E-06-2	E-06-3	E-06-1, 2&3
Tex-104, 105, 106, 116-E	Liquid Limit	x	21.0	21.0	21.0	18.4	18.0	14.0	18.0
		s	2.0	1.2	1.8	2.1	1.5	NA	2.1
		n	13	4	17	11	6	1	18
		Cv (%)	9.3	5.5	8.4	11.2	8.6	NA	11.4
	Plastic Limit	x	14.1	12.5	13.7	10.5	10.8	9.0	10.6
		s	1.1	1.7	1.4	1.4	1.7	NA	1.5
		n	13	4	17	11	6	1	18
		Cv (%)	7.9	13.9	10.2	13.7	15.9	NA	14.2
	Plasticity Index	x	6.9	8.5	7.3	7.8	7.2	5.0	7.4
		s	1.7	2.6	2.0	1.7	2.1	NA	1.9
		n	13	4	17	11	6	1	18
		Cv (%)	23.9	31.1	26.9	21.3	29.8	NA	24.9
	Wet Ball Mill Value	x	27.8	27.7	27.8	30.8	31.4	NA	31.0
		s	3.3	4.0	3.3	2.9	4.1	NA	3.3
		n	13	3	16	9	5	NA	14
		Cv (%)	11.8	14.6	11.8	9.6	13.1	NA	10.5
	WBM % Increase	x	8.5	11.0	9.0	7.3	7.8	NA	7.5
		s	1.0	1.0	1.4	0.9	0.8	NA	0.9
		n	13	3	16	9	5	NA	14
		Cv (%)	11.3	9.1	15.2	11.8	10.7	NA	11.4

Table 5.9. Summary of Atterberg Limits and Wet Ball Mill Results from Sources Sampled by Stockpile (Continued).

Producer/Pit - Stockpile			E-09-1	E-07-1	E-07-2	E-07-1&2	E-08-1	E-08-2	E-08-1&2
Tex-104, 105, 106, 116-E	Liquid Limit	x	17.1	16.8	18.3	17.3	16.7	16.2	16.5
		s	0.8	0.7	0.8	1.0	1.5	1.3	1.4
		n	11	13	6	19	13	6	19
		Cv (%)	4.9	4.3	4.5	6.1	8.9	8.2	8.6
	Plastic Limit	x	11.4	12.8	12.7	12.8	12.0	12.2	12.1
		s	1.5	1.4	1.5	1.4	1.6	1.6	1.6
		n	11	13	6	19	13	6	19
		Cv (%)	13.2	10.9	11.9	10.9	13.6	13.2	13.1
	Plasticity Index	x	5.7	3.9	5.7	4.5	4.7	4.0	4.5
		s	1.6	1.6	1.0	1.6	1.4	0.6	1.3
		n	11	13	6	19	13	6	19
		Cv (%)	27.2	39.6	18.2	36.0	30.6	15.8	28.2
	Wet Ball Mill Value	x	29.8	36.5	30.6	34.7	21.0	16.2	19.5
		s	2.4	4.6	4.4	5.2	1.8	1.3	2.8
		n	10	11	5	16	11	5	16
		Cv (%)	8.2	12.5	14.4	15.0	8.5	8.0	14.4
	WBM % Increase	x	11.0	12.2	12.6	12.3	6.2	5.2	5.9
		s	1.6	1.5	1.1	1.4	1.3	0.4	1.1
		n	10	11	5	16	11	5	16
		Cv (%)	14.2	12.6	9.0	11.4	20.2	8.6	19.5

Table 5.10. Summary of Washed Sieve Analysis Results from Sources Sampled by Stockpile.

Producer/Pit - Stockpile			E-03-6	E-03-4	E-03-6&4	E-05-1	E-04-1	E-04-2	E-04-1&2
Tex-200-F (Cumulative % Retained)	1 1/4"	x	3.7	6.1	5.3	6.0	3.6	5.6	4.0
		s	NA	3.4	2.8	1.6	1.3	2.1	1.6
		n	1	2	3	12	14	4	18
		Cv (%)	NA	55.6	52.3	27.1	35.3	37.1	40.8
	7/8"	x	14.7	24.6	21.3	17.2	14.5	19.6	15.7
		s	NA	7.3	7.7	3.2	2.7	4.3	3.7
		n	1	2	3	12	14	4	18
		Cv (%)	NA	29.7	36.1	18.9	18.6	22.0	23.6
	5/8"	x	24.2	39.6	34.5	28.2	26.7	32.5	28.0
		s	NA	10.5	11.6	4.9	3.5	5.3	4.5
		n	1	2	3	12	14	4	18
		Cv (%)	NA	26.4	33.6	17.3	13.0	16.3	16.1
	3/8"	x	38.7	54.2	49.0	42.2	42.8	48.7	44.1
		s	NA	11.3	12.0	5.6	4.5	6.2	5.3
		n	1	2	3	12	14	4	18
		Cv (%)	NA	20.9	24.5	13.2	10.5	12.7	12.1
	#4	x	51.9	65.3	60.8	58.1	59.2	63.8	60.2
		s	NA	9.6	10.3	5.5	4.3	5.8	4.9
		n	1	2	3	12	14	4	18
		Cv (%)	NA	14.7	16.9	9.5	7.3	9.1	8.2
	#40	x	70.0	75.8	73.8	82.2	80.7	82.7	81.1
		s	NA	7.6	6.3	2.7	3.1	3.3	3.1
		n	1	2	3	12	14	4	18
		Cv (%)	NA	10.0	8.5	3.3	3.8	4.0	3.9
	#200	x	82.0	87.6	85.7	88.5	86.7	88.8	87.2
		s	NA	3.5	4.0	1.5	2.5	2.0	2.5
		n	1	2	3	12	14	4	18
		Cv (%)	NA	4.0	4.7	1.7	2.9	2.2	2.8

Table 5.10. Summary of Washed Sieve Analysis Results from Sources Sampled by Stockpile (Continued).

Producer/Pit - Stockpile			E-06-1	E-06-2	E-06-3	E-06-1, 2&3	E-09-1
Tex-200-F (Cumulative % Retained)	1 1/4"	x	4.5	4.0	4.0	4.3	6.4
		s	1.2	1.1	NA	1.1	1.4
		n	11	6	1	18	11
		Cv (%)	26.3	26.4	NA	25.6	21.9
	7/8"	x	15.6	17.0	16.9	16.2	19.1
		s	2.8	3.5	NA	2.9	3.4
		n	11	6	1	18	11
		Cv (%)	17.8	20.7	NA	18.1	17.9
	5/8"	x	26.6	26.6	25.3	26.5	30.0
		s	3.9	4.7	NA	4.0	4.7
		n	11	6	1	18	11
		Cv (%)	14.8	17.9	NA	15.0	15.6
	3/8"	x	38.1	36.2	35.7	37.3	43.7
		s	4.2	5.6	NA	4.5	5.8
		n	11	6	1	18	11
		Cv (%)	11.1	15.4	NA	12.2	13.3
	#4	x	48.1	45.3	44.3	47.0	60.2
		s	4.0	5.9	NA	4.7	4.6
		n	11	6	1	18	11
		Cv (%)	8.3	13.1	NA	10.0	7.6
	#40	x	76.7	77.7	78.1	77.1	81.6
		s	2.5	4.7	NA	3.3	2.6
		n	11	6	1	18	11
		Cv (%)	3.3	6.1	NA	4.2	3.1
	#200	x	88.7	89.4	88.7	88.9	88.8
		s	1.4	2.5	NA	1.8	1.7
		n	11	6	1	18	11
		Cv (%)	1.6	2.8	NA	2.0	1.9

Table 5.10. Summary of Washed Sieve Analysis Results from Sources Sampled by Stockpile (Continued).

Producer/Pit - Stockpile			E-07-1	E-07-2	E-07-1&2	E-08-1	E-08-2	E-08-1&2
Tex-200-F (Cumulative % Retained)	1 1/4"	x	6.2	4.9	5.8	2.4	3.5	2.7
		s	0.1	NA	0.8	0.6	NA	0.8
		n	2	1	3	2	1	3
		Cv (%)	2.3	NA	13.1	27.1	NA	29.3
	7/8"	x	19.8	21.4	20.3	15.4	18.3	16.3
		s	2.4	NA	1.9	0.1	NA	1.7
		n	2	1	3	2	1	3
		Cv (%)	12.1	NA	9.5	0.5	NA	10.4
	5/8"	x	31.7	34.2	32.5	27.2	34.0	29.4
		s	2.8	NA	2.5	0.6	NA	4.0
		n	2	1	3	2	1	3
		Cv (%)	8.9	NA	7.6	2.3	NA	13.5
	3/8"	x	46.7	48.9	47.4	41.9	49.9	44.5
		s	2.2	NA	2.0	1.1	NA	4.7
		n	2	1	3	2	1	3
		Cv (%)	4.7	NA	4.3	2.5	NA	10.6
	#4	x	59.3	61.7	60.1	56.5	64.3	59.1
		s	2.4	NA	2.2	1.0	NA	4.6
		n	2	1	3	2	1	3
		Cv (%)	4.1	NA	3.6	1.8	NA	7.7
	#40	x	76.6	78.9	77.4	85.5	90.8	87.2
		s	1.8	NA	1.9	0.1	NA	3.1
		n	2	1	3	2	1	3
		Cv (%)	2.4	NA	2.4	0.1	NA	3.5
	#200	x	83.2	84.9	83.7	90.6	93.9	91.7
		s	1.6	NA	1.5	0.1	NA	1.9
		n	2	1	3	2	1	3
		Cv (%)	2.0	NA	1.8	0.2	NA	2.1

Table 5.11. Summary of Moisture-Density and Strength Tests from Sources Sampled by Stockpile.

Producer/Pit - Stockpile			E-03-6	E-03-2	E-03-1	E-03-4	E-03-6, 2, 1 &4	E-05-1
Tex-113, 117-E	Max Density (pcf)	x	130.1	127.6	126.0	126.6	127.5	141.1
		s	1.1	1.1	1.7	NA	2.1	0.6
		n	3	3	5	1	12	2
		Cv (%)	0.8	0.8	1.4	NA	1.7	0.4
	Opt. Moisture (%)	x	7.7	8.4	8.9	9.2	8.5	6.2
		s	0.1	0.6	0.4	NA	0.6	0.3
		n	3	3	5	1	12	2
		Cv (%)	1.3	6.6	4.2	NA	7.4	4.6
	0 psi Strength (psi)	x	24.6	34.1	49.8	24.9	36.4	35.3
		s	5.7	17.0	11.8	NA	15.3	21.4
		n	3	3	4	1	11	2
		Cv (%)	23.0	49.8	23.6	NA	42.0	60.8
	3 psi Strength (psi)	x	62.5	66.4	99.9	66.1	77.5	91.8
		s	13.5	19.3	9.4	NA	21.3	26.3
		n	3	3	4	1	11	2
		Cv (%)	21.6	29.0	9.4	NA	27.5	28.6
	15 psi Strength (psi)	x	126.9	143.2	194.3	133.0	156.4	199.7
		s	35.4	31.1	7.0	NA	37.5	4.9
		n	3	3	4	1	11	2
		Cv (%)	27.9	21.8	3.6	NA	24.0	2.4

Table 5.11. Summary of Moisture-Density and Strength Tests from Sources Sampled by Stockpile (Continued).

Producer/Pit - Stockpile			E-04-1	E-04-2	E-04-1&2	E-06-1	E-06-2	E-06-3	E-06-1, 2&3
Tex-113, 117-E	Max Density (pcf)	x	140.2	142.1	141.2	150.3	150.4	150.2	150.3
		s	NA	NA	1.3	0.6	NA	NA	0.3
		n	1	1	2	2	1	1	4
		Cv (%)	NA	NA	1.0	0.4	NA	NA	0.2
	Opt. Moisture (%)	x	6.2	6.0	6.1	5.4	5.6	5.4	5.5
		s	NA	NA	0.1	0.0	NA	NA	0.1
		n	1	1	2	2	1	1	4
		Cv (%)	NA	NA	2.3	0.0	NA	NA	1.8
	0 psi Strength (psi)	x	29.3	25.8	27.6	47.0	32.2	49.0	43.8
		s	NA	NA	2.5	20.3	NA	NA	14.1
		n	1	1	2	2	1	1	4
		Cv (%)	NA	NA	9.0	43.3	NA	NA	32.2
	3 psi Strength (psi)	x	105.0	117.4	111.2	112.3	128.9	130.3	120.9
		s	NA	NA	8.7	0.5	NA	NA	10.0
		n	1	1	2	2	1	1	4
		Cv (%)	NA	NA	7.9	0.4	NA	NA	8.3
	15 psi Strength (psi)	x	211.5	226.5	219.0	223.4	227.1	253.6	231.9
		s	NA	NA	10.6	16.1	NA	NA	17.3
		n	1	1	2	2	1	1	4
		Cv (%)	NA	NA	4.8	7.2	NA	NA	7.5

Table 5.11. Summary of Moisture-Density and Strength Tests from Sources Sampled by Stockpile (Continued).

Producer/Pit - Stockpile			E-09-1	E-07-1	E-07-2	E-07-1&2	E-08-1	E-08-2	E-08-1&2
Tex-113, 117-E	Max Density (pcf)	x	136.4	139.0	139.4	139.1	145.8	140.4	144.0
		s	NA	1.8	NA	1.3	0.0	NA	3.1
		n	1	2	1	3	2	1	3
		Cv (%)	NA	1.3	NA	0.9	0.0	NA	2.2
	Opt. Moisture (%)	x	7.9	7.2	7.1	7.1	6.5	6.5	6.5
		s	NA	0.4	NA	0.3	0.0	NA	0.0
		n	1	2	1	3	2	1	3
		Cv (%)	NA	4.9	NA	3.5	0.0	NA	0.0
	0 psi Strength (psi)	x	28.6	25.2	22.3	24.2	26.4	NA	26.4
		s	NA	4.2	NA	3.4	22.6	NA	22.6
		n	1	2	1	3	2	NA	2
		Cv (%)	NA	16.7	NA	14.1	85.7	NA	85.7
	3 psi Strength (psi)	x	102.9	86.2	81.9	84.8	119.9	NA	119.9
		s	NA	14.1	NA	10.3	23.4	NA	23.4
		n	1	2	1	3	2	NA	2
		Cv (%)	NA	16.3	NA	12.1	19.5	NA	19.5
	15 psi Strength (psi)	x	152.0	198.3	191.6	196.1	233.4	NA	233.4
		s	NA	10.0	NA	8.1	31.2	NA	31.2
		n	1	2	1	3	2	NA	2
		Cv (%)	NA	5.1	NA	4.1	13.4	NA	13.4

Investigation between Dry and Washed Sieve Analyses

As part of the testing program with existing specification tests, the research team selected nine samples from a total of five different materials to compare the gradation results between a dry and washed sieve analysis. This experiment was performed to document the differences, particularly in passing No. 200, which may exist between the two procedural methods. First, a dry sieve analysis was conducted, and the samples were retained for performance of a subsequent washed sieve analysis. After completing the washed sieve analyses, the research team analyzed the results for differences between the No. 200, No. 40, and No. 4 sieve sizes. Data from the tests performed can be seen in Table 5.12.

Results show that, with 95 percent confidence, less material is retained on the No. 200 sieve size with a washed sieve analysis than with a dry sieve analysis. With the samples tested and results obtained, it is estimated that 8 percent more material will pass the No. 200 sieve size during a washed sieve analysis than during a dry sieve analysis. However, the actual difference between dry and washed results will depend on the type of material and can even differ significantly within a given source, as evidenced by the results from source E-03 in Table 5.12.

Table 5.12. Data for Dry versus Washed Sieve Analysis.

Sample ID	Dry Sieve Analysis (TX-110-E) Cumulative % Retained							Washed Sieve Analysis (TX-200-F) Cumulative % Retained						
	1-1/4"	7/8"	5/8"	3/8"	No.4	No. 40	No. 200	1-1/4"	7/8"	5/8"	3/8"	No. 4	No. 40	No. 200
E-06-2-1	4	13	25	37	49	84	95	2.6	13.7	24.8	36.2	48.1	79.6	90.0
E-05-61-1	5	15	24	39	55	84	95	4.7	14.5	23.9	38.9	54.5	81.3	88.2
E-02-1-4-1	6	22	34	43	58	77	96	5.8	21.9	33.6	43.1	57.6	74.9	88.2
E-02-2-2-2	11	27	38	52	67	81	97	11.1	27.0	38.2	51.8	66.2	80.1	92.4
E-04-1-9	4	12	25	42	60	88	95	4.0	12.5	25.5	41.6	59.1	81.4	87.3
E-04-2-2	5	17	29	45	60	84	94	4.6	17.1	29.3	44.5	59.9	80.6	87.0
E-03-4-1-3	8.6	29	47	63	73	85	97	8.5	29.7	47.0	62.2	72.1	81.1	90.0
E-03-4-1-5	3.7	19	33	47	61	77	96	3.7	19.4	32.2	46.2	58.5	70.4	85.1
E-03-6-10-3	3.7	14	25	39	53	78	96	3.7	14.7	24.2	38.7	51.9	70.0	82.0

Data from the No. 40 sieve were not normally distributed, so a non-parametric test was performed. With 90 percent confidence, it can be said that less material is retained on the No. 40 sieve during a washed sieve analysis than during a dry sieve analysis. It is estimated that 4.5 percent more material will pass the No. 40 sieve during a washed sieve analysis than during a dry sieve analysis. Although more material passed the No. 4 sieve during the washed sieve analysis than during the dry sieve analysis for every sample that was tested, the differences were too small to make a statement with any statistical significance.

These results illustrate the methodology for evaluating particle size distribution has a significant impact on the test results, particularly for particle sizes smaller than the No. 40 sieve. For purposes of a QMP, the research team believes the washed method should be utilized, since it provides a more accurate measure of the particle size distribution of the soil binder. Using the washed method becomes more critical if the QMP or flexible base specification revisions will include a passing No. 200 element.

VARIABILITY OF EXISTING SPECIFICATION TESTS

The variability information of existing specification tests presented in Tables 5.4 through 5.11 can be used to set production tolerances. However, Chapter 3 of this report also presented variability information from other data sets. These other data sets included Historical TxDOT data, data from producers in Texas, and national data. Within each of these data sets, numerous sources were represented, which enables development of the distribution frequency of standard deviation within each data set. To contrast the observed variability information among the TxDOT, Texas producers, national, and TTI lab data, Figures 5.1 through 5.19 present the cumulative distribution frequency (CDF) of observed standard deviations for existing specification parameters for each of these data sets.

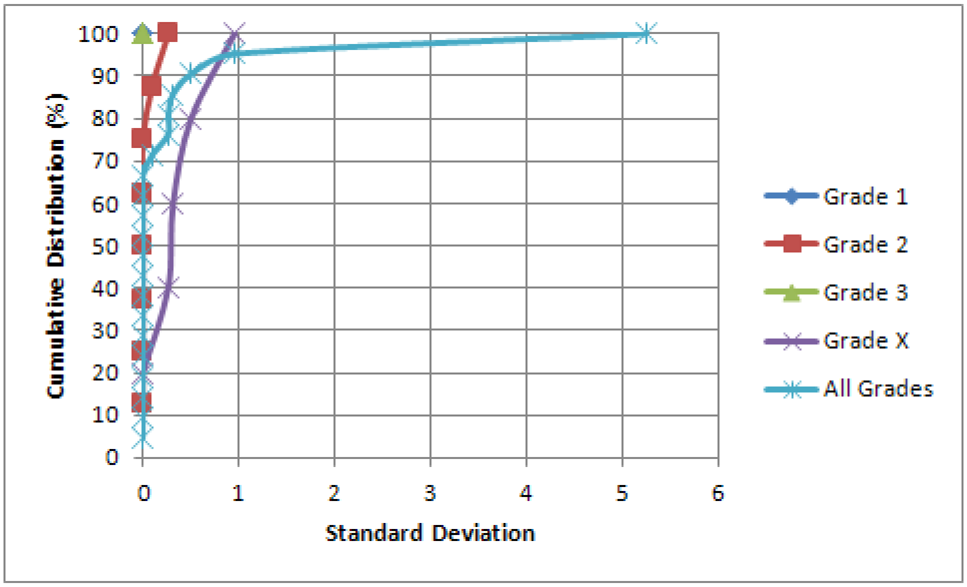

Figure 5.1. CDF of Standard Deviations for Cumulative Percent Retained on 1¾-Inch Sieve.

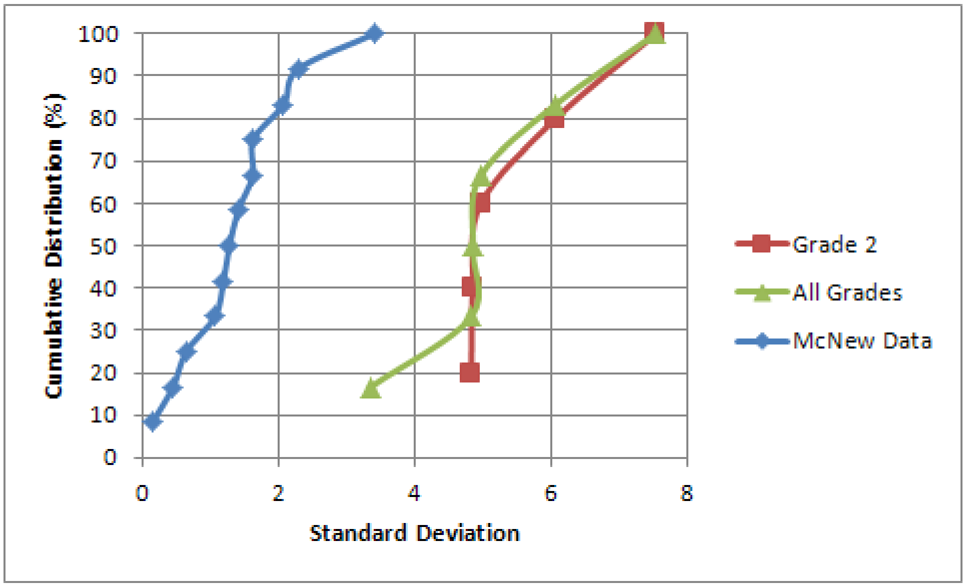

Figure 5.2. CDF of Standard Deviations for Cumulative Percent Retained on 1¼-Inch Sieve.

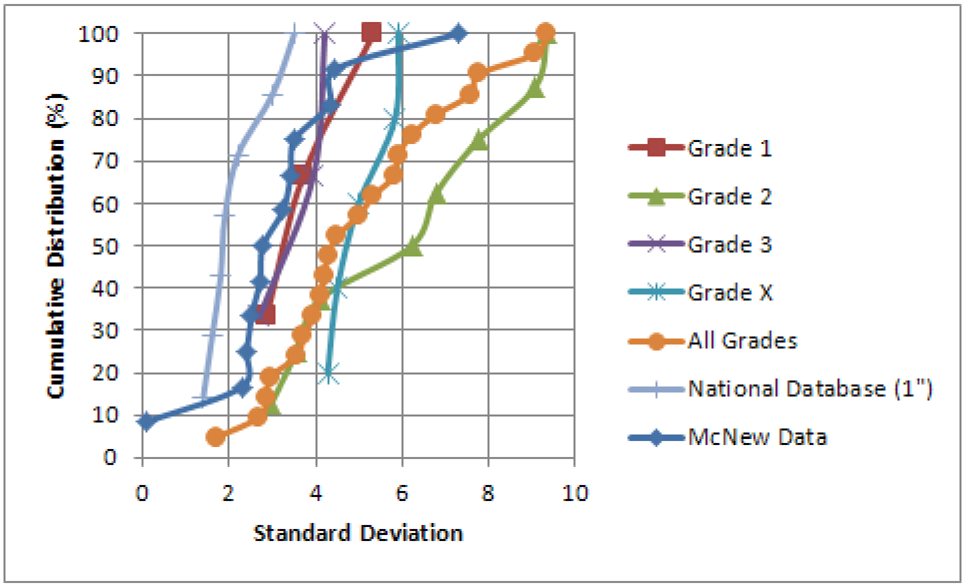

Figure 5.3. CDF of Standard Deviations for Cumulative Percent Retained on 7/8-Inch Sieve.

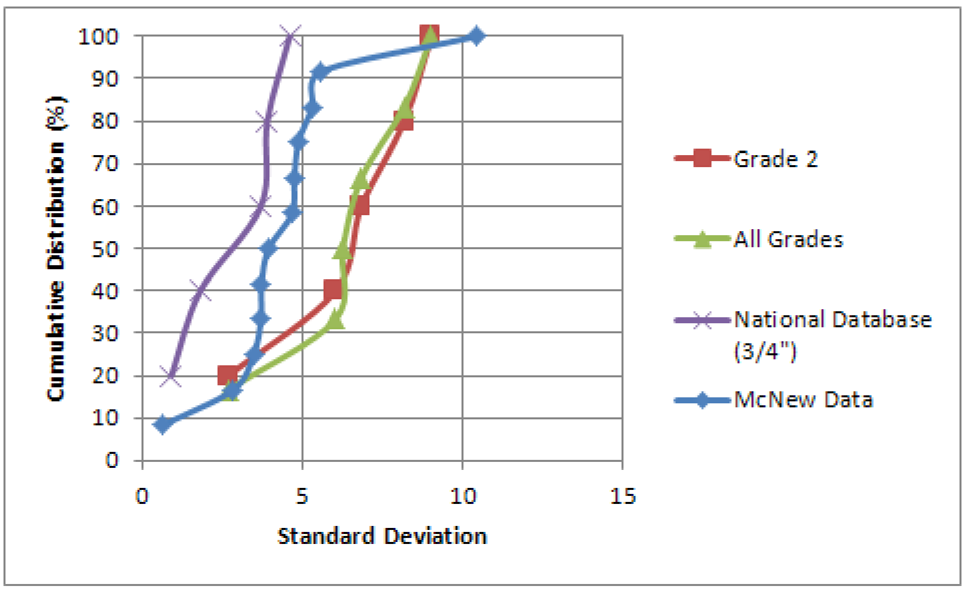

Figure 5.4. CDF of Standard Deviations for Cumulative Percent Retained on 5/8-Inch Sieve.

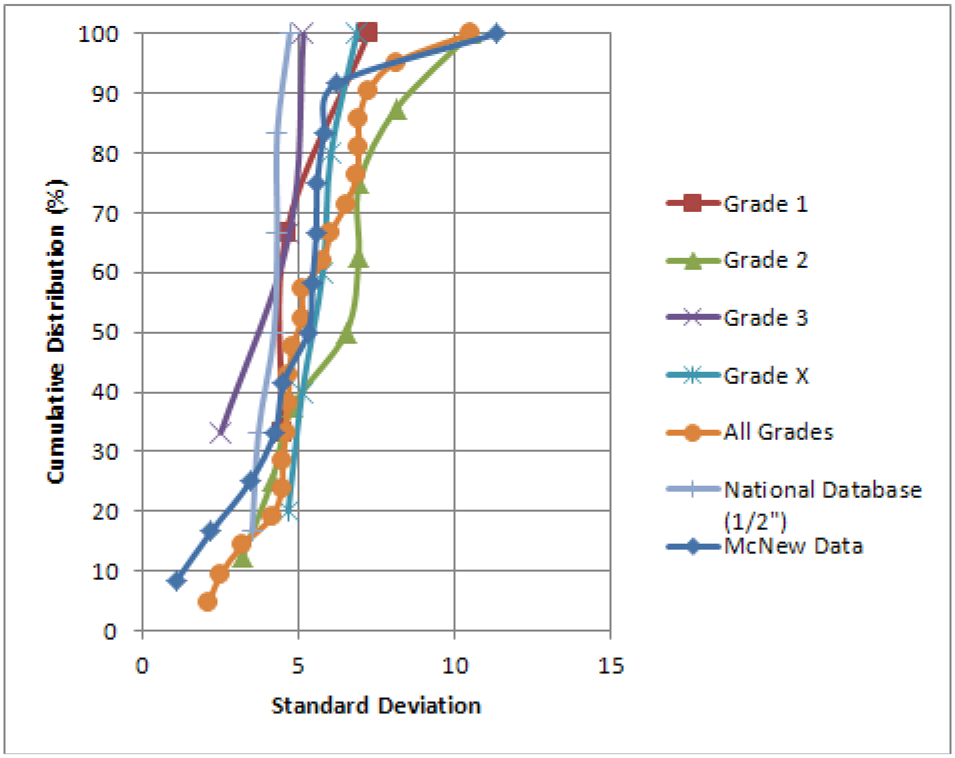

Figure 5.5. CDF of Standard Deviations for Cumulative Percent Retained on 3/8-Inch Sieve.

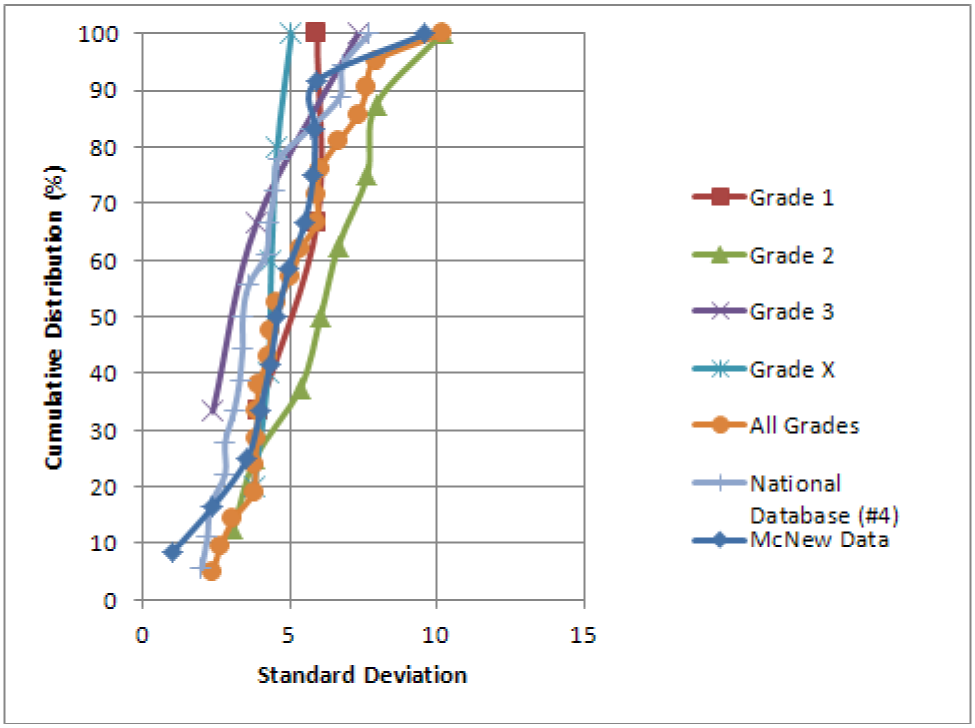

Figure 5.6. CDF of Standard Deviations for Cumulative Percent Retained on No. 4 Sieve.

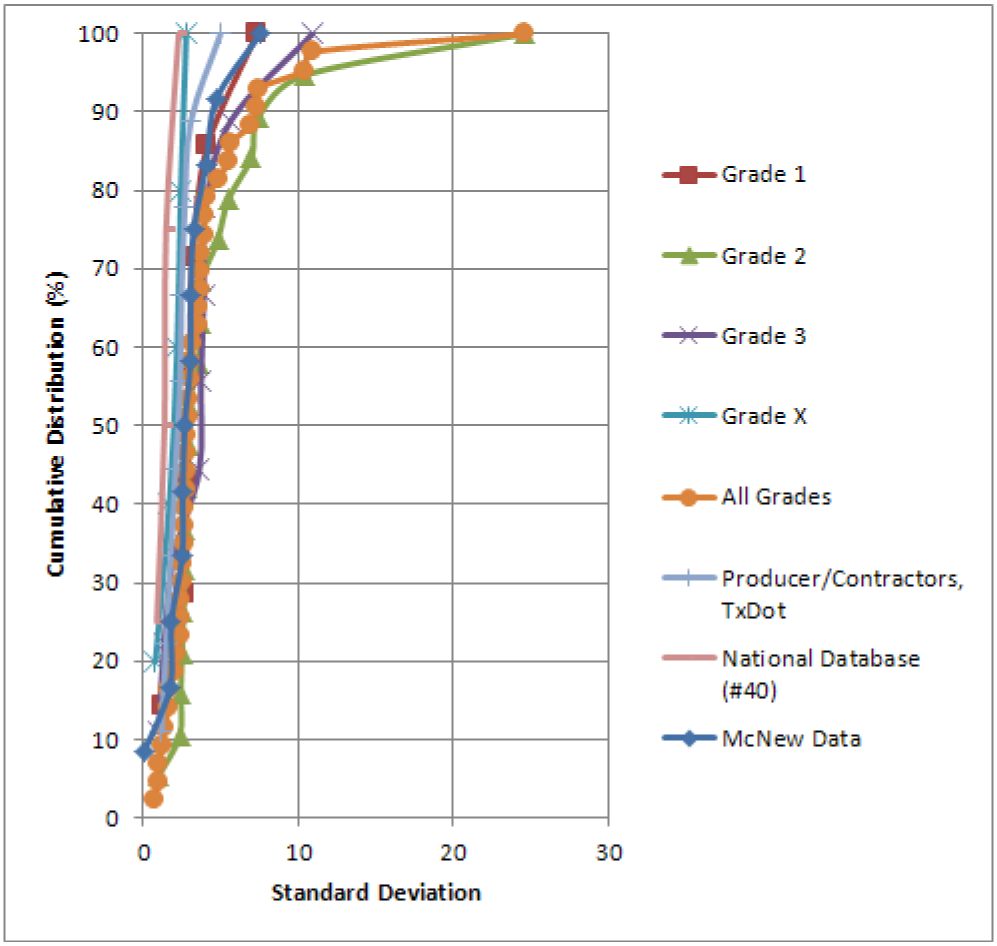

Figure 5.7. CDF of Standard Deviations of Cumulative Percent Retained on No. 40 Sieve.

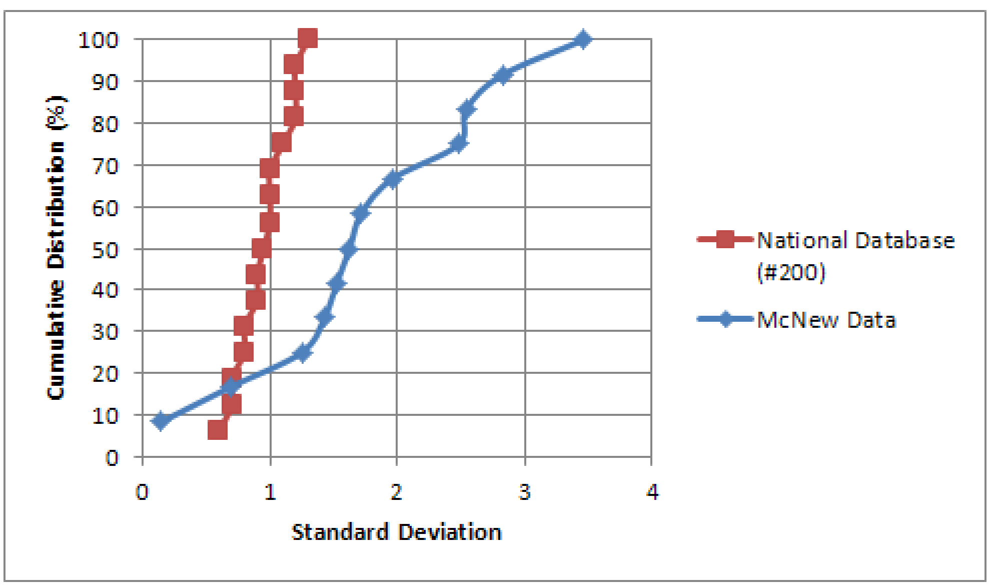

Figure 5.8. CDF of Standard Deviations for Cumulative Percent Retained on No. 200 Sieve.

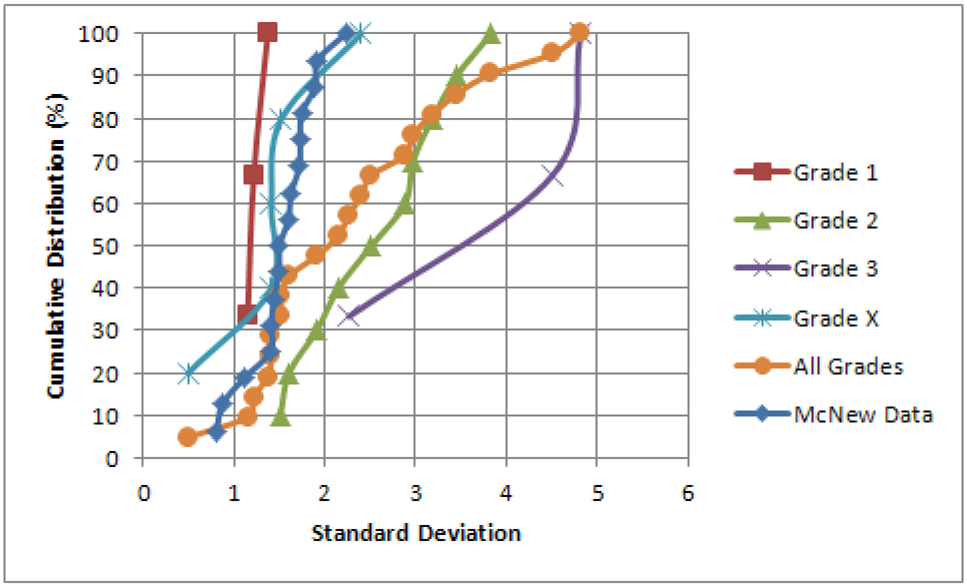

Figure 5.9. CDF of Standard Deviations for Plastic Limit.

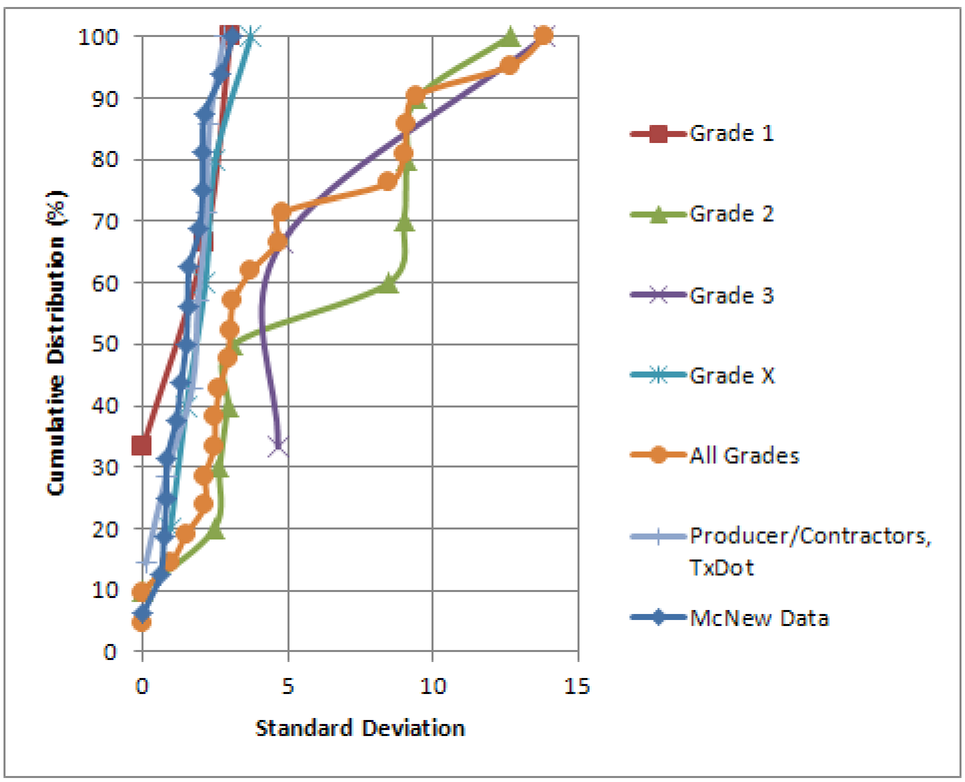

Figure 5.10. CDF of Standard Deviations for Liquid Limit.

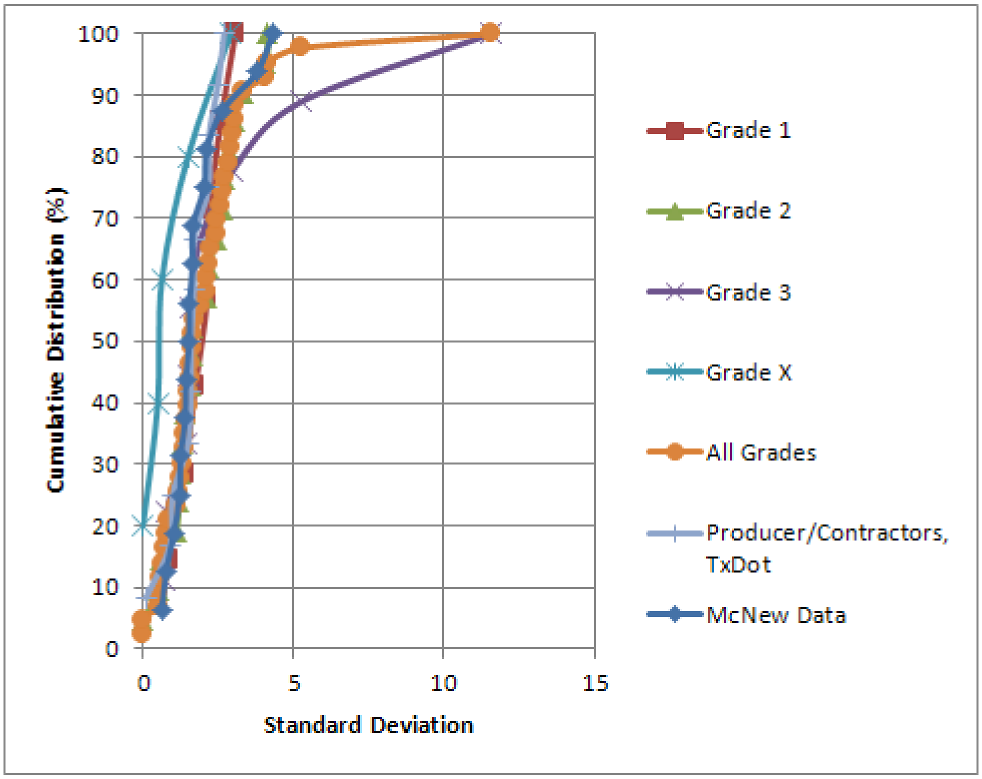

Figure 5.11. CDF of Standard Deviations for Plasticity Index.

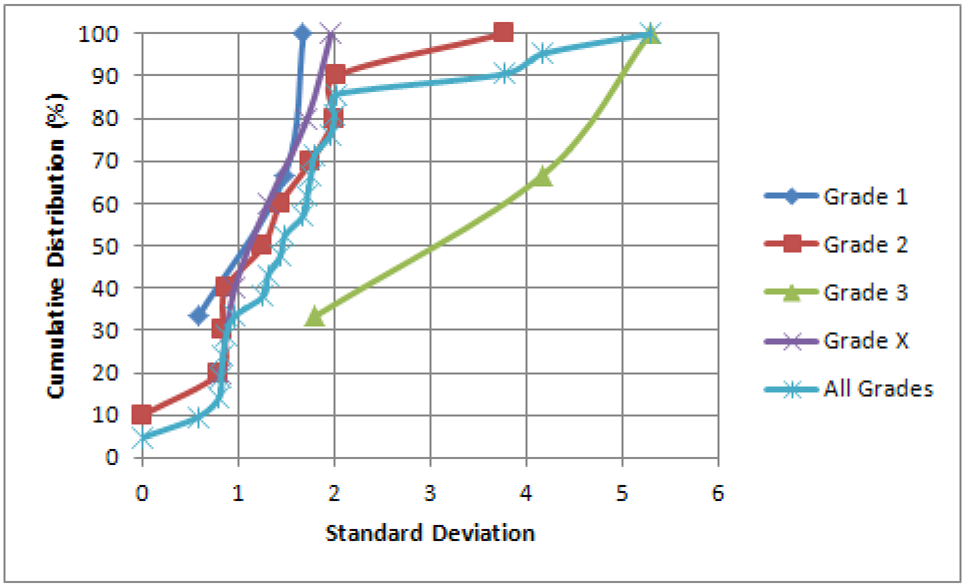

Figure 5.12. CDF of Standard Deviations for Linear Bar Shrinkage.

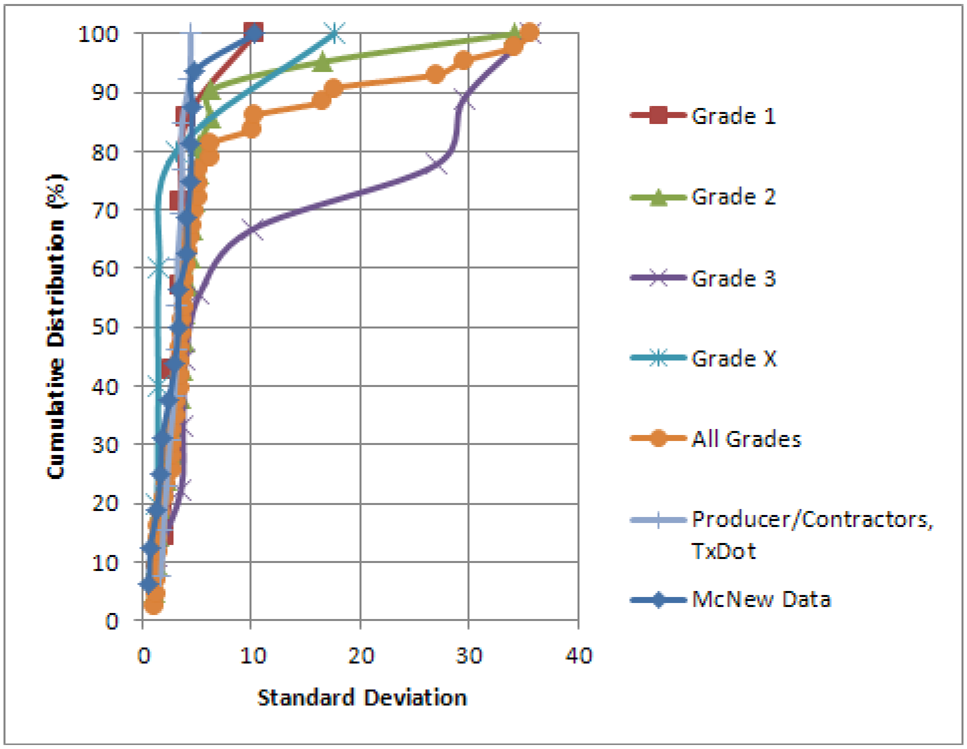

Figure 5.13. CDF of Standard Deviations for Wet Ball Mill Value.

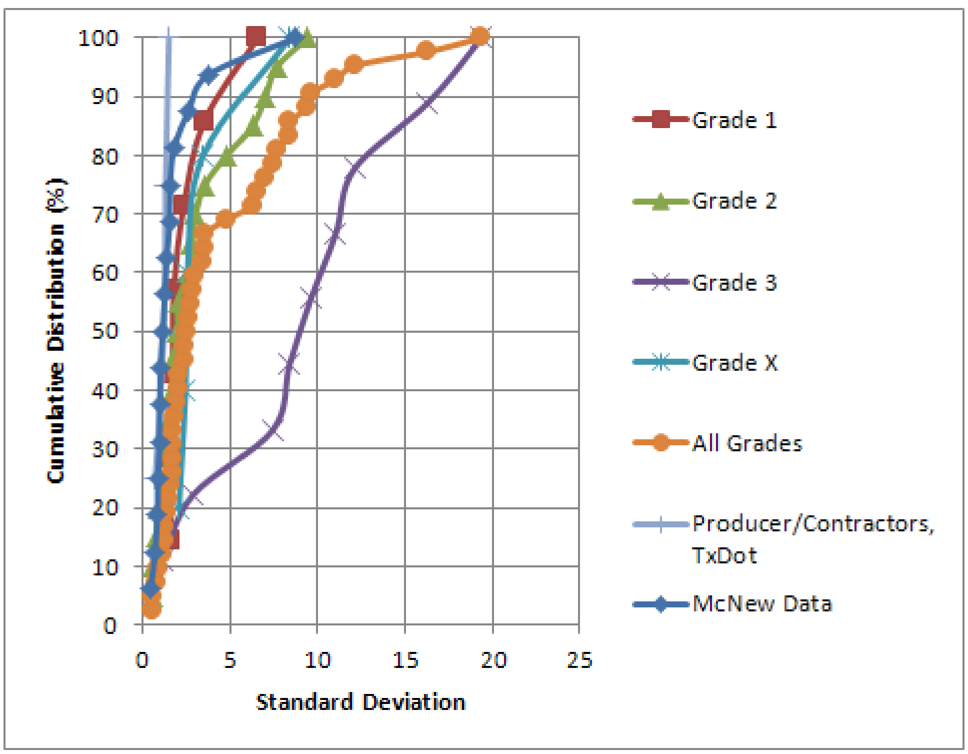

Figure 5.14. CDF of Standard Deviations for Wet Ball Mill Percent Increase.

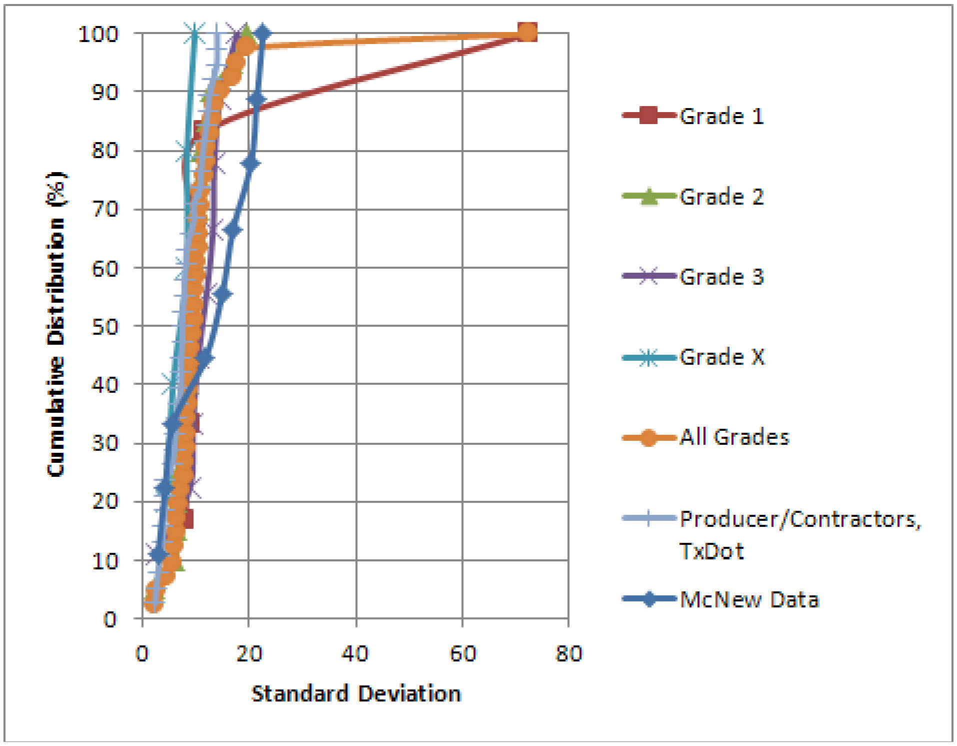

Figure 5.15. CDF of Standard Deviations for Strength with 0 psi Lateral Confinement.

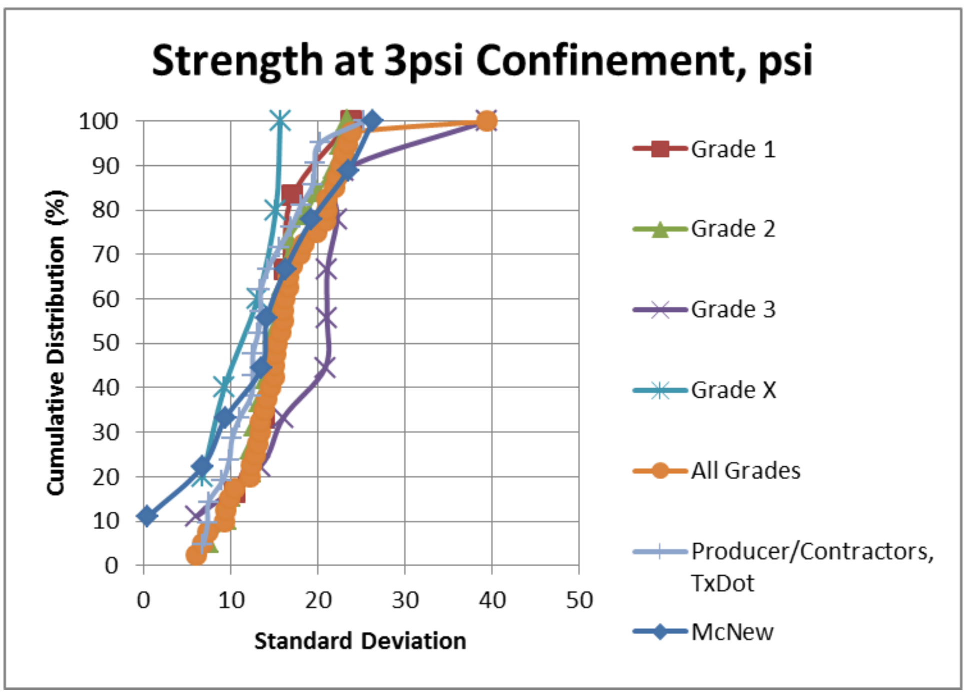

Figure 5.16. CDF of Standard Deviations for Strength with 3 psi Lateral Confinement.

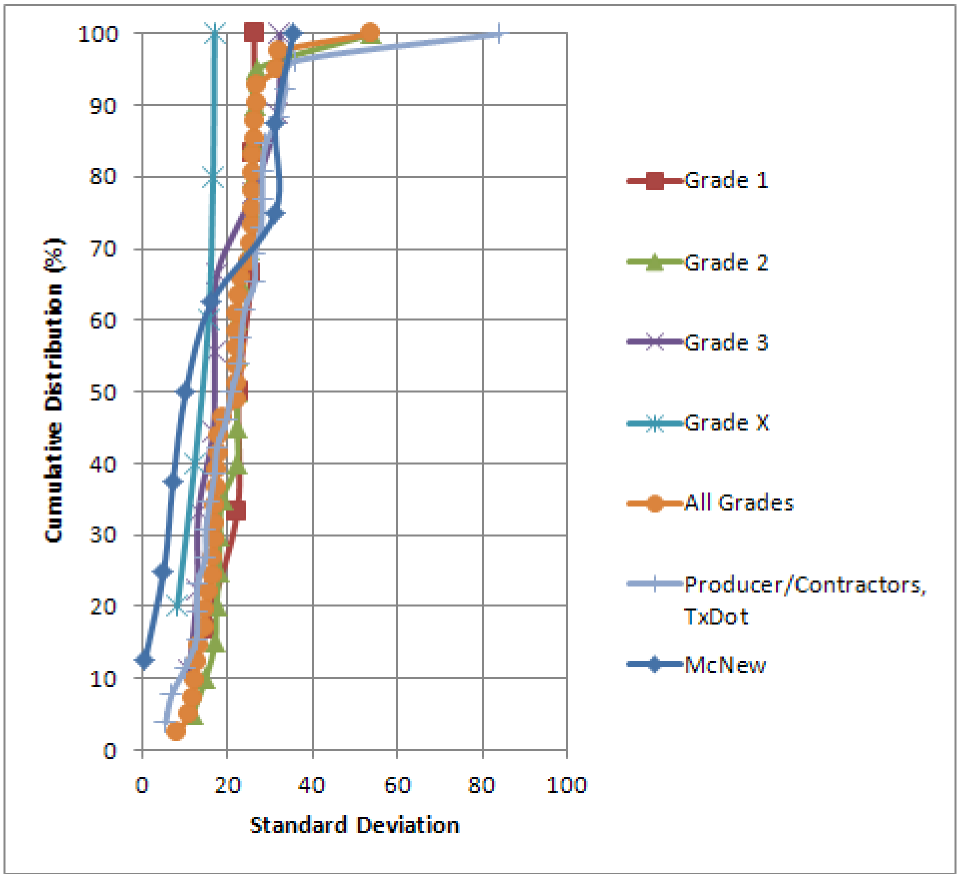

Figure 5.17. CDF of Standard Deviations for Strength with 15 psi Lateral Confinement.

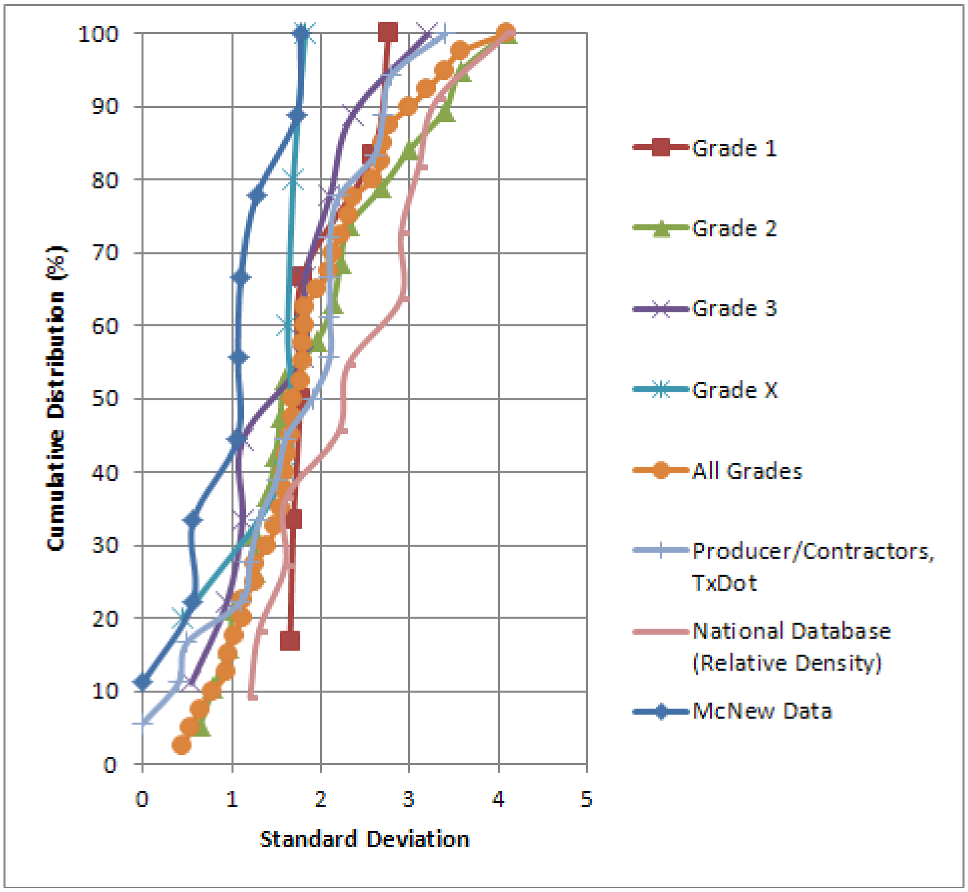

Figure 5.18. CDF of Standard Deviations for Maximum Dry Unit Weight.

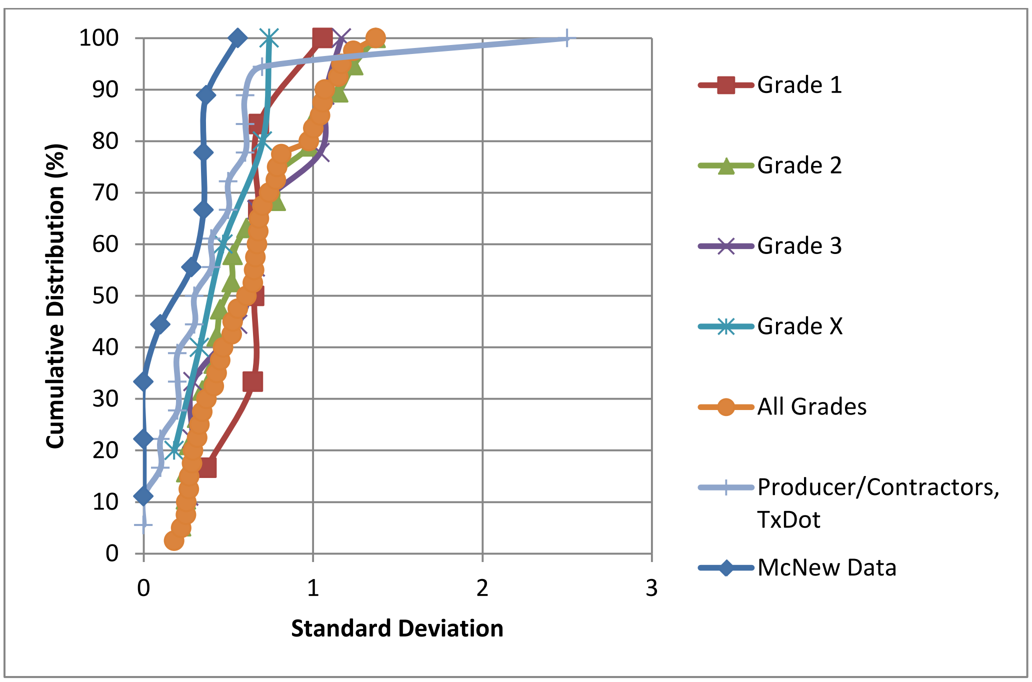

Figure 5.19. CDF of Standard Deviations for Optimum Water Content.

SELECTING STANDARD DEVIATION FOR EXISTING SPECIFICATION TESTS

Figures 5.1 through 5.19 clearly illustrate that different standard deviations exist depending on the source of the underlying data. Setting a production tolerance based upon real-world production variability requires selecting a single-point standard deviation from which to determine allowable production tolerances. Because use of the pooled standard deviation, which typically represents about the 50th percentile, would result in about half of producers at any given time being out of specification, the research team, instead, developed the 20th, 50th, 80th, and 90th percentile for each specification parameter and each data source. Tables 5.13 through 5.15 present these percentiles.

Since the historical TxDOT, Texas producers, and national data sets generally represent results collected over a long time span (sometimes over several years of production), the results from the testing program conducted in this project may represent the most relevant estimates of variability. The testing program conducted in this project represents individual stockpiles or short duration (1 month) time spans of production, these estimates of variability should better translate into acceptable variability estimates for project control, such as intended by construction specifications. The research team thus proposes using the 80th percentile standard deviation from the TTI McNew Lab data conducted in this project as a starting point for determining acceptable tolerances in a revised flexible base specification.

Table 5.13. Percentiles of Standard Deviations for Gradation Parameters.

Parameter	Data Base	Standard Deviation				n
		20th Percentile	50th Percentile	80th Percentile	90th Percentile	
Cumulative % Retained Above 1-3/4" Sieve	Historical TxDOT	0	0	0.27	0.49	21
	Producer/Contractors, TxDot	NA	NA	NA	NA	0
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	0	0	0	0	12
Cumulative % Retained Above 1-1/4" Sieve	Historical TxDOT	3.64	4.84	5.84	6.64	6
	Producer/Contractors, TxDot	NA	NA	NA	NA	0
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	0.52	1.27	1.89	2.24	12
Cumulative % Retained Above 7/8" Sieve	Historical TxDOT	3.08	4.39	6.67	7.75	21
	Producer/Contractors, TxDot	NA	NA	NA	NA	0
	National Data Base (1")	1.48	1.85	2.68	3.15	7
	McNew Lab Data	2.34	2.78	4	4.42	12
Cumulative % Retained Above 5/8" Sieve	Historical TxDOT	3.36	6.26	7.92	8.53	6
	Producer/Contractors, TxDot	NA	NA	NA	NA	0
	National Data Base (3/4")	0.9	2.75	3.9	4.25	5
	McNew Lab Data	3.09	3.94	5.13	5.52	12
Cumulative % Retained Above 3/8" Sieve	Historical TxDOT	4.19	4.94	6.9	7.19	21
	Producer/Contractors, TxDot	NA	NA	NA	NA	0
	National Data Base (1/2")	3.54	4.2	4.3	4.46	6
	McNew Lab Data	2.69	5.29	5.71	6.12	12
Cumulative % Retained Above #4 Sieve	Historical TxDOT	3.78	4.47	6.53	7.61	21
	Producer/Contractors, TxDot	NA	NA	NA	NA	0
	National Data Base	2.6	3.4	5.04	6.72	18
	McNew Lab Data	2.86	4.59	5.84	5.91	12
Cumulative % Retained Above #40 Sieve	Historical TxDOT	2.13	2.88	4.43	7.24	43
	Producer/Contractors, TxDot	1.44	2.25	2.78	3.29	9
	National Data Base	0.72	1.4	1.66	1.98	5
	McNew Lab Data	1.79	2.7	3.76	4.61	12
Cumulative % Retained Above #200 Sieve	Historical TxDOT	NA	NA	NA	NA	0
	Producer/Contractors, TxDot	NA	NA	NA	NA	0
	National Data Base	0.72	0.95	1.18	1.2	16
	McNew Lab Data	0.911	1.63	2.52	2.77	12

Table 5.14. Percentiles of Standard Deviations for Atterberg Limits, Linear Shrinkage, and Wet Ball Mill Parameters.

Parameter	Data Base	Standard Deviation 20th Percentile	Standard Deviation 50th Percentile	Standard Deviation 80th Percentile	Standard Deviation 90th Percentile	n
Plastic Limit	Historical TxDOT	1.38	2.03	3.15	3.8	21
	Producer/Contractors, TxDot	NA	NA	NA	NA	0
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	1.17	1.51	1.74	1.91	16
Liquid Limit	Historical TxDOT	1.63	2.97	8.9	9.41	21
	Producer/Contractors, TxDot	0.38	1.8	2.26	2.45	7
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	0.74	1.49	2.07	2.36	16
Plasticity Index	Historical TxDOT	0.82	1.66	2.87	3.23	43
	Producer/Contractors, TxDot	0.94	1.6	2.2	2.44	12
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	1.07	1.55	2.12	3.1	16
Linear Bar Shrinkage	Historical TxDOT	0.82	1.46	1.99	3.59	21
	Producer/Contractors, TxDot	NA	NA	NA	NA	0
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	NA	NA	NA	NA	0
Wet Ball Mill Value	Historical TxDOT	1.89	3.67	6.23	17.29	43
	Producer/Contractors, TxDot	2.08	3.15	3.6	4.09	13
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	1.37	3.29	4.45	4.68	16
Wet Ball Mill % Increase	Historical TxDOT	1.41	2.56	7.55	9.55	42
	Producer/Contractors, TxDot	0.7	1.2	1.34	1.42	4
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	0.84	1.14	1.74	3.08	16

Table 5.15. Percentiles of Standard Deviations for Strength, Maximum Unit Weight, and Optimum Water Content.

Parameter	Data Base	Standard Deviation				n
		20th Percentile	50th Percentile	80th Percentile	90th Percentile	
Strength at 0 psi Confinement, psi	Historical TxDOT	6.69	9.54	12.12	14.4	41
	Producer/Contractors, TxDot	4.1	7.4	11.32	12.64	38
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	3.94	13.35	20.56	21.56	9
Strength at 3 psi Confinement, psi	Historical TxDOT	12.24	15.19	21.03	22.66	40
	Producer/Contractors, TxDot	9.16	12.8	17.78	19.58	21
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	5.45	13.8	20.09	23.71	9
Strength at 15 psi Confinement, psi	Historical TxDOT	14.86	22.12	26.02	26.69	41
	Producer/Contractors, TxDot	12.72	20.8	28.1	32.7	26
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	3.15	10.04	31.17	32.05	8
Maximum Unit Weight, pcf	Historical TxDOT	1.12	1.69	2.58	3	40
	Producer/Contractors, TxDot	0.86	1.9	2.36	2.72	18
	National Data Base (Relative Density)	1.36	2.25	3.06	3.28	11
	McNew Lab Data	0.45	1.06	1.36	1.73	9
Optimum Water Content, %	Historical TxDOT	0.29	0.61	0.98	1.07	40
	Producer/Contractors, TxDot	0.1	0.3	0.6	0.62	18
	National Data Base	NA	NA	NA	NA	0
	McNew Lab Data	0	0.19	0.36	0.39	9

SELECTING REQUIRED NUMBER OF SAMPLES

With the production variability for important parameters defined, the required number of samples can be investigated. One approach to determine the required sample size is to simply select the risks that the buyer and seller are willing to assume, select a tolerable error, and calculate the sample size. However, this approach may yield large sample sizes that are not practical.

The recommended approach for determining the optimal sample sizes is to perform a sensitivity, which shows many combinations of seller (producer) risk, buyer (TxDOT) risk, tolerable error, and sample size. Before this analysis is conducted, a standard deviation must be chosen. As stated in the previous section, the 80th percentile standard deviation from the TTI McNew Lab data was chosen.

If a specification only states a maximum or a minimum test value, then the required sample size is based on a one-tailed statistical test and can be expressed by the following equation:

$$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2} \quad (Equation\ 5.1)$$

where n = required sample size, σ = standard deviation, e = tolerable error, and Z_α and Z_β are the Z-critical values for the seller and buyer risk, respectively.

If a specification states an acceptable range of values, 45 percent - 65 percent retained on the #4 sieve, for example, then the sample size is based on a two-tailed statistical test and expressed as:

$$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2} \quad (Equation\ 5.2)$$

To illustrate this concept, Table 5.16 presents the required sample sizes for plasticity index. Since the specification includes a maximum value, and some plan notes specify a minimum value, Equation 5.2 was used for this analysis. Appendix B presents similar tables for the different existing specification tests and different levels of TxDOT risk.

Table 5.16. Plasticity Index: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
						e	e	e	e	e	e	e	e	e	e	e	e	e	e	e
				β (TxDot Risk)	0.2	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
0.995	0.01	0.005	2.58	z_β	0.84	53	24	14	9	6	5	4	3	3	2	2	2	2	1	1
0.985	0.03	0.015	2.17	σ	2.12	41	19	11	7	5	4	3	3	2	2	2	1	1	1	1
0.975	0.05	0.025	1.96			36	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.965	0.07	0.035	1.81			32	15	8	6	4	3	2	2	2	2	1	1	1	1	1
0.955	0.09	0.045	1.7			29	13	8	5	4	3	2	2	2	1	1	1	1	1	1
0.945	0.11	0.055	1.6			27	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.935	0.13	0.065	1.51			25	12	7	4	3	3	2	2	1	1	1	1	1	1	1
0.925	0.15	0.075	1.44			24	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.915	0.17	0.085	1.37			23	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.905	0.19	0.095	1.31			21	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.895	0.21	0.105	1.25			20	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.885	0.23	0.115	1.2			19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.875	0.25	0.125	1.15			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.865	0.27	0.135	1.1			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.855	0.29	0.145	1.06			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.845	0.31	0.155	1.02			16	7	4	3	2	2	1	1	1	1	1	1	1	1	1

As evidenced by Equations 5.1 and 5.2, the required number of samples is a function of producer risk, consumer risk, standard deviation, and the maximum allowable error. The required number of samples decreases as risks and/or allowable error increase. A decrease in the standard deviation also reduces the required number of samples. Using plasticity index as an example, Figure 5.20 illustrates the required number of samples with different levels of producer and consumer risk using a maximum tolerable error of 2.0 and the 80th percentile standard deviation of plasticity index. The number of samples decreases as the producer and/or TxDOT are willing to accept more risk.

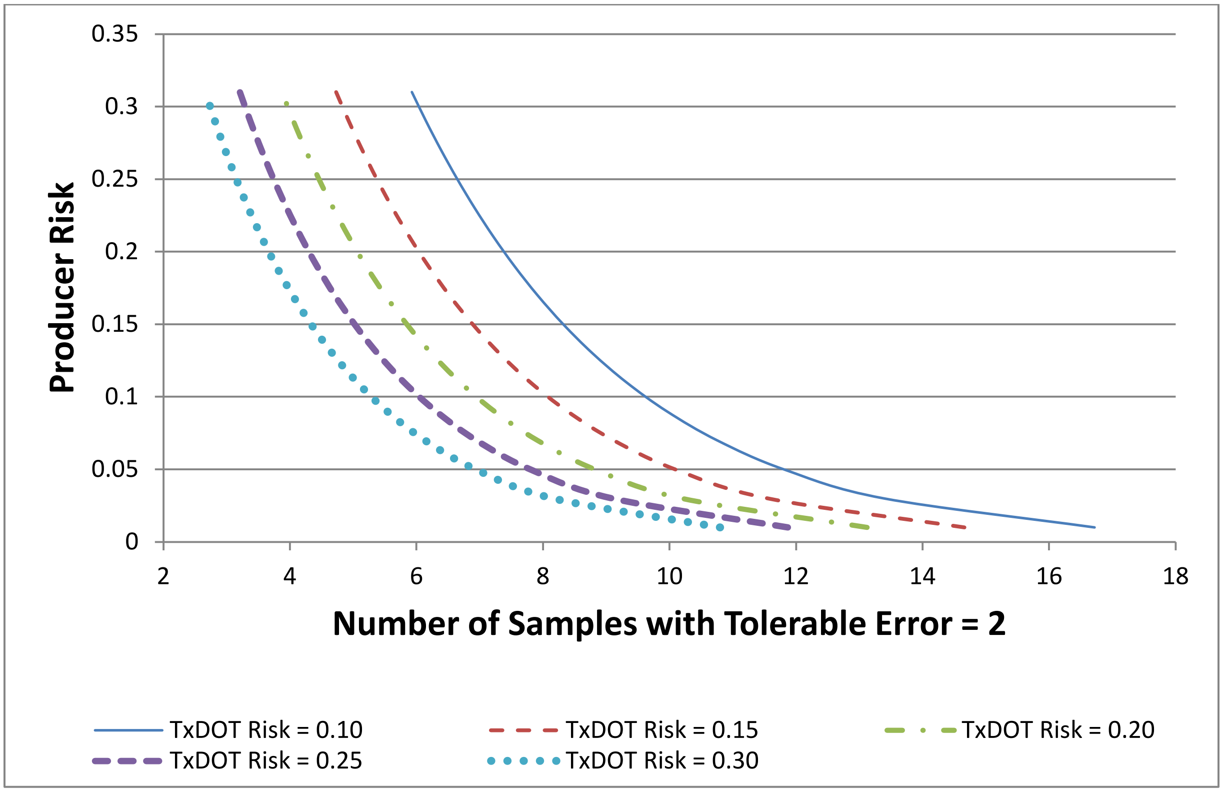

Figure 5.20. Plasticity Index: Number of Samples versus Producer Risk.

Figure 5.21 illustrates the impact of tolerating larger errors on the required number of samples. This figure assumes a TxDOT risk of 0.20 and shows that, as the tolerable error increases, the required number of samples rapidly decreases for any given level of producer and TxDOT risk. The tolerable error is one-half of the confidence interval width for population mean. For example, if a sampling and testing program measures a mean plasticity index of 11, and a tolerable error of 4 is used, the true population average plasticity index in the field could actually be anywhere from 7 to 15. Therefore, using large tolerable errors is not recommended as an approach for reducing the sample size.

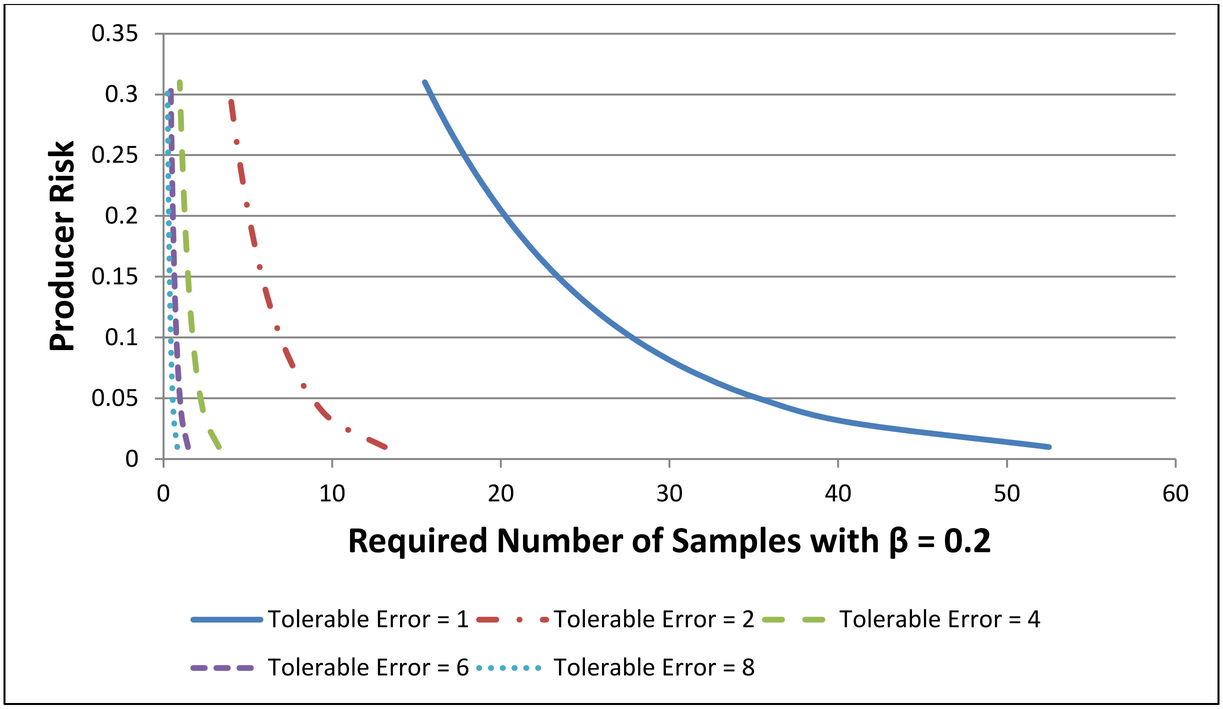

Figure 5.21. Plasticity Index: Required Number of Samples versus Producer Risk.

Other than increasing risk levels and tolerable error, the only remaining method for decreasing the sampling and testing burden is to decrease the standard deviation. This could be done by choosing the 50th percentile standard deviation as opposed to the 80th, but that approach would essentially mean that 50 percent of producers would be unable to comply at any given time. Alternatively, better production process control could result in an industry-wide reduced variation of production variability, which would lower the standard deviation and allow reduction of the required number of samples.

Using the 80th percentile standard deviation, and assuming equal TxDOT and producer risk of 25 percent, the tolerable errors and sample sizes in Table 5.17 should be considered. Note that these sample sizes are irrespective of lot size.

Table 5.17. Recommended n and e Values Using the 80th Percentile Standard Deviation and TxDOT and Producer Risk Equal at 25 Percent.

Test		Number of Samples (n)	Tolerable Error (e)
Gradation	Cumulative % Retained Above 1-1/4”	10	1.2
	Cumulative % Retained Above 7/8”	10	2.4
	Cumulative % Retained Above 5/8”	10	3
	Cumulative % Retained Above 3/8”	10	3.4
	Cumulative % Retained Above #4	10	3.5
	Cumulative % Retained Above #40	10	2.25
	Cumulative % Retained Above #200	10	1.5
Atterberg Limits	Plastic Limit	7	1.3
	Liquid Limit	7	1.1
	Plasticity Index	7	1.5
Ball Mill	Wet Ball Mill Value	6	2.5
	Wet Ball Mill % Increase	6	1
Strength	Unconfined Compressive Strength	10	9
	Compressive Strength with 3psi Confinement	10	9
	Compressive Strength with 15psi Confinement	10	13.8
Moisture Density Relationship	Maximum Dry Density	5	0.9
	Optimum Moisture Content	5	0.3

CHAPTER 6. PERFORMANCE-RELATED BASE COURSE PROPERTIES

INTRODUCTION

Current engineering design and the expected service life of pavements are based upon the modulus values of the individual pavement layers. In the design process, the layer modulus may either be assumed based upon experience or taken from laboratory tests of the materials that are expected to be used in the construction of the pavement or upon modulus values that have been inferred from nondestructive testing of in-service pavements. In the construction of each pavement layer, the objective should be to assure that layer is built so that its modulus matches as closely as possible the modulus that was used in its design.

However, the properties of the base course layer that are measured during construction are rarely, if ever, the modulus which was the basis of design. Most commonly it is the dry unit weight and water content which are compared with laboratory compaction curves to assure that an adequate level of compaction has been achieved. For decades, it has been recognized that there is a need to assure that the properties of base courses that were used in design are what have actually been placed.

A major obstacle to achieving this desired result is the difficulty of measuring the modulus and even more difficult, the permanent deformation properties of the base course properties. Quality assurance of the compacted base course must be conducted in a timely and efficient manner so as not to retard the pace of construction but must also be done with an accuracy and precision that can reasonably assure that the pavement will perform as it was designed.

What is needed is a quick, accurate, and simple process for determining reliable values of the in-place as compacted base course modulus and permanent deformation properties. In addition, the measurements that are made should also contribute to the assurance of the quality of the base course in every step of its production and handling from the quarry to the stockpile to the haul to the construction site and finally to its compaction in place.

The measurements presented in the following are aimed at satisfying that objective. Samples of base course materials were taken from several quarries in Texas and tested to determine their stress-dependent resilient moduli and permanent deformation properties. In addition to these properties, other, simpler and quicker tests of the characteristics of these base course aggregates were made to determine if there were any that were sound, repeatable and reliable predictors of the performance-related properties of base course aggregates. These tests include the Methylene Blue Test developed by the Grace corporation, the Horiba particle size analyzer to determine the percent fines content of the base course, the Filter Paper test to determine the suction of the base course, the Percometer test to determine the dielectric constant of the base course, the sieve analysis to determine the gradation of the particle sizes, the Aggregate Imaging test to determine the shape, angularity and texture of the aggregates, and the moisture diffusivity of the compacted base course test at high levels of relative humidity.

All of these tests are described below: their test setup, the test protocol and procedures, sample preparation, test results and their relations to each other and to the performance-related properties of the compacted base courses in Texas. Mechanics-based models of the stress-dependent resilient modulus and permanent deformation properties have been developed and are presented near the conclusion of this document. The coefficients of the model are shown to be well correlated to the measured aggregate characteristics. The ways in which these same tests may be run in the field during the entire production, stockpiling, hauling and compaction process are described. Finally, the ways in which the simply, quickly and accurately measured aggregate characteristics of base courses can be used to determine the in-place and as-compacted modulus and permanent deformation properties, which are described in the following.

PERFORMANCE TESTING

Triaxial repeated load tests were conducted to evaluate the laboratory performance of unbound granular material and to predict its long-term behavior in the field. The response of granular material under repeated loading applications can be characterized by a resilient (recoverable) strain and a permanent (unrecoverable) strain, as illustrated in Figure 6.1 (Kancherla 2004). The recoverable behavior of granular aggregate can be represented by resilient modulus which reflects the stiffness of the material. The unrecoverable strain can be accumulated under many cycles of load repetitions and is related to rutting damage. Therefore, the permanent deformation test can be used in the laboratory to determine the ability of a granular material to resist rutting.

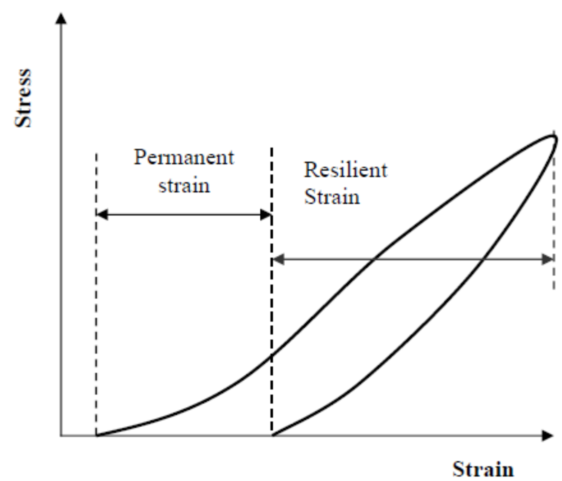

Figure 6.1. Response of Granular Material under One Loading Cycle (Kancherla 2004).

Resilient Modulus Testing

Test Protocol and Procedures

The loading protocol used in the resilient modulus test was developed based on the cross-anisotropic behavior of granular materials. Though the cross-anisotropic behavior of granular materials has been well recognized, the loading protocols developed by AASHTO T307 and NCHRP 1-28A did not take this behavior into consideration. A finite element model was developed to calculate the responses of aggregate layers under actual traffic loading using the cross-anisotropic characteristics of granular base materials. The calculated stress responses of an aggregate layer are shown in Figure 6.2. Figure 6.2 also plots the loading level and stress envelopes for AASHTO T307 and NCHRP 1-28A (Ashtiani 2009). It is obvious that the stress envelopes for AASHTO T307 and NCHRP 1-28A do not match the responses of the cross-anisotropic finite element model well. A new loading protocol was developed based on the stress state in base courses represented in the cross-anisotropic finite element model and on the calculated response of aggregate layers under various traffic loading types. Table 6.1 shows the loading sequences for the resilient modulus test. For each loading sequence, the samples were tested at a constant confining pressure and under a specific axial cyclic stress using a haversine shape with a 0.1 second load duration and a 1.0 second cycle duration.

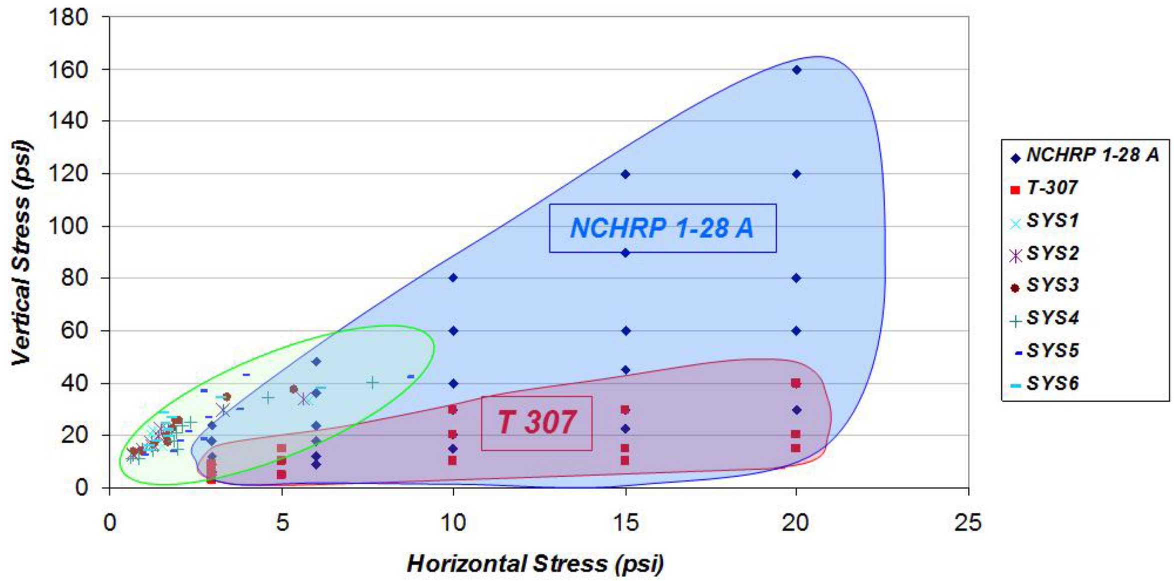

Figure 6.2. Anisotropic Solutions of Stress Responses of Base Layer and Laboratory Test Protocols (Ashtiani 2009).

Table 6.1. Loading Sequences for Resilient Modulus.

Sequence	Confining Pressure (psi)	Contact Stress (psi)	Cyclic Stress (psi)	Maximum Stress (psi)	N_{rep}
0	15	1.5	13.5	15	500 – 1000
1	2	.4	9.6	10	100
2	2	.4	14.6	15	100
3	2	.4	19.6	20	100
4	2	.4	24.6	25	100
5	2	.4	29.6	30	100
6	4	.8	9.2	10	100
7	4	.8	14.2	15	100
8	4	.8	24.2	25	100
9	4	.8	34.2	35	100
10	4	.8	44.2	45	100
11	6	1.2	18.8	20	100
12	6	1.2	28.8	30	100
13	6	1.2	38.8	40	100
14	6	1.2	48.8	50	100
15	6	1.2	58.8	60	100
16	8	1.6	18.4	20	100
17	8	1.6	28.4	30	100
18	8	1.6	38.4	40	100
19	8	1.6	48.4	50	100
20	8	1.6	58.4	60	100
21	10	2.0	18	20	100
22	10	2.0	28	30	100
23	10	2.0	38	40	100
24	10	2.0	48	50	100
25	10	2.0	58	60	100

Sample Preparation

Granular aggregate matrix specimens were prepared using a vibratory compaction method based on the recommendation of AASHTO T307. The specimens were compacted at the given moisture content and corresponding densities. In this study, the specimen dimensions used are 6 in. diameter with 12 in. height. Figure 6.3 illustrates the process of vibratory compaction. After demolding, the specimen was wrapped by a plastic membrane to avoid moisture loss and was kept for 14 hours or overnight to allow the water inside the specimen to distribute uniformly. Two Linear Variable Differential Transformers (LVDTs) were attached on opposite sides of the specimen before it was placed into the triaxial chamber. The gauge length of LVDTs used to compute strain was 6 inches. Figure 6.4 shows the specimen with LVDTs before the repeated loading test started.

Figure 6.3. Process of Vibratory Compaction.

Figure 6.4. Sample Preparation before Resilient Modulus Test Starts.

Test Configuration

The resilient modulus test was conducted on the cylindrical aggregate specimens using the triaxial chamber with the Material Testing System (MTS). Figure 6.5 illustrates the configuration of the resilient modulus test. Prior to the test, a membrane was placed on the sample and the chamber moved downward to seal the specimen; the pressure inside the chamber was increased until it reached the desired constant confining pressure. This confining pressure is applied directly to the sample. The MTS applied an axial load to the specimen through the loading frame. The entire testing process was controlled by a computer using programs that specified the axial load and the confining pressure. During each test, the two LVDTs measured the vertical deformations of the specimen. The test data were used to determine the recoverable and unrecoverable behavior of the granular material.

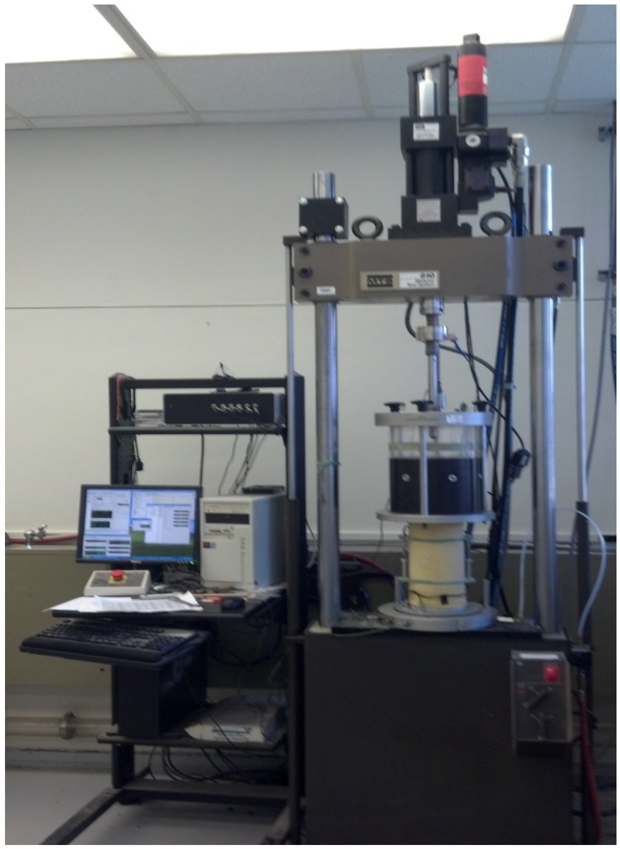

Figure 6.5. Configuration of Resilient Modulus Test.

Test Results

The resilient modulus value of the specimen was measured for each loading sequence. Because granular material is stress-dependent, the resilient modulus model needs to be developed to predict resilient modulus at a specific stress level. In this study, the universal model in AASHTO 2002 was used to determine the resilient modulus. The universal model is presented in Equation 6.1:

$$M_r = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2} \left(\frac{\tau_{oct}}{P_a} + 1\right)^{k_3} \tag{6.1}$$

where θ equals the bulk stress (the sum of the principal stresses); τ_{oct} equals the octahedral shear stress; P_a equals the atmospheric pressure; and k_1 , k_2 and k_3 are regression coefficients. The universal model was used to compute the resilient modulus at every stress level. After fitting the test data, three regression coeficients, k_1, k_2, and k_3 were obtained for each specimen. Table 6.2

gives examples of the results of the resilient modulus testing of all aggregate samples tested at the optimum moisture content and under a confining pressure of 7 psi and a deviatoric stress of 20 psi. The complete results of the resilient modulus tests are listed in Appendix C.

Table 6.2. Example Resilient Modulus Test Results for Aggregate Specimen at Optimum Moisture Content.

Material Type	k_1	k_2	k_3	Resilient Modulus (ksi)
E-06-1-13	1619.25	0.22	0.61	40.35
E-06-2-6	2029.78	0.00	0.85	45.46
E-05-61-12	2876.19	0.87	-0.76	70.81
E-05	1177.35	1.07	-0.2	46.97
E-02-1-3-4	685.99	0.91	-0.56	19.43
E-02-2-3-2	835.21	0.72	-0.11	24.33
E-04-1-3	1580.27	0.65	0.09	47.31
E-04-2-6	2098.18	0.9	-0.59	57.95
E-09-1-14	2228.59	0.55	0.06	59.32
E-07-69-1-14	1246.81	1.02	-0.59	38.95
E-07-68-2-6	1261.47	0.69	-0.28	32.75
E-08-235-1-12	1799.02	0.68	0.06	54.72
E-08-2-1-6	2508.41	0.61	0.00	68.93
E-01-1-3-2-3	3079.02	0.19	0.18	60.12
E-01	2984.08	0.32	0.23	68.25
E-03-6-10-3	1576.57	-0.04	0.52	28.78

In order to evaluate the moisture sensitivity of the granular specimens, three selected materials, E-05, E-01, and E-09, were tested at 1.5 percent above, and below, their optimum water contents. Table 6.3 shows the resilient modulus test results for granular materials at different water contents.

Table 6.3. Resilient Modulus Test Results for Selected Aggregate Material at Different Water Contents.

Material Type		k_1	k_2	k_3	Resilient Modulus (ksi)
E-05	Optimum Water Content	1177.35	1.07	-0.2	46.97
	Above Optimum Water Content	1653.32	0.29	0.57	43.40
	Below Optimum Water Content	2213.00	0.64	0.13	66.89
E-01	Optimum Water Content	2984.08	0.32	0.23	68.25
	Above Optimum Water Content	1247.19	0.69	0.11	39.29
	Below Optimum Water Content	4779.75	2.41	-4.51	89.06
E-09-1-14	Optimum Water Content	2228.59	0.55	0.06	59.32
	Above Optimum Water Content	1678.82	0.90	-0.19	56.54
	Below Optimum Water Content	2004.46	0.56	0.08	54.44

Permanent Deformation Testing

Permanent Deformation Models

A permanent deformation model needs to be developed to predict the long-term performance of granular materials accurately. The vast majority of permanent deformation models found in literature were developed based on using the laboratory test results. In this study, the VESYS model and Tseng-Lytton model were used to evaluate the permanent deformation behavior of aggregate materials (Zhou and Scullion 2002, Tseng and Lytton 1989).

VESYS Model

The VESYS model assumes that the relationship between permanent deformation and number of load applications is linear on a logarithm scale, which is expressed in Equation 6.2.

$$\varepsilon^{p}(N) = IN^{s} \tag{6.2}$$

By assuming the resilient strain is constant for each loading application, Equation 6.2 can be expressed as:

$$\frac{1}{\varepsilon_r}\left(\frac{\partial \varepsilon^{p}(N)}{\partial N}\right) = \left(\frac{IS}{\varepsilon_r}\right)N^{S-1} \tag{6.3}$$

Assuming $\mu = \dfrac{IS}{\varepsilon_r}$ and $\alpha = 1 - S$, Equation 6.3 can be rewritten as:

$$\frac{1}{\varepsilon_r}\left[\frac{\partial \varepsilon^P(N)}{\partial N}\right] = \mu N^{-\alpha} \tag{6.4}$$

in which ε_r is the resilient strain of the granular aggregate; ε^p is the permanent strain of the granular aggregate; N is the number of load cycles; μ is the parameter representing the constant of proportionality between permanent and resilient strain; and α is the parameter indicating the rate of decrease in permanent strain with the number of load applications.

Tseng-Lytton Model

Tseng and Lytton (1989) developed a three-parameter model to predict the relationship between permanent strain and number of loading cycles for the granular material, which is expressed in Equation 6.5:

$$\varepsilon_p = \varepsilon_0^p e^{-(\frac{\rho}{N})^\beta} \tag{6.5}$$

where ε_p is the permanent strain of the granular material; ε_0^p is the maximum permanent strain; ρ is the scale factor; and β is the shape factor.

In the MEPDG manual, this equation was modified to predict the permanent deformation of aggregate layers with thickness h, using Equation 6.6:

$$\varepsilon_p = (\frac{\varepsilon_0}{\varepsilon_r}) e^{-(\frac{\rho}{N})^\beta} \varepsilon_v h \tag{6.6}$$

where ε_v is the vertical strain in the granular aggregate layer; and h is the thickness of the aggregate layer.

Test Protocol and Procedures

As shown in Table 6.4, the permanent deformation test was initiated with sequence zero as preconditioning step. The following sequence (sequence one) was used to determine the unrecoverable behavior of the granular material. The stress level of sequence one was determined according to the actual stress response of the aggregate layer under standard traffic loading. The static confining pressure and haversine-shaped deviator stress with 0.1 second load period and 0.9 second rest period were applied to the specimen for 10,000 cycles. The cumulative plastic strains were recorded to characterize the permanent deformation behavior of aggregate material.

Table 6.4. Loading Sequences for Permanent Deformation.

Sequence	Confining Pressure (psi)	Contact Stress (psi)	Cyclic Stress (psi)	Maximum Stress (psi)	N_{rep}
0	15	1.5	13.5	15.0	500 – 1000
1	7	2.0	18	20.0	10000

Test Results

As discussed before, two permanent deformation models, VESYS model and Tseng-Lytton model, were used to analyze the permanent deformation test data. Table 6.5 summarizes the permanent deformation test results for different materials at optimum water content. The detailed test results are shown in Appendix D.

Table 6.5. Summary of the Permanent Deformation Test Results for Aggregate Specimen at Optimum Water Content.

Material Type	ε_r at 500th load application	VESYS Model Parameters		Tseng-Lytton Model Parameters		
		α	μ	ε_0	ρ	β
E-06-1-13	0.000389	0.811	0.437	8.38E-03	890	0.301
E-06-2-6	0.000307	0.769	0.294	5.04E-03	860	0.305
E-05-61-12	0.000359	0.776	0.461	9.32E-03	940	0.287
E-05	0.000406	0.727	0.888	2.72E-02	1500	0.307
E-02-1-3-4	0.000881	0.79	0.227	1.04E-02	860	0.305
E-02-2-3-2	Specimen broken during test					
E-04-1-3	0.000325	0.794	0.284	4.86E-03	940	0.292
E-04-2-6	0.000385	0.675	0.363	1.23E-02	970	0.293
E-09-1-14	0.000312	0.823	0.137	1.98E-03	820	0.310
E-07-69-1-14	0.000423	0.767	0.909	2.19E-02	900	0.300
E-07-68-2-6	0.000482	0.684	0.526	2.24E-02	1230	0.304
E-08-235-1-12	0.000361	0.711	0.349	9.19E-03	950	0.302
E-08-2-1-6	0.000228	0.647	0.196	4.50E-03	980	0.310
E-01-1-3-2-3	No permanent deformation observed					
E-01	0.000192	0.944	0.108	1.42E-03	980	0.100
E-03-6-10-3	0.000395	0.458	0.006	8.57E-04	1530	0.305

As done for the resilient modulus test, the permanent deformation test was also conducted on the three selected materials at 1.5 percent above, and below, their optimum water contents. Table 6.6 provides the summary of the permanent deformation test results for the aggregate materials at different water contents.

Table 6.6. Permanent Deformation Test Results for Selected Aggregate Materials at Different Water Content.

Material Type		ε_r at 500th load application	VESYS Model Parameters		Tseng-Lytton Model Parameters		
			α	μ	ε_0	ρ	β
E-05	Optimum Water Content	0.000406	0.727	0.888	2.72E-02	1500	0.307
	Above Optimum Water Content	0.000358	0.648	0.494	2.00E-02	1570	0.303
	Below Optimum Water Content	0.000223	0.84	0.106	1.24E-03	1520	0.302
E-01	Optimum Water Content	0.000192	0.944	0.108	1.42E-03	980	0.100
	Above Optimum Water Content	0.0000836	0.784	2.728	1.21E-02	810	0.289
	Below Optimum Water Content	0.000226	0.586	0.03	1.08E-03	1560	0.303
E-09-1-14	Optimum Water Content	0.000312	0.823	0.137	1.98E-03	820	0.310
	Above Optimum Water Content	0.000251	0.742	0.236	4.18E-03	1500	0.304
	Below Optimum Water Content	No Permanent Deformation was observed					

TESTS FOR AGGREGATE CHARACTERISTICS

Methylene Blue Value (MBV)

Engineering properties of soil and aggregates are strongly influenced by the clay fraction in a mixture. It is known from experience and extensive laboratory testing that the engineering characteristics of aggregate mixtures are significantly influenced by the amount and characteristics of the fines in the material. Because of this there is a need to determine engineering properties of these aggregate mixtures by analyzing the fines content of the mixtures, including both clay and non-clay fines. The physical properties of clays depend on the clay mineralogy. Methylene blue is a test method that has been validated to assess clay mineralogy changes with cation exchange capacity (CEC) and specific surface area (SSA).

W.R. Grace has proposed a methylene blue test to determine the Methylene Blue Value (MBV) in aggregate mixes. The MBV is an indicator that represents the solution concentration of percent fines content in the mix. This is a relatively rapid test. However, the test method was not set up to measure directly the amount of active clays in an aggregate base course mixture. Therefore, the W.R. Grace test method is calibrated to enable its use for different types of aggregate to determine the percent fines fraction in the mix. In addition, this test method is further modified to represent a direct relation between the methylene blue value and percent fines content in any type of aggregate mixture.

Methylene blue is a large organic polar molecule which is absorbed onto the negatively charged surface of a clay mineral. The concentration of negatively charged particle locations on the clay surface controls the amount of methylene blue absorbed by a given mass of soil. Therefore the relative surface areas of clay particles are determined by using a methylene blue solution of a known concentration (Phelps and Harris, 1967).

Since methylene blue molecules are absorbed at negatively charged clay locations, the absorbed methylene blue provides a measurement of the cation exchange capacity (CEC) of clay samples (Fairbairn and Robertson, 1957).

A number of researchers have assessed that the cation exchange capacity (CEC) is an indicator of methylene blue dye adsorption (Wang and Wang 1993). The methylene blue method is simple, rapid and reproducible. The methylene blue test was considered to be appropriate for industrial uses. A methylene blue test procedure was developed to determine the active clay content. This method is included in the European Standards to assess deleterious clay in concretes (Yool et al., 1998).

ASTM C 837 is a standard test method for a methylene blue test index of clay to assess the active fine particles in an aggregate mixture. The purpose of this test is to measure the amount of the methylene blue dye adsorbed by the clay. AASHTO T 330-07 is also a standard test method measuring the qualitative detection of harmful clays in the smectite group in an aggregate mix. This method determines the surface activity of the aggregate through identifying the smectite group material which is considered to be harmful clay. The Grace methylene blue test method is more time effective test method compared to both ASTM and AASHTO standards.

Percent Fines Content (pfc)

Horiba Laser Scattering Particle Size Distribution Analyzer is a device to determine the particle size fraction distribution of a soil mixture. A viscous solution, composed of soil and water, flows through a beam of light to detect the particle sizes. The light scattering device analyzes various particle dimensions in the viscous solution passing through the light beam. The data analysis runs through the Horiba software and produces a distribution of size fractions from the smallest to largest particle dimension.

The soil mixtures are analyzed in the laboratory with the particle size distribution analyzer version LA-910, which is produced by Horiba Instruments, Inc. The device picture is shown in

Figure 6.6. The sample passing the No. 40 sieve size is sieved again through the No. 200 sieve, which represents the desired largest sieve number that is used to analyze the soil sample for this project. The percent fines contents (pfc) represents the particle size fraction passing the No. 200 (0.075 mm, which equals 75 microns) sieve size. Thus, to achieve this purpose, the largest sieve size that must be used is the No. 200, and the fines content of that size must be analyzed.

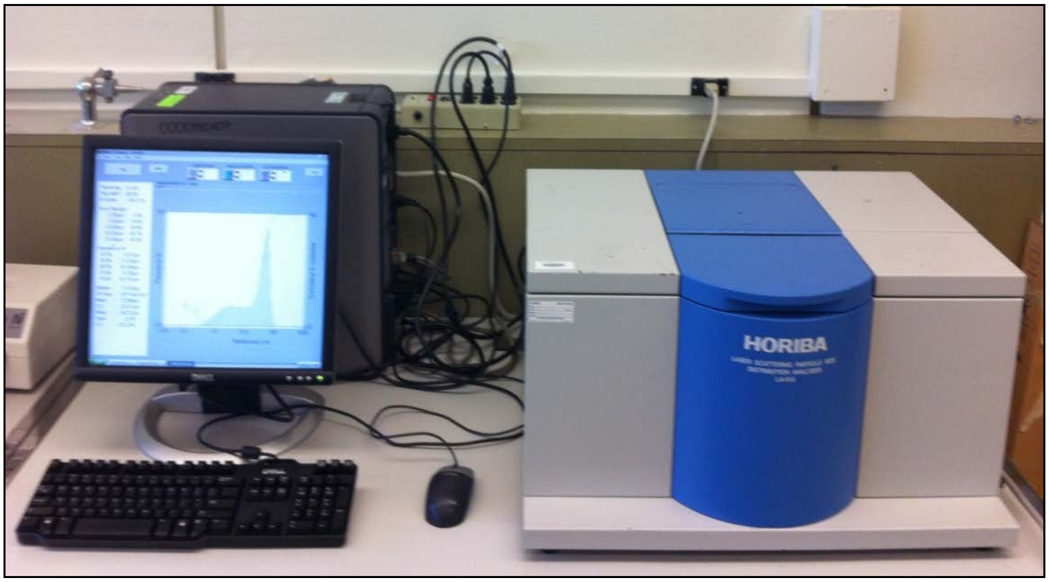

Figure 6.6. Horiba Laser Scattering Particle Size Distribution Analyzer.

The air dried soil sample which passes the No. 200 sieve size is employed to determine the cumulative percent size distribution curve. The total test process time is completed in less than 10 minutes and the cumulative distribution curve is generated in a minute. The percentage of the 2 micron size of the material is determined through the cumulative distribution curve. The percent fines content fraction (pfc) is the percent of the material passing the 2 micron size divided by the percent of the material passing the No. 200 sieve (75 micron size). The pfc was determined for base course samples for all of the nine-(9) aggregate quarries by using the same test process and the results are given in Appendix E.

An example particle size distribution for the E-02 quarry illustrates the outcome of the distribution analysis in Figure 6.7.

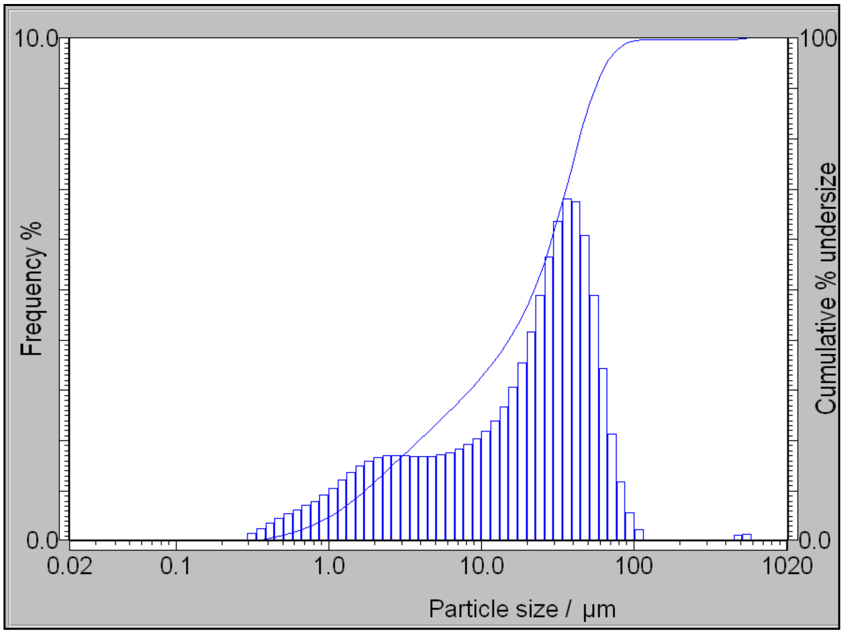

Figure 6.7. A Cumulative Size Distribution in Percent and Particle Size Computer Output Graph Is Given for E-02 Quarry.

Relationship between MBV and pfc

The methylene blue test evaluates the fines fraction of an aggregate. The methylene blue test is considered to be a more suitable test method compared to other standard methods to determine the deleterious fine particles in a mixture.

In addition to the traditional methylene blue test, the Grace methylene blue test is a significantly more rapid, reproducible and simple method to estimate the percent fines amount. This new test method has been improved to assess a relation between the adsorbed methylene blue and the percent fines fraction especially in aggregate mixes. This improvement warrants the assessment of the methylene blue value for the size fraction smaller than the No. 4 sieve rather than the size smaller than 2 mm. Additionally, the test method is applicable both in the laboratory and in field applications because the test method requires fewer experimental tools.

Various aggregate samples were collected throughout Texas to identify the percent fines content. Nine-(9) aggregate quarries provided samples within a three-(3) month time period. The portion passing the No.4 and the No. 200 sieve was employed to assess the percent fines content. The Grace methylene blue test and Horiba Particle Size Distribution Analyzer were performed on more than a hundred (100) aggregate samples. Based on the test outcomes a general mathematical relation was generated between the methylene blue value and the percent fines content. This relation shows a general form of methylene blue value and fine content for nine quarries in Texas. The relation between methylene blue value (MBV) and percent fines content (*pfc*) is shown in Figure 6.8.

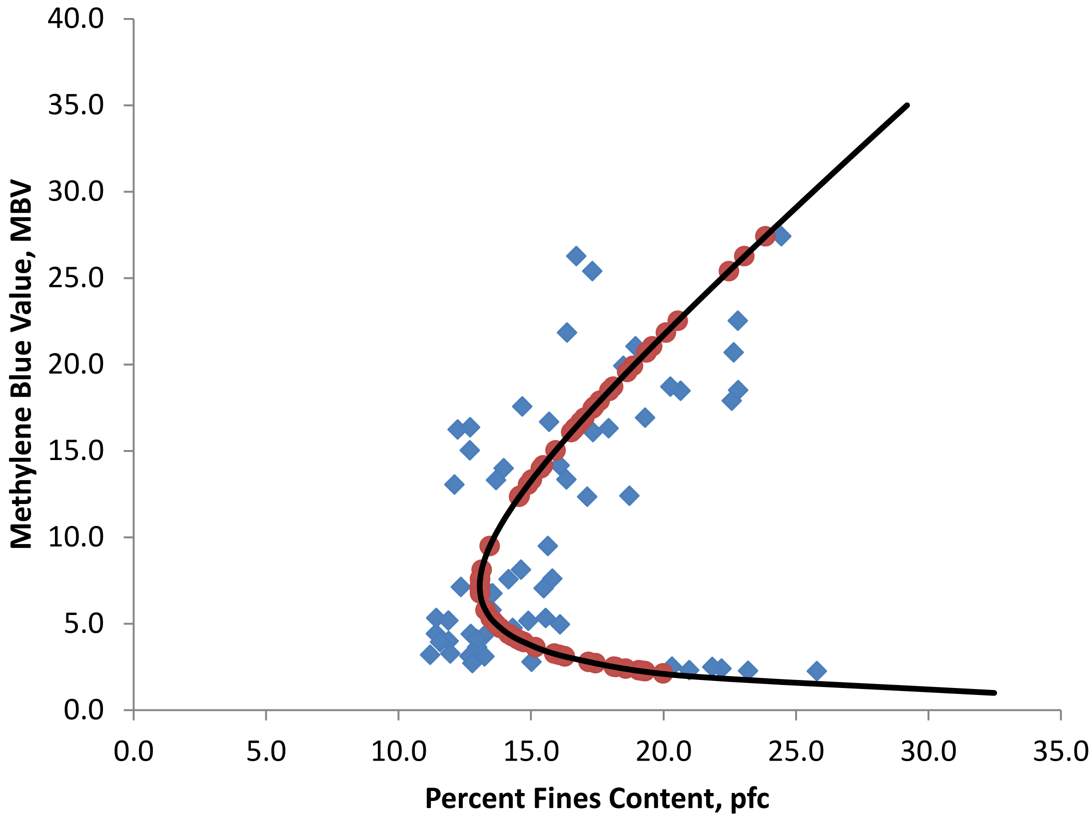

Figure 6.8. A Fitting Curve Represent Relation between Fine Material and Methylene Blue Value.

The curve relating the methylene blue value (MBV) and the percent fines content (*pfc*) is a "C" shaped curve. This curve in Figure 6.8 has been fitted through all experimental points. This curve is divided into two zones (Figure 6.9) based on the methylene blue value. Zone –II is where the methylene blue value is greater than 7 (mg/g), and Zone-I is where the methylene blue value is smaller than 7 (mg/g). The MBV value reading at 7 (mg/g) is considered as the critical methylene blue value (MBVc). There is an inverse ratio between the MBV and pfc when the MBV is below the critical MBV. As the MB value increases until 7 (mg/g), the pfc values decrease. There is a direct proportion in Zone-II where the MBV is above the critical MBV. If the MB value is above the critical MBV, then as the MB value increases, the pfc values increase. Furthermore, test results showed that if a sample is above the critical MBV point, they have higher liquid limit values. In other words samples located in Zone-II are more active than samples located in Zone-I. Typically, more active means having a higher surface area of the particles per unit weight.

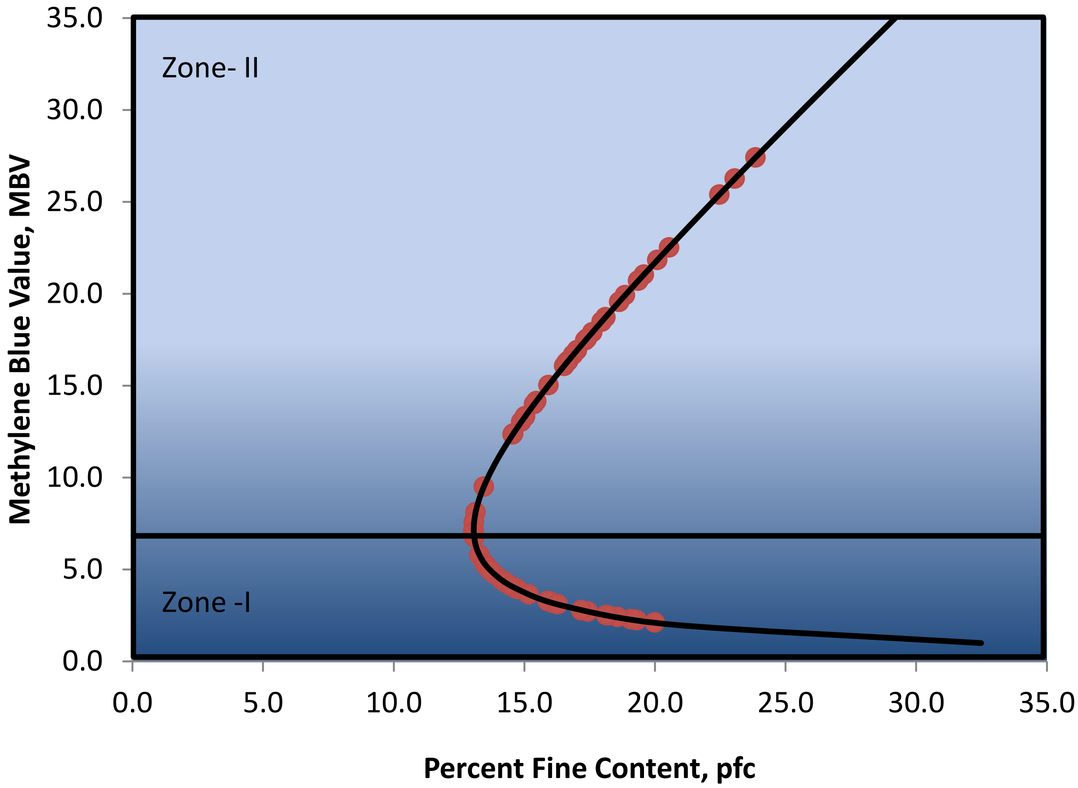

Figure 6.9. Zone-I and Zone-II Distinguished Based on Critical Methylene Blue Value.

Methylene blue value readings are obtained through a colorimeter device which detects color change in a methylene blue solution. The colorimeter operates between scale values of 0.00 and 7.50 mg/g. As the sample becomes more active, the MBV value becomes greater than 7.50 mg/g. According to the Grace test manual, the required amount of sample is 20.0 g to perform a methylene blue test. The improved methylene blue test method is calibrated based on the various weights of sample to perform the test. The MB test starts with a 20.0 g sample to measure a value on the MBV scale from 0.00 to 7.00. If the MB value reading is lower than critical MBV (7.00 mg/g), the reading is a valid number. If the MBV reading is higher than the critical MBV, the reading is invalid. In case of having an invalid reading, the test must be performed with a 10.0 g sample. The Grace Methylene blue test procedure is performed on the 10.0 g sample without any changes other than amount of the sample. The methylene blue reading is evaluated to assess whether the MBV is valid. If it is not valid, another sample half the previous size 5.0 g is used. This procedure is repeated until an MB value is lower than 7.00 mg/g. The methylene blue test method procedure is detailed in the schematic shown in Figure 6.10.

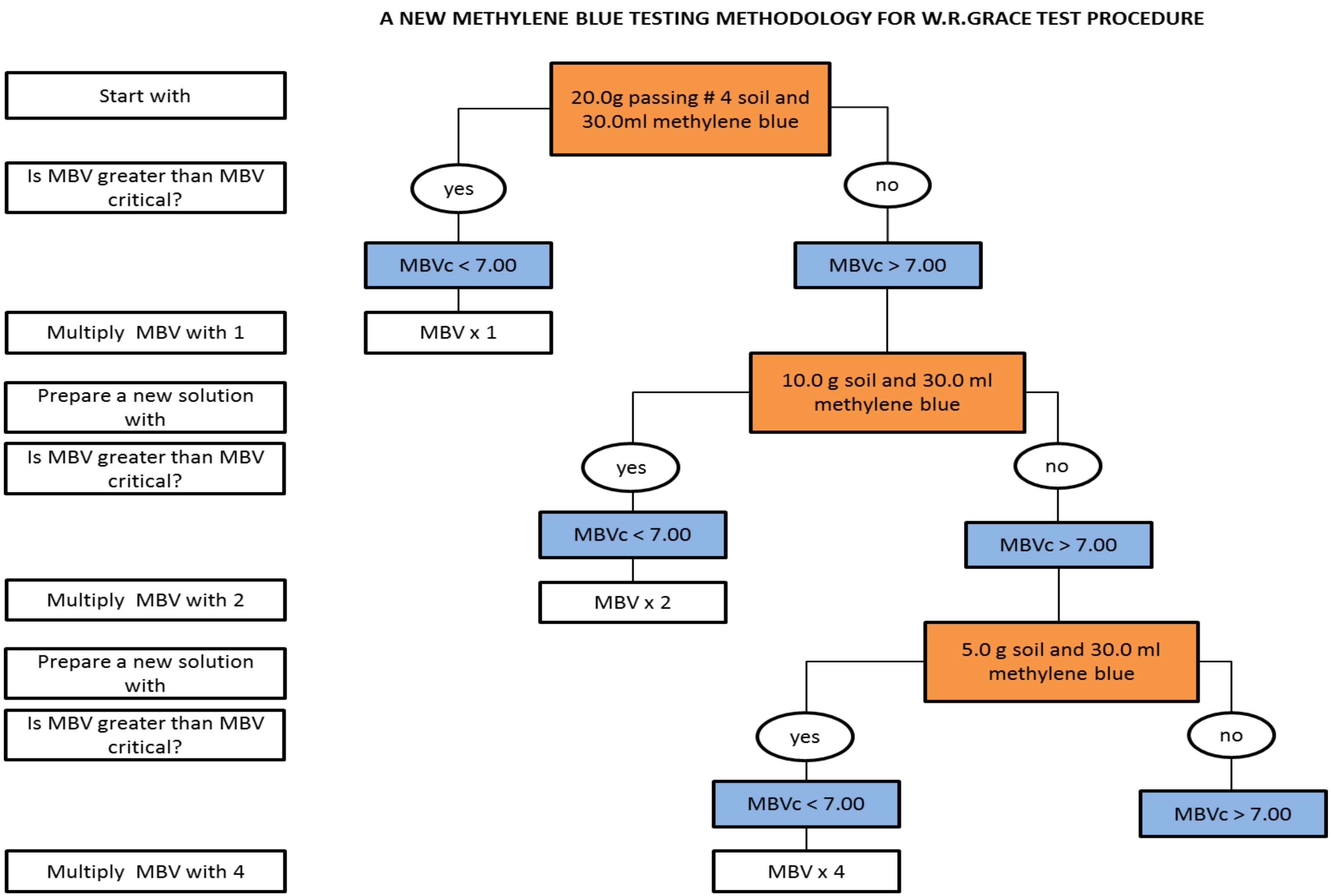

Figure 6.10. Methylene Blue Test Methodology Diagram Based on Changing Amount of Sample.

The methylene blue is a standard method of test for the qualitative detection of harmful clays of the smectite group in aggregates using in AASHTO T 330-07. A greater reading of the methylene blue value shows that a larger amount of active fines or organic materials exists. A scaled relation of the expected performance of the material and the methylene blue value is presented in Figure 6.11.

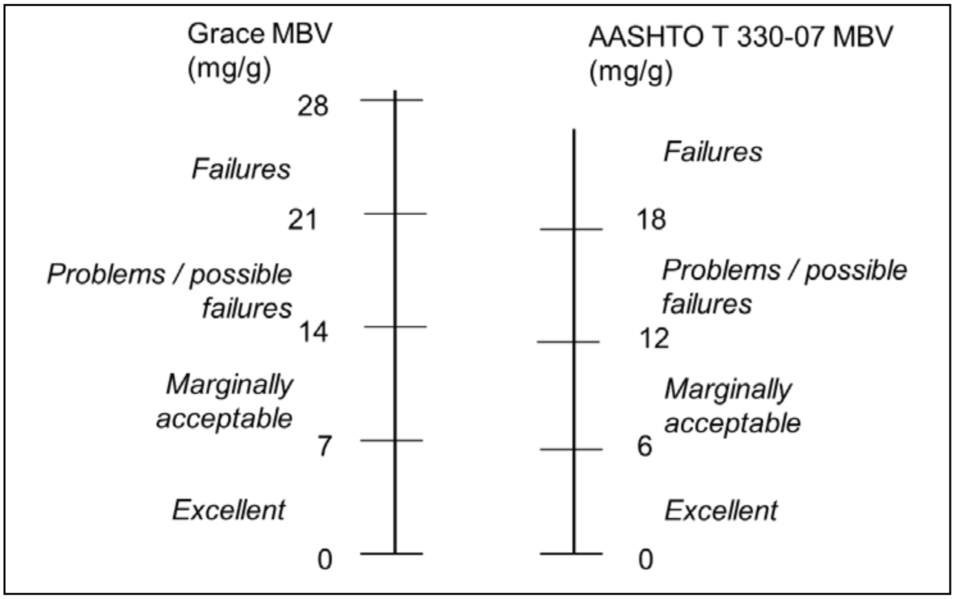

Figure 6.11. Grace MBV and AASHTO T 330-07 Methylene Blue Values Compared in a Scale.

Figure 6.11 illustrates that the AASHTO T330-07 methylene blue values range from 0 to 18 and can be related to performance. The scale values are divided into four groups of excellent, marginally acceptable, problems/possible failures and failure. The W. R. Grace methylene blue test, which is modified by Texas Transportation Institute (TTI), values are scaled from 0 to 28. Figure 6.11 illustrates that the W. R. Grace methylene blue value and AASHTO T330-07 are closely related. The mathematical form of the relation is shown in Equation 6.7.

$$MBV_{\text{Grace TTI}} = 1.167 MBV_{AASHTO\ T330} \quad (6.7)$$

Relationship between MBV and Liquid Limit

Atterberg limits consisting of liquid limit, plastic limit, and plasticity index are among the most extensively used soil index properties to determine engineering properties of soils. There are standard laboratory test procedures to determine the Atterberg limits. These standard test procedures require a certain amount of laboratory work and waiting time. Traditional Atterberg limit method for determination of moisture is very labor-intensive. For instance, in order to determine Atterberg limits, moisture content must be determined. According to the standard test manual, drying takes at least 12 hours by using a standard oven to measure water content. On the other hand the new methylene blue test is a test method capable of determining Atterberg limits in a shorter time, approximately 15 minutes.

The liquid limit defines a state at which the soil flows is defined based on moisture content. The liquid limit test is standard test method in ASTM D 4318. The liquid limit value is determined by using a standard laboratory test device which helps to measure the moisture content at the liquid state.

The methylene blue test value and soil liquid limit are correlated. The relation between liquid limit (LL) and methylene blue value (MBV) is shown in Figure 6.12. The methylene blue value increases in proportion to the liquid limit (LL). The fitting gives significantly consistent R^2 values in the range of 0.80. The 90 percent confidence level curves are also shown in Figure 6.12.

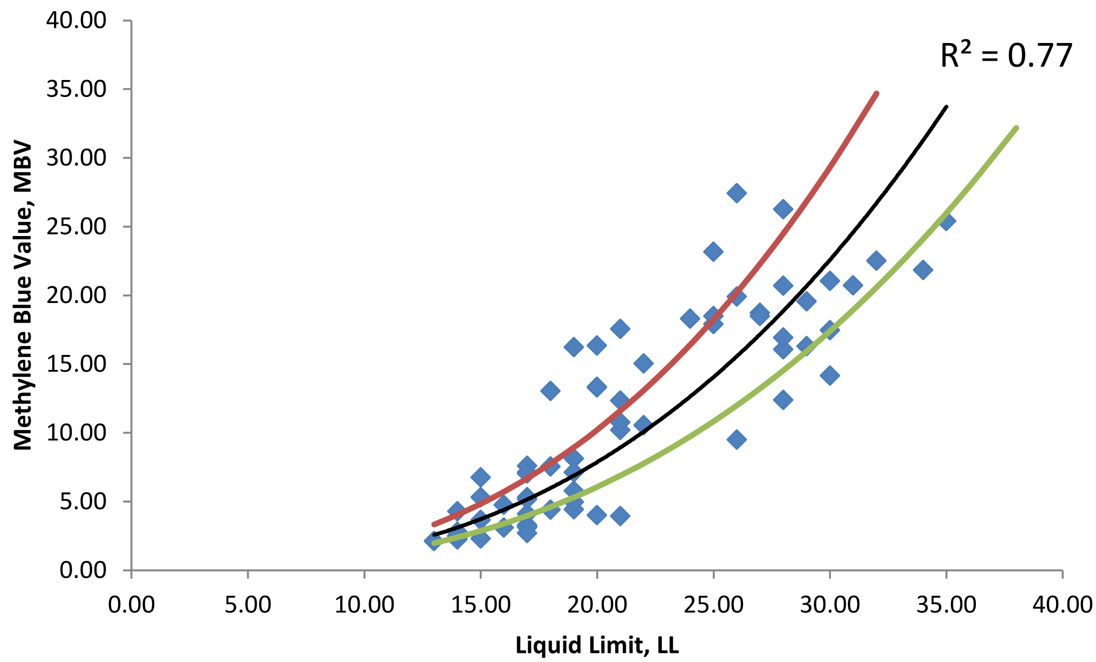

Figure 6.12. A Relation between Liquid Limit (LL) and Methylene Blue Value (MBV).

Relationship between MBV and Plasticity Index

The plastic limit (PL) is the boundary between plastic state and semi-solid state. Plastic limit is defined as the water content on this boundary. Plastic limit is a standard test method in ASTM D 4318. The test requires a certain amount of lab work, and also a waiting time is required to measure moisture content. If a conventional oven is used, the time is around 12 hours. Plasticity index is the difference between liquid limit and plastic limit test results.

The methylene blue test also has a good relation with the plasticity index (PI) as shown in Figure 6.13. The 90 percent confidence level boundaries are also shown.

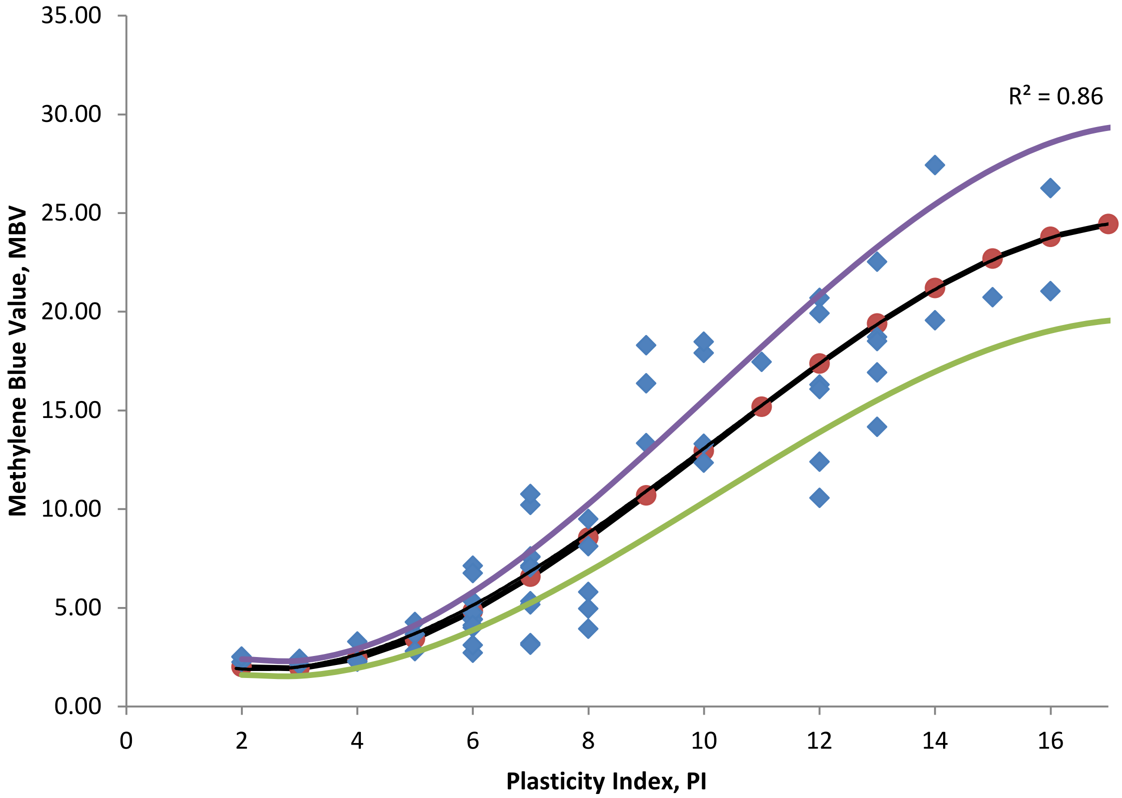

Figure 6.13. A Relation between Plasticity Index (PI) and Methylene Blue Value (MBV).

Filter Paper Test

Test Procedure

This tests method covers measure of soils suction by filter paper which is a method that has been used in unsaturated soil mechanic, and currently is a suitable for suction measurement. Both total and matric suction can be determined by means of the filter paper method. To measure the matric suction, the filter paper is placed between two samples. When the samples reach equilibrium, the suction in the sample and filter papers will be equal and will equal the matric suction. The total suction is measured with the two filter papers supported above the sample. When these filter papers reach equilibrium they are at the total suction. The ASTM Standard for this test is ASTM D5298. An illustration of the test sample setup is shown in Figure 6.14. In this project the prepared base mixture were used to estimate the suction at the present water content.

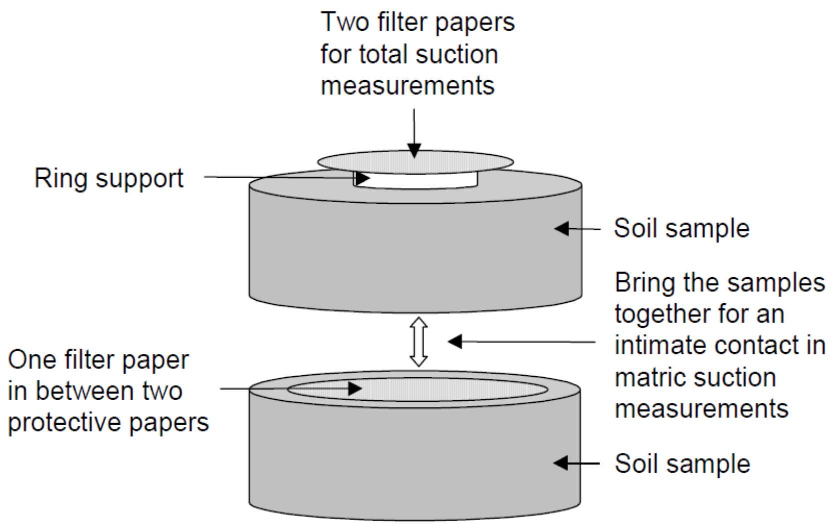

Figure 6.14. Soil Samples, Filter Papers for Matric and Total Suction (Lytton et al., 2004).

The standard filter paper suction test is used to measure the matric suction of the passing No.4 sieve size fraction. Two compacted aggregate samples are prepared by using the standard compaction method in ASTM D 698. The size of each compacted sample is 1.5 in. high and 3 in. in diameter. The compacted soil samples are kept in 100 percent humidity room to reach 2 percent moisture content. When the samples have reached the desired moisture content, they are taken from the environment room, and immediately the filter paper test is performed

The filter paper test set up is shown in Figure 6.15. One filter paper is placed in between two compacted samples to measure matric suction level. Then the samples are sealed with an electrical tape and placed into a jar. Two filter papers are placed on top of the sample to measure total suction level and sealed again. The samples are kept 7 days in the jar. Then the jar is opened and suction values are determined by measuring the moisture content of the placed filter papers and reading the suction value from the filter paper calibration curve.

Figure 6.15. Filter Papers Are Placed in between and on Top of the Samples and Samples Are Sealed.

Suction-Water Characteristic Curves (SWCC)

The soil water characteristic curve is a relation between soil suction and moisture content. The SWCC curve depends on the type of soil and aggregates. All of the measured test data have been used to generate a SWCC for each of the various aggregate sources.

The test results indicated that the methylene blue test and percent fines content (pfc) values are closely related to several important aggregate characteristics. The pfc is an input parameter with which the suction water characteristic curve (SWCC) and the suction dielectric characteristic curve (SDCC) can be generated. These curves are functions of four parameters, all of which are functions of the pfc. Consequently, the pfc is a vital parameter to be determined in order to generate the entire curve of both the SWCC and SDCC.

The four SWCC curve parameters depend upon two experimental parameters that come from the gradation curve and the Methylene Blue test. These parameters are the percent of soil weight smaller than 75 µm (#200 sieve) and 2 µm, the size of the fine clay portion of the soil. The second parameter is the percent of fines content which is the percent of the sample that is smaller than 2 microns (2µm) divided by the percent of the sample that is smaller than the 75 micron (75µm) size. Both sizes are determined by the particle size distribution curve. This percent value is denoted as the percent fines content (pfc) to represent the fine clay content which passes the No. 200 Sieve (Sahin, 2011). The mathematical formulation of the pfc is shown in Equation 6.8.

$$pfc = \frac{-2\mu m}{-No.200} x100 \tag{6.8}$$

where $-2\mu m$ is the sample weight smaller than 2 micrometers in percent; and $-No.200$ is the sample weight smaller than 75 micrometers in percent.

The methylene blue test is performed to determine the pfc for an aggregate mixture as explained previously.

The relation between the soil moisture content and soil suction is the soil water characteristic curve (SWCC). The form of the SWCC which is based on the volumetric water content and suction is by Fredlund and Xing (1994). The proposed SWCC curve relation is given in Equations 6.9 and 6.10.

$$\theta_w = C(h) \times \left[\frac{\theta_s}{\left[\ln\left[\exp(1) + \left(\frac{h}{a} \right)^b \right] \right]^c} \right] \tag{6.9}$$

$$C(h) = \left[1 - \frac{\ln\left(1 + \frac{h}{h_r} \right)}{\ln\left(1 + \frac{10^6}{h_r} \right)} \right] \tag{6.10}$$

where:

θ_s =Saturated volumetric water content

θ_w =Volumetric water content

a_f = a soil parameter which is primarily a function of the air entry value of the soil in kPa.

b_f = 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_f = 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 residual water content occurs in kPa. This report uses the pF-scale, a logarithmic scale of suction. The pF-scale is related to the kPA-scale as follows:

$$pF = \log_{10}(kPA) + 1.0083 \quad (6.11)$$

To be able to generate the SWCC curve, the four parameters in the Fredlund and Xing (1994) equation need to be calculated. The SWCC is generated with these four parameters: a_f, b_f, c_f and h_r and provides the full range of suction and water content values. A recent study showed that all of these four parameters depend upon the pfc value and a relation between each of the four parameters and pfc was proposed (Sahin 2011). This study found that each parameter has a unique function based on the pfc.

The four parameters in the Fredlund and Xing (1994) equation are estimated by using the SOLVER function in MS Excel. Based on the SOLVER data mathematical equations are developed for each parameter. Each parameter is a function of Percent Fines Content (pfc).

The air entry value of soil, a_f, is formulated based on the soil pfc value and given in Equation 6.12. The calculated value of a_f for each quarry in this report is shown in Figure 6.16. The rate of water extraction of the soil after exceeding the air entry value, b_f, is formulated in Equation 6.13. The calculated value of b_f for each quarry is shown in Figure 6.17. The b_f decreases as pfc value increases. The mathematical formulation for the residual water content of the soil of c_f is given in Equation 6.14. The calculated value of c_f for each quarry is shown in Figure 6.18. The mathematical formulation for the suction value at which the residual water content occurs, h_r is given in Equation 6.15. The calculated value of h_r is shown in Figure 6.19. Figure 6.20 illustrates the SWCC curves that demonstrate the volumetric water content and soil suction relationship for all of the quarries.

$$a_f\,(psi) = 0.6384e^{0.0369\,pfc} \tag{6.12}$$

$$b_f = 11.748e^{-0.037\,pfc} \tag{6.13}$$

$$c_f = 0.126e^{0.0211\,pfc} \tag{6.14}$$

$$h_r\,(psi) = -0.0018\,pfc^2 + 0.5206\,pfc + 2.4305 \tag{6.15}$$

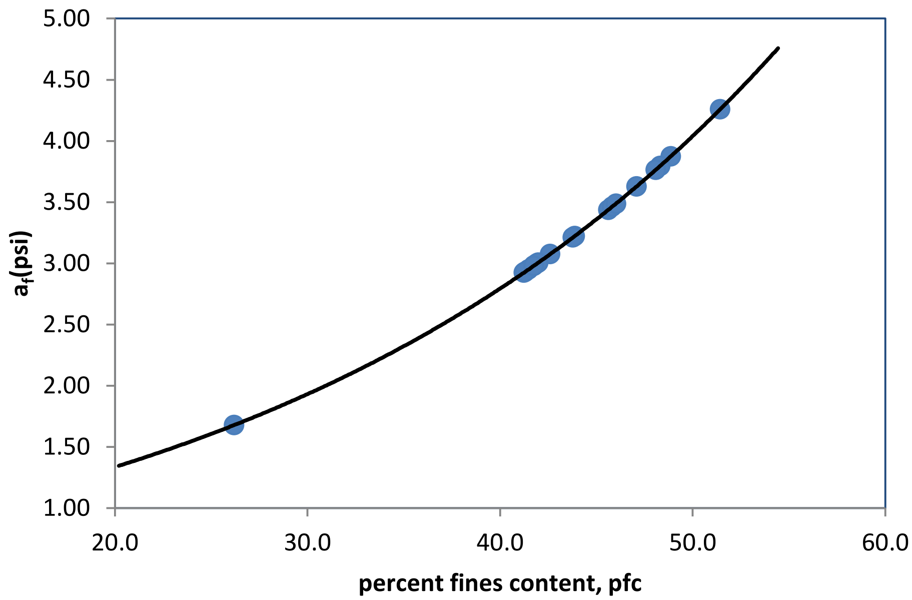

Figure 6.16. Change in a_f with Respect to Percent Fines Content (Sahin, 2011).

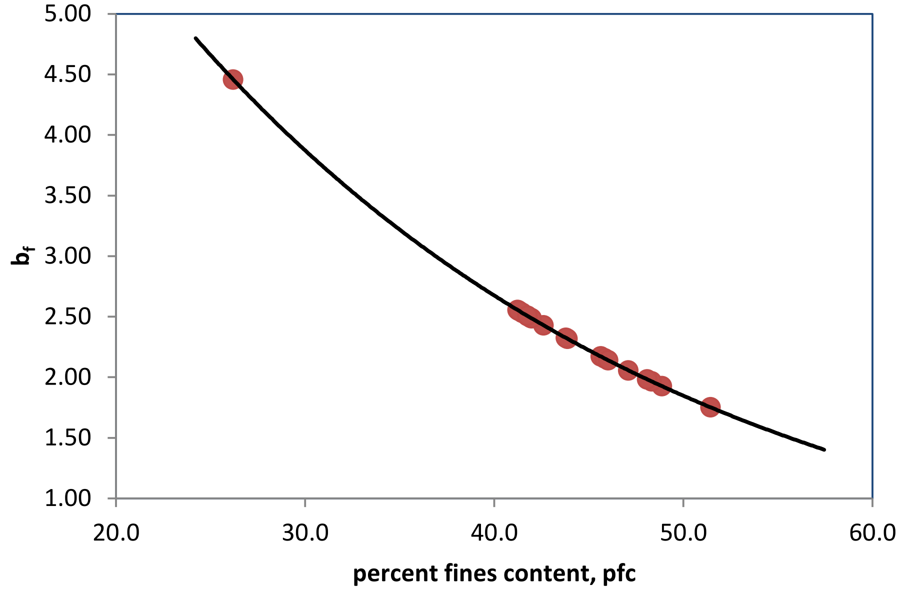

Figure 6.17. Change in b_f with Respect to Percent Fines Content (Sahin, 2011).

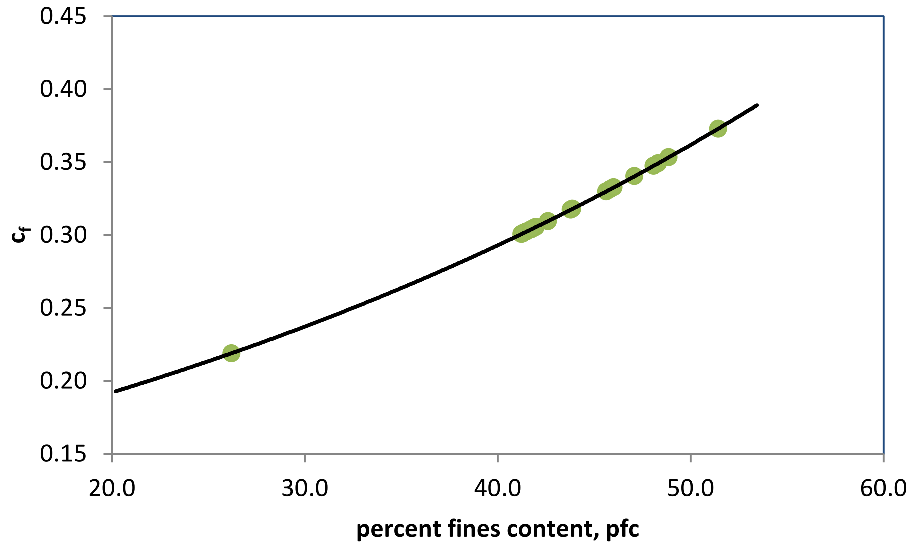

Figure 6.18. Change in c_f with Respect to Percent Fines Content, *pfc* (Sahin, 2011).

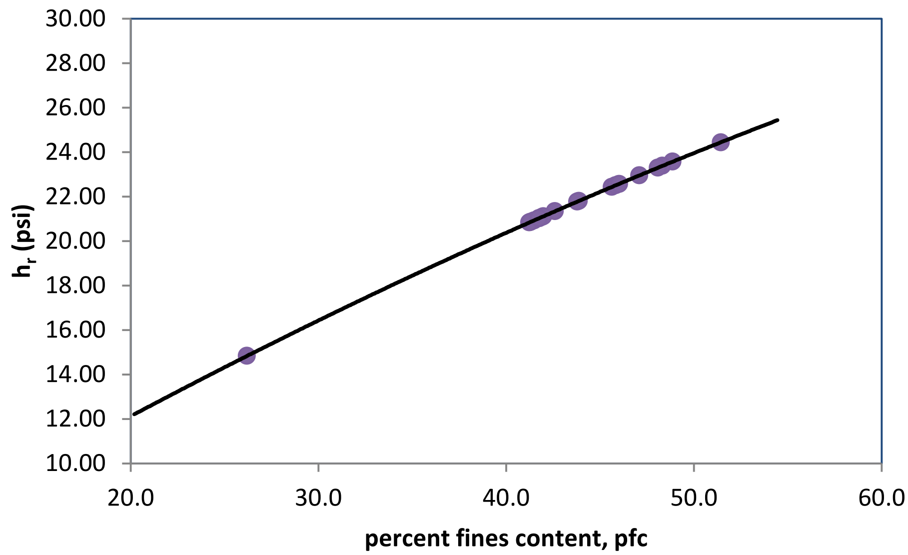

Figure 6.19. Change in h_r **with Respect to Percent Fines Content,** pfc **(Sahin, 2011).**

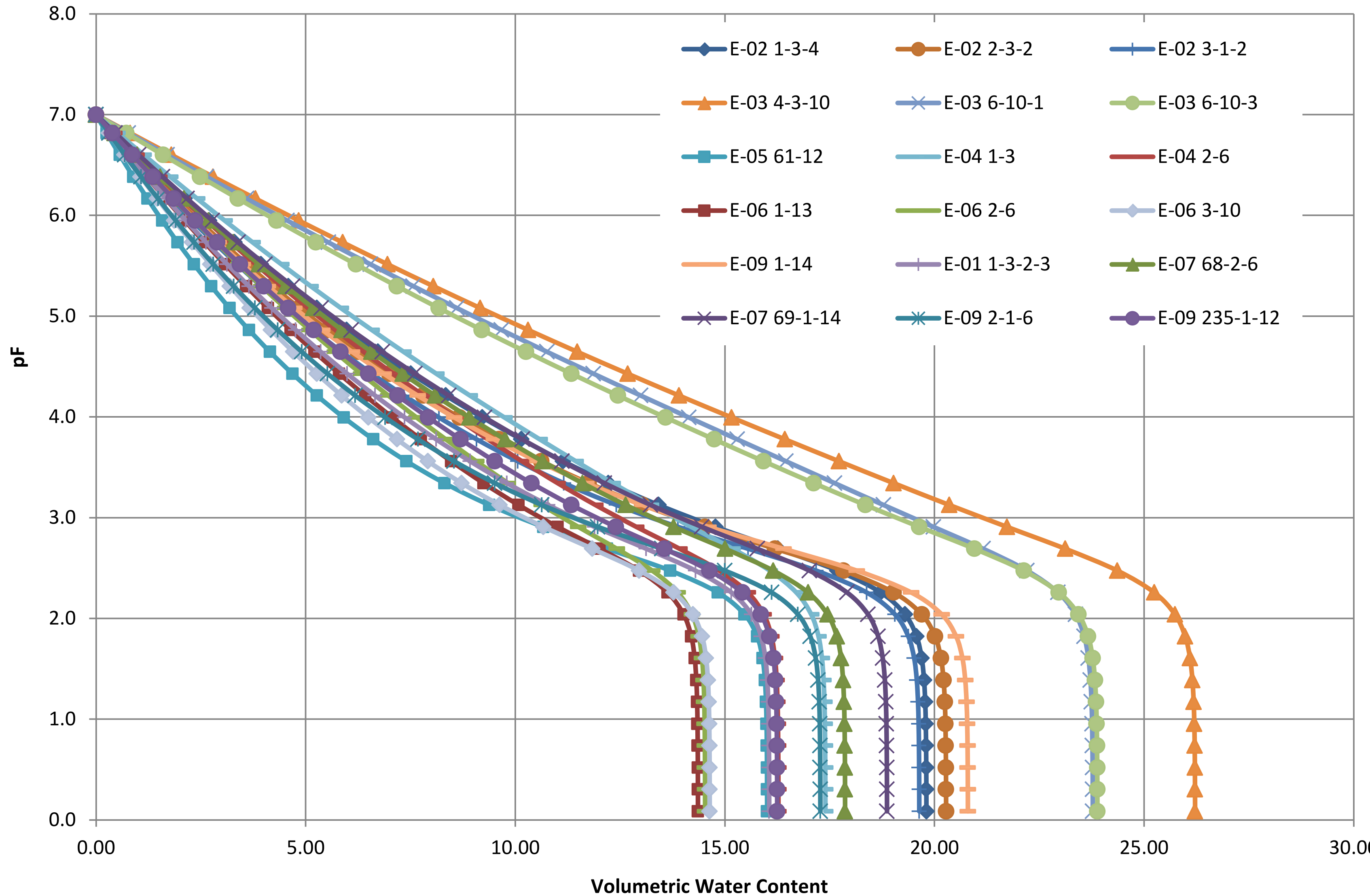

Figure 6.20. SWCC Curves to Shows Volumetric Water Content and Soil Suction Relationship for All of the Quarries.

The SWCC shown in Figure 6.21 is an example of the E-06 1-13 sample. The suction value of 4.86 pF corresponds to a volumetric moisture content of 3.70 in Figure 6.21. The point shown on the graph is the separately measured filter paper suction and water content.

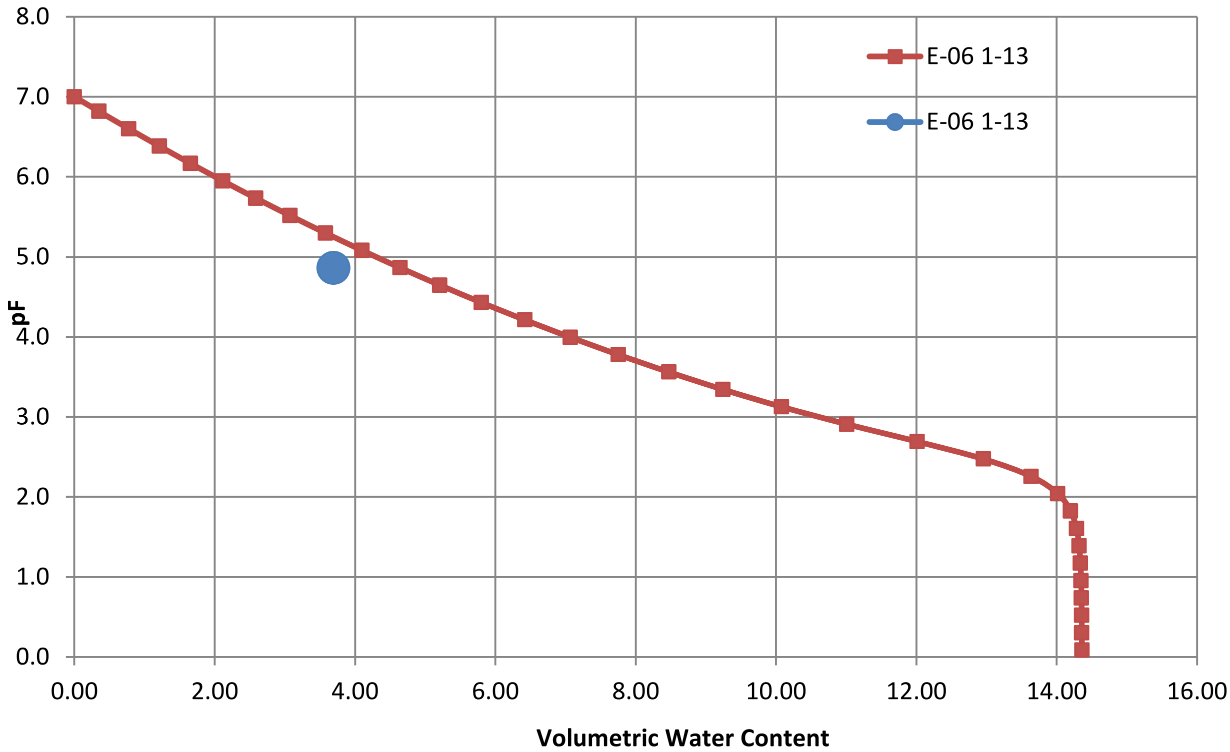

Figure 6.21. Suction Water Characteristic Curve (SWCC) for the E-06 1-13 Quarry.

For a known suction value the SWCC curve provides the moisture content at that suction. As will be shown subsequently in Figure 6.26, at the same value of suction of 4.86 pF, the dielectric value for E-06 1-13 is 9.46. Thus, measuring the dielectric value and entering the suction dielectric curve (SDCC) provides a suction value. That same suction value on the SWCC curve gives the water content at the corresponding suction. The dielectric value can be measured both in the laboratory and in the field with a Percometer, which is described in the next section.

Percometer Test

Test Procedure

The percometer is an instrument that measures dielectric constant, electrical conductivity, and temperature at the surface of a material. The word "percometer" is originated form the words permittivity (per…), conductivity (…co…) and meter (…meter). The percometer is used to measure soil dielectric permittivity and conductivity in soil studies (Yoe et al., 2012). The percometer is a non-destructive test instrument which can be used both in the laboratory and for in-situ testing, while providing quick (15 seconds) and accurate readings. A percometer monitor and a surface probe is shown in Figure 6.22. The percometer is a frequency domain device which measures at a frequency of 50 kHz. The accurate definition of dielectric constant (ε_r) is the real part of the relative complex electric permittivity which is directly related to the moisture content in the material (Saue et al., 2008).

Figure 6.22. A Standard Percometer Device Including a Surface Probe (Humboldt).

The dielectric value (ε_r) of a base course is a composite of the dielectric values of the components of the base course: solids, water, and air. Theoretical developments supported by laboratory and field measurements have shown that the composite dielectric is weighted by the volume concentration of the components as in the following Equation 6.16.

$$\varepsilon_r^n = \sum_{i=1}^{n} \varepsilon_{ri}^n c_i \qquad (6.16)$$

where

c_i : volume concentration of the ith component of a mixture

ε_r :the dielectric constant of the ith component

n :an exponent which may range between ¼ and 1

The most commonly used value of the exponent, $n = 1/2$ produces the Complex Refraction Index Model (CRIM).

Soil sample preparation is important to produce consistent readings. Thus soil samples passing the No. 4 sieve size fractions are compacted at the optimum moisture content by using the standard compaction equipment. The samples are 1.5 in. high and 3 in. in diameter, two compacted soil samples are prepared for each quarry. The dielectric reading is taken on each identical sample at the same moisture content. The compacted soil samples are placed into an 100 percent relative humidity environmental room and moisture content reductions were monitored. Once the samples reach around 2 percent moisture content dielectric readings were taken immediately before starting the filter paper test to determine the suction level. Dielectric value readings of the sample before the filter paper test are shown in Figure 6.23.

Figure 6.23. A Percometer Reads the Dielectric Constant of Compacted Soil Samples.

The Complex Refraction Index Model (CRIM) is used to determine the dielectric value of the aggregate mix and the dielectric constant of the solids ε_s value for the mix, as follows. Firstly, the dielectric value (ε_r) of the base course is measured by using the Percometer. Secondly, the relative dielectric value of the water in Equation 6.17 is a known parameter, 81, and the volumetric concentrations of solids and water are also known. Thirdly, because the only unknown parameter in equation 6.17 is the dielectric value of the solids, it is calculated. The saturated dielectric value of the material needs to be determined in Equation 6.18. The saturated dielectric value ε_r can be calculated by using both θ_{sat} and θ_{solid} in Equation 6.18. The two CRIM dielectric value equations are given as follows:

$$\sqrt{\varepsilon_r} = \left[\left(\sqrt{\varepsilon_s} - 1\right)\theta_{solid} + \left(\sqrt{\varepsilon_w} - 1\right)\theta_w + 1\right] \quad (6.17)$$

The saturated dielectric value is calculated in Equation 6.18:

$$\left(\sqrt{\varepsilon_r}\right)_{sat} = \left[\left(\sqrt{\varepsilon_s} - 1\right)\theta_{solid} + \left(\sqrt{\varepsilon_w} - 1\right)\theta_{sat} + 1\right] \quad (6.18)$$

where;

ε_r is the measured dielectric value; ε_s is the dielectric value of solid; ε_w is the dielectric value of water; θ_{solid} is the volumetric solids content;

θ_w is the volumetric water content; and θ_{sat} is the saturated volumetric water content

The relation between the base course material suction and the dielectric value was investigated by using a percometer and filter paper measurements of suction. A large number of these measurements were performed on various materials that are compiled from nine-(9) different quarries. All of these measurements were used to develop a unique suction-dielectric constant relationship which gives the whole range of suction change with the material dielectric constant. This model is denoted as Soil Dielectric Characteristic Curve (SDCC). The SDCC models for nine-(9) separate quarries are determined and shown in Figure 6.24.

Suction-Dielectric Characteristic Curves (SDCC)

A general relation was developed between soil suction and the dielectric value. The form of the Fredlund and Xing (1994) equation was modified to generate a curve that shows the entire suction variation with dielectric value for each aggregate quarry, as illustrated in Figure 6.24. This soil dielectric characteristic curve relation is denoted as SDCC. The mathematical form of the SDCC model is given in Equations 6.19 and 6.20.

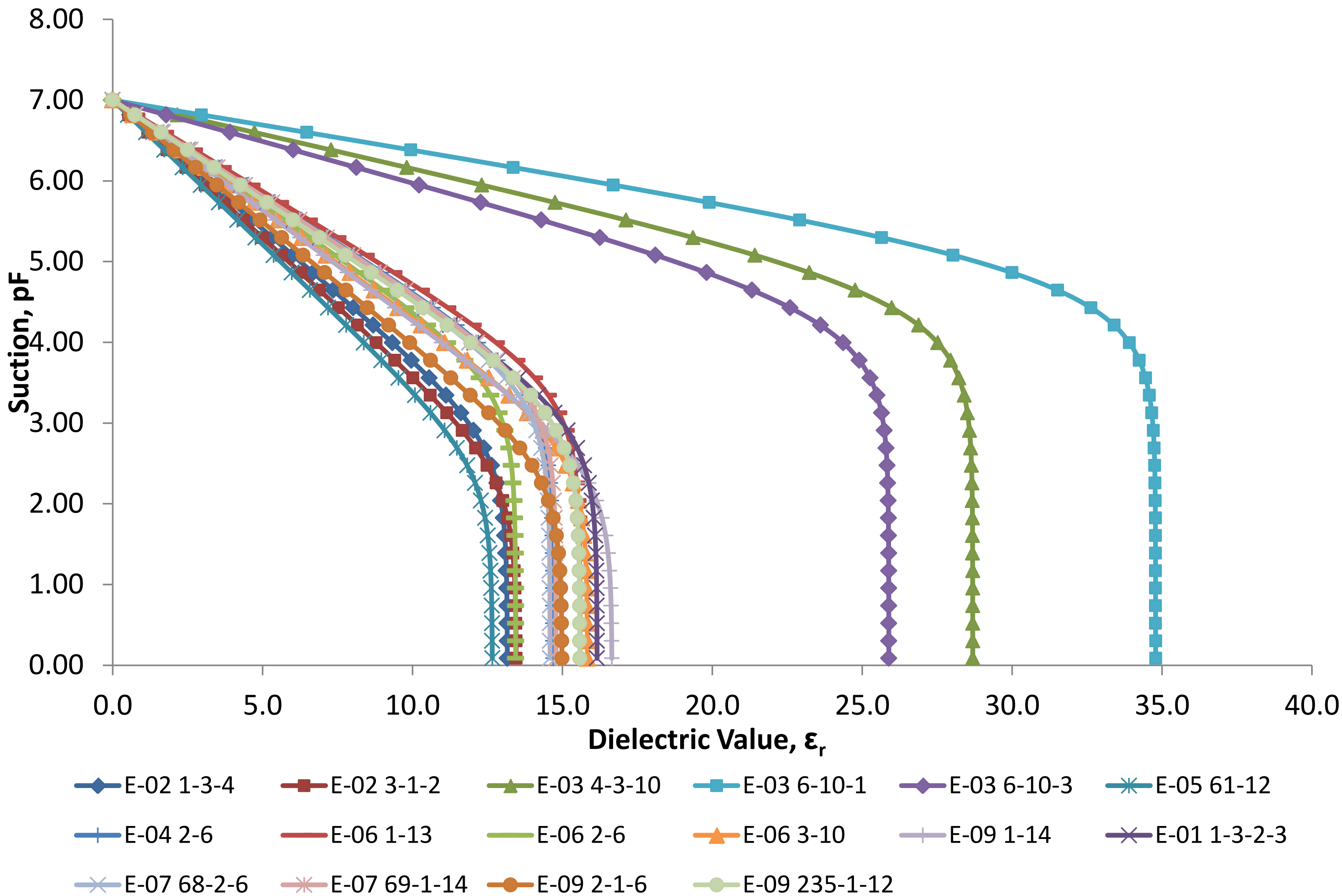

Figure 6.24. Generated SDCC Curves for Various Aggregate Quarries.

$$\varepsilon_r = C(h) \times \left[\frac{\varepsilon_{sat}}{\left[\ln\left[\exp(1) + \left(\frac{h}{a} \right)^b \right] \right]^c} \right] \quad (6.19)$$

$$C(h) = \left[1 - \frac{\ln\left(1 + \frac{h}{h_r}\right)}{\ln\left(1 + \frac{10^6}{h_r}\right)} \right] \quad (6.20)$$

where:

ε_{sat} = Saturated dielectric value

ε_r = Dielectric value

a_f = a soil parameter which is primarily a function of the air entry value of the soil in kPa.

b_f = 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_f = 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 occurs in kPa.

ε_{sat} = Saturated dielectric value

ε_r = Dielectric value

The SDCC Equations 6.19 and 6.20 consists of four parameters similar to those in the SWCC that allow the entire curve to be generated using the same methodology in the SWCC. These four parameters also depend entirely on the pfc and MBV of the mix.

The four parameters, a_f, b_f, c_f, and h_r are related to the MBV and *pfc*. Two sets of four parameters are given for the two conditions of the MBV value: MBV smaller than 7.0 mg/g and MBV larger than 7.0 mg/g.

The relations between a_f, b_f, c_f, h_r and the methylene blue value, MBV, and the percent fines content, *pfc* are illustrated in Figures 6.25 through 6.32 and an example SDCC is given in Figure 6.33.

With the methylene blue value smaller than 7.0 mg/g, the equations for a_f , b_f , c_f , and h_r are given in Equations 6.21 through 6.24. Each parameter is presented in Figures 6.25 to 6.28.

$$a_f = 3.976x(pfcxMBV)^{0.0015} \quad (6.21)$$

$$b_f = -0.00000004x(pfcxMBV)^2 + 0.0000004x(pfcxMBV) + 0.0301 \quad (6.22)$$

$$c_f = -0.0000001x(pfcxMBV)^2 + 0.000003x(pfcxMBV) + 0.0113 \quad (6.23)$$

$$h_r = 0.0023x(pfcxMBV)^{2.0183} \quad (6.24)$$

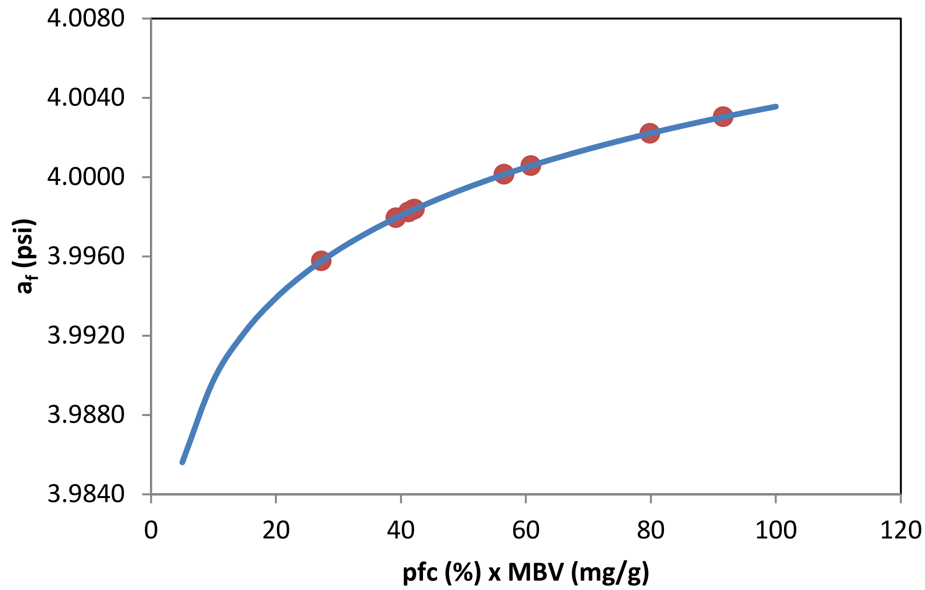

Figure 6.25. A Correlation Is Shown between a_f and ($pfc\ x\ MBV$).

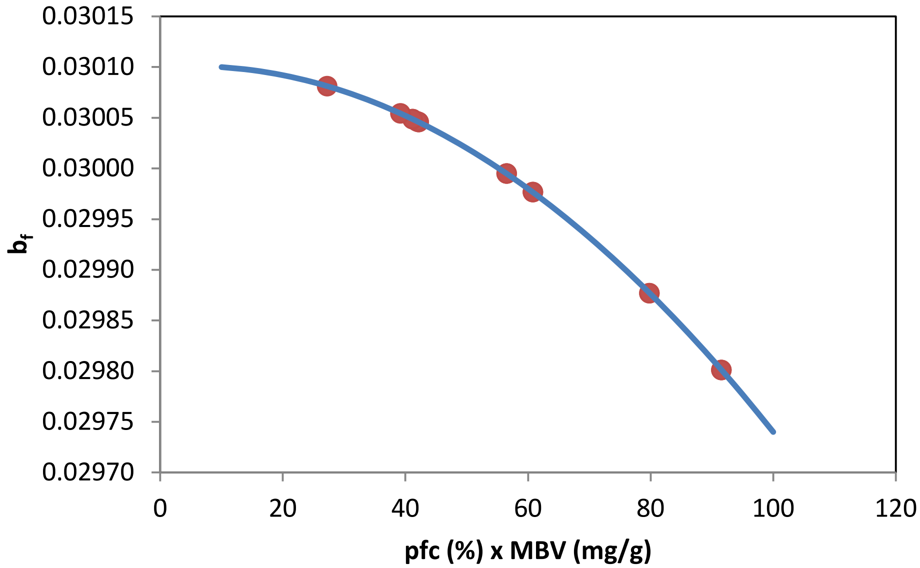

Figure 6.26. A Correlation Is Shown between b_f and ($pfc\ x\ MBV$).

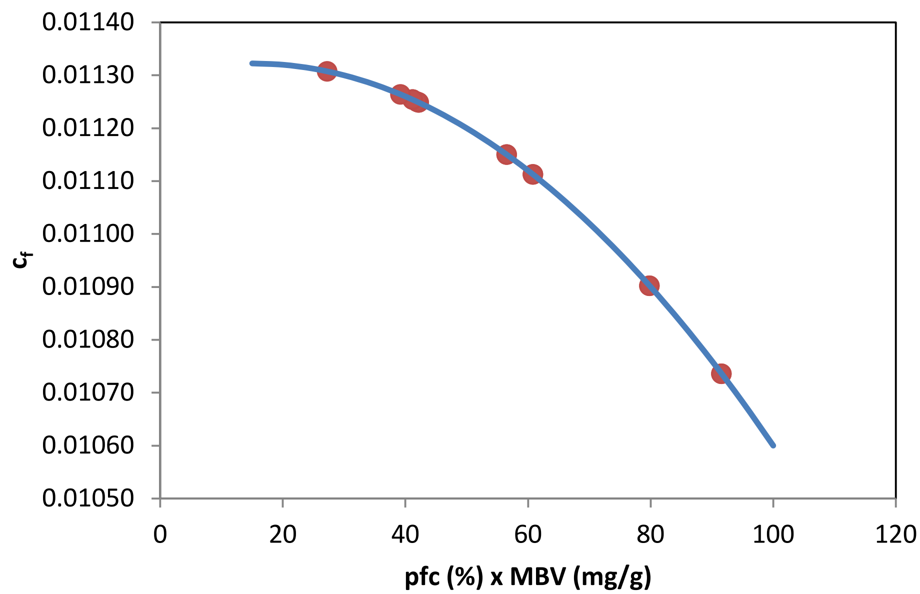

Figure 6.27. A Correlation Is Shown between c_f and ($pfc\ x\ MBV$).

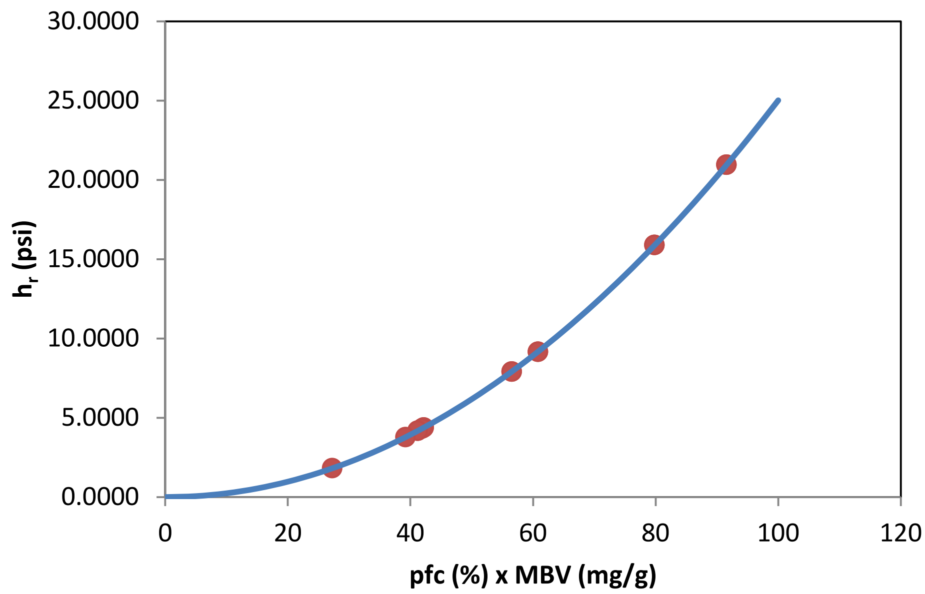

Figure 6.28. A Correlation Is Shown between h_r and ($pfc\ x\ MBV$).

With the methylene blue value greater than 7.00 mg/g, the equations for a_f, b_f, c_f, and h_r are given in Equations 6.25 through 6.28. Each parameter is presented in Figures 6.29 to 6.32.

$$a_f = 3.9649x(MBV)^{0.0054} \tag{6.25}$$

$$b_f = 0.0683x(MBV)^{-0.102} \tag{6.26}$$

$$c_f = 0.0095x(MBV)^{-0.461} \tag{6.27}$$

$$h_r = 2.9833x(MBV)^2 - 50.845x(MBV) + 254.75 \tag{6.28}$$

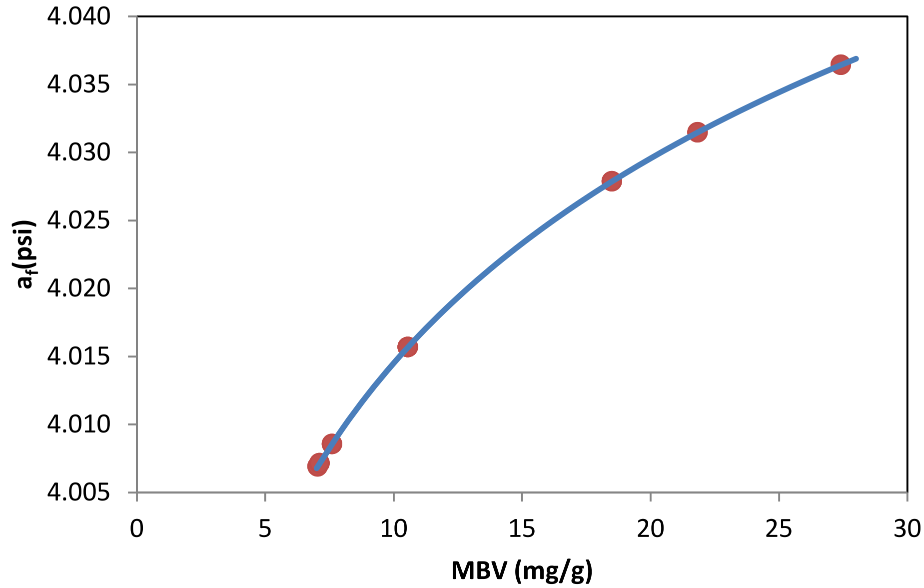

Figure 6.29. A Correlation Is Shown for a_f and MBV.

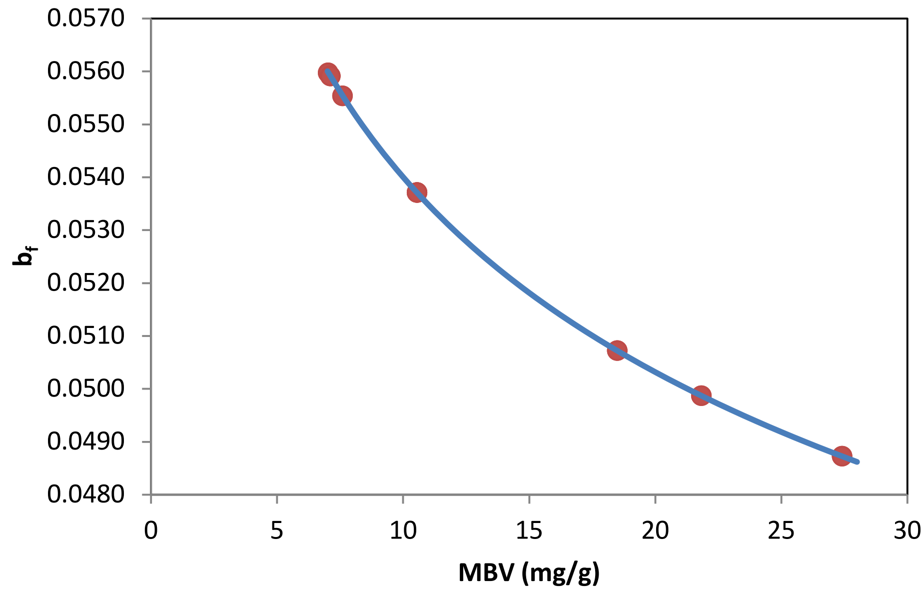

Figure 6.30. A Correlation Is Shown for b_f and MBV.

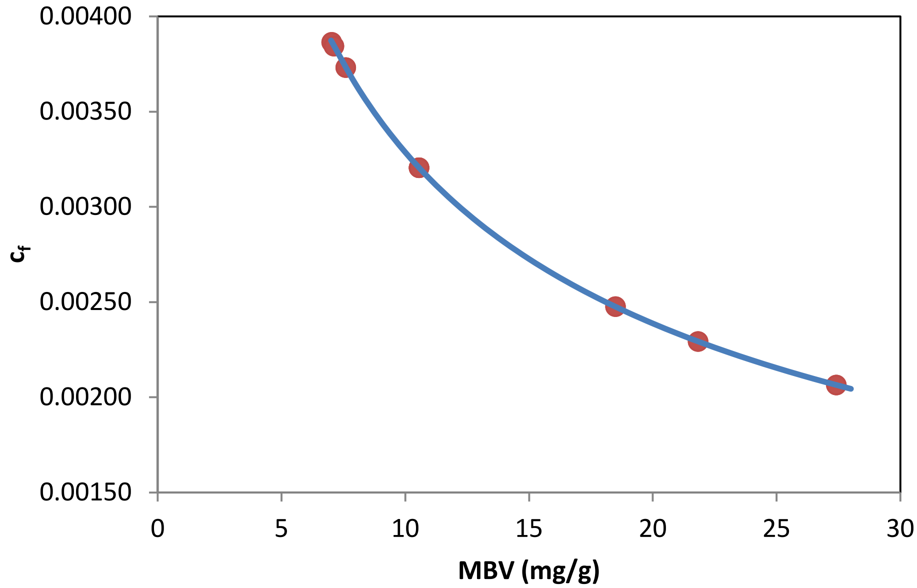

Figure 6.31. A Correlation Is Shown for c_f and MBV.

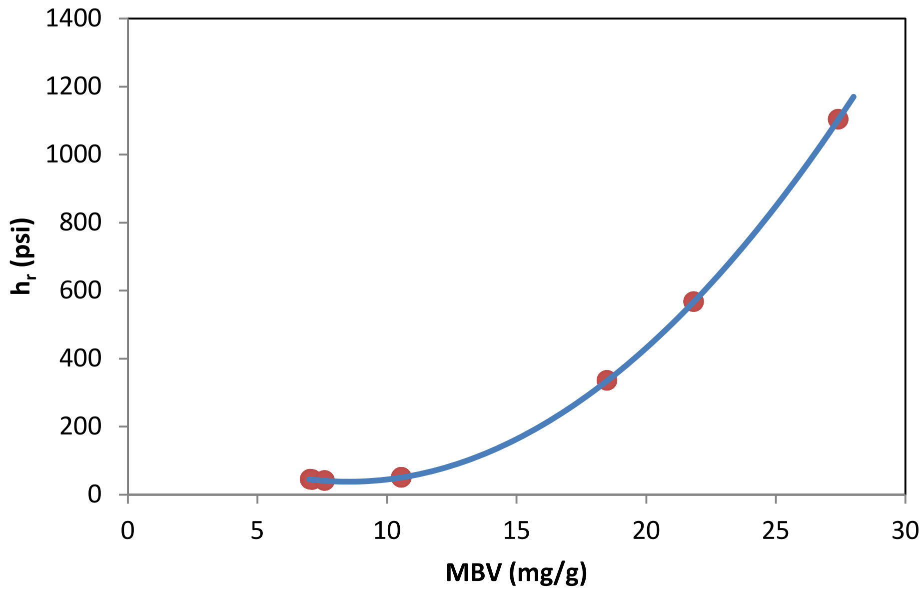

Figure 6.32. A Correlation Is Shown for h_r and MBV.

An example of an SDCC that is generated with these four coefficients is shown for an E-06 1-13 sample in Figure 6.33. The separately measured values of suction and dielectric constant for this quarry are also shown on this graph.

The original data from which the relationships of a_f, b_f, c_f, and h_r with MBV and pfc are presented in Appendix F.

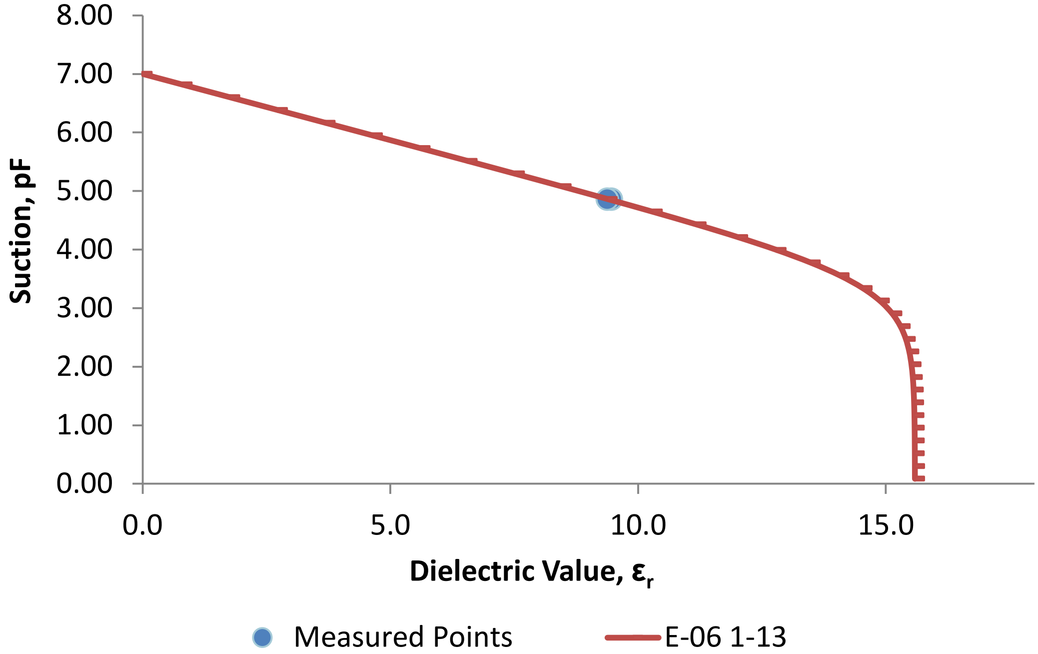

Figure 6.33. Suction Dielectric Characteristic Curve (SDCC) for the E-06 1-13 Quarry.

Use of Aggregate Characteristic Tests in Construction

Percent Fines Content versus MBV Characteristics for Quarries in Texas

Methylene blue value and percent fines content are integrated to determine the percent fines in an aggregate mixture. The generated method showed a unique relation for each of the nine quarries throughout Texas. The correlation depends on the clay mineralogy and each pit shows a unique correlation. Curves for the seven quarries named E-02, E-03, E-05, E-04, E-06, E-09, and A-42 are given in Figures 6.34 through 6.40. The 90 percent confidence levels are shown for the quarries, and two boundary lines are plotted to show the minimum and maximum accepted values. The confidence level may be used for quality control and quality assurance of the aggregate produced by each quarry.

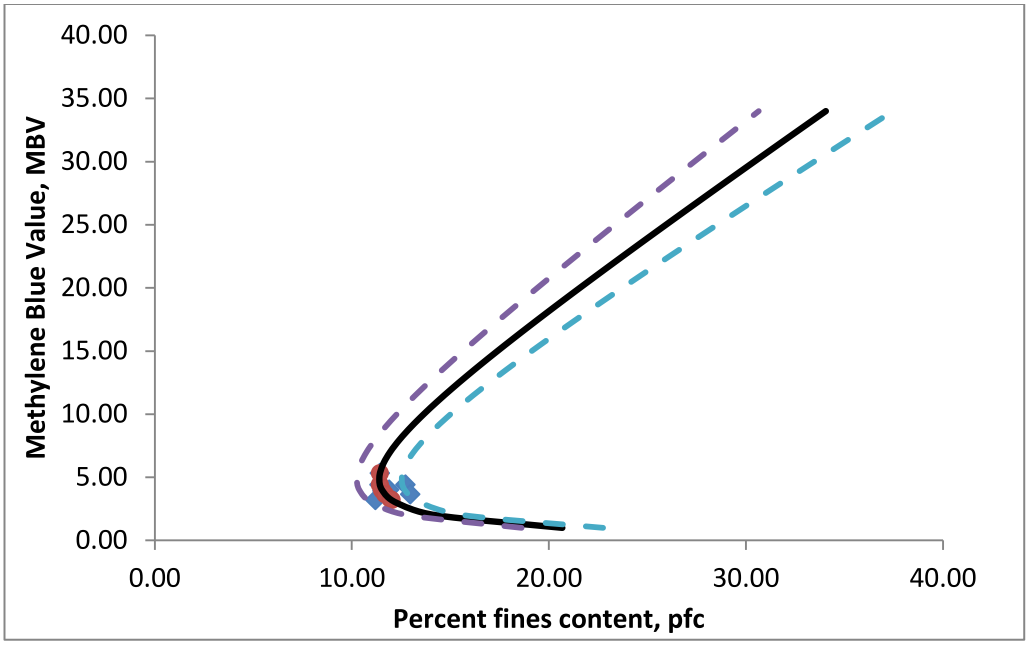

Figure 6.34. Relation between MBV and pfc Is Shown for E-02 Materials in 90 Percent Confidence Level.

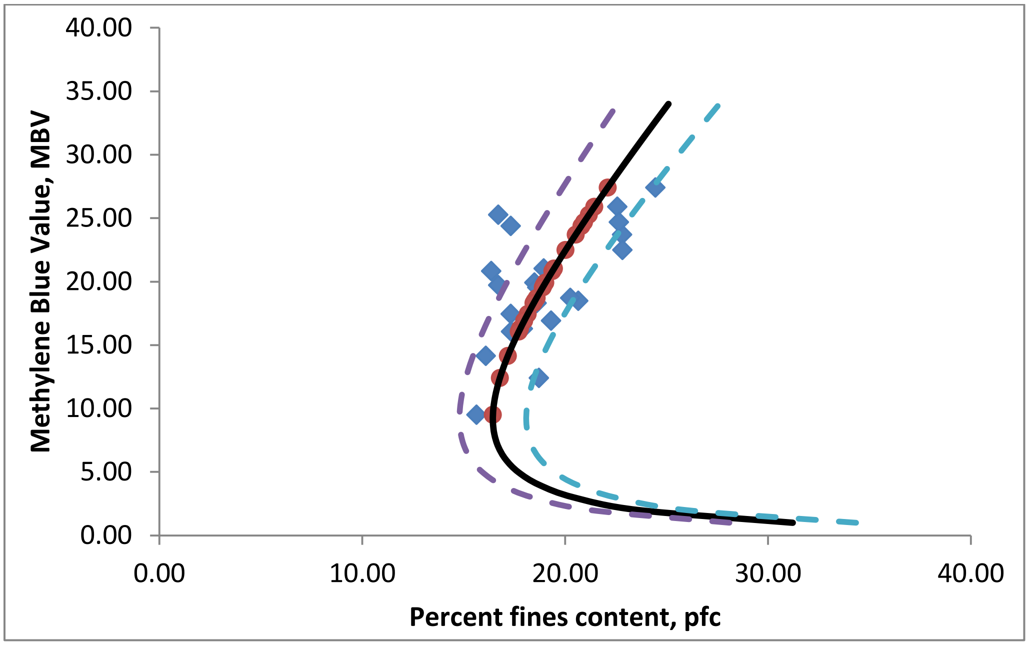

Figure 6.35. Relation between MBV and pfc Is Shown for E-03 Materials in 90 Percent Confidence Level.

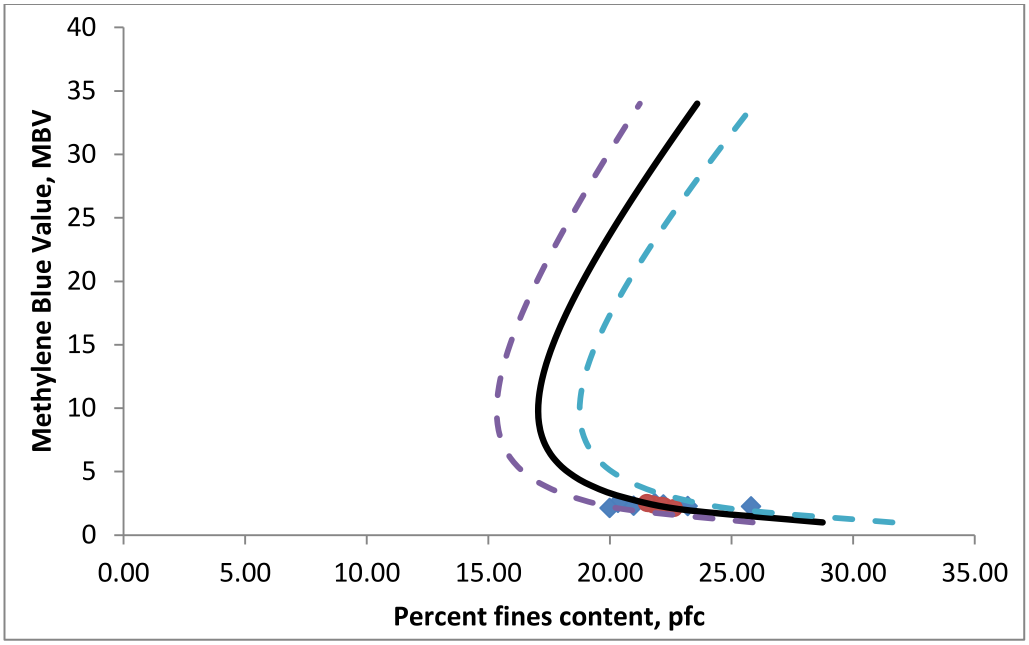

Figure 6.36. Relation between MBV and pfc Is Shown for E-05 Materials in 90 Percent Confidence Level.

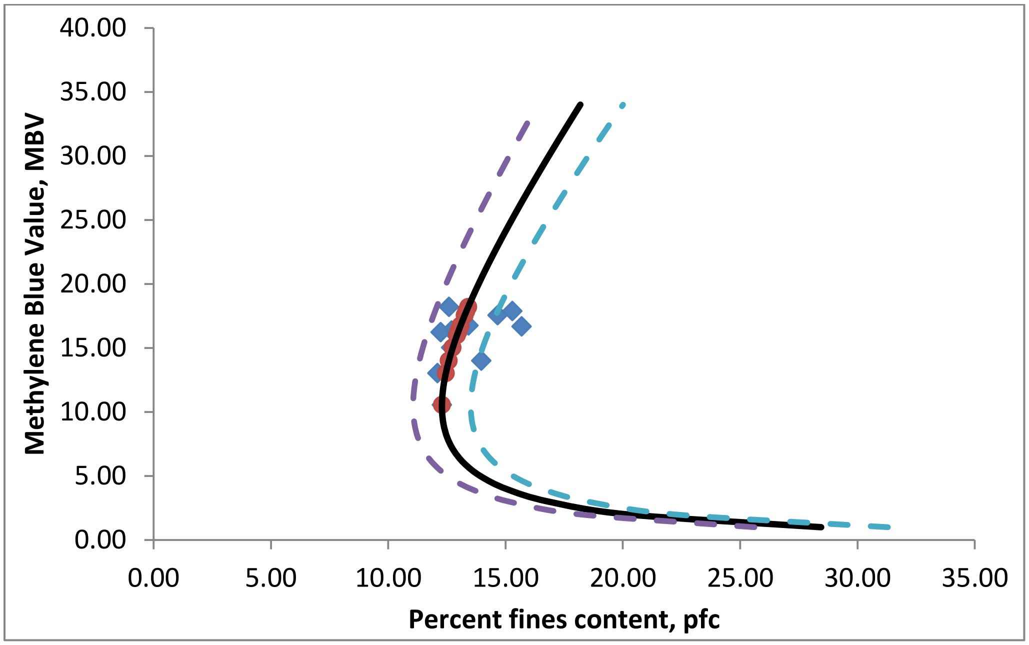

Figure 6.37. Relation between MBV and pfc Is Shown for E-04 Materials in 90 Percent Confidence Level.

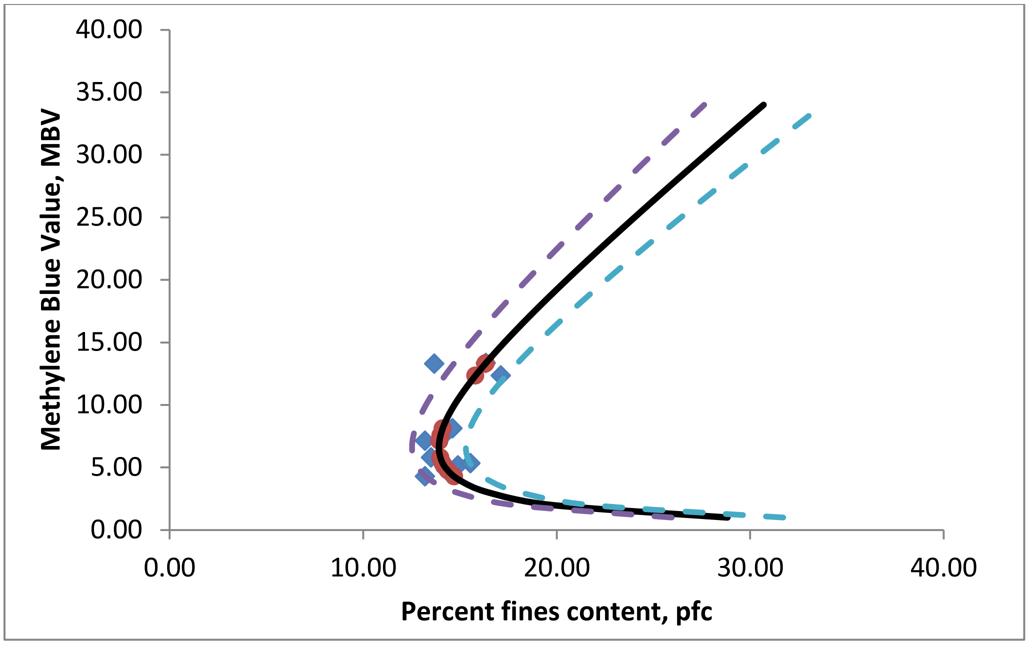

Figure 6.38. Relation between MBV and pfc Is Shown for E-06 Materials in 90 Percent Confidence Level.

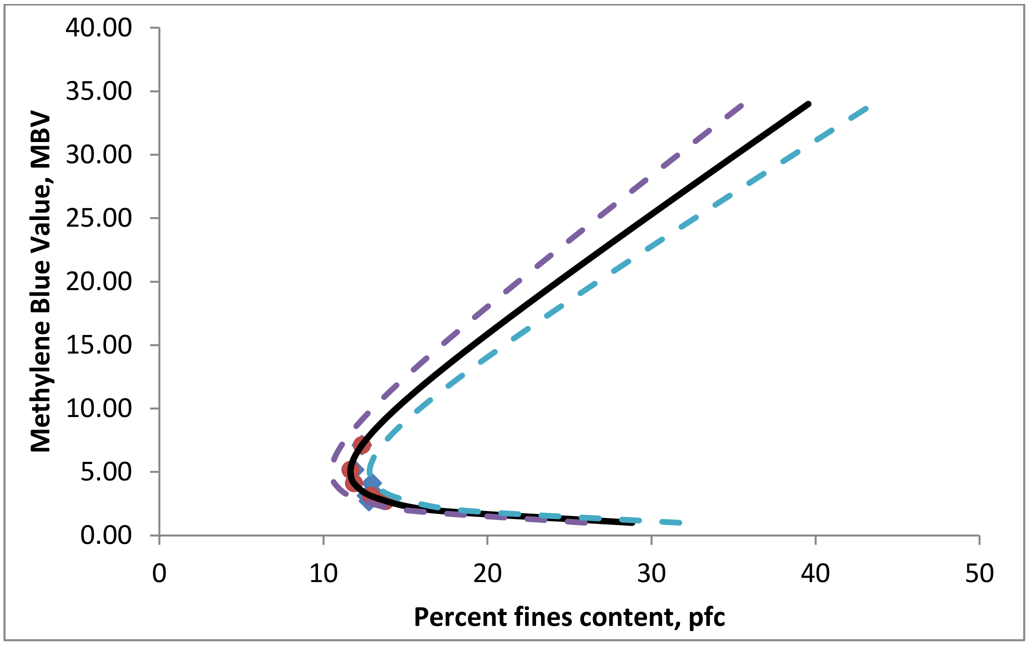

Figure 6.39. Relation between MBV and pfc Is Shown for E-09 Materials in 90 Percent Confidence Level.

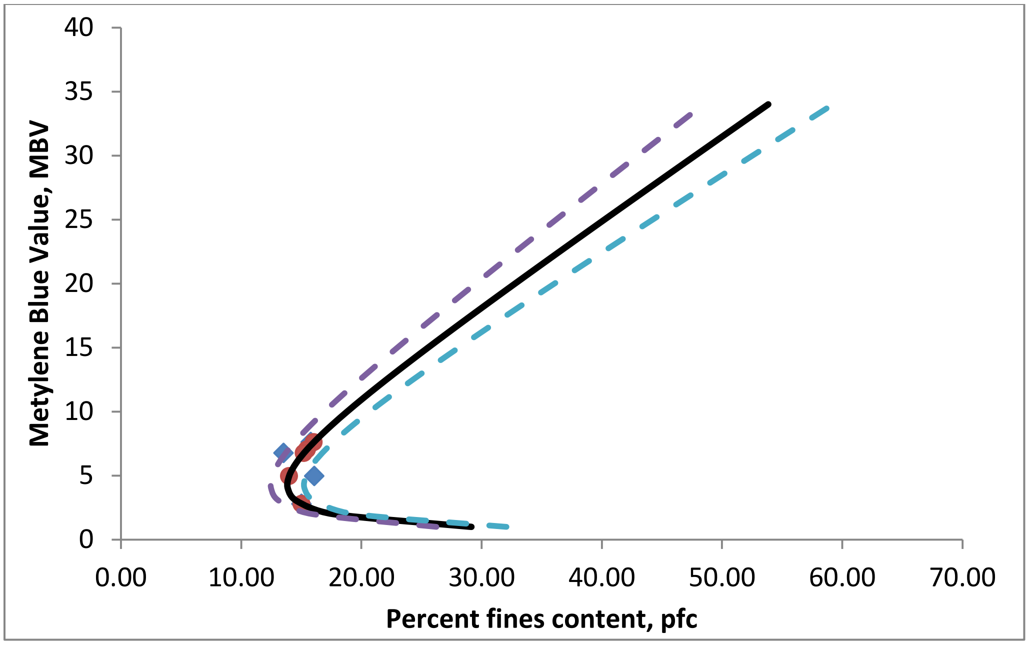

Figure 6.40. Relation between MBV and pfc Is Shown for F-42 Materials in 90 Percent Confidence Level.

Combined Use of MBV and Percometer in Field Measurements

The new methylene blue test is employed to determine pfc values based on the aggregate mix. The four parameters in the SWCC and two sets of four parameters in the SDCC equation are calculated by using the pfc and MBV for the mixture. The SDCC curve represents a suction (pF) for corresponding dielectric values. The SWCC curve provides water content (wc) for a corresponding suction (pF) value. All of these relations allow the suction and water content values for a soil mixture to be estimated. A schematic of this relation is given in Figure 6.41.

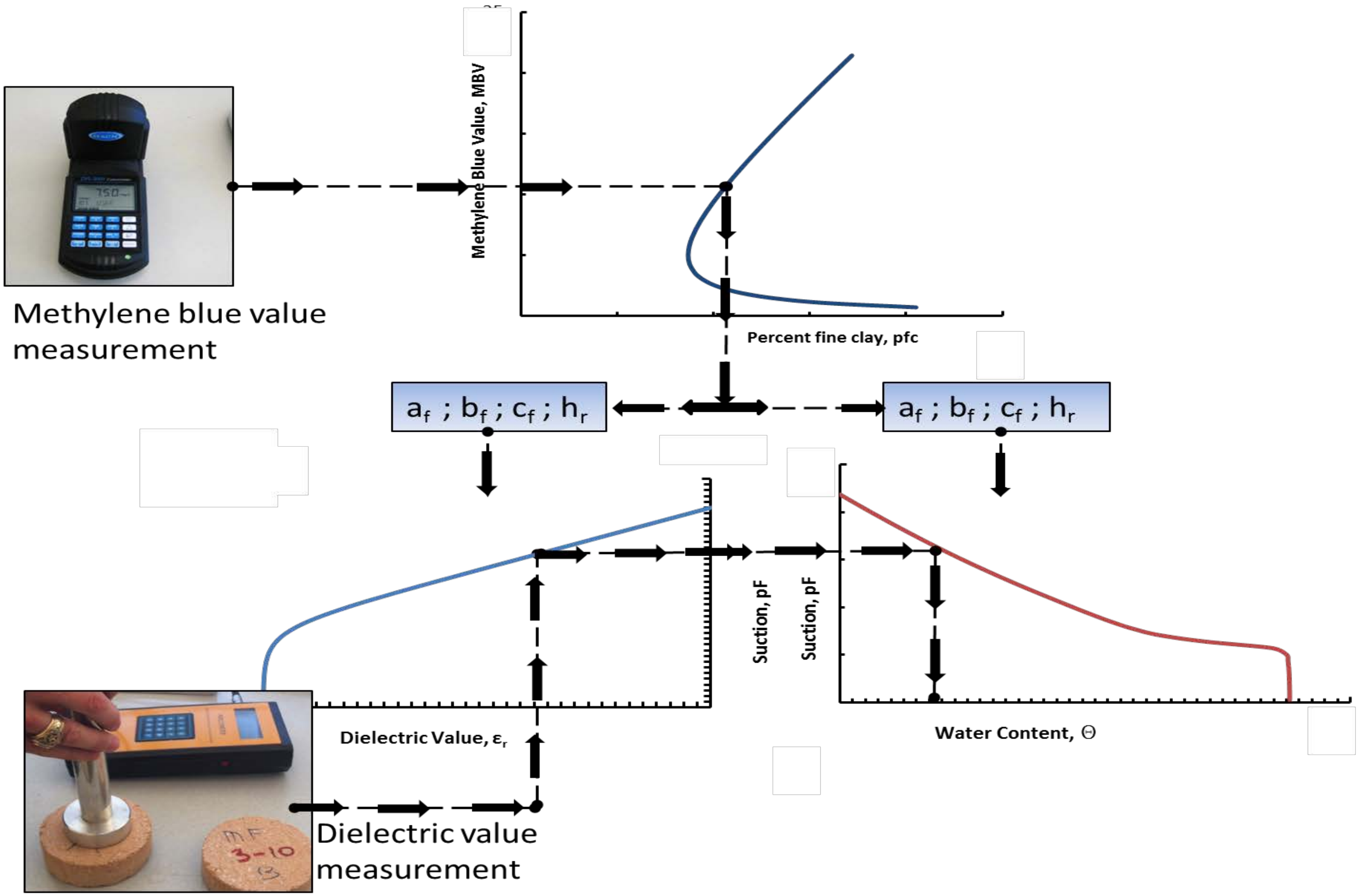

Figure 6.41. Interaction between pfc, Suction (h), SWCC, SDCC and Water Content (wc) Are Given in the Schematic Representation.

Aggregate Characteristics That Can Be Determined in the Field

The new methylene blue test is capable of measuring methylene blue values for various types of base course aggregate quarries. This test method provides a significant relation between the methylene blue value and the percent fines content in an aggregate base course mixture. In addition to this relation the methylene blue test value gives a correlation between methylene blue value and both liquid limit and plasticity index. All of the supporting data are found in Appendix E, Appendix G (plasticity index), Appendix H (liquid limit), and Appendix I (Activity ratio (Ac) and liquid limit activity).

The dielectric value and *pfc* are correlated to generate a unique soil dielectric characteristic curve. Additionally this dielectric value is used to estimate the aggregate suction values from a measured dielectric constant. All of these base course data (i.e., methylene blue value, percent fines clay content, suction and water content) are used in a vertical and horizontal base course modulus model. A schematic diagram of all the sequential connections between these experimental output data and the models is given in Figure 6.42.

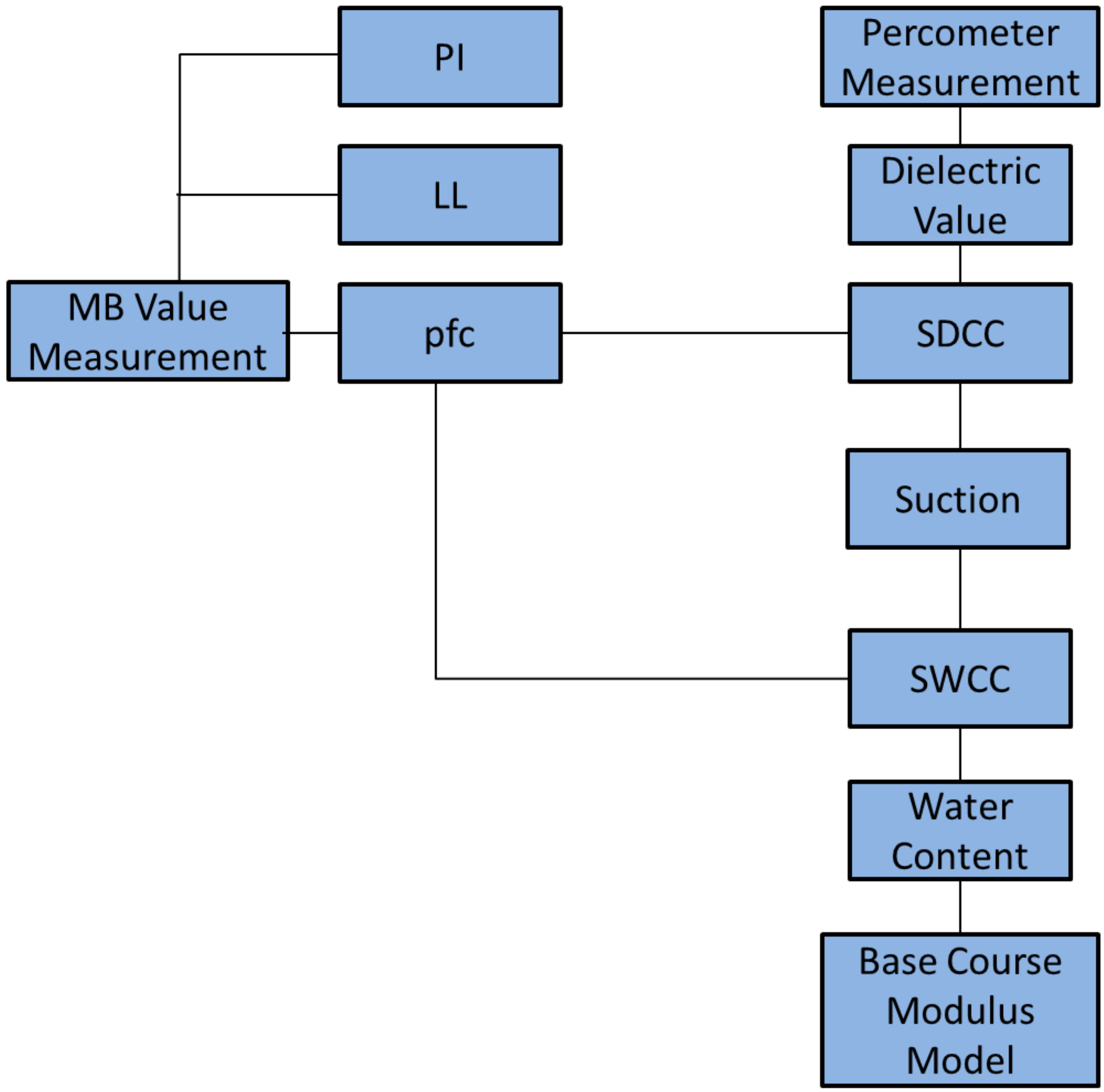

Figure 6.42. An Order of Data Flow Connections with the Models Demonstrates the Way of Determining the Aggregate Characteristics in the Field.

Aggregate Imaging System (AIMS) Test

Test Procedure

The Aggregate Image Measurement System (AIMS) is a computer integrated laboratory test device to analyze aggregate properties. The AIMS device measure aggregate shape, angularity, and texture properties, which affect the engineering properties of the unbound aggregate layers. Thus the AIMS test results provide material properties to design a base course layer through the aggregate characteristics of shape, angularity, and texture. The AIMS device is system which is comprised of a computer, image acquisition hardware, a high-resolution camera, microscope, aggregate tray and lighting system. The AIMS integrated hardware system is shown in Figure 6.43.

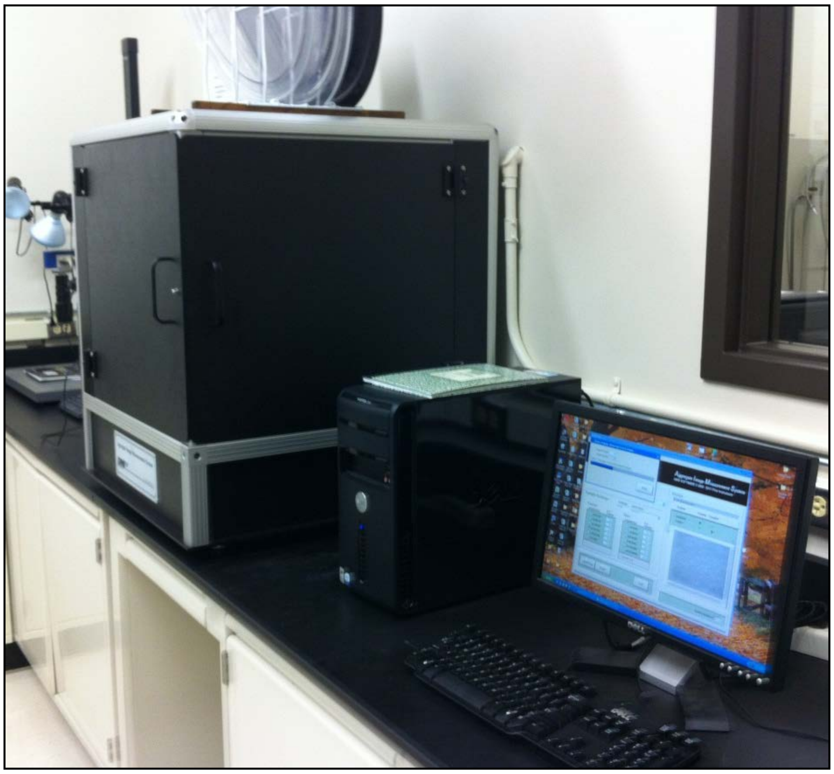

Figure 6.43. AIMS Device with the Integrated Hardware System Is Shown.

The AIMS is capable of analyzing the aggregate materials in the size range from 0.075 mm to 37.5 mm. The aggregates with a size larger than 4.75mm are considered coarse aggregates. The aggregates with a size smaller than 4.75mm are considered fine aggregates.

The AIMS test is conducted on base course aggregate from various quarries throughout Texas. The coarse aggregates analysis requires aggregates to be washed and separated based on three sieve sizes. The course aggregates are separated by retaining materials on *No: 1/2* in. *No: 3/8* in and *No: 4* sieve sizes. The washed and dried course aggregates are placed in separate trays. The tray rotates in the AIMS device to analyze each aggregate under the back lighting and with the camera. All of the aggregates on the tray are scanned and each aggregate image is captured to perform a shape, texture and angularity analysis. The AIMS software analyzes the aggregate characteristic data and outputs the analysis in MS Excel sheets.

Develop Weibull Distributions of Measured Gradation, Angularity, Shape, and Texture of Each Aggregate Type

Nine (9) different coarse aggregate quarries are tested by using the AIMS device. Three various representative sieve sizes of *1/2* in, *3/8* in and *No. 4* are employed to analyze aggregate geometric characteristics. Angularity, form, and texture are particle geometric characteristics that are fitted to a Weibull distribution. The reason to use Weibull distribution is that it provides a reasonable fit to both particle size and shape properties. The Weibull distribution contains two parameters of shape parameter (a) and scale parameter (l). The Weibull distribution parameters are given for each aggregate quarry in Table 6.7. The detailed Weibull distribution parameters are presented in Appendix J.

Table 6.7. Weibull Distribution Parameters of Angularity Form, Texture, and Gradation.

Sources	Code #	*Gradation*		*Angularity*		*Shape*		*Texture*	
		Shape Parameter (a_G)	Scale Parameter (λ_G)	Shape Parameter (a_A)	Scale Parameter (λ_A)	Shape Parameter (a_S)	Scale Parameter (λ_S)	Shape Parameter (a_T)	Scale Parameter (λ_T)
E-06	2-6	0.6652	9.585	4.76	3327.99	4.44	8.86	2.93	174.63
E-06	1-13	0.7279	10.61	4.76	3327.99	4.44	8.86	2.93	174.63
E-05	61-12	0.8761	11.28	3.79	3291.5	3.96	7.75	2.12	165.78
E-02	1-3-4	0.8663	14.57	5.09	3113.11	4.11	8.56	2.51	194.07
E-02	2-3-2	0.8555	15.67	5.09	3113.11	4.11	8.56	2.51	194.07
E-04	2-6	0.9297	12.65	5.1	3072.87	3.65	8.03	1.96	171.51
E-04	1-3	0.9278	10.32	5.1	3072.87	3.65	8.03	1.96	171.51
E-07	68-2-6	0.852	13.07	4.53	3210.45	4.63	7.97	1.86	138.83
E-07	69-1-14	0.8467	12.69	4.53	3210.45	4.63	7.97	1.86	138.83
E-08	235-1-12	0.884	10.81	4.99	3342.81	3.63	8.72	1.48	205.58
E-08	2-1-6	1.016	13.14	4.99	3342.81	3.63	8.72	1.48	205.58
E-01	1-3-2-3	0.8783	8.31	4.38	3336.93	4.66	8.19	3.16	287.58
E-03	6-10-3	0.747	9.859	3.25	3633.44	4.27	8.15	2.87	253.88
E-05		0.717	10.36	3.79	3291.5	3.96	7.75	2.12	165.78
E-09	1-14	0.9048	11.33	3.75	3228.12	4.48	7.6	1.75	205.47
E-01D		1.018	11.02	4.38	3336.93	4.66	8.19	3.16	287.58

Diffusivity of Aggregate Base Courses in Texas

Test Procedure

The soil diffusion rate for each quarry was determined based on the water weight loss test data. The test results have shown that there is a relation between percent fines content and diffusion rate. To determine soil diffusion two pieces of soil sample are compacted at the optimum moisture content and placed in a 100 percent relative humidity environment room at 23°C temperature and daily moisture loss was recorded.

The aggregate samples are compacted as two pieces for the diffusion test. The portion of aggregates smaller than Sieve *No. 4* is used to prepare an aggregate mixture. The mixture is compacted at optimum moisture content by using the standard compaction method in ASTM D 698. The compacted sample is a cylinder with a radius of 2 in. and height of 1.5 in. Two cylindrical soil samples are obtained by compaction and their shapes are shown in Figure 6.44.

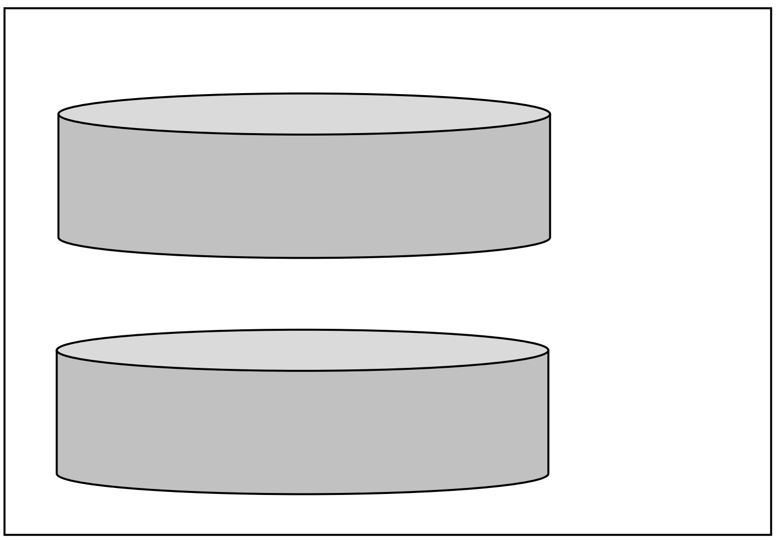

Figure 6.44. The Schematic Shows the Two Pieces Compacted Soil Samples.

The environment room provides a stable air condition for soil samples to lose moisture under uniform conditions. The moisture decreases as the soil samples are monitored daily and the sample moisture contents are calculated. The samples are kept in the environmental room to reach moisture content of 2 percent. Two soil samples placed in the environment room are shown in Figure 6.45. It is observed that the sample surface must be shielded from direct contact with liquid water drops while the samples are staying in the environment room.

Figure 6.45. Two Compacted Soil Samples Are Placed in an Environment Room.

The daily monitored data was evaluated to determine the diffusion rate. A mathematical function was derived from using Equation 6.29. The final form of the diffusion equation is given in Equation 6.31.

$$W(t) = Wo(1 - e^{\frac{-12Dt}{d^2}}) \tag{6.29}$$

$$\frac{dW(t)}{dt} = -Woe^{\frac{-12Dt}{d^2}} - \frac{12Dt}{d^2} = \frac{12Wo}{d^2}e^{\frac{-12Dt}{d^2}} \tag{6.30}$$

$$\ln\left[\frac{dW(t)}{dt}\right] = \ln\left(\frac{12WoD}{d^2}\right) - \left(\frac{12D}{d^2}\right)t \tag{6.31}$$

where

D: Diffusion rate of soil in (cm^2/sec)

t: passed time between two weight measurement in seconds

W_o: Maximum weight lost in grams

W(t): Weight of sample with time as water is lost in grams

d: the thickness of the sample, cn

Test Results

The diffusivity value of each quarry was determined for selected samples during the three months production period. The percent fines content was also determined by using the Horiba particle size distribution analyzer device for the selected soil samples. The diffusion test results and the corresponding pfc results are tabulated in Table 6.8.

Table 6.8. Tabulated Diffusivity and the Corresponding pfc Values Are Given for Each Quarry.

Source Name	Bucket Code (Number) and Sample Name (Letter)	Diffusivity D (cm^2/sec)	pfc %
E-03	4-3-10 A	1.8777E-06	16.36
E-03	4-3-10 B	2.7257E-06	16.36
E-03	6-10-1 A	6.6559E-07	24.45
E-03	6-10-1 B	8.8873E-07	24.45
E-03	6-10-3 A	1.9972E-06	20.26
E-03	6-10-3 B	1.5147E-06	20.26
E-04	2-6 A	3.4490E-06	12.71
E-04	2-6 B	2.7810E-06	12.71
E-06	1-13 A	2.6279E-06	14.21
E-06	1-13 B	2.5869E-06	14.21
E-07	68-2-6 A	2.4181E-06	15.81
E-07	68-2-6 B	2.8264E-06	15.81
E-07	69-1-14 A	2.5811E-06	15.48
E-07	69-1-14 B	2.1952E-06	15.48
E-06	2-6 A	3.3075E-06	12.28
E-06	2-6 B	2.7810E-06	12.28
E-06	3-10 A	3.1727E-06	13.21
E-06	3-10 B	3.1228E-06	13.21
E-09	1-14 A	3.3075E-06	13.25
E-09	1-14 B	3.3362E-06	13.25
E-01	1-3-2-3 A	2.8440E-06*	16.1
E-01	1-3-2-3 B	2.4539E-06*	16.1
E-08	2-1-6 A	1.5003E-06	15.03
E-08	2-1-6 B	1.5800E-06	15.03
E-08	235-1-12 A	2.9712E-06*	15.55
E-08	235-1-12 B	3.0604E-06*	15.55
E-02	1-3-4 A	3.0696E-06	11.43
E-02	1-3-4 B	2.9957E-06	11.43
E-02	2-3-2 A	2.4649E-06	12.97
E-02	2-3-2 B	2.1689E-06	12.97
E-02	3-1-2 A	2.4889E-06	11.96
E-02	3-1-2 B	2.6616E-06	11.96
E-05	61-12 A	8.4818E-07	19.9
E-05	61-12 B	1.0301E-06	19.9
** Additional weight was lost by friable particles*			

Diffusivity Dependence on Percent Fines Content

The diffusivity values and the percent fines content were plotted together, and it showed that there is a relation between the two variables. The soil samples that are used in the diffusivity tests were separated into two groups based on the MBV values. The percent fines content in the two different MBV groups were compiled to find a correlation with the diffusivity. The graph of the two relationships is given in Figure 6.46.

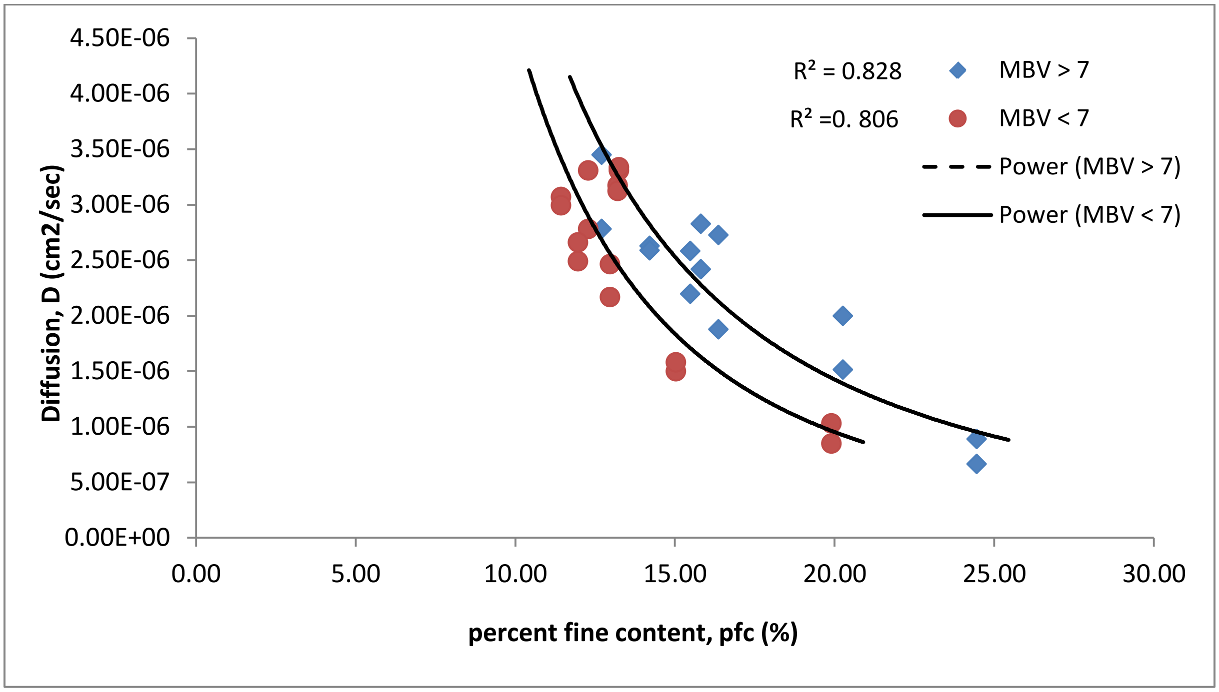

Figure 6.46. Two Empirical Relations between Percent Fine Clay and Diffusivity for Both Low and High Plastic Samples.

The test results illustrate the trends between the diffusivity values and the percent fines content and these relations are formulated as power equations. Thus the results were divided into two groups as the MBV is greater than 7 and smaller than 7. The forms of the diffusion equations based on the MBV levels are given in Equations 6.32 and 6.33.

$$D = 5.63E^{-0.4}(pfc)^{-2.00} \text{ for MBV greater than 7} \quad (6.32)$$

$$D = 8.88E^{-0.4}(pfc)^{-2.28} \text{ for MBV smaller than 7} \quad (6.33)$$

MODELING OF PERFORMANCE TESTING RESULTS

There are four parts to this section. The first describes the models of the resilient moduli that have been measured in this study; the second presents the models of both the VESYS and the MEPDG permanent deformation properties; the third shows the models of the compressive strength that have been measured at different confining stress level in this study; and the fourth describes how the indicators tests that are needed in these models are measured in the field.

Models of Resilient Modulus

The vertical moduli of every aggregate specimen that were measured in the triaxial test under different load levels were further modeled using a mechanistic model as shown in Equation 6.34:

$$E_y = k_1 P_a \left[\frac{I_1 - 3\theta f \left(h_m + \beta \frac{I_1}{3} + \alpha \tau_{oct} \right)}{P_a} \right]^{k_2} \left(\frac{\tau_{oct}}{P_a} \right)^{k_3} \tag{6.34}$$

where I_1 = the first invariant of the stress tensor; P_a = the atmospheric pressure; θ = the volumetric water content; h_m = the initial matric suction in the aggregate matrix; f = saturation factor, $1 \le f \le \frac{1}{\theta}$; τ_{oct} = the octahedral shear stress; α and β = pore water pressure parameters; and k_1 , k_2 and k_3 = material parameters that are dependent on material properties dry unit weight, water content, Methylene Blue Value, pfc, and aggregate gradation, angularity, shape, and texture.

During the modeling process, θ and f were firstly calculated based on the dry density (γ_d) and water content (ω). Then the Solver Function in the software Excel was used to search for h_m, α, β and k values while minimizing the fitting error. The modeling results show that the average R-squared value of all data sets was 0.943, which demonstrates the goodness of the model fit. Table 6.9 lists the determined model parameters and the R-squared values of the mechanistic model for every aggregate sample. The initial matric suction of the aggregate specimen was always negative since the aggregate system was unsaturated when it was compacted. For the same aggregate type with the same gradation, a higher water content was usually associated with a less negative initial matric suction. For example, when the E-09-1-14 aggregate specimen was at the optimum water content of 7.9 percent, the initial matric suction was −155.0 kPa (3.19 pF). When the water content of the same aggregate was increased to 9.4 percent, the initial matric suction was less negative and was equal to −138.1 kPa (3.14 pF). When its water content was decreased to 6.4 percent, the initial matric suction was more negative, which was −794.0 kPa (3.90 pF).

Table 6.9. Mechanistic Model Parameters and R-Squared Values.

Aggregate Source	Dry Density (kg/m³)	Water Content (%)	h_m (kPa)	β	α	k_1	k_2	k_3	R^2
E-06-2-6	2409	5.6	-115.47	0.944	-0.003	0.150	7.855	0.086	0.785
E-06-1-13	2414	5.4	-120.83	0.923	0.032	0.207	7.312	0.260	0.925
E-05-61-12	2267	6	-199.19	1.478	0.026	0.562	6.783	0.296	0.982
E-02-1-3-4	2196	7.1	-135.40	1.826	0.095	0.542	10.296	0.204	0.977
E-02-2-3-2	2183	7.2	-288.08	2.073	0.321	0.393	6.624	0.412	0.997
E-04-2-6	2276	6	-285.17	0.921	0.153	0.002	7.285	0.377	0.906
E-04-1-3	2246	6.2	-223.34	1.596	0.313	0.618	6.980	0.499	0.972
E-07-68-2-6	2233	7.1	-123.88	0.795	0.363	0.098	8.584	1.279	0.966
E-07-69-1-14	2206	7.4	-132.29	0.792	0.349	0.282	7.475	0.747	0.981
E-08-235-1-12	2335	6.5	-162.78	0.787	0.245	0.149	6.572	0.755	0.988
E-08-2-1-6	2249	6.5	-147.50	1.097	0.104	0.367	7.375	0.379	0.985
E-01-1-3-2-3	2291	5.8	-134	1.094	0.009	0.339	7.389	0.101	0.936
E-03-6-10-3	2092	7.7	-1626.86	5.558	0.056	0.935	3.721	0.108	0.768
E-05	2254	6.4	-133.46	0.985	0.138	0.315	7.415	0.376	0.988
	2220	7.9	-124.26	0.879	0.232	0.211	8.005	0.990	0.865
	2230	4.9	-820.15	8.746	0.248	0.027	12.142	0.415	0.991
E-09-1-14	2185	7.9	-155.02	0.973	0.082	0.220	6.758	0.339	0.982
	2110	9.4	-138.09	0.970	0.145	0.220	7.583	0.541	0.983
	2120	6.4	-793.96	6.661	0.371	0.026	9.868	0.206	0.916
E-01	2262	6.3	-139.81	1.108	0.034	0.360	7.416	0.195	0.969
	2240	7.8	-126.63	0.826	0.271	0.385	7.168	1.009	0.974
	2160	4.8	-563.91	6.049	0.380	0.129	11.353	-1.133	0.887

The initial matric suction term is essential to the vertical modulus, as modeled in Equation 6.34. When the pore water pressure component ($3\theta f\left(h_m+\beta\frac{I_1}{3}+\alpha\tau_{oct}\right)$) was excluded from the models, the R-squared values decreased significantly and the modulus was overestimated. The overestimation of the modulus is illustrated in Figure 6.47 in terms of the increase of the hardening component, $\left[\dfrac{I_1-3\theta f\left(h_m+\beta\frac{I_1}{3}+\alpha\tau_{oct}\right)}{P_a}\right]^{k_2}$, with depth within a 10 in thick base course.

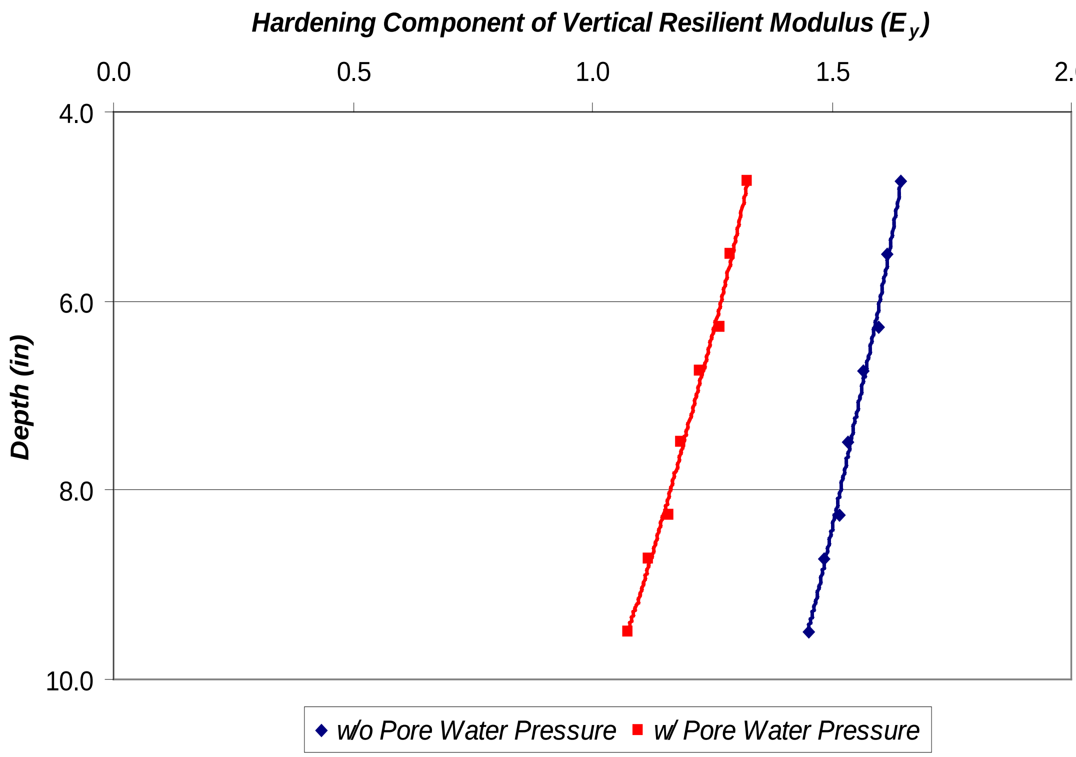

Figure 6.47. Hardening Component of Vertical Modulus (Ashtiani et al. 2010).

As shown in Figure 6.47, when addressing the effect of pore water pressure, the predicted hardening component is significantly smaller than that without the pore water pressure component. A smaller hardening component indicates a lower value of the predicted vertical modulus. In other words, not considering the pore water pressure overestimates the vertical modulus, which is not on the safe side in pavement design. The pore water pressure is important in determining the stiffness of the aggregate system and varies with the stress level that is applied by passing traffic to the aggregate system. When the compaction of an unbound aggregate base has just been completed and is tested for stiffness in the field, the stress within the aggregate base is due to the weight of the base course itself and to the tension in the pore water. The modulus of the aggregate base varies with the pore water pressure in the aggregate system. Figure 6.48 shows the vertical moduli of the Texas limestone base without external load at combinations of different levels of pore water pressure and k_2 values. At a specific k_2 value, the vertical modulus of the aggregate base decreases as the pore water pressure increases (or becomes less negative). If traffic load is applied to the aggregate base, the pore water pressure may build up to a positive (or compressive) level. As a result, the vertical modulus of the aggregate base will decrease as the pore water pressure increases. Figure 6.49 illustrates the vertical moduli of the same Texas limestone base under different levels of tire pressure. These are the instantaneous vertical moduli of the aggregate base when the tire is passing directly over the base. After the traffic load is removed, the modulus of the base will recover at different rates that depend on the percentage and type of fines in the aggregate system. The percent and water retention of the fines in the base course is reliably indicated by the Methylene Blue Value.

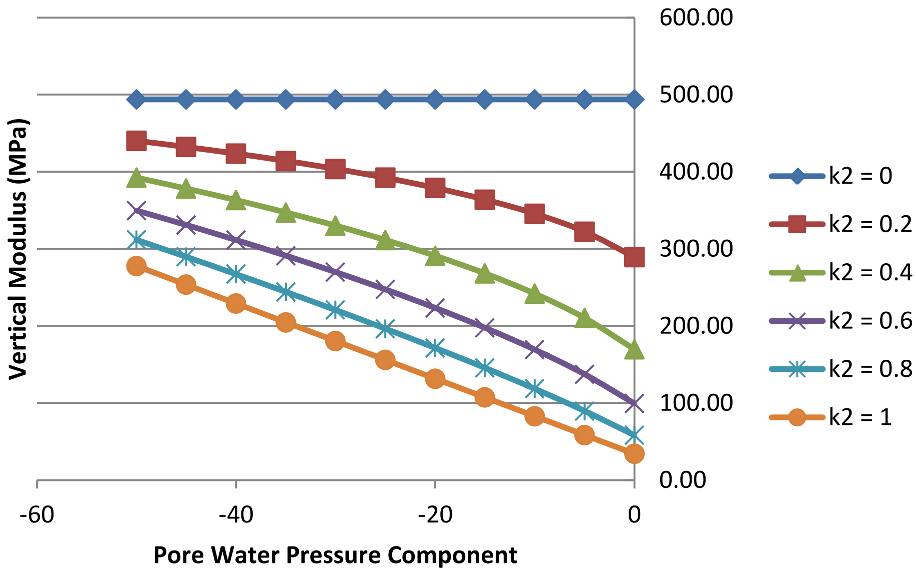

Figure 6.48. Effect of Pore Water Pressure in Aggregate Base.

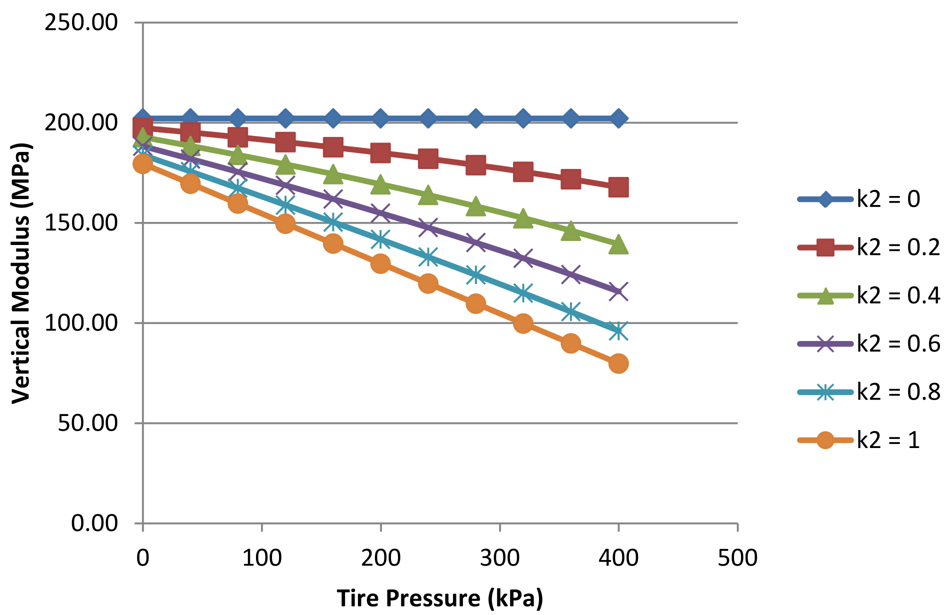

Figure 6.49. Vertical Modulus of Texas Limestone Base under Different Tire Pressure.

The predicted k values are material properties that depend on the properties of aggregate particles and aggregate matrix. Statistical analysis was performed to investigate the correlation between the k values and the aggregate properties, such as the dry density, water content, Methylene Blue Value (MBV), pfc, and aggregate gradation, angularity, shape and texture in terms of Weibull distribution parameters. Table 6.10 shows the results of the statistical analysis, in which properties with a check mark prove to be statistically significant in their correlation with the *k* values at a 95 percent confidence level. Equations 6.35 through 6.37 present the statistical models of k_1, k_2 and k_3.

$$k_1 = 28.458 - 0.34a_s + 0.225a_T - 3.53\ln\gamma_d + 0.012MBV \tag{6.35}$$

$$k_2 = 10.503 - 0.325\omega - 0.110MBV + 1.803a_A + 1.213a_S - 1.633\lambda_S \tag{6.36}$$

$$k_3 = -3.812 - 0.041MBV - 2.539a_G + 1.855a_A + 0.005\lambda_A - 2.318\lambda_S \tag{6.37}$$

Table 6.10. Correlation between Aggregate Properties and k Values.

Aggregate Property		k Values		
		k_1	k_2	k_3
γ_d (Dry Density)		√		
ω (Water Content)			√	
MBV		√	√	√
pfc				
Gradation	a_G			√
	λ_G			
Angularity	a_A		√	√
	λ_A		√	√
Shape	a_S	√	√	
	λ_S		√	√
Texture	a_T	√		
	λ_T			

Permanent Deformation Properties of Base Courses

The data were analyzed to determine two sets of permanent deformation properties of the base course: the VESYS properties and the MEPDG properties.

Models of the VESYS Permanent Deformation Properties

The μ and α properties of the base courses that were modeled by regression analysis to determine which of the indicator tests can reliably predict these properties. The μ-value is an estimate of the permanent strain that will develop in the base course on the first load application. A larger value of the μ-value denotes a base course that is more prone to permanent deformation. The equation that predicts it is in Equation (6.38):

$$\ln\mu = -247.466 + 33.533\ln\gamma_d - 0.008\lambda_A + 5.258\ln\omega + 0.194\,pfc \tag{6.38}$$

The α-value is an inverse measure of the rate at which permanent deformation develops in the base course. A larger value of the α-value means a slower rate of development of permanent deformation development in the base course. The equation that predicts it is in Equation (6.39):

$$\ln\alpha = -25.136 + 3.594\ln\gamma_d - 0.001\lambda_A + 0.473a_G - 0.170a_A + 0.100a_S \tag{6.39}$$

Models of the MEPDG Permanent Deformation Properties

The three MEPDG properties are the ε_0 , ρ , and β . The first of these, ε_0 , is the maximum permanent strain that will develop in the base course. The second symbol, ρ , is a measure of how many load applications that will cause 36.8% of this strain level, and the third symbol, β , is an inverse measure of the initial rate of rise of the permanent deformation. The equation for ε_0 is in Equation (6.40):

$$\ln\varepsilon_0 = -13.80 + 0.194pfc - 0.016\lambda_T + 1.579a_A + 4.317\ln\omega_V \tag{6.40}$$

A larger ρ -value indicates a longer service life under traffic. The equation for the ρ-value is in Equation (6.41):

$$\ln\rho = 33.072 - 3.348\ln\gamma_d - 0.795a_G + 0.026pfc \tag{6.41}$$

The β -value was practically constant for all of the base courses that were tested. A very good value of the β-value is its mean as is given in Equation (6.42):

$$\beta = 0.304 \tag{6.42}$$

The indicators of these permanent deformation properties are a mixture of those that can only be measured in the laboratory and others that can also be measured in the field. In the laboratory, the permanent deformation indicators that can be measured are the dry unit weight, the gradation and the Weibull measures of shape, angularity and texture. In the field, the permanent deformation indicators that can be measured, as described in the previous section, Section 6.3, are the Methylene Blue Value, the percent fines content and the water content. Even though the dry unit weight can also be measured in the field, it is not a very sensitive variable in these equations and can be assumed with sufficient accuracy for these purposes from the laboratory compaction curve for a known water content.

Models of Compressive Strength

Triaxial compressive strength test is a standard test used to determine the shearing resistance of base materials, which is documented in Tex-117-E. The axial load with a constant strain was applied on the aggregate matrix specimen under different confining stress levels until it is broken. Then the final axial load value was recorded as compressive strength at each confining stress level, and the Mohr's failure envelope tangent for all the stress circles was drawn.

Appendix K details the derivation of the compressive strength model. The two parameters, c' representing the true cohesion and ϕ' describing the true friction angle, are used to characterize the failure envelope tangent. Table 6.11 shows the results of c' and ϕ' for each kind of material.

Table 6.11. Results of Compressive Strength Model Parameters.

Material Type	c' (kPa)	ϕ' (degree)
E-01-1-3-2-3	5.034	51.718
E-02-1-3-4	10.164	59.842
E-02-2-3-2	13.111	61.521
E-04-1-3	1.734	53.704
E-04-2-6	13.310	57.539
E-05-61-12	19.481	55.807
E-06-1-13	10.509	55.124
E-06-2-6	3.394	54.965
E-07-69-1-14	2.067	51.439
E-07-68-2-6	0.208	51.378
E-08-235-1-12	0.877	54.212
E-09-1-14	25.176	57.011

The calculated c' and ϕ' are also material properties that depend on the properties of aggregate particles and aggregate matrix. The linear regression models were developed to indicate the correlation between the parameters of Mohr's failure envelope tangent and the aggregate properties, such as the dry density, water content, Methylene Blue Value (MBV), percent fine content (pfc), and aggregate gradation, angularity, shape and texture in terms of Weibull distribution parameters. Table 6.12 shows the results of the statistical analysis, in which properties with a check mark proved to be significant variables in the models at a 95 percent confidence level. Equation 6.43 and 6.44 describe the statistical models of c' and ϕ'.

$$c' = -1676.624 - 2.088MBV - 13.260a_A - 0.113\lambda_A + 270.722\ln\gamma_d + 38.778a_G \qquad (6.43)$$

$$\phi' = -2.827 - 0.016MBV - 0.0005\lambda_A - 0.051a_S + 0.763\ln\gamma_d - 0.008pfc \qquad (6.44)$$

Table 6.12. Correlation between Aggregate Properties and α, μ.

Aggregate Property		c'	ϕ'
γ_d (Dry Density)		√	
ω (Water Content)			
MBV		√	√
pfc			√
Gradation	a_G		
	λ_G		
Angularity	a_A	√	
	λ_A	√	√
Shape	a_S		√
	λ_S		
Texture	a_T		
	λ_T		

Field Testing for Performance Properties

Field measurements need to be made rapidly so as not to retard the pace of construction and accurately to provide a realistic expectation of the eventual performance that will be delivered by the recently compacted base course being tested. It is for this reason that for the resilient modulus properties, the field properties that are needed are the percent fines content, the water content, and the suction. These are determined by using the combination of the Methylene Blue Test and a Percometer to measure the dielectric constant of the in-place base course being tested, as is described in detail in the previous section, Section 6.3. The dry unit weight and the measures of aggregate shape and angularity can be measured in the laboratory while in the process of determining the characteristics of the base course from a given source. Although the dry unit weight is one of the variables in the equations for the permanent deformation properties and can be measured in the field, it is not a very sensitive variable and can be estimated accurately enough for these equations from the laboratory compaction curve and the water content.

The permanent deformation properties depend upon a similar mixture of indicators that can only be measured in the laboratory and those that can also be measured rapidly in the field. The needed indicators that can be tested in the field are the percent fines content and water content. As with the resilient modulus laboratory indicators, the dry unit weight, and Weibull gradation, angularity and shape indicators can be determined in the laboratory when determining the characteristics of the base course from a given quarry.

PAVEMENT PERFORMANCE ANALYSIS

The testing and modeling results detailed above were utilized to analyze the sensitivity of pavement performance to the material properties of flexible base. The pavement performance analysis was conducted using the pavement performance prediction models that were recently developed in the Research Project 0-6386 of the Texas Department of Transportation (TxDOT) (Gharaibeh et al. 2010). The newly developed models were calibrated using the extensive pavement condition data in TxDOT's Pavement Management Information System (PMIS). The general model form is shown in Equation 6.45.

$$L_i = \alpha e^{-\left(\frac{A}{Age_i}\right)^{\beta}} \tag{6.45}$$

where L_i = density of individual distress type; Age_i = pavement age since original construction or last maintenance or rehabilitation activity; α = distress rating with 100 being the maximum; and β and A = model coefficients.

In the sensitivity analysis of pavement performance, every aggregate property which was proved to be statistically significant to the aggregate base moduli was varied at three levels to investigate the variation of the aggregate base moduli, which led to variations of the rate of increase of the distress density and thus to widely varying expected lives of the same pavement placed in different climatic zones in Texas. Rutting life, fatigue cracking life and ride quality life models were developed. The following illustrates the rutting life analysis by varying the water content of the E-09-1-14 aggregate. The optimum water content of the E-09-1-14 aggregate was determined to be 7.9 percent, which was increased to 9.4 percent and then was decreased to 6.4 percent. The initial matric suction also changed with the change of the water content.

Pavement Family A presented in the TxDOT Project 0-6386 was chosen for the analysis. This Pavement Family includes the thick ACP (PMIS Pavement Type 4), Intermediate ACP (PMIS Pavement Type 5), and overlaid ACP (PMIS Pavement Type 9) (Gharaibeh et al. 2010). The Pavement Family was analyzed under the high traffic condition in the four climatic zones in Texas (shown in Figure 6.50). Table 6.13 lists the rutting model coefficients of Equation 6.38 for Pavement Family A with preventive maintenance under high traffic in the four climatic zones. When varying the water content of the E-09-1-14 aggregate base, the vertical modulus changed accordingly, which led to the change of the rate of increase of rutting as illustrated in Figures 6.51 to 6.54.

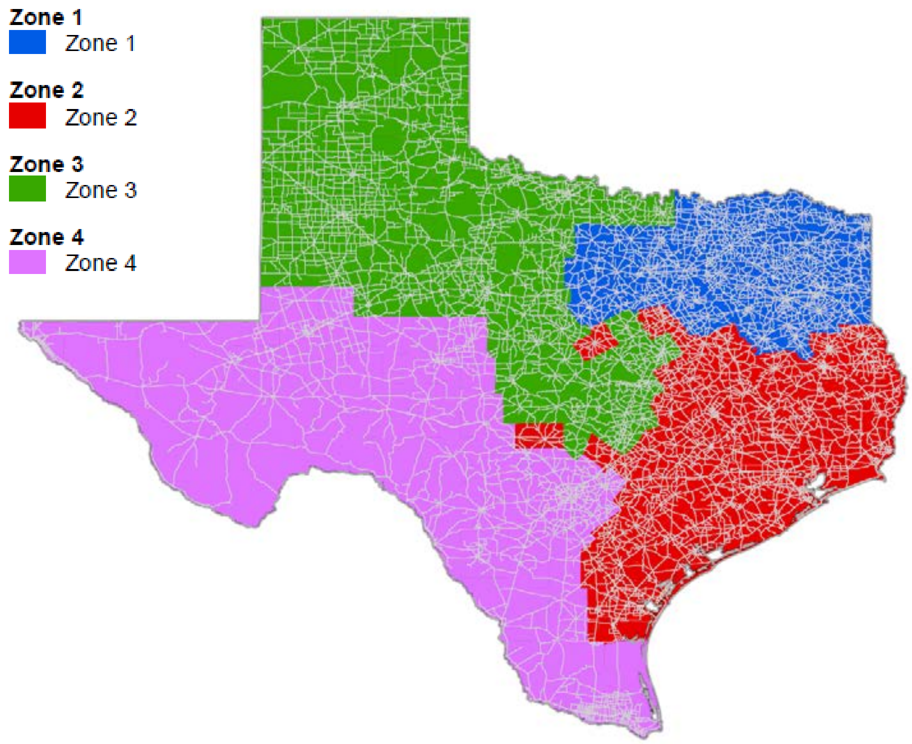

Figure 6.50. Climatic Zones in Texas (Gharaibeh et al. 2010).

Table 6.13. Deep Rutting Prediction Model Coefficients for Pavement Family A with Preventive Maintenance under High Traffic.

Climatic Zone	α	β	A
I	100	0.39	58.34
II	100	0.52	71.62
III	100	0.39	93.20
IV	100	0.55	94.44

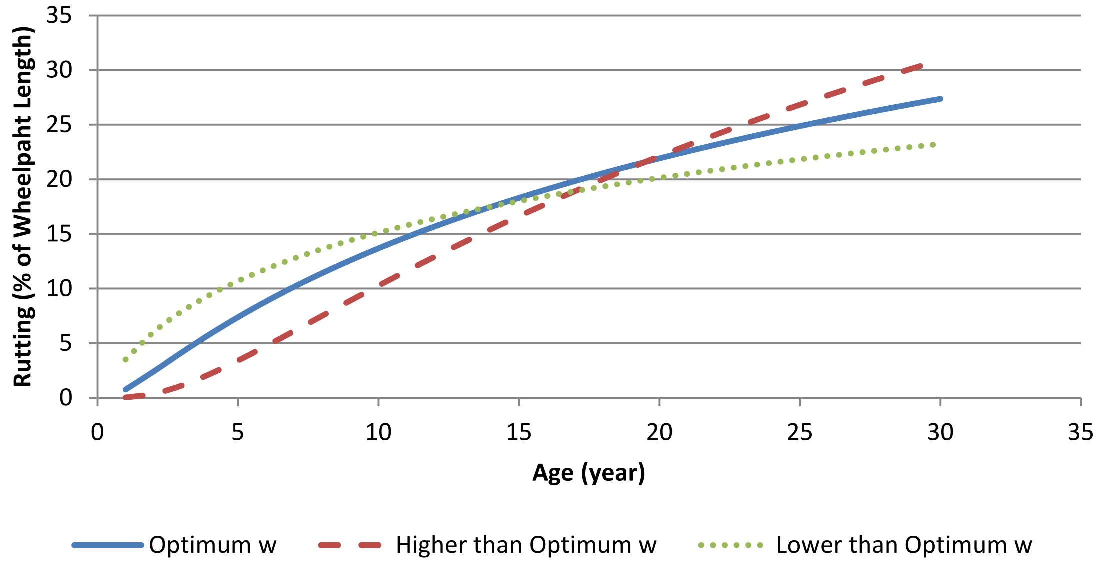

Figure 6.51. Predicted Rutting Life in Climatic Zone I.

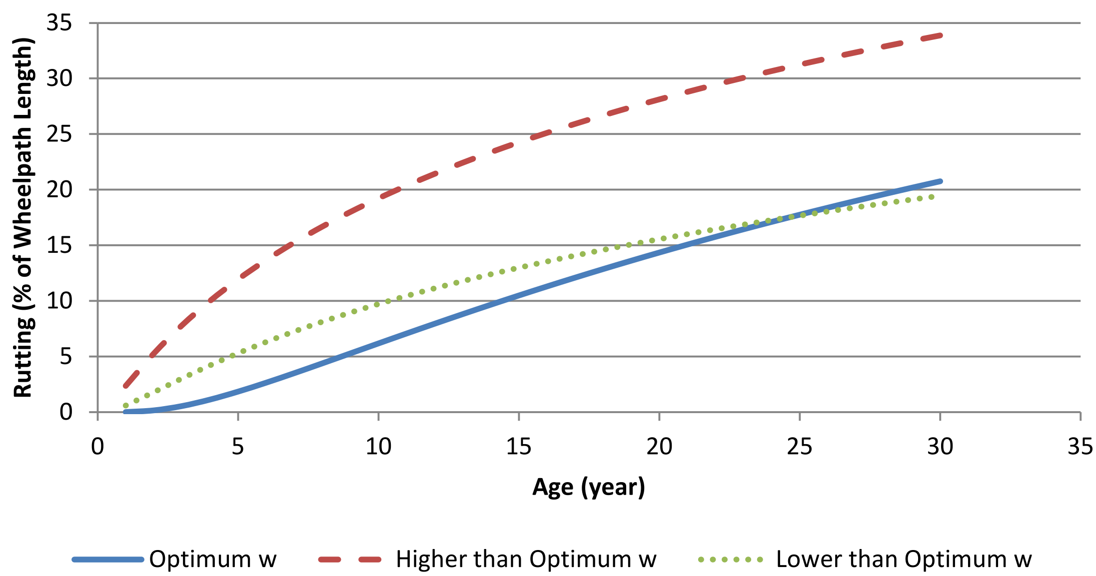

Figure 6.52. Predicted Rutting Life in Climatic Zone II.

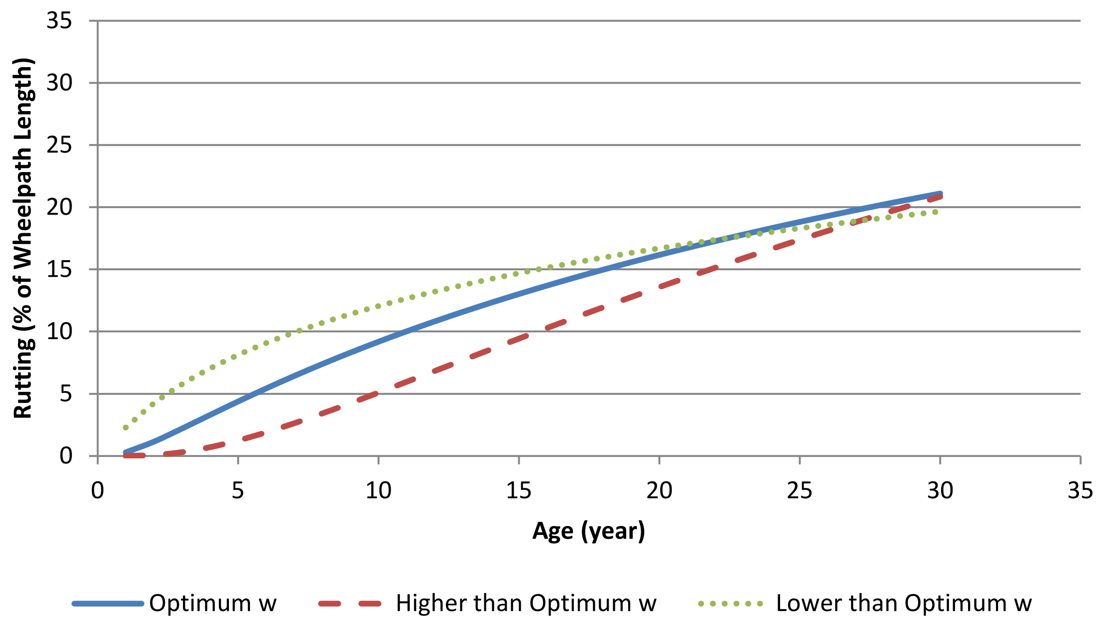

Figure 6.53. Predicted Rutting Life in Climatic Zone III.

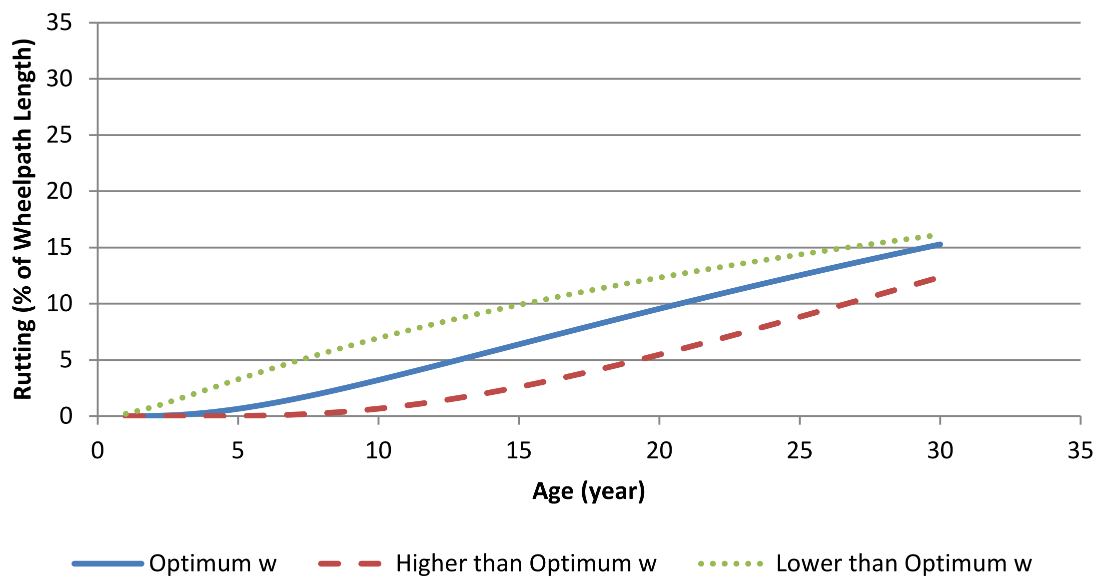

Figure 6.54. Predicted Rutting Life in Climatic Zone IV.

Zone I is in northeast Texas. In approximately 20 years, the wetter base course will impel an increasing rate of rutting past the level expected of the target base course with the optimum water content. As a contrast, the dotted curve representing the dryer base course will have the lowest rutting rate in about 17 years.

Zone II is in southeast Texas and along the coast of the Gulf of Mexico. A variation of the water content of the E-09-1-14 aggregate base demonstrates a wide range of rates of rutting. The wetter base course leads to the largest amount of rutting in the entire pavement life in the analysis. The target base course with the optimum water content exceeds the rutting of the dryer base course after 25 years.

Zone III is in north Texas and panhandle. Stiffer subgrades in this drier climate allow lesser amounts of rutting, especially with the wetter base course. All base courses reach approximately the same amount of rutting at the end of the analyzed pavement life.

Zone IV is in west Texas and in the Rio Grande Valley. The drier climate allows lesser amounts of rutting than in Zone I and II in eastern Texas, and even less than in Zone III.

These are sensitivity analyses of the rutting model developed by Gharaibeh et al. (2010) using the base course modulus model developed at TTI for E-09-1-14 aggregate. The graphs in Figures 6.51 to 6.54 show the results of varying the water content. In fact, the composition of the target base course and the as-compacted base course will vary in more than just the water content. For example, other sensitivity analyses have shown that the modulus of the base course is very sensitive to the pfc. The expected rate of increase of rutting and fatigue, and decrease of riding quality with age will depend upon how the as-compacted base course differ from the target base course in all of these values rather than in just one as shown in Figures 6.51 to 6.54. What these figures demonstrate is that the Gharaibeh performance models combined with the base course modulus model are sensitive to the mixture composition of the base course and to the climatic and subgrade soils in Texas. Not shown in these figures are the effects of different types of pavement and different levels of traffic, all of which are included in the compendium of calibrated pavement performance models developed by Gharaibeh et al. (2010). This model combination provides an approach that will allow the observed performance of Texas pavements as recorded in the PMIS database to be related directly to the measurable composition and properties of the base course as they are constructed in Texas.

SUMMARY

This chapter presents the results of a wide variety of tests to determine the properties of a variety of Texas base courses as they relate to performance. Repeated loading was applied to all base courses at different levels of confining pressure and the resilient moduli and permanent deformation properties were measured directly. Other indicator tests were made on the same materials to determine how well they were correlated to these performance related properties. These tests included the Methylene Blue test developed by the W.R. Grace Corporation, the percent fines content as determined by the Horiba particle size analyzer, Atterberg limits, water content, dry unit weight, filter paper suction, dielectric constant, moisture diffusivity of the compacted base course, gradation, and the Aggregate Imaging System to measure the shape, angularity, and texture of the coarse aggregate particles.

A number of very useful relations were found. The Grace Methylene Blue Value (MBV) which is recorded in mg of Methylene blue per gram of dry soil was found to have a scale that practically duplicates the Methylene Blue scale that is found in the AASHTO T330-07 specification. The Grace Methylene Blue Value was found to measure accurately and differentiate reliably the percent fines content (pfc) for each of the quarry products that we tested. The MBV-vs-percent fines content relation for each pit was unique and consistent.

Furthermore, when comparing the performance properties with the AASHTO MBV scale values, the expected qualitative in-service performance predictors matched the AASHTO descriptions very well.

Mechanics-based models were developed for the stress-dependent resilient moduli and permanent deformation properties of each base course. Three coefficients are needed with the resilient modulus model: k_1, k_2, and k_3. Regression models of these coefficients were developed showing the relations of these coefficients to the indicator tests. Water content and pfc are significant predictors of these k-values as well as measures of aggregate shape and angularity. The aggregate shape and angularity can be measured in the laboratory while determining the quality characteristics of each pit. However, the water content and pfc need to be measured quickly and accurately in field to assure that the modulus used in design and needed for performance is what has been compacted in the field. The tests also showed that the suction in the base course is a very significant variable that controls the magnitude of the resilient modulus. There is a need to measure this important variable quickly and accurately in the field, also.

Two sets of permanent deformation properties were determined from the measured data: the VESYS and the MEPDG properties. The VESYS properties require the water content and the pfc to predict the amount of rutting and require measures of gradation, shape, and angularity to predict the rate at which rutting develops. The MEPDG properties require the pfc, water content and measures of angularity and texture to predict the maximum amount of rutting that will occur. It requires the pfc and a measure of the gradation to predict the amount of traffic required for the rutting to develop.

Reviewing the properties that are necessary to measure in the field shows that the water content, suction, and percent fines content as determined by the MBV relation are necessary. A field method was developed to measure all of these rapidly and accurately and is described in detail in Section 6.3.8.2 of this chapter. The method requires the development of suction-vs-water content (SWCC) and suction-vs-dielectric constant (SDCC) curves for each source of base course in the laboratory prior to construction. The labor involved in doing this is less than what is required for compaction curves.

In the field, two measurements can be made on a sampling basis: a Grace MBV to determine the percent fines content and a Percometer test to determine the dielectric constant of the compacted base course. The percent fines content and MBV can be used to construct the suction-vs-water content (SWCC) and suction-vs-dielectric (SDCC) curves. The measured dielectric constant can be used with the suction-vs-dielectric curve to determine the suction. The suction can be used with the suction-vs-water content curve to determine the water content. The two tests, the MBV and dielectric constant test can be done in about ten minutes in the field. Both measurements are accurate and repeatable as well as rapid. A laptop computer can do the calculations to determine the pfc, suction, water content and resilient modulus of the base course in a matter of seconds. Furthermore, the permanent deformation properties which also depend significantly on the water content and pfc can also be calculated and the expected rutting and its variance can be calculated on the spot.

The fact that the Grace Methylene Blue test is so rapid and repeatable and that it has proven to be so reliable in determining the distribution of the fines content of a base course suggests that it can be used to track the amount by which the base course powders as it is handled from the pit to the stockpile to the job site and in the compaction process. As such, it may prove to be a process monitoring method to supplement the results of the Wet Ball Mill test.

The Introduction section of this chapter stated the objective of this investigation: to develop a quick, accurate and simple process for determining reliable values of the in-place as compacted base course modulus and permanent deformation properties. In addition, the measurements that are made should also contribute to the assurance of the quality of the process of taking the base course from its quarry, transfer it to a stockpile and then haul it to a job site and compact it in place. In summary, this has been accomplished. What remains is to apply the method and work out the operational kinks in the process.

REFERENCES

6.1 ASTM D5298 – 10. Standard Test Method for Measurement of Soil Potential (Suction) Using Filter Paper.

6.2 AASHTO T 330-07, "The Qualitative Detection of Harmful Clays of the Smectite Group in Aggregates Using Methylene Blue."

6.3 Fairbairn P.E. and Robertson R.H. (1957) "Liquid limit and dye adsorption," Clay Minerals Bulletin. 3, 129-136.

6.4 Fredlund, D.G., and Xing, A. (1994). "Equations for the soil-water characteristic curve," Canadian Geotechnical Journal, Vol. 31, pp. 521-532.

6.5 Gharaibeh, N., Saliminejad, S., Wimsatt, A., and Freeman, T. (2010). *Calibration of TxDOT's Asphalt Concrete Pavement (ACP) Performance Prediction Models*, Draft Report of TxDOT Project 0-6386, Texas Transportation Institute, Texas A&M University System, College Station, Texas.

6.6 Humboldt (2010). Testing equipment for construction materials for H-4112 Percometer manual. Web page: www.humboldtmfg.com 3801 North 25th Avenue Schiller Park, Illinois 60176 U.S.A.

6.7 Lytton, R., Aubeny C., Bulut R., Design (2004)."Procedure for Pavement on Expansive Soils," Volume 1, Report No. FHWA/TX-05/0-4518-1.

6.8 Kancherla, A. (2004). "*Resilient modulus and permanent deformation testing of unbound granular materials*." Master of Science Thesis, Texas A&M University, College Station, Texas.

6.9 Phelps G.W. and Harris D.L. (1967). "Specific surface and dry strength by methylene blue adsorption." American Ceramic Society Bulletin, Vol. 47, pp. 1146-1150.

6.10 Sahin, Hakan (2011). Characterization of expansive soil for retaining wall design. MS Thesis, Texas A&M University, College Station, Texas, USA.

6.11 Salehi Ashtiani, R. (2009). "Anisotropic characterization and performance prediction of chemically and hydraulically bounded pavement foundations." Ph.D. Dissertation, Texas A&M University, College Station, Texas.

6.12 Ashtiani, R. S., Luo, R. and Lytton, R. L. (2010). "Performance Prediction and Moisture Susceptibility of Anisotropic Pavement Foundations." *ASCE Geotechnical Special Publication No. 203, Paving Materials and Pavement Analysis,* American Society of Civil Engineers (ASCe), pp. 327-334.

6.13 Saue,T., Kadaja,J., and Plakk,T. (2008). "Measurement of soil water content by percometer," in Workshop Program and Papers: 1st Global Workshop on High Resolution Digital Soil Sensing and Mapping, Sydney, 2008, pp. 184-192.

6.14 Tseng, K.H. and Lytton, R.L. (1989). "Prediction of permanent deformation in flexible pavements materials, implication of aggregates in the design, construction, and performance of flexible pavements." ASTM STP 1016, American Society for Testing and Materials (ASTM), pp. 154-172, West Conshohocken, Pennsylvania.

6.15 Yeo, Y. S., Nikraz, H., and Jitsangiam, P. (2012). Tube Suction Test to Measure Moisture Susceptibility of Australian Pavements. *Engineering Journal, 16(4)*

6.16 Yool, A.I.G., Lees, T.P., and Fried, A., (1998). "Improvements to the Methylene blue dye test for harmful clay in aggregates for concrete and mortar." *Cement and Concrete Research*, Vol. 28, pp. 1417-1428.

6.17 Wang, M., Wang, S. and Wang, W. (1993). "Rapid estimation of cation exchange capacities of soils and clays with methylene blue exchange." *Soil Science American Journal*, Vol. 60, pp. 138-141.

6.18 Zhou, F., and Scullion, T. (2002). "*VESYS5 Rutting Model Calibrations with Local Accelerated Pavement Test Data and Associated Implementation*." Research Report FHWA/TX-03/9-1502-01-2, Texas Transportation Institute, The Texas A&M University System, College Station, Texas.

CHAPTER 7. SPECIFICATION DEVELOPMENT

INTRODUCTION

Chapter 1 of this report (Introduction) presents the scope, objective, and purpose of this research project. The project was directed to prepare a mixture-based specification for flexible base material utilizing as many current tests methods and acceptance criteria as possible without significant changes to the type and grade of materials specified in the current specification. The new specification was intended to be a "mixture- and performance-based" specification that would:

1. Test materials in the field rather than the stockpile.
2. Improve the efficiency of testing and acceptance of materials by TxDOT.
3. Reduce TxDOT workforce needs for sampling and testing.
4. Reduce acceptance time.
5. Increase responsibility of the contractor to control the consistency and quality of the material produced.

The specification was to be reviewed and revised by TxDOT and industry (producer/contractors) via the Project Monitoring Committee and the Industry Working Group.

The initial specification developed was formulated in a QC/QA (QC/QA) format following the style of the TxDOT specifications for asphalt mixtures. Based on TxDOT and industry review (October 26, 2012) the specification approach was changed to a Quality Monitoring Program Approach. Background information for these two approaches is provided below.

QUALITY CONTROL/QUALITY ASSURANCE APPROACH

The first draft of the QC/QA approach to the specification was available in December of 2010. The specification was reviewed and revised several times by the Project Director, research team, Project Monitoring Committee and the Industry Working Group. The general format of the specification remained unchanged and is shown below:

1.0 Description.
2.0 Materials.
3.0 Equipment.
4.0 Construction.
5.0 Measurement.
6.0 Payment.

Some of the specification items requiring considerable discussion included:

1. Quality control tests for production and placement.
2. Quality assurance tests for production and placement.
3. Quality control and quality assurance limits.
4. Acceptance criteria.
5. Mixture design requirements.

6. Job mix formula requirements.
7. Allowing job mix formula to change.
8. Approval of job mix formula.
9. Lot and sublot size.
10. Sampling location(s).
11. Dispute resolution.
12. Measurement.
13. Payment.
14. Pay adjustments.
15. Certification and accreditation.

The latest version of the QC/QA type of specification was completed on October 15, 2011, and is contained in the Appendix of Reference 8.1. It should be noted that this specification draft should not be used for implementation. This draft needs considerable revision relative to sample frequency, quality control/quality assurance limits, and acceptance criteria. Pay adjustment also needs to be review and revised based on performance information.

Quality control/quality assurance types of specification offer a framework for TxDOT to satisfy the majority of the objectives and desired outcomes identified in the Request for Proposal. Revision of the specification to reflect test variability information obtained from TxDOT districts, TxDOT central office, producer/contractor records as well from the sampling and testing program conducted in this study is needed as a minimum.

QUALITY MONITORING PROGRAM APPROACH

At the October 26, 2011, meeting of the Industry Working Group, a decision was made to develop a Quality Monitoring Program for flexible base materials. A draft of the specification was prepared by the research team on January 20, 2012. This draft was based on discussions with the Project Director, selected district materials engineers, as well as current TxDOT procedures and quality monitoring approaches utilized in other states. Specific references of interest for this development effort included the following:

- Tex-499-A — Aggregate Quality Monitoring Program.
- Tex-545-C — Asphalt Binder Quality Program.
- TxDOT — Aggregates (Bituminous Rated Source Quality Catalog).
- TxDOT — Aggregates (Concrete Rate Source Quality Catalog).
- TxDOT — Aggregate Base Quality Assurance Program.
- TxDOT DMS-6110 — Quality Monitoring Program-Epoxies/Adhesives.
- TxDOTDMS-7400 — Qualification Procedure for Laboratories Conducting Compaction and Triaxial Compression Testing for Soils and Base Materials.
- UDOT 509 — Asphalt Binder Quality Management System.
- AASHTO R 18 — Quality System for Construction Materials Testing Laboratories.
- AASHTO R 26 — Certification of Suppliers for PG Binders.

Key Concepts

Some of the key items contained in the draft of the "Flexible Base Quality Monitoring Program" (FB-QMP) are as follows:

- 1.1 The FB-QMP provides the requirements and procedures for the District and Construction Division, Materials and Pavements Section (CST/M&P) to accept flexible base materials produced from a designated source that has demonstrated continuing quality and uniformity.
- 1.2 The FB-QMP allows districts to use flexible base materials from rated sources without project specific testing for construction, reconstruction, and maintenance projects with total tonnages less than 10,000 tons.
- 1.3 The FB-QMP allows districts and CST/M&P to accept stockpiles of flexible base materials at the point of production of the material.
- 1.4 The FB-QMP allows suppliers to ship flexible base materials to multiple projects from the same stockpile.
- 1.5 The FB-QMP provides continuous process control, QC/QA of flexible base materials. The Program includes:
    - 1.5.1 Monitoring of the material source, production process, and materials storage by the supplier and Department.
    - 1.5.2 Process control and quality control sampling and testing of flexible base materials by the supplier.
    - 1.5.3 Quality assurance sampling and testing of flexible base materials by the Department.
    - 1.5.4 Statistical evaluation of supplier and Department QC/QA data.
    - 1.5.5 Expediency in flexible base material quality acceptance.
    - 1.5.6 Optimized resource utilization by reducing aggregate acceptance on a test-prior-to-use basis.
- 1.6 Flexible base material suppliers participate in the FB-QMP based on test history of a material products used on Department projects.
- 1.7 Flexible base suppliers may supply aggregate to a project that requires a higher quality classification by producing materials and storing materials that meet the higher quality specification requirements for the project based on supplier and Department sampling and testing.
- 1.8 Participation in the FB-QMP is not at the option of the flexible base material supplier.

The department has established the FB-QMP to improve efficiency of their operations.

Format

The format for the FB-QMP follows that of other TxDOT documents of a similar nature. The format utilized is shown below:

- 1.0 Scope.
- 2.0 Reference Documents.
- 3.0 Definitions.
- 4.0 Eligibility.
- 5.0 Technical Certification.

6.0 Laboratory Accreditation.
7.0 Responsibility.
8.0 Supplier Quality Control Plan.
9.0 Supplier Quality Control.
10.0 Department Quality Assurance.
11.0 Statistical Evaluation and Acceptance.
12.0 Removal/Reinstatement.
13.0 Dispute Resolution.
14.0 Maintenance.
15.0 Producer Lists.
16.0 Updates.

A copy of the draft document is not included in the Appendix, as it has not been reviewed by TxDOT or the industry working group.

ADDITIONAL DEVELOPMENT

Alternate approaches have been developed for production and placement approval methods to be inserted into the existing Item 247 specification as well as the latest draft of the proposed QC/QA specification. These recommendations have not been reviewed by TxDOT or the IWG and will not be placed in this report.

REFERENCES

7.1 Epps, J., Sebesta, S., Sahin, H., Button, J., Luo, R., and Lytton, R. "Developing a Mixture Design Specification for Flexible Base Construction." Report No. FHWA/TX-12/0-6621-1, Federal Highway Administration, Report 0-6621-1, Texas Transportation Institute, June 2011.

CHAPTER 8. TECHNICIAN CERTIFICATION AND LABORATORY ACCREDITATION

INTRODUCTION

Technician certification and laboratory accreditation are important components of QC/QA programs in many state departments of transportation (DOTs). Certified technicians that sample and test in an accredited laboratory typically have test results with lower variability as compared to technicians that are not certified and do not work in accredited laboratories. Lower within- and between-laboratory sampling and testing errors will provide improved QC/QA data sets from which to judge the acceptance of materials as well as for adjusting processes to improve material quality.

CURRENT PROGRAMS

Certification of Technicians

A number of state DOTs and national organizations offer programs for certification of technicians. Many of these programs offer training together with the certification. The National Institute for Certification in Engineering Technologies (NICET) is a non-profit organization created by the National Society of Professional Engineers to serve the certification needs of the engineering technology community. NISET is one of the most frequently used national technician certification organizations.

Accreditation of Laboratories

A number of laboratory accreditation organizations exist in the United States. The accreditation organization most frequently used is the AASHTO Accreditation Program (AAP). The AAP was established in 1988 to formally recognize the competence of testing laboratories to perform specific tests on construction materials. Nearly 1,500 individual laboratories are currently accredited under this program. The AASHTO Accreditation Program utilizes a laboratory assessment and proficiency sample service provided by the AASHTO Materials Reference Laboratory (AMRL) and Cement and Concrete Reference Laboratory (CCRL). AMRL also provides administrative coordination and technical support for AAP. Most state DOTs laboratories are accredited by AAP, and a significant number of private laboratories are accredited by this program.

PROGRAMS IN TEXAS

In 1993, TxDOT and the Texas Asphalt Pavement Association (TxAPA) developed a technician certification program, operated by TxAPA and under the direction of the TxDOT/HMAC JOINT QC/QA CERTIFICATION STEERING COMMITTEE. This program is named the "Hot Mix Asphalt Center." The program is considered one of the best if not the best in the nation and is recognized by the Federal Highway Administration.

In 2006, TxDOT and TxAPA developed a certification program for technicians that sample and test soils and base materials. All industry technicians are required to attend this program, and only a few TxDOT districts send their soils/base technicians to this program.

TxDOT also has a technician certification program and laboratory accreditation program. These programs are briefly discussed below.

Certification of Technicians

A hot mix asphalt technician certification program is available at the TxAPA facility in Buda, Texas. The program is conducted by TxAPA staff under the direction of the TxDOT/HMAC JOINT QC/QA CERTIFICATION STEERING COMMITTEE. This program has been in place and operational for over 19 years. There are three levels of certification; Level 1A – Plant Specialist, Level 1B – Roadway Specialist, and Level 2 – Mix Design Specialist.

In 2006, TxDOT and TxAPA developed a certification program for technicians that sample and test soils and bases. All industry technicians are required to attend this program. This program is optional for TxDOT technicians and currently, only a few districts send their soils/base technicians to this program. This is currently taught only at the TXAPA facility in Buda, Texas.

Currently, a mandatory soil and base certification program is in place for TxDOT employees. This existing program is managed and conducted by TxDOT central office employees primarily for district laboratory personnel where the central office employees travel to each district and certify district laboratory personnel who, in turn, then certify area office personnel. TxDOT employees are currently certified for certain tests. Many TxDOT technicians are certified for a number of test methods.

TxAPA has offered to travel to each TxDOT district and certify all TxDOT technicians in the Soil and Base Certification program starting in January 2013. TxDOT employees that have been certified by the existing TxDOT certification program will receive certifications by the TxAPA program, provided they hold certifications in all test methods associated with a particular level of certification. TxAPA will travel to the districts for certification training and evaluation as needed to reduce travel costs of TxDOT district personnel.

Five levels of certification are anticipated, as shown on Table 8.1. The certification levels were established to include laboratory and field testing specialists as well as specialists for in-place density and density-water content relationship determinations. Awarded certifications will be for a period of three years. The training and certification programs will require from one to five days, depending on the program. Anticipated costs of training and certification are shown on Table 8.1. Certain levels of certification will require successful completion of the testing of “proficiency samples” on an annual basis.

Test methods required for each certification level are shown on Table 8.2. Training will be offered for each test method. The evaluation portion of the program requires both a laboratory demonstrated capability to perform the test (visual evaluation by instructor) and a written examination. Management of the certification program will be provided by TxAPA.

As the flexible base material specification nears completion, the TxDOT/HMAC JOINT QC/QA CERTIFICATION STEERING COMMITTEE along with a committee of TxAPA, TxDOT, and research personnel should be appointed to review and revise the proposed program, as necessary. Some new test methods may be required and material acceptance procedures will need to be defined together with any software that will be developed to report test findings.

Accreditation of Laboratories

Accreditation of TxDOT laboratories can remain a TxDOT activity. The AASHTO Accreditation Program can be used to accredit producer/contractor laboratories. If needed, the AASHTO Accreditation Program can also be used to accredit TxDOT laboratories.

Table 8.1. Proposed TxAPA Technician Certification Program for Soils and Bases.

Level/Designation	Description	Duration, Days	Recertification, Yrs	Proficiency Sample	Current Certification Cost, $	Current Re-Certification Cost, $
SB 101	Lab Tests	3	3	Yes	700	350
SB 102	Field Tests	1	3	No	350	350
SB 103	Field Tests	1	3	Yes	350	350
SB 201	Density-Moisture Content Curve	3	3	Yes	700	350
SB 202	Strength Testing	5	3	No	1000	700

Table 8.2. Proposed Test Methods for Technician Certification Program for Soils and Bases.

Test Method		Certification Level/Designation				
Number	Description	SB 101	SB 102	SB 103	SB 201	SB 202
100-E	Sampling	X	X	X	X	X
101-E	Preparation	X	X	X	X	X
103-E	Moisture Content	X	X			
104-E	Liquid Limit	X				
105-E	Plastic Limit	X				
106-E	Plastic Index	X				
107-E	Shrinkage Index	X				
110-E	Gradation	X				
113-E	Moisture-Density				X	
114-E	Laboratory Compaction				X	
115-E	In-Place Density		X			
116-E	Wet Ball Mill	X				
117-E	Strength					X
120-E	Soil Stabilization					X
121-E	Lime Stabilization					X
128-E	pH			X		
129-E	Resistivity			X		
140-E	Thickness		X			
145-E	Sulfate-Colorimetric			X		
146-E	Sulfate-Conductivity			X		
198-E	Laboratory Quality	X	X		X	X
400-A	Sampling	X	X	X	X	

CHAPTER 9. IMPLEMENTATION

INTRODUCTION

Specification development associated with this project will need to be continued to produce a satisfactory product for use by TxDOT. This development effort includes meetings with TxDOT and industry representatives, the use of a "shadow specification" on several projects, analysis of premature distress information, analysis of the risks and economic benefits of implementing the specification, and conduct of an implementation effort including the development and delivery of a workshop to the TxDOT districts. Details are provided below.

CONTINUE DEVELOPMENT OF SPECIFICATION

The IWG established during the conduct of this research project will continue for the duration of this implementation effort. It is anticipated that four meetings will be held during the 18-month implementation period. These meetings will be held to review and revise the specification as well as review information gathered by the research team during the "shadow specification" implementation effort along with other tasks associated with the project.

SHADOW SPECIFICATION

A draft specification will be prepared and will be implemented on several projects. The draft specification will not be a requirement of the contract documents on these projects and will be implemented "on the side" or "in shadow" of the normal process of sampling, testing, and acceptance of flexible base materials. The sampling and testing program recommended is a two-phase program, as shown on Tables 9.1 and 9.2. The recommended sampling and testing program will be reviewed and revised based on the draft specification utilized for the implementation effort. After completion of the Phase I sampling and testing program, the specification will be revised and will be used as the basis for the Phase II sampling and testing program outlined on Table 9.2.

As described on Tables 9.1 and 9.2, approximately 16 stockpiles will be sampled and tested. It is anticipated that these stockpiles will be used on 20 projects, as some stockpiles will be shipped to multiple projects. Most sampling will be from stockpiles located at the point of production (quarry or pit) and identified as the "production" sample on these tables. Selected samples will be obtained from the point of delivery (for example, stockpile on project site) and identified as "delivery" on these tables. Additional samples will be obtained from the roadway after spreading and prior to compaction (identified as "roadway") on these tables. Gradation, Atterberg limits, wet ball mill, methylene blue, compressive strength, and resilient modulus tests will be performed, as identified on the tables. Based on past experience, the sampling and testing program will undergo some changes depending on availability of materials, projects, and sampling locations.

Note that samples will be obtained from "permanent quarries/pits" as well as "temporary quarries/pits." A total of 28 sampling locations are anticipated in this partial factorial experimental plan.

PREMATURE DISTRESS EVALUATION

Several districts indicated premature pavement distress associated with flexible base materials in the questionnaire/survey circulated in this study. Additional follow-up conversations will be held with these districts to gain an improved understanding of the premature distress and the likely cause of the distress. Forensic reports have been prepared by TxDOT for some pavements that have experienced premature pavement distress that is associated with flexible base materials. Some of these reports were supplied to the research team by TxDOT, and their results have been summarized in this report. Additional reports are available in TxDOT files and will be reviewed and summarized as part of this effort.

RISK AND ECONOMIC ANALYSIS

An analysis of risk to the materials producer/contractor and TxDOT resulting from the proposed specification change will be undertaken. Interviews will be conducted with material producer/contractors and with TxDOT personnel to provide data. Consideration of base material property variability, operating characteristic curves, and buyer and seller risk will be considered as part of this analysis.

A life-cycle cost analysis will be performed comparing the costs associated with the use of the old flexible base material specification with the new specification proposed in this effort. The cost of implementing the specification, cost of accepting materials under the old and new specifications, and the cost of the materials resulting from the change from the old to the new specification will be considered, as a minimum, in this analysis.

The life-cycle costs associated with providing an improved quality of base material will also be considered as part of this effort. This analysis will include the cost of the base material as well as construction costs and rehabilitation costs. The life cycle of different base materials will be estimated based on experience. In addition, different rehabilitation and maintenance requirements associated with improved quality base materials will be estimated based on experience.

WORKSHOPS

Presentation materials will be prepared and five workshops delivered to implement the specification developed on this project. The presentation materials will describe the specification as well as provide the technical basis for the specification. Forensic information, risk analysis, and life-cycle costs information will be presented by members of the research team and TxDOT. The five workshop presentation sites will be selected by TxDOT with consideration for geographic distribution as well as urban and rural district requirements.

Table 9.1. Phase I Sampling and Testing Program.

Aggregate Source	Stockpile	Project	Sample Location	Testing: Gradation*	Atterberg Limits*	Wet Ball Mill*	Methylene Blue*	Moisture Density*	Compressive Strength*	Resilient Modulus$^{\Delta}$	In-Place Density$^{\Delta}$
Permanent Quarry/Pit	A	1	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								
	B	2	Production	X	X	X	X	X	X	X	
			Delivery	X	X	X	X	X	X	X	
			Roadway	X	X	X	X	X	X	X	X
		3	Production	X	X	X	X	X	X	X	
			Delivery								
			Roadway								
	C	4	Production	X	X	X	X	X	X	X	
			Delivery								
			Roadway								
		5	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								
	D	6	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								
	E	7	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								
Temporary Quarry/Pit	F	8	Production	X	X	X	X	X	X	X	
			Delivery	X	X	X	X	X	X	X	
			Roadway	X	X	X	X	X	X	X	X
	G	9	Production	X	X	X	X	X	X	X	
			Delivery								
			Roadway								
	H	10	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								

* 14 Sites X 3 Samples = 42 Tests

$^{\Delta}$9 Sites X 3 Samples = 27 Tests

In-Place Density - TxDOT

Table 9.2. Field Sampling Phase II.

Aggregate Source	Stockpile	Project	Sample Location	Testing							
				Gradation*	Atterberg Limits*	Wet Ball Mill*	Methylene Blue*	Moisture Density*	Compressive Strength*	Resilient Modulus$^{\Delta}$	In-Place Density$^{\Delta}$
Permanent Quarry/Pit	I	11	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								
	J	12	Production	X	X	X	X	X	X	X	
			Delivery	X	X	X	X	X	X	X	
			Roadway	X	X	X	X	X	X	X	X
		13	Production	X	X	X	X	X	X	X	
			Delivery								
			Roadway								
	K	14	Production	X	X	X	X	X	X	X	
			Delivery								
			Roadway								
		15	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								
	L	16	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								
	M	17	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								
Temporary Quarry/Pit	N	18	Production	X	X	X	X	X	X	X	
			Delivery	X	X	X	X	X	X	X	
			Roadway	X	X	X	X	X	X	X	X
	O	19	Production	X	X	X	X	X	X	X	
			Delivery								
			Roadway								
	P	20	Production	X	X	X	X	X	X		
			Delivery								
			Roadway								

* 14 Sites X 3 Samples = 42 Tests

$^{\Delta}$9 Sites X 3 Samples = 27 Tests

In-Place Density - TxDOT

CHAPTER 10. SUMMARY AND CONCLUSIONS

SUMMARY

Background

The Texas Department of Transportation (TxDOT) currently utilizes Item 247 “Flexible Base” to specify a pavement foundation course. This current specification utilizes aggregate gradation, Atterberg Limits, Wet Ball Mill, and compressive strength to define the desired properties of a flexible base course. The specification limits based on these parameters are broad in order to accommodate the wide variety of aggregates sources available in Texas.

Research Project 0-6621 “Developing a Mixture Based Specification for Flexible Base” was developed by TxDOT to evaluate the current method of base course acceptance as is required in Item 247 and to investigate methods to replace materials approval based on stockpile sampling and testing with a mixture design methodology and quality control procedure. TxDOT envisioned that the project would provide a methodology that would provide a more uniform flexible base material that would meet specification requirements as placed in the field. In addition the methodology used in the specification would make the testing and acceptance of materials by TxDOT more efficient, reduce manpower requirement for TxDOT, reduce the time of acceptance/rejection of a material, and increase the responsibility of the contractor to produce a consistent, quality project.

Research Approach

The Texas A&M Transportation Institute prepared a proposal to perform the research. The key features of the work plan contained in the proposal were as follows:

1. Early formulation of a draft specification.
2. Utilization of TxDOT’s Project Monitoring Committee (PMC) to review and recommend changes to the specification.
3. Formation of an Industry Working Group (IWG) consisting of representatives from TxDOT and producer/contractors to review and recommend changes to the specification.
4. Utilization of existing information as much as possible to formulate acceptance criteria and limits for the specification.
5. Performance of research to fill the information gaps in the specification.
6. Perform implementation efforts consisting of certification and accreditation programs, shadow specification field projects, and training/workshops.

The initial efforts were focused on the development of a quality control/quality assurance type of specification for base course material. This specification contained the requirement for a Job Mix Formula developed by the producer/contractor, sampling and testing plans for the producer/contractor for quality control purposes, and sampling and testing plans for TxDOT for quality assurance. This type of specification format satisfied many of the objective and outcomes of the project and satisfied the scope of the research program. Review and revisions were made by the Project Director, Project Monitoring Committee, Industry Working Group, and members of the research staff. Numerous drafts of the quality control/quality assurance specification were prepared during the two-year duration of the project.

The specification development was re-directed toward a "Quality Monitoring Program" approached based on an October 15, 2011, meeting of the Industry Working Group. The first draft of this type of specification was supplied to TxDOT in January 2012.

Information Gathering

Considerable effort was expended to gather existing information that would assist in defining the types of tests to be utilized, the specification acceptance criteria, and acceptance limits. This information gathering phase included two extensive literature reviews, a questionnaire sent to TxDOT districts, interviews with district personnel, preparation of data summaries obtained from TxDOT districts and divisions, preparation of data summaries obtained from producers, producer/contactor interviews, and preparation of data summaries obtained from the national literature.

Sampling and Testing Program

This part of the research program provided data to identify tests that should be considered for inclusion in the specification as well as defining property variability of base course materials from nine pits/quarries in Texas. Tests utilized in this portion of the study included gradation (including No. 200 sieve), Atterberg Limits, Wet Ball Mill, unconfined compressive strength, methylene blue, percent clay fraction, aggregate shape and texture, soil water-suction curves, resilient modulus, and permanent deformation.

Other Activities

A number of other important activities were conducted in the study to produce information that is needed in a performance based, statistical specification. These activities included precision and bias statement development, production/placement variability, technician certification, laboratory accreditation, and the development of relationships that allow test property parameters to predict pavement performance.

An implementation effort was scheduled in the two-year project. The implementation included the use of "shadow specifications and the development and delivery of training/workshops to district personnel. These implementation efforts were not completed as part of this project.

Major conclusions from this research effort are provided below.

CONCLUSIONS

Conclusions from Historical Usage of Flexible Base

1. Approximately 6.7 million tons (3.7 million cubic yards) of base course are purchased by TxDOT statewide on an annual basis.
2. Approximately 95 percent of all base course materials used by TxDOT are purchased under contract to TxDOT.

3. The majority of the flexible base course materials used by TxDOT construction and maintenance operations are crushed stone or mixtures of crushed stone and recycled, crushed portland cement concrete that satisfy the requirements of either Type A or Type E.
4. Significant quantities of base course materials (62 percent) are purchased under "as shown on the plans" (Grade 4). Grade 2 (intermediate quality) and Grades 1and 5 (higher quality) quantities were utilized 20 percent and 17 percent, respectively.
5. Based on a district survey the majority of performance problems with flexible base course materials are located in the east and north Texas districts. West Texas districts and south Texas districts did not report a significant occurrence of premature distress associated with flexible base courses.

Conclusions from Evaluating Test Precision, Production Variability, and Sample Size

1. "Within" and "Between" laboratory precision statements have been prepared based on TxDOT "proficiency sample" test results for tests presently used in the base course specification.
2. Material property variability data were obtained from districts, divisions, material supplier/contractors, nationwide references, and a planned sampling and testing program. These variability data have been summarized on cumulative frequency distribution plots for use in specification development.
3. The number of samples needed when testing for a given test parameter have been determined based on production variability, producer/contractor risk, TxDOT risk, and maximum allowable error.

Conclusions from Evaluating Performance Indicators for Flexible Base

1. Some base course materials lose considerable strength at water contents 1 percent above optimum as measured by unconfined compressive strength.
2. Differences in gradation results are significantly different for "dry" and 'wet" sieve analysis methods on the No. 200 and No. 40 sieves. The difference between wet and dry sieve methods for the No. 200 sieve is about 8 percentage points depending on the type of material tested. The difference on the No. 4 sieve is about 4.5 percentage points depending on the type of material tested.
3. Pavement performance relationships (as influenced by base course properties) have been developed based on resilient modulus and permanent deformation laboratory tests.
4. Resilient modulus, permanent deformation, and pavement performance can be predicted from laboratory and field tests. For a given base course material source the size distribution, shape, and surface texture of a representative aggregate fraction above the No. 200 sieve needs to be determined together with the suction water content curve and the suction dielectric constant curve. These tests can be performed in about the same time as presently required for development of the moisture-density relationship. For field control, the methylene blue test and the dielectric constant test need to be performed on the compacted base course material. The methylene blue and dielectric constant test require about 10 minutes for field testing.

5. The methylene blue test is a predictor of the amount and type of clay minerals in a base course material and offers promise as a replacement for Atterberg Limit parameters. Appendix M presents a draft methylene blue test procedure.
6. A technique has been developed to simulate dry density-water content curves from limited laboratory data.

Conclusions for Progressing Toward a Revised Flexible Base Specification

1. Draft flexible base course specifications have been prepared in a "quality control/quality assurance" format as well as a "quality monitoring program" format.
2. An implementation project needs to be conducted to determine the accuracy of the developed pavement performance prediction techniques and the suitability of the specification including the types and limits of the test parameters in the specification.
3. Training materials need to be developed and workshops presented to districts and industry based on the specification finalized in the implementation effort.
4. TxAPA and TxDOT presently offer technician certification programs. As the specification moves toward a QMP, TxDOT should consider centralizing the technician certification program where all technicians receive certification from the same source.
5. TxDOT and national laboratory accreditation programs are available for some of the test methods utilized in the flexible base specification.

APPENDIX A: RESULTS FROM SAMPLING AND TESTING FOR EXISTING SPECIFICATION TESTS

Table A-1. Tex-110-E—Dry Sieve Analysis (Cumulative % Retained) for Sources Sampled by Calendar.

Material ID - Month-Week-Day-Sample # (For Days With >1 Sample)	1-3/4"	1-1/4"	7/8"	5/8"	3/8"	#4	#40
E-02-1-1-2	0.0	3.0	23.0	37.8	52.2	66.6	82.2
E-02-1-2-2-1	0.0	2.6	17.0	29.8	43.9	60.0	78.3
E-02-1-2-2-2	0.0	8.1	30.2	43.1	55.5	68.0	80.4
E-02-1-2-2-3	0.0	8.5	30.6	44.6	56.5	69.0	81.3
E-02-1-2-2-4	0.0	9.9	31.9	45.5	56.6	69.0	81.0
E-02-1-2-2-5	0.0	6.5	26.8	39.5	51.1	64.6	78.4
E-02-1-3-4	0.0	7.0	26.2	39.9	54.6	66.2	79.6
E-02-1-4-1	0.0	5.9	22.8	33.7	45.0	60.9	79.5
E-02-1-4-2	0.0	7.5	22.5	32.8	44.7	59.3	77.5
E-02-1-4-3	0.0	6.2	21.5	33.0	44.1	59.5	77.4
E-02-1-4-4	0.0	6.8	20.8	31.4	42.9	59.2	77.5
E-02-1-4-5	0.0	5.4	20.2	30.8	43.1	57.4	75.7
E-02-55-gal drum	0.0	2.6	18.9	32.8	46.0	55.8	69.7
E-02-2-2-2	0.0	9.1	26.8	38.7	52.2	67.9	81.3
E-02-2-3-1	0.0	12.1	32.4	46.9	59.4	74.7	86.4
E-02-2-4-3	0.0	10.4	28.0	40.3	52.5	67.6	81.2
E-02-2-3-2	0.0	11.6	30.1	41.8	54.1	68.2	81.5
E-01-1-1-2	0.0	1.4	9.9	21.2	39.7	58.5	90.1
E-01-1-2-2	0.0	1.6	11.3	21.4	38.3	58.0	91.5
E-01-1-3-2-3	0.0	1.5	8.3	17.7	33.9	54.4	90.1
E-01-1-4-1	0.0	0.6	4.6	12.3	27.5	47.7	87.3
E-01-1-4-2	0.0	1.4	7.5	15.6	29.7	49.8	89.3
E-01-1-4-3	0.0	1.7	10.3	19.6	35.6	57.5	91.3
E-01-55-gal drum	0.0	1.9	11.9	24.8	44.9	64.1	91.4

Table A-2. Tex-200-F—Washed Sieve Analysis (Cumulative % Retained) for Sources Sampled by Calendar.

Material ID - Month-Week-Day-Sample # (For Days With >1 Sample)	1-3/4"	1-1/4"	7/8"	5/8"	3/8"	#4	#40	#200
E-02-1-1-2	0.0	2.9	22.9	37.3	50.8	64.1	79.5	91.7
E-02-1-2-2-1	0.0	2.5	17.5	29.8	43.1	58.2	77.0	92.3
E-02-1-2-2-2	0.0	9.1	28.1	43.3	54.2	66.1	78.9	92.3
E-02-1-2-2-3	0.0	9.6	30.4	43.9	55.3	67.2	79.7	92.7
E-02-1-2-2-4	0.0	9.9	32.9	45.3	55.1	67.7	79.8	94.0
E-02-1-2-2-5	0.0	6.4	25.2	39.7	50.1	62.6	76.4	91.8
E-02-1-3-4	0.0	6.7	25.5	39.4	53.2	64.4	77.5	91.7
E-02-1-4-1	0.0	5.8	21.9	33.6	43.1	57.6	74.9	88.2
E-02-1-4-2	0.0	6.4	22.8	33.4	43.8	56.3	71.0	86.3
E-02-1-4-3	0.0	6.1	21.2	32.2	42.9	56.2	72.7	87.5
E-02-1-4-4	0.0	6.8	21.3	30.7	41.5	56.2	74.0	88.0
E-02-1-4-5	0.0	4.5	21.4	30.6	42.2	54.7	72.0	86.7
E-02-55-gal drum	0.0	5.4	18.9	31.3	45.7	54.8	66.2	86.1
E-02-2-2-2	0.0	11.1	27.0	38.2	51.8	66.2	80.1	92.4
E-02-2-3-1	0.0	14.1	32.5	47.0	59.1	73.3	85.5	93.7
E-02-2-4-3	0.0	14.0	28.8	40.6	52.3	66.4	80.4	92.3
E-02-2-3-2	0.0	11.4	29.7	42.2	52.7	66.0	78.3	92.3
E-01-1-1-2	0.0	1.4	10.1	21.7	37.0	56.0	83.2	89.7
E-01-1-2-2	0.0	1.7	11.2	21.1	37.2	55.2	84.3	89.0
E-01-1-3-2-3	0.0	2.7	8.2	17.4	31.4	51.3	85.3	90.7
E-01-1-4-1	0.0	2.0	4.6	13.1	27.0	44.8	82.5	89.1
E-01-1-4-2	0.0	1.4	7.4	15.4	28.9	46.8	83.1	89.2
E-01-1-4-3	0.0	1.9	7.3	17.4	32.1	54.1	82.8	88.0
E-01-55-gal drum	0.0	1.8	11.7	23.4	42.0	62.1	87.4	91.8

Table A-3. Tex-104, 105, 106, 116-E—Atterberg Limits and Wet Ball Mill for Sources Sampled by Calendar.

Material ID - Month-Week-Day-Sample # (For Days With >1 Sample)	Liquid Limit	Plastic Limit	Plasticity Index	Wet Ball Mill Value	Wet Ball Mill % Increase
E-02-1-2-2-1	17	10	7	33	10
E-02-1-2-2-2	20	14	6	35	14
E-02-1-2-2-3	19	13	6	31	11
E-02-1-2-2-4	21	13	8	23	12
E-02-1-2-2-5	18	12	6	34	10
E-02-1-3-4	15	9	6		
E-02-1-4-1				34	9
E-02-1-4-2				40	11
E-02-1-4-3	19	12	7	38	11
E-02-1-4-4	21	12	9	36	10
E-02-1-4-5	20	11	9	39	11
E-02-55-gal drum	16	8	8		
E-02-2-3-2	15	10	5		
E-01-1-1-2	18	10	8	21	4
E-01-1-2-2	21	11	10	25	9
E-01-1-3-2-3	19	11	8		
E-01-1-4-1	18	11	7	25	7
E-01-1-4-2	18	10	8	24	7
E-01-1-4-3	22	12	10	24	7
E-01-55-gal drum	19	12	7		

Table A-4. Tex-113, 117-E—Moisture Density Relations and Triaxial Compression Tests for Sources Sampled by Calendar.

Material ID - Month-Week-Day-Sample # (For Days With >1 Sample)	Max Dry Density (pcf)	Optimum Moisture Content (%)	0 psi Strength (psi)	3 psi Strength (psi)	15 psi Strength (psi)
E-02-1-3-4	137.1	7.1	15.0	94.2	226.8
E-02-55-gal drum	135.6	7.1	36.1	71.2	
E-02-2-3-2	136.3	7.2	18.2	114.9	271.4
E-01-1-3-2-3	143.0	5.8	33.0	87.1	192.3
E-01-55-gal drum	141.2	6.3	37.1	96.6	193.1

Table A-5. Tex-110-E—Dry Sieve Analysis (Cumulative % Retained) for Sources Sampled by Stockpile.

Material ID - Stockpile # - Sample #	1-3/4"	1-1/4"	7/8"	5/8"	3/8"	#4	#40
E-03-6-1	0.0	0.0	11.0	16.0	26.0	42.0	66.0
E-03-6-2	0.0	7.0	28.0	45.0	60.0	69.0	82.0
E-03-6-3	0.0	0.0	10.0	20.0	33.0	47.0	68.0
E-03-6-4	0.0	3.0	12.0	21.0	33.0	45.0	68.0
E-03-6-6	0.0	5.0	17.0	26.0	37.0	49.0	69.0
E-03-6-10-1	0.0	2.0	17.0	28.0	38.0	48.0	60.0
E-03-6-10-2	0.0	5.0	21.0	34.0	50.0	64.0	84.0
E-03-6-10-3	0.0	4.0	15.0	26.0	42.0	58.0	81.0
E-03-6-7	0.0	13.0	28.0	45.0	59.0	72.0	85.0
E-03-6-8	0.0	3.0	16.0	32.0	50.0	63.0	88.0
E-03-6-9	0.0	4.0	21.0	34.0	49.0	62.0	81.0
E-03-6-10	0.0	1.0	11.0	20.0	36.0	52.0	81.0
E-03-6-11	0.0	4.0	15.0	25.0	40.0	56.0	82.0
E-03-2-10-2	0.0	4.0	18.0	33.0	47.0	59.0	81.0
E-03-2-10-3	0.0	4.0	19.0	31.0	43.0	55.0	73.0
E-03-1-10-1	0.0	10.0	17.0	31.0	44.0	56.0	71.0
E-03-1-10-2	0.0	2.0	22.0	37.0	52.0	64.0	81.0
E-03-1-10-3	0.0	4.0	17.0	30.0	43.0	54.0	70.0
E-03-1-10-4	0.0	5.0	24.0	39.0	56.0	66.0	80.0
E-03-1-10-5	0.0	4.0	20.0	32.0	48.0	59.0	81.0
E-03-4-1	0.0	3.0	12.0	19.0	27.0	31.0	43.0
E-03-4-1-2	0.0	10.0	37.0	54.0	72.0	82.0	90.0
E-03-4-1-3	0.0	7.0	30.0	48.0	64.0	75.0	87.0
E-03-4-1-4	0.0	6.0	24.0	38.0	53.0	65.0	81.0
E-03-4-1-5	0.0	4.0	21.0	34.0	50.0	63.0	80.0
E-03-4-2-1	0.0	4.0	17.0	29.0	45.0	59.0	78.0
E-03-4-3-10	0.0	5.0	23.0	35.0	48.0	59.0	75.0
E-03-4-4	0.0	9.0	31.0	47.0	63.0	73.0	84.0
E-05-61-1	0.0	4.8	14.9	24.4	40.7	58.2	85.6
E-05-61-2	0.0	4.5	14.4	23.2	38.2	59.7	84.8
E-05-61-3	0.0	8.3	21.1	32.7	51.6	70.1	88.9
E-05-61-4	0.0	4.2	16.6	27.8	41.3	57.5	85.0
E-05-61-5	0.0	5.1	15.3	25.9	40.9	59.9	85.8
E-05-61-7	0.0	6.2	20.6	32.2	45.7	62.1	85.4

Table A-5. Tex-110-E—Dry Sieve Analysis (Cumulative % Retained) for Sources Sampled by Stockpile (Continued).

Material ID - Stockpile # - Sample #	1-3/4"	1-1/4"	7/8"	5/8"	3/8"	#4	#40
E-05-61-8	0.0	6.3	14.6	22.6	37.7	58.3	82.6
E-05-61-9	0.0	4.6	13.3	23.7	39.1	53.6	80.5
E-05-61-10	0.0	9.4	24.2	34.6	46.1	60.1	84.8
E-05-61-11	0.0	6.8	19.9	35.4	56.2	71.3	88.0
E-05-61-12	0.0	5.4	16.2	27.8	44.6	62.2	88.3
E-05-55-gal drum	0.0	7.5	19.1	28.9	41.6	55.4	86.0
E-04-1-1	0.0	2.5	10.9	21.6	40.1	60.0	91.5
E-04-1-2	0.0	4.1	18.1	32.3	51.2	69.4	92.5
E-04-1-3	0.0	3.0	12.8	23.7	41.2	61.0	91.2
E-04-1-4	0.0	1.7	12.0	24.5	41.5	58.1	86.7
E-04-1-5	0.0	5.0	18.1	30.1	47.7	64.1	89.4
E-04-1-6	0.0	1.8	11.5	23.5	41.3	58.3	88.7
E-04-1-7	0.0	2.7	13.0	25.1	43.0	61.5	89.5
E-04-1-8	0.0	2.5	15.1	28.9	47.4	65.2	89.9
E-04-1-9	0.0	3.2	15.1	29.0	46.5	64.4	89.2
E-04-1-10	0.0	4.1	14.7	26.3	43.8	61.5	89.7
E-04-1-11	0.0	4.3	16.8	30.4	50.1	68.0	91.7
E-04-1-12	0.0	3.9	14.5	26.0	41.2	57.5	87.6
E-04-1-13	0.0	4.1	15.7	27.2	39.0	56.4	89.1
E-04-1-14	0.0	4.1	16.6	31.3	51.4	69.1	92.3
E-04-2-2	0.0	4.7	17.0	29.3	45.7	61.2	85.3
E-04-2-3	0.0	3.7	16.8	28.5	45.7	61.1	84.7
E-04-2-4	0.0	8.1	25.5	41.0	59.6	74.2	91.8
E-04-2-6	0.0	4.9	19.1	32.0	49.4	65.2	87.8
E-06-1-1	0.0	3.1	13.3	23.4	35.8	47.4	80.6
E-06-1-3	0.0	4.9	18.0	29.2	41.1	51.5	85.0
E-06-1-4	0.0	4.4	17.6	27.3	36.3	45.2	84.9
E-06-1-5	0.0	2.9	16.4	28.3	41.4	52.7	85.6
E-06-1-6	0.0	4.4	18.2	31.3	44.1	53.7	84.5
E-06-1-7	0.0	5.4	19.6	30.3	41.7	51.6	84.5
E-06-1-8	0.0	2.7	14.9	26.9	39.9	50.3	85.1
E-06-1-9	0.0	4.6	19.1	32.1	45.4	54.3	83.1
E-06-1-11	0.0	2.6	13.7	22.8	34.0	44.7	85.3
E-06-1-13	0.0	6.6	18.7	30.3	44.0	54.6	86.4

Table A-5. Tex-110-E—Dry Sieve Analysis (Cumulative % Retained) for Sources Sampled by Stockpile (Continued).

Material ID - Stockpile # - Sample #	1-3/4"	1-1/4"	7/8"	5/8"	3/8"	#4	#40
E-06-2-1	0.0	3.1	14.5	25.6	39.7	50.8	84.9
E-06-2-2	0.0	4.9	20.0	30.6	40.7	49.3	82.9
E-06-2-3	0.0	3.9	13.7	21.7	30.5	38.6	79.1
E-06-2-4	0.0	6.3	19.9	31.3	43.3	52.9	82.5
E-06-2-5	0.0	3.1	12.5	20.9	30.3	39.2	80.4
E-06-2-6	0.0	5.7	20.1	30.5	40.1	48.8	87.2
E-06-3-10	0.0	4.2	16.7	26.7	36.9	46.4	86.6
E-09-1-1	0.0	8.2	22.2	33.9	47.6	63.3	85.5
E-09-1-2	0.0	6.3	19.8	31.7	48.3	64.1	85.7
E-09-1-4	0.0	9.1	26.3	40.4	55.7	68.9	85.9
E-09-1-5	0.0	4.1	15.7	26.5	42.1	59.5	81.0
E-09-1-7	0.0	4.7	15.2	23.1	35.2	60.3	84.2
E-09-1-8	0.0	6.1	20.6	33.3	48.4	67.1	84.4
E-09-1-9	0.0	5.5	16.2	26.2	39.9	60.0	82.1
E-09-1-10	0.0	7.2	20.5	33.8	51.4	70.4	86.8
E-09-1-11	0.0	5.2	17.7	28.3	42.4	58.5	82.0
E-09-1-13	0.0	7.2	19.1	29.6	42.0	57.9	80.5
E-09-1-14	0.0	5.0	16.3	27.4	42.8	65.1	87.3
E-07-69-1-1	0.0	8.0	18.0	31.0	44.0	56.0	75.0
E-07-69-1-2	0.0	6.0	19.0	32.0	47.0	60.0	75.0
E-07-69-1-3	0.0	0.0	13.0	34.0	44.0	57.0	75.0
E-07-69-1-4	0.0	6.0	19.0	31.0	48.0	60.0	76.0
E-07-69-1-5	0.0	12.0	28.0	41.0	56.0	65.0	78.0
E-07-69-1-6	0.0	0.0	9.0	19.0	27.0	40.0	65.0
E-07-69-1-7	0.0	4.0	24.0	38.0	55.0	67.0	81.0
E-07-69-1-8	0.0	8.0	24.0	38.0	55.0	66.0	82.0
E-07-69-1-9	0.0	4.0	15.0	28.0	41.0	54.0	76.0
E-07-69-1-10	0.0	3.0	8.0	14.0	24.0	39.0	67.0
E-07-69-1-11	0.0	3.0	10.0	18.0	28.0	43.0	69.0
E-07-69-1-14	0.0	6.2	20.8	33.7	49.7	63.5	83.9
E-07-55-gal drum	0.0	5.3	18.7	31.6	48.1	61.7	86.9
E-07-68-2-1	0.0	9.0	27.0	50.0	69.0	80.0	89.0
E-07-68-2-2	0.0	24.0	59.0	76.0	86.0	92.0	95.0
E-07-68-2-3	0.0	13.0	40.0	55.0	68.0	80.0	91.0

Table A-5. Tex-110-E—Dry Sieve Analysis (Cumulative % Retained) for Sources Sampled by Stockpile (Continued).

Material ID - Stockpile # - Sample #	1-3/4"	1-1/4"	7/8"	5/8"	3/8"	#4	#40
E-07-68-2-4	0.0	0.0	11.0	22.0	38.0	53.0	75.0
E-07-68-2-5	0.0	6.0	20.0	37.0	55.0	72.0	87.0
E-07-68-2-6	0.0	6.2	22.0	34.9	50.8	64.0	83.4
E-08-235-1-1	0.0	0.0	9.0	21.0	38.0	55.0	85.0
E-08-235-1-2	0.0	4.0	9.0	16.0	29.0	43.0	81.0
E-08-235-1-3	0.0	0.0	7.0	21.0	32.0	45.0	86.0
E-08-235-1-4	0.0	5.0	14.0	24.0	40.0	55.0	86.0
E-08-235-1-5	0.0	0.0	8.0	17.0	26.0	38.0	80.0
E-08-235-1-6	0.0	4.0	10.0	17.0	27.0	40.0	79.0
E-08-235-1-7	0.0	0.0	4.0	9.0	20.0	35.0	79.0
E-08-235-1-8	0.0	5.0	17.0	32.0	49.0	63.0	87.0
E-08-235-1-9	0.0	5.0	13.0	27.0	42.0	57.0	86.0
E-08-235-1-10	0.0	0.0	11.0	11.0	26.0	42.0	74.0
E-08-235-1-11	0.0	3.0	13.0	23.0	32.0	47.0	98.0
E-08-235-1-12	0.0	3.6	15.8	27.6	42.9	58.7	94.0
E-08-55-gal drum	0.0	3.1	15.3	28.6	45.3	60.3	91.3
E-08-2-1-1	0.0	3.0	8.0	21.0	34.0	53.0	87.0
E-08-2-1-2	0.0	3.0	21.0	29.0	47.0	61.0	89.0
E-08-2-1-3	0.0	7.0	32.0	49.0	67.0	82.0	95.0
E-08-2-1-4	0.0	2.0	17.0	30.0	48.0	66.0	91.0
E-08-2-1-5	0.0	10.0	22.0	28.0	42.0	59.0	89.0
E-08-2-1-6	0.0	3.6	17.9	34.6	50.8	66.4	93.2

Table A-6. Tex-200-F—Washed Sieve Analysis (Cumulative % Retained) for Sources Sampled by Stockpile.

Material ID - Stockpile # - Sample #	1-3/4"	1-1/4"	7/8"	5/8"	3/8"	#4	#40	#200
E-03-6-10-3	0.0	3.7	14.7	24.2	38.7	51.9	70.0	82.0
E-03-4-1-3	0.0	8.5	29.7	47.0	62.2	72.1	81.1	90.0
E-03-4-1-5	0.0	3.7	19.4	32.2	46.2	58.5	70.4	85.1
E-05-61-1	0.0	4.7	14.5	23.9	38.9	54.5	81.3	88.2
E-05-61-2	0.0	4.6	14.8	23.4	37.8	57.7	82.8	88.7
E-05-61-3	0.0	8.3	21.5	32.5	50.1	67.7	87.7	91.7
E-05-61-4	0.0	4.3	16.6	28.4	39.9	54.0	81.3	88.1
E-05-61-5	0.0	4.9	14.4	25.6	39.5	56.9	82.3	88.8
E-05-61-7	0.0	6.0	20.4	32.3	45.4	60.8	82.1	88.5
E-05-61-8	0.0	6.1	14.5	22.9	36.4	55.8	79.7	86.9
E-05-61-9	0.0	4.5	14.2	23.7	38.1	52.0	77.7	86.0
E-05-61-10	0.0	9.4	22.7	34.7	45.1	58.1	81.3	88.1
E-05-61-11	0.0	6.8	20.6	37.3	54.6	69.3	86.3	90.7
E-05-61-12	0.0	5.2	14.5	26.2	41.8	57.8	83.5	89.1
E-05-55-gal drum	0.0	6.7	17.5	27.7	38.9	52.1	80.8	87.6
E-04-1-1	0.0	2.2	10.6	20.4	36.6	54.9	78.5	85.3
E-04-1-2	0.0	4.7	20.4	32.4	49.8	64.4	83.1	88.1
E-04-1-3	0.0	1.7	12.7	22.5	38.8	56.6	79.9	87.0
E-04-1-4	0.0	1.7	11.1	23.3	39.0	56.1	79.2	86.1
E-04-1-5	0.0	5.2	18.1	29.9	46.1	62.9	83.4	89.1
E-04-1-6	0.0	1.8	12.3	24.2	40.3	56.4	79.8	86.6
E-04-1-7	0.0	4.0	12.5	25.5	41.6	59.1	81.4	87.3
E-04-1-8	0.0	4.0	15.0	28.2	46.0	62.3	83.7	89.0
E-04-1-9	0.0	3.0	15.3	28.6	43.7	59.6	79.6	85.9
E-04-1-10	0.0	4.0	14.5	26.1	41.9	58.5	80.8	86.8
E-04-1-11	0.0	4.3	16.5	30.0	49.2	65.6	86.4	90.8
E-04-1-12	0.0	5.2	13.8	25.4	39.6	55.1	75.9	82.3
E-04-1-13	0.0	4.4	14.3	26.5	37.5	51.9	75.2	81.6
E-04-1-14	0.0	4.1	16.3	31.0	48.8	65.5	82.8	88.0
E-04-2-2	0.0	4.6	17.1	29.3	44.5	59.9	80.6	87.0
E-04-2-3	0.0	4.0	17.7	29.0	45.2	60.8	82.1	88.7
E-04-2-4	0.0	8.6	26.1	40.3	57.8	72.4	87.5	91.5
E-04-2-6	0.0	5.1	17.6	31.4	47.1	62.1	80.6	87.8

Table A-6. Tex-200-F—Washed Sieve Analysis (Cumulative % Retained) for Sources Sampled by Stockpile (Continued).

Material ID - Stockpile # - Sample #	1-3/4"	1-1/4"	7/8"	5/8"	3/8"	#4	#40	#200
E-06-1-3	0.0	4.9	16.7	28.3	38.8	48.5	74.4	87.8
E-06-1-4	0.0	4.3	17.2	26.2	34.7	42.9	74.2	87.1
E-06-1-5	0.0	4.0	16.5	27.3	39.3	49.8	76.4	87.6
E-06-1-6	0.0	4.6	16.5	30.6	43.3	52.7	79.7	89.3
E-06-1-7	0.0	5.3	18.4	30.0	40.6	49.8	78.1	89.9
E-06-1-8	0.0	7.0	14.2	25.9	38.2	48.8	78.1	90.4
E-06-1-9	0.0	4.8	19.2	32.5	44.4	53.6	78.9	90.4
E-06-1-11	0.0	4.6	12.5	21.8	32.3	41.6	71.6	86.1
E-06-1-13	0.0	4.6	17.3	28.0	40.8	51.2	79.0	89.7
E-06-55-gal drum	0.0	2.5	9.9	19.5	31.5	43.6	75.5	88.0
E-06-2-1	0.0	2.6	13.7	24.8	36.2	48.1	79.6	90.0
E-06-2-2	0.0	5.2	19.8	31.2	40.1	48.3	76.4	88.9
E-06-2-3	0.0	3.7	14.7	21.5	29.4	37.6	70.9	85.3
E-06-2-4	0.0	5.2	19.5	30.5	42.8	52.2	80.1	91.3
E-06-2-5	0.0	3.2	13.1	20.9	29.7	38.4	74.7	88.1
E-06-2-6	0.0	4.2	21.0	30.4	39.1	47.2	84.5	92.5
E-06-3-10	0.0	4.0	16.9	25.3	35.7	44.3	78.1	88.7
E-09-1-1	0.0	7.9	21.9	33.4	46.6	60.0	81.6	89.4
E-09-1-2	0.0	6.4	20.8	31.1	47.1	61.7	82.2	90.5
E-09-1-4	0.0	9.0	26.0	39.3	54.7	65.6	83.8	90.0
E-09-1-5	0.0	3.9	15.7	26.4	41.3	55.3	78.7	86.5
E-09-1-7	0.0	5.9	15.2	22.9	34.3	57.4	80.0	88.3
E-09-1-8	0.0	6.2	21.1	33.1	47.3	64.4	82.8	89.3
E-09-1-9	0.0	7.2	15.9	26.1	38.3	57.0	80.1	87.3
E-09-1-10	0.0	6.3	20.8	33.9	49.0	68.0	84.9	90.5
E-09-1-11	0.0	5.3	17.1	28.8	41.2	54.2	78.4	86.9
E-09-1-13	0.0	7.1	19.5	29.0	40.3	56.2	78.9	86.8
E-09-1-14	0.0	5.1	15.9	26.3	40.1	62.7	85.8	91.3
E-07-69-1-14	0.0	6.1	21.5	33.7	48.2	61.0	77.9	84.3
E-07-55-gal drum	0.0	6.3	18.1	29.7	45.1	57.6	75.3	82.0
E-07-68-2-6	0.0	4.9	21.4	34.2	48.9	61.7	78.9	84.9
E-08-235-1-12	0.0	1.9	15.4	26.7	41.1	55.8	85.4	90.5
E-08-55-gal drum	0.0	2.8	15.3	27.6	42.6	57.2	85.5	90.7
E-08-2-1-6	0.0	3.5	18.3	34.0	49.9	64.3	90.8	93.9

Table A-7. Tex-104, 105, 106, 116-E—Atterberg Limits and Wet Ball Mill for Sources Sampled by Stockpile.

Material ID - Stockpile # - Sample #	Liquid Limit	Plastic Limit	Plasticity Index	Wet Ball Mill Value	Wet Ball Mill % Increase
E-03-6-1	28	15	13	51	20
E-03-6-2	30	14	16		
E-03-6-3	32	19	13	49	14
E-03-6-4	25	15	10	50	15
E-03-6-5	25	15	10	42	16
E-03-6-6	28	16	12	46	15
E-03-6-10-1	26	12	14	53	11
E-03-6-10-2	27	14	13	40	14
E-03-6-10-3	27	14	13	48	17
E-03-6-7	27	18	9	40	18
E-03-6-8	28	16	12	49	21
E-03-6-9	24	15	9	41	15
E-03-6-10	26	14	12	50	16
E-03-6-11	29	15	14	48	16
E-03-2-10-1	30	15	15		
E-03-2-10-2				46	17
E-03-2-10-3	30	17	13	45	18
E-03-1-10-1	28	15	13	39	10
E-03-1-10-2	26	19	7	40	16
E-03-1-10-3	32	18	14		
E-03-1-10-4	27	20	7	40	17
E-03-1-10-5	25	19	6		
E-03-4-1	28	12	16		
E-03-4-1-2	31	16	15	33	19
E-03-4-1-3	30	19	11	38	20
E-03-4-1-4	29	17	12	43	19
E-03-4-1-5	28	16	12	55	42
E-03-4-2-1	35	15	20	60	25
E-03-4-3-10	34	14	20	47	19
E-03-4-4	26	18	8	34	17
E-05-61-1	15	12	3	30	11
E-05-61-2	15	11	4	27	10
E-05-61-3	14	10	4	21	9
E-05-61-4	15	12	3	28	9

Table A-7. Tex-104, 105, 106, 116-E—Atterberg Limits and Wet Ball Mill for Sources Sampled by Stockpile (Continued).

Material ID - Stockpile # - Sample #	Liquid Limit	Plastic Limit	Plasticity Index	Wet Ball Mill Value	Wet Ball Mill % Increase
E-05-61-5	14	12	2	27	9
E-05-61-7	14	11	3	26	8
E-05-61-8	14	11	3	29	9
E-05-61-9	14	10	4	32	10
E-05-61-10	14	12	2	30	11
E-05-61-11	14	12	2	23	9
E-05-61-12	13	10	3		
E-04-1-1	21	15	6	29	7
E-04-1-2				26	9
E-04-1-3	20	11	9		
E-04-1-4	19	14	5	29	8
E-04-1-5	18	14	4	24	7
E-04-1-6	21	14	7	29	9
E-04-1-7	20	14	6	29	10
E-04-1-8	19	13	6	25	9
E-04-1-9	22	15	7	30	10
E-04-1-10	22	15	7	27	8
E-04-1-11	21	14	7	22	8
E-04-1-12	24	15	9	32	8
E-04-1-13	25	15	10	34	9
E-04-1-14	21	14	7	26	9
E-04-2-2	20	14	6	30	11
E-04-2-3	22	13	9	30	12
E-04-2-4	20	13	7	23	10
E-04-2-6	22	10	12		
E-06-1-1	16	11	5	29	7
E-06-1-3	21	11	10	33	7
E-06-1-4	19	11	8	32	6
E-06-1-5	22	13	9	31	7
E-06-1-6	16	10	6	27	7
E-06-1-7	18	8	10	30	8
E-06-1-8	18	11	7	29	7
E-06-1-9	19	11	8	29	8
E-06-1-11	20	11	9	37	9

Table A-7. Tex-104, 105, 106, 116-E—Atterberg Limits and Wet Ball Mill for Sources Sampled by Stockpile (Continued).

Material ID - Stockpile # - Sample #	Liquid Limit	Plastic Limit	Plasticity Index	Wet Ball Mill Value	Wet Ball Mill % Increase
E-06-55-gal drum	16	8	8		
E-06-2-1	19	13	6	28	8
E-06-2-2	17	13	4	31	7
E-06-2-3	20	10	10	38	9
E-06-2-4	17	10	7	28	8
E-06-2-5	19	10	9	32	7
E-06-2-6	16	9	7		
E-06-3-10	14	9	5		
E-09-1-1	17	11	6	29	11
E-09-1-2	17	9	8	33	15
E-09-1-4	19	12	7	27	11
E-09-1-5	17	10	7	32	11
E-09-1-7	17	10	7	30	10
E-09-1-8	16	13	3	29	12
E-09-1-9	18	13	5	30	10
E-09-1-10	17	13	4	25	10
E-09-1-11	17	11	6	32	10
E-09-1-13	17	13	4	31	10
E-09-1-14	16	10	6		
E-07-69-1-1	17	12	5	37	15
E-07-69-1-2	16	14	2	44	12
E-07-69-1-3	17	13	4	39	13
E-07-69-1-4	17	14	3	37	13
E-07-69-1-5	16	14	2	33	12
E-07-69-1-6	16	14	2	35	13
E-07-69-1-7	17	13	4	30	13
E-07-69-1-8	18	13	5	37	12
E-07-69-1-9	18	14	4	29	11
E-07-69-1-10	16	13	3	41	11
E-07-69-1-11	17	13	4	40	9
E-07-69-1-14	17	10	7		
E-07-55-gal drum	16	10	6		
E-07-68-2-1	19	13	6	31	12
E-07-68-2-2	19	13	6	23	13

Table A-7. Tex-104, 105, 106, 116-E—Atterberg Limits and Wet Ball Mill for Sources Sampled by Stockpile (Continued).

Material ID - Stockpile # - Sample #	Liquid Limit	Plastic Limit	Plasticity Index	Wet Ball Mill Value	Wet Ball Mill % Increase
E-07-68-2-3	19	14	5	33	14
E-07-68-2-4	18	14	4	32	11
E-07-68-2-5	18	12	6	34	13
E-07-68-2-6	17	10	7		
E-08-235-1-1	18	13	5	23	7
E-08-235-1-2	16	13	3	20	6
E-08-235-1-3	19	13	6	23	6
E-08-235-1-4	17	12	5	21	5
E-08-235-1-5	19	13	6	23	4
E-08-235-1-6	16	12	4	22	6
E-08-235-1-7	15	12	3	21	7
E-08-235-1-8	15	13	2	22	9
E-08-235-1-9	17	12	5	18	6
E-08-235-1-10	17	13	4	19	6
E-08-235-1-11	18	13	5	19	6
E-08-235-1-12	15	9	6		
E-08-55-gal drum	15	8	7		
E-08-2-1-1	17	13	4	16	5
E-08-2-1-2	17	13	4	17	5
E-08-2-1-3	17	13	4	15	5
E-08-2-1-4	15	12	3	18	6
E-08-2-1-5	17	13	4	15	5
E-08-2-1-6	14	9	5		

Table A-8. Moisture Density Relations and Triaxial Compression Tests for Sources Sampled by Stockpile.

Material ID - Stockpile # - Sample #	Max Dry Density (pcf)	Optimum Moisture Content (%)	0 psi Strength (psi)	3 psi Strength (psi)	15 psi Strength (psi)
E-03-6-10-1	130.8	7.6	21.3	46.9	87.5
E-03-6-10-2	128.8	7.8	21.4	71.1	137.0
E-03-6-10-3	130.6	7.7	31.2	69.5	156.2
E-03-2-10-1	127.0	7.9	48.5	74.0	150.3
E-03-2-10-2	126.9	9.0	15.4	44.5	109.1
E-03-2-10-3	128.8	8.3	38.5	80.7	170.2
E-03-1-10-1	128.7	8.3			
E-03-1-10-2	125.9	9.2	41.1	109.8	197.3
E-03-1-10-3	124.1	8.8	60.0	96.8	184.1
E-03-1-10-4	125.0	9.2	38.1	88.4	195.9
E-03-1-10-5	126.2	8.9	59.8	104.8	200.0
E-03-4-3-10	126.6	9.2	24.9	66.1	133.0
E-05-61-12	141.5	6.0	20.1	110.3	203.1
E-05-55-gal drum	140.7	6.4	50.4	73.2	196.2
E-04-1-3	140.2	6.2	29.3	105.0	211.5
E-04-2-6	142.1	6.0	25.8	117.4	226.5
E-06-1-13	150.7	5.4	32.6	111.9	212.0
E-06-55-gal drum	149.9	5.4	61.4	112.6	234.8
E-06-2-6	150.4	5.6	32.2	128.9	227.1
E-06-3-10	150.2	5.4	49.0	130.3	253.6
E-09-1-14	136.4	7.9	28.6	102.9	152.0
E-07-69-1-14	137.7	7.4	22.2	76.3	191.2
E-07-55-gal drum	140.2	6.9	28.1	96.2	205.4
E-07-68-2-6	139.4	7.1	22.3	81.9	191.6
E-08-235-1-12	145.8	6.5	10.4	136.5	211.3
E-08-55-gal drum	145.8	6.5	42.4	103.3	255.4

APPENDIX B: SAMPLE SIZE

Table B-1. Cumulative % Retained above 1-1/4 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
						e =	e =	e =	e =	e =	e =	e =	e =	e =	e =	e=	e=	e=	e=	e=
				β (TxDot Risk)	0.1	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
0.995	0.01	0.005	2.576	z_β	1.28	54	24	14	9	6	5	4	3	3	2	2	2	2	1	1
0.985	0.03	0.015	2.17	σ	1.89	43	19	11	7	5	4	3	3	2	2	2	2	1	1	1
0.975	0.05	0.025	1.96			38	17	10	7	5	4	3	2	2	2	2	1	1	1	1
0.965	0.07	0.035	1.812			35	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.955	0.09	0.045	1.695	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2\sigma^2}{e^2}$		32	15	8	6	4	3	2	2	2	2	1	1	1	1	1
0.945	0.11	0.055	1.598			30	14	8	5	4	3	2	2	2	1	1	1	1	1	1
0.935	0.13	0.065	1.514			28	13	7	5	4	3	2	2	2	1	1	1	1	1	1
0.925	0.15	0.075	1.44			27	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.915	0.17	0.085	1.372			26	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.905	0.19	0.095	1.311			25	11	7	4	3	2	2	2	1	1	1	1	1	1	1
0.895	0.21	0.105	1.254			23	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.885	0.23	0.115	1.2			23	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.875	0.25	0.125	1.15			22	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.865	0.27	0.135	1.103			21	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.855	0.29	0.145	1.058			20	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.845	0.31	0.155	1.015			19	9	5	4	3	2	2	1	1	1	1	1	1	1	1

Table B-2. Cumulative % Retained above 1-1/4 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
						e =	e =	e =	e =	e =	e =	e =	e =	e =	e =	e=	e=	e=	e=	e=
				β (TxDot Risk)	0.2	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
0.995	0.01	0.005	2.576	z_β	0.84	42	19	11	7	5	4	3	3	2	2	2	1	1	1	1
0.985	0.03	0.015	2.17	σ	1.89	33	15	9	6	4	3	3	2	2	2	1	1	1	1	1
0.975	0.05	0.025	1.96			29	13	8	5	4	3	2	2	2	1	1	1	1	1	1
0.965	0.07	0.035	1.812			26	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.955	0.09	0.045	1.695	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2\sigma^2}{e^2}$		23	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.945	0.11	0.055	1.598			22	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.935	0.13	0.065	1.514			20	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.925	0.15	0.075	1.44			19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.915	0.17	0.085	1.372			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.905	0.19	0.095	1.311			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.895	0.21	0.105	1.254			16	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.885	0.23	0.115	1.2			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.875	0.25	0.125	1.15			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.865	0.27	0.135	1.103			14	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.855	0.29	0.145	1.058			13	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.845	0.31	0.155	1.015			13	6	4	2	2	2	1	1	1	1	1	1	1	1	1

Table B-3. Cumulative % Retained above 1-1/4 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e= 6.5	e= 7	e= 7.5	e= 8
0.995	0.01	0.005	2.576	z_β	0.52	35	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.985	0.03	0.015	2.17	σ	1.89	26	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.975	0.05	0.025	1.96			23	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.965	0.07	0.035	1.812			20	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.955	0.09	0.045	1.695	$n = \frac{(Z_{\alpha/2}+Z_\beta)^2\sigma^2}{e^2}$		18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.945	0.11	0.055	1.598			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.935	0.13	0.065	1.514			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.925	0.15	0.075	1.44			14	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.915	0.17	0.085	1.372			13	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.905	0.19	0.095	1.311			13	6	4	2	2	1	1	1	1	1	1	1	1	1	1
0.895	0.21	0.105	1.254			12	6	3	2	2	1	1	1	1	1	1	1	1	1	1
0.885	0.23	0.115	1.2			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.875	0.25	0.125	1.15			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.865	0.27	0.135	1.103			10	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.855	0.29	0.145	1.058			9	4	3	2	1	1	1	1	1	1	1	1	1	1	1
0.845	0.31	0.155	1.015			9	4	3	2	1	1	1	1	1	1	1	1	1	1	1

Table B-4. Cumulative % Retained above 7/8 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	1.28	239	106	60	39	27	20	15	12	10	8	7	6	5	5	4
0.985	0.03	0.015	2.17	σ	4	191	85	48	31	22	16	12	10	8	7	6	5	4	4	3
0.975	0.05	0.025	1.96			169	75	43	27	19	14	11	9	7	6	5	4	4	3	3
0.965	0.07	0.035	1.81			154	69	39	25	18	13	10	8	7	6	5	4	4	3	3
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2}+Z_\beta)^2\sigma^2}{e^2}$		142	64	36	23	16	12	9	8	6	5	4	4	3	3	3
0.945	0.11	0.055	1.6			133	59	34	22	15	11	9	7	6	5	4	4	3	3	3
0.935	0.13	0.065	1.51			126	56	32	21	14	11	8	7	6	5	4	3	3	3	2
0.925	0.15	0.075	1.44			119	53	30	19	14	10	8	6	5	4	4	3	3	3	2
0.915	0.17	0.085	1.37			113	51	29	19	13	10	8	6	5	4	4	3	3	3	2
0.905	0.19	0.095	1.31			108	48	27	18	12	9	7	6	5	4	3	3	3	2	2
0.895	0.21	0.105	1.25			103	46	26	17	12	9	7	6	5	4	3	3	3	2	2
0.885	0.23	0.115	1.2			99	44	25	16	11	9	7	5	4	4	3	3	3	2	2
0.875	0.25	0.125	1.15			95	43	24	16	11	8	6	5	4	4	3	3	2	2	2
0.865	0.27	0.135	1.1			91	41	23	15	11	8	6	5	4	4	3	3	2	2	2
0.855	0.29	0.145	1.06			88	39	22	15	10	8	6	5	4	3	3	3	2	2	2
0.845	0.31	0.155	1.02			85	38	22	14	10	7	6	5	4	3	3	2	2	2	2

Table B-5. Cumulative % Retained above 7/8 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.84	187	84	47	30	21	16	12	10	8	7	6	5	4	4	3
0.985	0.03	0.015	2.17	σ	4	146	65	37	24	17	12	10	8	6	5	5	4	3	3	3
0.975	0.05	0.025	1.96			126	56	32	21	14	11	8	7	6	5	4	3	3	3	2
0.965	0.07	0.035	1.81			113	51	29	19	13	10	8	6	5	4	4	3	3	3	2
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		103	46	26	17	12	9	7	6	5	4	3	3	3	2	2
0.945	0.11	0.055	1.6			96	43	24	16	11	8	6	5	4	4	3	3	2	2	2
0.935	0.13	0.065	1.51			89	40	23	15	10	8	6	5	4	3	3	3	2	2	2
0.925	0.15	0.075	1.44			84	38	21	14	10	7	6	5	4	3	3	2	2	2	2
0.915	0.17	0.085	1.37			79	35	20	13	9	7	5	4	4	3	3	2	2	2	2
0.905	0.19	0.095	1.31			75	33	19	12	9	7	5	4	3	3	3	2	2	2	2
0.895	0.21	0.105	1.25			71	32	18	12	8	6	5	4	3	3	2	2	2	2	2
0.885	0.23	0.115	1.2			67	30	17	11	8	6	5	4	3	3	2	2	2	2	2
0.875	0.25	0.125	1.15			64	29	16	11	8	6	4	4	3	3	2	2	2	2	1
0.865	0.27	0.135	1.1			61	27	16	10	7	5	4	3	3	3	2	2	2	2	1
0.855	0.29	0.145	1.06			58	26	15	10	7	5	4	3	3	2	2	2	2	2	1
0.845	0.31	0.155	1.02			56	25	14	9	7	5	4	3	3	2	2	2	2	1	1

Table B-6. Cumulative % Retained above 7/8 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.52	154	69	39	25	18	13	10	8	7	6	5	4	4	3	3
0.985	0.03	0.015	2.17	σ	4	117	52	30	19	13	10	8	6	5	4	4	3	3	3	2
0.975	0.05	0.025	1.96			99	44	25	16	11	9	7	5	4	4	3	3	3	2	2
0.965	0.07	0.035	1.81			88	39	22	14	10	8	6	5	4	3	3	3	2	2	2
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		79	36	20	13	9	7	5	4	4	3	3	2	2	2	2
0.945	0.11	0.055	1.6			73	33	19	12	9	6	5	4	3	3	3	2	2	2	2
0.935	0.13	0.065	1.51			67	30	17	11	8	6	5	4	3	3	2	2	2	2	2
0.925	0.15	0.075	1.44			62	28	16	10	7	6	4	4	3	3	2	2	2	2	1
0.915	0.17	0.085	1.37			58	26	15	10	7	5	4	3	3	2	2	2	2	2	1
0.905	0.19	0.095	1.31			54	24	14	9	6	5	4	3	3	2	2	2	2	1	1
0.895	0.21	0.105	1.25			51	23	13	9	6	5	4	3	3	2	2	2	2	1	1
0.885	0.23	0.115	1.2			48	22	12	8	6	4	3	3	2	2	2	2	1	1	1
0.875	0.25	0.125	1.15			45	20	12	8	5	4	3	3	2	2	2	2	1	1	1
0.865	0.27	0.135	1.1			43	19	11	7	5	4	3	3	2	2	2	2	1	1	1
0.855	0.29	0.145	1.06			41	18	11	7	5	4	3	2	2	2	2	1	1	1	1
0.845	0.31	0.155	1.02			38	17	10	7	5	4	3	2	2	2	2	1	1	1	1

Table B-7. Cumulative % Retained above 5/8 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	1.28	392	175	98	63	44	32	25	20	16	13	11	10	8	7	7
0.985	0.03	0.015	2.17	σ	5.13	314	140	79	51	35	26	20	16	13	11	9	8	7	6	5
0.975	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2\sigma^2}{e^2}$		277	123	70	45	31	23	18	14	12	10	8	7	6	5	5
0.965	0.07	0.035	1.81			252	112	63	41	28	21	16	13	11	9	7	6	6	5	4
0.955	0.09	0.045	1.7			234	104	59	38	26	20	15	12	10	8	7	6	5	5	4
0.945	0.11	0.055	1.6			219	97	55	35	25	18	14	11	9	8	7	6	5	4	4
0.935	0.13	0.065	1.51			206	92	52	33	23	17	13	11	9	7	6	5	5	4	4
0.925	0.15	0.075	1.44			195	87	49	32	22	16	13	10	8	7	6	5	4	4	4
0.915	0.17	0.085	1.37			186	83	47	30	21	16	12	10	8	7	6	5	4	4	3
0.905	0.19	0.095	1.31			177	79	45	29	20	15	12	9	8	6	5	5	4	4	3
0.895	0.21	0.105	1.25			170	76	43	28	19	14	11	9	7	6	5	5	4	4	3
0.885	0.23	0.115	1.2			163	73	41	26	19	14	11	9	7	6	5	4	4	3	3
0.875	0.25	0.125	1.15			156	70	39	25	18	13	10	8	7	6	5	4	4	3	3
0.865	0.27	0.135	1.1			150	67	38	24	17	13	10	8	6	5	5	4	4	3	3
0.855	0.29	0.145	1.06			145	65	37	24	17	12	10	8	6	5	5	4	3	3	3
0.845	0.31	0.155	1.02			139	62	35	23	16	12	9	7	6	5	4	4	3	3	3

Table B-8. Cumulative % Retained above 5/8 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.84	308	137	77	50	35	26	20	16	13	11	9	8	7	6	5
0.985	0.03	0.015	2.17	σ	5.13	239	107	60	39	27	20	15	12	10	8	7	6	5	5	4
0.975	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2\sigma^2}{e^2}$		207	92	52	34	23	17	13	11	9	7	6	5	5	4	4
0.965	0.07	0.035	1.81			186	83	47	30	21	16	12	10	8	7	6	5	4	4	3
0.955	0.09	0.045	1.7			170	76	43	28	19	14	11	9	7	6	5	5	4	4	3
0.945	0.11	0.055	1.6			157	70	40	26	18	13	10	8	7	6	5	4	4	3	3
0.935	0.13	0.065	1.51			147	65	37	24	17	12	10	8	6	5	5	4	3	3	3
0.925	0.15	0.075	1.44			137	61	35	22	16	12	9	7	6	5	4	4	3	3	3
0.915	0.17	0.085	1.37			129	58	33	21	15	11	9	7	6	5	4	4	3	3	3
0.905	0.19	0.095	1.31			122	55	31	20	14	10	8	7	5	5	4	3	3	3	2
0.895	0.21	0.105	1.25			116	52	29	19	13	10	8	6	5	4	4	3	3	3	2
0.885	0.23	0.115	1.2			110	49	28	18	13	9	7	6	5	4	4	3	3	2	2
0.875	0.25	0.125	1.15			105	47	27	17	12	9	7	6	5	4	3	3	3	2	2
0.865	0.27	0.135	1.1			100	45	25	16	12	9	7	5	4	4	3	3	3	2	2
0.855	0.29	0.145	1.06			95	43	24	16	11	8	6	5	4	4	3	3	2	2	2
0.845	0.31	0.155	1.02			91	41	23	15	11	8	6	5	4	3	3	3	2	2	2

Table B-9. Cumulative % Retained above 5/8 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.52	253	113	64	41	29	21	16	13	11	9	8	6	6	5	4
0.985	0.03	0.015	2.17	σ	5.13	192	85	48	31	22	16	12	10	8	7	6	5	4	4	3
0.975	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		163	73	41	26	19	14	11	9	7	6	5	4	4	3	3
0.965	0.07	0.035	1.81			144	64	36	23	16	12	9	8	6	5	4	4	3	3	3
0.955	0.09	0.045	1.7			130	58	33	21	15	11	9	7	6	5	4	4	3	3	3
0.945	0.11	0.055	1.6			119	53	30	19	14	10	8	6	5	4	4	3	3	3	2
0.935	0.13	0.065	1.51			110	49	28	18	13	9	7	6	5	4	4	3	3	2	2
0.925	0.15	0.075	1.44			102	46	26	17	12	9	7	6	5	4	3	3	3	2	2
0.915	0.17	0.085	1.37			95	43	24	16	11	8	6	5	4	4	3	3	2	2	2
0.905	0.19	0.095	1.31			89	40	23	15	10	8	6	5	4	3	3	3	2	2	2
0.895	0.21	0.105	1.25			84	37	21	14	10	7	6	5	4	3	3	2	2	2	2
0.885	0.23	0.115	1.2			79	35	20	13	9	7	5	4	4	3	3	2	2	2	2
0.875	0.25	0.125	1.15			74	33	19	12	9	7	5	4	3	3	3	2	2	2	2
0.865	0.27	0.135	1.1			70	31	18	12	8	6	5	4	3	3	2	2	2	2	2
0.855	0.29	0.145	1.06			66	30	17	11	8	6	5	4	3	3	2	2	2	2	2
0.845	0.31	0.155	1.02			63	28	16	10	7	6	4	4	3	3	2	2	2	2	1

Table B-10. Cumulative % Retained above 3/8 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	1.28	486	216	122	78	54	40	31	24	20	17	14	12	10	9	8
0.985	0.03	0.015	2.17	σ	5.71	389	173	98	63	44	32	25	20	16	13	11	10	8	7	7
0.975	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		343	153	86	55	39	28	22	17	14	12	10	9	7	7	6
0.965	0.07	0.035	1.81			313	139	79	50	35	26	20	16	13	11	9	8	7	6	5
0.955	0.09	0.045	1.7			289	129	73	47	33	24	19	15	12	10	9	7	6	6	5
0.945	0.11	0.055	1.6			271	121	68	44	31	23	17	14	11	9	8	7	6	5	5
0.935	0.13	0.065	1.51			255	114	64	41	29	21	16	13	11	9	8	7	6	5	4
0.925	0.15	0.075	1.44			242	108	61	39	27	20	16	12	10	8	7	6	5	5	4
0.915	0.17	0.085	1.37			230	103	58	37	26	19	15	12	10	8	7	6	5	5	4
0.905	0.19	0.095	1.31			220	98	55	36	25	18	14	11	9	8	7	6	5	4	4
0.895	0.21	0.105	1.25			210	94	53	34	24	18	14	11	9	7	6	5	5	4	4
0.885	0.23	0.115	1.2			201	90	51	33	23	17	13	10	9	7	6	5	5	4	4
0.875	0.25	0.125	1.15			193	86	49	31	22	16	13	10	8	7	6	5	4	4	4
0.865	0.27	0.135	1.1			186	83	47	30	21	16	12	10	8	7	6	5	4	4	3
0.855	0.29	0.145	1.06			179	80	45	29	20	15	12	9	8	6	5	5	4	4	3
0.845	0.31	0.155	1.02			172	77	43	28	20	15	11	9	7	6	5	5	4	4	3

Table B-11. Cumulative % Retained above 3/8 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.84	381	170	96	61	43	32	24	19	16	13	11	10	8	7	6
0.985	0.03	0.015	2.17	σ	5.71	296	132	74	48	33	25	19	15	12	10	9	7	7	6	5
0.975	0.05	0.025	1.96			256	114	64	41	29	21	16	13	11	9	8	7	6	5	4
0.965	0.07	0.035	1.81			230	103	58	37	26	19	15	12	10	8	7	6	5	5	4
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2}+Z_\beta)^2\sigma^2}{e^2}$		210	94	53	34	24	18	14	11	9	7	6	5	5	4	4
0.945	0.11	0.055	1.6			195	87	49	32	22	16	13	10	8	7	6	5	4	4	4
0.935	0.13	0.065	1.51			181	81	46	29	21	15	12	9	8	6	6	5	4	4	3
0.925	0.15	0.075	1.44			170	76	43	28	19	14	11	9	7	6	5	5	4	4	3
0.915	0.17	0.085	1.37			160	72	40	26	18	14	10	8	7	6	5	4	4	3	3
0.905	0.19	0.095	1.31			152	68	38	25	17	13	10	8	7	5	5	4	4	3	3
0.895	0.21	0.105	1.25			144	64	36	23	16	12	9	8	6	5	4	4	3	3	3
0.885	0.23	0.115	1.2			136	61	34	22	16	12	9	7	6	5	4	4	3	3	3
0.875	0.25	0.125	1.15			130	58	33	21	15	11	9	7	6	5	4	4	3	3	3
0.865	0.27	0.135	1.1			124	55	31	20	14	11	8	7	5	5	4	3	3	3	2
0.855	0.29	0.145	1.06			118	53	30	19	14	10	8	6	5	4	4	3	3	3	2
0.845	0.31	0.155	1.02			113	50	29	18	13	10	8	6	5	4	4	3	3	2	2

Table B-12. Cumulative % Retained above 3/8 Inches: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.52	314	140	79	51	35	26	20	16	13	11	9	8	7	6	5
0.985	0.03	0.015	2.17	σ	5.71	237	106	60	38	27	20	15	12	10	8	7	6	5	5	4
0.975	0.05	0.025	1.96			202	90	51	33	23	17	13	10	9	7	6	5	5	4	4
0.965	0.07	0.035	1.81			178	80	45	29	20	15	12	9	8	6	5	5	4	4	3
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2}+Z_\beta)^2\sigma^2}{e^2}$		161	72	41	26	18	14	11	8	7	6	5	4	4	3	3
0.945	0.11	0.055	1.6			147	66	37	24	17	12	10	8	6	5	5	4	3	3	3
0.935	0.13	0.065	1.51			136	61	34	22	16	12	9	7	6	5	4	4	3	3	3
0.925	0.15	0.075	1.44			126	56	32	21	14	11	8	7	6	5	4	3	3	3	2
0.915	0.17	0.085	1.37			118	53	30	19	14	10	8	6	5	4	4	3	3	3	2
0.905	0.19	0.095	1.31			110	49	28	18	13	9	7	6	5	4	4	3	3	2	2
0.895	0.21	0.105	1.25			104	46	26	17	12	9	7	6	5	4	3	3	3	2	2
0.885	0.23	0.115	1.2			97	44	25	16	11	8	7	5	4	4	3	3	2	2	2
0.875	0.25	0.125	1.15			92	41	23	15	11	8	6	5	4	4	3	3	2	2	2
0.865	0.27	0.135	1.1			87	39	22	14	10	8	6	5	4	3	3	3	2	2	2
0.855	0.29	0.145	1.06			82	37	21	14	10	7	6	5	4	3	3	2	2	2	2
0.845	0.31	0.155	1.02			78	35	20	13	9	7	5	4	4	3	3	2	2	2	2

Table B-13. Cumulative % Retained above #4: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.01	2.58	z_β	1.28	508	226	127	82	57	42	32	26	21	17	15	13	11	10	8
0.985	0.03	0.02	2.17	σ	5.84	407	181	102	66	46	34	26	21	17	14	12	10	9	8	7
0.975	0.05	0.03	1.96			359	160	90	58	40	30	23	18	15	12	10	9	8	7	6
0.965	0.07	0.04	1.81			327	146	82	53	37	27	21	17	14	11	10	8	7	6	6
0.955	0.09	0.05	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		303	135	76	49	34	25	19	15	13	10	9	8	7	6	5
0.945	0.11	0.06	1.6			283	126	71	46	32	24	18	14	12	10	8	7	6	6	5
0.935	0.13	0.07	1.51			267	119	67	43	30	22	17	14	11	9	8	7	6	5	5
0.925	0.15	0.08	1.44			253	113	64	41	29	21	16	13	11	9	8	6	6	5	4
0.915	0.17	0.09	1.37			241	107	61	39	27	20	16	12	10	8	7	6	5	5	4
0.905	0.19	0.1	1.31			230	102	58	37	26	19	15	12	10	8	7	6	5	5	4
0.895	0.21	0.11	1.25			220	98	55	36	25	18	14	11	9	8	7	6	5	4	4
0.885	0.23	0.12	1.2			211	94	53	34	24	18	14	11	9	7	6	5	5	4	4
0.875	0.25	0.13	1.15			202	90	51	33	23	17	13	10	9	7	6	5	5	4	4
0.865	0.27	0.14	1.1			194	87	49	32	22	16	13	10	8	7	6	5	4	4	4
0.855	0.29	0.15	1.06			187	83	47	30	21	16	12	10	8	7	6	5	4	4	3
0.845	0.31	0.16	1.02			180	80	45	29	20	15	12	9	8	6	5	5	4	4	3

Table B-14. Cumulative % Retained above #4: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.01	2.58	z_β	0.84	399	178	100	64	45	33	25	20	16	14	12	10	9	8	7
0.985	0.03	0.02	2.17	σ	5.84	310	138	78	50	35	26	20	16	13	11	9	8	7	6	5
0.975	0.05	0.03	1.96			268	119	67	43	30	22	17	14	11	9	8	7	6	5	5
0.965	0.07	0.04	1.81			241	107	61	39	27	20	16	12	10	8	7	6	5	5	4
0.955	0.09	0.05	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		220	98	55	36	25	18	14	11	9	8	7	6	5	4	4
0.945	0.11	0.06	1.6			204	91	51	33	23	17	13	11	9	7	6	5	5	4	4
0.935	0.13	0.07	1.51			190	85	48	31	22	16	12	10	8	7	6	5	4	4	3
0.925	0.15	0.08	1.44			178	79	45	29	20	15	12	9	8	6	5	5	4	4	3
0.915	0.17	0.09	1.37			168	75	42	27	19	14	11	9	7	6	5	4	4	3	3
0.905	0.19	0.1	1.31			158	71	40	26	18	13	10	8	7	6	5	4	4	3	3
0.895	0.21	0.11	1.25			150	67	38	24	17	13	10	8	6	5	5	4	4	3	3
0.885	0.23	0.12	1.2			143	64	36	23	16	12	9	8	6	5	4	4	3	3	3
0.875	0.25	0.13	1.15			136	61	34	22	16	12	9	7	6	5	4	4	3	3	3
0.865	0.27	0.14	1.1			129	58	33	21	15	11	9	7	6	5	4	4	3	3	3
0.855	0.29	0.15	1.06			124	55	31	20	14	11	8	7	5	5	4	3	3	3	2
0.845	0.31	0.16	1.02			118	53	30	19	14	10	8	6	5	4	4	3	3	3	2

Table B-15. Cumulative % Retained above #4: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.01	2.58	z_β	0.52	328	146	82	53	37	27	21	17	14	11	10	8	7	6	6
0.985	0.03	0.02	2.17	σ	5.84	248	111	62	40	28	21	16	13	10	9	7	6	6	5	4
0.975	0.05	0.03	1.96			211	94	53	34	24	18	14	11	9	7	6	5	5	4	4
0.965	0.07	0.04	1.81			187	83	47	30	21	16	12	10	8	7	6	5	4	4	3
0.955	0.09	0.05	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		169	75	43	27	19	14	11	9	7	6	5	4	4	3	3
0.945	0.11	0.06	1.6			154	69	39	25	18	13	10	8	7	6	5	4	4	3	3
0.935	0.13	0.07	1.51			142	63	36	23	16	12	9	7	6	5	4	4	3	3	3
0.925	0.15	0.08	1.44			132	59	33	22	15	11	9	7	6	5	4	4	3	3	3
0.915	0.17	0.09	1.37			123	55	31	20	14	11	8	7	5	5	4	3	3	3	2
0.905	0.19	0.1	1.31			115	52	29	19	13	10	8	6	5	4	4	3	3	3	2
0.895	0.21	0.11	1.25			108	48	27	18	12	9	7	6	5	4	3	3	3	2	2
0.885	0.23	0.12	1.2			102	46	26	17	12	9	7	6	5	4	3	3	3	2	2
0.875	0.25	0.13	1.15			96	43	24	16	11	8	6	5	4	4	3	3	2	2	2
0.865	0.27	0.14	1.1			91	41	23	15	11	8	6	5	4	3	3	3	2	2	2
0.855	0.29	0.15	1.06			86	38	22	14	10	7	6	5	4	3	3	3	2	2	2
0.845	0.31	0.16	1.02			81	36	21	13	9	7	6	4	4	3	3	2	2	2	2

Table B-16. Cumulative % Retained above #40: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	1.28	211	94	53	34	24	18	14	11	9	7	6	5	5	4	4
0.985	0.03	0.015	2.17	σ	3.76	169	75	43	27	19	14	11	9	7	6	5	4	4	3	3
0.975	0.05	0.025	1.96			149	67	38	24	17	13	10	8	6	5	5	4	4	3	3
0.965	0.07	0.035	1.81			136	61	34	22	16	12	9	7	6	5	4	4	3	3	3
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		126	56	32	21	14	11	8	7	6	5	4	3	3	3	2
0.945	0.11	0.055	1.6			118	53	30	19	14	10	8	6	5	4	4	3	3	3	2
0.935	0.13	0.065	1.51			111	50	28	18	13	10	7	6	5	4	4	3	3	2	2
0.925	0.15	0.075	1.44			105	47	27	17	12	9	7	6	5	4	3	3	3	2	2
0.915	0.17	0.085	1.37			100	45	25	16	12	9	7	5	4	4	3	3	3	2	2
0.905	0.19	0.095	1.31			95	43	24	16	11	8	6	5	4	4	3	3	2	2	2
0.895	0.21	0.105	1.25			91	41	23	15	11	8	6	5	4	4	3	3	2	2	2
0.885	0.23	0.115	1.2			88	39	22	14	10	8	6	5	4	3	3	3	2	2	2
0.875	0.25	0.125	1.15			84	38	21	14	10	7	6	5	4	3	3	2	2	2	2
0.865	0.27	0.135	1.1			81	36	21	13	9	7	6	4	4	3	3	2	2	2	2
0.855	0.29	0.145	1.06			78	35	20	13	9	7	5	4	4	3	3	2	2	2	2
0.845	0.31	0.155	1.02			75	34	19	12	9	7	5	4	3	3	3	2	2	2	2

Table B-17. Cumulative % Retained above #40: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.84	166	74	42	27	19	14	11	9	7	6	5	4	4	3	3
0.985	0.03	0.015	2.17	σ	3.76	129	57	33	21	15	11	9	7	6	5	4	4	3	3	3
0.975	0.05	0.025	1.96			111	50	28	18	13	10	7	6	5	4	4	3	3	2	2
0.965	0.07	0.035	1.81			100	45	25	16	12	9	7	5	4	4	3	3	3	2	2
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		91	41	23	15	11	8	6	5	4	4	3	3	2	2	2
0.945	0.11	0.055	1.6			85	38	22	14	10	7	6	5	4	3	3	2	2	2	2
0.935	0.13	0.065	1.51			79	35	20	13	9	7	5	4	4	3	3	2	2	2	2
0.925	0.15	0.075	1.44			74	33	19	12	9	7	5	4	3	3	3	2	2	2	2
0.915	0.17	0.085	1.37			70	31	18	12	8	6	5	4	3	3	2	2	2	2	2
0.905	0.19	0.095	1.31			66	30	17	11	8	6	5	4	3	3	2	2	2	2	2
0.895	0.21	0.105	1.25			63	28	16	10	7	6	4	4	3	3	2	2	2	2	1
0.885	0.23	0.115	1.2			59	27	15	10	7	5	4	3	3	2	2	2	2	2	1
0.875	0.25	0.125	1.15			57	25	15	9	7	5	4	3	3	2	2	2	2	1	1
0.865	0.27	0.135	1.1			54	24	14	9	6	5	4	3	3	2	2	2	2	1	1
0.855	0.29	0.145	1.06			52	23	13	9	6	5	4	3	3	2	2	2	2	1	1
0.845	0.31	0.155	1.02			49	22	13	8	6	4	4	3	2	2	2	2	1	1	1

Table B-18. Cumulative % Retained above #40: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.52	136	61	34	22	16	12	9	7	6	5	4	4	3	3	3
0.985	0.03	0.015	2.17	σ	3.76	103	46	26	17	12	9	7	6	5	4	3	3	3	2	2
0.975	0.05	0.025	1.96			88	39	22	14	10	8	6	5	4	3	3	3	2	2	2
0.965	0.07	0.035	1.81			78	35	20	13	9	7	5	4	4	3	3	2	2	2	2
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		70	31	18	12	8	6	5	4	3	3	2	2	2	2	2
0.945	0.11	0.055	1.6			64	29	16	11	8	6	4	4	3	3	2	2	2	2	1
0.935	0.13	0.065	1.51			59	27	15	10	7	5	4	3	3	2	2	2	2	2	1
0.925	0.15	0.075	1.44			55	25	14	9	7	5	4	3	3	2	2	2	2	1	1
0.915	0.17	0.085	1.37			51	23	13	9	6	5	4	3	3	2	2	2	2	1	1
0.905	0.19	0.095	1.31			48	22	12	8	6	4	3	3	2	2	2	2	1	1	1
0.895	0.21	0.105	1.25			45	20	12	8	5	4	3	3	2	2	2	2	1	1	1
0.885	0.23	0.115	1.2			43	19	11	7	5	4	3	3	2	2	2	1	1	1	1
0.875	0.25	0.125	1.15			40	18	10	7	5	4	3	2	2	2	2	1	1	1	1
0.865	0.27	0.135	1.1			38	17	10	6	5	4	3	2	2	2	2	1	1	1	1
0.855	0.29	0.145	1.06			36	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.845	0.31	0.155	1.02			34	15	9	6	4	3	3	2	2	2	1	1	1	1	1

Table B-19. Cumulative % Retained above #200: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	1.28	95	42	24	16	11	8	6	5	4	4	3	3	2	2	2
0.985	0.03	0.015	2.17	σ	2.52	76	34	19	13	9	7	5	4	4	3	3	2	2	2	2
0.975	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		67	30	17	11	8	6	5	4	3	3	2	2	2	2	2
0.965	0.07	0.035	1.81			61	28	16	10	7	5	4	4	3	3	2	2	2	2	1
0.955	0.09	0.045	1.7			57	26	15	10	7	5	4	3	3	2	2	2	2	2	1
0.945	0.11	0.055	1.6			53	24	14	9	6	5	4	3	3	2	2	2	2	1	1
0.935	0.13	0.065	1.51			50	23	13	8	6	5	4	3	2	2	2	2	2	1	1
0.925	0.15	0.075	1.44			48	21	12	8	6	4	3	3	2	2	2	2	1	1	1
0.915	0.17	0.085	1.37			45	20	12	8	5	4	3	3	2	2	2	2	1	1	1
0.905	0.19	0.095	1.31			43	19	11	7	5	4	3	3	2	2	2	2	1	1	1
0.895	0.21	0.105	1.25			41	19	11	7	5	4	3	3	2	2	2	1	1	1	1
0.885	0.23	0.115	1.2			40	18	10	7	5	4	3	2	2	2	2	1	1	1	1
0.875	0.25	0.125	1.15			38	17	10	7	5	4	3	2	2	2	2	1	1	1	1
0.865	0.27	0.135	1.1			37	17	10	6	5	3	3	2	2	2	2	1	1	1	1
0.855	0.29	0.145	1.06			35	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.845	0.31	0.155	1.02			34	15	9	6	4	3	3	2	2	2	1	1	1	1	1

Table B-20. Cumulative % Retained above #200: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.84	75	33	19	12	9	7	5	4	3	3	3	2	2	2	2
0.985	0.03	0.015	2.17	σ	2.52	58	26	15	10	7	5	4	3	3	2	2	2	2	2	1
0.975	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		50	23	13	8	6	5	4	3	2	2	2	2	2	1	1
0.965	0.07	0.035	1.81			45	20	12	8	5	4	3	3	2	2	2	2	1	1	1
0.955	0.09	0.045	1.7			41	19	11	7	5	4	3	3	2	2	2	1	1	1	1
0.945	0.11	0.055	1.6			38	17	10	7	5	4	3	2	2	2	2	1	1	1	1
0.935	0.13	0.065	1.51			36	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.925	0.15	0.075	1.44			34	15	9	6	4	3	3	2	2	2	1	1	1	1	1
0.915	0.17	0.085	1.37			32	14	8	5	4	3	2	2	2	2	1	1	1	1	1
0.905	0.19	0.095	1.31			30	14	8	5	4	3	2	2	2	1	1	1	1	1	1
0.895	0.21	0.105	1.25			28	13	7	5	4	3	2	2	2	1	1	1	1	1	1
0.885	0.23	0.115	1.2			27	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.875	0.25	0.125	1.15			26	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.865	0.27	0.135	1.1			25	11	7	4	3	2	2	2	1	1	1	1	1	1	1
0.855	0.29	0.145	1.06			23	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.845	0.31	0.155	1.02			22	10	6	4	3	2	2	2	1	1	1	1	1	1	1

Table B-21. Cumulative % Retained above #200: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.52	62	28	16	10	7	5	4	4	3	3	2	2	2	2	1
0.985	0.03	0.015	2.17	σ	2.52	47	21	12	8	6	4	3	3	2	2	2	2	1	1	1
0.975	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		40	18	10	7	5	4	3	2	2	2	2	1	1	1	1
0.965	0.07	0.035	1.81			35	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.955	0.09	0.045	1.7			32	14	8	6	4	3	2	2	2	2	1	1	1	1	1
0.945	0.11	0.055	1.6			29	13	8	5	4	3	2	2	2	1	1	1	1	1	1
0.935	0.13	0.065	1.51			27	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.925	0.15	0.075	1.44			25	11	7	4	3	2	2	2	1	1	1	1	1	1	1
0.915	0.17	0.085	1.37			23	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.905	0.19	0.095	1.31			22	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.895	0.21	0.105	1.25			21	9	6	4	3	2	2	1	1	1	1	1	1	1	1
0.885	0.23	0.115	1.2			19	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.875	0.25	0.125	1.15			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.865	0.27	0.135	1.1			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.855	0.29	0.145	1.06			16	8	4	3	2	2	1	1	1	1	1	1	1	1	1
0.845	0.31	0.155	1.02			16	7	4	3	2	2	1	1	1	1	1	1	1	1	1

Table B-22. Plastic Limit: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
1	0.01	0.005	2.58	z_β	1.28	46	21	12	8	6	4	3	3	2	2	2	2	1	1	1
0.99	0.03	0.015	2.17	σ	1.74	37	17	10	6	5	3	3	2	2	2	2	1	1	1	1
0.98	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		32	15	8	6	4	3	2	2	2	2	1	1	1	1	1
0.97	0.07	0.035	1.81			29	13	8	5	4	3	2	2	2	1	1	1	1	1	1
0.96	0.09	0.045	1.7			27	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.95	0.11	0.055	1.6			26	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.94	0.13	0.065	1.51			24	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.93	0.15	0.075	1.44			23	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.92	0.17	0.085	1.37			22	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.91	0.19	0.095	1.31			21	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.9	0.21	0.105	1.25			20	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.89	0.23	0.115	1.2			19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.88	0.25	0.125	1.15			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.87	0.27	0.135	1.1			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.86	0.29	0.145	1.06			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.85	0.31	0.155	1.02			16	8	4	3	2	2	1	1	1	1	1	1	1	1	1

Table B-23. Plastic Limit: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
1	0.01	0.005	2.58	z_β	0.84	36	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.99	0.03	0.015	2.17	σ	1.74	28	13	7	5	4	3	2	2	2	1	1	1	1	1	1
0.98	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		24	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.97	0.07	0.035	1.81			22	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.96	0.09	0.045	1.7			20	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.95	0.11	0.055	1.6			19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.94	0.13	0.065	1.51			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.93	0.15	0.075	1.44			16	8	4	3	2	2	1	1	1	1	1	1	1	1	1
0.92	0.17	0.085	1.37			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.91	0.19	0.095	1.31			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.9	0.21	0.105	1.25			14	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.89	0.23	0.115	1.2			13	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.88	0.25	0.125	1.15			13	6	4	2	2	1	1	1	1	1	1	1	1	1	1
0.87	0.27	0.135	1.1			12	6	3	2	2	1	1	1	1	1	1	1	1	1	1
0.86	0.29	0.145	1.06			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.85	0.31	0.155	1.02			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1

Table B-24. Plastic Limit: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
1	0.01	0.005	2.58	z_β	0.52	30	13	8	5	4	3	2	2	2	1	1	1	1	1	1
0.99	0.03	0.015	2.17	σ	1.74	22	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.98	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.97	0.07	0.035	1.81			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.96	0.09	0.045	1.7			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.95	0.11	0.055	1.6			14	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.94	0.13	0.065	1.51			13	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.93	0.15	0.075	1.44			12	6	3	2	2	1	1	1	1	1	1	1	1	1	1
0.92	0.17	0.085	1.37			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.91	0.19	0.095	1.31			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.9	0.21	0.105	1.25			10	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.89	0.23	0.115	1.2			10	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.88	0.25	0.125	1.15			9	4	3	2	1	1	1	1	1	1	1	1	1	1	1
0.87	0.27	0.135	1.1			9	4	3	2	1	1	1	1	1	1	1	1	1	1	1
0.86	0.29	0.145	1.06			8	4	2	2	1	1	1	1	1	1	1	1	1	1	1
0.85	0.31	0.155	1.02			8	4	2	2	1	1	1	1	1	1	1	1	1	1	1

Table B-25. Liquid Limit: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α	α (Producer Risk)	α/2	Z_α	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.99	0.01	0.005	2.33	z_β	1.28	56	25	14	9	7	5	4	3	3	2	2	2	2	1	1
0.97	0.03	0.015	1.88	σ	2.07	43	20	11	7	5	4	3	3	2	2	2	2	1	1	1
0.95	0.05	0.025	1.64			37	17	10	6	5	3	3	2	2	2	2	1	1	1	1
0.93	0.07	0.035	1.48			33	15	9	6	4	3	3	2	2	2	1	1	1	1	1
0.91	0.09	0.045	1.34			30	14	8	5	4	3	2	2	2	1	1	1	1	1	1
0.89	0.11	0.055	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		27	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.87	0.13	0.065	1.13			25	12	7	4	3	3	2	2	1	1	1	1	1	1	1
0.85	0.15	0.075	1.04			24	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.83	0.17	0.085	0.95			22	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.81	0.19	0.095	0.88			20	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.79	0.21	0.105	0.81			19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.77	0.23	0.115	0.74			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.75	0.25	0.125	0.67			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.73	0.27	0.135	0.61			16	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.71	0.29	0.145	0.55			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.69	0.31	0.155	0.5			14	7	4	3	2	2	1	1	1	1	1	1	1	1	1

Table B-26. Liquid Limit: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α	α (Producer Risk)	α/2	Z_α	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.99	0.01	0.005	2.33	z_β	0.84	44	20	11	7	5	4	3	3	2	2	2	2	1	1	1
0.97	0.03	0.015	1.88	σ	2.07	32	15	8	6	4	3	2	2	2	2	1	1	1	1	1
0.95	0.05	0.025	1.64			27	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.93	0.07	0.035	1.48			24	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.91	0.09	0.045	1.34			21	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.89	0.11	0.055	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.87	0.13	0.065	1.13			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.85	0.15	0.075	1.04			16	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.83	0.17	0.085	0.95			14	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.81	0.19	0.095	0.88			13	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.79	0.21	0.105	0.81			12	6	3	2	2	1	1	1	1	1	1	1	1	1	1
0.77	0.23	0.115	0.74			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.75	0.25	0.125	0.67			10	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.73	0.27	0.135	0.61			10	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.71	0.29	0.145	0.55			9	4	3	2	1	1	1	1	1	1	1	1	1	1	1
0.69	0.31	0.155	0.5			8	4	2	2	1	1	1	1	1	1	1	1	1	1	1

Table B-27. Liquid Limit: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α	α (Producer Risk)	α/2	Z_α	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.99	0.01	0.005	2.33	z_β	0.52	35	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.97	0.03	0.015	1.88	σ	2.07	25	12	7	4	3	3	2	2	1	1	1	1	1	1	1
0.95	0.05	0.025	1.64			21	9	6	4	3	2	2	1	1	1	1	1	1	1	1
0.93	0.07	0.035	1.48			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.91	0.09	0.045	1.34			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.89	0.11	0.055	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		14	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.87	0.13	0.065	1.13			12	6	3	2	2	1	1	1	1	1	1	1	1	1	1
0.85	0.15	0.075	1.04			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.83	0.17	0.085	0.95			10	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.81	0.19	0.095	0.88			9	4	3	2	1	1	1	1	1	1	1	1	1	1	1
0.79	0.21	0.105	0.81			8	4	2	2	1	1	1	1	1	1	1	1	1	1	1
0.77	0.23	0.115	0.74			7	4	2	2	1	1	1	1	1	1	1	1	1	1	1
0.75	0.25	0.125	0.67			7	3	2	1	1	1	1	1	1	1	1	1	1	1	1
0.73	0.27	0.135	0.61			6	3	2	1	1	1	1	1	1	1	1	1	1	1	1
0.71	0.29	0.145	0.55			5	3	2	1	1	1	1	1	1	1	1	1	1	1	1
0.69	0.31	0.155	0.5			5	2	2	1	1	1	1	1	1	1	1	1	1	1	1

Table B-28. Plasticity Index: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	1.28	67	30	17	11	8	6	5	4	3	3	2	2	2	2	2
0.985	0.03	0.015	2.17	σ	2.12	54	24	14	9	6	5	4	3	3	2	2	2	2	1	1
0.975	0.05	0.025	1.96			48	21	12	8	6	4	3	3	2	2	2	2	1	1	1
0.965	0.07	0.035	1.81			44	20	11	7	5	4	3	3	2	2	2	2	1	1	1
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		40	18	10	7	5	4	3	2	2	2	2	1	1	1	1
0.945	0.11	0.055	1.6			38	17	10	6	5	4	3	2	2	2	2	1	1	1	1
0.935	0.13	0.065	1.51			36	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.925	0.15	0.075	1.44			34	15	9	6	4	3	3	2	2	2	1	1	1	1	1
0.915	0.17	0.085	1.37			32	15	8	6	4	3	2	2	2	2	1	1	1	1	1
0.905	0.19	0.095	1.31			31	14	8	5	4	3	2	2	2	1	1	1	1	1	1
0.895	0.21	0.105	1.25			29	13	8	5	4	3	2	2	2	1	1	1	1	1	1
0.885	0.23	0.115	1.2			28	13	7	5	4	3	2	2	2	1	1	1	1	1	1
0.875	0.25	0.125	1.15			27	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.865	0.27	0.135	1.1			26	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.855	0.29	0.145	1.06			25	11	7	4	3	3	2	2	1	1	1	1	1	1	1
0.845	0.31	0.155	1.02			24	11	6	4	3	2	2	2	1	1	1	1	1	1	1

Table B-29. Plasticity Index: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.84	53	24	14	9	6	5	4	3	3	2	2	2	2	1	1
0.985	0.03	0.015	2.17	σ	2.12	41	19	11	7	5	4	3	3	2	2	2	1	1	1	1
0.975	0.05	0.025	1.96			36	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.965	0.07	0.035	1.81			32	15	8	6	4	3	2	2	2	2	1	1	1	1	1
0.955	0.09	0.045	1.7			29	13	8	5	4	3	2	2	2	1	1	1	1	1	1
0.945	0.11	0.055	1.6			27	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.935	0.13	0.065	1.51	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		25	12	7	4	3	3	2	2	1	1	1	1	1	1	1
0.925	0.15	0.075	1.44			24	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.915	0.17	0.085	1.37			23	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.905	0.19	0.095	1.31			21	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.895	0.21	0.105	1.25			20	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.885	0.23	0.115	1.2			19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.875	0.25	0.125	1.15			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.865	0.27	0.135	1.1			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.855	0.29	0.145	1.06			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.845	0.31	0.155	1.02			16	7	4	3	2	2	1	1	1	1	1	1	1	1	1

Table B-30. Plasticity Index: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.995	0.01	0.005	2.58	z_β	0.52	44	20	11	7	5	4	3	3	2	2	2	2	1	1	1
0.985	0.03	0.015	2.17	σ	2.12	33	15	9	6	4	3	3	2	2	2	1	1	1	1	1
0.975	0.05	0.025	1.96			28	13	7	5	4	3	2	2	2	1	1	1	1	1	1
0.965	0.07	0.035	1.81			25	11	7	4	3	3	2	2	1	1	1	1	1	1	1
0.955	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		23	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.945	0.11	0.055	1.6			21	9	6	4	3	2	2	1	1	1	1	1	1	1	1
0.935	0.13	0.065	1.51			19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.925	0.15	0.075	1.44			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.915	0.17	0.085	1.37			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.905	0.19	0.095	1.31			16	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.895	0.21	0.105	1.25			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.885	0.23	0.115	1.2			14	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.875	0.25	0.125	1.15			13	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.865	0.27	0.135	1.1			12	6	3	2	2	1	1	1	1	1	1	1	1	1	1
0.855	0.29	0.145	1.06			12	6	3	2	2	1	1	1	1	1	1	1	1	1	1
0.845	0.31	0.155	1.02			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1

Table B-31. Wet Ball Mill Value: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α	α (Producer Risk)	α/2	Z_α	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.99	0.01	0.005	2.326	z_β	1.282	258	115	65	42	29	22	17	13	11	9	8	7	6	5	5
0.97	0.03	0.015	1.881	σ	4.45	199	89	50	32	23	17	13	10	8	7	6	5	5	4	4
0.95	0.05	0.025	1.645			170	76	43	28	19	14	11	9	7	6	5	5	4	4	3
0.93	0.07	0.035	1.476			151	67	38	25	17	13	10	8	7	5	5	4	4	3	3
0.91	0.09	0.045	1.341			137	61	35	22	16	12	9	7	6	5	4	4	3	3	3
0.89	0.11	0.055	1.227	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		125	56	32	20	14	11	8	7	5	5	4	3	3	3	2
0.87	0.13	0.065	1.126			115	52	29	19	13	10	8	6	5	4	4	3	3	3	2
0.85	0.15	0.075	1.036			107	48	27	18	12	9	7	6	5	4	3	3	3	2	2
0.83	0.17	0.085	0.954			99	44	25	16	11	9	7	5	4	4	3	3	3	2	2
0.81	0.19	0.095	0.878			93	42	24	15	11	8	6	5	4	4	3	3	2	2	2
0.79	0.21	0.105	0.806			87	39	22	14	10	8	6	5	4	3	3	3	2	2	2
0.77	0.23	0.115	0.739			81	36	21	13	9	7	6	4	4	3	3	2	2	2	2
0.75	0.25	0.125	0.674			76	34	19	13	9	7	5	4	4	3	3	2	2	2	2
0.73	0.27	0.135	0.613			72	32	18	12	8	6	5	4	3	3	2	2	2	2	2
0.71	0.29	0.145	0.553			67	30	17	11	8	6	5	4	3	3	2	2	2	2	2
0.69	0.31	0.155	0.496			63	28	16	11	7	6	4	4	3	3	2	2	2	2	1

Table B-32. Wet Ball Mill Value: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α	α (Producer Risk)	α/2	Z_α	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.99	0.01	0.005	2.326	z_β	0.842	199	89	50	32	23	17	13	10	8	7	6	5	5	4	4
0.97	0.03	0.015	1.881	σ	4.45	147	66	37	24	17	12	10	8	6	5	5	4	3	3	3
0.95	0.05	0.025	1.645			123	55	31	20	14	10	8	7	5	5	4	3	3	3	2
0.93	0.07	0.035	1.476			107	48	27	18	12	9	7	6	5	4	3	3	3	2	2
0.91	0.09	0.045	1.341			95	42	24	16	11	8	6	5	4	4	3	3	2	2	2
0.89	0.11	0.055	1.227	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		85	38	22	14	10	7	6	5	4	3	3	3	2	2	2
0.87	0.13	0.065	1.126			77	35	20	13	9	7	5	4	4	3	3	2	2	2	2
0.85	0.15	0.075	1.036			70	32	18	12	8	6	5	4	3	3	2	2	2	2	2
0.83	0.17	0.085	0.954			64	29	16	11	8	6	4	4	3	3	2	2	2	2	1
0.81	0.19	0.095	0.878			59	27	15	10	7	5	4	3	3	2	2	2	2	2	1
0.79	0.21	0.105	0.806			54	24	14	9	6	5	4	3	3	2	2	2	2	1	1
0.77	0.23	0.115	0.739			50	22	13	8	6	5	4	3	2	2	2	2	2	1	1
0.75	0.25	0.125	0.674			46	21	12	8	6	4	3	3	2	2	2	2	1	1	1
0.73	0.27	0.135	0.613			42	19	11	7	5	4	3	3	2	2	2	1	1	1	1
0.71	0.29	0.145	0.553			39	18	10	7	5	4	3	2	2	2	2	1	1	1	1
0.69	0.31	0.155	0.496			36	16	9	6	4	3	3	2	2	2	1	1	1	1	1

Table B-33. Wet Ball Mill Value: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α	α (Producer Risk)	α/2	Z_α	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.99	0.01	0.005	2.326	z_β	0.524	161	72	41	26	18	14	11	8	7	6	5	4	4	3	3
0.97	0.03	0.015	1.881	σ	4.45	115	51	29	19	13	10	8	6	5	4	4	3	3	3	2
0.95	0.05	0.025	1.645			94	42	24	15	11	8	6	5	4	4	3	3	2	2	2
0.93	0.07	0.035	1.476			80	36	20	13	9	7	5	4	4	3	3	2	2	2	2
0.91	0.09	0.045	1.341			69	31	18	12	8	6	5	4	3	3	2	2	2	2	2
0.89	0.11	0.055	1.227	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		61	27	16	10	7	5	4	3	3	3	2	2	2	2	1
0.87	0.13	0.065	1.126			54	24	14	9	6	5	4	3	3	2	2	2	2	1	1
0.85	0.15	0.075	1.036			49	22	13	8	6	4	4	3	2	2	2	2	1	1	1
0.83	0.17	0.085	0.954			44	20	11	7	5	4	3	3	2	2	2	2	1	1	1
0.81	0.19	0.095	0.878			39	18	10	7	5	4	3	2	2	2	2	1	1	1	1
0.79	0.21	0.105	0.806			36	16	9	6	4	3	3	2	2	2	1	1	1	1	1
0.77	0.23	0.115	0.739			32	15	8	6	4	3	2	2	2	2	1	1	1	1	1
0.75	0.25	0.125	0.674			29	13	8	5	4	3	2	2	2	1	1	1	1	1	1
0.73	0.27	0.135	0.613			26	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.71	0.29	0.145	0.553			24	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.69	0.31	0.155	0.496			21	10	6	4	3	2	2	2	1	1	1	1	1	1	1

Table B-34. Wet Ball Mill Percent Increase: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α	α (Producer Risk)	α/2	Z_α	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.99	0.01	0.01	2.33	z_β	1.28	40	18	10	7	5	4	3	2	2	2	2	1	1	1	1
0.97	0.03	0.02	1.88	σ	1.74	31	14	8	5	4	3	2	2	2	2	1	1	1	1	1
0.95	0.05	0.03	1.64			26	12	7	5	3	3	2	2	2	1	1	1	1	1	1
0.93	0.07	0.04	1.48			24	11	6	4	3	2	2	2	1	1	1	1	1	1	1
0.91	0.09	0.05	1.34			21	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.89	0.11	0.06	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		20	9	5	4	3	2	2	1	1	1	1	1	1	1	1
0.87	0.13	0.07	1.13			18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.85	0.15	0.08	1.04			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.83	0.17	0.09	0.95			16	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.81	0.19	0.1	0.88			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.79	0.21	0.11	0.81			14	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.77	0.23	0.12	0.74			13	6	4	2	2	2	1	1	1	1	1	1	1	1	1
0.75	0.25	0.13	0.67			12	6	3	2	2	1	1	1	1	1	1	1	1	1	1
0.73	0.27	0.14	0.61			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.71	0.29	0.15	0.55			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.69	0.31	0.16	0.5			10	5	3	2	2	1	1	1	1	1	1	1	1	1	1

Table B-35. Wet Ball Mill Percent Increase: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α	α (Producer Risk)	α/2	Z_α	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.99	0.01	0.01	2.33	z_β	0.84	31	14	8	5	4	3	2	2	2	2	1	1	1	1	1
0.97	0.03	0.02	1.88	σ	1.74	23	10	6	4	3	2	2	2	1	1	1	1	1	1	1
0.95	0.05	0.03	1.64	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		19	9	5	3	3	2	2	1	1	1	1	1	1	1	1
0.93	0.07	0.04	1.48			17	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.91	0.09	0.05	1.34			15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.89	0.11	0.06	1.23			13	6	4	3	2	2	1	1	1	1	1	1	1	1	1
0.87	0.13	0.07	1.13			12	6	3	2	2	1	1	1	1	1	1	1	1	1	1
0.85	0.15	0.08	1.04			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.83	0.17	0.09	0.95			10	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.81	0.19	0.1	0.88			9	4	3	2	1	1	1	1	1	1	1	1	1	1	1
0.79	0.21	0.11	0.81			9	4	3	2	1	1	1	1	1	1	1	1	1	1	1
0.77	0.23	0.12	0.74			8	4	2	2	1	1	1	1	1	1	1	1	1	1	1
0.75	0.25	0.13	0.67			7	4	2	2	1	1	1	1	1	1	1	1	1	1	1
0.73	0.27	0.14	0.61			7	3	2	2	1	1	1	1	1	1	1	1	1	1	1
0.71	0.29	0.15	0.55			6	3	2	1	1	1	1	1	1	1	1	1	1	1	1
0.69	0.31	0.16	0.5			6	3	2	1	1	1	1	1	1	1	1	1	1	1	1

Table B-36. Wet Ball Mill Percent Increase: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α	α (Producer Risk)	α/2	Z_α	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 1	e = 1.5	e = 2	e = 2.5	e = 3	e = 3.5	e = 4	e = 4.5	e = 5	e = 5.5	e= 6	e = 6.5	e = 7	e = 7.5	e = 8
0.99	0.01	0.01	2.33	z_β	0.52	25	11	7	4	3	3	2	2	1	1	1	1	1	1	1
0.97	0.03	0.02	1.88	σ	1.74	18	8	5	3	2	2	2	1	1	1	1	1	1	1	1
0.95	0.05	0.03	1.64	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		15	7	4	3	2	2	1	1	1	1	1	1	1	1	1
0.93	0.07	0.04	1.48			13	6	4	2	2	1	1	1	1	1	1	1	1	1	1
0.91	0.09	0.05	1.34			11	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.89	0.11	0.06	1.23			10	5	3	2	2	1	1	1	1	1	1	1	1	1	1
0.87	0.13	0.07	1.13			9	4	3	2	1	1	1	1	1	1	1	1	1	1	1
0.85	0.15	0.08	1.04			8	4	2	2	1	1	1	1	1	1	1	1	1	1	1
0.83	0.17	0.09	0.95			7	3	2	2	1	1	1	1	1	1	1	1	1	1	1
0.81	0.19	0.1	0.88			6	3	2	1	1	1	1	1	1	1	1	1	1	1	1
0.79	0.21	0.11	0.81			6	3	2	1	1	1	1	1	1	1	1	1	1	1	1
0.77	0.23	0.12	0.74			5	3	2	1	1	1	1	1	1	1	1	1	1	1	1
0.75	0.25	0.13	0.67			5	2	2	1	1	1	1	1	1	1	1	1	1	1	1
0.73	0.27	0.14	0.61			4	2	1	1	1	1	1	1	1	1	1	1	1	1	1
0.71	0.29	0.15	0.55			4	2	1	1	1	1	1	1	1	1	1	1	1	1	1
0.69	0.31	0.16	0.5			4	2	1	1	1	1	1	1	1	1	1	1	1	1	1

Table B-37. Compressive Strength at 0 psi Confining Pressure: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.1	e = 3	e = 6	e = 9	e = 12	e = 15	e = 18	e = 21	e = 24	e = 27	e = 30	e= 33	e = 36	e = 39	e = 42	e = 45
0.99	0.01	2.33	z_β	1.28	612	153	68	39	25	17	13	10	8	7	6	5	4	4	3
0.97	0.03	1.88	σ	20.6	470	118	53	30	19	14	10	8	6	5	4	4	3	3	3
0.95	0.05	1.64	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		403	101	45	26	17	12	9	7	5	5	4	3	3	3	2
0.93	0.07	1.48			358	90	40	23	15	10	8	6	5	4	3	3	3	2	2
0.91	0.09	1.34			323	81	36	21	13	9	7	6	4	4	3	3	2	2	2
0.89	0.11	1.23			296	74	33	19	12	9	7	5	4	3	3	3	2	2	2
0.87	0.13	1.13			273	69	31	18	11	8	6	5	4	3	3	2	2	2	2
0.85	0.15	1.04			253	64	29	16	11	8	6	4	4	3	3	2	2	2	2
0.83	0.17	0.95			235	59	27	15	10	7	5	4	3	3	2	2	2	2	2
0.81	0.19	0.88			220	55	25	14	9	7	5	4	3	3	2	2	2	2	1
0.79	0.21	0.81			205	52	23	13	9	6	5	4	3	3	2	2	2	2	1
0.77	0.23	0.74			192	48	22	12	8	6	4	3	3	2	2	2	2	1	1
0.75	0.25	0.67			180	45	20	12	8	5	4	3	3	2	2	2	2	1	1
0.73	0.27	0.61			169	43	19	11	7	5	4	3	3	2	2	2	1	1	1
0.71	0.29	0.55			159	40	18	10	7	5	4	3	2	2	2	2	1	1	1
0.69	0.31	0.5			149	38	17	10	6	5	4	3	2	2	2	2	1	1	1

Table B-38. Compressive Strength at 0 psi Confining Pressure: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.2	e = 3	e = 6	e = 9	e = 12	e = 15	e = 18	e = 21	e = 24	e = 27	e = 30	e= 33	e = 36	e = 39	e = 42	e = 45
0.99	0.01	2.33	z_β	0.84	472	118	53	30	19	14	10	8	6	5	4	4	3	3	3
0.97	0.03	1.88	σ	20.6	349	88	39	22	14	10	8	6	5	4	3	3	3	2	2
0.95	0.05	1.64	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		291	73	33	19	12	9	6	5	4	3	3	3	2	2	2
0.93	0.07	1.48			253	64	29	16	11	8	6	4	4	3	3	2	2	2	2
0.91	0.09	1.34			224	56	25	14	9	7	5	4	3	3	2	2	2	2	1
0.89	0.11	1.23			201	51	23	13	9	6	5	4	3	3	2	2	2	2	1
0.87	0.13	1.13			182	46	21	12	8	6	4	3	3	2	2	2	2	1	1
0.85	0.15	1.04			166	42	19	11	7	5	4	3	3	2	2	2	1	1	1
0.83	0.17	0.95			152	38	17	10	7	5	4	3	2	2	2	2	1	1	1
0.81	0.19	0.88			139	35	16	9	6	4	3	3	2	2	2	1	1	1	1
0.79	0.21	0.81			128	32	15	8	6	4	3	2	2	2	2	1	1	1	1
0.77	0.23	0.74			118	30	14	8	5	4	3	2	2	2	1	1	1	1	1
0.75	0.25	0.67			108	27	12	7	5	3	3	2	2	2	1	1	1	1	1
0.73	0.27	0.61			100	25	12	7	4	3	3	2	2	1	1	1	1	1	1
0.71	0.29	0.55			92	23	11	6	4	3	2	2	2	1	1	1	1	1	1
0.69	0.31	0.5			85	22	10	6	4	3	2	2	2	1	1	1	1	1	1

Table B-39. Compressive Strength at 0 psi Confining Pressure: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.3	e = 3	e = 6	e = 9	e = 12	e = 15	e = 18	e = 21	e = 24	e = 27	e = 30	e= 33	e = 36	e = 39	e = 42	e = 45
0.99	0.01	2.33	z_β	0.52	382	96	43	24	16	11	8	6	5	4	4	3	3	2	2
0.97	0.03	1.88	σ	20.6	272	68	31	17	11	8	6	5	4	3	3	2	2	2	2
0.95	0.05	1.64	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		222	56	25	14	9	7	5	4	3	3	2	2	2	2	1
0.93	0.07	1.48			188	47	21	12	8	6	4	3	3	2	2	2	2	1	1
0.91	0.09	1.34			164	41	19	11	7	5	4	3	3	2	2	2	1	1	1
0.89	0.11	1.23			144	36	16	9	6	4	3	3	2	2	2	1	1	1	1
0.87	0.13	1.13			128	32	15	8	6	4	3	2	2	2	2	1	1	1	1
0.85	0.15	1.04			115	29	13	8	5	4	3	2	2	2	1	1	1	1	1
0.83	0.17	0.95			103	26	12	7	5	3	3	2	2	2	1	1	1	1	1
0.81	0.19	0.88			93	24	11	6	4	3	2	2	2	1	1	1	1	1	1
0.79	0.21	0.81			84	21	10	6	4	3	2	2	2	1	1	1	1	1	1
0.77	0.23	0.74			75	19	9	5	3	3	2	2	1	1	1	1	1	1	1
0.75	0.25	0.67			68	17	8	5	3	2	2	2	1	1	1	1	1	1	1
0.73	0.27	0.61			61	16	7	4	3	2	2	1	1	1	1	1	1	1	1
0.71	0.29	0.55			55	14	7	4	3	2	2	1	1	1	1	1	1	1	1
0.69	0.31	0.5			49	13	6	4	2	2	1	1	1	1	1	1	1	1	1

Table B-40. Compressive Strength at 3 psi Confining Pressure: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.1	e = 3	e = 6	e = 9	e = 12	e = 15	e = 18	e = 21	e = 24	e = 27	e = 30	e= 33	e = 36	e = 39	e = 42	e = 45
0.99	0.01	2.33	z_β	1.282	584	146	65	37	24	17	12	10	8	6	5	5	4	3	3
0.97	0.03	1.88	σ	20.09	449	113	50	29	18	13	10	8	6	5	4	4	3	3	2
0.95	0.05	1.64	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		385	97	43	25	16	11	8	7	5	4	4	3	3	2	2
0.93	0.07	1.48			341	86	38	22	14	10	7	6	5	4	3	3	3	2	2
0.91	0.09	1.34			309	78	35	20	13	9	7	5	4	4	3	3	2	2	2
0.89	0.11	1.23			283	71	32	18	12	8	6	5	4	3	3	2	2	2	2
0.87	0.13	1.13			261	66	29	17	11	8	6	5	4	3	3	2	2	2	2
0.85	0.15	1.04			241	61	27	16	10	7	5	4	3	3	2	2	2	2	2
0.83	0.17	0.95			225	57	25	15	9	7	5	4	3	3	2	2	2	2	1
0.81	0.19	0.88			210	53	24	14	9	6	5	4	3	3	2	2	2	2	1
0.79	0.21	0.81			196	49	22	13	8	6	4	4	3	2	2	2	2	1	1
0.77	0.23	0.74			184	46	21	12	8	6	4	3	3	2	2	2	2	1	1
0.75	0.25	0.67			172	43	20	11	7	5	4	3	3	2	2	2	2	1	1
0.73	0.27	0.61			161	41	18	11	7	5	4	3	2	2	2	2	1	1	1
0.71	0.29	0.55			151	38	17	10	7	5	4	3	2	2	2	2	1	1	1
0.69	0.31	0.5			142	36	16	9	6	4	3	3	2	2	2	1	1	1	1

Table B-41. Compressive Strength at 3 psi Confining Pressure: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.2	e = 3	e = 6	e = 9	e = 12	e = 15	e = 18	e = 21	e = 24	e = 27	e = 30	e= 33	e = 36	e = 39	e = 42	e = 45
0.99	0.01	2.33	z_β	0.842	451	113	51	29	19	13	10	8	6	5	4	4	3	3	3
0.97	0.03	1.88	σ	20.09	333	84	37	21	14	10	7	6	5	4	3	3	2	2	2
0.95	0.05	1.64			278	70	31	18	12	8	6	5	4	3	3	2	2	2	2
0.93	0.07	1.48			241	61	27	16	10	7	5	4	3	3	2	2	2	2	2
0.91	0.09	1.34			214	54	24	14	9	6	5	4	3	3	2	2	2	2	1
0.89	0.11	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		192	48	22	12	8	6	4	3	3	2	2	2	2	1	1
0.87	0.13	1.13			174	44	20	11	7	5	4	3	3	2	2	2	2	1	1
0.85	0.15	1.04			159	40	18	10	7	5	4	3	2	2	2	2	1	1	1
0.83	0.17	0.95			145	37	17	10	6	5	3	3	2	2	2	2	1	1	1
0.81	0.19	0.88			133	34	15	9	6	4	3	3	2	2	2	1	1	1	1
0.79	0.21	0.81			122	31	14	8	5	4	3	2	2	2	2	1	1	1	1
0.77	0.23	0.74			113	29	13	8	5	4	3	2	2	2	1	1	1	1	1
0.75	0.25	0.67			104	26	12	7	5	3	3	2	2	2	1	1	1	1	1
0.73	0.27	0.61			95	24	11	6	4	3	2	2	2	1	1	1	1	1	1
0.71	0.29	0.55			88	22	10	6	4	3	2	2	2	1	1	1	1	1	1
0.69	0.31	0.5			81	21	9	6	4	3	2	2	1	1	1	1	1	1	1

Table B-42. Compressive Strength at 3 psi Confining Pressure: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.3	e = 3	e = 6	e = 9	e = 12	e = 15	e = 18	e = 21	e = 24	e = 27	e = 30	e= 33	e = 36	e = 39	e = 42	e = 45
0.99	0.01	2.33	z_β	0.524	365	92	41	23	15	11	8	6	5	4	4	3	3	2	2
0.97	0.03	1.88	σ	20.09	260	65	29	17	11	8	6	5	4	3	3	2	2	2	2
0.95	0.05	1.64			212	53	24	14	9	6	5	4	3	3	2	2	2	2	1
0.93	0.07	1.48			180	45	20	12	8	5	4	3	3	2	2	2	2	1	1
0.91	0.09	1.34			157	40	18	10	7	5	4	3	2	2	2	2	1	1	1
0.89	0.11	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		138	35	16	9	6	4	3	3	2	2	2	1	1	1	1
0.87	0.13	1.13			123	31	14	8	5	4	3	2	2	2	2	1	1	1	1
0.85	0.15	1.04			110	28	13	7	5	4	3	2	2	2	1	1	1	1	1
0.83	0.17	0.95			99	25	11	7	4	3	3	2	2	1	1	1	1	1	1
0.81	0.19	0.88			89	23	10	6	4	3	2	2	2	1	1	1	1	1	1
0.79	0.21	0.81			80	20	9	5	4	3	2	2	1	1	1	1	1	1	1
0.77	0.23	0.74			72	18	8	5	3	2	2	2	1	1	1	1	1	1	1
0.75	0.25	0.67			65	17	8	5	3	2	2	2	1	1	1	1	1	1	1
0.73	0.27	0.61			58	15	7	4	3	2	2	1	1	1	1	1	1	1	1
0.71	0.29	0.55			53	14	6	4	3	2	2	1	1	1	1	1	1	1	1
0.69	0.31	0.5			47	12	6	3	2	2	1	1	1	1	1	1	1	1	1

Table B-43. Compressive Strength at 15 psi Confining Pressure: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.1	e = 3	e = 6	e = 9	e = 12	e = 15	e = 18	e = 21	e = 24	e = 27	e = 30	e= 33	e = 36	e = 39	e = 42	e = 45
0.99	0.01	2.33	z_β	1.28	1406	352	157	88	57	40	29	22	18	15	12	10	9	8	7
0.97	0.03	1.88	σ	31.2	1080	270	120	68	44	30	23	17	14	11	9	8	7	6	5
0.95	0.05	1.64			925	232	103	58	37	26	19	15	12	10	8	7	6	5	5
0.93	0.07	1.48			821	206	92	52	33	23	17	13	11	9	7	6	5	5	4
0.91	0.09	1.34			743	186	83	47	30	21	16	12	10	8	7	6	5	4	4
0.89	0.11	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2\sigma^2}{e^2}$		680	170	76	43	28	19	14	11	9	7	6	5	5	4	4
0.87	0.13	1.13			626	157	70	40	26	18	13	10	8	7	6	5	4	4	3
0.85	0.15	1.04			581	146	65	37	24	17	12	10	8	6	5	5	4	3	3
0.83	0.17	0.95			540	135	60	34	22	15	12	9	7	6	5	4	4	3	3
0.81	0.19	0.88			504	126	56	32	21	14	11	8	7	6	5	4	3	3	3
0.79	0.21	0.81			471	118	53	30	19	14	10	8	6	5	4	4	3	3	3
0.77	0.23	0.74			441	111	49	28	18	13	9	7	6	5	4	4	3	3	2
0.75	0.25	0.67			414	104	46	26	17	12	9	7	6	5	4	3	3	3	2
0.73	0.27	0.61			388	97	44	25	16	11	8	7	5	4	4	3	3	2	2
0.71	0.29	0.55			364	91	41	23	15	11	8	6	5	4	4	3	3	2	2
0.69	0.31	0.5			342	86	38	22	14	10	7	6	5	4	3	3	3	2	2

Table B-44. Compressive Strength at 15 psi Confining Pressure: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.2	e = 3	e = 6	e = 9	e = 12	e = 15	e = 18	e = 21	e = 24	e = 27	e = 30	e= 33	e = 36	e = 39	e = 42	e = 45
0.99	0.01	2.33	z_β	0.84	1084	271	121	68	44	31	23	17	14	11	9	8	7	6	5
0.97	0.03	1.88	σ	31.2	801	201	89	51	33	23	17	13	10	9	7	6	5	5	4
0.95	0.05	1.64			668	167	75	42	27	19	14	11	9	7	6	5	4	4	3
0.93	0.07	1.48			580	145	65	37	24	17	12	10	8	6	5	5	4	3	3
0.91	0.09	1.34			515	129	58	33	21	15	11	9	7	6	5	4	4	3	3
0.89	0.11	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2\sigma^2}{e^2}$		462	116	52	29	19	13	10	8	6	5	4	4	3	3	3
0.87	0.13	1.13			419	105	47	27	17	12	9	7	6	5	4	3	3	3	2
0.85	0.15	1.04			381	96	43	24	16	11	8	6	5	4	4	3	3	2	2
0.83	0.17	0.95			349	88	39	22	14	10	8	6	5	4	3	3	3	2	2
0.81	0.19	0.88			320	80	36	20	13	9	7	5	4	4	3	3	2	2	2
0.79	0.21	0.81			294	74	33	19	12	9	6	5	4	3	3	3	2	2	2
0.77	0.23	0.74			270	68	30	17	11	8	6	5	4	3	3	2	2	2	2
0.75	0.25	0.67			249	63	28	16	10	7	6	4	4	3	3	2	2	2	2
0.73	0.27	0.61			229	58	26	15	10	7	5	4	3	3	2	2	2	2	2
0.71	0.29	0.55			211	53	24	14	9	6	5	4	3	3	2	2	2	2	1
0.69	0.31	0.5			194	49	22	13	8	6	4	4	3	2	2	2	2	1	1

Table B-45. Compressive Strength at 15 psi Confining Pressure: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α	α (Producer Risk)	$Z_α$	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.3	e = 3	e = 6	e = 9	e = 12	e = 15	e = 18	e = 21	e = 24	e = 27	e = 30	e= 33	e = 36	e = 39	e = 42	e = 45
0.99	0.01	2.33	$z_β$	0.52	878	220	98	55	36	25	18	14	11	9	8	7	6	5	4
0.97	0.03	1.88	σ	31.2	625	157	70	40	25	18	13	10	8	7	6	5	4	4	3
0.95	0.05	1.64			508	127	57	32	21	15	11	8	7	6	5	4	4	3	3
0.93	0.07	1.48			432	108	48	27	18	12	9	7	6	5	4	3	3	3	2
0.91	0.09	1.34			376	94	42	24	16	11	8	6	5	4	4	3	3	2	2
0.89	0.11	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		331	83	37	21	14	10	7	6	5	4	3	3	2	2	2
0.87	0.13	1.13			295	74	33	19	12	9	7	5	4	3	3	3	2	2	2
0.85	0.15	1.04			263	66	30	17	11	8	6	5	4	3	3	2	2	2	2
0.83	0.17	0.95			237	60	27	15	10	7	5	4	3	3	2	2	2	2	2
0.81	0.19	0.88			213	54	24	14	9	6	5	4	3	3	2	2	2	2	1
0.79	0.21	0.81			192	48	22	12	8	6	4	3	3	2	2	2	2	1	1
0.77	0.23	0.74			173	44	20	11	7	5	4	3	3	2	2	2	2	1	1
0.75	0.25	0.67			156	39	18	10	7	5	4	3	2	2	2	2	1	1	1
0.73	0.27	0.61			140	35	16	9	6	4	3	3	2	2	2	1	1	1	1
0.71	0.29	0.55			126	32	14	8	6	4	3	2	2	2	2	1	1	1	1
0.69	0.31	0.5			113	29	13	8	5	4	3	2	2	2	1	1	1	1	1

Table B-46. Maximum Dry Density: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α	α (Producer Risk)	$Z_α$	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.1	e = 0.3	e = 0.6	e = 0.9	e = 1.2	e = 1.5	e = 1.8	e = 2.1	e = 2.4	e = 2.7	e = 3	e= 3.3	e = 3.6	e = 3.9	e = 4.2	e = 4.5
0.99	0.01	2.33	$z_β$	1.28	268	67	30	17	11	8	6	5	4	3	3	2	2	2	2
0.97	0.03	1.88	σ	1.36	206	52	23	13	9	6	5	4	3	3	2	2	2	2	1
0.95	0.05	1.64			176	44	20	11	8	5	4	3	3	2	2	2	2	1	1
0.93	0.07	1.48			157	40	18	10	7	5	4	3	2	2	2	2	1	1	1
0.91	0.09	1.34			142	36	16	9	6	4	3	3	2	2	2	1	1	1	1
0.89	0.11	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		130	33	15	9	6	4	3	3	2	2	2	1	1	1	1
0.87	0.13	1.13			120	30	14	8	5	4	3	2	2	2	1	1	1	1	1
0.85	0.15	1.04			111	28	13	7	5	4	3	2	2	2	1	1	1	1	1
0.83	0.17	0.95			103	26	12	7	5	3	3	2	2	2	1	1	1	1	1
0.81	0.19	0.88			96	24	11	6	4	3	2	2	2	1	1	1	1	1	1
0.79	0.21	0.81			90	23	10	6	4	3	2	2	2	1	1	1	1	1	1
0.77	0.23	0.74			84	21	10	6	4	3	2	2	2	1	1	1	1	1	1
0.75	0.25	0.67			79	20	9	5	4	3	2	2	1	1	1	1	1	1	1
0.73	0.27	0.61			74	19	9	5	3	3	2	2	1	1	1	1	1	1	1
0.71	0.29	0.55			70	18	8	5	3	2	2	2	1	1	1	1	1	1	1
0.69	0.31	0.5			65	17	8	5	3	2	2	2	1	1	1	1	1	1	1

Table B-47. Maximum Dry Density: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.2	e = 0.3	e = 0.6	e = 0.9	e = 1.2	e = 1.5	e = 1.8	e = 2.1	e = 2.4	e = 2.7	e = 3	e= 3.3	e = 3.6	e = 3.9	e = 4.2	e = 4.5
0.99	0.01	2.33	z_β	0.84	207	52	23	13	9	6	5	4	3	3	2	2	2	2	1
0.97	0.03	1.88	σ	1.36	153	39	17	10	7	5	4	3	2	2	2	2	1	1	1
0.95	0.05	1.64			128	32	15	8	6	4	3	2	2	2	2	1	1	1	1
0.93	0.07	1.48			111	28	13	7	5	4	3	2	2	2	1	1	1	1	1
0.91	0.09	1.34			98	25	11	7	4	3	2	2	2	1	1	1	1	1	1
0.89	0.11	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		88	22	10	6	4	3	2	2	2	1	1	1	1	1	1
0.87	0.13	1.13			80	20	9	5	4	3	2	2	1	1	1	1	1	1	1
0.85	0.15	1.04			73	19	9	5	3	3	2	2	1	1	1	1	1	1	1
0.83	0.17	0.95			67	17	8	5	3	2	2	2	1	1	1	1	1	1	1
0.81	0.19	0.88			61	16	7	4	3	2	2	1	1	1	1	1	1	1	1
0.79	0.21	0.81			56	14	7	4	3	2	2	1	1	1	1	1	1	1	1
0.77	0.23	0.74			52	13	6	4	3	2	2	1	1	1	1	1	1	1	1
0.75	0.25	0.67			48	12	6	3	2	2	1	1	1	1	1	1	1	1	1
0.73	0.27	0.61			44	11	5	3	2	2	1	1	1	1	1	1	1	1	1
0.71	0.29	0.55			40	10	5	3	2	2	1	1	1	1	1	1	1	1	1
0.69	0.31	0.5			37	10	5	3	2	2	1	1	1	1	1	1	1	1	1

Table B-48. Maximum Dry Density: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α	α (Producer Risk)	Z_α	Other Factors		Sample Size (n)														
			β (TxDot Risk)	0.3	e = 0.3	e = 0.6	e = 0.9	e = 1.2	e = 1.5	e = 1.8	e = 2.1	e = 2.4	e = 2.7	e = 3	e= 3.3	e = 3.6	e = 3.9	e = 4.2	e = 4.5
0.99	0.01	2.33	z_β	0.52	168	42	19	11	7	5	4	3	3	2	2	2	1	1	1
0.97	0.03	1.88	σ	1.36	119	30	14	8	5	4	3	2	2	2	1	1	1	1	1
0.95	0.05	1.64			97	25	11	7	4	3	2	2	2	1	1	1	1	1	1
0.93	0.07	1.48			83	21	10	6	4	3	2	2	2	1	1	1	1	1	1
0.91	0.09	1.34			72	18	8	5	3	2	2	2	1	1	1	1	1	1	1
0.89	0.11	1.23	$n = \frac{(Z_\alpha + Z_\beta)^2 \sigma^2}{e^2}$		64	16	8	4	3	2	2	1	1	1	1	1	1	1	1
0.87	0.13	1.13			57	15	7	4	3	2	2	1	1	1	1	1	1	1	1
0.85	0.15	1.04			51	13	6	4	3	2	2	1	1	1	1	1	1	1	1
0.83	0.17	0.95			45	12	5	3	2	2	1	1	1	1	1	1	1	1	1
0.81	0.19	0.88			41	11	5	3	2	2	1	1	1	1	1	1	1	1	1
0.79	0.21	0.81			37	10	5	3	2	2	1	1	1	1	1	1	1	1	1
0.77	0.23	0.74			33	9	4	3	2	1	1	1	1	1	1	1	1	1	1
0.75	0.25	0.67			30	8	4	2	2	1	1	1	1	1	1	1	1	1	1
0.73	0.27	0.61			27	7	3	2	2	1	1	1	1	1	1	1	1	1	1
0.71	0.29	0.55			24	6	3	2	1	1	1	1	1	1	1	1	1	1	1
0.69	0.31	0.5			22	6	3	2	1	1	1	1	1	1	1	1	1	1	1

Table B-49. Optimum Moisture Content: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.1.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.1	e = 0.1	e = 0.2	e = 0.3	e = 0.4	e = 0.5	e = 0.6	e = 0.7	e = 0.8	e = 0.9	e = 1	e= 1.1	e = 1.2	e = 1.3	e = 1.4	e = 1.5
1	0.01	0.005	2.58	z_β	1.28	193	49	22	13	8	6	4	4	3	2	2	2	2	1	1
0.99	0.03	0.015	2.17	σ	0.36	155	39	18	10	7	5	4	3	2	2	2	2	1	1	1
0.98	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2\sigma^2}{e^2}$		137	35	16	9	6	4	3	3	2	2	2	1	1	1	1
0.97	0.07	0.035	1.81			125	32	14	8	5	4	3	2	2	2	2	1	1	1	1
0.96	0.09	0.045	1.7			115	29	13	8	5	4	3	2	2	2	1	1	1	1	1
0.95	0.11	0.055	1.6			108	27	12	7	5	3	3	2	2	2	1	1	1	1	1
0.94	0.13	0.065	1.51			102	26	12	7	5	3	3	2	2	2	1	1	1	1	1
0.93	0.15	0.075	1.44			96	24	11	6	4	3	2	2	2	1	1	1	1	1	1
0.92	0.17	0.085	1.37			92	23	11	6	4	3	2	2	2	1	1	1	1	1	1
0.91	0.19	0.095	1.31			88	22	10	6	4	3	2	2	2	1	1	1	1	1	1
0.9	0.21	0.105	1.25			84	21	10	6	4	3	2	2	2	1	1	1	1	1	1
0.89	0.23	0.115	1.2			80	20	9	5	4	3	2	2	1	1	1	1	1	1	1
0.88	0.25	0.125	1.15			77	20	9	5	4	3	2	2	1	1	1	1	1	1	1
0.87	0.27	0.135	1.1			74	19	9	5	3	3	2	2	1	1	1	1	1	1	1
0.86	0.29	0.145	1.06			71	18	8	5	3	2	2	2	1	1	1	1	1	1	1
0.85	0.31	0.155	1.02			69	18	8	5	3	2	2	2	1	1	1	1	1	1	1

Table B-50. Optimum Moisture Content: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.2.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.2	e = 0.1	e = 0.2	e = 0.3	e = 0.4	e = 0.5	e = 0.6	e = 0.7	e = 0.8	e = 0.9	e = 1	e= 1.1	e = 1.2	e = 1.3	e = 1.4	e = 1.5
1	0.01	0.005	2.58	z_β	0.84	152	38	17	10	7	5	4	3	2	2	2	2	1	1	1
0.99	0.03	0.015	2.17	σ	0.36	118	30	14	8	5	4	3	2	2	2	1	1	1	1	1
0.98	0.05	0.025	1.96	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2\sigma^2}{e^2}$		102	26	12	7	5	3	3	2	2	2	1	1	1	1	1
0.97	0.07	0.035	1.81			92	23	11	6	4	3	2	2	2	1	1	1	1	1	1
0.96	0.09	0.045	1.7			84	21	10	6	4	3	2	2	2	1	1	1	1	1	1
0.95	0.11	0.055	1.6			78	20	9	5	4	3	2	2	1	1	1	1	1	1	1
0.94	0.13	0.065	1.51			72	18	8	5	3	2	2	2	1	1	1	1	1	1	1
0.93	0.15	0.075	1.44			68	17	8	5	3	2	2	2	1	1	1	1	1	1	1
0.92	0.17	0.085	1.37			64	16	8	4	3	2	2	1	1	1	1	1	1	1	1
0.91	0.19	0.095	1.31			61	16	7	4	3	2	2	1	1	1	1	1	1	1	1
0.9	0.21	0.105	1.25			57	15	7	4	3	2	2	1	1	1	1	1	1	1	1
0.89	0.23	0.115	1.2			55	14	7	4	3	2	2	1	1	1	1	1	1	1	1
0.88	0.25	0.125	1.15			52	13	6	4	3	2	2	1	1	1	1	1	1	1	1
0.87	0.27	0.135	1.1			50	13	6	4	2	2	2	1	1	1	1	1	1	1	1
0.86	0.29	0.145	1.06			47	12	6	3	2	2	1	1	1	1	1	1	1	1	1
0.85	0.31	0.155	1.02			45	12	5	3	2	2	1	1	1	1	1	1	1	1	1

Table B-51. Optimum Moisture Content: Sensitivity Analysis Output with 80th Percentile Standard Deviation and TxDOT Risk of 0.3.

1-α/2	α (Producer Risk)	α/2	$Z_{\alpha/2}$	Other Factors		Sample Size (n)														
				β (TxDot Risk)	0.3	e = 0.1	e = 0.2	e = 0.3	e = 0.4	e = 0.5	e = 0.6	e = 0.7	e = 0.8	e = 0.9	e = 1	e= 1.1	e = 1.2	e = 1.3	e = 1.4	e = 1.5
1	0.01	0.005	2.58	z_β	0.52	125	32	14	8	5	4	3	2	2	2	2	1	1	1	1
0.99	0.03	0.015	2.17	σ	0.36	95	24	11	6	4	3	2	2	2	1	1	1	1	1	1
0.98	0.05	0.025	1.96			80	20	9	5	4	3	2	2	1	1	1	1	1	1	1
0.97	0.07	0.035	1.81			71	18	8	5	3	2	2	2	1	1	1	1	1	1	1
0.96	0.09	0.045	1.7	$n = \frac{(Z_{\alpha/2} + Z_\beta)^2 \sigma^2}{e^2}$		64	16	8	4	3	2	2	1	1	1	1	1	1	1	1
0.95	0.11	0.055	1.6			59	15	7	4	3	2	2	1	1	1	1	1	1	1	1
0.94	0.13	0.065	1.51			54	14	6	4	3	2	2	1	1	1	1	1	1	1	1
0.93	0.15	0.075	1.44			50	13	6	4	2	2	2	1	1	1	1	1	1	1	1
0.92	0.17	0.085	1.37			47	12	6	3	2	2	1	1	1	1	1	1	1	1	1
0.91	0.19	0.095	1.31			44	11	5	3	2	2	1	1	1	1	1	1	1	1	1
0.9	0.21	0.105	1.25			41	11	5	3	2	2	1	1	1	1	1	1	1	1	1
0.89	0.23	0.115	1.2			39	10	5	3	2	2	1	1	1	1	1	1	1	1	1
0.88	0.25	0.125	1.15			37	10	5	3	2	2	1	1	1	1	1	1	1	1	1
0.87	0.27	0.135	1.1			35	9	4	3	2	1	1	1	1	1	1	1	1	1	1
0.86	0.29	0.145	1.06			33	9	4	3	2	1	1	1	1	1	1	1	1	1	1
0.85	0.31	0.155	1.02			31	8	4	2	2	1	1	1	1	1	1	1	1	1	1

APPENDIX C: RESILIENT MODULUS TEST RESULTS

Table C-1. E-06-1-13.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.53	2.01	15.56	4.49	29.62
2	14.57	2	20.57	6.87	37.39
3	19.51	2.01	25.53	9.2	41.88
4	24.46	2	30.48	11.53	41.13
5	29.46	2	35.45	13.89	42.53
6	9.01	3.97	20.94	4.25	26.48
7	14.2	3.99	26.17	6.7	32.08
8	24.06	4	36.05	11.34	41.65
9	34.23	3.99	46.21	16.14	45.99
10	44.34	4	56.34	20.9	47.08
11	18.78	5.99	36.74	8.85	32.84
12	28.77	5.99	46.75	13.56	42.25
13	38.68	5.99	56.65	18.24	50.07
14	48.65	6	66.65	22.93	54.26
15	58.6	5.99	76.56	27.62	58.82
16	18.51	8.02	42.56	8.72	35.67
17	28.27	8.03	52.35	13.33	45.57
18	38.23	8.01	62.25	18.02	54.72
19	48.31	8.02	72.37	22.77	61.96
20	58.37	8.03	82.45	27.51	66.34
21	17.25	10.07	47.46	8.13	45.26
22	27.57	10.07	57.79	13	51.01
23	37.91	10.07	68.12	17.87	59.7
24	48.03	10.06	78.22	22.64	67.4
25	58.09	10.07	88.31	27.39	73.65

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1=1619.25

K2= 0.22

K3= 0.61

R^2= 0.88

Table C-2. E-06-2-6.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.57	2.05	15.72	4.51	40.52
2	14.51	2.05	20.65	6.84	49.02
3	19.66	2.06	25.83	9.27	52.2
4	24.81	2.04	30.94	11.7	50.27
5	29.93	2.02	36	14.11	51.61
6	9.2	4.06	21.38	4.34	32.72
7	13.97	4.08	26.2	6.58	40.75
8	24.46	4.07	36.68	11.53	51.67
9	35.04	4.08	47.27	16.52	52.34
10	45.1	4.15	57.54	21.26	53.54
11	18.79	6.25	37.54	8.86	37.03
12	29.19	6.26	47.96	13.76	47.11
13	39.76	6.24	58.49	18.74	55.5
14	50.12	6.25	68.88	23.63	61.42
15	60.1	6.26	78.87	28.33	63.58
16	18.96	8.29	43.83	8.94	37.01
17	28.51	8.32	53.46	13.44	50.3
18	39.43	8.29	64.3	18.59	61.15
19	49.79	8.31	74.72	23.47	69.35
20	59.97	8.31	84.88	28.27	75.15
21	18.13	10.37	49.25	8.55	49.89
22	27.89	10.37	59	13.15	57.35
23	38.69	10.37	69.81	18.24	68.9
24	47.73	10.39	78.9	22.5	79.68
25	57.72	10.39	88.9	27.21	91.58

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1=2029.78

K2= 0.00

K3= 0.85

R^2= 0.74

Table C-3. E-05-61-12.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.48	2.09	15.76	4.47	58.82
2	14.46	2.08	20.72	6.82	67.64
3	19.64	2.1	25.93	9.26	73.94
4	24.49	2.08	30.73	11.54	79.65
5	29.55	2.1	35.85	13.93	82.27
6	9.08	4.16	21.57	4.28	56.25
7	14.07	4.17	26.57	6.63	63.59
8	23.97	4.2	36.56	11.3	77.97
9	34.22	4.17	46.73	16.13	88.29
10	44.16	4.17	56.68	20.82	93.47
11	18.63	6.27	37.44	8.78	72.24
12	28.73	6.24	47.45	13.54	83.55
13	38.65	6.24	57.38	18.22	94.53
14	48.74	6.24	67.46	22.97	100.46
15	58.58	6.25	77.33	27.61	103.36
16	18.63	8.3	43.52	8.78	72.14
17	28.32	8.29	53.2	13.35	82.58
18	38.3	8.3	63.21	18.06	93.35
19	48.19	8.31	73.11	22.72	103.72
20	58.19	8.3	83.1	27.43	111.01
21	17.87	10.39	49.03	8.43	79.2
22	27.89	10.37	59	13.15	87.83
23	37.85	10.36	68.94	17.84	98.42
24	47.9	10.36	78.99	22.58	107.35
25	57.83	10.38	88.97	27.26	114.63

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R=K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1=3431.27

K2= 0.13

K3= 0.53

R^2= 0.97

Table C-4. E-05.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.42	2.04	15.56	4.44	18.31
2	14.51	2.04	20.62	6.84	23.53
3	19.56	2.04	25.68	9.22	27.32
4	24.55	2.04	30.68	11.57	31.93
5	29.21	2.04	35.35	13.77	37.82
6	8.96	4.06	21.14	4.22	25.02
7	14.07	4.07	26.26	6.63	29.87
8	23.81	4.06	35.99	11.22	40.07
9	33.74	4.05	45.89	15.9	49.28
10	43.44	4.06	55.61	20.48	58.47
11	18.62	6.09	36.89	8.78	40.31
12	28.85	6.05	47.01	13.6	52.37
13	38.77	6.09	57.04	18.28	61.14
14	48.26	6.07	66.47	22.75	69.12
15	56.54	6.08	74.77	26.65	87.24
16	18.47	8.12	42.83	8.7	47.51
17	28.53	8.11	52.87	13.45	65.7

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R=K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 =1177.35

K2 =1.07

K3 = -0.20

R^2 = 0.99

Table C-5. E-02-1-3-4.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.55	2.03	15.66	4.5	9.45
2	14.42	2.05	20.57	6.8	10.74
3	18.68	2.03	24.78	8.8	12.18
4	23.93	2.03	30.02	11.28	14.33
5	29.43	2.04	35.57	13.88	15.47
6	8.72	4.06	20.9	4.11	12.32
7	14.05	4.04	26.15	6.62	13.51
8	24.49	4.06	36.67	11.54	16.92
9	33.64	4.02	45.71	15.86	19.02

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R=K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 =685.99

K2 = 0.91

K3 = -0.56

R^2 = 0.99

Table C-6. E-02-2-3-2.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.37	2.05	15.52	4.42	13.11
2	14.59	2.04	20.71	6.88	14.94
3	19.68	2.05	25.82	9.28	17.44
4	24.38	2.06	30.57	11.49	19.14
5	29.64	2.05	35.81	13.97	20.75
6	8.37	4.08	20.61	3.94	14.77
7	13.5	4.16	25.98	6.37	17.42
8	24.09	4.1	36.39	11.35	22.51
9	34.24	4.18	46.77	16.14	26.18
10	44.1	4.17	56.62	20.79	28.21
11	18.54	6.23	37.23	8.74	22.59
12	28.85	6.23	47.53	13.6	27.18
13	38.7	6.24	57.43	18.24	30.96
14	48.64	6.25	67.4	22.93	33.45

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1
Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 835.21
K2 = 0.72
K3 = -0.11
R^2 = 0.99

Table C-7. E-04-1-3.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.37	2.06	15.57	4.42	26.74
2	14.49	2.05	20.65	6.83	32.85
3	19.38	2.05	25.53	9.14	35.66
4	24.38	2.05	30.54	11.49	38.86
5	29.19	2.04	35.32	13.76	40.1
6	8.94	4.09	21.22	4.22	26.72
7	14.23	4.08	26.46	6.71	32.99
8	24.12	4.07	36.34	11.37	43.09
9	33.65	4.07	45.85	15.86	48.04
10	41.81	4.06	53.99	19.71	55.58
11	18.87	6.1	37.16	8.9	46.53
12	28.72	6.1	47.02	13.54	58.3
13	37.26	6.12	55.61	17.56	66.36

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 1580.27

K2 = 0.65

K3 = 0.09

R^2 = 0.92

Table C-8. E-04-2-6.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.5	2.06	15.67	4.48	22.52
2	14.51	2.05	20.66	6.84	29.66
3	19.41	2.05	25.55	9.15	33.12
4	24.31	2.03	30.41	11.46	31.69
5	29.13	2.04	35.25	13.73	30.74
6	9.04	4.05	21.2	4.26	20.26
7	14.18	4.06	26.35	6.68	27.34
8	24.01	4.06	36.19	11.32	36.04
9	33.88	4.18	46.43	15.97	43.81
10	41.89	4.19	54.45	19.75	50.4

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 1115.22

K2 = 0.04

K3 = 1.21

R^2 = 0.87

Table C-9. E-09-1-14.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.47	1.99	15.43	4.46	35.63
2	14.6	1.97	20.52	6.88	40.17
3	19.64	1.99	25.62	9.26	46.44
4	24.54	1.98	30.49	11.57	51.04
5	29.55	1.98	35.49	13.93	53.54
6	10.3	3.9	22.01	4.86	43.77
7	15.03	3.9	26.73	7.08	41.69
8	24.18	3.9	35.88	11.4	54.12
9	34.52	3.89	46.19	16.27	64.32
10	44.57	3.89	56.25	21.01	70.41
11	18.79	5.88	36.42	8.86	53.15
12	28.68	5.88	46.32	13.52	62.86
13	38.94	5.88	56.6	18.36	73.21
14	48.96	5.87	66.56	23.08	80.45
15	59.05	5.88	76.69	27.84	85.34
16	18.64	7.91	42.36	8.79	58.48
17	28.23	7.9	51.93	13.31	67.03
18	38.36	7.91	62.07	18.08	75.03
19	48.47	7.9	72.18	22.85	82.41
20	58.62	7.89	82.29	27.63	88.76
21	18.29	9.93	48.09	8.62	67.69
22	28.28	9.93	58.07	13.33	72.57
23	38.34	9.93	68.13	18.07	79.69
24	48.54	9.94	78.37	22.88	87.69
25	58.89	9.95	88.73	27.76	93.05

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 2228.59

K2 = 0.55

K3 = 0.06

R^2 = 0.99

Table C-10. E-07-69-1-14.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.48	2.05	15.64	4.47	17.06
2	14.5	2.07	20.7	6.84	22.58
3	19.47	2.04	25.61	9.18	23.44
4	24.62	2.04	30.75	11.61	26.28
5	29.42	2.04	35.55	13.87	29.03
6	9.05	4.07	21.24	4.26	20.89
7	14	4.07	26.21	6.6	27.39
8	23.85	4.08	36.09	11.24	36.53

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1
Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 1246.81
K2 = 1.02
K3 = -0.59
R^2 = 0.90

Table C-11. E-07-68-2-6.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.55	2.04	15.68	4.5	17.87
2	14.56	2.04	20.68	6.86	23.31
3	19.38	2.04	25.51	9.13	24.79
4	24.21	2.04	30.34	11.41	25.14
5	28.92	2.05	35.07	13.63	24.41
6	9.0	4.08	21.24	4.24	19.51
7	14.16	4.08	26.39	6.67	26.1
8	23.91	4.07	36.12	11.27	33.27

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1
Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 1261.47
K2 = 0.69
K3 = -0.28
R^2 = 0.73

Table C-12. E-08-235-1-12.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.47	2.03	15.55	4.46	27.36
2	14.42	2.05	20.58	6.8	34.56
3	19.28	2.05	25.42	9.09	41.18
4	24.15	2.04	30.28	11.38	45.96
5	28.82	2.05	34.97	13.59	49.17
6	8.89	4.05	21.04	4.19	31.75
7	14.28	4.04	26.4	6.73	41.09
8	24.69	4.04	36.79	11.64	53.45
9	34.08	4.05	46.22	16.07	63.59
10	42.71	4.06	54.88	20.13	63.71
11	19.02	6.08	37.25	8.96	50.13
12	29.23	6.09	47.49	13.78	64.48
13	38.64	6.09	56.91	18.22	72.5
14	46.1	6.08	64.35	21.73	71.31

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 1799.02

K2 = 0.68

K3 = 0.06

R^2 = 0.98

Table C-13. E-08-2-1-6.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.44	2.04	15.57	4.45	39.4
2	14.62	2.05	20.78	6.89	49.5
3	19.56	2.05	25.7	9.22	57.17
4	24.36	2.05	30.5	11.48	60.54
5	29.13	2.03	35.21	13.73	60.36
6	8.8	4.05	20.93	4.15	41.15
7	14.05	4.04	26.16	6.62	51.3
8	24.19	4.04	36.3	11.4	64.37
9	33.92	4.05	46.06	15.99	72.75
10	43.6	4.07	55.8	20.56	74.66
11	18.69	6.08	36.93	8.81	59.83
12	28.88	6.1	47.17	13.61	72.87
13	38.85	6.08	57.1	18.31	85.2
14	48.76	6.08	67	22.99	92.42
15	58.26	6.07	76.48	27.47	97.42
16	18.6	8.1	42.91	8.77	66.66
17	28.5	8.1	52.8	13.43	79.14
18	38.77	8.11	63.11	18.28	90.48
19	48.85	8.12	73.23	23.03	100.17
20	58.11	8.12	82.48	27.39	107.12
21	17.91	10.17	48.4	8.44	83.66
22	28.16	10.15	58.6	13.27	90.6
23	37.97	10.15	68.42	17.9	98.09
24	48.08	10.15	78.54	22.67	108.3
25	57.97	10.15	88.43	27.33	114.35

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 2508.41

K2 = 0.61

K3 = 0.00

R^2 = 0.96

Table C-14. E-01-1-3-2-3.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.66	2.05	15.8	4.55	45.62
2	14.83	2.05	20.99	6.99	53.63
3	19.75	2.03	25.85	9.31	56.87
4	24.61	2.03	30.7	11.6	58.06
5	29.26	2.04	35.37	13.79	56.65
6	9.31	4.07	21.51	4.39	53.73
7	14.53	4.07	26.74	6.85	54.92
8	24.47	4.08	36.71	11.54	59.38
9	34.23	4.08	46.48	16.14	64.65
10	43.59	4.07	55.81	20.55	66.38
11	19.16	6.11	37.49	9.03	58.31
12	29.21	6.11	47.55	13.77	63.09
13	39.2	6.11	57.52	18.48	69.34
14	48.79	6.11	67.13	23	73.08
15	57.94	6.1	76.24	27.31	70.32
16	19.0	8.14	43.44	8.96	56.55
17	28.75	8.15	53.2	13.55	60.99
18	38.74	8.17	63.26	18.26	65.78
19	48.78	8.16	73.25	22.99	71.1
20	58.2	8.16	82.69	27.44	75.0
21	18.13	10.19	48.71	8.55	62.94
22	28.4	10.2	58.99	13.39	66.01
23	38.62	10.19	69.19	18.2	70.43
24	48.57	10.2	79.16	22.89	75.86
25	58.32	10.2	88.91	27.49	80.55

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 3079.02

K2 = 0.19

K3 = 0.18

R^2 = 0.93

Table C-15. E-01.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.38	2.03	15.46	4.42	51.96
2	14.49	2.01	20.53	6.83	55.18
3	19.4	2.02	25.45	9.15	57.67
4	24.22	2.04	30.33	11.42	58.73
5	29.08	2.0	35.08	13.71	64.95
6	8.88	4.0	20.88	4.19	50.36
7	14.0	4.0	26.02	6.6	55.73
8	24.05	4.0	36.06	11.34	68.22
9	33.93	4.01	45.95	15.99	76.11
10	43.27	4.02	55.34	20.4	77.45
11	18.51	6.03	36.6	8.73	64.5
12	28.67	6.02	46.73	13.51	75.2
13	38.89	6.04	57	18.33	83.91
14	48.62	6.04	66.75	22.92	90.85
15	57.97	6.03	76.07	27.33	88.23
16	18.44	8.04	42.57	8.69	63.22
17	28.3	8.04	52.43	13.34	72.22
18	38.46	8.04	62.59	18.13	81.01
19	48.5	8.04	72.61	22.87	88.99
20	58.33	8.05	82.49	27.5	97.28
21	18.21	10.1	48.5	8.58	75.2
22	28.29	10.09	58.56	13.34	81.11
23	38.39	10.1	68.68	18.1	89.23
24	48.47	10.1	78.78	22.85	97.47
25	58.54	10.1	88.83	27.59	105.08

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 2984.08

K2 = 0.32

K3 = 0.23

R^2 = 0.95

Table C-16. E-03-6-10-3.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.32	2.05	15.48	4.39	27.39
2	14.41	2.05	20.55	6.79	28.41
3	19.68	2.05	25.82	9.28	29.08
4	24.61	2.05	30.75	11.6	29.66
5	29.19	2.05	35.34	13.76	29.45
6	8.97	4.07	21.19	4.23	25.11
7	14.11	4.07	26.32	6.65	26.86
8	24.16	4.08	36.39	11.39	32.39
9	33.35	4.07	45.57	15.72	33.18

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1
Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 1576.57
K2 = -0.04
K3 = 0.52
R^2 = 0.76

Table C-17. E-05 above Optimum Water Content.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.4	2.04	15.53	4.43	26.41
2	14.46	2.05	20.6	6.82	37.04
3	19.4	2.03	25.5	9.15	42.81
4	23.68	2.03	29.79	11.16	43.53
5	28.55	2.05	34.69	13.46	37.13
6	9.2	4.07	21.4	4.34	29.09
7	14.15	4.08	26.38	6.67	36.28
8	24.31	4.08	36.56	11.46	46.17
9	33.17	4.08	45.41	15.64	51.27

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1
Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 1653.32
K2 = 0.29
K3 = 0.57
R^2 = 0.77

Table C-18. E-05 below Optimum Water Content.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.52	2.03	15.62	4.49	34.88
2	14.38	2.03	20.47	6.78	43.38
3	19.39	2.03	25.48	9.14	50.39
4	24.29	2.05	30.43	11.45	56.3
5	29.26	2.04	35.39	13.8	61.21
6	8.78	4.08	21.01	4.14	42.23
7	14.16	4.06	26.35	6.68	51.51
8	24.06	4.06	36.22	11.34	65.25
9	34.02	4.06	46.21	16.04	74.26
10	43.92	4.06	56.1	20.7	80.17
11	18.65	6.11	36.97	8.79	59.8
12	28.32	6.09	46.58	13.35	71.96
13	38.45	6.11	56.77	18.12	82.83
14	48.35	6.09	66.61	22.79	92.39
15	57.97	6.06	76.15	27.33	103.12
16	17.79	8.13	42.19	8.39	59.25
17	27.99	8.12	52.36	13.19	79.24
18	38.26	8.14	62.67	18.04	92.05
19	48.29	8.15	72.74	22.76	102.91
20	58.21	8.16	82.68	27.44	114.43
21	17.68	10.18	48.21	8.33	76.09
22	27.97	10.18	58.51	13.19	89.41
23	38.29	10.18	68.84	18.05	102.56
24	48.39	10.18	78.91	22.81	112.11
25	57.39	10.18	87.93	27.05	119.95

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 2213.00

K2 = 0.64

K3 = 0.13

R^2 = 0.98

Table C-19. E-01 above Optimum Water Content.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.35	2.04	15.48	4.41	18.23
2	14.23	2.04	20.37	6.71	24.71
3	19.31	2.04	25.44	9.1	29.8
4	24.24	2.05	30.39	11.43	35.05
5	28.68	2.06	34.86	13.52	34.52
6	8.99	4.07	21.19	4.24	23.5
7	14.25	4.08	26.48	6.72	29.36
8	24.36	4.08	36.6	11.48	38.51
9	33.55	4.08	45.78	15.81	39.8

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 1247.19

K2 = 0.69

K3 = 0.11

R^2 = 0.95

Table C-20. E-01 below Optimum Water Content.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.52	2.05	15.69	4.49	35.17
2	14.27	2.06	20.45	6.73	37.9
3	19.39	2.04	25.51	9.14	38.16
4	23.99	2.03	30.09	11.31	43.51
5	26.35	2.03	32.45	12.42	69.42
6	9	4.07	21.21	4.24	69.11
7	14.01	4.09	26.27	6.6	76.89

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 4776.75

K2 = 2.41

K3 = -4.51

R^2 = 0.77

Table C-21. E-09-1-14 above Optimum Water Content.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.1	2.05	15.24	4.29	24.24
2	14.38	2.04	20.51	6.78	30.74
3	19.48	2.05	25.64	9.19	37.89
4	24.31	2.05	30.45	11.46	43.25
5	29.16	2.04	35.29	13.74	46.49
6	9.01	4.06	21.19	4.25	31.05
7	13.95	4.07	26.17	6.58	38.15
8	24.18	4.06	36.37	11.4	50.66
9	33.73	4.07	45.94	15.9	62.6
10	41.59	4.07	53.81	19.61	66.43
11	18.07	6.11	36.41	8.52	51.61
12	28.11	6.1	46.42	13.25	62.42
13	34.32	6.11	52.65	16.18	65.34

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 1678.82

K2 = 0.90

K3 = -0.19

R^2 = 95

Table C-22. E-09-1-14 below Optimum Water Content.

Sequence	Deviator Stress (psi)	Confining Pressure (psi)	Theta (psi)	TAUoct (psi)	M_R-v (ksi)
1	9.31	2.05	15.45	4.39	33.75
2	14.64	2.05	20.79	6.9	40.01
3	19.81	2.05	25.95	9.34	45.8
4	24.46	2.04	30.6	11.53	48.84
5	29.21	2.04	35.35	13.77	52.6
6	8.69	4.08	20.92	4.1	34.22
7	13.74	4.07	25.93	6.48	40.57
8	23.99	4.06	36.16	11.31	50.51
9	33.87	4.05	46.01	15.96	58.55
10	43.62	4.06	55.78	20.56	60.74
11	18.24	6.09	36.5	8.6	45.22
12	28.62	6.1	46.91	13.49	54.68
13	38.73	6.1	57.02	18.26	62.27
14	47.05	6.1	65.33	22.18	60.23
15	57.1	6.11	75.43	26.92	77.73
16	18.44	8.14	42.86	8.69	46.22
17	28.44	8.15	52.88	13.41	59.88
18	38.16	8.13	62.54	17.99	64.09
19	48.08	8.14	72.49	22.66	74.79
20	56.96	8.13	81.34	26.85	92.52
21	18.05	10.18	48.57	8.51	69.89
22	27.68	10.18	58.2	13.05	79.89
23	37.91	10.17	68.41	17.87	85.79
24	47.65	10.18	78.18	22.46	93.85
25	55.67	10.18	86.2	26.24	96.35

AASHTO2002 Granular Base Resilient Modulus M_R-v Level1

Regression Equation: M_R = K1*Pa*(THETA/Pa)^K2*(TAUoct/Pa+1)^K3

k1 = 2004.46

K2 = 0.56

K3 = 0.08

R^2 = 0.88

APPENDIX D: PERMANENT DEFORMATION RESULTS

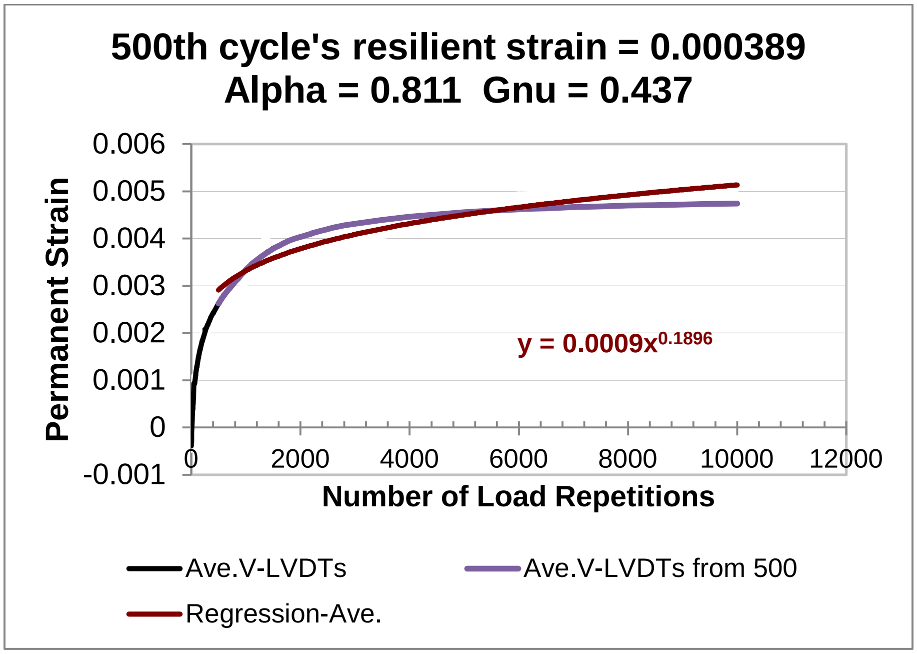

Figure D-1. E-06-1-13.

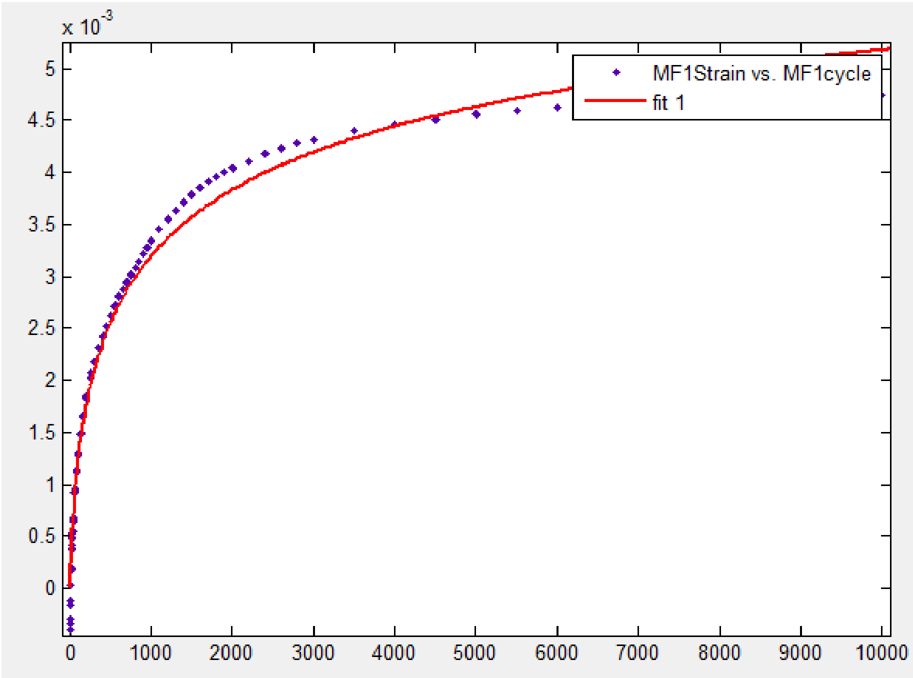

Figure D-2. E-06-1-13.

ε_0=8.38E-03 , ρ=890, β=0.301

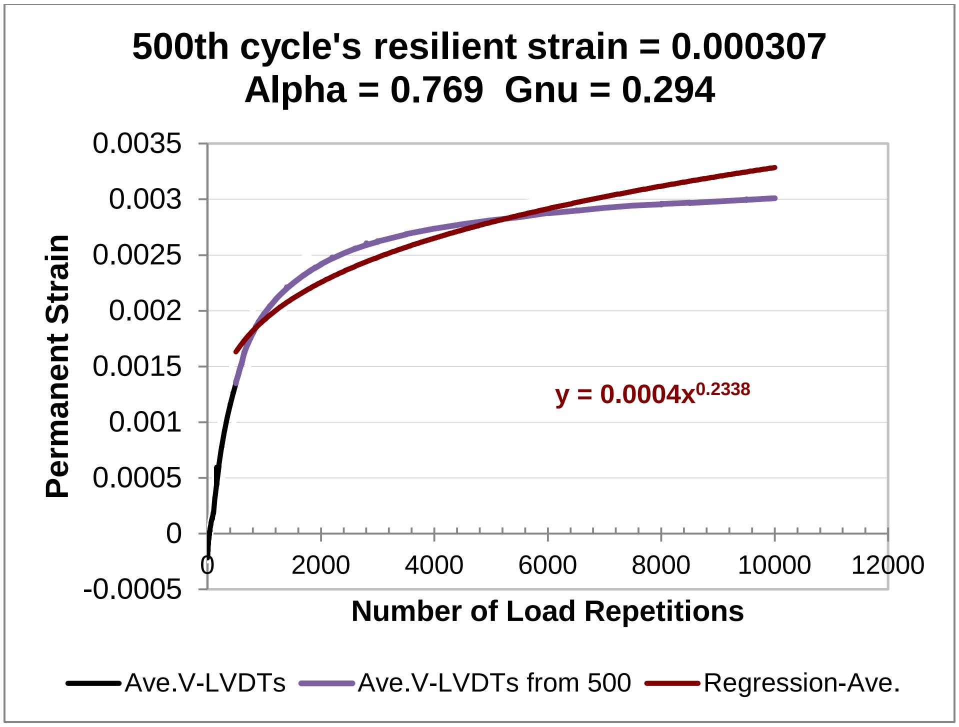

Figure D-3. E-06-2-6.

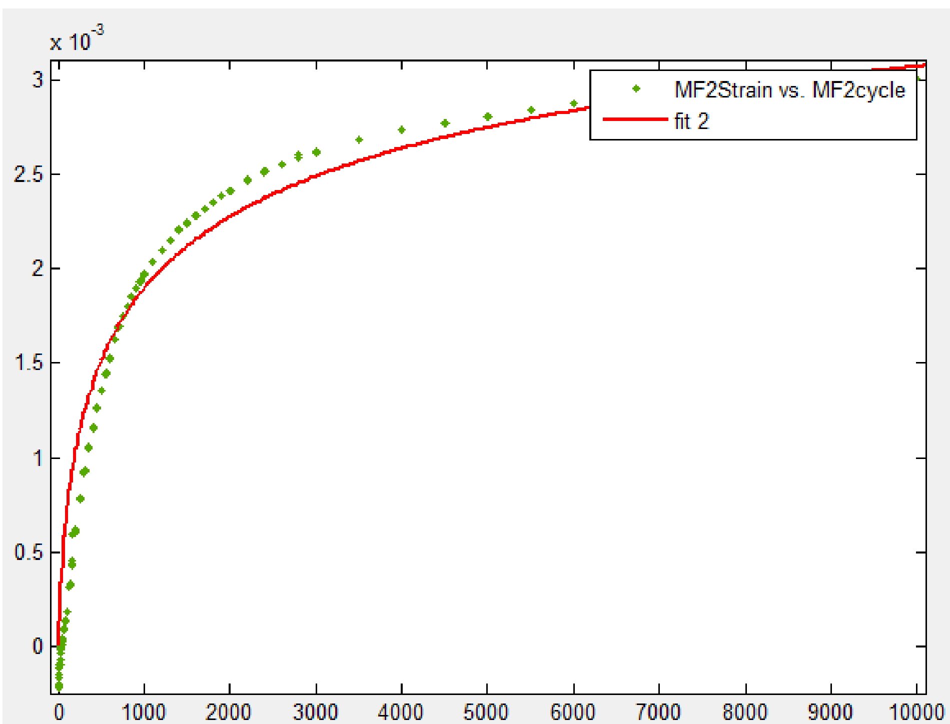

Figure D-4. E-06-2-6.

ε_0 =5.04E-03 , ρ =860, β =0.305

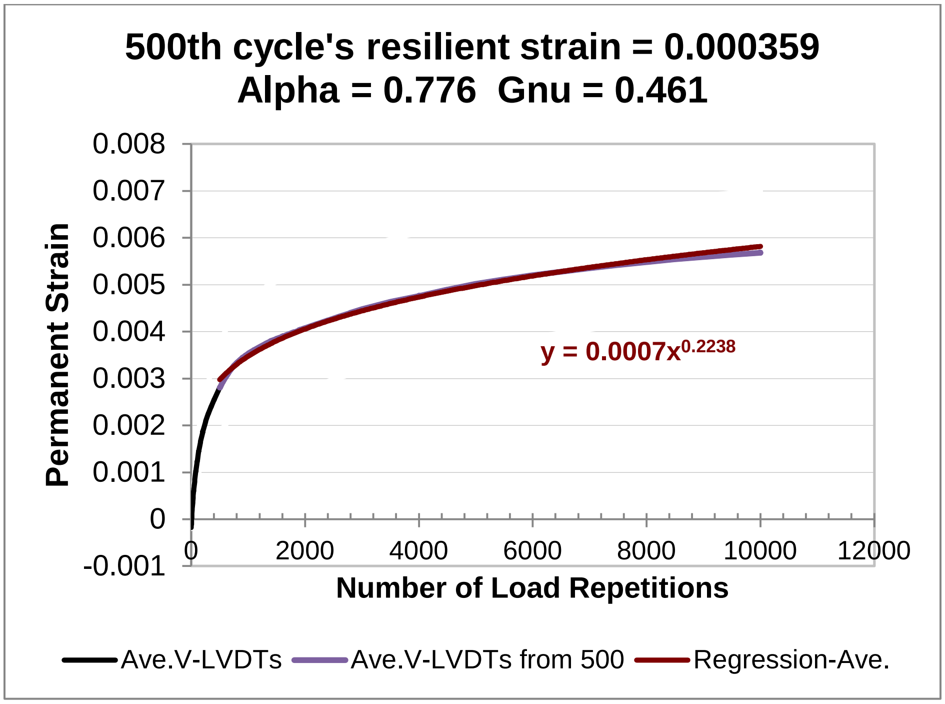

Figure D-5. E-05-61-12.

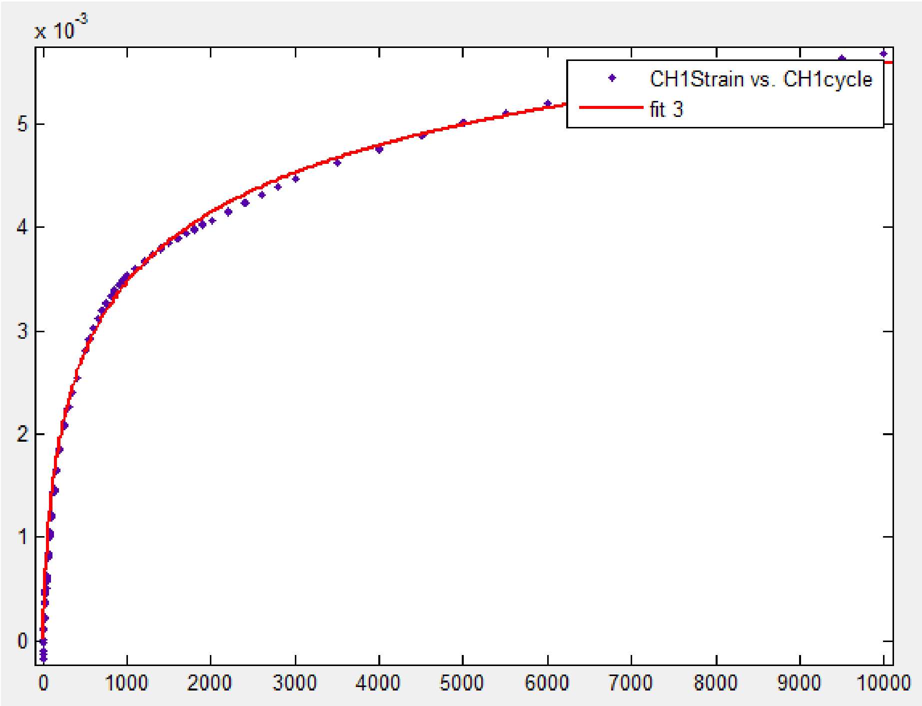

Figure D-6. E-05-61-12.

ε_0=4.86E-03 , ρ=940, β=0.292

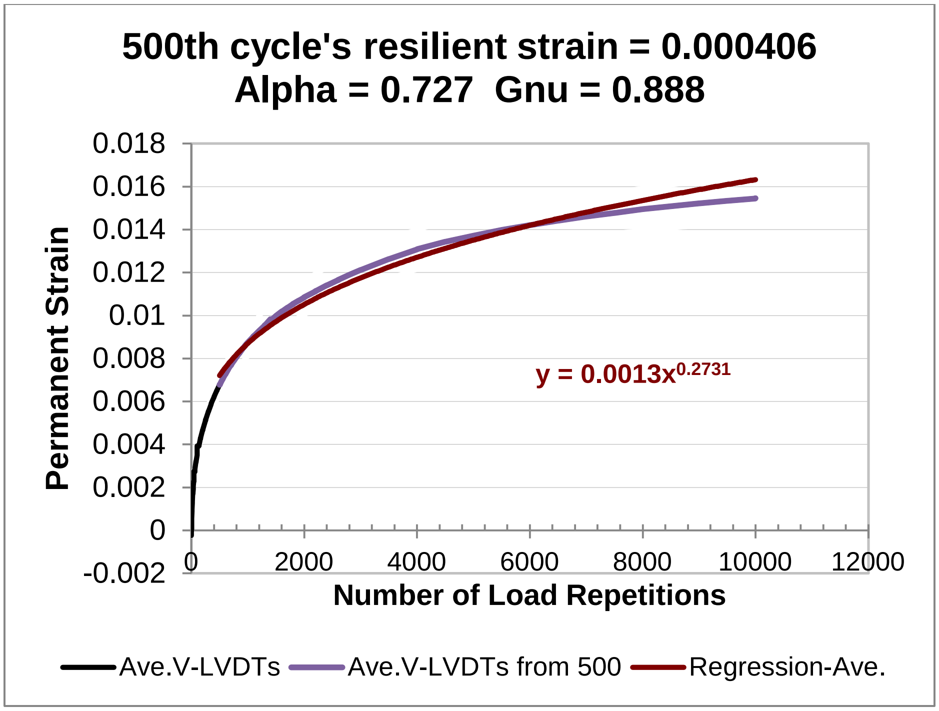

Figure D-7. E-05.

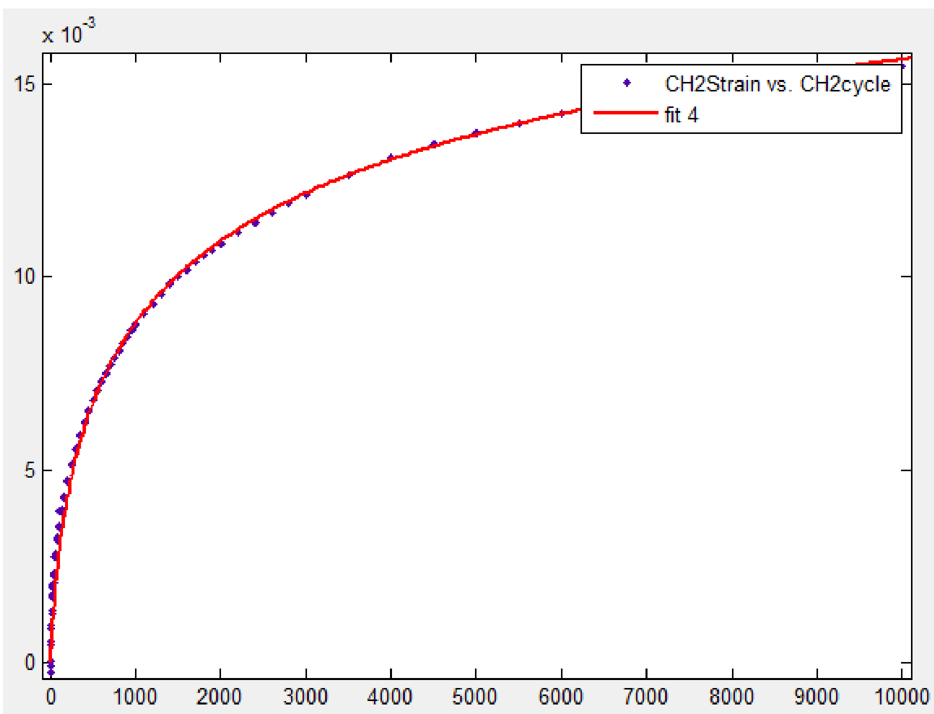

Figure D-8. E-05.

ε_0=2.72E-02 , ρ=1500, β=0.307

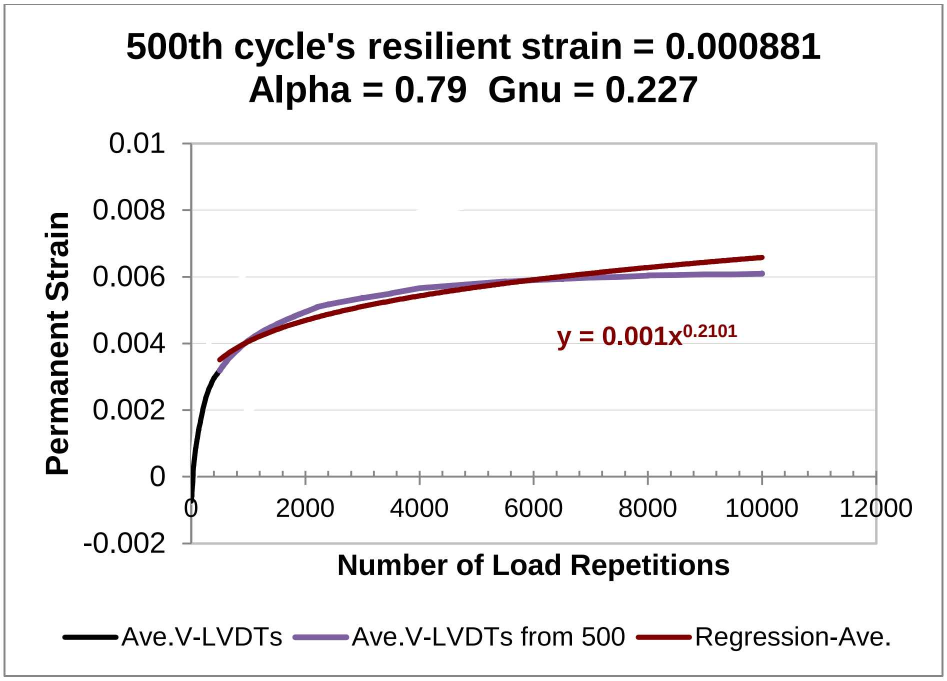

Figure D-9. E-02-1-3-4.

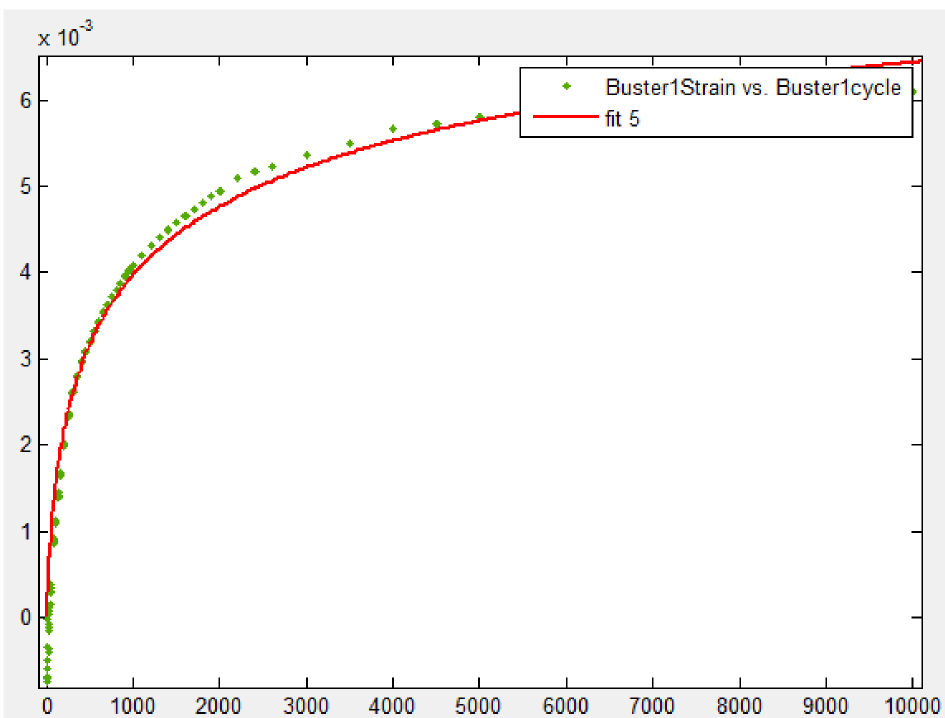

Figure D-10. E-02-1-3-4.

ε_0 =1.04E-02 , ρ =860, β =0.305

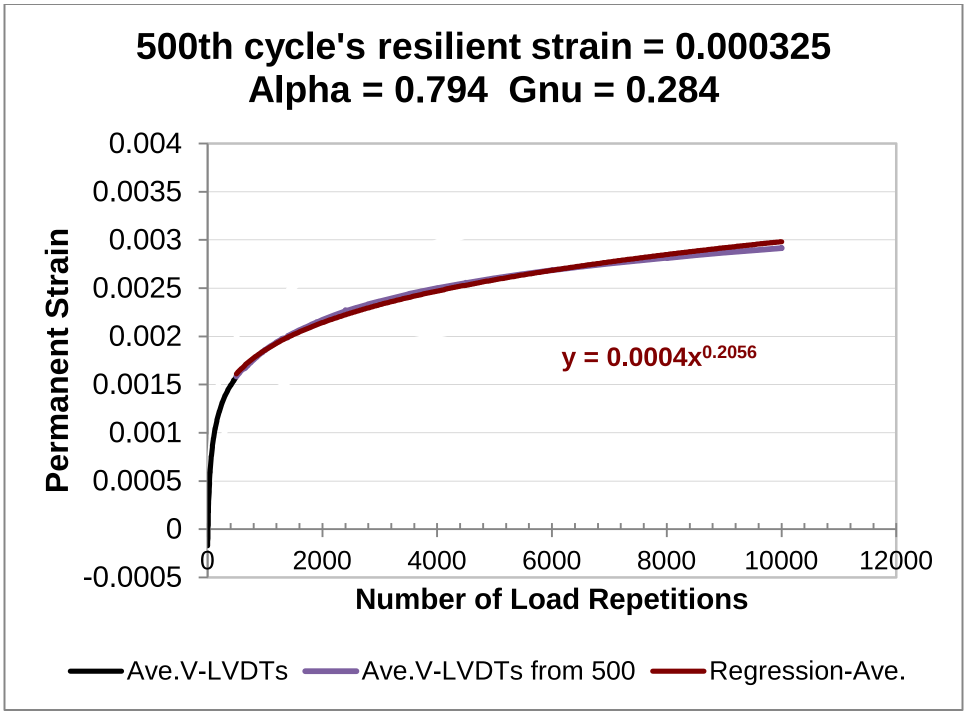

Figure D-11. E-04-1-3.

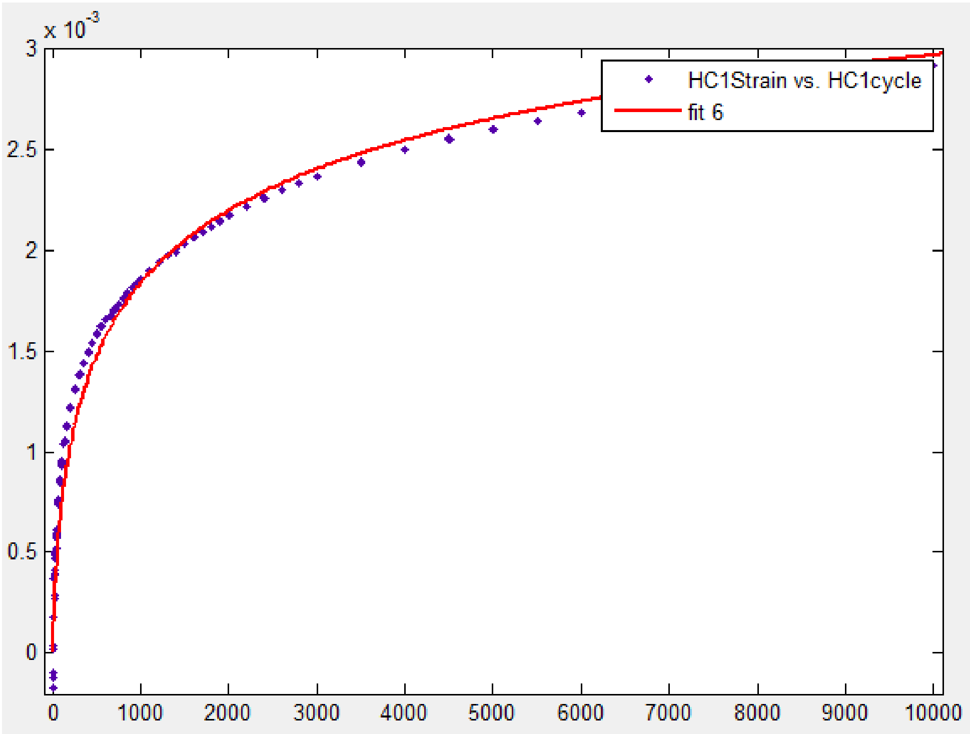

Figure D-12. E-04-1-3.

ε_0=4.86E-03 , ρ=940, β=0.292

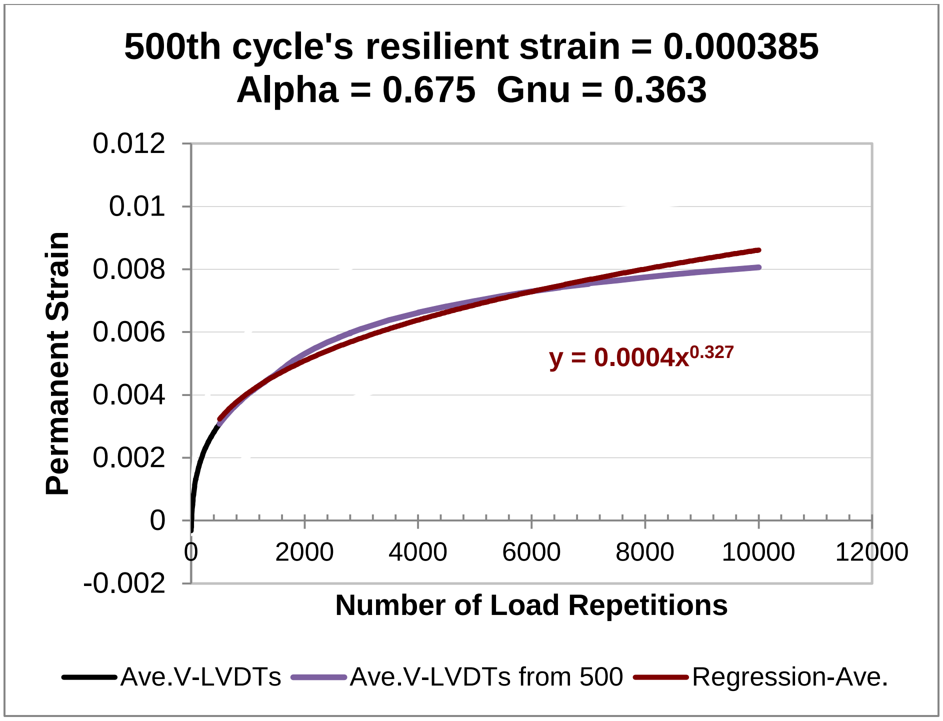

Figure D-13. E-04-2-6.

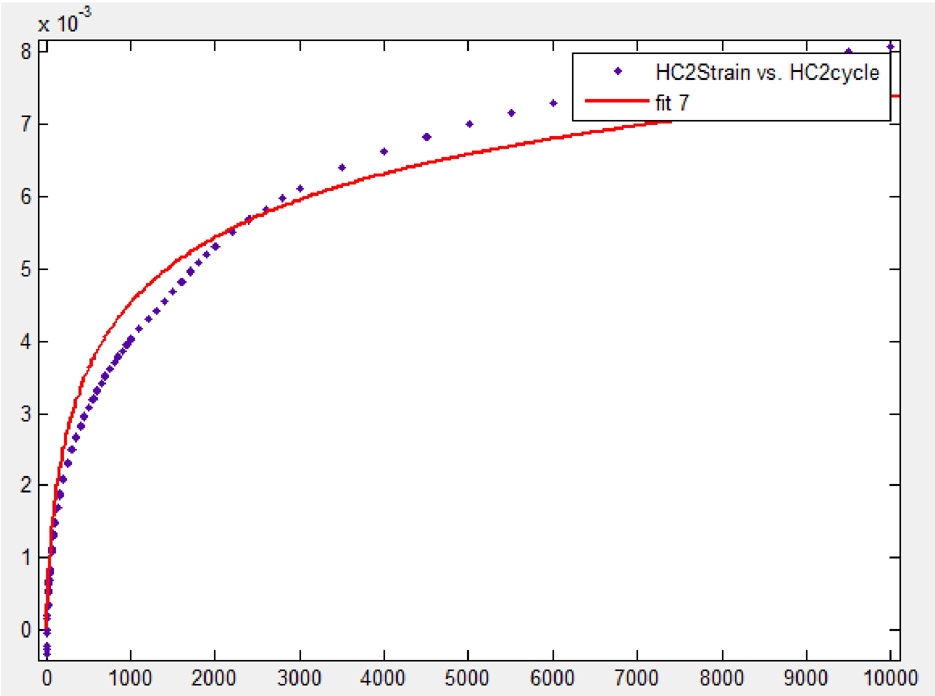

Figure D-14. E-04-2-6.

ε_0=1.23E-02 , ρ=970, β=0.293

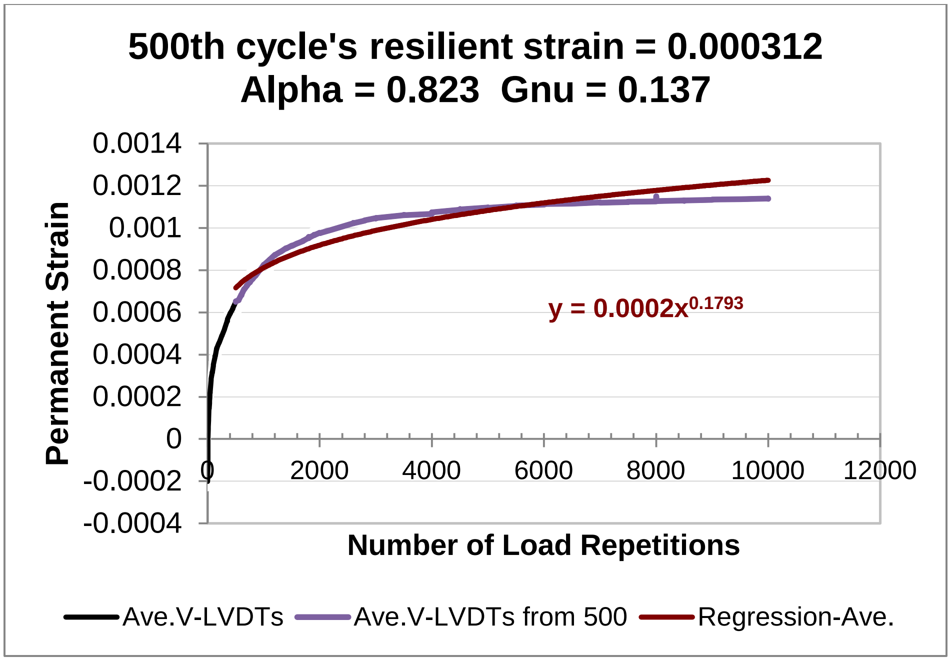

Figure D-15. E-09-1-14.

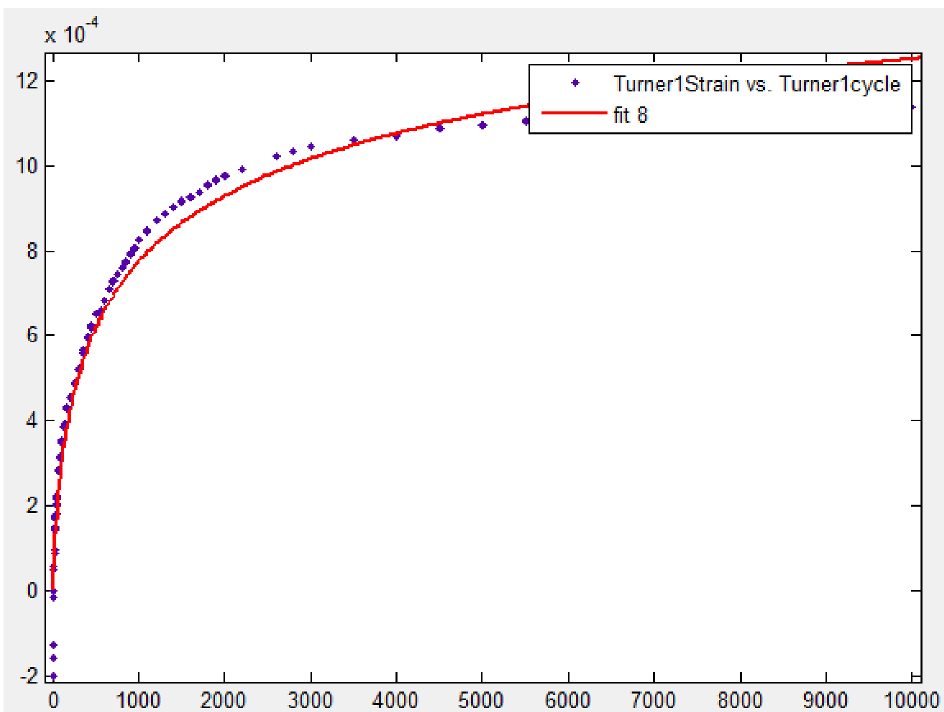

Figure D-16. E-09-1-14.

ε_0=1.98E-03 , ρ=820, β=0.310

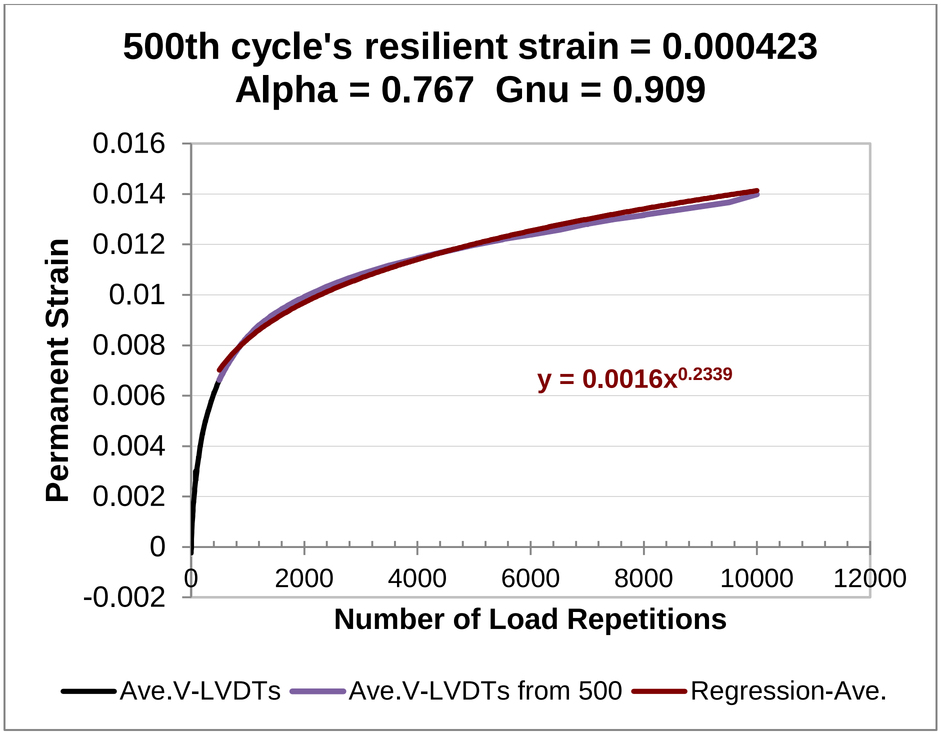

Figure D-17. E-07-69-1-14.

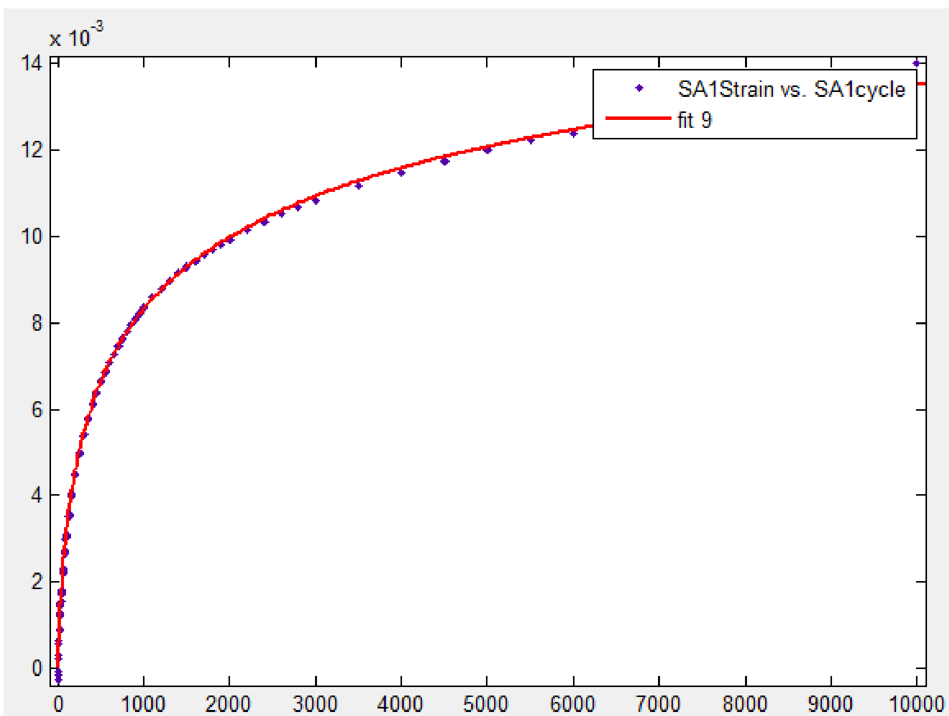

Figure D-18. E-07-69-1-14.

ε_0=2.19E-02 , ρ=900, β=0.300

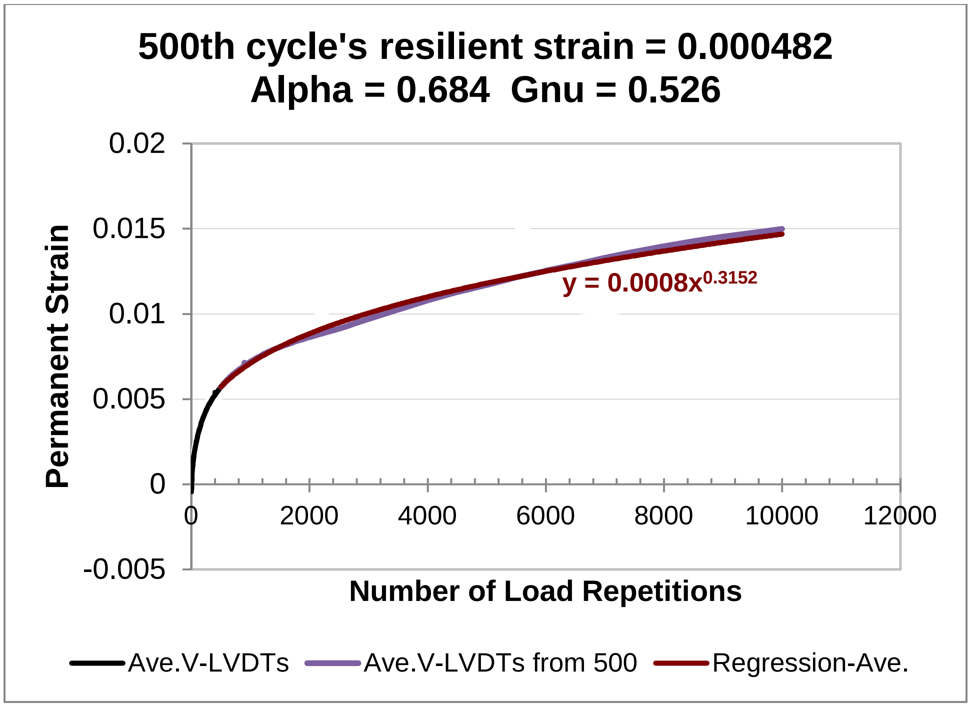

Figure D-19. E-07-68-2-6.

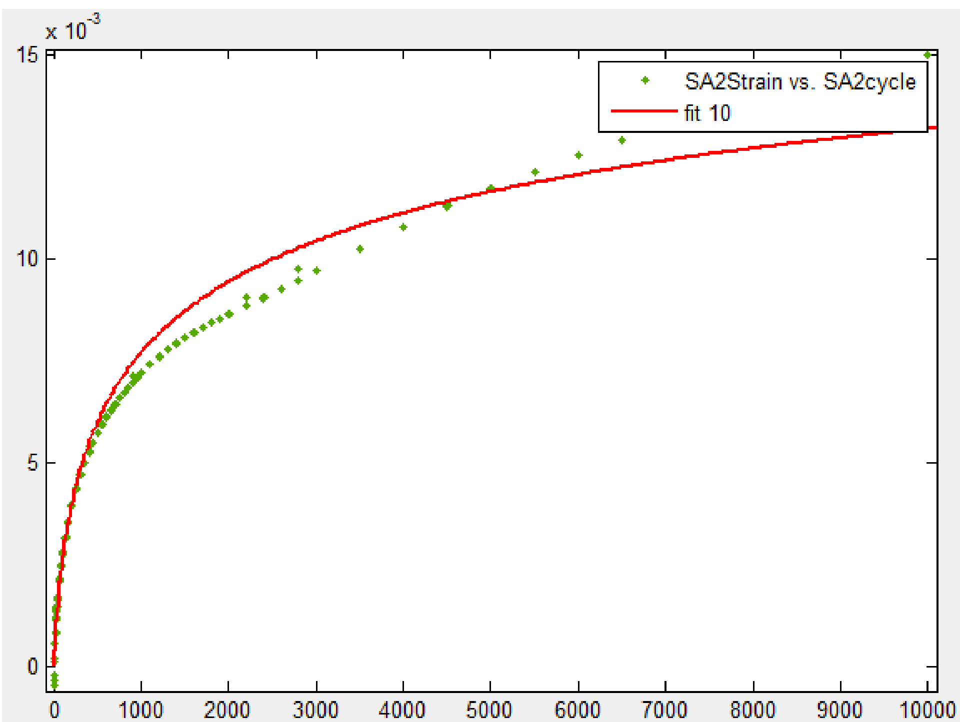

Figure D-20. E-07-68-2-6.

ε_0 =2.24E-02 , ρ =1230, β =0.304

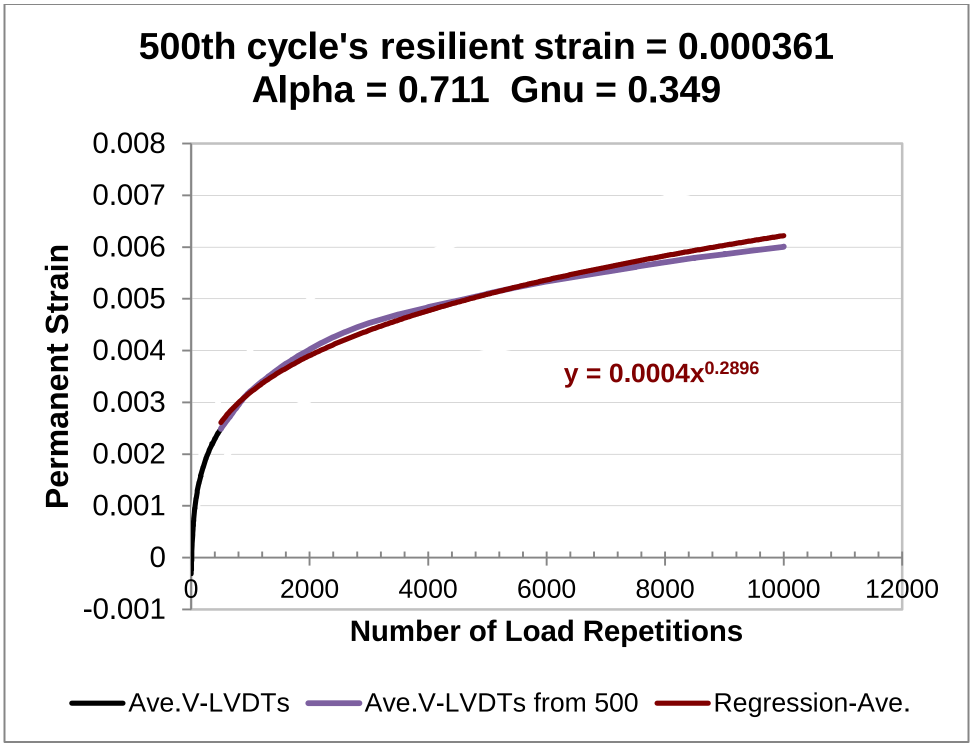

Figure D-21. E-08-235-1-12.

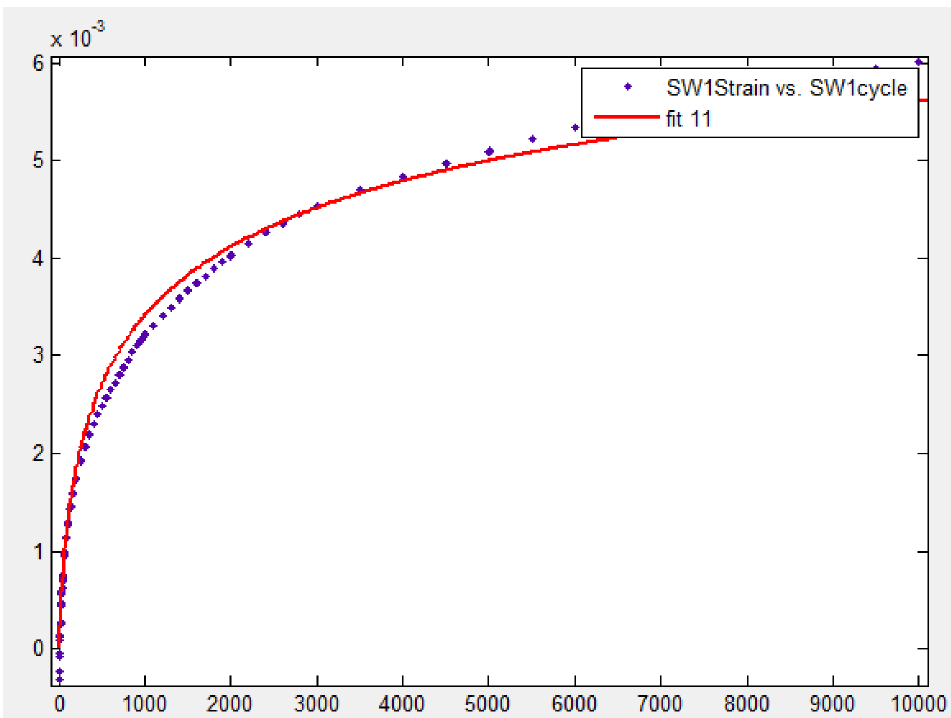

Figure D-22. E-08-235-1-12.

ε_0=9.19E-03 , ρ=950, β=0.302

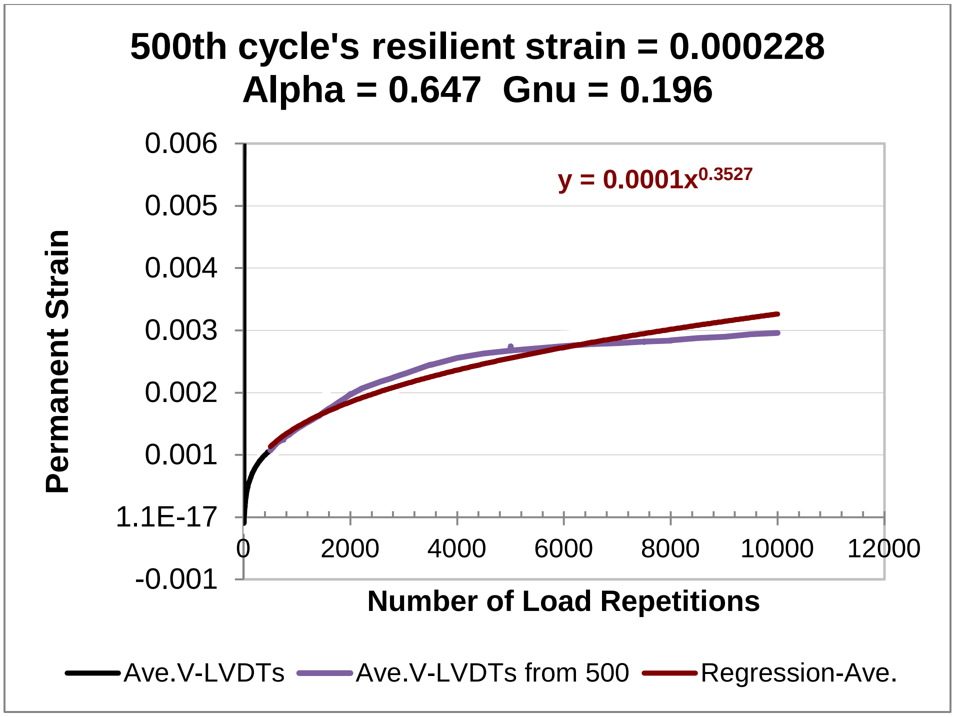

Figure D-23. E-08-2-1-6.

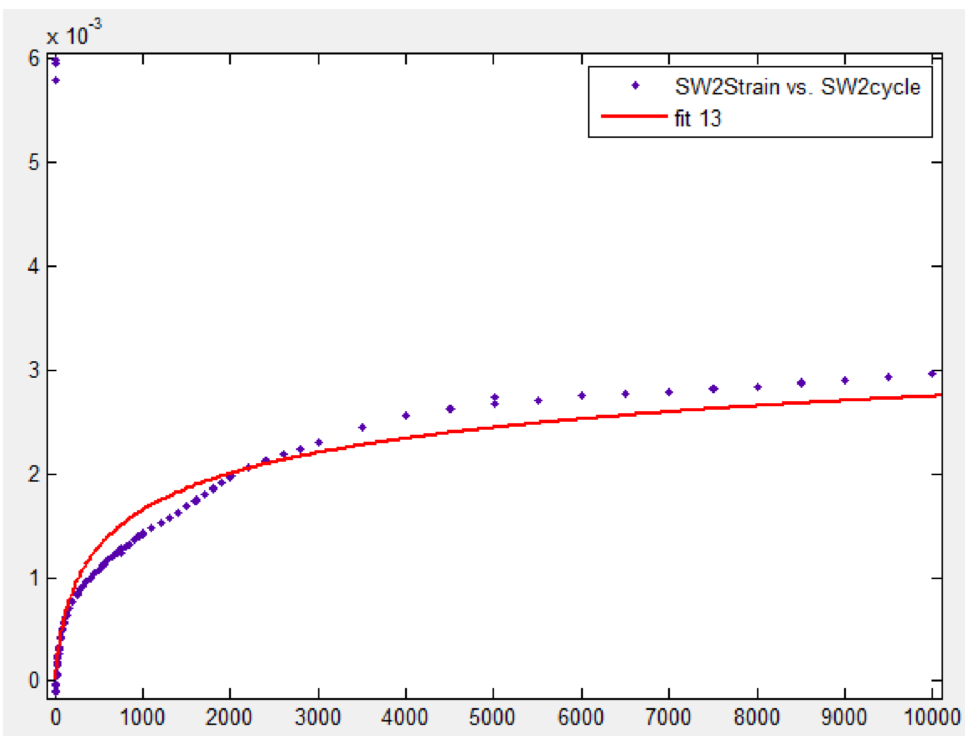

Figure D-24. E-08-2-1-6.

ε_0=4.50E-03 , ρ=980, β=0.310

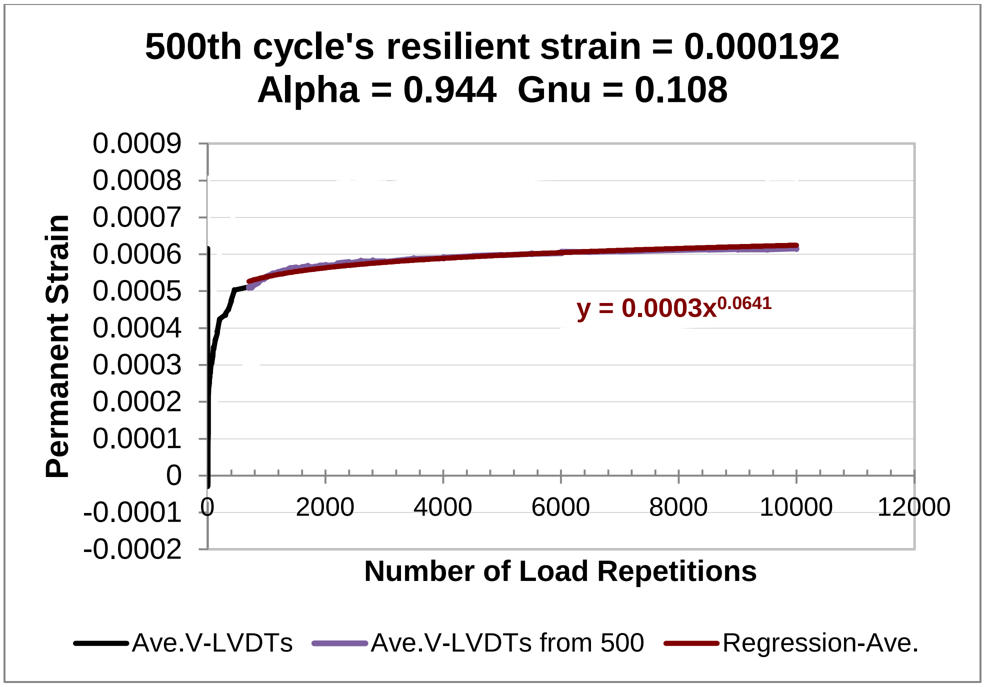

Figure D-25. E-01.

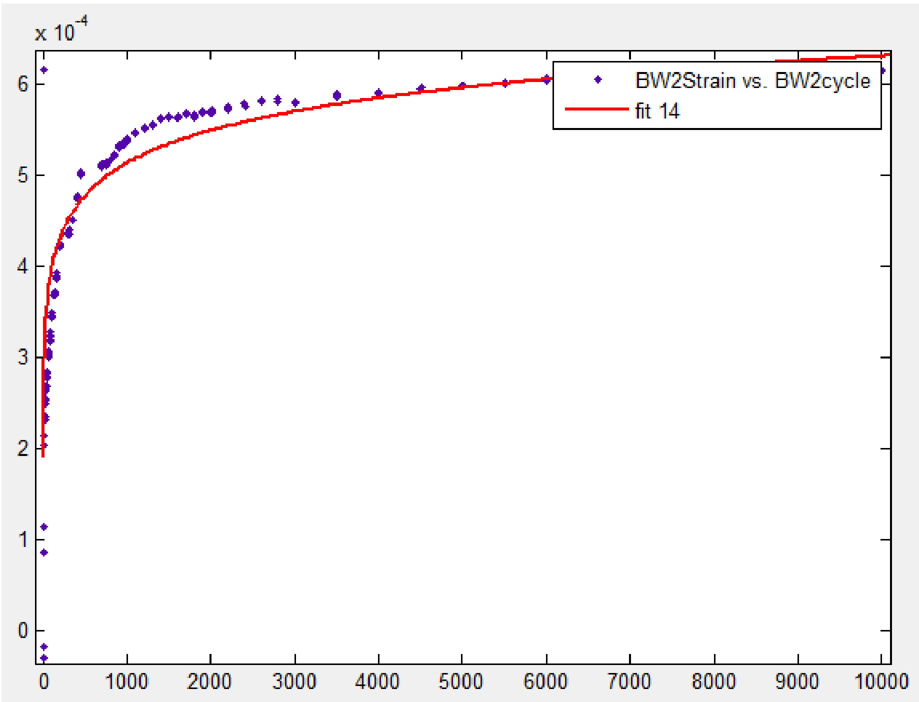

Figure D-26. E-01.

ε_0 =1.42E-03 , ρ =980, β =0.100

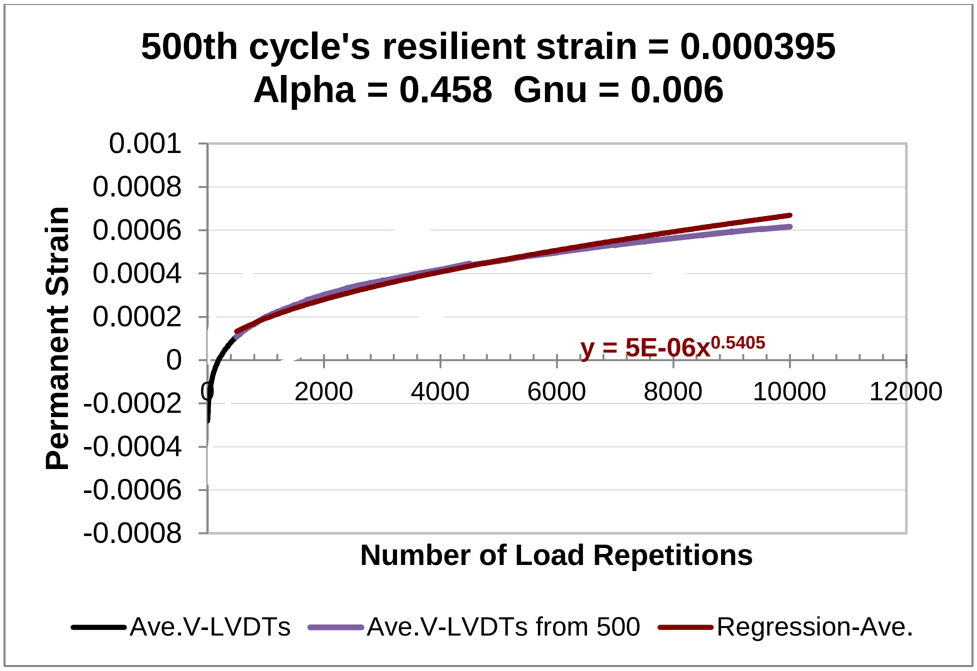

Figure D-27. E-03-6-10-3.

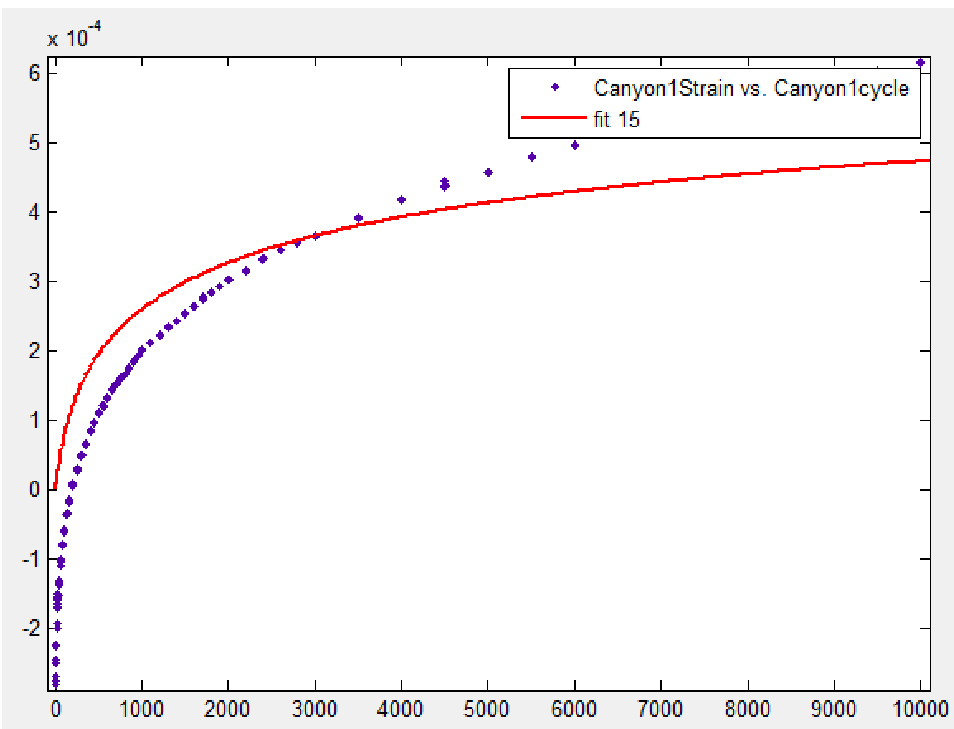

Figure D-28. E-03-6-10-3.

ε_0 =8.57E-04 , ρ =1530, β =0.305

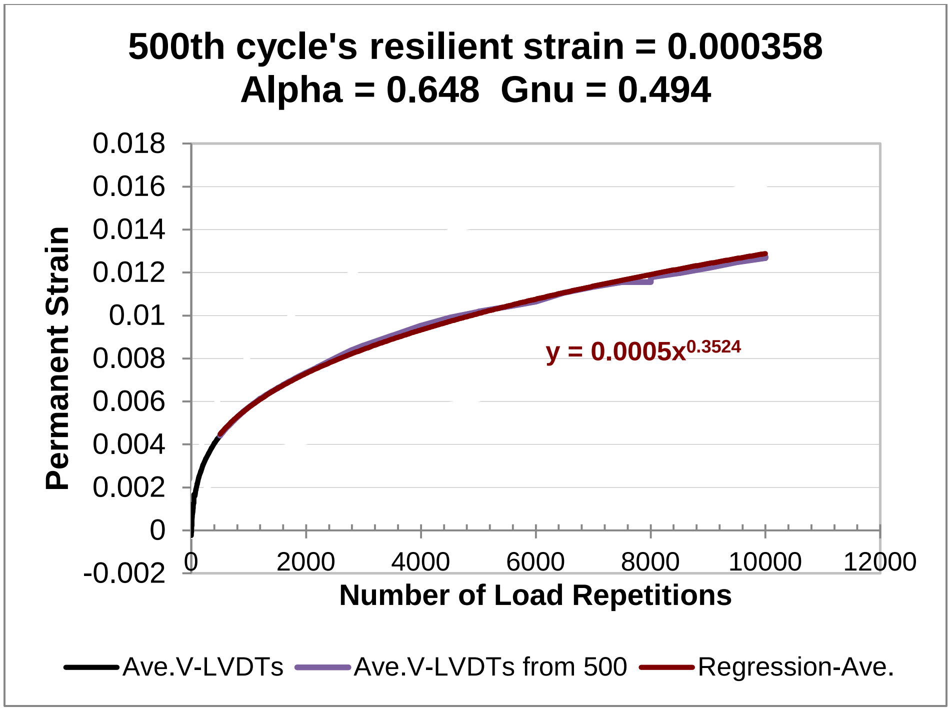

Figure D-29. E-05 above the Optimum Water Content.

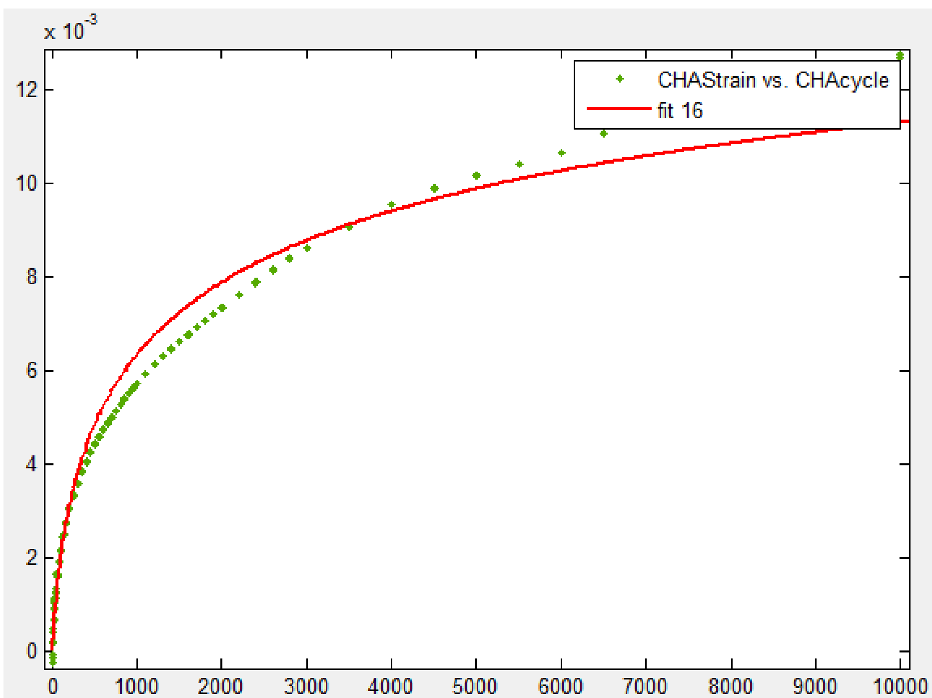

Figure D-30. E-05 above the Optimum Water Content.

ε_0=2.00E-02 , ρ=1570, β=0.303

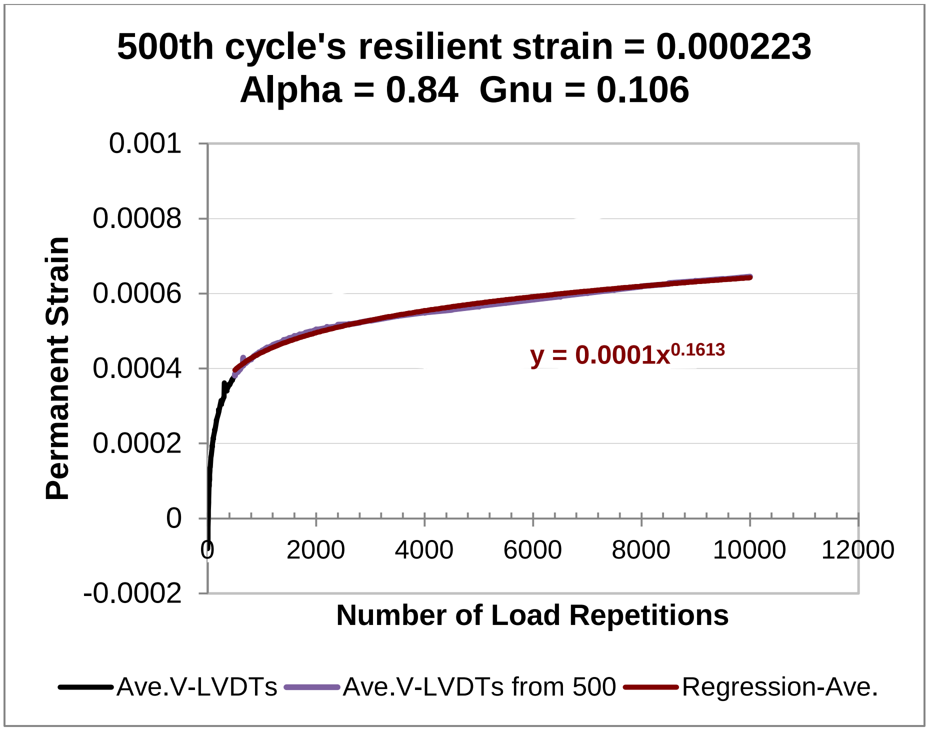

Figure D-31. E-05 below the Optimum Water Content.

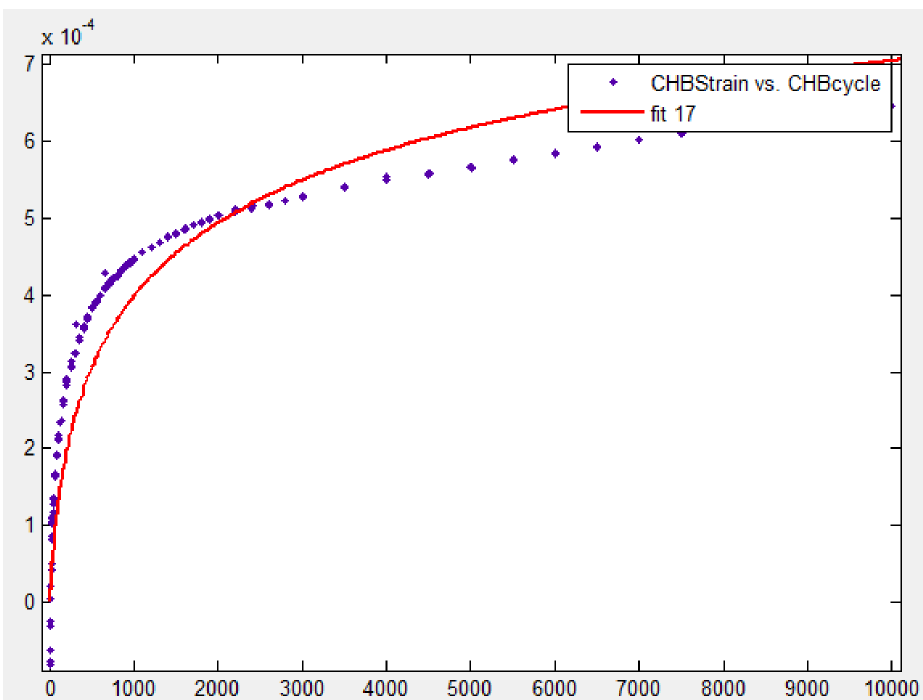

Figure D-32. E-05 below the Optimum Water Content.

ε_0 =1.24E-03 , ρ =1520, β =0.303

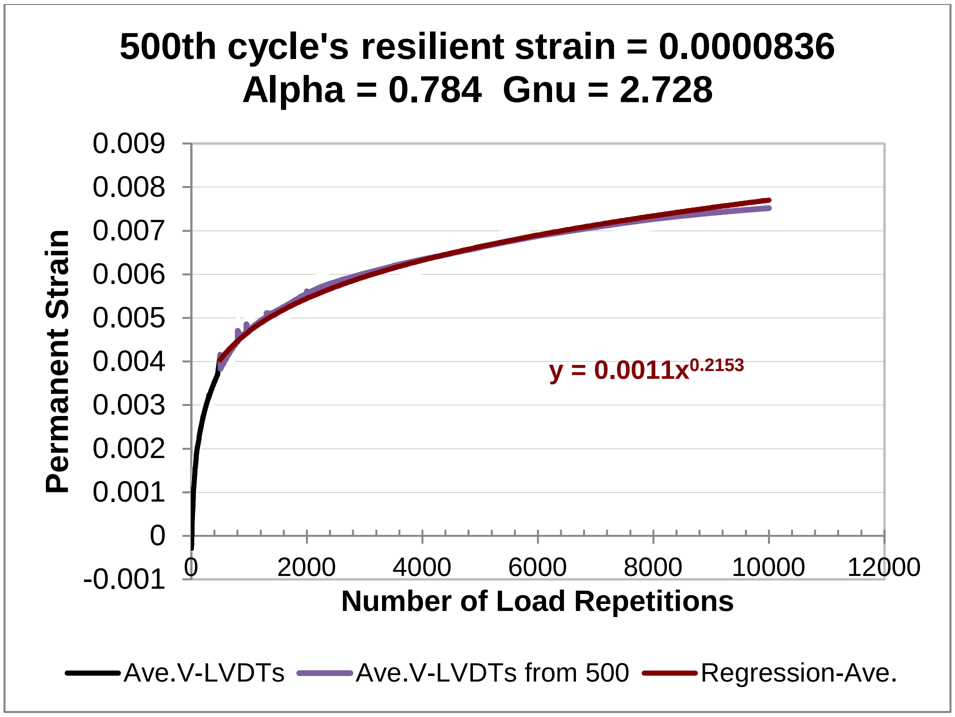

Figure D-33. E-0 above the Optimum Water Content.

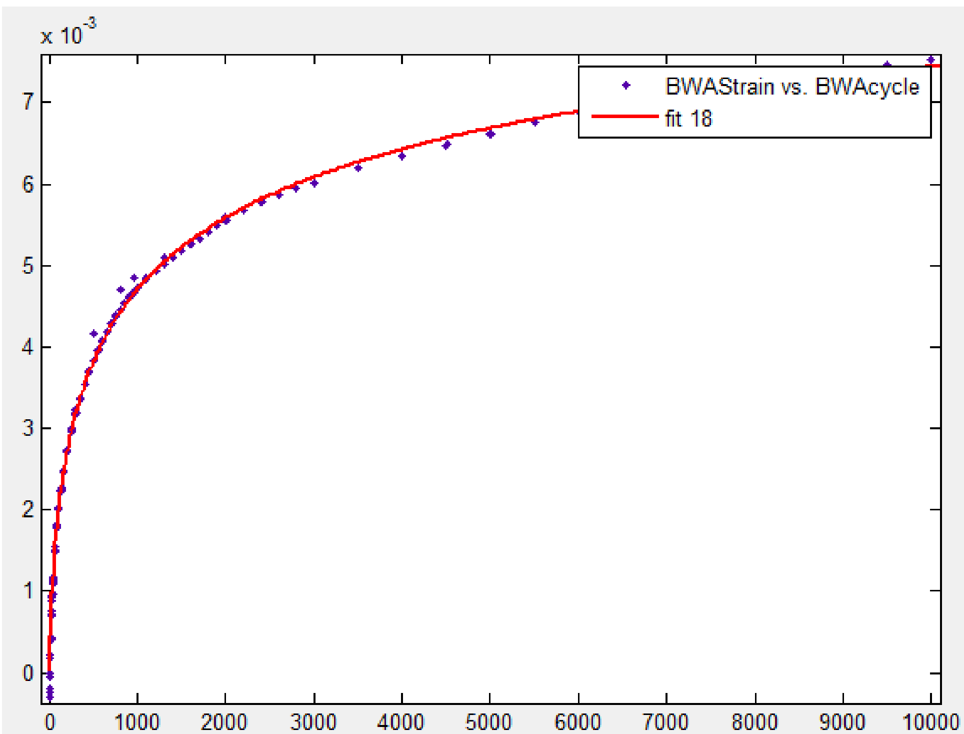

Figure D-34. E-0 above the Optimum Water Content.

ε_0 =1.21E-02 , ρ =810, β =0.289

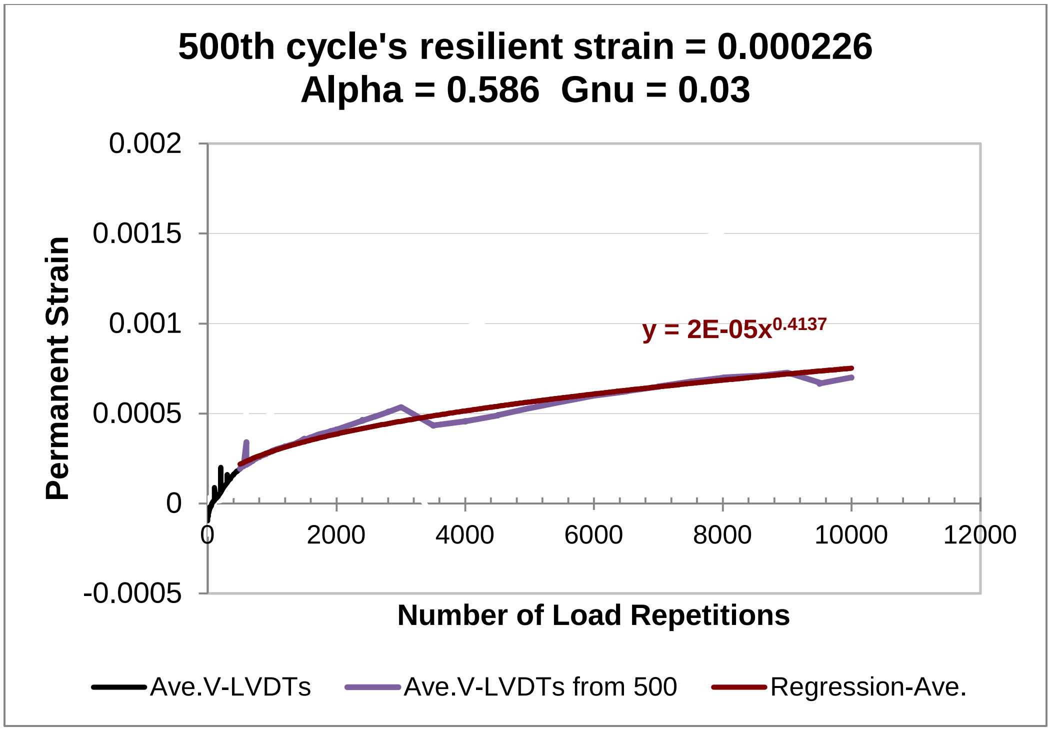

Figure D-35. E-01 below the Optimum Water Content.

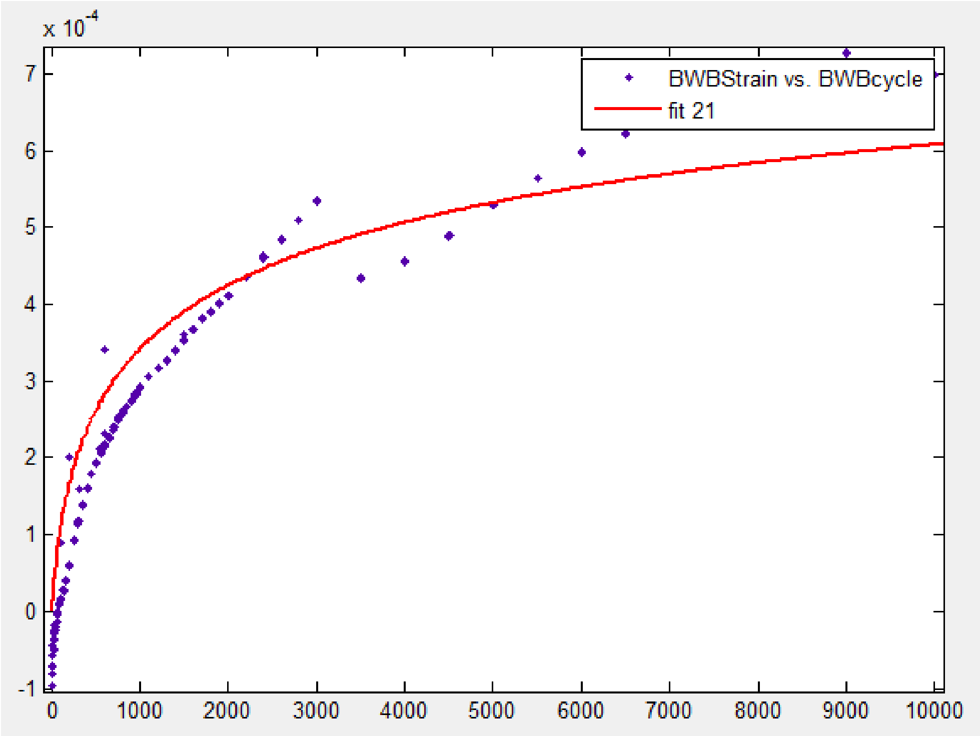

Figure D-36. E-01 below the Optimum Water Content.

ε_0=1.08E-03 , ρ=1560, β=0.303

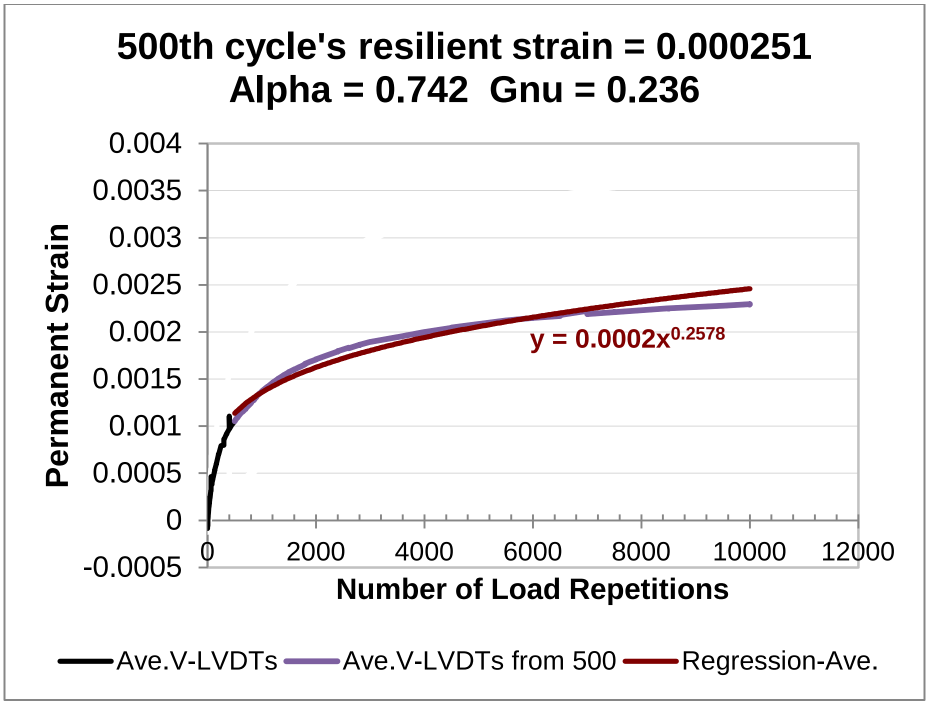

Figure D-37. E-09-1-14 above the Optimum Water Content.

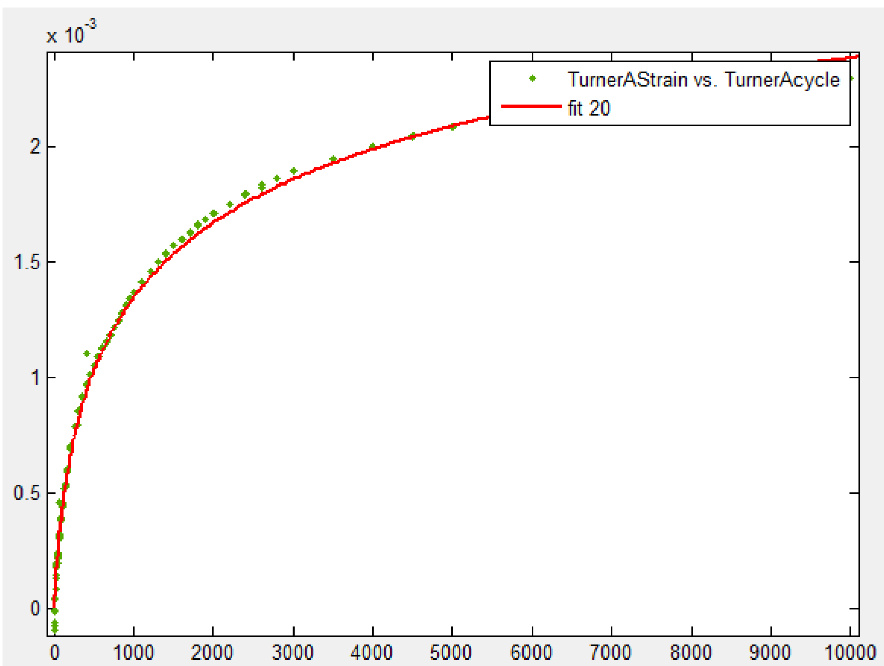

Figure D-38. E-09-1-14 above the Optimum Water Content.

ε_0=4.18E-03 , ρ=1500, β=0.304

APPENDIX E: TABLES OF TEST RESULTS

A number of various aggregate mixtures were collected from throughout Texas, and these materials were tested in the laboratory during the last 3 months of the project period. The methylene blue test, percent fines content (pfc) test, and Atterberg limits (plastic limit, liquid limit and plasticity index) tests were performed, and the tests result are tabulated in Table E-1. These test results were employed to find a mathematical relationship between methylene blue value (MBV) and both pfc and Atterberg limits.

Mean values, standard deviations, and coefficients of variation for each quarry were calculated, and the results are tabulated in Table E-2.

Table E-1. Laboratory Tests for All Aggregate Mixtures.

Material Source	Buckets Code	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	pfc	Activity Ratio, A_C (PI/pfc)	LL/pfc	MBV
	No	%	%	%	%	%	%	(mg/g)
E-02	1-2-2-1	17.0	10.00	7.00	11.20	0.63	1.52	3.20
E-02	1-2-2-2	20.0	14.00	6.00	11.90	0.50	1.68	4.00
E-02	1-2-2-3	19.0	13.00	6.00	11.42	0.53	1.66	4.42
E-02	1-2-2-4	21.0	13.00	8.00	11.57	0.69	1.82	3.93
E-02	1-2-2-5	18.0	12.00	6.00	12.73	0.47	1.41	4.41
E-02	1-3-4	15.0	9.00	6.00	11.43	0.52	1.31	5.32
E-02	1-4-1	-	-	-	12.57	-	-	-
E-02	1-4-2	-	-	-	12.47	-	-	-
E-02	1-4-3	19.0	12.00	7.00	12.15	0.58	1.56	-
E-02	1-4-4	21.0	12.00	9.00	12.59	0.71	1.67	-
E-02	1-4-5	20.0	11.00	9.00	12.62	0.71	1.58	-
E-02	2-3-2	15.0	10.00	5.00	12.97	0.39	1.16	3.65
E-02	3-1-2	17.0	13.00	4.00	11.96	0.33	1.42	3.28
E-03	2-10-3	30.0	17.00	13.00	16.09	0.81	1.86	14.16
E-03	4-1	28.00	12.00	16.00	16.71	0.96	1.68	26.26
E-03	4-1-2	31.0	16.00	15.00	16.71	0.90	1.86	20.72
E-03	4-1-3	30.0	19.00	11.00	17.32	0.64	1.73	17.46
E-03	4-1-4	29.0	17.00	12.00	17.93	0.67	1.62	16.30
E-03	4-1-5	28.0	16.00	12.00	17.34	0.69	1.61	16.08
E-03	4-2-1	35.0	15.00	20.00	17.32	1.15	2.02	25.40
E-03	4-3-10	34.0	14.00	20.00	16.36	1.22	2.08	21.84
E-03	4-4	26.0	18.00	8.00	15.64	0.51	1.66	9.50
E-03	6-1	28.0	15.00	13.00	19.31	0.67	1.45	16.92
E-03	6-2	30.0	14.00	16.00	18.95	0.84	1.58	21.04
E-03	6-3	32.0	19.00	13.00	22.81	0.57	1.40	22.52
E-03	6-4	25.0	15.00	10.00	22.58	0.44	1.11	17.90
E-03	6-5	25.0	15.00	10.00	20.65	0.48	1.21	18.48

Table E-1. Laboratory Tests for All Aggregate Mixtures (Continued).

Material Source	Buckets Code	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	pfc	Activity Ratio, A_C (PI/pfc)	LL/pfc	MBV
	No	%	%	%	%	%	%	(mg/g)
E-03	6-6	28.00	16.00	12.00	22.66	0.53	1.24	20.70
E-03	6-10-1	26.0	12.00	14.00	24.45	0.57	1.06	27.42
E-03	6-10-2	27.0	14.00	13.00	20.26	0.64	1.33	18.72
E-03	6-10-3	27.0	14.00	13.00	22.83	0.57	1.18	18.50
E-03	6-7	27.0	18.00	9.00	-	-	-	-
E-03	6-8	28.0	16.00	12.00	18.72	0.64	1.50	12.40
E-03	6-9	24.0	15.00	9.00	18.61	0.48	1.29	18.30
E-03	6-10	26.0	14.00	12.00	18.49	0.65	1.41	19.92
E-03	6-11	29.0	15.00	14.00	18.63	0.75	1.56	19.56
E-05	-	-	-	-	21.70	-	-	-
E-05	61-1	15.0	12.00	3.00	-	-	-	-
E-05	61-2	15.0	11.00	4.00	20.98	0.19	0.71	2.30
E-05	61-3	14.0	10.00	4.00	-	-	-	-
E-05	61-4	15.0	12.00	3.00	-	-	-	-
E-05	61-5	14.0	12.00	2.00	25.80	0.08	0.54	2.25
E-05	61-7	14.0	11.00	3.00	-	-	-	-
E-05	61-8	14.0	11.00	3.00	22.20	0.14	0.63	2.41
E-05	61-9	14.0	10.00	4.00	23.20	0.17	0.60	2.27
E-05	61-10	14.0	12.00	2.00	21.85	0.09	0.64	2.50
E-05	61-11	14.0	12.00	2.00	20.33	0.10	0.69	2.52
E-05	61-12	13.0	10.00	3.00	19.99	0.15	0.65	2.12
E-04	1-1	21.0	15.00	-	14.67	0.00	1.43	17.56
E-04	1-2	-	-	-	15.69	-	-	16.68
E-04	1-3	20.0	11.00	9.00	12.71	0.71	1.57	16.36
E-04	1-4	19.0	14.00	-	12.24	0.00	1.55	16.24
E-04	1-5	18.0	14.00	-	12.11	0.00	1.49	13.04
E-04	1-6	21.0	14.00	7.00	12.60	0.56	1.67	10.20
E-04	1-8-1	-	-	-	12.93	-	-	16.00
E-04	1-8-2	-	-	-	15.29	-	-	17.88
E-04	1-9	20.0	14.00	6.00	15.35	0.39	1.30	-
E-04	1-10	22.0	15.00	-	13.98	0.00	1.57	15.04
E-04	1-11	21.0	14.00	7.00	13.43	0.52	1.56	10.76
E-04	1-12	24.0	15.00	9.00	15.45	0.58	1.55	-
E-04	1-13	25.0	15.00	-	12.69	0.00	1.97	23.16
E-04	1-14	21.0	14.00	7.00	18.20	-	1.15	-
E-04	2-2	20.0	14.00	6.00	12.84	-	1.56	-
E-04	2-3	22.0	13.00	9.00	12.84	-	1.71	-

Table E-1. Laboratory Tests for All Aggregate Mixtures (Continued).

Material Source	Buckets Code	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	pfc	Activity Ratio, A_C (PI/pfc)	LL/pfc	MBV
	No	%	%	%	%	%	%	(mg/g)
E-04	2-4	20.0	13.00	7.00	13.85	-	1.44	-
E-04	2-6	22.0	10.00	12.00	12.29	0.98	1.79	10.56
E-06	--	-	-	-	14.90	-	-	5.16
E-06	1-1	16.0	11.00	5.00	14.26	0.35	1.12	-
E-06	1-3	21.0	11.00	10.00	17.13	0.58	1.23	12.34
E-06	1-4	19.0	11.00	8.00	13.51	0.59	1.41	5.79
E-06	1-5	22.0	13.00	9.00	18.13	0.50	1.21	-
E-06	1-6	16.0	10.00	6.00	14.31	0.42	1.12	4.76
E-06	1-7	18.0	8.00	10.00	13.50	0.74	1.33	-
E-06	1-8	18.0	11.00	7.00	14.16	0.49	1.27	7.56
E-06	1-9	19.0	11.00	8.00	14.63	0.55	1.30	8.12
E-06	1-11	20.0	11.00	9.00	16.34	0.55	1.22	13.34
E-06	1-13	17.0	11.00	6.00	13.20	0.45	1.29	7.12
E-06	2-1	19.0	13.00	6.00	16.12	0.37	1.18	-
E-06	2-2	17.0	13.00	4.00	14.43	0.28	1.18	-
E-06	2-3	20.0	10.00	10.00	13.68	0.73	1.46	13.30
E-06	2-4	17.0	10.00	7.00	15.55	0.45	1.09	5.32
E-06	2-5	19.0	10.00	9.00	13.27	0.68	1.43	-
E-06	2-6	16.0	9.00	7.00	12.28	0.57	1.30	-
E-06	3-10	14.0	9.00	5.00	13.21	0.38	1.06	4.28
E-09	1-1	17.0	11.00	6.00	12.96	0.46	1.31	4.11
E-09	1-2	17.0	9.00	8.00	12.68	0.63	1.34	-
E-09	1-4	19.0	12.00	7.00	12.35	0.57	1.54	7.12
E-09	1-5	17.0	10.00	7.00	11.89	0.59	1.43	5.17
E-09	1-7	17.0	10.00	7.00	12.68	0.55	1.34	3.12
E-09	1-8	16.0	13.00	3.00	-	-	-	-
E-09	1-9	18.0	13.00	5.00	13.26	0.38	1.36	-
E-09	1-10	17.0	13.00	4.00	12.73	0.31	1.34	-
E-09	1-11	17.0	11.00	6.00	12.79	0.47	1.33	2.71
E-09	1-13	17.0	13.00	4.00	-	-	-	-
E-09	1-14	16.0	10.00	6.00	13.25	0.45	1.21	3.11
E-01	-	-	-	-	19.70	-	-	-
E-01	1-1-2	18.0	10.00	8.00	16.79	0.48	1.07	-
E-01	1-2-2	21.0	11.00	10.00	19.84	0.50	1.06	-
E-01	1-3-2-3	19.0	11.00	8.00	16.10	0.50	1.18	4.96
E-01	1-4-1	18.0	11.00	7.00	17.50	0.40	1.03	-
E-01	1-4-2	18.0	10.00	8.00	15.62	0.51	1.15	-

Table E-1. Laboratory Tests for All Aggregate Mixtures (Continued).

Material Source	Buckets Code	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	pfc	Activity Ratio, A_C (PI/pfc)	LL/pfc	MBV
	No	%	%	%	%	%	%	(mg/g)
E-01	1-4-3	22.0	12.00	10.00	20.59	0.49	1.07	-
E-07	68-2-6	17.0	10.00	7.00	15.81	0.44	1.08	7.60
E-07	69-1-14	17.0	10.00	7.00	15.48	0.45	1.10	7.04
E-08	2-1-6	14.0	9.00	5.00	15.03	0.33	0.93	2.79
E-08	235-1-12	15.0	9.00	6.00	13.55	0.44	1.11	6.76

Table E-2. Mean Value, Standard Deviation, and Coefficient of Variation for Each Quarry.

Source Quarry Name	Mean Value MBV (mg/g), x	Standard Derivation ,σ	Sample Number, n	Coefficient of Variation, CV
E-02	4.03	0.69	8	0.17
E-03	19.10	4.24	21	0.22
E-05	2.34	0.14	8	0.06
E-04	15.29	3.72	12	0.24
E-06	7.92	3.48	12	0.44
E-09	4.22	1.68	6	0.40
E-01	5.83	1.97	6	0.34

APPENDIX F: RELATIONSHIP BETWEEN FINE AGGREGATE PARAMETERS AND PFC, MBV

MBV IS SMALLER THAN 7.00

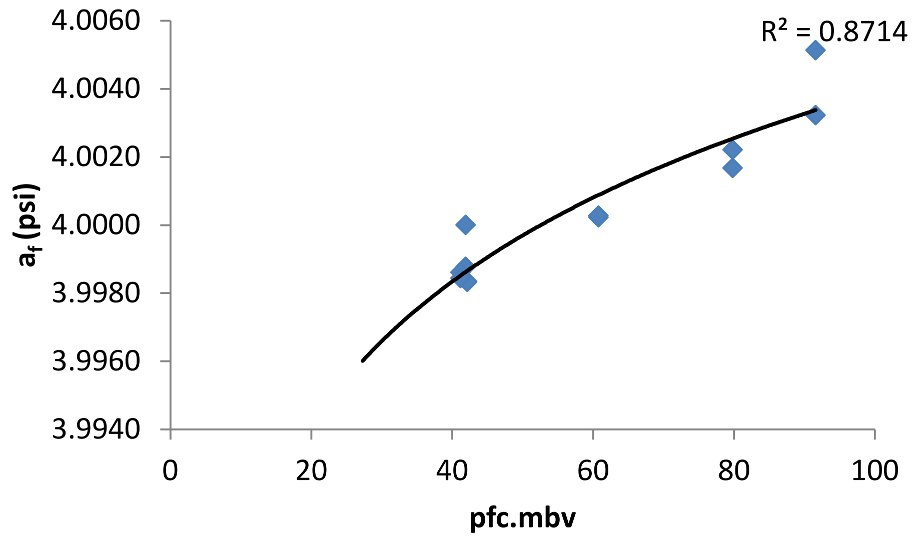

Figure F-1. Relationship between a_f and pfc Time MBV.

$$a_f = 3.976x(pfcxMBV)^{0.0015}$$

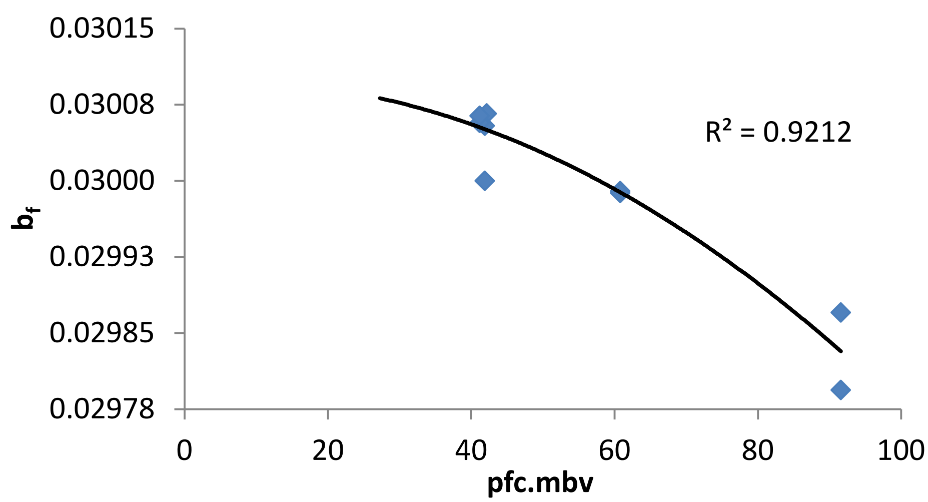

Figure F-2. Relationship between b_f and pfc Time MBV.

$$c_f = -0.0000001x(pfcxMBV)^2 + 0.000003x(pfcxMBV) + 0.0113$$

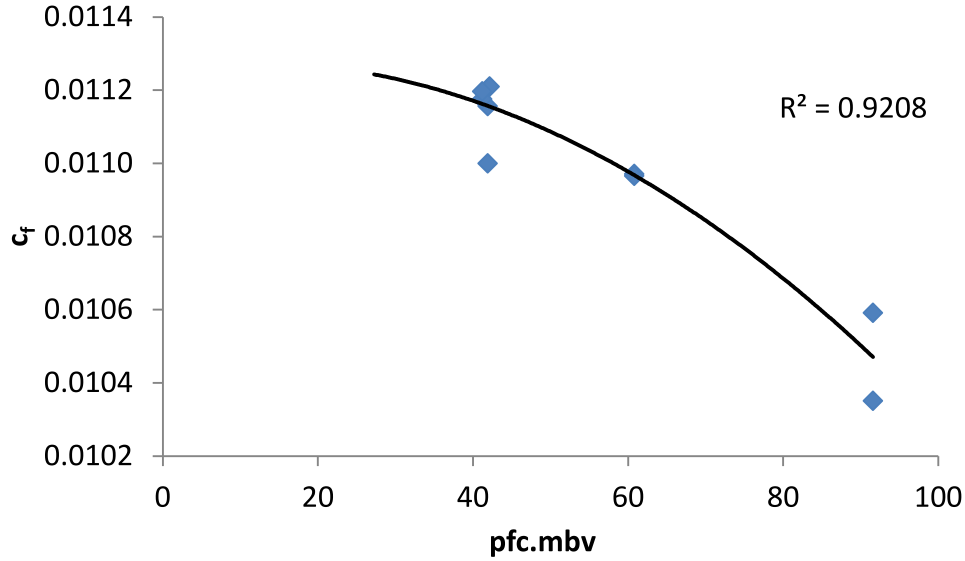

Figure F-3. Relationship between c_f and pfc Time MBV.

$$b_f = -0.00000004x(pfcxMBV)^2 + 0.0000004x(pfcxMBV) + 0.0301$$

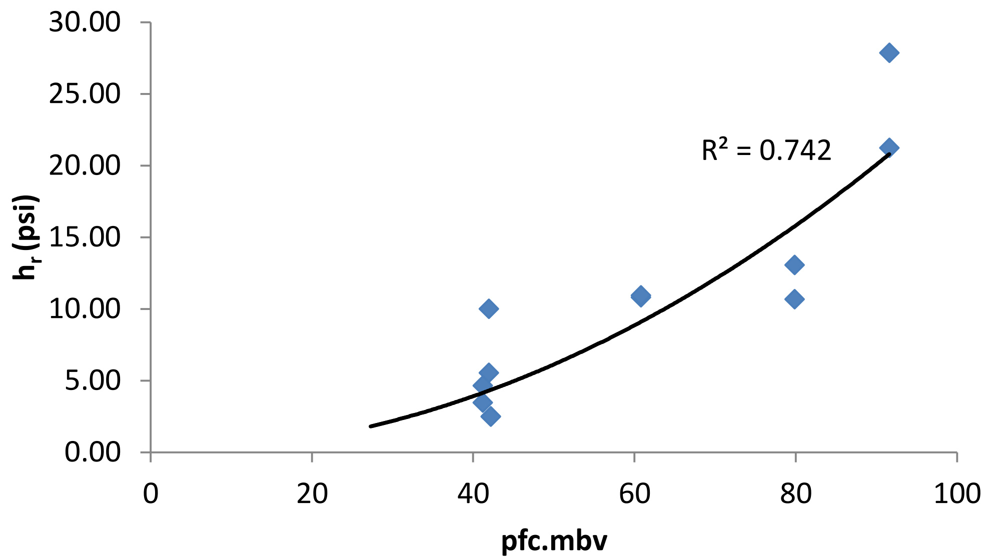

Figure F-4. Relationship between h_r and pfc Time MBV.

$$h_r = 0.0023x(pfcxMBV)^{2.0183}$$

MBV IS LARGER THAN 7.00

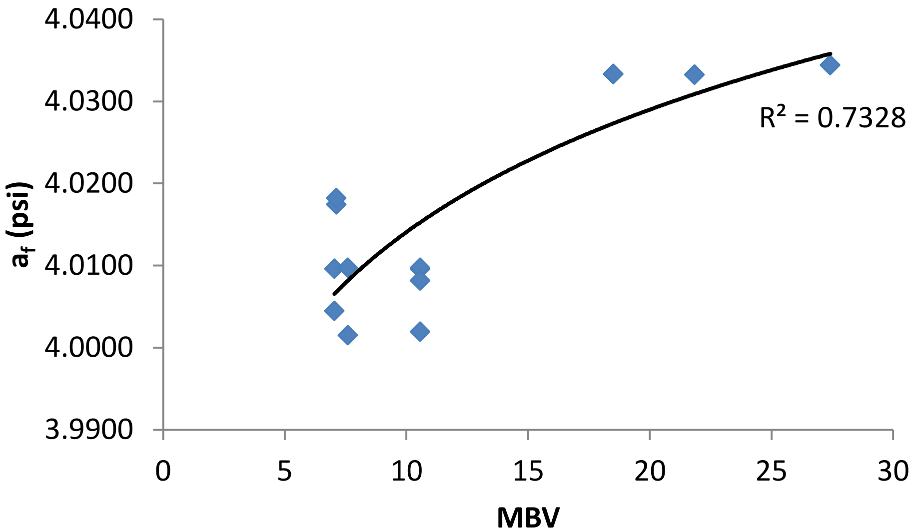

Figure F-5. Relationship between a_f and MBV.

$$a_f = 3.9649x(MBV)^{0.0054}$$

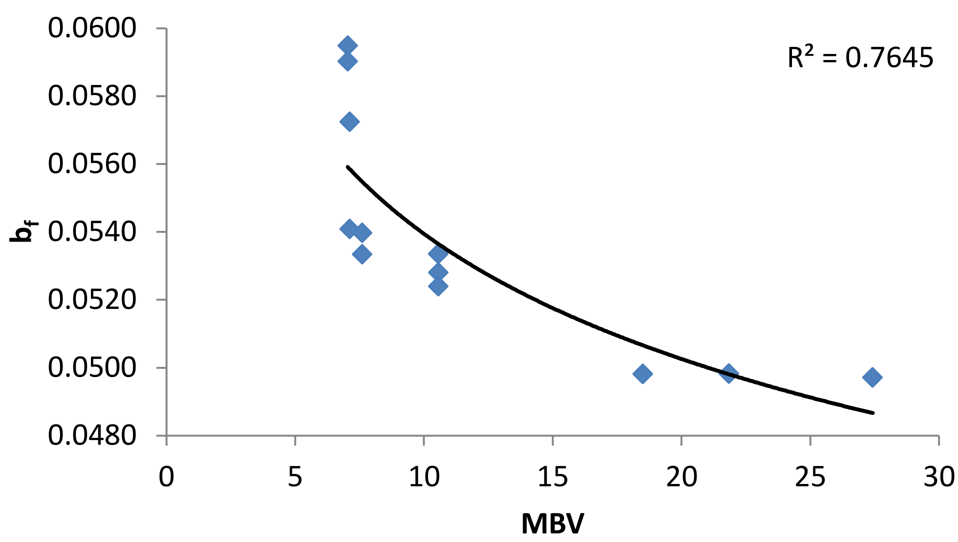

Figure F-6. Relationship between b_f and MBV.

$$b_f = 0.0683x(MBV)^{-0.102}$$

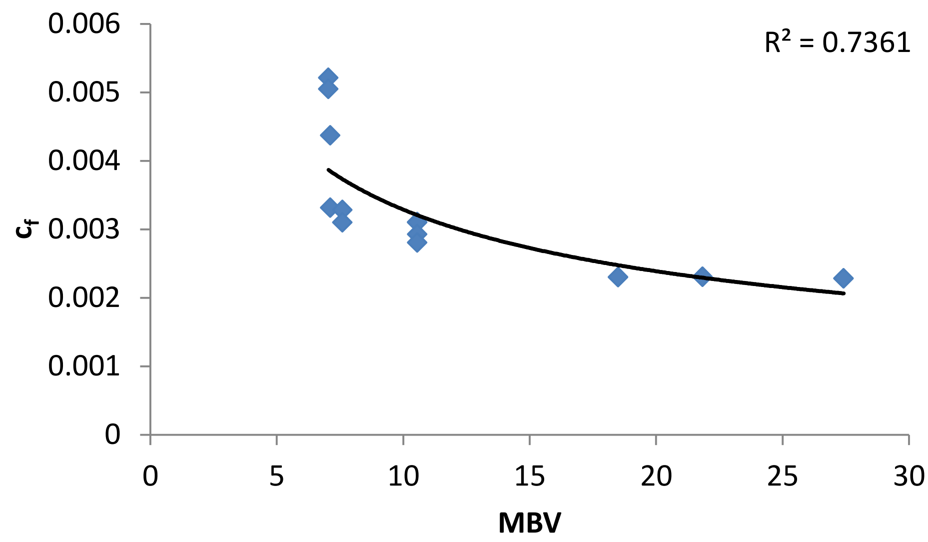

Figure F-7. Relationship between c_f and MBV.

$$c_f = 0.0095(MBV)^{-0.461}$$

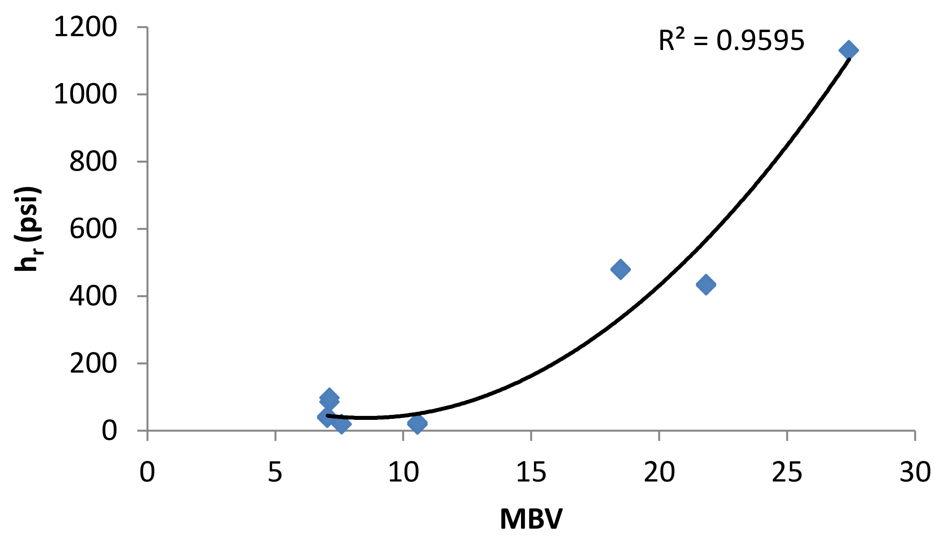

Figure F-8. Relationship between h_r and MBV.

$$h_r = 2.9833(MBV)^2 - 50.845(MBV) + 254.75$$

APPENDIX G: RELATIONSHIPS BETWEEN PLASTICITY INDEX AND METHYLENE BLUE VALUE

PLASTICITY INDEX

Test results have shown that a trend exists between the rate of increase in MBV and plasticity index and is defined by an exponential function. This relationship for all of the aggregate sources that were compiled and tested is shown in Figure G-1 along with the 90 percent confidence limits. A mathematical relationship was formulated and is given in Equation G-1.

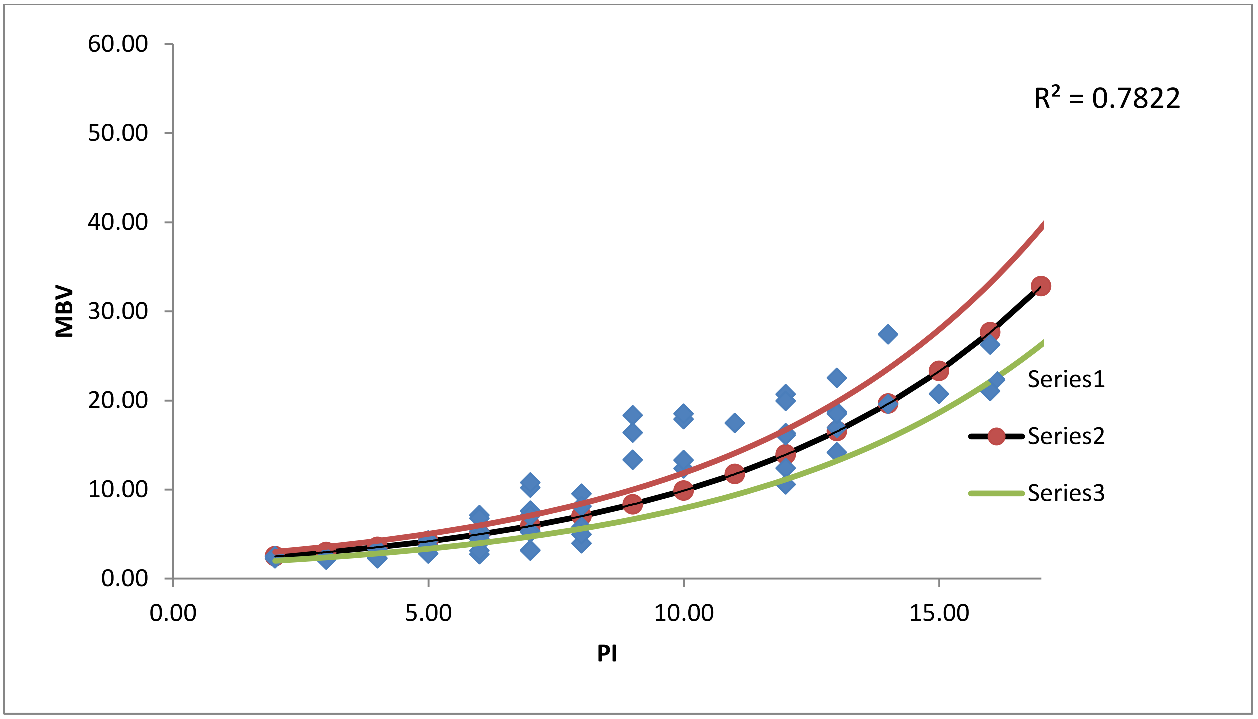

Figure G-1. General Methylene Blue Value and Plasticity Index Relationship with 90 Percent Confidence Limits for All Aggregate Sources Tested.

$$MBV = 1.7815e^{\,0.1714(PI)} \qquad \text{(Equation G-1)}$$

METHYLENE BLUE VALUE AND PLASTICITY INDEX RELATION FIGURES

The methylene blue value and plasticity index relationship is specified for each quarry. The mathematical form of the equation is the same for all the quarries, but the coefficient parameter in the equation is shifted based on the quarry and aggregate type. For each quarry, a figure is given to demonstrate the relationship, and an equation is given to show the mathematical function. The confidence level limits of 90 percent are given for each quarry in each figure in Appendix G.

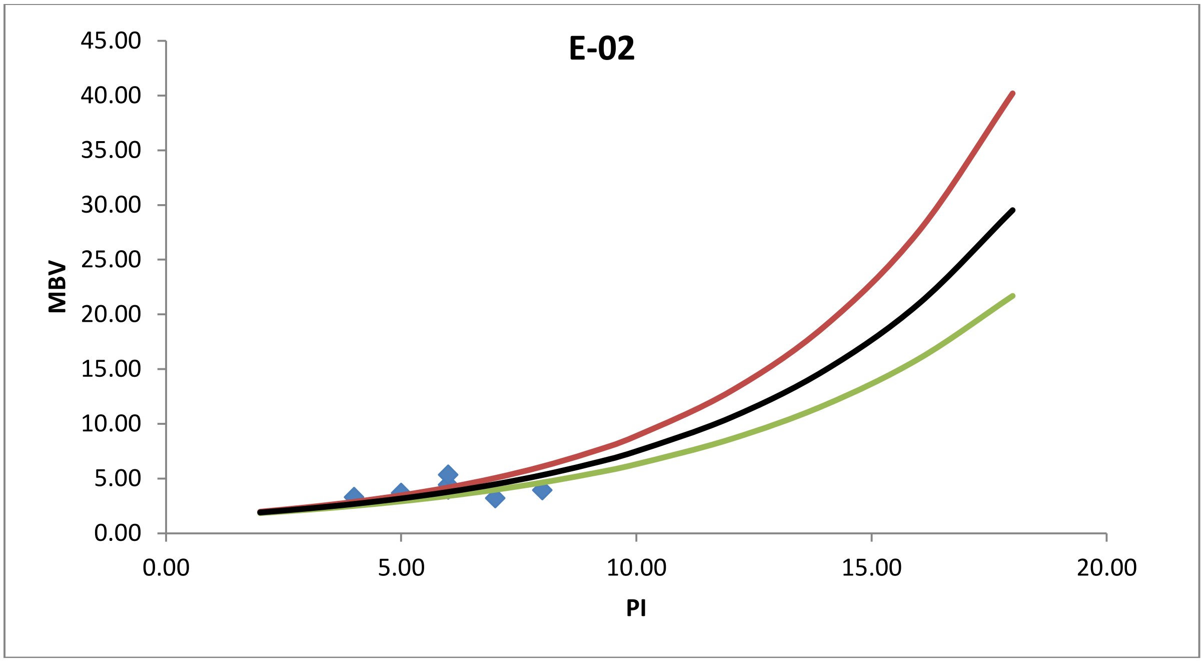

Figure G-2. Methylene Blue Value and Plasticity Index Relationship with 90 Percent Confidence Level Limits for E-02.

$$MBV = 1.35e^{0.1714(PI)} \quad \text{(Equation G-2)}$$

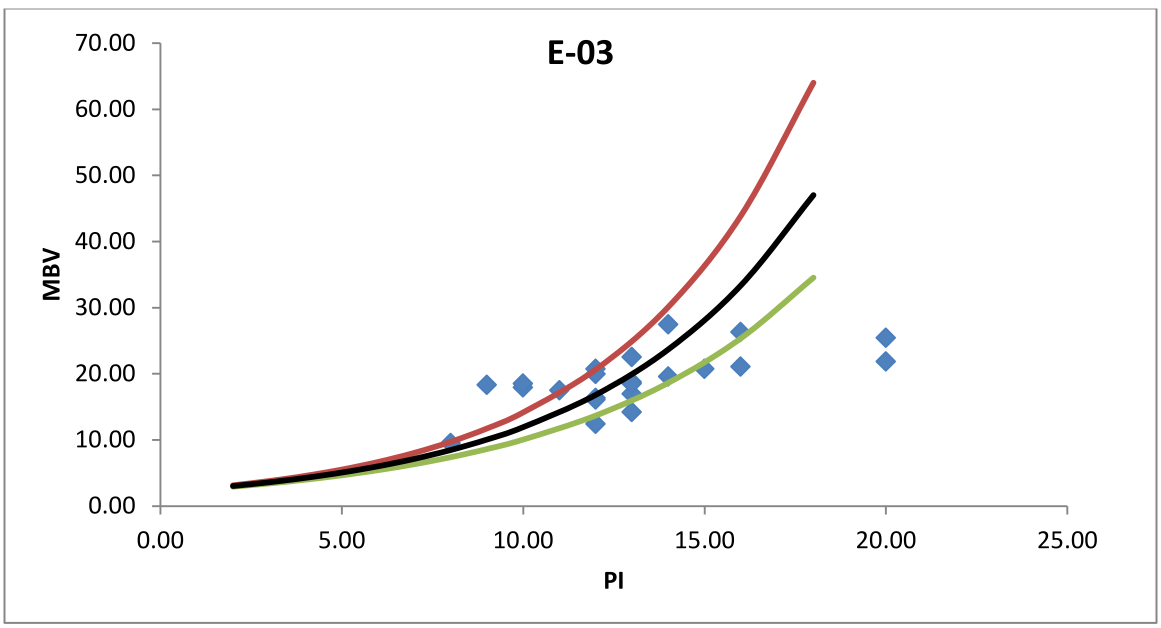

Figure G-3. Methylene Blue Value and Plasticity Index Relationship with 90 Percent Confidence Level Limits for E-03.

$$MBV = 2.15e^{0.1714(PI)} \qquad \text{(Equation G-3)}$$

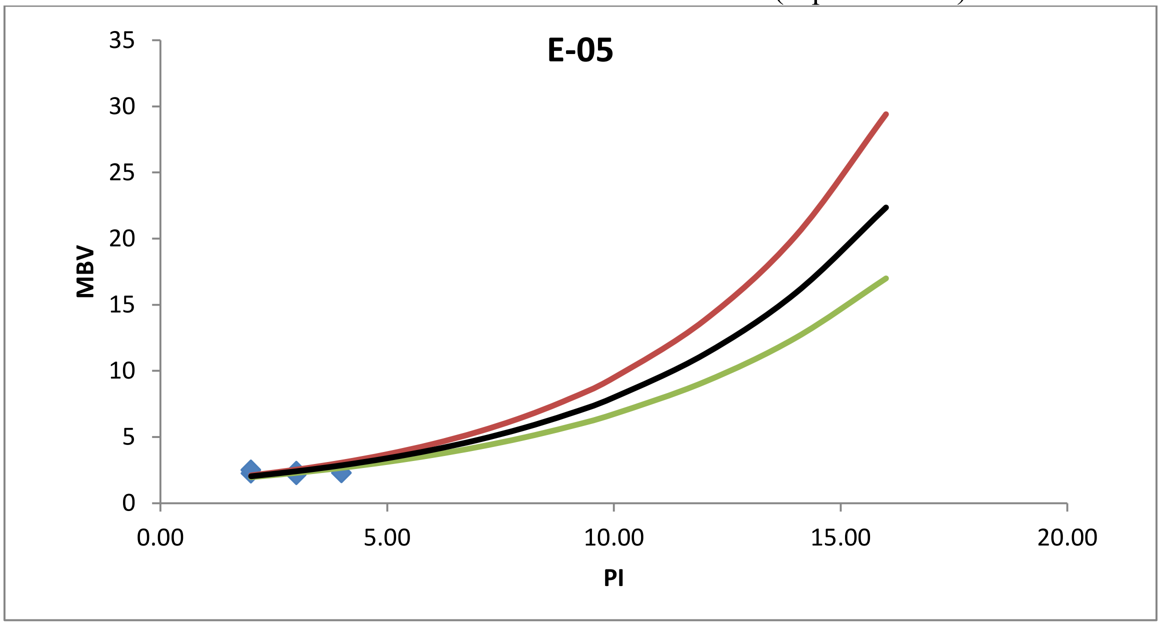

Figure G-4. Methylene Blue Value and Plasticity Index Relationship with 90 Percent Confidence Level Limits for E-05.

$$MBV = 1.44e^{0.1714(PI)} \qquad \text{(Equation G-4)}$$

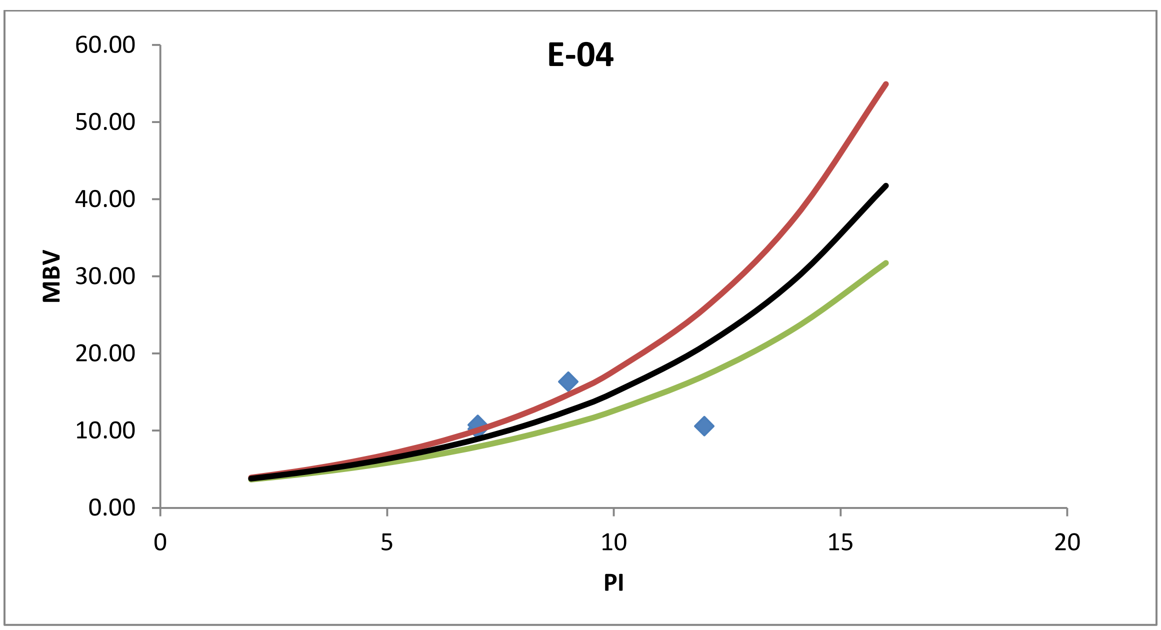

Figure G-5. Methylene Blue Value and Plasticity Index Relationship with 90 Percent Confidence Level Limits for E-04.

$$MBV = 2.69e^{0.1714(PI)} \qquad \text{(Equation G-5)}$$

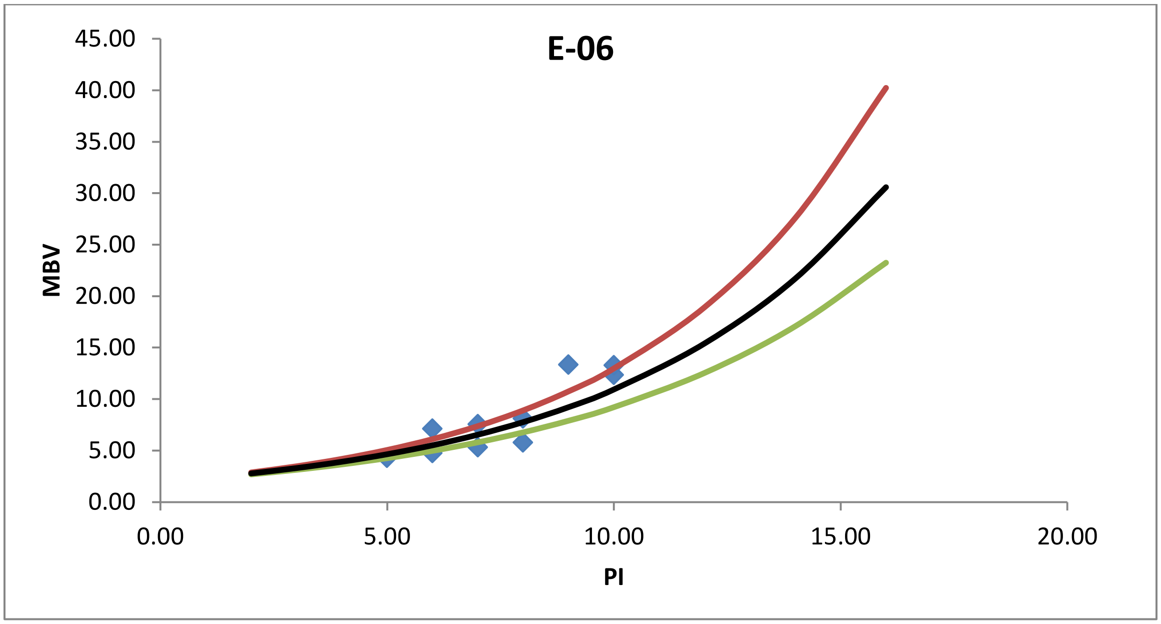

Figure G-6. Methylene Blue Value and Plasticity Index Relationship with 90 Percent Confidence Level Limits for E-06.

$$MBV = 1.97e^{0.1714(PI)} \qquad \text{(Equation G-6)}$$

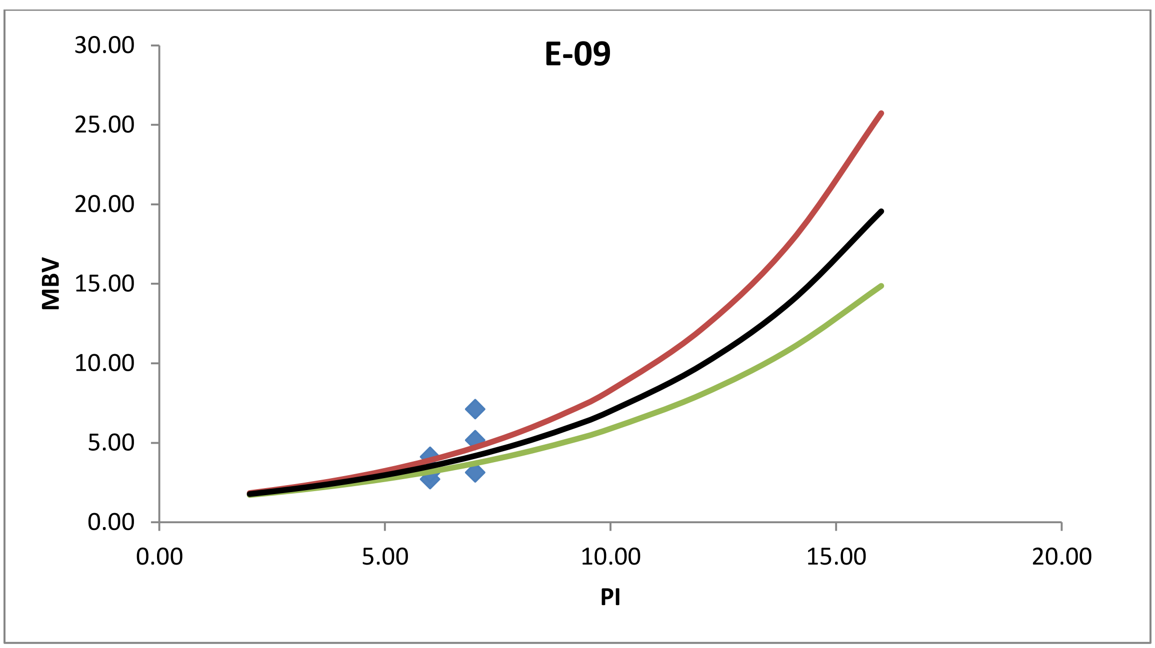

Figure G-7. Methylene Blue Value and Plasticity Index Relationship with 90 Percent Confidence Level Limits for E-09.

$$MBV = 1.26e^{0.1714(PI)} \quad \text{(Equation G-7)}$$

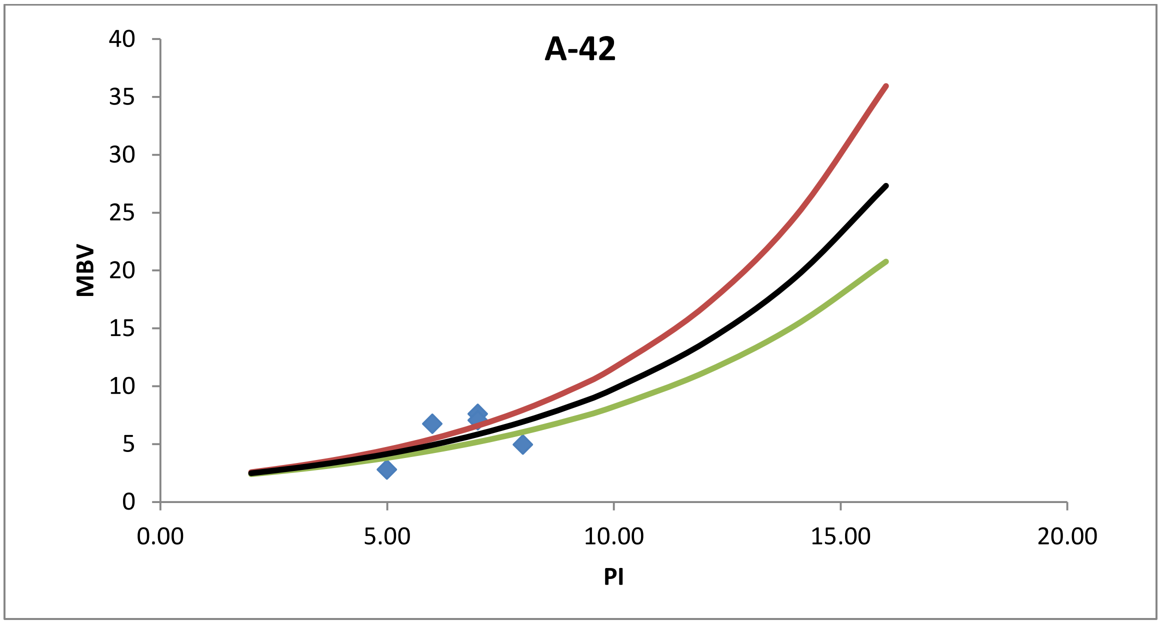

Figure G-8. Methylene Blue Value and Plasticity Index Relationship with 90 Percent Confidence Level Limits for A-42.

$$MBV = 1.76e^{0.1714(PI)} \quad \text{(Equation G-8)}$$

APPENDIX H: RELATIONSHIPS BETWEEN LIQUID LIMIT AND METHYLENE BLUE VALUE

LIQUID LIMIT

The methylene blue value and liquid limit give relationships based on the laboratory test results. This relation, for all of the aggregate sources that were compiled and tested, is shown in Figure H-1 along with 90 percent confidence level limits. A mathematical function was formulated and given in Equation H-1.

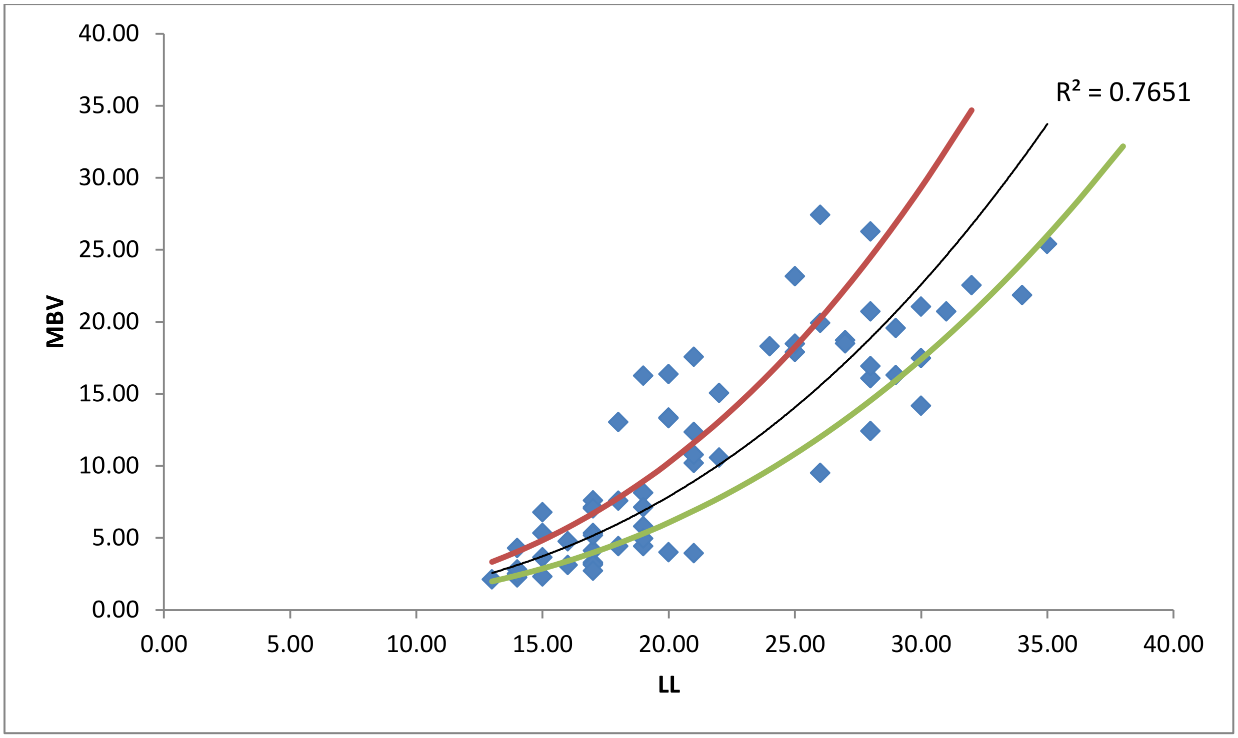

Figure H-1. General Relation between Liquid Limit and Methylene Blue Value with 90 Percent Confidence Level Limits.

$$MBV = 0.0033(LL)^{2.6004} \qquad \text{(Equation H-1)}$$

METHYLENE BLUE VALUE AND LIQUID LIMIT

The methylene blue value (MBV) and liquid limit (LL) relationships are plotted to show a unique correlation for each quarry. The mathematical form of each equation is the same for all of the quarries, but the coefficient parameter in the equation is shifted based on the quarry (aggregate type). All of the figures in Appendix H are given to demonstrate this relationship, and equations are given to show the mathematical function. The confidence level limits of 90 percent are also presented for each quarry in Figures H-3 to H-8.

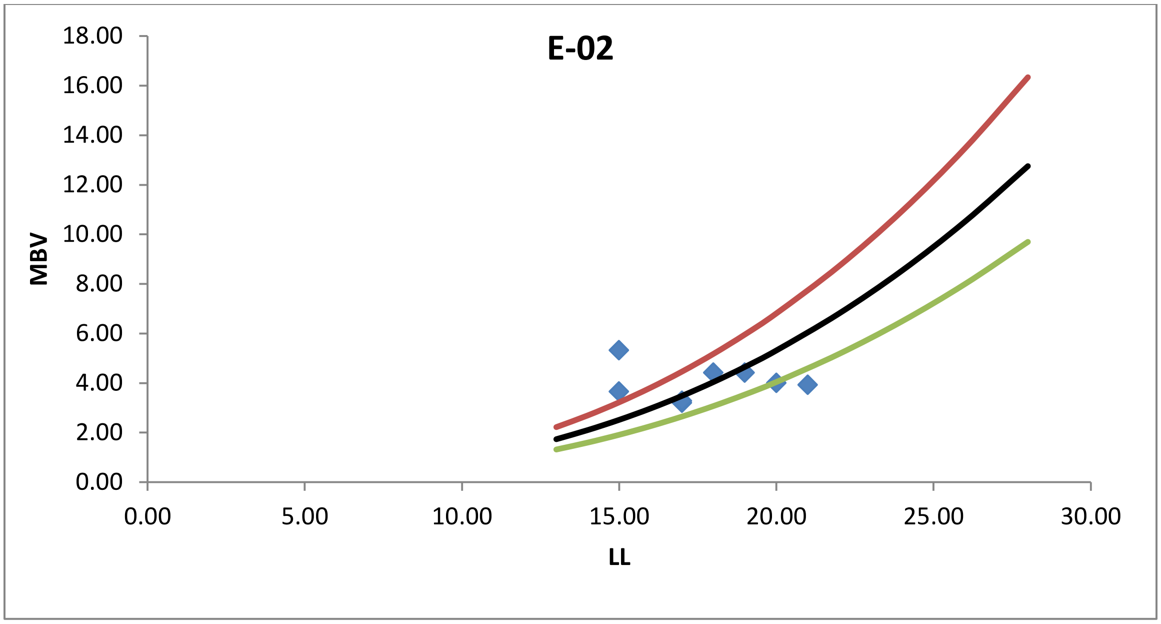

Figure H-2. General Relationship between Liquid Limit and Methylene Blue Value with 90 Percent Confidence Level Limits for E-02.

$$MBV = 0.0022(LL)^{2.6004} \qquad \text{(Equation H-2)}$$

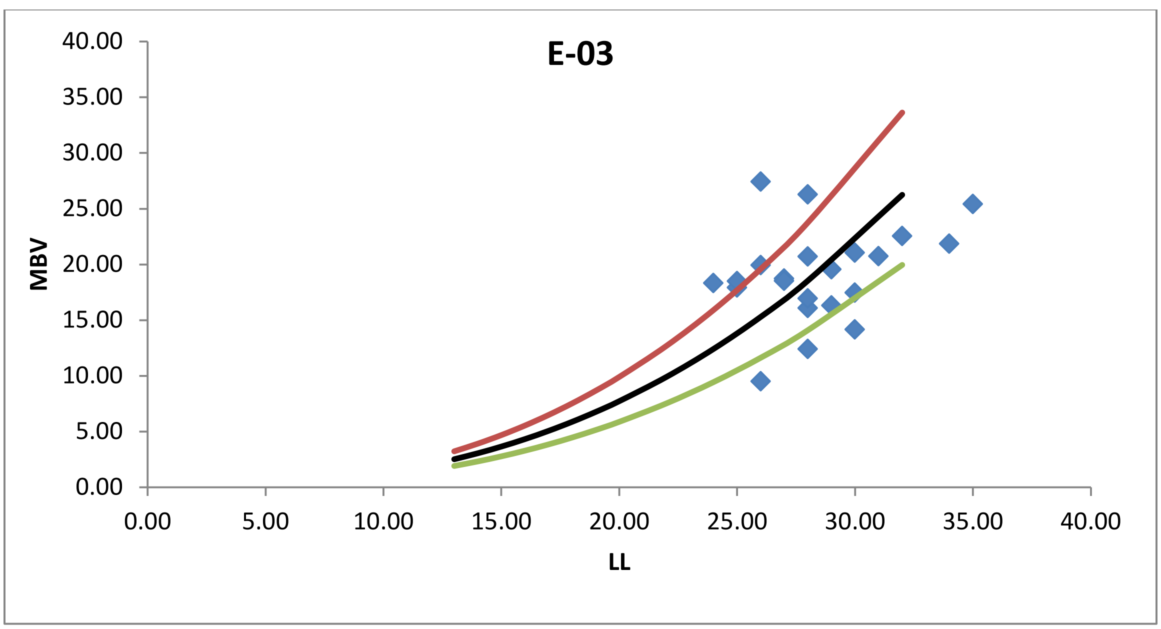

Figure H-3. General Relationship between Liquid Limit and Methylene Blue Value with 90 Percent Confidence Level Limits for E-03.

$$MBV = 0.0032(LL)^{2.6004} \qquad \text{(Equation H-3)}$$

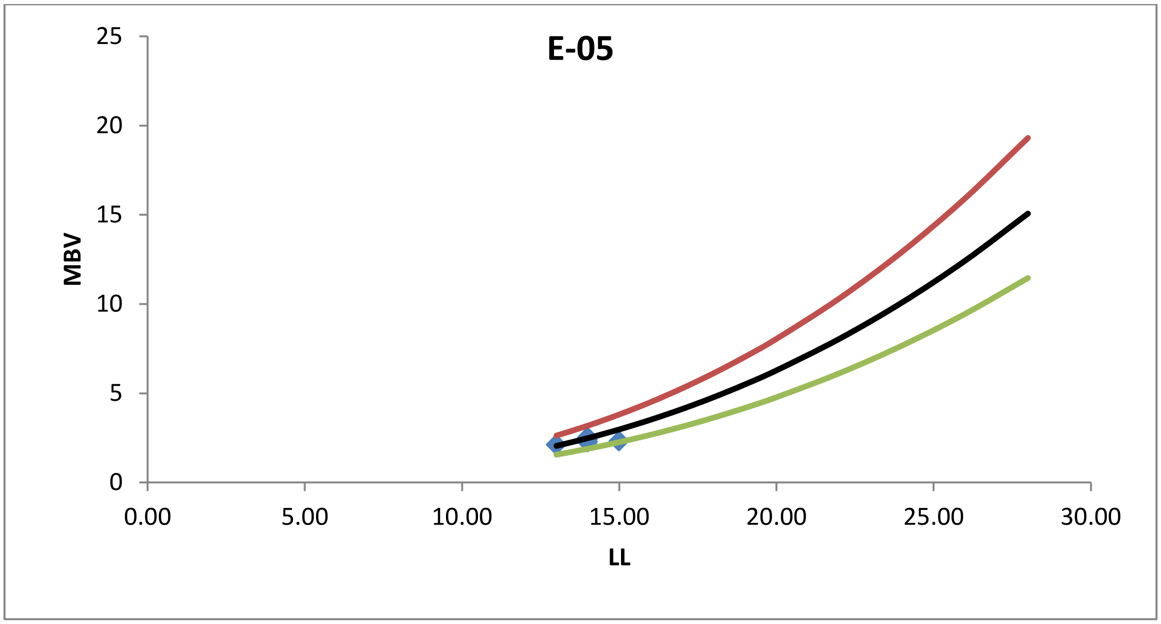

Figure H-4. General Relationship between Liquid Limit and Methylene Blue Value with 90 Percent Confidence Level Limits for E-05.

$$MBV = 0.0026(LL)^{2.6004} \qquad \text{(Equation H-4)}$$

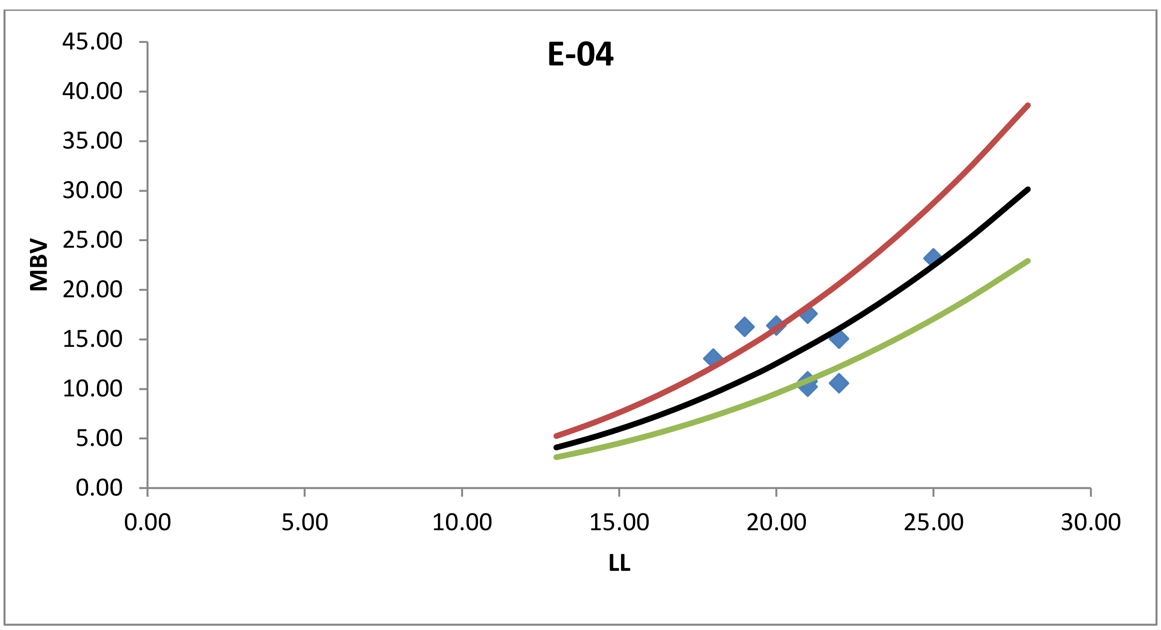

Figure H-5. General Relationship between Liquid Limit and Methylene Blue Value with 90 Percent Confidence Level Limits for E-04.

$$MBV = 0.0052(LL)^{2.6004} \qquad \text{(Equation H-5)}$$

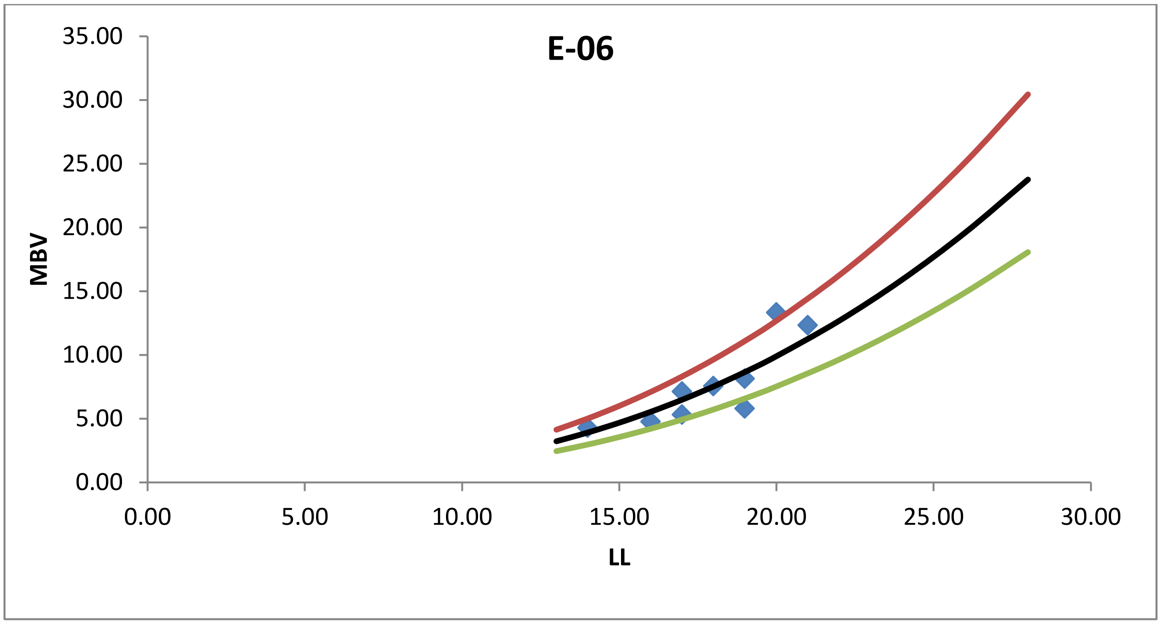

Figure H-6. General Relationship between Liquid Limit and Methylene Blue Value with 90 Percent Confidence Level Limits for E-06.

$$MBV = 0.0041(LL)^{2.6004} \quad \text{(Equation H-6)}$$

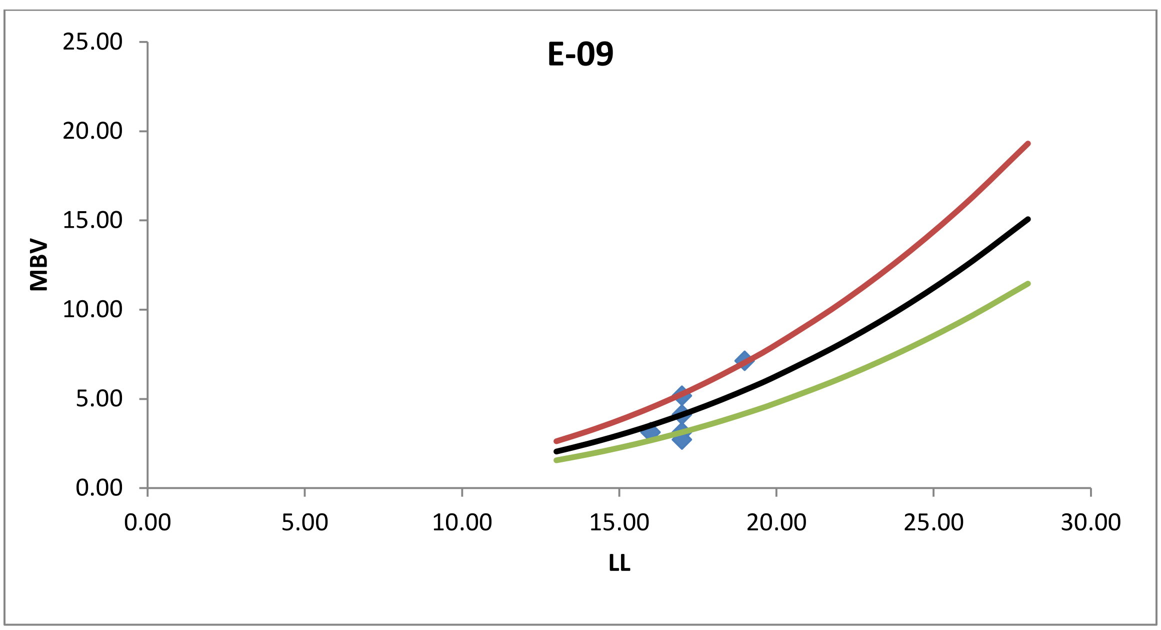

Figure H-7. General Relationship between Liquid Limit and Methylene Blue Value with 90 Percent Confidence Level Limits for E-09.

$$MBV = 0.0026(LL)^{2.6004} \quad \text{(Equation H-7)}$$

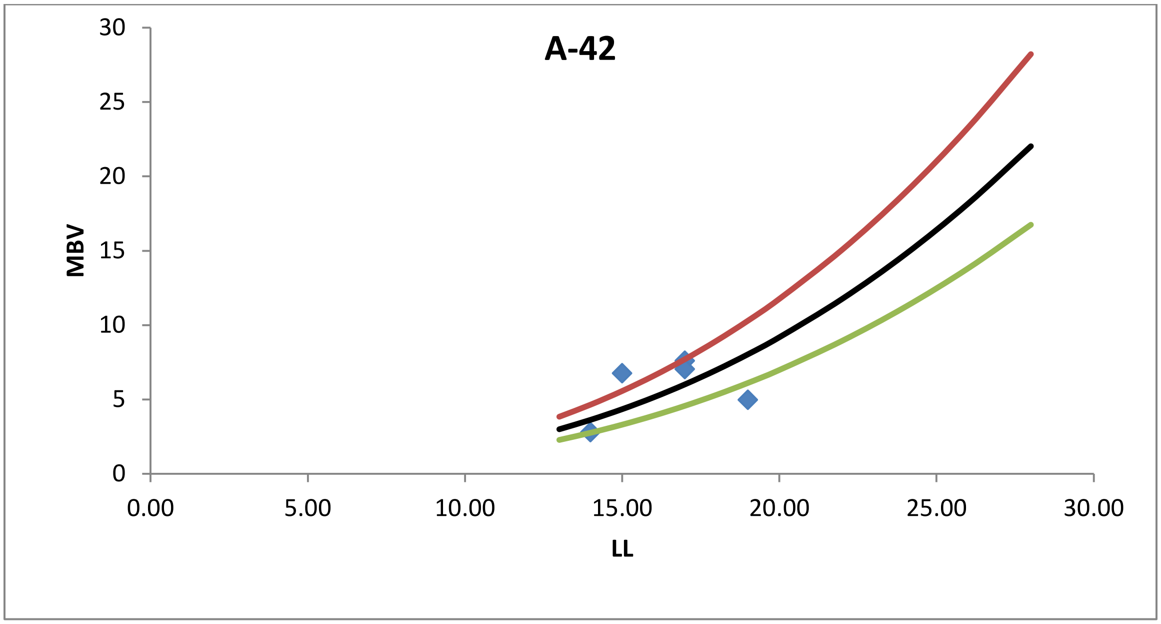

Figure H-8. General Relationship between Liquid Limit and Methylene Blue Value with 90 Percent Confidence Level Limits for A-42.

$$MBV = 0.0038(LL)^{2.6004} \qquad \text{(Equation H-8)}$$

APPENDIX I: RELATIONSHIPS BETWEEN PLASTICITY INDEX/PERCENT FINE CLAY AND LIQUID LIMIT/PERCENT FINES CONTENT

The plasticity index (PI) and liquid limit (LL) values are determined based on TxDOT Standard test procedures Tex-104-E and Tex-106-E. The percent fines content (pfc) is determined using the Horiba particle size distribution analyzer. The plasticity index and liquid limit are divided by pfc, and the results are denoted as PI/pfc and LL/pfc. The fraction of PI/pfc is the Activity Ratio (Ac). Test results have demonstrated that a correlation exists between activity ratio (Ac) and liquid limit/pfc, and it is shown in Figure I-1. This relationship has an R^2 value of 0.81, and the mathematical form of the relationship is given in Equation I-1.

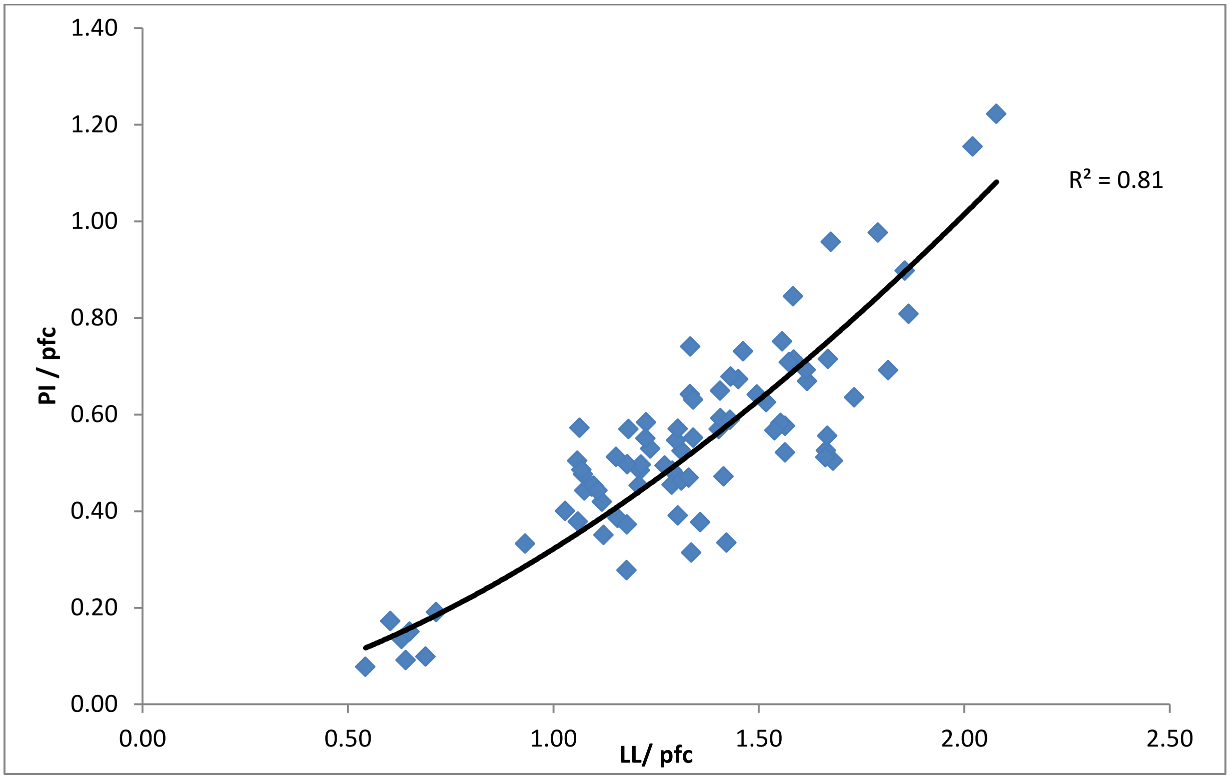

Figure I-1. Trend between Activity Ratio and Liquid Limit over pfc.

$$\left(\frac{Plasticity\ Index}{pfc}\right) = 0.3217\left(\frac{Liquid\ Limit}{pfc}\right)^{1.6569} \qquad \text{(Equation I-1)}$$

APPENDIX J: AGGREGATE IMAGING MEASUREMENT SYSTEM (AIMS) TEST DATA

AIMS is used to analyze aggregate geometric parameters of angularity, shape, and texture. These parameters are evaluated by using the Weibull cumulative distribution analysis. Ten quarries were analyzed through the Weibull distribution, and the analysis results are tabulated in Table J-1.

Table J-1. Tabulated Weibull Distribution Parameters.

Source	Representative Sieve	Angularity		Shape		Texture	
		Shape Parameter	Scale Parameter	Shape Parameter	Scale Parameter	Shape Parameter	Scale Parameter
E-05	1/2	4.07	3207.77	4.56	7.33	2.39	163.21
	3/8	3.79	3291.5	3.96	7.75	2.12	165.78
	#4	3.27	3272.77	4.12	8.59	1.78	94.17
E-06	1/2	3.81	3325.83	3.61	9.3	3.04	180.43
	3/8	4.76	3327.99	4.44	8.86	2.93	174.63
	#4	4.66	3481.14	4.2	8.66	2.08	107.76
E-02	1/2	4.35	3068.61	3.89	8.54	2.03	198.85
	3/8	5.09	3113.11	4.11	8.56	2.51	194.07
	#4	7.12	2949.7	5.54	8.6	2.44	137.12
E-09	1/2	3.91	3468.47	3.44	8.52	1.63	202.54
	3/8	3.75	3228.12	4.48	7.6	1.75	205.47
	#4	4.13	3005.48	3.89	7.86	1.61	102.08
A-42	1/2	4.03	3457.8	3.37	8.4	3.69	264.07
	3/8	4.38	3336.93	4.66	8.19	3.16	287.58
	#4	3.95	3490.31	4.43	7.95	2.66	180.7
E-07	1/2	4.12	3099.27	3.28	7.61	1.76	159.81
	3/8	4.53	3210.45	4.63	7.97	1.86	138.83
	#4	4.17	3192.53	3.88	7.89	2.27	98.44
E-08	1/2	3.77	3314.52	4.11	8.26	1.76	161.21
	3/8	4.99	3342.81	3.63	8.72	1.48	205.58
	#4	4.14	3266.97	3.65	8.33	1.82	115.4
E-04	1/2	4.07	3100.49	3.69	7.96	2.02	164.42
	3/8	5.1	3072.87	3.65	8.03	1.96	171.51
	#4	4.15	3135.33	3.81	8.17	2.25	106.75
E-03	1/2	3.18	3389.92	3.18	7.95	2.58	258.74
	3/8	3.25	3633.44	4.27	8.15	2.87	253.88
	#4	4.02	3613.27	4.5	8.69	2.61	167.2

APPENDIX K: DERIVATION OF COMPRESSIVE STRENGTH MODEL

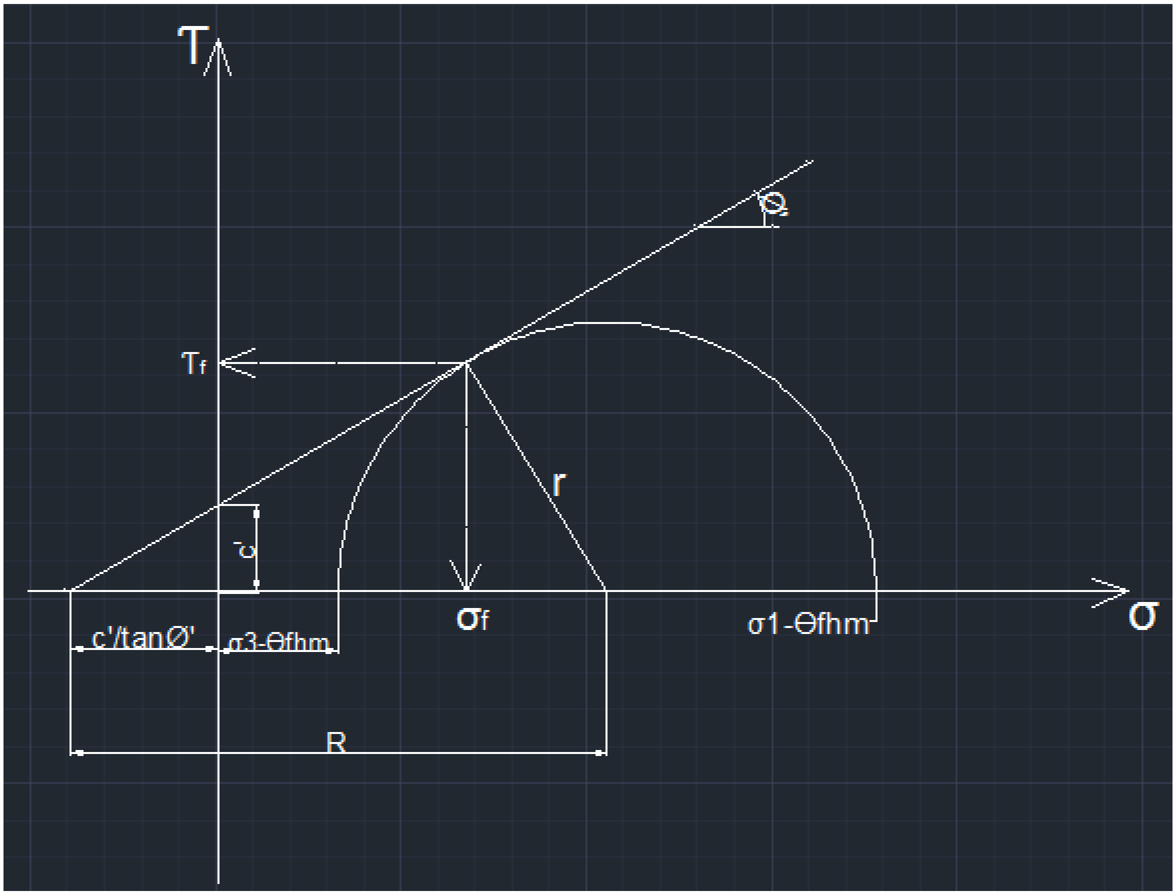

Figure K-1. Schematic Plot of Mohr's Circle at One Stress Level.

From the Figure K-1, $\sin\phi'$ can be expressed as:

$$\sin\phi' = \frac{r}{R} = \frac{\frac{(\sigma_1 - \sigma_3)}{2}}{\frac{c'}{\tan\phi'} + \frac{\sigma_1 - \sigma_3}{2} + \sigma_3 - \theta f h_m} \qquad \textit{(Equation K-1)}$$

Where h_m is matric suction measured from the soil water characteristic curve; θ is volumetric water content; f is the degree of saturation; σ_1 and σ_3 are the principal stresses.

Transpose Equation K-1 to obtain Equation K-2:

$$\frac{\sigma_1 - \sigma_3}{2} = \frac{c'\cos\phi'}{1-\sin\phi'} + (\sigma_3 - \theta f h_m)\frac{\sin\phi'}{1-\sin\phi'} \qquad \textit{(Equation K-2)}$$

Equation K-2 can be simplified as a linear function, which is expressed in Equation K-3:

$$y_i = a + bx_i \qquad \textit{(Equation K-3)}$$

Where $y_i = \frac{\sigma_1 - \sigma_3}{2}$;

$x_i = \sigma_3 - \theta f h_m$;

$$b = \frac{\sin\phi'}{1-\sin\phi'};$$

$$a = c'\frac{\cos\phi'}{1-\sin\phi'}.$$

In Equation K-3, a and b can be obtained using linear regression method. Then, c' and ϕ' can be calculated from Equations K-4 and K-5.

$$\phi' = \arcsin(\frac{b}{1+b}) \qquad \textit{(Equation K-4)}$$

$$c' = \frac{a(1-\sin\phi')}{\cos\phi'} \qquad \textit{(Equation K-5)}$$

Table K-1. Results of Compressive Strength Model Parameters.

Material Type	c' (kPa)	ϕ' (degree)
E-01-1-3-2-3	5.034	51.718
E-02-1-3-4	10.164	59.842
E-02-2-3-2	13.111	61.521
E-04-1-3	1.734	53.704
E-04-2-6	13.310	57.539
E-05-61-12	19.481	55.807
E-06-1-13	10.509	55.124
E-06-2-6	3.394	54.965
E-07-69-1-14	2.067	51.439
E-07-68-2-6	0.208	51.378
E-08-235-1-12	0.877	54.212
E-09-1-14	25.176	57.011

Table K-2. Summary of Measured Compressive Strength Value and Predicted Compressive Strength Value.

Material Type	Confining Pressure (kPa)	Range of Volumetric Water Content		Range of Suction (-kPa)		Measured Mean Strength (kPa)	Standard Deviation of Strength (kPa)	Predicted Range of Strength (kPa)	
		Upper	Lower	Upper	Lower			Upper	Lower
E-01-1-3-2-3	0	0.135	0.132	46.77	40.74	227.3	23.1	369.9	327.4
	20.68					600.5	80.5	541.5	499.1
	103.42					1326.1	119.7	1233.3	1185.7
E-02-1-3-4	0	0.145	0.139	114.8	87.1	103.2	16.3	274.8	236.7
	20.68					649.5	115.0	564.1	521.6
	103.42					1564.0	169.4	1703.6	1661.1
E-02-2-3-2	0	0.144	0.138	100	77.62	126.4	27.9	303.7	265.6
	20.68					792.9	248.6	624.8	586.7
	103.42					1873.1	506.3	1909.2	1871.1
E-04-1-3	0	0.138	0.137	100	95.5	202.2	9.0	458.3	394.4
	20.68					724.0	168.7	650.8	586.8
	103.42					1458.5	98.1	1420.7	1356.8
E-04-2-6	0	0.129	0.125	100	77.6	179.3	38.4	380.7	366.8
	20.68					809.7	221.9	624.7	610.8
	103.42					1561.7	110.4	1600.8	1586.9
E-05-61-12	0	0.134	0.133	40.7	36.3	138.6	38.3	322.7	315.4
	20.68					760.7	112.7	541.3	586.8
	103.42					1400.6	69.1	1415.7	1408.3
E-06-1-13	0	0.128	0.125	41.7	33.9	224.8	18.6	448.3	376.1
	20.68					294.4	118.3	657.9	585.6
	103.42					1461.7	23.4	1496.3	1424.0
E-06-2-6	0	0.127	0.124	50.1	43.7	229.9	45.9	475.5	416.6
	20.68					747.7	530.5	683.0	624.2
	103.42					1565.8	83.6	1513.3	1454.5

Table K-2. Summary of Measured Compressive Strength Value and Predicted Compressive Strength Value (Continued).

Material Type	Confining Pressure (kPa)	Range of Volumetric Water Content		Range of Suction (-kPa)		Measured Mean Strength (kPa)	Standard Deviation of Strength (kPa)	Predicted Range of Strength (kPa)	
		Upper	Lower	Upper	Lower			Upper	Lower
E-07-69-1-14	0	0.158	0.154	64.6	52.5	153.1	10.0	420.0	365.5
	20.68					525.8	54.6	589.0	534.4
	103.42					1318.3	38.0	1264.9	1210.4
E-07-68-2-14	0	0.15	0.145	60.3	50.1	154.0	38.0	426.3	330.7
	20.68					563.8	141.8	594.7	499.1
	103.42					1320.8	85.5	1268.4	1172.8
E-08-235-1-12	0	0.144	0.142	38.9	33.9	71.7	23.3	338.8	296.8
	20.68					773.6	73.8	537.2	495.2
	103.42					1456.9	168.4	1330.7	1288.7
E-09-1-14	0	0.153	0.152	67.6	60.3	197.2	4.1	329.1	276.9
	20.68					709.2	132.4	565.0	512.8
	103.42					1498.9	46.0	1508.4	1456.1

APPENDIX L: DRY UNIT WEIGHT MODEL BASED ON WATER CONTENT

Soil compaction is an optimization process of air, water, and density. The compaction effort increases the soil density through decreasing the air void ratio until there is no significant change in the volume of the soil. In general, the higher degree of the compaction the higher the shear strength, therefore, maximizing dry density will increase the soil strength significantly. The degree of compaction is measured in terms of dry unit weight.

Compaction properties of the soil are determined in a laboratory by using a compaction machine. A sample is placed in a cylindrical mold, and then a standard compaction effort is applied. A standard compaction procedure is applied on each soil layer separately to reach maximum dry density. After the sample compaction is completed, the water content is determined and then, by using the value of the water content, the dry density is calculated. This process is repeated at least three to four times during which the water content is increased in each time.

Dry density is plotted against the water content, and a general dry density vs. water content curve is the result. The curve represents a curvilinear relationship, and a typical one is shown in Figure L-1. The high point of the curve occurs at a particular value of water content that is the optimum moisture content. The maximum dry unit weight and the values of optimum water content are calculated from the compaction curve.

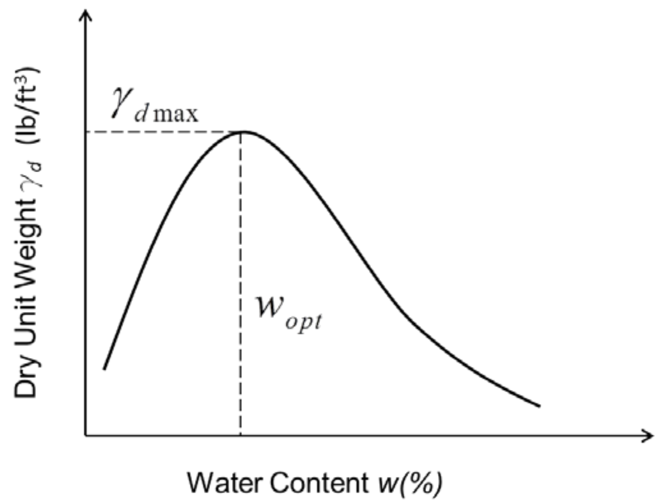

Figure L-1. Illustration of Dry Density and Water Content.

The optimum water content is significant because the dry density reaches its maximum at that moisture content. At a lower moisture content, the soil tends to be firm so it is difficult to compact. In contrast, at a higher moisture content voids become filled with water, which is nearly incompressible; therefore, although the soil loses most of its strength, the soil cannot be compacted to a high density. If all the voids in a soil are filled with water, that state is the saturated state for that soil.

The standard Tex-113 E test procedure for laboratory compaction characteristics and moisture-density relationship of base materials was followed to compact each of the samples.

A model was developed to determine dry unit weight of an aggregate mixture. The model finds a relationship between the dry unit weight and the water content of a compaction curve using the material properties. A model was developed based on the dry unit weight curve using an unsaturated condition.

The mathematical equation for dry unit weight in an unsaturated condition is as follows:

$$\frac{\gamma_d}{\gamma_w} = \frac{1}{\left(\frac{w}{S} + \frac{1}{Gs}\right)} \qquad \textit{(Equation L-1)}$$

where:
γd = Dry unit weight of base course material (lb/ft^3).
γw = Unit weight of water (lb/ft^3).
w = Water content (%).
S = Degree of saturation (%).
Gs = Specific gravity of the solids.

To develop the model, various aggregate sources are considered and the compaction test results are analyzed. The model consists of three parameters (a,b, and n) and three material properties; degree of saturation, specific gravity, and unit weight of water. The three parameters vary with aggregate sources and characteristics.

The mathematical formulation of the improved dry unit weight model is given as follows:

$$\left(\frac{\gamma d}{\gamma w}\right) = \left[\frac{a}{\left(\frac{w}{S} + \frac{1}{Gs}\right)} - \frac{b}{\left(\frac{w}{S} + \frac{1}{Gs}\right)^n}\right] \qquad \textit{(Equation L-2)}$$

where:
a, b, n = Three parameters which change with aggregate source.

The dry unit weight and water content relationship is shown in Figure L-. An equation at the 100 percent saturated level is provided to show its contrast with the dry unit weight.

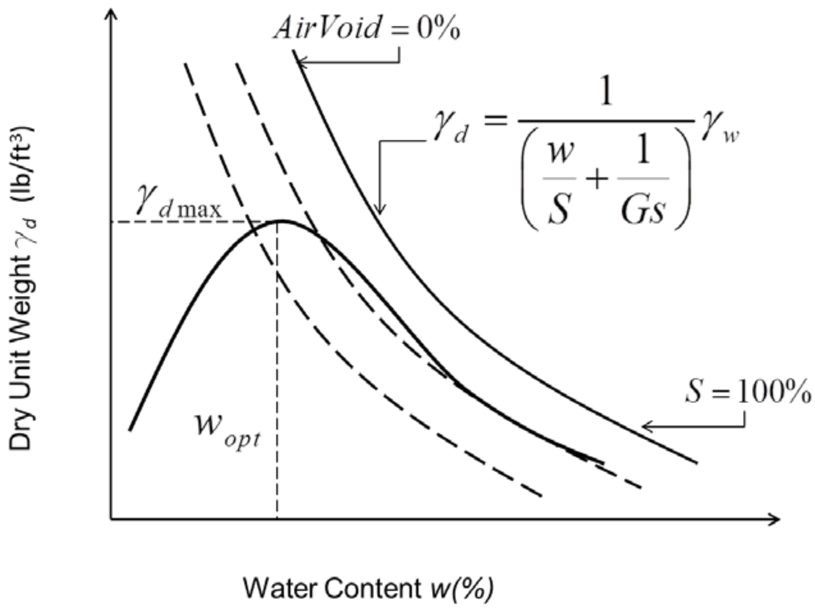

Figure L-2. Relationship between Dry Unit Weight and Water Content.

Table L-1. Test Results Comparing Laboratory and Measured Dry Unit Weight Results and Three Parameters for Each Source.

Source	a	b	n	Optimum Water Content (wc)	Maximum γ_{dry} (lb/ft^3)	Maximum $\gamma_{dry\text{-}model}$ (lb/ft^3)	Error in model (%)
E-01	1.29835	0.45013	0.50006	0.0580	143.00	143.14	-0.10
E-02	1.30432	0.44985	0.49975	0.0710	137.10	137.22	-0.09
E-03	1.31171	0.44903	0.49961	0.0760	130.90	130.90	0.00
E-04	1.30068	0.44994	0.50008	0.0600	142.10	142.46	-0.25
E-05	1.30230	0.45039	0.49990	0.0600	141.50	141.60	-0.07
E-06	1.29234	0.45060	0.50029	0.0560	150.40	150.71	-0.20
E-07	1.30463	0.44962	0.49984	0.0740	137.70	137.98	-0.20
E-08	1.29579	0.45033	0.50015	0.0650	145.80	145.97	-0.11
E-09	1.30549	0.44955	0.49981	0.0790	136.40	136.60	-0.15

Laboratory compaction test results for the optimum water content and maximum dry unit weight and the maximum dry unit weight from the model are compared for the various sources. The comparison shows that the modeled and measured results fit quite well.

The parameters a, b, and n were found to depend upon optimum moisture content as in the following mathematical forms.

$$a = 1.4291(wc)^{0.0343} \quad \textit{(Equation L-3)}$$

$$b = -0.6456(wc)^2 + 0.0325(wc) + 0.4507 \quad \textit{(Equation L-4)}$$

$$c = 0.4955(wc)^{-0.003} \quad \text{(Equation L-5)}$$

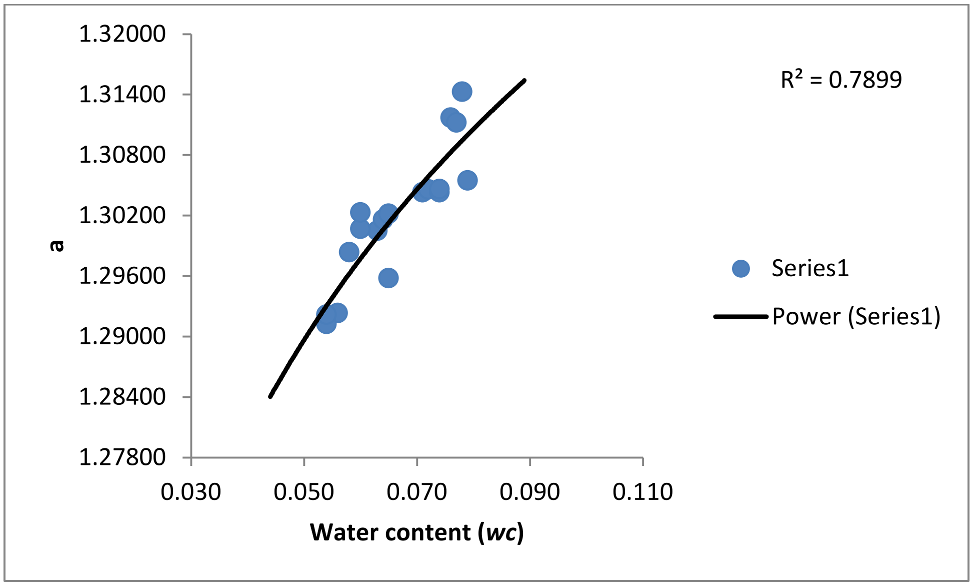

Figure L-3. Correlation between a and water content (wc).

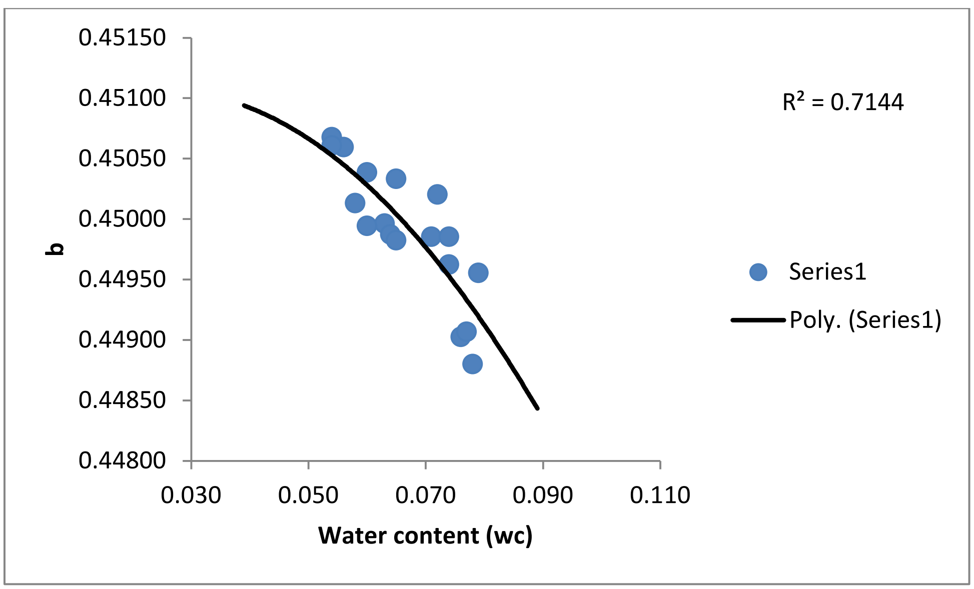

Figure L-4. Correlation between b and Water Content (wc).

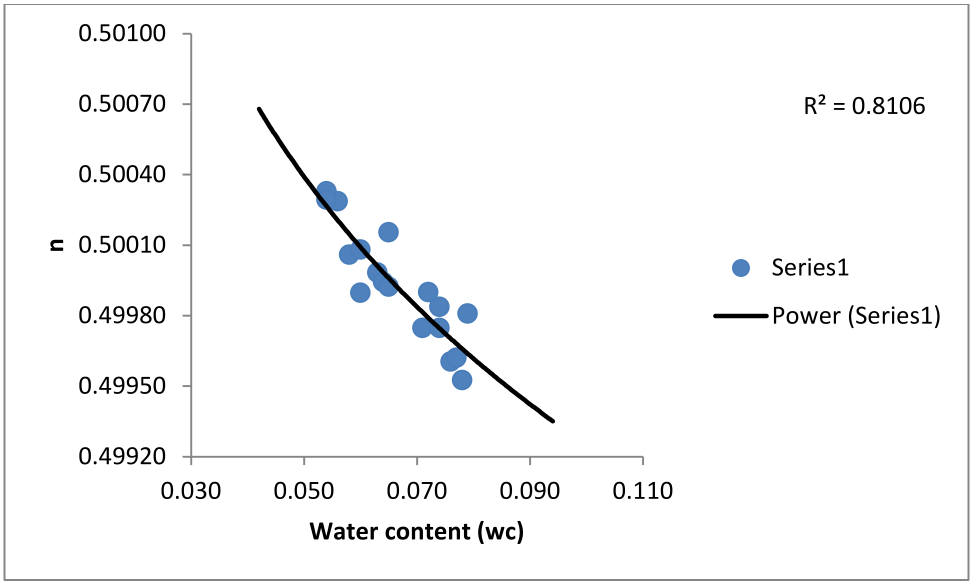

Figure L-5. Correlation between n and Water Content (wc).

The dry unit weight and the water content for the various aggregate sources are analyzed to develop a mathematical relationship based on the empirical test data. The relationships of both the laboratory data and the data calculated based upon the new model are given for each of the aggregate sources on the following pages. The individual data points of the water content and dry unit weight from the compaction curve for each of the sources are plotted together with the modeled compaction curve. Beneath each graph is a tabulation of the original compaction curve data, the predicted dry unit weight, and error in lb per cubic foot. It is expected that, as the compaction energy changes, the coefficients will probably change.

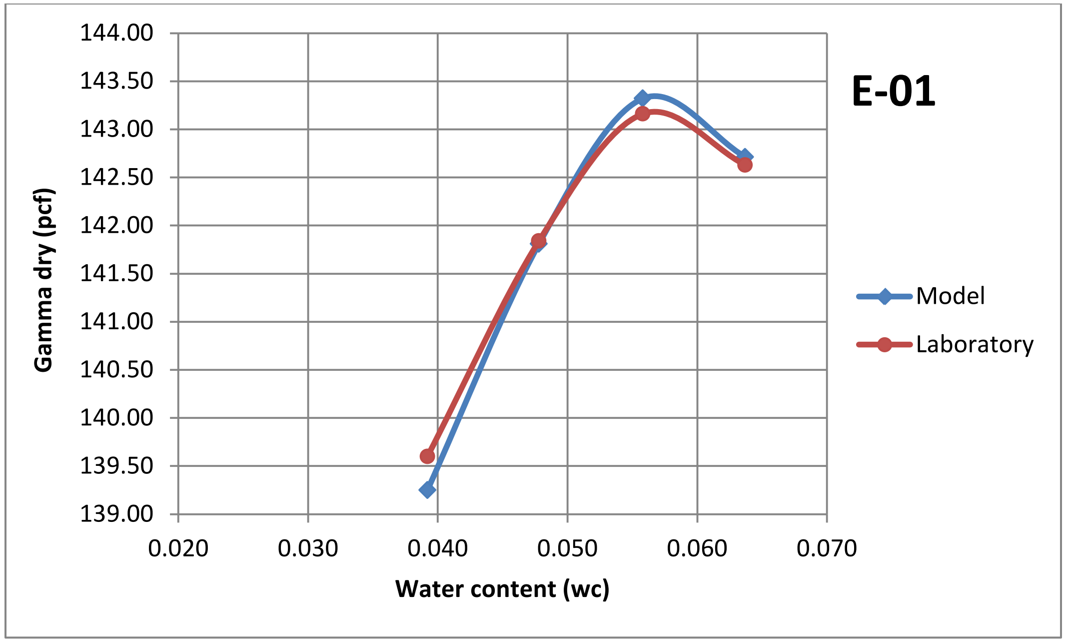

Figure L-6. Measured and Model Results for Dry Unit Weight and Water Content Relation for E-01.

Table L-2. Parameters a,b,n, and Gamma Dry (γ_d) Calculations Based upon Different Moisture Contents for the Source of E-01.

Code	γ_{dry} (pcf)	γ_d / γ_w	**wc**	$\left(\frac{wc}{S}+\frac{1}{Gs}\right)$	**S**	**a**	**b**	**n**	γ_d / γ_w model	γ_{dry} model
E-01	143.00	2.2917	0.0580	0.4364	0.8278	1.29835	0.45013	0.50006	2.2939	143.14
	139.60	2.2372	0.0392	0.4470	0.4858	1.29835	0.45013	0.50006	2.2314	139.24
	141.84	2.2731	0.0478	0.4399	0.6492	1.29835	0.45013	0.50006	2.2726	141.81
	143.16	2.2942	0.0558	0.4359	0.8020	1.29835	0.45013	0.50006	2.2969	143.33
	142.63	2.2857	0.0637	0.4375	0.8947	1.29835	0.45013	0.50006	2.2871	142.72

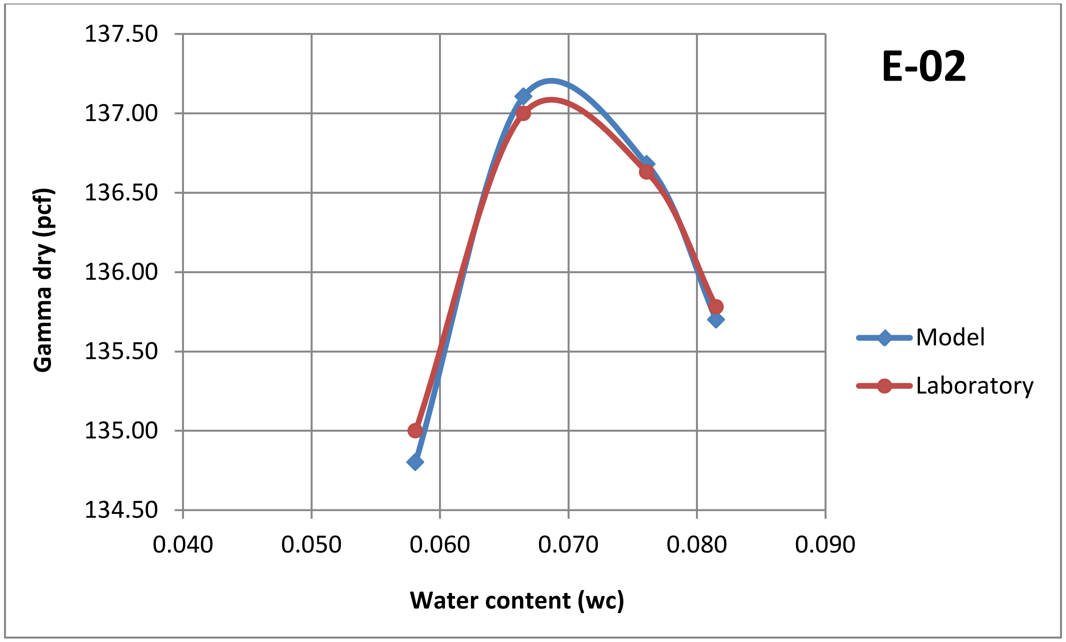

Figure L-7. Measured and Model Results for Dry Unit Weight and Water Content for E-02.

Table L-3. Parameters a,b,n, and Gamma Dry (γ_d) Calculations Based upon Different Moisture Contents for E-02.

Code	γ_{dry} (pcf)	γ_d / γ_w	wc	$\left(\frac{wc}{S}+\frac{1}{Gs}\right)$	S	a	b	n	γ_d / γ_w model	γ_{dry} model
E-02	137.10	2.1971	0.0710	0.4551	0.7873	1.30432	0.44985	0.49975	2.1991	137.22
	135.00	2.1635	0.0581	0.4622	0.5974	1.30432	0.44985	0.49975	2.1603	134.80
	137.00	2.1955	0.0665	0.4555	0.7347	1.30432	0.44985	0.49975	2.1972	137.11
	136.63	2.1896	0.0761	0.4567	0.8295	1.30432	0.44985	0.49975	2.1904	136.68
	135.78	2.1760	0.0815	0.4596	0.8615	1.30432	0.44985	0.49975	2.1747	135.70

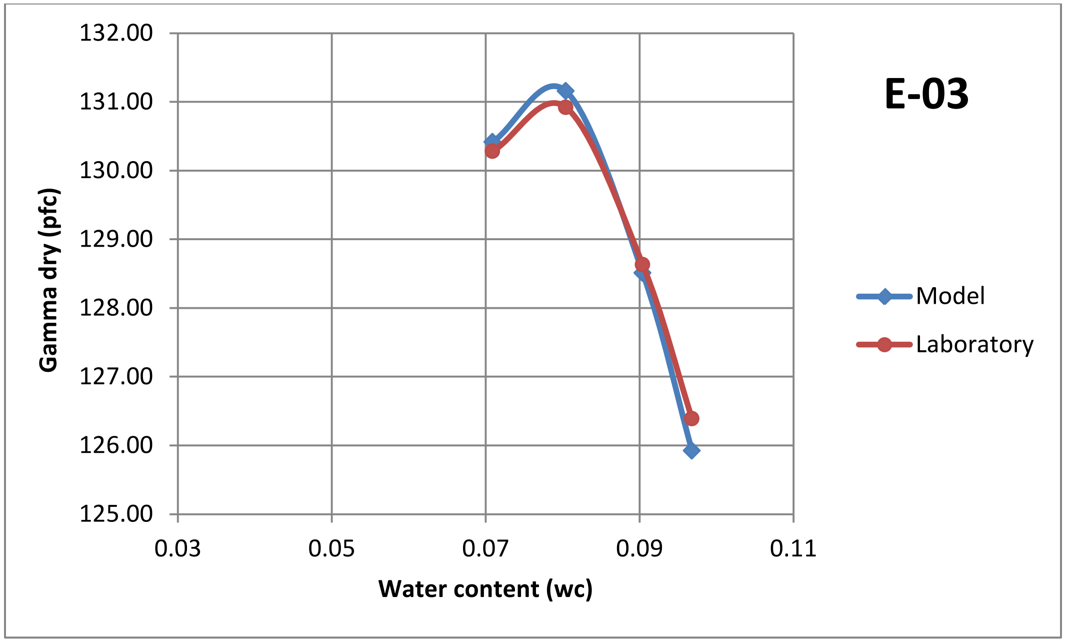

Figure L-8. Measured and Model Results for Dry Unit Weight and Water Content for E-03.

Table L-4. Parameters a,b,n, and Gamma Dry (γ_d) Calculations Based upon Different Moisture Contents for E-03.

Code	γ_{dry} (pcf)	γ_d / γ_w	**wc**	$\left(\frac{wc}{S}+\frac{1}{Gs}\right)$	**S**	**a**	**b**	**n**	γ_d / γ_w model	γ_{dry} model
E-03	130.80	2.0962	0.0760	0.4771	0.6700	1.31171	0.44903	0.49961	2.0996	131.02
	130.28	2.0878	0.0709	0.4790	0.6147	1.31171	0.44903	0.49961	2.0900	130.42
	130.92	2.0981	0.0804	0.4766	0.7116	1.31171	0.44903	0.49961	2.1019	131.16
	128.63	2.0614	0.0904	0.4851	0.7442	1.31171	0.44903	0.49961	2.0594	128.51
	126.39	2.0255	0.0968	0.4937	0.7442	1.31171	0.44903	0.49961	2.0180	125.92

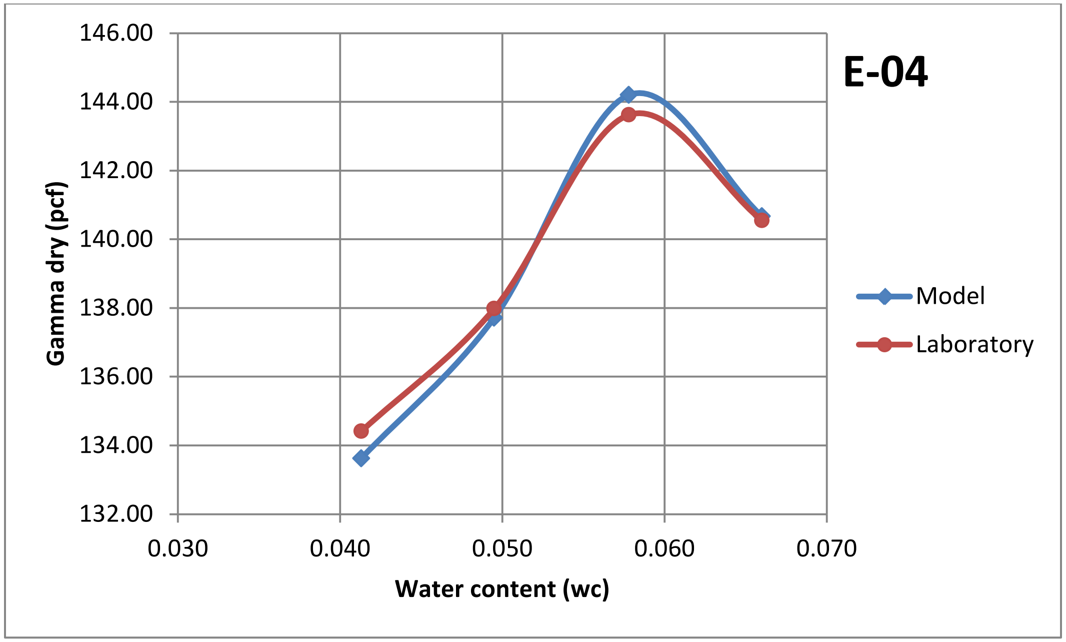

Figure L-9. Measured and Model Results for Dry Unit Weight and Water Content for E-04.

Table L-5. Parameters a,b,n, and Gamma Dry (γ_d) Calculations Based upon Different Moisture Contents for E-04.

Code	γ_{dry} (pcf)	γ_d / γ_w	**wc**	$\left(\frac{wc}{S}+\frac{1}{Gs}\right)$	**S**	**a**	**b**	**n**	γ_d / γ_w model	γ_{dry} model
E-04	142.10	2.2772	0.0600	0.4391	0.8394	1.30068	0.44994	0.50008	2.2829	142.45
	134.41	2.1540	0.0413	0.4643	0.4275	1.30068	0.44994	0.50008	2.1413	133.61
	137.98	2.2112	0.0495	0.4522	0.5852	1.30068	0.44994	0.50008	2.2070	137.71
	143.62	2.3016	0.0578	0.4345	0.8648	1.30068	0.44994	0.50008	2.3110	144.21
	140.55	2.2524	0.0660	0.4440	0.8647	1.30068	0.44994	0.50008	2.2543	140.67

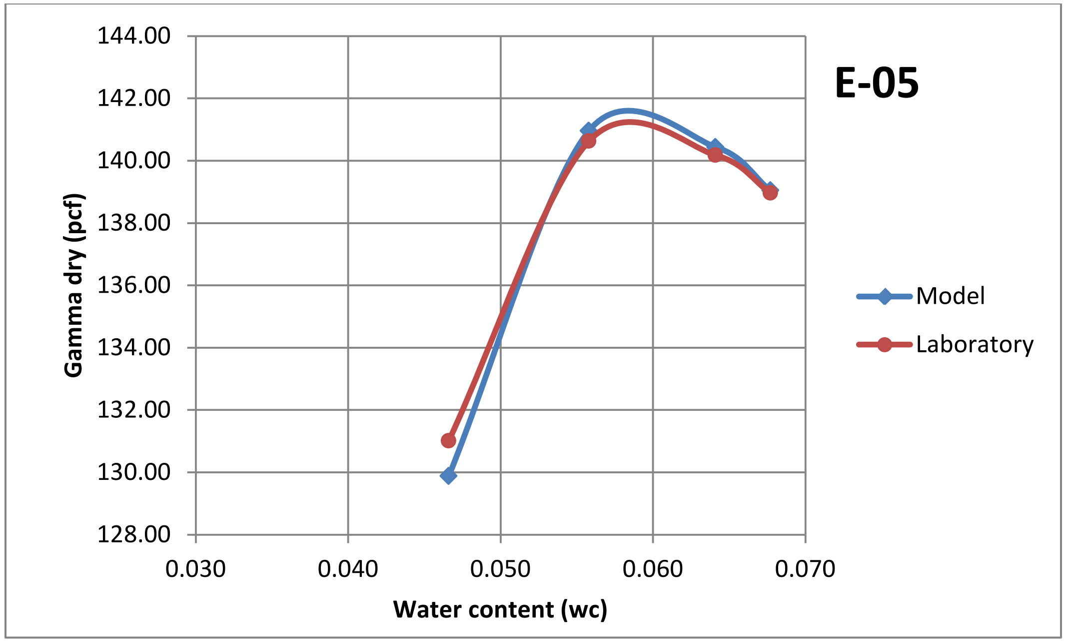

Figure L-10. Measured and Model Results for Dry Unit Weight and Water Content for E-05.

Table L-6. Parameters a,b,n, and Gamma Dry (γ_d) Calculations Based upon Different Moisture Contents for E-05.

Code	γ_{dry} (pcf)	γ_d/γ_w	**wc**	$\left(\frac{wc}{S}+\frac{1}{Gs}\right)$	**S**	**a**	**b**	**n**	γ_d/γ_w model	γ_{dry} model
E-05	141.50	2.2676	0.0600	0.4410	0.8496	1.30230	0.45039	0.49990	2.2750	141.96
	131.01	2.0995	0.0466	0.4763	0.4399	1.30230	0.45039	0.49990	2.0817	129.90
	140.63	2.2537	0.0558	0.4437	0.7608	1.30230	0.45039	0.49990	2.2589	140.96
	140.18	2.2465	0.0641	0.4451	0.8573	1.30230	0.45039	0.49990	2.2506	140.44
	138.97	2.2271	0.0677	0.4490	0.8608	1.30230	0.45039	0.49990	2.2283	139.04

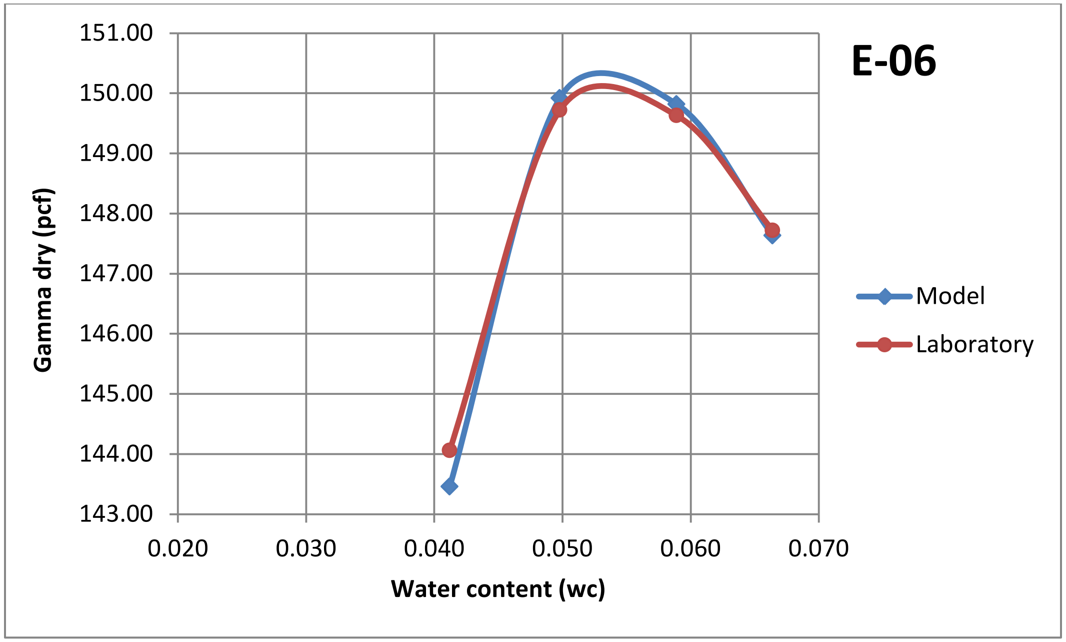

Figure L-11. Measured and Model Results for Dry Unit Weight and Water Content for E-06.

Table L-7. Parameters a,b,n, and Gamma Dry (γ_d) Calculations Based upon Different Moisture Contents for E-06.

Code	γ_{dry} (pcf)	γ_d / γ_w	**wc**	$\left(\frac{wc}{S}+\frac{1}{Gs}\right)$	**S**	**a**	**b**	**n**	γ_d / γ_w model	γ_{dry} model
E-06	150.40	2.4103	0.0560	0.4149	0.9289	1.29234	0.45060	0.50029	2.41515	150.71
	144.06	2.3087	0.0412	0.4332	0.5246	1.29234	0.45060	0.50029	2.29876	143.44
	149.72	2.3994	0.0498	0.4168	0.8011	1.29234	0.45060	0.50029	2.40266	149.93
	149.63	2.3979	0.0589	0.4170	0.9436	1.29234	0.45060	0.50029	2.40100	149.82
	147.72	2.3673	0.0664	0.4224	0.9792	1.29234	0.45060	0.50029	2.36592	147.63

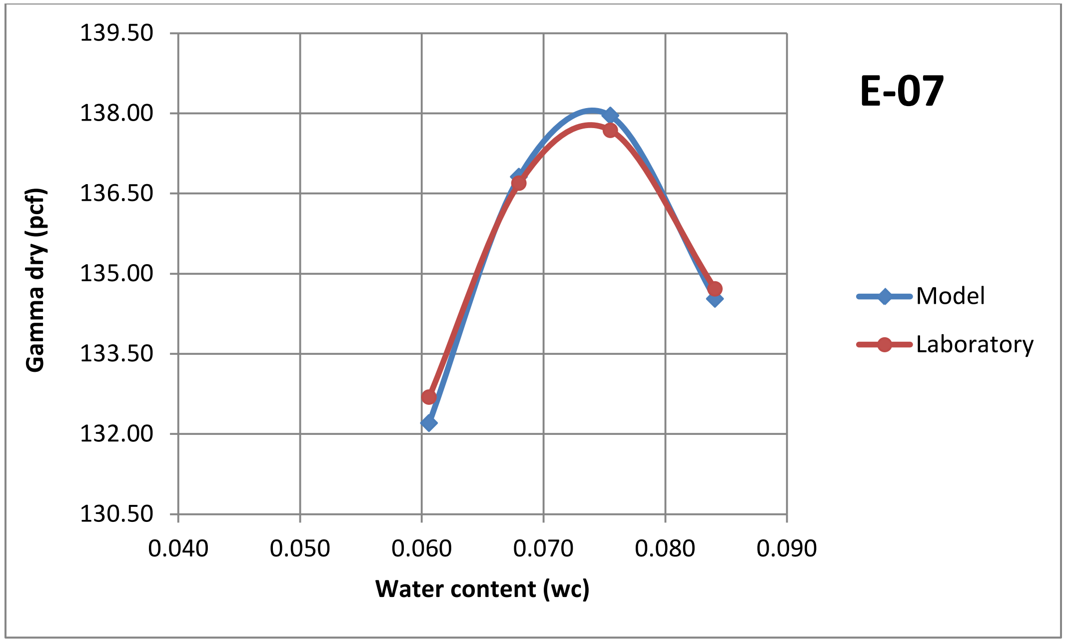

Figure L-12. Measured and Model Results for Dry Unit Weight and Water Content for E-07.

Table L-8. Parameters a,b,n, and Gamma Dry (γ_d) Calculations Based upon Different Moisture Contents for E-07.

Code	γ_{dry} (pcf)	γ_d / γ_w	**wc**	$\left(\frac{wc}{S}+\frac{1}{Gs}\right)$	**S**	**a**	**b**	**n**	γ_d / γ_w model	γ_{dry} model
E-07	137.70	2.2067	0.0740	0.4532	0.8654	1.30463	0.44962	0.49984	2.2111	137.98
	132.69	2.1264	0.0606	0.4703	0.5905	1.30463	0.44962	0.49984	2.1186	132.20
	136.69	2.1905	0.0680	0.4565	0.7652	1.30463	0.44962	0.49984	2.1925	136.81
	137.68	2.2064	0.0755	0.4532	0.8822	1.30463	0.44962	0.49984	2.2108	137.95
	134.71	2.1588	0.0841	0.4632	0.8800	1.30463	0.44962	0.49984	2.1559	134.53

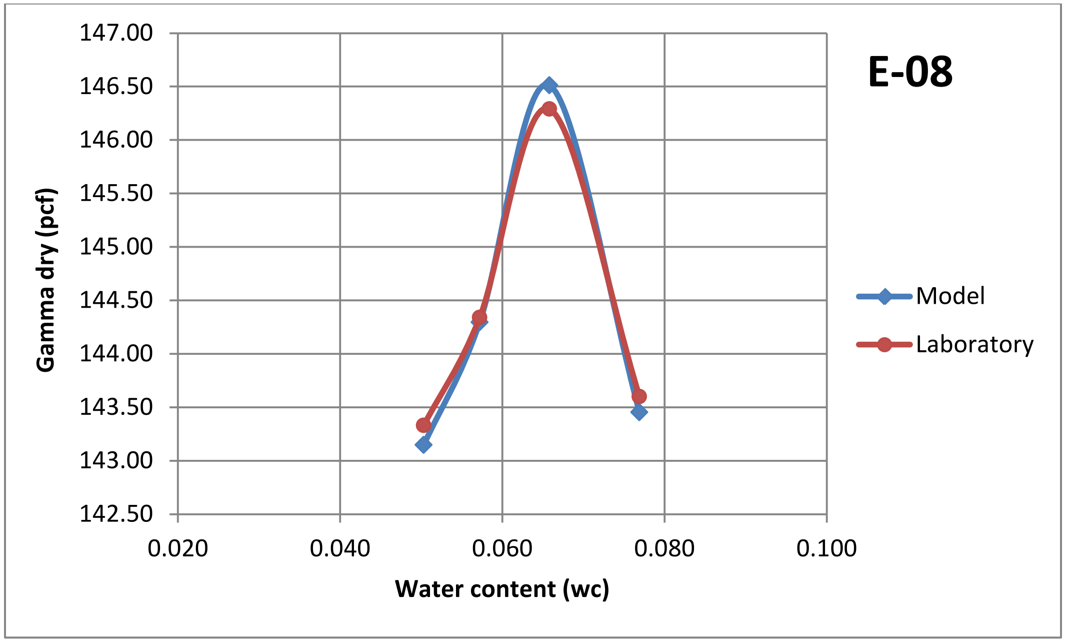

Figure L-13. Measured and Model Results for Dry Unit Weight and Water Content for E-08.

Table L-9. Parameters a,b,n, and Gamma Dry (γ_d) Calculations Based upon Different Moisture Contents for E-08.

Code	γ_{dry} (pcf)	γ_d / γ_w	**wc**	$\left(\frac{wc}{S}+\frac{1}{Gs}\right)$	**S**	**a**	**b**	**n**	γ_d / γ_w model	γ_{dry} model
E-08	145.80	2.3365	0.0650	0.4280	0.9344	1.295791	0.450331	0.500155	2.3392	145.97
	143.33	2.2970	0.0503	0.4354	0.6538	1.295791	0.450331	0.500155	2.2938	143.13
	144.34	2.3131	0.0572	0.4323	0.7741	1.295791	0.450331	0.500155	2.3123	144.29
	146.29	2.3444	0.0658	0.4266	0.9658	1.295791	0.450331	0.500155	2.3482	146.53
	143.60	2.3013	0.0769	0.4345	1.0103	1.295791	0.450331	0.500155	2.2987	143.44

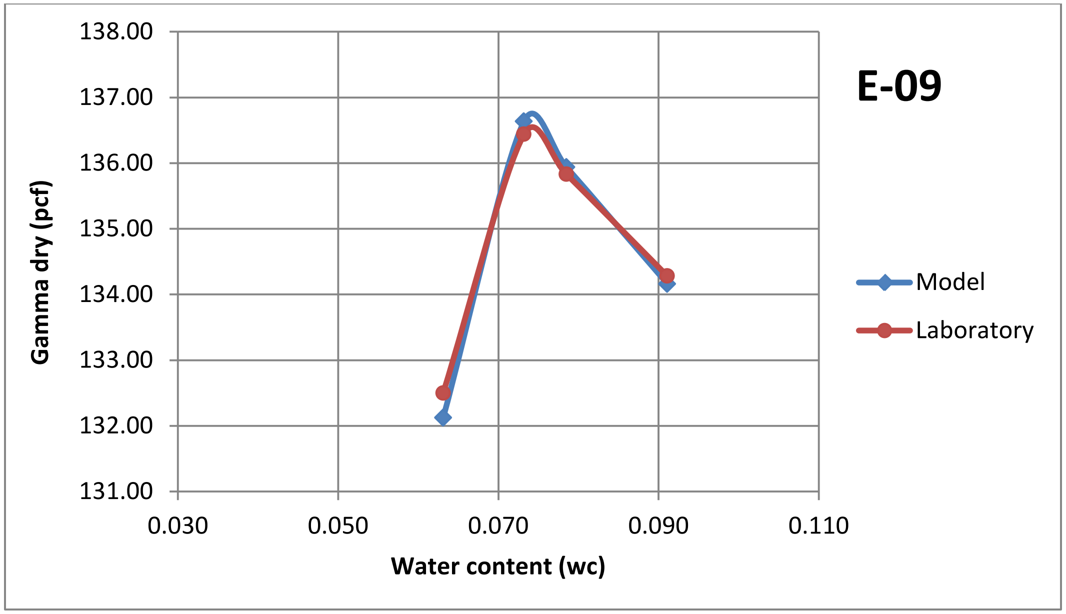

Figure L-14. Measured and Model Results for Dry Unit Weight and Water Content for E-09.

Table L-10. Parameters a,b,n, and Gamma Dry (γ_d) Calculations Based upon Different Moisture Contents for E-09.

Code	γ_{dry} (pcf)	γ_d / γ_w	wc	$\left(\frac{wc}{S}+\frac{1}{Gs}\right)$	S	a	b	n	γ_d / γ_w model	γ_{dry} model
E-09	136.40	2.1859	0.0790	0.4575	0.8302	1.30549	0.44955	0.49981	2.1891	136.60
	132.50	2.1234	0.0631	0.4709	0.5809	1.30549	0.44955	0.49981	2.1171	132.11
	136.44	2.1865	0.0732	0.4573	0.7703	1.30549	0.44955	0.49981	2.1898	136.65
	135.83	2.1768	0.0785	0.4594	0.8086	1.30549	0.44955	0.49981	2.1786	135.94
	134.28	2.1519	0.0911	0.4647	0.8898	1.30549	0.44955	0.49981	2.1499	134.16

APPENDIX M: MB TEST PROCEDURE

Test Procedure for
IMPROVED METHYLENE BLUE TEST FOR BASE MATERIALS

Texas Department of Transportation

TxDOT Designation: Tex-EE
Date: October 2012

1. SCOPE

1. Test method describes the measurement of methylene blue adsorbed by clay size fines. This measurement is denoted as the Methylene Blue Value (MBV).

2. Test method determines the amount of the fines content in an aggregate mixture.

3. Test method differentiates the fines property as clayey and non-clayey fines.

2. DEFINITIONS

1. *Methylene Blue Value (MBV)* – a measured reading from a colorimeter device and the MBV is an indicator of the amount of fines in the mixture.

2. *Critical Methylene Blue Value (MBV_C)* – a measured methylene blue value which is a threshold between clayey and non-clayey fines.

3. The unit of methylene blue value (MBV) is considered as milligrams of methylene blue per gram of dry soil sample (mg/g).

3. APPARATUS

1. *Hach DR Colorimeter device* – measures the color change of solution consisting of soil sample and methylene blue solution.

2. *Portable Weight Balance* must measure weight with a sensitivity of 0.01 gram.

3. *Methylene blue solution* which is a concentration of 1.00 percent aqueous solution. It is an anhydrous form of methylene blue ($C_{16}H_{18}N_3SCl$). The methylene blue concentration is diluted to 0.50 percent by weight.

4. *Micropipette which* is used to measure and transfer a 130 μL volume of methylene blue solutions.

5. *Pipet Tip* which is capable of holding a volume from 50 to 1000 microliter.

6. *Glass Tube Culture* which is a clear color, rounded cylindrical round shape and includes a screw cap. The size is O.D. x L. 16 x 100 mm, respectively.

7. *Syringe (without needles)* is a general purpose syringe which has a capacity of 3 mL with luer-lok adapter.

8. *Syringe Filter* has pore sizes of 0.20 micrometers and is capable of mounting a syringe.

9. *Plastic Tube* has a volume of 45 mL and a screw cap. It has visible gradations and is freestanding with conical a bottom.

10. *Plastic Storage Tubes* are capable of holding 1.4 mL volume, with a clear color, and screw cap.

11. *Weigh dish* is a pour boat to hold a minimum of 20.00 grams of sample.

12. *Eyedropper* is squeezed and has a capacity of 7.50 mL.

13. *Distilled water* has to be processed one or two times to become the distilled form.

14. *Disposable Latex Gloves* which are strong enough to protect hands.

15. *Funnel* will be used to add the sample into the 45 mL plastic tube.

16. *Timer* will count minutes while shaking the sample.

17. *No. 4 Sieve* will be used to obtain the passing No. 4 sieve portion.

18. *Blow drier* will be used for field operation to dry soil sample.

19. *Ziploc bag* to store and transport the soil samples.

20. *Beaker* will be used to store the distilled water during the test. For field operation, the top of the beaker must be covered to protect it from dirt or other contamination.

4. CALIBRATING SOLUTION

1. Methylene blue concentration must be calibrated due to different types of industrial methylene blue sources.

2. Correction factor must be determined for each new bottle of methylene blue concentration before testing.

3. Tare a new clean 45 mL plastic tube, and transfer 130 μL methylene blue concentration solution into the this plastic storage tube by using the micropipette.

4. Add accurately 45.00 g of distilled water into the plastic storage tube with the eyedropper.

5. Close the cap of the plastic tube and shake it gently.

6. Transfer the diluted solution into a glass tube and screw the cap.

7. Turn on the Hach DR Colorimeter and press the PRGM button. Type 106 then hit the ENTER key.

8. Insert a glass tube filled with water into the colorimeter and press the ZERO. The colorimeter must display the value of 0.00 ppm.

9. Insert the glass tube filled with the solution into the colorimeter and press the READ key.

10. The colorimeter will display a reading. The reading of 14.44 ppm corresponds to the 0.50 percent concentration by weight.

11. Convert the reading (ppm) to actual Methylene Blue concentration by weight, using the calculations provided in sections 8.2 to 8.4.

12. Actual Methylene blue concentration must be between 0.480% and 0.502%

13. If the converted methylene blue is higher than 0.502%, dilute the methylene blue solution with distilled water.

14. If the converted methylene blue solution is lower than 0.48%, discard the methylene blue solution and prepare a new solution.

15. Repeat the process until an actual methylene blue concentration is obtained.

5. SAMPLE PREPARATIONS (LABORATORY)

1. A representative sample of passing No. 4 sieve size is placed in a ziploc bag until the test.

2. Store samples in the container prior to test at a room temperature between 28^{o}C and 30^{o}C.

3. Keep the ziploc bag open. Allow sample to lose moisture and reduce the moisture to the air dry state. The drying process normally takes two days.

6. SAMPLE PREPARATIONS (FIELD)

1. Take a representative sample from the surface of the aggregate mixture.

2. Sieve the aggregate mixture with No. 4 sieve, and take the passing aggregate portion. Sieve a minimum of 200 g to permit replicate measurements.

3. Dry the sample by using an air drier. This process will require no more than 10 minutes.

4. Place the dried sample in a ziploc bag and keep the zipper open.

7. TEST PROCEDURE

1. Place a weigh dish on the balance and add a 20.00 g sample from the ziploc bag.
   Note 1- Always select a representative sample from the ziploc bag in all cases. Mix the sample thoroughly and do not allow segregation.

2. Add 30.00 mL of diluted methylene blue solution in a new clean 45 mL plastic tube.

3. Add the 20.00 g sample into the 30.00 mL solution by using a funnel and close the cap of the plastic tube.
   Note 2- Make sure all the sample is added into the plastic tube. Be careful not to pour any sample outside of the plastic tube.

4. Start off the timer, and at the same time begin shaking the plastic tube for 1 minute.

5. Allow the sample to rest for 3 minutes.

6. Shake the plastic tube after for additional 1 more minute.

7. Remove the plunger from the 3 mL- syringe and place a filter syringe on the luer-lok fitting.

8. Add nearly 2 mL solution (sample and methylene blue) to the syringe and place the plunger back.

9. Slowly push the plunger in and filter the solution into a plastic storage tube.
   Note 3- Initially there will be some resistance because of the very fine syringe filter pore size. The plunger has to be pushed but not hard. If the plunger is pushed harder than necessary, the syringe filter will explode.

10. Tare a new clean 45.00 mL plastic tube on the balance.

11. Take 130 μL filtered solution from the plastic storage tube, and then transfer it into the 45 mL plastic tube through the adjustable micropipette.
Note 4- Be careful to have accurate filtered solution. To do that, immerse nearly half of the pipet tip into plastic storage tube before aspirating the filtered solution.
Note 5- Make sure there is no solution stain on the pipet tip after dispersing the solution into the plastic tube.

12. Fill the plastic tube with distilled water accurately total to a 45.00 g using the balance.

13. Fill the glass tube almost full with the newly diluted solution and close the cap. The solution is read to measure the methylene blue value.

14. Turn on the colorimeter. Press the PRGM button and type 107 then hit the ENTER key.

15. Remove the colorimeter cover and place the glass tube filled with distilled water into the hole on the colorimeter. Next cover the glass tube and press the ZERO key.

16. The colorimeter will display a value of 7.50 mg/g which indicates there is no color change.

17. Place the glass tube filled with the solution after removing the tube filled with distilled water in the colorimeter. Then cover the tube and press the READ key.

18. The instrument will display a value that is the *Methylene Blue Value (MBV)*. The Methylene Blue Value expresses in *mg* methylene blue per g of dry sample.

19. If the methylene blue value is lower than 7.00 mg/g, it is a valid number.

20. This process will be closely repeated at least two times for each sample.

21. If the methylene blue value is higher than 7.00 mg/g then the sample size must be cut into half to 10.00 grams and this procedure will be repeated.

22. If sample size is10.00 g and the methylene blue value remains higher than 7.00 mg/g, cut the sample size to 5.00 g.
Note 6- The amount of methylene blue solution used will remain the same even though the sample size is reduced.

8. CALCULATION

1. Methylene blue value calculation

$$MBV_{real} = S_{correction} x (MBV_{reading} + C_{factor})$$

Where:

- $MBV_{reading} =$ methylene blue value reading from the colorimeter device, mg/g
- $MBV_{real} =$ real methylene blue value after applying two correction factors, mg/g
- $C_{factor} =$ Correction factor of concentration due to dilution, mg/g
- $S_{correction} =$ Sample correction factor due to size of sample used. $S_{correction}$ factor are shown in Table M.1.

Table M-1: Tabulated sample correction factor along with corresponding sample sizes.			
Sample Size (gram)	20.00	10.00	5.00
$S_{correction}$	1.0	2.0	4.0

2. Actual concentration of the methylene blue solution and determination of the correction factor

$$C_{initial\_actual} = (C_{PRGM106,ppm})\frac{45mL}{(130\mu L)(1000)}$$

3. If the methylene blue concentration used is not 0.5 % then the corrected methylene blue value ($MBV_{corrected}$) is determined.

$$MBV_{corrected} = \left[\frac{\left(C_{initial\_actual} - C_{initial\_theoretical} + \frac{MBV_{measured}(20g)}{(30mL)(1000)}\right)(30ml)}{20g}\right]x(1000)$$

4. A correction factor (C_{factor}) value is determined for each new bottle of the methylene blue concentration.

$$C_{factor} = MBV_{corrected} - MBV_{measured}$$

Where:

- $C_{PRGM106,ppm} =$ Initial concentration of the methylene blue solution, ppm.
- $C_{initial\_actual} =$ Actual methylene blue concentration in the solution by weight.
- $MBV_{corrected} =$ Corrected methylene blue value, mg/g.
- $C_{initial\_theoretical} =$ Theoretical concentration at 0.5 percent by weight.
- $MBV_{measured} =$ Measured methylene blue value, mg/g.

9. REPORT

1. Report shall include the following.
2. Material source or quarry, and material type.
3. Amount of material used to run the test in grams.
4. All the methylene blue value reading to nearest 0.01 mg/g.
5. Plot the data and check the value of the methylene blue value whether it is higher than the critical methylene blue value *(MBV_C)* of 7.00 mg/g.

APPENDIX N: DRAFT OF QC/QA SPECIFICATION

MB TEST PROCEDURE

Draft Specification
Draft 2.1: September 10, 2011

SPECIAL SPECIFICATION
248
FLEXIBLE BASE (QC/QA)

1.0 Description

Construct a pavement foundation course composed of a graded aggregate or flexible base.

2.0 Materials

2.1 Aggregate

2.1.1 Aggregate

Furnish uncontaminated aggregate of uniform quality to meet the Type and Grade shown on the plans and conforming to the requirements of the plans and specifications.

Notify the Engineer of all material sources. Specified base material can be from multiple sources. Notify the Engineer before changing any materials source or mixture formulation. When the contractor makes a materials source or formulation change, the Engineer will verify that the specifications requirements are met and may require a new laboratory mixture design and field trial section or both. The engineer may sample and test project materials at any time during the project to verify specification compliance.

Use Tex-100-E material definitions.

2.1.2 Material Type

Furnish the Type specified on the plans in accordance with the following:
Type A. Crushed stone produced and graded from oversize quarried aggregate that originates from a single, naturally occurring source. Do not use gravel or multiple sources.
Type B. Crushed or uncrushed gravel. Blending of 2 or more sources is allowed.
Type C. Crushed gravel with a minimum of 60 percent of the particles retained on a No. 4 sieve with 2 or more crushed faces as determined by Tex-460-A, Part I. Blending of 2 or more sources is allowed.
Type D. Type A material or crushed concrete. Crushed concrete containing gravel will be considered Type D material. Crushed concrete must meet the

requirements in Section 2.1.4.1, “Contractor Furnished Recycled Materials” and be managed in a way to provide for uniform quality. The Engineer may require separate dedicated stockpiles in order to verify compliance.
Type E. As shown on the plans.

2.1.3 Material Grade
Furnish the Grade specified on the plans in accordance with Table N-2.

2.1.4 Recycled Materials
Crushed recycled portland cement concrete (RPCC) and reclaimed asphalt pavement (RAP) may be utilized as flexible base material. Other recycled materials may be used when shown on the plans. The percentage limitations for other than RPCC and RAP recycled materials will be as shown on the plans. Request to blend 2 or more sources of recycled materials. The combined blends of recycled material(s) and naturally occurring aggregate must meet the requirements of Table N-2 for the grade specified.

Recycled Concrete (RPCC). Recycled portland cement concrete (RPCC) is salvaged, milled, pulverized, broken or crushed portland cement concrete. The RPCC must meet the requirements of Table N-2 for the Grade specified on the plans. In addition, the RPCC must be free from reinforcing steel and other objectionable materials and meet the requirements shown in Table N-3.

The Engineer may require separate dedicated stockpiles in order to verify compliance.

Reclaimed Asphalt Pavement (RAP). Reclaimed Asphalt Pavement (RAP) is salvaged, milled, pulverized, broken or crushed asphalt bound pavement. Crush or break RAP so that 100 percent of the particles pass the 2 in. sieve. RAP must be free from objectionable materials and meet the requirements of Table N-4. When RAP is allowed, do not exceed 20 percent RAP by weight of total base course material unless otherwise shown on the plans. Test RAP without removing the asphalt binder.

The Engineer may require separate dedicated stockpiles in order to verify compliance.

2.1.4.1 Contractor Furnished Recycled Materials.
The use of Contractor-owned recycled materials is allowed unless otherwise shown on the plans. Contractor-owned surplus recycled materials remain the property of the Contractor. Remove Contractor-owned recycled materials from the project and dispose in accordance with federal, state and local regulations before the project acceptance. Do not intermingle Contractor-owned recycled

materials with Department-owned recycled materials unless approved by the Engineer.

Certify compliance of all types of recycled materials with DMS-11000, "Evaluating and Using Nonhazardous Recyclable Materials Guidelines".

Contractor furnished
RPCC must meet the requirements of Table N-3. Contractor furnished RAP materials must meet the requirements of Table N-4. Other contractor furnished recycled materials (other than RPCC and RAP) must meet the requirements shown on the plans.

2.1.4.2 Department Furnished Recycled Materials.
Department-owned recycled material(s) are available to the Contractor only when shown on the plans. Return unused Department-owned recycled materials to the Department stockpile locations designated by the Engineer unless otherwise shown on the plans.

If Department-owned recycled materials are available for Contractor's use, the Contractor may use Contractor-owned recycled materials and replace the Contractor's used recycled material with an equal quantity of Department-owned recycled materials. Department-owned recycled materials generated through required work on the Contract are available for the Contractor's use when shown on the plans. When shown on the plans, the contractor will retain ownership of the recycled materials generated on the project.

Perform any necessary tests to ensure Department-owned RPCC meets the requirements of Table N-3 and RAP meets the requirements of Table N-4. Unless otherwise shown on the plans, the Department will not perform any tests or assume any liability for the quality of the Department-owned recycled materials.

The blended materials (naturally occurring aggregate and/or contractor furnished recycled material(s) and/or Department furnish recycled material(s)) must meet the requirements of Table N-2 as designed on the plans. Uniformly blend the materials to meet the requirements of Table N-2.

2.1.5 Additives
Do not use additives such as but not limited to lime, portland cement and fly ash to modify aggregates to meet the requirements of Table N-2, unless shown on the plans.

2.2 Water

Furnish water free of industrial wastes, other objectionable mater and with a sulfate concentration less than 3,000 ppm when tested in accordance with Tex-145-E.

2.3 Prime Coat

Unless otherwise shown on the plans or approved, furnish a prime materials in accordance with Item 300 "Asphalts, Oils and Emulsions."

3.0 Equipment

Provide machinery, tools and equipment necessary for proper execution of the work. Provide rollers in accordance with Item 210, "Rolling." Provide proof rollers in accordance with Item 216, "Proof Rolling," when required.

4.0 Construction

Construct each layer uniformly, free of loose or segregated areas and with the required density, moisture content and properties as specified and/or shown on the plans. Provide a smooth surface that conforms to the typical sections, lines and grades shown on the plans or as directed by the engineer.

The engineer may require removal and replacement or may allow the sublot or lot to be left in place with a reduced payment or without payment when the Contractor fails to comply with a specification requirement to suspend production or placement.

4.1 Certification

Personnel certified by the Department-approved Soil and Base Certification Program must conduct all mixture design, sampling and testing in accordance with Table N-5. Supply the Engineer with a list of certified personnel and copies of their current certificates before beginning production and/or placement when personnel changes are made. Provide a mixture design that is developed and signed by a Level SB 202 certified specialist. Provide a Level SB 101 certified specialist at the plant during production operations. Provide a Level SB 102 certified specialist to conduct placement tests.

The Engineer must approve the mix design based on interpretation of information supplied by certified technicians. The Engineer is not required to be certified. The Engineer is registered as a Professional Engineer in the State of Texas.

4.2 Reporting

Use Department-provided software to record and calculate all test data including but not limited to mixture design, production and placement QC/QA, control charts and pay factors. Obtain the latest version of the software at http://www.dot.state.tx.us/txdot_library/constultants_contractors/forms/site_manager/htm or from the Engineer. The Engineer and the Contractor shall provide any available test results to the other party when requested. The maximum allowable time for the Engineer and Contractor to exchange test data is as given in Table N-6 unless otherwise approved. The Engineer and the Contractor shall immediately report to the other party any test result that requires production to be suspended, a payment penalty or fails to meet the specification requirements. Record and submit all test results and pertinent information on Department-provided software to the Engineer electronically by means of a portable USB flash drive, compact disk or via email.

The Engineer will use the Department-provided software to calculate all pay adjustment factors for the sublot/lot. Sublot samples may be discarded after the Engineer and Contractor sign off on the pay adjustment summary documentation for the lot.

Use the procedures described in Tex-233-F to plot the results of all quality control (QC) and quality assurance (QA) testing. Update the control charts as soon as test results for each sublot become available. Make the control charts readily accessible at the field laboratory. The Engineer may suspend production for failure to update control charts.

4.3 Quality Control Program (QCP)

Develop and follow the Quality Control Program (QCP) in detail. The Engineer must approve the QCP. Obtain approval from the Engineer for changes to the QCP made during the project. The Engineer may suspend operations if the Contractor fails to comply with the QCP.

Submit a written QCP to the Engineer before the mandatory preproduction/placement meeting. If production is stopped for an extended period of time, the Engineer may require another preproduction/placement meeting prior to commencement of construction.

Receive the Engineer's approval of the QCP before beginning production and placement. Include the following items as a minimum in the QCP.

4.3.1 Project Personnel

For project personnel include:
-List of individuals responsible for Quality Control sampling and testing
-Person responsible for mixture design
-Person with authority to take corrective action
-Provide copies of current certificates for all personnel
-Provide contact information for all personnel

4.3.2 Production

-Pit or quarry mining plan
-Materials haul/transfer from pit/quarry to materials production facility
-Method for "charging" materials into the production facility
-Materials production facility process details (materials flow through the plant-screens, belts, crushers, washers, etc.)
-Stockpile location(s) from plant belts and re-established stockpiles

-Post production blending
-Sampling equipment and location
-Production process control plan (contractor's option)
-Production quality control plan (minimum requirements shown on Table N-7)

4.3.3 Material Delivery and Storage
-Location of stockpile site at quarry/pit or project
-Vehicles used for transportation
-Stockpiling procedures to avoid contamination and segregation
-Stockpile quality control/quality assurance plan (minimum requirements shown on Table N-7)
-Producers/contractors process control plan for stockpiling operation (contractor's option)

4.3.4 Loading and Transportation
-Loading and transportation equipment for movement of base course materials from quarry/pit or project stockpile to placement site
-Loading and transportation procedures to avoid contamination and segregation

4.3.5 Placement and Compaction
-Placement and compaction equipment
-Placement and compaction procedures to avoid contamination and segregation
-Placement and compaction procedures to provide uniform density and moisture content
-Contractors process control plan for placement and compaction operation (contractor's option)
-Placement and compaction quality control/quality assurance plan (minimum requirements shown on Table N-7)

4.3.6 Finishing and Curing Operation
-Finishing equipment
-Finishing procedure to insure conformance to lines and grades
-Equipment for application of prime coat
-Procedure to insure conformance to quality control for prime coat
-Procedure to insure moisture content of base course is within limits prior to placement of surface course

4.4 Mixture Design

4.4.1 Design Requirements
The Contractor shall use an approved laboratory to perform the base course mixture design. The Construction Division maintains a list of approved

laboratories at
http://www.dot.state.tx.us/txdot_library/publications/producer_list.htm
When shown on the plans, The Engineer will provide the mixture design.

The Contractor may submit a new mixture design at anytime during the project. The Engineer will approve all mixture designs before the Contractor can begin placement of the base course.

Provide the Engineer with a mixture design report using Department-provided software. The mixture design shall meet the requirements of Table N-2. Include only those items identified in the specification in the report:
-Aggregate gradation (Tex-110-E, Part II)
-Liquid Limit, Plastic Limit and Plastic Index (Tex-104-E, Tex-105-E, Tex-106-E)
-Wet Ball Mill (Tex-116-E)
-Compressive Strength (Tex-117-E)
-Sulfate Content (Tex-145-E)
-Moisture-density relationship (Tex-113-E)
-Percent by total mass of recycled portland cement concrete (RPCC) if utilized
-Properties of RPCC (Table N-3) gradation (Tex-110-E), deleterious materials (Tex-413-A) and sulfate content (Tex-145-E)
-Percent by total mass of reclaimed asphalt pavement (RAP) if utilized
-Properties of RAP (Table N-4), gradation (Tex-110-E), decantation (Tex-406-A) and deleterious materials (Tex-413-A)
-Signature of the Level SB 202 Certified Technician performing the mixture design
-Date the mixture design was performed and
-Unique identification number for the mixture design

4.4.2 Job Mix Formula Approval (JMF)

The job mix formula is the gradation, liquid limit, plastic index, wet ball mill and compressive strength as shown on Table N-2 as well as the moisture-density relationship determined by Tex-113-E. Job Mix Formula 1 (JMF 1) is determined from material stockpiled at the plant/ production site or the stockpile located at the project site. The Engineer may accept an existing mixture design previously used on a Department project and may waive the requirement for JMF 1.

“Conditional” approval for JMF 1 will be granted by the Engineer based on samples obtained from project dedicated stockpile provided the test results meet the specification requirements. If JMF 1 submitted by the Contractor does not meet all requirements, a new JMF 1 will be submitted to the Engineer for approval according to the methodology specified herein. It is possible that several JMF 1 mixture designs will be submitted by the Contractor and evaluated by the Engineer prior to conditional approval.

A trial section (Lot 1) will be placed on the project by the Contractor using JMF 1. The Engineer will select the location for the trial section (Lot 1).

Samples of the material will be obtained from the windrow during construction of the trial section (Lot 1). The Contractor's and Engineer's test results will be used to verify JMF 1. "Final" approval of JMF 1 will be based on acceptable test results from the trial section (Lot 1).

Changes in JMF 1 may be made by the Contractor based on results from this trial section (Lot 1). If changes are made, this mixture design will be identified as JMF 2.

The Contractor will use JMF 2 to place Lot 2. Materials will be sampled and tested during the placement of Lot 2. Based on these results JMF 2 may be changed by the Contractor. This mixture design become JMF 3 and will be used on Lot 3. Additional changes in JMF's may be made during the project as described in this specification.

4.4.3 Contractor's Responsibility

4.4.3.1 Provide Mixture Design Laboratory
Provide a TxDOT approved mixture design laboratory that meets the requirements of Tex-198-E.

4.4.3.2 Provide Certified Technicians
Provide TxDOT approved Technician(s) for conducting the mixture design in accordance with Table N-5.

4.4.3.3 Submit JMF 1
Furnish a mix design report (JMF 1) to the Engineer. JMF 1 must be submitted to the Engineer by the Contractor a minimum of 15 working days prior to placement of the trial section (Lot 1).

4.4.3.4 Supply Aggregate and Recycled Materials
Sample base course materials from the project stockpile for testing by the Engineer and Referee. Sampling will be performed according to Tex-400-A. The Engineer will witness the sampling. If blends of natural aggregate and recycled materials are proposed for use, supply sufficient quantities of these materials such that the total amount of materials supplied meets the requirements of Tex-400-A. Supply individual materials (natural, RPCC and RAP) in their approximate proportions.

4.4.3.5 Request Conditional Approval of JMF 1

Request conditional approval of JMF 1 from the Engineer. Conditional approval by the Engineer will be based on testing for requirements in Table N-2 (gradation, Liquid Limit, Plastic Index, Wet Ball Mill and Compressive Strength) and a moisture-density relationship. Testing will be performed on the materials supplied in section 4.4.3.4.

4.4.3.6 Request Approval for Placement of Trial Section (Lot 1)

Request approval for placement of trial section (Lot 1) from the Engineer.

4.4.3.7 Place Trial Section (Lot 1)

The purpose of the trial section (Lot 1) is to verify that both the material and mixture properties meet the requirements in JMF 1 and the materials can be placed at the specified in-place moisture content and in-place dry density. In addition, information is provided to insure that the difference in measured parameters by both the Contractor and Engineer are within certain limits.

Upon receiving conditional approval of JMF 1 and authorization from the Engineer to place a trial section (Lot 1), place materials from the project stockpile in the trial section (Lot 1).

For placement of the trial section (Lot 1), use only equipment and materials proposed for use on the project. Use a sufficient quantity of materials during the placement of the trial section (Lot 1) to ensure that the mixture meets the specification requirements. Typically the trial section will represent a lot of material.

Provide a trial section that meets the requirements of Table N-2 and Table N-8 and with an in-place density and in-place moisture content that meets the specification as shown on Table N-10.

Note the Engineer may require that the entire Lot be removed and replaced or reworked at the Contractor's expense for failing test results.

4.4.3.8 Number of Trial Sections

Place trial sections as necessary to obtain a mixture that meets the specification requirements.

4.4.3.9 Trial Section Sampling

Obtain representative samples of the materials placed on the trial section (Lot 1) from a windrow according to Tex-400-A. Split the sample into three equal portions. Label these portions as

"Contractor," "Engineer, and "Referee." Deliver samples to an appropriate laboratory as directed by the Engineer.

4.4.3.10 Trial Section (Lot 1) Testing

4.4.3.10.1 Material (Production) Properties

Test materials from the trial section to ensure that the materials produced using the proposed JMF 1 meet the requirements shown on Table N-2 for the following material parameters for the Grade identified on the Plans:
-master gradation
-Liquid Limit
-Plastic Index
-Wet Ball Mill
-Compressive Strength

A laboratory compacted moisture-density relationship is also determined from samples obtained from the windrow.

For the Contractor, sampling and testing frequency requirements assume that the trials section (Lot 1) is a lot. The minimum sampling and testing for the Contractor are shown on Table N-9 and Table N-10.

The test results must be within the "Allowable Difference from Current JMF Target" as shown in Table N-8. This "difference" is relative to JMF 1results obtained by the Contractor's JMF submittal information. Provide a copy of the trial section test results to the Engineer.

Both the Contractor and Engineer are required to sample and test material properties. The allowable difference between Contractor and Engineer test results are show on Table N-8 ("Allowable Difference between Contractor and Engineer Test Results").

If the material properties do not meet the requirements of Table N-2 and Table N-8, additional sampling and testing will be performed and/or a new trial section will be placed and evaluated as directed by the Engineer.

4.4.3.10.2 In-Place (Placement) Properties

Determine in-place density and in-place moisture content of the base course in the trial section according to Tex-115-E. Use the sampling and testing frequency shown for a Lot on Table N-10. The test results from the Contractor and Engineer must meet the specification requirements shown on Table N-10 as well as the "Allowable Difference between Contractor and Engineer Test Results" shown on Table N-10.

4.4.3.11 Request Final Approval of JMF 1

The Engineer will grant final approval of JMF 1 only after all of the Engineer's and Contractor's test results from the Trial Section (Lot 1) are available and all meet the requirements of Table N-2, Table N-8 and Table N-10 as specified above.

4.4.3.12 Development of JMF 2

Based on the results from the trial section (Lot 1), the Contractor may develop a new JMF. This new JMF becomes JMF 2 and will be used to place Lot 2. JMF 2 must meet all the requirements of Table N-2.

4.4.3.13 Production

After receiving approval for JMF 2, proceed to Lot 2 placement. Note the Engineer may require that the entire Lot be removed and replaced or reworked at the Contractor's expense for failing test results.

4.4.3.14 Development of JMF 3

Based on the results from the Lot 2, the Contractor may develop a new JMF. This new JMF becomes JMF 3 and will be used to place Lot 3. JMF 3 must meet all the requirements of Table N-2.

4.4.3.15 JMF Adjustments

If necessary, adjust the JMF before beginning a new lot.

-The adjusted JMF must be provided to the Engineer in writing before the start of a new lot

-The JMF must be numbered in sequence to the previous JMF

-The JMF must meet all other requirements shown in Table N-2

-The JMF must meet be verified according to the procedures shown in Section 4.4.3.10 for the next Lot placed.

4.4.3.16 Requesting Referee Testing

If needed, use referee testing in accordance with Section 4.14.1, "Referee Testing," to resolve testing differences with the Engineer.

4.4.4 Engineer's Responsibility

4.4.4.1 Provide Mixture Design Laboratory

Provide a TxDOT approved mixture design laboratory that meets the requirements of Tex-198-E.

4.4.4.2 Provide Certified Technicians

Provide TxDOT approved Technician(s) for conducting the mixture design in accordance with Table N-5.

4.4.4.3 Conditional Approval of JMF 1

The Engineer will evaluate JMF 1 with samples obtained from Section 4.4.3.4. Materials produced by the Contractor must meet the requirements of Table N-2.

The following tests will be conducted:
-gradation
-Liquid Limit
-Plastic Index
-Wet Ball Mill
-Compressive Strength
-Optimum Moisture Content
-Maximum Dry Density

The Engineer will consider approval of JMF 1 within 15 working days after receiving samples submitted as described in Section 4.4.3.4.

If JMF 1 submitted by the Contractor does not meet all requirements, a new JMF 1 will be submitted by the Contractor for approval according to the methodology specified herein. It is possible that several JMF 1 mixture designs will be submitted by the Contractor and evaluated by the Engineer prior to conditional approval.

The Engineer may sample and test project materials at any time during the project to verify specification compliance.

4.4.4.4 Approval for Placement of Trial Section (Lot 1)

The Engineer will consider approving the placement of the trial section within one working day of receipt of request for approval from the Contractor in accordance with Section 4.4.3.6. JMF 1 will be used to place the Trial Section (Lot 1).

4.4.4.5 Testing of Trial Section (Lot 1)

Within five working days, the engineer will sample and test materials from the trial section (Lot 1) to ensure that the material meets the requirements of Table N-2, Table N-8 and Table N-10.

The Engineer is required to perform a minimum of one test for gradation, Liquid Limit, Plastic Limit, Wet Ball Mill and Compressive Strength. These test results must meet the requirements of Table N-2, the "Allowable difference from Current JMF Target" shown on Table N-8 and "Allowable Difference between Contractor and Engineer Test Results" shown on Table N-8. When comparing the "Allowable Difference from Current JMF Target" utilize test results from JMF 1 testing in Section 4.4.4.3 of this specification. When comparing the "Allowable Difference between Contractor and Engineer Test Results" utilize test results from the Trial Section (Lot 1).

A single point on the moisture-density laboratory compaction curve will be determined according to Tex-113-F.

The single point determination for the moisture content and dry density relationship obtained by the Engineer on materials sampled from the Trial Section (Lot 1) must be within the "Allowable Difference from Current JMF Target" shown on Table N-8. and the "Allowable Difference between Contractor and Engineer Test Results" shown on Table N-8. When comparing the "Allowable Difference from Current JMF Target" utilize the test result from JMF 1 testing in Section 4.4.4.3 of this specification. When comparing the "Allowable Difference between Contractor and Engineer Test Results" utilize test results from the Trial Section (Lot 1).

The in-place moisture content and dry density for the Trial Section (Lot 1) will be determined at four (4) locations and must meet the specification requirements shown on Table N-10 and the "Allowable Difference between Contractor and Engineer Test Results" shown on Table N-10.

4.4.4.6 Final Approval of JMF 1

The Engineer will grant final approval of JMF 1 only after all of the Engineer's and Contractor's test results from the Trial Section (Lot 1) are available and all meet the requirements of Table N-2, Table N-8 and Table N-10 as specified above. The Engineer will notify the Contractor that an additional trial section is required if the trial section does not meet these requirements.

The Contractor may develop JMF 2 based on results from the Trial Section (Lot 1).

4.4.4.7 Conditional Approval of JMF 2 and Placement of Lot 2

The Engineer will provide conditional approval of JMF 2 within 1 working day if the submitted JMF meets the requirements shown on Table N-2. JMF 2 will be used to place Lot 2 at the Contractor's risk.

4.4.4.8 Final Approval of JMF 2

The Engineer will grant final approval of JMF 2 only after all of the Engineer's and Contractor's test results from Lot 2 are available and all meet the requirements of Table N-2, Table N-8 Table N-10. Sections 4.4.3.10 and 4.4.4.5 of this specification will be used to determine the acceptance of JMF 2.

The Contractor is allowed to submit a JMF 3 based on results from Lot 2. JMF 3 will be evaluated using the same process as described for JMF 2 in Section 4.4.4.8 of this specification.

The Contractor may submit a new mixture design at anytime during the project. The new mixture design will be approved on the next Lot produced according to Sections 4.4.3.10 and 4.4.4.5 of this specification.

4.5 Production Operation

Prepare a new mixture design if the materials source changes, plant operation changes or the plant location changes. Take corrective action and receive approval from the Engineer to proceed with production or placement after any production or placement suspension for noncompliance to the specification.

Flexible base materials may be produced and deposited directly into a stockpile at the aggregate crushing, sizing and beneficiation production facility or blended from several stockpiles of materials from different sources including RPCC and RAP.

Materials should be stockpiled at the production facility or at the job site using procedures and process that minimize segregation.

4.6 Hauling

Clean all truck beds to ensure that the materials are not contaminated. The Contractor may elect to use belly dumps, live bottom or end dump truck to haul and transfer material.

4.7 Preparation of Subgrade, Subbase or Existing Base

Clear, scarify, shape and compact subgrade to conform to the typical sections, lines and grades shown on the plans or as directed by the Engineer. When shown on the plans or as directed, proof-roll the roadbed in accordance with Item 216 "Proof Rolling," before pulverizing or scarifying the subgrade. Correct soft spots as directed.

Shape and compact subbase materials to meet specifications and the lines and grades as shown on the plans.

Remove, scarify or pulverize existing asphalt bound materials on the roadway in accordance with Item 105 "Removing Stabilized Base and Asphalt Pavement" or

Item 251 "Reworking Base Courses" when shown on the plans or as directed. Shape and compact the scarified or pulverized asphalt bound materials to meet the specification and the lines and grades as shown on the plans.

When new base is required to be mixed with existing subbase, base or pulverized asphalt bound materials; place and spread the new flexible base in the required amount per station in accordance with Item 251 "Reworking Base Courses." Thoroughly mix the new base with existing material to provide a uniform mixture to the specified depth before shaping and compacting.

4.8 Placing

Spread and shape base into a uniform layer on the grade with an approved spreader the same day as delivered unless otherwise approved. Construct layers to the thickness shown on the plans. Maintain the shape of the course. Control dust by sprinkling, as directed. Correct or replace segregated areas as directed, at no additional expense to the Department.

Place successive base courses and finish courses using the same construction methods required for the first course. When longitudinal construction joints are needed to successful place the base course, avoid placing the joint in the lane wheel path and at the same location in successive layers. Off-set longitudinal joints of successive layers 6 inches as a minimum.

4.9 Compaction

Compact using density control unless otherwise shown on the plans. Multiple lifts are permitted when shown on the plans or approved. The maximum compacted thickness of a lift is eight (8) inches.

Bring each layer to the moisture content shown in the mixture design. When necessary sprinkle the materials in accordance with Item 204 "Sprinkling."

Begin rolling longitudinally at the sides and proceed towards the center, overlapping on successive trips by at least ½ the width of the roller unit. On super-elevated curves, begin rolling at the low side and progress toward the high side. Offset alternative trips of the roller. Operate rollers at a speed between 2 and 6 mph.

The Contractor is allowed to rework, re-compact and refinish material that fails to meet a minimum pay factor of 1.00 before the next course is placed or the project is accepted. Continue work until the pay factor is 1.00 or above or the Engineer and Contractor accept a pay factor less than 1.00 but greater than 0.70. Materials with a pay factor of 0.70 or below must be reworked or removed. Perform the work at no additional expense to the Department.

Rework, re-compact and refinish material that fails to meet or that loses required moisture, density, stability or finish before the next course is placed or the project is accepted. Continue the work until specification requirements are met. Perform the work at no expense to the Department.

4.9.1 Ordinary Compaction

Ordinary compaction shall be used when shown on the plans.

Roll with approved compaction equipment as directed by the Engineer. Correct irregularities, depression and weak spots immediately by scarifying the areas affected, adding or removing approved material as required, reshaping and re-compacting as directed by the Engineer.

4.9.2 Density Control

Density control shall be used on all projects unless otherwise shown on the plans.

Density will be controlled as described in the "Acceptance Plan."

4.10 Finishing

After compaction is completed, clip, skin or tight-blade the surface with a maintainer or subgrade trimmer to a depth of approximately ¼ in. Remove loosened material and dispose at an approved location. Seal the clipped surface immediately by rolling with a pneumatic tire roller until a smooth surface is attained. Add small increments of water as needed during rolling. Shape and maintain the course and surface in conformity with the typical sections, lines and grades as shown on the plans or as directed.

The flushing of the fine base course fraction to the surface by the use of water and rolling is not allowed during this finishing operation.

In areas where surfacing is to be placed, correct grade deviations greater than ¼ in. in 16 ft. measured longitudinally or greater than ¼ in. over the entire width of the cross-section. Correct by loosening, adding or removing material. Reshape and re-compact the material.

4.11 Curing

Apply a prime coat when shown on the plans. Cure the finished section until the moisture content is at least 2 percentage points below optimum or as directed by the Engineer prior to applying the prime coat.

Apply prime coat uniformly at the rate shown on the plans or as directed by the Engineer. Use a prime coat material as shown on section 2.3 of this specification. Apply the prime coat in a uniform manner such that streaks and other irregular patterns are avoided. Prevent splattering of prime coat when placed adjacent to curb, gutter and structures.

4.12 Acceptance Plan

Pay adjustments for the material will be in accordance with Article 6, “Payment.”

Sample and test the flexible base material on a sublot and lot basis. If the production pay factor given in Section 6.5, “Production Pay Adjustment Factors,” for 2 consecutive lots or the placement pay factor calculated according to Section 6.6, “Placement Pay Adjustment Factors,” for 2 consecutive lots is below 1.000, suspend production until test results or other information indicate to the satisfaction of the Engineer that the next materials produced or placed will result in pay factors of a least 1.000.

4.12.1 Referee Testing

The Construction Division is the referee laboratory. The Contractor may request referee testing if a “rework,” “stop production” or a “remove and replace” condition is determined based on the Engineer’s test results, or if the differences between Contractor and Engineer test results exceed the maximum allowable difference shown on Table N-8 and the difference cannot be resolved. Make the request within two (2) working days after receiving test results and samples from the Engineer. Referee tests will be performed only on the sublot or lot in question and only for the particular test in question. Allow 15 working days from the time the samples are received at the referee laboratory for test results to be reported. The Department may require the Contractor to reimburse the Department for referee tests if more than 3 Referee tests per project are required and the Engineer’s test results are closer than the Contractor’s test results to the Referee test results.

Referee test results are final and will establish pay adjustment factors for the sublot or lot in question. The Contractor may decline referee testing and accept the Engineer’s test results.

4.12.2 Production Acceptance

4.12.2.1 Production Lot

A production lot consists of 4 equal sublots. The default quantity for Lot 1 is 1,000 tons: however, when requested by the Contractor, the Engineer may increase the quantity for Lot 1 to no more than 5,000 tons. The Engineer will select subsequent lot sizes based on the anticipated daily production such that approximately 2 to 4 sublots are produced each day. The lot size will be between 1,000 and 5,000 tons. The Engineer may change the lot size before the Contractor begins any lot.

4.12.2.1.1 Small Quantity Production

When the anticipated daily production is less than 250 tons, the total production for the project is less than 10,000 tons, when paving miscellaneous areas or when mutually agreed between the Engineer and the Contractor, the Engineer may waive all quality control and quality assurance (QC/QA) sampling and testing requirements. If the Engineer waives QC/QA sampling and testing, the production pay factors will be 1.000. However, the Engineer will retain the right to perform random acceptance tests for production and placement and may reject objectionable materials and workmanship.

When the Engineer waives all QC/QA sampling and testing requirements:
-Produce the mixture as directed by the Engineer
-Control mixture production to meet the requirements of Table N-2.

4.12.2.1.2 Incomplete Production Lots

If a lot is begun but cannot be completed, such as on the last day of production or in other circumstances deemed appropriate, the Engineer may close the lot. Adjust the payment for the incomplete lot in accordance with Section 6.4, "Production Pay Adjustment Factors," Close all lots within 5 working days, unless otherwise allowed by the Engineer.

4.12.2.2 Production Sampling

The Engineer will select random numbers for all production sublots on a Lot basis according to Tex-225-F at the pre-production meeting. The Contractor will identify the sample location in the Quality Control Plan. Sampling will be performed by the Contractor and witnessed by the Engineer in accordance with Tex-400-A. The Contractor will split samples according to Tex-400-A.

Production sampling can be performed at one of eight locations:
-From belt (belt sampler or stop belt) of production plant used to form the project material stockpile
-Stockpile of project material formed at end of production plant stockpile belt
-Stockpile of material formed after blending two or more materials (including recycled materials)
-from the back of a haul vehicle
-Dedicated stockpile of material at production plant site formed specifically for the project
-Dedicated stockpile of material at project site formed specifically for the project

-From the windrow as the material is placed on the grade
-From the shaped grade prior to compaction

The sampler will split each sample into three equal portions in accordance with Tex-400-A and label these portions as "Contractor," "Engineer," and "Referee." The Engineer will maintain the custody of the samples labeled "Engineer" and "Referee" until tested by the Department.

4.12.2.3 Production Testing

The Contractor and Engineer must perform production quality control/quality assurance tests in accordance with Table N-9. The Contractor has the option to verify the Engineer's test results on split samples. Determine compliance with Operational Tolerances listed in Table N-8 for all sublots and lots. The engineer may perform as many additional tests as deemed necessary.

4.12.2.4 Operational Tolerances

Production Operational Tolerances are defined on Table N-8 as the "Allowable Difference from Current JMF Target". Control the production process within the Operational Tolerances listed in Table N-8. When production is suspended, the Engineer will allow production to resume when test results or other information indicates that the next mixture produced will be within the Operational Tolerances.

4.12.2.4.1 Gradation

A sublot is defined as out of tolerance if either the Engineer's or the Contractor's test results are out of Operational Tolerance as shown under "Allowable Difference from Current JMF Target" on Table N-8. Unless otherwise directed, suspend production when test results for gradation exceed the Operational Tolerances for three consecutive sublots on the same sieve or four consecutive sublots on any of the specified sieves. The consecutive sublots may be from more than one lot.

4.12.2.4.2 Liquid Limit

A lot is defined as out of tolerance if either the Engineer's or the Contractor's test results are out of Operational Tolerance as shown under "Allowable Difference from Current JMF Target" on Table N-8 or the Liquid Limit exceeds the specification requirement shown on Table N-2 for the Grade specified. Unless otherwise directed, suspend production when test results for Liquid Limit exceed the Operational Tolerances for two consecutive lots.

4.12.2.4.3 Plastic Index

A lot is defined as out of tolerance if either the Engineer's or the Contractor's test results are out of Operational Tolerance as shown under "Allowable Difference from Current JMF Target" on Table N-8 or the Plastic Index is outside the minimum and maximum limits shown on Table N-2 for the Grade specified. Unless otherwise directed, suspend production when test results for Plastic Index exceed the Operational Tolerances for 2 consecutive lots for either the "minimum" or "maximum" limit or 3 consecutive lots for either parameter.

4.12.2.4.4 Wet Ball Mill

A lot is defined as out of tolerance if either the Engineer's or the Contractor's test results are out of Operational Tolerance as shown under "Allowable Difference from Current JMF Target" on Table N-8 or the Wet Ball Mill values exceed the maximum limits shown on Table N-2 for the Grade specified. Unless otherwise directed, suspend production when test results for Wet Ball Mill exceed the Operational Tolerances for 2 consecutive lots for either "percent max" or "percent passing the No. 40 sieve or 3 consecutive lots for either parameter.

4.12.2.4.5 Minimum Compressive Strength

A lot is defined as out of tolerance if either the Engineer's or the Contractor's test results are out of Operational Tolerance as shown under "Allowable Difference from Current JMF Target" on Table N-8 or the Compressive Strength is less than the minimum limits shown on Table N-2 for the Grade specified. Note that the Compressive Strength is not considered out of Operational Tolerance if the Compressive Strength of the production sample exceeds the "Allowable difference from Current JMF Target" shown on Table N-8. Unless otherwise directed, suspend production when test results for the Compressive Strength does not meet the Operational Tolerances for 2 consecutive lots for 0 psi lateral pressure, 3 psi lateral pressure or 15 psi lateral pressure individually or 3 consecutive lots for any of these parameters.

4.12.2.5 Individual Loads (Localized Areas) of Base

The Engineer can reject individual truck loads or localized areas of flexible base material. When the load of flexible base material is rejected for reasons other than contamination, the Contractor may request that the rejected load be tested. Make this request within 4 hr. of rejections. The Engineer will sample and test the mixtures. If test results are within the Operational Tolerances shown in Table N-8, payment will be made for the load. If test results are not within Operational Tolerances, no payment will be made for the load and the Engineer may require removal.

4.12.3 Placement Acceptance

4.12.3.1 Placement Lot

A placement lot consists of four placement sublots. A placement lot consists of the area placed with 4,000 tons of flexible base course material.

4.12.3.2 Lot 1 Placement

The Pay Adjustment Factor for Lot 1 will be 1.00. Rework or remove and replace any sublot in Lot 1 with in-place density is less than 98 percent relative density.

4.12.3.3 Lot 2 and Subsequent Lots

Pay Adjustment Factors for Lot 2 and subsequent lots will be in accordance with Section 6.4 "Placement Pay Adjustment Factors

4.12.3.4 Incomplete Placement Lots

If a lot is begun but cannot be completed, such as on the last day of production or in other circumstances deemed appropriate, the Engineer may close the lot. Adjust the payment for the incomplete lot in accordance with Section 6.5.1, "Production Pay Adjustment Factors," Close all lots within 5 working days, unless otherwise allowed by the Engineer.

Exclude "Miscellaneous Areas" as defined in Section 4.14.3.1.4 from the definition of "Incomplete Lots."

4.12.3.5 Shoulders, Ramps, etc.

Shoulders, ramps, intersections, acceleration lanes, deceleration lanes and turn lanes are subject to in-place density determination, unless designated on the plans as not eligible for in-place density determination. Intersections and detours may be considered miscellaneous areas when determined by the Engineer.

4.12.3.6 Miscellaneous Areas

Miscellaneous areas include areas that are not generally subject to primary traffic and typically involve handwork or discontinuous placement operations, such as driveways, mailbox turnouts, crossovers, gores, spot level-up areas and other similar areas. Intersections and temporary detours may be considered miscellaneous areas when determined by the Engineer. Miscellaneous areas are not eligible for random placement sampling locations. Compact areas that are not subject to in-place density determination in accordance with Section 4.9.1, "Ordinary Compaction."

4.12.3.7 Placement Sampling

The Engineer will select random numbers for all placement sublots and lots for quality control and quality assurance testing at the pre-placement meeting. The Engineer will provide the Contractor with the placement random numbers immediately after the sublot is completed. Mark the roadway locations at the completion of each sublot and record the station number. Determine 4 random sample locations for each placement sublot in accordance with Tex-225-F for in-place density and moisture content determination and 1 random sample location for each sublot for thickness determination and 1 random location for each lot for laboratory compacted moisture density relationship determination. The 1 random sample location per sublot for thickness determination and the 1 random sample location per lot for the laboratory compacted optimum moisture content and maximum dry density determination may be identical to a random sample location selected for in-place density and moisture content determination. If the randomly generated sample location is within 2 ft. of a joint or layer edge, adjust the location by not more than necessary to achieve a 2 ft. clearance.

Shoulders, ramps, intersections, detours, acceleration lanes, deceleration lanes and turn lanes are always eligible for selection as a random sample location; however, if a random sample locations falls on one of these areas and the area is designated on the plans as not subject to in-place density determination, density measurements will not be made for the sublot and a 1.000 pay factor will be assigned to that sublot.

Immediately after determining thickness and obtaining samples to perform laboratory moisture-density determinations, repair the disturbed area with additional base course and properly compact the material.

4.12.3.8 Placement Testing

The Contractor and Engineer must perform placement quality control/quality assurance tests in accordance with Table N-10. The Contractor has the option to verify the Engineer's test results on split samples. Determine compliance with operational tolerances listed in Table N-10 for all sublots and lots. The engineer may perform as many additional tests as deemed necessary.

4.12.3.8.1 In-place Density and Moisture Content

The Contractor and Engineer will measure in-place density and moisture content in accordance with one or more methods as described in Tex-115-E. In-place moisture content will be determined at the beginning and during compaction in accordance with Tex-115-E.

4.12.3.8.2 Thickness

The Contractor and Engineer will measure the layer thickness in accordance with Tex-140-E.

4.12.3.8.3 Moisture Content and Dry Density of Laboratory Compacted Material

The Contractor and Engineer will determine a single point, laboratory compacted moisture content and dry density in accordance with Tex-113-E.

4.12.3.9 Operational Tolerances

Control the placement within the operational tolerance listed in Table N-10. When placement is suspended, the Engineer will allow production to resume when test results or other information indicates that the next materials to be placed will be within the operational tolerances.

4.12.3.9.1 In-Placed Density and Moisture Content

A sublot is defined as out of tolerance if either the Engineer's or Contractor's in-place dry density or in-place moisture content determinations are out of the specification limits shown on Table N-10. Unless otherwise directed, suspend production when test results for in-place density or moisture content exceed the operational tolerances for 2 consecutive measurements for either "in-place density" or "moisture content" or 3 consecutive lots for either parameter.

4.12.3.9.2 Thickness

A sublot is defined as out of tolerance if either the Engineer's or the Contractor's test results are out of the specification limits shown on Table N-10. Unless otherwise directed, suspend placement when test results for thickness exceed the operational tolerances for 2 consecutive measurements.

Correct areas deficient in thickness by more than ½ inch by scarifying, adding material as required, reshaping, re-compacting and refinishing at the Contractor's expense. Correct areas with excess thickness by more than 0.5 in. by scarifying, removing material as required, reshaping, re-compacting and refinishing at the Contractor's expense.

4.12.3.9.3 Dry Density and Moisture Content of Laboratory Compacted Material

A lot is defined as out of tolerance if either the Engineer's or the Contractor's test results are out of operational tolerance as shown under "Allowable Difference from Current JMF Target" on Table N-10. Unless otherwise directed, suspend placement when test results exceed the operational tolerances for 2 consecutive lots for either "maximum dry density" or "optimum moisture content" or 3 consecutive lots for either parameter.

4.12.3.10 Irregularities

Identify and correct irregularities including but not limited to segregation, depressions, bumps, irregular texture, roller marks, tears, gouges, streaks, color etc. The Engineer may also identify irregularities, and in such cases, the Engineer will promptly notify the Contractor. If the Engineer determines that the irregularity will adversely affect pavement performance, the Engineer may require the Contractor to rework or remove and replace the area. If irregularities are detected, the Engineer may require the Contractor to immediately suspend operations or may allow the Contractor to continue operations for no more than 1 day while the Contractor is taking appropriate corrective action.

4.12.3.11 Smoothness

Smoothness requirements are provided in Section 4.10 "Finishing." Grade deviations should not be greater than ¼ in. in 16 ft. measured longitudinal or greater than ¼ in. over the entire width of the cross section.

5.0 Measurement

Flexible base will be measured as follows:

-Flexible Base (Complete in-place)-ton, square yard or any cubic yard method
-Flexible Base (Roadway Delivery)-ton or cubic yard in vehicle
-Flexible Base (Stockpile Delivery)-ton, cubic yard in vehicle or cubic yard in stockpile

Measurement by the cubic yard in final position and square yard is a plans quantity measurement. The quantity to be paid for is the quantity shown in the proposal unless modified by Article 9.2, “Plans Quantity Measurement.” Additional measurements or calculations will be made if adjustments of quantities are required.

Measurement is further defined for payment as follows.

5.1 Cubic Yard in Vehicle

By the cubic yard in vehicles of uniform capacity at the point of delivery

5.2 Cubic Yard in Stockpile

By cubic yard in the final stockpile position by the method of average end areas

5.3 Cubic Yard in Final Position

By the cubic yard in the completed and accepted final position. The volume of base course is computed in place by the method of average end areas between the original subgrade or existing base surfaces and the lanes, grades and slopes of the accepted base course as shown on the plans.

5.4 Square Yard

By the square yard of surface area in the completed and accepted final position. The surface area of the base course is based on the width and length of flexible base as shown on the plans.

5.5 Ton

By the ton of dry weight in vehicles as delivered. The dry weight is determined by deducting the weight of the moisture in the material at the time of weighing from the gross weight of the material. The Engineer will determine the moisture content in the materials in accordance with Tex-103-E from samples taken at the time of weighing.

When material is measured in trucks, the weight of the material will be determined on certified scales or the Contractor must provide a set of standard platform truck scales at a location approved by the Engineer. Scales must conform to the requirements of Item 520, “Weighing and Measuring Equipment.”

6.0 Payment

The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid for at the unit price bid for the types of work shown below. No additional payment will be made for thickness or width exceeding that shown on the typical section or provided on the plans for cubic yard in the final position or square yard measurement.

Sprinkling and rolling, except proof rolling, will not be paid for directly but will be subsidiary to this Item unless otherwise shown on the plans. When proof rolling is shown on the plans or directed, it will be paid for in accordance with Item 216, "Proof Rolling."

Where subgrade is constructed under this Contract, correction of soft spots in the subgrade will be at the Contractor's expense. Where subgrade is not constructed under this project, correction of soft spots in the subgrade will be paid in accordance with pertinent Items or Article 4.2, "Changes in the Work."

6.1 Flexible Base (Complete in Place)

Payment will be made for the type and grade specified. For cubic yard measurement, "In Vehicles," "In Stockpile" or "In Final Position" will be specified. For square yard measurement, a depth will be specified. This price is full compensation for furnishing materials, temporary stockpiling, assistance provided in stockpile sampling and operation to level stockpiles for measurement, loading, hauling, delivery of materials, spreading, blading, mixing, shaping, placing, compacting, reworking, finishing, correcting locations where thickness is deficient, curing, furnishing scales and labor for weighing and measuring and equipment, labor, tools and incidentals.

6.2 Flexible Base (Roadway Delivery)

Payment will be made for the type and grade specified. For cubic yard measurement, "In Vehicle" will be specified. The unit bid will not include processing at the roadway. This price is full compensation for furnishing materials, temporary stockpiling, assistance provided in stockpile sampling and operations to level stockpiles for measurement, loading, hauling, delivery of materials, furnishing scales and labor for weighing and measuring and equipment, labor, tools and incidentals.

6.3 Flexible Base (Stockpile Delivery)

Payment will be made for the type and grade specified. For cubic yard measurement, "In Vehicle" or "In Stockpile" will be specified. The unit price bid will not include processing at the roadway. This price is full compensation for furnishing and disposing of materials, preparing the stockpile area, temporary or permanent stockpiling, assistance provided in stockpile sampling and operations to level stockpiles for measurement, loading, hauling, delivery of materials to the stockpile, furnishing scales and labor for weighing and measuring and equipment, labor, tools and incidentals.

6.4 Pay Adjustments

Pay adjustments for bonuses and penalties will be applied as determined in this Item. Applicable pay adjustment bonuses will only be paid for sublots and lots when the Contractor supplies the Engineer with the required documentation for production and placement QC/QA test results in accordance with Section 4.2, "Reporting."

6.5 Production Pay Adjustment Factors

The production pay adjustment factor is based on the percent passing the No. X and No. Y sieves. A pay adjustment factor will be determined for each lot based on the Engineer's gradation test results. The Contractor test results must be verified by the Engineers test results. Verification of test results for a lot is based on the "Allowable Difference between the Contractor's and Engineer's test results being within the limits as shown on Table N-8 for the No. X and No. Y sieves. The Engineer can elect to test any lot at a frequency determined by the Engineer. The minimum test frequency for the Engineer is shown on Table N-9 as one test per 12 sublots or 1 test per 3 lots. The value representing a lot production as determined by the Engineer (single value or the average of several sublots) must be within the limits shown on Table N-8 when compared to the average value of the 4 sublot samples that represent the same lot as determined by the Contractor.

Note: The Engineer's frequency of testing for production pay adjustment factor has not been determined. The frequency is likely to be equivalent to that shown for the Contractor on Table N-9.

The Percent Within Limits (PWL) will be determined for the No. X and No. Y sieve on a Lot basis. PWL calculations will be performed according to the method contained in AASHTO R 42, pages 26 to 29 utilizing the specification limits shown on Table N-8.

The Production Pay Factor will be determined for the No. X and No. Y sieve according to the following formula

PF =0.50(PWL) + 55

where PF=pay factor for either the No. X and No. Y sieve

PWL=percent within limits for either the No. X and No. Y sieve

The Composite Production Pay Factor (CPPF1) will be determined according to the following formula

CPPF1=0.2 PF(No. X Sieve) + 0.8 PF(No. 200 Sieve)

where CPPF1=Composite Production Pay Factor

PF(No. X Sieve)=Pay Factor for No. X Sieve

PF(No. Y Sieve)=Pay Factor for No. Y Sieve

6.5.1 Payment for Incomplete Production Lots

Production pay adjustments for incomplete lots, described under Section 4.14.2.1.2, "Incomplete Production Lots," will be calculated using the information available for the sublots constructed. A production pay factor of 1.000 will be assigned to any lot when the random sampling plan did not result in the collection of 2 or more samples.

6.5.2 Production Sublots or Lots Subjected to Reworking or Removal and Replacement

If either the PWL for the No. X and No. Y sieve is below 70 percent, the Engineer may require reworking, removal and replacement or remain in place with reduced payment. Replacement material meeting the requirements of this Item will be paid for in accordance with this Article.

6.6 Placement Pay Adjustment Factors

The placement pay adjustment factor is based on the in-place density and in-place moisture content determined in accordance with Tex-115-E and thickness determination.

The pay adjustment factor for in-place density and moisture content will be determined for each lot based on the Engineer's test results. The Contractor test results must be verified by the Engineers test results. Verification of test results for a sublot is based on the "Allowable Difference between the Contractor's and Engineer's test results being within the limits as shown on Table N-8 for in-place density and in-place moisture content. The Engineer can elect to test any lot at a frequency determined by the Engineer. The minimum test frequency for the Engineer is shown on Table N-8 as one test per sublot. The value representing a sublot production as determined by the Engineer (single value or the average of several tests per sublot) must be within the limits shown on Table N-10 when compared to the average value of the 4 samples per sublot values that represent the same sublot as determined by the Contractor.

Note: The Engineer's frequency of testing for placement pay adjustment factor has not been determined. The frequency is likely to be equivalent to that shown for the Contractor on Table N-9.

The Percent Within Limit (PWL) will be determined for the in-place density and the in-place moisture content on a sublot basis. PWL calculations will be performed according to the method contained in AASHTO R 42, pages 26 to 29 utilizing the specification limits shown on Table N-8.

The Placement Pay Factor will be determined for the in-place density and in-place moisture content according to the following formula

$$PF=0.50(PWL) + 55$$

where PF=pay factor for either the in-place density or in-place moisture content
PWL=percent within limits for either the in-place density or in-place moisture content

The pay factor for thickness will be determined according to Table N-11.

The Composite Placement Pay Factor (CPPF2) will be determined according to the following formula

CPPF2=0.2PF (In-Place Moisture Content) + 0.50PF (In-Place Density) + 0.3PF (Thickness)

where CPPF2-Composite Placement Pay Factor
PF (In-Place Moisture Content)=Pay Factor for In-Place Moisture Content
PF (In-Place Density)=Pay Factor for In-Place Density
PF (Thickness)=Pay Factor for Thickness

6.6.1 Payment for Incomplete Placement Lots
Placement pay adjustments for incomplete lots, described under Section 4.14.3.1.2, "Incomplete Placement Lots," will be calculated using the information available for the sublots constructed. A production pay factor of 1.000 will be assigned to any sublot when the random sampling plan did not result in the collection of 2 or more samples.

6.6.2 Placement Lots Subjected to Removal and Replacement

If either the PWL for the in-place density or in-place moisture content is below 70 percent, the Engineer may require reworking, removal and replacement or remain in-place with reduced payment. Replacement materials meeting the requirements of this Item will be paid for in accordance with this Article.

6.7 Total Adjustment Pay Calculation
Total adjustment pay (TAP) will be based on the applicable pay adjustment factor for the project for production and placement for each lot. The pay adjustments will be separate for production and placement and will not be combined.

Table N-2. Material Requirements.

Property	Test Method	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Master gradation sieve size (cumulative % passing)						
2 ½ in	Tex-110-E	-	0	0	As shown on the plans	100
1 ¾ in		100	90-100	90-100		95-100
7/8 in		65-90	-	-		65-90
3/8 in		50-70	-	-		35-65
No. 4		35-55	25-55	25-55		25-50
No. 40		15-30	15-40	15-50		10-30
No. Y						
Liquid limit, % max[1]	Tex-104-E	35	40	40	As shown on the plans	35
Plastic index, max[1]	Tex-106-E	10	12	12	As shown on the plans	10
Plastic index, min[1]		As Shown on Plans				
Wet ball mill, max[2]	TEX-116-E	40	45	-	As shown on the plans	40
Wet ball mill, % max Increase passing the No. 40 sieve		20	20	-	As shown on the plans	20
Sulfate content, max ppm	Tex-145-E					
Min. compression strength, psi	Tex-117-E				As shown on the plans	
lateral pressure, 0 psi		45	35	-		-
lateral pressure, 3 psi		-	-	-		90
lateral pressure, 15 psi		175	175	-		175

[1] Determine plastic index in accordance with Tex-107-E (linear shrinkage) when liquid limit is unattainable as defined in Tex-104-E.

[2] When a soundness value is required by the plans, test material in accordance with Tex-411-A.

[3] When Classification is required by other plans, a triaxial Classification of 1.0 or less for Grades 1 and 2.3 or less for Grade 2 is required. The Classification requirement for Grade 4 will be as shown on the plans.

Table N-3. Requirements for Recycled Portland Cement Concrete (RPCC).

Property	Test Method	Requirement
Gradation Cumulative Percent Passing, Maximum 2 in	Tex-110-E	100
Deleterious Materials, Percent Maximum	Tex 413-A	1.5
Sulfate, ppm Maximum	Tex-145-E	3000

Table N-4. Requirements for Reclaimed Asphalt Pavement.

Property	Test Method	Requirement
Gradation Cumulative Percent Passing, Maximum 2 in	Tex-110-E	100
Decantation, Percent Maximum	Tex-406-A	5.0
Deleterious Materials, Percent Maximum	TEX-413-A	1.5

Table N-5. Test Methods, Test Responsibility, and Minimum Classification Levels.

Test Description	Test Method	Contractor	Engineer	Level
1. Aggregate and Recycle Material Testing				
Sampling	Tex-400-A	x	x	SB 101
Sample Preparation	Tex-101-E	x	x	SB 101
Liquid Limit	Tex-104-E	x	x	SB 101
Plastic Limit	Tex-105-E	x	x	SB 101
Calculate Plastic Index	Tex-106-E	x	x	SB 101
Linear Shrinkage	Tex-107-E	x	x	SB 101, 2
Sieve Analysis of Soils	Tex-110-E	x	x	SB 101
Wet Ball Mill	Tex-116-E	x	x	SB 101
Sulfate Content	Tex-145-E	x	x	SB 103
Dry Sieve	Tex-200-F, Part I	x	x	IA
Wet Sieve	Tex-200-F, Part II	x	x	IA
Decantation	Tex-406-A Tex-217-F, Part II	x	x	Not available 2
Sulfate Soundness	Tex-411-A	x	x	Not available
Deleterious Material	Tex-413-A Tex-217-F, Part I	x	x	Not available 2
Crushed Faces	Tex-460-A	x	x	2
2. Mix Design and Verification				
Moisture Content	Tex-103-E	x	x	SB 102
Moisture Content	Tex-115-E	x	x	SB 102
Moisture Density Relationships	Tex-113-E	x	x	SB 201
Triaxial Compression	Tex-117-E	x	x	SB 202

Test Description	Test Method	Contractor	Engineer	Level
3. Production Testing				
Sampling	Tex-100-E	x	x	SB 101
Sampling	Tex-400-A	x	x	SB 101
Sample Preparation	Tex-101-E	x	x	SB 101
Liquid Limit	Tex-104-E	x	x	SB 101
Plastic Limit	Tex-105-E	x	x	SB 101
Calculate Plastic Index	Tex-106-E	x	x	SB 101
Linear Shrinkage	Tex-107-E	x	x	SB 101
Sieve Analysis of Soils	Tex-110-E	x	x	SB 101
Wet Ball Mill	Tex-116-E	x	x	SB 101
Sulfate Content	Tex-145-E	x	x	SB 103
Dry Sieve	Tex-200-F, Part I	x	x	IA
Wet Sieve	Tex-200-F, Part II	x	x	IA
Decantation	Tex-406-A Tex-217-F, Part II	x	x	Not available 2
Sulfate Soundness	Tex-411-A	x	x	Not available
Deleterious Material	Tex-413-A Tex-217-F, Part I	x	x	Not available 2
Crushed Faces	Tex-460-A	x	x	2
Moisture Content	Tex-103-E	x	x	SB 102
Moisture Content	Tex-115-E	x	x	SB 102
Moisture Density Relationship	Tex-113-E	x	x	SB 201
Selecting Random Numbers	Tex-225-F, Part I	x	x	IA
Control Charts	Tex-233-F	x	x	IA
4. Placement Testing				
Moisture Content	Tex-103-E	x	x	SB 102
Moisture Density Relationship	Tex-113-E	x	x	

Test Description	Test Method	Contractor	Engineer	Level
Field In-Place Density	Tex-115-E	x	x	SB 102
Triaxial Compression	Tex-117-E	x	x	SB 202
Depth	Tex-140-E	x	x	SB 102
Selecting Random Numbers	Tex-225-F, Part II	x	x	IA
Control Charts	Tex-233-F	x	x	IA
5. Prime Coat				
Prime Coat Sampling	Tex-500-C, Part III	x	x	IA

Table N-6. Reporting Schedule.

Description	Reported by	Reported to	To Be Reported Within
Production Quality Control	Contractor	Engineer	1 working day of completion of the sublot or lot
Gradation, liquid limit, plastic index, wet ball mill, sulfate content, optimum moisture content, maximum dry density			
Production Quality Assurance	Engineer	Contractor	1 working day of completion of the sublot or lot
Gradation, liquid limit, plastic index, wet ball mill, sulfate content, optimum moisture content, maximum dry density			
Placement Quality Control	Contractor	Engineer	1 working day of completion of the sublot or lot
Optimum moisture content, maximum dry density, in-place density, in-place moisture content, thickness			
Placement Quality Assurance	Engineer	Contractor	1 working day of completion of the sublot or lot
Optimum moisture content, maximum dry density, in-place density, in-place moisture content, thickness			
Pay Adjustment Minus No. 4, Minus No. 200, in-place moisture content, in-place density	Engineer	Contractor	2 working days of performing all required tests and receiving contractors test data

Table N-7. Minimum Production and Placement Sampling and Testing Requirements.

Property	Test Method	Process Control [1]	Quality Control [2]	Quality Assurance [3]	Pay Adjustment [4]
Gradation Accumulative Percent Passing					
2 ½ in	Tex-110-E, Part II		1 per sublot	1 per 12 sublots	
1 ¾ in					
7/8 in					
3/8 in					
No. X					4 per lot
No. 40					
No. Y					4 per lot
Liquid Limit, % Max[1]	Tex-104-E		1 per lot	1 per 3 lots	
Plastic Index, Max[1]	Tex-105-E Tex-106-E		1 per lot	1 per 3 lots	
Plastic Index, Min[1]					
Wet Ball Mill, Max[2]	Tex-116-E	Determined by Contractor	1 per lot	1 per 3 lots	
Wet Ball Mill, % Max Increase Passing the No. 40 Sieve					
Sulfate Content, ppm[3]	Tex-145-E		1 per lot	1 per 3 lots	
Min. Compression Strength[3], psi Lateral Pressure, 0 psi Lateral Pressure, 3 psi Lateral Pressure, 15 psi	Tex-117-E		1 per lot	1 per 3 lots	
Optimum Moisture Content, %	Tex-113-E		1 per lot	1 per 3 lots	
Max Dry Density, lbs per cu. ft.					
In-place Density, % In-place Moisture Content, %	Tex-115-E		4 per sublot	1 per sublot	16 per lot 16 per lot
Thickness	Tex-140-E		1 per sublot	1 per lot	

[1] Determined by Contractor
[2] Performed by Contractor
[3] Performed by Engineer
[4] Performed by Engineer

Table N-8. Allowable Material Property (Production) Differences and Specification Limits.

Property	Test Method		Allowable Difference from Current JMR Target	Allowable Difference between Contractor and Engineer Test Results	Specification Limits for Pay Factor Determination
Gradation Accumulative Percent Passing					
2 ½ in	Tex-110-E				
1 ¾ in			5	5	
7/8 in			5	5	
3/8 in			5	5	
No. 4			5	5	Plus or minus 5
No. 40			3	3	
No. Y					Plus or minus
Liquid Limit	Tex-104-E		5	5	
Plastic Index	Tex-105-E Tex-106-E		4	4	
Wet Ball Mill, Max	Tex-116-E		5	5	
Wet Ball Mill, % Increase Passing the No. 40 Sieve Percentage Points			4	4	
Sulfate Content, ppm	Tex-145-E				
Min. Compression Strength, psi	Tex-117-E				
Lateral Pressure, 0 psi Lateral Pressure, 3 psi			10 15	8 12	
Lateral Pressure, 15 psi			20	15	
Optimum Moisture Content, %	Tex-113-E		0.3	0.3	
Max Dry Density, lbs per cu. ft.			1.0	1.0	

Table N-9. Production Testing Frequency.

Property	Test Method	Minimum Contractor Testing Frequency (Quality Control)	Minimum Engineer Testing Frequency (Quality Assurance)
Gradation			
2 ½ in	Tex-110-E	1 per sublot	1 per 12 sublots
1 ¾ in			
7/8 in			
3/8 in			
No. 4			
No. 40			
No. 200			
Liquid Limit	Tex-104-E	1 per lot	1 per 3 lots
Plastic Index	Tex-105-E Tex-106-E	1 per lot	1 per 3 lots
Wet Ball Mill	TEex116-E	1 per lot	1 per 3 lots
Sulfate Content, ppm	Tex-145-E	1 per lot	1 per 3 lots
Min. Compression Strength[3], psi Lateral Pressure, 0 psi Lateral Pressure, 3 psi Lateral Pressure, 15 psi	Tex-117-E	1 per lot	1 per 3 lots
Optimum Moisture Contend Maximum Dry Density	Te-113-E	1 per lot	1 per lot

Table N-10. Placement Testing Frequency, Allowable Differences, and Specification Limits.

Property	Test Method	Minimal Contractor Testing Frequency	Minimal Engineer Testing Frequency	Allowable Difference from Current JMF Target	Allowable Difference between Contractor and Engineer	Specification Limits
Optimum Moisture Content, %	Tex-113-E	1 per lot	1 per 3 lots	0.3 (percentage points)	0.3 (percentage points)	
Maximum Dry Density, lbs per cu. ft				1.0	1.0	
In-place Density, % [1]	Tex-115-E	4 per sublot	1 per sublot		2.0 (percentage points)	100
In-place Moisture Content, % [1]					0.5 (percentage points)	± 1.5
Thickness, in.	Tex-140-E	1 per sublot	1 per sublot		0.5	– 0.5 + 0.5

[1] Relative to max dry density and optimum moisture content as determined according to Tex-113-E

Table N-11. Pay Adjustment Factor for Thickness.

Deviation from Thickness Shown on Plans, inches	Pay Adjustment Factor
+ 1.5	0.70
+ 1.0	0.95
+ 05	1.00
0.0	1.00
-.05	1.00
- 1.0	0.80
- 1.5	0.70

Note: Consider using Table N-2 pg 185 of Item 276, Cement Treated (Plant-mixed) Base