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Development of a new test procedure to evaluate the moisture susceptibility of hot mix asphalt

by

Jason Paul Bausano

A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Civil Engineering (Civil Engineering Materials)

Program of Study Committee:
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Iowa State University
Ames, Iowa
2006

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LIST OF ACRONYMS

A	Witczak Predictive Equation Regression Intercept
AAPT	Association of Asphalt Paving Technologists
AASHTO	American Association of State and Highway Transportation Officials
AMS	Accumulated Microstrain at Minimum Slope
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
BSG (G_{mb})	Bulk Specific Gravity
COV	Coefficient of Variation
CTAA	Canadian Technical Asphalt Association
D60	Grain size that corresponds to 60 percent passing
E* and $\|E^*\|$	Complex Modulus and Dynamic Modulus, respectively
E' and E"	Elastic and Viscous Modulus, respectively
ESAL	Equivalent Single Axle Load
FAA	Fine Aggregate Angularity
FHWA	Federal Highway Administration
F_N	Flow Number
G_b	Asphalt Specific Gravity
GLM	General Linear Model
G_{sb}	Aggregate Bulk Specific Gravity
G_{se}	Aggregate Effective Specific Gravity
HRB	Highway Research Board
HMA	Hot Mix Asphalt
IDT	Indirect Tension Test
JMF	Job Mix Formula
LVDT	Linear Variable Differential Transducer
M-E	Mechanistic-Empirical
MTSG (G_{mm})	Maximum Theoretical Specific Gravity
MTU	Michigan Technological University
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NMAS	Nominal Maximum Aggregate Size
P_b	Asphalt Binder Content
P_{eff}	Effective Asphalt Binder Content
R^2	Coefficient of Determination
RAP	Recycled Asphalt Pavement
RTFO	Rolling Thin Film Oven
SGC	Superpave Gyratory Compactor
SHRP	Strategic Highway Research Program
SSD	Saturated Surface Dry
SPT	Simple Performance Test
SST	Superpave Shear Tester

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TAI	The Asphalt Institute
TSR	Tensile Strength Ratio
UTM	Universal Testing Machine
VTS	Witczak Predictive Equation Regression Slope
VFA	Voids Filled with Asphalt
VMA	Voids in the Mineral Aggregate
ε_o	Strain
ϕ	Phase Angle
σ_o	Stress

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ACKNOWLEDGEMENTS

I would first like to thank all of my family and friends who have supported throughout this journey in my life, especially my wife Mary, my children, along with my parents, brothers and sister.

I would also like to thank my advisor, mentor, and friend, Dr. R. Christopher Williams for his help and guidance throughout this project and many other projects. He always looked out for my best interest, even though I may not have known that at the time.

I would also like to extend thanks out to Vern Schaefer, Charles Jahren, Stephen Vardeman, Kejin Wang, and Stanley Vitton for serving on my graduate committee and providing insightful guidance.

I would also like to thank Brett Williams, James Vivian III, and Ed Tulppo for sampling the hot mix asphalt during the 2004 and 2005 construction seasons.

I would also like to thank Michelle Colling and the late Danielle Ladwig for their hard work and long hours in compacting and preparing specimens for testing.

Finally, I would like to thank Andrea Kvasnak for her knowledge of asphalt materials and statistics that helped me with my education.

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ABSTRACT

Moisture damage in hot mix asphalt (HMA) pavements has been extensively documented since the late 1970's. The current test method for detecting moisture susceptibility in HMA is American Association of State Highway and Transportation Officials (AASHTO) T283. Inclusion of this test method in Superpave did not consider the change in specimen diameter size from 100mm to 150mm nor corresponding heights, method of compaction, nor is AASHTO T283 a performance test to accompany the mix design procedure.

A new test procedure to evaluate the moisture susceptibility of HMA was developed in this dissertation. In addition, two sensitivity studies were undertaken: 1) Using AASHTO T283 to consider the number of freeze-thaw cycles, diameter size, and compaction method and 2) Evaluation of test temperature, conditioning, and dynamic modulus and flow number tests. This dissertation develops a moisture susceptibility procedure which utilizes the dynamic loading of saturated and unconditioned sets of specimens and compares the two sets of specimens. The Witzcak model is also analyzed to see how well the model predicts dynamic modulus on conditioned and unconditioned specimens. The major findings of this research are:

- Three freeze-thaw cycles for conditioning is satisfactory when using Superpave compacted specimens.
- To maintain the same probability level as attained with a TSR value for 80% for 100mm diameter Marshall compacted specimens, a TSR value of 87 and 85% should be used with 150mm and 100mm diameter Superpave compacted specimens, respectively.

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- It was determined that the effective test temperature for rutting would be used for dynamic modulus testing of moisture conditioned specimens and would follow the conditioning procedure outlined in AASHTO T283.
- The new test procedure uses a retained dynamic modulus of 60% of conditioned specimens to unconditioned specimens for all frequencies.
- A statistical analysis was performed: gradation, NMAS, traffic, polymer modification, aggregate type, permeability, asphalt content, FAA, RAP, and frequency for dynamic modulus testing. The factors affecting AASHTO T283 are polymer modification, aggregate type, permeability, and RAP. The factors affecting dynamic modulus are mix type, polymer modification, aggregate type, permeability, RAP, and frequency.
- Local calibration is needed for the Witczak model.

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CHAPTER 1 INTRODUCTION

1.1 Moisture Susceptibility

Moisture damage has been the cause of many hot mix asphalt (HMA) pavement failures which results in a decreased life of our nations roadways throughout the United States. Since the 1970's researchers have been trying to define the causes of moisture damage and why it happens. Moisture damage has been a national issue before Lottman (1978) developed a test for moisture damage, to the current state of the practice with NCHRP 9-34 (2002) which is considering the use of the simple performance test with moisture conditioning. A number of factors exist that are detrimental to HMA. Some factors are environmental conditions (e.g. moisture, temperature), drainage and the condition of the drainage system, pavement structure, mix design, construction variability, and traffic. Moisture damage is a major factor that impacts HMA; which includes the binder and the mixture component. Thus, there is a need for highway agencies to understand asphalt moisture susceptibility, in order to first solve this problem, we must first know: What is moisture susceptibility? When does it occur? How does it occur? Why is it important? and How can we fix it?

Moisture susceptibility is the loss of strength in HMA mixtures due to the effects of moisture. In HMA there are three components: aggregates, asphalt binder, and air voids. Moisture damage in HMA can occur in two ways: loss of adhesion between asphalt binder and aggregate, or the weakening of the asphalt mastic (asphalt binder plus fines (P200 material)) in the presence of moisture. Thus, selection of the appropriate aggregates (aggregate chemistry) and asphalt binder (binder chemistry) play an important role in moisture damage. Moisture damage can occur from a loss of adhesion between the

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aggregates and binder due to the chemistry of the aggregates. Siliceous aggregate sources are prone to stripping due to a high silica dioxide component. Stripping is the weakening or eventual loss of the adhesive bond between the aggregate surface and asphalt binder in the HMA mixture due to the presence of moisture (Roberts et al. 1996). The asphalt binder is hydrophilic with weaker bonds existing between the aggregate and binder, thus when moisture is present and the HMA is loaded repeatedly, the asphalt binder strips from the aggregate resulting in a loss of adhesion. Moisture damage is important because it diminishes the performance and service life of the HMA pavements resulting in increased maintenance and rehabilitation costs. It is anticipated that moisture susceptibility can be identified by developing tests to determine the effects of moisture damage on the HMA mixture.

1.2 Dissertation Objectives

The objectives of this dissertation are threefold. First, determine the number of freeze-thaw cycles in Superpave compacted specimens to induce moisture damage. Secondly, perform a sensitivity study to evaluate the simple performance test using moisture conditioned and unconditioned specimens. Thirdly, evaluate the new simple performance test using dynamic modulus and compare it to the current method which is AASHTO T283 and develop a criteria for the new method. Also, the evaluation of the Witczak model using the results of the dynamic modulus test and its impact on the pavement design guide will be evaluated.

1.3 Current State of the Practice for Moisture Testing

The current method for evaluating the moisture susceptibility of compacted bituminous mixtures is AASHTO T283 (1993), which is based on the Marshall mix design

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method (Roberts et al. 1996). To date current research is being conducted by highway agencies to evaluate the moisture susceptibility of their Superave mixtures based on AASHTO T283. The Superpave volumetric mix design procedure, however does not include a simple, mechanical test that is analogous to the Marshall stability and flow test criteria. Instead, the Superpave mix design systems relies on material specifications and volumetric criteria in order to ensure a quality performing mix design. Further inclusion of AASHTO T283 in Superpave did not consider the change in specimen diameter size from 100mm to 150mm. This change in specimen diameter then resulted in the initiation of NCHRP 9-13 in 1996 (Epps et al 2000). This research concluded that either AASHTO T283 does not evaluate moisture susceptibility or the criteria, using the tensile strength ratio is incorrectly specified. The research conducted in NCHRP Report 444 examined mixtures that have historically been moisture susceptible and ones that have not. The researchers also examined the current criteria using Marshall and Hveem compaction.

The procedures in AASHTO T283 and NCHRP Report 444 consider the loss of strength due to freeze/thaw cycling and the effects of moisture existing in specimens compared to unconditioned specimens (Epps et al. 2000). However, mixtures do not experience such a pure phenomenon. Pavements undergo cycling of environmental conditions, but when moisture is present, there is repeated hydraulic loading with development of pore pressure in mixtures. Thus, AASHTO T283 and NCHRP Report 444 do not consider the effect of pore pressure, but rather consider a single load effect on environmentally conditioned specimens.

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1.4 Overall Dissertation Experimental Plan

A sensitivity study is outlined here. The plan considered different mix types, aggregate sources, laboratory test systems, and conditioning approaches. The sensitivity study experimental plan included two integrated plans: one for the mixes and one for the planned laboratory tests. A sensitivity study on the effects of specimen size and compaction method was accomplished on a selected number of mixes to determine the amount of conditioning that should be done on larger Superpave compacted specimens. Table 1.1 below outlines the sensitivity experimental plan. Table 1.2 outlines the laboratory test plan executed for the sensitivity study. As previously mentioned, this plan partially duplicates the work done and reported in NCHRP 444 with the use of Michigan aggregate sources (Epps et al. 2000).

Table 1.1 Sensitivity Study Experimental Plan for Mix and Aggregate Types

		Traffic Level Equivalent Single Axle Loads (ESAL)	
	NMAS (mm)	<3,000,000	>3,000,000
Mix Size	25.0 or 19.0	Limestone Gravel	Limestone
Mix Size	12.5 or 9.5	Limestone Gravel	Limestone Slag/Gabbro

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Table 1.2 Sensitivity Study Experimental Plan for Effect of Compaction Method and Conditioning Period on Performance

Conditioning Period	Unconditioned			Conditioned		
	100 mm Marshall	100 mm Superpave	150 mm Superpave	100 mm Marshall	100 mm Superpave	150 mm Superpave
AASHTO T283, Standard Conditioning Time	XXXXX[1]	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
AASHTO T283, 2 Times Standard Conditioning Time	N/A[2]	N/A	N/A	XXXXX	XXXXX	XXXXX
AASHTO T283, 3 Times Standard Conditioning Time	N/A	N/A	N/A	XXXXX	XXXXX	XXXXX

[1]X Represents a tested sample;
[2]N/A is not applicable.

Superpave designed mixes were used in the study, but the method of compaction to achieve 7.0% air voids varied. It was also necessary to determine the conditioning time necessary to produce the same tensile strength ratios in larger specimens undergoing Superpave compaction compared with 100mm Marshall compacted specimens. The final expanded experimental plan is outlined in Table 1.3. Seven of the HMA mixes identified in Table 1.3 were used for the sensitivity study. The laboratory experimental plan conducted is outlined in Table 1.4 below.

Table 1.3 Expanded Experimental Plan

	NMAS (mm)	Traffic Level ESAL's	
		<3,000,000	>3,000,000
Mix Type	25 & 19	XXXXX	XXXXX
	12.5 & 9.5	XXXXX	XXXXX
	SMA	N/A	X

Table 1.4 Laboratory Experimental Plan

		Unconditioned	Conditioned
Test System	AASHTO T283	XXXXX	XXXXX
	Dynamic Complex Modulus Test	XXX	XXX

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Before the expanded experimental plan was undertaken, a sensitivity study using the simple performance test was accomplished that looked at additional factors such as test temperature and conditioning. The test temperatures for intermediate and high dynamic modulus and flow number are stipulated by an effective test temperature (T_{eff}) in NCHRP Report 465 (Witczak et al. 2002). Four conditioning cycles were considered: Control group, vacuum saturation plus freeze-thaw cycling, vacuum saturation only, vacuum saturation plus freeze-thaw cycling with flow number testing submerged under water.

1.5 Hypotheses for Testing Results

Hypotheses were formulated regarding the factors considered in the experimental plan based upon past research and testing from the literature review. The following hypotheses were analyzed:

- What number of freeze-thaw cycles should be used with 150mm diameter SGC specimens compared to 100mm diameter Marshall specimens?
- Does the dynamic complex modulus (E*) decrease due to conducting a flow number test after the initial E* testing?
- What are the effects of test temperature on conditioned and unconditioned specimens using the simple performance test?
- Which test procedure better simulates moisture damage: AASHTO T283 or the simple performance test?
- Do the HMA mixtures rank the same in terms of moisture damage when tested with both procedures?
- Does the dynamic complex modulus induce hydraulic loading?

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- Does the dynamic complex modulus using the conditioned procedures outlined in AASHTO T283 induce moisture damage in HMA mixtures?

1.6 Contents of this Document

Chapter 2 of this dissertation discusses past research and studies that have been related to moisture damage or moisture susceptibility and testing that is related to the new Superpave simple performance test (SPT). Included is a brief description of the research conducted along with the major findings of the study that directly apply to this research. Chapters 3 and 4 outline the experimental plan and the procedures used to sample, prepare, and test the specimens for the dissertation. Chapter 5 reviews the mixtures that were used and the specimen preparation in terms of volumetric properties in relation to the job mix formula (JMF). Chapter 6 outlines the testing setup for AASHTO T283, dynamic complex modulus and dynamic creep testing in addition to predicting dynamic complex modulus. Chapter 7 presents the results of the sensitivity study using AASHTO T283. Chapter 8 presents the results of the sensitivity study using the SPT. Chapter 9 presents the evaluation of all the mixes used in the experimental plan and analyzes the results that were tested using AASHTO T283 versus the SPT. Included in this chapter is the evaluation of the hypotheses that were formulated in Chapter 1. Chapter 10 presents the summary, conclusion, and recommendations for further research of the dissertation.

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CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

The damage of Hot Mix Asphalt (HMA) due to moisture is of significant concern to transportation agencies and researchers. It is of primary interest in northern states due to freeze/thaw action during the spring months, but it can be a problem wherever there is the significant amount of annual moisture. Currently there are many tests (Tables 2.1 and 2.2) available to test HMA or binder to determine if it is a mix problem, a binder problem, or both are moisture susceptible. However, the standard test method that highway agencies use is AASHTO T283 or ASTM D4867. Many of these tests have produced mixed results and a more mechanistic test is being sought that considers the micro-mechanical behavior and/or chemical behavior of moisture damage. A lot of time and resources have been spent on trying to validate these tests and to determine how well the results relate to the field performance of HMA.

2.2 Causes of Moisture Damage

According to Little and Jones (2003) moisture damage is defined as the loss of strength and durability in asphalt mixtures due to the effects of moisture. Moisture can damage the HMA in the following two ways: 1) loss of bond between the asphalt cement or mastic and the fine and coarse aggregate and 2) weakening of the mastic due to the presence of moisture. Six contributing factors have been attributed to causing moisture damage in HMA: detachment, displacement, spontaneous emulsification, pore-pressure induced damage, hydraulic scour, and environmental effects (Roberts et al. 1996, Little and Jones 2003). None of the above factors necessarily works alone in damaging an HMA pavement, as they can work in a combination of processes. Therefore, there is a need to look at the

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adhesive interface between the aggregate and asphalt and the cohesive strength and durability of the mastic (Graff 1986, Roberts et al. 1996, Little and Jones 2003, Cheng et al. 2003). A loss of the adhesive bond between the aggregate and asphalt can lead to stripping and raveling while a loss of cohesion can lead to a weakened pavement that is susceptible to premature cracking and pore pressure damage (Majidzadeh and Brovold 1966, Kandhal 1994, Birgission et al. 2003). The following sections explain the six types of damage that can cause HMA strength and durability loss.

2.2.1 Detachment

Majidzah and Brovold (1968) describe detachment as the separation of an asphalt film from an aggregate surface by a thin film of water without an obvious break in the asphalt film on the aggregate. Adhesive bond energy theory explains the rationale behind detachment. In order for detachment not to happen, a good bond must develop between the asphalt and aggregate; this is known as wettability (Scott 1978). As the free surface energy of adhesion or surface tension decreases the bond between the aggregate and asphalt increases. Consider a three phase system of aggregate, asphalt, and water. The water reduces the surface energy of the system since the aggregate surface has a stronger preference for water than asphalt because the asphalt is hydrophilic (Majidzadeh and Brovold 1968). Cheng et al. (2002) calculated the adhesive bond strengths by measuring the surface energies of the components, the asphalt-aggregate interface, in the presence of water and when under dry conditions.

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2.2.2 Displacement

Displacement differs from detachment in that it involves the displacement of asphalt at the aggregate surface through a break in the asphalt film where water can intrude and displace the asphalt from the aggregate (Fromm 1974, Tarrer and Wagh 1991). The break in the asphalt film can come from an incomplete coating of the aggregate particle, inadequate coating at sharp edges of the aggregate, or pinholes in the asphalt film. Chemical reaction theory can be used to explain stripping as a detachment mechanism according to Scott (1978). Stripping is a phenomena where the asphalt binder is removed (displaced) from the aggregate surface resulting in a compacted mixture to turn into a loose HMA mixture. The pH of the water at the point of the film rupture can increase the process of displacement thereby increasing the separation of the asphalt from the aggregate (Scott 1978, Tarrer and Wagh 1991, Little and Jones 2003).

2.2.3 Spontaneous Emulsification

Spontaneous emulsification is an inverted emulsion of water droplets in the asphalt cement (Little and Jones 2003). The water diffuses into the asphalt cement thereby attaching itself to the aggregate causing a separation between the asphalt and aggregate. A loss of adhesive bond occurs between the asphalt and aggregate. Clays and asphalt additives can further aggravate the emulsification process (Scott 1978, Fromm 1974, The Asphalt Institute 1981).

2.2.4 Pore Pressure

Pore pressure can develop in an HMA pavement due to entrapped water or water that traveled into the air voids system in vapor form (Kandhal 1994, Little and Jones 2003). The

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pore pressure in the HMA pavement can increase due to repeated traffic loading and/or increases in temperature. If an HMA pavement is permeable, then water can escape and flow out. However if it is impermeable or partially permeable, the resulting increased pore pressure may surpass the tensile strength of the HMA, and strip the asphalt film from the aggregate, causing microcracking (Majidzadeh and Brovold 1968, Little and Jones 2003). Microcracking from pore pressure can also be seen in the mastic under repeated loading thus resulting in an adhesive and/or cohesive failure (Little and Jones 2003). The rate of microcracking is accelerated by the increase in pore pressure and the presence of water in HMA due to the weakening of the mastic and the adhesive bond between the asphalt binder and aggregate. The air void system or permeability of the pavement is an important property in order to control pore pressure in an HMA pavement.

2.2.5 Hydraulic Scour

Hydraulic scour (stripping) occurs at the pavement surface and is a result of repeated traffic tires on a saturated pavement surface. Stripping is the weakening or eventual loss of the adhesive bond between the aggregate surface and asphalt binder in the HMA mixture due to the presence of moisture (Roberts et al. 1996). Water is pushed into the pavement by the tire rolling action (Little and Jones 2003). Hydraulic scour may occur due to osmosis or pullback (Fromm 1974). Osmosis is the movement of water molecules from an area of high concentration to an area of low concentration. In the case of HMA, osmosis occurs in the presence of salts or salt solutions in aggregate pores. The movement of these molecules creates a pressure gradient that pulls water through the asphalt film (Mack 1964, Little and Jones 2003). Cheng et al. (2002) show that there is a considerable amount of water that

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diffuses through the asphalt cement and asphalt mastics can hold a significant amount of water.

2.2.6 Environmental Effects

Factors such as temperature, air, and water have deleterious effects on the durability of HMA (Terrel and Shute 1989, Tandon et al. 1998). Other mechanisms such as high water tables, freeze-thaw cycles, and aging of the binder or HMA can affect the durability of HMA (Scherocman et al. 1986, Terrel and Al-Swailmi 1993, Choubane et al. 2000). Other considerations such as construction (segregation and raveling) and traffic are also important. All of those factors listed above work individually or collectively weakening the bond at the asphalt-aggregate interface or the mastic thus resulting in moisture damage which leads to other distresses such as rutting and cracking.

2.3 Adhesion Theories

Chemical reaction, surface energy, molecular orientation, and mechanical adhesion are theories used to describe the adhesion characteristics between asphalt and aggregates (Hicks 1991, Terrel and Al-Swailmi 1993). The above four theories are affected by the following aggregate and asphalt properties: surface tension of the asphalt cement and aggregate, chemical composition of the asphalt and aggregate, asphalt viscosity, surface texture of the aggregate, aggregate porosity, aggregate clay/silt content, aggregate moisture content, and temperature at the time of mixing with asphalt cement and aggregate (Terrel and Al-Swailmi 1993). The following sections describe the four types of adhesion theories and how they relate to moisture susceptibility of HMA.

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2.3.1 Chemical Reaction

The reaction of acidic and basic components of asphalt and aggregate form water insoluble compounds that resist stripping (Terrel and Al-Swailmi 1993). Using aggregates that are basic instead of acidic can lead to better adhesion of asphalt to the aggregate (Terrel and Al-Swailmi 1993). Thelen (1958) proposed that stripping in asphalt-aggregate mixtures can be reduced by a bond form by chemical sorption.

Chemical reaction is important because it allows for the use of hydrated lime or anti-stripping agents in the asphalt binder to be used in order to improve the moisture susceptibility of the aggregates or asphalt binder. Chemical reactions occur between the asphalt binder and aggregate.

Robertson (2000) states that the overall polarity within the organic molecules of the asphalt binder and aggregate promote attraction of polar asphalt components to the polar aggregate. The components of both form nonuniform charge distributions and behave as if they have they have charges that attract the opposite charge of the other material. Curtis et al. (1992) has shown that this charge distribution is affect by the environment. Robertson (2000) goes on to explain that at the molecular level reactions are going on between the polar aggregate surface and asphalt cement. At a molecular level, basic nitrogen compounds adhere to the aggregate surface while the carboxylic acids and monovalent cation salts in the asphalt cement can easily be removed from the aggregate surface because they are essentially surfactants which can be debonded under the action of traffic in the presence of water. The addition of hydrated lime which contains doubly charged salts of acids is much more resistant to the action of water (Plancher et al. 1977, Scott 1978, and Petersen et al. 1987).

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2.3.2 Surface Energy and Molecular Orientation

Surface energy can be described by how well asphalt or water attaches to aggregate particles (Terrel and Al-Swailmi 1993). Water is a better wetting agent because of its lower viscosity and lower surface tension than asphalt (Little and Jones 2003). Using surface energy theory to calculate the adhesive bond energy between asphalt and aggregate and the cohesive strength of the mastic is rather complex and will be discussed further under the Tests on Loose Mixtures in Section 2.5.1.

The structuring of asphalt molecules at the asphalt-aggregate interface is molecular orientation. The adhesion between the asphalt and aggregate is facilitated by a surface energy reduction at the aggregate surface where asphalt is adsorbed onto the surface (Terrel and Al-Swailmi 1993, Little and Jones 2003).

2.3.3 Mechanical Adhesion

Mechanical adhesion is a function of various aggregate physical properties such as surface texture, porosity, absorption, surface coatings, surface area, and particle size (Terrel and Al-Swailmi 1993, Little and Jones 2003). Past research has shown that acidic aggregates are hydrophobic while basic aggregates are hydrophilic, however there could be some exceptions to this rule of thumb. In short, one prefers an aggregate surface capable of maximizing the surface area and texture to support a strong physical bond that will improve the chemical bond between the aggregate and asphalt cement, even in the presence of water (Petersen et al. 1982, Little and Jones 2003).

The surface area of an aggregate affects its ability to be properly coated by the asphalt cement and a good coating is essential in order to prevent stripping (Maupin 1982). Surface

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energy measurements between granite and asphalt and between limestone and asphalt have shown that the surface energy was the highest per unit of surface area for granite and asphalt binder (Cheng et al. 2002). In addition to surface area, aggregate angularity plays a role in moisture susceptibility. It has been found that more angular aggregates may be prone to moisture susceptibility due to a bond rupture of the binder or mastic leaving a point of intrusion for moisture (Gzemski et al. 1968). Cheng et al. (2002) has shown that the bond between asphalt and aggregate is stronger than the bond between asphalt and aggregate.

The effects of crushed aggregate faces also play a role in moisture susceptibility. Tarrer and Wagh (1991) have found that newly crushed aggregate faces have a tendency to strip faster than stockpiled aggregates. This is because layers of water molecules on the aggregate surface have become strongly absorbed onto the aggregate surface as a result of electrochemical reactions. Over time, the water is replaced with organic contaminants present in the air (e.g. fatty acids and oils) that help reduce stripping (Thelen 1958).

Tarrer and Wagh (1991) state that the asphalt-aggregate bond can be improved by three processes: preheating the aggregate, weathering the aggregate, and removing aggregate coatings. Heating the aggregate drives water off of the surface improving the interfacial tension between the asphalt and aggregate thus improving the bond between the asphalt and aggregate surface. The weathering process replaces the water molecules with absorbed organic fatty acids from the air which again results in an improved asphalt aggregate bond (Fromm 1974). The dust coating increases stripping potential by decreasing the contact between the asphalt and aggregate.

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2.4 Cohesion Theories

According to Little and Jones (2003), cohesion is developed in the mastic and it is influenced by the rheology of the filled binder. The cohesive strength of a mastic is a function of the interaction between the asphalt cement and the mineral filler, not just of the individual components alone. The cohesive strength of a mastic is weakened due to the presence of water through increased saturation and void swelling or expansion (Terrel and Al-Swailmi 1993, Little and Jones 2003). Cheng et al. (2002) showed that the cohesive strength can be damaged in various mixtures by the diffusion of water into asphalt mastics.

2.5 Tests for Determining Moisture Susceptibility

Moisture damage has been a concern to highway agencies and asphalt researchers for many years. While a number of tests have been developed and implemented, there is still a need to develop a more definitive test method for predicting the moisture susceptibility of HMA. Table 2.1 lists tests on loose mixtures while Table 2.2 lists tests on compacted mixtures. All of these tests have been used to predict laboratory moisture susceptibility, but they either due not adequately determine moisture susceptibility or they lack the reliability of predicting moisture damage in the field. The following sections will provide a brief description of each test method and how well it predicts field moisture damage.

2.5.1 Tests on Loose Mixture

The tests on loose mixtures are conducted on only asphalt coated particles in the presence of water and are listed in Table 2.1. The most important advantages of these tests are that they are relatively simple to conduct and relatively inexpensive to run. A secondary advantage is that these tests use simple equipment and procedures to conduct the experiment

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(Solaimanian et al., 2003). However the draw back of the tests on loose mixtures is that they fail to simulate pore pressure and traffic.

Table 2.1 Moisture Sensitivity Tests on Loose Samples (Solaimanian et al. 2003)

Test Method	ASTM	AASHTO	Other
Methylene Blue			Technical Bulletin 145, International Slurry Seal Association
Film Stripping			California Test 302
Static Immersion	D1664*	T182	
Dynamic Immersion			No standard exists
Chemical Immersion			Standard Method TMH1 (Road Research Laboratory 1986, England)
Quick Bottle			Virginia Highway and Transportation Research Council (Maupin 1980)
Boiling	D3625		Tex 530-C Kennedy et al. 1984a
Rolling Bottle			Isacsson and Jorgensen, Sweden, 1987
Net Adsorption			SHRP-A-341 (Curtis et al. 1993)
Surface Energy			Thelen 1958, HRB Bulletin 192 Cheng et al., AAPT 2002
Pneumatic Pull-Off			Youtcheff and Aurilio (1997)

*No longer available as ASTM standard.

2.5.1.1 Methylene Blue Test

The methylene blue (MB) test is used to identify "dirty" aggregates that contain harmful clays and dust (Solaimanian et al. 2003). If dust or clay particles are on aggregate particles, an asphalt binder will not be able to fully coat the aggregate particles, and thus a potential for stripping may occur in the HMA. This test is used to identify those aggregates with clays or dust. Since no asphalt is used, this test cannot measure a potential for HMA stripping.

In this test, methylene blue is dissolved in water with a known concentration. At the same time, a known weight of mineral filler (smaller than 75 microns) is uniformly stirred and dispersed into a separate beaker. Drops of the MB solution are added to the mineral filler solution one at a time while stirring. After each drop of MB, one drop of the mineral

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filler/MB solution is removed using a stirring road and placed on filter paper. The test is continued until a light blue halo is formed around the drop. The blue halo forms because the clay particles absorb the methylene blue so the darker the halo around the drop, the more clay particles there are in the mineral filler.

2.5.1.2 Static Immersion Test (AASHTO T182)

A static immersion test is conducted by placing a sample of HMA mix, which is cured for two hours at 60ºC into a jar and covered with water. The jar is left undisturbed for 16 to 18 hours in a water bath at 25ºC. The amount of stripping is visually estimated by observing the HMA sample in the jar. The results of this test are given as either less than or greater than 95% of the aggregate surface is stripped (Solaimanian et al. 2003).

2.5.1.3 Film Stripping Test (California Test 302)

The film stripping test is a modified version of the static immersion test (AASHTO T182) where a loose mixture of asphalt coated aggregate is placed in a jar filled with water. The mix is aged in an oven at 60ºC for 15 to 18 hours before being placed in the jar to cool. The jar with the loose mix is rotated at 35 revolutions per minute (rpm) for 15 minutes to stir up the mix. Baffels in a jar stir up the mix to accelerate the stripping process. After 15 minutes the sample is removed and the loose mixture is viewed under a fluorescent light and the percentage of stripping is estimated. The results of this test are given in percentage of total aggregate surface stripped (Solaimanian et al. 2003).

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2.5.1.4 Dynamic Immersion Test

The dynamic immersion test (DIM) is similar to the previously discussed static immersion test but the DIM test uses an accelerated stripping effect. The loose mixture is agitated in a jar filled with water in order to produce a dynamic effect (Solaimanian et al. 2003). The DIM is different that the film stripping test in that the DIM is subjected to four hours of agitation while the film stripping test is subjected to agitation for only fifteen minutes. Again, the results show that as the period of agitation increases, the amount of stripping increases.

2.5.1.5 Chemical Immersion Test

A loose sample of asphalt-coated aggregate is placed in boiling water while increasing the amount of sodium carbonate. The sample is removed from the water and sodium carbonate solution and examined for stripping. The concentration of sodium carbonate is slowly increased until stripping occurs and the concentration of sodium carbonate is recorded. The recorded number is referred to as the Riedel and Weber (R&W) number. Zero refers to distilled water, 1 refers to 0.41 g of sodium carbonate in one liter of water and 9 refers to the highest concentration of sodium carbonate or 106 g in one liter of water (Solaimanian et al. 2003).

2.5.1.6 Surface Reaction Test

Several problems with the previous tests reviewed are that they rely upon on the visual observation of identifying stripping. The surface reaction test allows a researcher to quantify the level of stripping on loose asphalt mixtures. This procedure was developed by Ford et al. (1974). The surface reaction test looks at the reactivity of calcareous or siliceous

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aggregates and how they react in the presence of highly toxic and corrosive acids. As part of the chemical reaction, gas is emitted, which generates pressure that is directly proportional to the exposed aggregate surface area (Solaimanian et al. 2003). This test is based on the premise that different levels (severity) of stripping result in exposed surface areas of aggregates.

2.5.1.7 Boiling Water Test

The boiling water test is a combination of several boiling tests that have been developed by several state agencies, including one from the Texas State Department of Highways and Public Transportation (Kennedy et al. 1983 and 1984a). A visual inspection of stripping of the asphalt-aggregate particles is made after the sample has been subjected to the action of water at an elevated temperature for a specified time (Kennedy et al. 1983 and 1984a; Solaimanian et al. 2003). This test identifies mixes that are susceptible to moisture damage, but it does not account for mechanical properties nor include the effects of traffic (Kennedy et al. 1983 and 1984a, Solaimanian et al. 2003).

2.5.1.8 Rolling Bottle Test

Isacsson and Jorgenson developed the Rolling Bottle Test in Sweden in 1987. The test is similar to the dynamic immersion test in that aggregate chips are coated in asphalt and placed in a glass jar filled with water. The glass jar is rotated to agitate a loose HMA specimen. A visual inspection is completed to note how much asphalt has been stripped from the aggregate (Solaimanian et al. 2003).

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2.5.1.9 Net Adsorption Test

The Strategic Highway Research Program (SHRP) developed a test called the net adsorption test (NAT) in the early 1990's and is documented under SHRP-A-341 (Curtis et al. 1993). This test is used to determine the affinity of an asphalt-aggregate pair and the sensitivity of the system to water (Solaimanian et al. 2003). This test is performed in two steps. First asphalt is adsorbed onto an aggregate from a toluene solution. The amount of asphalt adsorbed can be determined by how much asphalt is remaining in the solution. Secondly, water is introduced into the system, the asphalt is then desorbed from the aggregate surface, the asphalt present in the solution can be measured, and the amount of asphalt remaining on the aggregate is calculated. In terms of other tests, the NAT gives mixed results when compared to the indirect tensile test when moisture conditioned (Solaimanian et al. 2003). The NAT was modified by researchers at the University of Nevada - Reno and the results were correlated with an environmental conditioning chamber (ECS) (Scholz et al. 1994). The water sensitivity of the binder as estimated by the NAT showed little or no correlation to wheel-tracking tests on the mixes according to SHRP-A-402 (Scholz et al. 1994).

2.5.1.10 Wilhelmy Plate Test and Universal Sorption Device

Researchers at Texas A&M University have conducted significant research into the cohesive and adhesive failure models of asphalt materials based on surface energy theory and moisture diffusion models based on the results from the Universal Sorption Device (USD) (Cheng et al. 2002). The principle behind surface energy theory is that the surface energy of the asphalt and aggregate is a function of the adhesive bond between the asphalt and

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aggregate and the cohesive bonding within the asphalt (Solaimanian et al. 2003). The Wilhelmy plate is used to determine the surface free energy of the asphalt binder where the dynamic contact angle is measured between asphalt and a liquid solvent (Cheng et al. 2003; Solaimanian et al. 2003). The USD is also used to determine the surface free energy of the aggregate (Cheng et al. 2003, Solaimanian et al. 2003). The surface free energy is then used to compute the adhesive bond between the asphalt binder and aggregate. Cheng et al. (2002) showed that the adhesive bond per unit area of aggregate is highly dependent on the aggregate and asphalt surface energies. Also, this test shows that stripping occurs because the affinity of the aggregate for water is much greater than that for asphalt thus weakening the bond at the asphalt-aggregate interface (Cheng et al. 2002).

Current research at Texas A & M (Bhasin et al. 2006 and Masad et al. 2006) has shown that the moisture resistance of asphalt-aggregate combinations depends on the surface energies of the asphalt binder and aggregate. The factors they have considered are film thickness, aggregate shape characteristics, surface energy, air void distribution and permeability. The ratio of adhesive bond energy under dry conditions to the adhesive bond energy under wet conditions can be used to identify moisture susceptible asphalt-aggregate combinations and a ratio of 0.80 should be used as a criteria to separate good and poor combinations of materials. Dynamic mechanical analysis (DMA) tests were conducted to evaluate the mixtures ability to accumulate damage under dry and moisture conditioned. A mechanistic approach using a form of the Paris law was used for the evaluation of moisture damage. The mechanical properties are influenced by aggregate gradation, aggregate shape characteristics, and film thickness. This approach captures the influence of moisture on crack growth and is able to distinguish between good and poor performing HMA mixtures.

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However, the test specimens used for the DMA testing are composed primarily of sand gradation using high asphalt contents, which is not typically of HMA mixtures that are placed in the field.

2.5.1.11 Pneumatic Pull-Off Test

Another method for evaluating the moisture susceptibility of asphalt binders is the pneumatic pull-off test. The properties being measured by this test are the tensile and bonding strength of the asphalt binder applied to a glass plate as a function of time while being exposed to water (Kantipong et al. 2003, Solaimanian et al. 2003, Kantipong et al. 2006b). Test results by Youtcheff et al. (1998) show that soak time appears to be an important factor. Additional results using the pneumatic pull-off test indicate that asphaltenes provide the viscosity structure and is disrupted by the presence of water while the maltenes (resins and oils) provide the resistance to moisture damage (Youtcheff et al. 1997). Asphaltenes and maltenes makes up the composition of asphalt cement. Asphaltenes are insoluble while maltenes are soluble when the asphalt cement is dissolved in pentane, hexane and heptane (Roberts et al. 1996).

2.5.2 Tests on Compacted Mixtures

Tests conducted on compacted mixtures include laboratory compacted specimens, field cores, and/or slabs compacted in the laboratory or taken from the field. Table 2.2 provides moisture sensitivity tests that have been performed on compacted specimens. From these tests, physical, fundamental/mechanical properties can be measured while accounting for traffic/water action and pore pressure effects (Solaimanian et al. 2003). Some

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disadvantages of conducting tests on compacted mixtures are the expensive laboratory testing equipment, longer testing times, and potentially labor intensive test procedures.

Table 2.2 Moisture Sensitivity Tests on Compacted Samples (Solaimanian et al. 2003)

Test Method	ASTM	AASHTO	Other
Moisture Vapor Susceptibility			California Test 307 Developed in late 1940's
Immersion-Compression	D1075	T165	ASTM STP 252 (Goode 1959)
Marshal Immersion			Stuart 1986
Freeze-Thaw Pedestal Test			Kennedy et al. 1983
Original Lottman Indirect Tension			NCHRP Report 246 (Lottman 1982); Transportation Research Record 515 (1974)
Modified Lottman Indirect Tension		T283	NCHRP Report 274 (Tunnicliff and Root 1984), Tex 531-C
Tunnicliff-Root	D4867		NCHRP Report 274 (Tunnicliff and Root 1984)
ECS with Resilient Modulus			SHRP-A-403 (Al-Swailmi and Terrel 1994)
Hamburg Wheel Tracking			1993 Tex-242-F
Asphalt Pavement Analyzer			Pavement Technology Inc., Operating Manual
ECS/SPT			NCHRP 9-34 (2002-06)
Multiple Freeze-Thaw			No standard exists

2.5.2.1 Immersion-Compression Test

The immersion-compression test (ASTM D1075 and AASHTO T165-55) is among the first moisture sensitivity tests developed based on testing 100mm diameter compacted specimens. A more detailed explanation of this test is provided in ASTM Special Technical Publication 252 (Goode 1959). This test consists of compacting specimens into: a control group and a moisture conditioned group. The moisture conditioned group is submerged in a 48.8°C water bath for four days (Roberts et al. 1996). The compressive strength of the

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conditioned and control group are then measured (Roberts et al. 1996). The average strength of the conditioned specimens over that of the control specimens is a measure of strength lost due to moisture damage (Solaimanian et al. 2003). Most agencies specified a minimum retained compressive strength of 70%.

2.5.2.2 Marshall Immersion Test

The procedure for producing and conditioning two groups of specimens is identical to the immersion-compression test with the only difference being that the Marshall stability test is used as the strength parameter as opposed to the compressive strength (Solaimanian et al. 2003). A minimum retained Mashall stability number could not be found in the literature.

2.5.2.3 Moisture Vapor Susceptibility

The moisture vapor susceptibility test was developed by the California Department of Transportation (California Test Method 307). A California kneading compactor is used to compact two specimens. The compacted surface of each specimen is sealed with an aluminum cap and a silicone sealant is applied to prevent the loss of moisture (Solaimanian, et al. 2003). After the specimens have been conditioned at an elevated temperature and suspended over water, they are tested. The Hveem stabilometer is used to test both the dry and moisture conditioned specimens. A minimum Hveem stabilometer value is required, which is less than that required for the dry specimens used in the mix design (Solaimanian et al. 2003).

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2.5.2.4 Repeated Pore Water Pressure Stressing and Double-Punch Method

The repeated pore water pressure stressing and double punch method was developed by Jimenez (1974) at the University of Arizona. This test takes into account the effects of dynamic traffic loading and mechanical properties. In order to capture the effects of pore water pressure, the specimens are conditioned by a cyclic stress under water. After the specimen has undergone the pore pressure stressing the tensile strength is measured using the double punch equipment. Compacted specimens are tested through steel rods placed at either end of the specimen in a punching configuration.

2.5.2.5 Original Lottman Method

The original Lottman test was developed at the University of Idaho by Robert Lottman (1978). The laboratory procedure consists of compacting three sets of 100mm diameter by 63.5mm high Marshall specimens to be tested dry or under accelerated moisture conditioning (Lottman et al. 1974). The laboratory conditions for each group are as follows:

- Group 1: Control group, dry;
- Group 2: Vacuum saturated with water for 30-minutes; and
- Group 3: Vacuum saturation followed by freeze cycle at -18°C for 15- hours and then subjected to a thaw at 60°C for 24-hours (Lottman et al., 1974).

After the conditioning phase the indirect tensile equipment is used to conduct tensile resilient modulus and tensile strength for the conditioned and dry specimens. All the specimens are tested at 13°C or 23°C at a loading rate of 1.65mm/min. The severity of the moisture damage is based on the ratio of the conditioned to dry specimens (tensile strength ratio, TSR) (Lottman et al. 1974, Lottman 1982). A minimum TSR value of 0.70 is

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recommended (Lottman 1982). Laboratory compacted specimens were compared to field cores and plotted against each other on a graph. The TSR from the laboratory and field core specimens closely follow the line of equality which means that laboratory and field TSR's are related.

2.5.2.6 Modified Lottman Test (AASHTO T283)

"Resistance of Compacted Bituminous Mixture to Moisture Induced Damage" AASHTO T283, is the most commonly used test method for determining moisture susceptibility of HMA. This test is similar to the original Lottman test with only a few exceptions which are as follows:

- Two groups, control and moisture conditioned,
- Vacuum saturation until a saturation level of 70% to 80% is achieved, and
- Test temperature and loading rate change to 50-mm/min at 25ºC.

A minimum TSR value of 0.70 is recommended (Roberts et al. 1996). AASHTO T283 was adopted by the Superpave system as the moisture test method of choice even though AASHTO T283 is based on Marshall mixture design. State highway agencies have reported mixed results when using AASHTO T283 and comparing the results to field performance (Kennedy et al. 1984b, Coplantz et al. 1988, Stroup-Gardiner et al. 1992, Solaimanian et al. 2003,). NCHRP Report 444 considered different factors affecting test results such as types of compaction, diameter of specimen, degree of saturation, and freeze-thaw cycles. Conclusions based on the previously mentioned factors are discussed in the NCHRP 444 Report (Epps et al., 2000). The researchers concluded that either AASHTO T283 does not evaluate moisture susceptibility or the criteria, the tensile strength ratio, is

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incorrectly specified. NCHRP Report 444 examined mixtures that have historically been moisture susceptible and ones that have not. The researchers also examined the current criteria using Marshall and Hveem compaction. A recent study at the University of Wisconsin found no relationship exists between TSR and field performance in terms of pavement distress index and moisture damage (surface raveling and rutting) (Kanitpong et al. 2006a). Additional factors such as production and construction, asphalt binder and gradation play important roles.

2.5.2.7 ASTM D4867 (Tunnicliff-Root Test Procedure)

"Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures," ASTM D4867 is comparable to AASHTO T283. The only difference between AASHTO T283 and ASTM D4867 is that the curing of the loose mixture at 60°C for 16 hours is eliminated in ASTM D4867. A minimum TSR of 0.70 to 0.80 are specified by highway agencies (Roberts et al. 1996).

2.5.2.8 Texas Freeze-Thaw Pedestal Test

This water susceptibility test was developed by Plancher et al. (1980) at Western Research Institute and later modified into the Texas freeze-thaw pedestal by Kennedy et al. (1983) at the University of Texas. Even though this test is empirical in nature, it is fundamentally designed to maximize the effects of bond and to minimize the effects of mechanical properties such as gradation, density, and aggregate interlock by using a uniform gradation (Kennedy et al. 1983). An HMA briquette is made according to the procedure outlined by Kennedy et al. (1983). The specimen is then placed on a pedestal in a jar of distilled water and covered. The specimen is subjected to thermal cycling and inspected each

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day for cracks. The number of cycles to induce cracking is a measure of the water susceptibility (Kennedy et al. 1983). Important results provided by the Texas freeze-thaw pedestal test are as follows:

- Bond failure at the asphalt aggregate interface (stripping) and
- Fracture of the thin asphalt films bonding aggregate particles (cohesive failure) by the formation of ice crystals (Solaimanian et al. 2003).

2.5.2.9 Hamburg Wheel-Tracking Device (HWTD)

The Hamburg wheel tracking device was developed by Esso A.G. and is manufactured by Helmut-Wind, Inc. of Hamburg, Germany (Aschenbrener et al. 1995, Romero and Stuart 1998). Two samples of hot mix asphalt beams are made with each beam having dimensions of 320mm long, 260mm wide, and 40mm thick. This device measures the effects of rutting and moisture damage by running a steel wheel over the compacted beams immersed in hot water (typically 50ºC) (Aschenbrener et al. 1995). The steel wheel is 47mm wide and applies a load of 705N while traveling at a maximum velocity of 340mm/sec in the center of the sample. The sample of HMA is loaded for 20,000 passes or until 20mm of permanent deformation occurs (Aschenbrener et al. 1995). Important results provided by the HWTD are as follows:

- Post-compaction consolidation: Deformation measured after 1,000 wheel passes;
- Creep Slope: Number of wheel passes to create a 1mm rut depth due to viscous flow;

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- Stripping Slope: Inverse of the rate of deformation in the linear region of the deformation curve; and
- Stripping Inflection Point: Number of wheel passes at the intersection of the creep slope and stripping slope (Aschenbrener et al. 1995).

2.5.2.10 Environmental Conditioning System (ECS)

The Environmental Conditioning System (ECS) was developed by Oregon State University as part of the SHRP-A-403 and later modified at Texas Technological University (Alam et al. 1998). The ECS subjects a membrane encapsulated HMA specimen that is 102mm in diameter by 102mm in height to cycles of temperature, repeated loading, and moisture conditioning (Al-Swailmi et al. 1992a, Al-Swailmi et al. 1992b, Al-Swailmi et al. 1992c, Terrel et al. 1993, Terrel and Al-Swailmi 1994). Important fundamental material properties obtained from using the ECS are the HMA's resilient modulus (M_R) before and after conditioning, air permeability, and a visual estimation of stripping after the specimen has been split open (Terrel and Al-Swailmi 1994). One of the largest advantages of using the ECS is the ability to influence the HMA specimens by traffic loading and the resulting effect of pore water pressure (Solaimanian et al. 2003) which is close to field conditions. The downfall of the test is that it does not provide a better relationship to field observation than what was observed using AASHTO T283. Also, AASHTO T283 is much less expensive to run and less complex than the ECS (Aschenbrener et al. 1995).

2.5.2.11 Flexural Fatigue Beam Test with Moisture Conditioning

Moisture damage is known to accelerate fatigue damage in pavements. Therefore, conditioning of flexural fatigue beams was completed by Shatnawi et al. (1995). Laboratory

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compacted beams prepared from HMA sampled in the field and corresponding field fatigue beams were cut from the pavement for testing. The conditioning of the beams were tested under the following conditions:

- Partial vacuum saturation of 60% to 80%,
- Followed by three repeated five-hour cycles at 60ºC followed by four hours at 25ºC while remaining submerged, and
- One five-hour cycle at -18ºC (Shatnawi et al. 1995).

The specimens were then removed from the conditioning chamber and tested according to AASHTO TP8. Initial stiffness and fatigue performance were affected significantly by conditioning the specimens (Shatnawi et al. 1995). For the laboratory compacted specimens, asphalt content and air void content were not independently controlled which resulted in higher air void contents when the binder was reduced by 0.5%, The high air void content and low binder content increased the moisture susceptibility of the HMA mixtures.

Some of the specimens obtained from the field had air void contents in excess of 12% which indicates that the moisture susceptibility in the field was related to construction compaction effort. The beam fatigue results show that those beams that used hydrated lime had improved performance than those that did not.

2.5.2.12 ECS/Simple Performance Test Procedures

New test procedures such as simple performance tests (SPT's) are now being evaluated and reported on in NCHRP Reports 465, 513, and 547. According to Witczak et al. (2002) an SPT is defined as "A test method(s) that accurately and reliably measures a mixture response or characteristic or parameter that is highly correlated to the occurrence of

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pavement distress (e.g. cracking and rutting) over a diverse range of traffic and climatic conditions." The mechanical tests being considered are the dynamic modulus |E*|, repeated axial load (F_N), and static axial creep tests (F_T). These tests are conducted at elevated temperatures to determine the mixture's resistance to permanent deformation. The dynamic modulus test is conducted at an intermediate and lower test temperature to determine a mixtures susceptibility to fatigue cracking. Witczak et al. (2002) has shown that dynamic modulus, flow time, and flow number give promising correlations to field performance. The advantages and disadvantages are provided in Table 2.3 from the work of Brown et al. (2001) and Witczak et al. (2002).

Table 2.3 SPT Advantages and Disadvantages (Witczak et al 2002 and Brown et al. 2001)

Test	Parameter	Test Condition	Model	R^2	Se/Sy	Advantages	Disadvantages
Dynamic Modulus	E*/sinϕ	Sinusoidal Linear 130°F 5 Hz	Power	0.91	0.310	Direct input for 2002 Pavement Design Guide Not forced to use master curves Easily linked to established regression equations Non destructive tests	Coring and sawing Arrangement of LVDTs Confined testing gave poor results Need further study of reliability of confined open graded specimens Equipment is more complex Difficult to obtain 1.5:1height-to-diameter ratio specimens in lab
Repeated Loading (Flow Number)	F_N	Unconfined 130°F Various Frequencies	Power	0.88	0.401	Better simulates traffic conditions	Equipment is more complex Restricted test temperature and load levels does not simulate field conditions Difficult to obtain 1.5:1height-to-diameter ratio specimens in lab

NCHRP 9-34 is currently investigating the aforementioned tests along with the ECS to develop new test procedures to evaluate moisture damage (Solaimanian et al. 2003). Solaimanian et al. (2006) reported that the results of the Phase I and Phase II testing of

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NCHRP 9-34 show that the dynamic modulus (DM) test should be coupled with the ECS for moisture sensitivity testing. Some preliminary findings from NCHRP 9-34 show that the ECS/DM test appear to separate good performing mixes from poor performing mixes in the field compared with the TSR testing from ASTM D4867. The dynamic complex modulus is determined by applying a uniaxial sinusoidal vertical compressive load to an unconfined or confined HMA cylindrical sample as shown in Figure 2.1.

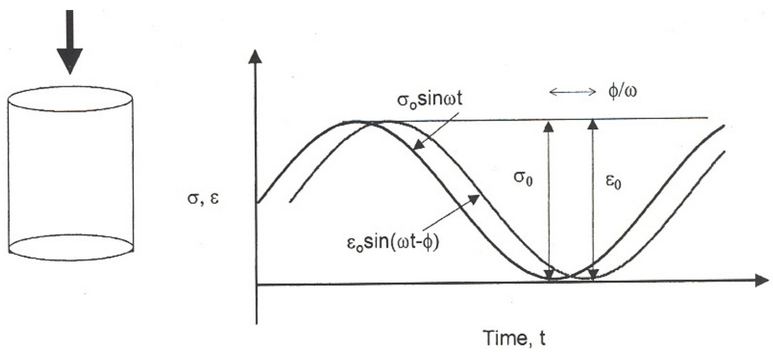

Figure 2.1 Haversine Loading Pattern or Stress Pulse for the Dynamic Modulus Test (Witczak et al. 2002)

The stress-to-strain relationship under a continuous sinusoidal load pattern for a linear viscoelastic material is defined by the complex modulus (dynamic modulus), E*. Mathematically, E* is equal to the maximum peak dynamic stress (σ_o) divided by the peak recoverable strain (ε_o):

$$|E^*| = \frac{\sigma_o}{\varepsilon_o} \quad \text{(equation 2.1)}$$

The real and imaginary parts of the dynamic modulus can be written as with a real and an imaginary component.

$$E^* = E' + iE'' \quad \text{(equation 2.2)}$$

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E' is referred to as the storage or elastic modulus component, while E" is referred to as the loss or viscous modulus. The angle by which the peak recoverable strain lags behind the peak dynamic stress is referred to as the phase angle, ϕ. The phase angle is an indicator of the viscous and elastic properties of the material being evaluated.

Mathematically, this is expressed as:

$$E^* = |E^*|\cos\phi + i|E^*|\sin\phi \qquad \text{(equation 2.3)}$$

$$\phi = \frac{t_i}{t_p} \times 360 \qquad \text{(equation 2.4)}$$

where

t_i = time lag between a cycle of stress and strain (s),
t_p = time for a stress cycle (s), and
i = imaginary number.

For a purely viscous material, the phase angle is 90° while for a purely elastic material the phase angle is 0° (Witczak et al. 2002). The dynamic modulus, which is a measurable "fundamental" property of an HMA mixture, is the relative stiffness of the mix.

The dynamic creep test (i.e. repeated load test, flow number test) is based on the repeated loading and unloading of an HMA specimen where the permanent deformation of the specimen is recorded as a function of the number of load cycles. The loading is for 0.1sec. followed by a 0.9sec. unloading of the specimen. There are three types of phases that occur during a repeated load test: primary, secondary, and tertiary flow. In the primary flow regime, there is a decrease in strain rate with time followed by a constant strain rate in the secondary flow regime, and finally an increase in strain rate in the tertiary flow regime. Tertiary flow signifies that the specimen is beginning to deform significantly and the individual aggregates that make up the matrix start to "flow". The flow number is based on

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the onset of tertiary flow (or the minimum strain rate recorded during the course of the test). The following description is shown graphically in Figure 2.2.

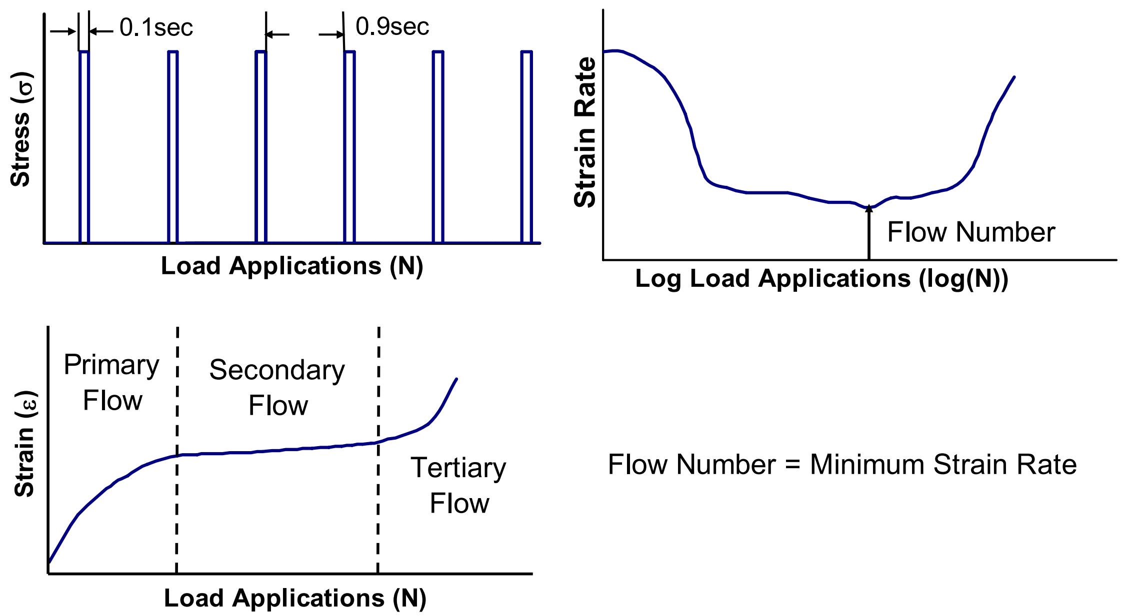

Figure 2.2 Flow Number Loading (Robinette 2005)

Flow number testing is similar to pavement loading because pavement loading is not continuous; there is a dwell period between loadings. This allows the pavement a certain amount of time to recover some of the strain induced by the loading.

2.6 Summary of Literature Review

Moisture damage is related to the adhesive strength between the asphalt binder and aggregate and cohesive strength of the asphalt binder and mastic. Moisture damage can be attributed to six factors such as detachment, displacement, spontaneous emulsification, pore-pressure induced damage, hydraulic scour, and environmental effects. Several theories exist that explain the process of moisture damage through chemical theory, molecular forces, surface energy theory, and mechanical properties of the asphalt binder, mastic, aggregate, and even the interface between the asphalt binder and aggregate.

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Numerous tests are available that determine the moisture susceptibility of hot mix asphalt in terms of loose mixture (Table 2.1) and compacted mixtures (Table 2.2). Currently, there has not been a transition from Marshall and Hveem mix design to Superpave mix design in terms of moisture susceptibility testing. The most promising tests are the Wilhelmy plate test and USD for considering if an asphalt binder or aggregate is moisture susceptible and the ECS/Simple Performance Test.

The Wilhelmy plate test and USD have been used at Texas A & M to determine if an aggregate or asphalt binder is moisture susceptible. This will allow for a highway agency to select which aggregate or binder to use for the mix design procedure. However, this test will not tell you how the HMA will perform under environmental conditions. Several research projects have evaluated the Lottman, modified Lottman, and Tunnicliff and Root test procedures to evaluate an HMA mixtures susceptibility to moisture damage. However, mixed results occur when relating TSR to field performance. The HWTD is a severe test for HMA mixtures and is an excellent screening device used to determine if a HMA mixture is moisture susceptible.

Currently, NCHRP 9-34 is evaluating the use of the ECS with the SPT. The SPT's in terms of dynamic modulus, flow number, and flow time, have been evaluated and found to be related to field performance. The dynamic modulus data can then be included into the design of flexible pavements using the forthcoming AASHTO mechanistic-empirical pavement design guide (MEPDG).

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CHAPTER 3 EXPERIMENTAL PLAN

3.1 Experimental Plan

This research was divided into three phases. The phase I testing was used to determine the number of freeze-thaw cycles that will cause the equivalent damage to AASHTO T283 specimens for different methods of compaction and specimen sizes. A phase II sensitivity study considered the effects of moisture conditioning and test temperature on dynamic modulus testing. Phase II testing of mixes for moisture damage used the results of Phase I for the AASHTO T283 testing on 150mm specimens and the results of Phase I and Phase II for dynamic modulus and AASHTO T283 testing. In the following sections, the mixture and laboratory testing experimental plans are outlined.

3.1.1 Phase I Testing – Sensitivity Study

The experimental plan considered different mix types, aggregate sources, laboratory test systems, conditioning approaches, and test specimen size. The experimental plan included two integrated plans: one for the mixes and one for the planned laboratory tests. A sensitivity study considering the effects of specimen size and compaction method was performed on a limited number of mixes to determine the amount of conditioning that should be done on larger Superpave compacted specimens. Table 3.1 below outlines the executed sensitivity experimental plan.

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Table 3.1 Sensitivity Experimental Plan for Mix and Aggregate Types

PHASE 1 MOISTURE		
NMAS (mm)	Traffic Level (ESAL)	
	≤ 3,000,000	>3,000,000
25.0 or 19.0	Limestone - M50 Dundee	Limestone - M59 Brighton
	Gravel - M21 St. Johns	
12.5 or 9.5	Limestone - BL96 Howell	Limestone - I-196 Grand Rapids
	Gravel - M21 Owosso	Slag/Gabbro - I-75 Clarkston

Table 3.2 outlines the laboratory test plan that was executed for the sensitivity study. As previously mentioned, this plan partially duplicates the work done and reported in NCHRP 444 (Epps et al. 2000). Twenty specimens per project per compaction method/diameter size were produced. This resulted in a total of 420 specimens tested for the sensitivity study. Superpave designed mixes were used in the study, but the method of compaction to achieve 7.0% air voids varied because the Superpave gyratory compacted and Marshall hammer were used to compacted specimens. It was also necessary to determine the conditioning time necessary to produce the same tensile strength ratios in larger specimens, 150mm diameter, undergoing Superpave compaction compared with 100mm Marshall compacted specimens. The standard conditioning of specimens was the same as outlined by AASHTO T283 for 150mm specimens. The 150mm specimens for Phase I testing were also used for the results for the AASHTO T283 testing for Phase II.

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Table 3.2 Sensitivity Experimental Plan for Effect of Compaction Method and Conditioning Period on Performance

Conditioning Period	Unconditioned			Conditioned		
	100mm Marshall	100mm Superpave	150mm Superpave	100mm Marshall	100mm Superpave	150mm Superpave
AASHTO T283, Standard Conditioning Time	XXXXX[1]	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
AASHTO T283, 2 Times Standard Conditioning Time	N/A[2]	N/A	N/A	XXXXX	XXXXX	XXXXX
AASHTO T283, 3 Times Standard Conditioning Time	N/A	N/A	N/A	XXXXX	XXXXX	XXXXX

[1]One X represents a specimen tested per job;
[2]Not applicable.

3.1.2 Phase II Testing – Sensitivity Study

A sensitivity study using the simple performance test was accomplished, which considered additional factors such as test temperature and conditioning, before the expanded experimental plan was undertaken. The projects selected for the sensitivity study were based on the results of the Phase I testing. The projects chosen were based on a good and poor performing HMA mixture in the AASHTO T283 testing. The gabbro/slag, I-75 Clarkston was the good performing mixture and a limestone mixture, I-196 Grand Rapids, was the poor performing mixture. The test temperatures for intermediate and high dynamic modulus and flow number are stipulated by an effective test temperature (T_{eff}) in NCHRP Report 465 (Witczak et al. 2002). Four conditioning cycles were considered: control group, vacuum saturation plus freeze-thaw cycling, vacuum saturation only, vacuum saturation plus freeze-thaw cycling with dynamic creep testing performed on specimens submerged under water.

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3.1.3 Phase II Testing

The Phase II experimental plan considered different mix types, aggregate sources, and laboratory test systems. The experimental plan included two integrated plans: one for the mixes and one for the planned laboratory tests. A sensitivity study that considered the effects of specimen size and compaction method was accomplished in the Phase I testing to determine the amount of conditioning that should be performed on larger Superpave compacted specimens. Table 3.3 below outlines the final expanded experimental plan.

Table 3.3 Expanded Experimental Plan for Phase II Projects

PHASE 2 MOISTURE		
NMAS (mm)	Traffic Level (ESAL's)	
	≤ 3,000,000	>3,000,000
25.0 or 19.0	Limestone - M50 Dundee	Limestone - M59 Brighton
	Limestone - M36 Pinckney	Limestone - Michigan Ave. Detroit
	Gravel - M45 Grand Rapids	Limestone - Vandyke Detroit
	Gravel - M21 St. Johns	Limestone - US23 Hartland
	Limestone - M84 Saginaw	Gravel - I-75 Levering Road
12.5 or 9.5	Limestone - BL96 Howell	Limestone - I-196 Grand Rapids
	Gravel - M21 Owosso	Slag/Gabbro - I-75 Clarkston
	Gravel - M66 Battle Creek	Gravel - M53 Detroit
	Limestone - M50 Dundee	Limestone - Michigan Ave. Detroit
	Limestone - US12 MIS	Gabbro I-75 Toledo (in MI)
SMA	N/A	Gabbro - I-94 SMA Ann Arbor

Table 3.4 below shows the laboratory testing experimental plan. The test temperature and moisture conditioning of the specimens was determined in the Phase I sensitivity study for the Phase II experimental plan. A proposed method of determining moisture susceptibility will be compared to the current method of determining moisture susceptibility from which conclusions and recommendations will be drawn upon.

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Table 3.4 Laboratory Experimental Plan for Phase II

		Unconditioned	Conditioned
Test System for Sensitivity Study	Dynamic Complex Modulus Testing followed by Flow Number Testing followed by Dynamic Complex Modulus Testing	XXX	XXX
Test System for Phase II Testing	AASHTO T283	XXXXX	XXXXX
	Dynamic Complex Modulus Testing	XXX	XXX

3.2 Sampled Projects

The majority of the projects were sampled during the 2004 construction season. Two projects were used from the 2000 construction season sampling and three projects were sampled in the 2005 construction season. The 2000 construction projects that were sampled were stored in a heated, metal building where the material was protected from the rain, heat, and snow. By sampling materials from across the state, a better cross section of materials is represented by the different contractors and different available materials that are in the state. The majority of the high volume mixes were found around the Detroit metro area whereas lower volume mixes were found across the state. Figure 3.1 shows the locations of the HMA mixes sampled for this research project, a symbol (dot) shows the approximate project location and the star shows the approximate location of Michigan Technological University, whereas Appendix A: Project Job Mix Formulas (JMF's) contains all the material properties related to each project/mixture.

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Michigan State University Center for Remote Sensing and Geographic Science (www.crs.msu.edu) "Base Map"

Figure 3.1 Project Locations

3.3 Sampling

For this research project all HMA was sampled from mini-stockpiles. The locations for sampling were selected from the base to the top of the pile and around its perimeter, while keeping in mind the different strata of the stockpile, in that, the bottom of the piles comprises the greatest percentage of the material and hence the greatest percentage of the material was

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sampled from this location. Figure 3.2 illustrates the composition of a cone stockpile in terms of its percentages with height.

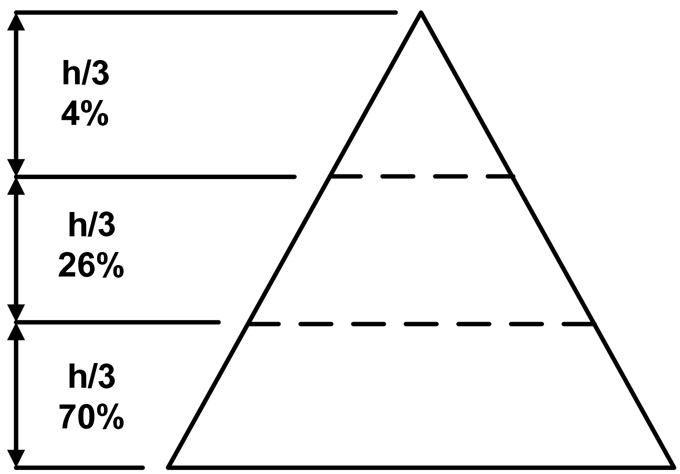

Figure 3.2 Stockpile Cone Proportions (Robinette, 2005)

The sampled materials were brought back from the various plant sites and stored either in the Water Resources Building or in the basement of Dillman Hall at Michigan Technological University prior to sample preparation.

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CHAPTER 4 PROCEDURES

4.1 Materials Collection

According to AASHTO T283 and NCHRP Report 465, three replicate specimens are required for testing the moisture sensitivity of HMA mixtures; three for the control group and three for the moisture conditioned group. Testing three specimens reduces the amount of testing variability inherent in each test procedure versus testing one or two specimens. For Phase I testing, twenty specimens per project (seven total projects) were required for AASHTO T283 testing. For Phase II testing, ten specimens per project (twenty-one total projects) were required. Therefore, thirty-four 5-gallon buckets of loose mix and two 5-gallon buckets of asphalt binder were sampled for Phase I projects and twenty 5-gallon buckets of loose mix and two 5-gallon buckets of asphalt binder were sampled for Phase II projects. Any additional material was then used for supplemental testing. The type of sampling used for this project was mini-stock pile sampling due to the amount of material being sampled. Sampling from the mini-stock pile was done in accordance with ASTM D140. Typically, sampling is done from behind the paver or out of the truck but because one to two tons of material was sampled, the mini-stock pile was the easiest and simplest way to sample. In addition to the material being sampled, the job mix formula (JMF) was collected in order to verify the HMA volumetrics.

4.2 Specimen Preparation and Testing

Specimen preparation used to procure Superpave gyratory and Marshall specimens are outlined below. This also includes splitting samples, maximum theoretical specific gravity testing, specimen compaction, bulk specific gravity testing, and specimen cutting and coring.

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4.2.1 Splitting

The loose mix that was sampled from the twenty-one jobs was heated up to 145 to 160°C for approximately two hours depending on the asphalt binder that was used. Each five-gallon bucket of HMA contained roughly 30 to 40kg of mix. Splitting was done in accordance with ASTM C702. Sample sizes included two, 2,000g sampled for maximum theoretical specific gravity tests. For Phase I testing, 20 samples per project were batched for 100mm Superpave specimens, 20 samples per project were batched for 150mm Superpave specimens, and 20 samples per project were batched for 100mm Marshall specimens. Phase II testing required 10 specimens per project for AASHTO T283 testing and 10 specimens per project for dynamic complex modulus testing.

4.2.2 Maximum Theoretical Specific Gravity (G_{mm})

Maximum theoretical specific gravity testing (G_{mm}) was done in accordance with ASTM D2041 for two, 2,000g samples. The G_{mm} was used to determine the volumetric properties of the gyratory and Marshall specimens, as well as the sawed and cored specimens. In addition, the G_{mm} was used to verify the G_{mm} on the JMF.

4.2.3 Superpave Gyratory Compaction

Superpave gyratory specimens were compacted with a Pine AFGC125X SGC according to the procedures outlined in Superpave Mix Design Manual (Asphalt Institute 2001). The 100mm diameter specimens were compacted to roughly 63.5mm in height and the 150mm diameter specimens were compacted to 95mm in height for Phase I. For Phase II, 150mm diameter specimens were compacted to 95mm in height for AASHTO T283 testing and dynamic complex modulus specimens were compacted to 170mm in height. All

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specimens were compacted to 7±1% air voids. An assumed appropriate correction factor of 1.02 was used based on gradation and nominal maximum aggregate size (NMAS). A new correction factor was calculated by taking the measured bulk specific gravity and dividing it by the estimated bulk specific gravity if the air voids were out of range (7.0%±1.0%) and additional specimens were procured.

4.2.4 Marshall Compaction

The Marshall compaction method was only used for Phase I of this research project. A double-sided, automated Marshall hammer was used to compact specimens that were 100mm diameter by 63.5mm in height. A double-sided mechanical compactor was selected instead of using the hand compactor for three reasons; first, the variability of the compaction procedure would be minimized, secondly, if this study was extended further, the compaction procedure would be uniform, and thirdly, 140 specimens had to be procured so this method was better suited for mass production of the samples. Before performance specimens could be procured, the determination of the number of blows to achieve 7±1% air voids was needed for each mix. Four specimens per job were compacted to 10, 25, 75 and 125 blows per side. A graph of air voids versus number of blows per side was used to determine the number of blows to achieve 7±1% air voids.

4.2.5 Bulk Specific Gravity (G_{mb})

The bulk specific gravity was determined for all laboratory compacted specimens and those specimens that were cut and cored. The testing was conducted in accordance with ASTM D2726. During the sawing and coring procedure, the specimens were exposed to water due to the fact that the saw blades and core barrel are water cooled. The dry weight of

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the specimen after cutting and coring is needed in order to determine the bulk specific gravity. According to ASTM D2726, the bulk specific gravity of a wet specimen must undergo a test temperature of 52°C for 24 hours in order to ensure a dry weight. Unfortunately at this temperature, the HMA specimen could undergo creep, thus changing the dimensions and volumetrics of the sample. Robinette (2005) found that specimens after two days of drying on a wire rack in front of a fan, the rate of weight change is asymptotical towards its true dry weight. This can be seen in Figure 4.1. Therefore, the submerged and saturated surface dry weight were taken immediately after sawing and coring, and the dry weight was taken two or more days after the submerged and saturated surface dry weight.

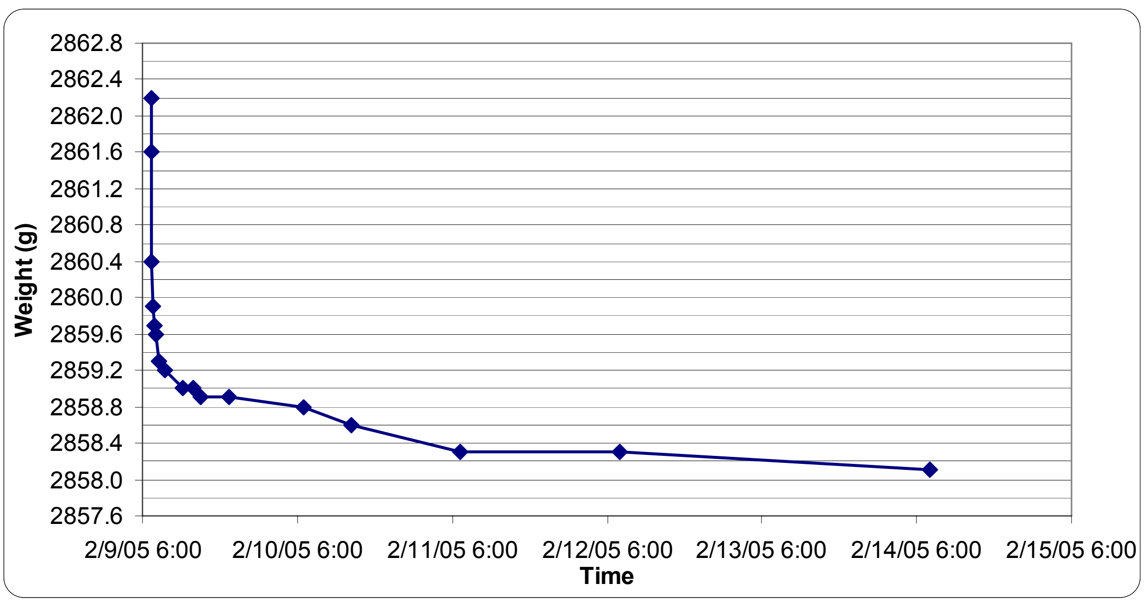

Figure 4.1 Changes in Weight of Specimen After G_{mb} Determination (Robinette 2005)

4.2.6 Specimen Cutting and Coring

Specimen cutting and coring was only used for Phase II specimen preparation for subsequent dynamic complex modulus testing of the samples. The draft test protocol from NCHRP Report 465 calls for 100mm diameter by 150mm high specimens after coring (Witczak et al. 2002). A sawing and coring device was developed by Shedworks, Inc. that

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does the sawing and coring in one piece of equipment. First, the diametrical ends of the specimen are sawed off with a water cooled, double-bladed, diamond tip saw in order to give the specimens a height of 150mm and to ensure parallelism between the top and bottom of the specimen. A coring machine was used to obtain the 100mm diameter specimen from the 150mm diameter gyratory compacted specimen.

4.3 Specimen Measurement

The AASHTO T283 samples were measured in accordance with AASHTO T283. Two diameter and four height measurements with digital calipers were taken and averaged. The dynamic complex modulus required a total of six diameter measurements (top, middle, and bottom of specimen) and four height measurements at 0°, 90°, 180°, and 270° and averaged. According to NCHRP Report 513, the diameter standard deviation was required to less than 2.5mm, otherwise the specimen is to be discarded. The only requirement on specimen height was that it should be within the range of 148 and 152mm (Bonaquist et al 2003).

4.4 Testing and Calculations

Outlined below are the testing procedures and calculations associated with this research project. The three types of tests are indirect tensile strength, dynamic modulus, and dynamic creep testing.

4.4.1 Indirect Tensile Strength Testing

The testing procedure described herein is derived from the AASHTO T283 Resistance of Compacted Bituminous Mixture to Moisture Induced Damage (AASHTO T283 1993). Specimens were compacted according to section 4.2.3 and divided into two subsets

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so that each subset had the same average air voids. The dry subset (control group) were wrapped with plastic and placed in a heavy-duty, leak-proof plastic bag and stored in a water bath at 25±0.5°C for 2 hours ± 10 minutes prior to testing. The conditioned subset specimens were placed in a pycnometer with a spacer. Approximately 25mm of water was placed above the specimens. Specimens were vacuum saturated for 5 to 10 minutes at 13-67 kPa and left submerged in a water bath for 5 to 10 minutes after vacuum saturating. The mass of the saturated, surface dry specimens were determined after partial vacuum saturation. Next, the volume of absorbed water was calculated. Finally, the degree of saturation was calculated. If the degree of saturation was between 70% and 80%, proceed on to testing. If the degree of saturation was less than 70% for a specimen, repeat the vacuum saturation procedure. If greater than 80%, the specimen is damaged and must be discarded. Each vacuum saturated specimen was tightly covered with plastic wrap and placed in a plastic bag with approximately 10±0.5 ml of water, and sealed. The plastic bags are placed in a freezer at -18±3°C for a minimum of 16 hours (freeze step). The specimens are removed from the freezer and placed in a water bath at 60±1°C for 24±1 hour with 25mm of water above the specimens (thaw step). For conducting multiple freeze thaw cycles the freeze and thaw steps are repeated. After 24 hours in the 60±1°C water bath, remove specimens and place in a water bath at 25±0.5°C for 2 hours ± 10 minutes. Approximately 25mm of water should be above the specimens. It may be necessary to add ice to the water bath to prevent the temperature from rising above 25±0.5°C. Not more than 15 minutes should be required for the water bath to reach 25±0.5°C. Remove specimens from water bath and test.

The indirect tensile strength of the dry and conditioned specimens were determined at 25°C. This was done by placing the specimens individually between two bearing plates in a

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testing machine such that the load is applied along the diameter of the specimen. A Universal Testing Machine (UTM) 100 by Industrial Process Controls Ltd. (IPC) was used to conduct the testing in accordance with AASHTO T283 (1993). The load was applied at a constant rate of movement of the testing machine head of 50mm per minute. The maximum load was recorded and the following equation was used to calculate the tensile strength.

$$S_t = \frac{2000 \times P}{\pi \times t \times D} \qquad \text{(equation 4.1)}$$

where:

S_t = tensile strength (kPa),

P = maximum load (N),

t = specimen thickness (mm), and

D = specimen diameter (mm).

A numerical index or resistance of an HMA mixture to the effects of water is the ratio of the original strength that is retained to that of the moisture conditioned strength is the tensile strength ratio (TSR) shown in equation 4.2.

$$TSR = \frac{S_2}{S_1} \qquad \text{(equation 4.2)}$$

where:

S_2 = average tensile strength of wet subset, and

S_1 = average tensile strength of dry subset.

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4.4.2 Dynamic Modulus Testing

The testing procedure for dynamic modulus testing was derived from NCHRP Report 513 Simple Performance Tester for Superpave Mix Design (Bonaquist et al. 2003). The conditioning of the specimens followed the procedure outline in AASHTO T283.

A 100mm diameter by 150mm high cylindrical specimen was tested under a repeated uniaxial, compressive, haversine unconfined load at the appropriate test temperatures. A Universal Testing Machine (UTM) 100 was used to conduct the testing with a temperature controlled testing chamber. The testing configurations for the dynamic modulus test are shown in Table 4.1.

Table 4.1 Dynamic Modulus Testing Configurations

	Fatigue	Rutting
Temperature	$T_{eff\ fatigue}$	$T_{eff\ rutting}$
Dynamic Load	Induce 75-150μstrain	Induce 75-150μstrain
Loading Rates	0.02 to 25Hz	0.02 to 25Hz

The effective test temperatures for fatigue and rutting are presented later in this dissertation. The dynamic stress was determined based on the 25 Hz conditioning cycle that caused corresponding strain in the HMA specimen that exceeded 75 – 150 microstrain.

There was a total of six test frequencies that were conducted at each test temperature. These test frequencies along with the number of loading cycles are given in Table 4.2. The testing sequence was conducted from high to low frequencies to mitigate the amount of deformation induced upon the specimens during testing.

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Table 4.2 Cycles for Test Sequence

Frequency, Hz	Number of Cycles
25	200
10	100
5	50
1	20
0.1	6
0.02	6

Three axial linear variable differential transducers (LVDT's) were fixed at 120° around the perimeter of the specimen in order to record the strain at the middle of the specimen over the length of the test. Witczak et al. (2002) found that as one increases the number of LVDT's and the number of replicate specimens, the standard error of the mean decreases. Three LVDT's were used as part of this study because of the availability of the device developed by Shedworks, Inc. The LVDT's were adjusted to the end of their linear range so the entire range of the LVDT's are available during the course of testing (Witczak et al. 2002).

Specimens were placed in the testing chamber until the effective test temperature was attained in the test specimen. This was found with the aid of a dummy specimen with a temperature sensor embedded in the center of the specimen placed in the test chamber. There was also another temperature probe not embedded in a specimen but placed on the wall in the environmental chamber that measured the skin (air) temperature. After the effective test temperature was reached, the specimen was then centered under the loading platens so as to not place an eccentric load on the specimen, and tested.

There are four main calculations that are performed by the associated software. The first is the loading stress, σ_o, that is applied to the specimen during the test.

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$$\sigma_o = \frac{\overline{P}}{A}$$ (equation 4.3)

where:

σ_o = stress (kPa),

$\overline{P}$ = average load amplitude (kN), and

A = area of specimen (m^2).

The recoverable axial strain from the individual strain gauges, ε_o, is determined as follows:

$$\varepsilon_o = \frac{\overline{\Delta}}{GL}$$ (equation 4.4)

Where:

ε_o = strain (microstrain/microstrain),

$\overline{\Delta}$ = average deformation amplitude (mm), and

GL = gauge length (mm).

Dynamic modulus, $|E^*|$ for each LVDT:

$$|E^*| = \frac{\sigma_o}{\varepsilon_o}$$ (equation 4.5)

The final equation is used to determine the phase angle, for each LVDT:

$$\phi = \frac{t_i}{t_p}(360)$$ (equation 4.6)

where:

ϕ = phase angle,

t_i = average time lag between a cycle of stress and strain (sec), and

t_p = average time for a stress cycle (sec).

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The software that was available for this project performed the above calculations was developed by IPC Global (2000a). The software reported the |E*| and the phase angle for the individual LVDTs and the averaged |E*| and the phase angle as well as the permanent and resilient micro-strain and the applied stress for each load cycle.

4.4.3 Dynamic Creep Testing

The testing procedure for dynamic creep testing was derived from NCHRP Report 513 Simple Performance Tester for Superpave Mix Design (Bonaquist et al. 2003). The conditioning of the specimens followed the procedure outline in AASHTO T283. The dynamic creep testing is done on the specimen after the dynamic modulus testing.

A 100mm diameter by 150mm high cylindrical specimen was tested under a repeated uniaxial, compressive, haversine unconfined load at the appropriate test temperatures. A Universal Testing Machine (UTM) 100 and UTM 5 were used to conduct the testing with a temperature controlled testing chamber in accordance with NCHRP Report 513 (Bonaquist et al. 2003). Two testing machines were used because dynamic creep testing is more time consuming than dynamic modulus testing, for example, to test a specimen can take up to forty-five minutes for dynamic creep testing and 15 minutes for dynamic modulus testing.

The strains (permanent deformation) were measured directly through the actuator on the machines. Again the specimens were placed in the testing chamber until the effective test temperature was attained on the test specimen. This was found with the aid of a dummy specimen with a temperature sensor embedded in the center of the specimen. After the effective test temperature was reached, the specimen was then centered under the loading platens so as to not place an eccentric load on the specimen. The loading regime for this test

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was modified because this test when conducted correctly will deform the specimen so that no further testing can be accomplished. The stress was changed from 600kPa to 300kPa and the test stopped at 10,000 load cycles as opposed to stopping the test after 30,000 microstrain which is excessive deformation. Also, the loading duration was changed from a 0.1 second load period followed by a 0.9 second dwell period to 0.1 second load period followed by a 0.1 second dwell period so that testing time decreased from about 4 hours to forty-five minutes.

There was a three step process for flow number calculation. The procedure consisted of 1) numerical calculation of the strain rate; 2) smoothing of the creep data; and 3) identification of the minimum smoothed creep rate, as this is where the flow number occurs. Again the software developed by IPC Global performed the following calculations (2000b). The following equation was used to determine the creep rate.

$$\frac{d(\varepsilon_p)_i}{dN} = \frac{(\varepsilon_p)_{i+\Delta N} - (\varepsilon_p)_{i-\Delta N}}{2\Delta N} \qquad \text{(equation 4.7)}$$

where:

$\frac{d(\varepsilon_p)_i}{dN}$ = rate of change of strain with respect to cycles or creep rate at i cycle (1/cycle),

$(\varepsilon_p)_{i+\Delta N}$ = strain at i+ΔN cycles,

$(\varepsilon_p)_{i-\Delta N}$ = strain at i-ΔN cycles, and

ΔN = number of cycles sampling points.

The next step required that the data be smoothed through a running average of five points. Two creep rates were used, before and after and including the creep rate at that instant.

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$$\frac{d\varepsilon_i^{'}}{dN} = \frac{1}{5}\left(\frac{d\varepsilon_{i-2\Delta N}}{dN} + \frac{d\varepsilon_{i-\Delta N}}{dN} + \frac{d\varepsilon_i}{dN} + \frac{d\varepsilon_{i+\Delta N}}{dN} + \frac{d\varepsilon_{i+2\Delta N}}{dN}\right)$$ (equation 4.8)

where:

$\frac{d\varepsilon_i^{'}}{dN}$ = smoothed creep rate at i sec (1/cycles),

$\frac{d\varepsilon_{i-2\Delta N}}{dN}$ = creep rate at i-2ΔN cycles (1/cycles),

$\frac{d\varepsilon_{i-\Delta N}}{dN}$ = creep rate at i-ΔN cycles (1/cycles),

$\frac{d\varepsilon_i}{dN}$ = creep rate at i cycles (1/cycles),

$\frac{d\varepsilon_{i+\Delta N}}{dN}$ = creep rate at i+ΔN cycles (1/cycles), and

$\frac{d\varepsilon_{i+2\Delta N}}{dN}$ = creep rate at i+2ΔN cycles (1/cycles).

The final step was to determine the cycle where the minimum creep rate occurs in the data set. If no minimum occurred during the test, then the flow number was reported as being greater than or equal to the number of loads applied during the course of the test. When several minimum creep rates occurred in a data set, then the first minimum value was reported as the flow number.

The dynamic creep test (i.e. repeated load test, flow number test) is based on the repeated loading and unloading of an HMA specimen where the permanent deformation of the specimen is recorded as a function of the number of load cycles. The standard loading is for 0.1 second followed by a 0.9 second unloading of the specimen. The following

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description can be shown graphically in Figure 4.2. The flow number is based up on the onset of tertiary flow (or the minimum strain rate recorded during the course of the test).

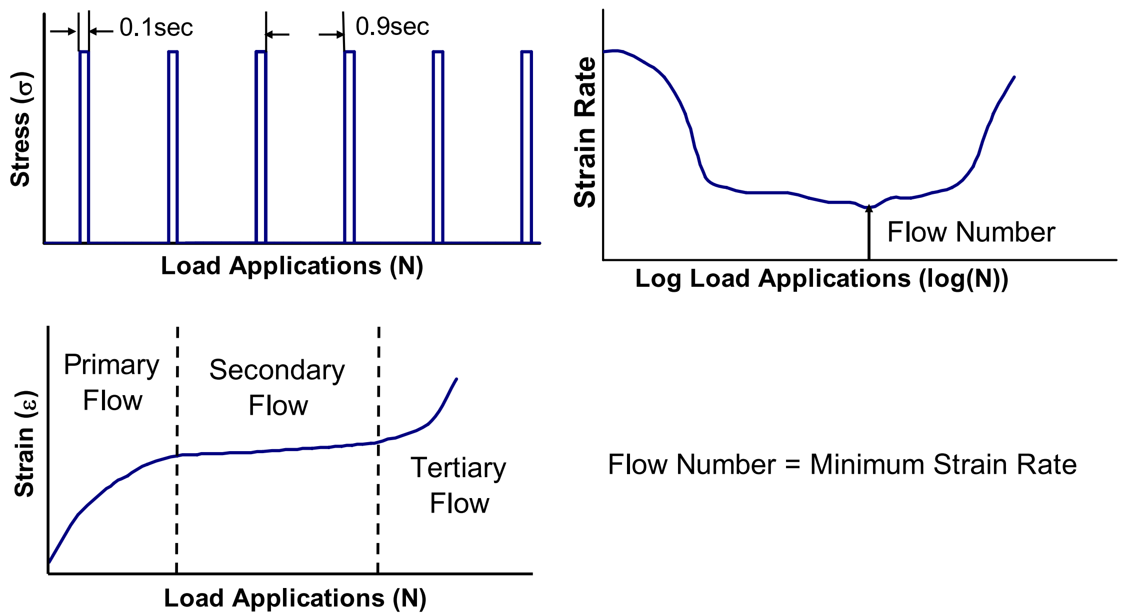

Figure 4.2 Flow Number Loading (Robinette, 2005)

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CHAPTER 5 SAMPLE PREPARATION

5.1 Introduction

The following sections discuss the procurement of samples that are representative of the field mix that was sampled during the 2000, 2004, and 2005 construction seasons.

5.2 Maximum Theoretical Specific Gravity (G_{mm})

The maximum theoretical specific gravity (G_{mm}), also known as the Rice specific gravity, was measured according to AASHTO T209. The precision outlined in the specification states that the acceptable range of two test results for a single operator is ±0.011 standard deviations from the mean, which is the difference of two properly conducted tests. For this research project field mix was used, in which there is not as much control as with laboratory mixtures. In order to achieve a representative sample, quartering of the mixture was done to mitigate differences between samples. In reviewing the standard deviations of the two G_{mm} samples for each project, it was found that all of the sampled mixtures fell within the single operator precision. Table 5.1 shows the mean and standard deviations for each of the mixes. Of the twenty-one mixes presented in Table 5.1, six of the HMA mixtures do not contain recycled asphalt pavement (RAP). RAP is a variable product because one stockpile can constitute several sources of RAP and each source has a unique gradation, binder content, age, and depth of milling. The addition of RAP to a mix can contribute to the variability in the characteristics of field samples.

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Table 5.1 G_{mm} Mean and Standard Deviation for Each Project

Project	Mix Type/Traffic	Mean ISU G_{mm}	Std. Dev.	Contractor JMF G_{mm}	RAP (%)
M-50 Dundee	3E1	2.519	0.0011	2.511	10.0
M-36 Pinckney	3E3	2.511	0.0028	2.488	15.0
M-45 Grand Rapids	3E3	2.513	0.0000	2.509	-
M-84 Saginaw	3E3	2.543	0.0151	2.550	20.0
M-21 St. Johns	3E3	2.489	0.0003	2.488	13.0
BL I-96 Howell	4E3	2.501	0.0089	2.480	15.0
M-21 Owosso	5E3	2.470	0.0031	2.470	10.0
M-66 Battle Creek	4E3	2.470	0.0043	2.480	15.0
M-50 Dundee	4E3	2.538	0.0025	2.520	-
US-12 MIS	4E3	2.491	0.0054	2.490	17.0
M-59 Brighton	3E10	2.502	0.0034	2.485	15.0
Michigan Ave. Dearborn	3E10	2.493	0.0025	2.496	15.0
VanDyke, Detroit	3E30	2.604	0.0103	2.577	-
US-23 Hartland	3E30	2.492	0.0019	2.494	15.0
I-75 Levering Road	3E10	2.443	0.0042	2.430	18.0
I-196 Grand Rapids	5E10	2.499	0.0018	2.499	-
I-75 Clarkston	4E30	2.487	0.0007	2.467	12.0
M-53 Detroit	4E10	2.563	0.0023	2.553	8.0
Michigan Ave. Dearborn	4E10	2.485	0.0012	2.464	10.0
I-75 Toledo	5E30	2.507	0.0074	2.510	-
I-94 Ann Arbor	4E30	2.515	0.0000	2.514	-

A comparison was made between Iowa State University (ISU) and the contractors' G_{mm} supplied in the JMF. Figure 5.1 illustrates the comparison of laboratory G_{mm} and contractor G_{mm}. Some differences exist between the ISU and contractor JMF G_{mm} as shown in Figures 5.1 and 5.2. As the asphalt content increases, the G_{mm} decreases due to the fact that asphalt cement has a lower specific gravity (approximately 1.020 to 1.030) than the aggregate. The increase of asphalt binder to a mixture results in a decrease in aggregate weight of the mix on a unit volume basis. Some of the mixtures do not fall within the multi-laboratory precision of 0.019. There are several explanations for this in addition to the RAP component. One reason for the difference is that these samples are from the field and there are numerous sources where variability and segregation can occur whereas the contractor values are from the mix design. Every attempt was made to obtain representative field samples from sampling from mini stock piles, but prior construction processes could be not

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be controlled. A second possible reason for the difference is that the changes could have been made to the mix design in production that deviates from the JMF. A third reason is that the binder content in JMF could be higher or lower than what was stated. This will be commented on in the next section.

A two-way analysis of variance (ANOVA) with no interaction was used to compare project versus the two methods of obtaining a G_{mm} (JMF versus laboratory obtained). A 5% level of significance (α=0.05) was used to determine region of acceptance (Ayyub et al. 1997).

Table 5.2 shows that there is a statistical difference between the contractor JMF and the laboratory obtained G_{mm} value. As discussed above, this can be due to changes in aggregate percentages, gradation, binder content, sampling, and RAP.

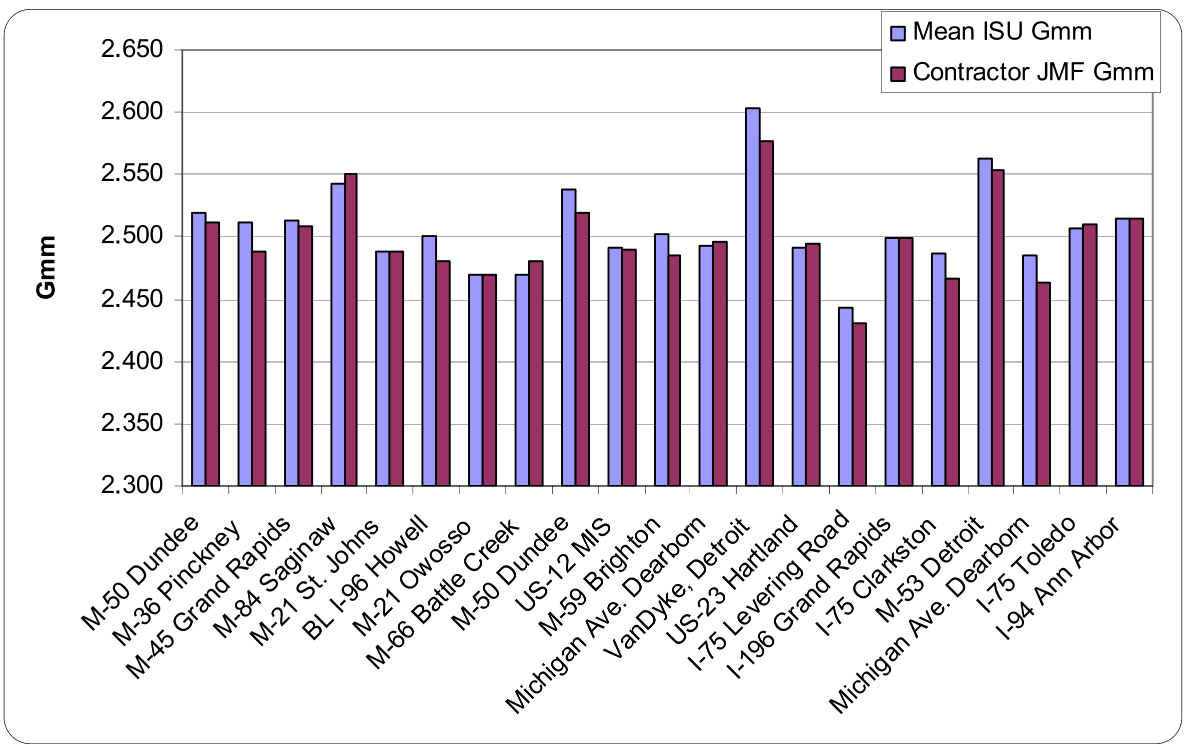

Figure 5.1 ISU and Contractor JMF G_{mm}

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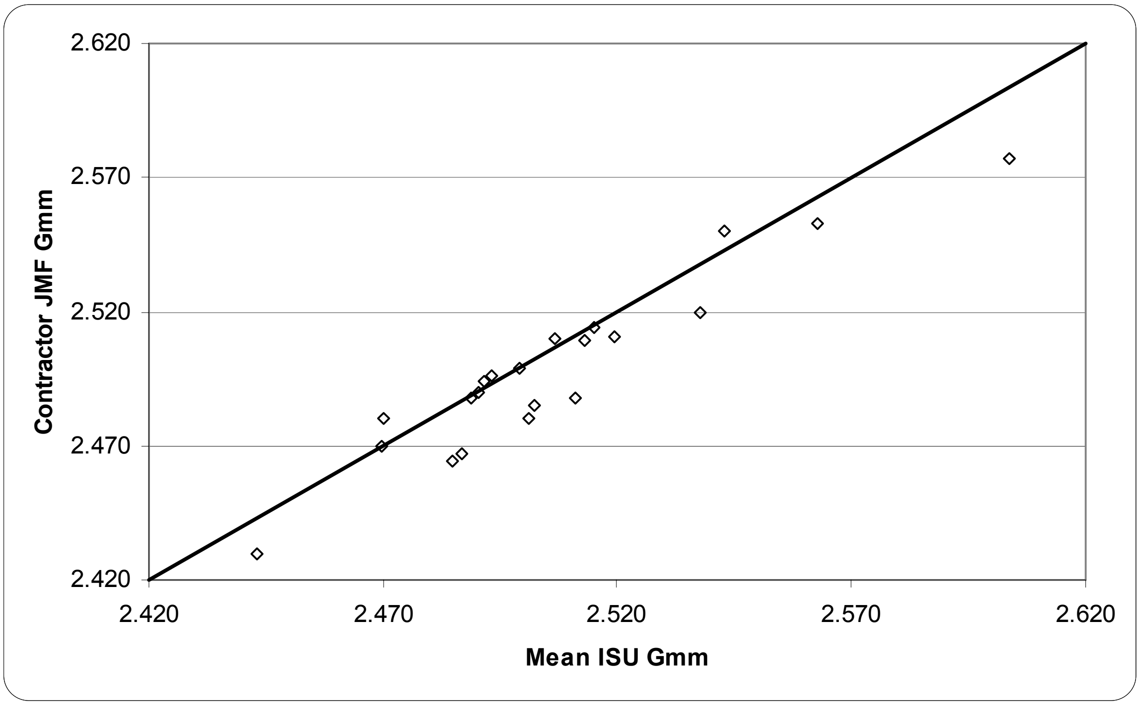

Figure 5.2 ISU and Contractor JMF G_{mm}

Table 5.2 2-Way ANOVA (With No Interaction) Comparing Laboratory G_{mm} to Contractor JMF

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Project	0.0444	20	0.00222	35.8551	1.6E-11	2.12416
Gmm Method	0.0006	1	0.0006	9.63832	0.00559	4.35124
Error	0.0012	20	6.2E-05			
Total	0.0462	41				

Asphalt binder constitutes the most expensive part of the HMA mixture. The differences in G_{mm} values between the contractor and ISU may be a result of differences in binder content. There can be an incentive for contractors to decrease the amount of asphalt binder in the mix to make the mix more economical in a low bid situation. In the state of Michigan, the production and placement of HMA is a single bid item and not separated between asphalt binder and aggregates, nor their placement. Thus a decrease in the binder

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content, yet still within specification tolerance, could save a contractor a substantial amount of money on a paving project.

5.3 Extraction Test

An important property of an HMA mixture is asphalt content. Satisfactory performance of an HMA mixture is a function of the asphalt content because mixtures with low asphalt contents are not durable, while ones with a high asphalt content are not stable. The asphalt content directly affects the volumetric properties such as air voids, voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), and film thickness. Asphalt content can also have an effect on HMA performance in terms of |E*| flow number, permanent deformation, and low temperature characteristics.

The asphalt content of the mixture was measured by an extraction test using the Abson method (ASTM D2172). The extraction test used solvents to dissolve the asphalt cement in the mix. The recovered asphalt cement and solvent are passed through filter paper not allowing the aggregate to pass through it. The advantage of this test is that it allows for the determination of the aggregate gradation and comparison to the JMF.

Table 5.3 summarizes the results of running extractions on each HMA mixture and comparing them to the JMF binder content. This table shows that fourteen of the twenty-one projects have lower binder contents than what the JMF reports. Another benefit of performing an extraction is that a sieve analysis can be done on the extracted aggregate and compared with the JMF. The JMF and the resulting extracted gradation can be seen in Appendix A. Figures 5.3 and 5.4 illustrate graphically the extracted binder content versus the JMF binder content. They clearly illustrate that the asphalt binder on majority of the

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projects is less than what the JMF calls for in production. This can result in G_{mm} values lower than what the JMF reports.

Table 5.3 Extracted Binder Content versus JMF Binder Content

Project	Mix Type/Traffic	Extracted Binder Content (%)	JMF Binder Content (%)
M-50 Dundee	3E1	5.0	5.4
M-36 Pinckney	3E3	5.2	5.8
M-45 Grand Rapids	3E3	4.9	5.1
M-84 Saginaw	3E3	4.7	4.6
M-21 St. Johns	3E3	4.5	5.4
BL I-96 Howell	4E3	5.0	5.5
M-21 Owosso	5E3	5.7	5.9
M-66 Battle Creek	4E3	5.4	5.5
M-50 Dundee	4E3	5.6	5.6
US-12 MIS	4E3	5.9	5.8
M-59 Brighton	3E10	5.2	5.7
Michigan Ave. Dearborn	3E10	5.9	5.6
VanDyke, Detroit	3E30	4.7	5.2
US-23 Hartland	3E30	5.7	5.5
I-75 Levering Road	3E10	4.7	5.5
I-196 Grand Rapids	5E10	5.7	5.6
I-75 Clarkston	4E30	5.3	5.8
M-53 Detroit	4E10	5.2	5.6
Michigan Ave. Dearborn	4E10	5.6	5.8
I-75 Toledo	5E30	5.4	5.4
I-94 Ann Arbor	4E30	6.0	6.6

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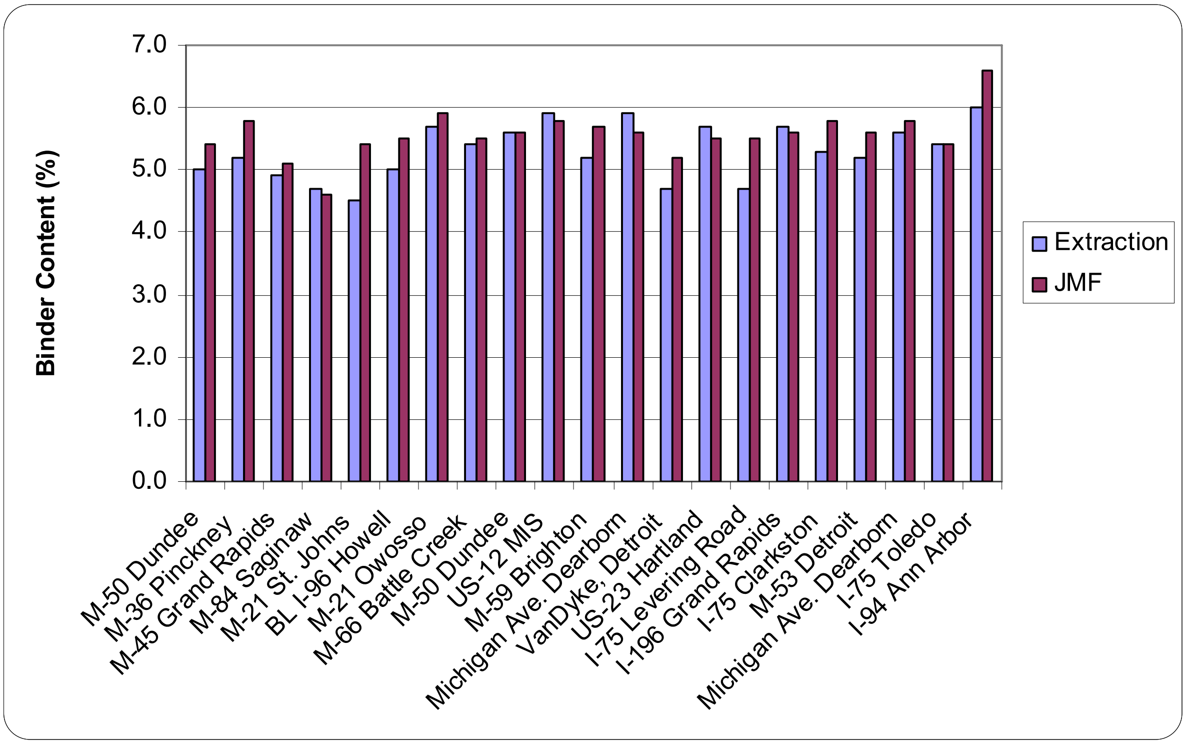

Figure 5.3 ISU and Contractor Binder Contents

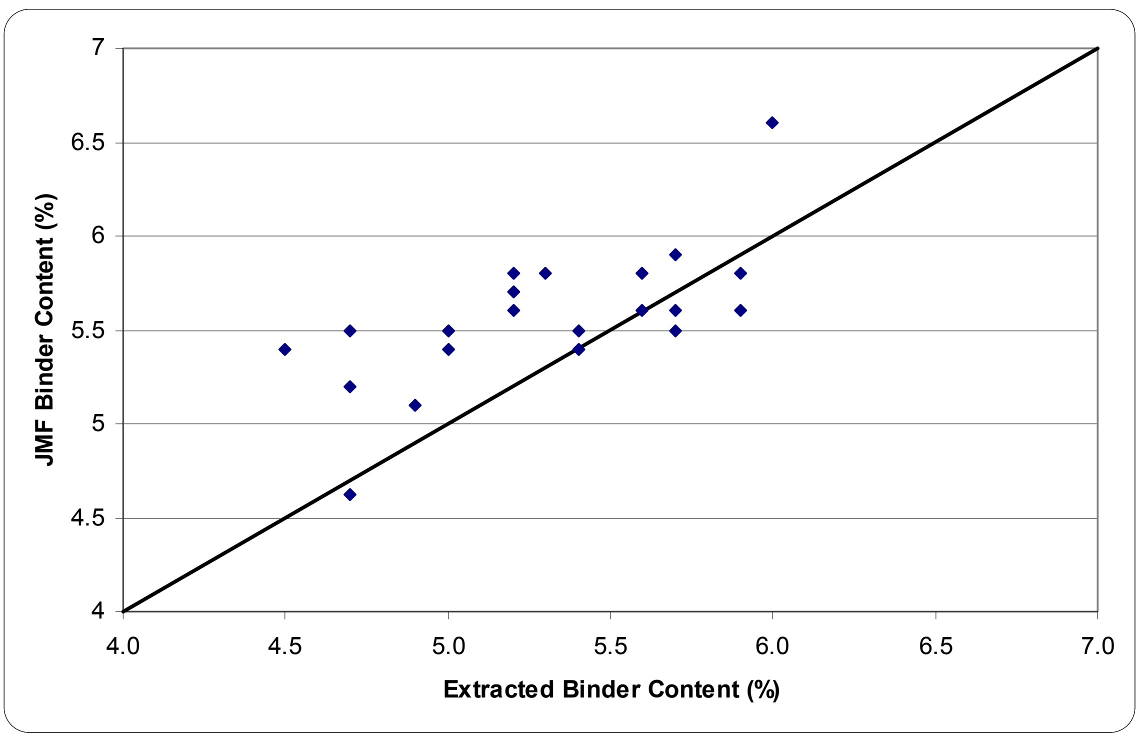

Figure 5.4 ISU versus Contractor Binder Contents

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A two-way ANOVA with no interaction was the statistical tool used to analyze the binder contents obtained from the laboratory and the JMF. A 5% level of significance (α=0.05) was used to determine region of acceptance (Ayyub et al. 1997). Table 5.4 shows that there is a statistical difference between the contractor JMF and the laboratory obtained binder content from field produced mixtures. This can be due to changes in gradation, RAP content, or decreasing the binder content at the plant.

Table 5.4 2-Way ANOVA (With No Interaction) Comparing Laboratory Extracted Binder Content to Contractor JMF

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Project	5.61219	20	0.28061	4.93948	0.00038	2.12416
Method	0.75201	1	0.75201	13.2374	0.00164	4.35124
Error	1.13619	20	0.05681			
Total	7.50039	41				

Two-way ANOVA's with no interaction were used at each sieve size to determine if the percentage of the aggregate weight has changed on the sieves. A 5% level of significance (α=0.05) was used to determine region of acceptance. Table 5.5 shows that the gradation at each sieve size is statistically the same except at the #200 sieve where statistical differences result. For the most part the contractor's JMF compares well with the gradation from the extraction procedure. Figure 5.5 shows a comparison of the sieve analysis results from the #200 sieve. The figure shows that there is a difference in #200 material between the contractor JMF and the results from the extraction and sieve analysis. On average, the material passing the #200 sieve was less from extracted field mixtures than the JMF.

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Table 5.5 2-Way ANOVA (With No Interaction) Comparing Laboratory Extracted Gradation to JMF Gradation

Sieve Size (mm) % Passing	2-Way ANOVA Results JMF vs. Extraction
1 (25)	Not Statistically Different
3/4 (19)	Not Statistically Different
1/2 (12.5)	Not Statistically Different
3/8 (9.5)	Not Statistically Different
#4 (4.75)	Not Statistically Different
#8 (2.36)	Not Statistically Different
#16 (1.18)	Not Statistically Different
#30 (0.60)	Not Statistically Different
#50 (0.30)	Not Statistically Different
#100 (0.15)	Not Statistically Different
#200 (0.075)	Statistically Different

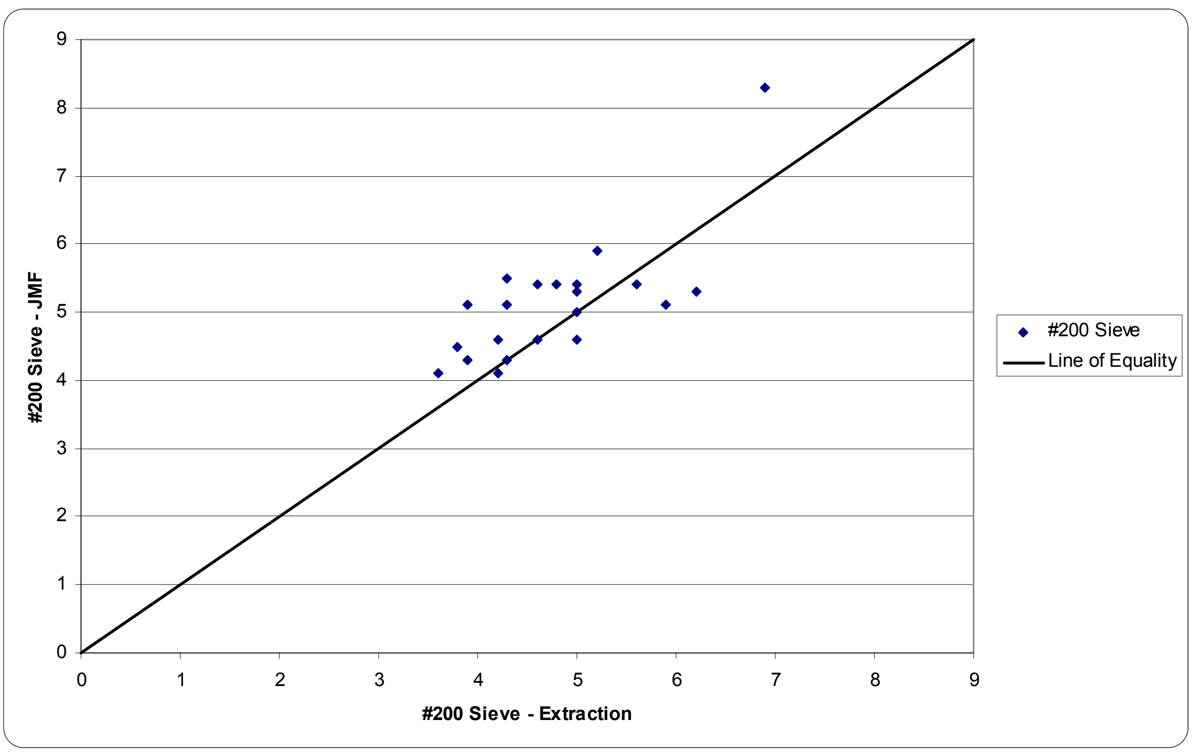

Figure 5.5 Comparison of Material Passing the #200 Sieve

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5.4 Compaction of Gyratory and Marshall Specimens

In Michigan, mix designs are based on compacting specimens to N_{des}, which allows for the air voids of the specimen to be measured according to AASHTO T166 (Barak 2005). In order to compact gyratory specimens, a correction factor is needed to compact the specimens to height. The ratio of the estimated G_{mb} via volumetric measurements of weight, height, and diameter to that of the measured G_{mb} via saturated surface dried constitutes the correction factor. Typically, HMA mixtures have a correction factor of 1.0 to 1.05. For Phase I and Phase II Superpave gyratory specimens, a correction factor of 1.02 was used for fine mixes and a correction factor of 1.04 was used for coarse mixtures. The correction factor was refined when the measured air voids were not between 7±1% and additional specimens were procured with a new correction factor and the air voids measured again. For the Marshall specimens, the sample mass was kept constant and graphs of air voids versus number of blows were constructed for each project. The number of blows to achieve 7% air voids was estimated from the graphical relationship for each mix. The air voids were measured for the specimens and if they were not within 7±1% then additional specimens were made by adjusting the number of blows.

All Superpave gyratory specimens for Phase I and Phase II were compacted with a Pine Superpave Gyratory (SGC) model AFGC125X in accordance with the Superpave Mix Design manual (Asphalt Institute 2001). This machine was selected because of availability, familiarity, and high production capability. The SGC was fully calibrated to ensure that the specimens were compacted to the correct height at an angle of 1.25° with a pressure of 600kPa in accordance with Superpave compaction criterion.

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Samples were split according to the weights required to achieve 63.5, 95, and 170mm for the SGC specimens. The Marshall specimens used a batch weight of 1,200g and then compacted to the required number of blows per side to achieve 7±1% since the Marshall specimen target height is 63.5mm. The SGC specimen weights were determined using the G_{mm} test results and the guidance outlined in Superpave Mix Design (Asphalt Institute 2001).

Specimens were left to cool until room temperature was achieved. At that time they were labeled and prepared for bulk specific gravity testing (G_{mb}). A total of 420 samples were compacted for Phase I and 420 samples were compacted for Phase II.

5.5 Bulk Specific Gravity of Gyratory and Marshall Specimens

The bulk specific gravity (G_{mb}) was measured on all the specimens using AASHTO T166. In according with AASHTO T283, all specimens (Superpave and Marshall) must have measured air voids of 7±1%. The air voids were measured using AASHTO T269. For those specimens that are cut and cored it was anticipated that the air voids would not change significantly, hence the 7±1% air void specification applies to gyratory compacted specimens. All volumetric data for the specimens of this project can be found in Appendix B.

5.6 Volumetrics of Sawed/Cored Test Specimens

The volumetrics of the sawed/cored specimens were measured on all the specimens using AASHTO T269. The volumetric properties of the sawed/cored specimens can be seen in Appendix B. It was noticed that on the average, the air voids of the sawed/cored specimens were lower than that of the gyratory specimens, this relationship can be seen in Figure 5.6. This relationship makes sense because high air voids exist around the perimeter and at the ends of gyratory compacted specimens. When the ends of the specimens were

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removed and the sample cored from the center of the Superpave gyratory compacted sample, some of the air voids are removed. The change in air voids ranged from -2.1 to +1.1%.

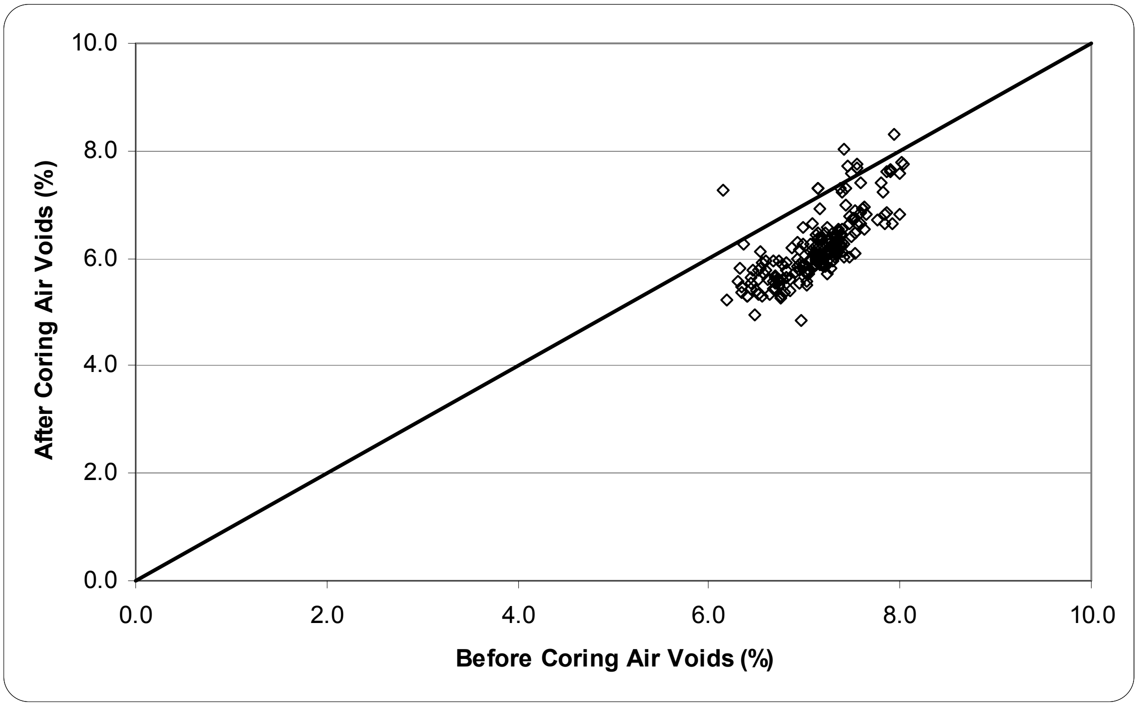

Figure 5.6 Air Voids Before and After Sawing/Coring

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CHAPTER 6 TESTING SETUP

6.1 Testing Parameters – Phase I

The testing parameters of conditioning period, compaction method, and diameter of specimen were examined before Phase II testing commenced. To address the conditioning period, the objective was to determine what number of freeze-thaw cycles will cause the same damage to SGC specimens compared to Marshall specimens of the same mixture for testing the resistance of compacted bituminous mixtures to moisture-induced damage using AASHTO T283. Section 3.2.1 provides a summary for conducting AASHTO T283.

6.2 Testing Parameters – Phase II

In order to address issues related to testing parameters, past literature was consulted, engineering judgment was exercised, and contacts were utilized and specimens were tested to verify the parameters if needed. The testing parameters are discussed in section 6.2.1 for AASHTO T283 and 6.2.2 for dynamic modulus testing.

6.2.1 AASHTO T283

The only testing parameter for AASHTO T283 testing for Phase II is the number of freeze-thaw cycles determined from Phase I. Additional parameters that are stated in the test procedure are air voids, saturation level, test temperature for freezing and thawing along with time requirements at each temperature, test temperature prior to testing, and loading rate. Please refer to section 3.4.1 to the testing parameters that are outlined for AASHTO T283.

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6.2.2 Dynamic Modulus

The testing parameters of test temperature, confinement, and stress level were determined prior to testing. The number of freeze-thaw cycles were determined from Phase I. Each parameter is discussed in more detail in the subsequent sections.

6.2.2.1 Test Temperatures

The testing temperatures for intermediate and high temperature dynamic modulus and flow number testing are stipulated by an effective temperature (T_{eff}) reported in NCHRP Report 465 (Witczak et al. 2002). Effective temperature is defined as "a single test temperature at which an amount of permanent deformation would occur equivalent to that measured by considering each season separately throughout the year" (Robinette 2005). The equation for effective temperature for rutting (dynamic modulus and flow number) is (Robinette 2005):

$$T_{eff\ rutting} = 30.8 - 0.12\ z_{cr} + 0.92\ MAAT_{design} \qquad \text{(equation 6.1)}$$

where:

z_{cr} = critical depth down from pavement surface (mm), and
$MAAT_{design}$ = mean annual air temperature (ºC).

$$MAAT_{design} = MAAT_{average} + K_{\alpha}\sigma_{MAAT} \qquad \text{(equation 6.2)}$$

where:

$MAAT_{average}$ = mean annual air temperature (ºC),
K_{α} = appropriate reliability level of 95% (1.645), and
σ_{MAAT} = standard deviation of distribution of MAAT for site location.

The critical depth to be considered was 20mm from the mixture surface. The $MAAT_{average}$ was collected from the Michigan State Climatology Office from stations that were located in close proximity to where each job was paved. The σ_{MAAT} was found in LTPPBind v2.1 as the high air temperature standard deviation. LTPPBind is a software program that provides

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guidance on asphalt binder grade selection based on climatic information. The rutting effective test temperatures based on equation 6.1 are summarized in Table 6.1.

Table 6.1 Rutting Effective Test Temperatures (°C)

Site	$MAAT_{design}$ (°C)	σ_{MAAT} (°C)	$T_{eff\ rutting}$ (°C)
M-45 Grand Rapids	10.4	1.1	37.9
Michigan Ave, Detroit 3E10	11.8	1.1	39.2
Michigan Ave, Detroit 4E10	11.8	1.1	39.2
M-66 Battle Creek	10.8	1.1	38.3
I-75 Levering	7.0	1.1	34.8
US-12 MIS	11.6	1.4	39.1
Vandyke	11.8	1.1	39.2
M-21 St. Johns	10.5	1.0	38.0
M-36 Pinckney	11.6	1.2	39.1
I-94 Ann Arbor SMA	11.6	1.2	39.1
Dundee M-50 3E1	11.2	1.3	38.7
M-53 Detroit 8 Mile	11.8	1.1	39.2
US-23 Hartland	10.0	1.1	37.6
Saginaw M-84	10.1	1.2	37.7
Toledo I-75	12.1	1.3	39.5
I-196 Grand Rapids	10.4	1.1	37.9
I-75 Clarkston	10.7	1.0	38.2
M-59 Brighton	10.1	1.0	37.7
M-21 Owosso	10.1	1.0	37.7
BL I-96 Howell	10.1	1.0	37.7
Dundee M-50 4E3	11.2	1.3	38.7

The effective pavement temperature for fatigue was determined by using the SHRP equation supplied by the FHWA and is shown in the following equations (Robinette 2005).

$$T_{eff\ fatigue} = 0.8\ MAPT - 2.7 \qquad \text{(equation 6.3)}$$

where:

MAPT = mean annual pavement temperature (ºC).

$$MAPT = T_{air} - 0.00618\ lat^2 + 0.2289\ lat + 42.2\ (0.9545) - 17.78 \qquad \text{(equation 6.4)}$$

where:

$MAPT = T_{20mm}$ = temperature at 20-mm depth from pavement surface (ºC),
T_{air} = mean annual air temperature (ºC), and
lat = latitude of location (degrees).

The $MAAT_{average}$ from equation 6.2 was used for T_{air} in equation 6.4. The latitude was determined by location of where the project was paved.

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Based on the above methods the following effective test temperatures were used for each individual project listed in Table 6.2 for fatigue testing.

Table 6.2 Fatigue Effective Test Temperatures (°C)

Site	T_{air} (°C)	Latitude (degrees)	MAPT (°C)	$T_{eff\ fatigue}$ (°C)
M-45 Grand Rapids	10.4	42.88	29.5	20.9
Michigan Ave, Detroit 3E10	11.8	42.42	31.0	22.1
Michigan Ave, Detroit 4E10	11.8	42.42	31.0	22.1
M-66 Battle Creek	10.8	42.37	30.0	21.3
I-75 Levering	7.0	45.57	25.3	17.5
US-12 MIS	11.6	42.23	30.4	21.6
Vandyke	11.8	42.42	31.0	22.1
M-21 St. Johns	10.5	43.02	29.7	21.1
M-36 Pinckney	11.6	42.30	30.8	21.9
I-94 Ann Arbor SMA	11.6	42.30	30.8	21.9
Dundee M-50 3E1	11.2	41.92	30.3	21.5
M-53 Detroit 8 Mile	11.8	42.42	31.0	22.1
US-23 Hartland	10.0	42.58	29.3	20.7
Saginaw M-84	10.1	43.53	28.9	20.4
Toledo I-75	12.1	41.83	31.2	22.3
I-196 Grand Rapids	10.4	42.88	29.5	20.9
I-75 Clarkston	10.7	42.65	30.1	21.4
M-59 Brighton	10.1	42.97	29.4	20.8
M-21 Owosso	10.1	42.97	29.4	20.8
BL I-96 Howell	10.1	42.97	29.4	20.8
Dundee M-50 4E3	11.2	41.92	30.3	21.5

6.2.2.2 Unconfined or Confined Testing

Due to the large volume of specimens that were tested for this project, all specimens were tested unconfined. Past research was consulted and it was found that Witczak et al. (2002) determined that both unconfined and confined testing for the two test configurations yielded high correlations with field recorded pavement deformation and there was no significant statistical difference.

6.2.2.3 Stress Level

Finally the magnitude of the stress level was to be determined for each test setup. A review of the testing conducted as part of NCHRP Report 465 yielded no definitive stress

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level for each test setup (Witczak et al. 2002). The stress levels used were a function of test temperature and location. According to Robinette (2005), it was found that the stress level for dynamic modulus was dependent on the materials' response to the loading. FHWA recommended that the permanent strain at the different frequencies should be between 75 to 150 micro-strain and the load should be adjusted accordingly (Robinette 2005). Thus through the conditioning cycles the stress levels were determined for the dynamic modulus test at the intermediate and high temperatures on an iterative basis.

6.2.3 Testing Parameters – Dynamic Creep Testing

The dynamic stress level that was used for flow number was modified to 300kPa (43psi) for 10,000 load cycles, which simulates the damage that occurs in a pavement over a certain period of time. After the damage is done, another dynamic modulus test was conducted to measure the loss of stiffness due to the damage. Typically, dynamic stress level that is used for flow number is 600kPa (87psi), which simulates the stress level of the gyratory compactor and the contact (static) stress was 30kPa (4.4psi). The test is continued out to 30,000 accumulated microstrain or the onset of tertiary flow.

6.2.4 Predicting Dynamic Modulus

Numerous models have been developed to predict dynamic modulus values of HMA by using measurable variables like aggregate and asphalt characteristics, as well as the loading regimen. An extensive study was undertaken by Akhter and Witczak (1985) in an effort to identify variables that were relevant to a dynamic modulus predictive equation. These variables apply to the mix design process because they have a direct influence on the stiffness of the pavement layer. Over 130 mix designs were evaluated under this study with

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data contributions being made by The Asphalt Institute. From an analysis of the mix designs, it was determined that the mixture temperature was the most significant variable in a dynamic modulus predictive equation. This was in addition to the already identified variables that were controllable in terms of material properties, which include the amount and type of asphalt (asphalt content and viscosity) and the gradation of the aggregate (percent retained on the 3/4in, 3/8in, and #4 sieves and percent passing the #200), and air voids in the mix. The frequency of loading also played a significant role in a dynamic modulus predictive equation. Equation 6.5 shows the latest dynamic modulus equation developed by Witczak et al. (2002).

$$\log|E^*| = -1.249937 + 0.029232(\rho_{200}) - 0.001767(\rho_{200})^2 - 0.002841(\rho_4) - 0.058097(V_a) - \frac{0.802208(V_{beff})}{V_{beff}+V_a} + \frac{3.871977 - 0.0021(\rho_4) + 0.003958(\rho_{3/8}) - 0.000017(\rho_{3/8})^2 + 0.005470(\rho_{3/4})}{1+e^{(-0.603313-0.313351\times\log(f)-0.393532\times\log(\eta))}}$$

(equation 6.5)

where:
E^* = dynamic modulus (10^5psi),
η = bitumen viscosity (10^6psi),
f = loading frequency (Hz),
V_a = air void content (%),
V_{beff} = effective bitumen content (% by volume),
$\rho_{3/4}$ = cumulative percent retained on 19mm sieve,
$\rho_{3/8}$ = cumulative percent retained on 9.5mm sieve,
ρ_4 = cumulative percent retained on 4.75mm sieve, and
ρ_{200} = percent passing 0.075mm sieve.

The gradation inputs and effective binder content are determined from the job mix formula (JMF) supplied by the contractor. The loading frequencies have been predetermined and were previously stated in Table 4.2. The air void content has been determined from the bulk specific gravity testing. Bitumen viscosity was the only property that needed to be measured.

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The bitumen viscosity was determined by three different methods. The first method was the viscosity of the original binder, rolling thin film oven (RTFO) aged binder viscosity, and finally a calculated binder viscosity (Mirza and Witzcak 1995) to simulate mix/laydown conditions. The RTFO aging simulates the aging of the asphalt binder during production and construction of an HMA pavement. The forthcoming AASHTO Mechanistic Empirical Pavement Design Guide (M-E PDG) specifies the test temperatures at which the bitumen viscosities are to be performed at as shown in Table 6.3 (NCHRP 1-37A, 2004).

Table 6.3 Conventional Binder Tests and Corresponding Test Temperatures

Test	Temperature, °C
Penetration	15
Penetration	25
Rotational Viscosity	80
Rotational Viscosity	100
Rotational Viscosity	121
Rotational Viscosity	135
Rotational Viscosity	176

Considering the temperature specification of 176°C it was realized that this test temperature was unreasonably high and aging of the binder may occur at this high test temperature even at the asphalt plant, so 165°C was selected because this is the high end temperature when conducting AASHTO TP48 in order to determine the mixing and compaction temperatures. In some cases with the RTFO aged binder a bitumen viscosity reading at 80°C could not be obtained due to the stiffness and lack of fluidity of the binder.

Penetration testing was conducted in accordance with ASTM D5. Penetration testing measures the consistency of asphalt binder by applying a weighted needle to the sample over a given period of time. The penetration results were then converted to an equivalent

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viscosity (cP) in order to determine the temperature susceptibility of the binder; the conversion equation follows (NCHRP 1-37A, 2004).

$$\log \eta = 10.5012 - 2.2601 \log(Pen) + 0.00389 \log(Pen)^2 \qquad \text{(equation 6.6)}$$

where:

η = viscosity, Poise, and
Pen = penetration, mm/10.

Rotational viscosity testing was conducted in accordance with AASHTO TP48. Viscosity is a fundamental measurement unit of an asphalt binder and it measures the workability of a binder. A vessel was filled with a 10.5gram sample and a standard spindle is submerged in the binder. The viscometer was typically set to 20rpm and three measurements are made at the above outlined temperatures. Every asphalt binder for this research has been tested in the outlined manner.

The Mirza and Witczak (1995) equation was developed to convert the original binder viscosities to mix/laydown conditions (similar to RTFO aged material).

$$\log \log \eta_{t=0} = a_0 + a_1 \log \log(\eta_{orig}) \qquad \text{(equation 6.7)}$$

$$a_0 = (0.054405 + 0.004082 \text{ code})$$

$$a_1 = (0.972035 + 0.010886 \text{ code})$$

where:

$\eta_{t=0}$ = mix/laydown viscosity (cp) at temperature T_R (Rankine),
η_{orig} = original viscosity (cp) at temperature T_R (Rankine), and
Code = hardening resistance (code = 0 for average).

The value of zero was used for the code value. Research by Birgisson et al. (2005) found that rotational viscosity testing on RTFO aged material and the derived mix/laydown equation above yielded similar results.

The temperature susceptibility of each asphalt binder was determined by statistically regressing the logarithm of the logarithm of the mix/laydown bitumen viscosity against the logarithm of the test temperature in Rankine. The regression equation is as follows.

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$$\log \log \eta_{t=0} = A + VTS \log T_R \qquad \text{(equation 6.8)}$$

where:

A = regression intercept,
VTS = regression slope of the viscosity temperature susceptibility, and
T_R = temperature, Rankine.

Each binder has a unique intercept and slope. An equivalent bitumen viscosity was determined using the effective test temperatures at each location. This bitumen viscosity was then used in the dynamic modulus predictive equation. Results for the penetration and viscosity testing can be found in Appendix C: Bitumen Temperature Susceptibility.

Witczak et al. (2002) found that dynamic modulus testing has a strong relationship with field performance data from WesTrack (a full-scale test track), the FHWA's Accelerated Loading Facility (ALF), and MnRoad (an experimental test road) for permanent deformation. 100mm diameter by 150mm high cylindrical specimens were procured from materials from the individual test sites and tested under confined and unconfined loads. Various frequencies and temperatures were tested and the strains induced by a dynamic load were recorded. Different models for measuring dynamic modulus values were employed and statistically analyzed for goodness-of-fit. The strongest relationship to field rutting performance was shown to be $E^*/\sin\phi$, where the specimen is tested unconfined and modeled linearly. Tests that were conducted with a confining stress exhibited a poor relationship when compared to field measured rutting. In addition to testing dynamic modulus to correlate to rut performance, dynamic modulus was run at low and intermediate temperatures by Witczak et al, (2002) to determine its relationship with that of thermal and fatigue cracking from materials procured from the ALF, MnROAD, and WesTrack test sites.

Recently, Christensen et al, (2003) developed an effective approach to estimating the HMA modulus using the Hirsch model, a variation of the Burger model. The Hirsch model

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is based upon the law of mixtures which combines series and parallel elements of phases. The HMA complex modulus can be estimated by knowing the volumetric properties of the HMA along with the binder complex modulus. The binder complex modulus was obtained from conducting frequency sweep tests using a dynamic shear rheometer at the same frequencies as the dynamic modulus test for the mixtures. A 25mm parallel plate is used at high temperatures while an 8mm parallel plate is used for intermediate temperatures. The Hirsch model for the complex extensional modulus for an HMA mixture are as follows:

$$|E^*|_{mix} = Pc\left[4,200,000\left(1-\frac{VMA}{100}\right)+3|G^*|_{binder}\left(\frac{VFA\times VMA}{10,000}\right)\right] + (1-Pc)\left[\frac{1-\frac{VMA}{100}}{4,200,000}+\frac{VMA}{3VFA|G^*|_{binder}}\right]^{-1} \quad \text{(equation 6.9)}$$

where

E* = dynamic modulus (10^5psi),

$$Pc = \frac{\left(20+\frac{VFA\times 3|G^*|_{binder}}{VMA}\right)^{0.58}}{650+\left(\frac{VFA\times 3|G^*|_{binder}}{VMA}\right)^{0.58}} \quad \text{(equation6.10)}$$

where Pc is a contact factor,

VMA = voids in mineral aggregate (%),
G* = dynamic shear modulus (10^5 psi), and
VFA = voids filled with asphalt (%).

Christensen et al. (2003) found that there was very good agreement between the measured and predicted complex modulus values when using the Hirsch model. Also, there is good agreement between the Hirsch and Witczak models.

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CHAPTER 7 SENSITIVITY STUDY – EVALUATION OF AASHTO T283

7.1 Introduction

In the late 1970's certain HMA pavements in the United States began to experience distresses such as stripping, raveling, and rutting. These distresses are associated with the moisture sensitivity of an HMA pavement. Also, moisture damage in HMA pavements accelerate distresses such as fatigue, longitudinal, transverse, and block cracking. Therefore, research under NCHRP 4-08 was undertaken by Lottman (1978) and then later on by Tunnicliff and Root (1982). The current method of AASHTO T283 is based on the work conducted by Lottman (1978) and Tunnicliff and Root (1982). This test method is currently based on Marshall or Hveem compacted specimens and not Superpave gyratory compacted samples. Therefore another research project was undertaken to evaluate the previous and current mix design methods on moisture sensitivity of HMA mixtures.

Epps et al. (2000) conducted research by comparing the use of 100mm to 150mm test specimens in order to evaluate the effect of specimen size and compaction method on moisture damage testing. The 100mm diameter specimens were compacted using standard Marshall and Hveem methods. The 150mm diameter specimens were compacted using the Superpave Gyratory Compaction (SGC) method. The concept of the study was to create a standard method of testing 150mm diameter SGC specimens. The results of the Epps et al. (2000) study shows that no statistical differences exist in TSR's of 100mm diameter Marshall compacted specimens at one freeze-thaw cycle and the larger 150mm diameter SGC specimens did yield significantly different results than the 100mm diameter Hveem compacted samples. The work by Epps et al. (2000) was published in NCHRP Report 444

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where a more complete summary of the analysis and findings of comparing AASHTO T283 test results on 100mm and 150mm diameter specimens and the effect of compaction method can be found. AASHTO T283 currently allows for the testing of failure parameters, namely tensile strength ratio, of 100mm diameter specimens that are compacted using the standard Marshall or Hveem compaction methods.

7.2 Experimental Plan

The variety of HMA's examined are outlined below in Table 7.1. Different mix types, aggregate sources, laboratory test systems, and conditioning approaches were considered. A sensitivity study on the effects of specimen size and compaction method was conducted on a limited number of mixes to determine the amount of conditioning that should be sustained by the larger Superpave compacted specimens. Table 7.2 outlines the laboratory test plan for the sensitivity study. This plan extends the work completed for NCHRP Report 444 (Epps et al. 2000).

Table 7.1 Sensitivity Study Experimental Plan for Mix and Aggregate Types

PHASE 1 MOISTURE		
NMAS (mm)	Traffic Level (ESAL)	
	≤ 3,000,000	>3,000,000
25.0 or 19.0	Limestone - M50 Dundee	Limestone - M59 Brighton
	Gravel - M21 St. Johns	
12.5 or 9.5	Limestone - BL96 Howell	Limestone - I-196 Grand Rapids
	Gravel - M21 Owosso	Slag/Gabbro - I-75 Clarkston

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Table 7.2 Sensitivity Study Experimental Plan for Effect of Compaction Method and Conditioning Period on Performance

Conditioning Period	Unconditioned			Conditioned		
	100mm Marshall	100mm Superpave	150mm Superpave	100mm Marshall	100mm Superpave	150mm Superpave
AASHTO T283, Standard Conditioning Time	XXXXX[1]	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
AASHTO T283, 2 Times Standard Conditioning Time	N/A[2]	N/A	N/A	XXXXX	XXXXX	XXXXX
AASHTO T283, 3 Times Standard Conditioning Time	N/A	N/A	N/A	XXXXX	XXXXX	XXXXX

[1]X Represents a tested sample;
[2]N/A is not applicable.

Testing both 100mm and 150mm diameter SGC specimens allowed for the determination of the conditioning time necessary to produce the same tensile strength ratios as the 100mm diameter Marshall compacted specimens considering method of compaction and sample size. The standard conditioning of specimens adhered to AASHTO T283 for 100 and 150mm diameter specimens.

7.3 Objectives of Sensitivity Study

The objectives of Phase I were to examine a number of field mixes to find an equivalent number of freeze-thaw cycles that would meet moisture damage effects of the original AASHTO T283 specification, which are based upon Marshall compaction, using the newer Superpave gyratory compaction method. The effect of size and compaction method on results obtained following AASHTO T283 procedure was analyzed. Finally, a new minimum tensile strength ratio (TSR) was determined by the analysis instead of using the old TSR ratio of 80% which is based on the original AASHTO T283 specification.

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7.4 AASHTO T283 Test Results

Figures 7.1 through 7.7 show the results of AASHTO T283 testing by looking at the average of five test specimens per freeze-thaw cycle along with 95% confidence interval about the mean. Most of these projects illustrate that the 100mm diameter Marshall specimens produce lower tensile strength ratios (TSRs) than the 100mm and 150mm diameter Superpave specimens. For the most part, there is a decrease in TSR with increasing number of freeze-thaw cycles. These trends are consistent for the two trafficking levels considered. However, some mixes did show an increase in TSR as the number of freeze-thaw cycles increased similar to the previous research done by Lottman (1978), Root and Tunicliff (1982), and Epps et al. (2000). Table 7.4 ranks the mixtures for each project based on number of freeze-thaw cycles, compaction, and size of specimens. The ranking is based on a scale from one to seven where one is most moisture susceptible and seven is least moisture susceptible. For the most part the projects had the same ranking based on number of freeze-thaw cycles. Based on compaction method and diameter size, some projects were more variable and their rankings fluctuated based on compaction method, diameter size, and freeze-thaw cycles. Overall, I-196 Grand Rapids was the most moisture susceptible followed by M-50 Dundee and M-59 Brighton. M-21 Owosso ranked in the middle. The least moisture susceptible mix was I-75 Clarkston and M-21 St. Johns followed by BL I-96 Howell.

Table 7.3 and Figures 7.8 and 7.9 show that the average lowest TSR are for the 100mm diameter Marshall compacted specimens. In general, the 100mm diameter Superpave specimens had the highest TSR. Even though all specimens were compacted to the same density and air voids (7±1%), differences exist between the compaction methods. It

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can be hypothesized that Superpave compaction provides a more realistic method of compaction compared to field compaction due to a kneading action of the gyratory. The Marshall hammer is an impact method of compaction which really does not simulate field compaction. The gyratory compacter compacts the aggregates in a denser configuration with more particle on particle contact. The Marshall hammer, because it is an impact blow, can fracture coarse aggregate particles leaving aggregate surfaces not coated with asphalt which in turn may provide a lower TSR ratio. The method and specimens with the lowest standard deviation were the Superpave specimens. Interestingly, according to Figures 7.1 through 7.7 and Table 7.3, the 100mm diameter Marshall specimens had the highest level of variability. These results indicate that the Superpave specimens are more precise and the data is less spread out than the TSR values for the Marshall specimens. The coefficient of variation in Table 7.3 supports the concept of the TSR results being less dispersed for the Superpave specimens as well.

As suspected, the TSR is lowest on average once the specimens endured three freeze-thaw cycles and the highest TSRs occurred after only one freeze-thaw cycle. The coefficients of variation indicate that for all three compaction and size categories, three freeze-thaw cycles led to more precise TSR values, while the least precise readings are obtained after one freeze-thaw for Marshall specimens while more precise readings are obtained at one freeze-thaw cycle and least precise readings are obtained at three freeze-thaw cycles for the 150mm and 100mm diameter Superpave specimens, respectively.

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Table 7.3 Summary Statistics for Phase I Sensitivity Study

Project	Mean for 1 Freeze-Thaw Cycle			Project	Standard Deviation for 1 Freeze-Thaw Cycle			Project	Coefficient of Variation for 1 Freeze-Thaw Cycle		
	M100	S100	S150		M100	S100	S150		M100	S100	S150
M-50 Dundee	77.8	69.1	89.7	M-50 Dundee	12.9	10.8	16.8	M-50 Dundee	16.6	15.7	18.8
BL I-96 Howell	107.1	122.6	102.1	BL I-96 Howell	17.9	8.5	2.9	BL I-96 Howell	16.7	7.0	2.9
M-21 Owosso	87.6	108.7	90.2	M-21 Owosso	7.9	4.3	9.2	M-21 Owosso	9.0	3.9	10.2
M-59 Brighton	89.0	99.3	87.3	M-59 Brighton	15.5	6.0	12.5	M-59 Brighton	17.4	6.1	14.3
I-196 Grand Rapids	69.8	72.8	83.8	I-196 Grand Rapids	10.3	3.5	6.2	I-196 Grand Rapids	14.8	4.8	7.3
I-75 Clarkston	96.1	92.0	92.7	I-75 Clarkston	7.8	8.5	8.4	I-75 Clarkston	8.1	9.2	9.1
M-21 St. Johns	94.3	119.3	107.3	M-21 St. Johns	14.4	10.1	6.1	M-21 St. Johns	15.3	8.4	5.7
Average Mean	88.8	97.7	93.3	Average Std. Dev.	12.4	7.4	8.9	Average COV	14.0	7.9	9.8
Project	Mean for 2 Freeze-Thaw Cycle			Project	Standard Deviation for 2 Freeze-Thaw Cycle			Project	Coefficient of Variation for 2 Freeze-Thaw Cycle		
	M100	S100	S150		M100	S100	S150		M100	S100	S150
M-50 Dundee	70.0	79.7	82.3	M-50 Dundee	12.0	15.6	12.4	M-50 Dundee	17.2	19.6	15.1
BL I-96 Howell	99.4	117.8	98.0	BL I-96 Howell	11.4	14.7	4.6	BL I-96 Howell	11.4	12.5	4.7
M-21 Owosso	77.5	105.9	84.0	M-21 Owosso	4.0	9.4	7.8	M-21 Owosso	5.2	8.9	9.3
M-59 Brighton	77.4	90.3	80.6	M-59 Brighton	8.3	12.7	6.8	M-59 Brighton	10.7	14.0	8.4
I-196 Grand Rapids	58.0	67.4	71.1	I-196 Grand Rapids	3.9	5.5	2.5	I-196 Grand Rapids	6.7	8.2	3.5
I-75 Clarkston	93.3	92.3	96.4	I-75 Clarkston	9.8	10.6	8.1	I-75 Clarkston	10.6	11.5	8.4
M-21 St. Johns	83.2	110.0	103.4	M-21 St. Johns	7.9	15.0	9.4	M-21 St. Johns	9.5	13.6	9.1
Average Mean	79.8	94.8	88.0	Average Std. Dev.	8.2	11.9	7.4	Average COV	10.2	12.6	8.4
Project	Mean for 3 Freeze-Thaw Cycle			Project	Standard Deviation for 3 Freeze-Thaw Cycle			Project	Coefficient of Variation for 3 Freeze-Thaw Cycle		
	M100	S100	S150		M100	S100	S150		M100	S100	S150
M-50 Dundee	63.2	65.1	90.2	M-50 Dundee	12.3	7.2	21.3	M-50 Dundee	19.5	11.1	23.7
BL I-96 Howell	90.1	80.6	86.8	BL I-96 Howell	24.3	13.3	4.4	BL I-96 Howell	26.9	16.5	5.1
M-21 Owosso	79.4	90.0	74.1	M-21 Owosso	5.1	4.1	8.3	M-21 Owosso	6.5	4.6	11.2
M-59 Brighton	63.1	110.8	79.2	M-59 Brighton	3.6	6.4	11.5	M-59 Brighton	5.6	5.8	14.5
I-196 Grand Rapids	51.5	54.3	63.6	I-196 Grand Rapids	6.2	4.8	5.1	I-196 Grand Rapids	12.1	8.9	8.1
I-75 Clarkston	95.2	89.2	91.1	I-75 Clarkston	9.4	9.5	8.3	I-75 Clarkston	9.8	10.6	9.1
M-21 St. Johns	79.0	94.8	99.9	M-21 St. Johns	6.4	6.3	13.1	M-21 St. Johns	8.1	6.7	13.2
Average Mean	74.5	83.5	83.5	Average Std. Dev.	9.6	7.4	10.3	Average COV	12.6	9.2	12.1

M100=100mm Marshall,
S100=100mm Superpave, and
S150=150mm Superpave.

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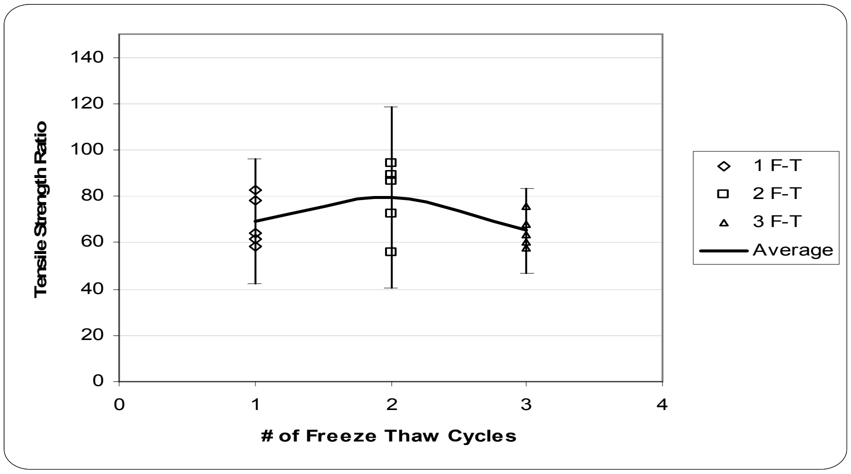
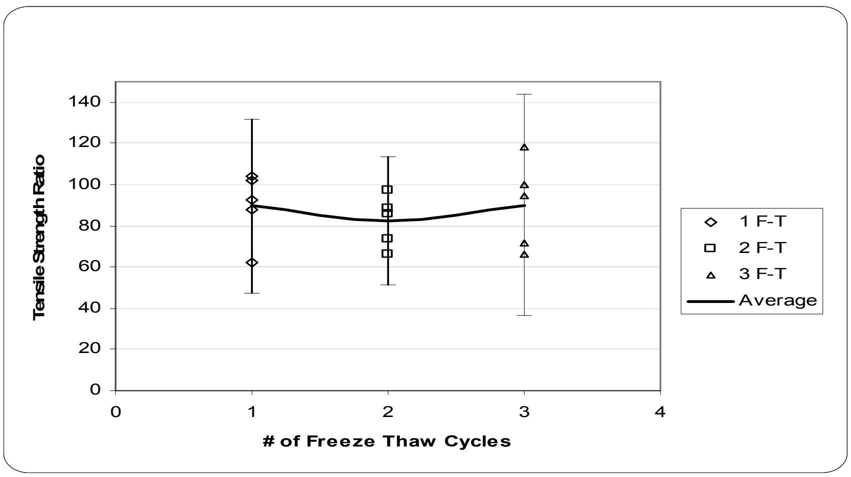
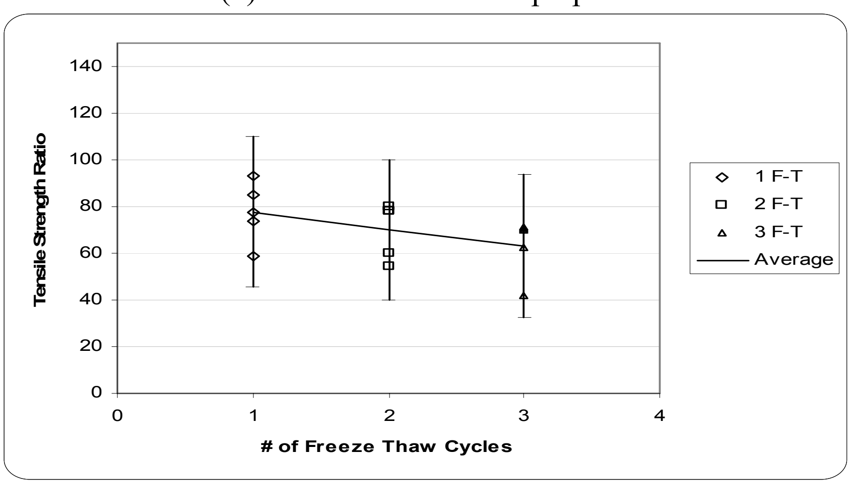


(a) 100mm Diameter Superpave



(b) 150mm Diameter Superpave



(c) 100mm Diameter Marshall

Figure 7.1 M-50 Dundee Average TSR versus Number of Freeze-Thaw Cycles with 95% Confidence Intervals

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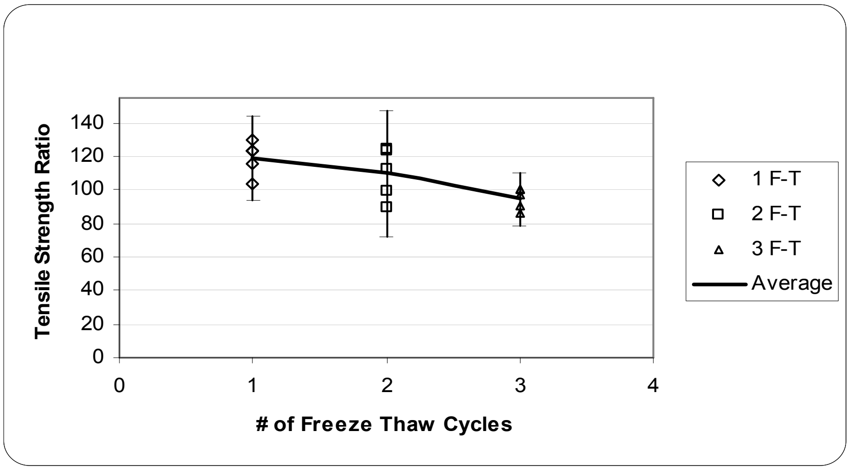
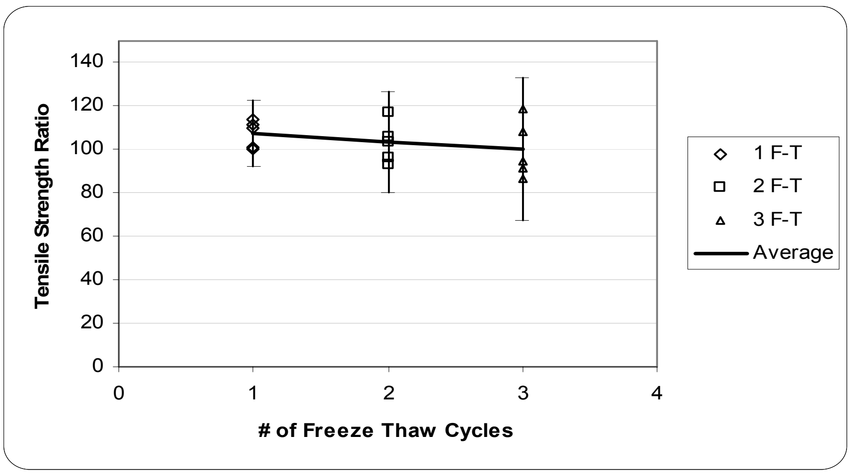
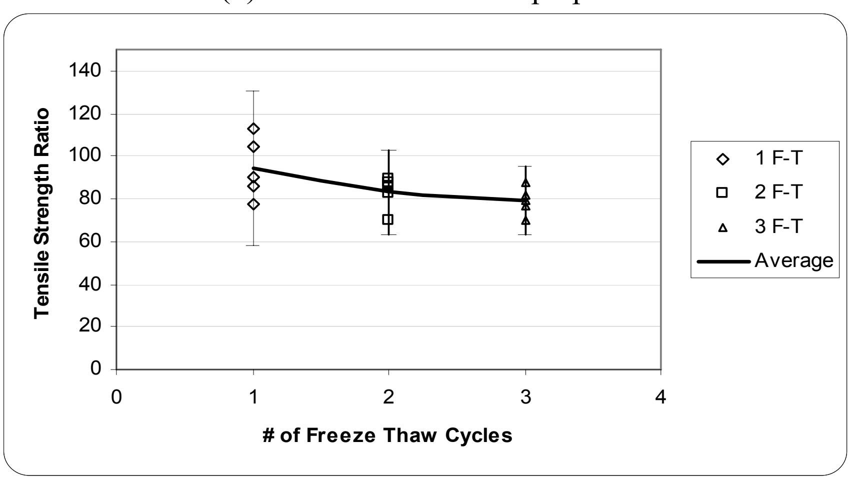


(a) 100mm Diameter Superpave



(b) 150mm Diameter Superpave



(c) 100mm Diameter Marshall

Figure 7.2 M-21 St. Johns Average TSR versus Number of Freeze-Thaw Cycles with 95% Confidence Intervals

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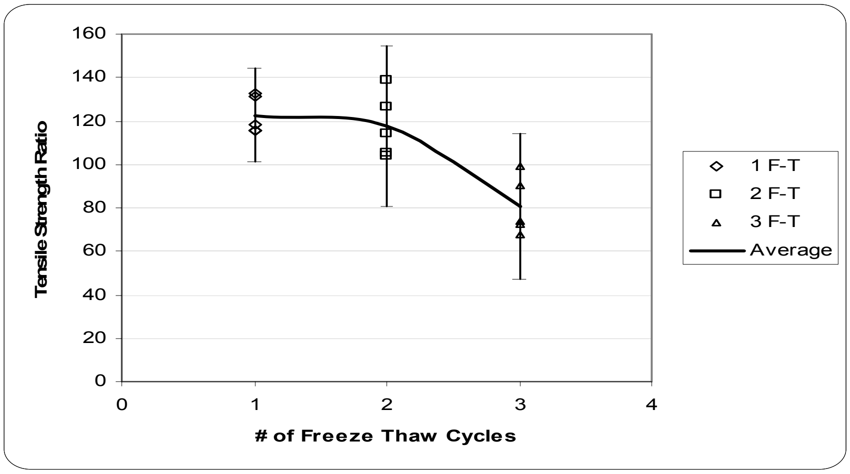
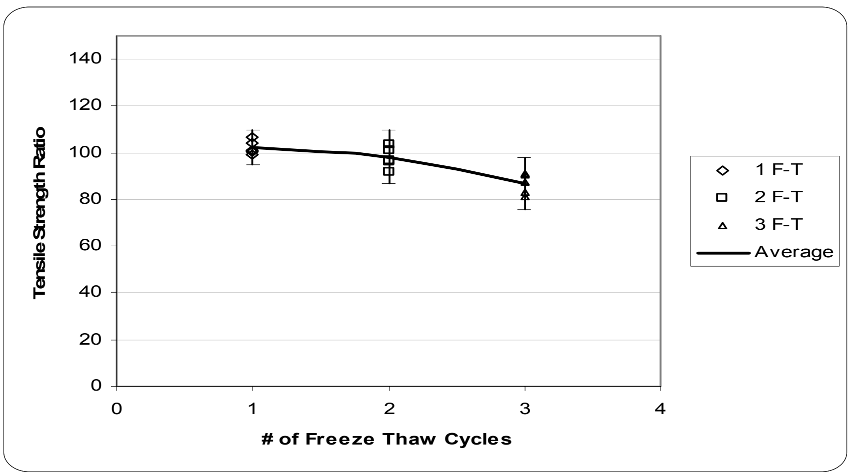
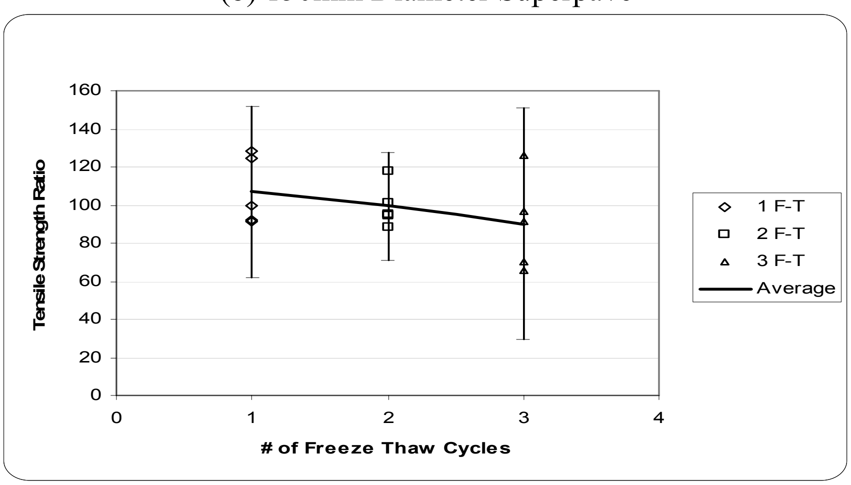


(a) 100mm Diameter Superpave



(b) 150mm Diameter Superpave



(c) 100mm Diameter Marshall

Figure 7.3 BL I-96 Howell Average TSR versus Number of Freeze-Thaw Cycles with 95% Confidence Intervals

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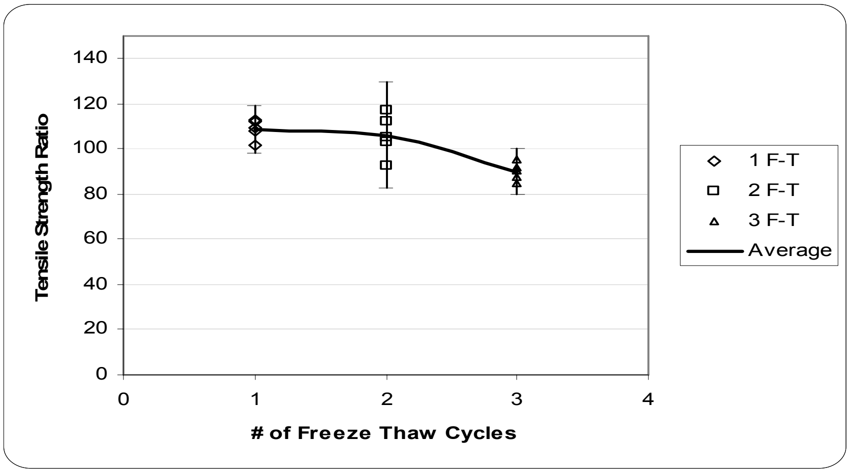
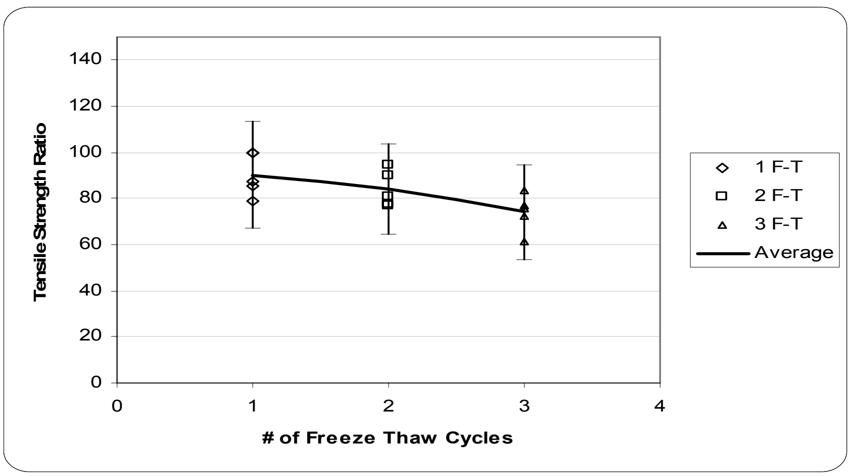
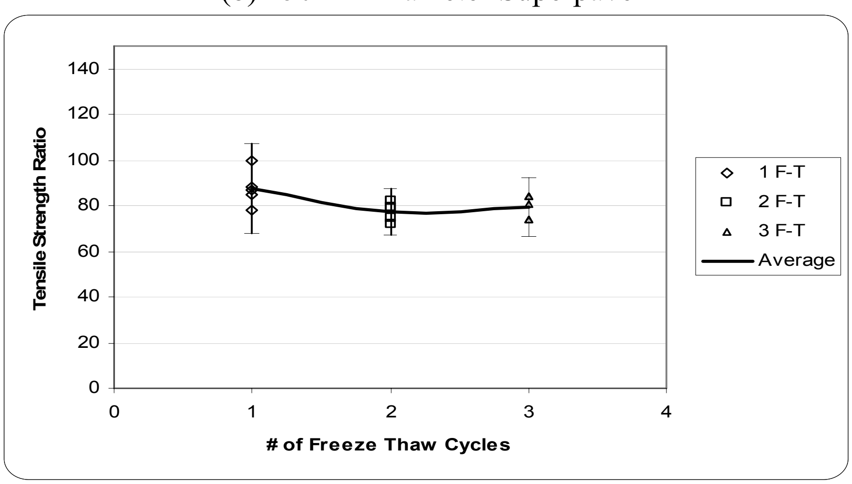


(a) 100mm Diameter Superpave



(b) 150mm Diameter Superpave



(c) 100mm Diameter Marshall

Figure 7.4 M-21 Owosso Average TSR versus Number of Freeze-Thaw Cycles with 95% Confidence Intervals

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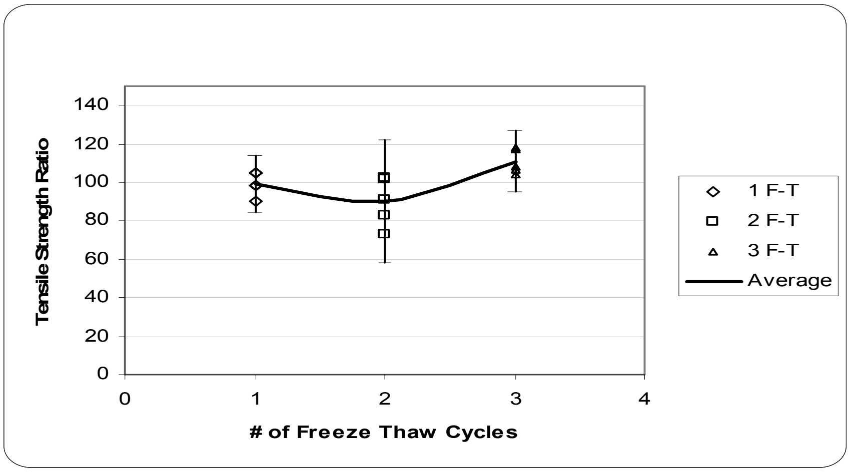
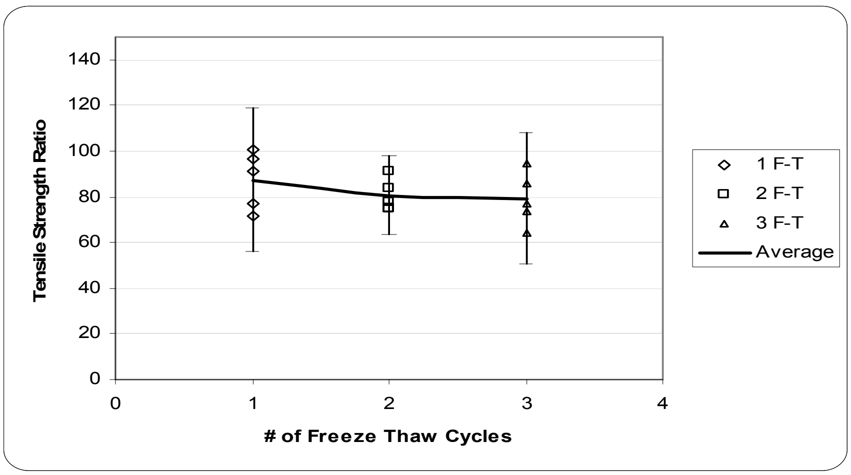
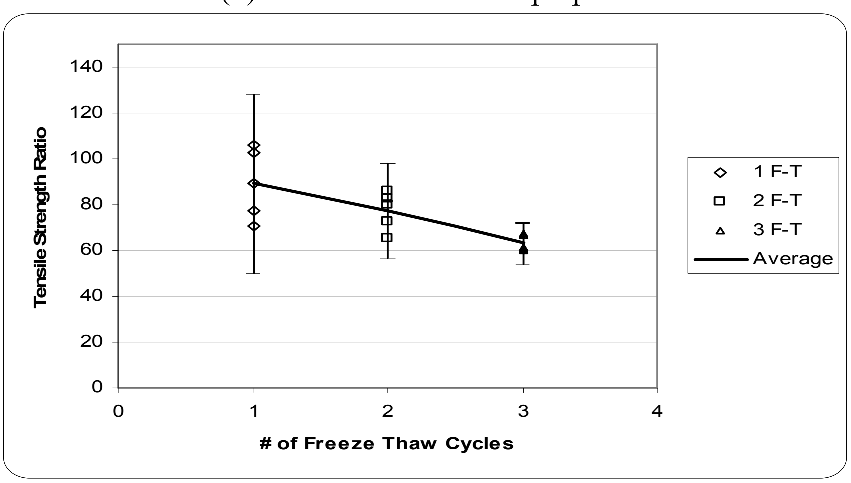


(a) 100mm Diameter Superpave



(b) 150mm Diameter Superpave



(c) 100mm Diameter Marshall

Figure 7.5 M-59 Brighton Average TSR versus Number of Freeze-Thaw Cycles with 95% Confidence Intervals

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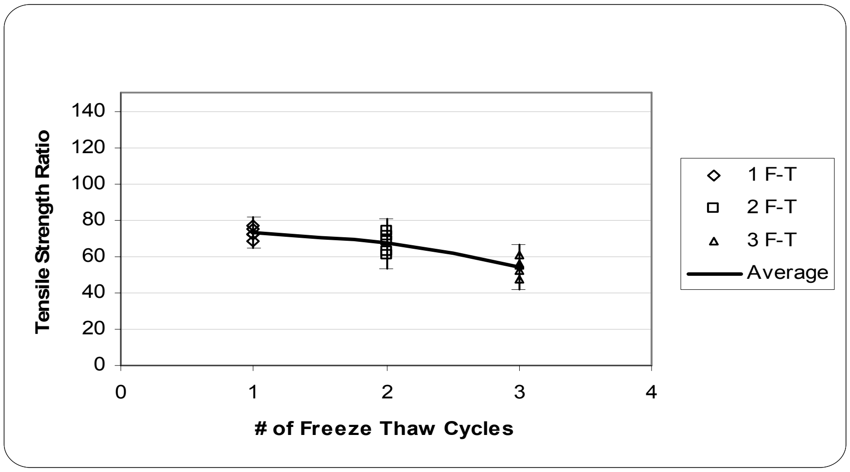
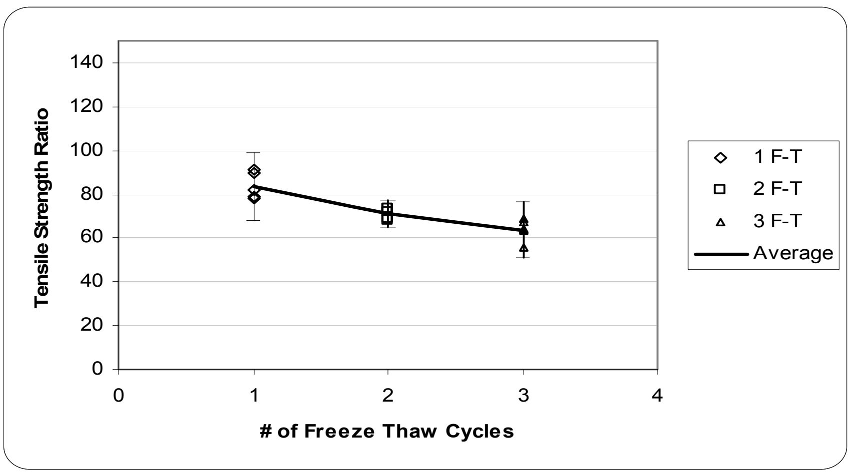
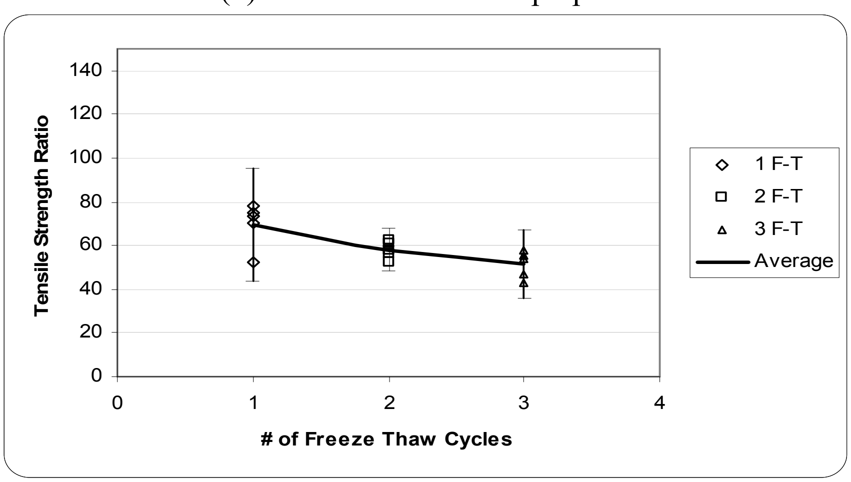


(a) 100mm Diameter Superpave



(b) 150mm Diameter Superpave



(c) 100mm Diameter Marshall

Figure 7.6 I-196 Grand Rapids Average TSR versus Number of Freeze-Thaw Cycles with 95% Confidence Intervals

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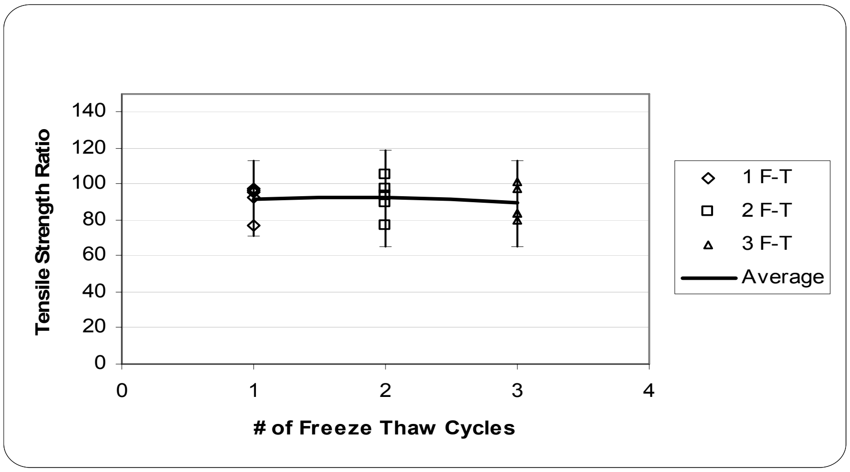
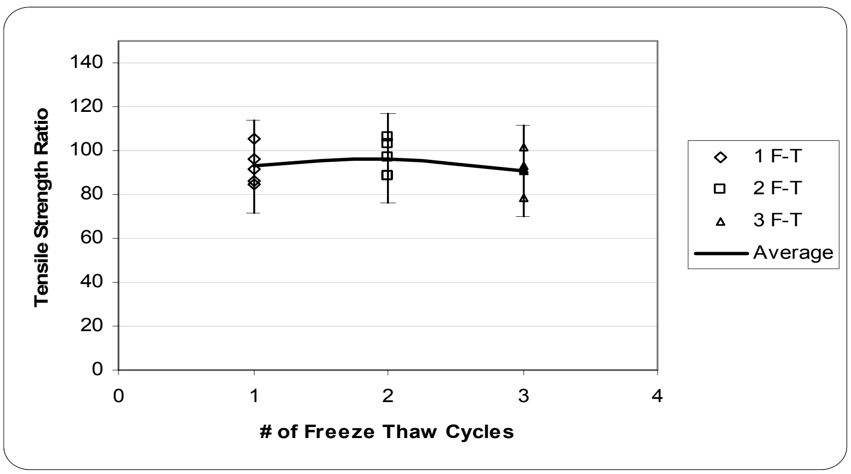
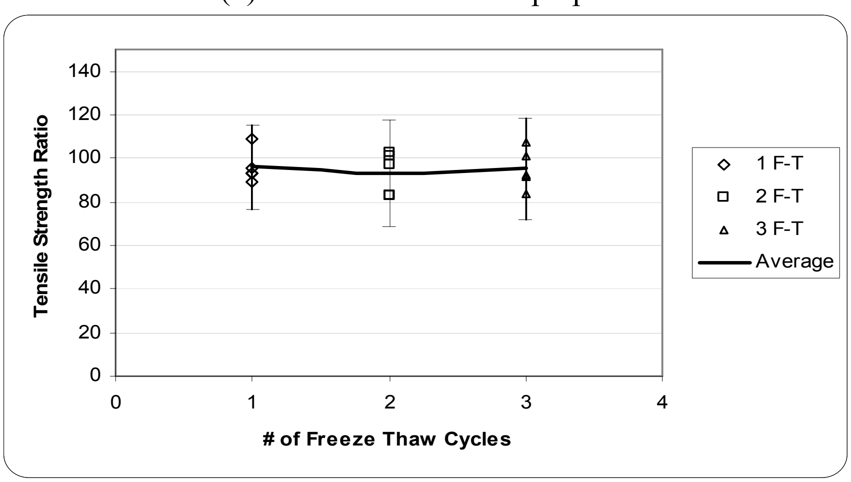


(a) 100mm Diameter Superpave



(b) 150mm Diameter Superpave



(c) 100mm Diameter Marshall

Figure 7.7 I-75 Clarkston Average TSR versus Number of Freeze-Thaw Cycles wit 95% Confidence Intervals

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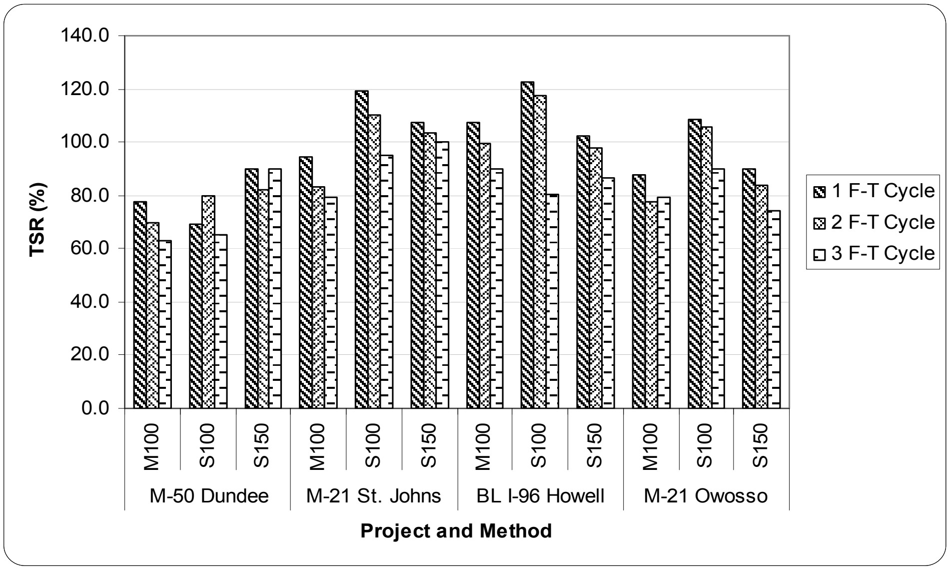

Figure 7.8 Average TSR Results for Traffic Level ≤3,000,000 ESAL's

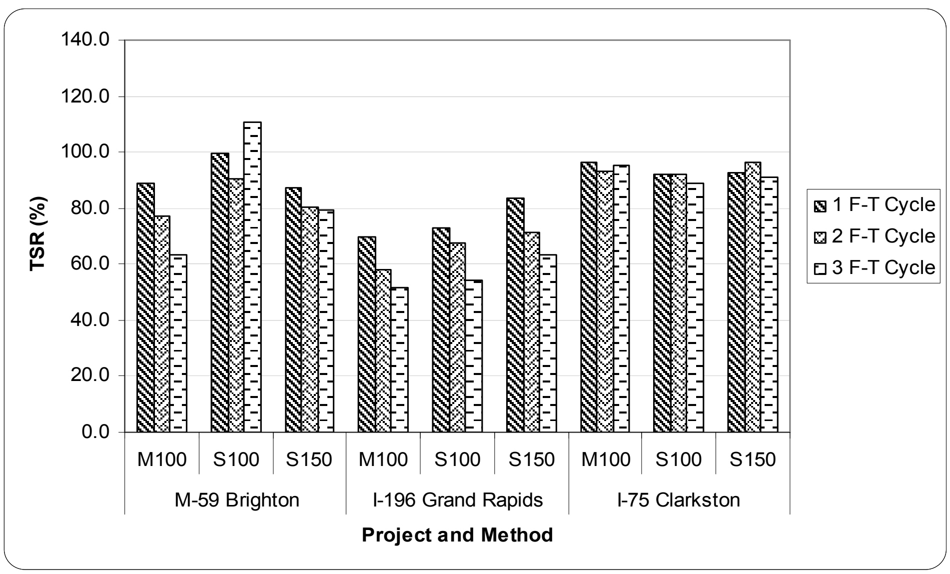

Figure 7.9 Average TSR Results for Traffic Level >3,000,000 ESAL's

Table 7.4 Ranking of Projects Based on TSR

Project	Average TSR for S100			Average TSR for M100			Average TSR for S150		
	TSR 1F-T	TSR 2F-T	TSR 3F-T	TSR 1F-T	TSR 2F-T	TSR 3F-T	TSR 1F-T	TSR 2F-T	TSR 3F-T
M-50 Dundee	1	2	2	2	2	3	3	3	5
BL I-96 Howell	7	7	3	7	7	6	6	6	4
M-21 Owosso	5	5	5	3	4	5	4	4	2
M-59 Brighton	4	3	7	4	3	2	2	2	3
I-196 Grand Rapids	2	1	1	1	1	1	1	1	1
I-75 Clarkston	3	4	4	6	6	7	5	5	6
M-21 St. Johns	6	6	6	5	5	4	7	7	7

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7.5 Analysis of Results

Two approaches were used to analyze the data in Phase I. The first approach was a statistical approach that analyzes the effects of project, compaction method, and number of freeze-thaw cycles. The second approach used a probabilistic analysis to determine a new minimum TSR ratio. The current minimum TSR ratio used is 80 percent for 100mm diameter Marshall compacted specimens.

The first statistical test used was the two-way Analysis of Variance (ANOVA) with no interactions to compare the dependent variable, TSR, and two independent factors are project and method of compaction (100mm Superpave, 150mm Superpave, and 100mm Marshall). A 5% level of significance (α=0.05) was used to determine region of acceptance. The goal of this analysis was to determine the number of freeze-thaw cycles required to attain an equivalent amount of damage of one freeze-thaw cycle for the 100mm diameter Marshall specimens for the SGC specimens. The compaction method, number of freeze-thaw cycles, and the change in size of the specimens are considered.

Five two-way ANOVA's with no interactions were constructed based on the available data. The analysis of this data provided the following five results:

1. 100mm Marshall versus 100mm Superpave versus 150mm Superpave at one freeze-thaw cycle shows that the TSR's are statistically the same based on method of compaction.
2. 100mm Marshall versus 100mm Superpave versus 150mm Superpave at two freeze-thaw cycles show that the TSR's are statistically the same based on method of compaction.

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3. 100mm Marshall versus 100mm Superpave versus 150mm Superpave at three freeze-thaw cycles show that the TSR's are statistically the same based on method of compaction.
4. 100mm Marshall at one freeze-thaw cycle versus 100mm Superpave at two freeze-thaw cycles versus 150mm Superpave at two freeze-thaw cycles show that the TSR's are statistically the same based on method of compaction.
5. 100mm Marshall at one freeze-thaw cycle versus 100mm Superpave at three freeze-thaw cycles versus 150mm Superpave at three freeze-thaw cycles show that the TSR's are statistically different based on method of compaction

Based on the results of the two-way ANOVA, in order to achieve the same moisture damage in the 100mm diameter Marshall specimens, three-freeze-thaw cycles are needed for the 150mm and 100mm diameter Superpave specimens. Generally, a highway agency does not have sufficient time to conduct three freeze-thaw cycles for each paving project during a construction season, therefore the criteria for the TSR ratio needs to be adjusted so one freeze-thaw cycle can still be used.

A second statistical analysis was undertaken to look at the effects of wet strength versus dry strength for each mixture. A two sample t-test was used to compare the mean dry strength to the mean wet strength (Ayyub et al. 1997). The following hypothesis was used:

$$H_o : \text{Dry Strength} = \text{Wet Strength}$$
$$\text{H}_\text{A} : \text{Dry Strength} \neq \text{Wet Strength}$$
$$\alpha = 0.05$$

Table 7.5 gives the results of the two-sample t-tests along with the average TSR for each group. The results show that when the dry strength and wet strength are statistically

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different, the average TSR is quite low or getting close to the threshold value of 80% except in some limited cases. The shaded in cells show those projects that have statistically different strengths for each of the three compaction methods and freeze-thaw cycles.

Table 7.5 Results of Two-Sample t-Tests

Project	100mm Diameter Marshall					
	1 Freeze-Thaw Cycle		2 Freeze-Thaw Cycle		3 Freeze-Thaw Cycle	
	Paired t-Test Results	Average TSR (%)	Paired t-Test Results	Average TSR (%)	Paired t-Test Results	Average TSR (%)
M-50 Dundee	*Statistically Different*	*78*	*Statistically Different*	*70*	*Statistically Different*	*63*
M-21 St. Johns	Not Statistically Different	94	*Statistically Different*	*83*	*Statistically Different*	*79*
BL I-96 Howell	Not Statistically Different	107	Not Statistically Different	99	Not Statistically Different	90
M-21 Owosso	*Statistically Different*	*88*	*Statistically Different*	*77*	*Statistically Different*	*79*
M-59 Brighton	Not Statistically Different	89	*Statistically Different*	*77*	*Statistically Different*	*63*
I-196 Grand Rapids	*Statistically Different*	*70*	*Statistically Different*	*58*	*Statistically Different*	*51*
I-75 Clarkston	Not Statistically Different	96	Not Statistically Different	93	Not Statistically Different	95
Project	**100mm Diameter Superpave**					
	1 Freeze-Thaw Cycle		**2 Freeze-Thaw Cycle**		**3 Freeze-Thaw Cycle**	
	Paired t-Test Results	**Average TSR (%)**	**Paired t-Test Results**	**Average TSR (%)**	**Paired t-Test Results**	**Average TSR (%)**
M-50 Dundee	*Statistically Different*	*69*	Not Statistically Different	80	*Statistically Different*	*65*
M-21 St. Johns	*Statistically Different*	*119*	Not Statistically Different	110	Not Statistically Different	95
BL I-96 Howell	*Statistically Different*	*123*	*Statistically Different*	*118*	*Statistically Different*	*81*
M-21 Owosso	*Statistically Different*	*109*	Not Statistically Different	106	*Statistically Different*	*90*
M-59 Brighton	Not Statistically Different	99	Not Statistically Different	90	*Statistically Different*	*111*
I-196 Grand Rapids	*Statistically Different*	*73*	*Statistically Different*	*67*	*Statistically Different*	*54*
I-75 Clarkston	Not Statistically Different	92	Not Statistically Different	92	Not Statistically Different	89
Project	**150mm DiameterSuperpave**					
	1 Freeze-Thaw Cycle		**2 Freeze-Thaw Cycle**		**3 Freeze-Thaw Cycle**	
	Paired t-Test Results	**Average TSR (%)**	**Paired t-Test Results**	**Average TSR (%)**	**Paired t-Test Results**	**Average TSR (%)**
M-50 Dundee	Not Statistically Different	90	Not Statistically Different	82	Not Statistically Different	90
M-21 St. Johns	Not Statistically Different	107	Not Statistically Different	103	Not Statistically Different	100
BL I-96 Howell	Not Statistically Different	102	Not Statistically Different	98	*Statistically Different*	*87*
M-21 Owosso	Not Statistically Different	90	*Statistically Different*	*84*	*Statistically Different*	*74*
M-59 Brighton	Not Statistically Different	87	*Statistically Different*	*81*	*Statistically Different*	*79*
I-196 Grand Rapids	*Statistically Different*	*84*	*Statistically Different*	*71*	*Statistically Different*	*64*
I-75 Clarkston	Not Statistically Different	93	Not Statistically Different	96	Not Statistically Different	91

A probabilistic analysis was used to determine a new minimum TSR for HMA using 100 and 150mm diameter SGC specimens. The lognormal distribution based on the Kolmogorov-Smirnov One-Sample Test using a p-value of 0.05 was selected for the TSR for the different compaction methods and number of freeze-thaw cycles since a lognormal distribution was applicable to all datasets investigated (Ayyub et al. 1997). In addition, a lognormal distribution is an appropriate selection since the TSR cannot be less than zero. The outputs containing the lognormal distribution and the appropriate test statistics can be seen in Appendix D and summarized below in Table 7.6.

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Table 7.6 Goodness of Fit Statistics for Phase I Distributions

Compaction Method	Diameter Size (mm)	# of Freeze-Thaw Cycles	Kolmogorov-Smirnov Statistic Lognormal Distribution	p-value
Superpave	150	1	0.15094143	0.045
Superpave	150	2	0.10983981	>0.150
Superpave	150	3	0.10919085	>0.150
Superpave	100	1	0.10134991	>0.150
Superpave	100	2	0.14599732	0.058
Superpave	100	3	0.07556771	>0.150
Marshall	100	1	0.13930827	0.084
Marshall	100	2	0.11497959	>0.150
Marshall	100	3	0.13629187	0.096

Historically, the Michigan Department of Transportation uses a TSR value of 80% after one freeze-thaw cycle for 100mm diameter Marshall specimens as the specification criteria for determining moisture susceptibility (Barak 2005). To determine an equivalent point with 150mm diameter Superpave specimens, all of the datasets were fit to a lognormal cumulative probability plot. The point of the 100mm diameter Marshall cumulative probability plot that coincided with a TSR value of 80% was determined. A horizontal line was then extended from that point to intersect with the cumulative probability plot for the 150mm diameter Superpave specimens tested after one freeze-thaw cycle. The point of intersection corresponded to a TSR value of 87%, as demonstrated in Figure 7.10 thus indicating that a threshold of 87% for TSR should be employed to maintain equivalent standards with the Marshall specimen usage. Following the same procedure, a threshold of 85% is recommended for 100mm diameter Superpave compacted specimens, as can be seen in Figure 7.11. Figure 7.12 shows the current 80% TSR specification for 150mm diameter Superpave gyratory compacted specimens is 70% TSR for 100mm diameter Marshall compacted specimens. These three figures illustrate that the current TSR specification of 80% needs to be changed if the same acceptance rate of mixtures is to be maintained.

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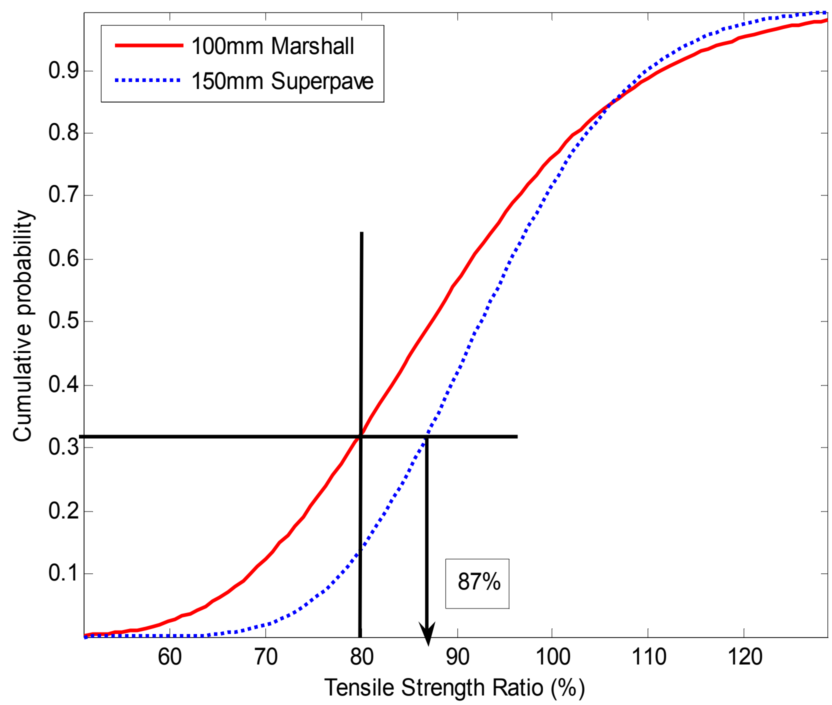

Figure 7.10 100mm Marshall versus 150mm Superpave at one freeze-thaw cycle

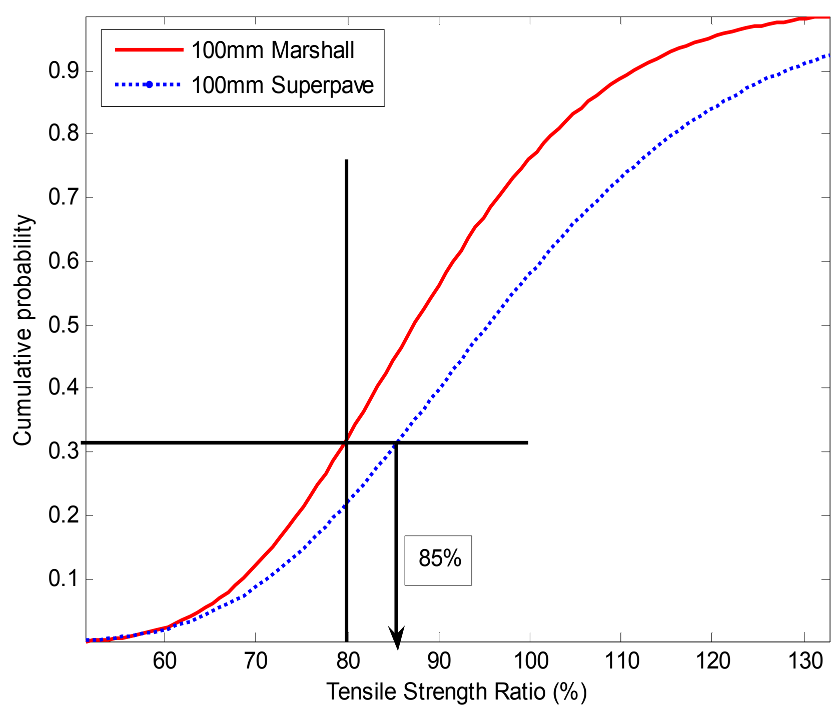

Figure 7.11 100mm Marshall versus 100mm Superpave at one freeze-thaw cycle

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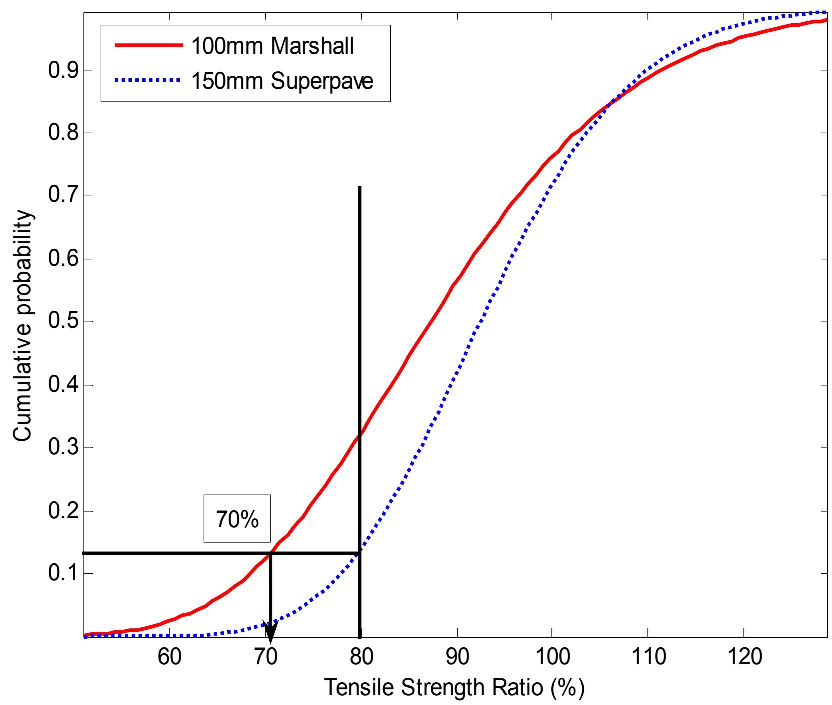

Figure 7.12 100mm Marshall versus 150mm Superpave at one freeze-thaw cycle

7.6 Comparison with NCHRP Report 444

The objective of Phase I of this dissertation is parallel to Task 2 in NCHRP Report 444 (Epps et al. 2000) which considered the comparison of four compaction methods. Phase I considered the use of seven HMA mixtures that were randomly selected and not knowing if that mixture is moisture susceptible. NCHRP Report 444 considered five aggregate sources; these sources are shown in Table 7.7 and the aggregates selected were based on whether they were moisture susceptible. Two aggregate sources are low to moderate moisture susceptible and three of the aggregate sources are known to be moisture susceptible.

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Table 7.7 Aggregate Information from NCHRP Report 444

State	Aggregate Type		Moisture Susceptibility
	Coarse	Fine	
Alabama	Limestone	Limestone	low to moderate
Colorado	Alluvial (partially crushed)	Alluvial (partially crushed)	known to be moisture susceptible
Maryland	Limestone	Limestone	known to be moisture susceptible
Nevada	Alluvial (partially crushed)	Alluvial (partially crushed)	known to be moisture susceptible
Texas	Limestone	Limestone	low to moderate

A probabilistic analysis was used to compare the TSR's from the NCHRP Report 444 study to that of this research project. The lognormal distribution was selected for the TSR for the different compaction methods on this research project and it was applied to the NCHRP 444 study to keep continuity of the analysis. In addition, a lognormal distribution is an appropriate selection since the TSR cannot be less than zero. Figure 7.13 and Figure 7.14 show that the results of this study give higher TSR's than the NCHRP Report 444 study, this is because the NCHRP 444 study used aggregates that were either known to be moisture susceptible or had low to moderate moisture susceptibility while this research project did not know whether or not the aggregates were moisture susceptible. A comparison was made in Figure 7.13 and Figure 7.14 by drawing a vertical line at a TSR of 80%. Then drawing horizontal lines where the vertical line intersects the cumulative probability density functions. The change in probability from 100mm diameter Marshall to 150mm diameter SGC and 100mm diameter Marshall to 100mm diameter Superpave for the two research studies were calculated. The change in probabilities from 100mm diameter Marshall to 150mm diameter SGC was 0.14 and 0.17 for the NCHRP Report 444 study and this research project, respectively. The change in probabilities from 100mm diameter Marshall to 100mm

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diameter SGC was 0.14 and 0.14 for the NCHRP Report 444 study and this research project, respectively. There is one difference obtained between NCHRP Report 444 and this study. Their study shows that the 100mm Marshall specimens perform better than 100mm Superpave specimens, and this study shows that the 100mm Superpave specimens performs better than 100mm Marshall specimens. Even though the curves are shifted for the two research studies the relative change from one compaction method to the other is relatively the same. Thus, one can conclude that similar results were obtained from this study compared to the NCHRP Report 444 study using 100mm Marshall versus 150mm Superpave whereas dissimilar results were obtained when comparing 100mm Marshall versus 100mm Superpave specimens.

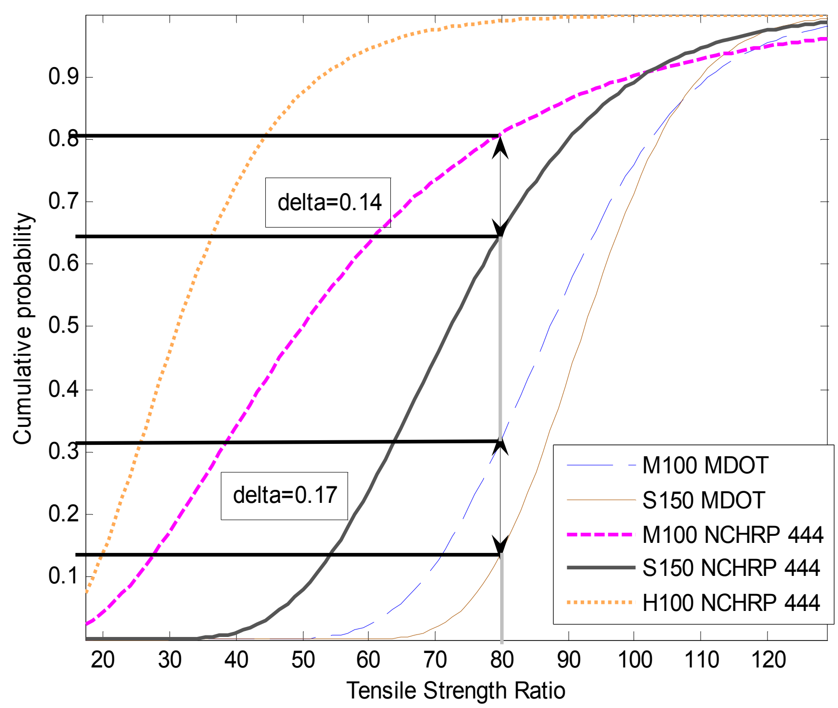

Figure 7.13 Comparison of 150mm SGC versus 100mm Marshall Samples for the NCHRP Report 444 Study and the Current Research Project

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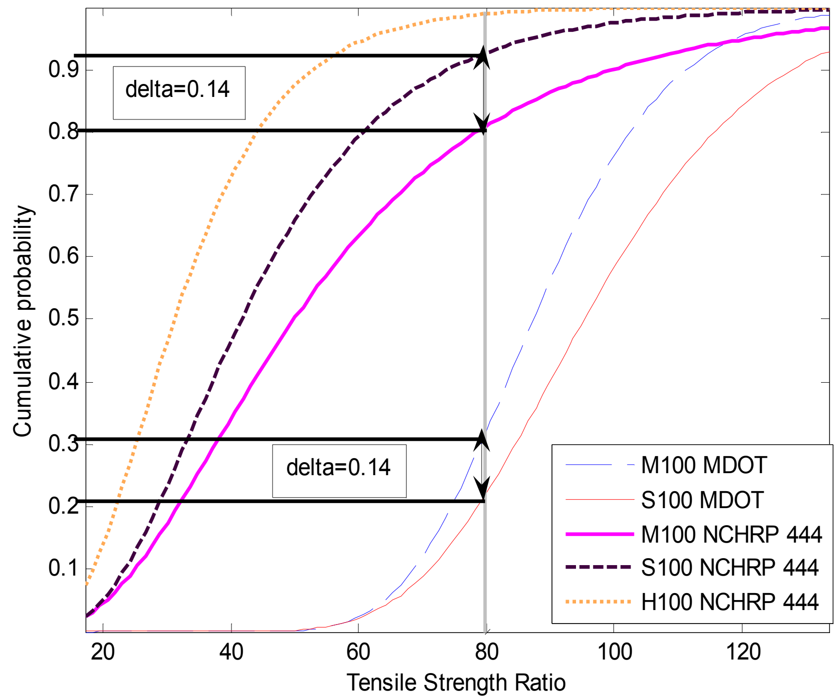

Figure 7.14 Comparison of 100mm SGC versus 100mm Marshall Samples for the NCHRP Report 444 Study and the Current Research Project

7.7 Conclusions

In this sensitivity study the factors affecting wet strength of a specimen and new thresholds for AASHTO T283 when Superpave compaction method was employed in lieu of the Marshall compaction method are identified. Testing included 100mm diameter Marshall, 100mm diameter Superpave, and 150mm diameter Superpave specimens. Four conditions of each mix type for every compaction and diameter combination were considered. The control condition was the dry state of a specimen and the other conditions were the strength of conditioned specimens after one, two, or three freeze-thaw cycles.

AASHTO T283 was developed based on 100mm diameter Marshall compacted specimens. With the transition from Marshall compacted specimens to Superpave compacted specimens it was felt that the requirements outlined in AASHTO T283 should be re-

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evaluated. It was discovered that three freeze-thaw cycles for conditioning is needed when using specimens created using the Superpave method. However, in order to still use one freeze-thaw cycle and to maintain the same probability level as attained with a TSR value for 80% for 100mm diameter Marshall compacted specimens, a TSR value of 87% and 85% should be used for 150mm diameter and 100mm diameter Superpave compacted specimens, respectively. If an 80% TSR for 150mm diameter Superpave specimens is used, this would correspond to a TSR ratio of 70% for 100mm diameter Marshall specimens.

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CHAPTER 8 SENSITIVITY STUDY – EVALUTION OF DYNAMIC MODUOUS TEST PROCEDURE FOR MOISTURE TESTING

8.1 Introduction

As a result of NCHRP Reports 465, 513, and 547, new test procedures for the simple performance tests such as dynamic modulus, repeated axial load (flow number), and static axial creep (flow time) tests are being evaluated. NCHRP 9-34 is currently looking at the use of the above mentioned simple performance tests along with the ECS to evaluate moisture susceptibility. Preliminary results of NCHRP 9-34 show that the dynamic modulus test is the most suited of three simple performance tests for use with the ECS in evaluating moisture damage in HMA mixes.

A sensitivity study using the simple performance test was conducted that considered additional factors such as conditioning, test temperature, and test history. An initial dynamic modulus frequency sweep was conducted, followed by the flow number test to cause some damage to the specimen followed by a second dynamic modulus frequency sweep to measure the loss in E* after being damaged. This sensitivity study was performed in order to determine what factors should be considered/used before developing the new test procedure.

8.2 Experimental Plan

The project sites selected for this sensitivity study were based on the results of the Phase I testing. Phase I results showed that I-196 Grand Rapids, a limestone HMA mixture, was the most moisture susceptible; and I-75 Clarkston, a gabbro/slag HMA mixture was the least moisture susceptible. The test temperatures for the intermediate and high temperature

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for I-196 Grand Rapids were 20.9 and 37.9°C and for I-75 Clarkston 21.4 and 38.2°C, respectively.

The testing procedure for moisture susceptibility testing using the simple performance test (i.e. dynamic modulus and dynamic creep testing) was as follows:

- Vacuum saturation of sample between 70 to 80%,
- 24 hour freeze cycle at -18°C,
- 24 hour thaw cycle at 60°C,
- 1.5 to 2 hour pre-conditioning at the intermediate testing temperature (T_{fat}) or if the high test temperature (T_{rut}) is being used then the pre-conditioning time is still the same.
- Run dynamic modulus test at 0.02, 0.1, 1.0, 5.0, 10.0, and 25.0 Hz and keeping the dynamic stress so the strain is in the range of 75 to 125 microstrain. The number of loading cycles for each frequency is 6, 6, 25, 50, 100, and 200.
- Run flow number test at 300 kPa for 10,000 cycles at high test temperature and 1,100 kPa for 10,000 cycles at intermediate test temperature. The load was applied for 0.1sec and a dwell period of 0.1sec.
- Run dynamic modulus test at 0.02, 0.1, 1.0, 5.0, 10.0, and 25.0 Hz and keeping the dynamic stress so the strain is in the range of 75 to 125 microstrain. The number of loading cycles for each frequency is 6, 6, 25, 50, 100, and 200.

8.3 Objectives of Sensitivity Study

The objectives of the sensitivity study with the new testing procedure were to determine what conditioning cycles to use, what test method to follow (dynamic modulus or flow number), and at what test temperatures to conduct the testing.

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8.4 Test Results

For the sensitivity study using the simple performance test device, three replicate specimens were tested for each temperature and conditioning period. The results were averaged and a standard deviation and coefficient of variation computed. This allows for the elimination of outliers, if any, that occurred while testing. NCHRP Report 465 suggests that if three linear variable differential transducers (LVDT's) are used, then only two replicate specimens need to be tested for the rutting and fatigue testing temperatures (Witczak et al 2002). This research study used three LVDT's on all of the specimens tested.

8.4.1 Dynamic Modulus Before Flow Number Testing

Initial dynamic modulus testing was conducted at the effective test temperature for rutting based on equation 6.1 which is a function of project location. The permanent micro-strain was controlled between 75-150 μstrain by controlling the dynamic stress level, which allowed for an accurate measurement of E* at each frequency. Figures 8.1 through 8.8 show the results of conducting the dynamic modulus tests after four conditioning procedures for I-196 Grand Rapids and I-75 Clarkston. Ninety-five percent confidence intervals were plotted around the mean values for each figure to show how confident the mean is, based on the variability of the data. The four conditioning procedures used were: control, vacuum saturation plus freeze-thaw method A (dynamic creep testing in air), vacuum saturation only, and vacuum saturation plus freeze-thaw method B (dynamic creep testing performed under water). The figures show that the variability is the highest at the 25 Hz for most of the conditioning cycles. The high variability at the 25 Hz level could be due to the control data acquisition system (CDAS) and the servo-hydraulic equipment used to run the test. Also the

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federal highway agency (FHWA) expert task group (ETG) on bituminous materials is considering dropping the 25 Hz frequency due to the high variability of the data that others have seen (Williams 2006). I-196 Grand Rapids freeze-thaw method B specimens and I-75 Clarkston vacuum saturated and freeze-thaw method B specimens show the highest variability. The variability in dynamic modulus values is because these specimens have been vacuum saturated with water, and some of the specimens have gone through freeze-thaw cycles thus weakening the asphalt binder and/or mastic, also the addition of water in the air void structure may lead to the variability in the results. It also should be noted that E* can not be negative even though a negative confidence interval is shown in Figure 8.7. The variability of the 10 Hz and 25 Hz frequencies for the freeze-thaw groups and vacuum saturated groups could be due to pore pressure build up in the air void system in the HMA specimen. Water in the void structure cannot escape due to the fast moving load and is therefore pushing back on the void space instead of being slowly squeezed out if the load was moving slower. Table 8.1 shows summary statistics such as the mean, standard deviation, and coefficient of variation (COV) for each moisture condition and test temperature. It appears that on the average, the vacuum saturation plus freeze-thaw cycles results in the most moisture damage but the variability is slightly higher when compared to vacuum saturation only. For the other factor which is test temperature, the effective test temperature for rutting provides the average lowest E* ratio and COV which is a measure of variability. I-75 Clarkston appears to perform better than I-196 Grand Rapids when comparing all the conditioning phases and test temperatures.

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Table 8.1 Summary Statistics for Sensitivity Study, E* Ratio Before Damage Cycles

			Before Damage Cycles											
			E* Ratio 0.1 Hz			E* Ratio 1.0 Hz			E* Ratio 5.0 Hz			E* Ratio 10.0 Hz		
Project	Conditioning	Test Temperature (°C)	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV
I-196 Grand Rapids	Vacuum Saturation + Freeze-Thaw Cycle	37.9	77.1	13.0	16.8	83.6	13.2	15.8	103.1	10.7	10.4	107.0	11.4	10.7
I-196 Grand Rapids	Vacuum Saturation Only	37.9	93.3	10.1	10.8	104.3	6.6	6.3	110.0	7.9	7.1	111.2	10.0	9.0
I-196 Grand Rapids	Vacuum Saturation + Freeze-Thaw Cycle	37.9	72.6	6.6	9.1	74.4	8.7	11.7	78.5	10.4	13.2	86.7	16.4	18.9
I-196 Grand Rapids	Vacuum Saturation + Freeze-Thaw Cycle	20.9	100.4	26.8	26.7	115.4	31.8	27.6	115.1	34.0	29.5	114.3	38.2	33.4
I-75 Clarkston	Vacuum Saturation + Freeze-Thaw Cycle	38.2	97.6	5.6	5.8	99.0	12.0	12.2	114.0	12.4	10.9	120.3	12.1	10.1
I-75 Clarkston	Vacuum Saturation Only	38.2	139.5	36.4	26.1	173.1	105.8	61.2	168.8	97.4	57.7	162.8	86.0	52.8
I-75 Clarkston	Vacuum Saturation + Freeze-Thaw Cycle	38.2	137.8	31.0	22.5	135.5	31.7	23.4	134.2	32.9	24.5	132.1	30.7	23.3
I-75 Clarkston	Vacuum Saturation + Freeze-Thaw Cycle	21.4	104.8	11.7	11.1	108.4	3.8	3.5	108.8	6.9	6.3	106.1	9.3	8.8

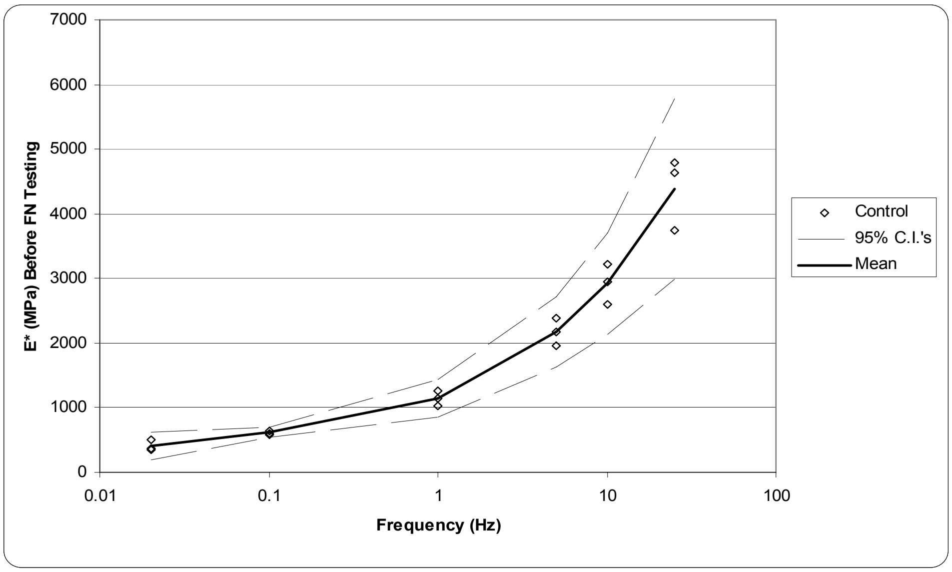

Figure 8.1 I-196 Grand Rapids Control Specimens with 95% Confidence Intervals

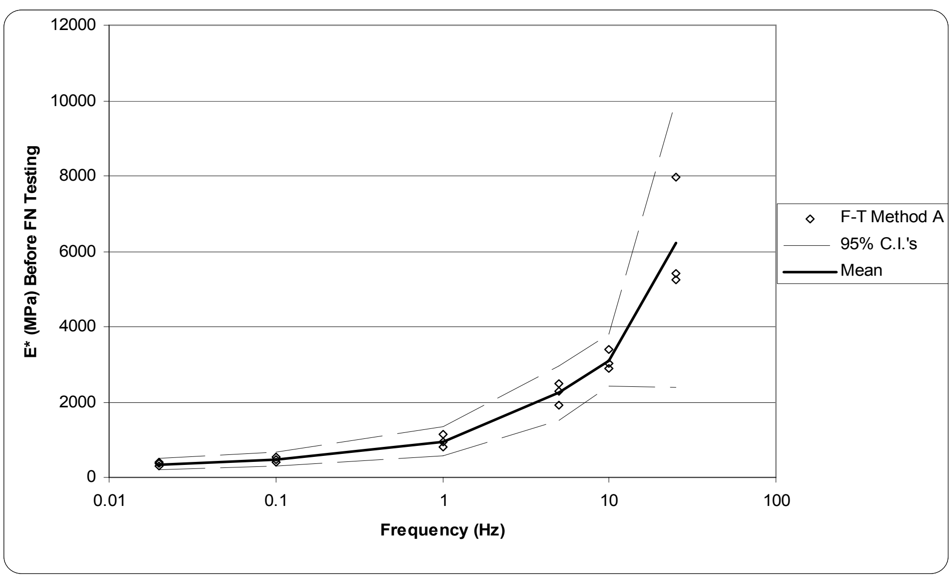

Figure 8.2 I-196 Grand Rapids Freeze-Thaw Method A Specimens with 95% Confidence Intervals

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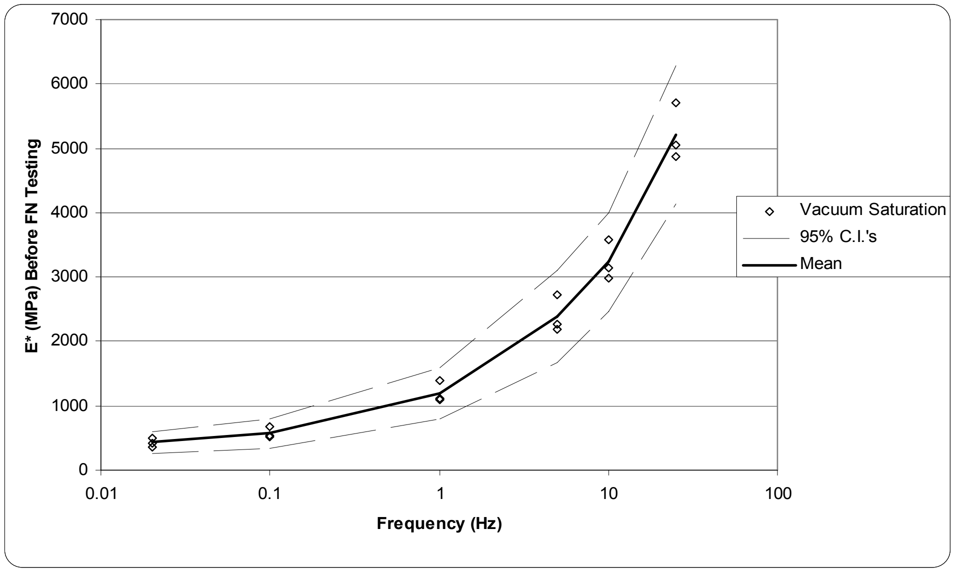

Figure 8.3 I-196 Grand Rapids Vacuum Saturated Specimens with 95% Confidence Intervals

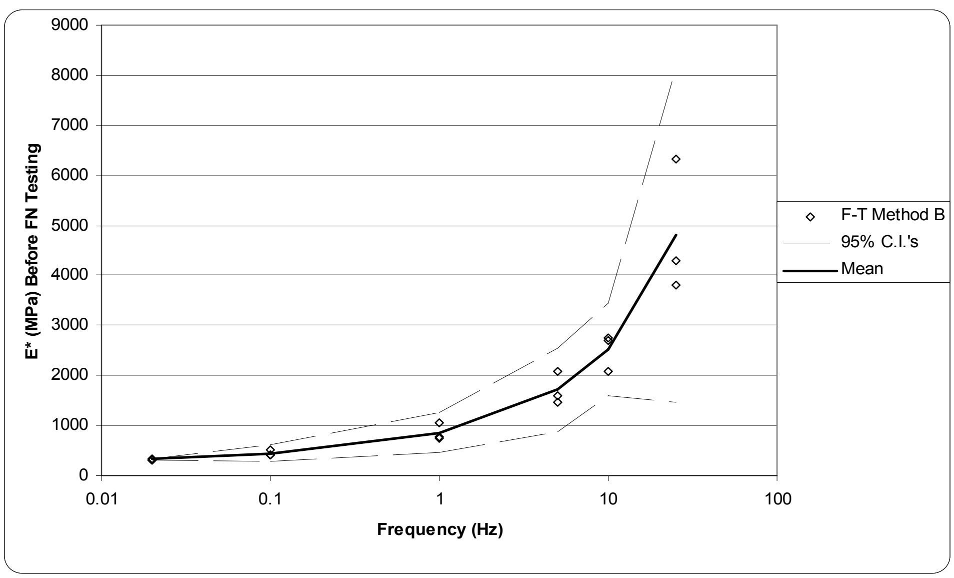

Figure 8.4 I-196 Grand Rapids Freeze-Thaw Method B Specimens with 95% Confidence Intervals

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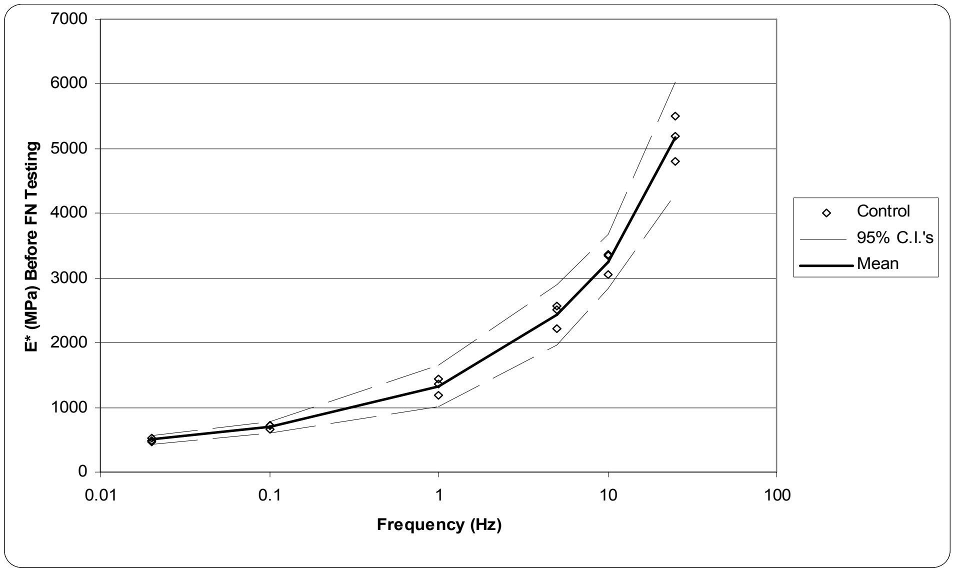

Figure 8.5 I-75 Clarkston Control Specimens with 95% Confidence Intervals

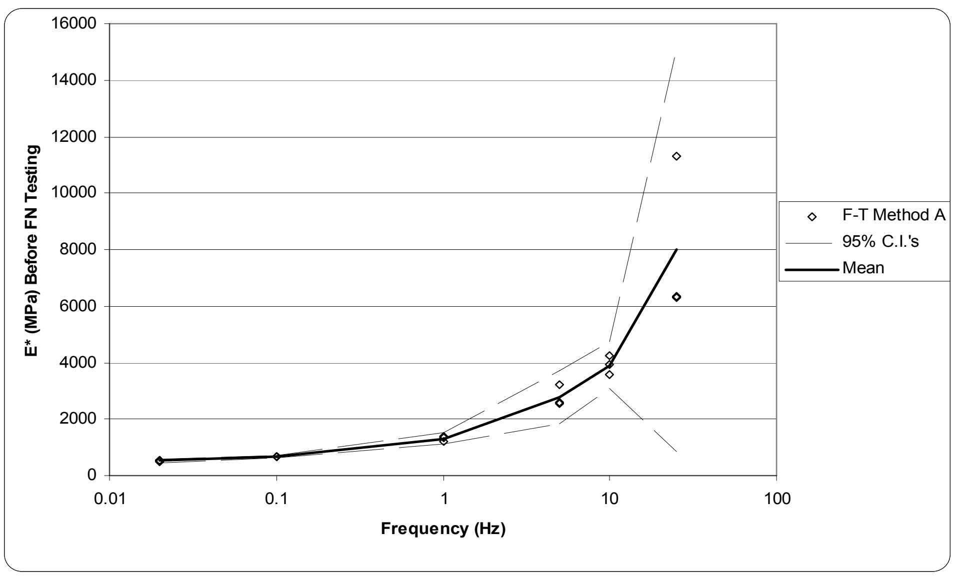

Figure 8.6 I-75 Clarkston Freeze-Thaw Method A Specimens with 95% Confidence Intervals

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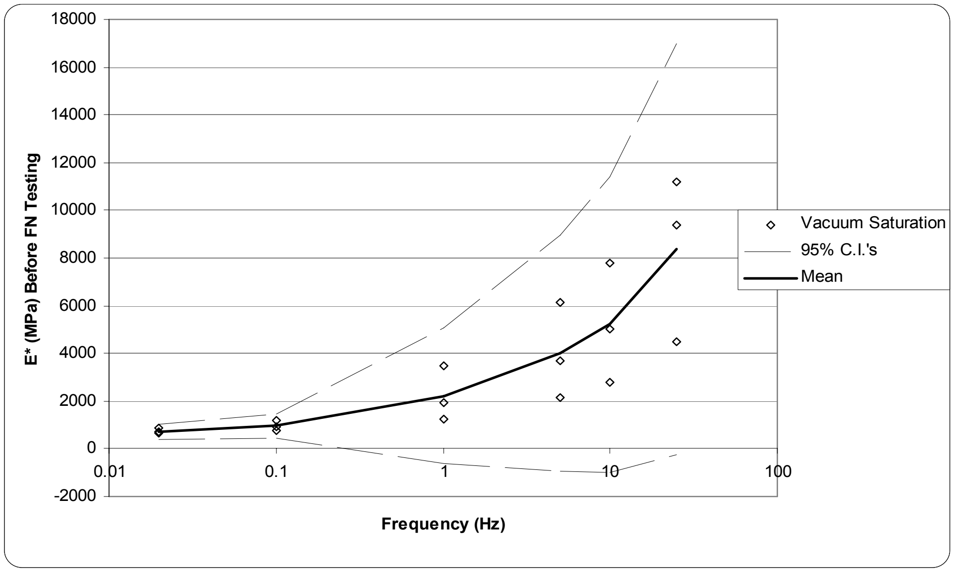

Figure 8.7 I-75 Clarkston Vacuum Saturated Specimens with 95% Confidence Intervals

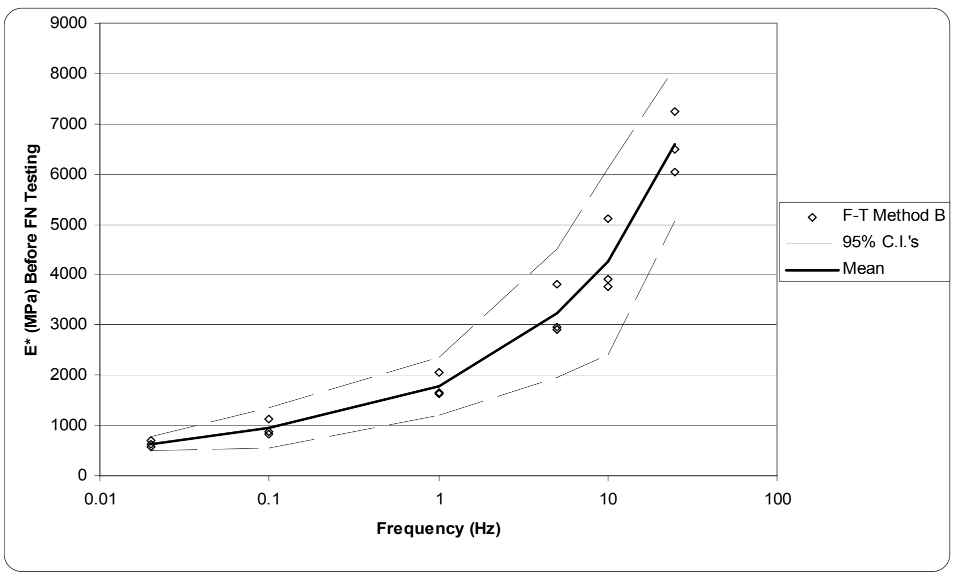

Figure 8.8 I-75 Clarkston Freeze-Thaw Method B Specimens with 95% Confidence Intervals

8.4.2 Dynamic Creep Testing

The test temperature for dynamic creep testing was performed at 37.9 and 38.2°C for I-196 Grand Rapids and I-75 Clarkston, respectively. The specimens underwent 10,000 loading cycles at a dynamic stress of 300kPa. This stress was selected because it would damage the specimen but not significantly. The control specimens for I-196 Grand Rapids

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and the vacuum saturated specimens for I-75 Clarkston showed the highest variability. The I-196 Grand Rapids control specimens showed more permanent deformation than the moisture conditioned samples; this relationship can be seen in Figure 8.9. Figure 8.10 show that the permanent deformation decreases with conditioning cycles for the I-75 Clarkston project.

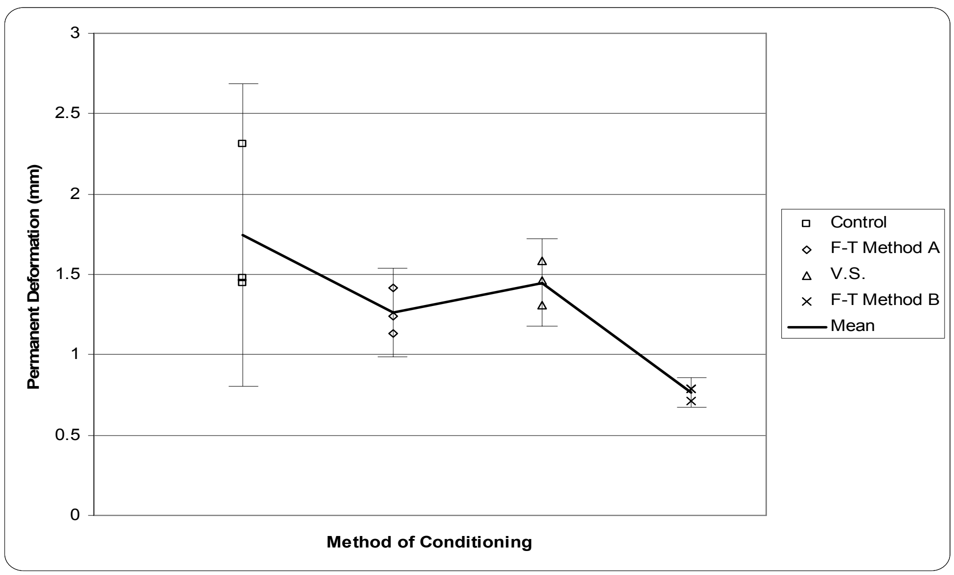

Figure 8.9 I-196 Grand Rapids: Effects of Conditioning on Permanent Deformation (95% Confidence Interval Plots)

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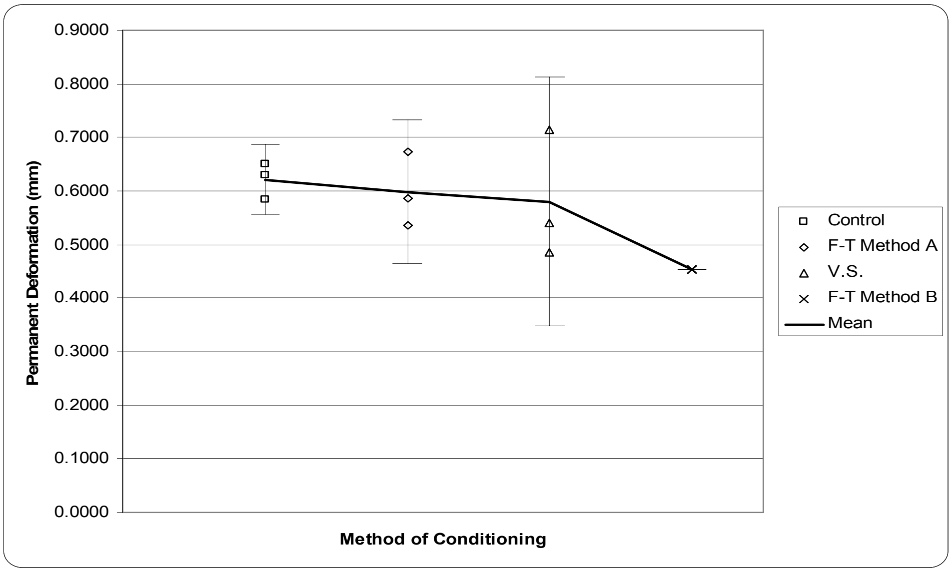

Figure 8.10 I-75 Clarkston: Effects of Conditioning on Permanent Deformation (95% Confidence Interval Plots)

8.4.3 Dynamic Modulus After Flow Number Testing

A second dynamic modulus test was performed after the dynamic creep test. A second test was performed to observe how the dynamic modulus changed. A statistical analysis was performed on the data to determine if the dynamic modulus increased or decreased after performing dynamic creep testing. The permanent micro-strain was again controlled between 75-150 μstrain by controlling the dynamic stress level, this allowed for an accurate measurement of E* at each frequency. Figures 8.11 through 8.18 show the results of conducting the dynamic modulus tests after four conditioning procedures for I-196 Grand Rapids and I-75 Clarkston. Ninety-five percent confidence intervals were plotted around the mean values for each figure to show how confident the mean is, based on the variability of the data. The four conditioning procedures used were: control, freeze-thaw method A (dynamic creep testing in air), vacuum saturation only, and freeze-thaw method B (dynamic creep testing). The figures show that the variability is the highest at the 25 Hz for most of the

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conditioning cycles. The high variability at the 25 Hz level could be due to the data acquisition unit and the servo-hydraulic equipment used to run the test as previously mentioned. The variability of the 10 Hz and 25 Hz frequencies for the freeze-thaw groups and vacuum saturated groups could be due to pore pressure build up in the air void system in the HMA specimen. Water in the void structure cannot escape due to the fast moving load and is therefore pushing back on the void space instead of being slowly squeezed out if the load was moving slower. I-196 Grand Rapids vacuum saturated specimens and I-75 Clarkston freeze-thaw method B specimens show the highest variability.

Table 8.2 shows summary statistics such as the mean, standard deviation, and coefficient of variation (COV) for each moisture condition and test temperature for E* ratio after damage cycles. It appears that on the average, the vacuum saturation plus freeze-thaw cycles results in the most moisture damage but the variability is slightly higher when compared to vacuum saturation only. The highest COV is for the vacuum saturation plus freeze-thaw cycles where the damage cycles are performed submerged. For the other factor which is test temperature, the effective test temperature for rutting provides the average lowest E* ratio and COV which is a measure of variability. I-75 Clarkston appears to perform better than I-196 Grand Rapids when comparing all the conditioning phases and test temperatures. When comparing Tables 8.1 and 8.2, the E* ratio stays relatively constant when comparing E* ratio before damage cycles versus E* ratio after damage cycles. One can conclude that the damage cycles did not really damage the specimen enough in order to get a distinguishable difference in E* ratios before and after the damage cycles.

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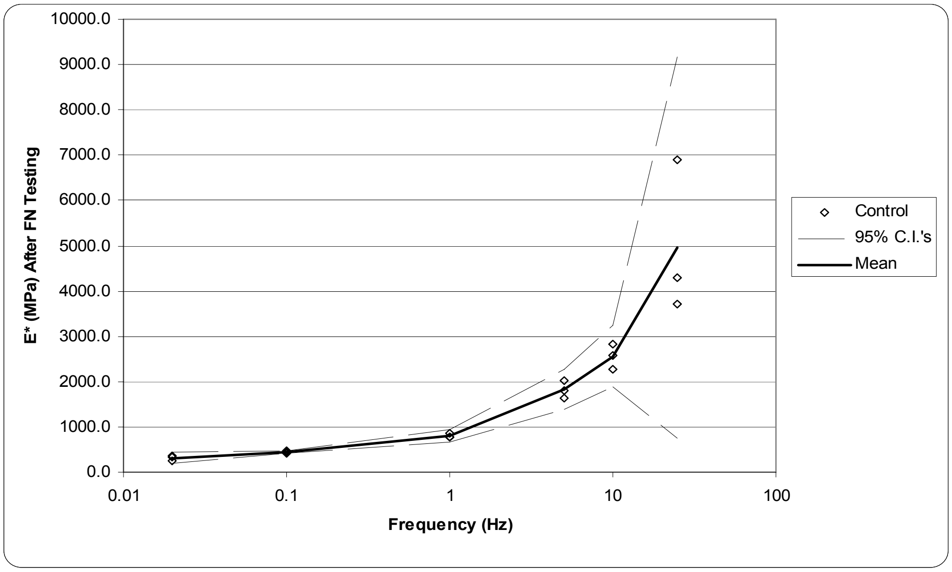

Figure 8.11 I-196 Grand Rapids Control Specimens with 95% Confidence Intervals

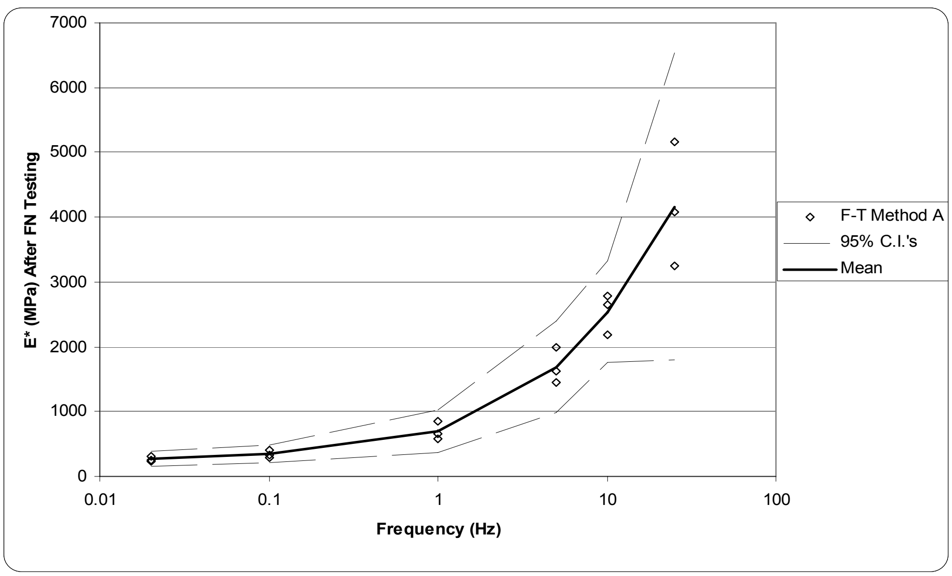

Figure 8.12 I-196 Grand Rapids Freeze-Thaw Method A Specimens with 95% Confidence Intervals

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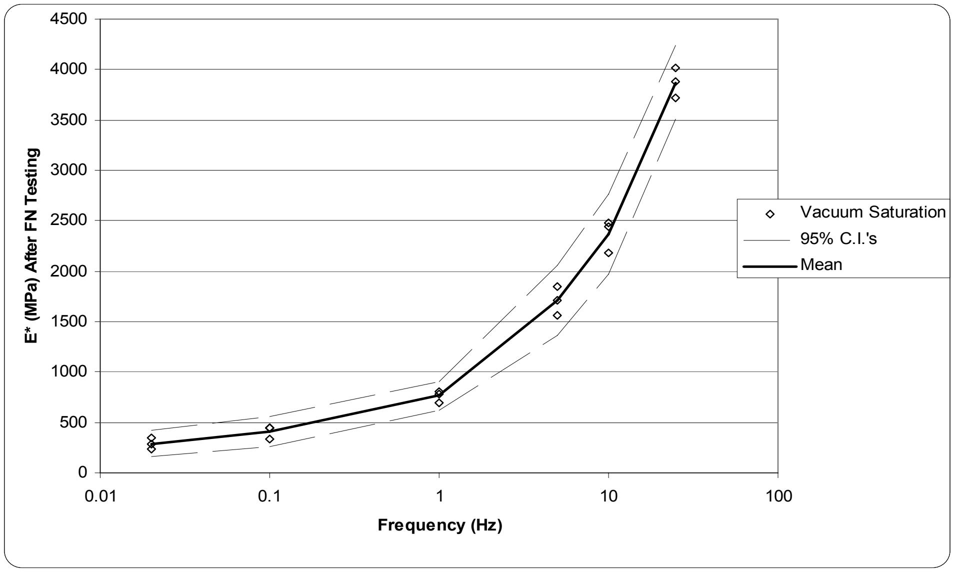

Figure 8.13 I-196 Grand Rapids Vacuum Saturated Specimens with 95% Confidence Intervals

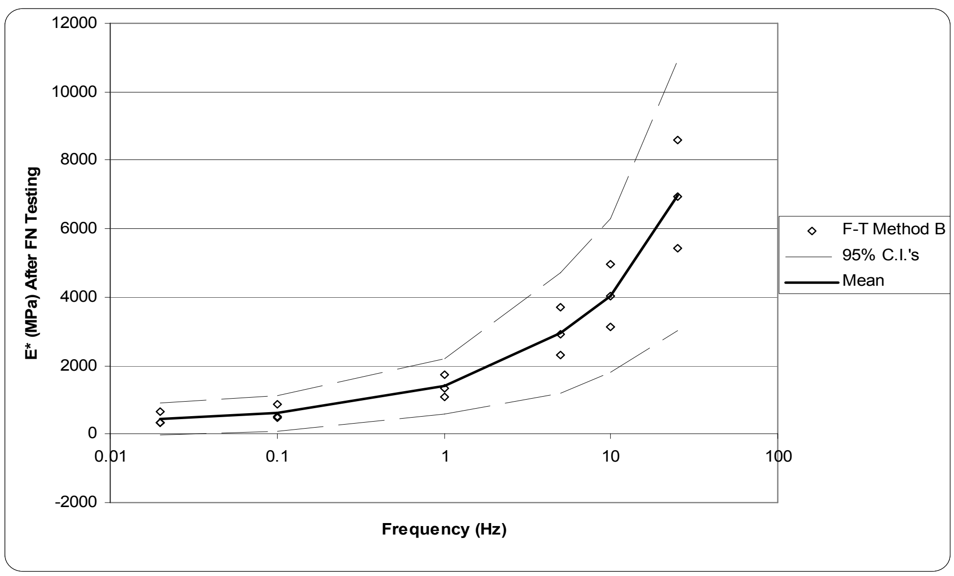

Figure 8.14 I-196 Grand Rapids Freeze-Thaw Method B Specimens with 95% Confidence Intervals

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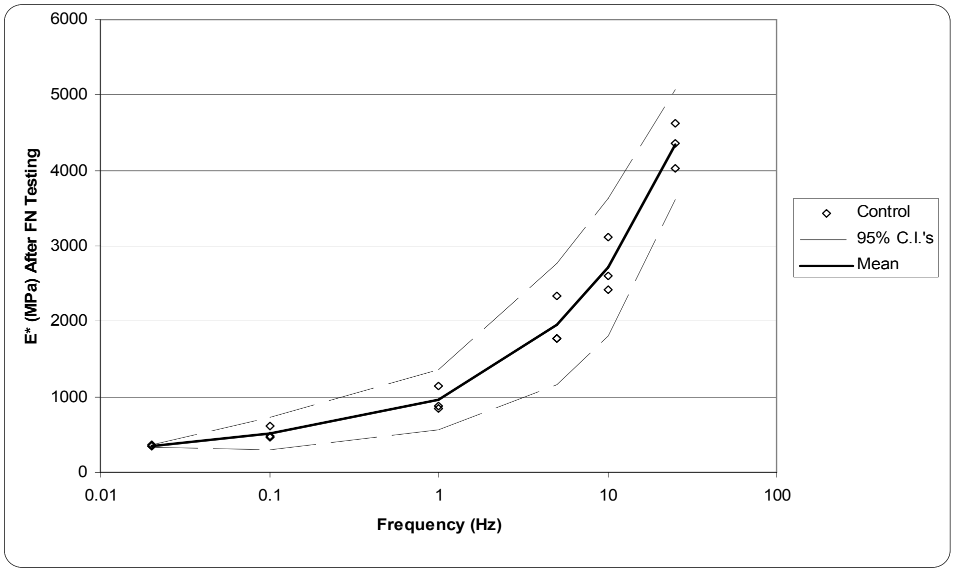

Figure 8.15 I-75 Clarkston Control Specimens with 95% Confidence Intervals

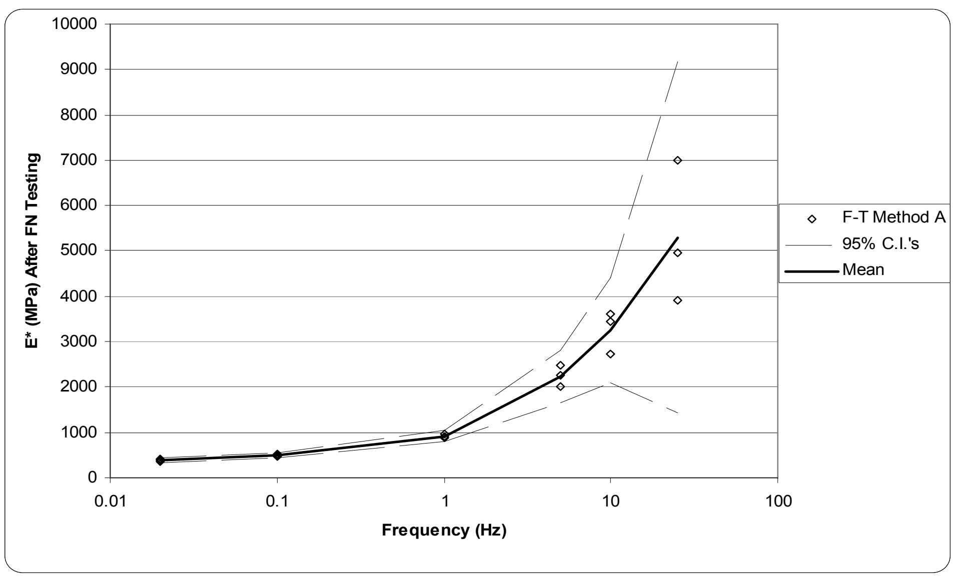

Figure 8.16 I-75 Clarkston Freeze-Thaw Method A Specimens with 95% Confidence Intervals

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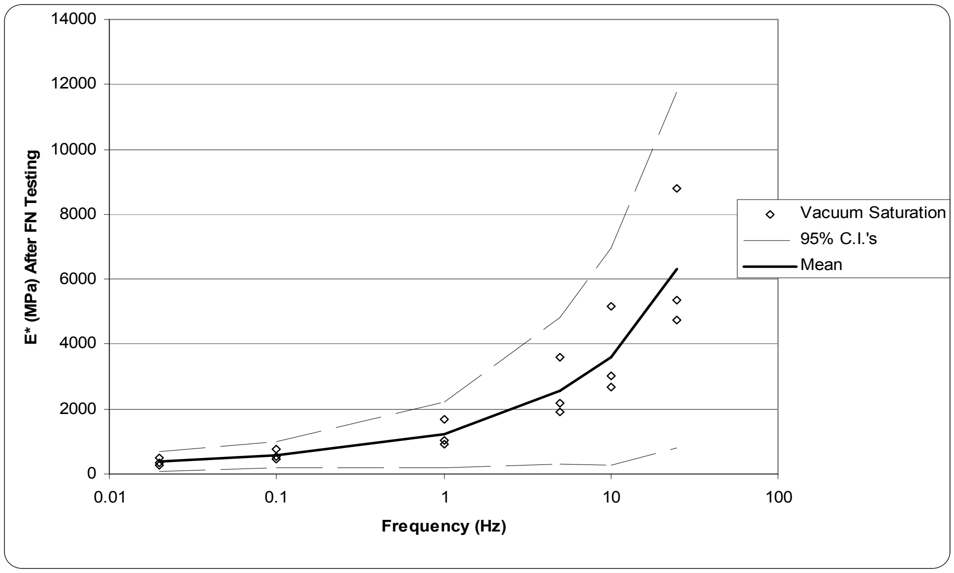

Figure 8.17 I-75 Clarkston Vacuum Saturation Specimens with 95% Confidence Intervals

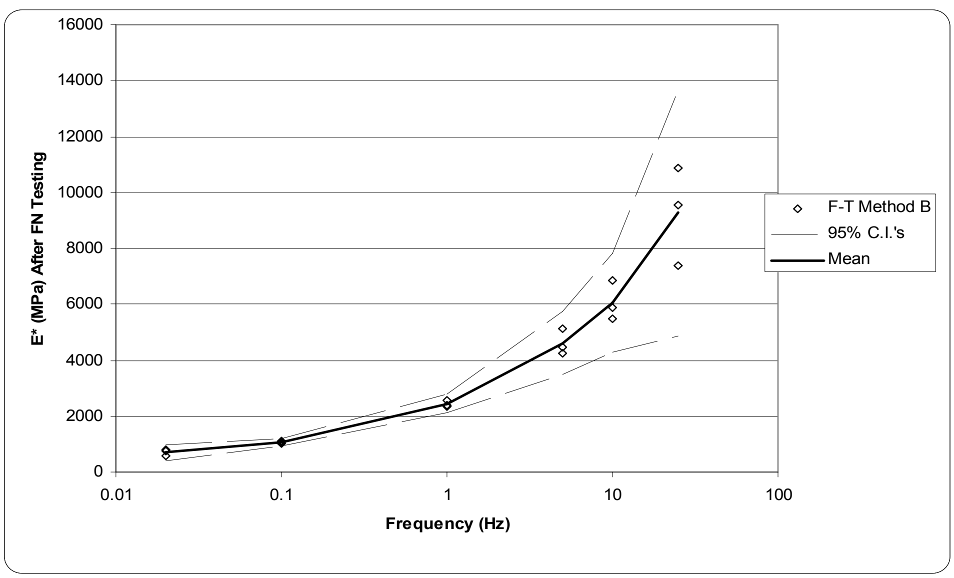

Figure 8.18 I-75 Clarkston Freeze-Thaw Method B Specimens with 95% Confidence Intervals

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Table 8.2 Summary Statistics for Sensitivity Study, E* Ratio After Damage Cycles

			After Damage Cycles											
			E* Ratio 0.1 Hz			E* Ratio 1.0 Hz			E* Ratio 5.0 Hz			E* Ratio 10.0 Hz		
Project	Conditioning	Test Temperature (°C)	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV
I-196 Grand Rapids	Vacuum Saturation + Freeze-Thaw Cycle	37.9	79.0	13.9	17.5	86.9	18.1	20.8	93.9	23.9	25.4	100.4	19.8	19.8
I-196 Grand Rapids	Vacuum Saturation Only	37.9	92.9	14.0	15.1	94.9	6.1	6.4	94.0	8.3	8.8	92.9	5.5	5.9
I-196 Grand Rapids	Vacuum Saturation + Freeze-Thaw Cycle Damge Cycles Performed Under Water	37.9	138.1	42.4	30.7	175.1	47.0	26.9	162.7	36.2	22.2	157.6	29.6	18.7
I-196 Grand Rapids	Vacuum Saturation + Freeze-Thaw Cycle	20.9	104.8	16.3	15.5	114.9	30.5	26.5	112.2	29.7	26.5	112.4	30.5	27.1
I-75 Clarkston	Vacuum Saturation + Freeze-Thaw Cycle	38.2	98.2	19.3	19.7	97.5	19.5	20.0	115.1	11.1	9.6	120.7	16.2	13.4
I-75 Clarkston	Vacuum Saturation Only	38.2	115.9	44.5	38.4	130.2	58.4	44.8	135.4	60.4	44.6	135.2	55.2	40.9
I-75 Clarkston	Vacuum Saturation + Freeze-Thaw Cycle Damge Cycles Performed Under Water	38.2	210.3	40.6	19.3	256.5	27.2	10.6	236.6	16.4	6.9	224.2	16.8	7.5
I-75 Clarkston	Vacuum Saturation + Freeze-Thaw Cycle	21.4	114.2	1.9	1.7	117.6	19.2	16.4	110.9	35.2	31.7	110.4	37.2	33.7

8.4.4 Additional Dynamic Modulus and Dynamic Creep Testing

Additional dynamic modulus and dynamic creep testing was performed on control specimens and freeze-thaw method A specimens at the intermediate (fatigue) test temperature. An initial dynamic modulus frequency sweep was performed followed by dynamic creep testing followed by a second dynamic modulus frequency sweep. Figures 8.19 through 8.22 shows the results of E* versus frequency with 95% confidence intervals around the mean for the control and moisture conditioned specimens for before and after dynamic creep testing for I-196 Grand Rapids. It appears that the moisture conditioned specimens show the highest variability. Figures 8.23 through 8.26 shows the results of E* versus frequency with 95% confidence intervals around the mean for the control and moisture conditioned specimens for before and after dynamic creep testing for I-75 Clarkston. It appears that the control specimens show the highest variability. This could be due to the fact that only two dynamic modulus after flow number testing specimens were tested for I-75 Clarkston. High variability was observed at the higher frequencies as well.

The dynamic creep testing showed mixed results. The permanent deformation increased from control to moisture conditioned specimens for I-196 Grand Rapids but the opposite trend was observed for I-75 Clarkston. This could be possible if I-75 Clarkston is

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not as moisture susceptible as I-196 Grand Rapids. In addition, high variability was observed for the moisture conditioned specimens as compared to the control samples.

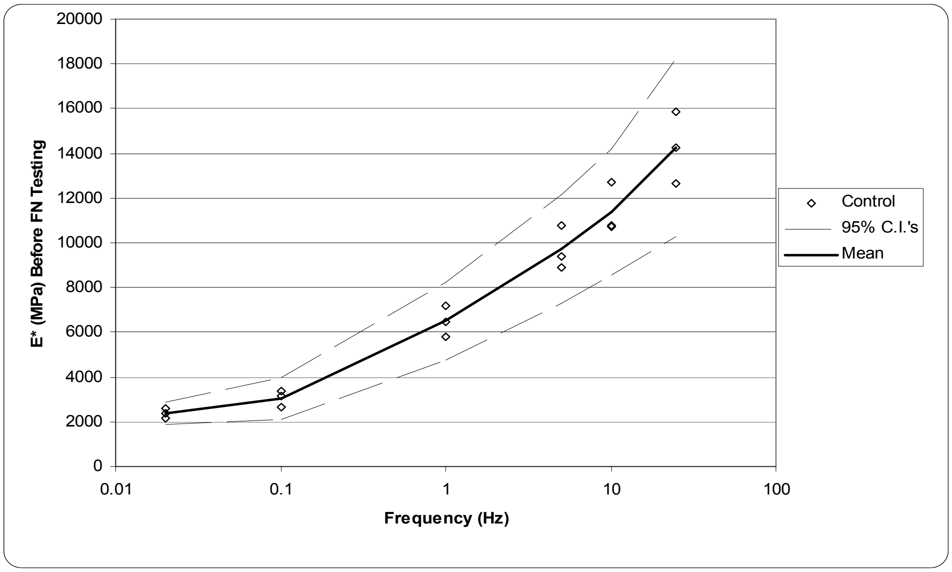

Figure 8.19 I-196 Grand Rapids Control Specimens with 95% Confidence Intervals

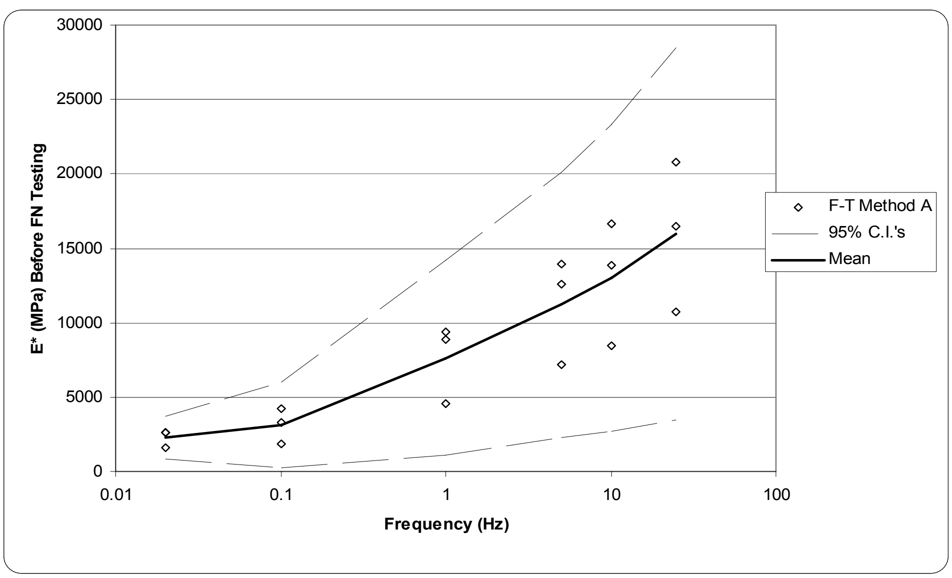

Figure 8.20 I-196 Grand Rapids Freeze-Thaw Method A Specimens with 95% Confidence Intervals

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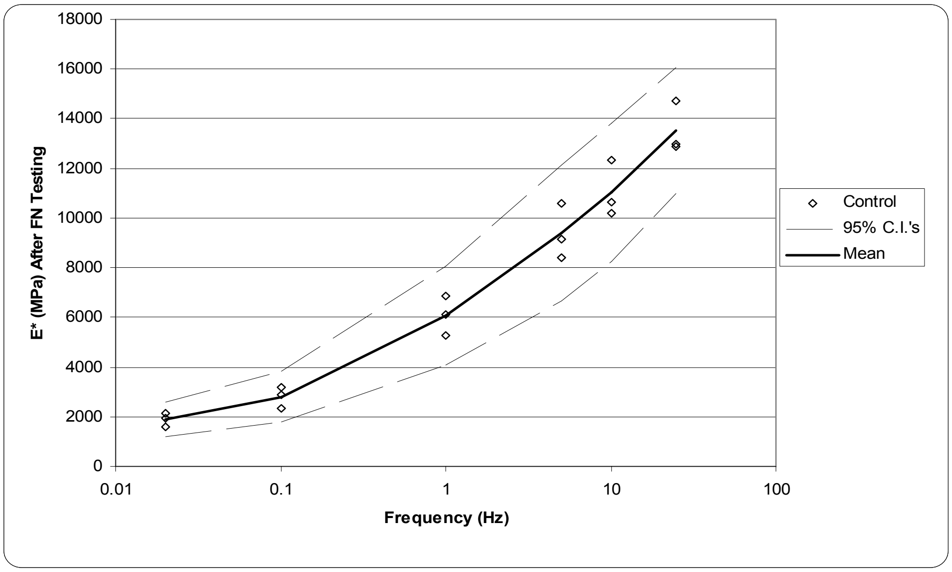

Figure 8.21 I-196 Grand Rapids Control Specimens with 95% Confidence Intervals

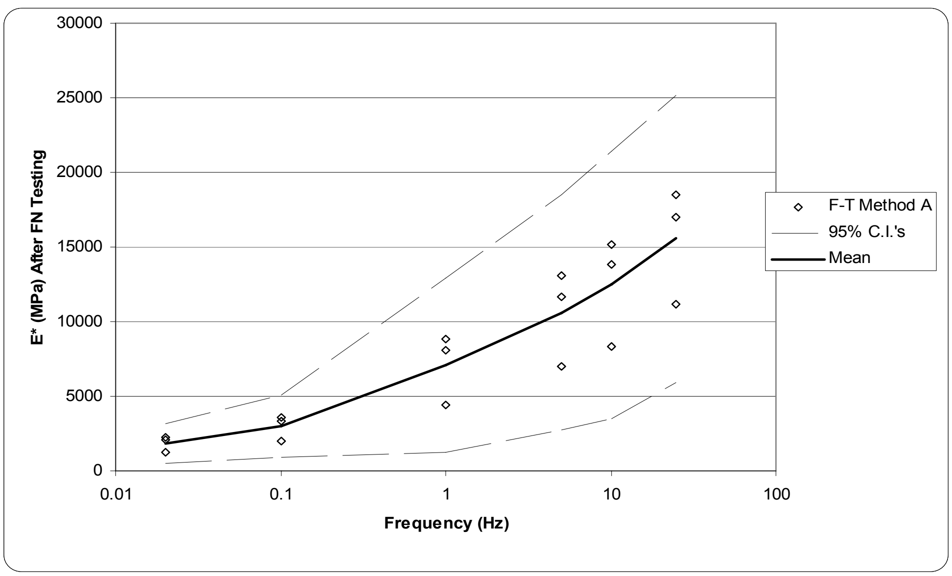

Figure 8.22 I-196 Grand Rapids Freeze-Thaw Method A Specimens with 95% Confidence Intervals

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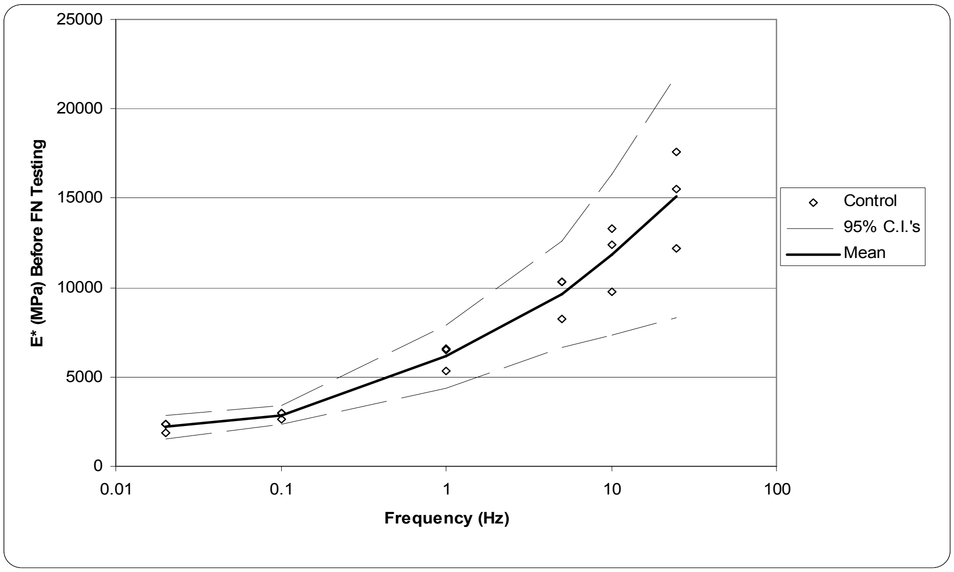

Figure 8.23 I-75 Clarkston Control Specimens with 95% Confidence Intervals

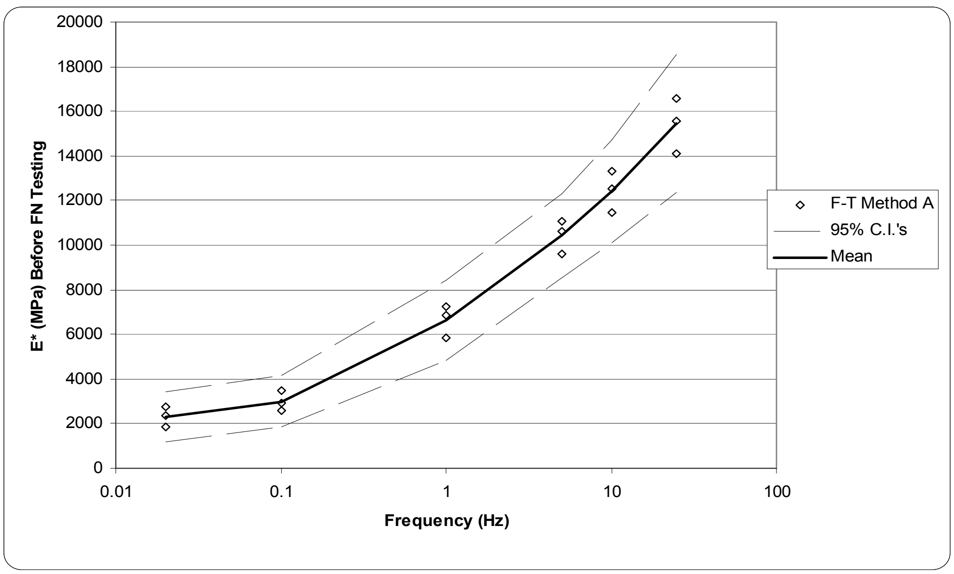

Figure 8.24 I-75 Clarkston Freeze-Thaw Method A Specimens with 95% Confidence Intervals

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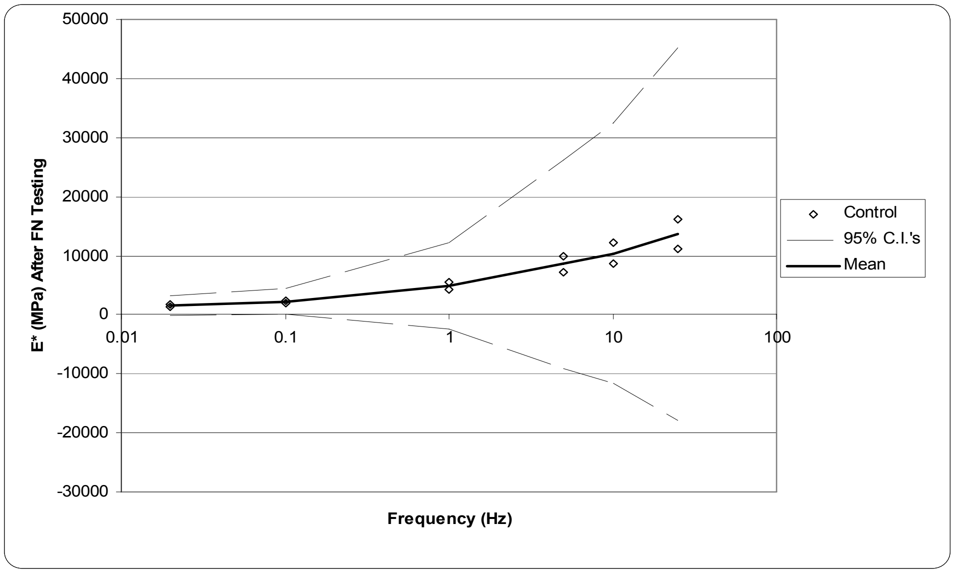

Figure 8.25 I-75 Clarkston Control Specimens with 95% Confidence Intervals

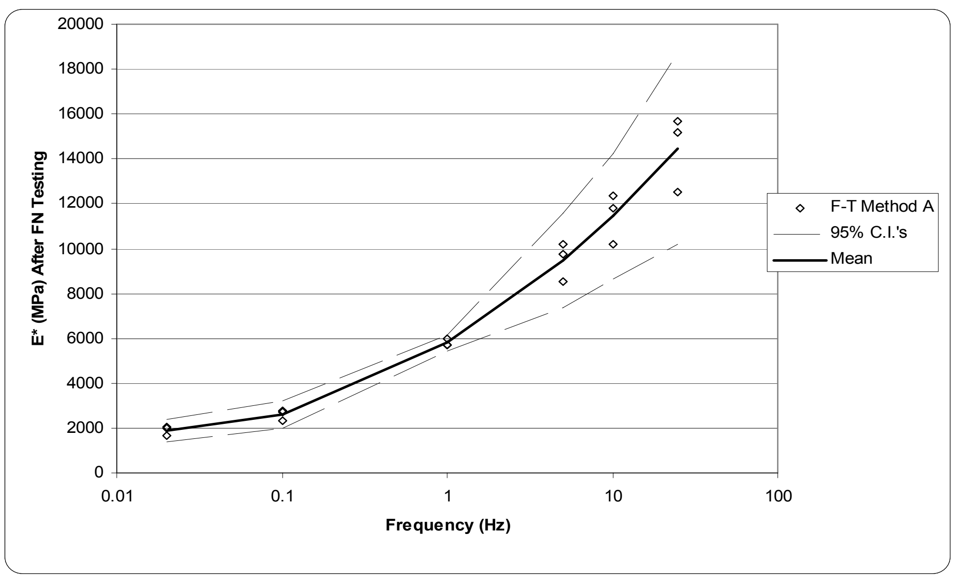

Figure 8.26 I-75 Clarkston Freeze-Thaw Method A Specimens with 95% Confidence Intervals

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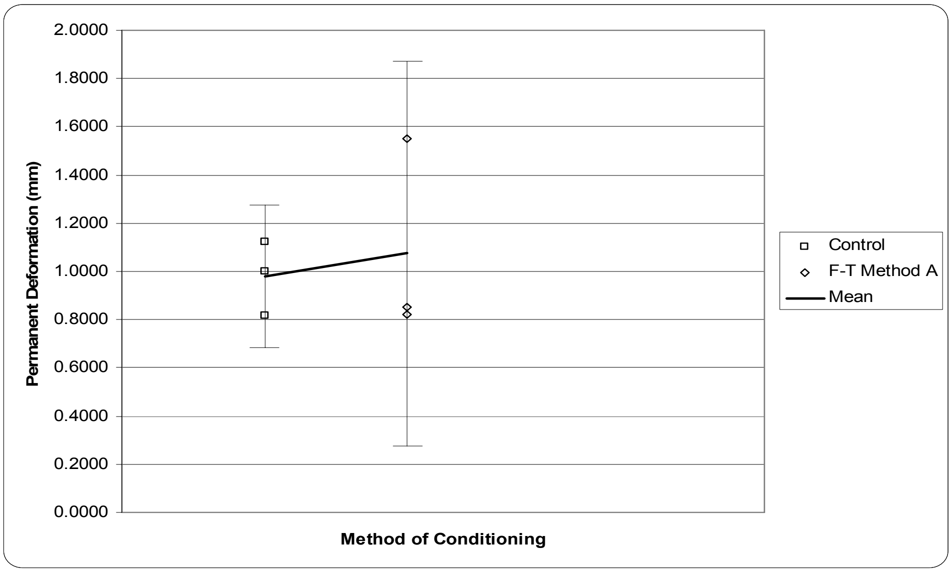

Figure 8.27 I-196 Grand Rapids: Effects of Conditioning on Permanent Deformation (95% Confidence Interval Plots)

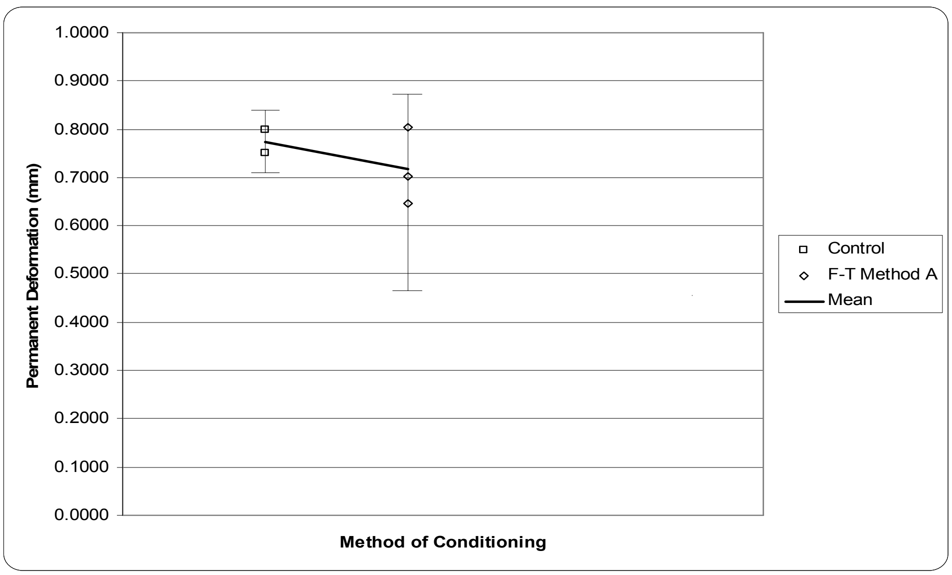

Figure 8.28 I-75 Clarkston: Effects of Conditioning on Permanent Deformation (95% Confidence Interval Plots)

8.5 Analysis of Results

Two-sample t-tests were performed on the data to observe changes in the behavior of the material. In all statistical tests, a 5.0% level of significance (α=0.05) was used. Table 8.3 shows the results when comparing the test history of the specimen. E* before flow number testing was compared to E* after flow number testing to observe if any changes had

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occurred (i.e. loss of stiffness). The data shows some scatter where in some cases the results showed statistical differences in E* when damaged while in other cases it did not. Therefore, an increase in the dynamic stress may be required in order to fully damage the specimen, but not so much as to cause excessive damage so another dynamic modulus test could be performed.

Table 8.3 Two sample t-tests on E* Before FN Testing versus E* After Flow Number Testing

		Before FN Testing vs. After Flow Number Testing			
Project	**Frequency (Hz)**	**E* Control t-test results**	**E* F-T Method A t-test results**	**E* Vacuum Saturation t-test results**	**E* F-T Method B t-test results**
I-196 Grand Rapids	0.02	Not Statistically Different	**Statistically Different**	Not Statistically Different	Not Statistically Different
	0.1	**Statistically Different**	**Statistically Different**	Not Statistically Different	Not Statistically Different
	1	**Statistically Different**	**Statistically Different**	**Statistically Different**	Not Statistically Different
	5	Not Statistically Different	**Statistically Different**	Not Statistically Different	Not Statistically Different
	10	Not Statistically Different	**Statistically Different**	**Statistically Different**	Not Statistically Different
	25	Not Statistically Different	**Statistically Different**	**Statistically Different**	**Statistically Different**
I-75 Clarkston	0.02	**Statistically Different**	**Statistically Different**	**Statistically Different**	Not Statistically Different
	0.1	**Statistically Different**	**Statistically Different**	**Statistically Different**	Not Statistically Different
	1	**Statistically Different**	**Statistically Different**	Not Statistically Different	Not Statistically Different
	5	Not Statistically Different	**Statistically Different**	Not Statistically Different	Not Statistically Different
	10	Not Statistically Different	Not Statistically Different	Not Statistically Different	Not Statistically Different
	25	Not Statistically Different	Not Statistically Different	Not Statistically Different	Not Statistically Different

Table 8.4 shows the results when comparing control group to the moisture conditioned groups. The two sample t-test results show that there is no statistical difference when comparing control to moisture conditioned specimens. This holds true, except for I-75 Clarkston at the effective rut test temperature when comparing control versus freeze-thaw method B (dynamic creep test specimen submerged under water).

Table 8.4 Two Sample t-Tests Control vs. Moisture Conditioned Specimens Using Permanent Deformation

		Permanent Deformation (mm)		
Project	Test Temperature (°C)	Control vs. F-T A	Control vs. V.S.	Control versus F-T B
I-196 Grand Rapids	High	Not Statistically Different	Not Statistically Different	Not Statistically Different
I-75 Clarkston	High	Not Statistically Different	Not Statistically Different	**Statistically Different**
I-196 Grand Rapids	Intermediate	Not Statistically Different	N/A	N/A
I-75 Clarkston	Intermediate	Not Statistically Different	N/A	N/A

The next analysis of the data was to compare E* control versus E* conditioned before dynamic creep testing to see if there is a statistical difference when subjecting specimens to

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some kind of moisture conditioning. E* before dynamic creep testing was analyzed because there did not appear to be statistically different results between the first dynamic modulus sweep and the second dynamic modulus sweep. Table 8.5 shows the results of conducting two sample t-tests; control versus the three conditioning types. Also included in the table is the E* ratio so if there are statistically different results then one can observe if the effect is detrimental or beneficial to the HMA. The only occurrences of statistically different results are at 0.1 and 1 Hz for I-196 Grand Rapids when the control samples are compared to freeze-thaw method B samples.

Table 8.5 Two Sample t-Tests E* Control vs. E*Moisture Conditioned Specimens on Initial Dynamic Modulus Frequency Sweep

		Before FN Testing					
Project	Frequency (Hz)	E* Control vs. F-T A t-test results	E* Ratio	E* Control vs. V.S. t-test results	E* Ratio	E* Control versus F-T B t-test results	E* Ratio
I-196 Grand Rapids	0.02	Not Statistically Different	90.2%	Not Statistically Different	108.3%	Not Statistically Different	81.4%
	0.1	Not Statistically Different	**77.1%**	Not Statistically Different	93.3%	**Statistically Different**	**72.6%**
	1	Not Statistically Different	83.6%	Not Statistically Different	104.3%	**Statistically Different**	**74.4%**
	5	Not Statistically Different	103.1%	Not Statistically Different	110.0%	Not Statistically Different	**78.5%**
	10	Not Statistically Different	107.0%	Not Statistically Different	111.2%	Not Statistically Different	86.7%
	25	Not Statistically Different	141.1%	Not Statistically Different	119.8%	Not Statistically Different	113.6%
I-75 Clarkston	0.02	Not Statistically Different	105.3%	Not Statistically Different	148.4%	Not Statistically Different	128.7%
	0.1	Not Statistically Different	97.6%	Not Statistically Different	139.5%	Not Statistically Different	137.8%
	1	Not Statistically Different	99.0%	Not Statistically Different	173.1%	Not Statistically Different	135.5%
	5	Not Statistically Different	114.0%	Not Statistically Different	168.8%	Not Statistically Different	134.2%
	10	Not Statistically Different	120.3%	Not Statistically Different	162.8%	Not Statistically Different	132.1%
	25	Not Statistically Different	157.3%	Not Statistically Different	165.1%	Not Statistically Different	128.5%

A one-way analysis of variance (ANOVA) with no interaction was used to examine the effects of conditioning on the dynamic creep test in terms of permanent deformation. In all statistical tests, a 5.0% level of significance (α=0.05) was used. The conditioning of I-196 Grand Rapids specimens appears to be statistically significant variable while conditioning of I-75 Clarkston specimens is not statistically significant. A one-way analysis of variance (ANOVA) with no interaction was used to look at the effects of conditioning on the dynamic complex modulus test in terms of E* ratio before dynamic creep testing. In all

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statistical tests, a 5.0% level of significance (α=0.05) was used. Table 8.6 shows that at a frequency of 1.0 and 5.0 Hz, the effects of conditioning on E* ratios are statistically significant for the I-196 Grand Rapids specimens while the conditioning of the I-75 Clarkston specimens is statistically the same.

Table 8.6 One-Way ANOVA (With no Interaction) Results: Effects of Conditioning on E*

Frequency (Hz)	I-196 Grand Rapids	I-75 Clarkston
0.02	Not Statistically Different	Not Statistically Different
0.1	Not Statistically Different	Not Statistically Different
1	**Statistically Different**	Not Statistically Different
5	**Statistically Different**	Not Statistically Different
10	Not Statistically Different	Not Statistically Different
25	Not Statistically Different	Not Statistically Different

Figures 8.29 through 8.34 show the results of E* ratio versus frequency with 95% confidence intervals around the mean for each conditioning type. The E* ratio is based on the E* results of the initial dynamic modulus frequency sweep. The data shows that the highest variability occurs at 0.02 and 25 Hz for I-196 Grand Rapids. I-75 Clarkston shows high variability in E* ratio at 25 Hz in Figure 8.32 while Figures 8.33 and 8.34 are all highly variable at each frequency tested.

Figures 8.35 through 8.46 illustrate the results of E* ratio versus test temperature with 95% confidence intervals around the mean. Freeze-thaw method A was used as the conditioning type at the intermediate test temperature, thus only one E* ratio resulted. I-196 Grand Rapids shows decreasing E* ratio with increasing frequency except at 25 Hz while I-75 Clarkston shows decreasing E* ratio with increasing frequency except at 5, 10, and 25 Hz. The results for both projects show moderate to slightly high variability of E* ratios at the intermediate and high test temperatures. A conservative approach would be to use the

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effective test temperature for rutting in future tests because it provides the lowest E* ratios. The rutting test temperature appears to give lower variable results except at high frequencies (25 Hz).

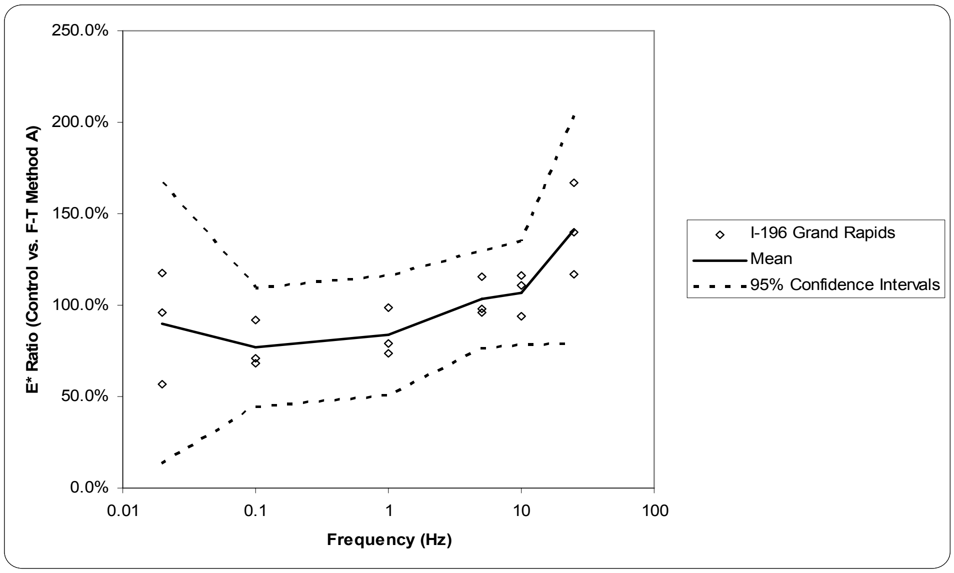

Figure 8.29 I-196 Grand Rapids: E* Ratio versus Frequency (95% Confidence Interval Plots)

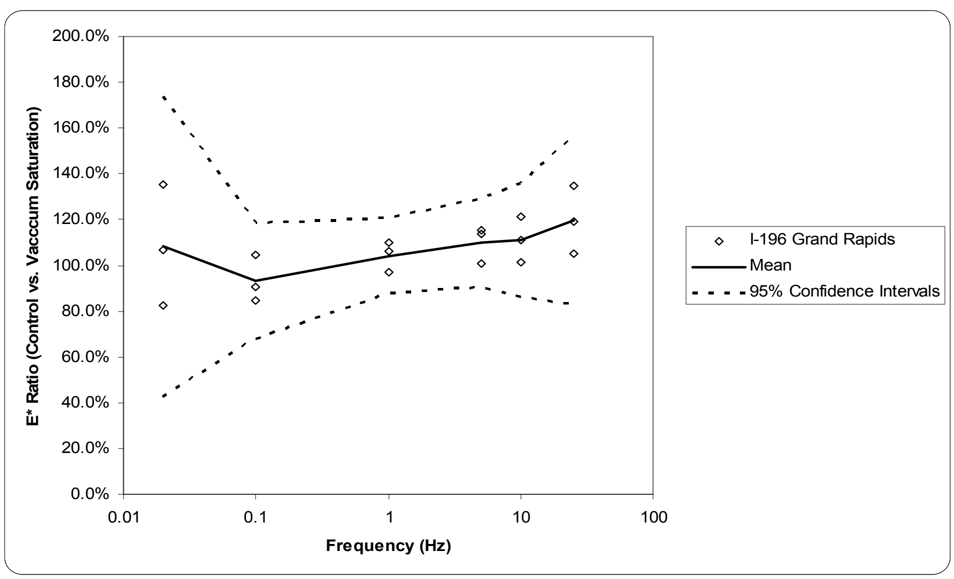

Figure 8.30 I-196 Grand Rapids: E* Ratio versus Frequency (95% Confidence Interval Plots)

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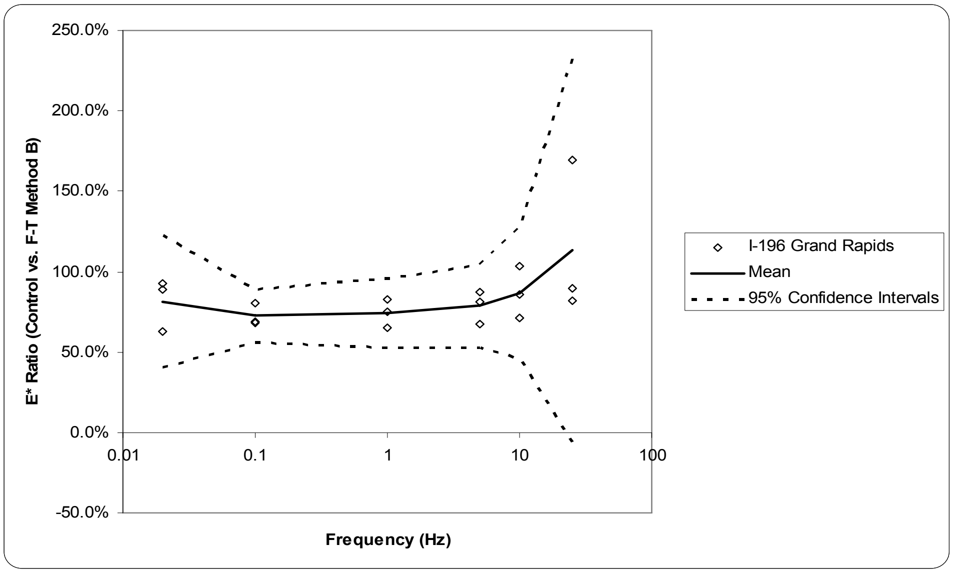

Figure 8.31 I-196 Grand Rapids: E* Ratio versus Frequency (95% Confidence Interval Plots)

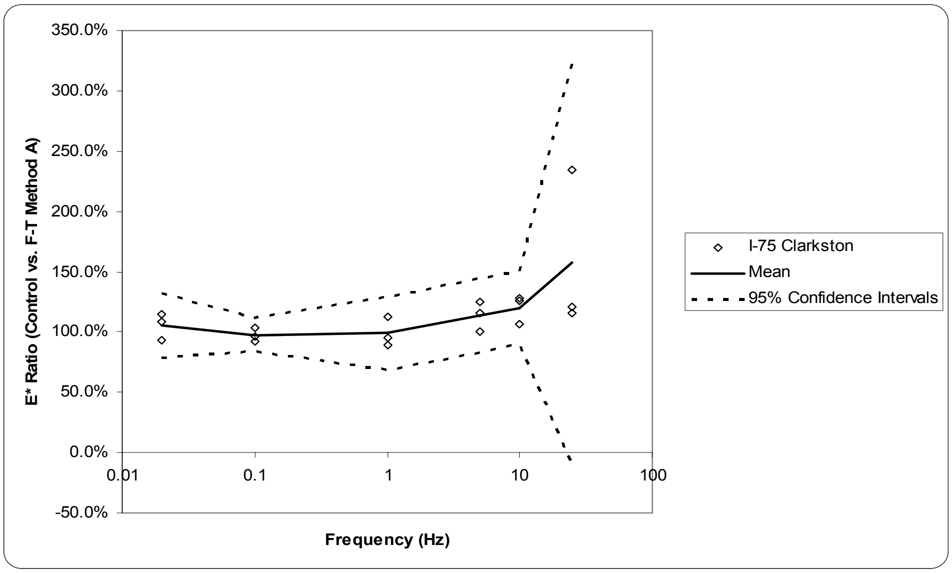

Figure 8.32 I-75 Clarkston: E* Ratio versus Frequency (95% Confidence Interval Plots)

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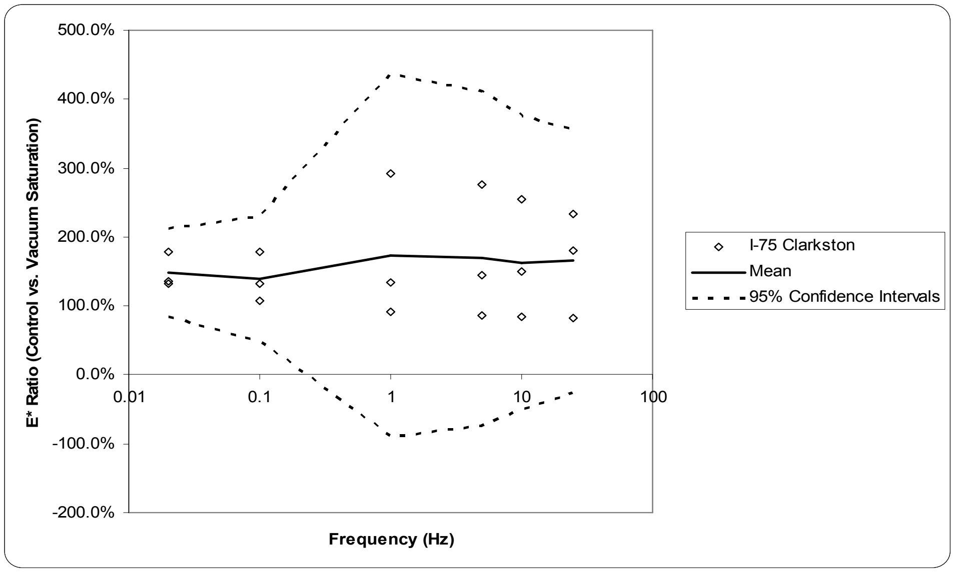

Figure 8.33 I-75 Clarkston: E* Ratio versus Frequency (95% Confidence Interval Plots)

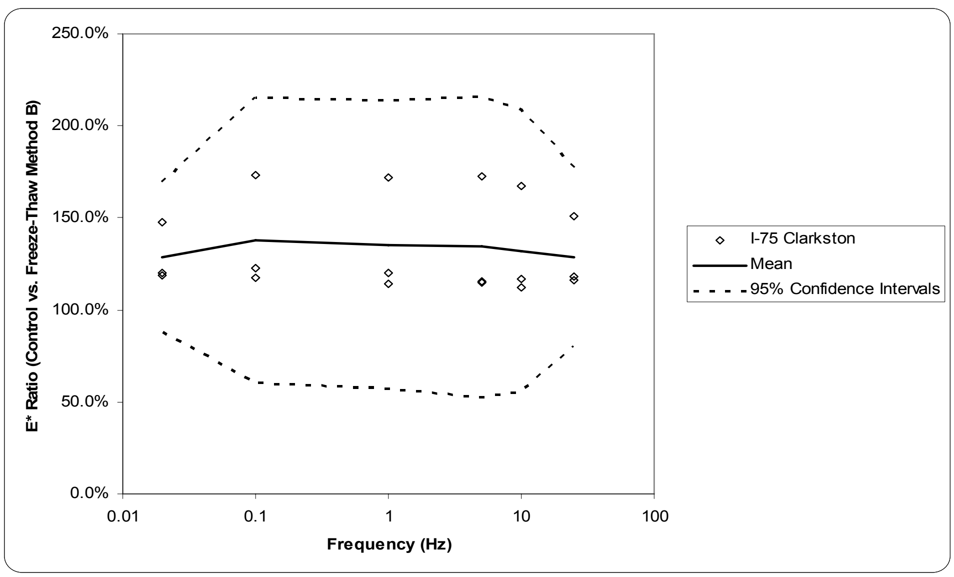

Figure 8.34 I-75 Clarkston: E* Ratio versus Frequency (95% Confidence Interval Plots)

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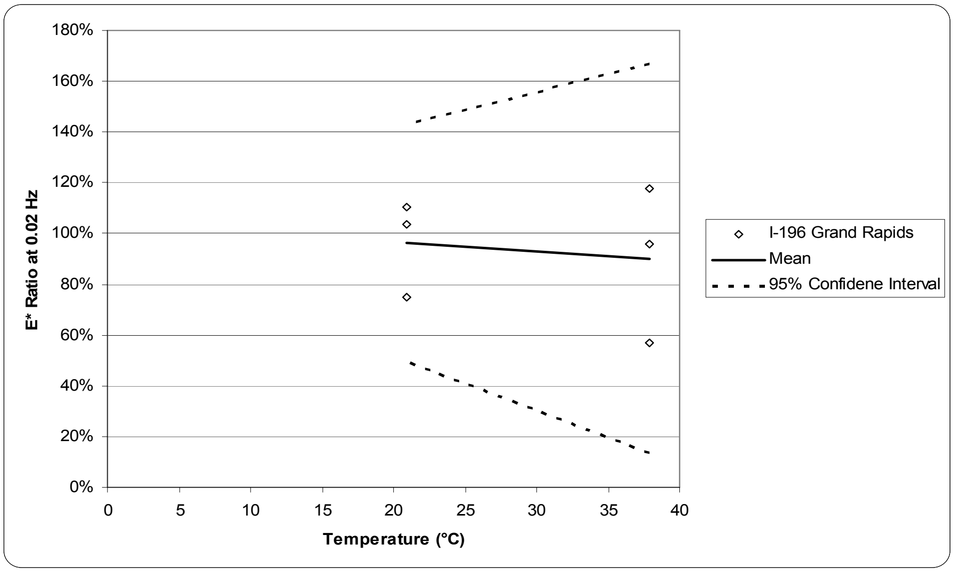

Figure 8.35 I-196 Grand Rapids: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

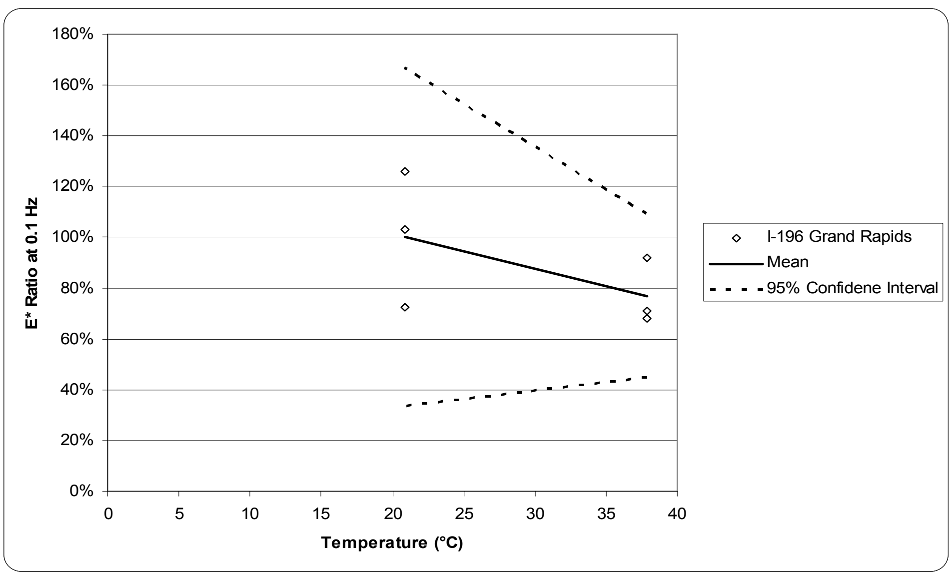

Figure 8.36 I-196 Grand Rapids: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

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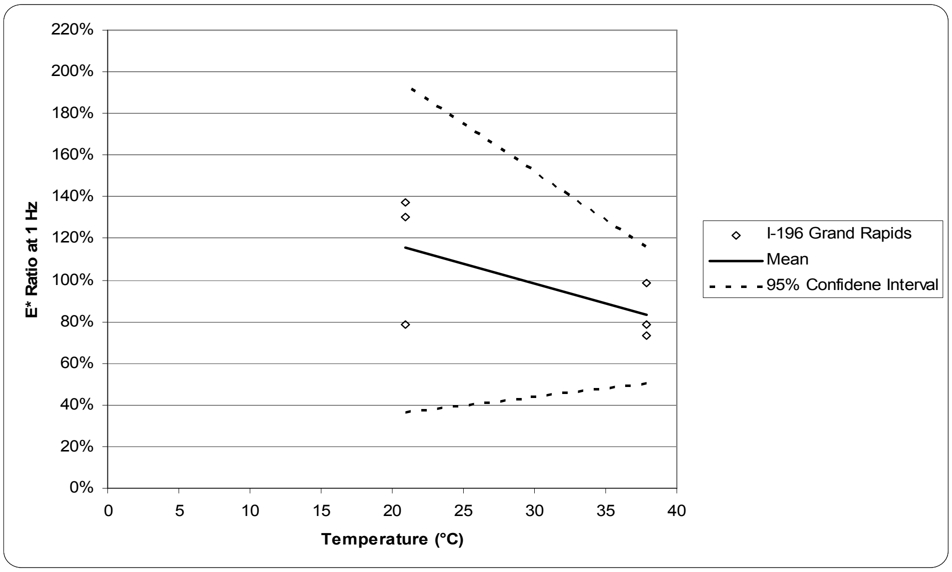

Figure 8.37 I-196 Grand Rapids: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

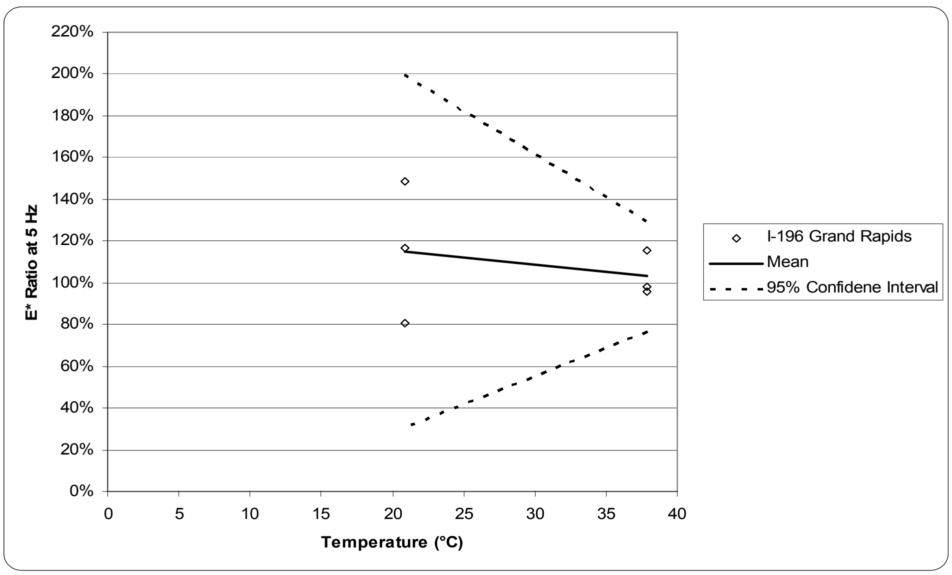

Figure 8.38 I-196 Grand Rapids: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

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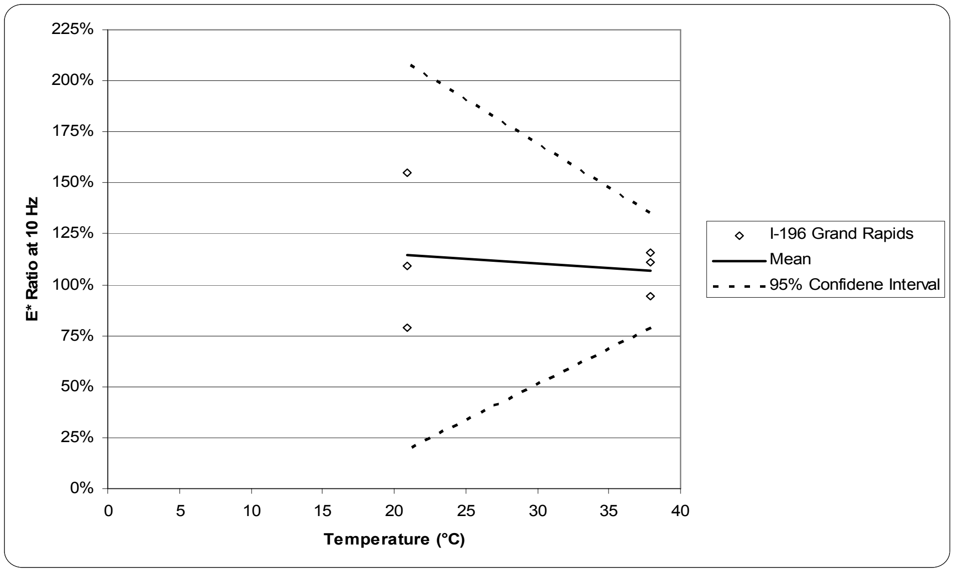

Figure 8.39 I-196 Grand Rapids: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

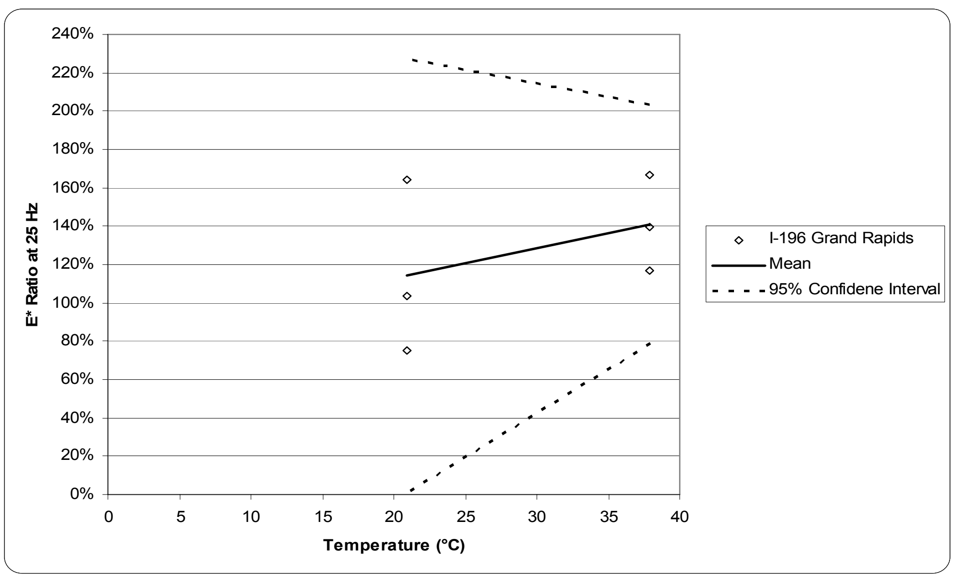

Figure 8.40 I-196 Grand Rapids: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

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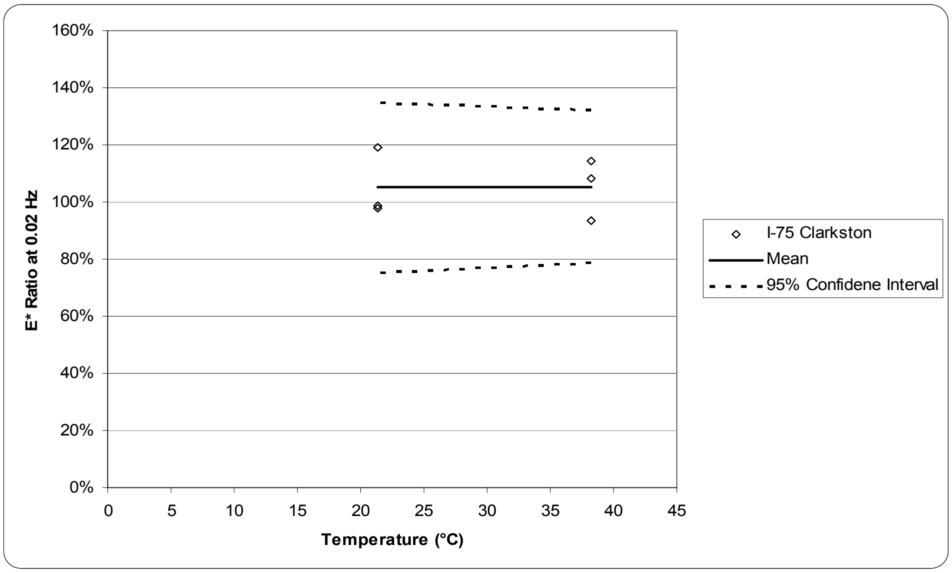

Figure 8.41 I-75 Clarkston: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

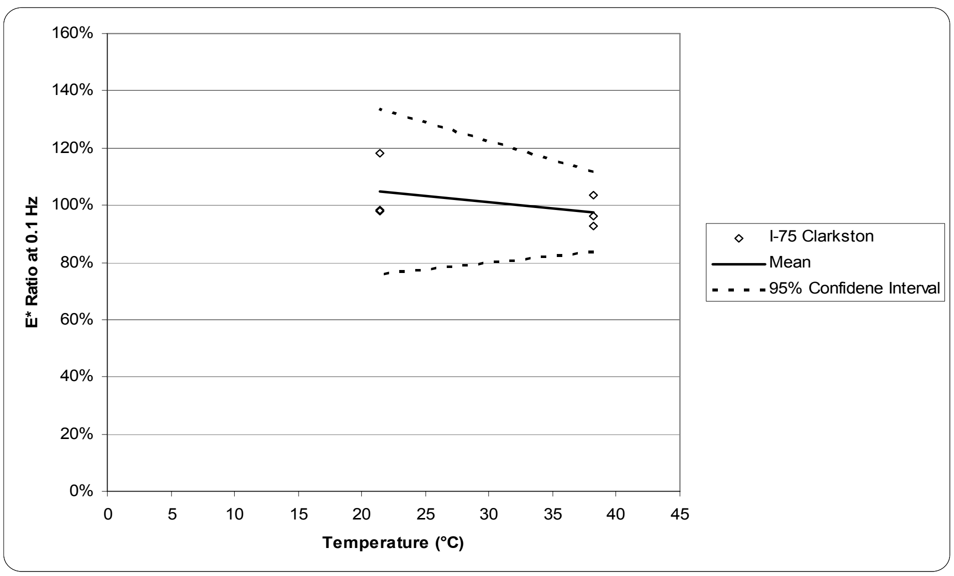

Figure 8.42 I-75 Clarkston: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

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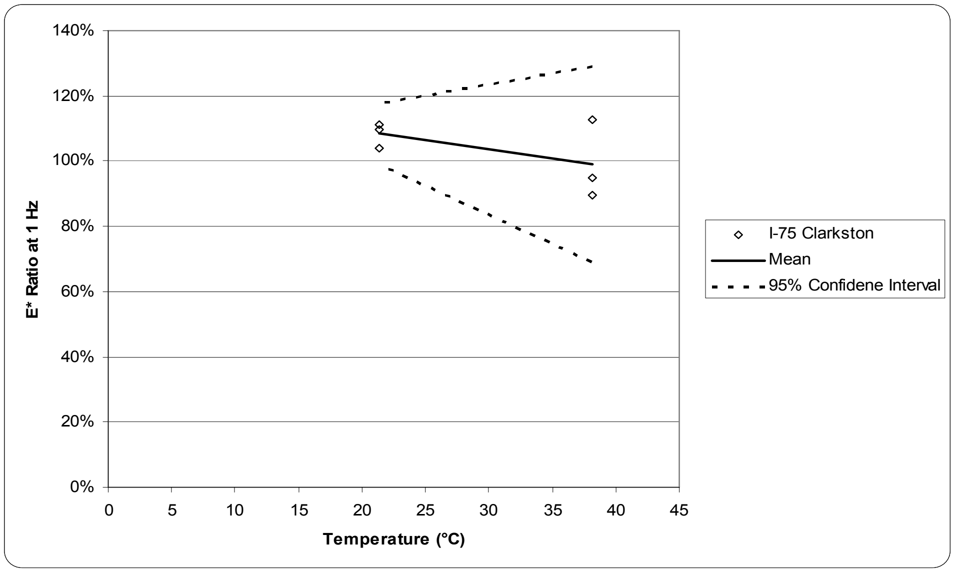

Figure 8.43 I-75 Clarkston: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

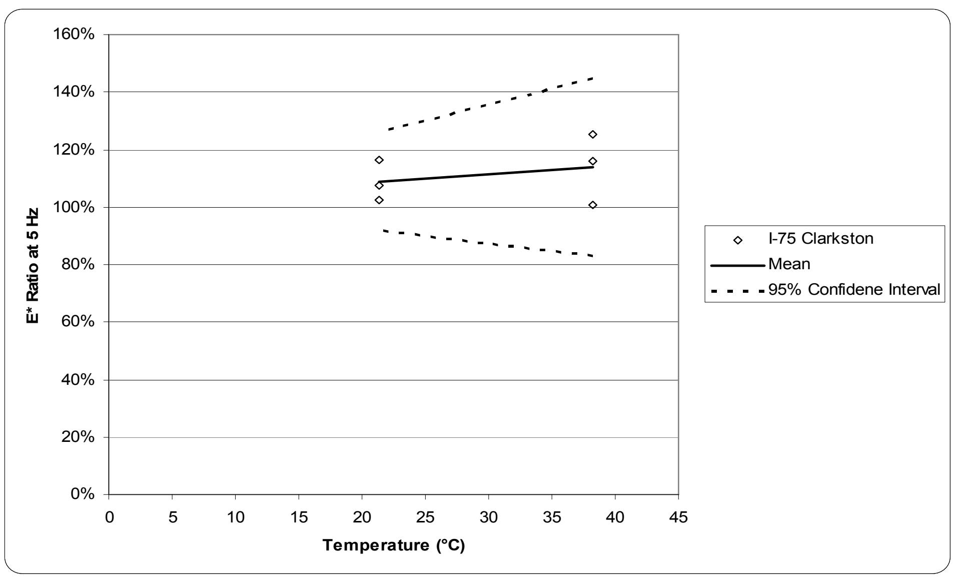

Figure 8.44 I-75 Clarkston: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

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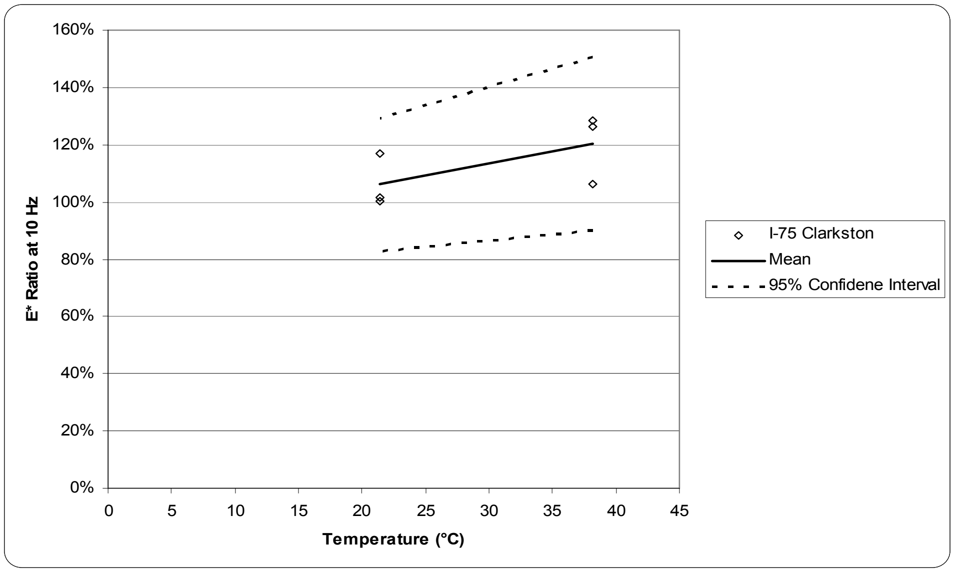

Figure 8.45 I-75 Clarkston: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

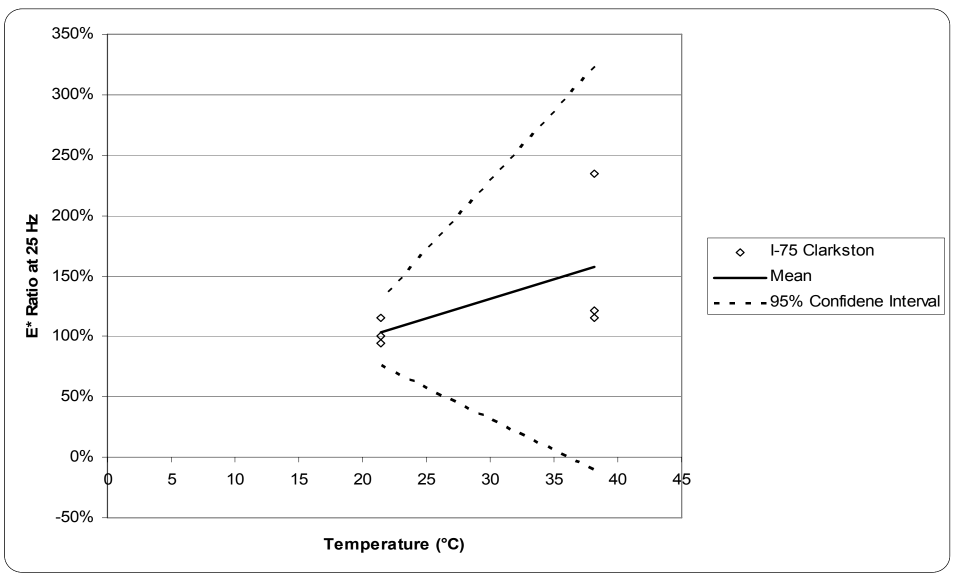

Figure 8.46 I-75 Clarkston: E* Ratio versus Test Temperature (95% Confidence Interval Plots)

8.6 Conclusions

Based on the results above and engineering judgment, it was decided that the effective test temperature for rutting would be used and the conditioning of the specimens would follow the conditioning procedure outlined in AASHTO T283. The effective test temperature for rutting was selected because the ECS that was developed at Oregon State

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University used a test temperature of 60°C, the Hamburg wheel tracking device uses a temperature of 50°C, and the test temperature used in the NCHRP 9-34 study is 60°C. From the literature if appears that moisture damage is accelerated at higher testing temperatures (Aschenbrener et al. 1998, Al-Swailmi et al. 1992a, Solaimanian et al. 2006). AASHTO T283 will be used as the baseline method so therefore the conditioning of the specimens will be a common characteristic between the previous method and the proposed new method. The effect of conditioning on specimens can show statistical differences which can be seen in Table 8.6 at a frequency of 1.0 and 5.0 Hz. I-75 Clarkston did not show any statistically significant effects to conditioning.

The t-tests showed that there was no statistical difference in E* control versus E* wet at freeze-thaw method A but there were differences in the E* ratios between the two projects. I-75 Clarkston exhibited higher E* ratios than I-196 Grand Rapids. I-196 Grand Rapids was thought to be moisture susceptible based on the results of Phase I testing because that project had TSR's lower than 80% which is the criterion used by many owner/agencies.

Flow number testing will not be conducted on the specimens from Phase II because there was no statistical difference in dry permanent deformation versus wet permanent deformation. Since flow number testing was not be conducted, a second frequency sweep to determine E* after damage cycles was not be performed.

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CHAPTER 9 DYNAMIC MODULUS AND AASHTO T283 TESTING OF MICHIGAN MIXES FOR MOISTURE DAMAGE

9.1 Introduction

This chapter presents the results of the final experimental phase which includes twenty-one HMA mixtures that were sampled throughout the state of Michigan. Along with the analysis of the testing results statistical procedures are used to analyze the data and to investigate properties that affect moisture damage including gradation, nominal maximum aggregate size (NMAS), traffic, polymer modification, aggregate type, permeability, asphalt content, fine aggregate angularity (FAA), recycled asphalt content (RAP), and frequency (for dynamic modulus only).

9.2 Experimental Plan

The Phase II final experimental plan considered different mix types, aggregate sources, and laboratory test systems. The experimental plan included two integrated plans: one for the mixes and one for the planned laboratory tests. A sensitivity study on the effects of specimen size and compaction method was accomplished in the Phase I testing to determine the amount of conditioning that should be done on larger Superpave compacted specimens. Another sensitivity study was undertaken to determine the effects of conditioning, test temperature, and test history on dynamic modulus. Table 9.1 below outlines the expanded experimental plan.

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Table 9.1 Expanded Experimental Plan for Phase II Projects

PHASE 2 MOISTURE		
NMAS (mm)	Traffic Level (ESAL's)	
	≤ 3,000,000	>3,000,000
25.0 or 19.0	Limestone - M50 Dundee	Limestone - M59 Brighton
	Limestone - M36 Pinckney	Limestone - Michigan Ave. Detroit
	Gravel - M45 Grand Rapids	Limestone - Vandyke Detroit
	Gravel - M21 St. Johns	Limestone - US23 Hartland
	Limestone - M84 Saginaw	Gravel - I-75 Levering Road
12.5 or 9.5	Limestone - BL96 Howell	Limestone - I-196 Grand Rapids
	Gravel - M21 Owosso	Slag/Gabbro - I-75 Clarkston
	Gravel - M66 Battle Creek	Gravel - M53 Detroit
	Limestone - M50 Dundee	Limestone - Michigan Ave. Detroit
	Limestone - US12 MIS	Gabbro I-75 Toledo (in MI)
SMA	N/A	Gabbro - I-94 SMA Ann Arbor

Table 9.2 below outlines the laboratory testing experimental plan. The test temperature and moisture conditioning of the specimens was determined in the Phase II sensitivity study. A proposed method of determining moisture susceptibility was compared to the current method of determining moisture susceptibility from which any conclusions and recommendations will be drawn upon.

Table 9.2 Laboratory Experimental Plan for Phase II

		Unconditioned	Conditioned
Test System	AASHTO T283	XXXXX	XXXXX
	Dynamic Complex Modulus Test	XXX	XXX

[1]XRepresents a tested sample

9.3 AASHTO T283 Test Results

Figures 9.1 and 9.2 illustrate the variability of tensile strength ratios among each project. Ninety-five percent confidence intervals around the mean were fit to the data. Figure 9.1 shows the TSR’s for low volume roads (≤3,000,000 ESAL’s) and Figure 9.2

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shows the TSR's for high volume roads (>3,000,000 ESAL's). The data shows that generally higher volume roads exhibited higher TSR's than lower volume roads. Figure 9.3 shows good agreement (correlation) between dry strength and wet strength. It appears that at low strengths the regression line is close to the line of equality but as the strength increases, the regression line diverges away from the line of equality.

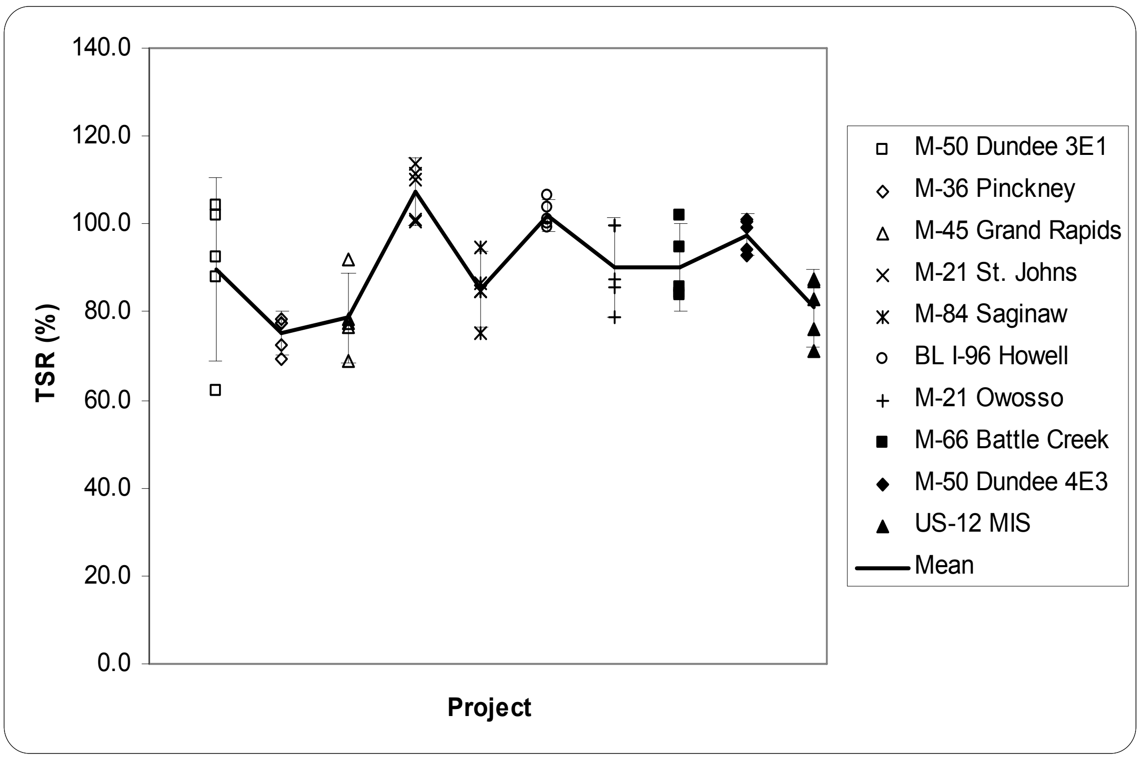

Figure 9.1 AASHTO T283 Test Results for Traffic Level ≤3,000,000 ESAL's with 95% Confidence Intervals

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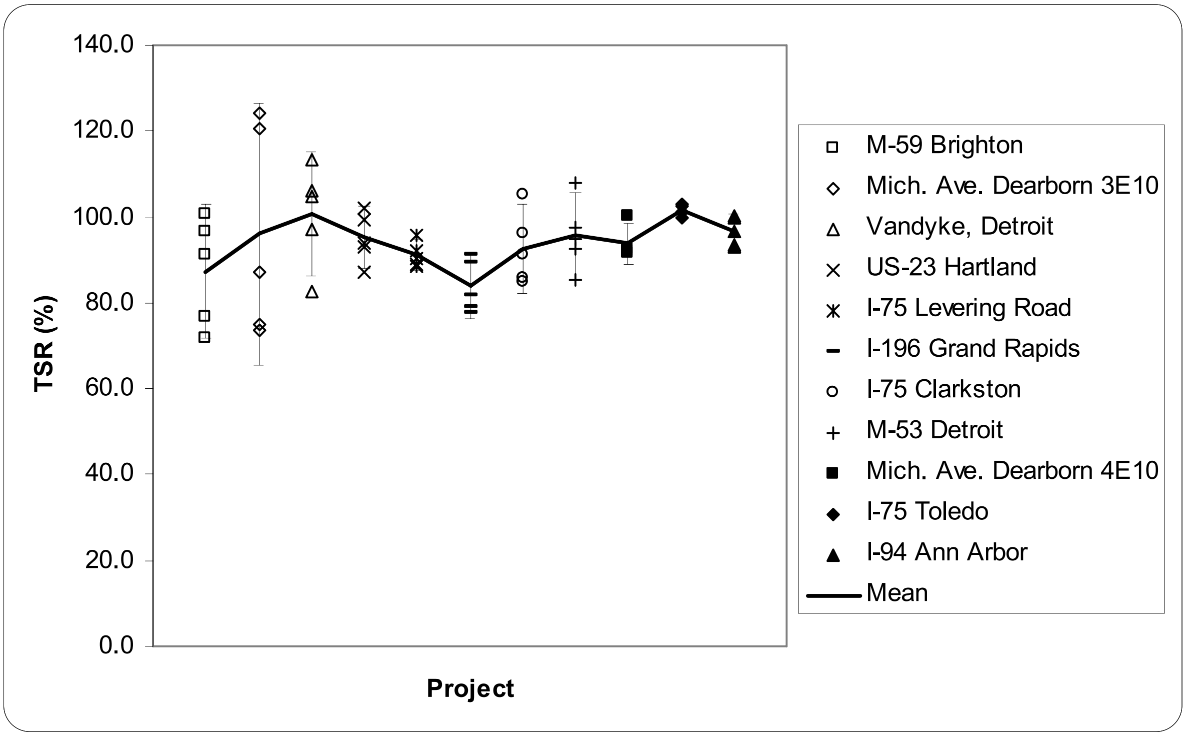

Figure 9.2 AASHTO T283 Test Results for Traffic Level >3,000,000 ESAL's with 95% Confidence Intervals

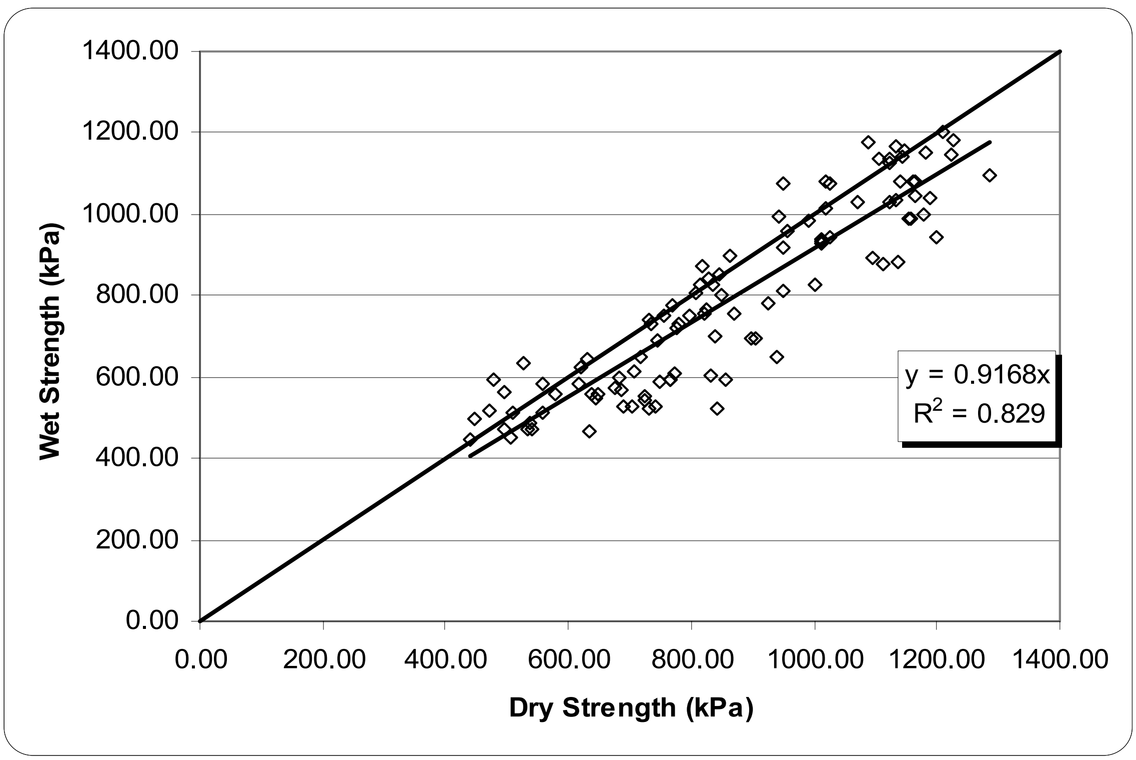

Figure 9.3 Dry Strength versus Wet Strength (Pooled Data)

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9.4 Dynamic Modulus Test Results

Figures 9.4 to 9.15 illustrate the variability of E* ratios at each frequency for each mixture. Ninety-five percent confidence intervals around the mean were fit to the data. Figures 9.4, 9.5, 9.6, 9.7, 9.8 and 9.9 shows the E* ratios for low volume roads (≤3,000,000 ESAL's) and Figures 9.10, 9.11, 9.12, 9.13, 9.14 and 9.15 shows the E* ratios for high volume roads (>3,000,000 ESAL's). For each mixture, three replicate specimens were tested for the control and conditioned specimens. One project, Michigan Avenue, Dearborn 4E10 had only two replicate specimens for the conditioned specimens because the buttons on which the LVDT's attach came off of one of the conditioned specimens. The test temperature that each project was conducted at was the effective test temperature for rutting. The data shows that higher volume roads have similar E* ratios to the lower volume roads. It should also be noted that an E* ratio cannot be negative and the confidence interval about E* ratio cannot be negative. A negative confidence interval is shown sometimes in Figures 9.4 to 9.15 to illustrate the symmetry of the confidence interval. Figure 9.16 shows a good agreement between unconditioned E* values and moisture conditioned E* values. It appears that at low E* values the regression line is close to the line of equality but as the E* increases, the regression line diverges from the line of equality similar to that of AASHTO T283 strength values. It was noticed that the 95% confidence intervals were rather broad, and this is due to the fact that only three samples were tested. Increasing the number of samples would likely reduce the variability. NCHRP Report 465 concludes that coefficient of variations (COV) less than 30% is good, and the data shown in the figures below exhibit COV values below this 30% level but looking at the 95% confidence intervals, much variability still exists (Witczak et al. 2002).

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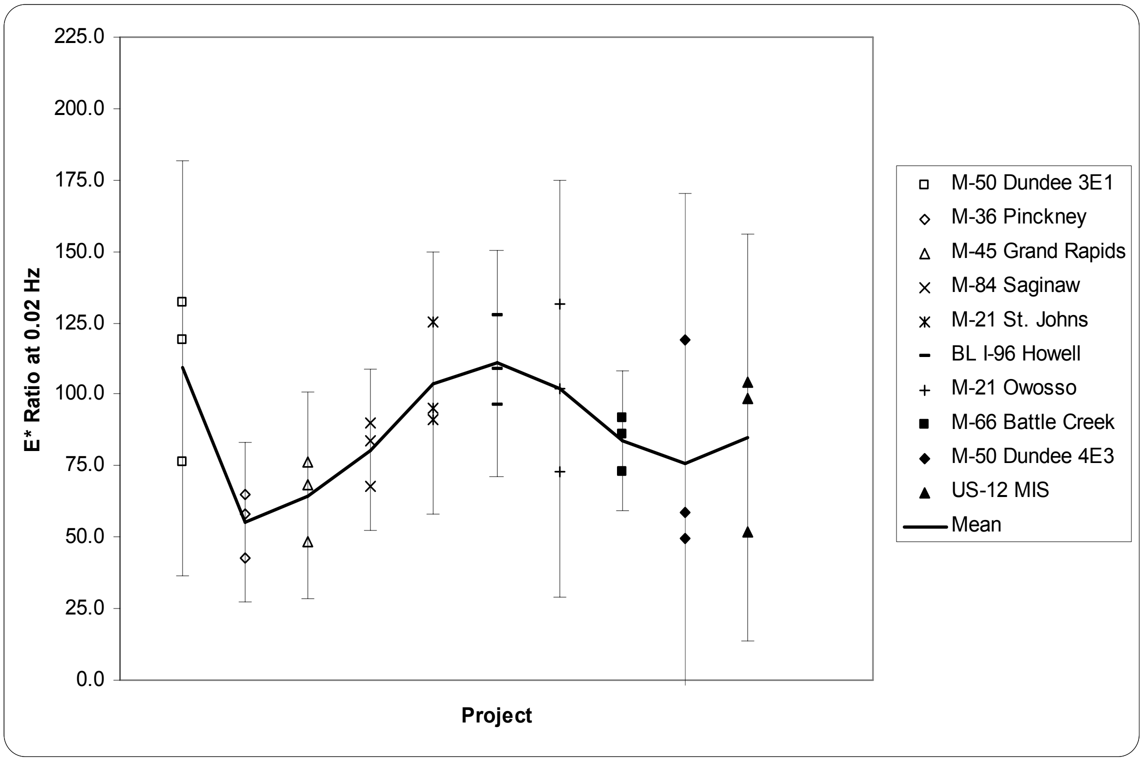

Figure 9.4 E* Ratio at 0.02Hz Test Results for Traffic Level ≤3,000,000 ESAL's with 95% Confidence Intervals

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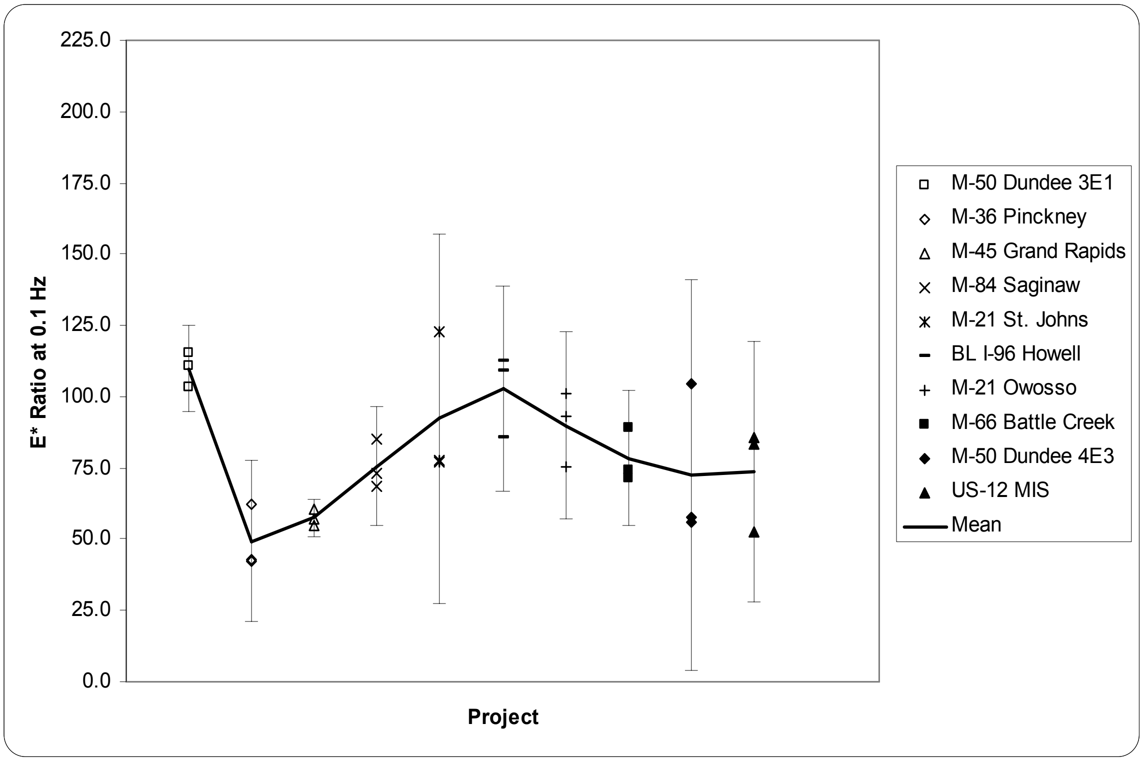

Figure 9.5 E* Ratio at 0.1Hz Test Results for Traffic Level ≤3,000,000 ESAL's with 95% Confidence Intervals

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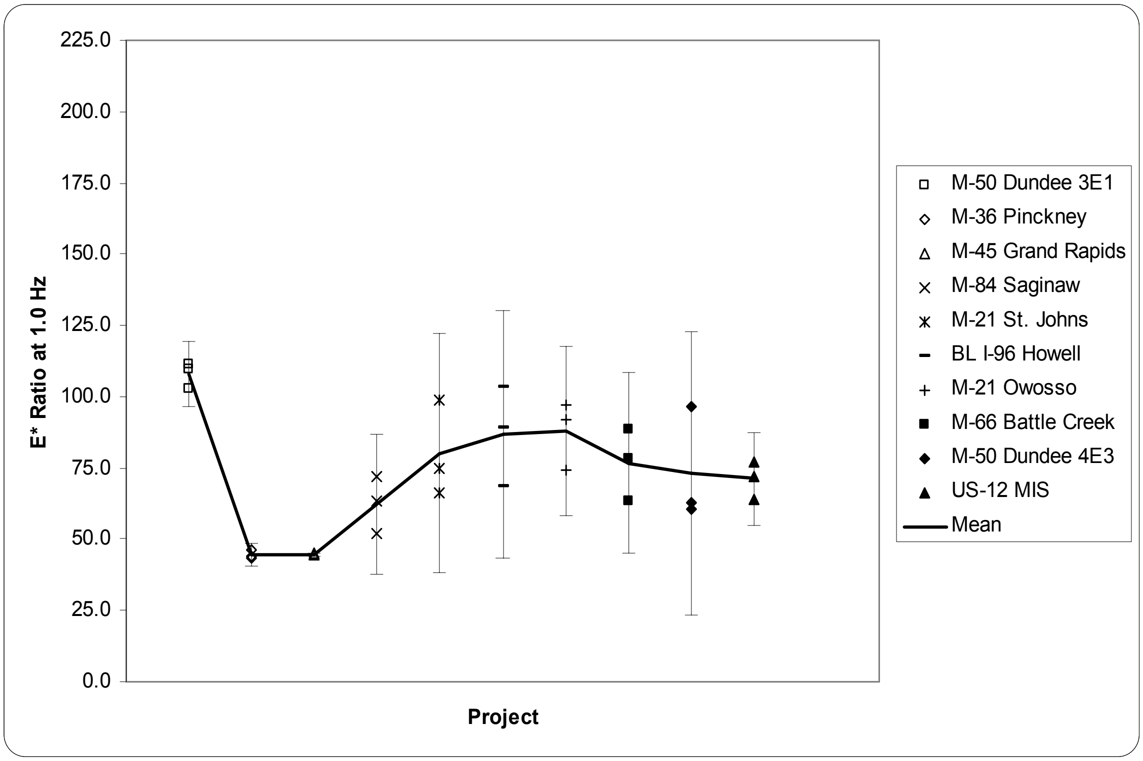

Figure 9.6 E* Ratio at 1.0HzTest Results for Traffic Level ≤3,000,000 ESAL's with 95% Confidence Intervals

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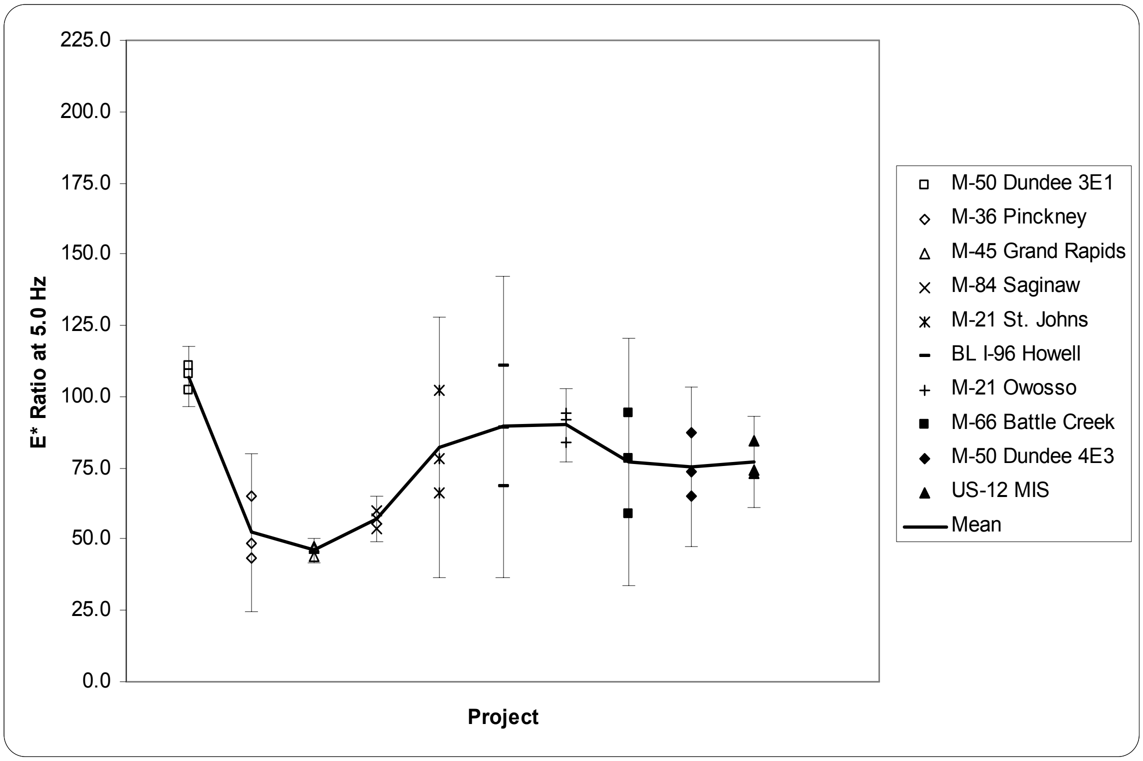

Figure 9.7 E* Ratio at 5.0Hz Test Results for Traffic Level ≤3,000,000 ESAL's with 95% Confidence Intervals

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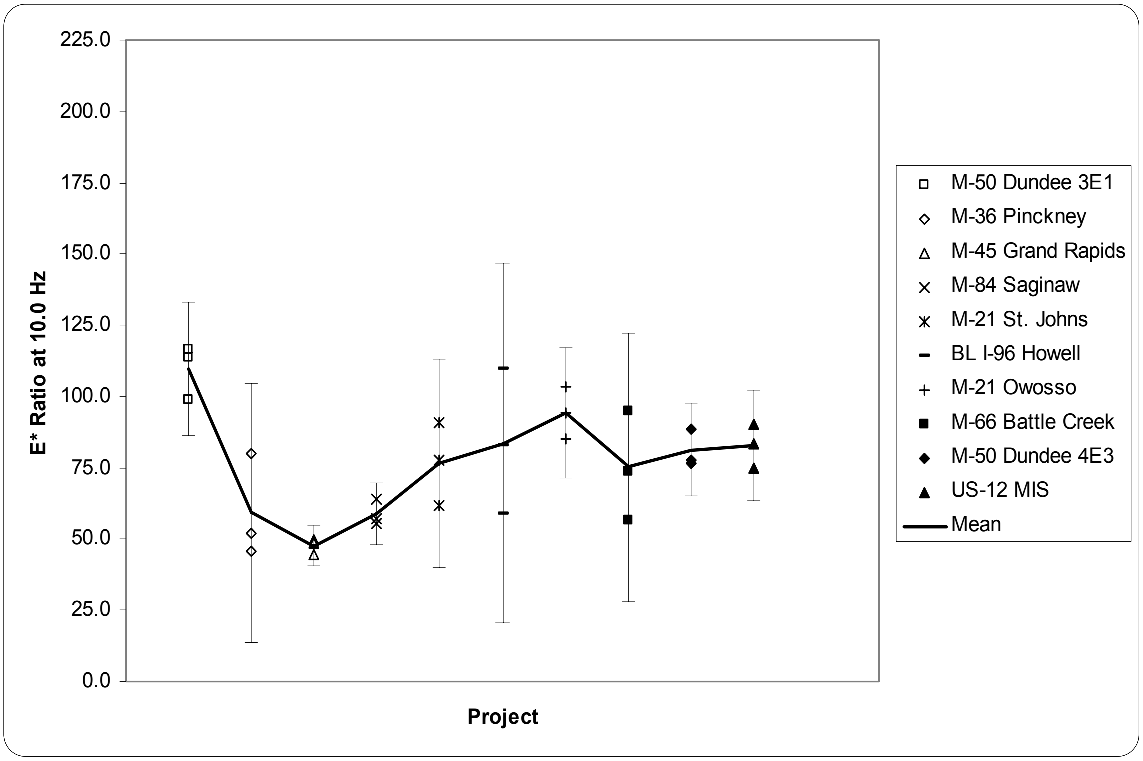

Figure 9.8 E* Ratio at 10.0Hz Test Results for Traffic Level ≤3,000,000 ESAL's with 95% Confidence Intervals

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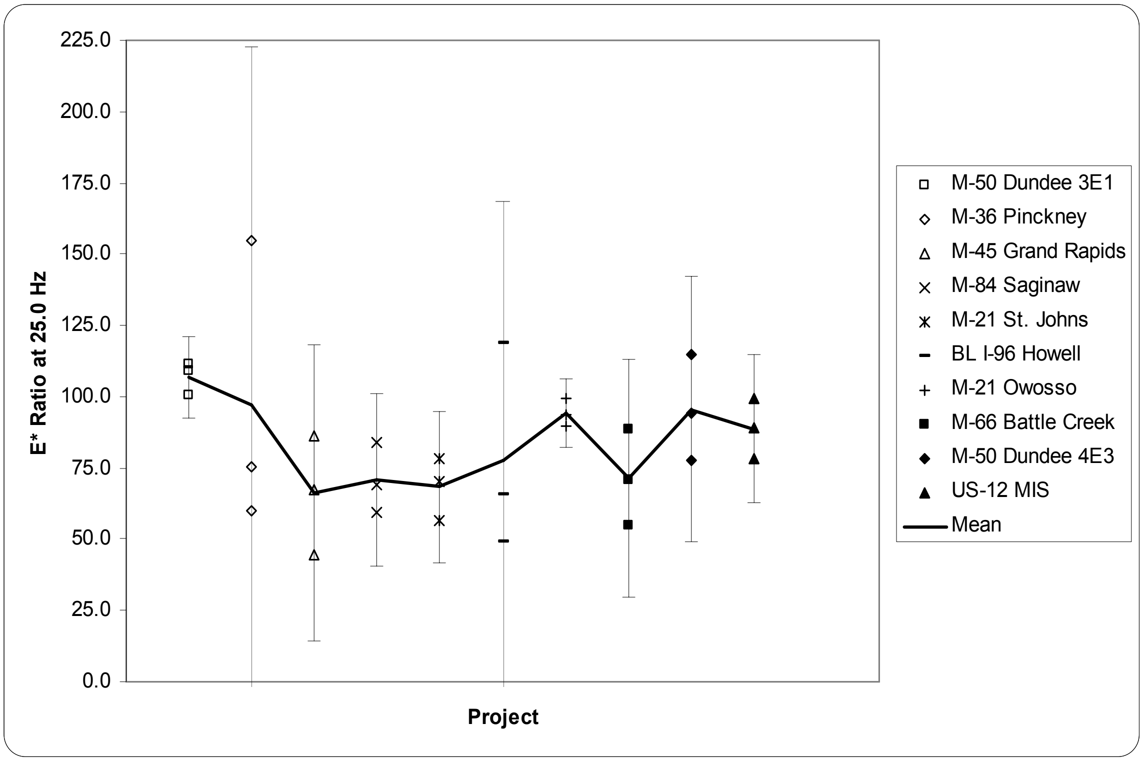

Figure 9.9 E* Ratio at 25.0Hz Test Results for Traffic Level ≤3,000,000 ESAL's with 95% Confidence Intervals

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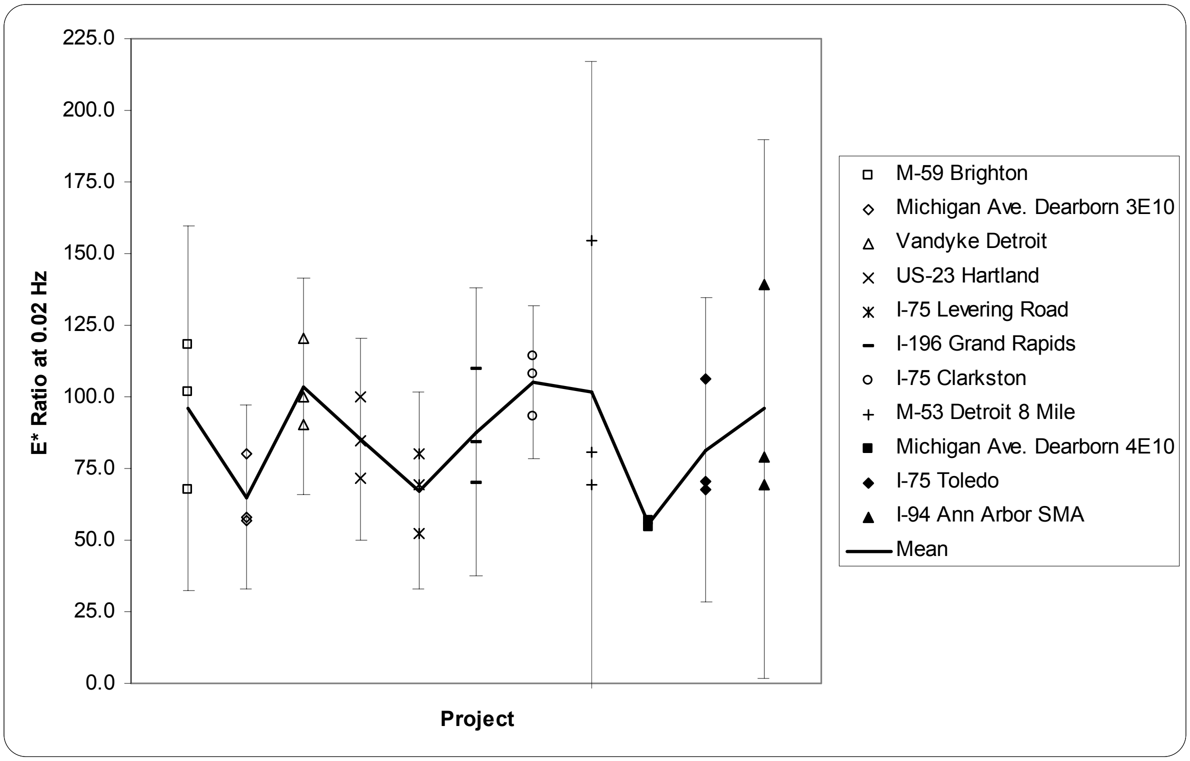

Figure 9.10 E* Ratio at 0.02Hz Test Results for Traffic Level >3,000,000 ESAL's with 95% Confidence Intervals

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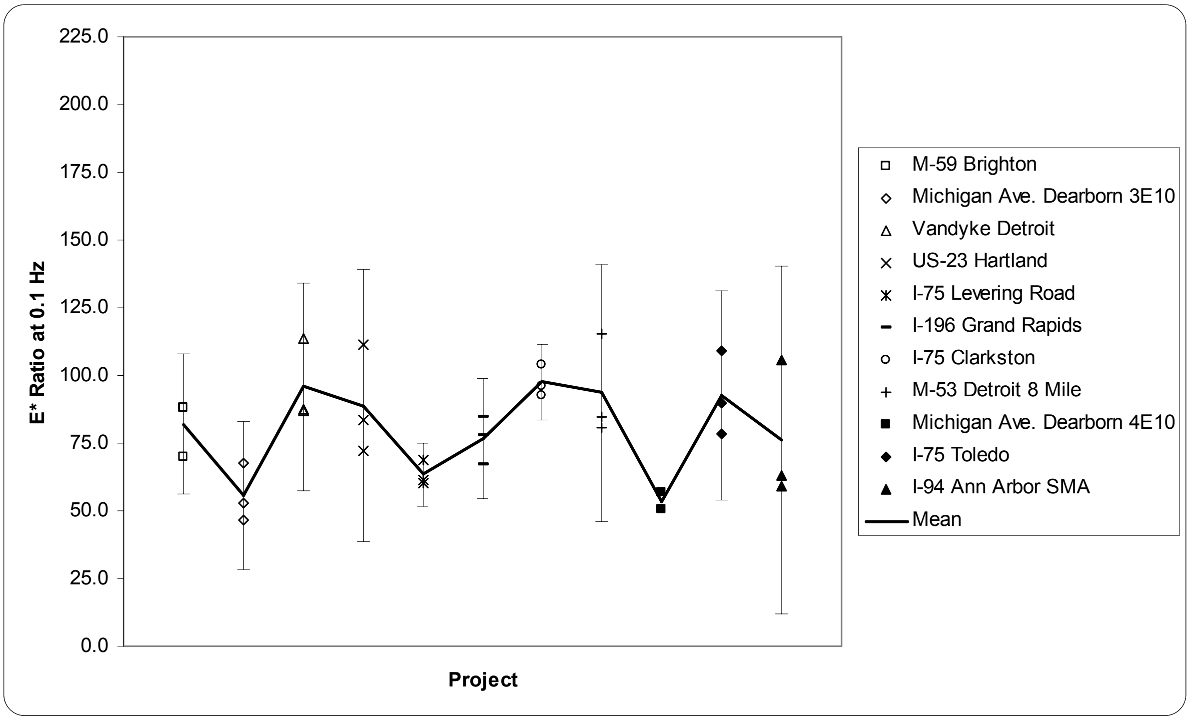

Figure 9.11 E* Ratio at 0.1HzTest Results for Traffic Level >3,000,000 ESAL's with 95% Confidence Intervals

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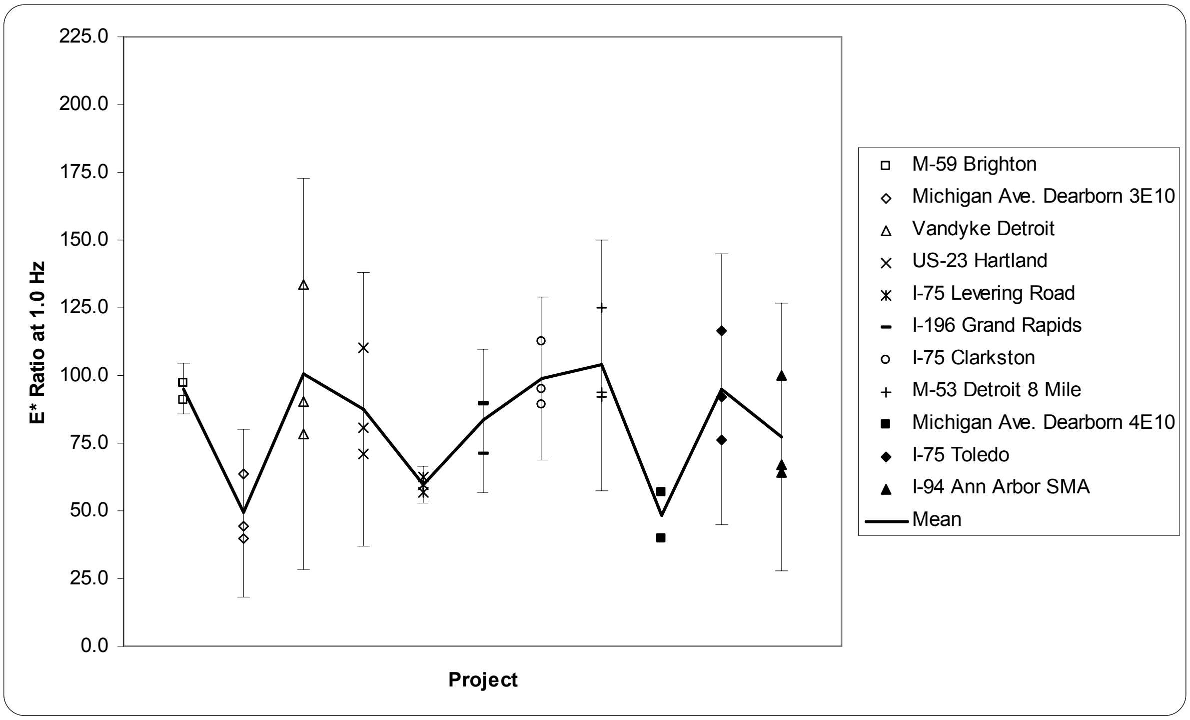

Figure 9.12 E* Ratio at 1.0HzTest Results for Traffic Level >3,000,000 ESAL's with 95% Confidence Intervals

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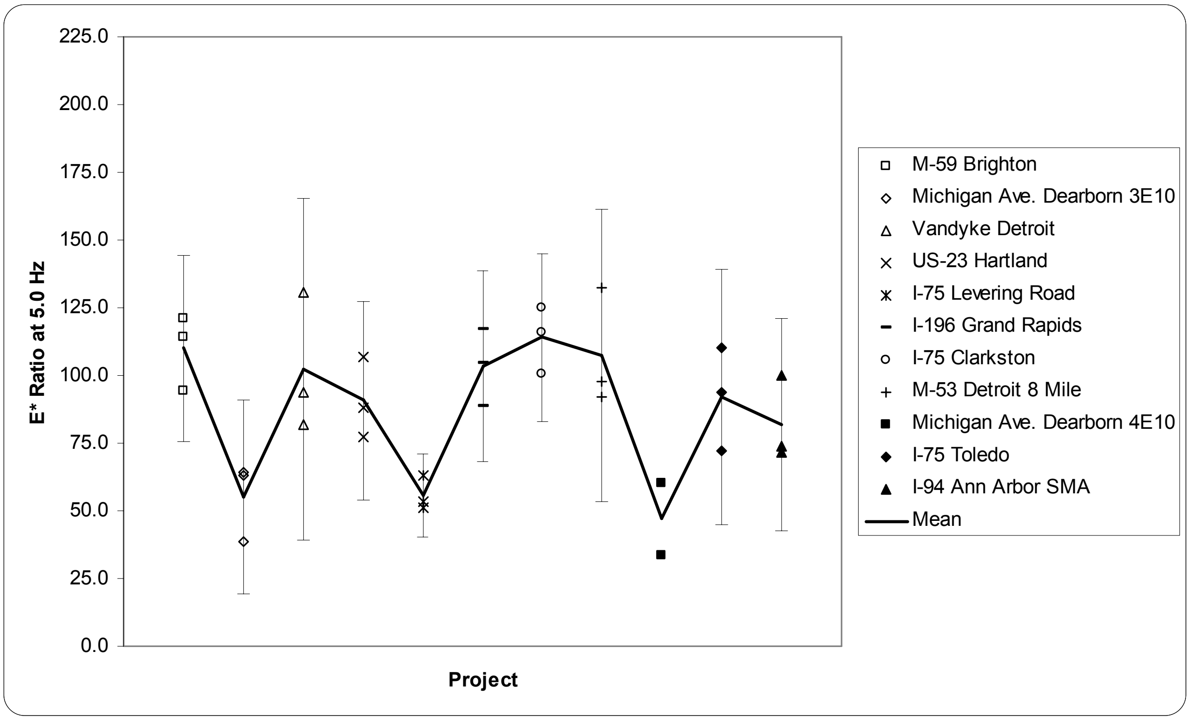

Figure 9.13 E* Ratio at 5.0Hz Test Results for Traffic Level >3,000,000 ESAL's with 95% Confidence Intervals

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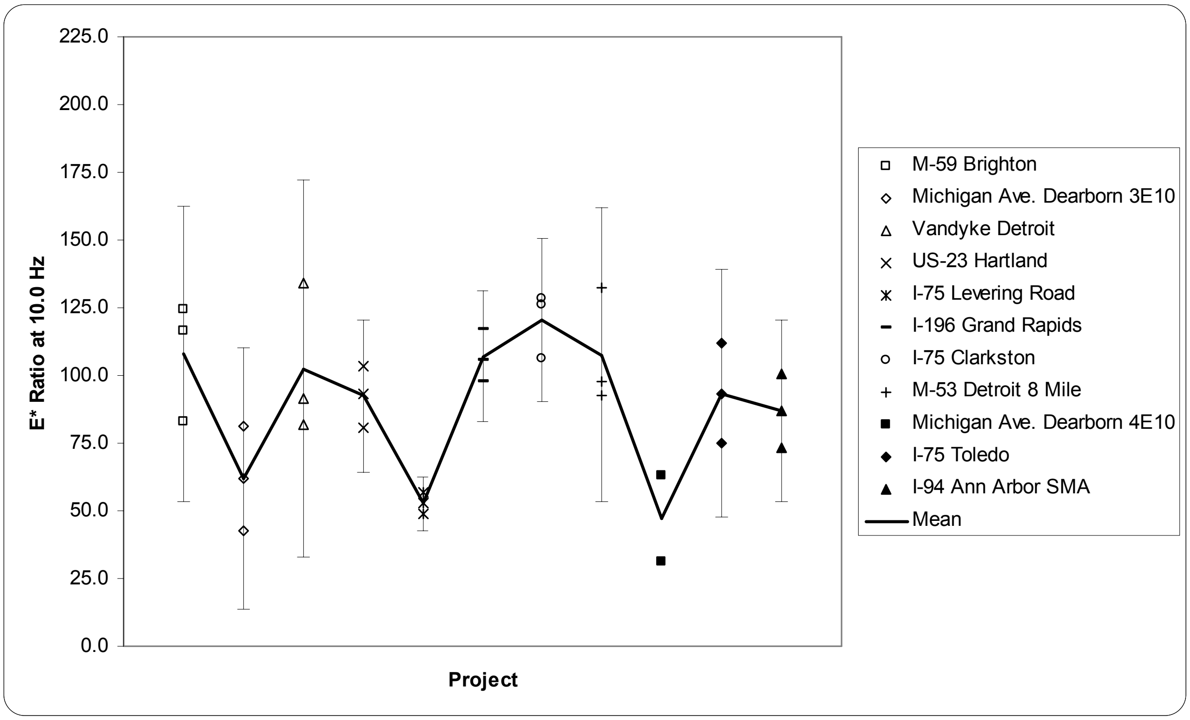

Figure 9.14 E* Ratio at 10.0Hz Test Results for Traffic Level >3,000,000 ESAL's with 95% Confidence Intervals

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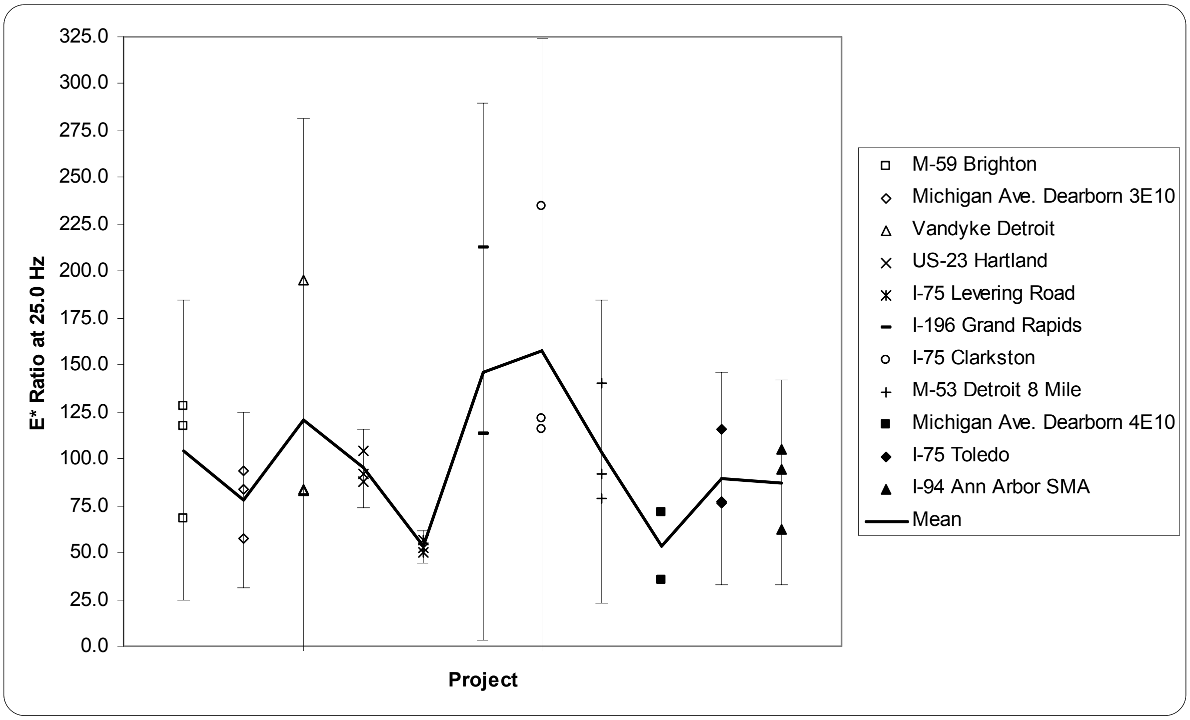

Figure 9.15 E* Ratio at 25.0Hz Test Results for Traffic Level >3,000,000 ESAL's with 95% Confidence Intervals

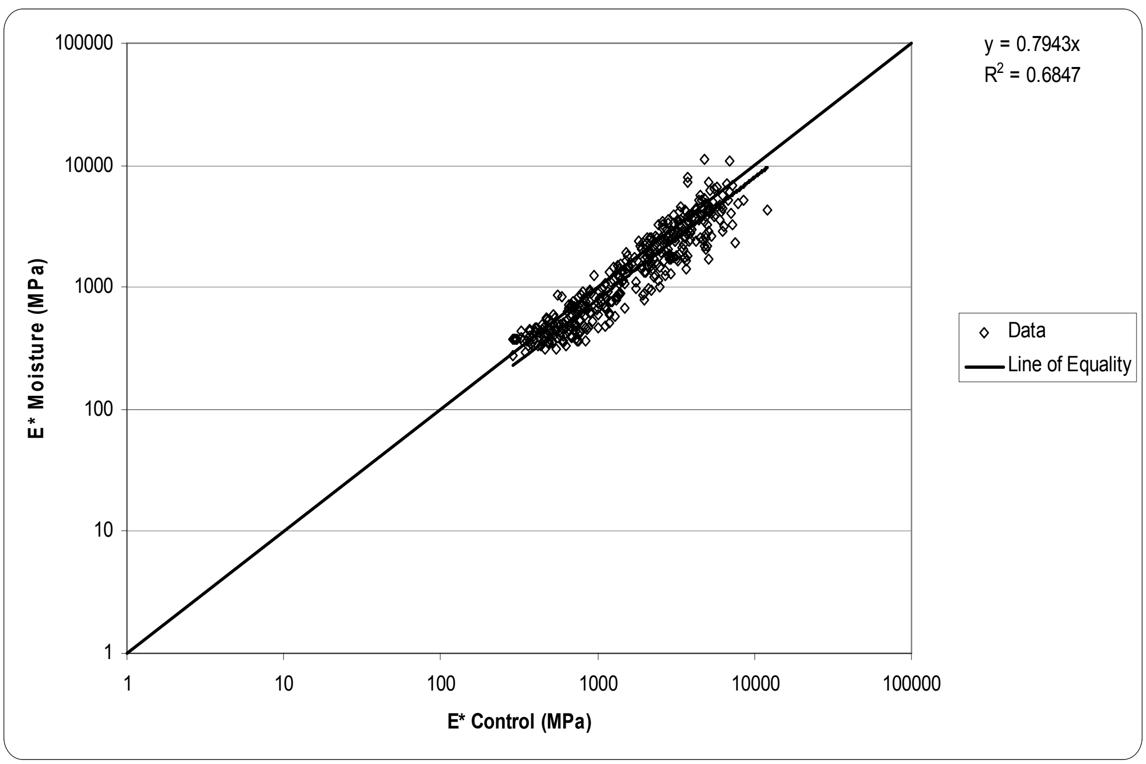

Figure 9.16 Dry E* versus Wet E* (Pooled Data)

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9.5 Analysis of Results

Two statistical procedures were used to analyze the data. First, two sample t-tests were used to compare dry strength to wet strength and dry dynamic modulus to wet dynamic modulus at each frequency using the following hypotheses:

$$H_o : \text{Dry Strength} = \text{Wet Strength}$$
$$\text{H}_\text{A} : \text{Dry Strength} \neq \text{Wet Strength}$$
$$\alpha = 0.05$$

$$H_o : \text{Dry E}^* = \text{Wet E}^*$$
$$\text{H}_\text{A} : \text{Dry E}^* \neq \text{Wet E}^*$$
$$\alpha = 0.05$$

A probabilistic analysis was used to determine the criterion for moisture susceptibility for HMA based on the dynamic modulus test using moisture conditioning outlined in AASHTO T283. The lognormal distribution based on the Kolmogorov-Smirnov One-Sample Test using a p-value of 0.05 was selected for the TSR and E* ratios since a lognormal distribution was applicable to most of the datasets investigated (Ayyub et al. 1997). A lognormal distribution is an appropriate selection since the TSR cannot be less than zero. Therefore a lognormal distribution was used to fit the TSR and E* ratio data at each frequency. The outputs containing the lognormal distribution and the appropriate test statistics can be seen in Appendix D and summarized below in Table 9.3.

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Table 9.3 Goodness of Fit Statistics for Phase II

Test Parameter	Frequency (Hz)	Kolmogorov-Smirnov Statistic Lognormal Distribution	p-value
TSR	N/A	0.08659458	0.051
E* Ratio	0.02	0.06143057	>0.150
E* Ratio	0.1	0.08809599	>0.150
E* Ratio	1.0	0.14446214	<0.010
E* Ratio	5.0	0.10132484	0.113
E* Ratio	10.0	0.11101509	0.057
E* Ratio	25.0	0.07586343	>0.150

Table 9.4 shows the results of the two-sample t-tests comparing dry strength to wet strength. The bolded entries in Table 9.4 are those HMA mixtures that have statistically different dry versus wet strengths and have an average TSR less than 80%. The two sample t-tests show that for certain projects, there are statistical differences in dry versus wet strength. In all statistical tests, a 5.0% level of significance (α=0.05) was used (Ayyub et al. 1997). The average TSR for each HMA mixture is also shown in Table 9.4, to understand that if there are statistical differences in the dry versus the wet strength, a determination of whether moisture damage is increasing or decreasing the strength of the HMA is made. The two sample t-test shows mixed results, in some cases the strengths are statistically different and the TSR's are less than the criterion or close to it, while there are a few cases where the strengths are statistically different and the TSR's are greater than the criterion. The bolded projects in Table 9.4 are those that are statistically different and have a TSR value less than the current threshold value of 80%. If the proposed criteria of 87% is implemented, then four more additional mixes would fail that criteria.

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Table 9.4 Two-Sample t-test Results Comparing Dry Strength to Wet Strength

	AASHTO T283	
Project	**t-Test Results**	**Average TSR (%)**
M-50 Dundee 3E1	Not Statistically Different	89.7
M-36 Pinckney	***Statistically Different***	***75.1***
M-45 Grand Rapids	***Statistically Different***	***78.7***
M-21 St. Johns	Not Statistically Different	107.3
M-84 Saginaw	*Statistically Different*	*85.1*
BL I-96 Howell	Not Statistically Different	102.1
M-21 Owosso	Not Statistically Different	90.2
M-66 Battle Creek	*Statistically Different*	*90.1*
M-50 Dundee 4E3	Not Statistically Different	97.6
US-12 MIS	*Statistically Different*	*80.9*
M-59 Brighton	Not Statistically Different	87.3
Michigan Ave. Dearborn 3E10	Not Statistically Different	96.0
Vandyke Detroit	Not Statistically Different	100.7
US-23 Hartland	Not Statistically Different	95.1
I-75 Levering Road	*Statistically Different*	*91.1*
I-196 Grand Rapids	*Statistically Different*	*83.8*
I-75 Clarkston	Not Statistically Different	92.7
M-53 Detroit 8 Mile	Not Statistically Different	95.6
Michigan Ave. Dearborn 4E10	*Statistically Different*	*93.7*
I-75 Toledo	Not Statistically Different	101.5
I-94 Ann Arbor SMA	Not Statistically Different	96.6

Figure 9.17 shows the TSR data pooled together and a lognormal distribution fitted to the data. A vertical line is drawn at 80% which is the TSR criterion and a horizontal line across to show how many specimens did not meet the criterion. Approximately 15% of the specimens failed to meet the TSR criterion of 80%.

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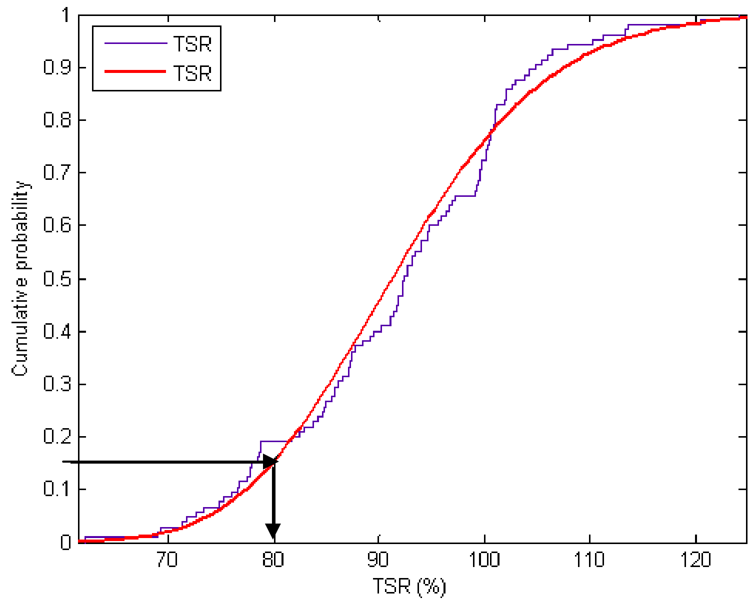

Figure 9.17 Lognormal Distribution of Tensile Strength Ratio's

Table 9.5 shows the results of the two-sample t-tests comparing dry dynamic modulus to moisture conditioned dynamic modulus. In all statistical tests, a 5.0% level of significance (α=0.05) was used. The two sample t-tests show that for certain HMA mixtures, there are significant statistical differences in dynamic modulus. The average E* ratio for each HMA mixture is shown in Table 9.5 to understand that if there are statistical differences in the dry versus the wet stiffness, then a determination of whether moisture damage is increasing or decreasing the stiffness of the HMA is made. The two sample t-test shows mixed results, in some cases the dynamic modulus values are statistically different and the E* ratios are less than the criterion while there are cases where the results are statistically the same and the E* ratio is less than the criterion. The criterion used is 80% which is the same as TSR but this value will be examined more in depth later in this chapter. The italicized text in Table 9.5 are those HMA mixtures that have statistically different E* dry versus E* wet and E* ratios less than 80%. The HMA mixtures that are shaded are those that have E* dry versus E* that

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which not statistically different and have E* ratios less than 80%. For example, if 1.0 Hz is selected as the frequency in order to conduct moisture susceptibility testing using dynamic modulus and a 60% E* ratio is implemented then five HMA mixtures would fail this criteria. If an agency decides to change the TSR criteria from 80% to 87% than this would change the criteria for the proposed test from 60% to 70% in order to keep the same percentage of mixtures failing AASHTO T283. An additional mixture would then fail to meet the 70% criteria.

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Table 9.5 Two-Sample t-test Results Comparing Control E* to Moisture Conditioned E*

	0.02 Hz		0.1 Hz		1 Hz	
Project	**t-test Results**	**E* Ratio**	**t-test Results**	**E* Ratio**	**t-test Results**	**E* Ratio**
M-50 Dundee 3E1	Not Statistically Different	109.1	Not Statistically Different	109.8	Not Statistically Different	108.0
M-36 Pinckney	*Statistically Different*	*55.2*	*Statistically Different*	*49.2*	*Statistically Different*	*44.6*
M-45 Grand Rapids	Not Statistically Different	64.4	*Statistically Different*	*57.5*	*Statistically Different*	*44.5*
M-21 St. Johns	Not Statistically Different	103.8	Not Statistically Different	92.5	Not Statistically Different	80.0
M-84 Saginaw	Not Statistically Different	80.6	Not Statistically Different	75.6	*Statistically Different*	*62.3*
BL I-96 Howell	Not Statistically Different	110.9	Not Statistically Different	102.6	Not Statistically Different	86.9
M-21 Owosso	Not Statistically Different	102.0	Not Statistically Different	89.8	Not Statistically Different	87.8
M-66 Battle Creek	Not Statistically Different	83.7	Not Statistically Different	78.2	Not Statistically Different	76.7
M-50 Dundee 4E3	Not Statistically Different	75.7	Not Statistically Different	72.5	Not Statistically Different	73.2
US-12 MIS	Not Statistically Different	84.9	Not Statistically Different	73.8	*Statistically Different*	*71.1*
M-59 Brighton	Not Statistically Different	95.9	Not Statistically Different	82.0	Not Statistically Different	95.1
Michigan Ave. Dearborn 3E10	Not Statistically Different	65.0	Not Statistically Different	55.7	*Statistically Different*	*49.2*
Vandyke Detroit	Not Statistically Different	103.6	Not Statistically Different	95.9	Not Statistically Different	100.7
US-23 Hartland	Not Statistically Different	85.4	Not Statistically Different	88.9	Not Statistically Different	87.5
I-75 Levering Road	Not Statistically Different	67.3	*Statistically Different*	*63.4*	*Statistically Different*	*59.7*
I-196 Grand Rapids	Not Statistically Different	87.7	*Statistically Different*	*76.8*	Not Statistically Different	83.4
I-75 Clarkston	Not Statistically Different	105.3	Not Statistically Different	97.6	Not Statistically Different	99.0
M-53 Detroit 8 Mile	Not Statistically Different	101.5	Not Statistically Different	93.6	Not Statistically Different	103.8
Michigan Ave. Dearborn 4E10	*Statistically Different*	*55.5*	Not Statistically Different	53.7	Not Statistically Different	48.3
I-75 Toledo	Not Statistically Different	81.4	Not Statistically Different	92.5	Not Statistically Different	94.8
I-94 Ann Arbor SMA	Not Statistically Different	95.9	Not Statistically Different	76.0	Not Statistically Different	77.1

	5 Hz		10 Hz		25 Hz	
Project	**t-test Results**	**E* Ratio**	**t-test Results**	**E* Ratio**	**t-test Results**	**E* Ratio**
M-50 Dundee 3E1	Not Statistically Different	107.1	Not Statistically Different	109.7	Not Statistically Different	106.8
M-36 Pinckney	*Statistically Different*	*52.3*	Not Statistically Different	59.1	Not Statistically Different	96.8
M-45 Grand Rapids	*Statistically Different*	*46.2*	*Statistically Different*	*47.5*	Not Statistically Different	66.2
M-21 St. Johns	Not Statistically Different	82.3	Not Statistically Different	76.7	Not Statistically Different	68.4
M-84 Saginaw	*Statistically Different*	*57.0*	*Statistically Different*	*58.8*	Not Statistically Different	70.8
BL I-96 Howell	Not Statistically Different	89.4	Not Statistically Different	83.6	Not Statistically Different	77.8
M-21 Owosso	Not Statistically Different	90.0	Not Statistically Different	94.4	Not Statistically Different	94.3
M-66 Battle Creek	Not Statistically Different	77.1	Not Statistically Different	75.1	Not Statistically Different	71.4
M-50 Dundee 4E3	*Statistically Different*	*75.4*	*Statistically Different*	*81.1*	Not Statistically Different	95.5
US-12 MIS	*Statistically Different*	*77.2*	Not Statistically Different	82.7	Not Statistically Different	88.8
M-59 Brighton	Not Statistically Different	110.0	Not Statistically Different	108.1	Not Statistically Different	104.5
Michigan Ave. Dearborn 3E10	Not Statistically Different	55.3	Not Statistically Different	61.9	Not Statistically Different	78.3
Vandyke Detroit	Not Statistically Different	102.2	Not Statistically Different	102.5	Not Statistically Different	120.8
US-23 Hartland	Not Statistically Different	90.7	Not Statistically Different	92.4	Not Statistically Different	94.8
I-75 Levering Road	*Statistically Different*	*55.8*	*Statistically Different*	*52.7*	*Statistically Different*	*52.9*
I-196 Grand Rapids	Not Statistically Different	103.4	Not Statistically Different	106.9	Not Statistically Different	146.4
I-75 Clarkston	Not Statistically Different	114.0	Not Statistically Different	120.3	Not Statistically Different	157.3
M-53 Detroit 8 Mile	Not Statistically Different	107.5	Not Statistically Different	107.5	Not Statistically Different	103.8
Michigan Ave. Dearborn 4E10	Not Statistically Different	47.0	Not Statistically Different	47.0	Not Statistically Different	53.3
I-75 Toledo	Not Statistically Different	92.0	Not Statistically Different	93.2	Not Statistically Different	89.8
I-94 Ann Arbor SMA	Not Statistically Different	81.9	Not Statistically Different	87.0	Not Statistically Different	87.3

Figures 9.18 through 9.23 shows the E* ratio data pooled for each frequency and a lognormal distribution fitted to the data. A horizontal line is drawn at a cumulative probability of 0.15 and a vertical line drawn where the horizontal line intersects the fitted distribution. This cumulative probability value was selected because 15% of the TSR specimens failed. By drawing the lines at a cumulative probability of 0.15 and drawing vertical lines where the horizontal line intersects the distribution function the E* ratio at 0.02,

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0.1, 1.0, 5.0, 10.0 and 25.0 Hz are approximately 60%, 60%, 57%, 58%, 58%, and 58%, respectively. Therefore an E* ratio criterion of 60% for each frequency should be considered.

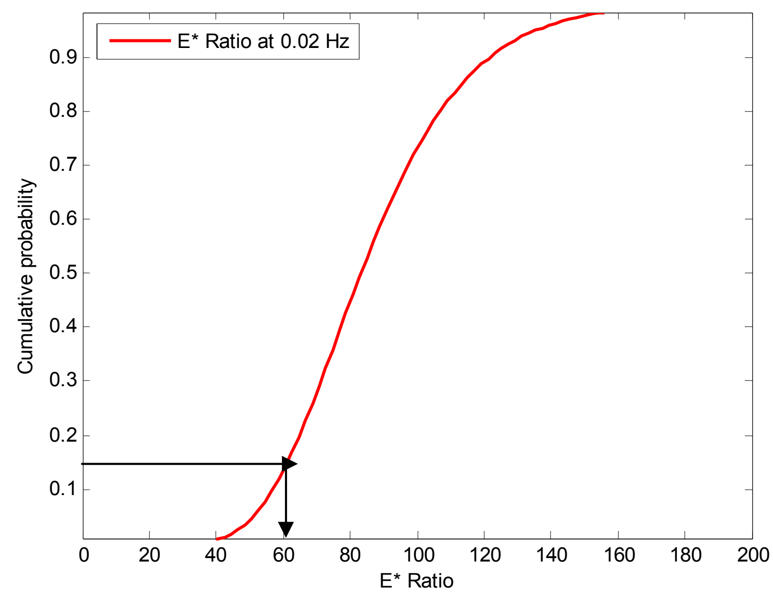

Figure 9.18 Lognormal Distribution of E* Ratio's at 0.02 Hz

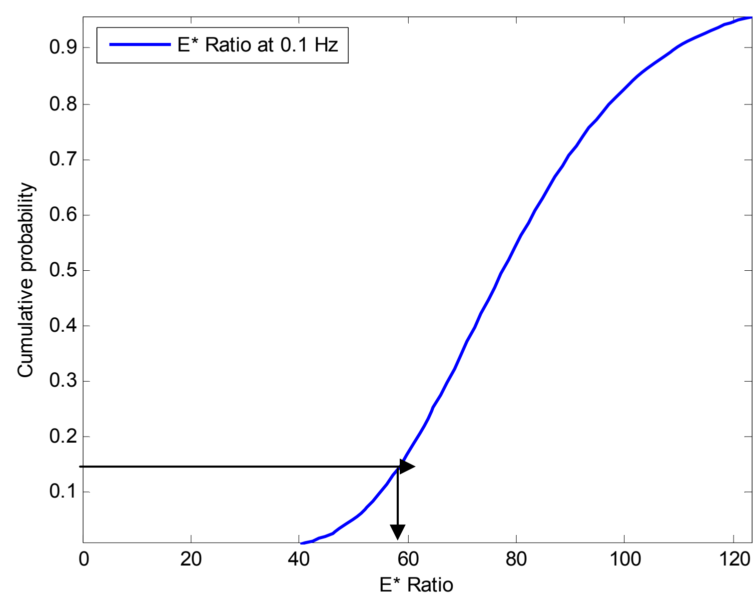

Figure 9.19 Lognormal Distribution of E* Ratio's at 0.1 Hz

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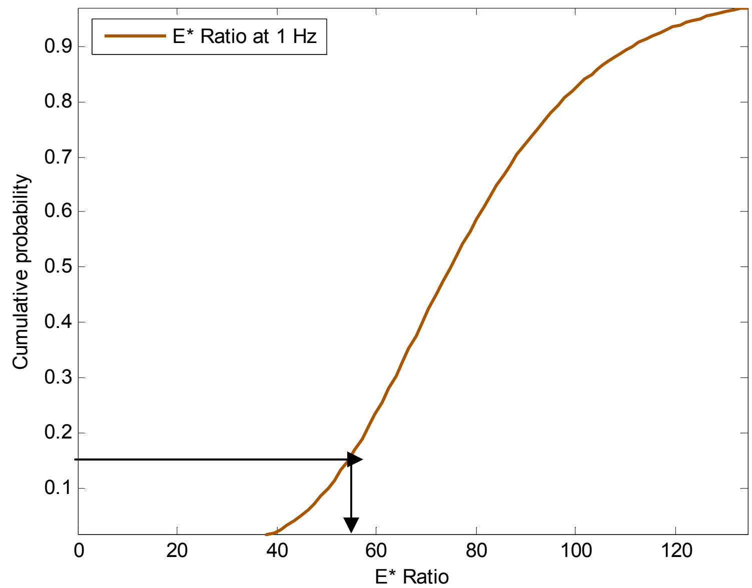

Figure 9.20 Lognormal Distribution of E* Ratio's at 1.0 Hz

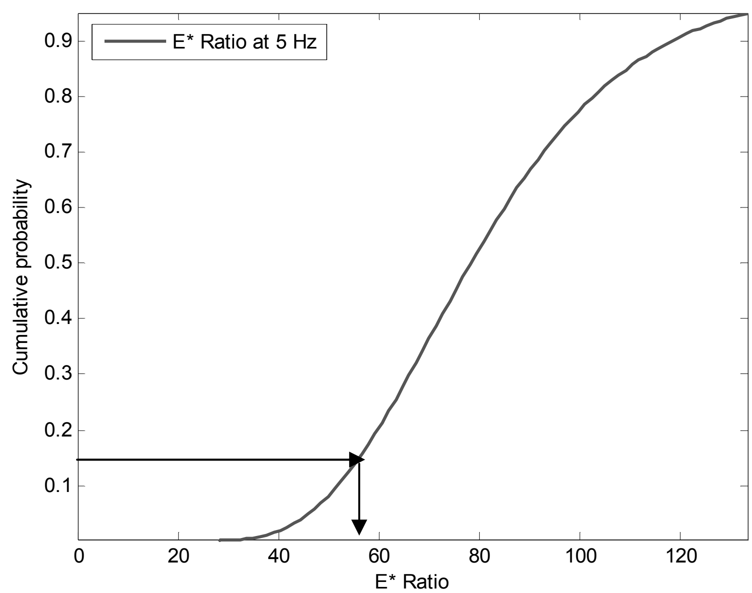

Figure 9.21 Lognormal Distribution of E* Ratio's at 5.0 Hz

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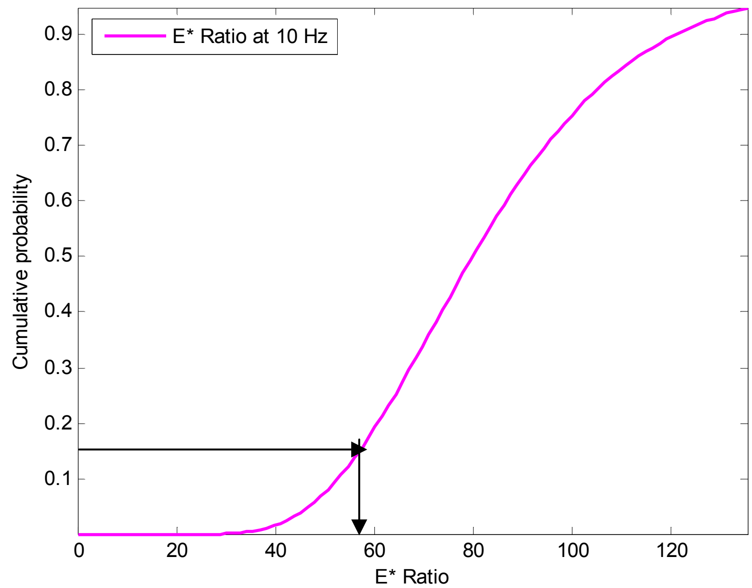

Figure 9.22 Lognormal Distribution of E* Ratio's at 10.0 Hz

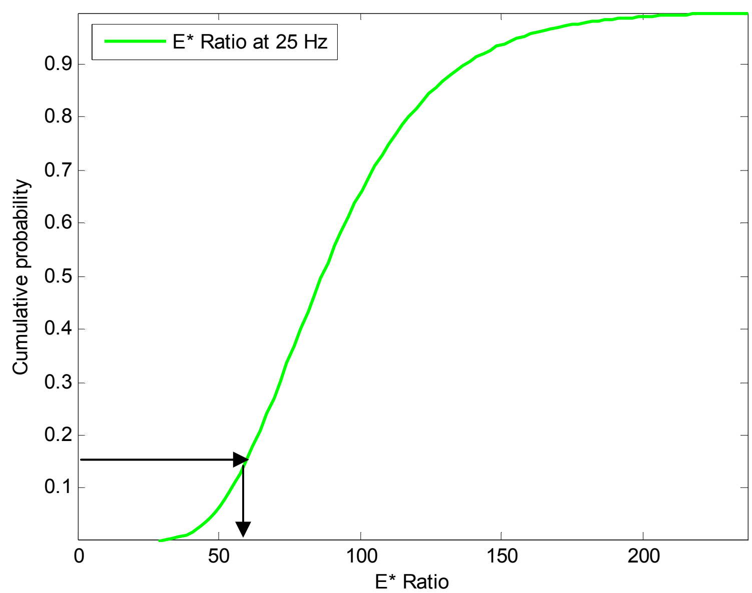

Figure 9.23 Lognormal Distribution of E* Ratio's at 25.0 Hz

Table 9.6 provides a summary of both test procedures by ranking the mixtures for each project based on AASHTO T283 TSR and the proposed moisture susceptibility test using E* ratio. The ranking is based on a scale from one to twenty-one where one is most moisture susceptible and twenty-one is least moisture susceptible. Both test procedures rank

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the first two mixtures about the same otherwise the two methods diverge in their ranking of the mixtures considerably. The proposed method does produce lower retained strength ratios and this is due to the dynamic loading of the specimen which produces hydraulic loading in the specimen thus reducing the strength of the HMA mixture. The bolded numbers in Table 9.6 represent where after that number the criterion for AASHTO T283 (80%) or proposed E* ratio (60%) is exceeded. There is a tendency for the proposed test procedure to identify additional mixes that are moisture susceptible than AASHTO T283. Table 9.7 shows a table of summary statistics such as the mean, standard deviation, and coefficient of variation (COV) for TSR and E* ratio at 0.1, 1.0, 5.0, and 10.0 Hz. This table shows that the TSR has lower variability than E* ratio but the average E* ratio is lower than the average TSR ratio. The lower variability in TSR specimens is due to the fact that five specimens were tested for TSR and only three specimens were tested for dynamic modulus. If additional specimens were tested, the standard deviation and COV would decrease. The dynamic modulus is a better test because it provides a dynamic loading at different traffic speeds which is a better representation of what occurs in the field.

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Table 9.6 Ranking of Projects Based on TSR and E* Ratio

Project	T283	0.02 Hz	0.1 Hz	1.0 Hz	5.0 Hz	10.0 Hz	25.0 Hz
M-36 Pinckney	1	1	1	2	3	4	14
M-45 Grand Rapids	2	2	3	1	1	1	3
US-12 MIS	3	7	6	7	9	11	11
I-196 Grand Rapids	4	12	10	12	17	18	20
M-84 Saginaw	5	8	9	6	6	5	7
M-59 Brighton	6	13	12	17	20	17	16
M-50 Dundee 3E1	7	19	21	21	19	20	18
M-66 Battle Creek	8	11	11	9	7	7	6
M-21 Owosso	9	16	14	15	14	15	13
I-75 Levering Road	10	5	5	5	5	3	1
I-75 Clarkston	11	20	19	19	21	21	21
Michigan Ave. Dearborn 4E10	12	4	4	4	2	2	2
US-23 Hartland	13	10	13	14	13	13	12
M-53 Detroit 8 Mile	14	15	17	20	18	19	17
Michigan Ave. Dearborn 3E10	15	3	2	3	4	6	8
I-94 Ann Arbor SMA	16	14	8	10	11	12	9
M-50 Dundee 4E3	17	6	7	8	8	10	15
Vandyke Detroit	18	17	18	18	16	16	19
I-75 Toledo	19	9	16	16	15	14	10
BL I-96 Howell	20	21	20	13	12	9	5
M-21 St. Johns	21	18	15	11	10	8	4

Table 9.7 Summary Statistics for Phase II Testing

Project	AASHTO T283 TSR			E* Ratio 0.1 Hz			E* Ratio 1.0 Hz			E* Ratio 5.0 Hz			E* Ratio 10.0 Hz		
	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV	Mean	Std. Dev.	COV
M-50 Dundee 3E1	89.7	16.8	18.8	109.8	6.0	5.5	108.0	4.6	4.3	107.1	4.3	4.1	109.7	9.5	8.7
M-36 Pinckney	75.1	4.0	5.3	49.2	11.3	23.0	44.6	1.5	3.5	52.3	11.2	21.3	59.1	18.2	30.8
M-45 Grand Rapids	78.7	8.2	10.5	57.5	2.6	4.5	44.5	0.3	0.7	46.2	1.7	3.7	47.5	2.8	6.0
M-21 St. Johns	107.3	6.1	5.7	92.5	26.1	28.2	80.0	16.9	21.1	82.3	18.4	22.4	76.7	14.7	19.1
M-84 Saginaw	85.1	6.9	8.1	75.6	8.5	11.2	62.3	9.9	15.9	57.0	3.2	5.6	58.8	4.4	7.4
BL I-96 Howell	102.1	2.9	2.9	102.6	14.5	14.1	86.9	17.5	20.1	89.4	21.3	23.8	83.6	25.4	30.4
M-21 Owosso	90.2	9.2	10.2	89.8	13.2	14.7	87.8	11.9	13.6	90.0	5.2	5.8	94.4	9.2	9.7
M-66 Battle Creek	90.1	8.0	8.9	78.2	9.5	12.2	76.7	12.8	16.7	77.1	17.5	22.8	75.1	19.0	25.3
M-50 Dundee 4E3	97.6	3.9	4.0	72.5	27.6	38.0	73.2	20.0	27.3	75.4	11.2	14.8	81.1	6.6	8.1
US-12 MIS	80.9	7.0	8.7	73.8	18.4	25.0	71.1	6.6	9.3	77.2	6.4	8.3	82.7	7.9	9.5
M-59 Brighton	87.3	12.5	14.3	82.0	10.3	12.6	95.1	3.8	4.0	110.0	13.8	12.5	108.1	22.0	20.3
Michigan Ave. Dearborn 3E10	96.0	24.6	25.6	55.7	10.9	19.5	49.2	12.5	25.5	55.3	14.4	26.1	61.9	19.5	31.5
Vandyke Detroit	100.7	11.7	11.7	95.9	15.4	16.1	100.7	29.0	28.8	102.2	25.4	24.8	102.5	28.0	27.3
US-23 Heartland	95.1	5.8	6.1	88.9	20.2	22.7	87.5	20.4	23.3	90.7	14.9	16.4	92.4	11.3	12.3
I-75 Levering Road	91.1	2.9	3.2	63.4	4.6	7.3	59.7	2.7	4.5	55.8	6.2	11.1	52.7	4.0	7.6
I-196 Grand Rapids	83.8	6.2	7.3	76.8	8.9	11.6	83.4	10.7	12.8	103.4	14.3	13.8	106.9	9.7	9.1
I-75 Clarkston	92.7	8.4	9.1	97.6	5.6	5.8	99.0	12.0	12.2	114.0	12.4	10.9	120.3	12.1	10.1
M-53 Detroit	95.6	8.2	8.5	93.6	19.1	20.4	103.8	18.6	18.0	107.5	21.7	20.2	107.5	21.9	20.3
Michigan Ave. Dearborn 4E10	93.7	3.7	3.9	53.7	4.2	7.8	48.3	11.7	24.2	47.0	18.6	39.7	47.0	22.5	48.0
I-75 Toledo	101.5	1.3	1.3	92.5	15.6	16.8	94.8	20.2	21.3	92.0	19.0	20.6	93.2	18.4	19.7
I-94 Ann Arbor SMA	96.6	3.3	3.4	76.0	25.9	34.0	77.1	19.9	25.8	81.9	15.8	19.2	87.0	13.5	15.5
Average	92.0	7.7	8.5	79.9	13.3	16.7	77.8	12.6	15.8	81.6	13.2	16.6	83.3	14.3	17.9

9.6 Moisture Damage Factors Affecting Mixtures

This section considers several factors that trigger moisture damage to occur in laboratory tested specimens. The factors being considered are gradation, NMAS, traffic level

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(mix type), polymer modification, aggregate type, permeability, asphalt content, FAA, RAP, and with dynamic modulus testing frequency. Table 9.8 shows the factors and levels considered for statistical analysis. The general linear model (GLM) procedure was used to determine which factors were considered statistically significant and a multiple comparison procedure using least squares difference (LSD) at a 5.0% level of significance to determine if there were statistical differences within the levels for each factor (SAS 2006). The GLM procedure gives an F-statistic for each factor based on Type I sum of squares error (SSE) and Type III SSE. For this analysis the Type I SSE was used to select the appropriate factors that are statistically significant. The GLM Type I SSE is analogous to performing an eight-way ANOVA. The GLM statement was selected over the ANOVA statement to prevent overweighting the categorical variables.

Some factors have levels that are determined prior to analysis. Other factors such as permeability, asphalt content, and RAP required classification. Classification was based on clustering observed in graphical representation of data. This method of classification has been employed for permeability in a previous MDOT study concerning the use of a Corelok (Williams et al. 2006). Figure 9.24 shows a graph of permeability versus TSR. From this figure one can see that there is a clear division at approximately 0.002 cm/s. Figure 9.25 shows a graph of RAP versus TSR. From this figure, there are approximately, four division, 0%, 1-10%, 10-15%, and greater than 15%. Figure 9.26 shows a graph of asphalt content versus TSR. From this figure one can see that approximately one-half of the data is less than 5.5% and the other half is greater than 5.5%.

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Table 9.8 Factors with Levels Considered for Statistical Analysis

Factors	Levels
Gradation	Coarse Fine
NMAS (mm)	19.0 12.5 9.5
Traffic ESAL's (millions)	E3 E10 E30
Polymer	Yes No
Aggregate Type	Gravel Limestone Gabbro
Permeability (cm/s)	<0.002 ≥0.002
Asphalt Content (%)	4.6-5.5 ≥5.5
FAA (%)	<45 ≥45
RAP (%)	0 1-10 10-15 ≥15
Frequency (Hz)	0.02 0.1 1.0 5.0 10.0 25.0

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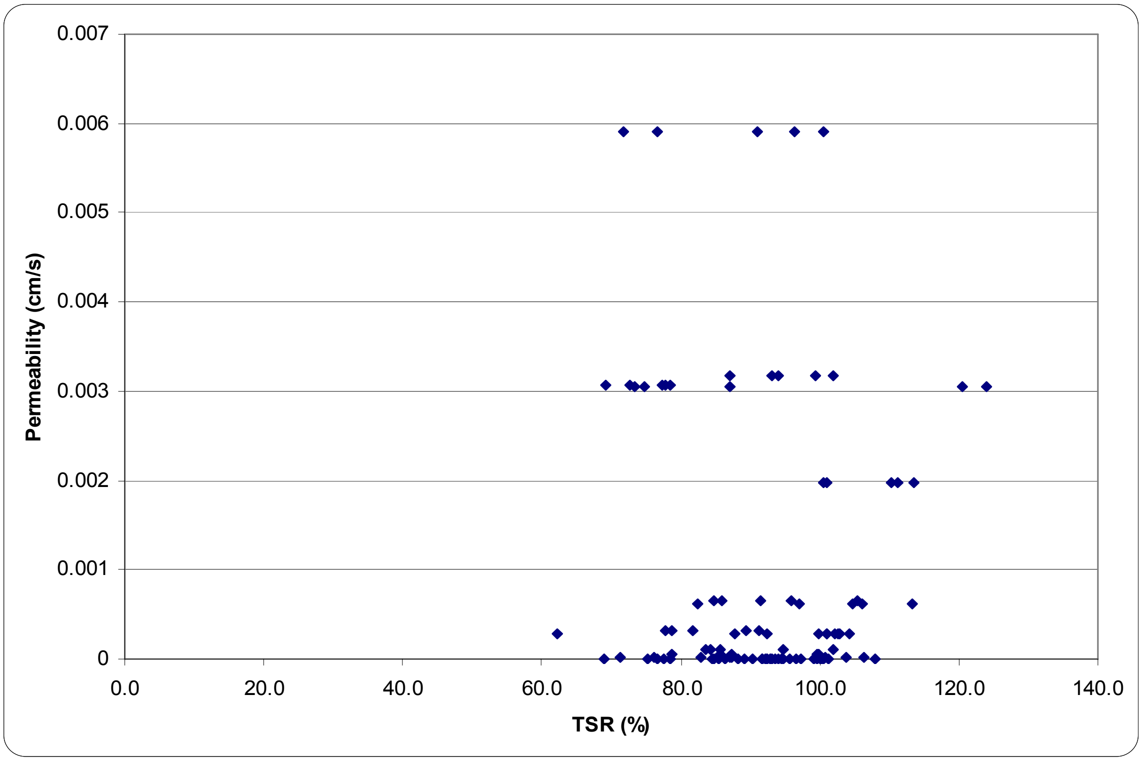

Figure 9.24 TSR versus Permeability

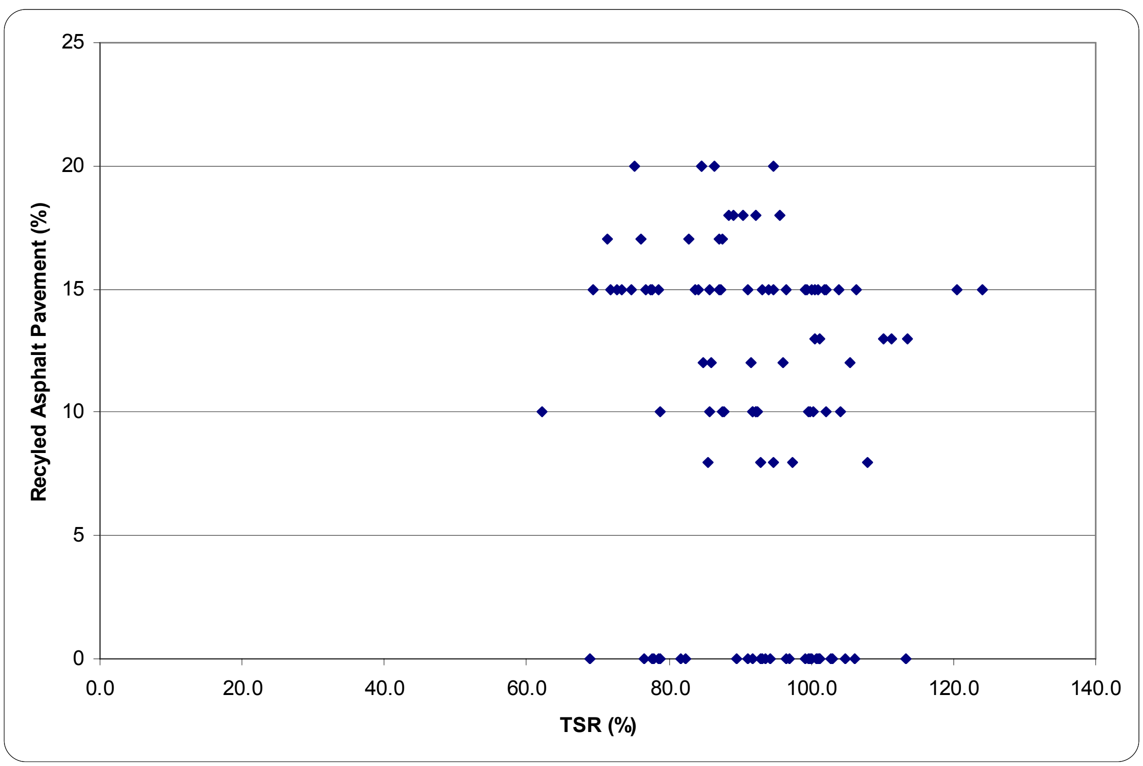

Figure 9.25 TSR versus RAP

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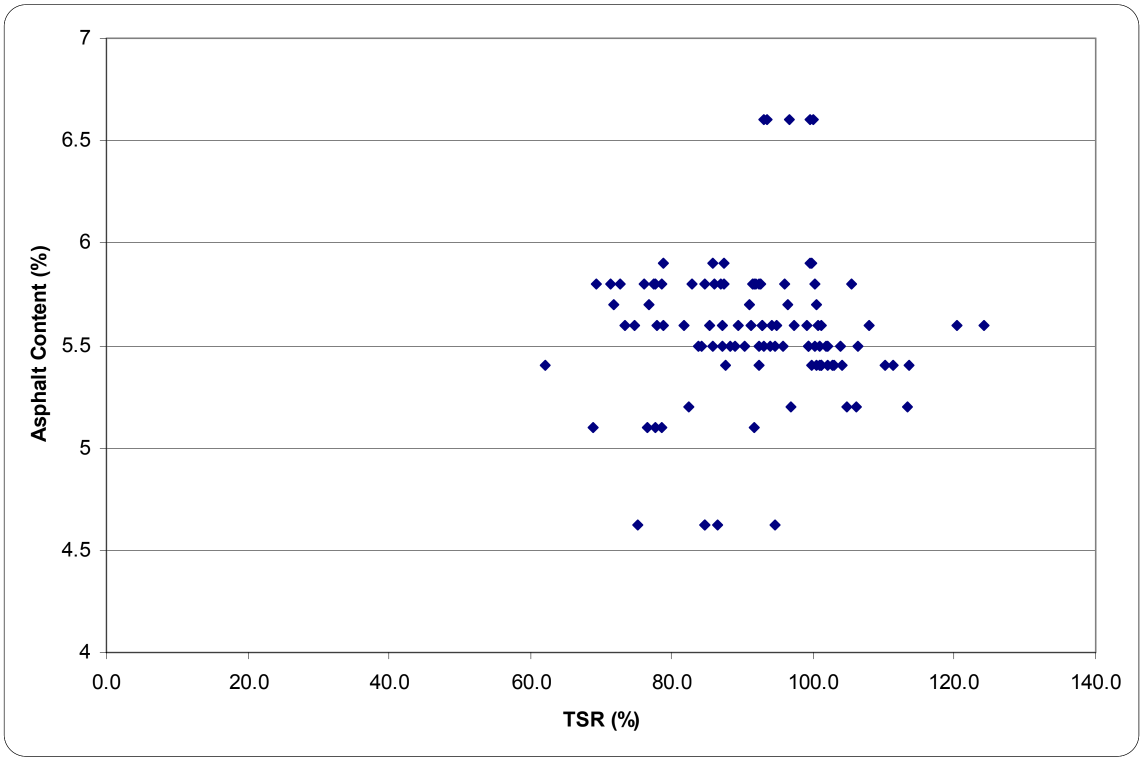

Figure 9.26 TSR versus Asphalt Content

The statistical results (Table 9.9) show that polymer, aggregate type, permeability, and RAP are statistically significant variables when TSR is the dependent variable based on Type I SSE using a 5% level of significance.

Table 9.9 GLM p-values Showing Statistically Significant Variables for TSR

Variable	DF	F-Statistic	p-value
Gradation	1	2.15	0.1478
NMAS	2	0.19	0.8269
Traffic	2	2.91	0.0618
Polymer	**1**	**5.96**	**0.0174**
Aggregate Type	**2**	**3.11**	**0.0513**
Permeability	**1**	**10.85**	**0.0016**
Asphalt Content	1	2.46	0.1213
FAA	1	1.70	0.1975
RAP	**3**	**4.47**	**0.0064**

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Table 9.10 shows the results of the LSD mean multiple comparison procedure using a 5% level of significance considering the levels within each factor for the TSR data. Means with the same letter are not statistically different. The LSD results show that for gradation, NMAS, aggregate type, permeability, and FAA there is no statistical difference among the levels within each factor. However, there are statistical differences among the mean levels of TSR for polymer modification and asphalt content. The traffic variable has statistical differences between E3 (3,000,000 ESAL's) and E30 (30,000,000 ESAL) mix types. In terms of RAP content, there are no statistical differences among the mean levels of TSR for 0, 1-10% and 10-15% RAP. However, there are statistical differences in mean TSR among those first three levels with the fourth level (≥15%).

Table 9.10 LSD Results for AASHTO T283

Levels	Factors								
	Gradation	NMAS (mm)	Traffic	Polymer	Aggregate Type	Permeability (cm/s)	Asphalt Content (%)	FAA (%)	RAP (%)
Coarse	A								
Fine	A								
19.0		A							
12.5		A							
9.5		A							
E3			A						
E10			B A						
E30			B						
Yes				A					
No				B					
Gravel					A				
Limestone					A				
Gabbro					A				
<0.002						A			
≥0.002						A			
4.6-5.5							A		
≥5.5							B		
<45								A	
≥45								A	
0									A
1-10									A
10-15									A
≥15									B

The same procedure was used to analyze E* ratio as the dependent variable considering gradation, NMAS, traffic, polymer modification, aggregate type, permeability,

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asphalt content, FAA, RAP, and frequency. The statistical analysis shows that traffic, aggregate type, permeability, RAP, and frequency are statistical significant variables based on Type I SSE using a 5% level of significance. The resulting p-values and F-statistic are shown in Table 9.11.

Table 9.11 GLM p-values Showing Statistically Significant Variables for E* Ratio

Variable	DF	F-Statistic	p-value
Gradation	1	0.57	0.4518
NMAS	2	2.46	0.0874
Traffic	**2**	**13.45**	**<0.0001**
Polymer	1	3.49	0.0627
Aggregate Type	**2**	**11.06**	**<0.0001**
Permeability	**1**	**17.04**	**<0.0001**
Asphalt Content	1	0.07	0.7915
FAA	1	0.32	0.5726
RAP	**3**	**5.13**	**0.0018**
Frequency	**5**	**3.06**	**0.0105**

Table 9.12 shows the results of the LSD multiple comparison procedure using a 5% level of significance the levels within each factor for the E* ratio data. Means with the same letter are not statistically different. The LSD results show that gradation and asphalt content show no statistical difference among the levels within each factor. The NMAS variable has statistical differences between 19.0mm and 9.5mm mix types. There are statistical differences among the mean levels of E* ratio for traffic, polymer modification, permeability, and FAA. There appears to be no statistical difference in mean E* values for limestone and gabbro aggregates but there are statistical differences in E* ratio values for between the gravel aggregate and the limestone and gabbro aggregates. In terms of RAP content, there appears to be no statistical difference in E* ratios for 0% and 1-10% RAP and between 10-15% and ≥15% RAP. However, there are statistical differences between 0% and 1-10% RAP and 10-15 and ≥15% RAP. In terms of frequency, E* ratio is statistically the

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same at 0.02, 0.1, 1.0, and 5.0 Hz while E* ratio is statistically the same at 0.1, 1.0, 5.0, 10.0, and 25.0 Hz.

Table 9.12 LSD Results for E* Ratio

Levels	Factors									
	Gradation	NMAS (mm)	Traffic	Polymer	Aggregate Type	Permeability (cm/s)	Asphalt Content (%)	FAA (%)	RAP (%)	Frequency (Hz)
Coarse	A									
Fine	A									
19.0		A								
12.5		B A								
9.5		B								
E3			A							
E10			B							
E30			C							
Yes				A						
No				B						
Gravel					A					
Limestone					B					
Gabbro					B					
<0.002						A				
≥0.002						B				
4.6-5.5							A			
≥5.5							A			
<45								A		
≥45								B		
0									A	
1-10									A	
10-15									B	
≥15									B	
0.02										A
0.1										A
1.0										A
5.0										A
10.0										A
25.0										B

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9.7 Predictive Equation for E*

The JMFs provided by the contractors were used to extract the necessary information for the Witczak predictive equation in addition to the viscosity-temperature susceptibility test data. The RTFO aged binder viscosities were used as it was the recommendation made by the Mechanistic-Empirical Pavement Design Guide (2004). The variables were then input into the Witczak predictive equation to determine the reliability of the equation to the mixes that were tested for this project. Figures 9.27 and 9.28 show the measured versus the predicted dynamic modulus for the control and moisture conditioned HMA mixtures.

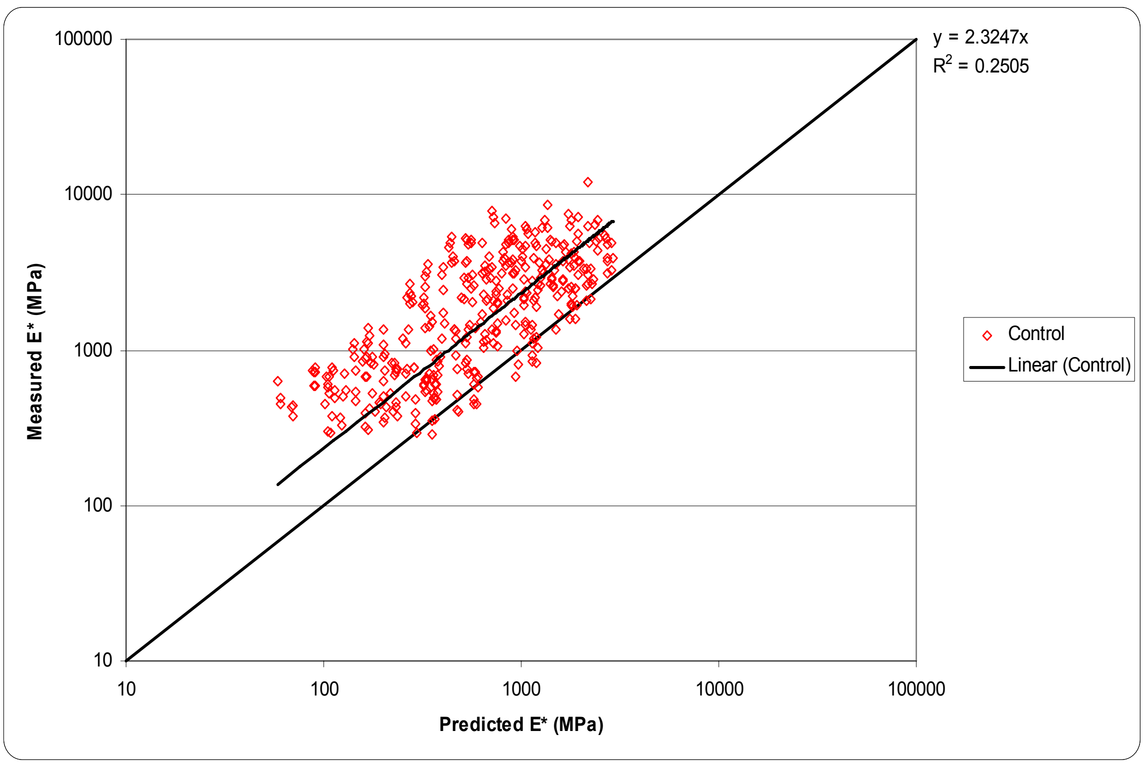

Figure 9.27 Witczak Predictive Equation for Control Michigan Mixtures

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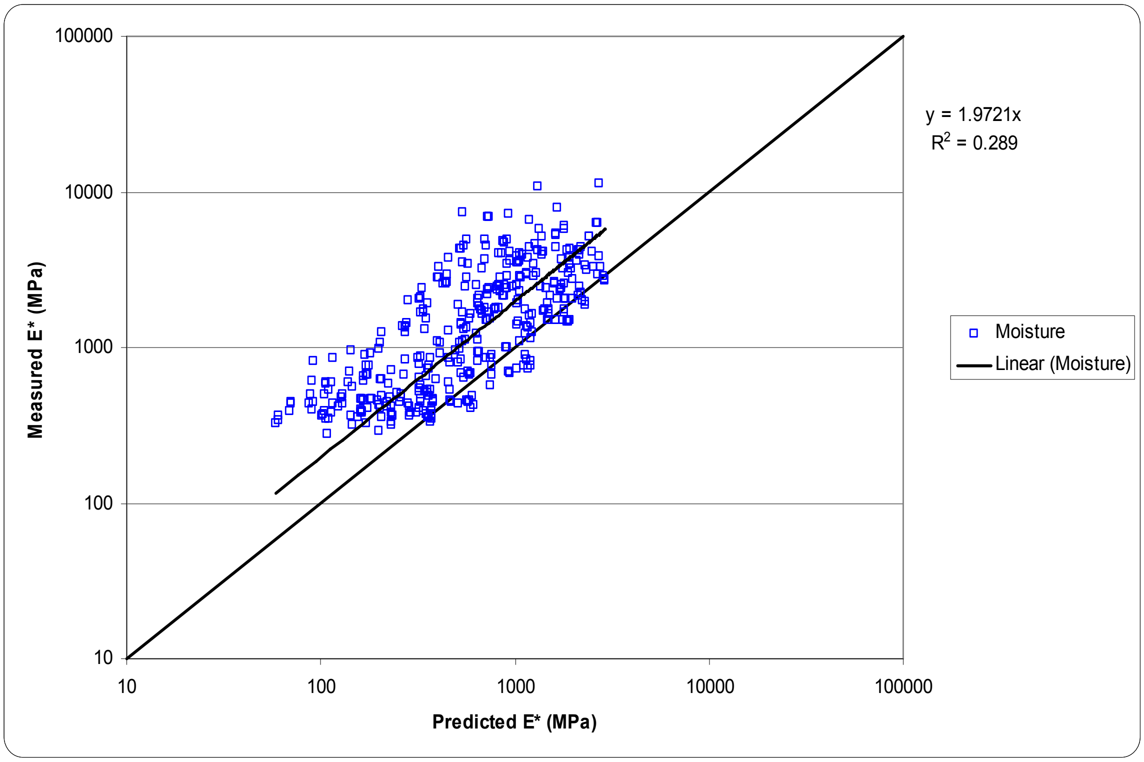

Figure 9.28 Witczak Predictive Equation for Conditioned Michigan Mixtures

Twenty-one HMA mixes were tested and are shown in the above figures and totals 756 data points. A general linear regression equation was fit to the dataset and was forced through a zero intercept because a measured dynamic modulus of zero corresponds to a predicted dynamic modulus of zero and was found to have a coefficient of determination (R^2) of 0.25 for control mixes and 0.29 for the conditioned mixes. This regression equation was not meant to be a predictive equation, but rather show the deviation of the predicted data points from that of the measured. Caution should also be exercised with the R^2 value stated as forcing the intercept to zero can result in a negative value which is an unreasonable result. The general trend in Figures 9.27 and 9.28 was that as frequency increased, the dynamic modulus value increased. What the plot indicates was that on the whole the Witczak predictive equation tends to underestimates dynamic modulus.

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In an effort to try to determine if one of the parameters used in the Witczak predictive equation was the source of the difference between the measured and predicted, further examination was done. For all of the parameters considered in the Witczak predictive equation there appeared to be bias. This means that the errors in the predictive equation are not attributable to one or two parameters which would indicate an error in measuring the parameters. The Witczak predictive equation was recalibrated to resolve the issue of overestimating dynamic modulus using the same form of the original equation.

9.8 Recalibration Procedure for the Witczak Predictive Equation

The base equation was used and only the coefficients that were present were manipulated (equation 9.1) to recalibrate the Witczak predictive equation.

$$\log|E^*| = c_1 + c_2(\rho_{200}) + c_3(\rho_{200})^2 + c_4(\rho_4) + c_5(V_a) + \frac{c_6(V_{beff})}{V_{beff}+V_a} + \frac{c_7 + c_8(\rho_4) + c_9(\rho_{3/8}) + c_{10}(\rho_{3/8})^2 + c_{11}(\rho_{3/4})}{1+e^{(c_{12}+c_{13}\times\log(f)+c_{14}\times\log(\eta))}} \quad \text{(equation 9.1)}$$

The variables are explained Section 6.2.4. The program Solver which is available with Microsoft Excel was used to solve for the optimal coefficients to yield the best fit to the dynamic modulus dataset for this project. The recalibrated coefficients along with the original coefficients are provided in Tables 9.12 and 9.13 for the control and conditioned HMA mixes. With the new coefficients for the base Witczak predictive equation, the new equation was calibrated to the twenty-one mixtures tested and would be referred to as a local calibration of the predictive equation.

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Table 9.13 Witczak and Recalibrated Predictive Equation Coefficients for Control Mixes

Coefficient	Witczak's Constants	Recalibrated Constants	Coefficient	Witczak's Constants	Recalibrated Constants
c1=	-1.249937	0.7308841	c8=	-0.002100	0.05923440
c2=	0.029232	-0.0549979	c9=	0.003958	0.11996137
c3=	-0.001767	0.0064486	c10=	-0.000017	-0.00984244
c4=	-0.002841	0.0041510	c11=	0.005470	0.14467633
c5=	-0.058097	-0.1183994	c12=	-0.603313	3.87361112
c6=	-0.802208	-1.1552681	c13=	-0.313351	-0.35370794
c7=	3.871977	46.0628645	c14=	-0.393532	-0.01188054

Table 9.14 Witczak and Recalibrated Predictive Equation Coefficients for Conditioned Mixes

Coefficient	Witczak's Constants	Recalibrated Constants	Coefficient	Witczak's Constants	Recalibrated Constants
c1=	-1.249937	1.8114617	c8=	-0.002100	0.14872510
c2=	0.029232	-0.3747254	c9=	0.003958	-0.88737890
c3=	-0.001767	0.0317783	c10=	-0.000017	0.01744029
c4=	-0.002841	0.0033337	c11=	0.005470	-1.53875196
c5=	-0.058097	-0.1077689	c12=	-0.603313	4.11393293
c6=	-0.802208	-1.2050671	c13=	-0.313351	-0.47397843
c7=	3.871977	46.0159820	c14=	-0.393532	-0.00497791

Comparisons were made between the measured dynamic modulus and that of the Witczak and recalibrated Witczak predictive equation for the control and conditioned mixes. To perform the analysis the, ANOVA procedure (with no interactions) was used to measure the mean of the three datasets. The ANOVA yielded an F_{stat} of 286.966 for the control group and 210.17 for the conditioned group (F_{crit} = 3.00 at an α = 0.05), which meant that there was a significant difference between the means of the three groups.

The recalibration of the Witczak predictive equation was meant to reduce the differences between that of the uncalibrated predicted and measured dynamic modulus, thus a comparison was conducted between the uncalibrated predicted and measured dynamic modulus. The ANOVA showed that there was a significant difference between the mean of the two datasets (Control Group: F_{stat} = 210.07 and a p-value = <0.0001 and Conditioned

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Group: F_{stat} = 127.44 and a p-value = <0.0001). To ensure that the recalibrated model produced a statistically similar mean to that of the measured values, an ANOVA was performed on the datasets. The analysis showed an F_{stat} of 18.15 (p-value = <0.0001) for the control group and F_{stat} of 0.73 (p-value = 0.3931) for the conditioned group. This demonstrates that the recalibrated equation for the moisture conditioned group is representative of the measured dataset; the control group is not, while the Witczak predictive equation does not accurately predict dynamic modulus for the twenty-one mixtures tested.

A comparison was also made between the coefficients of the two predictive equations. As with any predictive equation, the coefficients are expected to change with additional data factored into the recalibrated model. Tables 9.14 and 9.15 show the percent difference in the coefficients based on the uncalibrated Witczak predictive equation for the control and conditioned mixes.

Table 9.15 Percent Difference in Predictive Equation Coefficients for Control Mixes

Coefficient	% Difference	Coefficient	% Difference
c1=	-158.4736757	c8=	8.39180978
c2=	288.1427747	c9=	-210.9232873
c3=	-464.9444801	c10=	152.3661688
c4=	-246.1113172	c11=	3353.543018
c5=	-103.7960727	c12=	-3781.204939
c6=	-44.01104261	c13=	-3.493296713
c7=	1089.647162	c14=	0.828544791

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Table 9.16 Percent Difference in Predictive Equation Coefficients for Conditioned Mixes

Coefficient	% Difference	Coefficient	% Difference
c1=	-244.9242386	c8=	8.326154423
c2=	1381.901455	c9=	-237.8639975
c3=	-1898.429673	c10=	54.93470337
c4=	-217.3438761	c11=	46321.01437
c5=	-85.49821112	c12=	-4377.18685
c6=	-50.21877878	c13=	-13.32933575
c7=	1088.436346	c14=	0.844389442

As can be seen in Tables 9.14 and 9.15, there were significant changes in the coefficients and the negative percent difference indicates a sign change. These significant changes do not refute the reliability of the developed model as previous iterations of the predictive equation have undergone significant changes as were seen by Witczak and Fonseca (1996).

Figures 9.29 and 9.30 show plots of the measured versus predicted data using the recalibrated Witczak predictive equation for the control and conditioned mixtures, respectively.

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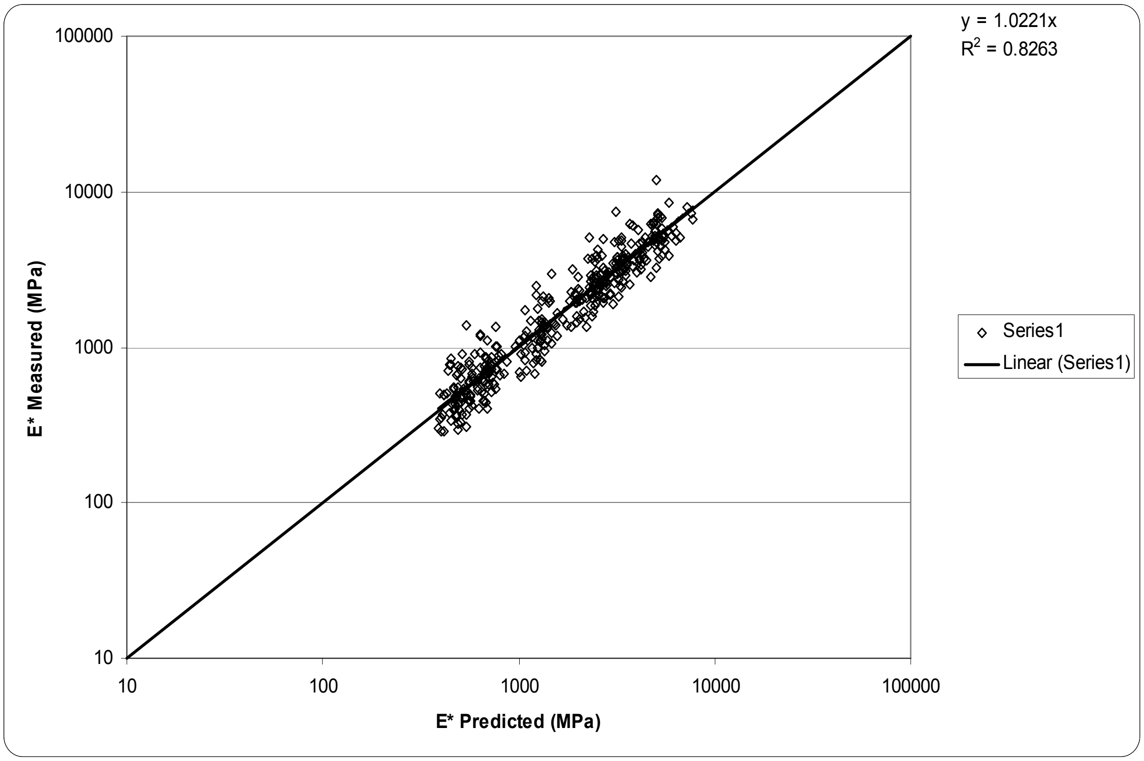

Figure 9.29 Recalibration of the Witczak Predictive Equation for Control Mixes

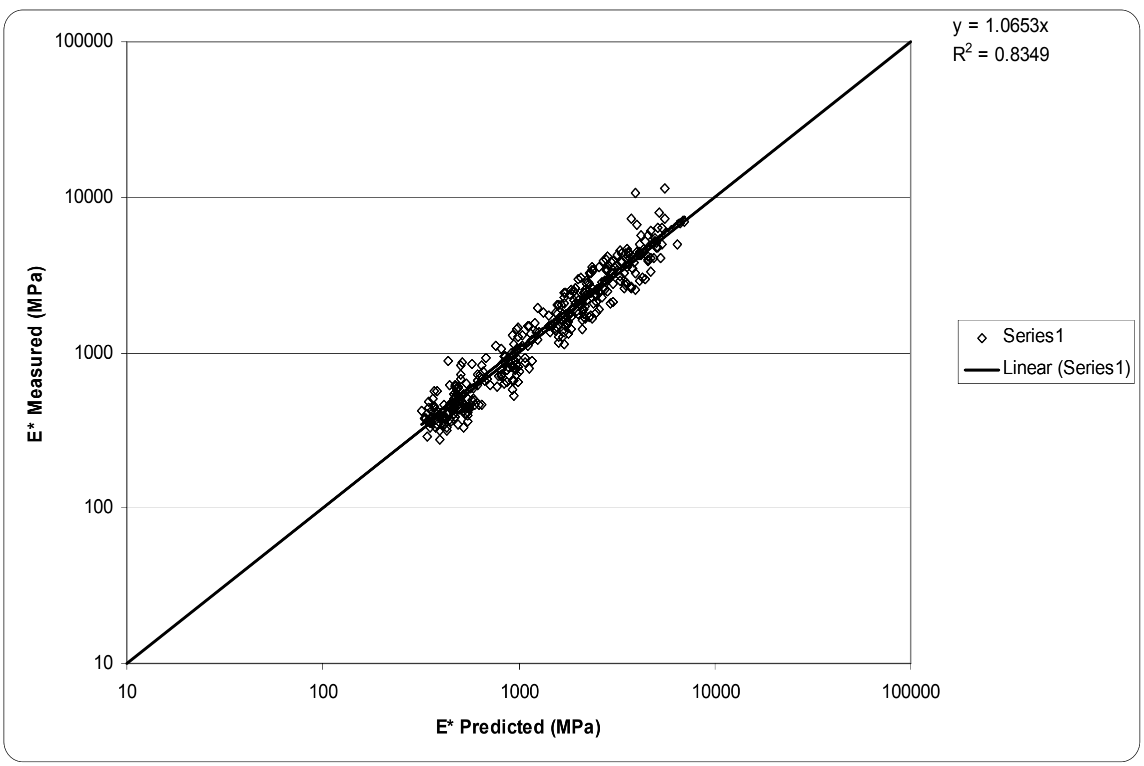

Figure 9.30 Recalibration of the Witczak Predictive Equation for Conditioned Mixes

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Again, a linear regression equation was fit to the recalibrated predictive results and as can be seen the R^2 was significantly increased to 0.8263 and 0.8349 for the control and conditioned mixes, respectively.

The recalibrated model appears to better represent the test results. Further emphasis needs to be placed on the fact that this model only applies to the twenty-one mixtures tested. Like any predictive equation, it should only be applied within the limits of the parameters from which it was created.

The recalibration of the predictive equation resolved the issues that were seen with the uncalibrated Witczak predictive equation. This recalibration now makes it possible to apply future predictions to these asphalt mixtures and with further testing. The recalibration procedure that has been presented is applicable to typical mixtures in the State of Michigan and can be further expanded with additional testing.

The forthcoming AASHTO M-E PDG uses dynamic modulus for the level 1 inputs for pavement design. The implications of not performing laboratory testing in order to determine dynamic modulus is very great. The uncalibrated Wiczak model underestimates the experimental dynamic modulus by a significant difference. However with enough data, the Witczak model can be recalibrated for the local HMA mixtures used and still provide adequate dynamic modulus values. In addition, the current version of the M-E PDG does not used a reduced dynamic modulus due to moisture conditioning. The recalibrated version of the Witczak model using moisture conditioned dynamic values if of value because, moisture conditioning is what occurs in the field, where as the unconditioned dynamic modulus rarely occurs in the field.

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CHAPTER 10 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

10.1 Summary

A number of factors exist that are detrimental to hot mix asphalt (HMA). Moisture damage is a significant factor that impacts HMA; which includes the binder and the mixture component. Moisture damage is important because it diminishes the performance and service life of HMA pavements resulting in increased maintenance and rehabilitation costs of highways. The current method of determining the moisture susceptibility of HMA mixtures is AASHTO T283. AASHTO T283 is based upon the Marshall mix design method but current state of the practice for HMA mixture design is the Superpave mix design method. There has not been a transition in test procedure from Marshall mix design to Superpave mix design.

The procedures in AASHTO T283 and NCHRP Report 444 consider the loss of strength due to freeze/thaw cycling and the effects of moisture existing in specimens compared to unconditioned specimens. However, mixtures do not experience such a pure phenomenon. Pavements undergo cycling of environmental conditions, but when moisture is present, there is repeated hydraulic loading with the development of pore pressure in mixtures. Thus, AASHTO T283 and the NCHRP Report 444 do not consider the effect of pore pressure, but rather consider a single load effect on environmentally conditioned specimens.

This dissertation develops of a moisture susceptibility procedure which utilizes the dynamic loading of specimens in saturated conditions and compared to unconditioned

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specimens in a dry test environment. The test procedure uses the dynamic complex modulus test to determine the moisture susceptibility of mixtures.

The work outlined in this dissertation has also formed a basis in which owner/agencies such as MDOT can update their current criteria for TSR and to also update their current method of determining the moisture susceptibility of HMA mixtures.

The objectives of this study developed moisture susceptibility test criteria using 150mm diameter Superpave gyratory compacted specimens. Laboratory testing included testing specimens according to current AASHTO and ASTM specifications, and the simple performance test using modified Lottman conditioning procedure.

10.2 Conclusions

Prior to testing of the Michigan asphalt mixtures, extensive research was conducted on determining an equivalent number of freeze-thaw cycles that would achieve the same moisture damage effects using the original AASHTO T283 specification, which are based upon Marshall compaction, using the newer SGC method. The effect of size and compaction method on results obtained following AASHTO T283 procedure was analyzed. Finally, a new minimum TSR was determined by the analysis instead of using the old TSR of 80% which was based on the original AASHTO T283 specification. A second preliminary study was conducted to consider the effects of test temperature and conditioning on dynamic modulus test specimens prior to testing all of the Michigan mixes. The conclusion of the preliminary testing and final testing is discussed below.

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10.2.1 AASHTO T283 – Phase I

The Phase I sensitivity study considered the factors affecting the wet strength of a specimen and new TSR criteria for AASHTO T283 when Superpave compaction method is employed in lieu of the Marshall compaction method are identified. AASHTO T283 was developed based on 100mm diameter Marshall compacted specimens. With the transition from Marshall compacted specimens to Superpave compacted specimens it was felt that the requirements outlined in AASHTO T283 should be re-evaluated. It was discovered that three freeze-thaw cycles for conditioning is satisfactory when using specimens created using the Superpave method. However, to maintain the same probability level as attained with a TSR value for 80% for 100mm diameter Marshall compacted specimens, a TSR value of 87% and 85% should be used with 150mm and 100mm diameter Superpave compacted specimens, respectively. Alternatively, the 80% TSR for 150mm diameter Superpave specimens corresponds to a TSR of 70% for 100 mm diameter Marshall specimens.

According to the results obtained from this dissertation, three freeze-thaw cycles are adequate when using the AASHTO T283 method in conjunction with 150mm Superpave specimens. Three freeze/thaw cycles for 150mm SGC specimens corresponds to one freeze/thaw cycle for 100mm Marshall specimens. The threshold value should be altered accordingly, as stated above, based on the specimen size for one freeze/thaw cycle.

10.2.2 SPT Moisture Testing – Phase II Sensitivity Study

Based on the results of the Phase II sensitivity study and engineering judgment, it was decided that the effective test temperature for rutting would be used and the conditioning of the specimens would follow the procedure outlined in AASHTO T283. AASHTO T283 was

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used as the baseline method so therefore the conditioning of the specimens will be common between the previous method and the proposed new method. The effects of conditioning on specimens can show statistical significance and can be seen in Table 8.6 at a frequency of 1 and 5 Hz. I-75 Clarkston which did not show any statistically significant effects to conditioning.

The two sample t-tests showed that there was no statistical difference in E* control versus E* wet at freeze-thaw method A but there were differences in the E* ratios between the two projects. I-75 Clarkston exhibited higher E* ratios than I-196 Grand Rapids. I-196 Grand Rapids was thought to be moisture susceptible based on the results of Phase I testing because that project had TSR’s lower than 80% which is the criterion used by MDOT.

Flow number testing was not conducted on the specimens from Phase II because there was no statistical difference in dry permanent deformation versus wet permanent deformation. Since flow number testing was not conducted, a second frequency sweep to determine E* after damage cycles was not performed as well.

10.2.3 SPT and AASHTO T283 Moisture Testing – Phase II

Phase II testing of Michigan HMA mixtures outlines a moisture susceptibility procedure and preliminary criteria that utilizes a repeated loading test device on specimens in saturated conditions and compares them to unconditioned specimens in a dry test environment. The test procedure uses a retained dynamic modulus of 60% of conditioned specimens to unconditioned specimens for all frequencies. The 60% criterion was nearly the same for all frequencies studied. This initial criteria was derived as it is the same percentage of mixtures that fail the AASHTO T283 criteria of the 21 field mixes, 15 percent.

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Comparison of mixtures performance ranked via AASHTO T283 and the proposed retained dynamic modulus criteria results in considerably different rankings. It was found that it was easier to attain higher TSR with lower dry tensile strengths (Figure 9.3) and to attain higher E* ratios with lower E* unconditioned values (Figure 9.16).

Pavements undergo cycling of environmental conditions, but when moisture is present, there is repeated hydraulic loading with development of pore pressure in mixtures. Thus, AASHTO T283 does not consider the effect of pore pressure, but rather considers a single load effect on environmentally conditioned specimens. Dynamic modulus testing of saturated mixtures better simulates the repeated hydraulic loading pavements undergo. Validation of the proposed criteria will need to be done through longer term field monitoring prior to implementing as a mix design specification for moisture susceptibility testing of HMA.

A number of factors exist that cause or accelerate moisture damage. A statistical analysis was performed to determine which factors are significant. The factors considered were gradation, NMAS, traffic, polymer modification, aggregate type, permeability, asphalt content, FAA, RAP, and frequency for dynamic modulus testing. Based on the test method, some common factors exist between them, but dynamic modulus appears to be more sensitive to changes in the factors considered. It appears that the factors affecting AASHTO T283 are polymer modification, aggregate type, permeability, and RAP. The factors affecting dynamic modulus are traffic, polymer modification, aggregate type, permeability, RAP, and frequency. It has been known that aggregate type, polymer modification, and permeability affect moisture damage. RAP is a highly variable material and it makes sense as to why it may impact moisture damage in HMA pavements.

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10.3 Recommendations

Extensive testing was conducted as part of this dissertation. This testing has brought to light many issues that are involved in determining the moisture susceptibility of HMA mixtures. These issues should be addressed prior to their implementation by owner/agencies and industry. Additional research is needed as discussed in the following points:

- The aggregate chemistry and asphalt binder chemistry should be looked at to consider if it is an aggregate issue or a binder issue or both. This testing could be accomplished by using the Wilhelmy Plate and Universal Sorption Device. Extra HMA and binder was sampled during the 2004 and 2005 construction season from each of projects tested, therefore the binder can be tested in the Wilhelmy Plate and the aggregate can be extracted from the HMA and then placed in the Universal Sorption Device.
- Additional dynamic modulus testing at the intermediate test temperature and mid-range temperatures to see if moisture damage occurs at intermediate and mid-range test temperatures.
- Conducting dynamic creep testing using a 0.1sec load time and a longer rest period instead of 0.1sec to consider the use of the dynamic creep test as a quality control indicator for moisture damage.
- Field cores of the sampled mixtures should be tested to correlate with the extensive laboratory study conducted here.
- An examination should be undertaken to apply the Hirsh predictive model. The Hirsh model is a newer predictive equation developed by Christensen and Bonaquist (2002)

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and has been shown to address the issues of over prediction seen with the Witczak model.

- Use the AASHTO Mechanistic-Empirical Pavement Design Guide (M-EPDG) to analyze these pavements using Level 1 mix design on the control and moisture conditioned specimens to look at how distress change when the E* changes due to moisture damage.

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APPENDIX A JOB MIX FORMULA'S

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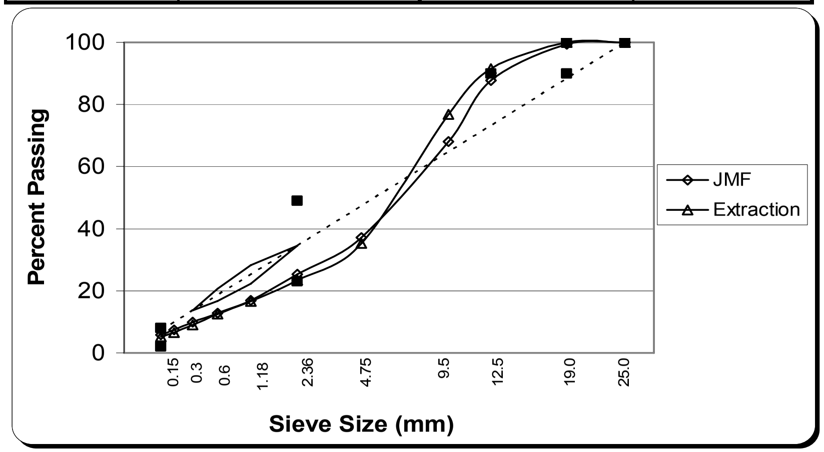
Project: M-50 Dundee

Project Information		Asphalt Information	
Project No.:	50651A	Asphalt Source:	Marathon Det.
Location:	M-50 Dundee	Asphalt Grade (PG):	58-28
Contractor:	Cadillac LLC Asphalt	Asphalt Content:	5.4
Traffic Level:	E1	Asphalt Additives:	None
Aggregate Type:	Limestone	Asphalt Additives (%):	N/A
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	45.1
Specifc Gravities		Dust Corr.:	
G_{mm}	2.511	1 Face Crush (%):	96.6
G_{mb}	2.436	2 Face Crush (%):	93.8
G_b	1.025	**Volumetrics**	
G_{se}	2.737	VMA:	14.9
G_{sb}	2.708	VFA:	79.9
Temperature		AV:	3
Mixing (^oF):	311-322	F/P_{be}:	1.1
Compacting (^oF):	275	P_{be}:	5.36

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	99.4
1/2 (12.5)	87.8
3/8 (9.5)	68.1
#4 (4.75)	37.1
#8 (2.36)	25.3
#16 (1.18)	16.9
#30 (0.60)	12.8
#50 (0.30)	9.9
#100 (0.15)	7.5
#200 (0.075)	5.9

Material/Producer	Percent
HL1	13
3/4 x 1/2	13
1/2 x 3/8	21
3/8 x 4	16
LimeSAND	27
RAP	10



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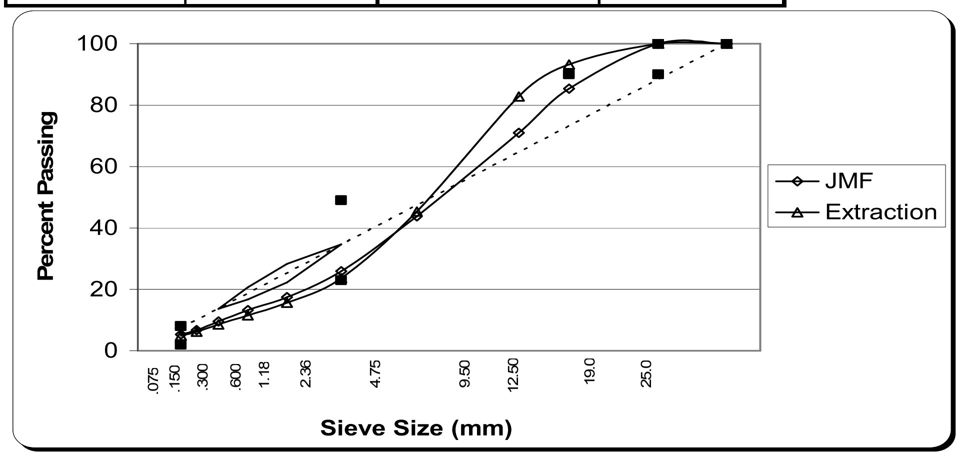
Project: M-36 Pinckney

Project Information		Asphalt Information	
Project No.:	50717A	Asphalt Source:	Marathon Det.
Location:	M-36	Asphalt Grade (PG):	64-22
Contractor:	Ajax Materials Corp.	Asphalt Content:	5.8
Traffic Level:	E3	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	45.4
Specifc Gravities		Dust Corr.:	0.4
G_{mm}	2.488	1 Face Crush (%):	99.3
G_{mb}	2.413	2 Face Crush (%):	98.8
G_b	1.031	**Volumetrics**	
G_{se}	2.725	VMA:	13.7
G_{sb}	2.634	VFA:	78
Temperature		AV:	3
Mixing (^oF):	312-323	F/P_{be}:	1.16
Compacting (^oF):	294	P_{be}:	4.57

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	100
1/2 (12.5)	85.3
3/8 (9.5)	71
#4 (4.75)	43.8
#8 (2.36)	25.9
#16 (1.18)	17.5
#30 (0.60)	13.3
#50 (0.30)	9.6
#100 (0.15)	6.8
#200 (0.075)	5.3

Material/Producer	Percent
4's	35
1/2"	25
Man. Sand	15
Man. Sand	10
RAP	15



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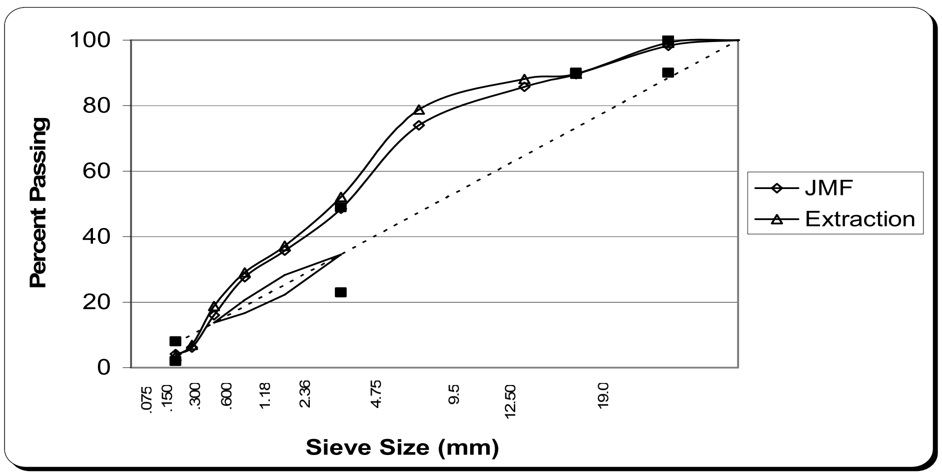
Project: M-45 Grand Rapids

Project Information		Asphalt Information	
Project No.:	06767A	Asphalt Source:	T & M Oil
Location:	M-45 Grand Rapids	Asphalt Grade (PG):	58-28
Contractor:	Thompson McCully	Asphalt Content:	5.1
Traffic Level:	E3	Asphalt Additives:	Anti-Strip Agent
Aggregate Type:		Asphalt Additives (%):	0.3
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Fine	Angularity (%):	42.2
Specifc Gravities		Dust Corr.:	0
G_{mm}	2.509	1 Face Crush (%):	92.4
G_{mb}	2.405	2 Face Crush (%):	N/A
G_b		**Volumetrics**	
G_{se}	2.72	VMA:	13.7
G_{sb}	2.644	VFA:	69.7
Temperature		AV:	4
Mixing:		F/P_{be}:	1.01
Compacting:	135	P_{be}:	4.06

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	98.3
1/2 (12.5)	89.6
3/8 (9.5)	85.7
#4 (4.75)	74
#8 (2.36)	48.5
#16 (1.18)	35.7
#30 (0.60)	27.6
#50 (0.30)	16
#100 (0.15)	6.1
#200 (0.075)	4.1

Material/Producer	Percent
6AA	17
Birdeye Sand	25
#4-0	48
WW Sand	8.5
Baghouse	1.5



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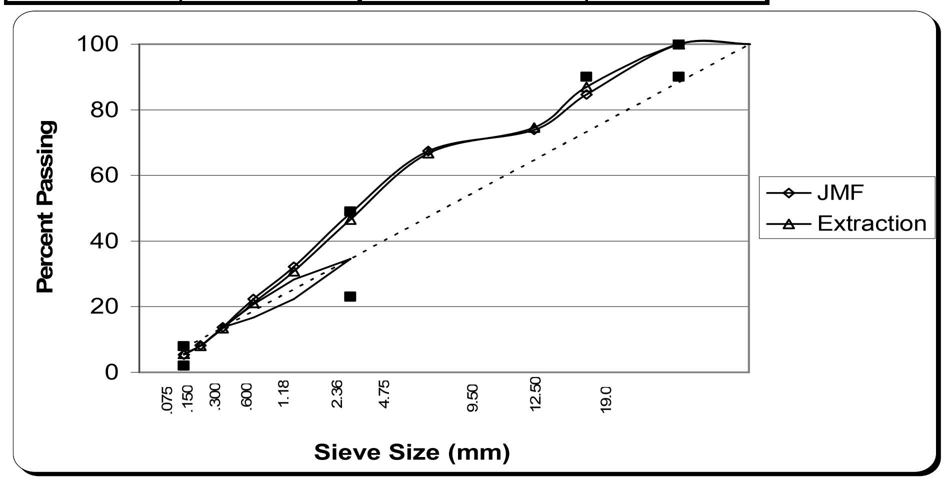
Project: M-84 Saginaw

Project Information		Asphalt Information	
Project No.:	31804A	Asphalt Source:	Marathon Detroit
Location:	M-84 Saginaw	Asphalt Grade (PG):	58-28
Contractor:	Saginaw Asphalt	Asphalt Content:	4.62
Traffic Level:	E3	Asphalt Additives:	None
Aggregate Type:	Slag	Asphalt Additives (%):	N/A
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Fine	Angularity (%):	44
Specifc Gravities		Dust Corr.:	0.5
G_{mm}	2.55	1 Face Crush (%):	98
G_{mb}	2.448	2 Face Crush (%):	N/A
G_b	1.022	**Volumetrics**	
G_{se}	2.749	VMA:	14.19
G_{sb}	2.721	VFA:	71.81
Temperature		AV:	4
Mixing:	303	F/P_{be}:	1.27
Compacting:	280	P_{be}:	4.25

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	100
1/2 (12.5)	84.6
3/8 (9.5)	73.9
#4 (4.75)	67.4
#8 (2.36)	48.5
#16 (1.18)	32.1
#30 (0.60)	22.3
#50 (0.30)	13.7
#100 (0.15)	8.2
#200 (0.075)	5.4

Material/Producer	Percent
5/8 CLR	29
3/16 Slag	15
JK	36
RAP	20



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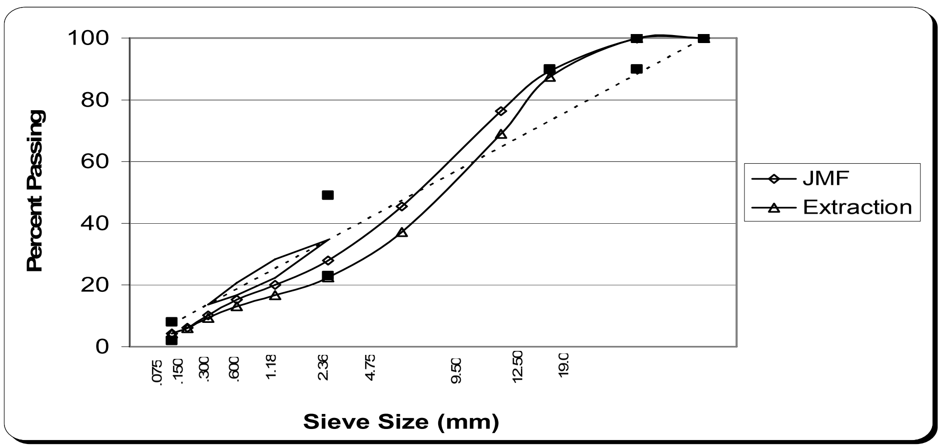
Project: M-21 St. Johns

Project Information		Asphalt Information	
Project No.:	46023A	Asphalt Source:	Michigan Paving & Materials
Location:	M-21 St. Johns	Asphalt Grade (PG):	58-22
Contractor:	Michigan Paving & Materials	Asphalt Content:	5.4
Traffic Level:	E3	Asphalt Additives:	None
Aggregate Type:	Gravel	Asphalt Additives (%):	N/A
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	46.8
Specifc Gravities		Dust Corr.:	0.4
G_{mm}	2.488	1 Face Crush (%):	94.3
G_{mb}	2.414	2 Face Crush (%):	N/A
G_b	1.028	**Volumetrics**	
G_{se}	2.708	VMA:	13.92
G_{sb}	2.653	VFA:	78.63
Temperature		AV:	2.99
Mixing:	292-299	F/P_{be}:	0.9
Compacting:	276	P_{be}:	4.78

Sieve Size	Mix/Gradation (%P)	Material/Producer	Percent
1 (25)	100	2304	15
3/4 (19)	99.9	2384	17
1/2 (12.5)	89.3	2217	17
3/8 (9.5)	76.3	2354	25
#4 (4.75)	45.4	2343	13
#8 (2.36)	27.9	RAP	13
#16 (1.18)	20.1		
#30 (0.60)	15.3		
#50 (0.30)	10.2		
#100 (0.15)	6.1		
#200 (0.075)	4.3		



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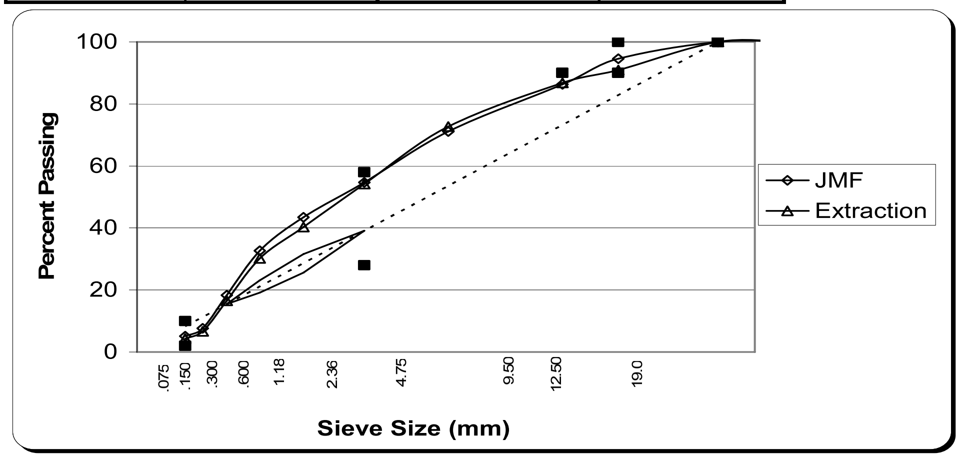
Project: BL I-96 Howell

Project Information		Asphalt Information	
Project No.:	50650A	Asphalt Source:	Michigan Paving & Materials
Location:	BL I-96Howell	Asphalt Grade (PG):	70-28 P
Contractor:	Rieth-Riley	Asphalt Content:	5.5
Traffic Level:	E3	Asphalt Additives:	None
Aggregate Type:	Limestone	Asphalt Additives (%):	N/A
Mix Size:	4	**SuperPave Consensus Properties**	
Gradation:	Fine	Angularity (%):	42.2
Specifc Gravities		Dust Corr.:	0.4
G_{mm}	2.48	1 Face Crush (%):	82.5
G_{mb}	2.381	2 Face Crush (%):	N/A
G_b	1.028	**Volumetrics**	
G_{se}	2.702	VMA:	14.8
G_{sb}	2.641	VFA:	73
Temperature		AV:	4
Mixing (°F):	313-319	F/P_{be}:	1.09
Compacting (°F):	295	P_{be}:	4.68

Sieve Size	Mix/Gradation (%P)	Material/Producer	Percent
1 (25)	100	25B	19
3/4 (19)	100	Chelsea Man. Sand	15
1/2 (12.5)	94.6	Fine Crush	16
3/8 (9.5)	86.3	2NS	35
#4 (4.75)	71.1	RAP	15
#8 (2.36)	54.7		
#16 (1.18)	43.5		
#30 (0.60)	32.7		
#50 (0.30)	18.3		
#100 (0.15)	7.6		
#200 (0.075)	5.1		



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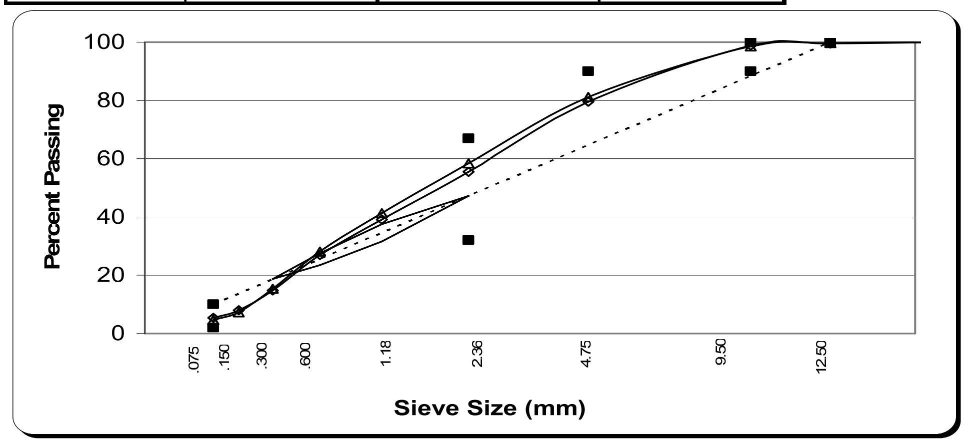
Project: M-21 Owosso

Project Information		Asphalt Information	
Project No.:	48612A	Asphalt Source:	Michigan Paving & Materials
Location:	M-21 Owosso	Asphalt Grade (PG):	64-28
Contractor:	Michigan Paving & Materials	Asphalt Content:	5.9
Traffic Level:	E3	Asphalt Additives:	None
Aggregate Type:	Limestone	Asphalt Additives (%):	N/A
Mix Size:	5	**SuperPave Consensus Properties**	
Gradation:	Fine	Angularity (%):	43.8
Specifc Gravities		Dust Corr.:	0.4
G_{mm}	2.47	1 Face Crush (%):	81.8
G_{mb}	2.371	2 Face Crush (%):	N/A
G_b	1.028	**Volumetrics**	
G_{se}	2.708	VMA:	15.4
G_{sb}	2.637	VFA:	74
Temperature		AV:	4
Mixing (°F):	302-315	F/P_{be}:	1.09
Compacting (°F):	266	P_{be}:	4.95

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	100
1/2 (12.5)	99.6
3/8 (9.5)	98.8
#4 (4.75)	79.5
#8 (2.36)	55.5
#16 (1.18)	39.1
#30 (0.60)	27
#50 (0.30)	14.8
#100 (0.15)	7.9
#200 (0.075)	5.4

Material/Producer	Percent
3/8 x 4	10
Blend Sand	35
Fine MFG Sand	15
MFG Sand	30
RAP	10



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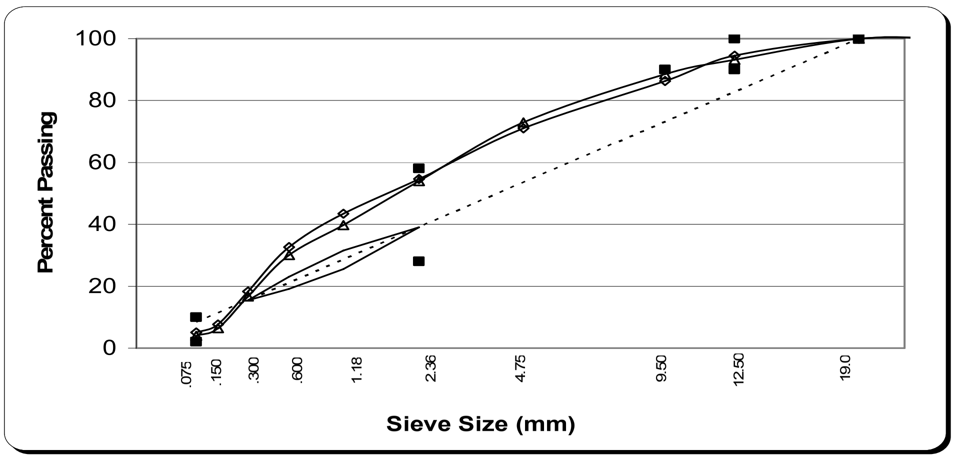
Project: M-66 Battle Creek

Project Information		Asphalt Information	
Project No.:	50759A	Asphalt Source:	Michigan Paving & Materials
Location:	Battle Creek	Asphalt Grade (PG):	64-28
Contractor:	Rieth-Riley	Asphalt Content:	5.5
Traffic Level:	E3	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	4	**SuperPave Consensus Properties**	
Gradation:	Fine	Angularity (%):	42.2
Specifc Gravities		Dust Corr.:	0.4
G_{mm}	2.48	1 Face Crush (%):	82.5
G_{mb}	2.38	2 Face Crush (%):	N/A
G_b	1.027	**Volumetrics**	
G_{se}	2.702	VMA:	14.8
G_{sb}	2.641	VFA:	72.8
Temperature		AV:	4
Mixing (°F):	302-315	F/P_{be}:	1.09
Compacting (°F):	266	P_{be}:	4.68

Sieve Size	Mix/Gradation (%P)	Material/Producer	Percent
1 (25)	100	25B	19
3/4 (19)	100	Chelsea Man. Sand	15
1/2 (12.5)	94.6	Fine Crush	16
3/8 (9.5)	86.3	2NS	35
#4 (4.75)	71.1	RAP	15
#8 (2.36)	54.7		
#16 (1.18)	43.5		
#30 (0.60)	32.7		
#50 (0.30)	18.3		
#100 (0.15)	7.6		
#200 (0.075)	5.1		



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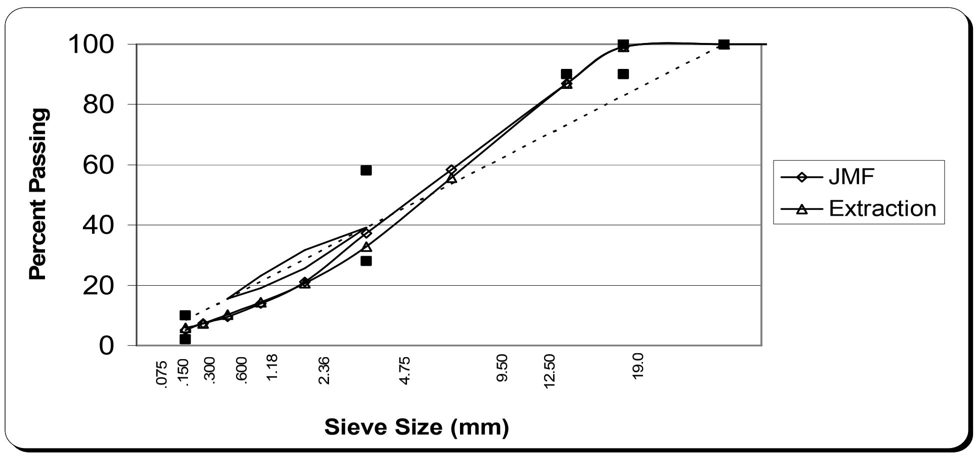
Project: M-50 Dundee

Project Information		Asphalt Information	
Project No.:	50651A	Asphalt Source:	MTM Oil
Location:	M-50	Asphalt Grade (PG):	64-28
Contractor:	Cadillac LLC Asphalt	Asphalt Content:	5.6
Traffic Level:	E3	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	4	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	46
Specifc Gravities		Dust Corr.:	
G_{mm}	2.52	1 Face Crush (%):	98
G_{mb}	2.419	2 Face Crush (%):	96
G_b	1.027	**Volumetrics**	
G_{se}	2.759	VMA:	16
G_{sb}	2.717	VFA:	74.9
Temperature		AV:	4
Mixing (^oF):	311-322	F/P_{be}:	1
Compacting (^oF):	275	P_{be}:	5.10

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	100
1/2 (12.5)	99.1
3/8 (9.5)	86.9
#4 (4.75)	58.3
#8 (2.36)	37.2
#16 (1.18)	21.1
#30 (0.60)	14
#50 (0.30)	9.5
#100 (0.15)	7.3
#200 (0.075)	5.1

Material/Producer	Percent
1/4 Chip	10
1/2 x 3/8	24
3/8 x 4	18
Trap. Sand	18
Lime Sand	30
RAP	0



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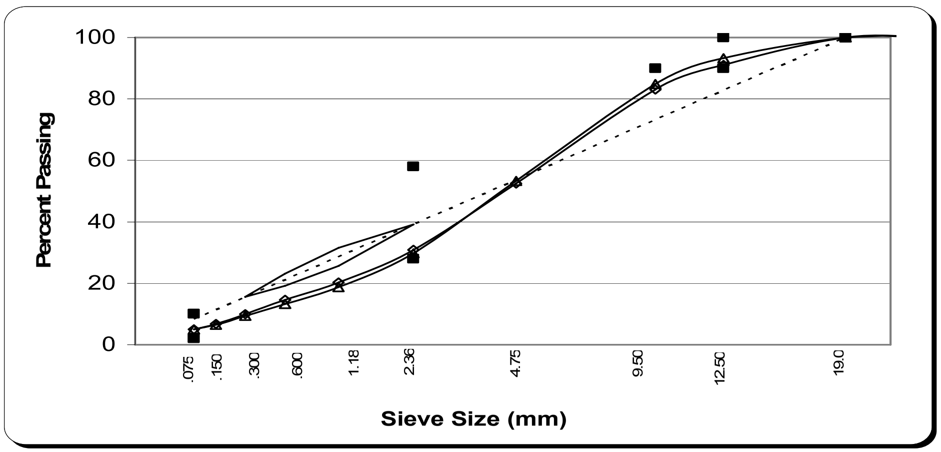
Project: US-12 MIS

Project Information		Asphalt Information	
Project No.:	50714A	Asphalt Source:	Marathon Det.
Location:	US-12 MIS	Asphalt Grade (PG):	64-28
Contractor:	Ajax Materials Corp.	Asphalt Content:	5.8
Traffic Level:	E3	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	4	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	42.4
Specifc Gravities		Dust Corr.:	
G_{mm}	2.49	1 Face Crush (%):	98.7
G_{mb}	2.39	2 Face Crush (%):	98.5
G_b	1.026	**Volumetrics**	
G_{se}	2.729	VMA:	14.8
G_{sb}	2.641	VFA:	72.9
Temperature		AV:	4
Mixing (°F):	309-321	F/P_{be}:	1.1
Compacting (°F):	286-296	P_{be}:	4.55

Sieve Size	Mix/Gradation (%P)	Material/Producer	Percent
1 (25)	100	Man. Sand	12
3/4 (19)	100	3/8 x #4	28
1/2 (12.5)	91	Man. Sand	26
3/8 (9.5)	83.1	3/4 x 1/2	17
#4 (4.75)	52.5	RAP	17
#8 (2.36)	30.8		
#16 (1.18)	20.2		
#30 (0.60)	14.6		
#50 (0.30)	9.9		
#100 (0.15)	6.7		
#200 (0.075)	5		



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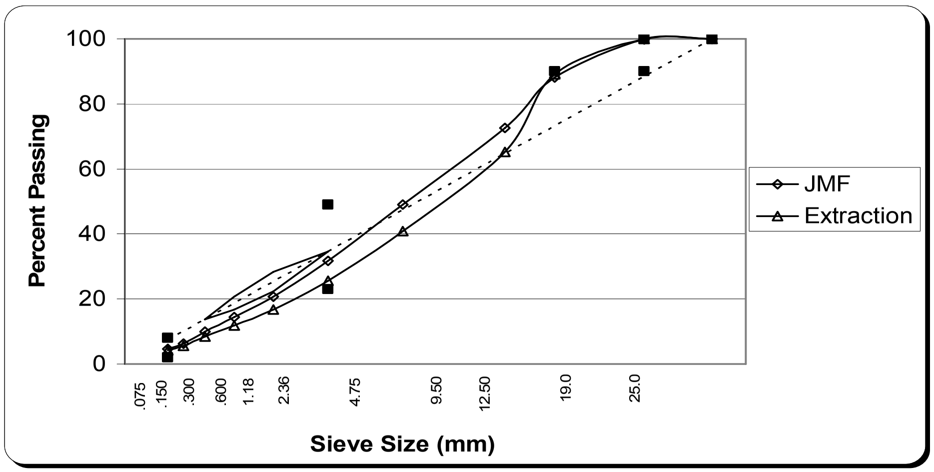
Project: M-59 Brighton

Project Information		Asphalt Information	
Project No.:	34519A	Asphalt Source:	Marathon Det.
Location:	US-23/M-59 Interchange	Asphalt Grade (PG):	58-22
Contractor:	Ajax	Asphalt Content:	5.7
Traffic Level:	E10	Asphalt Additives:	None
Aggregate Type:	Limestone	Asphalt Additives (%):	N/A
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	45.5
Specifc Gravities		Dust Corr.:	0.4
G_{mm}	2.485	1 Face Crush (%):	98.1
G_{mb}	2.41	2 Face Crush (%):	97.7
G_b	1.027	**Volumetrics**	
G_{se}	2.718	VMA:	14.3
G_{sb}	2.652	VFA:	78.9
Temperature		AV:	3
Mixing (^oF):	302-314	F/P_{be}:	0.96
Compacting (^oF):	284	P_{be}:	4.79

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	99.9
1/2 (12.5)	88.2
3/8 (9.5)	72.6
#4 (4.75)	49.1
#8 (2.36)	31.8
#16 (1.18)	20.7
#30 (0.60)	14.5
#50 (0.30)	9.9
#100 (0.15)	6.3
#200 (0.075)	4.6

Material/Producer	Percent
1/2 x 3/8	20
3/4 x 1/2	20
Man. Sand	15
Man. Sand	30
RAP	15



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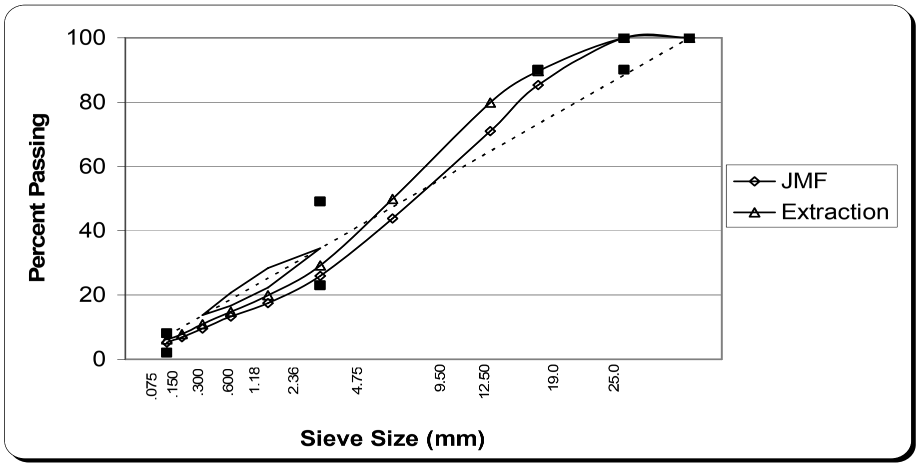
Project: Michigan Avenue, Dearborn

Project Information		Asphalt Information	
Project No.:	47064A	Asphalt Source:	Marathon Det.
Location:	Michigan Ave.	Asphalt Grade (PG):	58-28
Contractor:	Ajax Materials Corp.	Asphalt Content:	5.6
Traffic Level:	E10	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	45.4
Specifc Gravities		Dust Corr.:	
G_{mm}	2.496	1 Face Crush (%):	99.3
G_{mb}	2.419	2 Face Crush (%):	98.8
G_b	1.025	**Volumetrics**	
G_{se}	2.725	VMA:	13.3
G_{sb}	2.634	VFA:	76.7
Temperature		AV:	3.1
Mixing (°F):	297-309	F/P_{be}:	1.2
Compacting (°F):	274-284	P_{be}:	4.42

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	100
1/2 (12.5)	85.3
3/8 (9.5)	71
#4 (4.75)	43.8
#8 (2.36)	25.9
#16 (1.18)	17.5
#30 (0.60)	13.3
#50 (0.30)	9.6
#100 (0.15)	6.8
#200 (0.075)	5.3

Material/Producer	Percent
#4's	33
1/2"	25
Man. Sand	15
Man. Sand Sora	12
RAP	15



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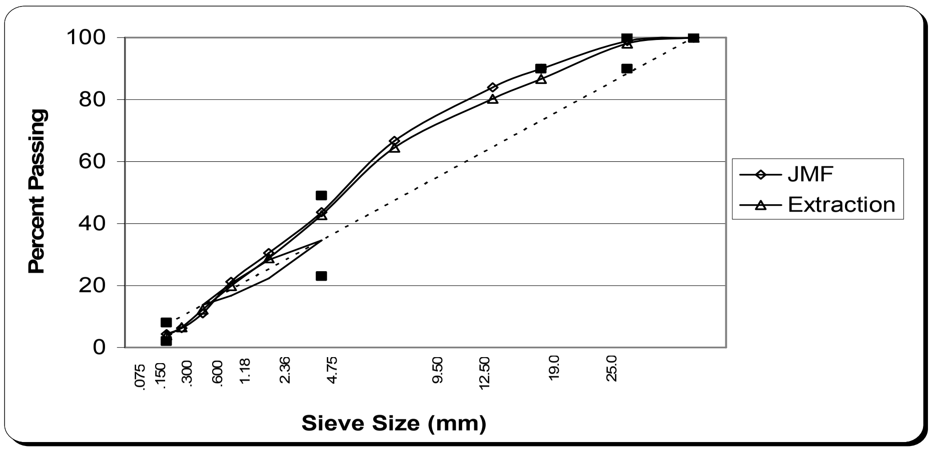
Project: Vandyke, Detroit

Project Information		Asphalt Information	
Project No.:	46273A	Asphalt Source:	Marathon Det.
Location:	M53/28 Mi to 31 Mi Rd.	Asphalt Grade (PG):	64-22
Contractor:	National Asphalt Products	Asphalt Content:	5.2
Traffic Level:	E30	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Fine	Angularity (%):	45.8
Specifc Gravities		Dust Corr.:	
G_{mm}	2.577	1 Face Crush (%):	98.4
G_{mb}	2.495	2 Face Crush (%):	98.4
G_b	1.031	**Volumetrics**	
G_{se}	2.81	VMA:	14.6
G_{sb}	2.769	VFA:	78.2
Temperature		AV:	3.2
Mixing (°F):	310-322	F/P_{be}:	0.86
Compacting (°F):	288-298	P_{be}:	5.00

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	98.9
1/2 (12.5)	90
3/8 (9.5)	83.9
#4 (4.75)	66.6
#8 (2.36)	43.7
#16 (1.18)	30.5
#30 (0.60)	21.2
#50 (0.30)	11
#100 (0.15)	6.2
#200 (0.075)	4.3

Material/Producer	Percent
2NS	15
HL3	8
Otr.	43
Mfg. Sand	15
6A	19
RAP	



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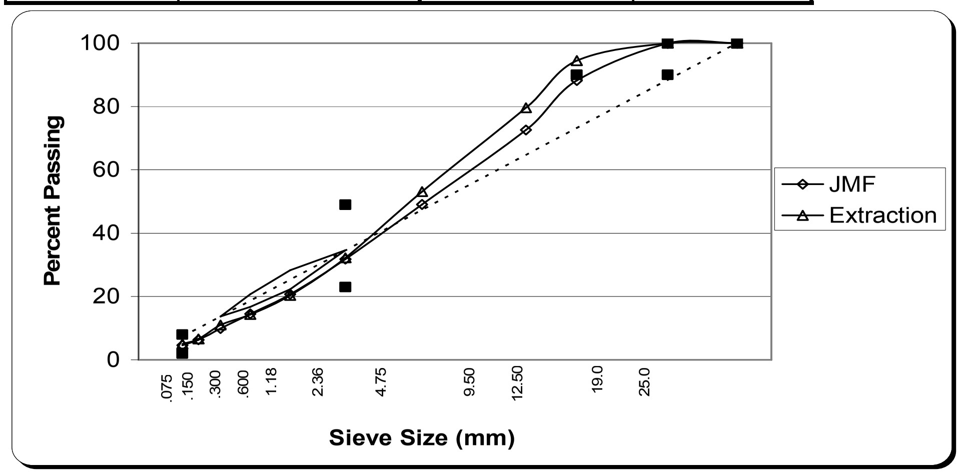
Project: US-23 Hartland

Project Information		Asphalt Information	
Project No.:	34519A	Asphalt Source:	Marathon Detroit
Location:	US-23/M-59 Interchange	Asphalt Grade (PG):	64-22
Contractor:	Ajax	Asphalt Content:	5.5
Traffic Level:	E30	Asphalt Additives:	None
Aggregate Type:	Limestone	Asphalt Additives (%):	N/A
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	45.5
Specifc Gravities		Dust Corr.:	0.4
G_{mm}	2.494	1 Face Crush (%):	98.1
G_{mb}	2.419	2 Face Crush (%):	97.7
G_b	1.031	**Volumetrics**	
G_{se}	2.718	VMA:	13.8
G_{sb}	2.652	VFA:	78.2
Temperature		AV:	3
Mixing (°F):	312-323	F/P_{be}:	1
Compacting (°F):	294	P_{be}:	4.60

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	99.9
1/2 (12.5)	88.2
3/8 (9.5)	72.6
#4 (4.75)	49.1
#8 (2.36)	31.8
#16 (1.18)	20.7
#30 (0.60)	14.5
#50 (0.30)	9.9
#100 (0.15)	6.3
#200 (0.075)	4.6

Material/Producer	Percent
1/2 x 3/8	20
3/4 x 1/2	20
Man. Sand	15
Man. Sand	30
RAP	15



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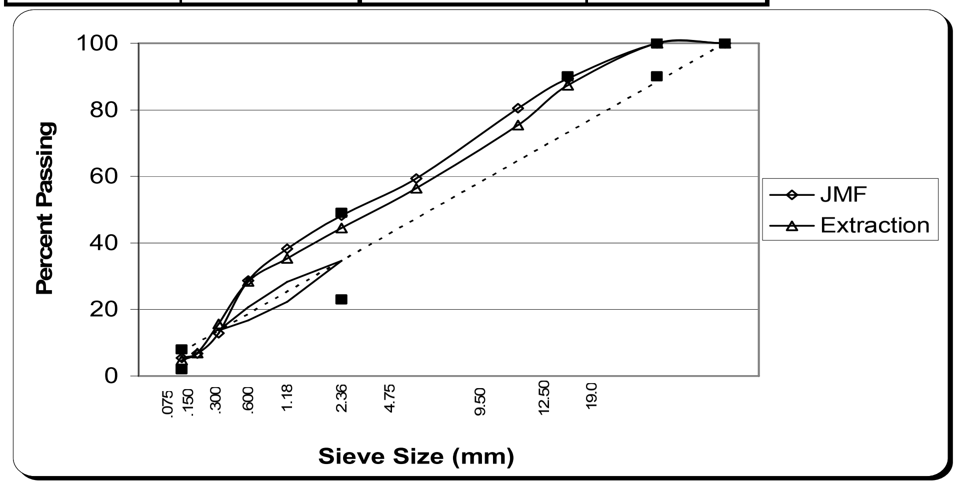
Project: I-75 Levering Road

Project Information		Asphalt Information	
Project No.:	53288A	Asphalt Source:	BP
Location:	I-75 Levering Rd.	Asphalt Grade (PG):	58-28
Contractor:	H & D Inc.	Asphalt Content:	5.5
Traffic Level:	E10	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	3	**SuperPave Consensus Properties**	
Gradation:	Fine	Angularity (%):	43.1
Specifc Gravities		Dust Corr.:	0.5
G_{mm}	2.43	1 Face Crush (%):	95.9
G_{mb}	2.357	2 Face Crush (%):	N/A
G_b	1.031	**Volumetrics**	
G_{se}	2.639	VMA:	14.1
G_{sb}	2.592	VFA:	79
Temperature		AV:	3
Mixing:	290	F/P_{be}:	1.11
Compacting:	266	P_{be}:	4.86

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	100
1/2 (12.5)	89.4
3/8 (9.5)	80.5
#4 (4.75)	59.3
#8 (2.36)	48.2
#16 (1.18)	38.3
#30 (0.60)	28.7
#50 (0.30)	12.9
#100 (0.15)	6.8
#200 (0.075)	5.4

Material/Producer	Percent
3/4" Stone	12
9/16" Stone	28
Wash Fines	17
Cr. Sand	25
RAP	18



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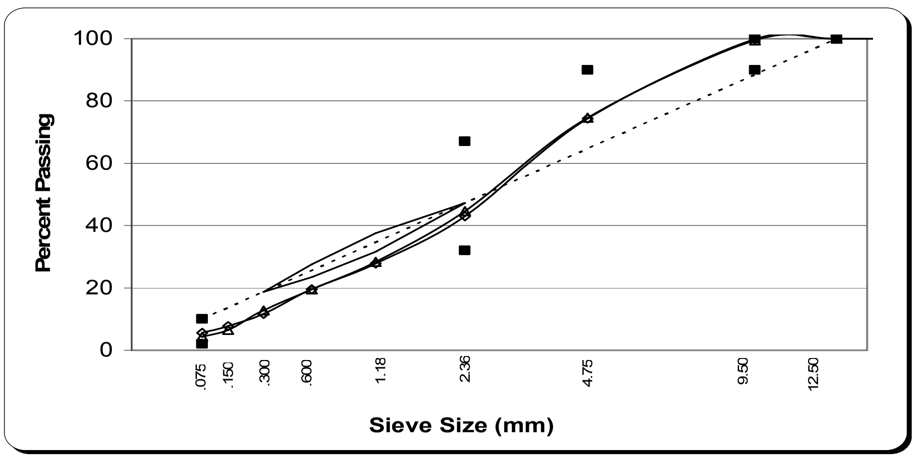
Project: I-196 Grand Rapids

Project Information		Asphalt Information	
Project No.:	74784A	Asphalt Source:	Michigan Paving & Materials
Location:	I-196 Grand Rapids	Asphalt Grade (PG):	64-22
Contractor:	Michigan Paving & Materials	Asphalt Content:	5.6
Traffic Level:	E10	Asphalt Additives:	None
Aggregate Type:	Limestone	Asphalt Additives (%):	N/A
Mix Size:	5	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	45.6
Specifc Gravities		Dust Corr.:	
G_{mm}	2.499	1 Face Crush (%):	91
G_{mb}	2.399	2 Face Crush (%):	86.3
G_b	1.036	**Volumetrics**	
G_{se}	2.73	VMA:	15.3
G_{sb}	2.637	VFA:	73.8
Temperature		AV:	4
Mixing (^{o}F):	311-322	F/P_{be}:	1.2
Compacting (^{o}F):	286-298	P_{be}:	4.58

Sieve Size	Mix/Gradation (%P)	Material/Producer	Percent
1 (25)	100	3/8 x 4	12
3/4 (19)	100	Man. Sand	45
1/2 (12.5)	100	31A	10
3/8 (9.5)	99.9	Fine Crush	20
#4 (4.75)	74.3	FA-20	13
#8 (2.36)	43		
#16 (1.18)	27.8		
#30 (0.60)	19.5		
#50 (0.30)	11.7		
#100 (0.15)	7.8		
#200 (0.075)	5.5		



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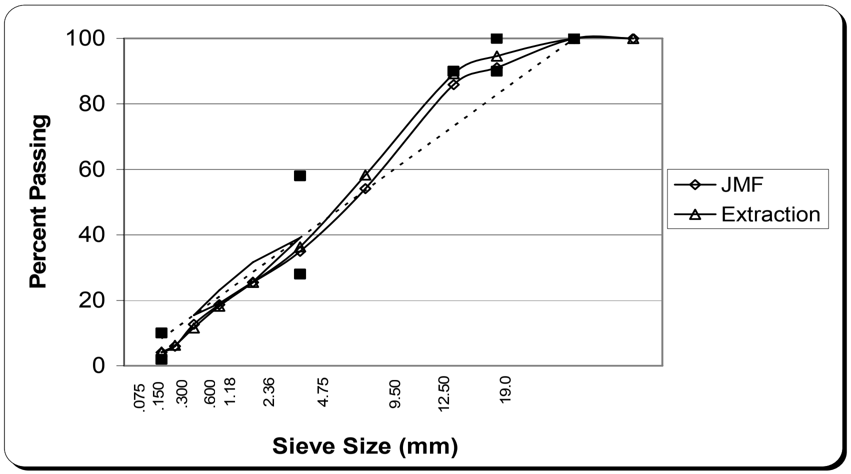
Project: I-75 Clarkston

Project Information		Asphalt Information	
Project No.:	51472A	Asphalt Source:	Marathon Det.
Location:	I-75 Clarkston	Asphalt Grade (PG):	70-22 P
Contractor:	Ace Asphalt & Paving	Asphalt Content:	5.8
Traffic Level:	E30	Asphalt Additives:	None
Aggregate Type:	Slag	Asphalt Additives (%):	N/A
Mix Size:	4	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	45.3
Specifc Gravities		Dust Corr.:	
G_{mm}	2.467	1 Face Crush (%):	98.5
G_{mb}	2.369	2 Face Crush (%):	95.1
G_b	1.035	**Volumetrics**	
G_{se}	2.699	VMA:	14.7
G_{sb}	2.616	VFA:	72.8
Temperature		AV:	4
Mixing (°F):	309-329	F/P_{be}:	0.9
Compacting (°F):	289-309	P_{be}:	4.56

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	100
1/2 (12.5)	91.1
3/8 (9.5)	85.9
#4 (4.75)	54.1
#8 (2.36)	35
#16 (1.18)	25.5
#30 (0.60)	18.7
#50 (0.30)	12.7
#100 (0.15)	6
#200 (0.075)	4.1

Material/Producer	Percent
3/8 x #4	16
MS-6	33
#3's	14
3CS	9
3/8 x #4 BF	15
RAP	12



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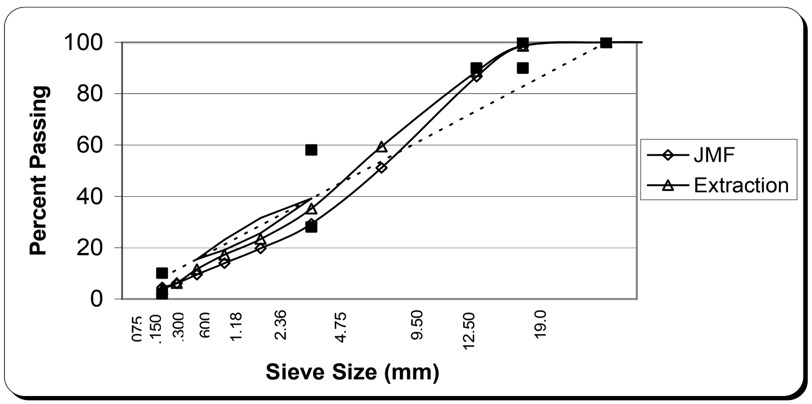
Project: M-53 Detroit, 8 Mile Road

Project Information		Asphalt Information	
Project No.:	52804A/52805A	Asphalt Source:	Marathon Det.
Location:	M-53/M-3 to M-102	Asphalt Grade (PG):	70-22 P
Contractor:	National Asphalt Products	Asphalt Content:	5.6
Traffic Level:	E10	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	4	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	45.9
Specifc Gravities		Dust Corr.:	
G_{mm}	2.553	1 Face Crush (%):	95.6
G_{mb}	2.451	2 Face Crush (%):	92.8
G_b	1.035	**Volumetrics**	
G_{se}	2.796	VMA:	15.5
G_{sb}	2.738	VFA:	74.2
Temperature		AV:	4
Mixing (^oF):	309-329	F/P_{be}:	0.99
Compacting (^oF):	289-309	P_{be}:	4.55

Sieve Size	Mix/Gradation (%P)	Material/Producer	Percent
1 (25)	100	1/2"	10
3/4 (19)	100	4 x 3/8"	13
1/2 (12.5)	98.6	Otr Sand	34
3/8 (9.5)	86.7	Mfg. Sand	11
#4 (4.75)	51.1	HL3	24
#8 (2.36)	29.3	RAP	8
#16 (1.18)	19.7		
#30 (0.60)	14		
#50 (0.30)	9.5		
#100 (0.15)	6.1		
#200 (0.075)	4.5		



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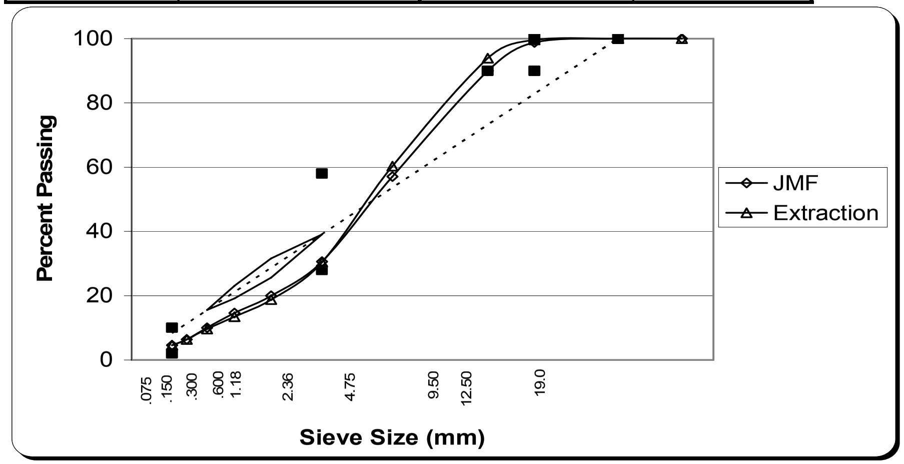
Project: Michigan Avenue, Dearborn

Project Information		Asphalt Information	
Project No.:	47064A	Asphalt Source:	Marathon Det.
Location:	Michigan Ave.	Asphalt Grade (PG):	70-22 P
Contractor:	Ajax Materials Corp.	Asphalt Content:	5.8
Traffic Level:	E10	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	4	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	45.5
Specifc Gravities		Dust Corr.:	
G_{mm}	2.464	1 Face Crush (%):	98.8
G_{mb}	2.366	2 Face Crush (%):	97.9
G_b	1.035	**Volumetrics**	
G_{se}	2.693	VMA:	15.7
G_{sb}	2.644	VFA:	74.5
Temperature		AV:	4
Mixing (°F):	309-329	F/P_{be}:	0.9
Compacting (°F):	289-309	P_{be}:	5.11

Sieve Size	Mix/Gradation (%P)
1 (25)	100
3/4 (19)	100
1/2 (12.5)	98.8
3/8 (9.5)	90
#4 (4.75)	57.1
#8 (2.36)	30.6
#16 (1.18)	20
#30 (0.60)	14.6
#50 (0.30)	10
#100 (0.15)	6.4
#200 (0.075)	4.6

Material/Producer	Percent
Man. Sand	10
1/2 x 3/8	25
Man. Sand	37
#9's	18
RAP	10



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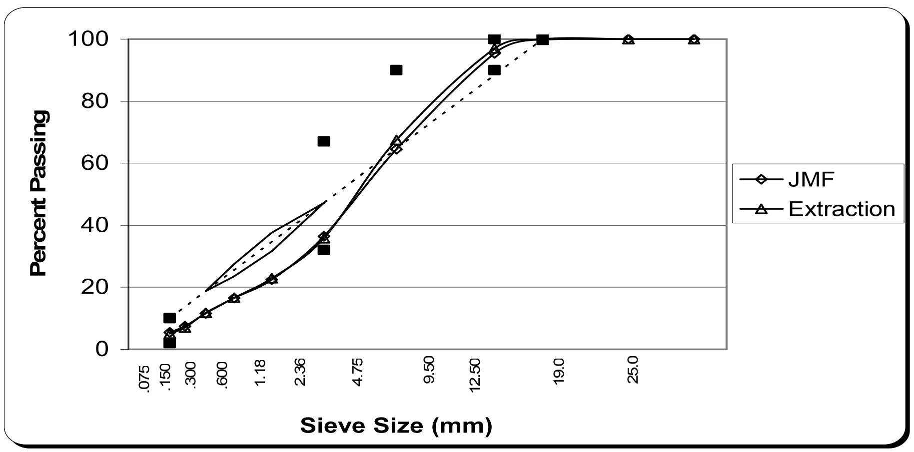
Project: I-75 Toledo

Project Information		Asphalt Information	
Project No.:	74577A	Asphalt Source:	6505 MPM Oil
Location:	I-75	Asphalt Grade (PG):	70-22 P
Contractor:	Cadillac Asphalt L.L.C.	Asphalt Content:	5.4
Traffic Level:	E30	Asphalt Additives:	None
Aggregate Type:		Asphalt Additives (%):	N/A
Mix Size:	5	**SuperPave Consensus Properties**	
Gradation:	Coarse	Angularity (%):	46
Specifc Gravities		Dust Corr.:	
G_{mm}	2.51	1 Face Crush (%):	98
G_{mb}	2.409	2 Face Crush (%):	96.1
G_b	1.029	**Volumetrics**	
G_{se}	2.737	VMA:	15.9
G_{sb}	2.711	VFA:	74.8
Temperature		AV:	4
Mixing (°F):	311-322	F/P_{be}:	1.07
Compacting (°F):	290	P_{be}:	5.05

Sieve Size	Mix/Gradation (%P)	Material/Producer	Percent
1 (25)	100	3/8 x #4	10
3/4 (19)	100	Man. Sand	28
1/2 (12.5)	100	Fine Crush	10
3/8 (9.5)	95.4	Man. Sand	32
#4 (4.75)	64.5	1/4" Chip	10
#8 (2.36)	36.4	1/2" Clear	10
#16 (1.18)	22.4		
#30 (0.60)	16.5		
#50 (0.30)	11.6		
#100 (0.15)	7.4		
#200 (0.075)	5.4		



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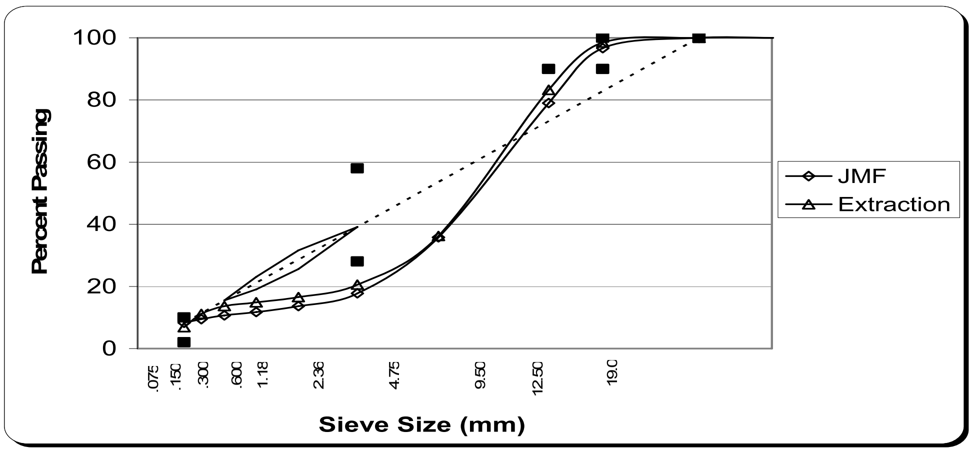
Project: I-94 Ann Arbor

Project Information		Asphalt Information	
Project No.:	47546A	Asphalt Source:	T & M Oil
Location:	I-94 Ann Arbor	Asphalt Grade (PG):	70-22 P
Contractor:	Thompson McCully	Asphalt Content:	6.6
Traffic Level:	E30	Asphalt Additives:	Cellulose Fibers
Aggregate Type:		Asphalt Additives (%):	0.3
Mix Size:	4	**SuperPave Consensus Properties**	
Gradation:	SMA	Angularity (%):	46.4
Specifc Gravities		Dust Corr.:	0.4
G_{mm}	2.514	1 Face Crush (%):	99.7
G_{mb}	2.413	2 Face Crush (%):	99.5
G_b		**Volumetrics**	
G_{se}	2.798	VMA:	17.8
G_{sb}	2.742	VFA:	77.4
Temperature		AV:	4
Mixing:		F/P_{be}:	1.41
Compacting:	163	P_{be}:	5.89

Sieve Size	Mix/Gradation (%P)	Material/Producer	Percent
1 (25)	100	3/8 x 0	21.5
3/4 (19)	100	3/8 x 4	14.7
1/2 (12.5)	96.7	3/8	14.7
3/8 (9.5)	79	Trap Chip	14.7
#4 (4.75)	35.8	HL1	28.3
#8 (2.36)	17.8	Mineral Filler	4
#16 (1.18)	13.7	Break-down	2.1
#30 (0.60)	11.8		
#50 (0.30)	10.7		
#100 (0.15)	9.5		
#200 (0.075)	8.3		



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APPENDIX B SPECIMEN VOLUMETRICS

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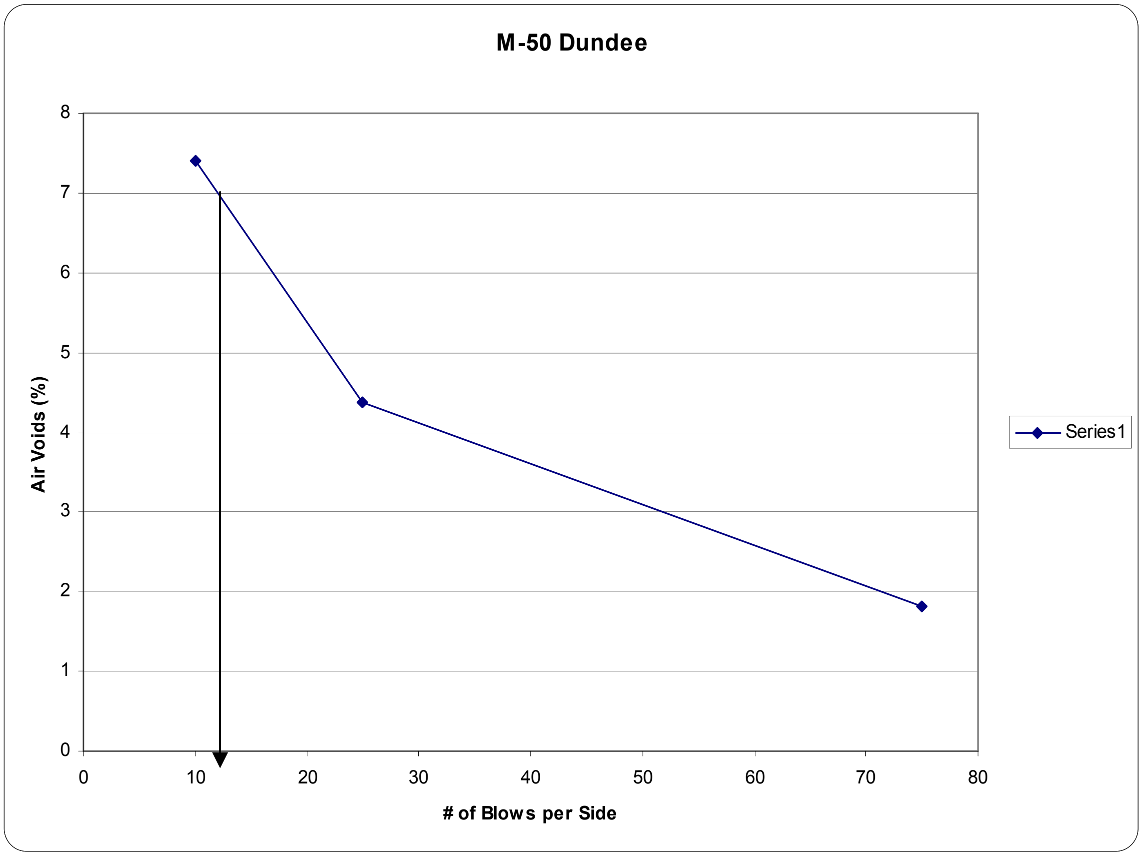
Phase I – Compaction Curves for Marshall Specimens



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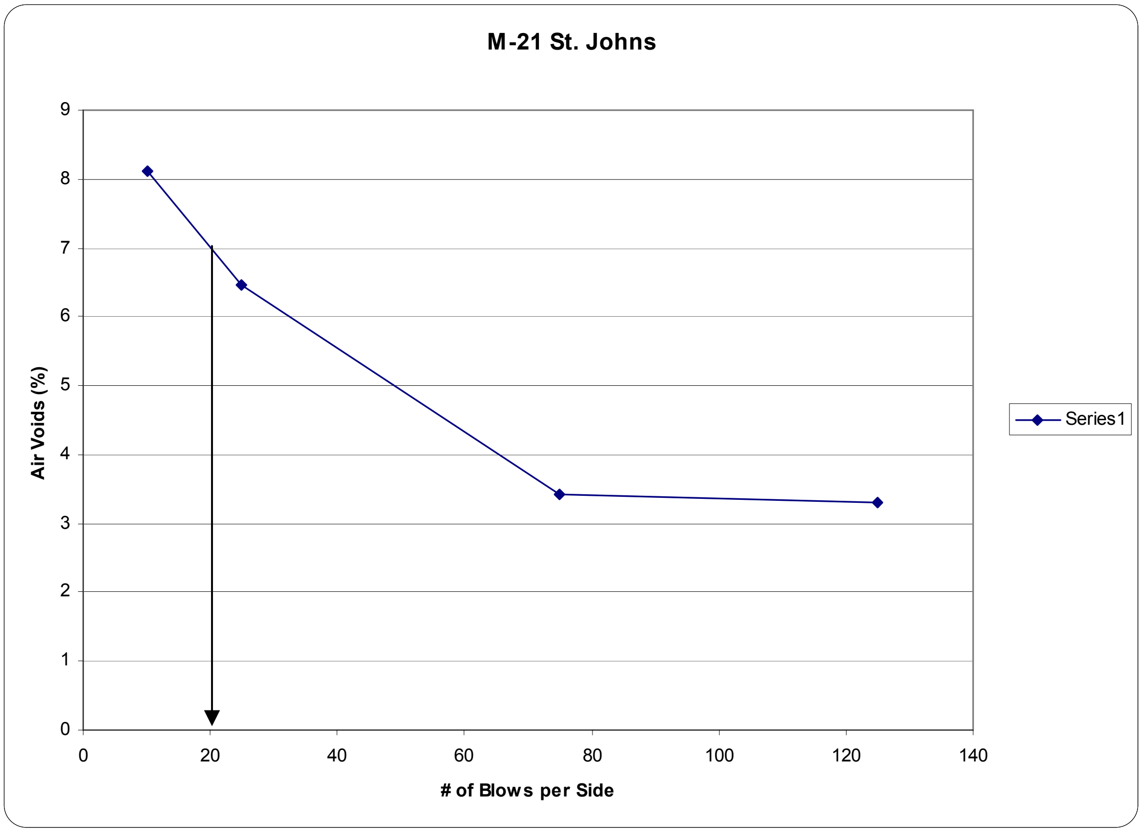

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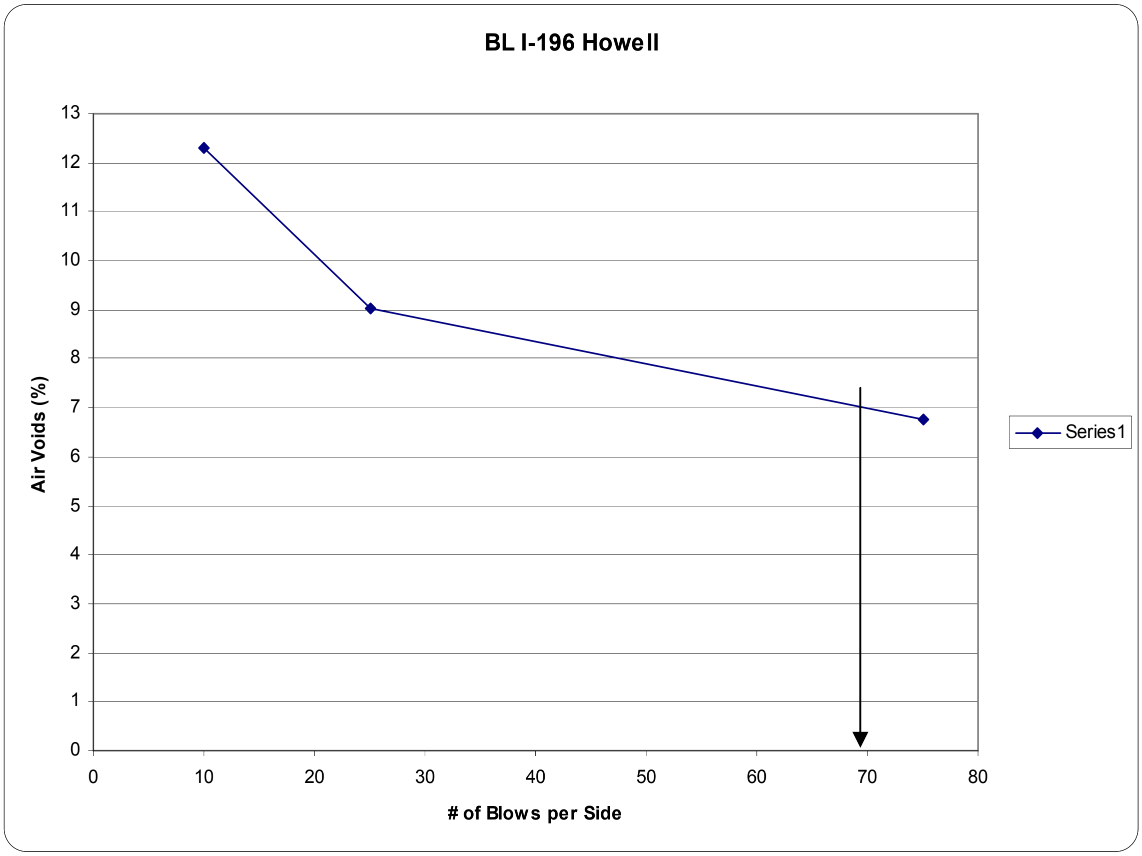

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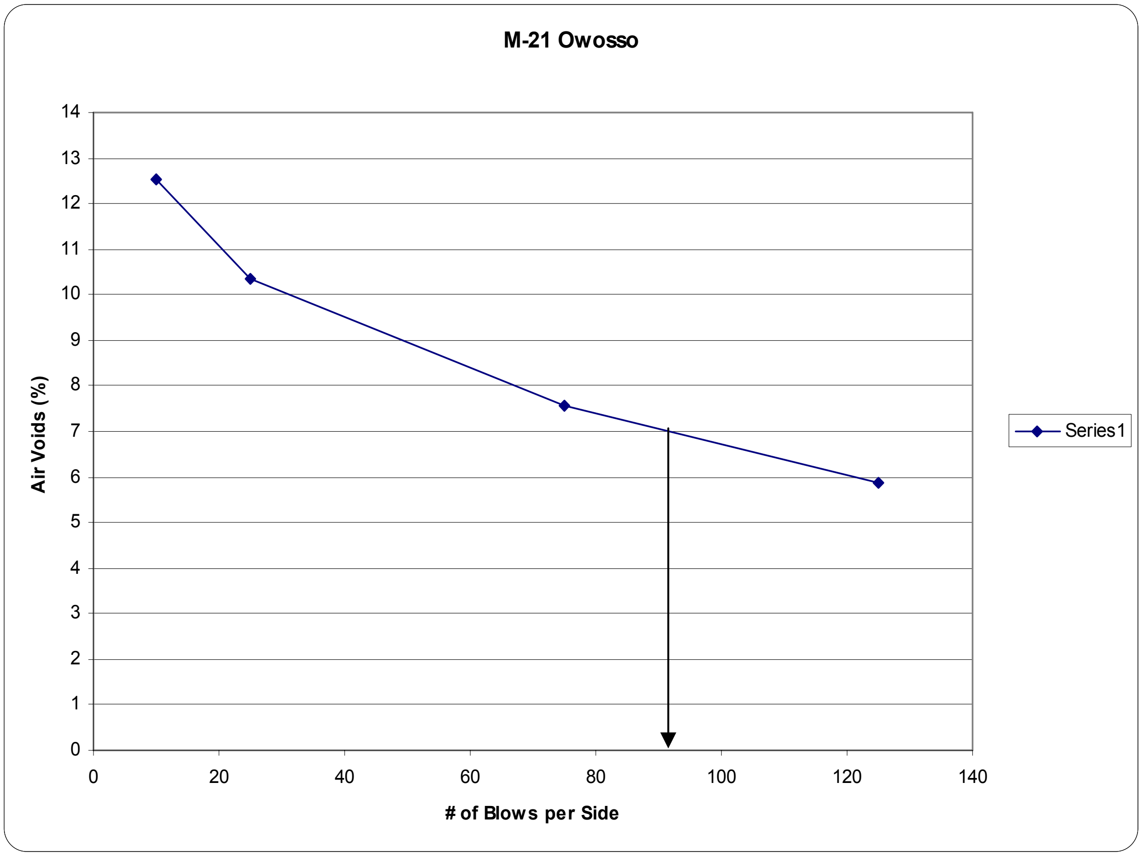

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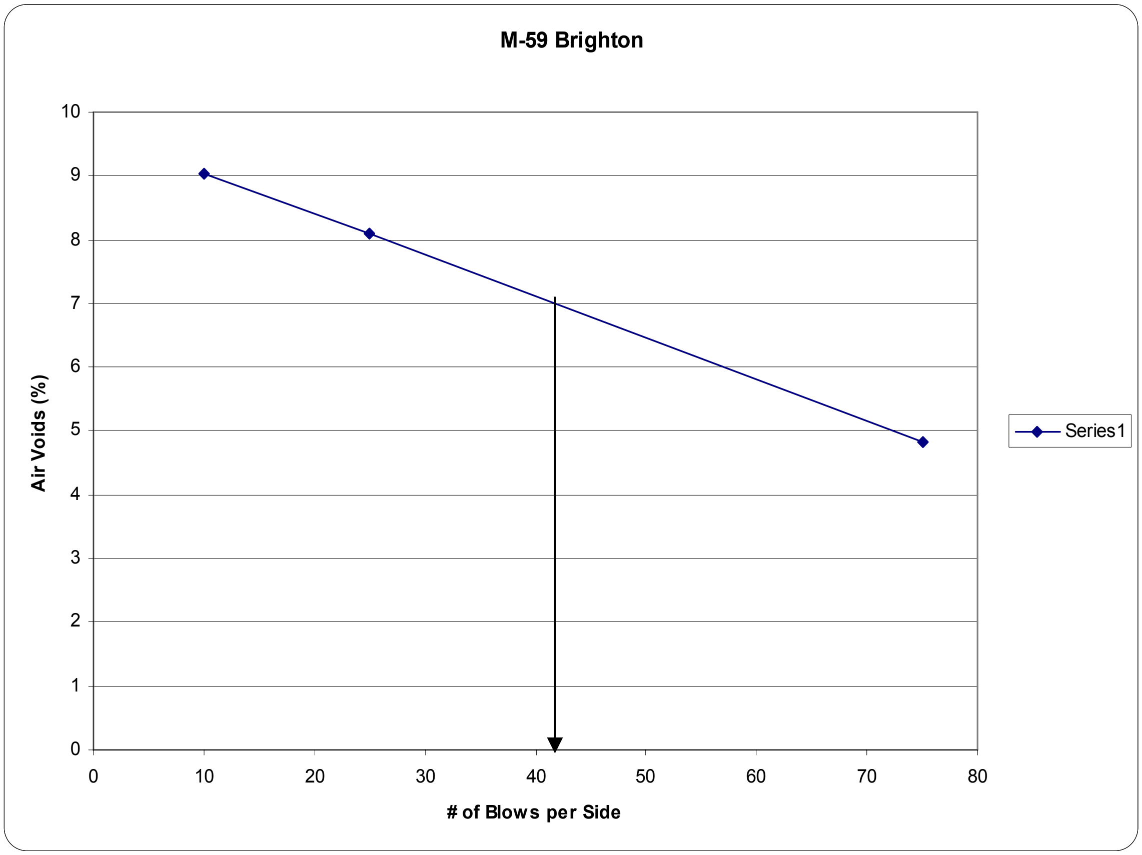

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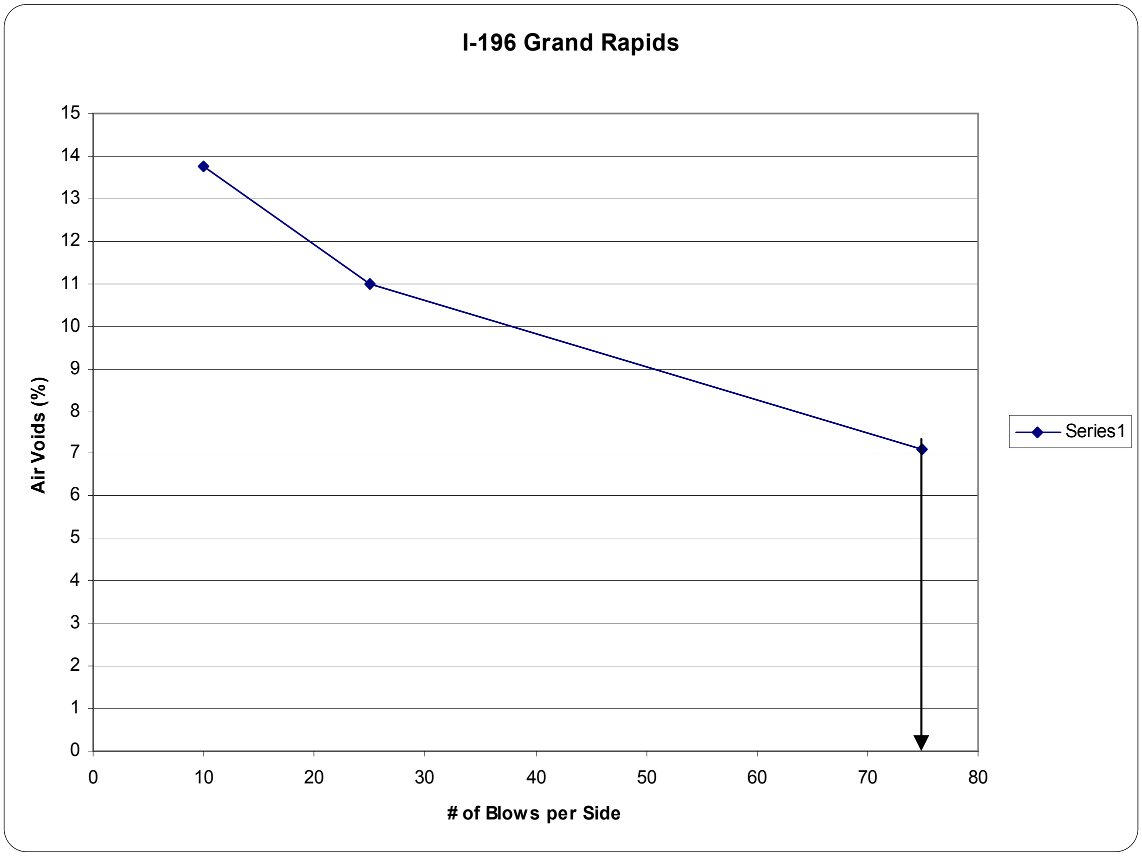

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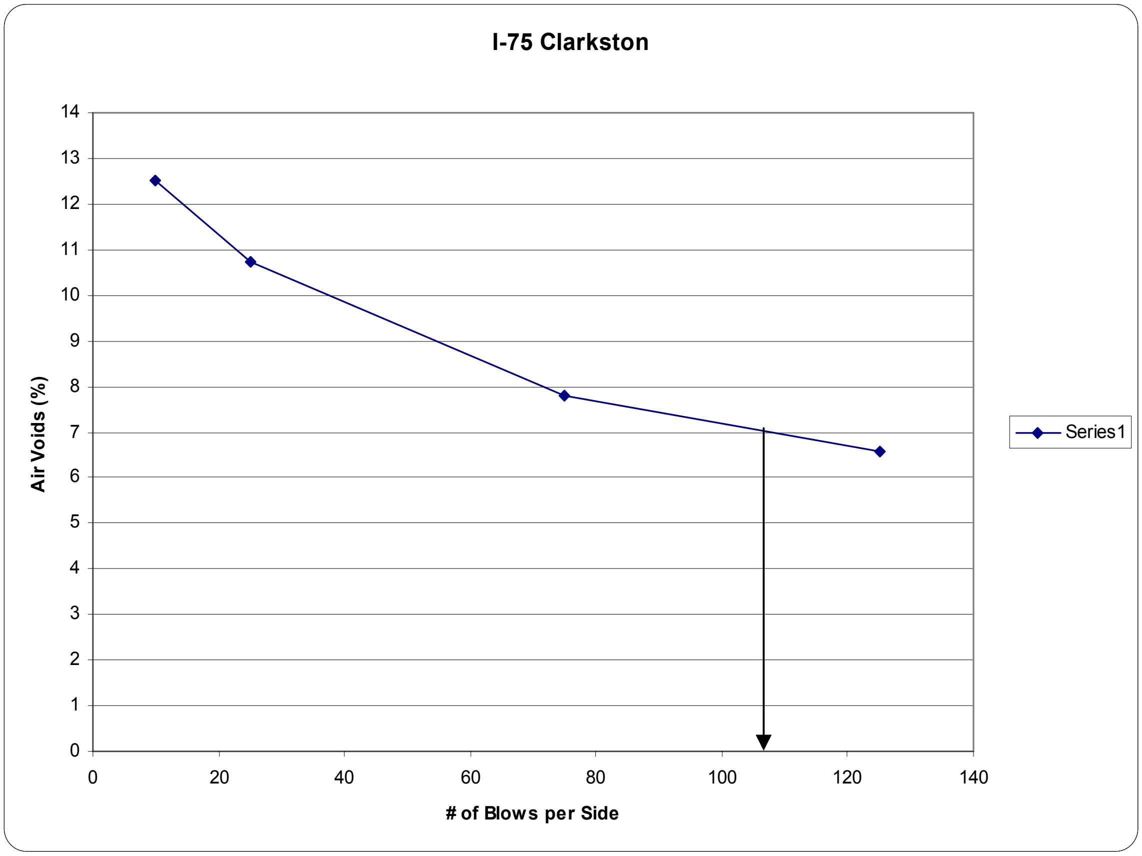

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Phase I – 100mm Marshall Specimens

Project Number:	50651A
Location:	M-50 Dundee
Contractor:	Cadillac LLC Asphalt
Mix:	3E1
Gradation:	Coarse
G_{mm}	2.52

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1195.8	1192.3	1193.7	1190.2	1194.9	1186.8	1199.7	1196.2	1198.3	1198.8	1194.3	1201.1	1192.4	1191.3	1194.8	1196.2	1196.6	1190	1186	1185.8
B	Height 1	66.90	66.74	65.13	64.32	67.06	64.73	68.04	66.53	67.28	66.20	64.40	67.34	68.47	69.00	68.71	68.57	68.01	68.63	67.73	66.65
C	Height 2	66.49	65.79	66.30	65.42	67.03	65.33	68.27	65.86	67.18	66.12	64.37	67.31	69.22	3.00	69.25	68.34	68.22	68.59	67.45	67.83
D	Height 3	66.59	65.89	66.09	65.65	67.40	64.41	68.53	65.42	67.21	66.31	64.94	67.92	68.47	68.80	68.68	68.72	68.57	68.07	67.49	68.04
E	Height 4	66.28	65.91	65.16	64.50	67.45	64.50	67.94	66.02	67.85	66.67	64.11	68.66	68.12	68.30	68.24	69.27	68.53	69.38	67.72	66.83
F	Average Height	66.57	66.08	65.67	64.97	67.24	64.74	68.20	65.96	67.38	66.33	64.46	67.81	68.57	67.97	68.72	68.73	68.33	68.67	67.60	67.34
G	Diameter 1	101.970	101.090	101.310	101.630	101.460	101.690	100.970	101.500	100.840	101.860	101.120	101.180	100.520	102.240	101.420	101.580	101.640	101.270	101.900	102.360
H	Diameter 2	101.270	101.050	101.350	101.410	101.930	101.900	101.240	101.770	101.540	101.940	101.220	101.140	101.390	101.770	100.960	101.190	101.520	101.500	101.720	102.100
I	Average Diameter	101.620	101.070	101.330	101.520	101.695	101.795	101.105	101.635	101.190	101.900	101.170	101.160	100.955	102.005	101.190	101.385	101.580	101.385	101.810	102.230
J	G_{mb} $[A/(F*\pi*I^2/4)]$	2.215	2.249	2.254	2.263	2.188	2.252	2.191	2.235	2.211	2.216	2.305	2.204	2.172	2.145	2.162	2.156	2.161	2.147	2.155	2.145
K	Air Voids $[(G_{mm}-J)/G_{mm}]$	12.1	10.8	10.6	10.2	13.2	10.6	13.0	11.3	12.2	12.1	8.5	12.5	13.8	14.9	14.2	14.4	14.3	14.8	14.5	14.9

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	3	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1195.8	1192.3	1193.7	1190.3	1194.9	1186.7	1199.7	1196.2	1198.3	1198.8	1194.3	1201.1	1192.3	1191.3	1194.3	1196.1	1196.4	1190	1185.7	1185.8
B	Submerged Mass	696.4	691.6	693.3	691.6	695.7	687.7	697.2	696.7	697.6	693.3	691.1	698.7	697.7	698.5	699.4	699.6	698.7	696.8	693.1	687.4
C	SSD Mass	1202.7	1196.7	1197.5	1194	1207.1	1192.1	1211.4	1202.8	1209.6	1205.8	1198.5	1210.6	1210.7	1212.4	1213	1213.6	1212.1	1207.5	1200.4	1198.5
D	G_{mb} $[A/(C-B)]$	2.362	2.361	2.368	2.369	2.337	2.353	2.333	2.364	2.340	2.339	2.354	2.346	2.324	2.318	2.325	2.327	2.330	2.330	2.337	2.320
E	Air Voids $[(G_{mm}-D)/G_{mm}]$	6.3	6.3	6.1	6.0	7.3	6.6	7.4	6.2	7.1	7.2	6.6	6.9	7.8	8.0	7.7	7.7	7.5	7.5	7.3	7.9

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Project Number:	46023A
Location:	M-21 St. Johns
Contractor:	Michigan Paving & Materials
Mix:	3E3
Gradation:	Coarse
G_{mm}	2.489

VOLUMETRIC ANALYSIS

	Sample	1	2	3	4	5	6	7	8	9	1	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	1196.9	1194.3	1182.8	1196.2	1194.6	1191.9	1204.7	1195.2	1190	1199.3	1196.2	1194.8	1212.4	1196.6	1196.4	1195.1	1206.8	1197.3	1200.4	1199.8
B	Height 1 (mm)	68.00	67.16	68.73	69.04	69.04	69.17	69.34	68.74	69.19	68.96	68.07	68.45	69.90	68.01	67.29	68.05	69.63	68.85	68.49	68.82
C	Height 2 (mm)	68.28	66.96	68.49	69.02	69.08	69.14	68.68	68.33	69.18	69.34	68.01	68.55	69.36	67.72	67.95	68.12	70.14	69.37	69.09	69.03
D	Height 3 (mm)	67.98	67.14	68.49	68.98	68.57	69.22	69.25	68.31	69.23	69.12	68.28	68.39	69.63	67.89	67.29	68.08	69.77	69.32	68.72	69.72
E	Height 4 (mm)	67.78	67.58	68.70	69.28	68.74	69.20	69.93	68.55	69.85	68.80	68.45	68.16	69.90	68.72	67.13	67.98	69.33	68.79	68.43	69.80
F	Average Height (mm)	68.01	67.21	68.60	69.08	68.86	69.18	69.30	68.48	69.36	69.06	68.20	68.39	69.70	68.09	67.42	68.06	69.72	69.08	68.68	69.34
G	Diameter 1 (mm)	102.41	101.94	102.05	102.26	102.25	101.76	101.95	102.13	102.55	102.03	102.28	102.43	102.20	102.24	101.77	102.01	102.24	102.14	102.85	102.79
H	Diameter 2 (mm)	102.83	101.81	101.84	102.77	102.79	101.79	101.99	102.14	102.60	102.10	101.93	102.51	102.55	102.02	101.90	102.01	102.13	102.36	102.45	101.90
I	Average Diameter (mm)	102.62	101.88	101.95	102.52	102.52	101.78	101.97	102.14	102.58	102.07	102.11	102.47	102.38	102.13	101.84	102.01	102.19	102.25	102.65	102.35
J	G_{mb} [A/(F*π*I²/4)]	2.128	2.180	2.112	2.098	2.102	2.118	2.129	2.130	2.076	2.123	2.142	2.119	2.113	2.145	2.179	2.149	2.111	2.111	2.112	2.103
K	Air Voids [(G_{mm}-J)/G_{mm}]	14.5	12.4	15.1	15.7	15.6	14.9	14.5	14.4	16.6	14.7	13.9	14.9	15.1	13.8	12.5	13.7	15.2	15.2	15.2	15.5

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	1	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	1196.9	1194.3	1182.8	1196.2	1194.6	1191.9	1204.7	1195.2	1190	1199.3	1196.2	1194.8	1212.4	1196.6	1196.4	1195.1	1206.8	1197.3	1200.4	1199.8
B	Submerged Mass (g)	686.4	685	690	691.6	689	692.6	697.3	688.7	687.4	691.7	692	689.1	702.4	689.4	685	687.5	699.1	693.5	692	695.8
C	SSD Mass (g)	1208.8	1203	1202.6	1210.9	1209.7	1209.9	1219.6	1209	1206.5	1214.8	1211.2	1210.1	1228.5	1210.3	1203.3	1207.1	1222.4	1216.1	1215.8	1217.7
D	G_{mb} [A/(C-B)]	2.29	2.31	2.31	2.30	2.29	2.30	2.31	2.30	2.29	2.29	2.30	2.29	2.30	2.30	2.31	2.30	2.31	2.29	2.29	2.30
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.9	7.4	7.3	7.5	7.8	7.4	7.3	7.7	7.9	7.9	7.4	7.9	7.4	7.7	7.3	7.6	7.3	8.0	7.9	7.6

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Project Number: 50650A

Location: BL I-96 Howell

Contractor: Rieth-Riley
Mix: Fine
Gradation: 4E3
G_{mm} 2.501

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1223.4	1265.2	1190.4	1190.3	1194.6	1195.1	1193	1198.6	1188.5	1198.6	1192.6	1196.5	1190.7	1201.5	1198	1193.8	1187.1	1203.8	1193.3	1200.9
B	Height 1	66.24	68.82	65.39	64.95	65.96	65.69	65.20	64.79	64.86	65.28	65.21	65.44	64.93	65.22	66.21	64.80	64.92	65.13	64.90	64.84
C	Height 2	67.42	68.59	65.30	64.20	65.36	66.12	65.63	65.65	64.47	64.94	64.65	65.24	64.48	65.50	65.72	64.47	65.18	65.59	65.81	64.63
D	Height 3	66.63	67.90	64.93	64.45	64.80	64.49	64.48	66.61	64.58	65.45	64.76	64.26	64.53	65.90	64.75	65.75	65.72	66.36	65.41	64.68
E	Height 4	65.56	68.17	64.00	65.37	64.41	65.65	64.38	64.96	65.33	66.79	65.27	64.91	65.14	65.62	65.38	65.40	64.92	65.57	65.19	64.68
F	Average Height	66.46	68.37	64.91	64.74	65.13	65.49	64.92	65.50	64.81	65.62	64.97	64.96	64.77	65.56	65.52	65.11	65.19	65.66	65.33	64.71
G	Diameter 1	101.55	101.2	100.83	101.76	101.3	101.44	101.53	101.65	101.36	101.35	101.37	101.65	101.28	101.39	101.47	101.55	101.47	101.67	101.2	101.88
H	Diameter 2	101.76	101.5	101.25	101.65	101.94	101.61	102.32	101.79	101.19	101.54	101.37	101.47	101.3	101.37	101.55	101.43	101.73	101.46	101.39	101.91
I	Average Diameter	101.655	101.350	101.040	101.705	101.620	101.525	101.925	101.720	101.275	101.445	101.370	101.560	101.290	101.380	101.510	101.490	101.600	101.565	101.295	101.895
J	G_{mb} [A/(F*π*I^2/4)]	2.268	2.294	2.287	2.263	2.261	2.254	2.252	2.252	2.276	2.260	2.274	2.274	2.281	2.270	2.259	2.267	2.246	2.263	2.267	2.276
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.3	8.3	8.5	9.5	9.6	9.9	10.0	10.0	9.0	9.6	9.1	9.1	8.8	9.2	9.7	9.4	10.2	9.5	9.4	9.0

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1223.4	1265.2	1190.4	1190.3	1194.6	1195.1	1193	1198.6	1188.5	1198.6	1192.6	1196.5	1190.7	1201.5	1198	1193.8	1187.1	1203.8	1193.3	1200.9
B	Submerged Mass	696.1	722.1	680.7	677.1	680.9	676.8	678.9	680	677.7	681.3	678.5	682.1	677.1	685.2	683.7	679.1	673.8	684.8	677.6	682.6
C	SSD Mass	1224.8	1267.6	1193	1192.5	1196.5	1196.3	1196.6	1200.9	1192.3	1202.2	1196.1	1199.6	1194.1	1203.9	1201	1197.4	1189.6	1206.7	1196	1204.5
D	G_{mb} [A/(C-B)]	2.314	2.319	2.324	2.309	2.317	2.300	2.304	2.301	2.310	2.301	2.304	2.312	2.303	2.316	2.316	2.303	2.301	2.307	2.302	2.301
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.5	7.3	7.1	7.7	7.4	8.0	7.9	8.0	7.7	8.0	7.9	7.6	7.9	7.4	7.4	7.9	8.0	7.8	8.0	8.0

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Project Number: 48612A
Location: M-21 Owosso
Contractor: Michigan Paving & Materials
Mix: 5E3
Gradation: Fine
G_{mm} 2.470

VOLUMETRIC ANALYSIS

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	1192.2	1209.6	1196.8	1212.8	1199.9	1212.1	1194.2	1197.1	1194.2	1199.9	1189.3	1192.6	1194	1179.3	1186	1191	1198.1	1191.1	1195.7	1194.2
B	Height 1 (mm)	64.49	65.46	64.93	66.19	66.31	66.06	65.74	65.82	64.64	67.33	66.48	65.11	66.58	63.85	63.98	64.24	65.60	65.88	65.86	65.33
C	Height 2 (mm)	65.34	65.44	65.46	67.19	65.02	65.68	65.83	65.62	64.70	65.13	64.88	65.92	65.41	64.43	64.14	65.45	64.70	65.49	65.65	65.96
D	Height 3 (mm)	64.43	66.01	65.52	66.81	65.31	66.02	64.97	65.05	65.87	65.35	65.10	66.30	64.47	64.81	65.47	65.68	66.30	65.34	64.48	65.44
E	Height 4 (mm)	64.41	66.04	65.60	65.83	66.57	66.36	65.13	65.32	65.86	66.12	65.97	64.66	65.13	64.68	65.44	64.85	66.83	65.58	64.65	64.42
F	Average Height (mm)	64.67	65.74	65.38	66.51	65.80	66.03	65.42	65.45	65.27	65.98	65.61	65.50	65.40	64.44	64.76	65.06	65.86	65.57	65.16	65.29
G	Diameter 1 (mm)	101.37	101.31	101.23	101.30	101.27	101.29	101.37	101.35	101.29	101.37	101.27	101.32	101.36	101.43	101.38	101.33	101.16	101.37	101.34	101.45
H	Diameter 2 (mm)	101.27	101.47	101.31	101.37	101.36	101.31	101.32	101.40	101.33	101.42	101.28	101.30	101.63	101.35	101.39	101.20	101.35	101.32	101.21	101.33
I	Average Diameter (mm)	101.32	101.39	101.27	101.34	101.32	101.30	101.35	101.38	101.31	101.40	101.28	101.31	101.50	101.39	101.39	101.27	101.26	101.35	101.28	101.39
J	G_{mb} [A/(F*π*I²/4)]	2.287	2.279	2.273	2.261	2.262	2.278	2.263	2.266	2.270	2.252	2.250	2.259	2.257	2.267	2.269	2.273	2.259	2.252	2.278	2.266
K	Air Voids [(G_{mm}-J)/G_{mm}]	7.4	7.7	8.0	8.5	8.4	7.8	8.4	8.3	8.1	8.8	8.9	8.6	8.6	8.2	8.2	8.0	8.5	8.8	7.8	8.3

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	1192.2	1209.6	1196.8	1212.8	1193.9	1212.1	1194.2	1197.1	1194.2	1199.9	1189.3	1192.6	1194	1179.3	1186	1191	1198.1	1191.1	1195.7	1194.2
B	Submerged Mass (g)	679.3	685.5	677.1	685.3	673.4	687.1	673.2	676.5	676	676.7	671.8	673.3	674.9	667	671	673.5	677	671.7	676	675.5
C	SSD Mass (g)	1194.4	1211.9	1198.8	1215.5	1196.4	1214.6	1197.2	1200.3	1196.9	1202.1	1192.7	1195.6	1196.8	1181.8	1187.8	1193.5	1200.5	1192.6	1197.8	1197
D	G_{mb} [A/(C-B)]	2.31	2.30	2.29	2.29	2.28	2.30	2.28	2.29	2.29	2.28	2.28	2.28	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.3	7.0	7.1	7.4	7.6	7.0	7.7	7.5	7.2	7.5	7.6	7.6	7.4	7.3	7.1	7.3	7.3	7.4	7.2	7.3

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Project Number: 34519A

Location: M-59 Brighton

Contractor: Ajax Paving
Mix: 3E10
Gradation: Coarse
G_{mm} 2.503

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1211.5	1194.8	1195.8	1198	1208.9	1197.1	1200.7	1203.8	1201.6	1198	1209.2	1188.6	1189.5	1192.9	1194	1195	1207	1196.4	1196.6	1186.7
B	Height 1	70.26	68.03	67.36	68.03	70.00	68.08	65.29	67.81	69.90	68.68	70.00	68.26	65.89	67.12	69.60	68.45	70.66	68.78	66.43	65.13
C	Height 2	70.43	68.79	67.50	68.34	69.86	68.52	65.03	67.73	69.80	69.29	70.26	68.07	65.82	67.48	69.48	67.90	71.69	68.56	65.56	65.36
D	Height 3	70.51	67.92	67.67	68.04	69.89	67.81	66.29	67.46	69.69	69.09	69.97	68.20	64.88	67.38	69.08	67.98	71.19	68.95	65.10	65.33
E	Height 4	69.96	67.62	68.07	67.77	69.87	67.51	65.97	68.20	70.03	68.54	69.51	68.84	64.98	67.13	69.07	68.35	70.84	68.98	65.23	65.84
F	Average Height	70.29	68.09	67.65	68.05	69.91	67.98	65.65	67.80	69.86	68.90	69.94	68.34	65.39	67.28	69.31	68.17	71.10	68.82	65.58	65.42
G	Diameter 1	101.23	101.41	101.38	101.49	100.86	101.56	101.61	101.51	101.18	101.26	101.22	101.28	102.28	101.29	101.24	100.89	101.48	101.41	101.31	101.42
H	Diameter 2	101.61	101.36	101.56	101.51	101.44	101.49	101.33	101.43	101.74	101.33	101.51	101.44	102.01	101.48	101.47	101.44	101.79	101.41	101.71	101.87
I	Average Diameter	101.420	101.385	101.470	101.500	101.150	101.525	101.470	101.470	101.460	101.295	101.365	101.360	102.145	101.385	101.355	101.165	101.635	101.410	101.510	101.645
J	G_{mb} [A/(F*π*I²/4)]	2.134	2.174	2.186	2.176	2.152	2.175	2.262	2.196	2.128	2.158	2.143	2.155	2.220	2.196	2.135	2.181	2.093	2.152	2.255	2.236
K	Air Voids [(G_{mm}-J)/G_{mm}]	14.8	13.2	12.7	13.1	14.0	13.1	9.6	12.3	15.0	13.8	14.4	13.9	11.3	12.3	14.7	12.9	16.4	14.0	9.9	10.7

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1211.5	1194.8	1195.8	1198	1208.9	1197.1	1200.7	1203.8	1201.6	1198	1209.2	1188.6	1189.5	1192.9	1194	1195	1207	1196.4	1196.6	1186.7
B	Submerged Mass	708.6	691.2	691.6	695.8	706.3	694.6	693.1	696.4	701.4	701.4	705.2	692.4	687.3	689	694.7	696.7	706.6	698	690.7	687.4
C	SSD Mass	1234.8	1207.4	1210.4	1212.2	1231.5	1211.2	1204.6	1217.4	1219.8	1221.2	1230.2	1207.9	1194.7	1206.5	1210.6	1209.6	1230.4	1216.3	1199.9	1193.4
D	G_{mb} [A/(C-B)]	2.30	2.31	2.30	2.32	2.30	2.32	2.35	2.31	2.32	2.30	2.30	2.31	2.34	2.31	2.31	2.33	2.30	2.31	2.35	2.35
E	Air Voids [(G_{mm}-D)/G_{mm}]	8.0	7.5	7.9	7.3	8.0	7.4	6.2	7.7	7.4	7.9	8.0	7.9	6.3	7.9	7.5	6.9	7.9	7.8	6.1	6.3

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Project Number:	74784A
Location:	I-196 Grand Rapids
Contractor:	Michigan Paving & Materials
Mix:	5E10
Gradation:	Coarse
G_{mm}	2.499

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1197.6	1213.2	1207.2	1199.9	1191.5	1220.7	1193.9	1200.9	1213.1	1201.5	1191.8	1221.4	1208	1203	1205.4	1193.8	1194.7	1199.2	1192.2	1197.5
B	Height 1	64.94	65.51	65.36	65.71	65.19	66.72	63.96	64.01	65.15	63.70	64.26	66.31	65.24	64.19	66.18	64.21	64.90	65.85	63.72	64.34
C	Height 2	64.60	64.39	64.21	65.38	64.94	65.66	63.82	64.97	65.21	64.20	64.92	66.62	64.88	65.44	64.75	64.76	64.09	64.89	65.13	65.52
D	Height 3	64.75	64.61	64.26	65.32	64.78	64.98	64.42	65.91	65.96	65.65	64.61	65.46	64.68	65.96	64.24	64.32	64.70	64.50	64.11	66.11
E	Height 4	64.87	65.27	65.35	65.80	65.11	65.46	65.46	65.06	66.36	64.87	64.60	65.00	64.83	64.29	64.68	64.02	65.44	64.57	63.75	64.60
F	Average Height	64.79	64.95	64.80	65.55	65.01	65.71	64.42	64.99	65.67	64.61	64.60	65.85	64.91	64.97	64.96	64.33	64.78	64.95	64.18	65.14
G	Diameter 1	102.300	101.720	101.180	101.420	101.410	101.220	101.540	101.270	101.870	101.070	101.060	101.360	101.280	101.370	101.260	101.440	101.500	101.110	101.240	101.610
H	Diameter 2	102.270	101.790	101.230	101.180	101.670	101.170	101.440	101.190	101.720	101.680	101.330	101.780	101.330	101.590	101.200	101.300	101.560	101.900	101.270	101.530
I	Average Diameter	102.285	101.755	101.205	101.300	101.540	101.195	101.490	101.230	101.795	101.375	101.195	101.570	101.305	101.480	101.230	101.370	101.530	101.505	101.255	101.570
J	G_{mb} [A/(F*π*I²/4)]	2.250	2.297	2.316	2.271	2.264	2.310	2.291	2.296	2.270	2.304	2.294	2.289	2.309	2.289	2.305	2.299	2.278	2.282	2.307	2.269
K	Air Voids [(G_{mm}-J)/G_{mm}]	10.0	8.1	7.3	9.1	9.4	7.6	8.3	8.1	9.2	7.8	8.2	8.4	7.6	8.4	7.7	8.0	8.9	8.7	7.7	9.2

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1197.6	1213.1	1207.3	1199.9	1191.5	1220.5	1193.9	1200.8	1213.2	1201.5	1191.8	1221.4	1208	1203	1205.4	1193.8	1194.8	1199.2	1192.2	1197.5
B	Submerged Mass	686.3	696.3	694.5	687.8	680.2	700.9	683.6	688	695.5	691.4	684.3	699.9	694.6	689.9	693.6	686.2	684.3	687.3	685	683.3
C	SSD Mass	1200.9	1215.6	1209.3	1205.2	1195.7	1222.4	1196.5	1204.1	1216.5	1203.2	1194.5	1223.8	1210.7	1205.8	1207.4	1196	1197.5	1201.9	1194.5	1201.1
D	G_{mb} [A/(C-B)]	2.327	2.336	2.345	2.319	2.311	2.340	2.328	2.327	2.329	2.348	2.336	2.331	2.341	2.332	2.346	2.342	2.328	2.330	2.340	2.313
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.9	6.5	6.2	7.2	7.5	6.3	6.9	6.9	6.8	6.1	6.5	6.7	6.3	6.7	6.1	6.3	6.8	6.7	6.4	7.5

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Project Number:	51472A
Location:	I-75 Clarkston
Contractor:	Ace Asphalt
Mix:	4E30
Gradation:	Coarse
G_{mm}	2.487

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1233.9	1191.8	1191.2	1197	1191.9	1201	1233	1204	1196.2	1193.6	1192.3	1203.5	1194.3	1197.1	1200.9	1196.1	1223.6	1197.4	1205	1199.2
B	Height 1	67.67	66.58	65.09	66.20	65.47	66.64	69.01	66.47	64.66	65.57	65.52	67.20	65.21	64.55	64.21	65.83	67.42	65.65	65.49	66.84
C	Height 2	67.22	66.30	65.93	65.18	65.16	65.81	69.10	67.15	65.37	63.81	64.78	67.10	65.98	64.62	64.40	64.76	66.98	65.16	66.50	65.10
D	Height 3	67.86	66.37	65.85	65.58	65.21	66.96	68.23	66.35	65.28	64.11	66.09	65.73	66.58	65.47	65.62	65.52	67.28	66.97	66.53	65.15
E	Height 4	67.44	66.54	64.90	66.12	65.36	65.75	68.58	65.73	65.59	65.27	66.09	65.58	66.13	65.75	65.41	66.62	68.49	66.87	65.83	66.33
F	Average Height	67.55	66.45	65.44	65.77	65.30	66.29	68.73	66.43	65.23	64.69	65.62	66.40	65.98	65.10	64.91	65.68	67.54	66.16	66.09	65.86
G	Diameter 1	101.19	101.67	101.32	101.21	101.37	101.34	101.44	101.22	101.33	101.22	101.68	101.75	101.01	101.25	101.13	101.2	101.15	101.48	101.31	101.38
H	Diameter 2	101.88	101.68	101.44	101.23	101.39	101.34	101.59	101.35	101.4	101.2	101.71	101.78	102.06	101.3	101.42	101.31	101.26	101.14	101.4	101.29
I	Average Diameter	101.535	101.675	101.380	101.220	101.380	101.340	101.515	101.285	101.365	101.210	101.695	101.765	101.535	101.275	101.275	101.255	101.205	101.310	101.355	101.335
J	G_{mb} [A/(F*π*I²/4)]	2.256	2.209	2.255	2.262	2.261	2.246	2.216	2.250	2.273	2.293	2.237	2.228	2.236	2.283	2.297	2.261	2.252	2.245	2.260	2.258
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.3	11.2	9.3	9.1	9.1	9.7	10.9	9.5	8.6	7.8	10.1	10.4	10.1	8.2	7.7	9.1	9.4	9.7	9.1	9.2

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1233.9	1191.8	1191.2	1197	1191.9	1201	1233	1204	1196.2	1193.6	1192.3	1203.5	1194.3	1197.1	1200.9	1196.1	1223.6	1197.4	1205	1199.2
B	Submerged Mass	705.9	678.2	681.1	684.6	681.3	685.3	706.6	690.9	685.1	683.2	678.5	686.3	680.8	685	686.8	684.6	695.4	679.8	687.3	683.8
C	SSD Mass	1240.8	1199.2	1193.8	1202.8	1195.7	1209.5	1243.6	1215	1201	1196.1	1197.4	1209.8	1200.2	1201.5	1204.1	1201.7	1229.3	1202	1210	1202.2
D	G_{mb} [A/(C-B)]	2.307	2.288	2.323	2.310	2.317	2.291	2.296	2.297	2.319	2.327	2.298	2.299	2.299	2.318	2.321	2.313	2.292	2.293	2.305	2.313
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.2	8.0	6.6	7.1	6.8	7.9	7.7	7.6	6.8	6.4	7.6	7.6	7.5	6.8	6.7	7.0	7.8	7.8	7.3	7.0

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Phase I – 100mm Superpave Specimens

Project Number: 50651A
Location: M-50 Dundee
Contractor: Cadillac LLC Asphalt
Mix: 3E1
Gradation: Coarse
G_{mm} 2.52

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1084.9	1085.7	1085.1	1084.9	1086.8	1085.7	1089.5	1091.7	1087	1088.1	1082.4	1084.9	1083.6	1089	1084.1	1089.5	1086.4	1086.3	1089.5	1083.5
B	Height 1	63.47	62.93	62.77	63.47	62.84	63.01	62.95	62.95	62.95	62.97	63.16	63.10	62.94	62.88	63.13	63.06	63.01	63.08	63.04	62.90
C	Height 2	62.90	62.95	63.00	62.90	63.05	62.97	63.04	63.06	62.81	62.91	63.08	63.19	63.03	62.95	63.13	63.12	63.31	63.06	63.14	63.10
D	Height 3	63.01	63.04	63.07	63.01	62.98	63.02	62.94	63.27	62.87	62.93	63.04	63.06	63.08	62.95	63.17	63.21	63.22	63.17	63.31	63.10
E	Height 4	63.53	63.03	63.31	63.53	62.81	63.16	63.13	63.12	62.95	63.47	62.93	63.12	63.19	62.92	62.97	63.14	63.19	63.19	63.30	63.02
F	Average Height	63.23	62.99	63.04	63.23	62.92	63.04	63.02	63.10	62.90	63.07	63.05	63.12	63.06	62.93	63.10	63.13	63.18	63.13	63.20	63.03
G	Diameter 1	99.540	99.590	98.950	99.540	99.180	99.560	99.190	99.800	99.260	99.770	99.570	99.770	99.280	99.400	99.420	99.510	99.950	99.570	99.680	99.630
H	Diameter 2	99.860	98.970	99.600	99.860	99.740	99.610	99.810	100.070	99.220	99.600	99.600	99.740	99.250	99.640	99.700	99.900	99.580	99.830	99.750	99.370
I	Average Diameter	99.700	99.280	99.275	99.700	99.460	99.585	99.500	99.935	99.240	99.685	99.585	99.755	99.265	99.520	99.560	99.705	99.765	99.700	99.715	99.500
J	G_{mb} [A/(F*π*I^2/4)]	2.198	2.227	2.224	2.198	2.223	2.211	2.224	2.206	2.234	2.211	2.204	2.199	2.220	2.225	2.207	2.210	2.200	2.204	2.208	2.211
K	Air Voids [(G_{mm}-J)/G_{mm}]	12.8	11.6	11.8	12.8	11.8	12.3	11.8	12.5	11.3	12.3	12.5	12.7	11.9	11.7	12.4	12.3	12.7	12.5	12.4	12.3

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1084.9	1085.7	1085.1	1084.9	1086.8	1085.7	1089.5	1091.7	1087	1088.1	1082.4	1084.9	1083.6	1089	1084.1	1089.5	1086.4	1086.3	1089.5	1083.5
B	Submerged Mass	633.3	633.4	632.9	633.3	634.8	632.2	636.4	637.6	634.9	635.2	629.7	632.6	632.1	637.6	633.2	634.8	635.9	635.2	634.3	631.6
C	SSD Mass	1092	1091.9	1091.4	1092	1094.9	1093.5	1096.1	1099.7	1094.3	1094.8	1089.1	1093.3	1092.2	1098.1	1091.8	1099.2	1094.9	1094.9	1098.4	1090
D	G_{mb} [A/(C-B)]	2.365	2.368	2.367	2.365	2.362	2.354	2.370	2.362	2.366	2.367	2.356	2.355	2.355	2.365	2.364	2.346	2.367	2.363	2.348	2.364
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.1	6.0	6.1	6.1	6.3	6.6	6.0	6.3	6.1	6.1	6.5	6.6	6.5	6.2	6.2	6.9	6.1	6.2	6.8	6.2

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Project Number:	46023A
Location:	M-21 St. Johns
Contractor:	Michigan Paving & Materials
Mix:	3E3
Gradation:	Coarse
G_{mm}	2.489

VOLUMETRIC ANALYSIS

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	1081.9	1084.9	1084.7	1092.6	1075.4	1077.8	1081.6	1088.8	1083.1	1087.6	1094.7	1089.7	1084.5	1085.3	1085.3	1079.2	1080.5	1079	1090	1071.1
B	Height 1 (mm)	62.98	63.07	63.12	63.02	62.99	63.31	63.14	62.65	62.86	63.11	63.08	63.08	63.02	63.10	63.06	63.03	62.96	63.05	63.07	63.02
C	Height 2 (mm)	62.90	63.12	63.15	62.98	62.99	63.20	62.99	63.03	62.97	63.19	63.03	63.04	63.08	63.15	62.96	62.99	63.03	62.85	62.94	63.03
D	Height 3 (mm)	63.13	63.05	63.14	62.94	62.90	63.39	63.04	63.08	63.08	63.11	63.09	63.06	63.02	63.11	63.26	62.98	62.88	62.88	63.12	62.96
E	Height 4 (mm)	63.07	62.85	63.16	62.79	62.82	63.25	63.24	63.03	63.18	63.16	63.13	62.99	63.12	63.05	63.07	63.04	63.01	62.85	63.00	63.10
F	Average Height (mm)	63.02	63.02	63.14	62.93	62.93	63.29	63.10	62.95	63.02	63.14	63.08	63.04	63.06	63.10	63.09	63.01	62.97	62.91	63.03	63.03
G	Diameter 1 (mm)	100.05	100.20	100.57	100.19	100.17	100.72	100.77	100.15	100.24	100.34	100.18	100.22	100.14	100.22	100.11	100.17	100.14	100.21	100.06	100.08
H	Diameter 2 (mm)	100.26	100.11	100.62	100.10	100.14	100.09	100.41	100.28	100.15	100.15	100.11	100.08	100.07	100.15	100.30	100.26	100.15	100.38	100.04	100.07
I	Average Diameter (mm)	100.16	100.16	100.60	100.15	100.16	100.41	100.59	100.22	100.20	100.25	100.15	100.15	100.11	100.19	100.21	100.22	100.15	100.30	100.05	100.08
J	G_{mb} [A/(F*π*I²/4)]	2.179	2.185	2.161	2.204	2.169	2.151	2.157	2.193	2.180	2.182	2.203	2.194	2.185	2.182	2.181	2.171	2.178	2.171	2.200	2.161
K	Air Voids [(G_{mm}-J)/G_{mm}]	12.5	12.2	13.2	11.4	12.8	13.6	13.3	11.9	12.4	12.3	11.5	11.8	12.2	12.3	12.4	12.8	12.5	12.8	11.6	13.2

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	1081.9	1084.9	1084.7	1092.6	1075.4	1077.8	1081.6	1088.8	1083.1	1087.6	1094.7	1089.7	1084.5	1085.3	1085.3	1079.2	1080.5	1079	1090	1071.1
B	Submerged Mass (g)	623.2	625.1	627.7	631.6	619.9	621.3	621.4	629.6	624.2	623.3	631.1	627.8	627.6	628.4	628.7	622.9	621.9	618.9	630.7	614.4
C	SSD Mass (g)	1089.7	1091.6	1092.1	1098.4	1083.3	1085.3	1089.4	1095.5	1089.7	1094.1	1100.2	1094.7	1091.5	1092.2	1093.1	1085.4	1087.3	1084.5	1097.8	1077.6
D	G_{mb} [A/(C-B)]	2.32	2.33	2.34	2.34	2.32	2.32	2.31	2.34	2.33	2.31	2.33	2.33	2.34	2.34	2.34	2.33	2.32	2.32	2.33	2.31
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.8	6.6	6.2	6.0	6.8	6.7	7.1	6.1	6.5	7.2	6.2	6.2	6.1	6.0	6.1	6.3	6.7	6.9	6.2	7.1

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Project Number:	50650A
Location:	BL I-96 Howell
Contractor:	Rieth-Riley
Mix:	Fine
Gradation:	4E3
G_{mm}	2.501

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1143.6	1142	1145.8	1141	1141.2	1144.6	1137.2	1142.9	1145	1141.2	1142.2	1145.1	1147.7	1147	1132.5	1144	1140.1	1139.2	1136	1139.6
B	Height 1	63.04	62.96	63.20	63.27	63.21	63.32	63.40	63.07	62.79	63.09	62.84	63.55	63.40	63.42	63.25	63.22	63.35	63.27	63.32	63.26
C	Height 2	63.07	63.29	63.02	63.09	63.27	63.02	63.35	63.37	63.07	63.42	63.14	62.87	63.45	63.25	63.35	63.25	63.42	63.30	63.27	63.23
D	Height 3	62.81	63.31	62.99	62.99	63.33	63.04	63.20	62.92	63.78	62.71	63.25	62.89	63.37	63.30	63.35	63.32	63.32	63.27	63.12	63.29
E	Height 4	62.81	63.33	63.12	63.07	63.21	62.99	63.20	62.99	63.12	62.74	62.89	63.22	63.75	63.40	63.42	63.25	63.27	63.35	63.32	63.28
F	Average Height	62.93	63.22	63.08	63.11	63.26	63.09	63.29	63.09	63.19	62.99	63.03	63.13	63.49	63.34	63.34	63.26	63.34	63.30	63.26	63.27
G	Diameter 1	99.7204	99.08	99.7712	99.6696	99.75	99.9236	99.949	99.8982	99.8728	99.7458	99.9744	99.8474	99.8474	99.8728	99.822	99.8474	99.8474	99.8474	99.9744	99.17
H	Diameter 2	99.695	99.89	99.8474	99.822	99.74	99.949	99.8982	99.9236	99.9236	99.9236	99.9236	99.9236	99.8728	99.8474	99.822	99.8728	99.8982	99.8982	99.8474	98.32
I	Average Diameter	99.708	99.485	99.809	99.746	99.745	99.936	99.924	99.911	99.898	99.835	99.949	99.886	99.860	99.860	99.822	99.860	99.873	99.873	99.911	98.745
J	G_{mb} [A/(F*π*I^2/4)]	2.327	2.324	2.321	2.314	2.309	2.313	2.291	2.311	2.312	2.314	2.310	2.315	2.308	2.312	2.285	2.309	2.298	2.297	2.291	2.352
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.9	7.1	7.2	7.5	7.7	7.5	8.4	7.6	7.6	7.5	7.7	7.4	7.7	7.6	8.7	7.7	8.1	8.1	8.4	6.0

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1143.6	1142	1145.8	1141	1141.2	1144.6	1137.2	1142.9	1145	1141.2	1142.2	1145.1	1147.7	1147	1132.5	1144	1140.1	1139.2	1136	1139.6
B	Submerged Mass	657.4	655.5	659	655.4	655.4	659.3	655.2	656.7	659.5	657.5	656.9	659.8	658.2	660.7	648.5	659.4	655.2	652.9	649.8	653.9
C	SSD Mass	1145.7	1144	1147.3	1142.6	1143.2	1146	1139.5	1144.1	1147	1143.9	1143.8	1146.8	1148.9	1148.7	1135.4	1146.2	1141.8	1140.9	1138.4	1142.2
D	G_{mb} [A/(C-B)]	2.342	2.338	2.347	2.342	2.339	2.352	2.348	2.345	2.349	2.346	2.346	2.351	2.339	2.350	2.326	2.350	2.343	2.334	2.325	2.334
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.4	6.5	6.2	6.4	6.5	6.0	6.1	6.2	6.1	6.2	6.2	6.0	6.5	6.0	7.0	6.0	6.3	6.7	7.0	6.7

المنارة للاستشارات

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Project Number:	48612A
Location:	M-21 Owosso
Contractor:	Michigan Paving & Materials
Mix:	5E3
Gradation:	Fine
G_{mm}	2.470

VOLUMETRIC ANALYSIS

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	1120.2	1124.5	1120.1	1126.9	1126.5	1124.4	1126.9	1128.4	1124.1	1127.8	1127	1121.5	1128.4	1128.8	1128.4	1123.6	1127	1129.6	1128.6	1129.5
B	Height 1 (mm)	63.25	63.35	63.25	63.39	63.50	63.25	63.25	62.99	63.50	63.25	63.25	63.25	62.99	63.41	62.99	63.39	62.99	62.99	62.99	63.25
C	Height 2 (mm)	63.25	63.67	63.23	63.30	63.75	63.50	63.25	63.25	63.25	63.25	62.99	63.25	63.25	63.45	63.50	63.28	62.99	63.25	63.25	62.99
D	Height 3 (mm)	63.25	63.23	63.28	63.24	63.50	62.99	62.99	63.25	63.25	63.50	63.25	63.50	63.50	63.45	63.25	63.32	63.25	63.50	63.25	63.25
E	Height 4 (mm)	62.99	63.28	63.32	63.27	63.25	63.25	62.99	63.25	63.50	63.50	63.25	63.25	62.99	63.40	63.25	63.28	63.25	63.25	62.99	63.25
F	Average Height (mm)	63.18	63.38	63.27	63.30	63.50	63.25	63.12	63.18	63.37	63.37	63.18	63.31	63.18	63.43	63.25	63.32	63.12	63.25	63.12	63.18
G	Diameter 1 (mm)	99.70	98.91	99.96	99.17	99.80	99.94	99.86	99.85	99.90	99.86	99.87	99.90	99.86	99.61	99.85	99.30	99.85	99.82	99.90	99.78
H	Diameter 2 (mm)	99.93	99.43	99.95	99.41	99.89	99.82	99.79	99.83	99.85	99.85	99.89	99.91	99.86	99.89	99.82	99.44	99.84	99.91	99.85	99.87
I	Average Diameter (mm)	99.82	99.17	99.96	99.29	99.85	99.88	99.83	99.84	99.88	99.86	99.88	99.91	99.86	99.75	99.84	99.37	99.85	99.87	99.88	99.83
J	G_{mb} $[A/(F*\pi*I^2/4)]$	2.266	2.297	2.256	2.299	2.266	2.269	2.281	2.281	2.264	2.272	2.277	2.260	2.280	2.277	2.279	2.288	2.280	2.280	2.282	2.284
K	Air Voids $[(G_{mm}-J)/G_{mm}]$	8.3	7.0	8.7	6.9	8.3	8.1	7.6	7.6	8.3	8.0	7.8	8.5	7.7	7.8	7.7	7.4	7.7	7.7	7.6	7.5

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	1120.2	1124.5	1120.1	1126.9	1126.5	1124.4	1126.9	1128.4	1124.1	1127.8	1127	1121.5	1128.4	1128.8	1128.4	1123.6	1127	1129.6	1128.6	1129.5
B	Submerged Mass (g)	636	640	636.5	642.8	640.9	640.1	641.3	643.4	638.5	642.3	642.7	636.3	643.2	645.3	644.1	640	641.5	643.6	643.2	644.3
C	SSD Mass (g)	1121.4	1126.8	1122.5	1129.1	1128.9	1126.4	1128.3	1129.5	1124.9	1129	1128.9	1123.1	1130.5	1131.6	1130.3	1126.6	1128.3	1130.8	1129.9	1130.7
D	G_{mb} $[A/(C-B)]$	2.31	2.31	2.30	2.32	2.31	2.31	2.31	2.32	2.31	2.32	2.32	2.30	2.32	2.32	2.32	2.31	2.32	2.32	2.32	2.32
E	Air Voids $[(G_{mm}-D)/G_{mm}]$	6.6	6.5	6.7	6.2	6.5	6.4	6.3	6.0	6.4	6.2	6.2	6.7	6.3	6.0	6.0	6.5	6.3	6.1	6.1	6.0

المنارة للاستشارات

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Project Number: 34519A

Location: M-59 Brighton

Contractor: Ajax Paving
Mix: 3E10
Gradation: Coarse
G_{mm} 2.503

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1082.7	1096.6	1098.8	1101.8	1091.8	1103.9	1083.2	1094.6	1084.5	1091.5	1088.7	1085.6	1084.1	1096.3	1098.5	1083	1085.1	1076.8	1099.1	1096.7
B	Height 1	63.47	63.54	63.64	63.13	63.51	63.29	63.22	63.31	63.10	63.15	63.08	63.25	63.23	63.35	64.05	63.10	63.05	63.01	63.44	63.30
C	Height 2	63.39	63.24	63.44	63.18	63.37	63.33	63.21	63.32	63.05	63.10	63.13	62.89	63.05	63.30	63.26	63.04	63.15	63.14	63.19	63.40
D	Height 3	63.37	63.17	63.25	63.22	63.30	63.30	63.17	63.32	63.10	63.33	63.09	63.20	63.27	63.31	63.34	63.24	63.24	63.17	63.36	63.71
E	Height 4	63.29	63.28	63.41	63.22	63.18	63.30	63.15	63.21	63.22	63.06	63.06	63.13	63.22	63.29	63.34	63.24	63.12	63.15	63.15	63.46
F	Average Height	63.38	63.31	63.44	63.19	63.34	63.31	63.19	63.29	63.12	63.16	63.09	63.12	63.19	63.31	63.50	63.16	63.14	63.12	63.29	63.47
G	Diameter 1	99.6	99.93	99.66	100.06	100.21	100.04	99.53	100.06	99.56	99.02	99.56	99.66	99.35	99.7	100.06	99.44	99.49	99.72	99.9	100.18
H	Diameter 2	99.87	99.2	99.94	100.06	100.11	100.01	99.25	99.98	99.71	99.53	99.51	99.64	99.72	99.9	99.96	99.61	99.4	99.7	99.93	100.09
I	Average Diameter	99.735	99.565	99.800	100.060	100.160	100.025	99.390	100.020	99.635	99.275	99.535	99.650	99.535	99.800	100.010	99.525	99.445	99.710	99.915	100.135
J	G_{mb} [A/(F*π*I²/4)]	2.187	2.225	2.214	2.217	2.188	2.219	2.210	2.201	2.204	2.233	2.218	2.205	2.205	2.214	2.202	2.204	2.213	2.185	2.215	2.194
K	Air Voids [(G_{mm}-J)/G_{mm}]	12.6	11.1	11.5	11.4	12.6	11.3	11.7	12.1	12.0	10.8	11.4	11.9	11.9	11.6	12.0	11.9	11.6	12.7	11.5	12.3

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1082.7	1096.6	1098.8	1101.8	1091.8	1103.9	1083.2	1094.6	1084.5	1091.5	1088.7	1085.6	1084.1	1096.3	1098.5	1083	1085.1	1076.8	1099.1	1096.7
B	Submerged Mass	629.7	636.4	637.2	642.1	633.7	637.1	626.8	633.7	630.4	634.8	634.5	629.6	626.4	637.2	637.9	631.5	630.6	620.2	636	639.2
C	SSD Mass	1090.6	1103.3	1105	1110.3	1098.4	1109.5	1091.9	1100.3	1091.9	1099.5	1097.6	1093.5	1090.6	1103.7	1104.7	1093.1	1092.7	1086.6	1104.5	1105.8
D	G_{mb} [A/(C-B)]	2.35	2.35	2.35	2.35	2.35	2.34	2.33	2.35	2.35	2.35	2.35	2.34	2.34	2.35	2.35	2.35	2.35	2.31	2.35	2.35
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.1	6.2	6.2	6.0	6.1	6.6	7.0	6.3	6.1	6.2	6.1	6.5	6.7	6.1	6.0	6.3	6.2	7.8	6.3	6.1

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Project Number:	74784A
Location:	I-196 Grand Rapids
Contractor:	Michigan Paving & Materials
Mix:	5E10
Gradation:	Coarse
G_{mm}	2.499

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1125.5	1126.6	1130.1	1130	1127	1131.3	1132.8	1123.1	1130.9	1135.2	1129.3	1129.4	1130.7	1131.1	1126.7	1135.1	1133.2	1128.2	1129.3	1133.4
B	Height 1	63.37	63.36	63.14	63.44	63.28	63.07	63.42	63.71	63.12	63.35	63.35	63.71	63.30	63.48	63.34	63.35	63.09	63.56	63.80	63.31
C	Height 2	63.30	63.47	63.30	63.42	63.43	63.45	63.09	63.39	63.30	63.50	63.45	63.51	63.20	63.38	63.25	63.09	63.14	63.46	63.54	63.35
D	Height 3	63.17	63.30	63.53	63.43	63.38	63.50	63.20	63.53	63.32	63.32	63.22	63.61	63.22	63.47	63.41	63.17	63.35	63.42	63.63	63.31
E	Height 4	63.27	63.34	63.47	63.42	63.40	63.45	63.37	63.61	63.09	63.17	63.27	63.50	63.35	63.53	63.43	63.30	63.30	63.43	63.60	63.31
F	Average Height	63.28	63.37	63.36	63.43	63.37	63.37	63.27	63.56	63.21	63.34	63.32	63.58	63.27	63.47	63.36	63.23	63.22	63.47	63.64	63.32
G	Diameter 1	99.797	99.940	99.924	99.950	99.700	99.924	99.949	99.450	99.898	99.873	99.593	99.690	99.974	99.500	99.520	99.924	99.898	99.460	99.430	99.410
H	Diameter 2	99.873	99.950	99.949	99.720	99.570	99.847	99.974	99.780	99.898	99.644	99.720	99.700	99.949	99.790	99.550	99.898	99.949	99.330	99.580	99.760
I	Average Diameter	99.835	99.945	99.937	99.835	99.635	99.886	99.962	99.615	99.898	99.759	99.657	99.695	99.962	99.645	99.535	99.911	99.924	99.395	99.505	99.585
J	G_{mb} [A/(F*π*I²/4)]	2.272	2.266	2.274	2.276	2.281	2.278	2.281	2.267	2.283	2.293	2.286	2.275	2.277	2.285	2.285	2.290	2.286	2.291	2.282	2.298
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.1	9.3	9.0	8.9	8.7	8.8	8.7	9.3	8.7	8.2	8.5	8.9	8.9	8.5	8.5	8.4	8.5	8.3	8.7	8.0

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1125.5	1126.6	1130.1	1130	1127	1131.3	1132.8	1123.1	1130.9	1135.2	1129.3	1129.4	1130.7	1131.1	1126.7	1135.1	1133.2	1128.2	1129.3	1133.4
B	Submerged Mass	651	649.9	648.4	652.4	648.4	651.1	653.3	646.1	653.2	655.6	650.3	651.7	651.8	653.4	649.9	654.6	654.4	652.2	651.3	654.5
C	SSD Mass	1130.6	1130.3	1131.8	1133.5	1131.4	1135	1136.8	1128.2	1136.2	1138.7	1132.3	1134.5	1134.2	1135.2	1132.2	1138.1	1137.3	1133.7	1134.1	1138.4
D	G_{mb} [A/(C-B)]	2.347	2.345	2.338	2.349	2.333	2.338	2.343	2.330	2.341	2.350	2.343	2.339	2.344	2.348	2.336	2.348	2.347	2.343	2.339	2.342
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.1	6.2	6.4	6.0	6.6	6.4	6.2	6.8	6.3	6.0	6.2	6.4	6.2	6.1	6.5	6.1	6.1	6.2	6.4	6.3

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Project Number:	51472A
Location:	I-75 Clarkston
Contractor:	Ace Asphalt
Mix:	4E30
Gradation:	Coarse
G_{mm}	2.487

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1112.5	1112.6	1112.3	1110.5	1107.1	1113.3	1110.8	1111	1113.9	1111.4	1115.6	1099.5	1117.8	1117.4	1119.2	1118.6	1114	1113.4	1114.4	1115.1
B	Height 1	63.19	63.59	63.53	63.42	63.17	63.55	63.35	63.13	63.22	63.30	63.29	63.28	63.57	63.30	63.31	63.26	63.52	63.45	63.23	62.48
C	Height 2	63.38	63.34	63.38	63.30	63.18	63.34	63.19	63.16	63.30	63.32	63.26	63.24	63.50	63.31	63.29	63.28	63.34	63.29	63.19	63.37
D	Height 3	63.42	63.34	63.37	63.28	63.28	63.30	63.22	63.19	63.29	63.40	63.30	63.31	63.76	63.27	63.22	63.27	63.20	63.21	63.09	63.25
E	Height 4	63.50	63.38	63.39	63.27	63.20	63.24	63.28	63.18	63.31	63.38	63.22	63.21	63.39	63.27	63.41	63.42	63.22	63.19	63.20	63.25
F	Average Height	63.37	63.41	63.42	63.32	63.21	63.36	63.26	63.17	63.28	63.35	63.27	63.26	63.56	63.29	63.31	63.31	63.32	63.29	63.18	63.09
G	Diameter 1	99.9	99.91	99.77	99.97	99.83	99.89	99.61	99.83	99.85	99.92	99.9	99.56	99.93	99.86	99.87	99.84	99.82	99.85	99.88	99.88
H	Diameter 2	99.83	99.95	99.87	99.87	99.64	99.81	99.95	99.86	99.67	99.82	99.86	99.7	99.78	99.66	99.77	99.86	99.83	99.72	99.86	99.84
I	Average Diameter	99.865	99.930	99.820	99.920	99.735	99.850	99.780	99.845	99.760	99.870	99.880	99.630	99.855	99.760	99.820	99.850	99.825	99.785	99.870	99.860
J	G_{mb} [A/(F*π*I²/4)]	2.241	2.237	2.241	2.237	2.242	2.244	2.246	2.246	2.252	2.240	2.251	2.229	2.246	2.259	2.259	2.256	2.248	2.250	2.252	2.257
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.9	10.0	9.9	10.1	9.9	9.8	9.7	9.7	9.4	9.9	9.5	10.4	9.7	9.2	9.2	9.3	9.6	9.5	9.5	9.3

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	1112.5	1112.6	1112.3	1110.5	1107.1	1113.3	1110.8	1111	1113.9	1111.4	1115.6	1099.5	1117.8	1117.4	1119.2	1118.6	1114	1113.4	1114.4	1115.1
B	Submerged Mass	638.7	640.8	638.2	637.2	634.1	639.8	639.1	638.1	639.6	636.7	640.5	631.3	643.4	643.5	646.1	644.2	640.7	640.6	641.2	640.1
C	SSD Mass	1116.6	1118.7	1118.5	1115.7	1115.7	1119.2	1115.6	1118	1119.4	1116.3	1120.1	1106	1123.4	1121.5	1124.6	1123.4	1121	1119.9	1120.6	1119.8
D	G_{mb} [A/(C-B)]	2.328	2.328	2.316	2.321	2.299	2.322	2.331	2.315	2.322	2.317	2.326	2.316	2.329	2.338	2.339	2.334	2.319	2.323	2.325	2.325
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.4	6.4	6.9	6.7	7.6	6.6	6.3	6.9	6.7	6.8	6.5	6.9	6.4	6.0	6.0	6.1	6.7	6.6	6.5	6.5

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Phase I – 150mm Superpave Specimens

Project Number: 50651A
Location: M-50 Dundee
Contractor: Cadillac LLC Asphalt
Mix: 3E1
Gradation: Coarse
G_{mm} 2.52

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3723	3715.7	3724.2	3720.8	3727.4	3723.9	3723	3731.4	3722.8	3723.4	3720.6	3726.6	3719.5	3720.9	3719.8	3722.4	3719.2	3719.6	3721.9	3716.9
B	Height 1	94.56	94.59	94.33	94.70	94.29	94.44	94.61	94.29	94.42	94.69	94.46	94.80	94.20	94.12	94.50	94.29	94.24	94.70	94.31	94.23
C	Height 2	94.41	94.61	94.59	94.72	94.64	94.54	94.44	94.51	94.39	94.31	94.50	94.41	94.33	94.40	94.32	94.24	94.09	94.56	94.38	94.24
D	Height 3	94.48	94.50	94.90	94.35	94.49	94.34	94.56	94.44	94.67	94.55	94.39	94.47	94.44	94.47	94.23	94.70	94.37	94.31	94.32	94.17
E	Height 4	94.49	94.33	94.56	94.40	94.32	94.39	94.47	94.49	94.34	94.84	94.52	94.52	94.63	94.62	94.35	94.38	94.84	94.39	94.27	94.32
F	Average Height	94.49	94.51	94.60	94.54	94.44	94.43	94.52	94.43	94.46	94.60	94.47	94.55	94.40	94.40	94.35	94.40	94.39	94.49	94.32	94.24
G	Diameter 1	150.630	150.540	150.200	150.590	150.360	150.420	149.800	150.200	150.090	150.840	150.260	150.250	150.870	150.250	150.300	150.660	150.480	150.510	150.320	150.710
H	Diameter 2	150.590	150.680	150.510	150.410	150.480	150.360	150.150	149.810	150.360	150.230	150.360	150.590	150.600	150.610	150.470	150.890	150.320	150.440	150.610	150.460
I	Average Diameter	150.610	150.610	150.355	150.500	150.420	150.390	149.975	150.005	150.225	150.535	150.310	150.420	150.735	150.430	150.385	150.775	150.400	150.475	150.465	150.585
J	G_{mb} [A/(F*π*I²/4)]	2.212	2.207	2.217	2.212	2.221	2.220	2.230	2.236	2.224	2.212	2.220	2.218	2.208	2.218	2.220	2.208	2.218	2.214	2.219	2.215
K	Air Voids [(G_{mm}-J)/G_{mm}]	12.2	12.4	12.0	12.2	11.9	11.9	11.5	11.3	11.8	12.2	11.9	12.0	12.4	12.0	11.9	12.4	12.0	12.2	11.9	12.1

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3723	3715.7	3724.2	3720.8	3727.4	3723.9	3723	3731.4	3722.8	3723.4	3720.6	3726.6	3719.5	3720.9	3719.8	3722.4	3719.2	3719.6	3721.9	3716.9
B	Submerged Mass	2163.9	2156.6	2167.9	2164	2166.7	2174.2	2168	2176.7	2172.8	2164.1	2163.8	2170.8	2148.4	2158.4	2163	2167.7	2159.3	2164.1	2162.4	2156.5
C	SSD Mass	3748.7	3734.8	3747.8	3746.6	3753.7	3747.6	3742.5	3758.3	3748.5	3744	3742.1	3752.4	3738.7	3738.6	3739.7	3745.5	3742.9	3739.8	3742.3	3741.2
D	G_{mb} [A/(C-B)]	2.349	2.354	2.357	2.351	2.349	2.367	2.365	2.359	2.363	2.357	2.357	2.356	2.339	2.355	2.359	2.359	2.349	2.361	2.356	2.345
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.8	6.6	6.5	6.7	6.8	6.1	6.2	6.4	6.2	6.5	6.5	6.5	7.2	6.6	6.4	6.4	6.8	6.3	6.5	6.9

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Project Number:	46023A
Location:	M-21 St. Johns
Contractor:	Michigan Paving & Materials
Mix:	3E3
Gradation:	Coarse
G_{mm}	2.489

VOLUMETRIC ANALYSIS

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	3657.7	3655.9	3665.4	3656.6	3658.8	3666.3	3657.8	3664.2	3659.2	3662.2	3662.4	3658.7	3660.9	3655.9	3665.3	3659.3	3660.7	3660.2	3662.3	3655.2
B	Height 1 (mm)	94.24	94.20	94.29	94.63	94.34	94.22	94.10	94.44	94.14	94.28	94.24	94.14	94.08	94.24	94.43	94.18	94.32	94.23	94.56	94.48
C	Height 2 (mm)	94.08	94.31	94.20	94.39	94.05	94.14	94.25	94.08	94.25	94.26	94.05	94.29	94.14	94.06	94.19	94.48	94.28	94.21	94.40	94.44
D	Height 3 (mm)	94.36	94.45	94.39	94.54	94.27	94.09	94.25	94.25	94.04	94.24	94.40	94.29	94.24	94.35	94.23	94.37	94.14	94.29	94.49	94.38
E	Height 4 (mm)	94.38	94.20	94.49	94.52	94.19	94.28	94.13	94.13	94.21	94.17	94.20	94.23	94.26	94.43	94.34	94.06	94.49	94.34	94.61	94.37
F	Average Height (mm)	94.27	94.29	94.34	94.52	94.21	94.18	94.18	94.23	94.16	94.24	94.22	94.24	94.18	94.27	94.30	94.27	94.31	94.27	94.52	94.42
G	Diameter 1 (mm)	150.28	150.27	150.36	150.51	150.60	150.44	150.78	150.40	150.55	150.46	150.53	150.33	150.26	150.34	150.31	150.65	150.70	150.74	150.57	151.03
H	Diameter 2 (mm)	150.46	150.10	150.49	150.62	150.35	150.54	150.43	150.46	150.49	150.43	150.57	150.32	150.30	150.40	150.55	150.70	150.75	150.43	150.30	150.53
I	Average Diameter (mm)	150.37	150.19	150.43	150.57	150.48	150.49	150.61	150.43	150.52	150.45	150.55	150.33	150.28	150.37	150.43	150.68	150.73	150.59	150.44	150.78
J	G_{mb} [A/(F*π*I^2/4)]	2.185	2.189	2.186	2.173	2.184	2.189	2.180	2.188	2.184	2.186	2.184	2.188	2.191	2.184	2.187	2.177	2.175	2.180	2.180	2.168
K	Air Voids [(G_{mm}-J)/G_{mm}]	12.2	12.1	12.2	12.7	12.3	12.1	12.4	12.1	12.3	12.2	12.3	12.1	12.0	12.3	12.1	12.5	12.6	12.4	12.4	12.9

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	3657.7	3655.9	3665.4	3656.6	3658.8	3666.3	3657.8	3664.2	3659.2	3662.2	3662.4	3658.7	3660.9	3655.9	3665.3	3659.3	3660.7	3660.2	3662.3	3655.2
B	Submerged Mass (g)	2118.4	2119.3	2131.9	2117.1	2119.5	2115.9	2109.5	2118.9	2118.9	2120.2	2114.4	2117.7	2113.1	2107.4	2114.6	2114.9	2108.9	2105.3	2107.6	2107.7
C	SSD Mass (g)	3696.3	3688.4	3708.1	3691	3692.8	3697.4	3692.4	3693.4	3696.3	3698.5	3691.3	3689.7	3694.8	3692.6	3703.7	3694.8	3698.1	3695.1	3693.8	3694.5
D	G_{mb} [A/(C-B)]	2.32	2.33	2.33	2.32	2.33	2.32	2.31	2.33	2.32	2.32	2.32	2.33	2.31	2.31	2.31	2.32	2.30	2.30	2.31	2.30
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.9	6.4	6.6	6.7	6.6	6.9	7.2	6.5	6.8	6.8	6.7	6.5	7.0	7.3	7.3	6.9	7.5	7.5	7.2	7.5

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Project Number: 50650A

Location: BL I-96 Howell

Contractor: Rieth-Riley
Mix: Fine
Gradation: 4E3
G_{mm} 2.501

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3857.9	3855	3852.7	3856.4	3848.2	3860.8	3858	3859.5	3857.9	3858	3857.6	3860.6	3863.2	3862.9	3859.7	3860.8	3860.7	3862.5	3859.4	3854.4
B	Height 1	94.56	94.61	94.52	94.55	94.53	94.45	94.59	94.47	94.50	94.44	94.50	94.52	94.48	94.55	94.55	94.36	94.53	94.48	94.43	94.40
C	Height 2	94.34	94.47	94.41	94.35	94.72	94.45	94.51	94.40	94.52	94.48	94.42	94.47	94.33	94.46	94.29	94.44	94.65	94.41	94.43	94.42
D	Height 3	94.45	94.41	94.42	94.53	94.55	94.43	94.45	94.45	94.53	94.46	94.46	94.48	94.47	94.48	94.51	94.46	94.48	94.34	94.44	94.36
E	Height 4	94.53	94.47	94.49	94.64	94.55	94.37	94.42	94.50	94.58	94.49	94.52	94.36	94.48	94.49	94.59	94.44	94.40	94.48	94.40	94.27
F	Average Height	94.47	94.49	94.46	94.52	94.59	94.43	94.49	94.46	94.53	94.47	94.48	94.46	94.44	94.50	94.49	94.43	94.52	94.43	94.43	94.36
G	Diameter 1	150.04	150.13	150.08	150.36	150.08	150.03	150.12	149.99	150.12	149.92	149.97	150.02	150.05	150.01	150.02	150.38	150.06	149.84	149.98	150.03
H	Diameter 2	150.11	150.07	150.2	150.13	149.96	150.03	149.87	149.98	150.19	149.92	150.05	150.04	149.99	149.97	150.02	150.15	150	150.04	149.93	150.02
I	Average Diameter	150.075	150.100	150.140	150.245	150.020	150.030	149.995	149.985	150.155	149.920	150.010	150.030	150.020	149.990	150.020	150.265	150.030	149.940	149.955	150.025
J	G_{mb} [A/(F*π*I²/4)]	2.309	2.306	2.304	2.301	2.302	2.313	2.311	2.313	2.305	2.314	2.310	2.312	2.314	2.314	2.311	2.306	2.311	2.317	2.314	2.311
K	Air Voids [(G_{mm}-J)/G_{mm}]	7.7	7.8	7.9	8.0	8.0	7.5	7.6	7.5	7.9	7.5	7.6	7.6	7.5	7.5	7.6	7.8	7.6	7.4	7.5	7.6

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3857.9	3855	3852.7	3856.4	3848.2	3860.8	3858	3859.5	3857.9	3858	3857.6	3860.6	3863.2	3862.9	3859.7	3860.8	3860.7	3862.5	3859.4	3854.4
B	Submerged Mass	2216.3	2210.5	2208.9	2209.1	2204.9	2219	2216.4	2216.9	2210.6	2214.6	2216	2220.3	2221.2	2218.7	2217.6	2213.8	2220.1	2223	2221	2211.7
C	SSD Mass	3862	3862.2	3859.2	3861.7	3852.5	3865.9	3862.1	3863.2	3863.4	3862.5	3861.8	3865.2	3867.1	3866.8	3864.1	3865.5	3866	3867.7	3865.5	3858
D	G_{mb} [A/(C-B)]	2.344	2.334	2.335	2.334	2.336	2.344	2.344	2.344	2.334	2.341	2.344	2.347	2.347	2.344	2.344	2.337	2.346	2.348	2.347	2.341
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.3	6.7	6.7	6.7	6.6	6.3	6.3	6.3	6.7	6.4	6.3	6.2	6.2	6.3	6.3	6.5	6.2	6.1	6.2	6.4

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Project Number: 48612A
Location: M-21 Owosso
Contractor: Michigan Paving & Materials
Mix: 5E3
Gradation: Fine
G_{mm} 2.470

VOLUMETRIC ANALYSIS

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	3814.9	3816.1	3816.9	3815	3815.3	3813	3813.1	3816.4	3812.5	3815	3815.1	3812.7	3819.3	3818.7	3815.5	3815.9	3801.2	3814.5	3818.6	3792
B	Height 1 (mm)	94.59	94.50	94.54	94.42	94.54	94.61	94.59	94.68	94.49	94.49	94.57	94.32	94.54	94.58	94.52	94.39	94.42	94.52	94.40	94.49
C	Height 2 (mm)	94.52	94.53	94.53	94.53	94.63	94.54	94.45	94.57	94.46	94.53	94.44	94.29	94.53	94.50	94.38	94.51	94.69	94.57	94.56	94.55
D	Height 3 (mm)	94.56	94.60	94.53	94.59	94.58	94.47	94.50	94.55	94.47	94.56	94.53	94.30	94.47	94.55	94.46	94.49	94.49	94.60	94.44	94.36
E	Height 4 (mm)	94.60	94.56	94.60	94.52	94.50	94.46	94.59	94.47	94.58	94.56	94.50	94.28	94.45	94.53	94.50	94.38	94.43	94.36	94.37	94.40
F	Average Height (mm)	94.57	94.55	94.55	94.52	94.56	94.52	94.53	94.57	94.50	94.54	94.51	94.30	94.50	94.54	94.47	94.44	94.51	94.51	94.44	94.45
G	Diameter 1 (mm)	150.01	149.95	150.01	149.99	149.84	150.02	150.01	149.88	150.01	150.05	150.00	149.99	150.01	149.94	150.03	150.01	149.94	150.02	150.02	149.76
H	Diameter 2 (mm)	149.99	149.95	150.10	150.02	149.95	150.01	150.02	150.03	150.01	149.95	149.90	150.05	149.96	149.85	150.05	149.96	149.56	150.06	150.01	149.95
I	Average Diameter (mm)	150.00	149.95	150.06	150.01	149.90	150.02	150.02	149.96	150.01	150.00	149.95	150.02	149.99	149.90	150.04	149.99	149.75	150.04	150.02	149.86
J	G_{mb} [A/(F*π*I^2/4)]	2.283	2.286	2.283	2.284	2.286	2.282	2.282	2.285	2.283	2.284	2.286	2.287	2.288	2.289	2.284	2.287	2.284	2.283	2.288	2.276
K	Air Voids [(G_{mm}-J)/G_{mm}]	7.6	7.5	7.6	7.5	7.4	7.6	7.6	7.5	7.6	7.5	7.5	7.4	7.4	7.3	7.5	7.4	7.5	7.6	7.4	7.8

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass (g)	3814.9	3816.1	3816.9	3815	3815.3	3813	3813.1	3816.4	3812.5	3815	3815.1	3812.7	3819.3	3818.7	3815.5	3815.9	3801.2	3814.5	3818.6	3792
B	Submerged Mass (g)	2172.2	2174.3	2174	2174.1	2175.7	2173.4	2173.6	2178.2	2174.8	2176.8	2175.2	2177.1	2180.1	2181.4	2179.2	2178.1	2159.7	2177.1	2180.4	2152.2
C	SSD Mass (g)	3819.8	3820.8	3822.1	3821.6	3820.9	3819.5	3819	3822.5	3819.5	3822	3822.3	3819	3824.2	3825.6	3822.5	3822.2	3806.8	3820.9	3825.2	3798.7
D	G_{mb} [A/(C-B)]	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.31	2.32	2.32	2.30
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.3	6.2	6.2	6.2	6.1	6.2	6.2	6.0	6.2	6.1	6.2	6.0	6.0	6.0	6.0	6.0	6.6	6.1	6.0	6.8

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Project Number:	34519A
Location:	M-59 Brighton
Contractor:	Ajax Paving
Mix:	3E10
Gradation:	Coarse
G_{mm}	2.503

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3747.4	3742.1	3743.3	3750.5	3751.3	3752.3	3719.8	3718.5	3754.6	3753.3	3753.1	3757.3	3750.8	3749.5	3748.4	3748.3	3750.7	3751.2	3749.7	3753.5
B	Height 1	94.68	94.45	94.35	94.66	94.47	94.53	94.61	94.47	94.56	94.85	94.47	94.45	94.42	94.69	94.40	94.47	94.37	94.54	94.62	94.43
C	Height 2	94.54	94.68	94.38	94.63	94.83	94.66	94.64	94.51	94.61	94.76	94.45	94.54	94.48	94.74	94.42	94.55	94.44	94.49	94.64	94.51
D	Height 3	94.79	94.48	94.27	94.39	94.79	94.29	94.80	94.39	94.62	94.32	94.70	94.27	94.52	94.48	94.65	94.44	94.57	94.54	94.77	94.50
E	Height 4	94.64	94.50	94.45	94.64	94.59	94.51	94.37	94.47	94.38	94.55	94.52	94.51	94.45	94.29	94.46	94.30	94.46	94.47	94.78	94.48
F	Average Height	94.66	94.53	94.36	94.58	94.67	94.50	94.61	94.46	94.54	94.62	94.54	94.44	94.47	94.55	94.48	94.44	94.46	94.51	94.70	94.48
G	Diameter 1	150.44	150.4	150.76	150.48	150.3	150.35	150.22	149.63	150.23	151.09	150.1	150.24	150.32	150.32	150.16	150.13	150.14	150.29	151.6	150.28
H	Diameter 2	150.39	150.95	151.1	150.51	150.49	150.42	150.14	150.39	150.18	150.87	150.25	150.22	150.37	150.15	150.12	150.07	150.09	150.32	150.97	150.11
I	Average Diameter	150.415	150.675	150.930	150.495	150.395	150.385	150.180	150.010	150.205	150.980	150.175	150.230	150.345	150.235	150.140	150.100	150.115	150.305	151.285	150.195
J	G_{mb} [A/(F*π*I²/4)]	2.228	2.220	2.217	2.229	2.231	2.236	2.220	2.227	2.241	2.216	2.241	2.244	2.237	2.237	2.241	2.243	2.244	2.237	2.203	2.242
K	Air Voids [(G_{mm}-J)/G_{mm}]	11.0	11.3	11.4	10.9	10.9	10.7	11.3	11.0	10.5	11.5	10.5	10.3	10.6	10.6	10.5	10.4	10.4	10.6	12.0	10.4

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3747.4	3742.1	3743.3	3750.5	3751.3	3752.3	3719.8	3718.5	3754.6	3753.3	3753.1	3757.3	3750.8	3749.5	3748.4	3748.3	3750.7	3751.2	3749.7	3753.5
B	Submerged Mass	2162.5	2157.8	2151.4	2163.7	2161.3	2167.6	2138.1	2136.2	2173.7	2159.6	2175.1	2169.8	2175.3	2164.5	2174.2	2170.3	2171.7	2162.4	2148	2164.3
C	SSD Mass	3765.4	3756.1	3755.7	3765.9	3766.7	3767.3	3736.8	3742.3	3771.9	3775	3770.8	3772.7	3769	3767.1	3767.1	3767.4	3766.4	3765.7	3769.5	3768.5
D	G_{mb} [A/(C-B)]	2.34	2.34	2.33	2.34	2.34	2.35	2.33	2.32	2.35	2.32	2.35	2.34	2.35	2.34	2.35	2.35	2.35	2.34	2.31	2.34
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.6	6.5	6.8	6.5	6.6	6.3	7.0	7.5	6.1	7.2	6.0	6.3	6.0	6.5	6.0	6.2	6.0	6.5	7.6	6.5

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Project Number: 74784A
Location: I-196 Grand Rapids
Contractor: Michigan Paving & Materials
Mix: 5E10
Gradation: Coarse
G_{mm} 2.499

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3825	3822.9	3824.3	3825.3	3823.8	3821.6	3822.4	3826.4	3824.2	3823.6	3822.2	3822.9	3821.5	3827.6	3822.2	3826.2	3824.6	3829.2	3823.9	3826.1
B	Height 1	94.63	94.58	94.43	94.42	94.63	94.56	94.42	94.55	94.49	94.62	94.62	94.46	94.68	94.73	94.61	94.50	94.49	94.63	94.62	94.60
C	Height 2	94.55	94.51	94.41	94.56	94.60	94.46	94.47	94.63	94.42	94.44	94.60	94.56	94.53	94.52	94.53	94.79	94.58	94.53	94.45	94.60
D	Height 3	94.64	94.58	94.54	94.49	94.61	94.51	94.53	94.44	94.54	94.57	94.57	94.46	94.61	94.61	94.60	94.69	94.59	94.50	94.51	94.52
E	Height 4	94.62	94.59	94.47	94.51	94.58	94.61	94.45	94.58	94.55	94.54	94.73	94.38	94.40	94.61	94.61	94.72	94.68	94.51	94.58	94.64
F	Average Height	94.61	94.57	94.46	94.50	94.61	94.54	94.47	94.55	94.50	94.54	94.63	94.47	94.56	94.62	94.59	94.68	94.59	94.54	94.54	94.59
G	Diameter 1	150.090	150.000	149.990	150.040	150.000	150.090	150.010	150.010	150.040	149.970	150.090	150.030	150.040	150.140	150.020	150.150	150.040	149.980	150.080	149.890
H	Diameter 2	150.110	150.010	150.150	150.030	150.060	150.010	149.930	150.020	150.010	150.010	150.090	150.000	149.990	150.020	149.970	149.980	150.020	150.040	149.980	149.930
I	Average Diameter	150.100	150.005	150.070	150.035	150.030	150.050	149.970	150.015	150.025	149.990	150.090	150.015	150.015	150.080	149.995	150.065	150.030	150.010	150.030	149.910
J	G_{mb} [A/(F*π*I²/4)]	2.285	2.288	2.289	2.290	2.286	2.286	2.291	2.290	2.289	2.289	2.283	2.290	2.287	2.287	2.287	2.285	2.287	2.292	2.288	2.292
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.6	8.5	8.4	8.4	8.5	8.5	8.3	8.4	8.4	8.4	8.6	8.4	8.5	8.5	8.5	8.6	8.5	8.3	8.4	8.3

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3825	3822.9	3824.3	3825.3	3823.8	3821.6	3822.4	3826.4	3824.2	3823.6	3822.2	3822.9	3821.5	3827.6	3822.2	3826.2	3824.6	3829.2	3823.9	3826.1
B	Submerged Mass	2207.4	2203.1	2202	2208.6	2202	2201.8	2201.3	2199.9	2202.1	2202.1	2198.7	2207.2	2202.4	2203.4	2200	2205.9	2207.5	2212.5	2200.9	2208.9
C	SSD Mass	3840.8	3837.8	3836	3836.7	3836.7	3834.6	3834.3	3836.5	3835	3835.8	3833.3	3837.3	3833	3837.3	3835	3838.3	3838.6	3844.2	3834.7	3839.3
D	G_{mb} [A/(C-B)]	2.342	2.339	2.340	2.350	2.339	2.341	2.341	2.338	2.342	2.340	2.338	2.345	2.344	2.343	2.338	2.344	2.345	2.347	2.340	2.347
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.3	6.4	6.3	6.0	6.4	6.3	6.3	6.4	6.3	6.3	6.4	6.2	6.2	6.3	6.5	6.2	6.2	6.1	6.3	6.1

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Project Number:	51472A
Location:	I-75 Clarkston
Contractor:	Ace Asphalt
Mix:	4E30
Gradation:	Coarse
G_{mm}	2.487

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3766.4	3770.4	3768.5	3767.6	3770.1	3773.3	3768.5	3769.8	3772.8	3770.2	3769	3772.6	3774.8	3770.6	3771	3769.9	3769.2	3766.9	3776	3768.5
B	Height 1	94.67	94.63	94.67	94.53	94.51	94.60	94.55	94.48	94.42	94.51	94.49	94.54	94.54	94.65	94.54	94.46	94.57	94.60	94.51	94.60
C	Height 2	94.65	94.60	94.71	94.46	94.60	94.68	94.60	94.56	94.60	94.51	94.45	94.64	94.48	94.59	94.63	94.44	94.54	94.63	94.54	94.54
D	Height 3	94.53	94.59	94.57	94.76	94.66	94.55	94.48	94.50	94.51	94.50	94.49	94.67	94.59	94.50	94.63	94.47	94.53	94.62	94.58	94.60
E	Height 4	94.55	94.61	94.61	94.58	94.51	94.59	94.55	94.71	94.56	94.38	94.52	94.54	94.48	94.61	94.61	94.57	94.48	94.53	94.44	94.62
F	Average Height	94.60	94.61	94.64	94.58	94.57	94.61	94.55	94.56	94.52	94.48	94.49	94.60	94.52	94.59	94.60	94.49	94.53	94.60	94.52	94.59
G	Diameter 1	150.06	149.91	149.94	150	149.96	150.01	149.99	149.98	150.02	150.07	149.92	150.05	150.07	149.94	150.02	150	149.96	150.08	150.06	149.96
H	Diameter 2	150.04	149.97	150.03	150.05	149.93	150.08	150.05	149.9	149.99	149.96	149.88	150.07	149.94	149.9	150	150.03	149.96	150.06	150.05	149.97
I	Average Diameter	150.050	149.940	149.985	150.025	149.945	150.045	150.020	149.940	150.005	150.015	149.900	150.060	150.005	149.920	150.010	150.015	149.960	150.070	150.055	149.965
J	G_{mb} [A/(F*π*I²/4)]	2.252	2.257	2.254	2.253	2.258	2.256	2.255	2.258	2.259	2.258	2.260	2.255	2.260	2.258	2.255	2.257	2.258	2.251	2.259	2.256
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.5	9.2	9.4	9.4	9.2	9.3	9.3	9.2	9.2	9.2	9.1	9.3	9.1	9.2	9.3	9.2	9.2	9.5	9.2	9.3

SATURATED SURFACE DRY METHOD

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	Dry Mass	3766.4	3770.4	3768.5	3767.6	3770.1	3773.3	3768.5	3769.8	3772.8	3770.2	3769	3772.6	3774.8	3770.6	3771	3769.9	3769.2	3766.9	3776	3768.5
B	Submerged Mass	2159.3	2159.1	2163.5	2154.3	2159	2166.8	2155.9	2157.7	2161.4	2160.3	2159.3	2159.2	2164.4	2165.3	2161.2	2160	2163.3	2157.5	2163.5	2167.1
C	SSD Mass	3782.1	3782.5	3784.8	3784.6	3784.8	3788.8	3781.3	3783.2	3786.5	3785.2	3782.2	3785.6	3788	3784.6	3787.1	3783.3	3783.3	3783.1	3789.3	3785.5
D	G_{mb} [A/(C-B)]	2.321	2.323	2.324	2.311	2.319	2.326	2.319	2.319	2.322	2.320	2.322	2.320	2.325	2.329	2.319	2.322	2.327	2.317	2.323	2.329
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.7	6.6	6.5	7.1	6.8	6.5	6.8	6.7	6.7	6.7	6.6	6.7	6.5	6.4	6.7	6.6	6.4	6.8	6.6	6.4

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Phase II – 150mm Superpave Specimens for AASHTO T283

Project Number:
Location: M-50 Dundee
Contractor:
Mix: 3E1
Gradation:
G_{mm} 2.52

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3701.4	3702.8	3701.1	3701.1	3697.5	3697.2	3699.4	3690.6	3699	3702.8
B	Height 1	93.53	93.87	93.72	93.89	93.99	93.97	94.08	93.92	94.16	94.27
C	Height 2	93.83	93.84	93.72	93.96	93.89	94.04	93.89	93.92	93.9	94.09
D	Height 3	93.96	93.88	94.25	93.86	93.94	93.95	94.15	93.9	94.14	94.22
E	Height 4	93.73	93.88	94.05	93.94	94.09	93.83	93.95	93.81	94.16	94.26
F	Average Height	93.7625	93.8675	93.935	93.9125	93.9775	93.9475	94.0175	93.8875	94.09	94.21
G	Diameter 1	150.49	150.31	150.35	150.49	150.6	150.4	150.31	150.27	150.32	150.89
H	Diameter 2	151.36	150.7	150.29	150.39	150.38	150.28	150.35	150.28	150.14	150.53
I	Average Diameter	150.925	150.505	150.32	150.44	150.49	150.34	150.33	150.275	150.23	150.71
J	G_{mb} [A/(F*π*I^2/4)]	2.207	2.217	2.220	2.217	2.212	2.217	2.217	2.216	2.218	2.203
K	Air Voids [(G_{mm}-J)/G_{mm}]	12.4	12.0	11.9	12.0	12.2	12.0	12.0	12.1	12.0	12.6

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3701.4	3702.8	3701.1	3701.1	3697.5	3697.2	3699.4	3690.6	3699	3702.8
B	Submerged Mass	2147.1	2149.8	2151.8	2145.7	2144	2150.5	2160.3	2150.5	2153.2	2153.7
C	SSD Mass	3729.4	3729.8	3727.8	3730.8	3724.8	3725.6	3736.9	3719.1	3726.6	3737.5
D	G_{mb} [A/(C-B)]	2.339	2.344	2.348	2.335	2.339	2.347	2.346	2.353	2.351	2.338
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.2	7.0	6.8	7.3	7.2	6.9	6.9	6.6	6.7	7.2

Project Number:
Location: M-36 Pinckney
Contractor:
Mix:
Gradation:
G_{mm} 2.511

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3694.1	3700.3	3695.2	3691.1	3730.3	3691.4	3692.7	3726.1	3730.4	3696.1
B	Height 1	94.55	94.34	94.65	94.35	94.44	94.39	94.6	94.47	94.56	94.45
C	Height 2	94.47	94.56	94.63	94.23	94.69	94.53	94.22	94.5	94.66	94.51
D	Height 3	94.53	94.38	94.42	94.52	94.6	94.54	94.38	94.57	94.62	94.57
E	Height 4	94.51	94.38	94.52	94.49	94.43	94.44	94.46	94.63	94.52	94.66
F	Average Height	94.515	94.415	94.555	94.3975	94.54	94.475	94.415	94.5425	94.59	94.5475
G	Diameter 1	150.21	150.45	150.21	150.17	150.18	150.1	150.25	150.07	150.066	150.35
H	Diameter 2	150.15	150.44	150.06	150.19	150.27	150.2	150.26	150.09	150.09	150.38
I	Average Diameter	150.18	150.445	150.135	150.18	150.225	150.15	150.255	150.08	150.078	150.365
J	G_{mb} [A/(F*π*I^2/4)]	2.206	2.205	2.207	2.207	2.226	2.207	2.206	2.228	2.229	2.201
K	Air Voids [(G_{mm}-J)/G_{mm}]	12.1	12.2	12.1	12.1	11.3	12.1	12.2	11.3	11.2	12.3

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3694.1	3700.3	3695.2	3691.1	3730.3	3691.4	3692.7	3726.1	3730.4	3696.1
B	Submerged Mass	2127.4	2135.8	2127.3	2122.2	2154.3	2122	2124.2	2150.2	2164	2118.1
C	SSD Mass	3719.3	3730.6	3721.5	3715.5	3758	3715.9	3717.8	3754.1	3765	3718.5
D	G_{mb} [A/(C-B)]	2.321	2.320	2.318	2.317	2.326	2.316	2.317	2.323	2.330	2.309
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.6	7.6	7.7	7.7	7.4	7.8	7.7	7.5	7.2	8.0

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Project Number:
Location: M-21 St. Johns
Contractor:
Mix:
Gradation:
G_{mm} 2.489

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3662.2	3662.1	3671.9	3666.7	3660.6	3665.4	3665.9	3665.5	3656.8	3665
B	Height 1	94.4	94.46	94.4	93.9	94.44	93.47	94.49	94.16	94.28	94.86
C	Height 2	94.73	94.23	94.51	94.35	94.38	94.43	94.37	94.56	94.5	94.48
D	Height 3	94.6	94.18	94.29	94.58	94.56	94.31	94.23	94.14	94.55	94.53
E	Height 4	94.5	94.54	94.49	94.63	94.2	94.39	94.38	94.29	94.54	94.62
F	Average Height	94.5575	94.3525	94.4225	94.365	94.395	94.15	94.3675	94.2875	94.4675	94.6225
G	Diameter 1	150.59	150.21	150.15	149.65	149.85	149.76	150.19	150.32	150.66	150.85
H	Diameter 2	150.03	150.12	150.4	150.62	150.6	149.91	150.12	150.03	150.53	149.83
I	Average Diameter	150.31	150.165	150.275	150.135	150.225	149.835	150.155	150.175	150.595	150.34
J	G_{mb} [A/(F*π*I^2/4)]	2.183	2.192	2.193	2.195	2.188	2.208	2.194	2.195	2.173	2.182
K	Air Voids [(G_{mm}-J)/G_{mm}]	12.3	12.0	11.9	11.8	12.1	11.3	11.9	11.8	12.7	12.3
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3662.3	3662.7	3672.3	3667.3	3660.8	3665.6	3666.5	3654.7	3656.8	3655
B	Submerged Mass	2121.5	2113.9	2130.3	2118.8	2111.5	2119.2	2117.8	2108.4	2110.1	2091.6
C	SSD Mass	3700.3	3696.7	3704.5	3695.5	3696.5	3697.7	3694.9	3687.2	3689.5	3681.1
D	G_{mb} [A/(C-B)]	2.320	2.314	2.333	2.326	2.310	2.322	2.325	2.315	2.315	2.299
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.8	7.0	6.3	6.6	7.2	6.7	6.6	7.0	7.0	7.6

Project Number:
Location: M-45 Grand Rapids
Contractor:
Mix:
Gradation:
G_{mm} 2.513

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3831.9	3839.3	3837.2	3837.4	3845.3	3843.4	3850	3844.1	3843.8	3841.8
B	Height 1	94.64	94.88	94.38	94.43	94.43	94.42	94.25	94.32	94.22	94.18
C	Height 2	95.37	94.75	94.58	94.28	94.39	94.28	94.17	94.22	94.26	94.47
D	Height 3	94.35	95.15	94.69	94.4	94.4	94.5	94.05	94.3	94.31	94.5
E	Height 4	94.97	95.91	94.36	94.31	94.57	94.38	94.13	94.58	94.14	94.2
F	Average Height	94.8325	95.1725	94.5025	94.355	94.4475	94.395	94.15	94.355	94.2325	94.3375
G	Diameter 1	150.07	150.41	150.04	149.94	149.85	149.95	149.99	149.91	149.97	150.1
H	Diameter 2	150.1	150.82	149.884	149.99	149.93	150.15	150	150	149.97	150.11
I	Average Diameter	150.085	150.615	149.962	149.965	149.89	150.05	149.995	149.955	149.97	150.105
J	G_{mb} [A/(F*π*I^2/4)]	2.284	2.264	2.299	2.303	2.307	2.303	2.314	2.307	2.309	2.301
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.1	9.9	8.5	8.4	8.2	8.4	7.9	8.2	8.1	8.4
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3831.9	3839.3	3837.2	3837.4	3845.3	3843.4	3850	3844.1	3843.8	3841.8
B	Submerged Mass	2205.1	2203	2205.1	2221.2	2219.3	2214.9	2212.9	2214.9	2208.1	2216.4
C	SSD Mass	3848	3860	3849.2	3852.9	3858.9	3854.4	3856.3	3853.8	3850.9	3852.9
D	G_{mb} [A/(C-B)]	2.332	2.317	2.334	2.352	2.345	2.344	2.343	2.346	2.340	2.348
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.2	7.8	7.1	6.4	6.7	6.7	6.8	6.7	6.9	6.6

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Project Number:
Location: M-84 Saginaw
Contractor:
Mix:
Gradation:
G_{mm} 2.543

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3826.2	3879.4	3883.9	3879.8	3887.4	3883.7	3887.8	3885	3882.5	3883.4
B	Height 1	94.67	94.23	94.45	94.04	94.28	94.06	94.12	94.34	94.12	94.39
C	Height 2	94.35	94.36	94.4	94.06	94.35	94.16	94.26	94.3	94.39	94.41
D	Height 3	94.43	94.56	94.66	94.37	94.17	94.24	94.7	94.24	94.34	94.28
E	Height 4	94.03	94.2	94.32	94.49	94.8	94.31	93.76	94.41	94.76	94.45
F	Average Height	94.37	94.3375	94.4575	94.24	94.4	94.1925	94.21	94.3225	94.4025	94.3825
G	Diameter 1	150.08	150.22	149.79	149.86	149.87	149.73	149.54	149.57	149.83	149.81
H	Diameter 2	150.54	150.04	149.73	149.91	149.84	149.76	149.94	149.77	149.88	149.77
I	Average Diameter	150.31	150.13	149.76	149.885	149.855	149.745	149.74	149.67	149.855	149.79
J	G_{mb} [A/(F*π*I^2/4)]	2.285	2.323	2.334	2.333	2.335	2.341	2.343	2.341	2.332	2.335
K	Air Voids [(G_{mm}-J)/G_{mm}]	10.1	8.6	8.2	8.2	8.2	7.9	7.9	7.9	8.3	8.2
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3876.6	3880	3884.3	3880.2	3887.3	3884	3887.7	3884.9	3882.3	3883.2
B	Submerged Mass	2264	2265.5	2264.1	2260.7	2269.6	2267.6	2271.1	2267.1	2263.1	2267.9
C	SSD Mass	3895.6	3901.5	3898.9	3894.9	3904.5	3903.6	3903.2	3901.8	3901.6	3902.2
D	G_{mb} [A/(C-B)]	2.376	2.372	2.376	2.374	2.378	2.374	2.382	2.377	2.369	2.376
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.6	6.7	6.6	6.6	6.5	6.6	6.3	6.5	6.8	6.6

Project Number:
Location: BL I-96 Howell
Contractor:
Mix:
Gradation:
G_{mm} 2.501

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3845.3	3841.3	3841.2	3850.3	3820.8	3844.8	3849.2	3847.7	3847.7	3847.1
B	Height 1	94.78	94.67	94.59	94.77	94.7	94.75	94.71	94.5	94.51	94.52
C	Height 2	94.88	94.83	94.79	94.92	94.76	94.55	94.63	94.54	94.55	94.5
D	Height 3	94.91	94.87	94.8	94.83	97.62	94.54	94.58	94.62	94.63	94.65
E	Height 4	94.86	94.8	94.69	94.86	94.9	94.68	94.74	94.68	94.6	94.52
F	Average Height	94.8575	94.7925	94.7175	94.845	95.495	94.63	94.665	94.585	94.5725	94.5475
G	Diameter 1	150.25	150.15	149.78	150.04	150.06	150.02	150.07	149.3	150.05	150.07
H	Diameter 2	150.28	150.25	150.14	150.01	150.04	150.06	150.09	150	150.01	150.09
I	Average Diameter	150.265	150.2	149.96	150.025	150.05	150.04	150.08	149.65	150.03	150.08
J	G_{mb} [A/(F*π*I^2/4)]	2.286	2.287	2.296	2.296	2.263	2.298	2.299	2.313	2.301	2.300
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.6	8.6	8.2	8.2	9.5	8.1	8.1	7.5	8.0	8.0
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3845.3	3841.3	3841.2	3850.3	3820.8	3844.8	3849.2	3847.7	3847.7	3847.1
B	Submerged Mass	2204.9	2201	2200.7	2207.8	2209.3	2206	2209.2	2207.5	2212.1	2205.2
C	SSD Mass	3855	3852	3850.4	3858.1	3857.8	3853.6	3858.9	3856.9	3858.2	3855.6
D	G_{mb} [A/(C-B)]	2.330	2.327	2.328	2.333	2.318	2.334	2.333	2.333	2.337	2.331
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.8	7.0	6.9	6.7	7.3	6.7	6.7	6.7	6.5	6.8

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Project Number:
Location: M-21 Owosso
Contractor:
Mix:
Gradation:
G_{mm} 2.47

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3798.3	3796	3841	3796.1	3796.4	3799.4	3800.6	3796.6	3815.9	3797.9
B	Height 1	94.43	94.39	94.49	94.41	94.3	94.41	94.5	94.36	94.28	94.37
C	Height 2	94.4	94.33	94.29	94.52	94.35	94.46	94.36	94.48	94.35	94.43
D	Height 3	94.32	94.4	94.36	94.38	94.32	94.4	94.37	94.41	94.38	94.51
E	Height 4	94.35	94.34	94.35	94.35	94.37	94.35	94.36	94.32	94.33	94.29
F	Average Height	94.375	94.365	94.3725	94.415	94.335	94.405	94.3975	94.3925	94.335	94.4
G	Diameter 1	149.96	149.71	149.93	149.92	149.85	149.96	149.88	149.91	149.9	149.95
H	Diameter 2	149.83	149.78	149.92	149.98	149.86	149.98	149.95	149.93	149.88	149.91
I	Average Diameter	149.895	149.745	149.925	149.95	149.855	149.97	149.915	149.92	149.89	149.93
J	G_{mb} [A/(F*π*I^2/4)]	2.281	2.284	2.305	2.277	2.282	2.278	2.281	2.278	2.292	2.279
K	Air Voids [(G_{mm}-J)/G_{mm}]	7.7	7.5	6.7	7.8	7.6	7.8	7.7	7.8	7.2	7.7

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3798.3	3796	3841	3796.1	3796.4	3799.4	3800.6	3796.6	3815.9	3797.9
B	Submerged Mass	2166.7	2163.1	2203.3	2159.9	2162.7	2164.8	2160.6	2156.5	2178.2	2156.9
C	SSD Mass	3809.5	3806.1	3848.9	3804.8	3805.7	3809.3	3807.7	3804.2	3823.5	3804.7
D	G_{mb} [A/(C-B)]	2.312	2.310	2.334	2.308	2.311	2.310	2.307	2.304	2.319	2.305
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.4	6.5	5.5	6.6	6.5	6.5	6.6	6.7	6.1	6.7

Project Number:
Location: M-66 Battle Creek
Contractor:
Mix:
Gradation:
G_{mm} 2.47

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3822.1	3829.2	3806.2	3804.9	3813.3	3809.2	3825.4	3822.3	3807.9	3822.9
B	Height 1	94.47	94.51	94.36	94.49	94.51	94.53	94.5	94.37	94.42	94.24
C	Height 2	94.5	94.37	94.41	94.58	94.49	94.52	94.49	94.44	94.32	94.32
D	Height 3	94.44	94.4	94.45	94.45	94.49	94.37	94.46	95.04	94.43	94.28
E	Height 4	94.48	94.47	94.36	94.47	94.55	94.56	94.76	94.92	94.51	94.47
F	Average Height	94.4725	94.4375	94.395	94.4975	94.51	94.495	94.5525	94.6925	94.42	94.3275
G	Diameter 1	149.95	149.94	149.99	149.99	150.02	149.94	150.23	150.07	149.97	149.76
H	Diameter 2	149.94	149.98	149.92	149.98	150.01	150.06	149.88	149.84	149.99	149.99
I	Average Diameter	149.945	149.96	149.955	149.985	150.015	150	150.055	149.955	149.98	149.875
J	G_{mb} [A/(F*π*I^2/4)]	2.291	2.296	2.283	2.279	2.283	2.281	2.288	2.286	2.283	2.297
K	Air Voids [(G_{mm}-J)/G_{mm}]	7.2	7.1	7.6	7.7	7.6	7.6	7.4	7.5	7.6	7.0

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3822.1	3829.2	3806.2	3804.9	3813.3	3809.2	3825.4	3822.3	3807.9	3822.9
B	Submerged Mass	2181.8	2187.5	2166.7	2162.3	2173.6	2168.8	2184.8	2179.8	2167.5	2180.6
C	SSD Mass	3829.5	3836.9	3812.7	3811.3	3820.3	3817	3832.3	3828.7	3815.2	3829.8
D	G_{mb} [A/(C-B)]	2.320	2.322	2.312	2.307	2.316	2.311	2.322	2.318	2.311	2.318
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.1	6.0	6.4	6.6	6.2	6.4	6.0	6.2	6.4	6.2

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Project Number:
Location: M-50 Dundee
Contractor:
Mix: 4 E 3
Gradation:
G_{mm} 2.538

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3823.3	3824.6	3825.3	3825.7	3829.5	3827	3829.8	3826.7	3829.5	3831.4
B	Height 1	94.65	94.3	94.5	94.42	94.28	94.37	94.38	94.24	94.4	94.19
C	Height 2	94.24	94.46	94.45	94.41	94.44	94.47	94.19	94.18	94.45	94.3
D	Height 3	94.34	94.35	94.58	94.58	94.49	94.41	94.28	94.1	94.51	94.8
E	Height 4	94.36	94.71	94.54	94.33	94.56	94.5	94.28	94.4	94.39	94.37
F	Average Height	94.3975	94.455	94.5175	94.435	94.4425	94.4375	94.2825	94.23	94.4375	94.415
G	Diameter 1	150.01	149.97	149.93	150.12	150	150	150.05	150.01	150.02	150.15
H	Diameter 2	150.06	149.96	149.96	149.99	149.91	150.11	150.01	150.04	150.05	150.01
I	Average Diameter	150.035	149.965	149.945	150.055	149.955	150.055	150.03	150.025	150.035	150.08
J	G_{mb} [A/(F*π*I^2/4)]	2.291	2.292	2.292	2.291	2.296	2.292	2.298	2.297	2.294	2.294
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.7	9.7	9.7	9.7	9.5	9.7	9.5	9.5	9.6	9.6
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3823.3	3824.6	3825.3	3825.7	3829.5	3827	3829.8	3826.7	3829.5	3831.4
B	Submerged Mass	2221.1	2220.8	2220.3	2226	2231.4	2231	2229.4	2229	2231.9	2232.9
C	SSD Mass	3838.2	3839.8	3840.4	3841.4	3849.3	3851.1	3846.4	3842.1	3847.6	3849.5
D	G_{mb} [A/(C-B)]	2.364	2.362	2.361	2.368	2.367	2.362	2.368	2.372	2.370	2.370
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.8	6.9	7.0	6.7	6.7	6.9	6.7	6.5	6.6	6.6

Project Number:
Location: US-12 MIS
Contractor:
Mix:
Gradation:
G_{mm} 2.491

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3741.2	3713.7	3740.4	3714.4	3711.4	3741.3	3715.3	3717.5	3719.9	3722.1
B	Height 1	94.6	94.41	94.63	94.39	94.32	94.48	94.33	94.33	94.33	94.33
C	Height 2	94.4	94.34	94.59	94.74	94.54	94.39	94.3	94.24	94.29	94.39
D	Height 3	94.47	94.53	94.55	94.36	94.5	94.37	94.36	94.29	94.42	94.52
E	Height 4	94.5	94.33	94.62	94.55	94.52	94.4	94.29	94.29	94.36	94.39
F	Average Height	94.4925	94.4025	94.5975	94.51	94.47	94.41	94.32	94.2875	94.35	94.4075
G	Diameter 1	150.11	150.15	150.09	150.31	150.22	150.31	150.21	150.1	150.16	150.16
H	Diameter 2	150.06	150.29	150.1	150.29	150.39	150.14	150.3	150.14	150.06	150.17
I	Average Diameter	150.085	150.22	150.095	150.3	150.305	150.225	150.255	150.12	150.11	150.165
J	G_{mb} [A/(F*π*I^2/4)]	2.238	2.220	2.235	2.215	2.214	2.236	2.221	2.228	2.228	2.226
K	Air Voids [(G_{mm}-J)/G_{mm}]	10.2	10.9	10.3	11.1	11.1	10.2	10.8	10.6	10.6	10.6
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3741.2	3713.7	3740.4	3714.4	3711.4	3741.3	3715.3	3717.5	3719.9	3722.1
B	Submerged Mass	2143.9	2112.9	2144	2125.1	2130	2128.6	2139.3	2137.9	2143.6	2136.6
C	SSD Mass	3760.1	3732.1	3760.3	3739.8	3731.1	3739.9	3747.5	3745.3	3748.9	3747.1
D	G_{mb} [A/(C-B)]	2.315	2.294	2.314	2.300	2.318	2.322	2.310	2.313	2.317	2.311
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.1	7.9	7.1	7.7	6.9	6.8	7.3	7.2	7.0	7.2

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Project Number:
Location: M-59 Brighton
Contractor:
Mix:
Gradation:
G_{mm} 2.503

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3716.6	3722.2	3727.5	3717.7	3725	3725.1	3725.5	3718.8	3721	3719.6
B	Height 1	94.13	94.29	94.79	94.42	94.3	94.28	94.39	94.38	94.48	94.84
C	Height 2	94.19	94.47	94.41	94.12	94.37	94.18	94.3	94.2	94.43	94.45
D	Height 3	94.55	93.87	94.29	94.42	94.21	94.7	94.5	94.42	94.1	94.43
E	Height 4	94.32	94.54	94.98	94.49	94.48	94.25	94.56	94.35	94.63	94.54
F	Average Height	94.2975	94.2925	94.6175	94.3625	94.34	94.3525	94.4375	94.3375	94.41	94.565
G	Diameter 1	149.89	149.87	150.73	150.2	149.85	150.16	149.89	150.28	150.22	149.88
H	Diameter 2	150.25	149.91	150.85	150.11	150.04	149.98	149.99	150.12	150.19	150.08
I	Average Diameter	150.07	149.89	150.79	150.155	149.945	150.07	149.94	150.2	150.205	149.98
J	G_{mb} [A/(F*π*I^2/4)]	2.228	2.237	2.206	2.225	2.236	2.232	2.234	2.225	2.224	2.226
K	Air Voids [(G_{mm}-J)/G_{mm}]	11.0	10.6	11.9	11.1	10.7	10.8	10.7	11.1	11.1	11.0
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3716.6	3722.2	3727.5	3717.7	3725	3725.1	3725.5	3718.8	3721	3719.6
B	Submerged Mass	2136.5	2145.7	2142.5	2139.6	2149.5	2143.9	2161.3	2160.7	2143.5	2150.6
C	SSD Mass	3737	3740.3	3748.4	3738	3747.2	3744.4	3749.8	3740.5	3743	3740.7
D	G_{mb} [A/(C-B)]	2.322	2.334	2.321	2.326	2.331	2.327	2.345	2.354	2.326	2.339
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.2	6.7	7.3	7.1	6.9	7.0	6.3	6.0	7.1	6.5

Project Number:
Location: Michigan Ave. Dearborn
Contractor:
Mix: 3 E 10
Gradation:
G_{mm} 2.493

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3749.2	3768.2	3755.1	3743.4	3748.4	3735.4	3745.3	3754.4	3743.5	3762
B	Height 1	94.74	94.42	94.29	95.04	94.86	94.89	95.04	94.42	94.4	94.55
C	Height 2	94.71	94.29	94.42	95.01	94.61	96.52	95.12	94.52	94.9	94.5
D	Height 3	94.97	94.29	94.31	95.05	94.49	95.2	94.8	94.4	94.82	94.39
E	Height 4	94.6	94.39	95.37	95.12	94.8	94.89	95.26	94.44	94.35	94.6
F	Average Height	94.755	94.3475	94.5975	95.055	94.69	95.375	95.055	94.445	94.6175	94.51
G	Diameter 1	149.5	150.05	151.37	150.5	149.73	149.86	150.32	150.65	149.8	150.5
H	Diameter 2	149.72	149.98	150.68	149.81	149.5	149.95	149.92	150.38	149.64	150.57
I	Average Diameter	149.61	150.015	151.025	150.155	149.615	149.905	150.12	150.515	149.72	150.535
J	G_{mb} [A/(F*π*I^2/4)]	2.251	2.260	2.216	2.224	2.252	2.219	2.226	2.234	2.247	2.237
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.7	9.4	11.1	10.8	9.7	11.0	10.7	10.4	9.9	10.3
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3749.2	3768.2	3755.1	3743.4	3748.4	3735.4	3745.3	3754.4	3743.5	3762
B	Submerged Mass	2156	2171.1	2138.8	2160	2154.3	2118.8	2131.3	2146.4	2139.6	2151.8
C	SSD Mass	3760.7	3780.8	3764.5	3759	3756	3743.1	3750.8	3760.9	3750.9	3769.5
D	G_{mb} [A/(C-B)]	2.336	2.341	2.310	2.341	2.340	2.300	2.313	2.325	2.323	2.326
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.3	6.1	7.3	6.1	6.1	7.8	7.2	6.7	6.8	6.7

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Project Number:
Location: Vandyke, Detroit
Contractor:
Mix:
Gradation:
G_{mm} 2.604

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3977.7	3982.6	3985.4	3967	3982.1	3983.6	3977.8	3962	3980.7	3958.8
B	Height 1	94.39	94.46	94.4	94.73	94.35	94.34	94.47	94.61	94.14	94.66
C	Height 2	94.48	94.37	94.43	94.69	94.42	94.4	94.38	94.55	94.37	94.61
D	Height 3	94.36	94.5	94.44	94.62	94.53	94.31	94.33	94.69	94.41	94.5
E	Height 4	94.51	94.38	94.43	94.83	94.2	94.33	94.29	94.64	94.37	94.62
F	Average Height	94.435	94.4275	94.425	94.7175	94.375	94.345	94.3675	94.6225	94.3225	94.5975
G	Diameter 1	150.1	149.99	150.02	149.96	150.04	150	150.02	149.92	150.16	150.05
H	Diameter 2	149.96	150.1	149.94	149.95	150	150.13	149.99	150.02	150.06	149.93
I	Average Diameter	150.03	150.045	149.98	149.955	150.02	150.065	150.005	149.97	150.11	149.99
J	G_{mb} [A/(F*π*I^2/4)]	2.383	2.385	2.389	2.371	2.387	2.387	2.385	2.370	2.385	2.368
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.5	8.4	8.3	8.9	8.3	8.3	8.4	9.0	8.4	9.0
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3977.7	3982.6	3985.4	3967	3982.1	3983.6	3977.8	3962	3980.7	3958.8
B	Submerged Mass	2362.2	2360.9	2363.2	2341.5	2360.7	2367.6	2364.8	2339.8	2364.7	2337.2
C	SSD Mass	3990.9	3993	3992.1	3981.4	3992.2	3995.6	3989.6	3976.9	3996.5	3973.8
D	G_{mb} [A/(C-B)]	2.442	2.440	2.447	2.419	2.441	2.447	2.448	2.420	2.439	2.419
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.2	6.3	6.0	7.1	6.3	6.0	6.0	7.1	6.3	7.1

Project Number:
Location: US-23 Hartland
Contractor:
Mix:
Gradation:
G_{mm} 2.492

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3683.5	3676.6	3680	3675	3684.4	3684	3680.1	3681.2	3681.5	3680.5
B	Height 1	94.3	94.3	94.44	94.31	94.5	94.5	94.76	94.69	94.77	94.5
C	Height 2	94.34	94.39	94.18	94.55	94.3	94.66	94.55	94.75	95.21	93.91
D	Height 3	94.16	94.21	94.86	94.6	94.98	94.15	94.44	94.91	94.55	94.54
E	Height 4	94.4	94.31	94.3	94.84	94.42	94.74	94.57	94.66	95.13	94.52
F	Average Height	94.3	94.3025	94.445	94.575	94.55	94.5125	94.58	94.7525	94.915	94.3675
G	Diameter 1	150.04	149.87	150.04	149.67	149.91	150.2	150.11	150.32	149.77	150.01
H	Diameter 2	150.24	149.99	150.17	150.21	150.54	150.22	150.23	150.04	150.66	150.14
I	Average Diameter	150.14	149.93	150.105	149.94	150.225	150.21	150.17	150.18	150.215	150.075
J	G_{mb} [A/(F*π*I^2/4)]	2.206	2.208	2.202	2.201	2.199	2.200	2.197	2.193	2.189	2.205
K	Air Voids [(G_{mm}-J)/G_{mm}]	11.5	11.4	11.6	11.7	11.8	11.7	11.8	12.0	12.2	11.5
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3683.5	3676.6	3680	3675	3684.4	3684	3680.2	3681.1	3681.5	3680.5
B	Submerged Mass	2108.7	2108.1	2101.8	2123.7	2126.6	2128.8	2122.2	2114.2	2105.9	2108.5
C	SSD Mass	3713.6	3704.8	3706.2	3708.6	3715.1	3711.4	3710.8	3706.6	3706.2	3703.4
D	G_{mb} [A/(C-B)]	2.295	2.303	2.294	2.319	2.319	2.328	2.317	2.312	2.301	2.308
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.9	7.6	8.0	7.0	6.9	6.6	7.0	7.2	7.7	7.4

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Project Number:
Location: I-75 Levering Rd
Contractor:
Mix:
Gradation:
G_{mm} 2.443

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3737.1	3737.7	3736.4	3734.9	3736.2	3742.7	3737.9	3736.3	3743.9	3738.3
B	Height 1	94.88	94.29	94.6	94.31	94.3	94.46	94.41	94.34	94.29	94.56
C	Height 2	94.77	94.28	94.75	94.37	94.3	94.61	94.68	94.54	94.33	94.38
D	Height 3	94.45	94.84	94.82	94.25	94.5	94.41	94.33	94.76	94.3	94.53
E	Height 4	94.57	94.13	94.34	94.26	94.57	94.32	94.46	94.4	94.42	94.36
F	Average Height	94.6675	94.385	94.6275	94.2975	94.4175	94.45	94.47	94.51	94.335	94.4575
G	Diameter 1	149.96	149.76	150.07	149.88	149.94	150	150.01	149.96	149.67	149.96
H	Diameter 2	149.91	149.9	150.03	149.88	150.02	149.98	150.03	149.94	150	150
I	Average Diameter	149.935	149.83	150.05	149.88	149.98	149.99	150.02	149.95	149.835	149.98
J	G_{mb} [A/(F*π*I²/4)]	2.236	2.246	2.233	2.245	2.240	2.243	2.238	2.239	2.251	2.240
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.5	8.1	8.6	8.1	8.3	8.2	8.4	8.4	7.9	8.3
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3736.9	3737.4	3736.5	3734.9	3736.2	3742.6	3737.5	3736.1	3743.7	3738.6
B	Submerged Mass	2111.3	2115.6	2110.8	2113.6	2121.8	2124.6	2118	2115.2	2123.3	2118.9
C	SSD Mass	3747.3	3748.9	3747.5	3748.7	3750.7	3753.9	3752.8	3748.5	3757.3	3750.8
D	G_{mb} [A/(C-B)]	2.284	2.288	2.283	2.284	2.294	2.297	2.286	2.287	2.291	2.291
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.5	6.3	6.6	6.5	6.1	6.0	6.4	6.4	6.2	6.2

Project Number:
Location: I-196 Grand Rapids
Contractor:
Mix:
Gradation:
G_{mm} 2.499

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3806.2	3810.7	3806.6	3808.3	3808.8	3806.3	3805.4	3812.1	3806.1	3804.2
B	Height 1	94.48	94.5	94.27	94.73	94.53	94.58	94.64	94.49	94.51	94.56
C	Height 2	94.57	94.53	94.36	94.44	94.48	94.41	94.48	94.56	94.46	94.65
D	Height 3	94.5	94.51	94.51	94.49	94.58	94.57	94.73	94.59	94.75	94.46
E	Height 4	94.41	94.53	94.5	94.88	94.55	94.53	94.7	94.4	94.54	94.46
F	Average Height	94.49	94.5175	94.41	94.635	94.535	94.5225	94.6375	94.51	94.565	94.5325
G	Diameter 1	150.05	149.98	150.02	150.12	150.03	149.9	150.15	150.02	150.05	150.07
H	Diameter 2	150.08	150.2	150.03	150.15	150.11	150.07	150.06	150.14	150.08	150.1
I	Average Diameter	150.065	150.09	150.025	150.135	150.07	149.985	150.105	150.08	150.065	150.085
J	G_{mb} [A/(F*π*I²/4)]	2.277	2.279	2.281	2.273	2.278	2.279	2.272	2.280	2.276	2.275
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.9	8.8	8.7	9.0	8.9	8.8	9.1	8.8	8.9	9.0
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3806.2	3810.7	3806.6	3808.3	3808.8	3806.3	3805.4	3812.1	3806.1	3804.2
B	Submerged Mass	2184.4	2193.5	2190.2	2185.2	2185.7	2187.7	2183.5	2193.6	2186	2188.6
C	SSD Mass	3819.6	3829.5	3823.3	3826.1	3822.6	3821.2	3819.4	3827.4	3822.2	3822.5
D	G_{mb} [A/(C-B)]	2.328	2.329	2.331	2.321	2.327	2.330	2.326	2.333	2.326	2.328
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.9	6.8	6.7	7.1	6.9	6.8	6.9	6.6	6.9	6.8

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Project Number:
Location: I-75 Clarkston
Contractor:
Mix:
Gradation:
G_{mm} 2.487

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3764.5	3763.5	3770.9	3766.9	3766.3	3763.7	3767.2	3770.3	3763.3	3767.8
B	Height 1	94.39	94.44	94.46	94.42	94.42	94.36	94.37	94.36	94.33	94.4
C	Height 2	94.56	94.46	94.64	94.36	94.34	94.28	94.52	94.48	94.23	94.34
D	Height 3	94.39	94.42	94.39	94.3	94.3	94.49	94.59	94.4	94.47	94.42
E	Height 4	94.26	94.49	94.45	94.31	94.52	94.4	94.44	94.34	94.45	94.39
F	Average Height	94.400	94.453	94.485	94.348	94.395	94.383	94.480	94.395	94.370	94.388
G	Diameter 1	150.18	150.07	149.96	150.09	149.96	150.06	150.14	149.94	150.14	150.01
H	Diameter 2	150.08	150.11	150.04	150	150.07	150.03	150.31	149.92	150.08	150.02
I	Average Diameter	150.130	150.090	150.000	150.045	150.015	150.045	150.225	149.930	150.110	150.015
J	G_{mb} [A/(F*π*I²/4)]	2.253	2.252	2.258	2.258	2.257	2.255	2.250	2.262	2.253	2.258
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.4	9.4	9.2	9.2	9.2	9.3	9.5	9.0	9.4	9.2

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3764.5	3763.5	3770.9	3766.9	3766.3	3763.7	3767.2	3770.3	3763.3	3767.8
B	Submerged Mass	2155.2	2158.2	2162.9	2154.6	2157.2	2156.6	2152.4	2158.6	2154.1	2155.9
C	SSD Mass	3778.3	3781.5	3784.5	3782.5	3781.4	3778.3	3782.5	3783.8	3778.9	3780
D	G_{mb} [A/(C-B)]	2.319	2.318	2.325	2.314	2.319	2.321	2.311	2.320	2.316	2.320
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.7	6.8	6.5	7.0	6.8	6.7	7.1	6.7	6.9	6.7

Project Number:
Location: M-53 Detroit
Contractor:
Mix:
Gradation:
G_{mm} 2.563

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3884	3886.4	3891.6	3884.7	3878.5	3883.8	3878.4	3879.4	3879.4	3877.3
B	Height 1	94.39	94.25	94.3	94.31	94.48	94.31	94.28	94.55	94.29	94.43
C	Height 2	94.31	94.3	94.59	94.46	94.23	94.35	94.4	94.36	94.45	94.34
D	Height 3	94.35	94.18	94.41	94.51	94.28	94.36	94.4	94.45	94.53	94.37
E	Height 4	94.4	94.54	94.34	94.72	94.5	94.37	94.41	94.41	94.4	94.57
F	Average Height	94.3625	94.3175	94.41	94.5	94.3725	94.3475	94.3725	94.4425	94.4175	94.4275
G	Diameter 1	150.02	150.11	149.98	149.95	150.09	150.07	149.98	150.07	150.01	150.17
H	Diameter 2	150.19	150.03	150.1	150	150.16	150.09	149.95	150.17	150.26	150.06
I	Average Diameter	150.105	150.07	150.04	149.975	150.125	150.08	149.965	150.12	150.135	150.115
J	G_{mb} [A/(F*π*I²/4)]	2.326	2.330	2.331	2.327	2.322	2.327	2.327	2.321	2.321	2.320
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.2	9.1	9.0	9.2	9.4	9.2	9.2	9.5	9.4	9.5

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3884	3886.4	3891.6	3884.7	3878.5	3883.8	3878.4	3879.4	3879.4	3877.3
B	Submerged Mass	2293.8	2290.2	2294.1	2289.5	2279.5	2288.9	2284.4	2276.4	2278.6	2272.6
C	SSD Mass	3905.9	3907.9	3911.7	3903.1	3897.3	3904	3898	3898.5	3896.7	3894.5
D	G_{mb} [A/(C-B)]	2.409	2.402	2.406	2.407	2.397	2.405	2.404	2.392	2.398	2.391
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.0	6.3	6.1	6.1	6.5	6.2	6.2	6.7	6.5	6.7

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Project Number:
Location: Michigan Ave Dearborn
Contractor:
Mix: 4 E 10
Gradation:
G_{mm} 2.485

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3740.3	3735.1	3738.8	3747.1	3742.2	3746.6	3742.2	3747.3	3748.3	3748.2
B	Height 1	94.45	94.41	94.55	94.28	94.38	94.18	94.44	94.28	94.54	94.27
C	Height 2	94.46	94.53	94.6	94.25	94.46	94.39	94.33	94.3	94.43	94.37
D	Height 3	94.9	94.38	94.46	94.41	94.34	94.43	94.32	94.54	94.32	94.41
E	Height 4	94.5	94.5	94.34	94.27	94.45	94.27	94.45	94.34	94.25	94.42
F	Average Height	94.5775	94.455	94.4875	94.3025	94.4075	94.3175	94.385	94.365	94.385	94.3675
G	Diameter 1	150.09	150.27	150.46	150.13	150.18	150.17	150.06	150.01	150.17	150.15
H	Diameter 2	150.2	150.22	150.24	150.16	150.09	150.09	149.97	150.05	150.08	150.06
I	Average Diameter	150.145	150.245	150.35	150.145	150.135	150.13	150.015	150.03	150.125	150.105
J	G_{mb} [A/(F*π*I^2/4)]	2.234	2.230	2.229	2.244	2.239	2.244	2.243	2.246	2.244	2.245
K	Air Voids [(G_{mm}-J)/G_{mm}]	10.1	10.2	10.3	9.7	9.9	9.7	9.7	9.6	9.7	9.7
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3740.3	3735.1	3738.8	3747.1	3742.2	3746.6	3742.2	3747.3	3748.3	3748.2
B	Submerged Mass	2139.7	2136.7	2139.5	2146	2139.5	2146.8	2144.8	2141	2146	2141.6
C	SSD Mass	3753.5	3749.7	3752.4	3760.5	3754.7	3763.1	3762.1	3758.2	3766.5	3762
D	G_{mb} [A/(C-B)]	2.318	2.316	2.318	2.321	2.317	2.318	2.314	2.317	2.313	2.313
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.7	6.8	6.7	6.6	6.8	6.7	6.9	6.8	6.9	6.9

Project Number:
Location: I-75 Toledo
Contractor:
Mix:
Gradation:
G_{mm} 2.507

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3808.9	3801.3	3802.1	3812.6	3803.6	3805.5	3803.6	3808.4	3805.9	3806.9
B	Height 1	94.45	94.46	94.52	94.27	94.5	94.37	94.38	94.43	94.46	94.39
C	Height 2	94.37	94.39	94.41	94.42	94.54	94.43	94.49	94.55	94.47	94.62
D	Height 3	94.35	94.43	94.35	94.41	94.49	94.4	94.62	94.42	94.41	94.5
E	Height 4	94.47	94.45	94.37	94.46	94.46	94.54	94.46	94.37	94.42	94.3
F	Average Height	94.41	94.4325	94.4125	94.39	94.4975	94.435	94.4875	94.4425	94.44	94.4525
G	Diameter 1	149.92	150.14	150.14	149.94	150.07	149.98	150.06	150.04	149.95	150.09
H	Diameter 2	149.98	150.09	150.13	149.97	150.07	149.99	150.07	150.04	150.02	150.23
I	Average Diameter	149.95	150.115	150.135	149.955	150.07	149.985	150.065	150.04	149.985	150.16
J	G_{mb} [A/(F*π*I^2/4)]	2.285	2.274	2.275	2.287	2.276	2.281	2.276	2.281	2.281	2.276
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.9	9.3	9.3	8.8	9.2	9.0	9.2	9.0	9.0	9.2
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3808.9	3801.3	3802.1	3812.6	3803.6	3805.5	3803.6	3808.4	3805.9	3806.9
B	Submerged Mass	2203.3	2196.7	2197.7	2207.1	2206.8	2205	2202.5	2203.1	2204.1	2200.5
C	SSD Mass	3826.4	3822.4	3823.2	3831.1	3828.5	3829.6	3823.7	3828.1	3827.3	3826.5
D	G_{mb} [A/(C-B)]	2.347	2.338	2.339	2.348	2.345	2.342	2.346	2.344	2.345	2.341
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.4	6.7	6.7	6.4	6.4	6.6	6.4	6.5	6.5	6.6

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Project Number:
Location: I-94 Ann Arbor
Contractor:
Mix: SMA
Gradation:
G_{mm} 2.515

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3757.4	3758.7	3750	3753.8	3759.2	3756.3	3754.7	3757	3756.8	3757.7
B	Height 1	94.24	94.11	94.37	94.33	94.46	94.34	94.38	94.23	94.26	94.27
C	Height 2	94.3	94.3	94.36	94.59	94.23	94.41	94.23	94.3	94.45	94.25
D	Height 3	94.03	94.3	94.17	95.16	94.07	94.17	94.21	94.36	94.4	94.34
E	Height 4	93.84	94.25	94.37	94.39	94.26	94.06	94.36	94.37	94.25	94.53
F	Average Height	94.1025	94.24	94.3175	94.6175	94.255	94.245	94.295	94.315	94.34	94.3475
G	Diameter 1	150.01	150.12	150	149.98	149.93	149.96	150.15	149.93	149.94	150.04
H	Diameter 2	150.25	150.16	150.06	150.2	149.9	149.95	150.06	149.98	149.92	150.07
I	Average Diameter	150.13	150.14	150.03	150.09	149.915	149.955	150.105	149.955	149.93	150.055
J	G_{mb} [A/(F*π*I^2/4)]	2.256	2.253	2.249	2.242	2.259	2.257	2.250	2.256	2.256	2.252
K	Air Voids [(G_{mm}-J)/G_{mm}]	10.3	10.4	10.6	10.8	10.2	10.3	10.5	10.3	10.3	10.5
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3757.4	3758.7	3750	3753.8	3759.2	3756.3	3754.7	3757	3756.8	3757.7
B	Submerged Mass	2197.4	2198.4	2191.2	2189.1	2192.4	2190.1	2189.2	2189.5	2198.8	2186.8
C	SSD Mass	3786.3	3787.8	3783.2	3784.4	3788	3782.5	3783.4	3782.8	3789.2	3781.6
D	G_{mb} [A/(C-B)]	2.365	2.365	2.356	2.353	2.356	2.359	2.355	2.358	2.362	2.356
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.0	6.0	6.3	6.4	6.3	6.2	6.4	6.2	6.1	6.3

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Phase II – 150mm Superpave Specimens for Dynamic Modulus (Sensitivity Study)

G_{mb}'s

Project I-196 Grand Rapids
Gmm 2.499

H_2O Temp: ____________

Saturated Surface Dry Method

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A) Dry Mass	6809.1	6816.0	6815.2	6814.0	6820.3	6813.4	6816.7	6815.1	6809.2	6812.4	6813.1	6816.5	6822.2	6813.5	6816.1	6809.9	6815.1	6820.1
B) Submerged Mass	3899.4	3903.5	3903.8	3914.3	3906.0	3910.5	3906.7	3910.4	3907.4	3916.8	3914	3910.4	3910.5	3909.6	3908.1	3911.9	3907.5	3907
C) SSD Mass	6853.2	6853.7	6856.7	6865.9	6860.6	6863.7	6870.2	6860.1	6860.9	6863.6	6864.4	6861.8	6861.4	6859	6863.4	6858.2	6861.6	6859.6
D) G_{mb} [A/(C-B)]	2.305	2.310	2.308	2.309	2.308	2.307	2.300	2.310	2.305	2.312	2.309	2.310	2.312	2.310	2.306	2.311	2.307	2.310
E) Air Voids [$(G_{mm}$-D)/G_{mm}]	7.8%	7.5%	7.6%	7.6%	7.6%	7.7%	8.0%	7.5%	7.7%	7.5%	7.6%	7.6%	7.5%	7.6%	7.7%	7.5%	7.7%	7.6%

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G_{mb}'s

Project: I-75 Clarkston
Gmm: 2.487

H_2O Temp: ____________

Saturated Surface Dry Method

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A) Dry Mass	6741.4	6742.7	6753.5	6741.6	6751.4	6743.0	6748.8	6749.6	6748.3	6750.9	6745.1	6747.3	6749.9	6752.1	6742.3	6746.8	6749.1	6748.4
B) Submerged Mass	3842.8	3842.0	3861.5	3849.1	3860.2	3853.8	3853.4	3852.7	3857	3855.5	3850.6	3856.5	3855.5	3860.8	3851.5	3850.3	3860.1	3847.9
C) SSD Mass	6783.4	6781.2	6799.2	6786.8	6792.1	6785.2	6789.3	6791.4	6791	6792.8	6785.5	6787.9	6790.5	6796.8	6785.3	6787.6	6793.9	6784.9
D) G_{mb} [A/(C-B)]	2.293	2.294	2.299	2.295	2.303	2.300	2.299	2.297	2.300	2.298	2.298	2.302	2.300	2.300	2.298	2.297	2.300	2.298
E) Air Voids [$(G_{mm}-D)/G_{mm}$]	7.8%	7.8%	7.6%	7.7%	7.4%	7.5%	7.6%	7.6%	7.5%	7.6%	7.6%	7.4%	7.5%	7.5%	7.6%	7.6%	7.5%	7.6%

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Phase II – 100mm Superpave Specimens for Dynamic Modulus (Sensitivity Study) Cut and Cored from 150mm Diameter Superpave Specimens

Project Number:
Location: I-196 Grand Rapids
Contractor:
Mix:
Gradation:
G_{mm} 2.499

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	Dry Mass	2842.8	2847.9	2848.9	2850	2854.5	2853.9	2846.9	2857.3	2849.6	2858.7	2861.4	2855.6	2859.4	2858.5	2855.8	2862.7	2855.3	2855.1
B	Height 1	151.3	151.35	151.23	151.52	151.39	151.32	151.37	151.45	151.23	151.33	151.49	151.38	151.52	151.45	151.55	151.92	151.43	151.54
C	Height 2	151.43	151.31	151.18	151.34	151.36	151.44	151.47	151.47	151.44	151.33	151.34	151.44	151.41	151.42	151.45	151.69	151.34	151.55
D	Height 3	151.41	151.36	151.46	151.27	151.41	151.34	151.43	151.66	151.25	151.27	151.37	151.45	151.4	151.5	151.55	151.55	151.43	151.47
E	Height 4	151.21	151.48	151.37	151.51	151.41	151.61	151.42	151.43	151.43	151.44	151.44	151.33	151.63	151.42	151.59	151.53	151.53	151.53
F	Average Height	151.3375	151.375	151.31	151.41	151.3925	151.4275	151.4225	151.5025	151.3375	151.3425	151.41	151.4	151.49	151.4475	151.535	151.6725	151.4325	151.5225
G	Top Diameter 1	100.98	100.98	101.01	101.02	101.08	101.04	101	101.08	101.12	101.15	101.09	101.14	101.05	101.07	101.07	101.07	101	101.13
H	Top Diameter 2	101.09	101.07	101.1	101.09	101.06	101.05	101.07	101.08	101.1	101.05	101.1	101.05	101.08	101.01	101.04	100.96	101.03	100.93
	Middle Diameter 1	100.98	100.98	101.06	101.02	101.02	101	101	100.99	101.05	101.13	101.06	101.05	101.03	101.12	101.05	101.06	101.05	101.04
	Middle Diameter 2	100.97	101.02	101.03	101.03	101.07	101.13	101.13	101.03	101.07	100.97	101.06	101.02	101.09	101.09	101.03	101.02	101.03	100.96
	Bottom Diameter 1	101.01	101.06	101.16	101.08	101.08	101.06	101.08	101.1	101.1	101.15	101.15	101.21	101.12	101.09	101.02	101.08	101.07	101.06
	Bottom Diameter 2	101.01	101.03	101.02	101.01	101.02	101	101.03	101.05	101.1	101.04	101.04	101.09	101.06	101.06	101.09	101.05	101.01	101.05
I	Average Diameter	101.0067	101.0233	101.0633	101.0417	101.055	101.0467	101.0517	101.055	101.09	101.0817	101.0833	101.0933	101.0717	101.0733	101.05	101.04	101.0317	101.0283
J	G_{mb} [A/(F*π*I²/4)]	2.344	2.347	2.347	2.347	2.351	2.350	2.344	2.351	2.346	2.354	2.355	2.350	2.353	2.352	2.350	2.354	2.352	2.351
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.2	6.1	6.1	6.1	5.9	6.0	6.2	5.9	6.1	5.8	5.8	6.0	5.9	5.9	6.0	5.8	5.9	5.9

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	Dry Mass	2842.8	2847.9	2848.9	2850	2854.5	2853.9	2846.9	2857.3	2849.6	2858.7	2861.4	2855.6	2859.4	2858.5	2855.8	2862.7	2855.3	2855.1
B	Submerged Mass	1635.5	1639.6	1639.4	1643.5	1644.1	1645	1638.1	1647.3	1640.8	1650.3	1651.2	1645.4	1648.6	1648.2	1645.4	1652.3	1645.6	1645.2
C	SSD Mass	2855.5	2860	2859.6	2863.8	2866	2866	2859.6	2868.2	2860.6	2869.8	2871.8	2865.9	2869.3	2868.9	2866.6	2874	2866.7	2866.8
D	G_{mb} [A/(C-B)]	2.330	2.334	2.335	2.335	2.336	2.337	2.331	2.340	2.336	2.344	2.344	2.340	2.342	2.342	2.339	2.343	2.338	2.337
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.8	6.6	6.6	6.5	6.5	6.5	6.7	6.3	6.5	6.2	6.2	6.4	6.3	6.3	6.4	6.2	6.4	6.5

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Project Number:
Location: I-75 Clarkston
Contractor:
Mix:
Gradation:
G_{mm} 2.487

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	Dry Mass	2828.9	2827.4	2840.5	2827.7	2832.3	2839.3	2841.5	2829.7	2859.8	2842.8	2840.1	2847.9	2840.2	2847.3	2835.9	2841.1	2843.7	2847.2
B	Height 1	151.45	151.41	151.4	151.39	151.33	151.27	151.31	151.51	151.69	151.45	151.72	151.13	151.3	151.22	151.4	151.48	151.2	151.35
C	Height 2	151.22	151.57	151.45	151.38	151.34	151.33	151.51	151.32	151.67	151.36	151.64	151.14	151.21	151.38	151.37	151.56	151.68	151.28
D	Height 3	151.2	151.42	151.39	151.43	151.2	151.64	151.4	151.4	152.02	151.16	151.25	151.33	151.34	151.4	151.26	151.36	151.26	151.43
E	Height 4	151.4	151.5	151.38	151.26	151.38	151.47	151.26	151.44	151.87	151.15	151.33	151.6	151.41	151.5	151.37	151.43	151.67	151.56
F	Average Height	151.3175	151.475	151.405	151.365	151.3125	151.4275	151.37	151.4175	151.8125	151.28	151.485	151.3	151.315	151.375	151.35	151.4575	151.4525	151.405
G	Top Diameter 1	101.28	100.99	101.01	101.07	101.03	100.99	101.08	100.96	101.11	101.1	101.01	101.09	101.03	101.05	101.1	101.08	100.94	101.02
H	Top Diameter 2	101.04	101.01	101.11	100.97	101.08	101.02	101.02	101.09	100.98	100.96	100.55	101.04	100.96	101.02	100.96	100.93	100.66	101.15
	Middle Diameter 1	101.03	100.99	100.98	101.01	100.99	100.95	101.12	101.05	101.03	101	100.86	100.97	101.01	101.02	101.07	100.99	100.69	101.01
	Middle Diameter 2	101	100.99	101.07	100.99	100.99	101.03	100.99	101.13	100.93	101.01	100.98	101.04	100.96	101.11	100.99	100.93	101.13	101.05
	Bottom Diameter 1	100.97	101.05	101.03	100.95	101	101.04	100.98	100.99	101.04	100.98	101	100.94	100.95	101.16	100.95	101.13	100.99	101.23
	Bottom Diameter 2	101.1	100.97	101.06	101.06	101.01	100.93	101.04	101.01	101.03	100.97	101.01	101.07	101.11	100.98	101.12	100.94	101.04	101.03
I	Average Diameter	101.07	101.00	101.04	101.01	101.02	100.99	101.04	101.04	101.02	101.00	100.90	101.03	101.00	101.06	101.03	101.00	100.91	101.08
J	G_{mb} [$A/(F*\pi*I^2/4)$]	2.330	2.330	2.340	2.331	2.336	2.341	2.341	2.331	2.350	2.345	2.345	2.348	2.343	2.345	2.337	2.341	2.348	2.343
K	Air Voids [$(G_{mm}-J)/G_{mm}$]	6.3	6.3	5.9	6.3	6.1	5.9	5.9	6.3	5.5	5.7	5.7	5.6	5.8	5.7	6.0	5.9	5.6	5.8

	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	Dry Mass	2828.9	2827.4	2840.5	2827.7	2832.3	2839.3	2841.5	2829.7	2859.8	2842.8	2840.1	2847.9	2840.2	2847.3	2835.9	2841.1	2843.7	2847.2
B	Submerged Mass	1623.1	1619.5	1632.8	1620.5	1626	1629.3	1633.3	1621.2	1646.1	1630.3	1634.8	1638.9	1631	1637.9	1627.6	1632.1	1638.3	1637.1
C	SSD Mass	2842.5	2838.5	2852.4	2838.8	2843.9	2849.6	2852.4	2840.3	2870.1	2850.4	2852	2858	2849.5	2857.1	2846.9	2852.2	2854.4	2857.4
D	G_{mb} [$A/(C-B)$]	2.320	2.319	2.329	2.321	2.326	2.327	2.331	2.321	2.336	2.330	2.333	2.336	2.331	2.335	2.326	2.329	2.338	2.333
E	Air Voids [$(G_{mm}-D)/G_{mm}$]	6.7	6.7	6.4	6.7	6.5	6.4	6.3	6.7	6.1	6.3	6.2	6.1	6.3	6.1	6.5	6.4	6.0	6.2

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Phase II – 150mm Superpave Specimens for Dynamic Modulus Testing

Project Number:
Location: M-50 Dundee
Contractor:
Mix: 3 E 1
Gradation:
G_{mm} 2.52

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6695.8	6614.4	6693.8	6622	6621.5	6677.9	6619.6	6682.8	6622.6	6623.73
B	Height 1	168.31	168.92	168.04	168.35	168.21	168.53	168.4	168.24	168.51	168.74
C	Height 2	168.4	168.59	167.93	168.36	168.52	168.72	168.65	168.09	168.45	168.74
D	Height 3	168.15	168.68	167.81	168.5	168.42	168.43	168.63	168.54	168.34	168.57
E	Height 4	168.39	169.07	168.04	168.47	168.53	168.72	168.82	168.46	168.08	168.47
F	Average Height	168.3125	168.815	167.955	168.42	168.42	168.6	168.625	168.3325	168.345	168.63
G	Diameter 1	150.61	150.61	150.18	150.91	150.49	150.36	150.77	150.13	150.76	150.46
H	Diameter 2	150.58	150.58	150.42	150.41	150.63	150.38	150.63	150.03	151.11	150.27
I	Average Diameter	150.595	150.595	150.3	150.66	150.56	150.37	150.7	150.08	150.935	150.365
J	G_{mb} [A/(F*π*I^2/4)]	2.233	2.200	2.246	2.206	2.208	2.230	2.201	2.244	2.199	2.212
K	Air Voids [(G_{mm}-J)/G_{mm}]	11.4	12.7	10.9	12.5	12.4	11.5	12.7	10.9	12.8	12.2
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6695.8	6614.4	6693.8	6622	6621.5	6677.9	6619.6	6682.8	6622.6	6623.73
B	Submerged Mass	3852.7	3840.2	3848.4	3839	3865.1	3856.8	3843.8	3890	3847.1	3871.1
C	SSD Mass	6738.2	6679.2	6728.1	6695.3	6695.5	6732.5	6699.6	6750.3	6700.8	6701.8
D	G_{mb} [A/(C-B)]	2.320	2.330	2.324	2.318	2.339	2.322	2.318	2.336	2.321	2.340
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.9	7.5	7.8	8.0	7.2	7.8	8.0	7.3	7.9	7.1

Project Number:
Location: M-36 Pinckney
Contractor:
Mix:
Gradation:
G_{mm} 2.511

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6611.6	6616	6705.6	6617	6713.5	6715.2	6714.6	6707.6	6611.5	6711.9
B	Height 1	169.03	169.2	169.26	169.23	169.31	169.3	169.38	169.23	169.29	169.27
C	Height 2	169.02	169.2	169.38	169.07	169.28	169.32	169.34	169.62	169.05	169.26
D	Height 3	169.3	169.08	169.27	169.32	169.46	169.34	169.21	169.34	169.19	169.32
E	Height 4	169.08	169.04	169.25	169.26	169.56	169.26	169.17	169.25	169.33	169.25
F	Average Height	169.1075	169.13	169.29	169.22	169.4025	169.305	169.275	169.36	169.215	169.275
G	Diameter 1	150.21	150.12	150.11	150.08	150.16	150.14	150.02	150.02	150.13	150.07
H	Diameter 2	150.06	150.14	150.03	150.25	150.24	150.26	150.02	150.08	150.14	149.97
I	Average Diameter	150.135	150.13	150.07	150.165	150.2	150.2	150.02	150.05	150.135	150.02
J	G_{mb} [A/(F*π*I^2/4)]	2.208	2.210	2.239	2.208	2.237	2.239	2.244	2.240	2.207	2.243
K	Air Voids [(G_{mm}-J)/G_{mm}]	12.0	12.0	10.8	12.1	10.9	10.9	10.6	10.8	12.1	10.7
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6611.6	6616	6705.6	6617	6713.5	6715.2	6714.6	6707.6	6611.5	6711.9
B	Submerged Mass	3835.5	3830.9	3873.3	3835.5	3876.9	3885	3883.8	3865.6	3843.1	3870.1
C	SSD Mass	6681.9	6682.2	6763.4	6681.2	6769.9	6765.8	6775.3	6764.5	6687.4	6755
D	G_{mb} [A/(C-B)]	2.323	2.320	2.320	2.325	2.321	2.331	2.322	2.314	2.324	2.327
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.5	7.6	7.6	7.4	7.6	7.2	7.5	7.9	7.4	7.3

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Project Number:
Location: M-45 Grand Rapids
Contractor:
Mix:
Gradation:
G_{mm} 2.513

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6877.6	6876.8	6879.6	6874.6	6877.6	6875.6	6880.3	6878.9	6886.1	6878.9
B	Height 1	168.91	168.49	168.81	168.65	168.72	168.97	168.64	168.82	168.57	168.73
C	Height 2	168.63	168.73	169.05	169.04	168.77	168.78	168.91	168.73	168.94	168.72
D	Height 3	168.66	168.64	168.9	168.84	169.11	168.66	168.86	168.65	168.9	168.84
E	Height 4	168.84	168.6	168.68	168.7	168.94	168.7	168.61	168.81	168.75	169.26
F	Average Height	168.76	168.615	168.86	168.8075	168.885	168.7775	168.755	168.7525	168.79	168.8875
G	Diameter 1	149.99	149.9	149.93	149.93	150.01	150.01	149.93	149.97	149.98	150.11
H	Diameter 2	150.02	149.97	150	149.94	149.93	149.98	149.99	149.91	150.05	149.97
I	Average Diameter	150.005	149.935	149.965	149.935	149.97	149.995	149.96	149.94	150.015	150.04
J	G_{mb} [A/(F*π*I^2/4)]	2.306	2.310	2.307	2.307	2.305	2.305	2.308	2.309	2.308	2.304
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.2	8.1	8.2	8.2	8.3	8.3	8.1	8.1	8.2	8.3
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6877.6	6876.8	6879.6	6874.6	6877.6	6875.6	6880.3	6878.9	6886.1	6878.9
B	Submerged Mass	3976.8	3973.5	3973.1	3963.4	3969.4	3972.4	3973.3	3967.3	3954.6	3969.9
C	SSD Mass	6922	6922.8	6925.8	6915.4	6916.9	6919.1	6924.6	6918.4	6916	6923.7
D	G_{mb} [A/(C-B)]	2.335	2.332	2.330	2.329	2.333	2.333	2.331	2.331	2.325	2.329
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.1	7.2	7.3	7.3	7.1	7.1	7.2	7.2	7.5	7.3

Project Number:
Location: M-21 St. Johns
Contractor:
Mix:
Gradation:
G_{mm} 2.489

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6550.4	6553.7	6555.1	6551	6553.3	6556.7	6549.6	6559	6547.5	6557.7
B	Height 1	168.71	168.56	168.44	168.62	169.93	168.94	168.42	168.46	168.91	168.88
C	Height 2	169.27	168.44	168.36	168.48	169.93	168.82	168.47	168.34	169.14	168.54
D	Height 3	168.8	169.35	168.75	168.33	168.77	168.74	168.54	168.44	169.02	169.12
E	Height 4	168.88	168.86	168.44	168.96	168.91	168.68	168.6	168.69	168.88	169.66
F	Average Height	168.915	168.8025	168.4975	168.5975	169.385	168.795	168.5075	168.4825	168.9875	169.05
G	Diameter 1	150.03	150.25	150.37	150.86	150.24	150.06	150.37	150.52	150.3	150.26
H	Diameter 2	150.07	150.32	150.08	150.58	150.25	150.2	150.18	150.23	150.2	150.2
I	Average Diameter	150.05	150.285	150.225	150.72	150.245	150.13	150.275	150.375	150.25	150.23
J	G_{mb} [A/(F*π*I^2/4)]	2.193	2.189	2.195	2.178	2.182	2.194	2.191	2.192	2.185	2.188
K	Air Voids [(G_{mm}-J)/G_{mm}]	11.9	12.1	11.8	12.5	12.3	11.8	12.0	11.9	12.2	12.1
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6551.2	6553.5	6556.1	6551.7	6554	6557.2	6550	6559.7	6547.7	6558.1
B	Submerged Mass	3788.9	3784.8	3781.1	3773.2	3792.3	3797.2	3787.2	3781	3789.8	3799
C	SSD Mass	6645.4	6647.7	6641.2	6631.2	6640.5	6643.3	6628.2	6643.6	6632.2	6644.7
D	G_{mb} [A/(C-B)]	2.293	2.289	2.292	2.292	2.301	2.304	2.306	2.292	2.304	2.305
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.9	8.0	7.9	7.9	7.5	7.4	7.4	7.9	7.4	7.4

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Project Number:
Location: M-84 Saginaw
Contractor:
Mix:
Gradation:
G_{mm} 2.543

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6946.1	6945.2	6947.1	6948.9	6948	6951.5	6944.6	6944.4	6948.1	6952.9
B	Height 1	169.16	168.87	169.98	169.94	169.34	168.71	168.86	168.86	168.88	169.09
C	Height 2	168.87	168.93	168.84	168.92	169.12	168.71	169.36	168.96	168.69	169.04
D	Height 3	169.05	168.68	169.12	169.91	168.82	169.14	169.09	169.9	169.04	168.63
E	Height 4	168.7	168.64	169.17	169.02	169.15	168.9	169.08	169.21	169.13	169.11
F	Average Height	168.945	168.78	169.2775	169.4475	169.1075	168.865	169.0975	169.2325	168.935	168.9675
G	Diameter 1	149.93	149.5	149.68	150.08	149.31	149.83	149.96	149.45	149.86	149.8
H	Diameter 2	149.85	150.32	149.81	150.27	149.76	149.83	149.75	149.82	149.76	149.66
I	Average Diameter	149.89	149.91	149.745	150.175	149.535	149.83	149.855	149.635	149.81	149.73
J	G_{mb} [A/(F*π*I^2/4)]	2.330	2.331	2.330	2.315	2.339	2.335	2.329	2.333	2.333	2.337
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.4	8.3	8.4	9.0	8.0	8.2	8.4	8.2	8.2	8.1

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6947.1	6945.8	6947.7	6949.7	6948.6	6952.4	6945.2	6945	6948.7	6953.5
B	Submerged Mass	4047.2	4046.6	4047.9	4045.9	4050.8	4055	4039.5	4053.4	4033.6	4063.8
C	SSD Mass	6992.1	6991.1	6992.3	6991.9	6992.7	6991.9	6987.3	6993.9	6979.1	6997.7
D	G_{mb} [A/(C-B)]	2.359	2.359	2.360	2.359	2.362	2.367	2.356	2.362	2.359	2.370
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.2	7.2	7.2	7.2	7.1	6.9	7.4	7.1	7.2	6.8

Project Number:
Location: BL I-96 Howell
Contractor:
Mix:
Gradation:
G_{mm} 2.501

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6892.8	6890.7	6887	6883.7	6885.9	6886.7	6889.1	6893.8	6892.8	6883.4
B	Height 1	169.75	169.46	169.53	169.49	169.48	169.71	169.85	169.4	169.52	169.42
C	Height 2	169.42	169.73	169.42	169.69	169.33	169.39	170.2	169.56	169.59	169.84
D	Height 3	169.65	169.81	169.45	169.37	169.35	169.56	169.77	169.59	169.58	169.57
E	Height 4	169.36	170.04	169.76	169.59	169.42	169.67	169.68	169.41	169.49	169.59
F	Average Height	169.545	169.76	169.54	169.535	169.395	169.5825	169.875	169.49	169.545	169.605
G	Diameter 1	149.99	149.84	150.04	149.98	150.08	150.14	149.87	150	149.45	150.05
H	Diameter 2	150.02	150.16	149.94	150.04	150.13	150.04	149.85	150.07	149.94	150.01
I	Average Diameter	150.005	150	149.99	150.01	150.105	150.09	149.86	150.035	149.695	150.03
J	G_{mb} [A/(F*π*I^2/4)]	2.300	2.297	2.299	2.297	2.297	2.295	2.299	2.301	2.310	2.296
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.0	8.2	8.1	8.1	8.2	8.2	8.1	8.0	7.6	8.2

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6893.2	6891	6888.1	6884.1	6885.9	6886.7	6889.1	6893.8	6892.8	6883.4
B	Submerged Mass	3944.4	3934.9	3936.8	3938.8	3949.6	3952.1	3954.6	3953.3	3958.2	3945.1
C	SSD Mass	6906.7	6903.3	6900.4	6901.1	6916.6	6917.3	6916.2	6919	6920.9	6903.6
D	G_{mb} [A/(C-B)]	2.327	2.321	2.324	2.324	2.321	2.323	2.326	2.325	2.327	2.327
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.0	7.2	7.1	7.1	7.2	7.1	7.0	7.1	7.0	7.0

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Project Number:
Location: M-21 Owosso
Contractor:
Mix:
Gradation:
G_{mm} 2.47

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6799.3	6792.1	6796.4	6794.6	6797	6797.4	6797.4	6797.8	6797.1	6797.2
B	Height 1	169.14	169.3	169.17	169.29	169.52	169.56	169.36	169.53	169.27	169.39
C	Height 2	169.29	169.47	169.17	169.22	169.32	169.33	169.41	169.28	169.38	169.43
D	Height 3	169.42	169.3	169.26	169.4	169.13	169.18	169.27	169.2	169.39	169.26
E	Height 4	169.33	169.43	169.32	169.48	169.36	169.41	169.19	169.45	169.25	169.21
F	Average Height	169.295	169.375	169.23	169.3475	169.3325	169.37	169.3075	169.365	169.3225	169.3225
G	Diameter 1	149.93	149.9	150.04	149.89	149.97	150	149.94	149.96	150	150.03
H	Diameter 2	149.86	150.14	149.91	149.89	149.86	149.98	149.94	149.88	150.02	149.91
I	Average Diameter	149.895	150.02	149.975	149.89	149.915	149.99	149.94	149.92	150.01	149.97
J	G_{mb} [A/(F*π*I^2/4)]	2.276	2.269	2.273	2.274	2.274	2.271	2.274	2.274	2.271	2.273
K	Air Voids [(G_{mm}-J)/G_{mm}]	7.9	8.2	8.0	7.9	7.9	8.0	7.9	7.9	8.0	8.0
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6799.3	6792.1	6796.4	6794.6	6797	6797.4	6797.4	6797.8	6797.1	6797.2
B	Submerged Mass	3861.6	3862.9	3859.7	3850.2	3853.9	3857	3861.4	3853.8	3848.6	3858.3
C	SSD Mass	6819.6	6824.6	6823.1	6820.3	6817.7	6821.4	6824	6816.5	6815.9	6822.1
D	G_{mb} [A/(C-B)]	2.299	2.293	2.293	2.288	2.293	2.293	2.294	2.294	2.291	2.293
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.9	7.2	7.1	7.4	7.2	7.2	7.1	7.1	7.3	7.1

Project Number:
Location: M-66 Battle Creek
Contractor:
Mix:
Gradation:
G_{mm} 2.47

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6840.3	6836.2	6841	6842.3	6841.4	6844	6845.1	6845.8	6844.9	6847
B	Height 1	169.37	169.47	169.42	169.06	169.27	169.31	169.04	169.11	169.14	169.1
C	Height 2	169.68	169.44	169.46	169.19	169.17	169.26	169.08	169.17	169.01	169.18
D	Height 3	169.4	169.29	169.48	169.08	169.22	169.34	169.43	169.29	169.3	169.29
E	Height 4	169.34	169.57	169.18	169.05	169.17	169.32	169.14	169.27	169.21	169.21
F	Average Height	169.4475	169.4425	169.385	169.095	169.2075	169.3075	169.1725	169.21	169.165	169.195
G	Diameter 1	149.99	150.01	149.98	149.94	149.89	149.96	150.05	150.06	150.03	150.02
H	Diameter 2	150.01	150.02	150.05	149.89	150.11	149.94	150.04	149.71	150.08	149.92
I	Average Diameter	150	150.015	150.015	149.915	150	149.95	150.045	149.885	150.055	149.97
J	G_{mb} [A/(F*π*I^2/4)]	2.284	2.283	2.285	2.292	2.288	2.289	2.288	2.293	2.288	2.291
K	Air Voids [(G_{mm}-J)/G_{mm}]	7.5	7.6	7.5	7.2	7.4	7.3	7.4	7.2	7.4	7.2
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6841.2	6838.9	6841.7	6843.3	6842.2	6844.7	6845.8	6846.8	6845.7	6851.8
B	Submerged Mass	3896.7	3899.9	3901.2	3894.4	3899.5	3897.5	3906.7	3911.8	3901.9	3904.8
C	SSD Mass	6861.8	6864.5	6857.7	6855.6	6859.3	6859.5	6867.9	6866.4	6861.3	6866.6
D	G_{mb} [A/(C-B)]	2.307	2.307	2.314	2.311	2.312	2.311	2.312	2.317	2.313	2.313
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.6	6.6	6.3	6.4	6.4	6.4	6.4	6.2	6.3	6.3

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Project Number:
Location: M-50 Dundee
Contractor:
Mix: 4 E 3
Gradation:
G_{mm} 2.538

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6848	6842	6842.6	6845.6	6851.8	6840.2	6845.2	6849.1	6846.6	6842.4
B	Height 1	169.04	168.88	168.79	168.85	168.89	169.03	168.98	168.73	168.83	168.84
C	Height 2	168.84	168.87	169.09	168.88	168.83	168.76	169.01	168.89	169.02	168.8
D	Height 3	168.8	168.73	169.07	168.9	168.78	168.79	168.98	168.93	169.11	168.85
E	Height 4	168.86	168.93	168.89	168.82	168.83	168.98	168.85	168.83	168.93	168.85
F	Average Height	168.885	168.8525	168.96	168.8625	168.8325	168.89	168.955	168.845	168.9725	168.835
G	Diameter 1	149.98	150.02	150.05	149.95	150.02	149.98	150	149.8	150.02	149.96
H	Diameter 2	150	150.01	149.92	150.04	149.98	150	149.98	149.93	150.11	149.94
I	Average Diameter	149.99	150.015	149.985	149.995	150	149.99	149.99	149.865	150.065	149.95
J	G_{mb} [A/(F*π*I^2/4)]	2.295	2.293	2.292	2.294	2.297	2.292	2.293	2.300	2.291	2.295
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.6	9.7	9.7	9.6	9.5	9.7	9.7	9.4	9.7	9.6
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6848	6842	6842.6	6845.6	6851.8	6840.2	6845.2	6849.1	6846.6	6842.4
B	Submerged Mass	3996.7	3995.1	3994.3	3993.8	3997.3	3995.4	3994.9	4001.4	3997.4	3995.2
C	SSD Mass	6905	6904.6	6903.8	6903.7	6904	6903.6	6901.3	6910.8	6904.5	6903.5
D	G_{mb} [A/(C-B)]	2.355	2.352	2.352	2.353	2.357	2.352	2.355	2.354	2.355	2.353
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.2	7.3	7.3	7.3	7.1	7.3	7.2	7.2	7.2	7.3

Project Number:
Location: US-12 MIS
Contractor:
Mix:
Gradation:
G_{mm} 2.491

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6755.5	6753.5	6754.9	6751.3	6752	6751.7	6653.8	6756.2	6752.7	6647.8
B	Height 1	169.15	169.28	169.31	169.57	169.3	169.42	169.38	169.17	169.22	169.27
C	Height 2	169.21	169.22	169.26	169.3	169.37	169.33	169.22	169.15	169.26	169.28
D	Height 3	169.2	169.16	169.24	169.62	169.24	169.24	169.07	169.4	169.39	169.31
E	Height 4	169.26	169.33	169.33	169.65	169.26	169.23	169.11	169.14	169.36	169.22
F	Average Height	169.205	169.2475	169.285	169.535	169.2925	169.305	169.195	169.215	169.3075	169.27
G	Diameter 1	150.01	150.1	150.19	150.42	150.05	150	150.04	150.12	150.4	150.05
H	Diameter 2	150.06	150.05	150.11	150.24	150.25	149.98	149.93	150.09	150.04	150.03
I	Average Diameter	150.035	150.075	150.15	150.33	150.15	149.99	149.985	150.105	150.22	150.04
J	G_{mb} [A/(F*π*I^2/4)]	2.258	2.256	2.254	2.244	2.252	2.257	2.226	2.256	2.250	2.221
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.3	9.4	9.5	9.9	9.6	9.4	10.6	9.4	9.7	10.8
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6755.5	6753.5	6754.9	6751.3	6752	6751.7	6653.8	6756.2	6752.7	6647.8
B	Submerged Mass	3877.8	3866.3	3863.6	3851.4	3870.7	3869.4	3838.3	3875	3870.8	3830
C	SSD Mass	6799.3	6794.2	6791.1	6785.1	6801.6	6796	6729.9	6800.4	6789.7	6725
D	G_{mb} [A/(C-B)]	2.312	2.307	2.307	2.301	2.304	2.307	2.301	2.309	2.313	2.296
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.2	7.4	7.4	7.6	7.5	7.4	7.6	7.3	7.1	7.8

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Project Number:
Location: M-59 Brighton
Contractor:
Mix:
Gradation:
G_{mm} 2.503

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6671	6659.1	6667.5	6667.4	6657.1	6669.3	6664.7	6661.6	6661.9	6668.9
B	Height 1	168.59	168.56	168.85	168.71	168.72	168.88	168.71	168.82	168.75	169.08
C	Height 2	168.79	168.32	168.98	168.76	169.06	168.76	168.88	168.91	168.65	168.74
D	Height 3	168.88	168.86	168.58	169.04	169.09	168.55	168.94	168.99	168.63	168.65
E	Height 4	168.81	168.73	168.78	169.03	168.84	168.77	168.95	168.49	168.74	168.97
F	Average Height	168.7675	168.6175	168.7975	168.885	168.9275	168.74	168.87	168.8025	168.6925	168.86
G	Diameter 1	150.44	150.89	149.92	150.02	150.04	149.66	150.18	150.22	149.95	149.94
H	Diameter 2	150.48	149.88	149.99	150.22	149.86	150.02	150.04	150.03	149.95	149.91
I	Average Diameter	150.46	150.385	149.955	150.12	149.95	149.84	150.11	150.125	149.95	149.925
J	G_{mb} [A/(F*π*I^2/4)]	2.223	2.223	2.237	2.230	2.232	2.241	2.230	2.229	2.236	2.237
K	Air Voids [(G_{mm}-J)/G_{mm}]	11.2	11.2	10.6	10.9	10.8	10.5	10.9	10.9	10.7	10.6

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6670.9	6659	6657.5	6664.8	6654.8	6669.3	6663.5	6661.3	6661.9	6668.8
B	Submerged Mass	3848.6	3845.8	3848.6	3855.1	3853.2	3847.4	3853	3845	3834.8	3881.6
C	SSD Mass	6717.5	6717.3	6715.4	6716	6716.2	6724.6	6721.3	6716.5	6713.8	6742.4
D	G_{mb} [A/(C-B)]	2.325	2.319	2.322	2.330	2.324	2.318	2.323	2.320	2.314	2.331
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.1	7.4	7.2	6.9	7.1	7.4	7.2	7.3	7.6	6.9

Project Number:
Location: Michigan Ave. Dearborn
Contractor:
Mix: 3 E 10
Gradation:
G_{mm} 2.493

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6719.5	6731	6724.4	6723.4	6729.9	6715.1	6728.8	6725.9	6709.9	6716.2
B	Height 1	169.17	169.35	169.19	169.21	169.07	169.49	169	169.3	168.75	169.02
C	Height 2	169.1	169.02	169	168.86	169.21	169.05	169.15	169.07	168.73	169.06
D	Height 3	169.24	169.41	168.89	169.31	169.02	169.31	169.05	169.35	169.05	169.04
E	Height 4	168.93	169.02	168.9	169.05	169.19	169.52	169.08	169.21	168.81	168.86
F	Average Height	169.11	169.2	168.995	169.1075	169.1225	169.3425	169.07	169.2325	168.835	168.995
G	Diameter 1	149.95	149.86	149.95	149.91	150.04	149.92	149.98	149.95	149.87	150.31
H	Diameter 2	149.96	149.98	150.14	149.86	149.99	149.88	149.94	149.7	149.95	149.8
I	Average Diameter	149.955	149.92	150.045	149.885	150.015	149.9	149.96	149.825	149.91	150.055
J	G_{mb} [A/(F*π*I^2/4)]	2.250	2.254	2.250	2.253	2.251	2.247	2.253	2.254	2.252	2.247
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.8	9.6	9.7	9.6	9.7	9.9	9.6	9.6	9.7	9.9

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6719.5	6731	6724.4	6723.4	6729.9	6715.1	6728.8	6725.9	6709.9	6716.2
B	Submerged Mass	3879.5	3886.2	3877.6	3873.4	3875.8	3866.4	3881	3876.2	3853.2	3848.4
C	SSD Mass	6765.1	6771.8	6772.1	6763.6	6771.3	6760.4	6768.2	6768	6744.9	6750.1
D	G_{mb} [A/(C-B)]	2.329	2.333	2.323	2.326	2.324	2.320	2.331	2.326	2.320	2.315
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.6	6.4	6.8	6.7	6.8	6.9	6.5	6.7	6.9	7.2

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Project Number:
Location: Vandyke Detroit
Contractor:
Mix:
Gradation:
G_{mm} 2.604

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	7127.5	7127.8	7129.1	7127.3	7125.1	7123.6	7153.8	7125.8	7124.8	7130.6
B	Height 1	169.09	169.08	169.02	169.18	169	169.14	169.3	169.05	169.25	169.12
C	Height 2	169.1	168.97	169.11	169.05	169.15	169.24	169.19	169.15	169.09	169.2
D	Height 3	169.29	169.03	169.28	169.04	169.17	169.08	169.01	169.33	169.08	169.47
E	Height 4	169.27	169.21	169.34	169.19	169.07	169.03	169.19	169.21	169.16	169.18
F	Average Height	169.1875	169.0725	169.1875	169.115	169.0975	169.1225	169.1725	169.185	169.145	169.2425
G	Diameter 1	150	150.05	150.06	150.1	150.01	150.01	150.25	150.13	150.03	150.01
H	Diameter 2	150.06	150.06	149.98	150.1	150.04	149.98	150.05	150.05	150.01	150.07
I	Average Diameter	150.03	150.055	150.02	150.1	150.025	149.995	150.15	150.09	150.02	150.04
J	G_{mb} [A/(F*π*I^2/4)]	2.383	2.384	2.384	2.382	2.384	2.384	2.388	2.381	2.383	2.383
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.5	8.5	8.5	8.5	8.5	8.5	8.3	8.6	8.5	8.5
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	7127.5	7127.8	7129.1	7127.3	7125.1	7123.6	7153.8	7125.8	7124.8	7130.6
B	Submerged Mass	4236.5	4229.2	4236.3	4235.1	4236.5	4234.7	4233.6	4222.9	4227.5	4225.1
C	SSD Mass	7171.1	7163.8	7165.9	7176.2	7168.3	7166.7	7173.1	7166.2	7164.7	7163.4
D	G_{mb} [A/(C-B)]	2.429	2.429	2.433	2.423	2.430	2.430	2.434	2.421	2.426	2.427
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.7	6.7	6.5	6.9	6.7	6.7	6.5	7.0	6.8	6.8

Project Number:
Location: US-23 Hartland
Contractor:
Mix:
Gradation:
G_{mm} 2.492

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6592.6	6704.4	6702.2	6586.2	6705	6699	6703.9	6705.4	6708.5	6586.9
B	Height 1	169.04	169.12	169.23	169.12	169.07	169.05	168.91	169.01	168.88	169.07
C	Height 2	169.33	169.15	169.13	168.76	168.95	168.95	169.32	169.17	168.96	169.14
D	Height 3	169.19	169.13	168.94	168.86	168.83	169.07	169.07	169.28	169.07	169.25
E	Height 4	169.25	169.2	169.25	169.53	169.14	169.08	168.76	169.1	169.07	169.28
F	Average Height	169.2025	169.15	169.1375	169.0675	168.9975	169.0375	169.015	169.14	168.995	169.185
G	Diameter 1	150.04	150.06	149.92	150.04	150.06	150.23	150.01	150.03	150.1	150.16
H	Diameter 2	150.19	150.13	150	149.4	150.03	150.16	149.94	150.32	150.09	150.14
I	Average Diameter	150.115	150.095	149.96	149.72	150.045	150.195	149.975	150.175	150.095	150.15
J	G_{mb} [A/(F*π*I^2/4)]	2.201	2.240	2.244	2.213	2.244	2.237	2.245	2.238	2.244	2.199
K	Air Voids [(G_{mm}-J)/G_{mm}]	11.7	10.1	10.0	11.2	10.0	10.2	9.9	10.2	10.0	11.8
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6721.1	6704.4	6702.2	6586.2	6705	6699	6703.9	6705.4	6708.5	6586.9
B	Submerged Mass	3885.8	3882.5	3883	3795.8	3870.6	3849.1	3884.3	3863.7	3865.5	3856.5
C	SSD Mass	6769.2	6768.4	6769.3	6662.5	6773.9	6759.9	6767.7	6772.9	6764.5	6701
D	G_{mb} [A/(C-B)]	2.331	2.323	2.322	2.297	2.309	2.301	2.325	2.305	2.314	2.316
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.5	6.8	6.8	7.8	7.3	7.6	6.7	7.5	7.1	7.1

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Project Number:
Location: I-75 Levering Rd.
Contractor:
Mix:
Gradation:
G_{mm} 2.443

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6682.4	6687.5	6683.7	6684.6	6685.7	6681.6	6684.5	6680.5	6686.2	6686.1
B	Height 1	168.94	168.69	168.72	168.98	169.15	168.65	168.62	168.57	169.11	169.06
C	Height 2	168.63	168.81	168.92	169.06	168.81	168.51	168.89	168.94	168.57	168.43
D	Height 3	168.96	169.4	169.02	169.01	169.03	168.89	168.85	168.96	168.87	168.73
E	Height 4	168.88	168.97	169.82	168.81	169	169.05	169.15	168.58	169.22	168.95
F	Average Height	168.8525	168.9675	169.12	168.965	168.9975	168.775	168.8775	168.7625	168.9425	168.7925
G	Diameter 1	149.7	149.65	149.66	149.97	149.6	149.76	149.85	149.65	149.88	149.63
H	Diameter 2	149.92	149.83	149.77	149.92	149.63	150.2	149.76	149.83	149.66	149.93
I	Average Diameter	149.81	149.74	149.715	149.945	149.615	149.98	149.805	149.74	149.77	149.78
J	G_{mb} [A/(F*π*I^2/4)]	2.245	2.247	2.245	2.240	2.250	2.241	2.246	2.248	2.246	2.248
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.1	8.0	8.1	8.3	7.9	8.3	8.1	8.0	8.0	8.0
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6684.7	6689.8	6686.1	6685.8	6687.3	6682.9	6686.7	6682.7	6687.7	6687.8
B	Submerged Mass	3793.3	3793.4	3787.6	3768.2	3766.9	3783.7	3785	3776	3769.8	3784
C	SSD Mass	6719.7	6733	6722.8	6712.8	6716.6	6716.6	6716.5	6717.3	6714.9	6717.3
D	G_{mb} [A/(C-B)]	2.284	2.276	2.278	2.271	2.267	2.279	2.281	2.272	2.271	2.280
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.5	6.8	6.8	7.1	7.2	6.7	6.6	7.0	7.0	6.7

Project Number:
Location: I-196 Grand Rapids
Contractor:
Mix:
Gradation:
G_{mm} 2.499

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6814.9	6813.8	6793.8	6818.3	6812.5	6818.7	6814.1	6817.3	6812	6815
B	Height 1	169	170.4	169.66	169.67	169.41	169.27	169.26	169.44	169.64	169.33
C	Height 2	169.45	170.59	169.52	169.35	169.35	169.49	169.3	169.62	169.62	169.5
D	Height 3	169.93	170.35	169.85	169.27	169.5	169.44	169.29	169.68	170.09	169.46
E	Height 4	169.25	169.93	170.22	169.6	169.48	169.32	169.33	169.52	169.7	169.35
F	Average Height	169.4075	170.3175	169.8125	169.4725	169.435	169.38	169.295	169.565	169.7625	169.41
G	Diameter 1	150.06	150.22	150.2	150.04	150.23	150.07	150	150.05	150.05	149.96
H	Diameter 2	150.02	150.07	150.12	150.01	149.99	149.96	149.99	150.06	150.18	149.95
I	Average Diameter	150.04	150.145	150.16	150.025	150.11	150.015	149.995	150.055	150.115	149.955
J	G_{mb} [A/(F*π*I^2/4)]	2.275	2.260	2.259	2.276	2.272	2.278	2.278	2.273	2.267	2.278
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.0	9.6	9.6	8.9	9.1	8.9	8.9	9.0	9.3	8.9
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6814.9	6813.8	6793.8	6818.3	6812.5	6818.7	6814.1	6817.3	6812	6815
B	Submerged Mass	3922.6	3914.3	3914.3	3926.4	3918.9	3935.3	3922.2	3921.6	3916	3926.4
C	SSD Mass	6870.5	6819.6	6863.9	6871.7	6868.8	6878.5	6865.1	6871.7	6878.5	6867.9
D	G_{mb} [A/(C-B)]	2.312	2.345	2.303	2.315	2.309	2.317	2.315	2.311	2.299	2.317
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.5	6.2	7.8	7.4	7.6	7.3	7.3	7.5	8.0	7.3

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Project Number:
Location: I-75 Clarkston
Contractor:
Mix:
Gradation:
G_{mm} 2.487

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6747.8	6749.7	6736	6742.5	6750.5	6747.1	6742.7	6816.5	6746.2	6745.4
B	Height 1	169.42	169.03	169.11	169.17	169.19	169.13	169.09	169.26	169.16	169.18
C	Height 2	169.24	169.16	169.26	169.1	169.28	169.25	169.21	169.12	169.26	169.19
D	Height 3	168.99	169.12	169	169.22	169.28	169.05	169.02	169.02	169.25	169.33
E	Height 4	169.08	169.14	169.07	169.06	169.19	169.07	169.14	169.18	169.16	169.26
F	Average Height	169.1825	169.1125	169.11	169.1375	169.235	169.125	169.115	169.145	169.2075	169.24
G	Diameter 1	149.95	150.09	149.99	150.01	150.06	149.95	150.06	149.9	149.95	149.95
H	Diameter 2	149.97	150.01	150.06	149.99	149.99	149.98	150.18	149.95	150.02	149.91
I	Average Diameter	149.96	150.05	150.025	150	150.025	149.965	150.12	149.925	149.985	149.93
J	G_{mb} [A/(F*π*I^2/4)]	2.258	2.257	2.253	2.256	2.256	2.259	2.253	2.283	2.257	2.258
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.2	9.2	9.4	9.3	9.3	9.2	9.4	8.2	9.3	9.2
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6747.8	6749.7	6736	6742.5	6750.5	6747.1	6742.7	6816.5	6746.2	6745.4
B	Submerged Mass	3870.9	3871.2	3862.9	3860	3871.1	3869	3860.2	3924.3	3864.2	3861.6
C	SSD Mass	6788.2	6793.4	6785.3	6791.9	6793.8	6792.5	6787.6	6855.2	6793.8	6786.6
D	G_{mb} [A/(C-B)]	2.313	2.310	2.305	2.300	2.310	2.308	2.303	2.326	2.303	2.306
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.0	7.1	7.3	7.5	7.1	7.2	7.4	6.5	7.4	7.3

Project Number:
Location: M-53 Detroit
Contractor:
Mix:
Gradation:
G_{mm} 2.563

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6949.6	6947.4	6947.3	6943	6947.4	6937.7	6952.6	6949.7	6947.8	6951.3
B	Height 1	168.9	168.91	168.99	169.09	168.89	168.91	168.92	168.88	168.99	168.97
C	Height 2	169.08	169.08	169.19	168.79	169.27	169.16	168.92	169.14	169.2	168.92
D	Height 3	169.06	168.93	168.87	168.71	168.96	168.91	169.06	169.13	169.04	169.06
E	Height 4	168.9	168.97	168.71	168.88	168.76	168.79	168.83	169.06	168.84	168.78
F	Average Height	168.985	168.9725	168.94	168.8675	168.97	168.9425	168.9325	169.0525	169.0175	168.9325
G	Diameter 1	149.97	149.93	149.91	149.94	149.97	149.9	149.98	149.97	149.93	149.92
H	Diameter 2	149.98	150.05	150.04	149.9	149.94	149.94	150	150.08	149.95	149.91
I	Average Diameter	149.975	149.99	149.975	149.92	149.955	149.92	149.99	150.025	149.94	149.915
J	G_{mb} [A/(F*π*I^2/4)]	2.328	2.327	2.328	2.329	2.328	2.326	2.329	2.326	2.328	2.331
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.2	9.2	9.2	9.1	9.2	9.2	9.1	9.3	9.2	9.0
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6949.6	6947.4	6947.3	6943	6947.4	6937.7	6952.6	6949.7	6947.8	6951.3
B	Submerged Mass	4083.9	4079.8	4081.1	4084.2	4085.6	4073.6	4097.9	4096.7	4076.7	4093.5
C	SSD Mass	7000.7	6995.4	6996.5	6995.2	7001.5	6989.8	7006.8	7005.2	7000.9	7003
D	G_{mb} [A/(C-B)]	2.383	2.383	2.383	2.385	2.383	2.379	2.390	2.389	2.376	2.389
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.0	7.0	7.0	6.9	7.0	7.2	6.7	6.8	7.3	6.8

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Project Number:
Location: Michigan Ave. Dearborn
Contractor:
Mix: 4 E 10
Gradation:
G_{mm} 2.485

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6703.2	6704.4	6700	6705.5	6701.2	6700.8	6701.3	6704.4	6702.1	6701.8
B	Height 1	169.04	169.26	169.16	169.07	169.35	169.15	169.46	169.53	169	169.27
C	Height 2	169.58	169.18	169.08	169.92	169.59	169.33	169.33	169.63	169.19	169.24
D	Height 3	169.21	169.35	169.2	169.47	169.37	169.6	169.41	169.12	169.59	169.38
E	Height 4	169.37	169.34	169.67	169.58	169.45	169.49	169.5	169.47	169.61	169.35
F	Average Height	169.3	169.2825	169.2775	169.51	169.44	169.3925	169.425	169.4375	169.3475	169.31
G	Diameter 1	149.94	150.05	150.03	149.49	149.93	149.98	149.97	150.04	150.04	150.04
H	Diameter 2	149.97	150.19	150.07	149.96	149.94	149.95	149.97	149.96	150.09	150.03
I	Average Diameter	149.955	150.12	150.05	149.725	149.935	149.965	149.97	150	150.065	150.035
J	G_{mb} [A/(F*π*I^2/4)]	2.242	2.238	2.238	2.247	2.240	2.240	2.239	2.239	2.238	2.239
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.8	10.0	9.9	9.6	9.9	9.9	9.9	9.9	10.0	9.9

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6703.4	6704.1	6699.6	6705.9	6700.8	6701	6700.9	6704.7	6701.7	6702.3
B	Submerged Mass	3836	3839.8	3826.3	3841.4	3827.4	3826.5	3830.8	3831.8	3828.8	3840.7
C	SSD Mass	6753.4	6751.7	6736.5	6751	6738.9	6746	6745.1	6746	6743.3	6747.5
D	G_{mb} [A/(C-B)]	2.298	2.302	2.302	2.305	2.301	2.295	2.299	2.301	2.299	2.306
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.5	7.4	7.4	7.3	7.4	7.6	7.5	7.4	7.5	7.2

Project Number:
Location: I-75 Toledo
Contractor:
Mix:
Gradation:
G_{mm} 2.507

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6813.8	6818.3	6811.9	6809.6	6811.5	6809.8	6814.8	6811.8	6811.9	6812.9
B	Height 1	169.3	169.36	169.19	169.4	169.37	169.32	169.38	169.28	169.17	169.28
C	Height 2	169.33	169.49	169.26	169.24	169.26	169.18	169.35	169.38	169.46	169.36
D	Height 3	169.1	169.34	169.32	169.19	169.12	169.25	169.32	169.51	169.45	169.31
E	Height 4	169.19	169.26	169.33	169.35	169.27	169.37	169.27	169.23	169.23	169.24
F	Average Height	169.23	169.3625	169.275	169.295	169.255	169.28	169.33	169.35	169.3275	169.2975
G	Diameter 1	150.01	149.86	150.11	149.99	149.96	150.04	149.94	149.98	150.03	149.94
H	Diameter 2	149.96	150.01	149.98	149.88	149.98	150.08	150.01	150.02	149.97	150.04
I	Average Diameter	149.985	149.935	150.045	149.935	149.97	150.06	149.975	150	150	149.99
J	G_{mb} [A/(F*π*I^2/4)]	2.279	2.280	2.276	2.278	2.278	2.275	2.278	2.276	2.277	2.278
K	Air Voids [(G_{mm}-J)/G_{mm}]	9.1	9.0	9.2	9.1	9.1	9.3	9.1	9.2	9.2	9.2

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6813.8	6818.3	6811.9	6809.6	6811.5	6809.8	6814.8	6811.8	6811.9	6812.9
B	Submerged Mass	3945.2	3958.5	3951.8	3945.5	3951.8	3946.8	3954.7	3947.9	3947.1	3950.2
C	SSD Mass	6877.6	6881.3	6883.1	6874.5	6877.7	6872.9	6877.2	6873.4	6879.2	6875.9
D	G_{mb} [A/(C-B)]	2.324	2.333	2.324	2.325	2.328	2.327	2.332	2.328	2.323	2.329
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.3	6.9	7.3	7.3	7.1	7.2	7.0	7.1	7.3	7.1

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Project Number:
Location: I-94 Ann Arbor
Contractor:
Mix: SMA
Gradation:
G_{mm} 2.515

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6730	6729.3	6720.4	6722.6	6730.7	6724	6729.9	6727.7	6721.8	6727.8
B	Height 1	168.95	168.95	168.81	168.9	168.79	168.96	168.97	168.91	169.04	168.89
C	Height 2	168.65	168.92	169.03	168.99	169.16	169.03	168.85	168.84	169.15	169.01
D	Height 3	168.65	168.82	168.7	168.84	168.92	168.89	168.8	168.62	168.91	168.97
E	Height 4	168.89	168.89	168.79	168.8	169.06	168.91	168.75	168.54	168.85	168.8
F	Average Height	168.785	168.895	168.8325	168.8825	168.9825	168.9475	168.8425	168.7275	168.9875	168.9175
G	Diameter 1	149.92	149.97	149.9	149.98	150.15	149.93	150.01	150	149.96	149.93
H	Diameter 2	150.12	150	150	149.95	149.94	150.02	150	149.99	149.98	150.12
I	Average Diameter	150.02	149.985	149.95	149.965	150.045	149.975	150.005	149.995	149.97	150.025
J	G_{mb} [A/(F*π*I^2/4)]	2.256	2.255	2.254	2.254	2.253	2.253	2.255	2.257	2.252	2.253
K	Air Voids [(G_{mm}-J)/G_{mm}]	10.3	10.3	10.4	10.4	10.4	10.4	10.3	10.3	10.5	10.4
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	6730	6729.3	6720.4	6722.6	6730.7	6724	6729.9	6727.7	6721.8	6727.8
B	Submerged Mass	3937.5	3935.3	3927.1	3936.8	3939.9	3941.4	3940.2	3942.7	3930.6	3938.4
C	SSD Mass	6801.4	6797.4	6792.2	6801.8	6796.5	6801.5	6803.3	6809.1	6791.6	6795.1
D	G_{mb} [A/(C-B)]	2.350	2.351	2.346	2.346	2.356	2.351	2.351	2.347	2.349	2.355
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.6	6.5	6.7	6.7	6.3	6.5	6.5	6.7	6.6	6.4

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Phase II – 100mm Superpave Specimens for Dynamic Modulus Testing Cut and Cored from 150mm Diameter Superpave Specimens

Project Number:
Location: M-50 Dundee
Contractor:
Mix: 3 E 1
Gradation:
G_{mm} 2.52

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2869.3	2816.3	2868.7	2825.2	2834.7	2859.7	2809.2	2893	2803.4	2832.8
B	Height 1	151.03	151.11	151.17	151.5	151.13	150.89	151.01	150.85	150.97	150.95
C	Height 2	151.52	151.13	151.45	151.48	151.31	151.11	150.88	150.92	150.98	151.02
D	Height 3	151.14	151.3	151.23	151.54	151.24	150.88	151.19	151.24	150.89	151.03
E	Height 4	150.96	151.37	151.12	151.34	151.02	151.07	151.07	151.06	150.81	150.82
F	Average Height	151.1625	151.2275	151.2425	151.465	151.175	150.9875	151.0375	151.0175	150.9125	150.955
G	Top Diameter 1	101.5	101.37	101.22	101.12	101.41	101.2	101.31	101.45	101.27	101.24
H	Top Diameter 2	101.26	101.32	101.44	101.42	101.43	101.31	101.43	101.4	101.27	101.28
	Middle Diameter 1	101.22	101.27	101.29	101.3	100.99	101.11	101.32	101.2	101.3	101.13
	Middle Diameter 2	101.3	101.29	101.22	101.35	101.27	101.25	101.26	101.27	101.25	101.35
	Bottom Diameter 1	101.49	101.28	101.44	101.27	101.36	101.06	101.45	101.32	101.23	101.11
	Bottom Diameter 2	101.43	101.28	101.26	101.41	101.25	101.35	101.26	101.29	101.38	101.49
I	Average Diameter	101.3667	101.3017	101.3	101.3117	101.285	101.2133	101.3383	101.3217	101.2833	101.2667
J	G_{mb} [A/(F*π*I^2/4)]	2.352	2.311	2.353	2.314	2.327	2.354	2.306	2.376	2.306	2.330
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.7	8.3	6.6	8.2	7.6	6.6	8.5	5.7	8.5	7.5

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2869.3	2816.3	2868.7	2825.2	2834.7	2859.7	2809.2	2893	2803.4	2832.8
B	Submerged Mass	1664.3	1634.6	1663.4	1637.6	1654	1658	1625.2	1692	1623.9	1649.4
C	SSD Mass	2884.1	2846.3	2883.7	2850.7	2862.4	2875.8	2834	2910.7	2828.1	2861.9
D	G_{mb} [A/(C-B)]	2.352	2.324	2.351	2.329	2.346	2.348	2.324	2.374	2.328	2.336
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.7	7.8	6.7	7.6	6.9	6.8	7.8	5.8	7.6	7.3

Project Number:
Location: M-36 Pinckney
Contractor:
Mix:
Gradation:
G_{mm} 2.511

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2821.1	2835.1	2852.2	2840.7	2852.2	2874.5	2869.3	2850.3	2845.3	2887.7
B	Height 1	151.55	151.34	151.85	151.62	151.35	151.17	152.41	151.51	151.44	152.82
C	Height 2	151.39	151.45	151.52	151.48	151.41	151.42	152.25	151.34	151.5	152.05
D	Height 3	151.37	151.58	151.47	151.47	151.31	151.29	152.57	151.3	151.58	152.13
E	Height 4	151.55	151.56	151.38	151.52	151.38	151.32	152.61	151.34	151.46	152.15
F	Average Height	151.47	151.48	151.56	151.52	151.36	151.30	152.46	151.37	151.50	152.29
G	Top Diameter 1	102.05	101.94	102.05	102.12	101.82	102.07	102	102.01	101.86	102.13
H	Top Diameter 2	101.93	102.03	102.1	102.03	102.03	102.01	102.08	101.88	101.91	102.03
	Middle Diameter 1	101.63	101.67	101.79	101.66	101.62	101.74	101.58	101.53	101.76	101.57
	Middle Diameter 2	101.63	101.66	101.71	101.71	101.6	101.74	101.67	101.48	101.72	101.56
	Bottom Diameter 1	101.61	101.83	101.76	101.64	101.6	101.64	101.59	101.51	101.63	101.54
	Bottom Diameter 2	101.82	101.64	101.74	101.53	101.88	101.79	101.6	101.66	101.64	101.62
I	Average Diameter	101.78	101.80	101.86	101.78	101.76	101.83	101.75	101.68	101.75	101.74
J	G_{mb} [A/(F*π*I^2/4)]	2.289	2.300	2.310	2.304	2.317	2.333	2.314	2.319	2.310	2.332
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.8	8.4	8.0	8.2	7.7	7.1	7.8	7.6	8.0	7.1

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2821.1	2835.1	2852.2	2840.7	2852.2	2874.5	2869.3	2850.3	2845.3	2887.7
B	Submerged Mass	1627	1636	1649.8	1642.7	1651	1672	1656.6	1645.4	1648	1671.9
C	SSD Mass	2842.6	2855.2	2870	2862	2870.3	2891	2883.7	2864	2866.1	2899.7
D	G_{mb} [A/(C-B)]	2.321	2.325	2.337	2.330	2.339	2.358	2.338	2.339	2.336	2.352
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.6	7.4	6.9	7.2	6.8	6.1	6.9	6.9	7.0	6.3

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Project Number:
Location: M-45 Grand Rapids
Contractor:
Mix:
Gradation:
G_{mm} 2.513

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2901.3	2901.3	2895.4	2897.7	2898.2	2905.9	2902.8	2910.1	2902.4	2898.3
B	Height 1	151.23	151.46	151.4	151.61	151.68	151.97	151.8	151.54	151.64	151.7
C	Height 2	151.32	151.4	151.32	151.42	151.43	151.54	151.79	151.58	151.61	151.84
D	Height 3	151.5	151.53	151.52	151.57	151.35	151.67	151.67	151.51	151.64	151.86
E	Height 4	151.36	151.4	151.51	151.41	151.22	151.55	151.68	151.4	151.69	151.77
F	Average Height	151.35	151.45	151.44	151.50	151.42	151.68	151.74	151.51	151.65	151.79
G	Top Diameter 1	101.95	101.95	101.97	102.03	101.96	101.93	101.95	101.92	101.93	101.89
H	Top Diameter 2	101.97	101.82	101.87	101.91	101.89	102.18	102.02	101.86	101.98	102.02
	Middle Diameter 1	101.67	101.48	101.69	101.5	101.51	101.63	101.73	101.74	101.55	101.52
	Middle Diameter 2	101.53	101.57	101.43	101.71	101.6	101.61	101.55	101.65	101.51	101.5
	Bottom Diameter 1	101.42	101.65	101.46	101.91	101.66	101.56	101.54	101.5	101.53	101.62
	Bottom Diameter 2	101.75	101.31	101.87	101.61	101.51	101.83	101.81	101.83	101.92	101.44
I	Average Diameter	101.72	101.63	101.72	101.78	101.69	101.79	101.77	101.75	101.74	101.67
J	G_{mb} [A/(F*π*I^2/4)]	2.359	2.362	2.353	2.351	2.357	2.354	2.352	2.362	2.354	2.352
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.1	6.0	6.4	6.5	6.2	6.3	6.4	6.0	6.3	6.4
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2901.3	2901.3	2895.4	2897.7	2898.2	2905.9	2902.8	2910.1	2902.4	2898.3
B	Submerged Mass	1687.1	1686.6	1681.9	1682.3	1681.2	1688.7	1687.5	1692.3	1684.5	1680.7
C	SSD Mass	2913.4	2913	2908.6	2909.7	2908.4	2917.3	2915.9	2920.6	2913.5	2909.4
D	G_{mb} [A/(C-B)]	2.366	2.366	2.360	2.361	2.362	2.365	2.363	2.369	2.362	2.359
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.9	5.9	6.1	6.1	6.0	5.9	6.0	5.7	6.0	6.1

Project Number:
Location: M-21 St. Johns
Contractor:
Mix:
Gradation:
G_{mm} 2.489

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2821.8	2818.6	2831.5	2831.5	2827.1	2840.4	2833.2	2785.4	2812.7	2814.7
B	Height 1	151.96	152.57	153.07	152.98	153.53	153.28	153.03	151.76	152.07	152.58
C	Height 2	152.16	152.67	153.05	153.55	153.73	152.9	152.9	151.52	152.14	152.89
D	Height 3	152.46	152.09	153.33	153.6	153.06	153.03	152.47	151.54	152.45	153.02
E	Height 4	152.25	152.14	153.46	153.03	152.87	153.49	152.55	151.66	152.6	152.83
F	Average Height	152.21	152.37	153.23	153.29	153.30	153.18	152.74	151.62	152.32	152.83
G	Top Diameter 1	101.68	101.53	101.65	101.41	101.56	101.37	101.74	101.4	101.51	101.42
H	Top Diameter 2	101.48	101.42	101.35	101.48	101.31	101.49	101.42	101.37	101.4	101.67
	Middle Diameter 1	101.56	101.51	101.53	101.46	101.54	101.56	101.48	101.52	101.56	101.62
	Middle Diameter 2	101.74	101.67	101.57	101.42	101.47	101.59	101.49	101.63	101.62	101.55
	Bottom Diameter 1	101.69	101.59	101.65	101.69	101.46	101.56	101.65	101.62	101.65	101.53
	Bottom Diameter 2	101.57	101.71	101.57	101.54	101.57	101.5	101.42	101.44	101.63	101.65
I	Average Diameter	101.62	101.57	101.55	101.50	101.49	101.51	101.53	101.50	101.56	101.57
J	G_{mb} [A/(F*π*I^2/4)]	2.286	2.283	2.281	2.283	2.280	2.291	2.291	2.271	2.279	2.273
K	Air Voids [(G_{mm}-J)/G_{mm}]	8.2	8.3	8.3	8.3	8.4	7.9	8.0	8.8	8.4	8.7
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2821.8	2818.6	2831.5	2831.5	2827.1	2840.4	2833.2	2785.4	2812.7	2814.7
B	Submerged Mass	1616.1	1612.5	1618.9	1619.8	1621.2	1630.2	1627	1590.2	1611.2	1612.2
C	SSD Mass	2843.3	2840.1	2850.8	2851.5	2851.6	2861.2	2854.9	2810.7	2835.9	2841.6
D	G_{mb} [A/(C-B)]	2.299	2.296	2.298	2.299	2.298	2.307	2.307	2.282	2.297	2.289
E	Air Voids [(G_{mm}-D)/G_{mm}]	7.6	7.8	7.7	7.6	7.7	7.3	7.3	8.3	7.7	8.0

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Project Number:
Location: M-84 Saginaw
Contractor:
Mix:
Gradation:
G_{mm} 2.543

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2950.9	2944.7	2931.1	2916.1	2937.5	2953.6	2951.6	2952.9	2940.7	2965.8
B	Height 1	152.6	152.41	151.83	151.65	151.65	152.04	152.93	152.89	152.08	152.52
C	Height 2	152.42	152.83	152.06	151.64	152.13	152.11	152.97	153.07	152	152.44
D	Height 3	152.5	152.83	151.77	151.74	152.01	152.29	152.54	153.1	152.28	152.82
E	Height 4	152.75	152.46	151.78	151.57	151.78	152.53	152.64	153.22	152.23	152.15
F	Average Height	152.57	152.63	151.86	151.65	151.89	152.24	152.77	153.07	152.15	152.48
G	Top Diameter 1	101.43	101.53	101.52	101.59	101.42	101.49	101.48	101.49	101.46	101.54
H	Top Diameter 2	101.55	101.53	101.39	101.46	101.71	101.54	101.43	101.43	101.54	101.58
	Middle Diameter 1	101.53	101.66	101.45	101.47	101.58	101.47	101.43	101.52	101.58	101.56
	Middle Diameter 2	101.56	101.52	101.53	101.65	101.45	101.48	101.44	101.49	101.56	101.65
	Bottom Diameter 1	101.53	101.44	101.5	101.59	101.6	101.59	101.58	101.65	101.58	101.66
	Bottom Diameter 2	101.59	101.51	101.56	101.56	101.52	101.4	101.34	101.55	101.53	101.53
I	Average Diameter	101.53	101.53	101.49	101.55	101.55	101.50	101.45	101.52	101.54	101.59
J	G_{mb} [A/(F*π*I^2/4)]	2.389	2.383	2.386	2.374	2.388	2.398	2.390	2.383	2.387	2.400
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.1	6.3	6.2	6.6	6.1	5.7	6.0	6.3	6.1	5.6
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2950.9	2944.7	2931.1	2916.1	2937.5	2953.6	2951.6	2952.9	2940.7	2965.8
B	Submerged Mass	1725	1719.2	1712.4	1697.8	1717.1	1730.4	1723.6	1723.5	1718.7	1738.4
C	SSD Mass	2960.9	2952.7	2940.4	2925.2	2946.3	2962.7	2960	2961.8	2949.5	2974.3
D	G_{mb} [A/(C-B)]	2.388	2.387	2.387	2.376	2.390	2.397	2.387	2.385	2.389	2.400
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.1	6.1	6.1	6.6	6.0	5.7	6.1	6.2	6.0	5.6

Project Number:
Location: BL I-96 Howell
Contractor:
Mix:
Gradation:
G_{mm} 2.501

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2897.3	2880.6	2907.8	2901.8	2899.8	2846.9	2882.1	2890.9	2894.7	2888.5
B	Height 1	152.08	151.66	152.72	152.68	152.38	152.3	151.73	152.3	152.64	151.89
C	Height 2	152.39	151.92	152.8	152.89	152.92	152.54	151.59	152.24	152.7	152.11
D	Height 3	152.09	151.9	153.08	152.86	153.09	152.24	151.71	152.39	152.17	151.86
E	Height 4	152.02	151.67	153.29	152.67	152.48	152.07	151.63	152.49	152.26	151.68
F	Average Height	152.15	151.79	152.97	152.78	152.72	152.29	151.67	152.36	152.44	151.89
G	Top Diameter 1	101.37	101.47	101.49	101.5	101.51	99.88	101.43	101.51	101.49	101.42
H	Top Diameter 2	101.57	101.66	101.59	101.58	101.39	99.79	101.39	101.55	101.35	101.55
	Middle Diameter 1	101.59	101.61	101.49	101.53	101.43	100.24	101.67	101.51	101.43	101.57
	Middle Diameter 2	101.52	101.46	101.54	101.48	101.54	101.31	101.61	101.58	101.53	101.58
	Bottom Diameter 1	101.52	101.6	101.58	101.48	101.54	101.69	101.51	101.59	101.62	101.63
	Bottom Diameter 2	101.55	101.55	101.55	101.56	101.52	101.57	101.68	101.54	101.52	101.58
I	Average Diameter	101.52	101.56	101.54	101.52	101.49	100.75	101.55	101.55	101.49	101.56
J	G_{mb} [A/(F*π*I^2/4)]	2.353	2.343	2.347	2.346	2.347	2.345	2.346	2.343	2.347	2.348
K	Air Voids [(G_{mm}-J)/G_{mm}]	5.9	6.3	6.1	6.2	6.1	6.2	6.2	6.3	6.1	6.1
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2897.3	2880.6	2907.8	2901.8	2899.8	2846.9	2882.1	2890.9	2894.7	2888.5
B	Submerged Mass	1674.1	1658.4	1679	1674	1671.3	1661.2	1664.4	1669.2	1666.4	1641.5
C	SSD Mass	2905.2	2888.5	2917.3	2910.3	2907.9	2889	2897.9	2902.5	2895.6	2855.1
D	G_{mb} [A/(C-B)]	2.353	2.342	2.348	2.347	2.345	2.319	2.337	2.344	2.355	2.380
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.9	6.4	6.1	6.2	6.2	7.3	6.6	6.3	5.8	4.8

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Project Number:
Location: M-21 Owosso
Contractor:
Mix:
Gradation:
G_{mm} 2.47

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2855.8	2848.3	2849.8	2842	2845.1	2847.8	2848.6	2856.8	2840.5	2860
B	Height 1	151.77	151.81	151.67	151.53	151.66	151.61	151.78	151.85	151.65	152.4
C	Height 2	151.86	151.52	151.67	151.53	151.6	151.7	151.94	152.19	151.62	152.67
D	Height 3	151.62	151.48	151.62	151.76	151.66	151.49	151.59	152.09	151.67	152.71
E	Height 4	151.65	151.55	151.91	151.49	151.52	151.59	151.62	151.79	151.56	152.32
F	Average Height	151.73	151.59	151.72	151.58	151.61	151.60	151.73	151.98	151.63	152.53
G	Top Diameter 1	101.56	101.56	101.55	101.55	101.42	101.51	101.52	101.53	101.56	101.47
H	Top Diameter 2	101.58	101.49	101.58	101.48	101.49	101.44	101.5	101.5	101.54	101.53
	Middle Diameter 1	101.61	101.58	101.57	101.56	101.54	101.58	101.52	101.57	101.59	101.58
	Middle Diameter 2	101.58	101.59	101.57	101.55	101.54	101.54	101.57	101.63	101.6	101.56
	Bottom Diameter 1	101.55	101.54	101.55	101.58	101.56	101.61	101.56	101.59	101.55	101.53
	Bottom Diameter 2	101.56	101.52	101.61	101.54	101.55	101.48	101.56	101.58	101.58	101.55
I	Average Diameter	101.57	101.55	101.57	101.54	101.52	101.53	101.54	101.57	101.57	101.54
J	G_{mb} [A/(F*π*I^2/4)]	2.323	2.320	2.318	2.315	2.318	2.320	2.318	2.320	2.312	2.316
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.0	6.1	6.1	6.3	6.1	6.1	6.1	6.1	6.4	6.2

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2855.8	2848.3	2849.8	2842	2845.1	2847.8	2848.6	2856.8	2840.5	2860
B	Submerged Mass	1635.4	1629.2	1630.8	1621.5	1624	1629.1	1628.4	1632.9	1620.1	1635.3
C	SSD Mass	2863.8	2857.2	2857.7	2848.5	2851.6	2856	2856.4	2864.1	2848.4	2868.8
D	G_{mb} [A/(C-B)]	2.325	2.319	2.323	2.316	2.318	2.321	2.320	2.320	2.313	2.319
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.9	6.1	6.0	6.2	6.2	6.0	6.1	6.1	6.4	6.1

Project Number:
Location: M-66 Battle Creek
Contractor:
Mix:
Gradation:
G_{mm} 2.47

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2858.6	2862.1	2863.9	2863.4	2876.6	2866.3	2876.8	2873.2	2869.5	2867.1
B	Height 1	152.09	151.75	151.81	151.82	151.88	151.77	151.67	151.65	151.67	151.71
C	Height 2	151.66	151.55	151.67	151.71	151.95	151.83	151.73	151.7	151.58	151.71
D	Height 3	151.67	151.68	151.75	151.9	151.91	151.89	152.09	151.77	151.56	151.52
E	Height 4	152.08	151.71	151.84	151.76	151.99	151.88	151.83	151.54	151.64	151.65
F	Average Height	151.88	151.67	151.77	151.80	151.93	151.84	151.83	151.67	151.61	151.65
G	Top Diameter 1	101.43	101.48	101.42	101.57	101.34	101.57	101.65	101.46	101.63	101.5
H	Top Diameter 2	101.55	101.44	101.53	101.47	101.52	101.58	101.45	101.53	101.59	101.47
	Middle Diameter 1	101.59	101.47	101.63	101.6	101.63	101.59	101.48	101.59	101.57	101.54
	Middle Diameter 2	101.56	101.63	101.54	101.58	101.51	101.64	101.62	101.61	101.64	101.53
	Bottom Diameter 1	101.59	101.6	101.61	101.59	101.54	101.71	101.63	101.59	101.71	101.62
	Bottom Diameter 2	101.56	101.51	101.65	101.64	101.65	101.53	101.53	101.6	101.57	101.58
I	Average Diameter	101.55	101.52	101.56	101.58	101.53	101.60	101.56	101.56	101.62	101.54
J	G_{mb} [A/(F*π*I^2/4)]	2.324	2.331	2.329	2.328	2.338	2.328	2.339	2.338	2.334	2.335
K	Air Voids [(G_{mm}-J)/G_{mm}]	5.9	5.6	5.7	5.8	5.3	5.7	5.3	5.3	5.5	5.5

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2858.6	2862.1	2863.9	2863.4	2876.6	2866.3	2876.8	2873.2	2869.5	2867.1
B	Submerged Mass	1638.8	1642.8	1644.2	1641.6	1654.8	1645	1653.4	1653	1648.8	1647.4
C	SSD Mass	2867.2	2870.4	2872	2870.2	2884.4	2873.4	2883.3	2880.4	2876.3	2875.4
D	G_{mb} [A/(C-B)]	2.327	2.331	2.333	2.331	2.339	2.333	2.339	2.341	2.338	2.335
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.8	5.6	5.6	5.6	5.3	5.5	5.3	5.2	5.4	5.5

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Project Number:
Location: M-50 Dundee
Contractor:
Mix: 4 E 3
Gradation:
G_{mm} 2.538

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2919.3	2913	2907.1	2916.7	2919.9	2911	2922	2921.2	2932.3	2915.5
B	Height 1	151.37	151.13	151.17	151.27	151.51	151.29	151.3	151.53	151.9	151.41
C	Height 2	151.38	151.2	151.18	151.24	151.58	151.22	151.22	151.84	151.93	151.35
D	Height 3	151.27	151.19	151.17	151.2	151.57	151.22	151.15	151.65	152.19	151.16
E	Height 4	151.39	151.2	151.28	151.3	151.47	151.18	151.15	151.65	152.02	151.19
F	Average Height	151.3525	151.18	151.2	151.2525	151.5325	151.2275	151.205	151.6675	152.01	151.2775
G	Top Diameter 1	101.83	101.76	101.84	101.95	101.92	102	101.89	101.9	101.87	101.89
H	Top Diameter 2	101.96	101.82	101.98	101.81	101.89	101.96	101.87	101.97	101.95	101.86
	Middle Diameter 1	101.53	101.46	101.58	101.64	101.67	101.63	101.64	101.55	101.42	101.71
	Middle Diameter 2	101.65	101.71	101.55	101.62	101.65	101.59	101.51	101.47	101.63	101.56
	Bottom Diameter 1	101.69	101.87	101.52	101.65	101.41	101.7	101.56	101.53	101.7	101.6
	Bottom Diameter 2	101.48	101.68	101.63	101.69	101.5	101.74	101.56	101.73	101.65	101.48
I	Average Diameter	101.69	101.72	101.68	101.73	101.67	101.77	101.67	101.69	101.70	101.68
J	G_{mb} [A/(F*π*I^2/4)]	2.375	2.371	2.368	2.373	2.373	2.366	2.380	2.371	2.375	2.373
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.4	6.6	6.7	6.5	6.5	6.8	6.2	6.6	6.4	6.5
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2919.3	2913	2907.1	2916.7	2919.9	2911	2922	2921.2	2932.3	2915.5
B	Submerged Mass	1706.9	1702	1694.8	1702.9	1706.2	1701.5	1710.2	1706.6	1712.7	1705.8
C	SSD Mass	2929	2924.2	2916.9	2925.9	2930.8	2922.8	2933.1	2932.1	2942.3	2928.6
D	G_{mb} [A/(C-B)]	2.389	2.383	2.379	2.385	2.384	2.384	2.389	2.384	2.385	2.384
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.9	6.1	6.3	6.0	6.1	6.1	5.9	6.1	6.0	6.1

Project Number:
Location: US-12 MIS
Contractor:
Mix:
Gradation:
G_{mm} 2.491

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2864.2	2859.6	2854.2	2831.8	2830.3	2840	2859.1	2850.1	2854.6	2814.9
B	Height 1	151.54	151.24	151.17	151.23	151.14	151.14	153.33	151.32	151.14	151.13
C	Height 2	151.47	151.35	151.04	151.12	150.97	151.24	153.38	151.24	151.05	151.28
D	Height 3	151.48	151.6	151.22	151.19	151.24	151.55	153.61	151.22	151.14	151.6
E	Height 4	151.66	151.27	151.07	151.09	151.25	151.03	153.66	151.31	151.17	151.26
F	Average Height	151.54	151.37	151.13	151.16	151.15	151.24	153.50	151.27	151.13	151.32
G	Top Diameter 1	102.05	102.08	101.96	101.89	101.73	101.94	101.82	101.74	101.84	101.86
H	Top Diameter 2	101.87	102.01	101.9	102.06	101.94	101.8	101.75	101.65	101.8	101.73
	Middle Diameter 1	101.66	101.65	101.69	101.52	101.58	101.33	101.49	101.52	101.52	101.51
	Middle Diameter 2	101.62	101.74	101.67	101.65	101.53	101.68	101.7	101.55	101.58	101.47
	Bottom Diameter 1	101.85	101.77	101.82	101.66	101.29	101.42	101.61	101.52	101.55	101.51
	Bottom Diameter 2	101.73	101.67	101.81	101.57	101.39	101.39	101.41	101.45	101.41	101.5
I	Average Diameter	101.80	101.82	101.81	101.73	101.58	101.59	101.63	101.57	101.62	101.60
J	G_{mb} [A/(F*π*I^2/4)]	2.322	2.320	2.320	2.305	2.311	2.316	2.296	2.325	2.329	2.295
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.8	6.9	6.9	7.5	7.2	7.0	7.8	6.7	6.5	7.9
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2864.2	2859.6	2854.2	2831.8	2830.3	2840	2859.1	2850.1	2854.6	2814.9
B	Submerged Mass	1645.1	1641.6	1637.6	1619	1621.4	1631.3	1642	1639.9	1643.5	1613.3
C	SSD Mass	2871.8	2866.8	2862.4	2840.2	2839.3	2849.7	2875.5	2859.7	2863.3	2831.4
D	G_{mb} [A/(C-B)]	2.335	2.334	2.330	2.319	2.324	2.331	2.318	2.337	2.340	2.311
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.3	6.3	6.4	6.9	6.7	6.4	6.9	6.2	6.1	7.2

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Project Number:
Location: M-59 Brighton
Contractor:
Mix:
Gradation:
G_{mm} 2.503

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2881.1	2870.2	2861.9	2869.9	2858.7	2873.6	2870.4	2875.2	2863.7	2876.1
B	Height 1	151.62	151.5	151.55	151.7	152.02	151.84	151.76	151.66	151.73	151.82
C	Height 2	151.59	151.7	151.55	151.68	151.63	151.84	151.91	151.84	151.68	151.8
D	Height 3	151.77	151.59	151.74	151.77	151.69	151.77	151.98	151.8	151.72	151.98
E	Height 4	151.86	151.72	151.65	151.58	151.78	151.54	151.93	151.81	151.95	152.53
F	Average Height	151.71	151.6275	151.6225	151.6825	151.78	151.7475	151.895	151.7775	151.77	152.0325
G	Top Diameter 1	101.33	101.3	101.32	101.34	101.39	101.39	101.34	101.27	101.28	101.32
H	Top Diameter 2	101.3	101.35	101.33	101.34	101.38	101.46	101.33	101.54	101.6	101.25
	Middle Diameter 1	101.33	101.4	101.35	101.37	101.37	101.38	101.31	101.56	101.43	101.36
	Middle Diameter 2	101.35	101.38	101.28	101.37	101.41	101.49	101.32	101.3	101.49	101.35
	Bottom Diameter 1	101.29	101.33	101.43	101.38	101.3	101.24	101.36	101.39	101.41	101.49
	Bottom Diameter 2	101.35	101.42	101.47	101.39	101.47	101.37	101.27	101.3	101.47	101.35
I	Average Diameter	101.325	101.3633	101.3633	101.365	101.3867	101.3883	101.3217	101.3933	101.4467	101.3533
J	G_{mb} [A/(F*π*I²/4)]	2.355	2.346	2.339	2.345	2.333	2.346	2.344	2.346	2.334	2.345
K	Air Voids [(G_{mm}-J)/G_{mm}]	5.9	6.3	6.6	6.3	6.8	6.3	6.4	6.3	6.7	6.3
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2881.1	2870.2	2861.9	2869.9	2858.7	2873.6	2870.4	2875.2	2863.7	2876.1
B	Submerged Mass	1678.2	1665.6	1659.8	1666.9	1660.5	1665.5	1660.6	1666	1654.4	1672.5
C	SSD Mass	2900.7	2890.5	2882.5	2890.6	2881.4	2889.8	2885.7	2891.7	2879.7	2897.4
D	G_{mb} [A/(C-B)]	2.357	2.343	2.341	2.345	2.341	2.347	2.343	2.346	2.337	2.348
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.8	6.4	6.5	6.3	6.5	6.2	6.4	6.3	6.6	6.2

Project Number:
Location: Michigan Ave. Dearborn
Contractor:
Mix: 3 E 10
Gradation:
G_{mm} 2.493

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2860.4	2888.4	2871.8	2881.7	2875.2	2871.7	2887.9	2880.7	2875.1	2873.1
B	Height 1	151.41	151.65	151.66	151.83	151.94	151.77	151.81	151.94	151.89	151.97
C	Height 2	151.27	151.59	151.84	151.7	152	151.66	151.72	151.52	151.65	151.92
D	Height 3	151.06	151.83	151.72	151.72	151.8	151.65	151.93	151.9	151.69	151.9
E	Height 4	151.17	151.81	151.86	151.8	151.78	151.66	151.87	151.79	151.68	151.93
F	Average Height	151.23	151.72	151.77	151.76	151.88	151.69	151.83	151.79	151.73	151.93
G	Top Diameter 1	101.66	101.64	101.42	101.48	101.52	101.52	101.46	101.53	101.56	101.49
H	Top Diameter 2	101.7	101.6	101.5	101.43	101.53	101.52	101.65	101.54	101.72	101.57
	Middle Diameter 1	101.6	101.54	101.43	101.54	101.59	101.63	101.57	101.6	101.68	101.53
	Middle Diameter 2	101.6	101.49	101.54	101.67	101.55	101.43	101.57	101.62	101.53	101.53
	Bottom Diameter 1	101.58	101.47	101.45	101.59	101.58	101.7	101.6	101.41	101.46	101.68
	Bottom Diameter 2	101.48	101.61	101.64	101.49	101.67	101.45	101.65	101.64	101.71	101.35
I	Average Diameter	101.60	101.56	101.50	101.53	101.57	101.55	101.58	101.56	101.61	101.53
J	G_{mb} [A/(F*π*I²/4)]	2.333	2.350	2.339	2.345	2.336	2.338	2.347	2.343	2.337	2.336
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.4	5.7	6.2	5.9	6.3	6.2	5.9	6.0	6.3	6.3
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2860.4	2888.4	2871.8	2881.7	2875.2	2871.7	2887.9	2880.7	2875.1	2873.1
B	Submerged Mass	1652	1673.8	1658.2	1666.1	1661.5	1658.4	1674.9	1667.7	1663.5	1657.8
C	SSD Mass	2872.2	2899	2882.6	2891.3	2886.7	2883.7	2898.6	2892	2888.5	2884.6
D	G_{mb} [A/(C-B)]	2.344	2.357	2.345	2.352	2.347	2.344	2.360	2.353	2.347	2.342
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.0	5.4	5.9	5.7	5.9	6.0	5.3	5.6	5.9	6.1

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Project Number:
Location: Vandyke Detroit
Contractor:
Mix:
Gradation:
G_{mm} 2.604

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3011.6	3007.4	3016.3	3002.3	3011.5	3014.6	3002.4	3011.8	3008.4	3009.1
B	Height 1	151.18	151.29	151.28	151.33	151.11	151.22	151.28	151.3	151.24	151.72
C	Height 2	151.23	151.33	151.16	151.18	151.2	151.34	151.21	151.35	151.24	151.39
D	Height 3	151.24	151.13	151.18	151.36	151.08	151.28	151.4	151.37	151.1	151.7
E	Height 4	151.19	151.2	151.32	151.06	151.18	151.14	151.35	151.25	151.34	151.66
F	Average Height	151.21	151.24	151.24	151.23	151.14	151.25	151.31	151.32	151.23	151.62
G	Top Diameter 1	101.82	101.96	101.93	101.9	101.85	101.84	101.9	101.8	101.91	101.84
H	Top Diameter 2	101.86	101.94	101.89	101.97	101.84	101.89	101.99	101.89	101.87	102.07
	Middle Diameter 1	101.65	101.53	101.67	101.55	101.55	101.6	101.69	101.57	101.71	101.56
	Middle Diameter 2	101.49	101.48	101.57	101.6	101.66	101.69	101.53	101.73	101.52	101.69
	Bottom Diameter 1	101.53	101.73	101.69	101.8	101.75	101.87	101.47	101.84	101.63	101.64
	Bottom Diameter 2	101.68	101.48	101.6	101.57	101.62	101.73	101.79	101.54	101.5	101.64
I	Average Diameter	101.67	101.69	101.73	101.73	101.71	101.77	101.73	101.73	101.69	101.74
J	G_{mb} [A/(F*π*I^2/4)]	2.453	2.449	2.454	2.442	2.452	2.450	2.441	2.449	2.449	2.441
K	Air Voids [(G_{mm}-J)/G_{mm}]	5.8	6.0	5.8	6.2	5.8	5.9	6.2	6.0	5.9	6.2
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	3011.6	3007.4	3016.3	3002.3	3011.5	3014.6	3002.4	3011.8	3008.4	3009.1
B	Submerged Mass	1797.3	1793.3	1802.3	1788.1	1797	1800.1	1785.9	1797	1792.1	1792.1
C	SSD Mass	3021.3	3016.6	3025.6	3011.6	3019.8	3024.1	3010.1	3020.9	3016.1	3018.4
D	G_{mb} [A/(C-B)]	2.460	2.458	2.466	2.454	2.463	2.463	2.453	2.461	2.458	2.454
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.5	5.6	5.3	5.8	5.4	5.4	5.8	5.5	5.6	5.8

Project Number:
Location: US-23 Hartland
Contractor:
Mix:
Gradation:
G_{mm} 2.492

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2904.8	2897.3	2902.7	2854.3	2883.3	2860.5	2900.6	2861.4	2878.5	2863.8
B	Height 1	153.66	152.63	152.94	153.9	152.61	153.08	153.63	152.14	152.16	153.43
C	Height 2	153.55	152.6	152.75	153.81	152.53	152.31	153.33	152.34	152.49	153.09
D	Height 3	153.21	153.09	152.13	153.25	153.23	152.7	152.85	152.27	151.98	153.18
E	Height 4	153.43	153.07	152.39	153.32	153.18	152.6	152.69	152.62	152.09	153.62
F	Average Height	153.46	152.85	152.55	153.57	152.89	152.67	153.13	152.34	152.18	153.33
G	Top Diameter 1	101.43	101.44	101.56	101.48	101.53	101.55	101.59	101.48	101.56	101.4
H	Top Diameter 2	101.47	101.48	101.44	101.63	101.56	101.59	101.52	101.59	101.51	101.6
	Middle Diameter 1	101.55	101.59	101.65	101.56	101.57	101.54	101.56	101.53	101.52	101.55
	Middle Diameter 2	101.64	101.5	101.61	101.52	101.58	101.62	101.61	101.64	101.58	101.51
	Bottom Diameter 1	101.54	101.48	101.53	101.53	101.6	101.6	101.54	101.64	101.73	101.29
	Bottom Diameter 2	101.46	101.52	101.6	101.51	101.53	101.58	101.53	101.51	101.65	101.52
I	Average Diameter	101.52	101.50	101.57	101.54	101.56	101.58	101.56	101.57	101.59	101.48
J	G_{mb} [A/(F*π*I^2/4)]	2.339	2.343	2.349	2.295	2.328	2.312	2.338	2.318	2.333	2.309
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.2	6.0	5.8	7.9	6.6	7.2	6.2	7.0	6.4	7.3
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2904.8	2897.3	2902.7	2854.3	2883.3	2860.5	2900.6	2861.4	2878.5	2863.8
B	Submerged Mass	1682	1679.3	1684.9	1638.2	1667.8	1645.5	1684.4	1649.1	1663.2	1659.1
C	SSD Mass	2919	2911.1	2919.2	2875	2901	2877.5	2916.8	2880.3	2891	2889.9
D	G_{mb} [A/(C-B)]	2.348	2.352	2.352	2.308	2.338	2.322	2.354	2.324	2.344	2.327
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.8	5.6	5.6	7.4	6.2	6.8	5.6	6.7	5.9	6.6

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Project Number:
Location: I-75 Levering Rd.
Contractor:
Mix:
Gradation:
G_{mm} 2.443

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2848.2	2850.6	2849.6	2834.8	2828.2	2845.8	2858.7	2836.5	2832.8	2845.2
B	Height 1	151.81	152.46	151.82	152.27	151.92	152.37	152.95	152.28	152.1	151.76
C	Height 2	151.93	152.04	151.71	152.2	151.98	152.39	152.55	152.28	151.89	151.93
D	Height 3	152.05	151.99	151.89	152.06	152.18	151.89	152.36	151.98	151.96	152.26
E	Height 4	152.17	152.33	151.96	152.21	152.27	151.88	152.56	152	152.31	152.46
F	Average Height	151.99	152.21	151.85	152.19	152.09	152.13	152.61	152.14	152.07	152.10
G	Top Diameter 1	101.63	101.56	101.55	101.68	101.66	101.66	101.54	101.6	101.49	101.44
H	Top Diameter 2	101.45	101.52	101.45	101.58	101.3	101.42	101.44	101.42	101.57	101.43
	Middle Diameter 1	101.49	101.69	101.54	101.49	101.45	101.48	101.44	101.5	101.57	101.59
	Middle Diameter 2	101.63	101.6	101.53	101.64	101.64	101.58	101.69	101.59	101.52	101.58
	Bottom Diameter 1	101.59	101.58	101.65	101.74	101.7	101.69	101.58	101.72	101.37	101.63
	Bottom Diameter 2	101.54	101.66	101.44	101.54	101.65	101.49	101.38	101.51	101.59	101.65
I	Average Diameter	101.56	101.60	101.53	101.61	101.57	101.55	101.51	101.56	101.52	101.55
J	G_{mb} [A/(F*π*I^2/4)]	2.313	2.310	2.318	2.297	2.295	2.309	2.315	2.302	2.301	2.309
K	Air Voids [(G_{mm}-J)/G_{mm}]	5.3	5.4	5.1	6.0	6.0	5.5	5.3	5.8	5.8	5.5
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2848.2	2850.6	2849.6	2834.8	2828.2	2845.8	2858.7	2836.5	2832.8	2845.2
B	Submerged Mass	1623.9	1626.3	1626.6	1610	1605.6	1621.4	1630	1611.8	1608.9	1619.9
C	SSD Mass	2856.2	2859.6	2858.2	2843.9	2837	2854.8	2866	2845.5	2841.9	2853.3
D	G_{mb} [A/(C-B)]	2.311	2.311	2.314	2.297	2.297	2.307	2.313	2.299	2.297	2.307
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.4	5.4	5.3	6.0	6.0	5.6	5.3	5.9	6.0	5.6

Project Number:
Location: I-196 Grand Rapids
Contractor:
Mix:
Gradation:
G_{mm} 2.499

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2865.7	2837.7	2851.1	2869.8	2859.3	2868.4	2871.8	2862.4	2851.3	2872.1
B	Height 1	151.02	151.28	151.07	151.31	151.33	151.33	151.17	151.25	151.19	151.29
C	Height 2	151	151.38	151.21	151.09	151.36	151.57	151.42	151.09	151.28	151.33
D	Height 3	150.87	151.28	151.28	151.05	151.3	151.25	151.07	151.14	151.39	151.2
E	Height 4	150.92	151.33	151.2	151.15	151.45	151.22	151.22	151.17	151.29	151.29
F	Average Height	150.9525	151.3175	151.19	151.15	151.36	151.3425	151.22	151.1625	151.2875	151.2775
G	Top Diameter 1	101.37	101.32	101.47	101.35	101.3	101.38	101.34	101.36	101.37	101.366
H	Top Diameter 2	101.4	101.28	101.33	101.27	101.16	101.3	101.36	101.43	101.34	101.4
	Middle Diameter 1	101.4	101.26	101.41	101.28	101.24	101.35	101.28	101.3	101.33	101.44
	Middle Diameter 2	101.38	101.22	101.41	101.33	101.23	101.23	101.17	101.54	101.31	101.46
	Bottom Diameter 1	101.47	101.24	101.19	101.39	101.27	101.59	101.31	101.32	101.28	101.33
	Bottom Diameter 2	101.36	101.25	101.39	101.28	101.28	101.33	101.3	101.36	101.4	101.42
I	Average Diameter	101.3967	101.2617	101.3667	101.3167	101.2467	101.3633	101.2933	101.385	101.3383	101.4027
J	G_{mb} [A/(F*π*I^2/4)]	2.351	2.329	2.337	2.355	2.346	2.349	2.357	2.346	2.337	2.351
K	Air Voids [(G_{mm}-J)/G_{mm}]	5.9	6.8	6.5	5.8	6.1	6.0	5.7	6.1	6.5	5.9
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2865.7	2837.7	2851.1	2869.8	2859.3	2868.4	2871.8	2862.4	2851.3	2872.1
B	Submerged Mass	1648.8	1628.4	1641.8	1656.6	1645.3	1657.4	1659.5	1650	1641.2	1657.6
C	SSD Mass	2873.8	2853	2864.1	2881.6	2871	2881.3	2883.9	2874.7	2865.8	2883.6
D	G_{mb} [A/(C-B)]	2.339	2.317	2.333	2.343	2.333	2.344	2.345	2.337	2.328	2.343
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.4	7.3	6.7	6.3	6.7	6.2	6.1	6.5	6.8	6.3

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Project Number:
Location: I-75 Clarkston
Contractor:
Mix:
Gradation:
G_{mm} 2.487

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2863.3	2857.5	2838.5	2849.3	2855.9	2854.1	2850.6	2889.7	2855.5	2850.6
B	Height 1	151.14	151.05	150.79	150.84	151.03	151	150.89	151.25	150.97	151.09
C	Height 2	151.15	151.43	151.14	150.86	150.99	150.97	150.97	151.09	151.11	151.2
D	Height 3	151.34	151.36	151.09	150.99	151.02	151.01	151.03	151.14	151.16	151.24
E	Height 4	151.37	151.04	151.19	151.07	151.2	151.06	150.95	151.17	150.98	151.07
F	Average Height	151.25	151.22	151.0525	150.94	151.06	151.01	150.96	151.1625	151.055	151.15
G	Top Diameter 1	101.83	101.84	101.8	101.77	101.84	101.79	101.84	101.83	101.83	101.94
H	Top Diameter 2	101.85	101.76	101.78	101.97	101.85	101.73	101.86	101.77	101.9	101.91
	Middle Diameter 1	101.62	101.5	101.62	101.61	101.5	101.54	101.58	101.58	101.58	101.55
	Middle Diameter 2	101.62	101.52	101.57	101.51	101.52	101.7	101.5	101.6	101.56	101.6
	Bottom Diameter 1	101.61	101.73	101.75	101.37	101.53	101.83	101.53	101.52	101.46	101.73
	Bottom Diameter 2	101.48	101.66	101.81	101.53	101.81	101.59	101.61	101.73	101.62	101.49
I	Average Diameter	101.67	101.67	101.72	101.63	101.68	101.70	101.65	101.67	101.66	101.70
J	G_{mb} [A/(F*π*I^2/4)]	2.332	2.328	2.312	2.327	2.328	2.327	2.327	2.355	2.329	2.321
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.2	6.4	7.0	6.4	6.4	6.4	6.4	5.3	6.4	6.7
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2863.3	2857.5	2838.5	2849.3	2855.9	2854.1	2850.6	2889.7	2855.5	2850.6
B	Submerged Mass	1651.2	1645.1	1629.8	1640.6	1646.7	1643.7	1638.7	1675.2	1644.9	1640.8
C	SSD Mass	2872.7	2867.1	2849.7	2860.5	2866.7	2865.2	2859.5	2897.8	2866.6	2862.6
D	G_{mb} [A/(C-B)]	2.344	2.338	2.327	2.336	2.341	2.337	2.335	2.364	2.337	2.333
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.7	6.0	6.4	6.1	5.9	6.0	6.1	5.0	6.0	6.2

Project Number:
Location: M-53 Detroit
Contractor:
Mix:
Gradation:
G_{mm} 2.563

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2953.2	2957.8	2957.9	2961.8	2955.4	2954.5	2982.1	2964.7	2944.4	2963.8
B	Height 1	151.1	151.22	151.23	150.95	151.31	151.3	151.56	151.44	150.91	150.95
C	Height 2	151.16	151.11	151.17	151.22	151.09	151.26	151.71	151.05	151.07	151.07
D	Height 3	150.95	151.28	151.09	151.21	151.3	151.26	151.76	151.05	150.85	151
E	Height 4	151.23	151.12	151.3	151.12	151.26	151.24	151.6	151.27	151.08	150.88
F	Average Height	151.11	151.1825	151.1975	151.125	151.24	151.265	151.6575	151.2025	150.9775	150.975
G	Top Diameter 1	101.31	101.33	101.28	101.51	101.54	101.34	101.54	101.34	101.33	101.3
H	Top Diameter 2	101.42	101.47	101.39	101.51	101.34	101.33	101.34	101.32	101.38	101.32
	Middle Diameter 1	101.35	101.47	101.3	101.29	101.27	101.23	101.3	101.39	101.25	101.29
	Middle Diameter 2	101.43	101.36	101.34	101.32	101.33	101.3	101.32	101.17	101.27	101.27
	Bottom Diameter 1	101.38	101.52	101.27	101.45	101.33	101.43	101.31	101.36	101.32	101.39
	Bottom Diameter 2	101.49	101.36	101.31	101.36	101.39	101.5	101.3	101.34	101.31	101.19
I	Average Diameter	101.3967	101.4183	101.315	101.4067	101.3667	101.355	101.3517	101.32	101.31	101.2933
J	G_{mb} [A/(F*π*I^2/4)]	2.420	2.422	2.427	2.427	2.421	2.421	2.437	2.432	2.419	2.436
K	Air Voids [(G_{mm}-J)/G_{mm}]	5.6	5.5	5.3	5.3	5.5	5.5	4.9	5.1	5.6	5.0
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2953.2	2957.8	2957.9	2961.8	2955.4	2954.5	2982.1	2964.7	2944.4	2963.8
B	Submerged Mass	1741.8	1746.8	1744.2	1749.3	1743.6	1737.2	1763.7	1752.3	1734.5	1752.5
C	SSD Mass	2964.7	2969.1	2968.1	2972.7	2966.3	2962.2	2992	2974.1	2956.1	2974.4
D	G_{mb} [A/(C-B)]	2.415	2.420	2.417	2.421	2.417	2.412	2.428	2.427	2.410	2.426
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.8	5.6	5.7	5.5	5.7	5.9	5.3	5.3	6.0	5.4

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Project Number:
Location: Michigan Ave. Dearborn
Contractor:
Mix: 4 E 10
Gradation:
G_{mm} 2.485

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2841	2842	2844.6	2846.5	2842	2844.8	2835.3	2852.8	2844.3	2853.9
B	Height 1	151.76	151.72	151.71	151.64	151.66	151.75	151.77	151.66	151.77	151.79
C	Height 2	151.58	151.72	151.75	151.71	151.74	151.55	151.81	151.59	151.74	151.76
D	Height 3	151.54	151.81	151.76	151.76	151.6	151.79	151.69	151.77	151.75	151.81
E	Height 4	151.51	151.82	151.58	151.81	151.93	151.57	151.8	151.65	151.82	151.78
F	Average Height	151.60	151.77	151.70	151.73	151.73	151.67	151.77	151.67	151.77	151.79
G	Top Diameter 1	101.47	101.42	101.45	101.55	101.45	101.49	101.53	101.51	101.58	101.46
H	Top Diameter 2	101.48	101.48	101.42	101.55	101.42	101.46	101.52	101.57	101.47	101.55
	Middle Diameter 1	101.54	101.55	101.51	101.54	101.52	101.53	101.47	101.57	101.53	101.58
	Middle Diameter 2	101.52	101.46	101.51	101.58	101.51	101.54	101.52	101.59	101.56	101.63
	Bottom Diameter 1	101.55	101.57	101.52	101.62	101.59	101.58	101.59	101.7	101.7	101.58
	Bottom Diameter 2	101.5	101.58	101.56	101.48	101.57	101.64	101.56	101.58	101.58	101.63
I	Average Diameter	101.51	101.51	101.50	101.55	101.51	101.54	101.53	101.59	101.57	101.57
J	G_{mb} [A/(F*π*I^2/4)]	2.316	2.314	2.318	2.316	2.314	2.316	2.307	2.321	2.313	2.320
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.8	6.9	6.7	6.8	6.9	6.8	7.1	6.6	6.9	6.6
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2841	2842	2844.6	2846.5	2842	2844.8	2835.3	2852.8	2844.3	2853.9
B	Submerged Mass	1629.4	1629.9	1627.9	1634.3	1629.4	1629.9	1623.2	1637.9	1629.4	1640.2
C	SSD Mass	2851.6	2853.1	2852.7	2857.8	2853.2	2854.6	2847	2862.4	2855.4	2864.3
D	G_{mb} [A/(C-B)]	2.324	2.323	2.323	2.327	2.322	2.323	2.317	2.330	2.320	2.331
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.5	6.5	6.5	6.4	6.5	6.5	6.8	6.2	6.6	6.2

Project Number:
Location: I-75 Toledo
Contractor:
Mix:
Gradation:
G_{mm} 2.507

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2874.2	2882.7	2881.4	2878	2877.4	2878.7	2880.4	2879.9	2871.2	2868.2
B	Height 1	151.4	151.9	151.93	151.55	151.61	151.93	151.63	151.57	151.61	151.55
C	Height 2	151.71	151.87	152.02	151.5	151.78	151.63	151.64	151.61	151.66	151.58
D	Height 3	151.29	151.52	151.93	151.59	151.76	151.59	151.85	151.68	151.62	151.53
E	Height 4	151.54	151.77	151.88	151.64	151.94	151.7	151.74	151.6	151.58	151.7
F	Average Height	151.49	151.77	151.94	151.57	151.77	151.71	151.72	151.62	151.62	151.59
G	Top Diameter 1	101.5	101.52	101.46	101.36	101.46	101.55	101.37	101.4	101.38	101.5
H	Top Diameter 2	101.53	101.53	101.71	101.63	101.58	101.45	101.61	101.36	101.41	101.51
	Middle Diameter 1	101.59	101.54	101.64	101.48	101.5	101.6	101.58	101.38	101.56	101.47
	Middle Diameter 2	101.48	101.57	101.51	101.54	101.55	101.43	101.52	101.46	101.48	101.47
	Bottom Diameter 1	101.54	101.59	101.64	101.53	101.64	101.52	101.57	101.47	101.58	101.52
	Bottom Diameter 2	101.53	101.58	101.62	101.58	101.56	101.51	101.56	101.48	101.52	101.56
I	Average Diameter	101.53	101.56	101.60	101.52	101.55	101.51	101.54	101.43	101.49	101.51
J	G_{mb} [A/(F*π*I^2/4)]	2.344	2.345	2.339	2.346	2.341	2.345	2.345	2.351	2.341	2.338
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.5	6.5	6.7	6.4	6.6	6.5	6.5	6.2	6.6	6.7
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2874.2	2882.7	2881.4	2878	2877.4	2878.7	2880.4	2879.9	2871.2	2868.2
B	Submerged Mass	1661	1670.1	1667.8	1664	1664.4	1664.7	1670	1671.8	1662.7	1659.8
C	SSD Mass	2885.8	2895.3	2893.9	2888.9	2890.3	2890.4	2895.5	2893.1	2886.3	2882.4
D	G_{mb} [A/(C-B)]	2.347	2.353	2.350	2.350	2.347	2.349	2.350	2.358	2.347	2.346
E	Air Voids [(G_{mm}-D)/G_{mm}]	6.4	6.1	6.3	6.3	6.4	6.3	6.2	5.9	6.4	6.4

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Project Number:
Location: I-94 Ann Arbor
Contractor:
Mix: SMA
Gradation:
G_{mm} 2.515

	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2906.1	2913.9	2902.1	2885	2907.7	2907.7	2889.2	2890.7	2895	2881.1
B	Height 1	152.01	152.24	152.36	151.03	152.19	152.97	151.82	151.82	151.85	151.75
C	Height 2	152.32	152.26	152.38	151.14	152.2	152.65	151.93	151.5	151.98	151.95
D	Height 3	152.18	152.32	152.93	151.16	152.02	152.79	151.77	151.56	151.84	151.62
E	Height 4	151.84	152.39	152.69	151.06	151.94	152.72	151.95	151.77	151.95	151.68
F	Average Height	152.0875	152.3025	152.59	151.0975	152.0875	152.7825	151.8675	151.6625	151.905	151.75
G	Top Diameter 1	101.38	101.44	101.59	101.32	101.31	101.31	101.3	101.33	101.35	101.49
H	Top Diameter 2	101.48	101.56	101.59	101.34	101.34	101.3	101.25	101.33	101.31	101.3
	Middle Diameter 1	101.64	101.46	101.63	101.33	101.27	101.36	101.28	101.32	101.48	101.28
	Middle Diameter 2	101.48	101.59	101.59	101.28	101.3	101.3	101.33	101.31	101.32	101.36
	Bottom Diameter 1	101.62	101.6	101.83	101.35	101.33	101.3	101.34	101.32	101.32	101.29
	Bottom Diameter 2	101.6	101.62	101.61	101.28	101.27	101.33	101.37	101.47	101.45	101.43
I	Average Diameter	101.5333	101.545	101.64	101.3167	101.3033	101.3167	101.3117	101.3467	101.3717	101.3583
J	G_{mb} [A/(F*π*I^2/4)]	2.360	2.362	2.344	2.368	2.372	2.361	2.360	2.363	2.361	2.353
K	Air Voids [(G_{mm}-J)/G_{mm}]	6.2	6.1	6.8	5.8	5.7	6.1	6.2	6.1	6.1	6.4
	Sample	1	2	3	4	5	6	7	8	9	10
A	Dry Mass	2906.1	2913.9	2902.1	2885	2907.7	2907.7	2889.2	2890.7	2895	2881.1
B	Submerged Mass	1696.1	1703.1	1684.5	1692.4	1703.9	1709.9	1691.7	1689.6	1696.3	1678.1
C	SSD Mass	2924.4	2932.9	2911.4	2908.7	2931.2	2934.7	2915.4	2911.8	2917.1	2900.1
D	G_{mb} [A/(C-B)]	2.366	2.369	2.365	2.372	2.369	2.374	2.361	2.365	2.371	2.358
E	Air Voids [(G_{mm}-D)/G_{mm}]	5.9	5.8	5.9	5.7	5.8	5.6	6.1	6.0	5.7	6.3

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APPENDIX C VISCOSITY TEST RESULTS

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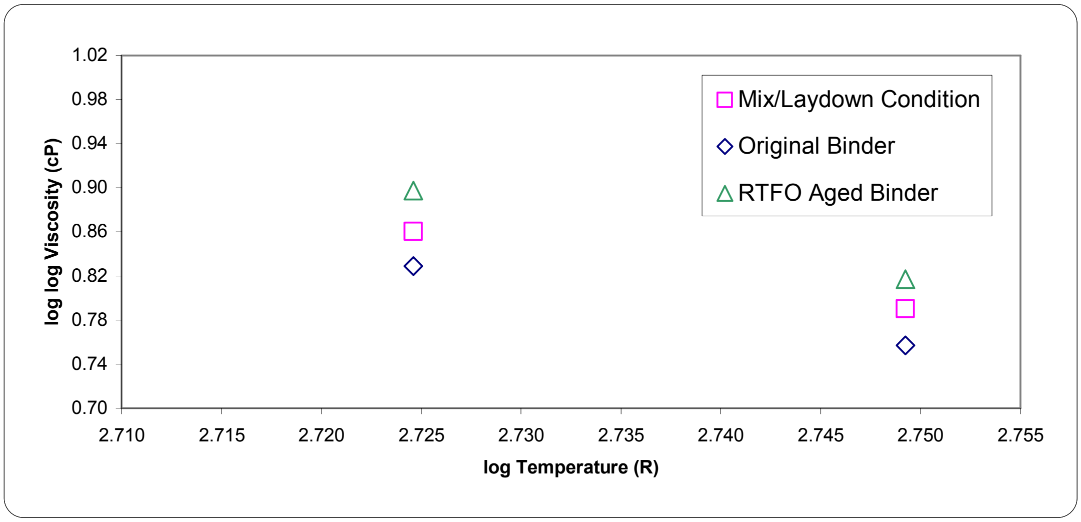
Job:	M-50 Dundee
Mix Type:	19.0mm Coarse
Traffic Level:	E-1
Binder Grade (PG):	58-28

		A	VTS
Original Binder	η_{orig}	8.783	-2.919
Mix/Laydown Condition	$\eta_{t=0}$	8.592	-2.838
RTFO Aged Viscosity Tested	η_{vis}	9.793	-3.265

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		21.5	38.7
Original Binder	η_{orig}	5.6	0.5
Mix/Laydown Condition	$\eta_{t=0}$	17.7	1.5
RTFO Aged Viscosity Tested	η_{vis}	78.8	3.6



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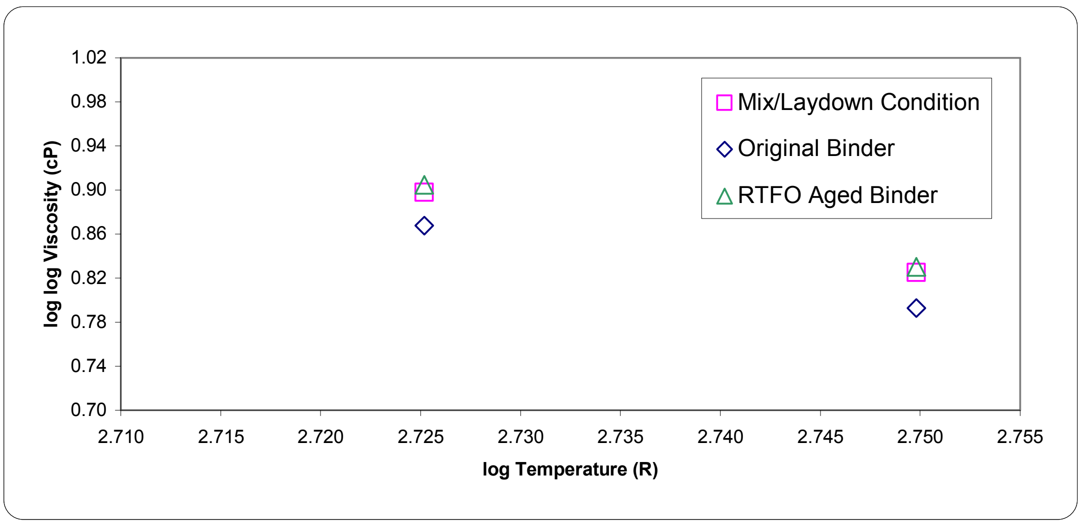
Job: M-36 Pinckney
Mix Type: 19.0mm Coarse
Traffic Level: E-3
Binder Grade (PG): 64-22

		A	VTS
Original Binder	η_{orig}	9.144	-3.037
Mix/Laydown Condition	$\eta_{t=0}$	8.943	-2.952
RTFO Aged Viscosity Tested	η_{vis}	9.135	-3.020

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		21.9	39.1
Original Binder	η_{orig}	23.6	1.6
Mix/Laydown Condition	$\eta_{t=0}$	80.1	4.9
RTFO Aged Viscosity Tested	η_{vis}	106.2	5.8



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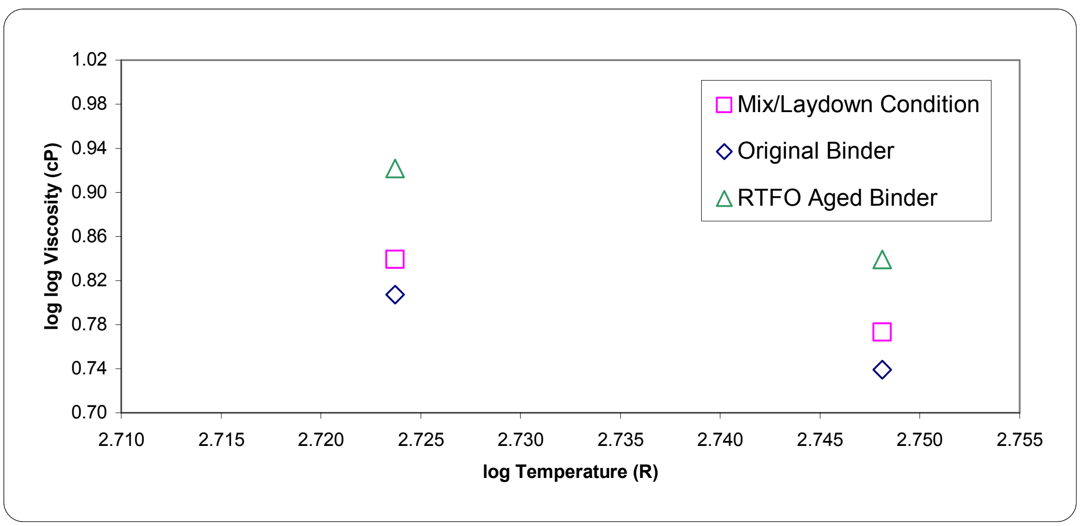
Job:	M-45 Grand Rapids
Mix Type:	19.0mm Fine
Traffic Level:	E-3
Binder Grade (PG):	58-28

		A	VTS
Original Binder	η_{orig}	8.386	-2.782
Mix/Laydown Condition	$\eta_{t=0}$	8.206	-2.705
RTFO Aged Viscosity Tested	η_{vis}	10.134	-3.382

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temprature (°C)
		20.9	37.9
Original Binder	η_{orig}	2.6	0.3
Mix/Laydown Condition	$\eta_{t=0}$	8.0	0.9
RTFO Aged Viscosity Tested	η_{vis}	226.1	8.1



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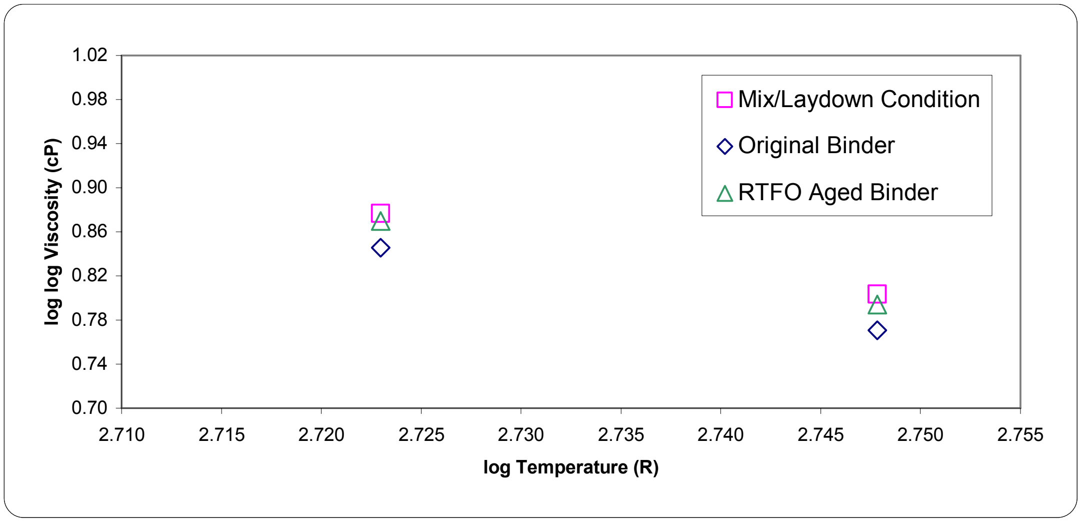
Job:	M-84 Saginaw
Mix Type:	19.0mm Fine
Traffic Level:	E-3
Binder Grade (PG):	58-28

		A	VTS
Original Binder	η_{orig}	9.075	-3.022
Mix/Laydown Condition	$\eta_{t=0}$	8.876	-2.938
RTFO Aged Viscosity Tested	η_{vis}	9.178	-3.051

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		20.4	37.7
Original Binder	η_{orig}	10.2	0.8
Mix/Laydown Condition	$\eta_{t=0}$	33.5	2.3
RTFO Aged Viscosity Tested	η_{vis}	25.6	1.7



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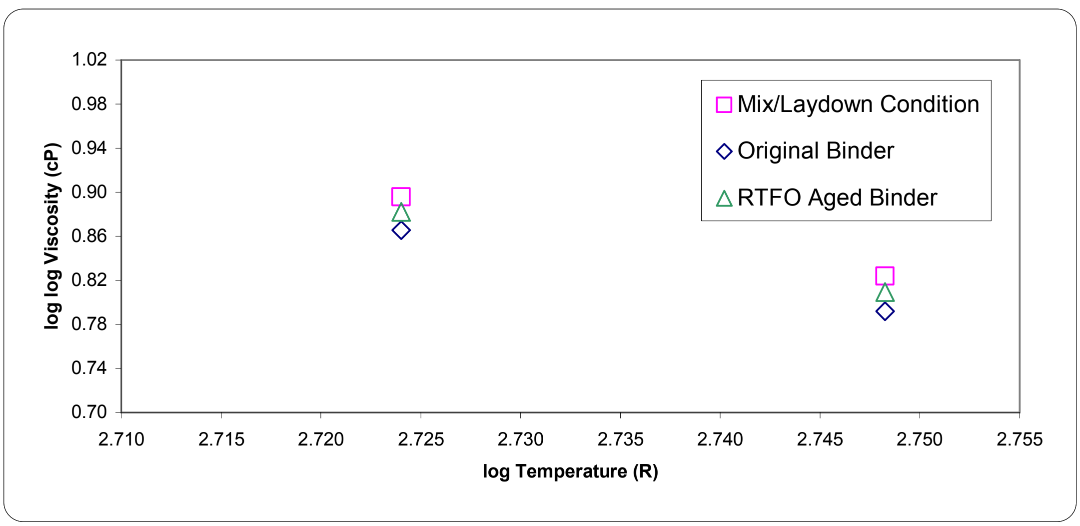
Job:	**M-21 St. Johns**
Mix Type:	**19.0mm Coarse**
Traffic Level:	**E-3**
Binder Grade (PG):	**58-22**

		A	VTS
Original Binder	η_{orig}	9.134	-3.035
Mix/Laydown Condition	$\eta_{t=0}$	8.933	-2.951
RTFO Aged Viscosity Tested	η_{vis}	9.073	-3.007

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		21.1	38.0
Original Binder	η_{orig}	21.6	1.6
Mix/Laydown Condition	$\eta_{t=0}$	72.9	4.7
RTFO Aged Viscosity Tested	η_{vis}	42.0	2.8



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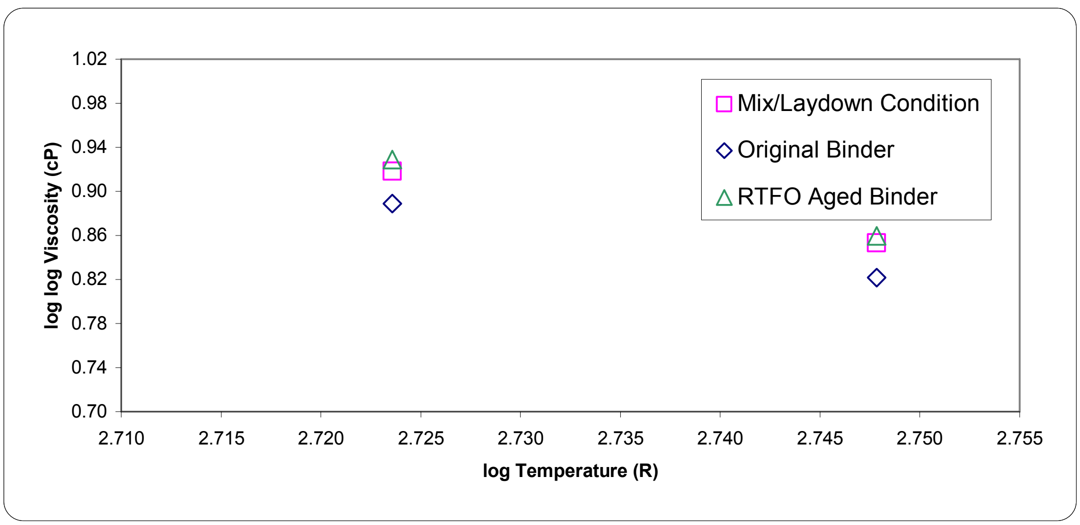
Job:	**BL I-96 Howell**
Mix Type:	**12.5mm Fine**
Traffic Level:	**E-3**
Binder Grade (PG):	**78-28P**

		A	VTS
Original Binder	η_{orig}	8.390	-2.754
Mix/Laydown Condition	$\eta_{t=0}$	8.210	-2.677
RTFO Aged Viscosity Tested	η_{vis}	8.724	-2.862

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		20.8	37.7
Original Binder	η_{orig}	55.0	4.3
Mix/Laydown Condition	$\eta_{t=0}$	192.9	13.6
RTFO Aged Viscosity Tested	η_{vis}	308.6	17.1



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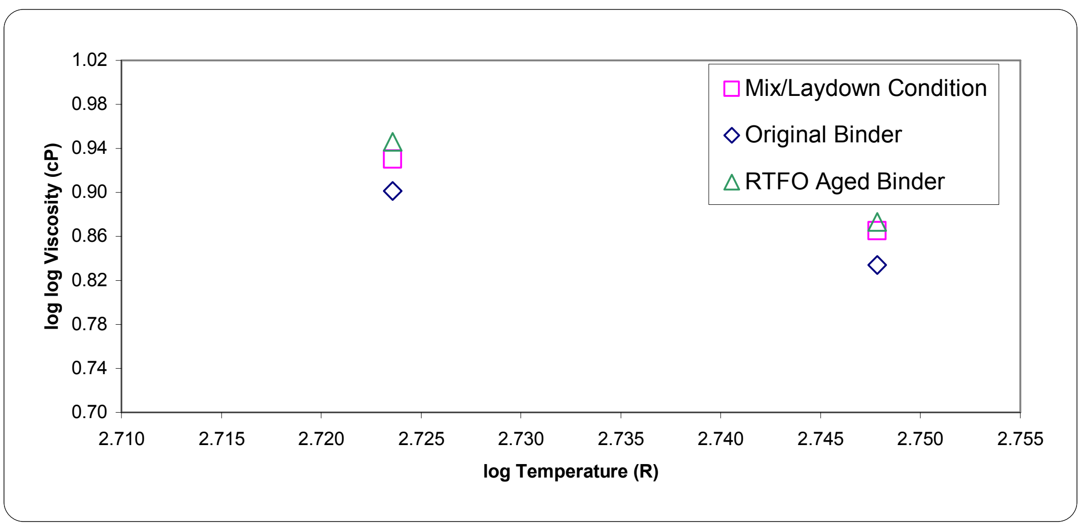
Job:	**M-21 Owosso**
Mix Type:	**9.5mm Fine**
Traffic Level:	**E-3**
Binder Grade (PG):	**64-28**

		A	VTS
Original Binder	η_{orig}	8.413	-2.758
Mix/Laydown Condition	$\eta_{t=0}$	8.232	-2.681
RTFO Aged Viscosity Tested	η_{vis}	9.082	-2.987

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		20.8	37.7
Original Binder	η_{orig}	91.9	6.7
Mix/Laydown Condition	$\eta_{t=0}$	329.1	21.5
RTFO Aged Viscosity Tested	η_{vis}	670.7	29.5



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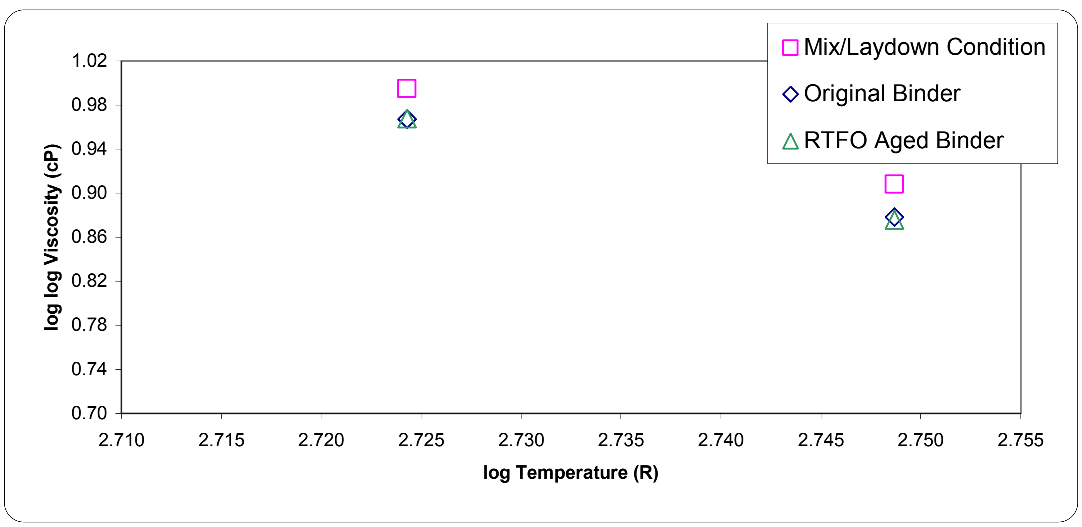
Job:	**M-66 Battle Creek**
Mix Type:	**12.5mm Fine**
Traffic Level:	**E-3**
Binder Grade (PG):	**64-28**

		A	VTS
Original Binder	η_{orig}	10.907	-3.648
Mix/Laydown Condition	$\eta_{t=0}$	10.656	-3.546
RTFO Aged Viscosity Tested	η_{vis}	11.243	-3.772

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		21.3	38.3
Original Binder	η_{orig}	1,885.6	36.1
Mix/Laydown Condition	$\eta_{t=0}$	7,558.7	124.6
RTFO Aged Viscosity Tested	η_{vis}	1,901.6	32.3



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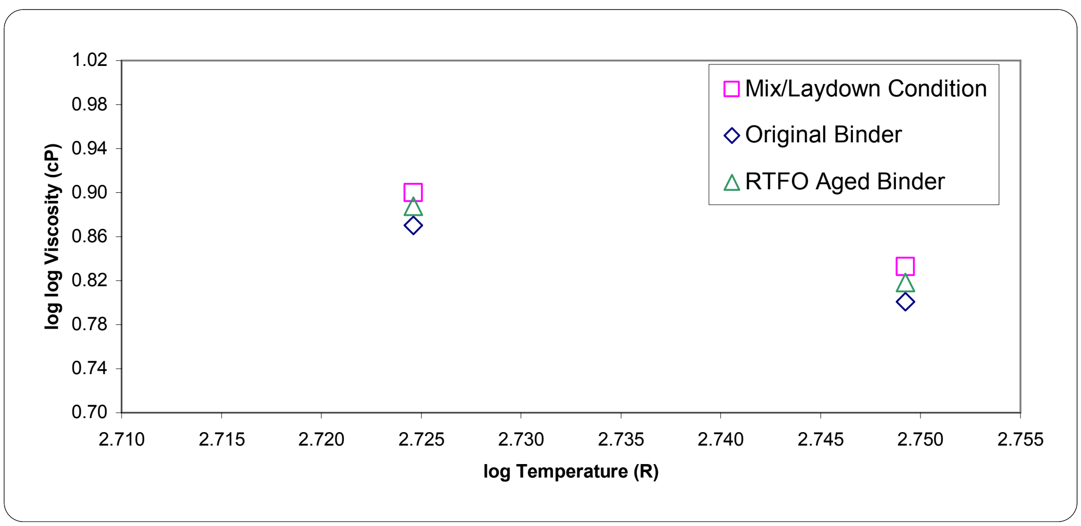
Job:	**M-50 Dundee**
Mix Type:	**12.5mm Coarse**
Traffic Level:	**E-3**
Binder Grade (PG):	**64-28**

		A	VTS
Original Binder	η_{orig}	8.554	-2.820
Mix/Laydown Condition	$\eta_{t=0}$	8.369	-2.741
RTFO Aged Viscosity Tested	η_{vis}	8.531	-2.805

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		21.5	38.7
Original Binder	η_{orig}	26.0	2.1
Mix/Laydown Condition	$\eta_{t=0}$	88.5	6.3
RTFO Aged Viscosity Tested	η_{vis}	52.5	3.8



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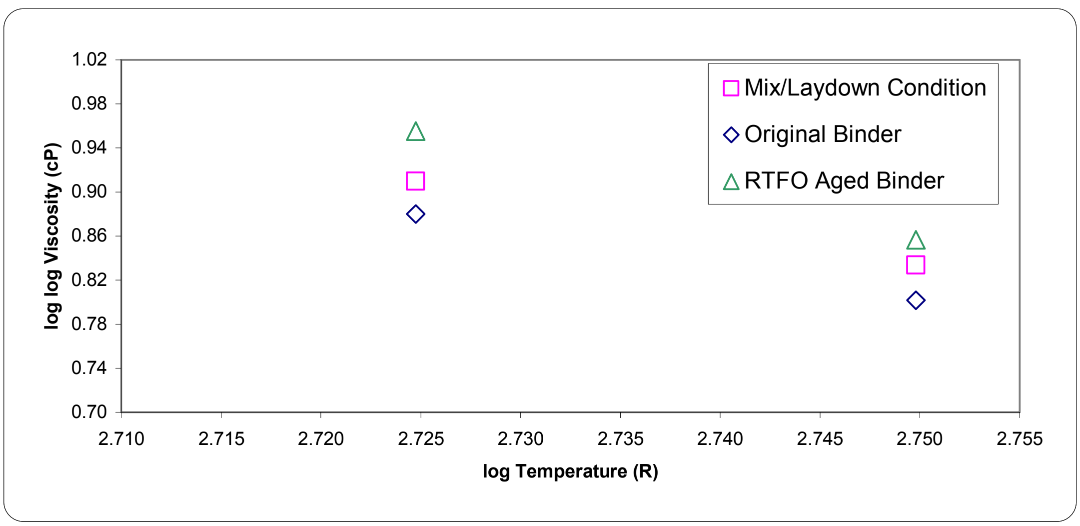
Job:	**US-12 MIS**
Mix Type:	**12.5mm Coarse**
Traffic Level:	**E-3**
Binder Grade (PG):	**64-28**

		A	VTS
Original Binder	η_{orig}	9.399	-3.126
Mix/Laydown Condition	$\eta_{t=0}$	9.190	-3.039
RTFO Aged Viscosity Tested	η_{vis}	11.705	-3.945

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		21.6	39.1
Original Binder	η_{orig}	38.7	2.2
Mix/Laydown Condition	$\eta_{t=0}$	133.7	6.6
RTFO Aged Viscosity Tested	η_{vis}	1,051.8	15.3



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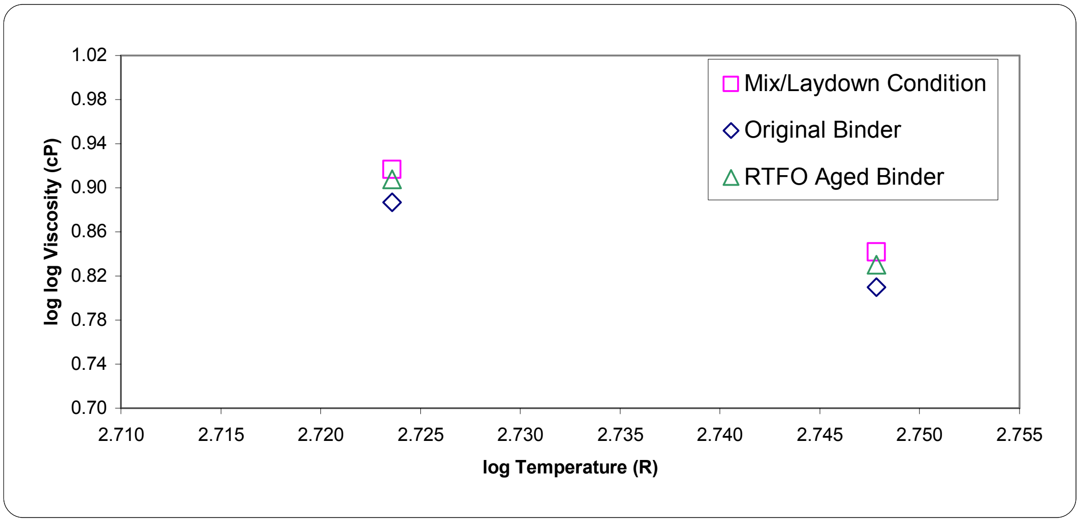
Job:	**M-59 Brighton**
Mix Type:	**19.0mm Coarse**
Traffic Level:	**E-10**
Binder Grade (PG):	**58-22**

		A	VTS
Original Binder	η_{orig}	9.527	-3.173
Mix/Laydown Condition	$\eta_{t=0}$	9.315	-3.084
RTFO Aged Viscosity Tested	η_{vis}	9.584	-3.186

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		20.8	37.7
Original Binder	η_{orig}	50.9	2.8
Mix/Laydown Condition	$\eta_{t=0}$	178.1	8.8
RTFO Aged Viscosity Tested	η_{vis}	120.7	5.8



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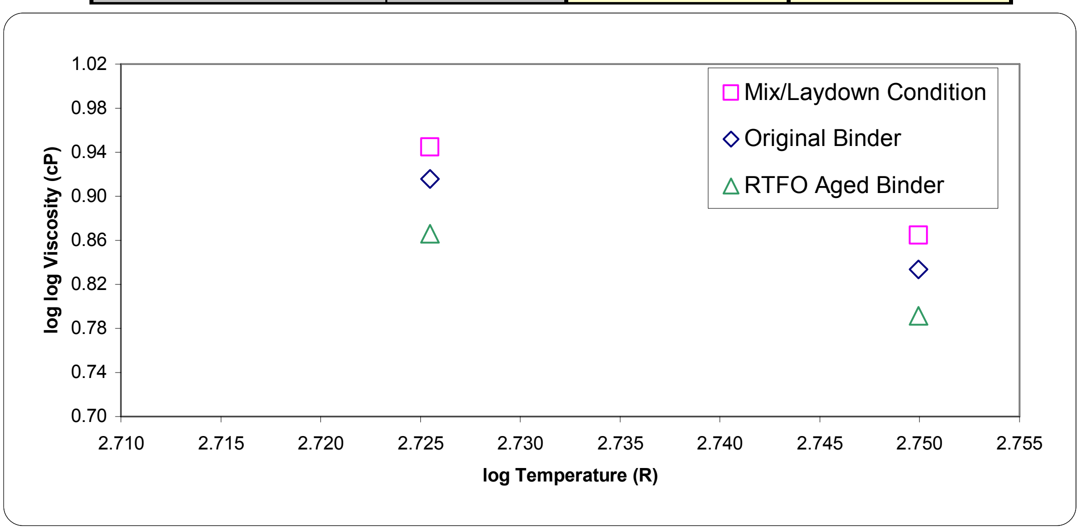
Job:	**Michigan Avenue, Dearborn**
Mix Type:	**19.0mm Coarse**
Traffic Level:	**E-10**
Binder Grade (PG):	**58-28**

		A	VTS
Original Binder	η_{orig}	10.103	-3.371
Mix/Laydown Condition	$\eta_{t=0}$	9.875	-3.277
RTFO Aged Viscosity Tested	η_{vis}	9.145	-3.038

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		22.1	39.2
Original Binder	η_{orig}	173.7	6.5
Mix/Laydown Condition	$\eta_{t=0}$	637.5	21.0
RTFO Aged Viscosity Tested	η_{vis}	22.0	1.5



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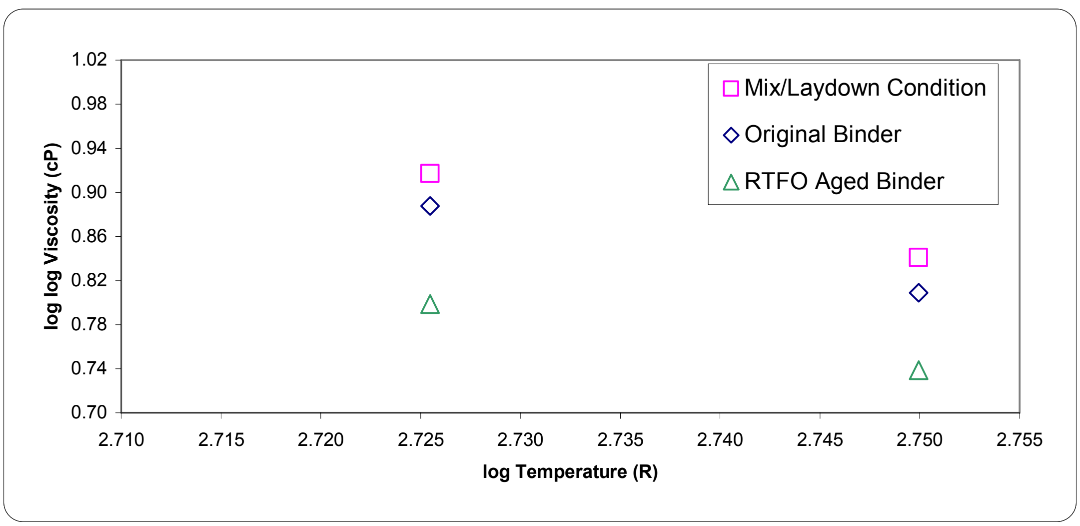
Job:	**VanDyke, Detroit**
Mix Type:	**19.0mm Fine**
Traffic Level:	**E-30**
Binder Grade (PG):	**64-22**

		A	VTS
Original Binder	η_{orig}	9.638	-3.211
Mix/Laydown Condition	$\eta_{t=0}$	9.423	-3.121
RTFO Aged Viscosity Tested	η_{vis}	7.520	-2.466

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		22.1	39.2
Original Binder	η_{orig}	52.30	2.77
Mix/Laydown Condition	$\eta_{t=0}$	183.07	8.53
RTFO Aged Viscosity Tested	η_{vis}	1.97	0.30



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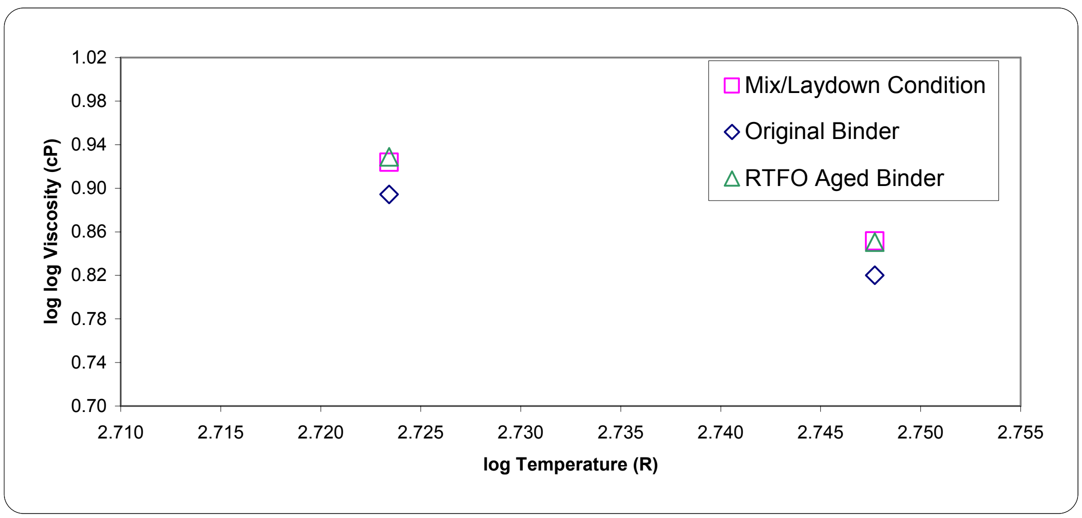
Job:	US-23 Hartland
Mix Type:	19.0mm Coarse
Traffic Level:	E-30
Binder Grade (PG):	64-22

		A	VTS
Original Binder	η_{orig}	9.220	-3.057
Mix/Laydown Condition	$\eta_{t=0}$	9.017	-2.972
RTFO Aged Viscosity Tested	η_{vis}	9.714	-3.226

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temprature (°C)	High Temeprature (°C)
		20.7	37.6
Original Binder	η_{orig}	69.4	4.1
Mix/Laydown Condition	$\eta_{t=0}$	245.8	12.8
RTFO Aged Viscosity Tested	η_{vis}	308.5	12.3



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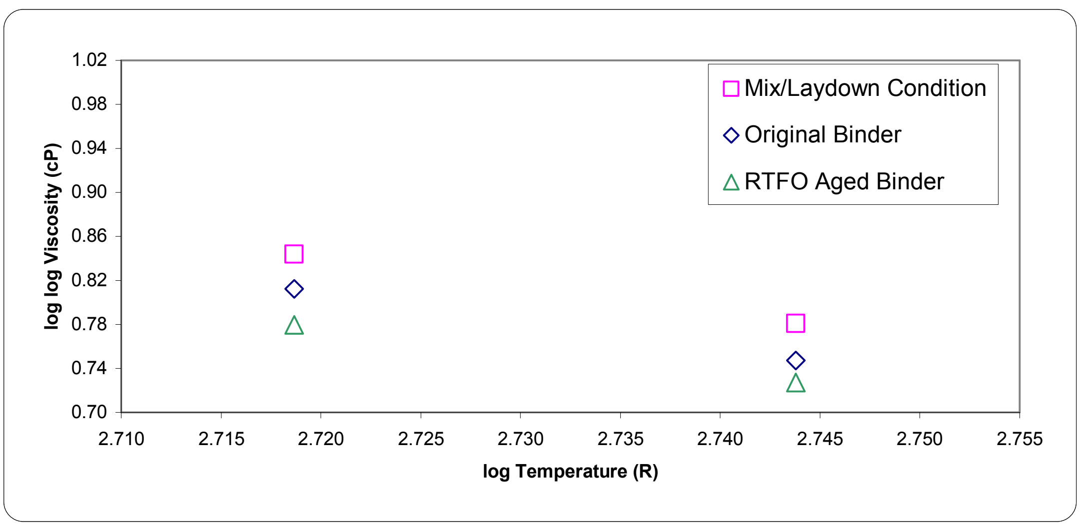
Job:	I-75 Levering Road
Mix Type:	19.0mm Coarse
Traffic Level:	E-10
Binder Grade (PG):	58-28

		A	VTS
Original Binder	η_{orig}	7.841	-2.585
Mix/Laydown Condition	$\eta_{t=0}$	7.676	-2.513
RTFO Aged Viscosity Tested	η_{vis}	6.447	-2.085

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		17.5	34.8
Original Binder	η_{orig}	3.09	0.39
Mix/Laydown Condition	$\eta_{t=0}$	9.58	1.09
RTFO Aged Viscosity Tested	η_{vis}	1.04	0.22



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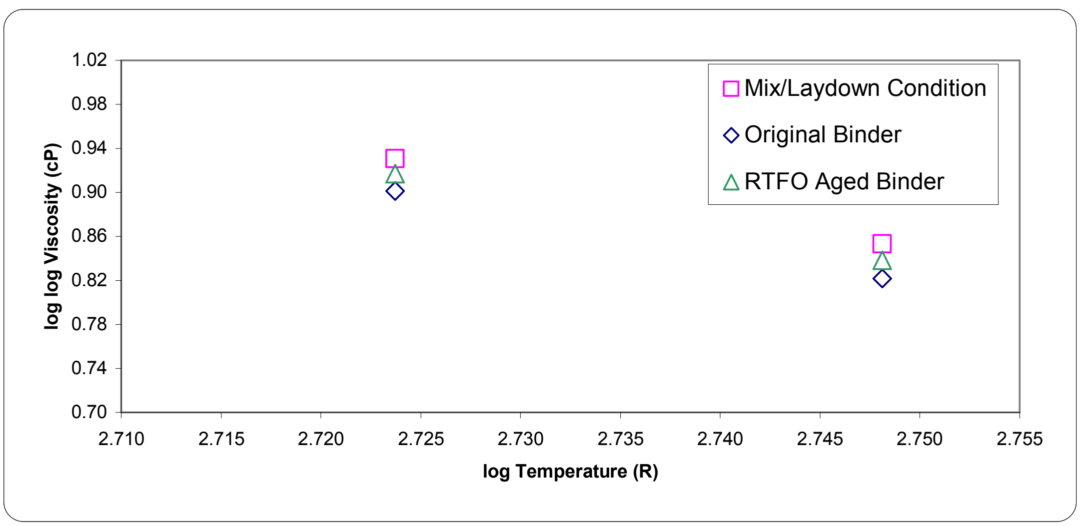
Job:	I-196 Grand Rapids
Mix Type:	9.5mm Coarse
Traffic Level:	E-10
Binder Grade (PG):	64-22

		A	VTS
Original Binder	η_{orig}	9.774	-3.258
Mix/Laydown Condition	$\eta_{t=0}$	9.555	-3.167
RTFO Aged Viscosity Tested	η_{vis}	9.686	-3.220

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		20.9	37.9
Original Binder	η_{orig}	92.6	4.3
Mix/Laydown Condition	$\eta_{t=0}$	331.6	13.5
RTFO Aged Viscosity Tested	η_{vis}	182.7	7.8



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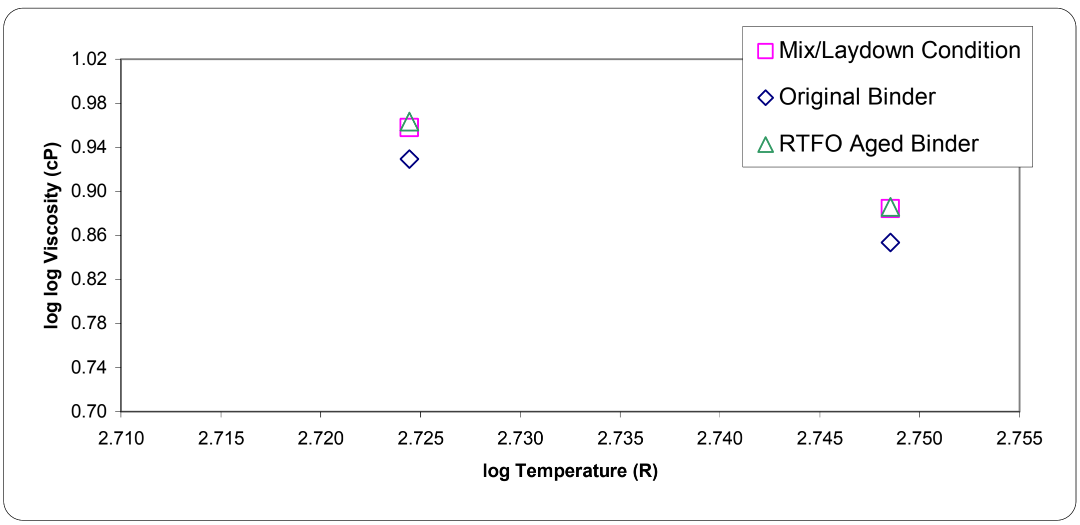
Job:	**I-75 Clarkston**
Mix Type:	**12.5mm Coarse**
Traffic Level:	**E-30**
Binder Grade (PG):	**70-22P**

		A	VTS
Original Binder	η_{orig}	9.483	-3.140
Mix/Laydown Condition	$\eta_{t=0}$	9.272	-3.052
RTFO Aged Viscosity Tested	η_{vis}	9.715	-3.212

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		21.4	38.2
Original Binder	η_{orig}	316.3	13.9
Mix/Laydown Condition	$\eta_{t=0}$	1,187.8	45.9
RTFO Aged Viscosity Tested	η_{vis}	1,549.9	49.0



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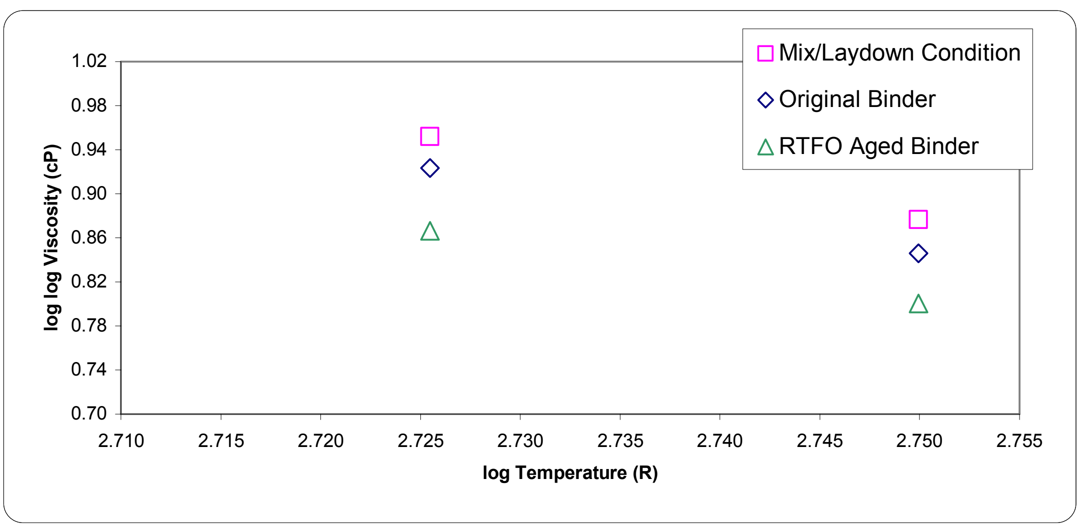
Job:	M-53 Detroit, 8 Mile
Mix Type:	12.5mm Coarse
Traffic Level:	E-10
Binder Grade (PG):	70-22P

		A	VTS
Original Binder	η_{orig}	9.571	-3.173
Mix/Laydown Condition	$\eta_{t=0}$	9.358	-3.084
RTFO Aged Viscosity Tested	η_{vis}	8.246	-2.708

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		22.1	39.2
Original Binder	η_{orig}	243.1	10.3
Mix/Laydown Condition	$\eta_{t=0}$	904.0	33.8
RTFO Aged Viscosity Tested	η_{vis}	22.5	2.1



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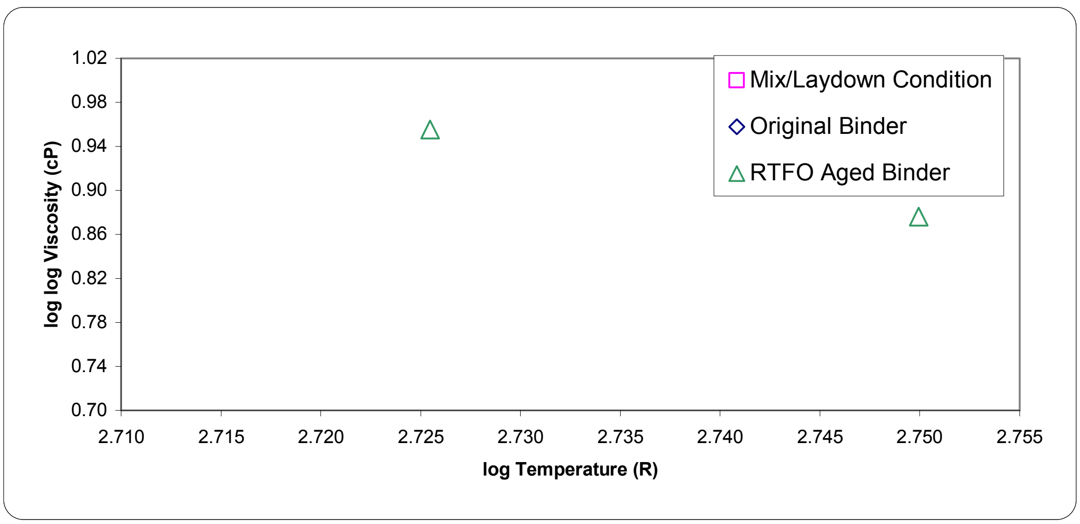
Job:	**Michigan Avenue, Dearborn**
Mix Type:	**12.5mm Coarse**
Traffic Level:	**E-10**
Binder Grade (PG):	**70-22P**

		A	VTS
Original Binder	η_{orig}	#NUM!	#NUM!
Mix/Laydown Condition	$\eta_{t=0}$	#NUM!	#NUM!
RTFO Aged Viscosity Tested	η_{vis}	9.788	-3.241

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		22.1	39.2
Original Binder	η_{orig}	#NUM!	#NUM!
Mix/Laydown Condition	$\eta_{t=0}$	#NUM!	#NUM!
RTFO Aged Viscosity Tested	η_{vis}	1,057.7	33.1



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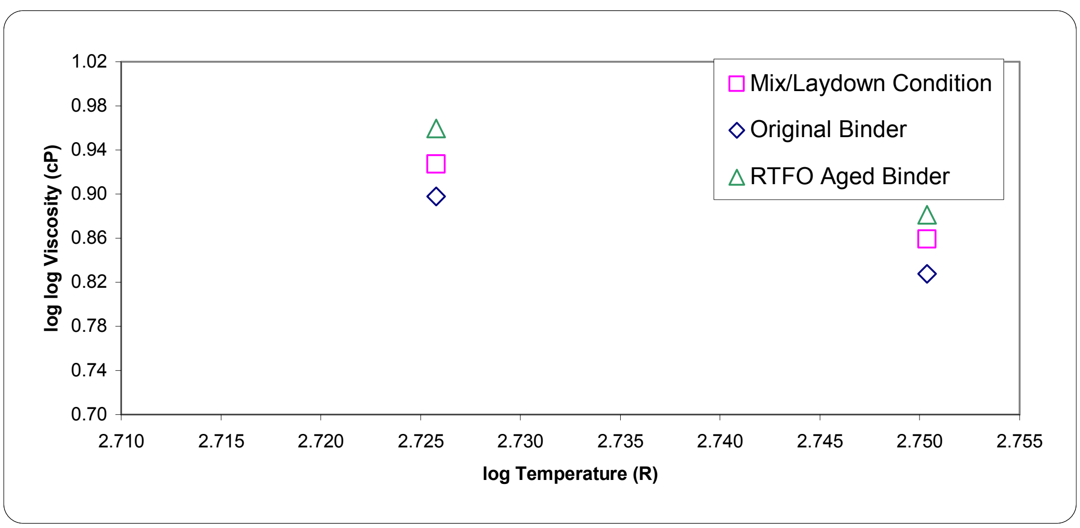
Job:	**I-75 Toledo**
Mix Type:	**9.5mm Coarse**
Traffic Level:	**E-30**
Binder Grade (PG):	**70-22P**

		A	VTS
Original Binder	η_{orig}	8.688	-2.858
Mix/Laydown Condition	$\eta_{t=0}$	8.500	-2.778
RTFO Aged Viscosity Tested	η_{vis}	9.622	-3.178

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		22.3	39.5
Original Binder	η_{orig}	80.4	5.3
Mix/Laydown Condition	$\eta_{t=0}$	286.5	16.9
RTFO Aged Viscosity Tested	η_{vis}	1,285.0	40.7



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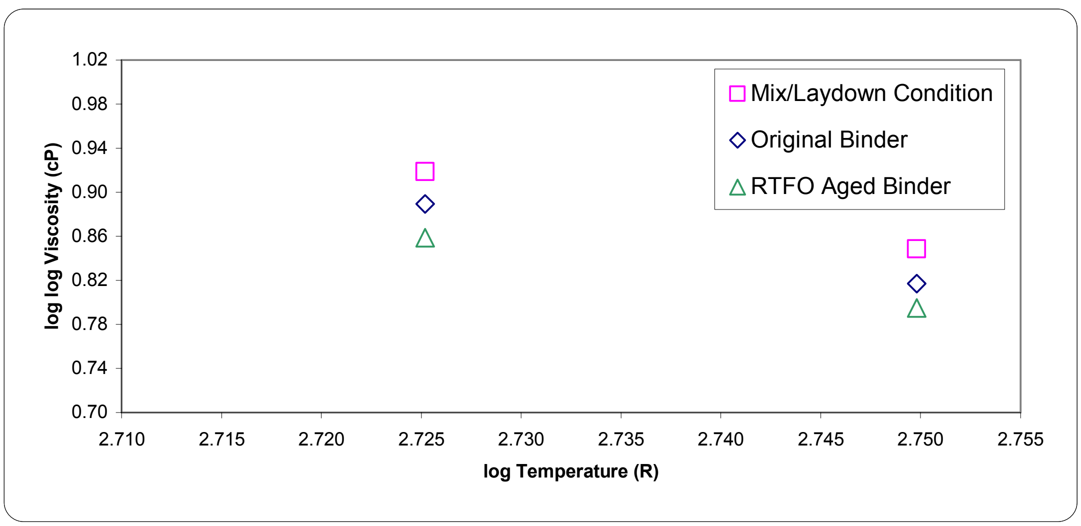
Job:	I-94 Ann Arbor
Mix Type:	12.5mm SMA
Traffic Level:	E-30
Binder Grade (PG):	70-22P

		A	VTS
Original Binder	η_{orig}	8.885	-2.934
Mix/Laydown Condition	$\eta_{t=0}$	8.691	-2.852
RTFO Aged Viscosity Tested	η_{vis}	7.939	-2.598

A = regression intercept

VTS = Regression slope of viscosity temperature susceptibility

Viscosity (10^6cPoise):		Int. Temperature (°C)	High Temeprature (°C)
		21.9	39.1
Original Binder	η_{orig}	56.0	3.6
Mix/Laydown Condition	$\eta_{t=0}$	196.7	11.4
RTFO Aged Viscosity Tested	η_{vis}	16.8	1.7



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APPENDIX D SAS OUTPUTS

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Distribution Fitting Outputs for Phase I and Phase II
Phase I Moisture Study
150mm Superpave – 1 Freeze-Thaw Cycle

The UNIVARIATE Procedure
Variable: tsrS1

Moments

N	35	Sum Weights	35
Mean	93.2857143	Sum Observations	3265
Std Deviation	11.8534468	Variance	140.504202
Skewness	-0.5350362	Kurtosis	0.019754
Uncorrected SS	309355	Corrected SS	4777.14286
Coeff Variation	12.7066046	Std Error Mean	2.0035982

Basic Statistical Measures

Location		Variability	
Mean	93.2857	Std Deviation	11.85345
Median	96.0000	Variance	140.50420
Mode	100.0000	Range	52.00000
		Interquartile Range	15.00000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	46.55909	Pr > |t|	<.0001
Sign	M	17.5	Pr >= |M|	<.0001
Signed Rank	S	315	Pr >= |S|	<.0001

Fitted Distributions for tsrS1

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	93.28571
Std Dev	Sigma	11.85345

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.14302463	Pr > D	0.070
Cramer-von Mises	W-Sq	0.07795230	Pr > W-Sq	0.220
Anderson-Darling	A-Sq	0.43589260	Pr > A-Sq	>0.250

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.527278
Shape	Sigma	0.133903
Mean		93.3395
Std Dev		12.55466

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.15094143	Pr > D	0.045
Cramer-von Mises	W-Sq	0.10546672	Pr > W-Sq	0.093
Anderson-Darling	A-Sq	0.63226708	Pr > A-Sq	0.093

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	98.27725
Shape	C	9.635224
Mean		93.34722
Std Dev		11.63131

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.05761474	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.29976607	Pr > A-Sq	>0.250

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150mm Superpave – 2 Freeze-Thaw Cycle

The UNIVARIATE Procedure
Variable: tsrS2

Moments

N	35	Sum Weights	35
Mean	87.9428571	Sum Observations	3078
Std Deviation	13.0315067	Variance	169.820168
Skewness	0.09469332	Kurtosis	-0.8544696
Uncorrected SS	276462	Corrected SS	5773.88571
Coeff Variation	14.8181526	Std Error Mean	2.20272667

Basic Statistical Measures

Location		Variability	
Mean	87.94286	Std Deviation	13.03151
Median	89.00000	Variance	169.82017
Mode	73.00000	Range	51.00000
		Interquartile Range	22.00000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	39.92454	Pr > |t|	<.0001
Sign	M	17.5	Pr >= |M|	<.0001
Signed Rank	S	315	Pr >= |S|	<.0001

Fitted Distributions for tsrS2

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	87.94286
Std Dev	Sigma	13.03151

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.12012127	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.06963466	Pr > W-Sq	>0.250

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Anderson-Darling A-Sq 0.45030797 Pr > A-Sq >0.250

Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.465882
Shape	Sigma	0.149769
Mean		87.97896
Std Dev		13.25076

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.10983981	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.09047980	Pr > W-Sq	0.147
Anderson-Darling	A-Sq	0.53068504	Pr > A-Sq	0.170

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	93.5345
Shape	C	7.540292
Mean		87.82856
Std Dev		13.77098

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.05364863	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.41954107	Pr > A-Sq	>0.250

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150mm Superpave – 3 Freeze-Thaw Cycle

The UNIVARIATE Procedure
Variable: tsrS3

Moments

N	35	Sum Weights	35
Mean	83.4857143	Sum Observations	2922
Std Deviation	15.5324545	Variance	241.257143
Skewness	0.32710397	Kurtosis	-0.2173961
Uncorrected SS	252148	Corrected SS	8202.74286
Coeff Variation	18.604925	Std Error Mean	2.625464

Basic Statistical Measures

Location		Variability	
Mean	83.48571	Std Deviation	15.53245
Median	84.00000	Variance	241.25714
Mode	91.00000	Range	63.00000
		Interquartile Range	21.00000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	31.79846	Pr > |t|	<.0001
Sign	M	17.5	Pr >= |M|	<.0001
Signed Rank	S	315	Pr >= |S|	<.0001

Fitted Distributions for tsrS3

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	83.48571
Std Dev	Sigma	15.53245

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.08639713	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.03624281	Pr > W-Sq	>0.250

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Anderson-Darling A-Sq 0.28216379 Pr > A-Sq >0.250

Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.407805
Shape	Sigma	0.187024
Mean		83.53737
Std Dev		15.76111

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.10919085	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.04567675	Pr > W-Sq	>0.500
Anderson-Darling	A-Sq	0.27629087	Pr > A-Sq	>0.500

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	89.93046
Shape	C	5.782065
Mean		83.2585
Std Dev		16.69232

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.04837711	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.43219627	Pr > A-Sq	>0.250

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100mm Marshall – 1 Freeze-Thaw Cycle

The UNIVARIATE Procedure
Variable: tsrM1
Moments

N	35	Sum Weights	35
Mean	97.7714286	Sum Observations	3422
Std Deviation	21.0895649	Variance	444.769748
Skewness	-0.2211672	Kurtosis	-0.9689605
Uncorrected SS	349696	Corrected SS	15122.1714
Coeff Variation	21.5702739	Std Error Mean	3.5647871

Basic Statistical Measures

Location		Variability	
Mean	97.7714	Std Deviation	21.08956
Median	99.0000	Variance	444.76975
Mode	116.0000	Range	73.00000
		Interquartile Range	39.00000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	27.427	Pr > |t|	<.0001
Sign	M	17.5	Pr >= |M|	<.0001
Signed Rank	S	315	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	97.77143
Std Dev	Sigma	21.08956

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.09900318	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.06880207	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.43242541	Pr > A-Sq	>0.250

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.558176
Shape	Sigma	0.229319
Mean		97.9512
Std Dev		22.76068

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.13930827	Pr > D	0.084
Cramer-von Mises	W-Sq	0.12833590	Pr > W-Sq	0.045
Anderson-Darling	A-Sq	0.72762170	Pr > A-Sq	0.053

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	106.1106
Shape	C	5.522241
Mean		97.98391
Std Dev		20.49222

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.04951851	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.35492956	Pr > A-Sq	>0.250

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100mm Marshall – 2 Freeze-Thaw Cycle

The UNIVARIATE Procedure
Variable: tsrM2
Moments

N	35	Sum Weights	35
Mean	94.7428571	Sum Observations	3316
Std Deviation	20.0826862	Variance	403.314286
Skewness	0.00533005	Kurtosis	-0.4631701
Uncorrected SS	327880	Corrected SS	13712.6857
Coeff Variation	21.1970452	Std Error Mean	3.39459354

Basic Statistical Measures

Location		Variability	
Mean	94.7429	Std Deviation	20.08269
Median	94.0000	Variance	403.31429
Mode	105.0000	Range	83.00000
		Interquartile Range	28.00000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	27.90993	Pr > |t|	<.0001
Sign	M	17.5	Pr >= |M|	<.0001
Signed Rank	S	315	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	94.74286
Std Dev	Sigma	20.08269

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.07773968	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.03579673	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.22153527	Pr > A-Sq	>0.250

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.528125
Shape	Sigma	0.221542
Mean		94.88501
Std Dev		21.28165

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.11497959	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.07922535	Pr > W-Sq	0.213
Anderson-Darling	A-Sq	0.43786178	Pr > A-Sq	0.293

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	102.751
Shape	C	5.343813
Mean		94.70432
Std Dev		20.41195

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.03110473	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.21469917	Pr > A-Sq	>0.250

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100mm Marshall – 3 Freeze-Thaw Cycle

The UNIVARIATE Procedure
Variable: tsrM3
Moments

N	35	Sum Weights	35
Mean	83.4571429	Sum Observations	2921
Std Deviation	19.1454846	Variance	366.54958
Skewness	-0.1889456	Kurtosis	-0.8930737
Uncorrected SS	256241	Corrected SS	12462.6857
Coeff Variation	22.9404985	Std Error Mean	3.23617755

Basic Statistical Measures

Location		Variability	
Mean	83.45714	Std Deviation	19.14548
Median	86.00000	Variance	366.54958
Mode	68.00000	Range	71.00000
		Interquartile Range	31.00000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	25.7888	Pr > |t|	<.0001
Sign	M	17.5	Pr >= |M|	<.0001
Signed Rank	S	315	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	83.45714
Std Dev	Sigma	19.14548

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.09087113	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.06741259	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.40882763	Pr > A-Sq	>0.250

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.396524
Shape	Sigma	0.244979
Mean		83.6408
Std Dev		20.80157

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.13629187	Pr > D	0.096
Cramer-von Mises	W-Sq	0.13019416	Pr > W-Sq	0.043
Anderson-Darling	A-Sq	0.72986888	Pr > A-Sq	0.052

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	90.92177
Shape	C	5.146386
Mean		83.62063
Std Dev		18.65498

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.04754713	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.32296421	Pr > A-Sq	>0.250

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100mm Superpave – 1 Freeze-Thaw Cycle

The UNIVARIATE Procedure
Variable: tsrS1
Moments

N	35	Sum Weights	35
Mean	88.8	Sum Observations	3108
Std Deviation	16.4742223	Variance	271.4
Skewness	0.27572465	Kurtosis	0.48623737
Uncorrected SS	285218	Corrected SS	9227.6
Coeff Variation	18.5520521	Std Error Mean	2.78465181

Basic Statistical Measures

Location		Variability	
Mean	88.80000	Std Deviation	16.47422
Median	89.00000	Variance	271.40000
Mode	78.00000	Range	76.00000
		Interquartile Range	22.00000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	31.88909	Pr > |t|	<.0001
Sign	M	17.5	Pr >= |M|	<.0001
Signed Rank	S	315	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	88.8
Std Dev	Sigma	16.47422

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.11366899	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.04746100	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.30226604	Pr > A-Sq	>0.250

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.469278
Shape	Sigma	0.189772
Mean		88.87983
Std Dev		17.01994

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.10134991	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.04657419	Pr > W-Sq	>0.500
Anderson-Darling	A-Sq	0.30444000	Pr > A-Sq	>0.500

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	95.59641
Shape	C	5.746508
Mean		88.47348
Std Dev		17.83878

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.08698467	Pr > W-Sq	0.162
Anderson-Darling	A-Sq	0.55683460	Pr > A-Sq	0.156

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100mm Superpave – 2 Freeze-Thaw Cycle

The UNIVARIATE Procedure
Variable: tsrS2
Moments

N	35	Sum Weights	35
Mean	79.8857143	Sum Observations	2796
Std Deviation	15.2966191	Variance	233.986555
Skewness	0.12837539	Kurtosis	-0.0897758
Uncorrected SS	231316	Corrected SS	7955.54286
Coeff Variation	19.1481283	Std Error Mean	2.58560054

Basic Statistical Measures

Location		Variability	
Mean	79.88571	Std Deviation	15.29662
Median	80.00000	Variance	233.98655
Mode	83.00000	Range	65.00000
		Interquartile Range	18.00000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	30.89639	Pr > |t|	<.0001
Sign	M	17.5	Pr >= |M|	<.0001
Signed Rank	S	315	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	79.88571
Std Dev	Sigma	15.29662

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.10808692	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.05481793	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.33928688	Pr > A-Sq	>0.250

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.362207
Shape	Sigma	0.196774
Mean		79.96324
Std Dev		15.88827

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.14599732	Pr > D	0.058
Cramer-von Mises	W-Sq	0.09973698	Pr > W-Sq	0.111
Anderson-Darling	A-Sq	0.55293931	Pr > A-Sq	0.147

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	86.13012
Shape	C	5.732775
Mean		79.70183
Std Dev		16.10556

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.05705911	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.37172290	Pr > A-Sq	>0.250

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100mm Superpave – 3 Freeze-Thaw Cycle

The UNIVARIATE Procedure

Variable: tsrS3

Moments

N	35	Sum Weights	35
Mean	74.4857143	Sum Observations	2607
Std Deviation	18.2311489	Variance	332.37479
Skewness	0.55300249	Kurtosis	0.70812845
Uncorrected SS	205485	Corrected SS	11300.7429
Coeff Variation	24.4760342	Std Error Mean	3.08162661

Basic Statistical Measures

Location		Variability	
Mean	74.48571	Std Deviation	18.23115
Median	71.00000	Variance	332.37479
Mode	70.00000	Range	84.00000
		Interquartile Range	23.00000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	24.17091	Pr > |t|	<.0001
Sign	M	17.5	Pr >= |M|	<.0001
Signed Rank	S	315	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	74.48571
Std Dev	Sigma	18.23115

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.09009951	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.03320896	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.22272842	Pr > A-Sq	>0.250

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.281421
Shape	Sigma	0.247093
Mean		74.58571
Std Dev		18.71454

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.07556771	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.02364675	Pr > W-Sq	>0.500
Anderson-Darling	A-Sq	0.17885336	Pr > A-Sq	>0.500

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	81.54436
Shape	C	4.310017
Mean		74.22941
Std Dev		19.46317

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.05684418	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.39553700	Pr > A-Sq	>0.250

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Phase II Moisture Study - TSR

The UNIVARIATE Procedure
Variable: tsr
Moments

N	105	Sum Weights	105
Mean	91.952381	Sum Observations	9655
Std Deviation	11.57813	Variance	134.053095
Skewness	-0.0367541	Kurtosis	-0.0117542
Uncorrected SS	901741.76	Corrected SS	13941.5219
Coeff Variation	12.5914413	Std Error Mean	1.1299098

Basic Statistical Measures

Location		Variability	
Mean	91.95238	Std Deviation	11.57813
Median	92.50000	Variance	134.05310
Mode	92.30000	Range	62.00000
		Interquartile Range	15.60000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	81.38028	Pr > |t|	<.0001
Sign	M	52.5	Pr >= |M|	<.0001
Signed Rank	S	2782.5	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	91.95238
Std Dev	Sigma	11.57813

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.07719145	Pr > D	0.125
Cramer-von Mises	W-Sq	0.07815315	Pr > W-Sq	0.223
Anderson-Darling	A-Sq	0.49132013	Pr > A-Sq	0.223

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.51321
Shape	Sigma	0.128664
Mean		91.97225
Std Dev		11.88264

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.08659458	Pr > D	0.051
Cramer-von Mises	W-Sq	0.15037342	Pr > W-Sq	0.024
Anderson-Darling	A-Sq	0.86510204	Pr > A-Sq	0.025

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	97.01041
Shape	C	8.590305
Mean		91.66893
Std Dev		12.72391

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.07307117	Pr > W-Sq	0.242
Anderson-Darling	A-Sq	0.64161236	Pr > A-Sq	0.093

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Phase II Moisture Study – E* Ratio

The UNIVARIATE Procedure
Variable: estar 0.02 Hz

Moments

N	62	Sum Weights	62
Mean	86.9080645	Sum Observations	5388.3
Std Deviation	25.527679	Variance	651.662393
Skewness	0.46366812	Kurtosis	-0.3990607
Uncorrected SS	508038.13	Corrected SS	39751.406
Coeff Variation	29.3731993	Std Error Mean	3.24201847

Basic Statistical Measures

Location		Variability	
Mean	86.90806	Std Deviation	25.52768
Median	83.80000	Variance	651.66239
Mode	76.30000	Range	111.90000
		Interquartile Range	35.80000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	26.80678	Pr > |t|	<.0001
Sign	M	31	Pr >= |M|	<.0001
Signed Rank	S	976.5	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	86.90806
Std Dev	Sigma	25.52768

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.09684781	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.08336662	Pr > W-Sq	0.191
Anderson-Darling	A-Sq	0.51915095	Pr > A-Sq	0.189

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.422043
Shape	Sigma	0.297241
Mean		87.02706
Std Dev		26.45008

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.06143057	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.04192032	Pr > W-Sq	>0.500
Anderson-Darling	A-Sq	0.27122326	Pr > A-Sq	>0.500

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	96.32195
Shape	C	3.691709
Mean		86.91536
Std Dev		26.21509

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.07911830	Pr > W-Sq	0.208
Anderson-Darling	A-Sq	0.52055657	Pr > A-Sq	0.195

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The UNIVARIATE Procedure
Variable: estar 0.1 Hz

Moments

N	62	Sum Weights	62
Mean	80.3080645	Sum Observations	4979.1
Std Deviation	20.7464182	Variance	430.413868
Skewness	0.15279987	Kurtosis	-0.881308
Uncorrected SS	426117.13	Corrected SS	26255.246
Coeff Variation	25.8335428	Std Error Mean	2.63479775

Basic Statistical Measures

Location		Variability	
Mean	80.30806	Std Deviation	20.74642
Median	79.55000	Variance	430.41387
Mode	60.20000	Range	80.30000
		Interquartile Range	30.60000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	30.47978	Pr > |t|	<.0001
Sign	M	31	Pr >= |M|	<.0001
Signed Rank	S	976.5	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	80.30806
Std Dev	Sigma	20.74642

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.07683534	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.06178074	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.48208726	Pr > A-Sq	0.230

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.351487
Shape	Sigma	0.268491
Mean		80.44152
Std Dev		21.99301

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.08809599	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.06645013	Pr > W-Sq	0.326
Anderson-Darling	A-Sq	0.46893534	Pr > A-Sq	0.245

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	88.27489
Shape	C	4.342228
Mean		80.39079
Std Dev		20.93678

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.07277117	Pr > W-Sq	0.242
Anderson-Darling	A-Sq	0.53598981	Pr > A-Sq	0.180

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The UNIVARIATE Procedure
Variable: estar 1.0 Hz

Moments

N	62	Sum Weights	62
Mean	78.2645161	Sum Observations	4852.4
Std Deviation	22.8424906	Variance	521.779376
Skewness	0.15583434	Kurtosis	-0.6377257
Uncorrected SS	411599.28	Corrected SS	31828.5419
Coeff Variation	29.1862669	Std Error Mean	2.9009992

Basic Statistical Measures

Location		Variability	
Mean	78.26452	Std Deviation	22.84249
Median	76.85000	Variance	521.77938
Mode	44.40000	Range	93.70000
		Interquartile Range	31.80000

NOTE: The mode displayed is the smallest of 5 modes with a count of 2.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	26.97847	Pr > |t|	<.0001
Sign	M	31	Pr >= |M|	<.0001
Signed Rank	S	976.5	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	78.26452
Std Dev	Sigma	22.84249

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.11159274	Pr > D	0.054
Cramer-von Mises	W-Sq	0.08062584	Pr > W-Sq	0.207
Anderson-Darling	A-Sq	0.50855646	Pr > A-Sq	0.201

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.31521
Shape	Sigma	0.308956
Mean		78.48729
Std Dev		24.83946

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.14446214	Pr > D	<0.010
Cramer-von Mises	W-Sq	0.12531582	Pr > W-Sq	0.050
Anderson-Darling	A-Sq	0.87500643	Pr > A-Sq	0.024

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	86.65676
Shape	C	3.827929
Mean		78.35128
Std Dev		22.87194

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.07165103	Pr > W-Sq	0.248
Anderson-Darling	A-Sq	0.46314926	Pr > A-Sq	0.249

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The UNIVARIATE Procedure
Variable: estar 5.0 Hz

Moments

N	62	Sum Weights	62
Mean	82.1564516	Sum Observations	5093.7
Std Deviation	24.536561	Variance	602.042827
Skewness	0.05808302	Kurtosis	-0.8134506
Uncorrected SS	455204.93	Corrected SS	36724.6124
Coeff Variation	29.8656533	Std Error Mean	3.11614637

Basic Statistical Measures

Location		Variability	
Mean	82.15645	Std Deviation	24.53656
Median	83.00000	Variance	602.04283
Mode	60.20000	Range	98.50000
		Interquartile Range	37.80000

NOTE: The mode displayed is the smallest of 3 modes with a count of 2.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	26.36476	Pr > |t|	<.0001
Sign	M	31	Pr >= |M|	<.0001
Signed Rank	S	976.5	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	82.15645
Std Dev	Sigma	24.53656

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.06415837	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.04640869	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.28258419	Pr > A-Sq	>0.250

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.360459
Shape	Sigma	0.322349
Mean		82.46825
Std Dev		27.28929

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.10132484	Pr > D	0.113
Cramer-von Mises	W-Sq	0.09662889	Pr > W-Sq	0.125
Anderson-Darling	A-Sq	0.59715939	Pr > A-Sq	0.119

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	91.0848
Shape	C	3.786947
Mean		82.30549
Std Dev		24.26081

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.04026210	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.24437811	Pr > A-Sq	>0.250

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The UNIVARIATE Procedure
Variable: estar 10.0 Hz

Moments

N	62	Sum Weights	62
Mean	83.8387097	Sum Observations	5198
Std Deviation	25.0797244	Variance	628.992575
Skewness	0.04089549	Kurtosis	-0.7006048
Uncorrected SS	474162.16	Corrected SS	38368.5471
Coeff Variation	29.9142538	Std Error Mean	3.18512818

Basic Statistical Measures

Location		Variability	
Mean	83.83871	Std Deviation	25.07972
Median	83.15000	Variance	628.99258
Mode	.	Range	103.30000
		Interquartile Range	38.80000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	26.32193	Pr > |t|	<.0001
Sign	M	31	Pr >= |M|	<.0001
Signed Rank	S	976.5	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	83.83871
Std Dev	Sigma	25.07972

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.07933165	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.04215164	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.31214487	Pr > A-Sq	>0.250

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.380063
Shape	Sigma	0.325821
Mean		84.19564
Std Dev		28.17716

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.11101509	Pr > D	0.057
Cramer-von Mises	W-Sq	0.14502390	Pr > W-Sq	0.027
Anderson-Darling	A-Sq	0.79593914	Pr > A-Sq	0.039

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	92.93645
Shape	C	3.777766
Mean		83.96732
Std Dev		24.80494

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.03745174	Pr > W-Sq	>0.250
Anderson-Darling	A-Sq	0.28262365	Pr > A-Sq	>0.250

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The UNIVARIATE Procedure
Variable: estar 25.0 Hz

Moments

N	62	Sum Weights	62
Mean	92.3306452	Sum Observations	5724.5
Std Deviation	37.0172294	Variance	1370.27527
Skewness	1.79088158	Kurtosis	4.55105856
Uncorrected SS	612133.57	Corrected SS	83586.7918
Coeff Variation	40.0920294	Std Error Mean	4.70119284

Basic Statistical Measures

Location		Variability	
Mean	92.33065	Std Deviation	37.01723
Median	87.25000	Variance	1370
Mode	83.70000	Range	199.50000
		Interquartile Range	39.80000

NOTE: The mode displayed is the smallest of 3 modes with a count of 2.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	19.63983	Pr > |t|	<.0001
Sign	M	31	Pr >= |M|	<.0001
Signed Rank	S	976.5	Pr >= |S|	<.0001

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	92.33065
Std Dev	Sigma	37.01723

Goodness-of-Fit Tests for Normal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.13900007	Pr > D	<0.010
Cramer-von Mises	W-Sq	0.29676684	Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	2.06508708	Pr > A-Sq	<0.005

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Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	4.458921
Shape	Sigma	0.359555
Mean		92.16323
Std Dev		34.23815

Goodness-of-Fit Tests for Lognormal Distribution

Test	---Statistic----		-----p Value-----	
Kolmogorov-Smirnov	D	0.07586343	Pr > D	>0.150
Cramer-von Mises	W-Sq	0.04381118	Pr > W-Sq	>0.500
Anderson-Darling	A-Sq	0.35843326	Pr > A-Sq	0.457

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	103.8658
Shape	C	2.561806
Mean		92.21539
Std Dev		38.60632

Goodness-of-Fit Tests for Weibull Distribution

Test	---Statistic----		-----p Value-----	
Cramer-von Mises	W-Sq	0.28834246	Pr > W-Sq	<0.010
Anderson-Darling	A-Sq	2.01222721	Pr > A-Sq	<0.010

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GENERAL LINEAR MODEL - REGRESSION
AASHTO T283

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The GLM Procedure

Class Level Information

Class	Levels	Values
grad	2	0 1
nmas	3	0 1 2
traf	3	0 1 2
poly	2	0 1
agg	3	0 1 2
k	2	0 1
ac	2	0 1
faa	2	0 1
rap	4	0 1 2 3

Number of Observations Read	105
Number of Observations Used	80

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The GLM Procedure

Dependent Variable: tsr

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	5174.25688	369.58978	3.50	0.0003
Error	65	6870.63700	105.70211		
Corrected Total	79	12044.89388			

R-Square	Coeff Var	Root MSE	tsr Mean
0.429581	11.07182	10.28115	92.85875

Source	DF	Type I SS	Mean Square	F Value	Pr > F
grad	1	226.787042	226.787042	2.15	0.1478
nmas	2	40.287944	20.143972	0.19	0.8269
traf	2	614.550361	307.275181	2.91	0.0618
poly	1	629.918099	629.918099	5.96	0.0174
agg	2	657.623067	328.811533	3.11	0.0513
k	1	1146.676766	1146.676766	10.85	0.0016
ac	1	260.459703	260.459703	2.46	0.1213
faa	1	179.168042	179.168042	1.70	0.1975
rap	3	1418.785851	472.928617	4.47	0.0064

Source	DF	Type III SS	Mean Square	F Value	Pr > F
grad	1	1165.367405	1165.367405	11.03	0.0015
nmas	2	1463.532377	731.766189	6.92	0.0019
traf	2	1187.556818	593.778409	5.62	0.0056
poly	1	1869.826118	1869.826118	17.69	<.0001
agg	2	1816.637940	908.318970	8.59	0.0005
k	1	684.352000	684.352000	6.47	0.0133
ac	1	291.852800	291.852800	2.76	0.1014
faa	1	953.285950	953.285950	9.02	0.0038
rap	3	1418.785851	472.928617	4.47	0.0064

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The ANOVA Procedure

t Tests (LSD) for tsr

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	65
Error Mean Square	113.6925
Critical Value of t	1.99714
Least Significant Difference	5.4983
Harmonic Mean of Cell Sizes	30

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	grad
A	95.775	20	1
A			
A	91.887	60	0

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The ANOVA Procedure

t Tests (LSD) for tsr

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	65
Error Mean Square	113.6925
Critical Value of t	1.99714
Least Significant Difference	6.2345
Harmonic Mean of Cell Sizes	23.33333

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	nmas
A	93.167	30	1
A			
A	93.031	35	0
A			
A	91.840	15	2

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The ANOVA Procedure

t Tests (LSD) for tsr

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	65
Error Mean Square	113.6925
Critical Value of t	1.99714
Least Significant Difference	6.1473
Harmonic Mean of Cell Sizes	24

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping		Mean	N	traf
	A	97.510	20	2
	A			
B	A	91.623	40	0
B				
B		90.680	20	1

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The ANOVA Procedure

t Tests (LSD) for tsr

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	65
Error Mean Square	113.6925
Critical Value of t	1.99714
Least Significant Difference	5.4983
Harmonic Mean of Cell Sizes	30

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	poly
A	97.995	20	0
B	91.147	60	1

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The ANOVA Procedure

t Tests (LSD) for tsr

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	65
Error Mean Square	113.6925
Critical Value of t	1.99714
Least Significant Difference	6.4798
Harmonic Mean of Cell Sizes	21.6

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	agg
A	95.867	15	0
A			
A	94.885	20	2
A			
A	90.956	45	1

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The ANOVA Procedure

t Tests (LSD) for tsr

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	65
Error Mean Square	113.6925
Critical Value of t	1.99714
Least Significant Difference	5.1365
Harmonic Mean of Cell Sizes	34.375

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	k
A	93.173	55	0
A			
A	92.168	25	1

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The ANOVA Procedure

t Tests (LSD) for tsr

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	65
Error Mean Square	113.6925
Critical Value of t	1.99714
Least Significant Difference	4.7993
Harmonic Mean of Cell Sizes	39.375

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	ac
A	98.069	35	0
B	88.807	45	1

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The ANOVA Procedure

t Tests (LSD) for tsr

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	65
Error Mean Square	113.6925
Critical Value of t	1.99714
Least Significant Difference	5.4983
Harmonic Mean of Cell Sizes	30

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	faa
A	93.537	60	1
A			
A	90.825	20	0

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The ANOVA Procedure

t Tests (LSD) for tsr

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	65
Error Mean Square	113.6925
Critical Value of t	1.99714
Least Significant Difference	8.8016
Harmonic Mean of Cell Sizes	11.70732

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	rap
A	95.890	20	0
A			
A	93.215	40	2
A			
A	91.853	15	1
B	80.900	5	3

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Dynamic Modulus

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The GLM Procedure

Class Level Information

Class	Levels	Values
grad	2	0 1
nmas	3	0 1 2
traf	3	0 1 2
poly	2	0 1
agg	3	0 1 2
k	2	0 1
ac	2	0 1
faa	2	0 1
rap	4	0 1 2 3
freq	6	0 1 2 3 4 5

Number of Observations Read	372
Number of Observations Used	288

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The GLM Procedure

Dependent Variable: estar

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	54938.7583	2891.5136	5.59	<.0001
Error	268	138719.8074	517.6112		
Corrected Total	287	193658.5658			

R-Square	Coeff Var	Root MSE	estar Mean
0.283689	25.33635	22.75107	89.79618

Source	DF	Type I SS	Mean Square	F Value	Pr > F
grad	1	293.88334	293.88334	0.57	0.4518
nmas	2	2546.66251	1273.33125	2.46	0.0874
traf	2	13922.15758	6961.07879	13.45	<.0001
poly	1	1808.01875	1808.01875	3.49	0.0627
agg	2	11448.72186	5724.36093	11.06	<.0001
k	1	8819.90288	8819.90288	17.04	<.0001
ac	1	36.25349	36.25349	0.07	0.7915
faa	1	165.21534	165.21534	0.32	0.5726
rap	3	7971.68895	2657.22965	5.13	0.0018
freq	5	7926.25366	1585.25073	3.06	0.0105

Source	DF	Type III SS	Mean Square	F Value	Pr > F
grad	1	2288.290932	2288.290932	4.42	0.0364
nmas	2	3637.787637	1818.893818	3.51	0.0312
traf	2	1179.722080	589.861040	1.14	0.3215
poly	1	1943.952196	1943.952196	3.76	0.0537
agg	2	2485.267833	1242.633916	2.40	0.0926
k	1	11.793185	11.793185	0.02	0.8801
ac	1	3220.128290	3220.128290	6.22	0.0132
faa	1	3411.955796	3411.955796	6.59	0.0108
rap	3	7412.616266	2470.872089	4.77	0.0029
freq	5	7926.253657	1585.250731	3.06	0.0105

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	5.4322
Harmonic Mean of Cell Sizes	108

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	grad
A	91.546	72	1
A			
A	89.213	216	0

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	6.1595
Harmonic Mean of Cell Sizes	84

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping		Mean	N	nmas
	A	94.800	54	2
	A			
B	A	91.014	108	1
B				
B		86.608	126	0

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	6.0733
Harmonic Mean of Cell Sizes	86.4

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	traf
A	100.100	72	2
B	90.953	72	1
C	84.066	144	0

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	5.4322
Harmonic Mean of Cell Sizes	108

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	poly
A	100.246	72	0
B	86.313	216	1

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	6.4019
Harmonic Mean of Cell Sizes	77.76

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	agg
A	104.872	54	2
B	89.235	72	0
B			
B	85.020	162	1

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	5.0596
Harmonic Mean of Cell Sizes	124.4931

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	k
A	94.864	197	0
B	78.824	91	1

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	4.7416
Harmonic Mean of Cell Sizes	141.75

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	ac
A	92.296	126	0
A			
A	87.852	162	1

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	5.4322
Harmonic Mean of Cell Sizes	108

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	faa
A	91.255	216	1
B	85.419	72	0

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	8.7239
Harmonic Mean of Cell Sizes	41.87406

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	rap
A	102.010	52	1
A			
A	93.643	72	0
B	84.786	146	2
B			
B	79.767	18	3

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The ANOVA Procedure

t Tests (LSD) for estar

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	268
Error Mean Square	411.0663
Critical Value of t	1.96886
Least Significant Difference	8.1482

Means with the same letter are not significantly different.

t Grouping	Mean	N	freq
A	99.715	48	5
B	90.952	48	4
B			
B	90.690	48	0
B			
B	89.110	48	3
B			
B	84.460	48	1
B			
B	83.850	48	2

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www.manaraa.com

REFERENCES

AASHTO TP48 (1997) Standard Test Procedure for Viscosity Determination of Asphalt Binders Using Rotational Viscometer. *Standard Specifications for Transportation Materials and Methods and Sampling and Testing Part II: Tests*. Washington D.C.

AASHTO T165-55. (1997) Effect of Water on Cohesion of Compacted Bituminous Mixtures. *Standard Specifications for Transportation Materials and Methods and Sampling and Testing Part II: Tests*. Washington D.C.

AASHTO T166-93. (1997) Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens. *Standard Specifications for Transportation Materials and Methods and Sampling and Testing Part II: Tests*. Washington D.C.

AASHTO T182-84. (1997) Coating and Stripping of Bitumen-Aggregate Mixtures. *Standard Specifications for Transportation Materials and Methods and Sampling and Testing Part II: Tests*. Washington D.C.

AASHTO T209-94. (1997) Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures. *Standard Specifications for Transportation Materials and Methods and Sampling and Testing Part II: Tests*. Washington D.C.

AASHTO T269-94. (1997) Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures. *Standard Specifications for Transportation Materials and Methods and Sampling and Testing Part II: Tests*. Washington D.C.

AASHTO T283-89. (1993) Resistance of Compacted Bituminous Mixture to Moisture Induced Damage. *Standard Specifications for Transportation Materials and Methods and Sampling and Testing Part II: Tests*. Washington D.C.

ASTM D5. (2004) Standard Test Method for Penetration of Bituminous Materials. *Annual Book of ASTM Standards* 4.03. West Conshohocken, PA: ASTM International.

ASTM D140. (2004) Standard Practice for Sampling Bituminous Materials. *Annual Book of ASTM Standards* 4.03. West Conshohocken, PA: ASTM International.

ASTM D1075. (2004) Standard Test Method for Effect of Water on Compressive Strength of Compacted Bituminous Mixtures. *Annual Book of ASTM Standards* 4.03. West Conshohocken, PA: ASTM International.

ASTM D2041. (2004) Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures. *Annual Book of ASTM Standards* 4.03. West Conshohocken, PA: ASTM International.

www.manaraa.com

ASTM D2172. (2004) Standard Test Method for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures. *Annual Book of ASTM Standards* 4.03. West Conshohocken, PA: ASTM International.

ASTM D2726. (2004) Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures. *Annual Book of ASTM Standards* 4.03. West Conshohocken, PA: ASTM International.

ASTM D4867. (2004) Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures. *Annual Book of ASTM Standards* 4.03. West Conshohocken, PA: ASTM International.

ASTM C702. (2004) Standard Practice for Reducing Samples of Aggregate to Testing Size. *Annual Book of ASTM Standards* 4.02. West Conshohocken, PA: ASTM International.

Akhter, G. F., and M.W. Witczak, "Sensitivity of Flexible Pavement Performance to Bituminous Mix Properties." *Transportation Research Record 1034,* TRB, National Highway Research Council, Washington D.C., 1985, pp. 70–79, 1985.

Alam, Muhammad Murshed; Tandon, Vivek; Nazarian, Soheil; and Tahmoressi; Maghsoud. "Identification of Moisture-Susceptible Asphalt Concrete Mixes Using Modified Environmental Conditioning System." *Transportation Research Record 1630*, TRB, National Highway Research Council, Washington, D.C., 1998, pp. 106–116.

Al-Swailmi, Saleh and Terrel, Ronald. "Evaluation of Water Damage of Asphalt Concrete Mixtures Using the Environmental Conditioning System (ECS)." *Journal of the Association of Asphalt Paving Technologists*, Vol. 61, 1992a, pp. 405–435.

Al-Swailmi, Saleh and Terrel, Ronald. "Evaluation of the Environmental Conditioning System (ECS) with AASHTO T-283." *Journal of the Association of Asphalt Paving Technologists*, Vol. 61, 1992b, pp. 150–171.

Al-Swailmi, Saleh; Scholz, Todd V.; and Terrel, Ronald L. "Development and Evaluation of Test System to Induce and Monitor Moisture Damage to Asphalt Concrete Mixtures." *Transportation Research Record 1353*, TRB, National Highway Research Council, Washington, D.C., 1992c, pp. 39–45.

Aschenbrener, T.; McGennis, R.B; and Terrel, R.L. "Comparison of Several Moisture Susceptibility Tests to Pavements of Known Field Performance." *Journal of the Association of Asphalt Paving Technologists*, Vol. 64, 1995, pp. 163–208.

Asphalt Institute. *Cause and Prevention of Stripping in Asphalt Pavements*. Educational Series No. 10, College Park, Md. 1981.

Asphalt Institute. *Superpave Mix Design*. Superpave Series No. 2. 2001.

المنارة للاستشارات
www.manaraa.com

Ayyub, Bilal and McCuen, Richard. *Probability, Statistics, and Reliability for Engineers*. 1st Ed. 1997.

Barak, John, Michigan Department of Transportation Bituminous Engineer, Email correspondence, Fall 2005.

Bhasin, Amit; Masad, Eyad; Little, Dallas; and Lytton, Robert. "Limits of Adhesive Bond Energy for Improved Resistance to Hot Mix Asphalt to Moisture Damage." *Transportation Research Board CD-ROM*. 85th Annual Meeting, January 22-26, 2006.

Birgisson, Bjorn; Roque, Reynaldo; and Page, Gale C. "Evaluation of Water Damage Using Hot Mix Asphalt Fracture Mechanics." *Association of Asphalt Paving Technologists* CD-ROM. 2003.

Birgisson, B, G. Sholar, R. Roque, "Evaluation of Predicted Dynamic Modulus for Florida Mixtures," Transportation Research Board CD-ROM. 84th Annual Meeting, January 9-13, 2005.

Bonaquist, Ramon and Christensen, Donald. *NCHRP Report 513: Simple Performance Tester for Superpave Mix Design: First Article Development and Evaluation.* Transportation Research Board, National Highway Research Council, Washington D.C. 2003.

Brown, E.R.; Kandhal, P.S.; Zhang, J. "Performance Testing for Hot Mix Asphalt," National Center for Asphalt Technology (NCAT) Report 2001-05, 2001.

California Test 302. "Method of Test for Film Stripping." State of California Department of Transportation. 1999.

California Test 307. "Method of Test for Moisture Vapor Susceptibility of Bituminous Mixtures." State of California Department of Transportation. 2000.

Cheng, DingXin; Little, Dallas N.; Lytton, Robert L.; Holste, James C . "Surface Energy Measurements of Asphalt and Its Application to Predicting Fatigue and Healing in Asphalt Mixtures." *Transportation Research Record 1810,* TRB, National Highway Research Council, Washington, D.C., 2002, pp. 44–53.

Cheng, DingXin; Little, Dallas N.; Lytton, Robert L.; Holste, James C . "Moisture Damage Evaluation of Asphalt Mixtures by Considering Both Moisture Diffusion and Repeated-Load Conditions." *Transportation Research Record 1832,* TRB, National Highway Research Council, Washington, D.C., 2003, pp. 42–49.

المنارة للاستشارات

www.manaraa.com

Choubane, Bouzid; Page, Gale; and Musselman, James. "Effects of Water Saturation Level on Resistance of Compacted Hot-Mix Asphalt Samples to Moisture-Induced Damage." *Transportation Research Record 1723*, TRB, National Highway Research Council, Washington, D.C., 2000, pp. 97–106.

Christensen, D.; Pellinen, T.; and Bonaquist, R., "Hirsch Model for Estimating the Modulus of Asphalt Concrete", *Journal of the Association of Asphalt Paving Technologists*, Vol. 72, 2003, pp. 97–121.

Coplantz, John and Newcomb, David. "Water Sensitivity Test Methods for Asphalt Concrete Mixtures: A Laboratory Comparison." *Transportation Research Record 1171*, TRB, National Highway Research Council, Washington, D.C., 1988, pp. 44–50.

Curtis, C.W.; Lytton, Robert L.; and Brannan, C.J. "Influence of Aggregate Chemistry on the Adsorption and Desorption of Asphalt." *Transportation Research Record 1362,* TRB, National Highway Research Council, Washington, D.C., 1992, pp. 1–9.

Curtis, C.W.; Ensley, K; and Epps, J. "Fundamental Properties of Asphalt-Aggregate Interactions Including Adhesion and Absorption." SHRP-A-341. Strategic Highway Research Program, National Highway Research Council, Washington, D.C., 1993.

DATAPAVE, http://www.datapave.com, LTPP DataPave Online 2004.

Epps, J.; Sebaaly, Peter; Penaranda, Jorge; Maher, Michele; McCann, Martin; and Hand Adam. *NCHRP 444: Compatibility of a Test for Moisture-Induced Damage with Superpave Volumetric Mix Design*. Transportation Research Board, National Highway Research Council, Washington, D.C. 2000.

Ford, M.C.; Manke, P.G.; and O'Bannon, C.E. "Quantitative Evaluation of Stripping by the Surface Reaction Test." *Transportation Research Record 515,* TRB, National Highway Research Council, Washington, D.C., 1974, pp. 40–54.

Fromm, H.J. The Mechanisms of Asphalt Stripping from Aggregate Surfaces. *Journal of the Association of Asphalt Paving Technologists*, Vol. 43, 1974, pp 191–223.

Goode, F.F. "Use of Immersion Compression Test in Evaluating and Designing Bituminous Paving Mixtures." In American Society of Testing and Materials (ASTM) Special Technical Publication (STP) 252, 1959, pp. 113–126.

Graf, Peter. "Factors Affecting Moisture Susceptibility of Asphalt Concrete Mixes." *Journal of the Association of Asphalt Paving Technologists*, Vol. 55, 1986, pp. 175 –204.

Gzemski, F.C.; McGlashan, D.W.; and Dolch, W.L. *Highway Research Circular 78*: Thermodynamic Aspects of the Stripping Problem. HRB, National Highway Research Council, Washington D.C., 1968.

المنارة للاستشارات

www.manaraa.com

Hicks, Gary. *NCHRP 175: Moisture Damage in Asphalt Concrete*. Transportation Research Board, National Highway Research Council, Washington, D.C. 1991.

IPC Global. UTM 38 Dynamic Modulus Software Package, Version 1.01, 2000a.

IPC Global. UTM 19 Dynamic Creep Software Package, Version 1.0, 2000b.

Isacsson, W. and Jorgensen, T. Laboratory Methods for Determination of the Water Susceptibility of Bituminous Pavements. VIT Report, Swedish Road and Traffic Research Institute, No. 324A, 1987.

Jimenez, R.A. "Testing for Debonding of Asphalt from Aggregates." *Transportation Research Record 515,* TRB, National Highway Research Council, Washington, D.C., 1974, pp. 1–17.

Kandhal, P. "Field and Laboratory Investigation of Stripping in Asphalt Pavements: State of the Art Report." *Transportation Research Record 1454,* TRB, National Highway Research Council, Washington, D.C., 1994, pp. 36–47.

Kanitpong, K. and H.U. Bahia, "Role of Adhesion and Thin Film Tackiness of Asphalt Binders in Moisture Damage of HMA." *Journal of the Association of Asphalt Paving Technologists*, Vol. 72, 2003, pp 502–528.

Kanitpong, Kunnawee and Bahia, Hussain. "Evaluation of HMA Moisture Damage in Wisconsin as it Related to Pavement Performance." Transportation Research Board CD-ROM. 85th Annual Meeting, January 22-26, 2006a.

Kanitpong, Kunnawee and Bahia, Hussain. "Relating Adhesion and Cohesion of Asphalts to Effect of Moisture ON Asphalt Mixtures' Laboratory Performance." Transportation Research Board CD-ROM. 85th Annual Meeting, January 22-26, 2006b.

Kennedy, Thomas W; Roberts, Freddy, L.; and Lee, Kang W. "Evaluation of the Moisture Effects on Asphalt Concrete Mixtures." *Transportation Research Record 911,* TRB, National Highway Research Council, Washington, D.C., 1983, pp. 134–143.

Kennedy, Thomas W; Roberts, Freddy, L.; and Lee, Kang W. "Evaluating Moisture Susceptibility of Asphalt Mixtures Using the Texas Boiling Test." *Transportation Research Record 968,* TRB, National Highway Research Council, Washington, D.C., 1984a , pp. 45–54,

Kennedy, T.W. and W.V. Ping, "Comparison Study of Moisture Damage Test Methods for Evaluating Antistripping Treatments in Asphalt Mixtures." *Transportation Research Record 1323*, TRB, National Highway Research Council, Washington D.C., 1984b. pp 94–111.

www.manaraa.com

Little, Dallas N. and Jones IV, David R. "Chemical and Mechanical Processes of Moisture Damage in Hot-Mix Asphalt Pavements." Moisture Sensitivity of Asphalt Pavements A National Seminar. February 4-6, 2003.

Lottman, R.P. *NCHRP 192: Predicting Moisture-Inducted Damage to Asphaltic Concrete*. Transportation Research Board, National Highway Research Council, Washington, D.C. 1978.

Lottman, R.P. *NCHRP 246: Predicting Moisture-Inducted Damage to Asphaltic Concrete – Field Evaluation*. Transportation Research Board, National Highway Research Council, Washington, D.C. 1982.

Lottman, Robert P.; Chen, R.P.; Kumar, K.S.; and Wolf, L.W. "A Laboratory Test System for Prediction of Asphalt Concrete Moisture Damage." *Transportation Research Record 515,* TRB, National Highway Research Council, Washington, D.C., 1974, pp. 18–26.

Lottman, Robert P. "Laboratory Test Method for Predicting Moisture-Induced Damage to Asphalt Concrete." *Transportation Research Record 843,* TRB, National Highway Research Council, Washington, D.C., 1982, pp. 88–95.

Mack, C. *Bituminous Materials*, Vol. 1 (A Holberg, ed.), Interscience Publishers, New York. 1964

Majidzadeh, K. and Brovold, F.N. "Special Report 98: State of the Art: Effect of Water on Bitumen-Aggregate Mixtures." *Highway Research Board (HRB)*, National Research Council, Washington, D.C. 1968.

Masad, Eyad; Zollinger, Corey; Bulut, Rifat; Little, Dallas; and Lytton, Robert. "Characterization of HMA Moisture Damage Using Surface Energy and Fracture Properties." *Association of Asphalt Paving Technologists* CD-ROM. 2006.

Maupin, G.W. "The Use of Antistripping Additives in Virginia." Submitted at the 51st Association of Asphalt Paving Technologists, Kansas City, MO. 1981.

Michigan State Climatology Office, http://climate.geo.msu.edu/, 1/11/2006.

Mirza, M.W., M.W. Witczak, "Development of a Global Aging System for Short and Long Term Aging of Asphalt Cements." *Journal of the Association of Asphalt Paving Technologists*, Vol.64, 1995, pp.393–430.

NCHRP 1-37A. Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, National Cooperative Highway Research Program, March 2004.

NCHRP 9-34. Improved Conditioning Procedure for Predicting the Moisture Susceptibility of HMA Pavements, National Cooperative Highway Research Program, March 2002.

المنارة للاستشارات

www.manaraa.com

Petersen, J.C., H. Plancher, E.K. Ensley, R.L. Venable, and G. Miyake, "Chemistry of Asphalt-Aggregate Interaction: Relationship with Pavement Moisture-Damage Prediction Test." *Transportation Research Record 843*, TRB, National Highway Research Council, Washington D.C., 1982. pp 95–104.

Petersen, J.C.; Plancher, H.; and Harnsberger, P.M. *Lime Treatment of Asphalt – Final Report*. National Lime Association. 1987.

Plancher, H.; Dorrence, S.; and Petersen, J.C. "Identification of Chemical Types in Asphalts Strongly Absorbed at the Asphalt-Aggregate Interface and Their Relative Displacement by Water." *Journal of the Association of Asphalt Paving Technologists*, Vol. 46, 1977, pp.151–175.

Plancher, H.; Miyake, G.; Venable, R.L.; and Peterson, J.C. "A Simple Laboratory Test to Indicate Moisture Susceptibility of Asphalt-Aggregate Mixtures to Moisture Damage During Repeated Freeze-Thaw Cycling." *Canadian Technical Asphalt Association Proceedings*, Vol. 25, 1980, pp. 247–262.

Robertson, R.E. *Transportation Research Circular 499*: "Chemical Properties of Asphalts and Their Effects on Pavement Performance." TRB, National Highway Research Council, Washington D.C. 2000.

Roberts, Freddy L.; Kandhal, Prithvi S.; Brown, E. Ray; Lee, Dah-Yinn; and Kennedy, Thomas W. *Hot Mix Asphalt Materials, Mixture Design, and Construction*. 2nd Ed. 1996.

Robinette, Christopher. "Testing Wisconsin Asphalt Mixtures for the 2002 AASHTO Mechanistic Design Guide." Master Thesis, Michigan Technological University, 2005.

Romero, F.L. and Stuart, K.D. "Evaluating Accelerated Rut Testers." *Public Roads*, Vol. 62, No. 1, July-August, pp 50–54. 1998.

SAS Institute, Inc. SAS for Windows XP Version 9.1.3, 2006.

Scherocman, James; Mesch, Keith; and Proctor, J. Joseph. "The Effect of Multiple Freeze-Thaw Cycle Conditioning on the Moisture Damage of Asphalt Concrete Mixtures." *Journal of the Association of Asphalt Paving Technologists*, Vol. 55, 1986, pp. 213–228.

Scholz, T.V.; Terrel, R.L.; Al-Joaib, A; and Bea, J. "Water Sensitivity: Binder Validation." SHRP-A-402. Strategic Highway Research Program, National Research Council, Washington, D.C., 1994.

Scott, J.A.N. "Adhesion and Disbonding Mechanisms of Asphalt Used in Highway Construction and Maintenance." *Journal of the Association of Asphalt Paving Technologists*, Vol. 47, 1978. pp19–44.

المنارة للاستشارات
www.manaraa.com

Shatnawi, S; Nagarajaiah, M.; and Harvey, J. "Moisture Sensitivity Evaluation of Binder-Aggregate Mixtures." *Transportation Research Record 1492,* TRB, National Highway Research Council, Washington, D.C., 1995, pp. 71–84.

Solaimanian, Mansour; Harvey, John; Tahmoressi, Maghsoud; and Tandon, Vivek. "Test Methods to Predict Moisture Sensitivity of Hot-Mix Asphalt Pavements." *Moisture Sensitivity of Asphalt Pavements A National Seminar*. February 4-6, 2003.

Solaimanian, Mansour; Fedor, David; Bonaquist, Ramon; Soltani, Ali; and Tandon, Vivek. "Simple Performance Test for Moisture Damage Prediction in Asphalt Concrete." *Association of Asphalt Paving Technologists CD-ROM*. 2006.

Stroup-Gardiner, Mary and Epps, J. "Laboratory Tests for Assessing Moisture Damage of Asphalt Concrete Mixtures." *Transportation Research Record 1353*, TRB, National Highway Research Council, Washington, D.C., 1992, pp. 15–23.

Tandon, Vivek; Alam, Muhammad Murshed; Nazarian, Soheil; and Vemuri, Nalini. "Significance of Conditioning Parameters Affecting Distinction of Moisture Susceptible Asphalt Concrete Mixtures in the Laboratory." *Journal of the Association of Asphalt Paving Technologists*, Vol. 67, 1998, pp. 334–353.

Tarrer, A.R. and Wagh, V. *The Effect of the Physical and Chemical Characteristics of the Aggregate on Bonding*. Strategic Highway Research Program, National Highway Research Council, Washington, DC., 1991.

Terrel, R.L. and Shute, W.J. Summary Report on Water Sensitivity. SHRP-A/IR-89-003. Strategic Highway Research Program, National Research Council, Washington D.C., 1989.

Terrel, R.L. and Al-Swailmi, S. "Final Report on Water Sensitivity of Asphalt-Aggregate Mixtures Test Development." SHRP-A-403. Strategic Highway Research Program, National Research Council, Washington, D.C., 1994.

Terrel, Ronald and Al-Swailmi, Saleh. "Role of Pessimum Voids Concept in Understanding Moisture Damage to Asphalt Concrete Mixtures." *Transportation Research Record 1386*, TRB, National Highway Research Council, Washington, D.C., 1993, pp. 31–37.

Thelen, Edmund. "Surface Energy and Adhesion Properties in Asphalt-Aggregate Systems." *Highway Research Board*, Volume 192, 1958, pp. 63–74.

Tunnicliff, D.G. and Root, R. 1982. *NCHRP Report 274*: *Use of Antistripping Additives in Asphaltic Concrete Mixtures. Laboratory phase*. TRB, National Highway Research Council, Washington, DC.

www.manaraa.com

Tunnicliff, D.G. and R.E. Root. *NCHRP 373: Use of Antistripping Additives in Asphalt Concrete Mixtures – Field Evaluation*. Transportation Research Board, National Highway Research Council, Washington, D.C., 1995.

Witczak, M.W.; Kaloush, K.; Pellinen, T.; El-Basyouny, M.; and Von Quintus, H. *NCHRP 465: Simple Performance Test for Superpave Mix Design.* Transportation Research Board, National Highway Research Council, Washington D.C., 2002.

Witczak, M.W. *NCHRP Report 547: Simple Performance Tests: Summary of Recommended Methods and Database.* Transportation Research Board, National Highway Research Council, Washington D.C., 2005.

Youtcheff, J.S. and Aurilio, V. "Moisture Sensitivity of Asphalt Binders: Evaluation and Modeling of the Pneumatic Adhesion Test Results." *Canadian Technical Asphalt Association Proceedings,* 1997.

Youtcheff, J.S.; Williams, R.C.; and Branthaver, J. "Evaluation of Relationships Between Moisture Sensitivity of Paving Asphalts, Modified Asphalt Binders, and Asphalt Components, and Their Chemistries." *American Chemical Society – Fuel Division, Symposium*, Vol. 34, 1998.

Williams, R. Christopher. Iowa State University Associate Professor, Personal Conversion, Fall 2006.

Williams, Brett; Bausano, Jason**;** and Williams, R. Christopher. "Permeability Criterion Test for Method Selection in Determining the Bulk Specific Gravity of Hot Mix Asphalt." Accepted for Publication in *Journal of ASTM International (JAI),* 2006.

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www.manaraa.com