A COMPARATIVE EVALUATION OF THE CORELOK DEVICE IN DETERMINING RELIABLE BULK SPECIFIC GRAVITY AND MAXIMUM SPECIFIC GRAVITY TEST RESULTS

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16. Abstract:

This study was initiated to systematically compare the specific gravity values of laboratory compacted Hot Mix Asphalt (HMA) mixtures using AASHTO and vacuum sealing procedure (using CoreLok device). In this comparative evaluation program, a series of bulk and maximum specific gravity tests were conducted using CoreLok as well as AASHTO procedures on laboratory compacted HMA mixtures. The asphalt mixtures, aggregate types and compaction levels selected to prepare the samples truly represented Ohio's materials and construction practices. A thorough statistical analysis of the data was conducted. The test results revealed that the maximum specific gravity (G_{mm}) values obtained by both the test procedures (CoreLok and AASHTO) are statistically similar at a confidence interval of 95%. The bulk specific gravity (G_{mb}) values obtained using the CoreLok test procedure are always lower than the AASHTO G_{mb} values and the difference is statistically significant. It was also noted that, the difference in G_{mb} values between the two procedures is statistically significant regardless of the type of mix, type of aggregate and compaction level. Air voids values estimated using the CoreLok device are always greater than corresponding AASHTO values. In general, the difference in air voids is 1-2% with a maximum of 4.5% for a gap graded mix. The difference in air void content obtained from the two procedures is statistically significant at 95% confidence interval. There could be potential advantages in specifying this device in terms of reduced testing time. If the Ohio Department of Transportation intends on using the CoreLok, it is recommended not to change its current specification which is based on historical data and instead use an appropriate correlation factor to relate the CoreLok and AASHTO values.

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DISCLAIMER

A COMPARATIVE EVALUATION OF CORELOK DEVICE IN DETERMINING RELIABLE BULK SPECIFIC GRAVITY AND MAXIMUM SPECIFIC GRAVITY TEST RESULTS

1. INTRODUCTION

1.1 Definition of Bulk and Maximum Specific Gravity

In physics, the word *specific* implies a ratio. Weight is the measure of the earth's attraction for a body and is defined as *gravity*. Thus, the ratio of the weight of a substance to the weight of an equal volume of a standard substance, measured under standard pressure and temperature conditions, is called specific gravity. The most widely used standard substance for determining the specific gravities is water at 4^0C (39^0F). There are a number of ways to express specific gravity with the most common expression being:

$$Specific\ Gravity = \frac{\text{weight of the substance}}{\text{weight of an equal volume of water at } 4^0\text{ c } (39^0\text{ F})}$$

If the densities of the substance of interest and the standard material are known in the same units (e.g., both in g/cm^3 or lb/ft^3), then the specific gravity of the substance is equal to the density of the substance divided by the density of the standard material. Unlike density which has units of mass per volume, specific gravity is a pure number. This means, specific gravity is dimensionless and has no associated unit of measure. At 4^0C, 1.0 cubic centimeter of water weighs 1.0 gram. Hence, the density of water is 1.0 g/cm^3 at 4^0C and its specific gravity is also 1.0. Therefore, density and specific gravity have the same numerical value at this temperature. Specific gravity can also be expressed as the weight of a substance relative to water. As an example, if the specific gravity of a mineral aggregate is 2.70, this means the weight of the aggregate is 2.70 times that of an equal volume of water [1].

Several types of specific gravity exist with the most commonly used in asphalt mix design being Bulk Specific Gravity and Theoretical Maximum Specific Gravity.

Bulk specific gravity of compacted Hot Mix Asphalt (HMA) specimens is the ratio of the weight in air of a unit volume of a compacted specimen of HMA (including permeable voids) at a standard temperature to the weight of an equal volume of water at a stated temperature [2]. The value is used to determine the weight per unit volume of the compacted mixture. The bulk specific gravity (G_{mb}) of a compacted asphalt mixture is equal to:

$$G_{mb} = \frac{W_D}{W_{SSD} - W_{Sub}}$$

Where,

W_D	=	Dry weight, grams
W_{SSD}	=	Saturated Surface Dry (SSD) weight, grams
W_{Sub}	=	Saturated surface dry weight submerged in water, grams

Theoretical maximum specific gravity, G_{mm}, is the ratio of the weight in air of a unit volume of uncompacted bituminous paving mixture at a stated temperature to the weight of an equal amount of water at a stated temperature. It is also called Rice Specific Gravity (after James Rice who developed the test procedure). The theoretical maximum specific gravity (G_{mm}) of bituminous paving mixture is equal to:

$$G_{mm} = \frac{W_D}{W_D - (W_{Sub} - W_{Con})}$$

Where

W_D = Dry Weight, grams

W_{Con} = Weight of container submerged in water, grams

W_{Sub} = Weight of container with sample submerged in water, grams

1.2 Need for Specific Gravity Measurements in Hot Mix Asphalt Design Process

Hot mix asphalt mix design is essentially a volumetric process. The design procedure involves determination of an appropriate blend of aggregates and asphalt cement to produce the desired properties. Among the many properties, the percentage of air voids (AV) and voids in the mineral aggregate (VMA) in a compacted HMA mixture are of particular interest in the paving operations. Air voids can be defined as the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture. Voids in the mineral aggregate is defined as the volume of inter-granular void space between the aggregate particles of a compacted paving mixture that includes air voids and the volume of the asphalt not absorbed into the aggregate (effective asphalt content), expressed as a percent of the total volume. Asphalt mixtures with higher voids tend to allow water and air to penetrate, and thereby increase the potential for damage such as stripping, raveling, cracking, and excessive oxidation of the asphalt binder. Hence, an understanding of the void content is known to provide indication about the durability and in-service performance of constructed asphalt pavements.

Direct measurement of AV and VMA of compacted HMA samples is difficult because of the complex structure of voids. However, by using specific gravity, it is possible to calculate the volume using the equation below:

$$Volume\ (V) = \frac{Weight\ (W)}{Specific\ Gravity\ (SG)\ x\ Density\ of\ Water\ (D_w)}$$

Thus, the use of appropriate specific gravity values, can lead to the determination of AV and VMA of compacted HMA specimens.

1.3 Current Procedures for the Determination of G_{mb} and G_{mm}

Tests to determine G_{mb} and G_{mm} values of HMA samples are routinely conducted by state departments of transportation, paving contractors and private testing labs. Generally these agencies adopt one of the following test specifications, while some agencies have slightly modified versions of the same specification:

- Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures [3-5]:
  - ASTM D2726
  - AASHTO T-166 (for asphalt mixtures with less than 2% water absorption)
  - AASHTO T-275 (for asphalt mixtures with greater than 2% water absorption)
- Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures [6-7]:
  - ASTM D2041
  - AASHTO T-209

The ASTM D2726 and AASHTO T166 test methods cover the determination of bulk specific gravity and density of compacted bituminous mixtures for asphalt mixtures with less than 2%

water absorption. According to this procedure, a compacted specimen is immersed in a water bath at 25°C and the submerged weight is recorded when the pores are completely saturated. The specimen is then removed from the water bath, quickly blotted with a damp towel, and immediately weighed in air. This condition of the sample is termed *saturated surface dry* (SSD). These values along with a dry weight are used to calculate the bulk specific gravity. AASHTO T-275 is specified for mixtures with water absorption greater than 2%.

The procedure for the determination of Theoretical Maximum Specific Gravity is described in ASTM D2041 and AASHTO T-209. As outlined in these procedures, a weighed sample of oven-dry bituminous mixture in a loose condition is placed in a tared vacuum vessel (pycnometer). Water is added to completely submerge the specimen. Vacuum is then applied to thoroughly remove air within the specimen. The vacuum is then removed and the volume of the sample is determined by completely filling the pycnometer with water and weighing in air.

1.4 Limitations of Current Procedures

The current ASTM and AASHTO procedures have proved adequate for conventional dense graded mixtures. However, erroneous specific gravity values have been reported when the tests were performed on coarse graded mixtures. As shown in the equation in Section 1.1, the bulk specific gravity calculation requires the measurement of dry weight, submerged weight and SSD weight of the sample. Of these weight measurements, weight of the sample at SSD condition is found to yield inconsistent values for the coarse graded samples which has resulted in erroneous G_{mb} values. This problem is particularly true for some Superpave and for Stone Mix Asphalt (SMA) mixes which are coarse in nature. The internal air voids for these mixes can become interconnected which allows water to infiltrate the sample quickly during the saturation process. When measuring the SSD weight of these samples, the water tends to drain out quickly from the sample. This drainage of water from the sample was causing errors in the SSD weight measurement and later in the calculation of G_{mb}.

1.5 Proposed Solution

In order to improve the accuracy of specific gravity measurement, particularly for the open and coarse graded mixtures, a new device namely, CoreLok, was developed in the 1990's [8]. The CoreLok is a vacuum sealing device that has been designed to determine G_{mb} and G_{mm} of asphalt mixture samples as well as G_{mb} of coarse and fine aggregates. A number of agencies are exploring the use of CoreLok equipment for the determination of specific gravity values. The primary intent of this effort is to obtain faster results while, at the same time, improving the accuracy of results. Based on its performance claims and some in-house evaluations, several state agencies including Alabama, Indiana, Kansas, Minnesota, North Carolina, Oklahoma and Texas, have specified its use while New York, New Mexico, Colorado, New Jersey, Connecticut, Maine, Arkansas, Michigan, Missouri and Wisconsin are evaluating the use of CoreLok in determining G_{mb} values of bituminous mixtures.

1.6 Significance of the Present Study

In Ohio, the percent of air voids in a compacted mixture is an important factor in the quality control of constructed pavements. Percent air voids is obtained by using the equation below:

$$Percent\ Air\,Voids = (1 - \frac{G_{mb}}{G_{mm}})\,x100$$

As seen in this equation, percent air voids in a compacted mixture is a function of bulk and maximum specific gravity values. Generally ODOT's asphalt mixes are designed to have an air void content of 3.5±0.5%. According to ODOT's current policy, if air voids are greater than 7%

or less than 1%, the constructed material will have to be removed. Material having air voids greater than 6% or less than 2% will be evaluated for removal. If the material is allowed to remain, pay adjustment of the bid price will be 20% for a surface course or 10% for other courses [9]. Thus, errors in specific gravity values can potentially affect both the agency and the producers.

Asphalt pavements constructed by ODOT over the years have used dense graded mixes. However, in the recent years, there has been an increased use of coarse graded mixes which include some Superpave and Stone Mix Asphalt (SMA) mixes. These mixes tend to have larger internal air voids than the conventional mixes, though the volume of air voids may be the same. These internal air voids for such mixtures can become interconnected allowing water to infiltrate the samples quickly during the saturation process. When measuring the SSD weight of these samples, the water tends to drain out quickly from the sample and thus cannot be measured accurately resulting in erroneous and inconsistent G_{mb} and G_{mm} values. As a result, ODOT is interested in alternate test procedures that can improve the consistency and accuracy of G_{mb} and G_{mm} of such asphalt mixtures.

Various studies have been carried out in the last five years to evaluate the reliability and performance of the CoreLok device with respect to the traditional AASHTO and ASTM procedures [11-16]. Although the studies reported comparable performance for dense graded mixes, discrepancies were observed with specific gravity values for coarse graded mixes and concluded that further research is necessary to better define when the CoreLok method should be used.

The present study was initiated to perform a systematic evaluation of CoreLok device with ODOT's procedures for the determination of G_{mb} and G_{mm} of asphalt mixtures used in Ohio.

The basic focus of this study was: "*Does the CoreLok device have potential applicability to Ohio's conditions?*" The study included a range of materials and multiple tests to arrive at sound conclusions as to the device reliability, repeatability, precision and durability.

The study was performed jointly by the University of Cincinnati (UC) and Valley Asphalt Corporation, in association with ODOT's Office of Materials Management. This report includes a description of the experimental plan, materials and asphalt mixtures used in the investigation, types and extent of tests carried out, and analysis of data. The report will conclude with comments on CoreLok's capability to improve test results, reduce testing time, durability and recommendations to ODOT.

2. OBJECTIVES OF THE STUDY

1. Conduct a review of CoreLok investigations by other agencies
2. Develop an experiment to include appropriate experimental variables
3. Prepare physical samples and conduct specific gravity tests using CoreLok and ODOT's current procedure
4. Analyze the data
5. Prepare recommendations to ODOT based on the capability, precision and durability of the CoreLok equipment.

3. WORKING PRINCIPLE AND PERFORMANCE CLAIMS OF CORELOK EQUIPMENT

Figure 1 shows the CoreLok equipment and briefly illustrates the sequence of operation. The equipment consists of a vacuum chamber, a 1.25 hp vacuum pump, electronic units to control the vacuum level, and essential accessories like plastic bags and filler plates. This device can be used for the determination of G_{mb} of compacted HMA samples, G_{mm} of loose asphalt samples, porosity of compacted field and laboratory samples and specific gravity and absorption of fine and coarse aggregates [10].

CoreLok device

Placing filler plate

Placing sliding plate

Inserting sample in plastic bag

Inserting sample in plastic bag

Placing plastic inside sealing chamber

Closing CoreLok lid

Weighing sealed sample in water

Figure 1. CoreLok Device and Testing Procedure

Determination of G_{mb} requires inserting a compacted HMA sample inside a specially designed plastic bag, careful placement of the bag into the vacuum chamber and activating the vacuum pump by closing the door. The internal controls regulate the vacuum pump and ensure appropriate operation until the sample is subjected to 99% of full vacuum which relates to absolute vacuum. Next, an automatic sealing strip inside the chamber heat-seals the bag. At this point, air is allowed to enter the chamber in a controlled manner. In doing so, the bag will form a tight fit and conform to the shape of the compacted cylindrical sample. The door of the vacuum chamber then opens to allow the technician to remove the sample and weigh it in water. This weight is used in the calculation of bulk specific gravity.

Determination of G_{mm} follows a similar procedure except that loose sample is placed in the bag instead of compacted HMA mixture.

The manufacturer of the CoreLok equipment claims the following benefits with its use, over the traditional ASTM/AASHTO procedures [8]:

- Accurate specific gravity and air voids determination
- Excellent repeatability
- Improved correlation between field, laboratory and nuclear gauge density results
- No wax dipping, wrapping with film or trimming required
- Samples remain dry and uncontaminated for further testing purposes
- Complete sealing process in approximately two minutes
- Minimal operator involvement

4. CONCEPTUAL DIFFERENCES BETWEEN THE AASHTO AND CORELOK PROCEDURES

The AASHTO procedure has been in use for several decades for the determination of G_{mb} and G_{mm} of HMA samples. This procedure requires the following three weight measurements to be made in the laboratory on the HMA mixtures to enable the determination of specific gravity:

1. Dry weight of sample in air, grams
2. Weight of sample in water, grams
3. Weight of the saturated surface-dry specimen in air, grams

Of these three measurements, the SSD weight often involves subjectivity and can lead to inconsistent results. This is more so in the case of open and coarse graded samples. Any source of error in this measurement would lead to inaccurate calculation of air voids. It is essential that the testing program should strive to be objective, reduce subjectivity and reduce sources of error.

In contrast, the use of CoreLok only requires the measurement of dry weight and weight of sealed sample in water. Thus the CoreLok method essentially bypasses SSD weight measurement on its way to determine the specific gravity. The CoreLok vacuum sealing procedure is automated and allows no room for subjectivity or individual differences in technician experience or competence.

5. RECENTLY COMPLETED STUDIES TO EVALUATE THE APPLICABILITY OF CORELOK EQUIPMENT

Several states have reported studies carried out in the recent past to evaluate the applicability of CoreLok equipment for the determination of specific gravity values. The primary intent of these studies has been to evaluate the device reliability, repeatability, precision and durability for determining the G_{mm} and G_{mb} of asphalt mixtures. Tests have been carried out on a range of representative materials normally used within the state to compare the results of CoreLok with existing departmental procedures that included SSD weight determination. It is evident that all studies emphasized the need for accurate specific gravity measurements and consequences on the air void content.

Sholar et al. [11] performed comparative tests on a range of materials and asphalt mixtures used by the Florida Department of Transportation. They collected an adequate amount of data to conduct statistical analysis of the test results. Their study identified that the test results for G_{mm} determined by the CoreLok device were equivalent to the values obtained by the Florida procedure for mixtures containing low absorptive aggregates. As the water absorption of the aggregate increased, the CoreLok test procedure yielded higher G_{mm} values compared to the departmental procedure. The investigators concluded that the difference between the G_{mm} values obtained using the CoreLok device and the existing procedure were statistically significant for coarse mixes and mixes that contain high absorptive aggregates. Simultaneously, the researchers conducted tests on compacted asphalt mixtures to determine G_{mb} and then to calculate percent air voids. The results showed that the percent air voids determined by the CoreLok procedure were approximately 1% higher than the Florida procedure. A visual examination of the compacted specimens lead to believe that the plastic bags were not able to completely conform to the rough surface texture of the top and bottom surfaces of the compacted specimens. Hence, a limited study was carried out by trimming off the top and bottom surfaces of the cylindrical samples. The test results showed improved correlation between the two test procedures.

Washington State DOT [12] reported tests on 96 core samples that were obtained from seven project sites, representing three types of mixes – fine graded, Superpave and coarse graded-- for determining the G_{mb} values. The study reported the variation in calculated air voids. While comparative results were noted for fine grade mixtures, the results were found to deviate from the other two mixes with CoreLok results always showing higher air voids. A further investigation of the samples revealed that most of the materials had water absorption in excess of 2% which indicates inappropriate use of the AASHTO T-166 test procedure. The study concluded that G_{mb} values obtained by using the CoreLok device are a better representation of the actual values.

Buchanan [13] compared four methods of determining bulk specific gravity (G_{mb}), water displacement (AASHTO T-166), vacuum sealing (CoreLok), Parafilm and dimensional analysis. The G_{mb} was obtained for each test procedure on samples of 150 mm in diameter for various mixture types compacted to multiple levels of gyration. Additionally, some of the samples were then saw cut into 75 mm cubes to eliminate the effect of surface texture and tested again using all the four methods identified above. The study concluded that both the vacuum sealing and AASHTO methods provided similar results for fine graded Superpave mixtures at all levels of gyrations. However, for coarse graded Superpave mixtures, as the air voids and percent water absorption levels increased, there existed significant differences between the G_{mb} values determined by the CoreLok and the AASHTO methods. This difference was not found among the cut cubical sample on which both the tests provided similar G_{mb} values in every case. The research concluded that the Corelok vacuum sealing device provides a better measure of internal air voids content of coarse graded mixes than other conventional methods.

Hall et al. [14] and Crouch et al. [15] performed similar studies as Buchanan but without any saw cut being performed on the specimens. They observed that the CoreLok method tends to measure lower G_{mb} values (which would result in higher air voids estimation) than the standard AASHTO T-166 method for a wide variety of mixture types tested. Hall et al. also examined operator variability for measuring the G_{mb} of Hot Mix Asphalt (HMA) mixes. The tests were performed on 144 lab compacted HMA samples to determine the variability of the AASHTO T-166, dimensional analysis and the CoreLok methods. The reports indicated that the within lab (operator) variability for the CoreLok method was less than the water displacement method (AASHTO T-166) and also it was observed that by changing the method of measuring the G_{mb}, an air void difference of 0.39 to 0.90 percent can be obtained.

The National Center for Asphalt Technology (NCAT) [16] coordinated a comprehensive round-robin study to determine the repeatability and reproducibility of the test procedure and also to evaluate the reasons for the differences between the CoreLok and AASHTO T-166 test procedures for the determination of G_{mb} values. Eighteen labs participated in the round-robin study. Samples were prepared by the NCAT and were provided to the participating labs for testing. Each lab was provided with 27 samples, made from three mix types (fine gradation, coarse gradation and SMA) and three compaction levels (15 gyrations, 50 gyrations and 100 gyrations). All the samples were of 150 mm in diameter and the height of the sample varied depending upon the level of gyration. Eighteen labs performed tests for determining G_{mb} using both CoreLok and the AASHTO SSD method. First the CoreLok method was performed and then using the same sample the AASHTO test was performed as the CoreLok method uses a plastic bag to maintain the sample in dry condition throughout the test. Based upon the statistical analysis, it was identified that the repeatability of the AASHTO T-166 test was slightly better than the CoreLok device, but the within lab and between lab standard deviations for both tests were similar in value. The reasons for the variability of values obtained using the CoreLok device was attributed to the lack of experience by the operators in using the CoreLok device.

Based on the test results, the report concluded that the CoreLok device is a viable option for determining the bulk specific gravity of compacted HMA specimens.

5.1 Summary Findings

- All the studies stated that the CoreLok device can be used to determine G_{mb} and G_{mm} in addition to G_{sb}, G_{sa} and water absorption.
- The primary focus of using the CoreLok device has been on the measurement of G_{mb}, particularly for mixes with water absorption greater than 2%.
- The NCAT study demonstrates that the CoreLok device is capable of providing accurate G_{mb} measurements at high levels of water absorption and high air void levels.
- In general the G_{mb} values were found to be repeatable.
- The studies did not find any consensus opinion on operator variability.

6. DESIGN OF EXPERIMENT

In the present study, an experiment was designed to systematically compare the bulk and maximum specific gravity values of a variety of lab compacted asphalt mixtures through a series of well-controlled experiments that involved CoreLok and AASHTO procedures. Design of experiment refers to the process of planning these experiments so that the appropriate data to be analyzed will be collected, resulting in statistically valid and objective conclusions. The primary issues considered in the design of experiment are:

- Developing a Study Team
- Choice of experimental variables
- Identification and collection of representative materials
- Performing the experiment

6.1 The Study Team

The study team consisted of the following agencies:

- University of Cincinnati (UC) researchers
- Office of Materials Management, ODOT
- Valley Asphalt Corporation

All tests were conducted at Valley Asphalt Corporation's Quality Control (QC) Lab. The Valley Asphalt Corporation is a Cincinnati based asphalt paving company. This company provided the following specific equipment and services for the testing program:

- CoreLok machine and accessories
- Aggregate and asphalt materials
- Equipment required for G_{mb} and G_{mm} determination using AASHTO procedure
- Asphalt technicians, certified by ODOT

6.2 Choice of Experimental Variables

It is important that the experimental variables used in the study should truly reflect the materials, asphalt mixtures and testing practices in Ohio. Based on the review of published literature and discussions among the study team, three experimental variables were chosen for the study: type of asphalt mix, type of aggregate (source), and compaction levels.

In Ohio, the asphalt materials used in the surface and intermediate courses are predominantly dense graded with water absorption less than 2%. Superpave is fully implemented for routes with heavy truck traffic (i.e., greater than 1500 trucks/day) and high levels of pavement stress. Some of the Superpave mixes and aggregate base materials (designated as ODOT 302) are coarse graded. Ohio has experienced limited application of SMA but intends to see more statewide use of this type of mix. Open Graded Friction Course (OGFC) is not widely used in the state. Based on the current practice in Ohio, the various types of asphalt mixtures used in the present study are:

- Dense graded
- Superpave
- SMA
- ODOT 302

A cursory look at the types of aggregates used in Ohio illustrates over 95% of aggregates are either gravel and limestone with limited use (2%) of slag. Majority of the aggregates (90%) are low absorptive with water absorption being less than 2%. As a result, in the present study, it was decided to use limestone and gravel in asphalt mixtures along with limited samples containing slag.

The amount of compaction applied to the samples during the mix design process significantly affects the void structure and in turn the specific gravity values of such samples. Compaction level can also influence the design binder content of the mix. To obtain mixes with a higher content of binder (and, higher potential durability), ODOT modified the Superpave compaction requirements by specifying a lower number of required gyrations in the compaction apparatus (i.e., N_{des} = 75 vs. a standard 100). The department expects to further reduce the required gyrations from N_{des} = 75 to 65. Two compaction levels – medium and heavy – were included in the present study. The medium compaction involves a total number of 50 blows or 65 gyrations and the heavy compaction induces 75 blows or 100 gyrations.

6.3 Identification and Collection of Representative Materials

The Valley Asphalt Corporation maintains an extensive database of all ongoing paving jobs as well as those completed by the company over the years. The database consists of the location of project, construction date, aggregate materials (sources and sizes), type and grade of asphalt cement, and job mix formula with details about proportion and gradation of aggregates and percent of asphalt. In association with ODOT's project liaison and Valley's staff, the UC researchers first reviewed the database. The goal of this effort was to identify and generate a set of mix designs from the actual paving jobs in Ohio for use in the present study. During this process, four tree diagrams were developed as shown in Appendix C. These diagrams provide a complete description of experimental variables, number of samples and job mix formula assigned for each test. It should be realized that the materials and mix designs selected in the experiment truly reflect the practices in Ohio.

For each of the job mix formulas shown in the diagrams, adequate amounts of aggregate and asphalt samples were collected from the respective sources so as to reconstruct the mix designs and produce compacted cylindrical samples (for bulk specific gravity tests) as well as loose mixtures (for maximum specific gravity tests).

6.4 Performing the Experiment

The experiments included conducting bulk and maximum specific gravity tests using the AASHTO T-166 procedure as well as the CoreLok equipment. It was decided to first conduct a pilot study on a set of representative materials. The primary objective of the pilot study was to develop consensus and to establish exact direction for a full range of tests. All the tests were conducted at the Valley Asphalt Lab by the ODOT certified technicians. Limited tests were conducted at the ODOT's material testing lab.

7. PILOT STUDY

The pilot study was conducted on six asphalt mixtures representing three mix types as shown:

- Dense graded asphalt concrete (2 designs)
- Superpave mix (2 designs)
- ODOT 302 (2 designs)

Six technicians worked independently and prepared three cylindrical samples of each of the six mix designs. This task studied operator variability. To begin with, the technicians were trained in the use of the CoreLok device. Several test runs were made to get them acquainted with the test procedure. The samples were first tested in the CoreLok device for bulk specific gravity determination and later using the AASHTO T-166 water absorption procedure. Two sets of these samples were also tested at ODOT's materials lab. Analysis of the data observed the following:

- Variation within a technician
- Variation between technicians

The results, in general, indicated very little to no variation within and between technicians for both test types. A small amount of variation was noticed, particularly for ODOT 302 mixes. This is a coarse asphalt concrete base mix with about 25% of aggregate being greater than 2.54cm (1.0"). However, statistical analysis of the test results showed differences to be statistically insignificant. As a result, one test was run for all the samples shown in the tree diagrams randomly choosing any of the technicians at the Valley Asphalt lab. It was also decided to spot check the test results at ODOT's lab.

8. COMPARATIVE STUDY

Detailed evaluation of the CoreLok device included a series of tests to compare the test results with the AASHTO test procedures. The number of samples for each design and the size of compacted specimens followed ODOT's current practices. A breakdown of the number of samples tested is given in Table 1 below:

Table 1. Number of Samples Tested

Asphalt Mixture Type	Number of samples for:	
	Bulk Specific Gravity Tests	Maximum Specific Gravity Tests
Dense grade asphalt concrete (cylindrical samples 10.2cm (4") diameter x 6.4cm (2.5") height)	39	11
Superpave (cylindrical samples 15.2cm (6") diameter x 7.6cm (3") height)	22	11
Stone Mix Asphalt (cylindrical samples 15.2cm (6") diameter x 10.2cm (4") height)	24	7
ODOT 302 (cylindrical samples 15.2cm (6") diameter x 10.2cm (4") height)	24	4
TOTAL	109	33

A database was created to include all the relevant data. The database includes the test type, mix type, compaction type, aggregate type and the Job Mix Formula (JMF).

8.1 Maximum Specific Gravity Test Results

A total of 33 samples were tested for determining the maximum specific gravity values using the AASHTO T-209 and CoreLok test procedures. The G_{mm} values thus obtained are listed in Table A1 of Appendix A. A graphical illustration of the variation in G_{mm} values can be seen in Figure 2.

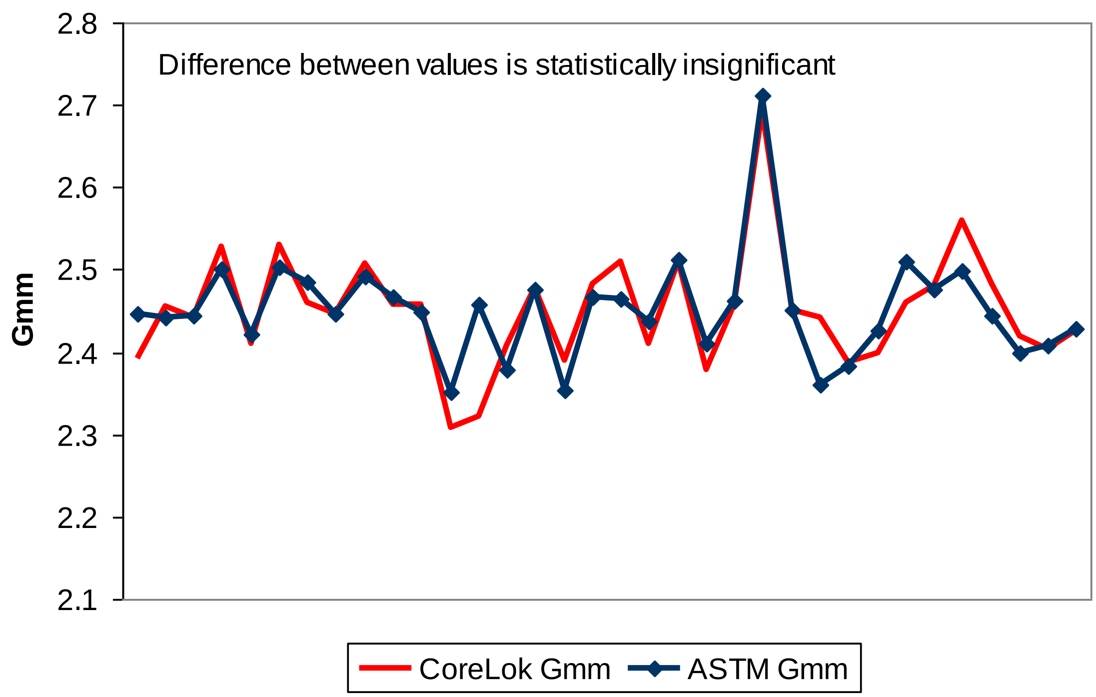

Figure 2. Comparing G_{mm} Values

The peaks and valleys for most of the graph are similar for both test procedures. The G_{mm} values determined using both test procedures appear to be identical.

A statistical paired t-test was conducted to compare the means of results from the two test procedures. This test computes the difference between the average values of the two variables for each case and tests whether the values differ from zero. The hypothesis follows:

Null Hypothesis H_o: The difference between the average CoreLok G_{mm} value and the average AASHTO G_{mm} value = 0

Alternative Hypothesis H_a: The difference between the average CoreLok G_{mm} value and the average AASHTO G_{mm} value ≠ 0

To Test: Whether the difference in the results between the two test procedures is statistically significant or not at 95% Confidence Interval (CI)

The results of the t-test are shown in Table 2.

Table 2. Paired t-Test on G_{mm} Values

Number of Samples	33
Degrees of Freedom (d_f)	32
CoreLok Mean	2.444
AASHTO T-209 Mean	2.444
Mean Difference	0.0
Difference in Standard Deviation	0.0389
Standard Error of Mean	0.00677
Lower Limit Values (at 95% CI)	0.0137
Upper Limit Values (at 95% CI)	0.0139
t-statistic	0.009
p-value	0.99
Significant Difference	**NO**

It is interesting to observe that the mean value of both test procedures is equal to 2.444 and the standard error of the mean is extremely small. The t-test performed returned a *p*-value of 0.99 at a 95% confidence interval. The probability value or the *p*-value of a statistical hypothesis test is the probability of getting a value of the test statistic as extreme as or more extreme than that observed by chance alone, if the null hypothesis H_0 is true. It is equal to the significance level of the test for which we would only reject the null hypothesis. Small *p*-values suggest that the null hypothesis is unlikely to be true. The smaller it is the more convincing is the rejection of the null hypothesis. The *p*-value indicates the strength of evidence for say, rejecting the null hypothesis H_0, rather than simply concluding 'reject H_0' or 'do not reject H_0' [17]. Thus if the *p*-value is less than that of the α-value, we reject H_0 and if the *p*-value is greater than that of the α-value, we accept H_o.

The analysis yielded a *p*-value of 0.99, which is greater than α-value (equal to 0.05). We accept the null hypothesis which states that, at 95% confidence interval, there is no statistically significant difference between the G_{mm} values determined using the AASHTO T-209 and CoreLok procedures.

Using both the test procedures, a scatter plot (Figure 3) of the G_{mm} values shows that the points are equally distributed along both sides of the line of equality. Certain points are right on the line of equality suggesting that in many cases, the values coincided.

A regression analysis was performed to explore a statistical relationship between the G_{mm} values from the two test procedures. The linear regression model along with test statistic are shown in Figure 4.

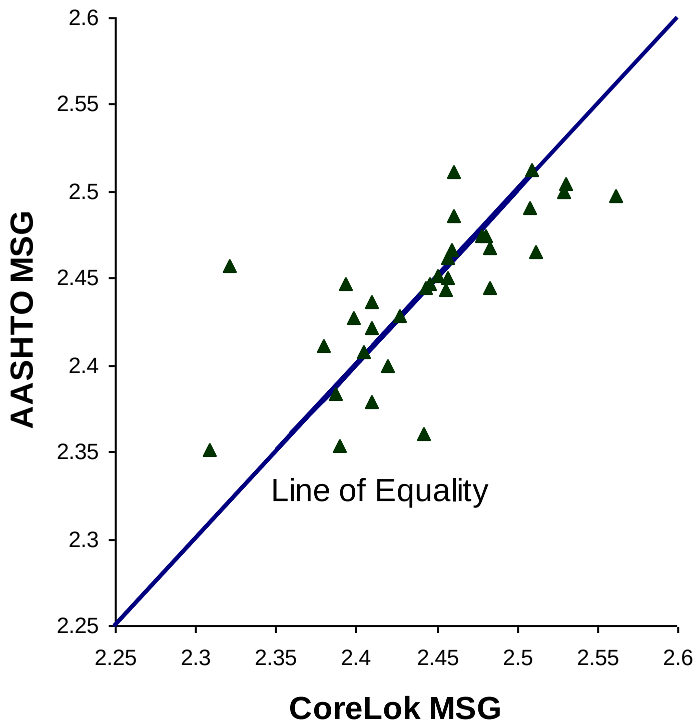

Figure 3. Scatter Plot of G_{mm} Values

Regression analysis models are used to predict the value of one variable from one or more other variables whose values can be predetermined. However, the intent of developing such a model in the present study was primarily to further investigate the amount of variation between the two values through the use of correlation coefficient (*r*). In the current study, the analysis is performed with regard to the value of coefficient of correlation (*r*), rather than the coefficient of regression value (R^2), as the relation between the AASHTO and the CoreLok values is expressed effectively by the use of *r* rather than R^2. The R^2 expresses the total variation in the values determined using the AASHTO and CoreLok procedures, whereas the *r* value expresses how best the AASHTO and the CoreLok values can be related based upon a linear relation between them. Typically *r* values ranging from 0.80 to 1.00 are considered as very strong correlation while values 0.60 to 0.79 are regarded as strong correlation.

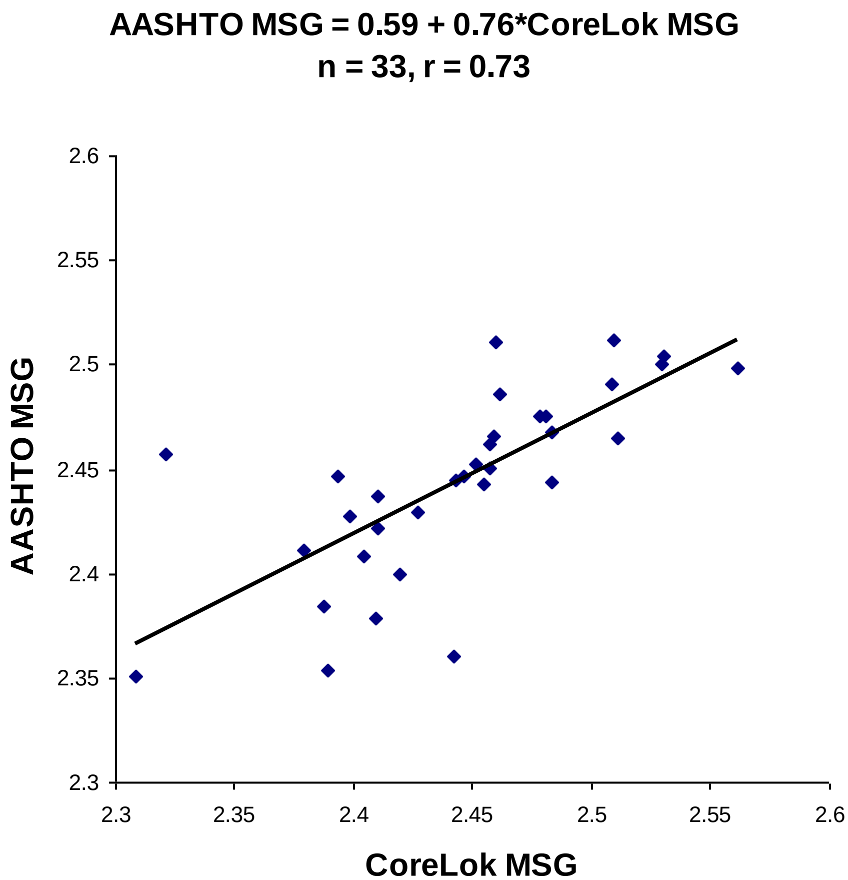

Figure 4 Regression Model for G_{mm} Values

8.2 Bulk Specific Gravity Test Results

A total of 109 laboratory prepared specimens were tested for the bulk specific gravity values using both the AASHTO T-166 and the CoreLok procedures. These 109 samples consisted of four mix types, two compaction levels and three aggregate types. Tests were performed on two to four replicate samples with similar mix type, compaction level and aggregate type. The data obtained from these tests is presented in Table A2 of Appendix A. Figure 5 shows a graphical variation of bulk specific gravity values for all mix types.

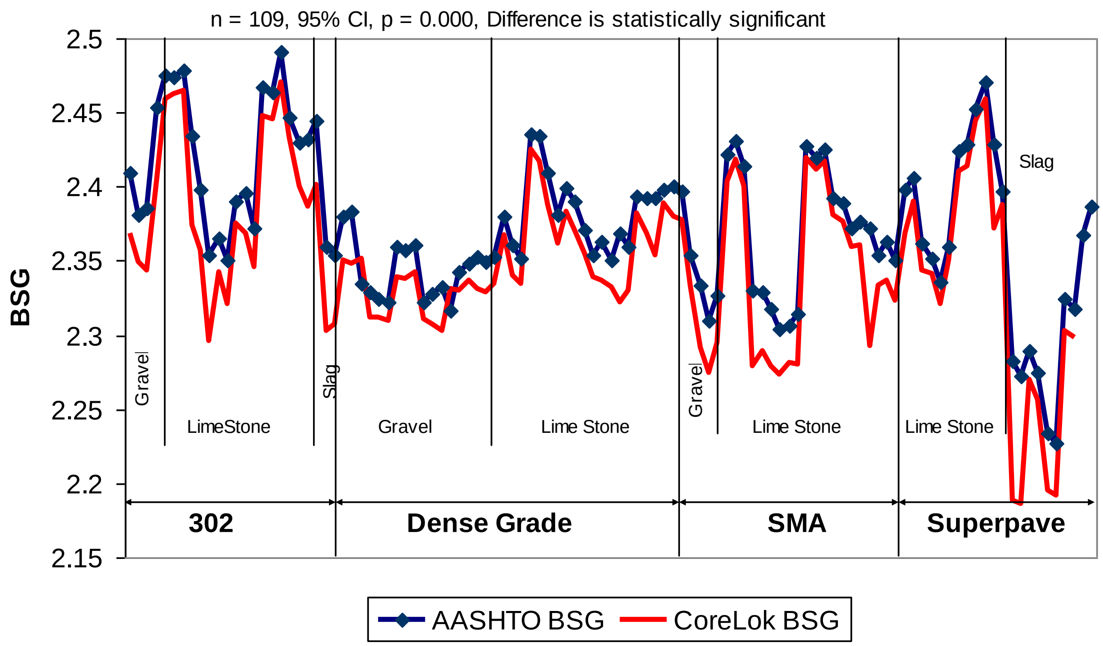

Figure 5. Comparing G_{mb} Values

The trend of these lines indicates the G_{mb} values determined using the CoreLok device are always lower than that of the G_{mb} values determined using the AASHTO T-166 procedure, for all types of mixes. Table 2 illustrates the descriptive statistics.

Table 3. Descriptive Statistics for Bulk Specific Gravity Values

	CoreLok G_{mb}	AASHTO G_{mb}
Number of Samples (N)	109	109
Minimum values	2.186	2.23
Maximum Value	2.471	2.49
Mean	2.349	2.374
Standard Deviation	0.055	0.055
Variance	0.003	0.003
Std. Error of Mean	0.006	0.005

The difference between the mean of the CoreLok G_{mb} value and the mean of the AASHTO G_{mb} values is 0.025. The variance of the values determined using the CoreLok device is similar to the variance of AASHTO G_{mb} (0.003). This is in contrast to the Gmm values where the mean values from the two test procedures were equal.

A statistical paired t-test was conducted for the G_{mb} values determined using these CoreLok and the AASHTO test procedures. The hypothesis was set as shown below:

Null Hypothesis H_o: The difference between the average CoreLok G_{mb} value and the average AASHTO G_{mb} value = 0

Alternative Hypothesis H_a: The difference between the average CoreLok G_{mb} value and the average AASHTO G_{mb} value ≠ 0

To Test: Whether the difference in the results between the two test procedures is statistically significant or not at 95% Confidence Interval (CI)

The results of the t-test performed are presented in Table 4. The t-test performed returned a *p*-value of 0.00 at 95% confidence interval. Since the *p*-value is less than 0.05, the null hypothesis is rejected, meaning there exists statistically significant difference between the G_{mb} values obtained from the two test procedures.

Further analysis was performed to investigate probable influence of the experimental variables on the observed variation. The data was divided into 9 groups based on four mix types, three aggregate types and two compaction levels. The 9 individual datasets obtained through this process are presented in Tables A4 – A12 of Appendix A. Appendix B provides graphical illustration of these variations.

Table 4. Paired t- Test on G_{mb} Values

Number of Samples	109
Degrees of Freedom (d_f)	108
CoreLok Mean	2.3744
AASHTO Mean	2.3493
Mean Difference	0.02513
Difference in Standard Deviation	0.0178
Standard Error of Mean	0.0017
Lower Limit Values (at 95% CI)	0.0217
Upper Limit Values (at 95% CI)	0.0285
t-statistic	14.75
p-value	0.00
Significant Difference	**YES**

The important observation to be made from all the line plots is that the values of the CoreLok G_{mb} are always lower than the AASHTO G_{mb} values and the visual observations indicate that difference in test results exists regardless of mix types, aggregate types and compaction levels.

To ascertain the visual observation and to determine if the difference is statistically significant a statistical paired t-test was conducted. The hypothesis was set as shown:

Null Hypothesis H_o:	The difference between the average CoreLok G_{mb} value and the average AASHTO G_{mb} value = 0
Alternative Hypothesis H_a:	The difference between the average CoreLok G_{mb} value and the average AASHTO G_{mb} value ≠ 0
To Test:	Whether the difference in the results between the two test procedures is statistically significant or not at 95% Confident Interval (CI)

The results of the t-tests performed on these individual datasets can be viewed in Table 5 below:

Table 5. Statistical Tests on G_{mb} values for Different Datasets

Variable	Mix Type				Aggregate Type			Compaction	
	Dense Grade	Super-pave	SMA	302	Lime Stone	Gravel	Slag	Heavy	Medium
Number of samples	39	22	24	24	69	28	12	71	38
Degrees of freedom (d_f)	38	21	23	23	68	27	11	70	37
CoreLok Mean	2.348	2.325	2.338	2.385	2.368	2.339	2.263	2.361	2.328
AASHTO Mean	2.366	2.354	2.364	2.417	2.392	2.361	2.307	2.385	2.355
Mean Difference	0.0180	0.029	0.026	0.032	0.023	0.021	0.044	0.024	0.027
Difference in Std. Dev.	0.011	0.026	0.017	0.015	0.015	0.015	0.028	0.016	0.021
Std. Error Mean	0.001	0.0055	0.0034	0.003	0.0017	0.0033	0.008	0.002	0.003
Lower Limit Value (At 95% CI)	0.014	0.018	0.019	0.026	0.019	0.015	0.026	0.020	0.020
Upper Limit Value (At 95% CI)	0.0217	0.041	0.033	0.039	0.027	0.027	0.062	0.028	0.034
t-statistic	10.05	5.283	7.603	10.325	13.421	7.49	5.394	12.719	7.968
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Significant Difference?	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**

It can be seen that the *p*-value for all the tests is equal to 0.00. At 95% confidence interval, when the *p*-value is less than 0.05, the null hypothesis is rejected meaning the difference in the specific gravity values determined by the two test procedures is statistically significant. Thus, this analysis proves that regardless of the type of mix, aggregate and compaction level, statistically significant differences exist in the G_{mb} values obtained by the two test procedures.

Figure 6 shows a scatter plot of bulk specific gravity values determined from AASHTO T-166 and CoreLok procedures along with the line of equality.

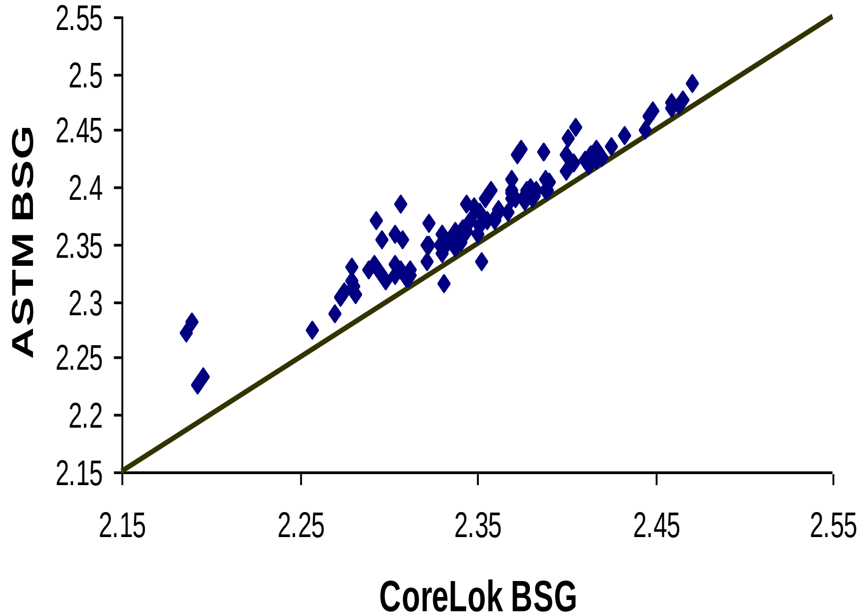

Figure 6. Scatter Plot of G_{mb} Values

The scatter plot suggests that the AASHTO Bulk Specific Gravity values are consistently higher than the CoreLok Bulk Specific Gravity values. This is in conformity with the findings of other researchers.

The scatter plot also suggests that a linear relationship may exist between the CoreLok G_{mb} values and the AASHTO G_{mb} values. Thus, a regression analysis was performed with the AASHTO G_{mb} values as Y variable and the CoreLok G_{mb} values as the X-variable. The linear regression model obtained is shown in Figure 7.

The correlation coefficient *r* is 0.95 indicating a very strong correlation between the G_{mb} values obtained using AASHTO and CoreLok procedures.

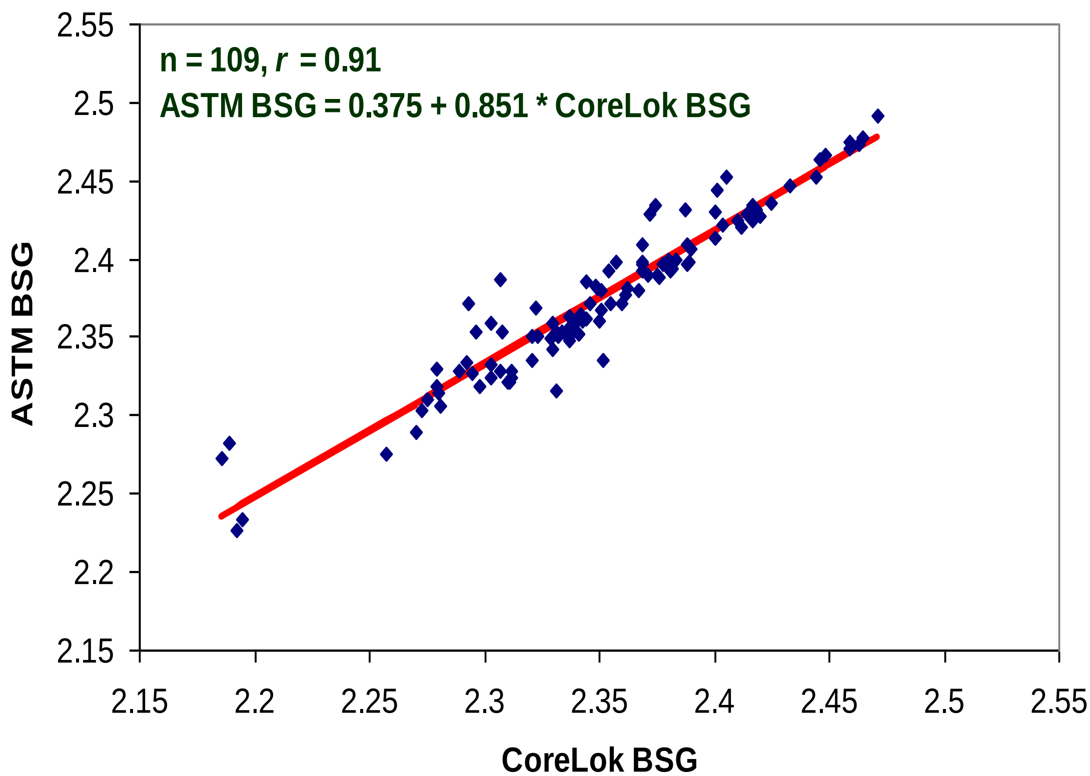

Figure 7. Regression for G_{mb} Values

Higher values of correlation coefficient serve as a justification for the existence of a linear relationship between the CoreLok G_{mb} and the AASHTO G_{mb} values.

In addition, similar analysis was performed for the nine individual groups. A summary of the results is presented in Table 6.

Table 6. G_{mb} Tests - Correlation Coefficients for Individual Datasets

Variable	'*r*'	Variable	'*r*'
All samples AASHTO BSG = 0.375 + 0.851*CoreLok BSG	0.95	Compaction-Medium AASHTO BSG = 0.45 + 0.818*CoreLok BSG	0.95
Dense Grade AASHTO BSG = 0.114 + 0.959*CoreLok BSG	0.93	Lime stone AASHTO BSG = 0.385 + 0.847*CoreLok BSG	0.96
Superpave AASHTO BSG = 0.472 + 0.81*CoreLok BSG	0.96	Gravel AASHTO BSG = 0.065 + 0.981*CoreLok BSG	0.94
SMA AASHTO BSG = 0.574 + 0.77*CoreLok BSG	0.97	Slag AASHTO BSG = 0.523 + 0.789*CoreLok BSG	0.87
302 AASHTO BSG = 0.477 + 0.814*CoreLok BSG	0.97		
Compaction-Heavy AASHTO BSG = 0.335 + 0.868*CoreLok BSG	0.95		

Although there is a statistically significant difference between the Gmb results obtained from the two test procedures, a very strong relationship exists between them, for all types of variables studied in this project.

8.3 Repeatability of G_{mb} Test Results

One of the essential issues concerning the CoreLok test procedure is the repeatability of the experimental values. Some earlier studies indicated that the CoreLok G_{mb} values were highly repeatable. To verify the repeatability of CoreLok G_{mb} results for the asphalt mixes used in the present study, repeatability tests were conducted on five representative Ohio asphalt mixes. Five repetitive tests were conducted on same samples of each mix type. The results are shown in Table 7:

Table 7. G_{mb} Values from Repetitive Tests

Mix type	Sample ID	CoreLok BSG Value
	1	2.266
	2	2.268
	3	2.267
	4	2.268
SMA	5	2.282
	1	2.401
	2	2.407
	3	2.403
	4	2.406
302	5	2.407
	1	2.409
	2	2.414
	3	2.421
	4	2.425
SMA	5	2.422
	1	2.312
	2	2.312
	3	2.306
	4	2.304
Superpave	5	2.32
	1	2.412
	2	2.418
	3	2.418
	4	2.416
Superpave	5	2.411

One sample t-test was performed to determine the statistical significance of the repetitive tests. At a 95% confidence interval, the one sample t-test provides the upper and lower limits for the data range and tests whether the mean of a single variable differs from a specified constant. The results of the t-test are shown in Table 8.

Table 8. Statistical Verification of Repeatability Tests

Sample ID	Mix type	Sample ID	CoreLok BSG	One Sample t-test, 95% CI		Comments
				Lower Limit	Upper Limit	
		1	2.266			
		2	2.268			
		3	2.267			
		4	2.268			
28	SMA	5	2.282	2.261	2.278	Repeatable
		1	2.401			
		2	2.407			
		3	2.403			
		4	2.406			
38	302	5	2.407	2.401	2.408	Repeatable
		1	2.409			
		2	2.414			
		3	2.421			
		4	2.425			
29	SMA	5	2.422	2.41	2.426	Repeatable
		1	2.312			
		2	2.312			
		3	2.306			
		4	2.304			
22	Superpave	5	2.32	2.3	2.319	Repeatable
		1	2.412			
		2	2.418			
		3	2.418			
		4	2.416			
24	Superpave	5	2.411	2.411	2.419	Repeatable

It was observed in each case that the individual G_{mb} values were within the lower and upper control limit calculated at a 95% confidence interval. This analysis reiterates the repeatability of CoreLok test results as evidenced by previous investigations. Such tests were not conducted using the ASTM procedure.

8.4 Benchmark Testing

In the case of a measuring instrument, repeatability is the inherent ability of the device to consistently repeat its readings. Although this is an important specification to consider, it should not be assumed that a highly repeatable system will also be accurate. Without an instrument uncertainty or accuracy statement, a repeatability statement alone provides no useful benefit. Most labs historically have relied on calibration units to verify the precision of measurements. Such tests, often termed benchmark tests, are based on a repeatable environment so that the same test run under the same conditions will yield results that we can legitimately compare.

In the present study, specific gravity tests were performed on blocks and cylinders of comparable sizes, with well-defined geometric shapes, exclusively prepared for this evaluation. These samples were made of steel, aluminum and rocks with very little to no water absorption. Volume was calculated by precisely measuring the height, width and/or diameter. These samples were repeatedly tested using CoreLok as well as AASHTO procedures. The specific gravity results were extremely comparable with a difference < 0.002 in each case. This is in sharp contrast with Florida and Tennessee studies which reported significant difference. The significance of this finding is in further verification of the consistency of results obtained from CoreLok and also in the establishment of a calibration unit. ODOT can develop and use a calibration to periodically verify the performance of CoreLok device as well as the precision of test data.

8.5 Air Voids Content Results

The primary use of the maximum and bulk specific gravity values are in the determination of air void content of asphalt mixes. The percent air void serves as an indicator for the correctness of the field compacted mix when it is compared to the actual design mix prepared in the laboratory. Air voids are calculated using the following expression:

$$\text{Percent Air Voids} = (1 - G_{mb}/G_{mm}) * 100$$

It is evident that both G_{mm} and G_{mb} test results are needed in order to calculate air voids. In this study, air void content was obtained for 85 samples. The calculated air voids along with the specific gravity values is presented in Table A3 of Appendix A. A graphical illustration of the variation in air voids is presented in Figure 8.

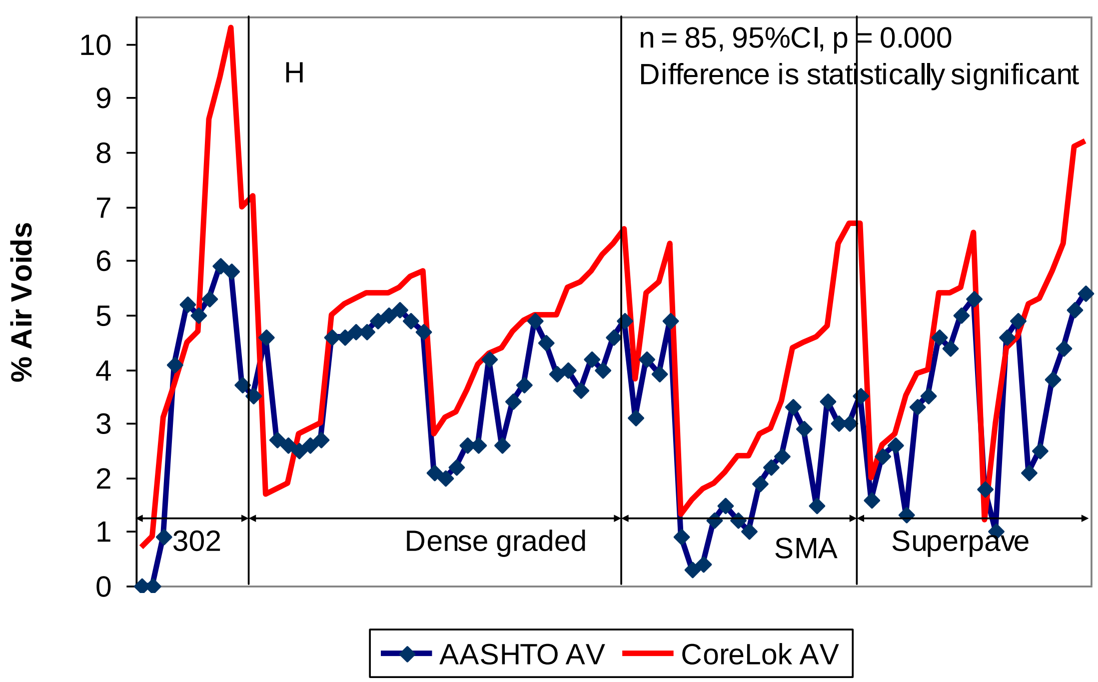

Figure 8. Comparing Air Voids

The line diagram indicates that the air void values estimated using the CoreLok device is always greater than the values determined using the comparative AASHTO procedure. Higher air voids for the CoreLok procedure can be attributed to the low bulk specific gravity values determined by the CoreLok device in comparison with the AASHTO procedure. In general, the difference in air voids is 1 to 2% for all mix types. For certain 302 and SMA mixes, the difference was greater than 3%. Maximum difference of 4.5% was recorded for a 302 mix with limestone aggregate, subjected to medium compaction. Table 9 illustrates the descriptive statistics for the percent air void values.

Table 9. Descriptive Statistics for Percent Air Voids

	CoreLok AV	AASHTO AV
Number of Samples (N)	85	85
Minimum value	0.70	0.00
Maximum Value	10.30	5.90
Mean	4.5212	3.3365
Standard Deviation	0.4592	0.402
Variance	3.782	2.220
Std. Error of Mean	0.2109	0.1616
Correlation Coefficient (*r*)	0.78	

The average difference between the mean of the CoreLok air void values and the mean of the AASHTO air void values is 1.85%. A statistical paired t-test was conducted to investigate the significance of difference in air void values between the two procedures. The hypothesis was set as below:

Null Hypothesis H_o: The difference between the mean CoreLok air void value and the mean AASHTO air void value = 0

Alternative Hypothesis H_a: The difference between the mean CoreLok air void value and the mean AASHTO air void Value ≠ 0

To Test: Whether the Difference is Statistically Significant or Not at 95% CI

The results of the t-test performed can be viewed in Table 10.

Table 10. Statistical Tests for Air Voids Values

	Paired t-test for all samples
Sample Types	All
Number of Samples	85
Degrees of Freedom (d_f)	84
CoreLok Mean	4.5212
AASHTO Mean	3.3365
Mean Difference	1.1847
Difference in Standard Deviation	1.219
Standard Error of Mean	0.1322
Lower Limit Values (at 95% CI)	0.0923
Upper Limit Values (at 95% CI)	1.448
t-statistic	8.98
p-value	0.00
Significant Difference	**YES**

The t-test performed returned a *p*-value of 0.00 at a 95% confidence interval. Since the observed *p*-value is less than α-value (0.05), the null hypothesis is rejected. This means, at 95% confidence interval, there is a statistically significant difference between the percent air void values determined using the AASHTO procedure and the CoreLok procedure. Figure 9 illustrates a scatter plot between the two air void values.

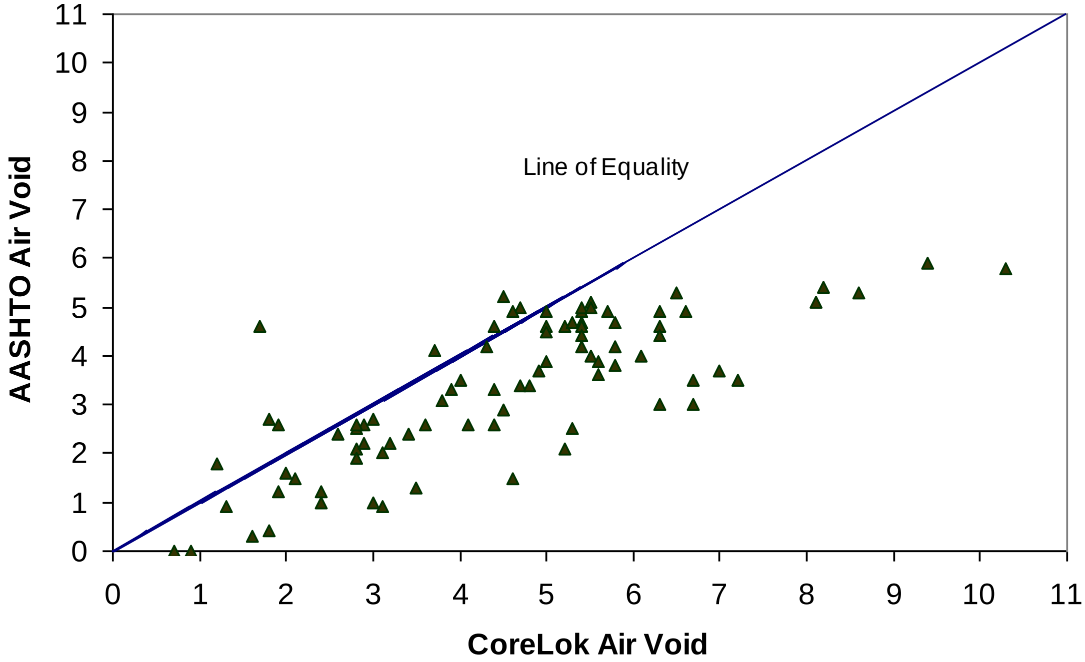

Figure 9. Scatter plot of Air Void Values

It is evident from the figure that the AASHTO air void values are lower than the air void values determined using the CoreLok procedure. While both test procedures estimated identical G_{mm} values, CoreLok G_{mb} values were always lower than AASHTO G_{mb} values. In the equation for air voids, if G_{mm} is held constant, it can be seen that air voids are inversely proportional to G_{mb}. As a result, the air void values obtained from CoreLok tests are always higher. Figure 10 shows a linear regression model along with the sample size and the correlation coefficient.

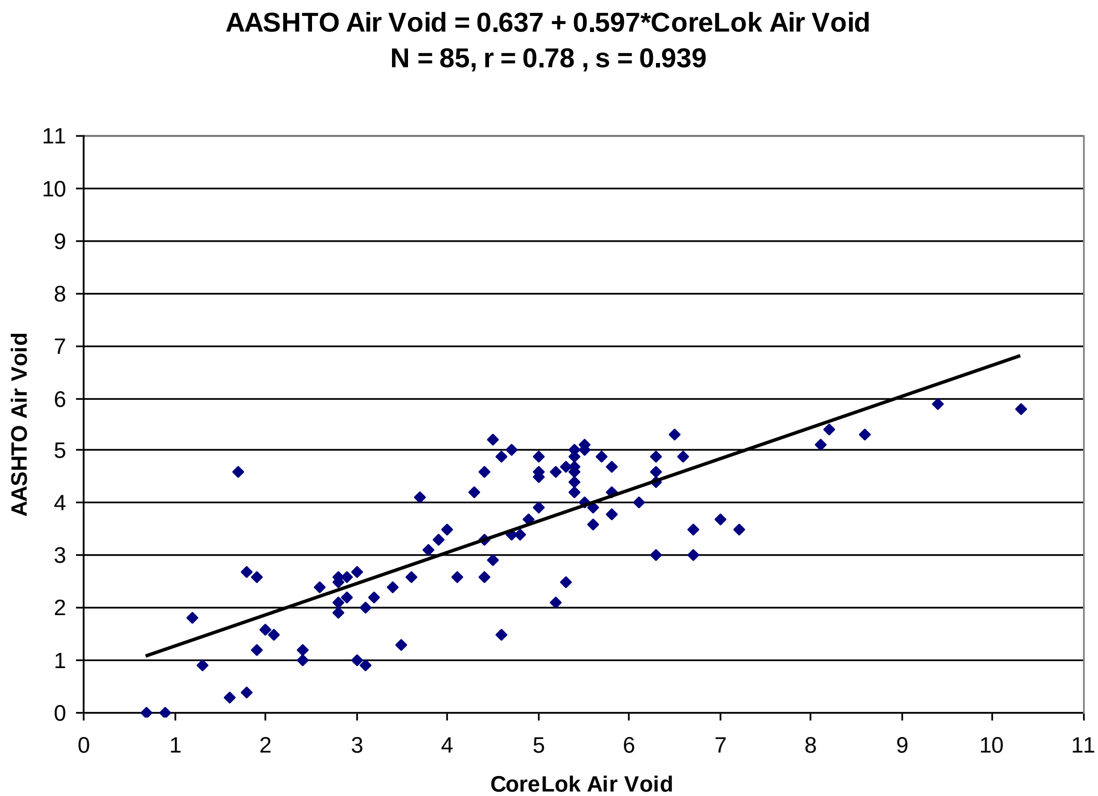

Figure 10. Regression for Air Voids

9. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Specific gravity is not a directly measured quantity. Instead, it is calculated using certain directly measured properties. Two quantities essential to calculate specific gravity are weight and volume. The weight of a given substance can be measured with precision. Volume is obtained either by direct measurement using a water displacement method (based on Archimedes principle) or by precisely measuring geometrics of the substance and going through certain simple calculations. If the substance is of irregular shape and/or porous, volume calculation based on measurement of geometrics is not applicable. In such cases, the water displacement method is used.

The water displacement method requires the use of a graduated cylinder. The cylinder is filled with distilled water and maintained at a constant temperature. The initial water level is noted and then the substance is immersed in water. As a result of this, the water level will increase. The change in water level is reported as the volume of the substance. This is perhaps the most common method adopted for determining the specific gravity of minerals and precious stones. The accuracy of the results depends on how accurately the change in water level can be recorded.

As the size of the graduated cylinders increase, it becomes increasingly difficult to accurately measure the changes in water level. In such cases, the graduated cylinders do not permit great precision in measuring volume. To circumvent this problem, for compacted asphalt samples that are 10.2cm (4") in diameter x 6.4cm (2.5") in height (or larger as in Superpave samples), AASHTO recommends three weight measurements namely, weight in air (W_a), weight in water (W_w) and weight of saturated surface dry sample (W_{ssd}). The AASHTO procedure for specific gravity determination is a standardized procedure and has been in use for many decades, particularly for dense grade asphalt mixtures. However, when used with coarse graded asphalt mixtures like the Superpave and Stone Matrix Asphalt (SMA), the test results can be inconsistent. This is mainly because the AASHTO procedure involves the use of the Saturated Surface Dried (SSD) weight of the compacted sample. In Superpave and the SMA mixes which are coarse in nature, the internal air voids can become interconnected and allow water to infiltrate into the sample quickly during the saturation process. When measuring the SSD weight of these samples, the water tends to drain out quickly from the sample and thus results in inaccurate specimen volume and specific gravities. The CoreLok is a vacuum sealing device, developed to overcome the limitations.

The CoreLok vacuum sealing device basically assists in obtaining volume of compacted asphalt specimens. The primary difference between CoreLok and the water displacement procedure is that the CoreLok procedure bypasses the SSD condition which is a significant variable. In some ways, it is analogous to the AASHTO procedure for asphalt mixtures with water absorption greater than 2.0% (use of paraffin coating).

The present study was initiated to systematically compare the specific gravity values of laboratory compacted HMA mixtures using AASHTO and vacuum sealing procedure using CoreLok device. In this comparative evaluation program, a series of bulk and maximum specific gravity tests were conducted using CoreLok as well as AASHTO procedures on laboratory compacted HMA mixtures. The asphalt mixtures, aggregate types and compaction levels selected to prepare the samples truly represented Ohio's materials and construction practices. A thorough statistical analysis of the data was conducted. The test data and the analysis led to the following conclusions:

1. Based on the test results obtained on 34 samples, the maximum specific gravity (G_{mm}) values obtained by both the test procedures (CoreLok and AASHTO) are found to be statistically similar at a confidence interval of 95%.
2. A strong correlation exists between the G_{mm} values determined from AASHTO and CoreLok procedures.
3. Tests on 109 samples showed that the bulk specific gravity (G_{mb}) values obtained using the CoreLok test procedure are lower than the AASHTO G_{mb} values. A statistical analysis conducted using a confidence interval of 95% revealed that the difference in G_{mb} values determined obtained from the two test procedures are statistically significant.

4. The difference in G_{mb} values between the two procedures is statistically significant regardless of the type of mix, type of aggregate and compaction level.
5. Repeatability tests indicated that CoreLok G_{mb} values are highly repeatable.
6. Air voids values estimated using the CoreLok device are always 1 to 2% greater than corresponding AASHTO values. The difference in air void content obtained from the two procedures is statistically significant at 95% confidence interval.
7. In general, the CoreLok equipment is capable of producing precise, consistent and repeatable test results. Additionally, the equipment was found to be user-friendly and easy to maintain. One test can be completed in less than 10 minutes resulting in a time savings of approximately 30 minutes for each test and hence appear to be an economically viable alternative.

9.1 Implementation Potential

The CoreLok device is contemplated by a few state departments of transportation as an alternate test method for the accurate measurement of bulk and maximum specific gravities of open graded (>10% air voids) and highly absorptive (>2%) asphalt mixes. The Indiana DOT for instance, specifies the use of CoreLok for asphalt mixes with air voids exceeding 15% while the Washington DOT reported the device better represents asphalt mixtures at air voids greater than 12%. Oklahoma uses CoreLok to test asphalt mixes with greater than 2% absorption as an alternate to AASHTO T-275. The NCAT pooled fund study, comprised of 18 labs and 9 materials, included asphalt mixes with absorptions up to 8%, air voids ranging from 2 to 15% and compactions from 15 to 100 gyrations. A comparison between mix design practices in Ohio and these agencies reveals a sharp difference in the mix specifications, particularly in terms of air voids, absorption and compaction. Ohio's asphalt mixes, whether dense graded (Superpave, 302) or gap graded (as in SMA), are always designed to have air voids between 2 and 6%. Ohio does not typically use open graded mixtures. As a result, even coarse mixes are usually well under 6% air voids. Water absorption of Ohio's asphalt mixes is typically below 2%. Minimum compaction specified for Superpave mixes is as high as 65 gyrations. By any standards, most of Ohio's asphalt mixes can be regarded as dense graded.

The question is 'which method is more appropriate for Ohio's conditions?' As appropriately pointed out by the Florida researchers, the actual specific gravity values (and hence air voids) are somewhere in between the AASHTO and CoreLok procedures. Thus neither method can be considered accurate. However, the AASHTO procedure is always used as the reference in lieu of a bench mark procedure. That being the case, the question now is: 'should ODOT specify the CoreLok device for the measurement of specific gravity of asphalt mixes'? Several issues (related to anticipated benefits) need to be considered before answering this question namely,

- Accuracy and consistency
- Repeatability
- Testing time
- Reduced operator error
- Equipment cost
- Ruggedness

The present study shows that, overall, the CoreLok method for determining specific gravity of asphalt mixtures shows promise as an alternative method to the traditional AASHTO test method. The individual test results exhibit repeatable, consistent and comparable results. The equipment is user-friendly, durable and fairly inexpensive. With continued use, perhaps it is possible to further refine the test data. There could be potential advantages in specifying this device in terms of reduced testing time. Apparently, the other state DOTs have not made any changes in their mix design specifications while specifying the use of CoreLok. If ODOT intends on using the CoreLok, it is recommended not to change its current specification which is based on historical data and instead use an appropriate correlation factor to relate the CoreLok and AASHTO values.

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Appendix A

Tables for G_{mm}, G_{mb} and Air Void Values Determined using the CoreLok and the AASHTO Test Procedures

Table A1- Maximum Specific Gravity (MSG) Values from AASHTO and CoreLok Test Procedures						
Sl. No.	**Trial No.**	**Mix Type**	**Compaction**	**Aggregate Type**	**AASHTO MSG**	**CoreLok MSG**
1	1	Dense Grade	Heavy	Gravel	2.447	2.393
2	2	Dense Grade	Heavy	Lime Stone	2.443	2.455
3	3	Dense Grade	Heavy	Gravel	2.445	2.443
4	4	Dense Grade	Heavy	Lime Stone	2.5	2.529
5	5	Dense Grade	Heavy	Gravel	2.422	2.41
6	6	Dense Grade	Heavy	Lime Stone	2.504	2.53
7	7	Dense Grade	Heavy	Lime Stone	2.486	2.461
8	8	Dense Grade	Medium	Gravel	2.447	2.446
9	11	Dense Grade	Medium	Lime Stone	2.491	2.508
10	12	Dense Grade	Medium	Gravel	2.466	2.459
11	13	Dense Grade	Medium	Lime Stone	2.45	2.457
12	14	Superpave	Medium	Slag	2.351	2.308
13	15	Superpave	Medium	Lime Stone	2.457	2.321
14	16	Superpave	Medium	Slag	2.379	2.409
15	17	Superpave	Medium	Lime Stone	2.475	2.478
16	18	Superpave	Medium	Slag	2.354	2.389
17	19	Superpave	Medium	Lime Stone	2.468	2.483
18	20	Superpave	Heavy	Lime Stone	2.465	2.511
19	21	Superpave	Heavy	Slag	2.437	2.41
20	22	Superpave	Heavy	Lime Stone	2.512	2.509
21	23	Superpave	Heavy	Slag	2.411	2.379
22	24	Superpave	Heavy	Lime Stone	2.462	2.457
23	26	SMA	Heavy	Lime Stone	2.452	2.451
24	27	SMA	Heavy	Lime Stone	2.36	2.442
25	28	SMA	Heavy	Lime Stone	2.384	2.387
26	29	SMA	Heavy	Lime Stone	2.427	2.398
27	30	302	Heavy	Gravel	2.511	2.46
28	32	302	Medium	Gravel	2.475	2.481
29	33	302	Medium	Lime	2.498	2.561
30	34	302	Medium	Slag	2.444	2.483
31	39	SMA	Heavy	Lime Stone	2.4	2.419
32	40	SMA	Heavy	Lime Stone	2.408	2.404
33	41	SMA	Heavy	Gravel	2.429	2.427

Table A2 - Bulk Specific Gravity Values from AASHTO and CoreLok Test Procedures

Sl. No.	Trial. No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
1	32	3	B322084	302	Medium	M1	Gravel	2.474	2.463
2	32	2	B322084	302	Medium	M1	Gravel	2.475	2.459
3	23	1	B442485	Superpave	Heavy	H3	Slag	2.368	2.351
4	26	2	NOJMF	SMA	Heavy	H1	Lime Stone	2.431	2.418
5	39	1	NOJMF	SMA	Heavy		Lime Stone	2.392	2.381
6	1	3	B413593	Dense Grade	Heavy	H1	Gravel	2.335	2.352
7	1	1	B413593	Dense Grade	Heavy	H1	Gravel	2.38	2.351
8	39	2	NOJMF	SMA	Heavy		Lime Stone	2.389	2.376
9	1	2	B413593	Dense Grade	Heavy	H1	Gravel	2.383	2.348
10	26	1	NOJMF	SMA	Heavy	H1	Lime Stone	2.422	2.404
11	22	2	B413051	Superpave	Heavy	H2	Lime Stone	2.471	2.459
12	26	3	NOJMF	SMA	Heavy	H1	Lime Stone	2.414	2.4
13	39	3	NOJMF	SMA	Heavy		Lime Stone	2.372	2.36
14	39	4	NOJMF	SMA	Heavy		Lime Stone	2.377	2.361
15	22	1	B413051	Superpave	Heavy	H2	Lime Stone	2.452	2.444
16	5	3	B413461	Dense Grade	Heavy	H3	Gravel	2.361	2.343
17	13	1	B413389	Dense Grade	Medium	M3	Lime Stone	2.398	2.389
18	24	2	B442485	Superpave	Heavy	H3	Lime Stone	2.397	2.388
19	40	3	NOJMF	SMA	Heavy		Lime Stone	2.363	2.337
20	5	1	B413461	Dense Grade	Heavy	H3	Gravel	2.36	2.339
21	40	2	NOJMF	SMA	Heavy		Lime Stone	2.354	2.334
22	5	2	B413461	Dense Grade	Heavy	H3	Gravel	2.357	2.338
23	23	2	B442485	Superpave	Heavy	H3	Slag	2.387	2.307
24	13	2	B413389	Dense Grade	Medium	M3	Lime Stone	2.4	2.38
25	32	1	B322084	302	Medium	M1	Gravel	2.453	2.405
26	13	3	B413389	Dense Grade	Medium	M3	Lime Stone	2.397	2.378
27	40	4	NOJMF	SMA	Heavy		Lime Stone	2.351	2.323
28	24	1	B442485	Superpave	Heavy	H3	Lime Stone	2.429	2.372

Sl. No	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
29	2	1	B412072	Dense Grade	Heavy	H1	Lime Stone	2.38	2.367
30	30	1	B321986	302	Heavy	H1	Gravel	2.409	2.369
31	41	1	NOJMF	SMA	Heavy		Gravel	2.354	2.334
32	20	2	B412359	Superpave	Heavy	H1	Lime Stone	2.429	2.414
33	20	1	B412359	Superpave	Heavy	H1	Lime Stone	2.424	2.41
34	4	1	B444381	Dense Grade	Heavy	H2	Lime Stone	2.436	2.425
35	7	1	B412418	Dense Grade	Heavy	H3	Lime Stone	2.371	2.355
36	4	2	B444381	Dense Grade	Heavy	H2	Lime Stone	2.434	2.417
37	21	1	B413051	Superpave	Heavy	H2	Slag	2.324	2.303
38	28	2	PIQUA	SMA	Heavy	H1	Lime Stone	2.306	2.281
39	28	3	PIQUA	SMA	Heavy	H1	Lime Stone	2.314	2.28
40	30	2	B321986	302	Heavy	H1	Gravel	2.381	2.349
41	21	2	B413051	Superpave	Heavy	H2	Slag	2.318	2.298
42	40	1	NOJMF	SMA	Heavy		Lime Stone	2.372	2.293
43	2	2	B412072	Dense Grade	Heavy	H1	Lime Stone	2.361	2.34
44	30	3	B321986	302	Heavy	H1	Gravel	2.386	2.344
45	28	1	PIQUA	SMA	Heavy	H1	Lime Stone	2.304	2.273
46	2	3	B412072	Dense Grade	Heavy	H1	Lime Stone	2.352	2.335
47	7	2	B412418	Dense Grade	Heavy	H3	Lime Stone	2.354	2.339
48	7	3	B412418	Dense Grade	Heavy	H3	Lime Stone	2.363	2.337
49	11	1	B444174	Dense Grade	Medium	M2	Lime Stone	2.394	2.382
50	12	3	B412044	Dense Grade	Medium	M3	Gravel	2.353	2.335
51	12	1	B412044	Dense Grade	Medium	M3	Gravel	2.353	2.331
52	14	1	B444584	Superpave	Medium	M1	Slag	2.282	2.189
53	12	2	B412044	Dense Grade	Medium	M3	Gravel	2.349	2.329
54	14	2	B444584	Superpave	Medium	M1	Slag	2.272	2.186
55	3	1	B412258	Dense Grade	Heavy	H2	Gravel	2.329	2.312
56	3	2	B412258	Dense Grade	Heavy	H2	Gravel	2.324	2.312
57	3	3	B412258	Dense Grade	Heavy	H2	Gravel	2.322	2.31
58	17	1	B413575	Superpave	Medium	M2	Lime Stone	2.362	2.344
59	19	2	B413499	Superpave	Medium	M3	Lime Stone	2.36	2.35

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
60	41	4	NOJMF	SMA	Heavy		Gravel	2.327	2.295
61	8	1	B412039	Dense Grade	Medium	M1	Gravel	2.322	2.311
62	11	2	B444174	Dense Grade	Medium	M2	Lime Stone	2.392	2.369
63	17	2	B413575	Superpave	Medium	M2	Lime Stone	2.352	2.341
64	4	3	B444381	Dense Grade	Heavy	H2	Lime Stone	2.409	2.388
65	41	2	NOJMF	SMA	Heavy		Gravel	2.334	2.292
66	8	2	B412039	Dense Grade	Medium	M1	Gravel	2.328	2.307
67	6	2	B412418	Dense Grade	Heavy	H3	Lime Stone	2.399	2.383
68	8	3	B412039	Dense Grade	Medium	M1	Gravel	2.332	2.303
69	16	1	B413575	Superpave	Medium	M2	Slag	2.289	2.27
70	11	3	B444174	Dense Grade	Medium	M2	Lime Stone	2.392	2.354
71	6	3	B412418	Dense Grade	Heavy	H3	Lime Stone	2.39	2.371
72	16	2	B413575	Superpave	Medium	M2	Slag	2.275	2.257
73	27	2	NOJMF	SMA	Heavy	H2	Lime Stone	2.329	2.289
74	41	3	NOJMF	SMA	Heavy		Gravel	2.31	2.275
75	19	1	B413499	Superpave	Medium	M3	Lime Stone	2.336	2.321
76	6	1	B412418	Dense Grade	Heavy	H3	Lime Stone	2.381	2.362
77	27	1	NOJMF	SMA	Heavy	H2	Lime Stone	2.33	2.279
78	27	3	NOJMF	SMA	Heavy	H2	Lime Stone	2.318	2.279
79	34	2	B322083	302	Medium	M1	Slag	2.354	2.308
80	34	1	B322083	302	Medium	M1	Slag	2.359	2.303
81	18	1	B412359	Superpave	Medium	M3	Slag	2.234	2.195
82	18	2	B412359	Superpave	Medium	M3	Slag	2.227	2.192
83	33	2	B322083	302	Medium	M1	Lime Stone	2.365	2.342
84	33	3	B322083	302	Medium	M1	Lime Stone	2.35	2.321
85	33	1	B322083	302	Medium	M1	Lime Stone	2.354	2.296
86	9	1	B413026	Dense Grade	Medium	M1	Lime Stone	2.351	2.332
87	9	2	B413026	Dense Grade	Medium	M1	Lime Stone	2.369	2.322
88	9	3	B413026	Dense Grade	Medium	M1	Lime Stone	2.359	2.33
89	10	1	B444002	Dense Grade	Medium	M2	Gravel	2.316	2.331
90	10	2	B444002	Dense Grade	Medium	M2	Gravel	2.343	2.33

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
91	10	3	B444002	Dense Grade	Medium	M2	Gravel	2.348	2.337
92	15	1	B444584	Superpave	Medium	M1	Lime Stone	2.398	2.369
93	15	2	B444584	Superpave	Medium	M1	Lime Stone	2.406	2.39
94	29	1	Lynchburg	SMA	Heavy	H1	Lime Stone	2.427	2.42
95	29	2	Lynchburg	SMA	Heavy	H1	Lime Stone	2.42	2.412
96	29	3	Lynchburg	SMA	Heavy	H1	Lime Stone	2.425	2.417
97	31	1	B322057	302	Heavy	H1	Lime Stone	2.478	2.465
98	31	2	B322057	302	Heavy	H1	Lime Stone	2.434	2.374
99	31	3	B322057	302	Heavy	H1	Lime Stone	2.398	2.357
100	35	1	NOJMF	302	Heavy	H1	Lime Stone	2.39	2.375
101	35	2	NOJMF	302	Heavy	H1	Lime Stone	2.396	2.369
102	35	3	NOJMF	302	Heavy	H1	Lime Stone	2.372	2.346
103	36	1	NOJMF	302	Heavy	H1	Lime Stone	2.467	2.448
104	36	2	NOJMF	302	Heavy	H1	Lime Stone	2.464	2.446
105	36	3	NOJMF	302	Heavy	H1	Lime Stone	2.491	2.471
106	37	1	NOJMF	302	Heavy	H1	Lime Stone	2.447	2.433
107	38	1	NOJMF	302	Heavy	H1	Lime Stone	2.43	2.4
108	38	2	NOJMF	302	Heavy	H1	Lime Stone	2.432	2.387
109	38	3	NOJMF	302	Heavy	H1	Lime Stone	2.444	2.401

Table A3 - Percent Air Void Values from AASHTO and CoreLok Procedures

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO AV	Corelok AV
1	32	3	B322084	302	Medium	M1	Gravel	0	0.7
2	32	2	B322084	302	Medium	M1	Gravel	0	0.9
3	32	1	B322084	302	Medium	M1	Gravel	0.9	3.1
4	30	1	B321986	302	Heavy	H1	Gravel	4.1	3.7
5	30	2	B321986	302	Heavy	H1	Gravel	5.2	4.5
6	30	3	B321986	302	Heavy	H1	Gravel	5	4.7
7	33	2	B322083	302	Medium	M1	Lime Stone	5.3	8.6
8	33	3	B322083	302	Medium	M1	Lime Stone	5.9	9.4
9	33	1	B322083	302	Medium	M1	Lime Stone	5.8	10.3
10	34	2	B322083	302	Medium	M1	Slag	3.7	7
11	34	1	B322083	302	Medium	M1	Slag	3.5	7.2
12	1	3	B413593	Dense Grade	Heavy	H1	Gravel	4.6	1.7
13	1	1	B413593	Dense Grade	Heavy	H1	Gravel	2.7	1.8
14	1	2	B413593	Dense Grade	Heavy	H1	Gravel	2.6	1.9
15	5	3	B413461	Dense Grade	Heavy	H3	Gravel	2.5	2.8
16	5	1	B413461	Dense Grade	Heavy	H3	Gravel	2.6	2.9
17	5	2	B413461	Dense Grade	Heavy	H3	Gravel	2.7	3
18	12	3	B412044	Dense Grade	Medium	M3	Gravel	4.6	5
19	12	1	B412044	Dense Grade	Medium	M3	Gravel	4.6	5.2
20	12	2	B412044	Dense Grade	Medium	M3	Gravel	4.7	5.3
21	3	1	B412258	Dense Grade	Heavy	H2	Gravel	4.7	5.4
22	3	2	B412258	Dense Grade	Heavy	H2	Gravel	4.9	5.4
23	3	3	B412258	Dense Grade	Heavy	H2	Gravel	5	5.4
24	8	1	B412039	Dense Grade	Medium	M1	Gravel	5.1	5.5
25	8	2	B412039	Dense Grade	Medium	M1	Gravel	4.9	5.7
26	8	3	B412039	Dense Grade	Medium	M1	Gravel	4.7	5.8
27	13	1	B413389	Dense Grade	Medium	M3	Lime Stone	2.1	2.8
28	13	2	B413389	Dense Grade	Medium	M3	Lime Stone	2	3.1
29	13	3	B413389	Dense Grade	Medium	M3	Lime Stone	2.2	3.2

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO AV	Corelok AV
30	2	1	B412072	Dense Grade	Heavy	H1	Lime Stone	2.6	3.6
31	4	1	B444381	Dense Grade	Heavy	H2	Lime Stone	2.6	4.1
32	7	1	B412418	Dense Grade	Heavy	H3	Lime Stone	4.2	4.3
33	4	2	B444381	Dense Grade	Heavy	H2	Lime Stone	2.6	4.4
34	2	2	B412072	Dense Grade	Heavy	H1	Lime Stone	3.4	4.7
35	2	3	B412072	Dense Grade	Heavy	H1	Lime Stone	3.7	4.9
36	7	2	B412418	Dense Grade	Heavy	H3	Lime Stone	4.9	5
37	7	3	B412418	Dense Grade	Heavy	H3	Lime Stone	4.5	5
38	11	1	B444174	Dense Grade	Medium	M2	Lime Stone	3.9	5
39	11	2	B444174	Dense Grade	Medium	M2	Lime Stone	4	5.5
40	4	3	B444381	Dense Grade	Heavy	H2	Lime Stone	3.6	5.6
41	6	2	B412418	Dense Grade	Heavy	H3	Lime Stone	4.2	5.8
42	11	3	B444174	Dense Grade	Medium	M2	Lime Stone	4	6.1
43	6	3	B412418	Dense Grade	Heavy	H3	Lime Stone	4.6	6.3
44	6	1	B412418	Dense Grade	Heavy	H3	Lime Stone	4.9	6.6
45	41	1	NOJMF	SMA	Heavy		Gravel	3.1	3.8
46	41	4	NOJMF	SMA	Heavy		Gravel	4.2	5.4
47	41	2	NOJMF	SMA	Heavy		Gravel	3.9	5.6
48	41	3	NOJMF	SMA	Heavy		Gravel	4.9	6.3
49	26	2	NOJMF	SMA	Heavy	H1	Lime Stone	0.9	1.3
50	39	1	NOJMF	SMA	Heavy		Lime Stone	0.3	1.6
51	39	2	NOJMF	SMA	Heavy		Lime Stone	0.4	1.8
52	26	1	NOJMF	SMA	Heavy	H1	Lime Stone	1.2	1.9
53	26	3	NOJMF	SMA	Heavy	H1	Lime Stone	1.5	2.1
54	39	3	NOJMF	SMA	Heavy		Lime Stone	1.2	2.4
55	39	4	NOJMF	SMA	Heavy		Lime Stone	1	2.4
56	40	3	NOJMF	SMA	Heavy		Lime Stone	1.9	2.8
57	40	2	NOJMF	SMA	Heavy		Lime Stone	2.2	2.9
58	40	4	NOJMF	SMA	Heavy		Lime Stone	2.4	3.4
59	28	2	PIQUA	SMA	Heavy	H1	Lime Stone	3.3	4.4
60	28	3	PIQUA	SMA	Heavy	H1	Lime Stone	2.9	4.5

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO AV	Corelok AV
61	40	1	NOJMF	SMA	Heavy		Lime Stone	1.5	4.6
62	28	1	PIQUA	SMA	Heavy	H1	Lime Stone	3.4	4.8
63	27	2	NOJMF	SMA	Heavy	H2	Lime Stone	3	6.3
64	27	1	NOJMF	SMA	Heavy	H2	Lime Stone	3	6.7
65	27	3	NOJMF	SMA	Heavy	H2	Lime Stone	3.5	6.7
66	22	2	B413051	Superpave	Heavy	H2	Lime Stone	1.6	2
67	22	1	B413051	Superpave	Heavy	H2	Lime Stone	2.4	2.6
68	24	2	B442485	Superpave	Heavy	H3	Lime Stone	2.6	2.8
69	24	1	B442485	Superpave	Heavy	H3	Lime Stone	1.3	3.5
70	20	2	B412359	Superpave	Heavy	H1	Lime Stone	3.3	3.9
71	20	1	B412359	Superpave	Heavy	H1	Lime Stone	3.5	4
72	17	1	B413575	Superpave	Medium	M2	Lime Stone	4.6	5.4
73	19	2	B413499	Superpave	Medium	M3	Lime Stone	4.4	5.4
74	17	2	B413575	Superpave	Medium	M2	Lime Stone	5	5.5
75	19	1	B413499	Superpave	Medium	M3	Lime Stone	5.3	6.5
76	23	1	B442485	Superpave	Heavy	H3	Slag	1.8	1.2
77	23	2	B442485	Superpave	Heavy	H3	Slag	1	3
78	21	1	B413051	Superpave	Heavy	H2	Slag	4.6	4.4
79	21	2	B413051	Superpave	Heavy	H2	Slag	4.9	4.6
80	14	1	B444584	Superpave	Medium	M1	Slag	2.1	5.2
81	14	2	B444584	Superpave	Medium	M1	Slag	2.5	5.3
82	16	1	B413575	Superpave	Medium	M2	Slag	3.8	5.8
83	16	2	B413575	Superpave	Medium	M2	Slag	4.4	6.3
84	18	1	B412359	Superpave	Medium	M3	Slag	5.1	8.1
85	18	2	B412359	Superpave	Medium	M3	Slag	5.4	8.2

Table A4 - Bulk Specific Gravity Value from AASHTO and CoreLok Test Procedures (Dense Grade Mixes)									
Sl. No.	**Trial No.**	**Sample Number**	**JMF**	**Mix Type**	**Compaction**	**Gradation**	**Aggregate Type**	**AASHTO BSG**	**Corelok BSG**
1	1	3	B413593	Dense Grade	Heavy	H1	Gravel	2.335	2.352
2	1	1	B413593	Dense Grade	Heavy	H1	Gravel	2.38	2.351
3	1	2	B413593	Dense Grade	Heavy	H1	Gravel	2.383	2.348
4	5	3	B413461	Dense Grade	Heavy	H3	Gravel	2.361	2.343
5	13	1	B413389	Dense Grade	Medium	M3	Lime Stone	2.398	2.389
6	5	1	B413461	Dense Grade	Heavy	H3	Gravel	2.36	2.339
7	5	2	B413461	Dense Grade	Heavy	H3	Gravel	2.357	2.338
8	13	2	B413389	Dense Grade	Medium	M3	Lime Stone	2.4	2.38
9	13	3	B413389	Dense Grade	Medium	M3	Lime Stone	2.397	2.378
10	2	1	B412072	Dense Grade	Heavy	H1	Lime Stone	2.38	2.367
11	4	1	B444381	Dense Grade	Heavy	H2	Lime Stone	2.436	2.425
12	7	1	B412418	Dense Grade	Heavy	H3	Lime Stone	2.371	2.355
13	4	2	B444381	Dense Grade	Heavy	H2	Lime Stone	2.434	2.417
14	2	2	B412072	Dense Grade	Heavy	H1	Lime Stone	2.361	2.34
15	2	3	B412072	Dense Grade	Heavy	H1	Lime Stone	2.352	2.335
16	7	2	B412418	Dense Grade	Heavy	H3	Lime Stone	2.354	2.339
17	7	3	B412418	Dense Grade	Heavy	H3	Lime Stone	2.363	2.337
18	11	1	B444174	Dense Grade	Medium	M2	Lime Stone	2.394	2.382
19	12	3	B412044	Dense Grade	Medium	M3	Gravel	2.353	2.335
20	12	1	B412044	Dense Grade	Medium	M3	Gravel	2.353	2.331
21	12	2	B412044	Dense Grade	Medium	M3	Gravel	2.349	2.329
22	3	1	B412258	Dense Grade	Heavy	H2	Gravel	2.329	2.312
23	3	2	B412258	Dense Grade	Heavy	H2	Gravel	2.324	2.312
24	3	3	B412258	Dense Grade	Heavy	H2	Gravel	2.322	2.31
25	8	1	B412039	Dense Grade	Medium	M1	Gravel	2.322	2.311
26	11	2	B444174	Dense Grade	Medium	M2	Lime Stone	2.392	2.369
27	4	3	B444381	Dense Grade	Heavy	H2	Lime Stone	2.409	2.388
28	8	2	B412039	Dense Grade	Medium	M1	Gravel	2.328	2.307

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
29	6	2	B412418	Dense Grade	Heavy	H3	Lime Stone	2.399	2.383
30	8	3	B412039	Dense Grade	Medium	M1	Gravel	2.332	2.303
31	11	3	B444174	Dense Grade	Medium	M2	Lime Stone	2.392	2.354
32	6	3	B412418	Dense Grade	Heavy	H3	Lime Stone	2.39	2.371
33	6	1	B412418	Dense Grade	Heavy	H3	Lime Stone	2.381	2.362
34	9	1	B413026	Dense Grade	Medium	M1	Lime Stone	2.351	2.332
35	9	2	B413026	Dense Grade	Medium	M1	Lime Stone	2.369	2.322
36	9	3	B413026	Dense Grade	Medium	M1	Lime Stone	2.359	2.33
37	10	1	B444002	Dense Grade	Medium	M2	Gravel	2.316	2.331
38	10	2	B444002	Dense Grade	Medium	M2	Gravel	2.343	2.33
39	10	3	B444002	Dense Grade	Medium	M2	Gravel	2.348	2.337

Table A5 - Bulk Specific Gravity Value from AASHTO and CoreLok Test Procedures (Superpave Mixes)

Sl. No	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
1	23	1	B442485	Superpave	Heavy	H3	Slag	2.368	2.351
2	22	2	B413051	Superpave	Heavy	H2	Lime Stone	2.471	2.459
3	22	1	B413051	Superpave	Heavy	H2	Lime Stone	2.452	2.444
4	24	2	B442485	Superpave	Heavy	H3	Lime Stone	2.397	2.388
5	23	2	B442485	Superpave	Heavy	H3	Slag	2.387	2.307
6	24	1	B442485	Superpave	Heavy	H3	Lime Stone	2.429	2.372
7	20	2	B412359	Superpave	Heavy	H1	Lime Stone	2.429	2.414
8	20	1	B412359	Superpave	Heavy	H1	Lime Stone	2.424	2.41
9	21	1	B413051	Superpave	Heavy	H2	Slag	2.324	2.303
10	21	2	B413051	Superpave	Heavy	H2	Slag	2.318	2.298
11	14	1	B444584	Superpave	Medium	M1	Slag	2.282	2.189
12	14	2	B444584	Superpave	Medium	M1	Slag	2.272	2.186
13	17	1	B413575	Superpave	Medium	M2	Lime Stone	2.362	2.344
14	19	2	B413499	Superpave	Medium	M3	Lime Stone	2.36	2.35
15	17	2	B413575	Superpave	Medium	M2	Lime Stone	2.352	2.341
16	16	1	B413575	Superpave	Medium	M2	Slag	2.289	2.27
17	16	2	B413575	Superpave	Medium	M2	Slag	2.275	2.257
18	19	1	B413499	Superpave	Medium	M3	Lime Stone	2.336	2.321
19	18	1	B412359	Superpave	Medium	M3	Slag	2.234	2.195
20	18	2	B412359	Superpave	Medium	M3	Slag	2.227	2.192
21	15	1	B444584	Superpave	Medium	M1	Lime Stone	2.398	2.369
22	15	2	B444584	Superpave	Medium	M1	Lime Stone	2.406	2.39

Table A6 - Bulk Specific Gravity Value from AASHTO and CoreLok Test Procedures (SMA Mixes)									
Sl. No.	**Trial No.**	**Sample Number**	**JMF**	**Mix Type**	**Compaction**	**Gradation**	**Aggregate Type**	**AASHTO BSG**	**Corelok BSG**
1	26	2	NOJMF	SMA	Heavy	H1	Lime Stone	2.431	2.418
2	39	1	NOJMF	SMA	Heavy		Lime Stone	2.392	2.381
3	39	2	NOJMF	SMA	Heavy		Lime Stone	2.389	2.376
4	26	1	NOJMF	SMA	Heavy	H1	Lime Stone	2.422	2.404
5	26	3	NOJMF	SMA	Heavy	H1	Lime Stone	2.414	2.4
6	39	3	NOJMF	SMA	Heavy		Lime Stone	2.372	2.36
7	39	4	NOJMF	SMA	Heavy		Lime Stone	2.377	2.361
8	40	3	NOJMF	SMA	Heavy		Lime Stone	2.363	2.337
9	40	2	NOJMF	SMA	Heavy		Lime Stone	2.354	2.334
10	40	4	NOJMF	SMA	Heavy		Lime Stone	2.351	2.323
11	41	1	NOJMF	SMA	Heavy		Gravel	2.354	2.334
12	28	2	PIQUA	SMA	Heavy	H1	Lime Stone	2.306	2.281
13	28	3	PIQUA	SMA	Heavy	H1	Lime Stone	2.314	2.28
14	40	1	NOJMF	SMA	Heavy		Lime Stone	2.372	2.293
15	28	1	PIQUA	SMA	Heavy	H1	Lime Stone	2.304	2.273
16	41	4	NOJMF	SMA	Heavy		Gravel	2.327	2.295
17	41	2	NOJMF	SMA	Heavy		Gravel	2.334	2.292
18	27	2	NOJMF	SMA	Heavy	H2	Lime Stone	2.329	2.289
19	41	3	NOJMF	SMA	Heavy		Gravel	2.31	2.275
20	27	1	NOJMF	SMA	Heavy	H2	Lime Stone	2.33	2.279
21	27	3	NOJMF	SMA	Heavy	H2	Lime Stone	2.318	2.279
22	29	1	Lynchburg	SMA	Heavy	H1	Lime Stone	2.427	2.42
23	29	2	Lynchburg	SMA	Heavy	H1	Lime Stone	2.42	2.412
24	29	3	Lynchburg	SMA	Heavy	H1	Lime Stone	2.425	2.417

Table A7 - Bulk Specific Gravity Value from AASHTO and CoreLok Test Procedures (302 Mixes)

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
1	32	3	B322084	302	Medium	M1	Gravel	2.474	2.463
2	32	2	B322084	302	Medium	M1	Gravel	2.475	2.459
3	32	1	B322084	302	Medium	M1	Gravel	2.453	2.405
4	30	1	B321986	302	Heavy	H1	Gravel	2.409	2.369
5	30	2	B321986	302	Heavy	H1	Gravel	2.381	2.349
6	30	3	B321986	302	Heavy	H1	Gravel	2.386	2.344
7	34	2	B322083	302	Medium	M1	Slag	2.354	2.308
8	34	1	B322083	302	Medium	M1	Slag	2.359	2.303
9	33	2	B322083	302	Medium	M1	Lime Stone	2.365	2.342
10	33	3	B322083	302	Medium	M1	Lime Stone	2.35	2.321
11	33	1	B322083	302	Medium	M1	Lime Stone	2.354	2.296
12	31	1	B322057	302	Heavy	H1	Lime Stone	2.478	2.465
13	31	2	B322057	302	Heavy	H1	Lime Stone	2.434	2.374
14	31	3	B322057	302	Heavy	H1	Lime Stone	2.398	2.357
15	35	1	NOJMF	302	Heavy	H1	Lime Stone	2.39	2.375
16	35	2	NOJMF	302	Heavy	H1	Lime Stone	2.396	2.369
17	35	3	NOJMF	302	Heavy	H1	Lime Stone	2.372	2.346
18	36	1	NOJMF	302	Heavy	H1	Lime Stone	2.467	2.448
19	36	2	NOJMF	302	Heavy	H1	Lime Stone	2.464	2.446
20	36	3	NOJMF	302	Heavy	H1	Lime Stone	2.491	2.471
21	37	1	NOJMF	302	Heavy	H1	Lime Stone	2.447	2.433
22	38	1	NOJMF	302	Heavy	H1	Lime Stone	2.43	2.4
23	38	2	NOJMF	302	Heavy	H1	Lime Stone	2.432	2.387
24	38	3	NOJMF	302	Heavy	H1	Lime Stone	2.444	2.401

Table A8 - Bulk Specific Gravity Value from AASHTO and CoreLok Test Procedures (Lime Stone Aggregate)									
Sl. No.	**Trial No.**	**Sample Number**	**JMF**	**Mix Type**	**Compaction**	**Gradation**	**Aggregate Type**	**AASHTO BSG**	**Corelok BSG**
1	33	2	B322083	302	Medium	M1	Lime Stone	2.365	2.342
2	33	3	B322083	302	Medium	M1	Lime Stone	2.35	2.321
3	33	1	B322083	302	Medium	M1	Lime Stone	2.354	2.296
4	31	1	B322057	302	Heavy	H1	Lime Stone	2.478	2.465
5	31	2	B322057	302	Heavy	H1	Lime Stone	2.434	2.374
6	31	3	B322057	302	Heavy	H1	Lime Stone	2.398	2.357
7	35	1	NOJMF	302	Heavy	H1	Lime Stone	2.39	2.375
8	35	2	NOJMF	302	Heavy	H1	Lime Stone	2.396	2.369
9	35	3	NOJMF	302	Heavy	H1	Lime Stone	2.372	2.346
10	36	1	NOJMF	302	Heavy	H1	Lime Stone	2.467	2.448
11	36	2	NOJMF	302	Heavy	H1	Lime Stone	2.464	2.446
12	36	3	NOJMF	302	Heavy	H1	Lime Stone	2.491	2.471
13	37	1	NOJMF	302	Heavy	H1	Lime Stone	2.447	2.433
14	38	1	NOJMF	302	Heavy	H1	Lime Stone	2.43	2.4
15	38	2	NOJMF	302	Heavy	H1	Lime Stone	2.432	2.387
16	38	3	NOJMF	302	Heavy	H1	Lime Stone	2.444	2.401
17	13	1	B413389	Dense Grade	Medium	M3	Lime Stone	2.398	2.389
18	13	2	B413389	Dense Grade	Medium	M3	Lime Stone	2.4	2.38
19	13	3	B413389	Dense Grade	Medium	M3	Lime Stone	2.397	2.378
20	2	1	B412072	Dense Grade	Heavy	H1	Lime Stone	2.38	2.367
21	4	1	B444381	Dense Grade	Heavy	H2	Lime Stone	2.436	2.425
22	7	1	B412418	Dense Grade	Heavy	H3	Lime Stone	2.371	2.355
23	4	2	B444381	Dense Grade	Heavy	H2	Lime Stone	2.434	2.417
24	2	2	B412072	Dense Grade	Heavy	H1	Lime Stone	2.361	2.34
25	2	3	B412072	Dense Grade	Heavy	H1	Lime Stone	2.352	2.335
26	7	2	B412418	Dense Grade	Heavy	H3	Lime Stone	2.354	2.339
27	7	3	B412418	Dense Grade	Heavy	H3	Lime Stone	2.363	2.337
28	11	1	B444174	Dense Grade	Medium	M2	Lime Stone	2.394	2.382

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
29	11	2	B444174	Dense Grade	Medium	M2	Lime Stone	2.392	2.369
30	4	3	B444381	Dense Grade	Heavy	H2	Lime Stone	2.409	2.388
31	6	2	B412418	Dense Grade	Heavy	H3	Lime Stone	2.399	2.383
32	11	3	B444174	Dense Grade	Medium	M2	Lime Stone	2.392	2.354
33	6	3	B412418	Dense Grade	Heavy	H3	Lime Stone	2.39	2.371
34	6	1	B412418	Dense Grade	Heavy	H3	Lime Stone	2.381	2.362
35	9	1	B413026	Dense Grade	Medium	M1	Lime Stone	2.351	2.332
36	9	2	B413026	Dense Grade	Medium	M1	Lime Stone	2.369	2.322
37	9	3	B413026	Dense Grade	Medium	M1	Lime Stone	2.359	2.33
38	26	2	NOJMF	SMA	Heavy	H1	Lime Stone	2.431	2.418
39	39	1	NOJMF	SMA	Heavy		Lime Stone	2.392	2.381
40	39	2	NOJMF	SMA	Heavy		Lime Stone	2.389	2.376
41	26	1	NOJMF	SMA	Heavy	H1	Lime Stone	2.422	2.404
42	26	3	NOJMF	SMA	Heavy	H1	Lime Stone	2.414	2.4
43	39	3	NOJMF	SMA	Heavy		Lime Stone	2.372	2.36
44	39	4	NOJMF	SMA	Heavy		Lime Stone	2.377	2.361
45	40	3	NOJMF	SMA	Heavy		Lime Stone	2.363	2.337
46	40	2	NOJMF	SMA	Heavy		Lime Stone	2.354	2.334
47	40	4	NOJMF	SMA	Heavy		Lime Stone	2.351	2.323
48	28	2	PIQUA	SMA	Heavy	H1	Lime Stone	2.306	2.281
49	28	3	PIQUA	SMA	Heavy	H1	Lime Stone	2.314	2.28
50	40	1	NOJMF	SMA	Heavy		Lime Stone	2.372	2.293
51	28	1	PIQUA	SMA	Heavy	H1	Lime Stone	2.304	2.273
52	27	2	NOJMF	SMA	Heavy	H2	Lime Stone	2.329	2.289
53	27	1	NOJMF	SMA	Heavy	H2	Lime Stone	2.33	2.279
54	27	3	NOJMF	SMA	Heavy	H2	Lime Stone	2.318	2.279
55	29	1	Lynchburg	SMA	Heavy	H1	Lime Stone	2.427	2.42
56	29	2	Lynchburg	SMA	Heavy	H1	Lime Stone	2.42	2.412
57	29	3	Lynchburg	SMA	Heavy	H1	Lime Stone	2.425	2.417
58	22	2	B413051	Superpave	Heavy	H2	Lime Stone	2.471	2.459
59	22	1	B413051	Superpave	Heavy	H2	Lime Stone	2.452	2.444

Sl. No	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
60	24	2	B442485	Superpave	Heavy	H3	Lime Stone	2.397	2.388
61	24	1	B442485	Superpave	Heavy	H3	Lime Stone	2.429	2.372
62	20	2	B412359	Superpave	Heavy	H1	Lime Stone	2.429	2.414
63	20	1	B412359	Superpave	Heavy	H1	Lime Stone	2.424	2.41
64	17	1	B413575	Superpave	Medium	M2	Lime Stone	2.362	2.344
65	19	2	B413499	Superpave	Medium	M3	Lime Stone	2.36	2.35
66	17	2	B413575	Superpave	Medium	M2	Lime Stone	2.352	2.341
67	19	1	B413499	Superpave	Medium	M3	Lime Stone	2.336	2.321
68	15	1	B444584	Superpave	Medium	M1	Lime Stone	2.398	2.369
69	15	2	B444584	Superpave	Medium	M1	Lime Stone	2.406	2.39

Table A9 - Bulk Specific Gravity Value from AASHTO and CoreLok Test Procedures (Gravel Aggregate)

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
1	32	3	B322084	302	Medium	M1	Gravel	2.474	2.463
2	32	2	B322084	302	Medium	M1	Gravel	2.475	2.459
3	32	1	B322084	302	Medium	M1	Gravel	2.453	2.405
4	30	1	B321986	302	Heavy	H1	Gravel	2.409	2.369
5	30	2	B321986	302	Heavy	H1	Gravel	2.381	2.349
6	30	3	B321986	302	Heavy	H1	Gravel	2.386	2.344
7	1	3	B413593	Dense Grade	Heavy	H1	Gravel	2.335	2.352
8	1	1	B413593	Dense Grade	Heavy	H1	Gravel	2.38	2.351
9	1	2	B413593	Dense Grade	Heavy	H1	Gravel	2.383	2.348
10	5	3	B413461	Dense Grade	Heavy	H3	Gravel	2.361	2.343
11	5	1	B413461	Dense Grade	Heavy	H3	Gravel	2.36	2.339
12	5	2	B413461	Dense Grade	Heavy	H3	Gravel	2.357	2.338
13	12	3	B412044	Dense Grade	Medium	M3	Gravel	2.353	2.335
14	12	1	B412044	Dense Grade	Medium	M3	Gravel	2.353	2.331
15	12	2	B412044	Dense Grade	Medium	M3	Gravel	2.349	2.329
16	3	1	B412258	Dense Grade	Heavy	H2	Gravel	2.329	2.312
17	3	2	B412258	Dense Grade	Heavy	H2	Gravel	2.324	2.312
18	3	3	B412258	Dense Grade	Heavy	H2	Gravel	2.322	2.31
19	8	1	B412039	Dense Grade	Medium	M1	Gravel	2.322	2.311
20	8	2	B412039	Dense Grade	Medium	M1	Gravel	2.328	2.307
21	8	3	B412039	Dense Grade	Medium	M1	Gravel	2.332	2.303
22	10	1	B444002	Dense Grade	Medium	M2	Gravel	2.316	2.331
23	10	2	B444002	Dense Grade	Medium	M2	Gravel	2.343	2.33
24	10	3	B444002	Dense Grade	Medium	M2	Gravel	2.348	2.337
25	41	1	NOJMF	SMA	Heavy		Gravel	2.354	2.334
26	41	4	NOJMF	SMA	Heavy		Gravel	2.327	2.295
27	41	2	NOJMF	SMA	Heavy		Gravel	2.334	2.292
28	41	3	NOJMF	SMA	Heavy		Gravel	2.31	2.275

Table A10 - Bulk Specific Gravity Value from AASHTO and CoreLok Test Procedures (Slag Aggregate)									
Sl. No	**Trial No.**	**Sample Number**	**JMF**	**Mix Type**	**Compaction**	**Gradation**	**Aggregate Type**	**AASHTO BSG**	**Corelok BSG**
1	34	2	B322083	302	Medium	M1	Slag	2.354	2.308
2	34	1	B322083	302	Medium	M1	Slag	2.359	2.303
3	23	1	B442485	Superpave	Heavy	H3	Slag	2.368	2.351
4	23	2	B442485	Superpave	Heavy	H3	Slag	2.387	2.307
5	21	1	B413051	Superpave	Heavy	H2	Slag	2.324	2.303
6	21	2	B413051	Superpave	Heavy	H2	Slag	2.318	2.298
7	14	1	B444584	Superpave	Medium	M1	Slag	2.282	2.189
8	14	2	B444584	Superpave	Medium	M1	Slag	2.272	2.186
9	16	1	B413575	Superpave	Medium	M2	Slag	2.289	2.27
10	16	2	B413575	Superpave	Medium	M2	Slag	2.275	2.257
11	18	1	B412359	Superpave	Medium	M3	Slag	2.234	2.195
12	18	2	B412359	Superpave	Medium	M3	Slag	2.227	2.192

Table A11 - Bulk Specific Gravity Value from AASHTO and CoreLok Test Procedures (Heavy Compaction)									
Sl. No	**Trial No.**	**Sample Number**	**JMF**	**Mix Type**	**Compaction**	**Gradation**	**Aggregate Type**	**AASHTO BSG**	**Corelok BSG**
1	30	1	B321986	302	Heavy	H1	Gravel	2.409	2.369
2	30	2	B321986	302	Heavy	H1	Gravel	2.381	2.349
3	30	3	B321986	302	Heavy	H1	Gravel	2.386	2.344
4	1	3	B413593	Dense Grade	Heavy	H1	Gravel	2.335	2.352
5	1	1	B413593	Dense Grade	Heavy	H1	Gravel	2.38	2.351
6	1	2	B413593	Dense Grade	Heavy	H1	Gravel	2.383	2.348
7	5	3	B413461	Dense Grade	Heavy	H3	Gravel	2.361	2.343
8	5	1	B413461	Dense Grade	Heavy	H3	Gravel	2.36	2.339
9	5	2	B413461	Dense Grade	Heavy	H3	Gravel	2.357	2.338
10	3	1	B412258	Dense Grade	Heavy	H2	Gravel	2.329	2.312
11	3	2	B412258	Dense Grade	Heavy	H2	Gravel	2.324	2.312
12	3	3	B412258	Dense Grade	Heavy	H2	Gravel	2.322	2.31
13	41	1	NOJMF	SMA	Heavy		Gravel	2.354	2.334
14	41	4	NOJMF	SMA	Heavy		Gravel	2.327	2.295
15	41	2	NOJMF	SMA	Heavy		Gravel	2.334	2.292
16	41	3	NOJMF	SMA	Heavy		Gravel	2.31	2.275
17	31	1	B322057	302	Heavy	H1	Lime Stone	2.478	2.465
18	31	2	B322057	302	Heavy	H1	Lime Stone	2.434	2.374
19	31	3	B322057	302	Heavy	H1	Lime Stone	2.398	2.357
20	35	1	NOJMF	302	Heavy	H1	Lime Stone	2.39	2.375
21	35	2	NOJMF	302	Heavy	H1	Lime Stone	2.396	2.369
22	35	3	NOJMF	302	Heavy	H1	Lime Stone	2.372	2.346
23	36	1	NOJMF	302	Heavy	H1	Lime Stone	2.467	2.448
24	36	2	NOJMF	302	Heavy	H1	Lime Stone	2.464	2.446
25	36	3	NOJMF	302	Heavy	H1	Lime Stone	2.491	2.471
26	37	1	NOJMF	302	Heavy	H1	Lime Stone	2.447	2.433

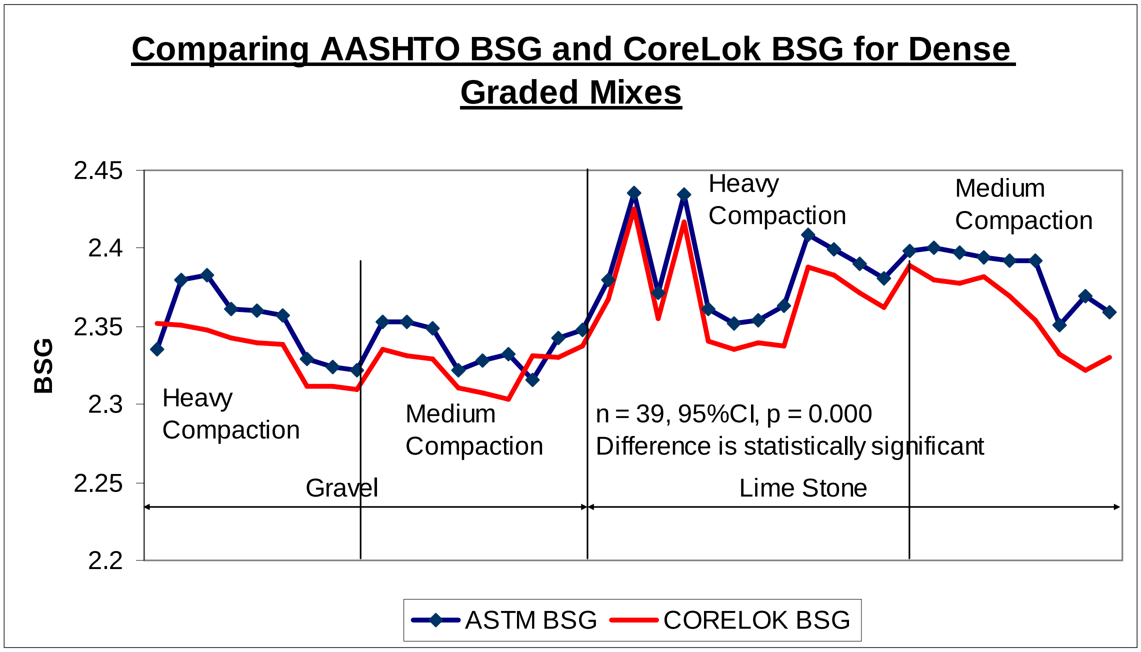
Sl. No.	**Trial No.**	**Sample Number**	**JMF**	**Mix Type**	**Compaction**	**Gradation**	**Aggregate Type**	**AASHTO BSG**	**Corelok BSG**
27	38	1	NOJMF	302	Heavy	H1	Lime Stone	2.43	2.4
28	38	2	NOJMF	302	Heavy	H1	Lime Stone	2.432	2.387
29	38	3	NOJMF	302	Heavy	H1	Lime Stone	2.444	2.401
30	2	1	B412072	Dense Grade	Heavy	H1	Lime Stone	2.38	2.367
31	4	1	B444381	Dense Grade	Heavy	H2	Lime Stone	2.436	2.425
32	7	1	B412418	Dense Grade	Heavy	H3	Lime Stone	2.371	2.355
33	4	2	B444381	Dense Grade	Heavy	H2	Lime Stone	2.434	2.417
34	2	2	B412072	Dense Grade	Heavy	H1	Lime Stone	2.361	2.34
35	2	3	B412072	Dense Grade	Heavy	H1	Lime Stone	2.352	2.335
36	7	2	B412418	Dense Grade	Heavy	H3	Lime Stone	2.354	2.339
37	7	3	B412418	Dense Grade	Heavy	H3	Lime Stone	2.363	2.337
38	4	3	B444381	Dense Grade	Heavy	H2	Lime Stone	2.409	2.388
39	6	2	B412418	Dense Grade	Heavy	H3	Lime Stone	2.399	2.383
40	6	3	B412418	Dense Grade	Heavy	H3	Lime Stone	2.39	2.371
41	6	1	B412418	Dense Grade	Heavy	H3	Lime Stone	2.381	2.362
42	26	2	NOJMF	SMA	Heavy	H1	Lime Stone	2.431	2.418
43	39	1	NOJMF	SMA	Heavy		Lime Stone	2.392	2.381
44	39	2	NOJMF	SMA	Heavy		Lime Stone	2.389	2.376
45	26	1	NOJMF	SMA	Heavy	H1	Lime Stone	2.422	2.404
46	26	3	NOJMF	SMA	Heavy	H1	Lime Stone	2.414	2.4
47	39	3	NOJMF	SMA	Heavy		Lime Stone	2.372	2.36
48	39	4	NOJMF	SMA	Heavy		Lime Stone	2.377	2.361
49	40	3	NOJMF	SMA	Heavy		Lime Stone	2.363	2.337
50	40	2	NOJMF	SMA	Heavy		Lime Stone	2.354	2.334
51	40	4	NOJMF	SMA	Heavy		Lime Stone	2.351	2.323
52	28	2	PIQUA	SMA	Heavy	H1	Lime Stone	2.306	2.281
53	28	3	PIQUA	SMA	Heavy	H1	Lime Stone	2.314	2.28
54	40	1	NOJMF	SMA	Heavy		Lime Stone	2.372	2.293
55	28	1	PIQUA	SMA	Heavy	H1	Lime Stone	2.304	2.273
56	27	2	NOJMF	SMA	Heavy	H2	Lime Stone	2.329	2.289
57	27	1	NOJMF	SMA	Heavy	H2	Lime Stone	2.33	2.279

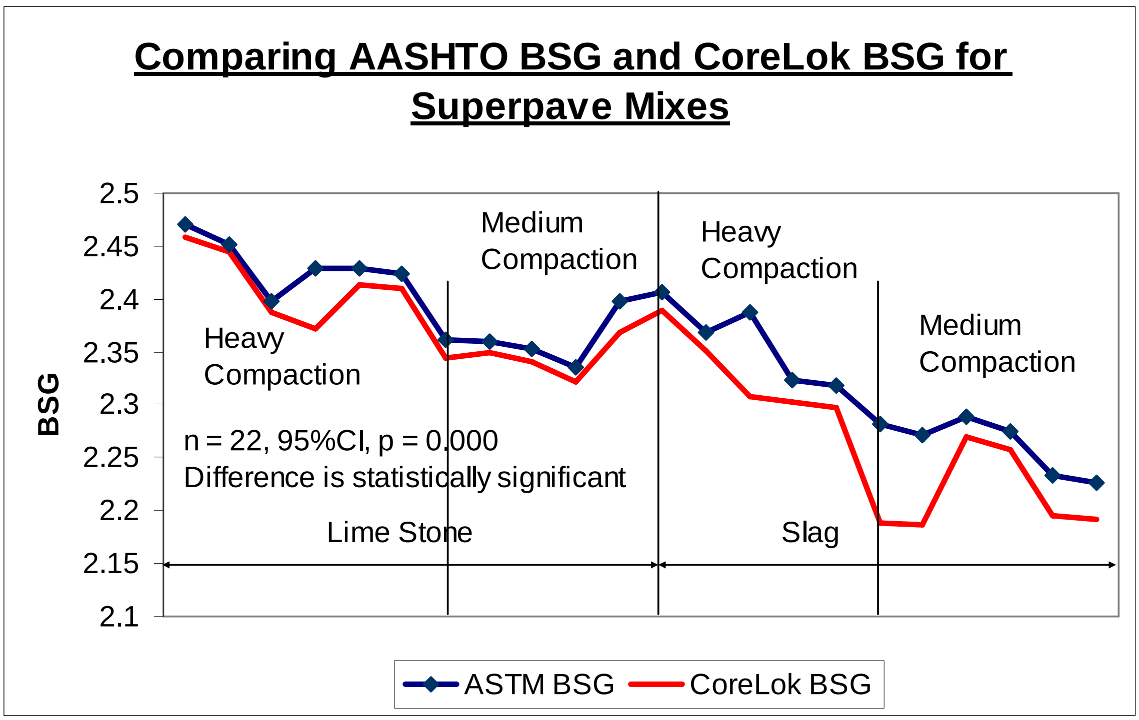
Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
58	27	3	NOJMF	SMA	Heavy	H2	Lime Stone	2.318	2.279
59	29	1	Lynchburg	SMA	Heavy	H1	Lime Stone	2.427	2.42
60	29	2	Lynchburg	SMA	Heavy	H1	Lime Stone	2.42	2.412
61	29	3	Lynchburg	SMA	Heavy	H1	Lime Stone	2.425	2.417
62	22	2	B413051	Superpave	Heavy	H2	Lime Stone	2.471	2.459
63	22	1	B413051	Superpave	Heavy	H2	Lime Stone	2.452	2.444
64	24	2	B442485	Superpave	Heavy	H3	Lime Stone	2.397	2.388
65	24	1	B442485	Superpave	Heavy	H3	Lime Stone	2.429	2.372
66	20	2	B412359	Superpave	Heavy	H1	Lime Stone	2.429	2.414
67	20	1	B412359	Superpave	Heavy	H1	Lime Stone	2.424	2.41
68	23	1	B442485	Superpave	Heavy	H3	Slag	2.368	2.351
69	23	2	B442485	Superpave	Heavy	H3	Slag	2.387	2.307
70	21	1	B413051	Superpave	Heavy	H2	Slag	2.324	2.303
71	21	2	B413051	Superpave	Heavy	H2	Slag	2.318	2.298

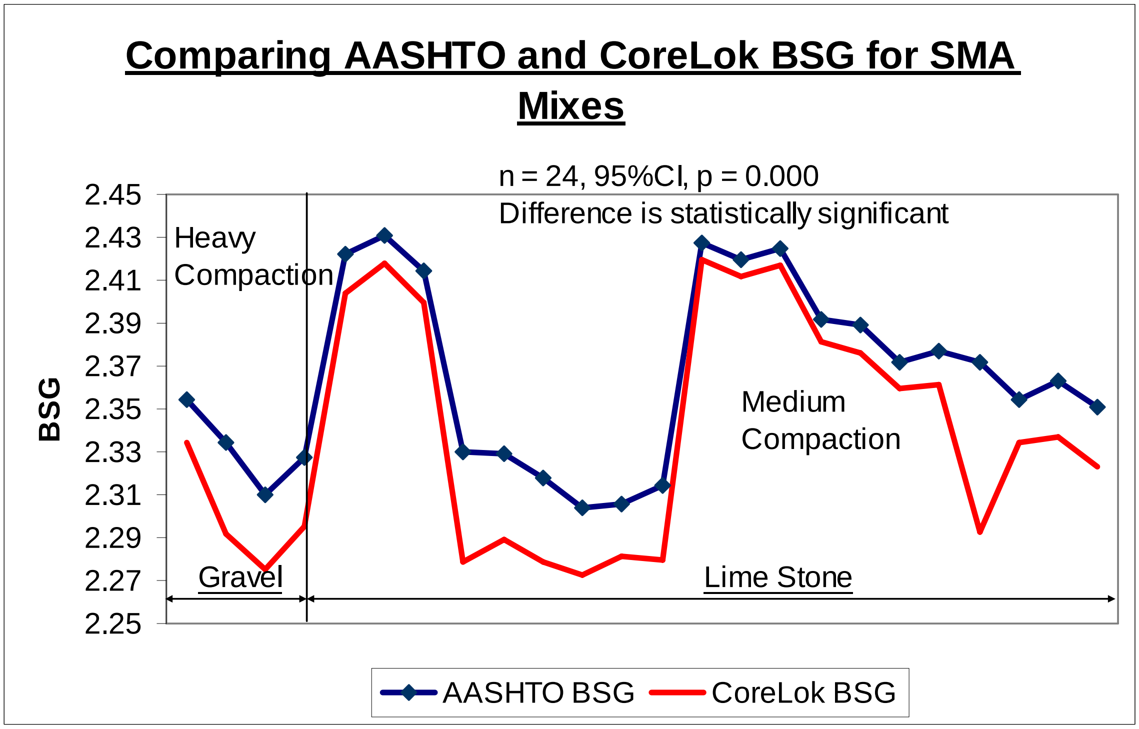
Table A12 - Bulk Specific Gravity Value from AASHTO and CoreLok Test Procedures (Medium Compaction)									
Sl. No.	**Trial No.**	**Sample Number**	**JMF**	**Mix Type**	**Compaction**	**Gradation**	**Aggregate Type**	**AASHTO BSG**	**Corelok BSG**
1	32	3	B322084	302	Medium	M1	Gravel	2.474	2.463
2	32	2	B322084	302	Medium	M1	Gravel	2.475	2.459
3	32	1	B322084	302	Medium	M1	Gravel	2.453	2.405
4	12	3	B412044	Dense Grade	Medium	M3	Gravel	2.353	2.335
5	12	1	B412044	Dense Grade	Medium	M3	Gravel	2.353	2.331
6	12	2	B412044	Dense Grade	Medium	M3	Gravel	2.349	2.329
7	8	1	B412039	Dense Grade	Medium	M1	Gravel	2.322	2.311
8	8	2	B412039	Dense Grade	Medium	M1	Gravel	2.328	2.307
9	8	3	B412039	Dense Grade	Medium	M1	Gravel	2.332	2.303
10	10	1	B444002	Dense Grade	Medium	M2	Gravel	2.316	2.331
11	10	2	B444002	Dense Grade	Medium	M2	Gravel	2.343	2.33
12	10	3	B444002	Dense Grade	Medium	M2	Gravel	2.348	2.337
13	33	2	B322083	302	Medium	M1	Lime Stone	2.365	2.342
14	33	3	B322083	302	Medium	M1	Lime Stone	2.35	2.321
15	33	1	B322083	302	Medium	M1	Lime Stone	2.354	2.296
16	13	1	B413389	Dense Grade	Medium	M3	Lime Stone	2.398	2.389
17	13	2	B413389	Dense Grade	Medium	M3	Lime Stone	2.4	2.38
18	13	3	B413389	Dense Grade	Medium	M3	Lime Stone	2.397	2.378
19	11	1	B444174	Dense Grade	Medium	M2	Lime Stone	2.394	2.382
20	11	2	B444174	Dense Grade	Medium	M2	Lime Stone	2.392	2.369
21	11	3	B444174	Dense Grade	Medium	M2	Lime Stone	2.392	2.354
22	9	1	B413026	Dense Grade	Medium	M1	Lime Stone	2.351	2.332
23	9	2	B413026	Dense Grade	Medium	M1	Lime Stone	2.369	2.322
24	9	3	B413026	Dense Grade	Medium	M1	Lime Stone	2.359	2.33
25	17	1	B413575	Superpave	Medium	M2	Lime Stone	2.362	2.344

Sl. No.	Trial No.	Sample Number	JMF	Mix Type	Compaction	Gradation	Aggregate Type	AASHTO BSG	Corelok BSG
26	19	2	B413499	Superpave	Medium	M3	Lime Stone	2.36	2.35
27	17	2	B413575	Superpave	Medium	M2	Lime Stone	2.352	2.341
28	19	1	B413499	Superpave	Medium	M3	Lime Stone	2.336	2.321
29	15	1	B444584	Superpave	Medium	M1	Lime Stone	2.398	2.369
30	15	2	B444584	Superpave	Medium	M1	Lime Stone	2.406	2.39
31	34	2	B322083	302	Medium	M1	Slag	2.354	2.308
32	34	1	B322083	302	Medium	M1	Slag	2.359	2.303
33	14	1	B444584	Superpave	Medium	M1	Slag	2.282	2.189
34	14	2	B444584	Superpave	Medium	M1	Slag	2.272	2.186
35	16	1	B413575	Superpave	Medium	M2	Slag	2.289	2.27
36	16	2	B413575	Superpave	Medium	M2	Slag	2.275	2.257
37	18	1	B412359	Superpave	Medium	M3	Slag	2.234	2.195
38	18	2	B412359	Superpave	Medium	M3	Slag	2.227	2.192

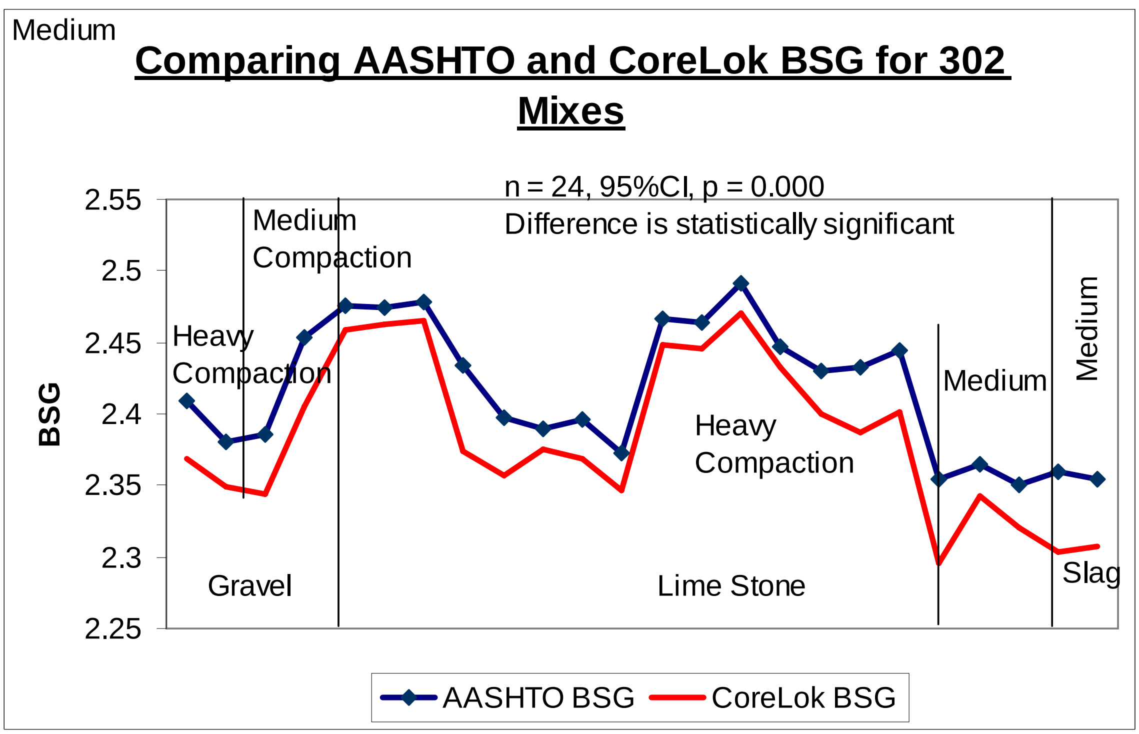
Appendix B
Effect of Experimental Variables on Bulk Specific Gravity Values between CoreLok and ASSHTO Procedures


Comparing AASHTO BSG and CoreLok BSG for Dense Graded Mixes
BSG
2.45
2.4
2.35
2.3
2.25
2.2
Heavy Compaction
Medium Compaction
Heavy Compaction
Medium Compaction
n = 39, 95%CI, p = 0.000
Difference is statistically significant
Gravel
Lime Stone
ASTM BSG
CORELOK BSG

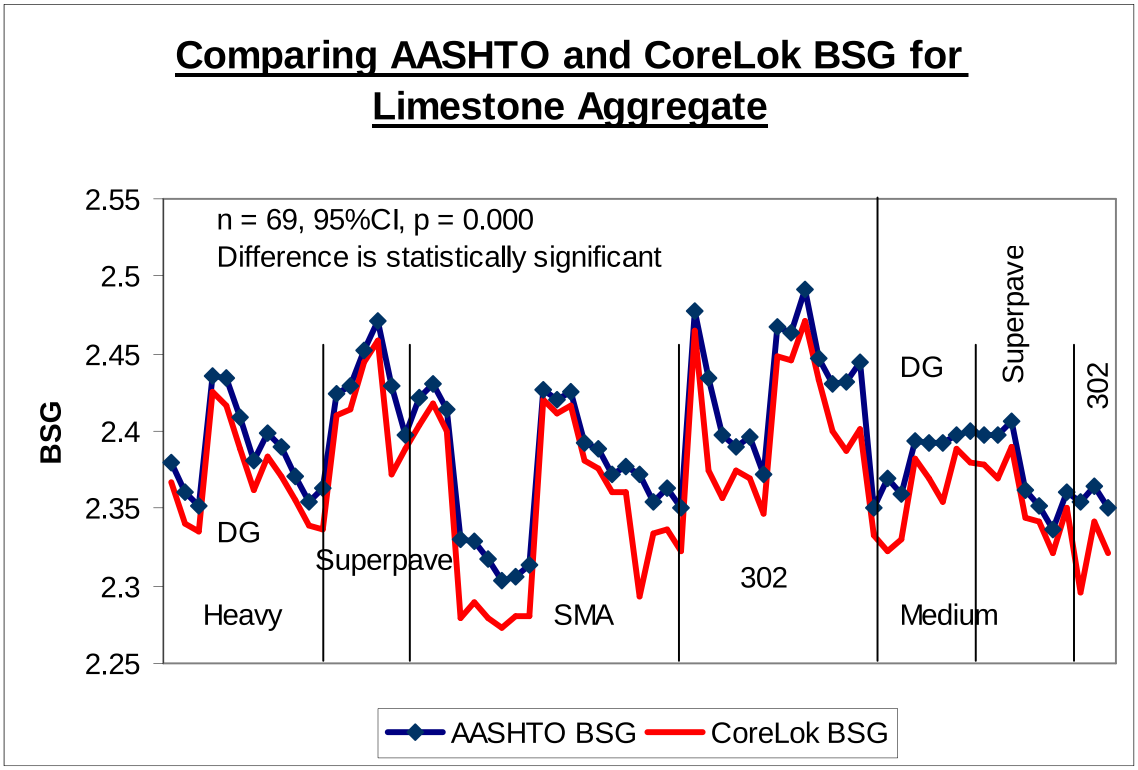

Comparing AASHTO BSG and CoreLok BSG for Superpave Mixes
BSG
2.5
2.45
2.4
2.35
2.3
2.25
2.2
2.15
2.1
Medium Compaction
Heavy Compaction
Heavy Compaction
Medium Compaction
n = 22, 95%CI, p = 0.000
Difference is statistically significant
Lime Stone
Slag
ASTM BSG
CoreLok BSG



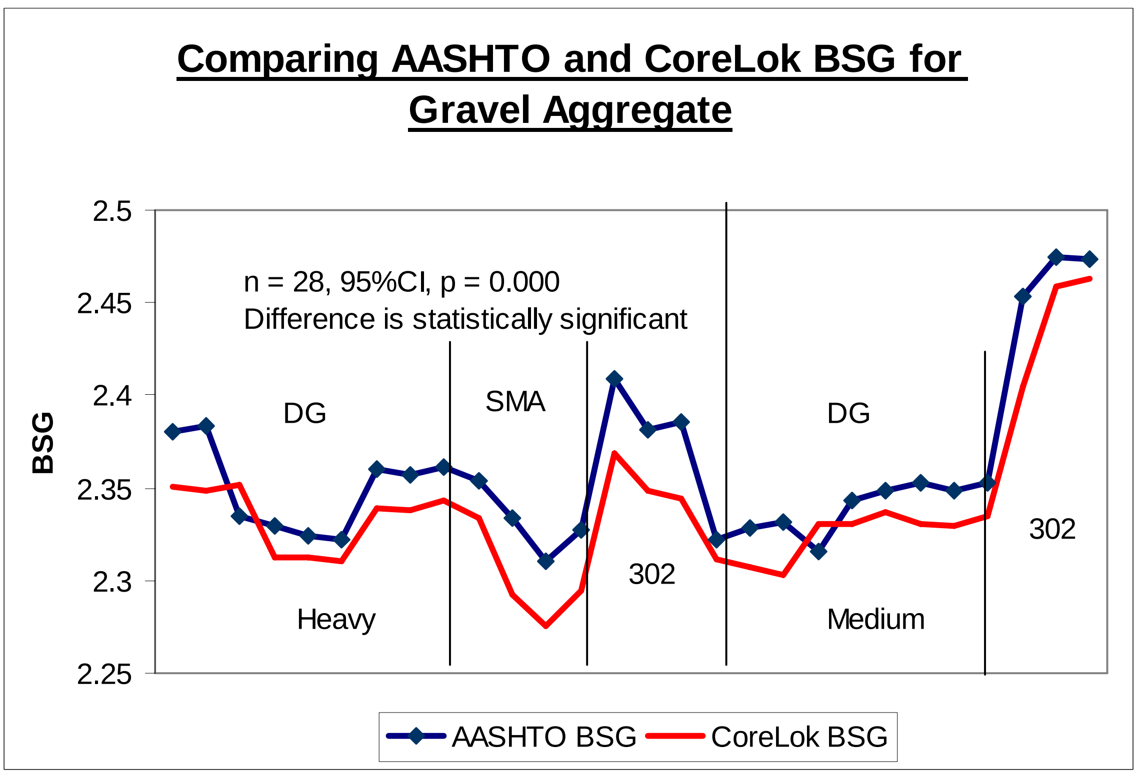
Comparing AASHTO and CoreLok BSG for SMA Mixes
n = 24, 95%CI, p = 0.000
Difference is statistically significant
BSG
2.45
2.43
2.41
2.39
2.37
2.35
2.33
2.31
2.29
2.27
2.25
Heavy Compaction
Medium Compaction
Gravel
Lime Stone
AASHTO BSG
CoreLok BSG



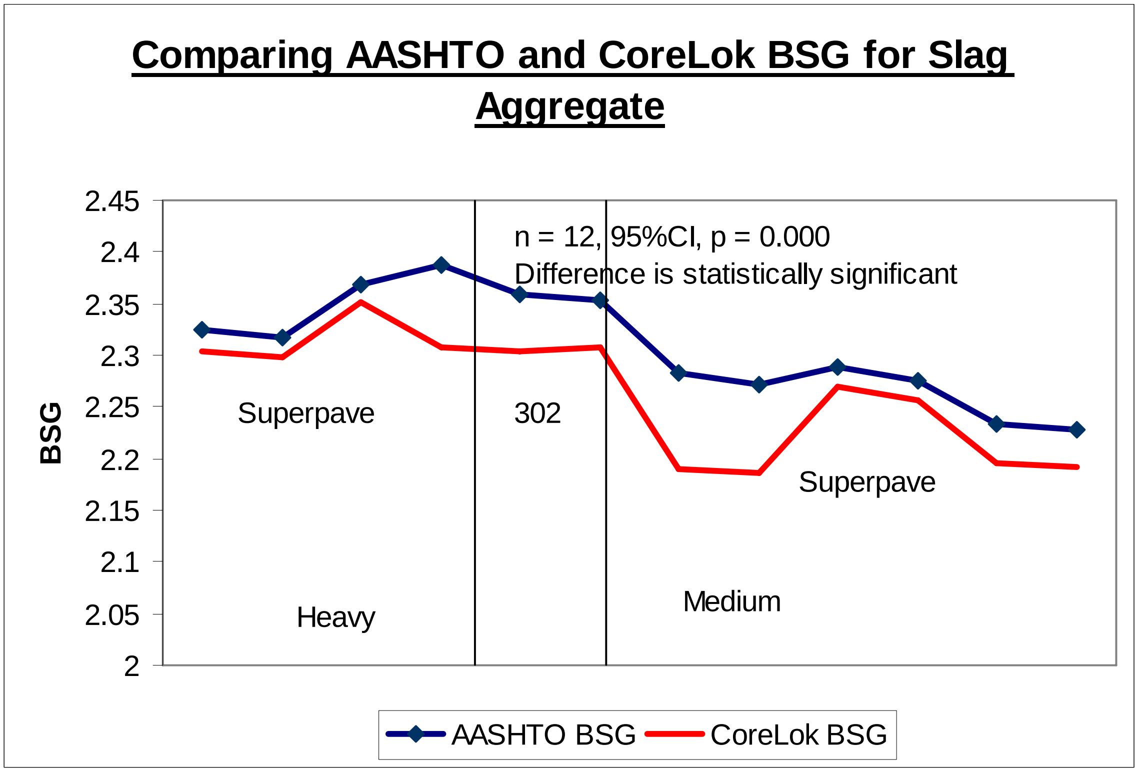
Medium
Comparing AASHTO and CoreLok BSG for 302 Mixes
n = 24, 95%CI, p = 0.000
Difference is statistically significant
BSG
2.55
2.5
2.45
2.4
2.35
2.3
2.25
Medium Compaction
Heavy Compaction
Heavy Compaction
Medium
Medium
Gravel
Lime Stone
Slag
AASHTO BSG
CoreLok BSG

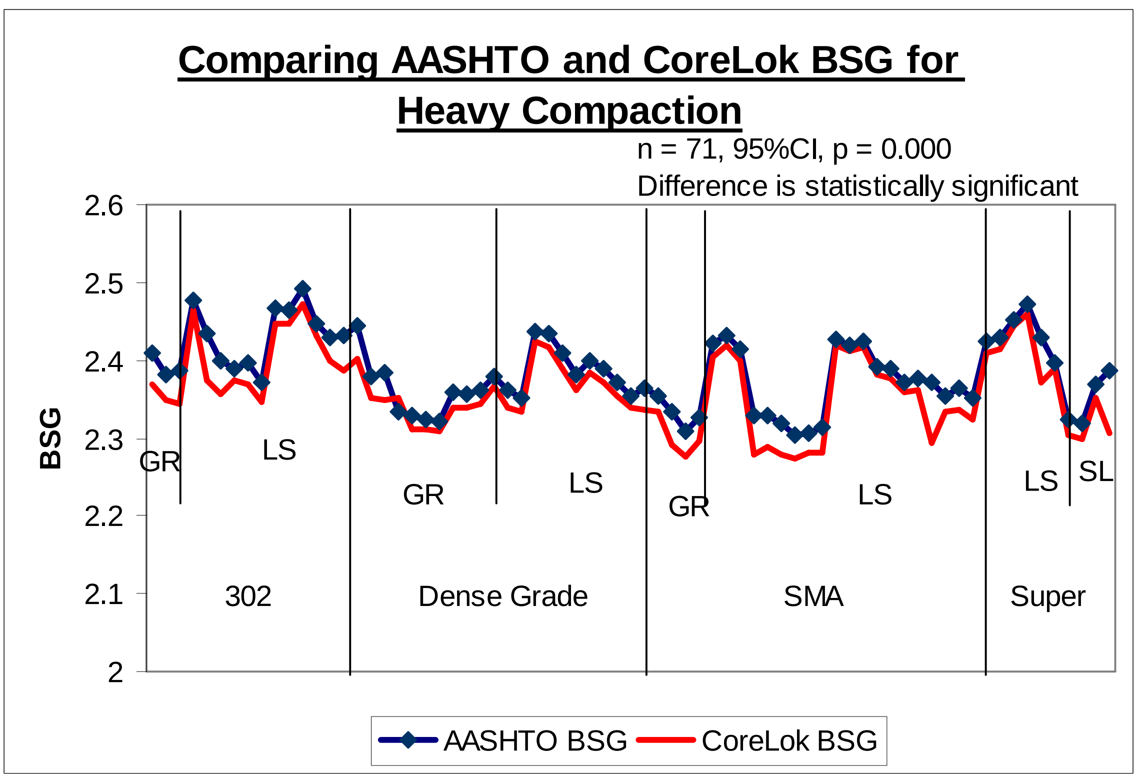


Comparing AASHTO and CoreLok BSG for Limestone Aggregate
n = 69, 95%CI, p = 0.000
Difference is statistically significant
BSG
2.55
2.5
2.45
2.4
2.35
2.3
2.25
DG
Heavy
Superpave
SMA
302
DG
Superpave
302
Medium
AASHTO BSG
CoreLok BSG



Comparing AASHTO and CoreLok BSG for Gravel Aggregate
n = 28, 95%CI, p = 0.000
Difference is statistically significant
BSG
2.5
2.45
2.4
2.35
2.3
2.25
DG
Heavy
SMA
302
DG
Medium
302
AASHTO BSG
CoreLok BSG


Comparing AASHTO and CoreLok BSG for Slag Aggregate
n = 12, 95%CI, p = 0.000
Difference is statistically significant
2.45
2.4
2.35
2.3
2.25
2.2
2.15
2.1
2.05
2
BSG
Superpave
302
Superpave
Heavy
Medium
AASHTO BSG
CoreLok BSG


Comparing AASHTO and CoreLok BSG for Heavy Compaction
n = 71, 95%CI, p = 0.000
Difference is statistically significant
2.6
2.5
2.4
2.3
2.2
2.1
2
BSG
GR
LS
GR
LS
GR
LS
LS
SL
302
Dense Grade
SMA
Super
AASHTO BSG
CoreLok BSG

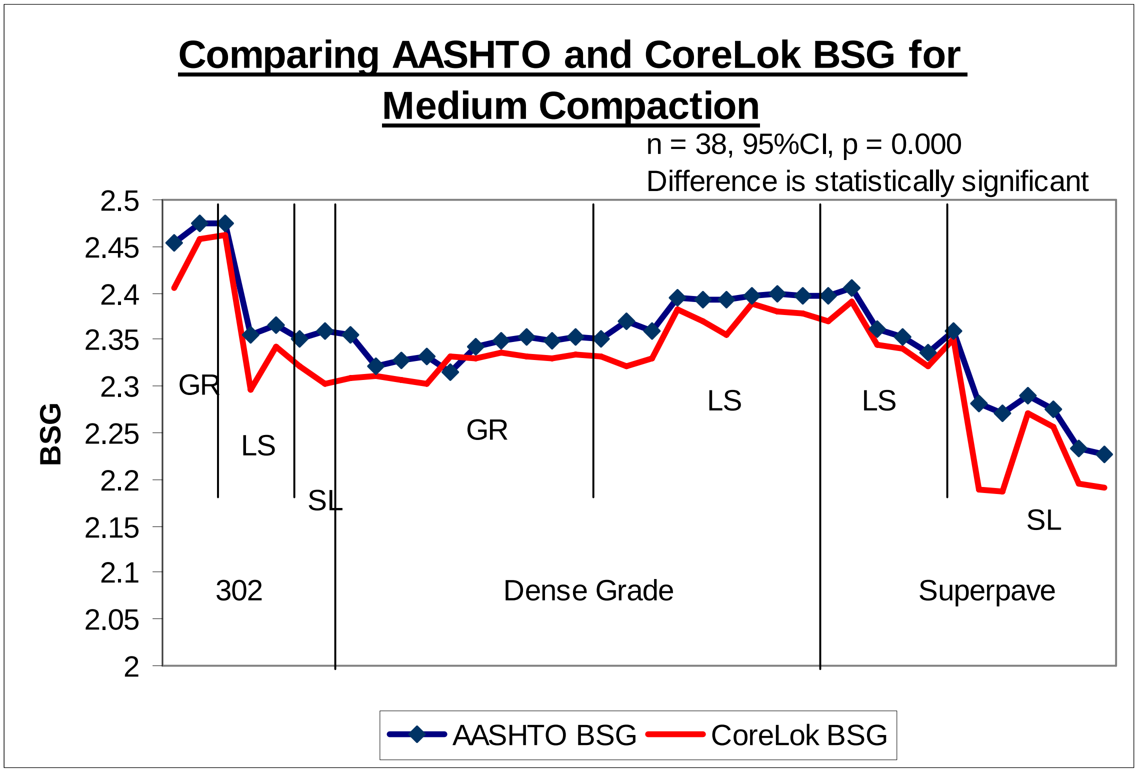

Comparing AASHTO and CoreLok BSG for Medium Compaction
n = 38, 95%CI, p = 0.000
Difference is statistically significant
BSG
2.5
2.45
2.4
2.35
2.3
2.25
2.2
2.15
2.1
2.05
2
GR
LS
SL
GR
LS
LS
SL
302
Dense Grade
Superpave
AASHTO BSG
CoreLok BSG

Figure C1. Evaluation of Corelok device - Experimental Plan for Dense Graded Mixes

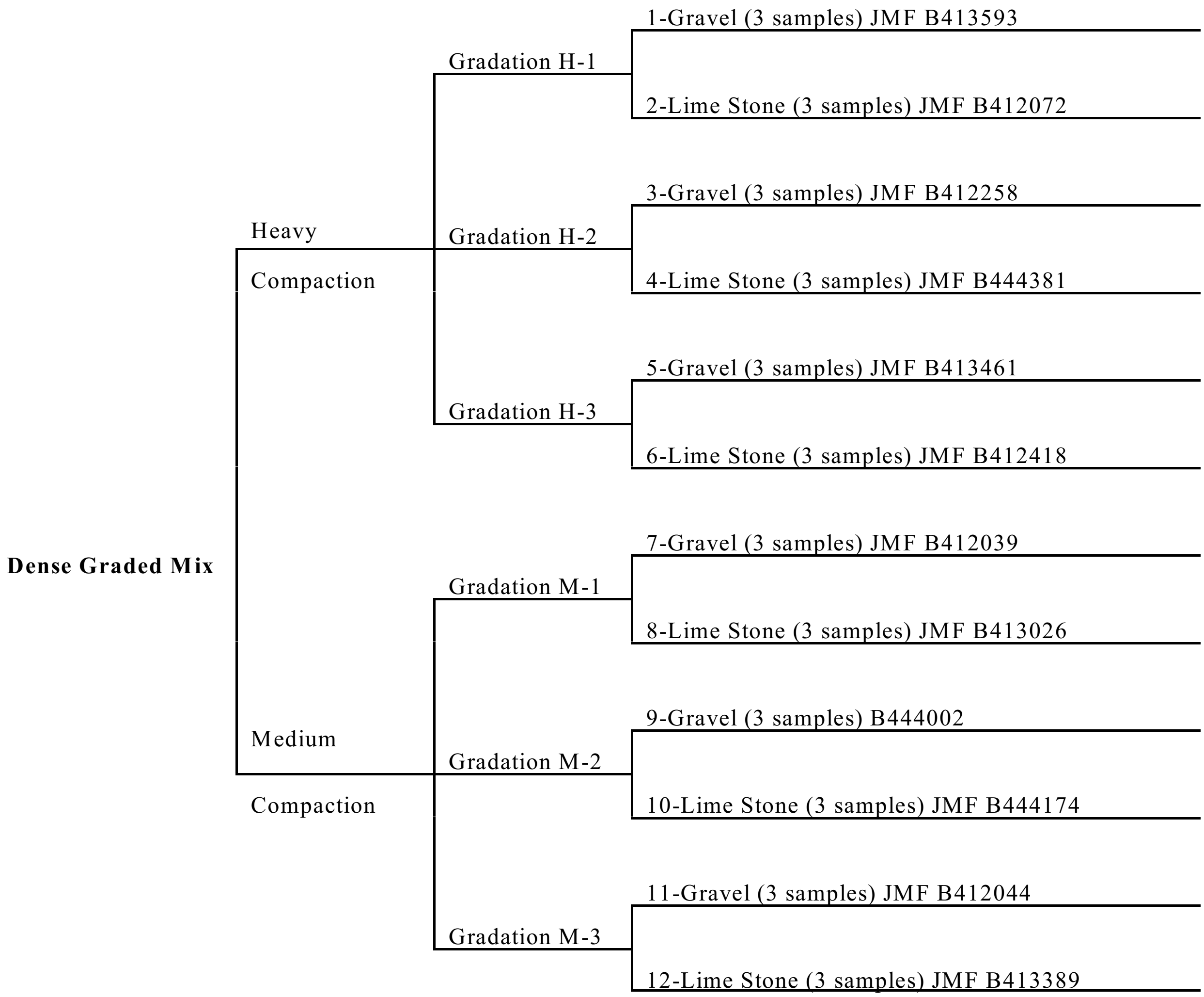


Figure C2. Evaluation of Corelok device - Experimental Plan for Superpave Mixes

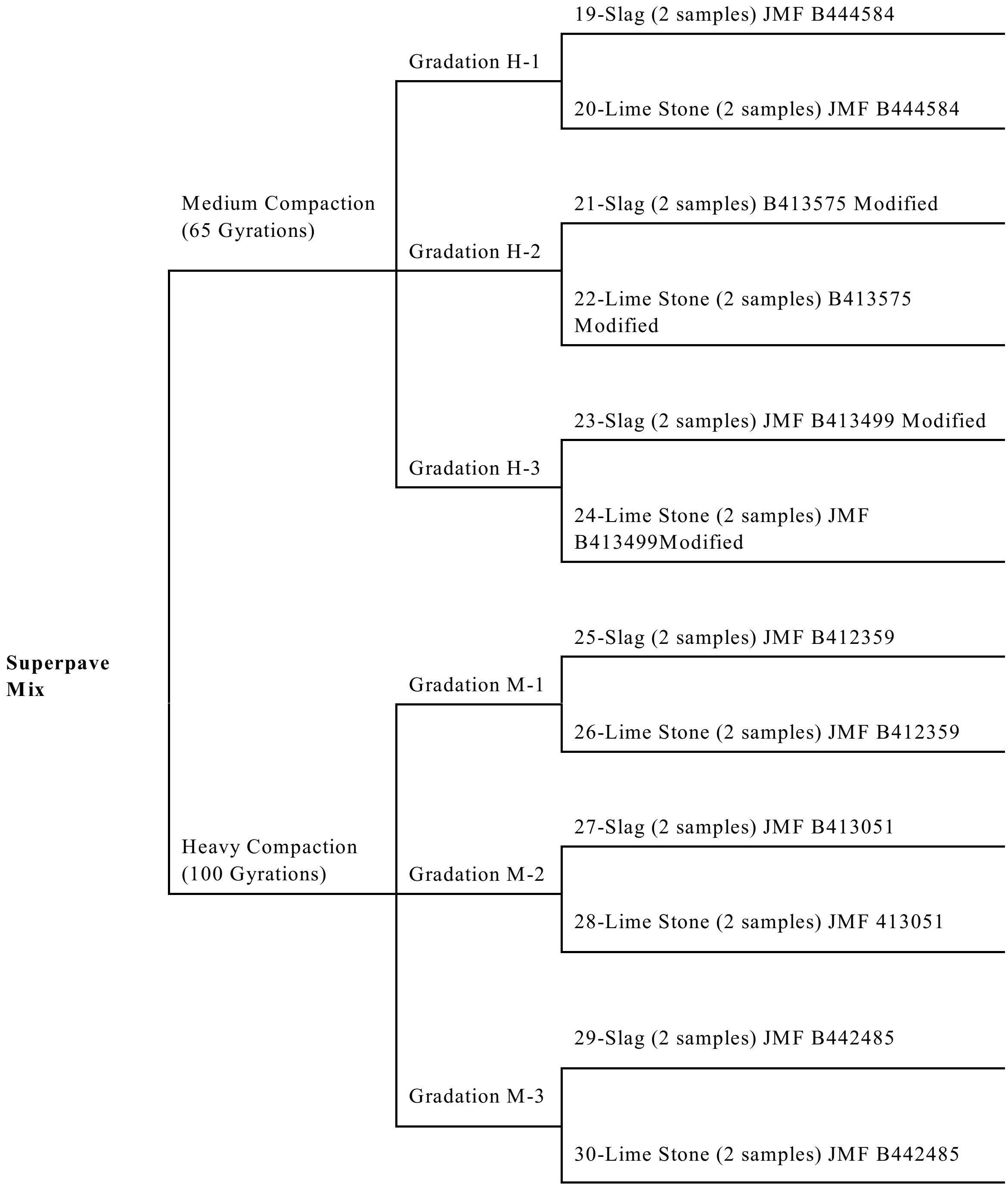


Figure C3. Evaluation of Corelok device - Experimental Plan for Stone Mix Asphalt Mixes

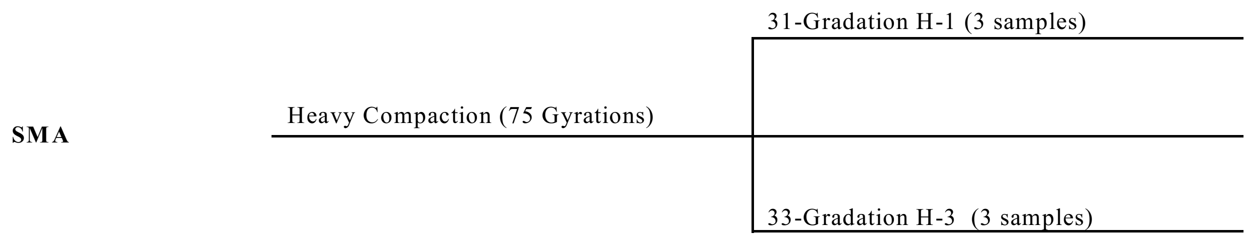


Figure C4. Evaluation of Corelok device - Experimental Plan for 302 Mixes