IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

Development of a Correlation between CoreLok® and AASHTO T 85 Tests for Specific Gravity of Coarse Aggregates used in Idaho

RP 286

By

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University of Idaho

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16. Abstract

Specific gravity and absorption values of coarse aggregates are typically measured in accordance with the AASHTO T 85 standard. The test requires considerable experience to recognize the stage when a soaked sample reaches the saturated surface dry (SSD) condition upon drying. The CoreLok device offers an alternative approach which can be completed in less than 45 minutes compared to the 24 hours required by the AASHTO procedure. This study investigated the results from AASHTO T 85 and CoreLok testing of coarse aggregates to develop a correlation between bulk (dry) specific gravity (G_{sb}) values measured using the two test procedures. Blended samples, consisting of coarse and fine aggregates, were also tested to evaluate the use of the CoreLok method to reliably determine G_{sb} values. After testing 15 coarse aggregates and 17 blended aggregates, this study developed three equations that may be used to modify the CoreLok G_{sb} results to more closely reflect G_{sb} values based on AASHTO T 85 tests. The recommended equation uses the CoreLok G_{sb} and the fine aggregate percentage to predict the equivalent AASHTO T 85 G_{sb} with an $R^2 = 0.967$. Furthermore, five reclaimed asphalt pavement (RAP) materials were also tested to see if the G_{sb} of the uncoated aggregate could be determined using the CoreLok method. Preliminary results indicate that the CoreLok G_{sb} results can be reliably calculated if the effective and absorbed binder content is known, or presumed, based on experience.

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Technical Advisory Committee

Each research project is overseen by a Technical Advisory Committee (TAC), which is led by an ITD project sponsor and project manager. The TAC is responsible for monitoring project progress, reviewing deliverables, ensuring that study objectives are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

AASHTO .... American Association of State Highway and Transportation Officials

Abs .... Absorption

cAbs .... Corrected Absorption from a CoreLok test

cG_{sa} .... Corrected Apparent Specific Gravity from a CoreLok test

cG_{sb} .... Corrected Bulk (Dry) Specific Gravity from a CoreLok test

cm .... Centimeters

DOT .... Department of Transportation

FHWA .... Federal Highway Agency

ITD.............................. Idaho Transportation Department

G_{mm} .... Maximum Specific Gravity of mix

G_{sa} .... Apparent Specific Gravity

G_{sb} .... Bulk (Dry) Specific Gravity

$G_{sb,RAP}$ .... Corrected Bulk (Dry) Specific Gravity of aggregate in RAP

G_{sb} *SSD*......................... Bulk Saturated Surface Dry (SSD) Specific Gravity

$G_{se,RAP}$ .... Effective Corrected Bulk (Dry) Specific Gravity of RAP material

HMA .... Hot Mix Asphalt

mm .... Millimeters

P_b .... Binder content in percent

P_{ba} .... Absorbed binder content in percent

P_e .... Effective binder content in percent

RAP .... Recycled Asphalt Pavement

uAbs .... Uncorrected Absorption from a CoreLok test

uG_{mm} .... Maximum Specific Gravity of RAP mix from a CoreLok test

uG_{sa} .... Uncorrected Apparent Specific Gravity from a CoreLok test

uG_{sb} .... Uncorrected Corrected Bulk (Dry) Specific Gravity from a CoreLok test

Executive Summary

Introduction

The design of asphalt mixtures requires information about the bulk (dry) specific gravity (G_{sb}) and Absorption (*Abs*) characteristics of coarse and fine aggregates. The adoption of realistic values for design will have a direct impact on cost, durability and compactibility as well as current ITD pay factors.

This data is often determined using the American Association of State Highway Transportation Officials (AASHTO) T 84 and T 85 test procedures, which usually take about 24 hours to complete. Both test procedures rely on the experience of the operator to recognize the critical saturated surface dry (SSD) condition. In an attempt to overcome some of the operator-dependent errors associated with the AASHTO test procedures, an alternative method which uses the CoreLok device was developed about twenty years ago. This method is quick, reliable, portable, and provides consistent, repeatable results for coarse and fine aggregates when the technician is properly trained in this method. The CoreLok device consistently overestimates the bulk (dry) specific gravity, G_{sb}, in comparison to the results from AASHTO tests; thus, there is a need to correlate the G_{sb} values determined using the AASHTO and CoreLok test procedures.

Fine aggregates were studied in a previous research project (RP252) by Sharma et al. (2020), which recommended a correction to align the CoreLok results with AASHTO T 84 values more closely. This study focused primarily on coarse aggregates, but also tested blended aggregates consisting of a mixture of coarse and fine materials.

Project Objectives and Tasks

The objective of this study is to develop a single or multiple correlations which may be used to correct the bulk (dry) specific gravity (G_{sb}) results from CoreLok testing of coarse aggregates to align with AASHTO T 85 values more closely. Also, the researchers evaluated the CoreLok test procedures thoroughly and provided recommendations of methods suitable for adoption by ITD for the determination of specific gravities of coarse aggregates using the CoreLok device. To achieve this objective, 15 aggregates that are typically used for highway construction were tested at the University of Idaho (UI Lab) using the AASHTO T 85 and CoreLok test procedures. A statistical analysis of the test results provided information on potential correlation between the CoreLok and AASHTO T 85 results.

Blended aggregates, consisting of coarse and fine aggregate components, were also tested using the CoreLok device. The results were used to develop appropriate correction equations to predict G_{sb} values which agree with calculated values. This would allow testing blended aggregates without having to separate them into the coarse and fine fractions.

Key Findings

Data collected from AASHTO T 85 and CoreLok test procedures were compiled into their respective categories: (1) coarse only, and (2) blends consisting of a mixture of coarse and fine aggregates. The G_{sa} and G_{sb} values from the AASHTO T 85 and CoreLok tests were averaged for each sample and these averages were statistically analyzed for possible correlations for correcting the CoreLok results. The main conclusions are given below.

1. In all cases, the CoreLok test procedure overestimated the values of $G_{sb,}$ and underestimated the absorption values compared to the AASHTO T 85 results. The G_{sa} results from both tests were very similar.
2. The paired t-tests indicated a statistically significant difference in the mean values of the absorption (*Abs*) and bulk (dry) specific gravity (G_{sb}) results based on the AASHTO T 85 and the CoreLok test procedures. Values of the apparent specific gravity, G_{sa}, were found to be the "same" at the 95 percent significance level.
3. For typical Idaho coarse aggregates and the blended aggregates tested in this study, the best regression models for predicting the bulk specific gravity, cG_{sb}, are shown below. These models use the uncorrected bulk (dry) specific gravity (uG_{sb}) from the CoreLok device and percent fine aggregate (P_F) in the blend.

   Coarse Aggregate Only

   $$cG_{sb} = -8.657 + 7.299 \times uG_{sb} - 1.147 \times {uG_{sb}}^2$$

   $R^2 = 0.9696$

   Blended Aggregate

   $$cG_{sb} = -14.08 + 11.40 \times uG_{sb} - 1.925 \times {uG_{sb}}^2 - 0.000260 \times P_F$$

   $R^2 = 0.9720$

4. By using the data collected for fine aggregates from RP252 (Sharma et al., 2020) and the coarse and blended aggregate data from this study, an additional regression model was determined as shown below. This model uses the uncorrected bulk (dry) specific gravity (uG_{sb}) from the CoreLok device and percent fine aggregate (P_F) in the blend.

   All Coarse, Blended, and Fine Aggregate Data (Comprehensive Model)

   $$cG_{sb} = -12.94 \times uG_{sb} + 10.58 \times uG_{sb} - 1.776 \times {uG_{sb}}^2 - 0.000219 \times P_F$$

   $R^2 = 0.9670$

5. The corrected absorption (*cAbs*) for an aggregate may be calculated using the apparent and bulk (dry) specific gravity values from CoreLok test procedure (cG_{sa} and cG_{sb}) using the equation shown below.

   $$cAbs\ (\%) = \left(\frac{1}{cG_{sb}} - \frac{1}{cG_{sa}}\right) \times 100$$

6. The CoreLok maximum specific gravity, uG_{mm}, of RAP material is statistically equivalent to the maximum specific gravity, G_{mm}, determined from the Rice test (AASHTO T 209).

Recommendations

Based on the testing of aggregates,

- There is no statistical difference between the apparent specific gravity value (cG_{sa} or uG_{sa}) from the CoreLok test procedure and the value determined using to the AASHTO T 85 test.
- It is recommended that for coarse aggregates tested using the CoreLok test procedure outlined in Chapter 4, the uG_{sb} values be corrected using the equation shown below.

$$cG_{sb} = -8.657 + 7.299 \times uG_{sb} - 1.147 \times uG_{sb}{}^{2}$$

- For a blend of coarse and fine aggregate, it is recommended that the uG_{sb} value from the CoreLok device be corrected using the equation shown below.

$$cG_{sb} = -12.94 \times uG_{sb} + 10.58 \times uG_{sb} - 1.776 \times uG_{sb}{}^{2} - 0.000219 \times P_F$$

- With the cG_{sa} and the corrected value cG_{sb} determined, the absorption may be calculated using the equation shown below.

$$cAbs\ (\%) = \left(\frac{1}{cG_{sb}} - \frac{1}{cG_{sa}}\right) \times 100$$

1. Introduction and Background

Overview and Problem Statement

The American Association of State and Highway Transportation Officials (AASHTO) T 85 test procedure: "Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate" is used to determine the specific gravities of coarse aggregates. This test procedure requires approximately 24-hours to complete. Operator judgement and experience are required to recognize the saturated surface dry (SSD) condition. The SSD condition is reached when no free water remains on the surface of the particles. The volume of the aggregate, at the SSD condition, is determined using a water bath. The weight of the wet aggregate at the SSD condition and the weight of the dried aggregate is used to determine the absorption value.

Many factors influence achieving the SSD condition, including the type of towel or cloth used to dry the particles, the moisture content in the type of towel or cloth used to dry the particles, and the experience of the operator. In addition, when multiple consecutive measurements are performed on different samples, if the same towel or cloth are used to dry the particles, each subsequent sample will have a slightly different SSD condition.

Instrotek developed a test procedure which uses a vacuum chamber (CoreLok device) and volumeter to shorten the testing period to less than 45 minutes. This method creates a vacuum in a plastic bag containing the test aggregates, which is then opened under water to quickly soak the particles and determine their volume. The volumeter is used to determine the volume of the "unsoaked" aggregate and the surface accessible voids. As there is no subjectivity inherent in the CoreLok test procedure, most sources of operator error are eliminated, thus reducing variability between operators. However, these studies have found that the results produced by the CoreLok test procedure do not directly equate to the AASHTO T 85 results; thus, an adjustment equation is needed if the CoreLok is to be used in-place of the AASHTO T 85 test procedure.

The research conducted in this study tested 15 unique coarse aggregate samples collected from different districts in Idaho using the AASHTO T 85 and CoreLok test procedures. The test results were used to develop a correlation between the AASHTO T 85 and CoreLok test procedures. One can predict the specific gravities values based on the AASHTO T 85 test procedure by conducting the test using the CoreLok procedure. In addition, this study also investigated the case of testing aggregate blends, containing both coarse and fine aggregates, using the CoreLok procedure. The current practice is to use two separate methods: AASHTO T 85 and AASHTO T 84 for measuring the specific gravities of coarse and fine aggregates, respectively.

Objectives of the Study

The objective of this research is to examine the correlation between the specific gravity of coarse aggregate calculated using the AASHTO T 85 test procedure and the values calculated using the CoreLok device. This study developed a regression model for predicting specific gravity based on the AASHTO T 85 test procedure using the CoreLok device. As the CoreLok test procedure does not require a sample at the saturated surface dry (SSD) condition, it eliminates the subjectivity regarding the determination of SSD condition required by the AASHTO T 85 procedure. In addition, this study evaluated and developed similar regression models for the aggregate blends instead of measuring the specific gravity of coarse and fine aggregates separately. Such a regression equation will allow the transportation agencies in Idaho to use the "non-subjective" CoreLok test procedure to determine the specific gravities, effectively bypassing the care and experience required to correctly identify the SSD condition I the AASHTO T 85 test.

Research Tasks

To achieve the objectives of this research study the following tasks were conducted.

Task 1: Review of Published Literature

The researchers conducted a literature review that covers the significance of the absorption and specific gravity parameters in relation to mix design, volumetrics, and physical characteristics of the material. The researchers reviewed the standard test methods used for measuring the specific gravity of coarse and fine aggregates and documented the findings of previous research studies on the correlation between AASHTO test procedures and the CoreLok device.

Task 2: Identify and Collect Different Aggregates Across the State of Idaho

Under this task, the researchers identified and selected several aggregate types and sources distributed across Idaho. These aggregates have unique values of specific gravity and absorption. In addition, the researchers created different blends consisting of coarse and fine aggregate (combinations of aggregates) for testing under Task 4.

Task 3: Conduct Round-Robin Testing

Under this task, the researchers distributed samples to laboratories in Idaho and the surrounding region to gather test data for the AASHTO T 85 and CoreLok test procedures. This data was used to confirm that the values produced in the University of Idaho research laboratory were within tolerance of values produced locally.

Task 4: Conduct AASHTO T 85 and CoreLok Testing

The researchers tested 47 CoreLok samples and 55 AASHTO T 85 samples. An additionally 37 blended samples were tested using the CoreLok device. These samples were comprised of 15 aggregates gathered from across Idaho. Data points were averaged for each aggregate and blend samples for analysis under Task 5.

Task 5: Perform Statistical Analysis on Test Data

Under this task, the data from each test was grouped into the category of coarse aggregate, aggregate blend, and RAP material to be analyzed using statical software. Correlations between variables were identified and regression models were built so that the CoreLok values could be modeled to equate the AASHTO T 85 test results.

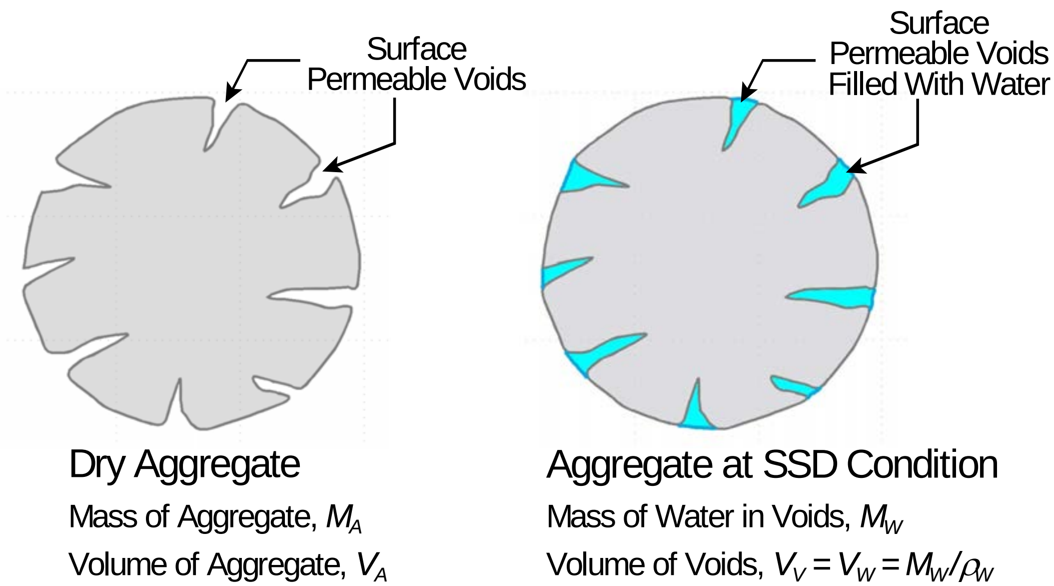

Figure 1.1 Definition of Mass and Volumes for an Aggregate Particle at the SSD Condition

Definition of Aggregate Specific Gravities

Specific gravity is defined as the ratio of mass of a volume of aggregate to the equivalent volume of water at a specific temperature. Figure 1.1 shows the masses and volumes for a unit aggregate particle that may be determined from an AASHTO T 85 test. By considering the volume of water permeable voids in the aggregate, three different specific gravities are defined in practice (Richardson and Lusher, 2005). If the masses and volumes are measured in grams and cubic centimeters, respectively, the following equations may be used to calculate the specific gravities.

Apparent Specific Gravity

$$G_{sa} = \frac{M_A}{V_A} \tag{1.1}$$

Apparent Specific Gravity (G_{sa}) is defined as the ratio of mass (M_A) to volume (V_A) of an aggregate particle. The volume considered here is the volume of the aggregate, including the impermeable voids and excluding voids permeable to water. This value is the highest of all the specific gravities because it only considers the volume of aggregate particle.

In this study, the term G_{sa} represents the apparent specific gravity, as determined by the AASHTO T 85 test. The term uG_{sa} is the "uncorrected" apparent specific gravity determined with the CoreLok device. The term cG_{sa} represents the "corrected" value of the apparent specific gravity. As a correction for this case was considered unnecessary, the corrected and uncorrected values are the same. The term "G_{sa}" is also used to describe apparent specific gravity in the generic sense.

Bulk (Dry) Specific Gravity

$$G_{sb} = \frac{M_A}{V_T} \tag{1.2}$$

Bulk Dry Specific Gravity (G_{sb}) is defined as the ratio of the mass of aggregate (M_A) to the total volume consisting of the aggregate plus the volume of the surface permeable voids, i.e., $V_T = V_A + V_V$. This value is smaller than the apparent specific gravity, G_{sa}, because the total volume includes the volume of the water permeable voids.

In this study, the term G_{sb} represents the bulk (dry) specific gravity, as determined by the AASHTO T 85 test. The term uG_{sb} is the "uncorrected" bulk (dry) specific gravity determined directly with the CoreLok device. The term cG_{sb} represents the "corrected" value of the bulk (dry) specific gravity and will be the value reported from CoreLok testing. The term "G_{sb}" is also used to describe bulk (dry) specific gravity in the generic sense.

Bulk Saturated Surface Dry Specific Gravity

$$G_{sb}, SSD = \frac{M_T}{V_T} \tag{1.3}$$

Bulk Saturated Surface Dry Specific Gravity (G_{sbSSD}) is defined as the ratio of the total mass (M_T) of an aggregate particle at the SSD condition, to the total volume (V_T). The total mass of the aggregate includes the mass of the aggregate and the water in the surface permeable voids, i.e., $M_T = M_A + M_W$. The value of G_{sb} *SSD* lies between the G_{sb} and G_{sa} values.

Definition of Absorption

$$Abs\ (\%) = \frac{M_W}{M_A} \times 100 \tag{1.4}$$

Absorption is defined as the percent increase of mass of the aggregate due to water in the water permeable voids at the SSD condition. This is the same as the gravimetric water content in percent at the SSD condition.

In this study, the term *Abs* represents the absorption, as determined by the AASHTO T 85 test procedure. The term *uAbs* is the "uncorrected" absorption determined directly with the CoreLok test procedure using uG_{sa} and uG_{sb}. The term *cAbs* represents the "corrected" value of the absorption based on cG_{sa} and cG_{sb} and will be the value reported from CoreLok testing. The term *Abs* may also be used in the generic sense to describe absorption.

Additional relationships between these four variables, G_{sa}, G_{sb}, G_{sb} *SSD*, and *Abs*, may be derived, as shown in the equations presented below.

Bulk SSD Specific Gravity,

$$G_{sb}, SSD = \left(1 + \frac{Abs}{100\%}\right) \times G_{sb} \tag{1.5}$$

Apparent Specific Gravity,

$$G_{sa} = \frac{G_{sb}}{\left(1 - \frac{Abs}{100\%} \times G_{sb}\right)} \tag{1.6}$$

Absorption,

$$Abs\ (\%) = \left(\frac{1}{G_{sb}} - \frac{1}{G_{sa}}\right) \times 100 \tag{1.7}$$

The two methods for determining the Specific Gravity and Absorption properties of coarse aggregates used in this analysis are: (1) AASHTO T 85 test, and (2) CoreLok device. Both methods require the accurate measurement of the volume of aggregate and the amount of water that may be absorbed by the dry aggregate.

Organization of the Report

This report consists of seven chapters and an Appendix.

Chapter 1 provides an overview, objective, research tasks, and report organization. It also includes the definitions for specific gravities, absorption, and binder content.

Chapter 2 presents a literature review with information from state DOTs and university research projects concerning the determination of specific gravities of coarse aggregates.

Chapter 3 details the sampling procedures used in the preparation stage of testing. These methods ensure that replicate samples share the same conditions. The test materials included coarse aggregates, fine aggregates, aggregate blends, and asphalt mixtures that simulate RAP material.

Chapter 4 discusses the test procedures used for coarse and blended samples. The AASHTO T 85 and CoreLok test procedures are detailed along with graphics to assist the reader in understanding the methods. A discussion of the round robin tests on coarse aggregates performed as part of this project are also discussed in detail.

Chapter 5 discusses the results from the CoreLok and AASHTO T 85 test procedures. Round robin results are presented and compared and analyzed. The testing results of coarse aggregate, aggregate blends, and RAP materials are presented.

Chapter 6 presents the statistical analysis methods used to develop correlations between the CoreLok and AASHTO T 85 results. Several regression models are presented in this chapter to estimate AASHTO T 85 values using the CoreLok results. Regression models are proposed for coarse aggregates as well as aggregate blends.

Chapter 7 provides a summary of the research, along with conclusions based on the collected data and analysis. Finally, recommendations are made for implementing the regression models to bring the CoreLok results closer to the AASHTO T 85 values.

Appendix A includes information about preparing a HMA mix that was aged for three days, and then tested using the CoreLok test procedure to find the maximum specific gravity (uG_{mm}) of the RAP. This value was then used to estimate the effective specific gravity (G_{se}) and the bulk (dry) specific gravity (G_{sb}) of the virgin, uncoated aggregate in the RAP mix.

Appendix B includes the complete data used for the specific gravity and absorption calculations for all aggregate and RAP samples tested using the AASHTO T 85 and CoreLok test procedures at the University of Idaho.

2. Literature Review

Introduction

Chapter 2 provides a review of the AASHTO T 85 and CoreLok test procedures and information collected from a literature search. The literature review focused on investigating the advantages of the two test methods under consideration and potential correlations that have been proposed for using CoreLok results to predict AASHTO T 85 values. In addition, Chapter 2 includes a review of the literature regarding the determination of specific gravities for asphalt coated particles.

AASHTO T 85 Test Procedure

The current test procedure used by the Idaho Transportation Department (ITD) for determining the specific gravities of coarse aggregates is the American Association of State Highway and Transportation Officials (AASHTO) T 85 procedure: *Specific Gravity of Coarse Aggregate.* These methods use the dry weight of aggregate, the submerged weight, and the SSD weight to determine the specific gravities and absorptions of aggregate.

In this procedure, the operator soaks the aggregate under water for 17 ± 2 hours to achieve a condition where all surface permeable voids are filled with water. After this, the aggregate is quickly drained and the surface moisture is removed, with a dry towel plus a stream of air, if deemed necessary. The Saturated Surfaced Dry (SSD) condition is achieved when the free water on the surface is removed while water remains in the permeable voids. Finally, the aggregate is submerged in a water bath and the submerged weight is measured to determine the volume of the aggregate.

It should be noted that, achieving the SSD condition can be highly subjective, depending on the experience of the operator. As the SSD condition is subjective to assess, the SSD weight of the same aggregate can vary by several grams between different operators. For example, a one-gram variation will lead to a 0.1 percent change in the reported absorption value. This directly affects the subsequent calculations used to determine specific gravity. Additionally, as part of this test procedure the aggregate is washed, dried, sieved, and then submerged for 15 to 19 hours before testing before being dried again. The whole test procedure takes about 24 hours, which is large time commitment for laboratory operators.

The American Society of Testing Materials (ASTM) has similar standards for measuring the specific gravities of coarse and fine aggregates. The test procedure for coarse aggregate, ASTM C127: *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate*, has a slightly longer soaking time (24 ± 4 hours). The test procedure for fine aggregate, ASTM C128: *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate,* has the same soaking time as ASTM C127.

CoreLok Test Procedure for Coarse and Fine Aggregates

The CoreLok test procedure (Instrotek, 2003, and ASTM, 2009) contains two testing elements: (1) a vacuum chamber is used to remove air from a known mass of an aggregate sample in a bag, which is then opened underwater to determine the volume of the aggregate, and (2) a known mass of aggregate is quickly placed in a volumeter to determine the bulk volume.

The vacuum chamber determines the G_{sa} of the aggregate, and the volumeter data is used to calculate the G_{sb}. The G_{sb} *SSD* and *Abs* are then calculated based on the G_{sa} and G_{sb} values. One portion of the sample is inserted into a plastic bag where the vacuum is drawn on the specimen. Once the vacuum is achieved, the sample is submerged, and the vacuum is released. This allows for water to be pulled into the water permeable surface voids. A submerged weight of the sample is then taken. The G_{sa} can be calculated given the submerged weight, dry weight of the test sample, and weight of the rubber bag.

The volumeter has a known weight for water filling the volumeter. Once the aggregate is placed inside, the volume of water displaced provides a measure of the volume of the aggregate. The mass of the aggregate and volume is used to calculate the G_{sb} of the sample.

The CoreLok test procedure can provide similar results to AASHTO T 85 while avoiding the soaking and dry-back procedure. This allows for a more efficient test that can be completed in about 45 minutes, which is considerably less than the 24 hours required for completing the AASHTO T 85 test.

While the results produced by the CoreLok are similar to the values that result from the AASHTO T 85 procedure, they are not exactly the same. The G_{sb} values are overestimated by the CoreLok device which results in calculating absorption values that are not representative of the aggregate. This overestimation is likely caused by some water being absorbed into the surface voids during the two-minute volumeter test, which results in a lower estimation of the total volume of the aggregate. Cross and Mgonella (2005) also reported that the G_{sb} values were consistently overestimated by the CoreLok device.

In comparing the differences in absorption values from the CoreLok device and AASHTO testing, Cross and Mgonella (2005) found that the fine aggregates differences were greater than the differences noted for coarse aggregates. Additionally, they found that the G_{sa} determined by AASHTO T 85 and T 84 test methods were statistically similar to those determined by the CoreLok device within a 95 percent confidence level.

To correct for the issue in variance of G_{sb} values, Instrotek developed correction factors for the fine aggregate. This correction was based on a regression model of the absorption values produced by both test procedures. The modified absorption was then used with the G_{sa} to calculate a modified G_{sb}. There is currently no test procedure adopted by ITD to adjust readings from the CoreLok test procedure to match the AASHTO T 85 results for coarse aggregates.

Fine Aggregate

Cross and Mgonella (2005) determined through the analysis mentioned above that the CoreLok test procedure involving the regression equation was still unable to produce results comparable to the AASHTO T 84 procedure. Similarly, the CoreLok test procedure for coarse aggregates did not produce replicable results to the AASHTO T 85 within a 95 percent confidence level. The study used 15 fine aggregate samples with specific gravities ranging between 2.393 and 2.780. At the conclusion of this study, it was recommended that the CoreLok test procedure not be used until the completion of further studies.

Another study, conducted by Tran et al. (2015), examined fine aggregates as well as coarse and blended aggregates. Their study involved three different test methods which are presented in Table 2.1.

Table 2.1 Specific Gravity Testing Methods for Fine Aggregates (adapted from Tran et al., 2015)

#	Selected Test Method	Material Used for Evaluation
1.	AASHTO T 84 and ASTM C128	Fine aggregate passing sieve No. 4
2.	Modification to Materials Tested in AASHTO T 84/ASTM C128	Fine aggregate passing sieve No. 4 and retained on sieve No. 200
3.	SSDetect System	Fine aggregate passing sieve No. 4
4.	Modification of Materials Tested in SSDetect System	Fine aggregate passing sieve No. 4 and retained on sieve No. 200
5.	Volumetric Immersion using Phunque Flasks	Fine aggregate passing sieve No. 4

The SSDetect System, listed in Table 2.1, is an electronic device that identifies the SSD condition of a sample using an infrared laser system calibrated to detect loss of moisture on the surface of a small particle by way of reflectance. Figure 2.3 shows the SSDetect measurement system.

Figure 2.1 SSDetect System used to identify the SSD condition of Fine Aggregates (For Construction Pros.com, 2022)

Figure 2.2 shows two sizes of Phunque flasks available to test coarse or fine aggregates (Table 2.1). A Phunque flask is like a volumeter in the sense that it measures the volume of water displaced by the aggregate, allowing the calculation of the G_{sb} value.

Figure 2.2 Phunque Flasks used for Coarse and Fine Aggregate (Humboldt Mfg. Co.)

Tran et al. (2015) examined the effect of the presence of fine materials on specific gravity calculations using the AASHTO T 84 procedure. Tran et al. (2015) concluded that when the presence of materials passing Sieve No. 200 exceeded 10 percent of the entire sample weight, AASHTO T 84 no longer produced accurate results. The accuracy was based on whether the average of the test fell within two standard deviations of other test methods. The SSDetect did produce replicable results for fine samples that both included and excluded material passing Sieve No. 200.

Sharma et al. (2020), developed a regression model for fine aggregates using the AASHTO T 84 method as the base comparison values. The researchers found that the G_{sa} values were statistically similar at the 95 percent confidence level for the t-results obtained with the AASHTO T 84 and CoreLok test procedures. The G_{sb} values were then regressed and an equation involving the CoreLok cG_{sa}, and uncorrected CoreLok uG_{sb} was recommended to calculate cG_{sb} values obtained with the CoreLok device. The regression equation is presented below.

$$\begin{aligned} cG_{sb} &= -5.5937 + 15.9435 \times uG_{sb} - 10.5729 \times cG_{sa} \\ &\quad +3.7309 \times (uG_{sb} \times uG_{sa}) - 4.5893 \times {uG_{sb}}^2 \end{aligned} \tag{2.1}$$

Equation 2.1 was able to predict a value that was similar to the G_{sb} obtained following the AASHTO T 84 procedure with an R^2 of 0.9668. A plot of the regression equation is presented as Figure 2.5.

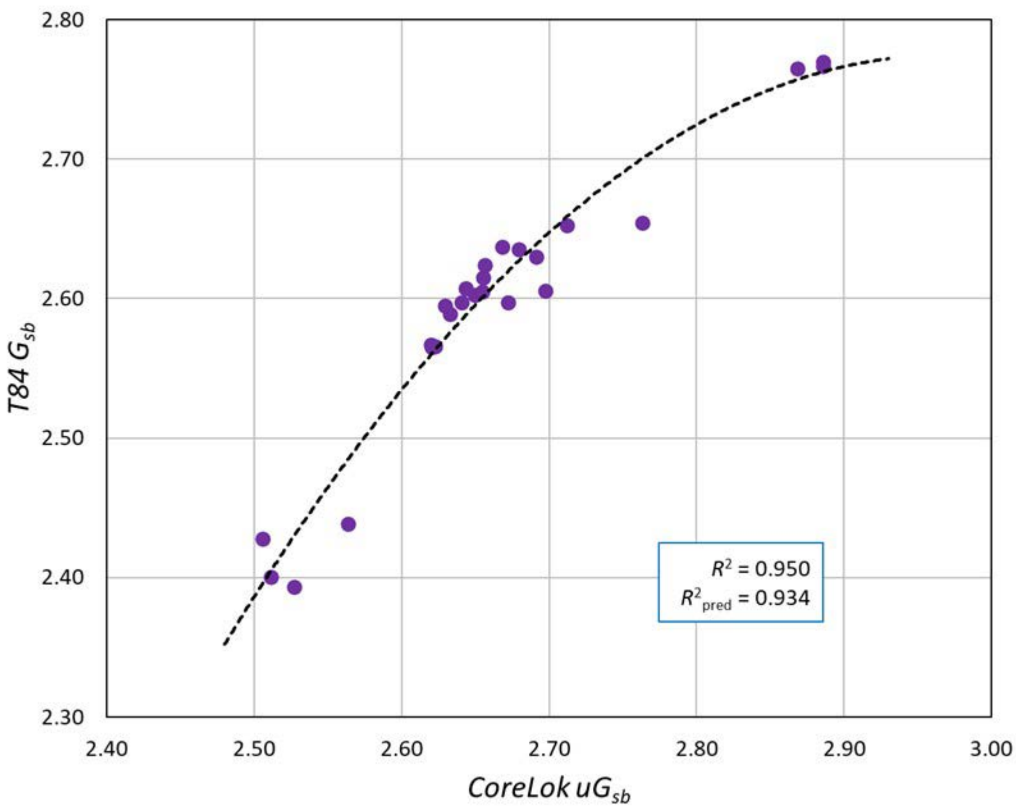

Figure 2.3 Non-linear Regression of G_{sb} from the CoreLok and AASHTO T 84 Test Procedure (Sharma et al., 2020)

Coarse Aggregate

Cross and Mgonella (2005) measured the specific gravity of eight coarse aggregate samples using the CoreLok and AASHTO T 85 test procedures. The testing results from the CoreLok device and AASHTO T 85 showed similar trends to the fine aggregates. The G_{sa} values were statistically similar at the 95 percent confidence level while the G_{sb} values were not. They concluded that the results from the CoreLok device should not be used without modification.

Tran et al. (2015) also studied various specific gravity test methods that were available for coarse aggregates, which are summarized in Table 2.2. Following testing, Cross et al. (2005) and Tran et al. (2015) had opposite findings when comparing the results of AASHTO T 85 and the Phunque flask. The AASHTO T 85 test procedure produced more replicable results for G_{sa}, G_{sb}, G_{sb} SSD, and *Abs*. These results are based on aggregates with less than 2 percent absorption and the results were confirmed using Bartlett's statistical test and Tukey's method of analysis. The difference of G_{sb} between aggregates tested following AASHTO T 85 test procedure ranged between 0.003 and 0.0045, whereas the variance of aggregates tested using the Phunque Flask ranged between 0.007 and 0.0085.

Table 2.2 Specific Gravity Testing Methods for Coarse Aggregates (adapted from Tran et al., 2015)

#	Selected Test Method	Material Used for Evaluation
1.	AASHTO T 85 and ASTM C127	Coarse aggregate retained on sieve No. 4
2.	Rapid AASHTO T 85 with CoreLok	Coarse aggregate retained on sieve No. 4
3.	Volumetric Immersion using Phunque Flasks	Coarse aggregate retained on sieve No. 4 and Combined (coarse and fine) aggregate

Bikya (2012), presented similar findings to the earlier work by Cross and Mgonella (2005). Bikya tested two fine limestone and slag aggregates, and one coarse limestone aggregate consisting of four different aggregate sizes. The study tested five samples of the six aggregates for a total of 30 tests using the CoreLok device and the AASHTO T 84 or T 85 procedures. Bikya (2012) found that the CoreLok test procedure overestimated the G_{sb} values and underestimated the G_{sa} values. The G_{sa} conclusion contrasts the findings from Cross and Mgonella (2005), but both studies agreed on the G_{sb} conclusion. When testing samples consisting of the same aggregate and different maximum aggregate particle size, Bikya (2012) found that there was no noticeable increase in variation from the average. This means that for coarse aggregates ranging from passing the ¾-inch sieve to retained on Sieve No. 4, the particle size did not appear to influence the specific gravity of the coarse limestone aggregate. Bikya (2012) concluded that further examination of test methods needs to be conducted before adoption of a new test method.

Sholar et al. (2005) measured the specific gravities of coarse aggregates using the AASHTO T 85 test procedure and the CoreLok procedure. In total, 44 tests were performed on 11 aggregate samples consisting of granite and limestone, and different sizes. Comparing the two test procedures, Sholar et al. (2005), found that the G_{sa} values were nearly identical for low absorption aggregates (i.e., granite);

however, for high absorption aggregate (i.e., limestone), the CoreLok G_{sa} values were on average about 0.104 higher. The absorptions for the granite ranged between 0.48 and 0.83 percent and the limestone ranged between 2.72 and 4.09 percent. The CoreLok reported higher G_{sb} values for all aggregates regardless of the percent absorption. They concluded that the increased G_{sa} readings for high absorption aggregate may be because the CoreLok test procedure does not include G_{sb} SSD in the calculation, which for high absorption aggregate is highly influential.

Richardson and Lusher (2006) examined data from 180 test results from CoreLok and AASHTO T 85 tests performed on coarse, fine, and blended aggregates in the state of Missouri between 2002 and 2006. The aim of data collection was to analyze the specific gravity relationships and determine a calibration equation for the CoreLok procedure. When performing a hypothesis test on the means of the sample data where the null hypothesis was that the means were equal with a confidence limit of 5 percent (α = 0.05), Richardson and Lusher's data failed to accept the null hypothesis for G_{sa}, G_{sb}, and Abs results. This means that it could not be concluded that the AASHTO T 85 and CoreLok procedures yielded equal means for any of the specific gravity terms. Richardson and Lusher (2006) then developed prediction equations for G_{sa} and G_{sb} terms. The stipulation to the prediction equations was that they were not calibrated for aggregates with specific gravities greater than 2.90 based on available data. The equations proposed by Richardson and Lusher (2006) for predicting cG_{sa} and cG_{sb} for coarse and fine aggregates are given in Equations (2.2) through (2.4).

$$cG_{sa} = 0.24680896 + 0.90993947 \times uG_{sa} - 0.02031058 \times uAbs \tag{2.2}$$

$$cG_{sb} = 0.342355 + 0.87551137 \times uG_{sb} - 0.051843 \times Abs_{T85} \tag{2.3}$$

$$cG_{sb} = \exp\{0.5172953 + 0.42536397 \times [\ln(uG_{sb})]^2 + 0.047810382 \times e^{-uAbs}\} \tag{2.4}$$

where:

cG_{sa} = Predicted G_{sa} value based on regression fit of CoreLok data

uG_{sa} = Uncorrected G_{sa} value determined using the CoreLok test procedure

cG_{sb} = Predicted G_{sb} value based on regression fit of CoreLok data

uG_{sb} = Uncorrected G_{sb} value determined using the CoreLok test procedure

Abs_{T85} = Absorption value determined using the AASHTO T 84/T 85 test procedure

$uAbs$ = Uncorrected absorption value determined using the CoreLok test procedure

It should be noted that Equation (2.3) includes the variable, Abs_{T85}, which means that an AASHTO T 84/T 85 test must be performed along with the CoreLok test procedure. This negates the advantage of the quick CoreLok test if the 24-hour AASHTO T 85 test procedure must also be performed to use these suggested equations. If only the CoreLok data is available, the researchers recommend using Equation (2.4) which uses the uncorrected values of G_{sb} and Abs from the CoreLok test procedure and assume that cG_{sa} is equal to uG_{sa}. Once the cG_{sa} and cG_{sb} values are available, the absorption may be calculated using Equation (1.7).

Blended Aggregates

For the examination of aggregate blends (coarse and fine aggregates), Hall (2004) examined 10 different aggregate gradations ranging from 21 percent retained on the ¾-inch sieve to 2 percent retained on Sieve No. 4. Five replicates for each blend were tested using the CoreLok test procedure for coarse aggregates and the equivalent AASHTO T 85/T 84 values were calculated using a combined gradation equation that weights the specific gravities based on the percentage present in the blend. Hall's findings suggest that for each specific gravity term, a positive linear relationship exists between the AASHTO-calculated values and the CoreLok-calculated values. The concluding remarks of these experiments were that the data suggests that trends could be developed for blended aggregates.

Summary

The findings of the literature review presented in Chapter 2 show that while the CoreLok is not a direct replacement for the AASHTO T 85 test procedure, a strong correlation can be made between the CoreLok and AASHTO test results. This provides a baseline for developing a prediction equation of equivalent AASHTO T 85 measured values based on the CoreLok results. Several researchers found that the G_{sa} values using both tests showed statistical similarity, whereas all studies showed that the G_{sb} values of the aggregates tested were not similar. Researchers were able to develop several prediction equations that resulted in strong correlations between the predicted and measured G_{sb} values using the AASHTO T 85 procedure.

3. Materials

Introduction

There are six districts in the state of Idaho as shown in Figure 3.1. Each district has a variety of aggregate sources which are often used in highway construction. In this study, each district's Materials Engineer was asked to identify and provide representative coarse aggregate samples from local sources. The coarse aggregate samples were passing the ¾-inch (19 mm) sieve and retained on Sieve No. 4 (4.75mm). A total of 11 aggregate samples were delivered to the University of Idaho laboratory by November 2020. The bagged samples ranged in weight from 33 kg to 132 kg. Aggregate samples were received from all districts, except District 4.

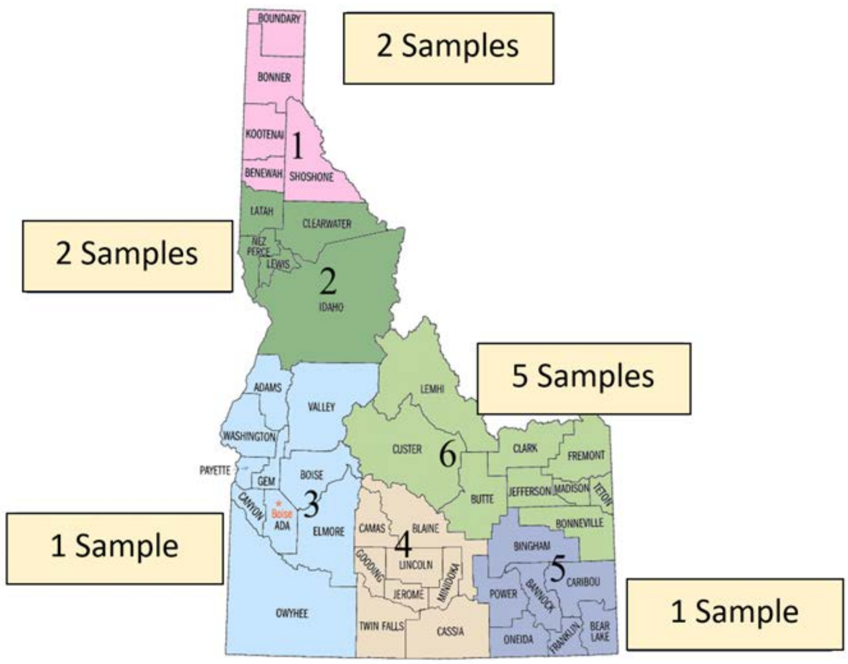

Figure 3.1 Distribution of Aggregates supplied by ITD Districts

Material Composition

A total of 11 quarries were represented in the received materials. Several quarries were represented by multiple grading samples from ¾ inch, ½ inch and ⅜ inch stockpiles. A total of 15 samples were received for testing. Each sample was labelled with an ITD tag, and a unique identifier based on the source of the sample, and the order in which it was tested. A numerical and alphabetical value was assigned to each sample. The numerical value indicates the ITD district, and the alphabetical portion shows the order in which the sample was tested in the laboratory. For instance, a sample labelled "6A" would have come from District 6 and was the first sample tested. Whereas a sample with the label "3H" comes from

District 3 and was the eighth sample tested. This method of labelling was used to allow for an easy identification of samples and the order in which they were tested. A table identifying each sample tested as well as the mineralogy, quarry name, and ITD labelling is presented in Table 3.1.

Table 3.1 Mineralogy and Source of Aggregate Samples

District	ITD Identification	UI Label	Quarry Information	Mineralogy
1	Kt-213c	1E	Rathdrum	Quartzite, Argillite/Siltite, Calcareous Siltstone/Siltite, and Granodiorite
1	Kt-222c ¾-inch	1F	Stateline	Quartz
1	Kt-222c ⅜-inch	1H	Stateline	Quartz
2	WCW-23c	2C	Poe Jorstad	Basalt
2	NP-82c	2D	Atlas Concrete Pit	Basalt, Rhyolite, Quartzite, and Andesite
3	OW-94	3G	Owyhee Co.	Diorite
5	BG-111c Pile A	5I	Mickelsen Const., Blackfoot	Rhyolite/Andesite
5	BG-111c Pile B	5J	Mickelsen Const., Blackfoot	Quartzite, Sandstone, Basalt, Rhyolite, Obsidian, and Opal
6	Fr-104c Pile B	6A	Teton Pit – Teton	Basalt, Rhyolite, Andesite, Obsidian, Granite, Quartzite, Chert
6	BN-59s Pile B	6B	ITD Poplar Pit - Ririe	Quartzite, Limestone, Granodiorite, Diorite
6	LE-91s ⅜-inch	6K	No Data	No Data
6	LE-91s ¾-inch	6L	No Data	No Data
6	Le-160c	6M	Dahle Pit – US-93 Salmon River	Quartzite, Rhyolite, granite, Argillite, Siltite, Siltstone, Dacite, Andesite Gneiss
6	BN-156c Pile A	6N	HK Willow Creek Pit	Quartzite, Rhyolite, Basalt, Granodiorite, Sandstones, Chert
6	BN-156c Pile B	6O	HK Willow Creek Pit	Quartzite, Rhyolite, Basalt, Granodiorite, Sandstones, Chert

Representative samples of the eleven received aggregates were tested for their grain size distribution. The distribution of these particle sizes within the coarse fraction is shown in Appendix C, Figure C.1.

Preparing Coarse Aggregate

Once the samples were received and properly labelled, they were prepared for testing according to the AASHTO T 85 and CoreLok test procedures. After mixing, sieving, washing, and drying, the entire sample was separated into appropriate sample sizes suitable for testing. This process is described below.

Mixing

Samples were delivered in multiple canvas bags from each quarry. The individual bags were combined and mixed to create a homogenous sample in case the material in the bags were sampled from different locations within the stockpile. To ensure proper mixing of the samples all bags were emptied onto a working surface, typically the laboratory floor. The heaped sample was then “folded” over itself a minimum of four times with a flat shovel. The sample was then quartered and separated into four portions. Two diagonally opposite portions were saved for possible future testing, and the remaining two were “folded” over each other a minimum of four times. This procedure was repeated until a final sample size of approximately 26 kg remained for testing. This procedure is shown in Figure 3.3.

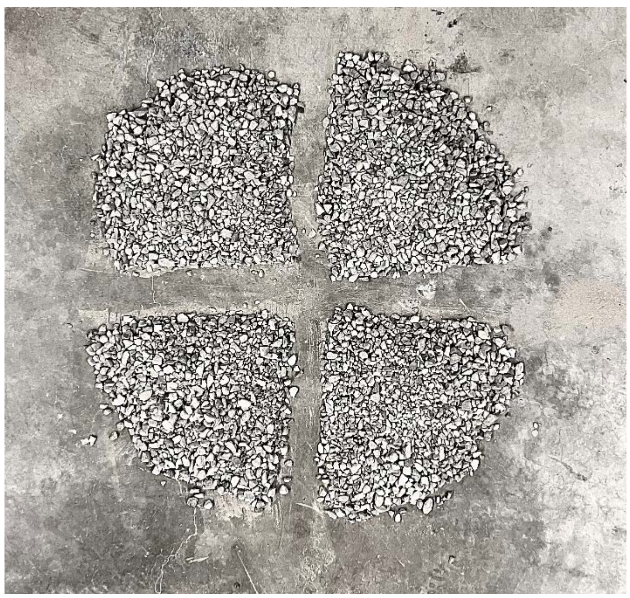

Figure 3.2 Quartering Aggregate Samples on Laboratory Floor

Sieving

Coarse aggregates had particle sizes that ranged from ¾ inch (19 mm) to Sieve No. 4 (4.75 mm). To achieve this size requirement, the sample was processed according to AASHTO T 27 *Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates*. The sample was sieved for 10 minutes in a Gilson TS-1 Sieve Shaker. The materials were then removed from each screen and weighed. Material retained on the ¾ inch (19 mm) sieve and the material passing Sieve No. 4 was removed from the test samples. The final test samples consisted of material which passed the ¾ inch (19 mm) sieve and was retained on Sieve No. 4.

Washing

The coarse aggregate samples, with particle sizes ranging between ¾ inch (19 mm) and Sieve No. 4 (4.75 mm), were then placed in a mechanical washing machine to remove any remaining fines (i.e., material passing Sieve No. 200). The aggregate sample was tumbled in a drum that was at a fixed angle and washed with water. In this setup, as the drum rotated, excess water containing the fine material poured out of the opening on the Sieve No. 200, as shown in Figure 3.4. This procedure was repeated with aggregate weight of approximately 4 to 5 kg to not overload the mechanical washer. All materials were washed over Sieve No. 200 screen until the water ran clear.

Figure 3.3 Mechanical Aggregate Washer

Drying

After washing, the sample was placed in a temperature-controlled oven at 230 ± 9°F (110 ± 5°C) until the sample reached constant mass. Constant mass was reached when there was no more than 0.1 percent change in mass after a specified amount of time in a temperature-controlled oven. This drying was performed in accordance with AASHTO T 255 *Standard Method of Test for Total Evaporable Moisture Content of Aggregate by Drying*. In this study, the samples were left overnight in a temperature-controlled oven until constant mass was achieved.

Portioning Test Samples

After drying, the materials were split using a one-inch, riffle box, as shown in Figure 3.5. The material was split into 1 or 2 kg samples suitable for testing according to the AASHTO T 85 or CoreLok test procedures, shown in Table 3.2. Essentially, each aggregate sample was split to create 15 representative samples consisting of 12 × 1 kg and 3 × 2 kg bags. In total, the aggregate sample was reduced to 18 kg of material in 15 bags.

Table 3.2 Material Required for Testing

Sample Breakdown	AASHTO T 85	CoreLok Volumeter	CoreLok Vacuum Device
Sample Size	1 kg	1 kg	2 kg
Number of Tests	3	3 × 3	3
Total Material Required	3 kg	9 kg	6 kg

Figure 3.4 Coarse Aggregate Riffle Box used for Sample Preparation

Preparing Fine Aggregate

These samples were required for the preparation of the blended aggregate samples that consisted of coarse and fine aggregate. The fine aggregate was prepared using similar techniques to the coarse aggregate with minor deviations from the test procedures. Fine aggregates are defined as particles passing Sieve No. 4 and retained on Sieve No. 200. Any material outside of this range was discarded from the sample during preparation. The fine remaining aggregate was washed using the same mechanical washer over Sieve No. 200. A smaller riffle box was used to split the fine aggregates into smaller samples suitable for testing.

Summary

For the laboratory testing phase of this project, twelve × 1 kg and three x 2 kg representative samples were prepared for each of the 15 test aggregates. Additionally, fifty-six x 1 kg and twenty x 2 kg samples were also prepared and distributed for the “Round Robin” testing phase, which is discussed further in Chapter 5. The preparation of all samples for testing followed the procedures outlined in this chapter to ensure minimal sample variability. The testing procedures and the test results are presented in Chapters 4 and 5, respectively.

4. Methodology

Introduction

Chapter 4 discusses different methods used to determine the specific gravities of coarse aggregates and aggregate blends.

The AASHTO T 85 test procedure is a standard and commonly used method to determine the specific gravity of coarse aggregates. The CoreLok device has been introduced as an alternative for this method for improved efficiency and accuracy. The test procedures used for both methods rely on the same volumetric relationships for determining bulk (dry) specific gravity of the aggregate.

In typical laboratory settings, a technician is required to separate coarse and fine aggregate so the respective AASHTO specific gravity tests can be run on the sample. If the step of separating the aggregate could be avoided, laboratories would be able to save several man hours of testing. The University of Idaho (UI) laboratory tested aggregate blends using the CoreLok device to identify trends between the computed AASHTO specific gravities and ones determined using the CoreLok device. The test procedures for measuring these values are discussed in this chapter.

Round-Robin Testing

After the initial sample preparation was completed, the UI laboratory worked with laboratories across the state to compare test results. This effort is referred to as "round-robin testing."

Selection of Aggregates

Two aggregates were selected based on their absorption, bulk specific gravity, morphology, and availability. The absorption and specific gravity judgements were based on results presented in ITD RP 252 report on fine aggregates which were obtained from the same aggregate sources. The selected aggregates are designated as 6A (Fr-104c) and 6B (BN-59s). These samples were provided by ITD District 6. Sample 6A has a higher absorption and lower specific gravity than sample 6B. Aggregate 6B is similar to river-gravel, whereas 6A is a typical crushed rock aggregate.

Sample Distribution

The UI lab distributed samples to four ITD District laboratories for testing. In addition to the ITD laboratories, two commercial laboratories were contacted to assist in the round-robin testing effort. The laboratories selected were GeoProfessional Innovations (Pullman, WA) and ALLWEST Testing and Engineering (Meridian, ID).

Samples 6A and 6B were selected for round-robin testing as they have different absorption values. Two samples of each aggregate were tested using AASHTO T 85 procedure. Additionally, the ITD-Boise and District 4 laboratories were asked to test the samples using the CoreLok device. All aggregate samples were sieved, washed, and dried and reduced in accordance with the procedures outlined in Chapter 3, before testing. Each sample was split into either 2 or 5 replicates depending on if the laboratory was testing the aggregates using AASHTO T 85 test procedure or both AASHTO T 85 and CoreLok test procedures. Replicates were given different identification codes (A to F) to randomize testing orders. Four bags were shipped for AASHTO T 85 testing, and six bags for CoreLok testing. Labs which tested using the AASHTO T 85 and CoreLok test procedures, received a total of 10 sample bags. Table 4.1 provides a summary of the samples shipped to each laboratory with the assigned identification.

Table 4.1 Sample Identification for the Round-Robin Testing

UI Sample Identification	Assigned RR Identification	Recipient Laboratory	Number of Samples Received	Test Performed
6A	D1-A	ITD District 1	1	AASHTO T 85
6B	D1-B	ITD District 1	1	AASHTO T 85
6A	D1-C	ITD District 1	1	AASHTO T 85
6B	D1-D	ITD District 1	1	AASHTO T 85
6A	D2-A	ITD District 2	1	AASHTO T 85
6B	D2-B	ITD District 2	1	AASHTO T 85
6A	D2-C	ITD District 2	1	AASHTO T 85
6B	D2-D	ITD District 2	1	AASHTO T 85
6A	D3-A	ITD District 3	1	AASHTO T 85
6B	D3-B	ITD District 3	1	AASHTO T 85
6A	D3-C	ITD District 3	1	AASHTO T 85
6B	D3-D	ITD District 3	1	AASHTO T 85
6A	D4-A	ITD District 4	1	AASHTO T 85
6B	D4-B	ITD District 4	1	AASHTO T 85
6A	D4-C	ITD District 4	1	AASHTO T 85
6B	D4-D	ITD District 4	1	AASHTO T 85
6A	D4-E	ITD District 4	3	CoreLok
6B	D4-F	ITD District 4	3	CoreLok
6A	ITD-A	ITD HQ (Boise)	1	AASHTO T 85
6B	ITD-B	ITD HQ (Boise)	1	AASHTO T 85
6A	ITD-C	ITD HQ (Boise))	1	AASHTO T 85
6B	ITD-D	ITD HQ (Boise)	1	AASHTO T 85

UI Sample Identification	Assigned RR Identification	Recipient Laboratory	Number of Samples Received	Test Performed
6A	ITD-E	ITD HQ (Boise)	3	CoreLok
6B	ITD-F	ITD HQ (Boise)	3	CoreLok
6A	D6-A	ITD District 6	1	AASHTO T 85
6B	D6-B	ITD District 6	1	AASHTO T 85
6A	D6-C	ITD District 6	1	AASHTO T 85
6B	D6-D	ITD District 6	1	AASHTO T 85
6A	AW-A	ALLWEST	1	AASHTO T 85
6B	AW-B	ALLWEST	1	AASHTO T 85
6A	AW-C	ALLWEST	1	AASHTO T 85
6B	AW-D	ALLWEST	1	AASHTO T 85
6A	AW-A	GPI	1	AASHTO T 85
6B	AW-B	GPI	1	AASHTO T 85
6A	AW-C	GPI	1	AASHTO T 85
6B	AW-D	GPI	1	AASHTO T 85

Round-robin testing concluded in July 2021. The results from the round-robin testing are presented in Chapter 5.

Test Conditions

To accurately report the quantities measured using the AASHTO T 85 and the CoreLok test procedures, the baseline measurement devices should be the same to eliminate possible laboratory errors. The water-bath temperature specified by Instrotek is 25 ± 1°C (77 ± 2°F), while AASHTO T 85 specifies a water-bath temperature of 23.0 ± 1.7°C (73.4 ± 3°F). For consistency, this study used the AASHTO T 85 recommended temperature range of 25 ± 1°C (77 ± 2°F) for all calibrations and testing as this is the temperature setting used for a water-bath in most testing laboratories.

For this study the water-bath temperature was maintained close to 24.5°C (77.1°F) to satisfy the requirements of both procedures. An underwater temperature regulation system that also gently circulated water in the tank without disturbing the samples during the weigh-under process was used to maintain a consistent temperature within the water-bath. The same digital scale, measuring to 0.1 g, was used to measure weights throughout the testing process. The metal volumeter used for CoreLok test was submerged for at least 10 minutes in the water bath until it reached an equilibrium temperature with the water bath. A 10-minute submersion duration is recommended by Instrotek in their documentation for the CoreLok test procedure (Instrotek Inc, 2003). Additionally, the oven used to dry the aggregates to a constant mass was maintained at 110 ± 5°C (230 ± 9°F).

AASHTO T 85 Test Procedure

The AASHTO T 85 test procedure requires preliminary washing, sieving, and drying of the test samples. All samples used for testing were prepared in accordance with AASHTO T 85 and were stored in sealed bags until ready for testing. The test procedure involves an extended soaking period, reaching SSD condition, obtaining a submerged aggregate weight, and drying the material again to constant mass. All test procedures will be detailed in the sections below with accompanying photographs.

Initial Preparation

For a maximum aggregate size of ½-inch (12.7 mm), AASHTO T 85 recommends a minimum sample size of two kilograms. However, a smaller sample of one kilogram was selected for the T 85 tests as it was easier to dry to the SSD condition. As multiple tests were run for each aggregate, the use of average values is expected to overcome this modification.

The aggregate sample is initially dried to a constant mass in a temperature-controlled oven. Once the aggregate has reached a state of constant mass, it is cooled down before soaking in water for 17 ± 2 hours.

SSD Condition

This portion of the test is critical because the materials can quickly change from the SSD condition to being too dry; therefore, it requires an experienced operator. If the sample becomes too dry, the T 85 test procedure requires that the sample be submerged again for at least 30 minutes to reach a wetter condition than SSD. As this step is time sensitive, it is recommended that all necessary supplies and equipment be assembled ahead of time.

After the initial soaking, the sample is drained of excess water and the aggregate is placed on a towel and gently dried until there is no free moisture on the surface of the aggregate. For this project, the moment when the aggregate lost the "shine" caused by water on the surface and appeared "dull" was deemed the point when SSD condition was achieved. Immediately following this determination, the sample was weighed, and the weight was recorded as "SSD Weight." These conditions are depicted in Figure 4.1.

Submersion

After recording the SSD weight, the sample was placed in a wire basket and submerged in a water bath as shown in Figure 4.2. While suspended, the basket was agitated underwater to remove any trapped air bubbles. After agitation, the basket was attached to a weigh-under device on the scale. The water was allowed to settle for 10 minutes, and the weight was recorded as the "Submerged Weight." The submerged weight of the sample is measured to determine the volume of the sample. At the SSD condition, all surface voids are filled with water. This means that the volume displaced by the SSD aggregate will correspond to the volume of the aggregate only and is used to calculate the apparent specific gravity, G_{sa}.

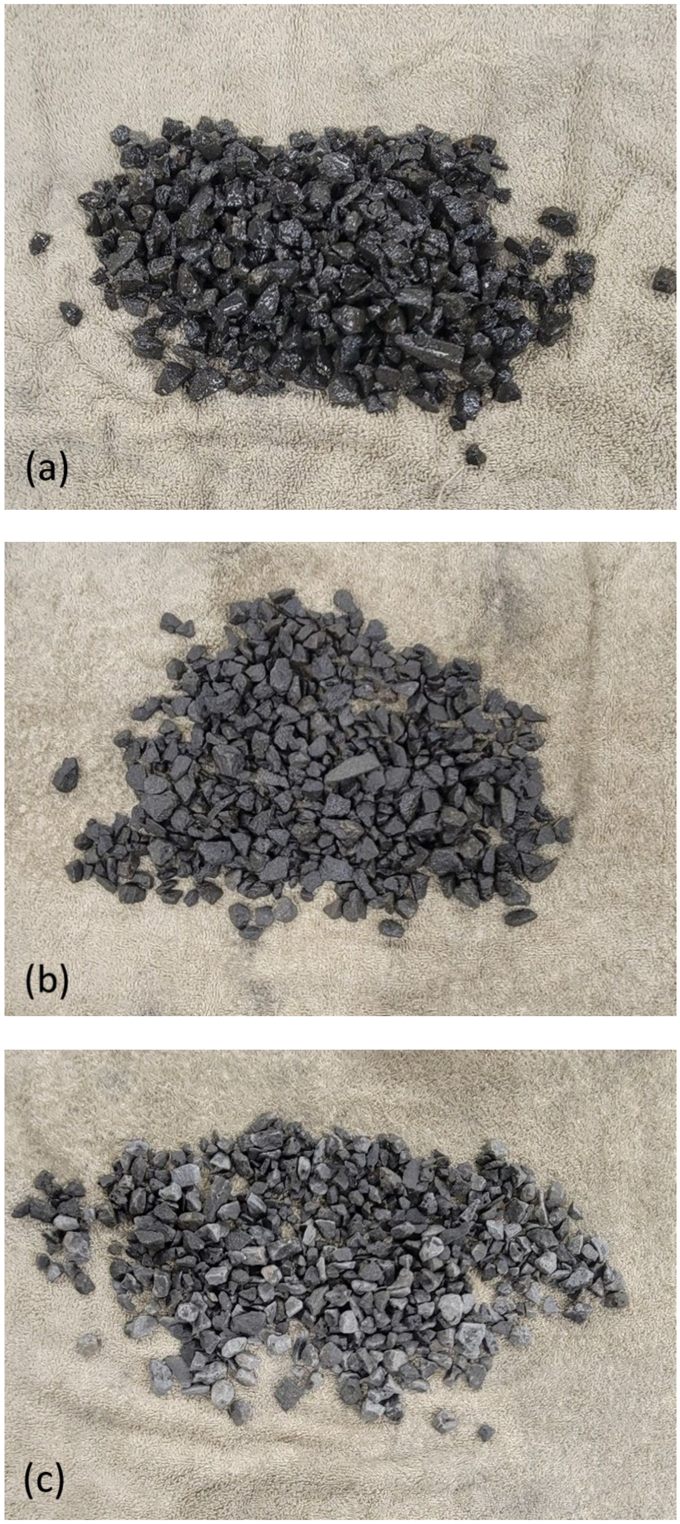

Figure 4.1 Aggregate Appearance at Various Stages of Drying. (a) "Shiny" Aggregate on wet side of SSD, (b) Aggregate at SSD Condition, and (c) Aggregate on dry side of SSD

Figure 4.2 Aggregate Submersion in Water Bath

Drying

After weighing the submerged aggregate, all material is carefully removed from the basket and dried overnight in a temperature-controlled oven. Once dried, the sample is removed from the oven and allowed to cool to room temperature. The weight of the dried aggregate is then recorded as the "Dry Weight."

AASHTO T 85 Calculations

Table 4.2 summarizes the data obtained from the AASHTO T 85 test procedure.

Table 4.2 AASHTO T 85 Test Data

Weight	Parameter
Mass of oven-dry test sample in air	A
Mass of saturated-surface-dry test sample in air	B
Mass of saturated test sample in water	C

Using the above data, the specific gravities and absorption may be computed using the equations given below. The bulk specific gravity, G_{sb}, is given by Equation 4.1.

$$G_{sb} = \frac{A}{B - C} \tag{4.1}$$

The bulk specific gravity at the SSD condition, G_{sb},*SSD*, is given by Equation 4.2.

$$G_{sb}, SSD = \frac{B}{B - C} \tag{4.2}$$

The apparent specific gravity, G_{sa}, may be computed using Equation 4.3.

$$G_{sa} = \frac{A}{A - C} \tag{4.3}$$

The absorption, *Abs*, is computed using Equation 4.4.

$$Abs\ (\%) = \frac{B - A}{A} \times 100 \tag{4.4}$$

Shortcomings of the AASHTO T 85 Test Procedure

For this test procedure, the operator needs to carefully dry the surface of the soaked aggregate particles to achieve the required SSD condition. With the presence of different sized particles, considerable experience and judgement are required to recognize the moment when SSD condition is reached. What can be considered SSD condition to some technicians, can appear to be too dry or too wet to others.

Furthermore, the 19-hour soaking time required by the AASHTO T 85 test procedure adds to the overall time required to complete specific gravity testing.

CoreLok Test Procedure

The CoreLok test procedure (Instrotek, 2003; ASTM, 2009) consists of two different tests. The first test involves a volumeter which consists of an aluminum cannister and lid with a fixed, internal volume. This assists in determining the volume of water displaced by a sample which is then used to calculate the bulk specific gravity. Figure 4.3 shows the volumeter and tools used during the testing procedure. The second test involves a vacuum chamber and a plastic bag that acts as a membrane around the sample; the bag allows for a vacuum to be drawn around the sample and the vacuum to be held until the bag is submerged underwater. These tests are further explained in the following sections.

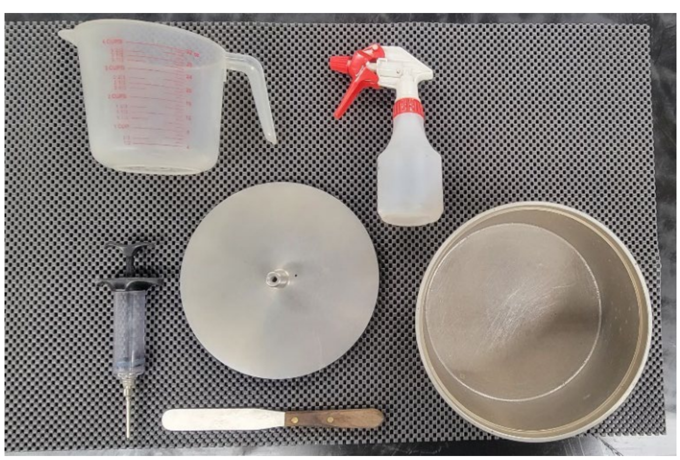

Figure 4.3 Volumeter Tools used in the CoreLok Test Procedure

CoreLok Test Volumeter

The volumeter provided by Instrotek is an aluminum cannister with an internal diameter of 7.776 ± 0.008 inches (198 ± 0.8 mm) and an internal height of 4.5 ± 0.003 inches (114 ± 0.8 mm). The cannister is machined to have flat surfaces. A lid accompanies the canister and fits into a notched rim on the interior of the cannister. The lid is machined to have a 5-degree cone centered on the underside. Drilled into the lid are two holes, measuring ⅛ inch (3.175 mm) and ¼ inch (6.35 mm). The larger hole is centered on the lid and the smaller one is offset to allow the water to flow out of the cannister.

Calibration

To calibrate the volumeter, the lid and cannister are placed in a water bath with a calibrated temperature. Instrotek recommends a temperature of 73.4 ± 3°F (23 ± 3°C), this deviates from the recommended water bath temperature specified in the AASHTO T 85 test procedure. For consistency, this study used the AASHTO T 85 recommended temperature range of 25 ± 1°C (77 ± 2°F) for all calibrations and testing.

The volumeter is placed in the bath for 10 minutes to reach equilibrium temperature with the water. The assembly is then removed from the water and placed on a level working surface. Once the outside of the cannister is dry, it is filled with water at the same temperature as the water bath. The cannister is filled until a ⅜ inch (9.5 mm) gap remains between the water surface and the rim. The lid is then placed on the cannister, and water is added using a syringe via the ¼ inch (6.4 mm) hole until water is expelled from the smaller ⅛ inch (3.2 mm) hole. The exiting water indicates that the volumeter is completely full. The water filled assembly is then weighed. This process is repeated three times and the average weight is recorded as the "Calibration Weight."

Sample Testing

The volumeter test procedure must be completed within a two-minute time frame, as specified by Instrotek. This ensures that water does not permeate into the surface voids and adversely influence the calculation of the bulk specific gravity. Once testing begins, a 2.2 lb (1 kg) sample, prepared in accordance with the procedures outlined in Chapter 3, is placed in the calibrated volumeter. Water is added to the cannister until it covers the aggregate by about 1 inch (25 mm). The sample is then quickly stirred using the spatula eight times, as shown in Figure 4.4. The first four times are in a cross pattern followed by an additional four more in another cross pattern rotated 45 degrees.

Water is added to the cannister in the same manner as in the calibration routine until it nearly fills the volumeter. Before placing the lid on the volumeter, the surface of the water is sprayed three times with isopropyl alcohol to ensure that any suspended material on the surface sinks into the water, as shown in Figure 4.5. The lid is placed, and water is added through the central ¼ inch hole using the syringe, as shown in Figure 4.6. Water exiting out of the ⅛ inch hole indicates that the volumeter is full and ready to be weighed.

The volumeter test procedure is repeated once more, and values are averaged to ensure representative numbers. If the final weights from the two tests vary by more than 0.01 lb. (5 g), the test is repeated once again; the average of the two closest weights are then used for the calculations.

Figure 4.4 Stirring the Aggregate Sample in a Cross Pattern

Figure 4.5 Spraying Isopropyl Alcohol on the Water Surface of the Volumeter

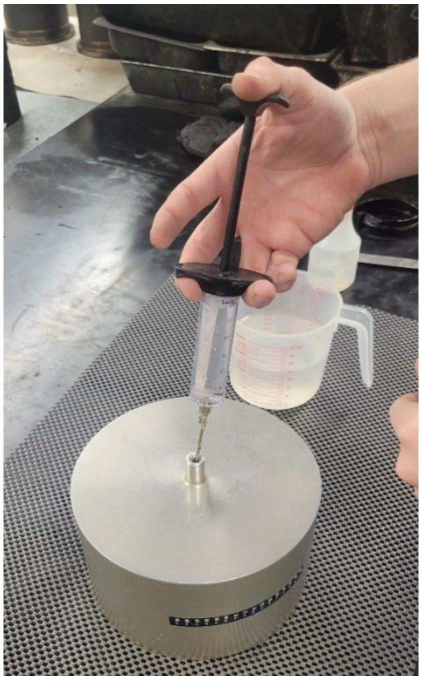

Figure 4.6 Injecting Water into the Volumeter

CoreLok Test Vacuum Chamber

A separate 4.4 lb (2 kg) sample is used for the vacuum portion of the CoreLok test procedure. The aggregate is placed inside a perforated plastic bag which is then placed inside another non-perforated bag. The inner bag is separated from the outer bag by two rubber sheets that ensure aggregate does not pierce through the outside bag upon application of the vacuum. A cross-section of the arrangement of the items in the prepared bag assembly is shown in Figure 4.7.

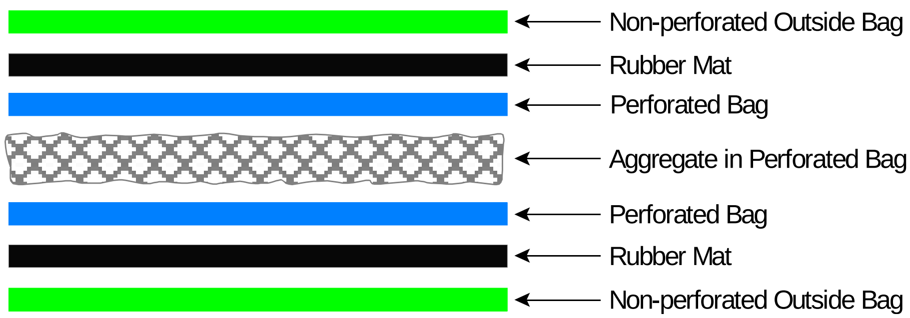

Figure 4.7 Cross section of Bag-Aggregate Assembly used in the CoreLok Device

In this study, the researchers found that the use of the perforated bag helped to hold the sample in place within the outside bag during the application of the vacuum. However, the inside perforated bag can be omitted, but care must be taken to ensure that aggregate does not get trapped near the edges of the outer bag.

For overall confidence, the rubber mats were used for all tests performed at UI. However, in a few separate tests without the rubber sheets, the researchers did not observe any signs of punctures after application of the vacuum.

Instrotek outlines two test procedures for the vacuum chamber. For this set of tests, Program No. 2 was run to achieve the required vacuum. The 300-second dwell period ensured that enough time was allowed to achieve a proper vacuum. Program No. 1 is used for asphalt cores, which typically most of the aggregate voids filled with asphalt, which requires a lower draw time on the vacuum. The settings for the two available programs are shown in Table 4.3.

Table 4.3 CoreLok Vacuum Chamber Programs

Control	Program #1	Program #2	Description
Power Switch	On	On	Operation begins when lid is closed
Vacuum Control	99%	99%	Vacuum in chamber is 99 percent of absolute vacuum
Dwell (seconds)	15	300	Ensures that a vacuum of 99 percent is achieved
Seal (seconds)	1.0	1.0	Time setting of seal bar

Once the coarse sample aggregate has been assembled in the bag, the bag is placed inside the chamber (Figure 4.8). Upon closing the lid, the vacuum process starts automatically, and the bag is sealed when the vacuum reaches a maximum of 99 percent in about 300 seconds. After the bag is sealed, the bag is retrieved from the CoreLok device for the water-bath process. Figure 4.9 shows a sealed bag containing coarse aggregate after completion of the automated vacuum sealing process in the CoreLok device.

Figure 4.8 CoreLok Device with Sample Bag

Figure 4.9 Vacuum Sealed CoreLok Bag with Coarse Aggregate

Next the vacuum-sealed bag is placed in the water bath equipped with a weigh-under scale. With the bag submerged in the water, the outer bag seal is removed by cutting a 4 inch (10 centimeter [cm]) slit along both sides of the bag and allowing water to be drawn into the aggregate pores because of the vacuum. A photo of the bag being cut is shown in Figure 4.10.

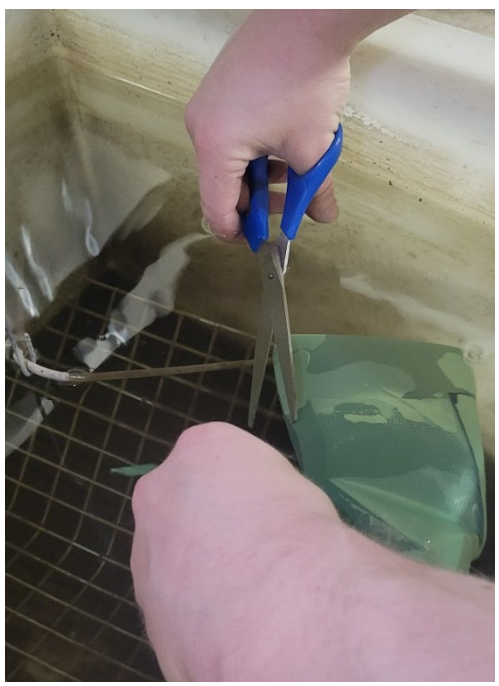

Figure 4.10 Cutting Vacuum Sealed Bag Under Water

Calculations

The data from the testing process is used to calculate the "uncorrected" values uG_{sb}, uG_{sa}, and *uAbs* of the aggregate. The information gathered during the test procedure is presented in Table 4.4.

Table 4.4 Data collected from the CoreLok Test Procedure

Mass (in grams)	Parameter
Average calibration mass of volumeter filled with water	$W_{Calibration}$
Mass of dry aggregate placed in the volumeter	W_{Agg2}
Mass of volumeter with aggregate W_{agg2} and water	W_{Vol}
Mass of dry aggregate placed in the plastic bag	W_{Agg1}
Mass of submerged aggregate in water	$W_{Submerged}$
Mass of plastic bags	W_{Bag}
Mass of rubber sheets	W_{Rubber}
Density of plastic bags	ρ_{Bag}
Density of rubber sheets	ρ_{Rubber}

Apparent Specific Gravity

The apparent specific gravity is determined by isolating the weight of the submerged aggregate in the water bath. This is achieved by dividing the weight of the bag and the rubber sheets by their densities (ρ_{Bag} and ρ_{Rubber}). The density values used by the UI lab are 0.903 g/cm^3 and 1.353 g/cm^3 for the bag and rubber sheets, respectively. These values were provided by the bag and rubber mat supplier, Instrotek. The quantities are then subtracted from the equation leaving the volume of the submerged aggregate using Equation 4.5.

$$Volume = \left(W_{Bag} + W_{Rubber} + W_{Agg1} - W_{Submerged}\right) - \frac{W_{Bag}}{\rho_{Bag}} - \frac{W_{Rubber}}{\rho_{Rubber}} \tag{4.5}$$

With the volume calculated, the CoreLok G_{sa} (cG_{sa}) is given by Equation 4.6:

$$cG_{sa} = \frac{W_{Agg1}}{Volume} \tag{4.6}$$

Bulk (Dry) Specific Gravity

The bulk (dry) specific gravity is determined from the volumeter test. The volume of water displaced is determined by taking the difference between the weights of the calibrated volumeter and the volumeter filled with aggregate as given in Equation 4.7.

$$Volume = W_{Calibration} - \left(W_{Vol} - W_{Agg2}\right) \tag{4.7}$$

The bulk (dry) specific gravity (G_{sbCL}) is given by Equation 4.8.

$$uG_{sb} = \frac{W_{Agg2}}{Volume} \tag{4.8}$$

Absorption

The absorption is calculated by finding the difference between the apparent and bulk specific gravities. The G_{sa} term indirectly reflects the volume of the aggregate without considering the surface voids. The G_{sb} term uses the same volume as used for the G_{sa} and includes the volume of the water permeable surface voids. Absorption, quoted in percent, quantifies the amount of water that can fill the surface voids in reference to the total dry weight. Absorption may be calculated using Equation 4.9.

$$cAbs\ (\%) = \left(\frac{1}{cG_{sb}} - \frac{1}{cG_{sa}}\right) \times 100 \tag{4.9}$$

Aggregate Blends

The blended aggregate mixes, consisting of coarse and fine materials, were tested using only the CoreLok test procedure as there is no equivalent AASHTO standard test method that can test both coarse and fine material together. The theoretical specific gravity of a blended aggregate was calculated using Equation 4.10.

$$G = \left(\frac{p_1 + p_2 + \cdots p_n}{\frac{p_1}{G_1} + \frac{p_2}{G_2} + \cdots \frac{p_n}{G_n}}\right) \tag{4.10}$$

where $p_1, p_2, \ldots p_n$ are the percentages of different aggregates used and $GS_1, GS_2, \ldots GS_n$ are the corresponding specific gravities.

The absorption of a blended aggregate was determined using Equation 4.11.

$$Abs\ (\%) = p_1 Abs_1 + p_2 Abs_2 + \cdots p_n Abs_n \tag{4.11}$$

where $p_1, p_2, \ldots p_n$ are the percentages of different aggregates used, and $Abs_1, Abs_2, \ldots Abs_n$ are the corresponding absorptions.

The specific gravity and absorption of a blended aggregate is essentially a weighted percentage-based average that is typically used to blend bulk specific gravities at quarries that have multiple stockpiles with known G_{sb} and *Abs* values.

Variability in Test Procedures

When testing aggregates using the AASHTO T 85 test procedure, the onset of the SSD condition determined by the operator is highly subjective. Furthermore, the AASHTO T 85 test procedure requires transferring the aggregate sample between containers when submerging the sample, which may lead to some aggregate loss in the middle of the testing procedure. Such loss will adversely affect the value of the calculated specific gravity. To avoid this issue, the operator must exercise great care to ensure that that aggregate is not lost during the transfer of the SSD aggregate to/from the wire cage.

The CoreLok test procedure negates these issues by using an automated vacuum process and using two samples to determine the specific gravities. In theory, the only variability in the CoreLok test procedure is the type of aggregates tested with respect to its absorption.

Summary

The methodologies describe in Chapter 4 ensured that all samples were tested using the same standards. This allowed for confidence when averaging data points because the samples went through the same exact test procedures. Chapter 5 provides the results from the tests conducted using the samples and methods described in Chapters 3 and 4.

5. Test Results

Introduction

The results from testing 15 coarse aggregates samples using the AASHTO T 85 and CoreLok test procedures are presented in this chapter. Additional results from the round-robin testing are also included in this chapter. All results were determined using the test procedures outlined in Chapter 4. The data points shown are the individual tests along with averages to represent the entire tested sample. The averages are the values used for statistical analysis in Chapter 6. If a sample was not used in the data analysis it is marked with an asterisk with a note of explanation.

Round Robin Testing

Of the seven participating laboratories, all performed the AASHTO T 85 test procedure on the distributed samples and two performed the CoreLok test procedure on the test aggregates. The compiled data is listed below with laboratory names, minimum and maximum values, range of values, averages, and a range based on two standard deviations (SD). A two SD range was selected to identify outliers as it encompasses a 95 percent confidence level based on the data following a normal distribution.

AASHTO T 85 Test Procedure - Aggregate 6A

Tables 5.1 and 5.2 show the average AASHTO T 85 test results for aggregate 6A and related statistics. Only the results from District 1 were very slightly outside (by 0.001) of the proposed ± 2SD. Despite the few laboratories that presented results outside of the range, the data shows good similarity between the laboratories that participated in the round-robin testing. UI laboratory test data deviates only 0.007 from the average G_{sb} and 0.005 from the average G_{sa}. The difference in the absorption value from the average was 0.082 percent.

Table 5.1 Round-Robin testing results for Aggregate 6A Using AASHTO T 85

Lab	G_{sb}	G_{sb} *SSD*	G_{sa}	*Abs*
ITD D1	2.433	2.493	2.589	2.480
ITD D2	2.527	2.565	2.625	1.525
ITD D3	2.531	2.567	2.626	1.477
ITD D4	2.528	2.566	2.628	1.555
ITD D6	2.525	2.568	2.636	1.714
ITD HQ	2.620	2.637	2.665	0.644

Lab	G_{sb}	G_{sb} *SSD*	G_{sa}	*Abs*
ALLWEST	2.525	2.564	2.625	1.548
GPI	2.554	2.584	2.632	1.200
UI	2.522	2.562	2.626	1.610

Table 5.2 Round-Robin Statistics for Aggregate 6A Using AASHTO T 85

Statistic	G_{sb}	G_{sbSSD}	G_{sa}	*Abs*
Min	2.433	2.493	2.589	0.644
Max	2.620	2.637	2.665	2.480
Range	0.188	0.144	0.076	1.837
Average	2.529	2.567	2.628	1.528
Average + 2SD	2.625	2.640	2.667	2.488
Average – 2SD	2.434	2.494	2.589	0.569

AASHTO T 85 Testing Procedure – Aggregate 6B

Tables 5.3 and 5.4 show the average AASHTO T 85 test results for aggregate 6B and related statistics. The average of all laboratories fell within the range of ± 2 standard deviations. This shows good relative similarity between the laboratories that participated in the round-robin testing. UI laboratory test data deviates a 0.023 from the average G_{sb} and 0.018 from the average G_{sa}. The difference in the absorption value from the average was 0.211 percent. This process confirmed that the tests performed by the UI laboratory are reliable and fully meet expectations of quality testing.

Table 5.3 Round-Robin Testing Results for Aggregate 6B Using AASHTO T 85

Lab	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*
ITD D1	2.528	2.565	2.624	1.485
ITD D2	2.534	2.570	2.630	1.485
ITD D3	2.528	2.565	2.624	1.485
ITD D4	2.446	2.504	2.596	2.353
ITD D6	2.530	2.570	2.636	1.643
ITD HQ	2.450	2.506	2.597	2.322
ALLWEST	2.522	2.561	2.623	1.576
GPI	2.444	2.502	2.593	2.350
UI	2.524	2.563	2.627	1.600

Table 5.4 Round-Robin Statistics for Aggregate 6B Using AASHTO T 85

Statistic	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*
Min	2.444	2.502	2.593	1.485
Max	2.534	2.570	2.636	2.353
Range	0.089	0.069	0.043	0.868
Average	2.501	2.545	2.617	1.811
Average + 2SD	2.582	2.607	2.650	2.615
Average – 2SD	2.419	2.483	2.584	1.007

CoreLok Testing Procedure – Aggregate 6A

Tables 5.5 and 5.6 show the average CoreLok test results for aggregate 6B and related statistics. The average of all laboratories fell within the range of ± 2 standard deviations. This shows good relative similarity between the laboratories that participated in the round-robin testing. UI laboratory test data deviates a 0.005 from the average G_{sb} and 0.013 from the average G_{sa}. The difference in the absorption value from the average was 0.112 percent.

Table 5.5 Round-Robin Testing Results for Aggregate 6A using the CoreLok Test Procedure

Lab	uG_{sb}	uG_{sb} SSD	uG_{sa}	uAbs
ITD D4	2.550	2.581	2.633	1.246
ITD HQ	2.529	2.565	2.625	1.456
UI	2.532	2.562	2.610	1.182

Table 5.6 Round-Robin Statistics for Aggregate 6A using the CoreLok Test Procedure

Statistic	uG_{sb}	uG_{sb} SSD	uG_{sa}	uAbs
Min	2.529	2.562	2.610	1.182
Max	2.550	2.581	2.633	1.456
Range	0.021	0.019	0.023	0.274
Average	2.537	2.570	2.623	1.294
Average + 2SD	2.559	2.590	2.646	1.581
Average – 2SD	2.514	2.549	2.600	1.008

CoreLok Testing Procedure – Aggregate 6B

Tables 5.7 and 5.8 show the average CoreLok testing results for aggregate 6B and related statistics. The average of all laboratories fell within the range of ± 2 standard deviations. This shows good relative similarity between the laboratories that participated in the round-robin testing. UI laboratory test data deviated 0.006 from the average G_{sb} and 0.012 from the average G_{sa}. The difference in the absorption value from the average was 0.079 percent. This process confirmed that the tests performed by the UI laboratory are reliable and fully meet expectations of quality testing.

Table 5.7 Round-Robin Testing Results for Aggregate 6B using the CoreLok Test Procedure

Lab	uG_{sb}	uG_{sb} SSD	uG_{sa}	uAbs
ITD D4	2.648	2.661	2.683	0.491
ITD HQ	2.647	2.658	2.677	0.418
UI	2.638	2.647	2.662	0.336

Table 5.8 Round-Robin Statistics for Aggregate 6B using the CoreLok Test Procedure

Statistic	uG_{sb}	uG_{sb} SSD	uG_{sa}	*uAbs*
Min	2.638	2.647	2.662	0.336
Max	2.648	2.661	2.683	0.491
Range	0.010	0.014	0.021	0.155
Average	2.644	2.655	2.674	0.415
Average + 2SD	2.655	2.670	2.696	0.570
Average – 2SD	2.634	2.641	2.652	0.260

Discussion

Of the data presented in Tables 5.1 to 5.8, only one laboratory (District 1, AASHTO T 85 aggregate 6A) produced results that fell very slightly (by 0.001) outside of the ± 2 standard deviation range for all reported results. This provides strong evidence that most laboratories participating in the round-robin testing can produce results that are similar to each other. Furthermore, the data lends itself to the conclusion that the UI laboratory operates within tolerance of regional laboratories and can perform tests that are representative of the aggregates used in this study.

AASHTO T 85 versus CoreLok Test Procedures

In this section data will be presented for the 15 aggregate types that were gathered from five of the six ITD Districts. In total 138 average values are presented in this chapter. Each average represents two to four tests that were performed on the sample. The number of tests conducted depended on the material that the UI laboratory had on hand. Forty-seven of these averages are for the AASHTO T 85 test procedure, and the remaining 91 are for samples tested with the CoreLok test procedure.

In addition to running tests on coarse aggregate, this study also tested blends of coarse and fine aggregates. Blends ranged from 25 percent to 90 percent fine aggregate with the other portion of the blend being made up of coarse aggregate. The blends were tested using only the CoreLok test procedure as there is no recognized AASHTO test procedure for testing the specific gravities of blended aggregates. The blends were prepared in accordance with the methodology detailed in Chapter 4.

Testing results from each of the five ITD districts are presented below. Aggregates are labelled with the assigned identification followed by a number representing its sequence. For example, 1E-2 represents the second replicate tested aggregate 1E (fifth overall sample tested that originated from District 1 as explained in Table 3.1). The date tested and district are also provided for each sample.

The four values reported for the AASHTO T 85 test procedure are: (1) Bulk (Dry) Specific Gravity (G_{sb}), (2) Saturated Surface Dry Bulk Specific Gravity (G_{sb} SSD), (3) Apparent Specific Gravity (G_{sa}), and (4) Absorption (*Abs*).

The CoreLok test procedure yields the following three values: (1) Bulk (Dry) Specific Gravity (uG_{sb}), (2) Apparent Specific Gravity (uG_{sa}), and (3) Absorption (*uAbs*). If desired, the saturated surface dry bulk specific gravity (G_{sb} SSD) may be calculated using the volumetric Equation (1.6). Essentially, the prefix "*u*" refers to an uncorrected value. Once corrected, the prefix "*u*" is replaced by "*c*". The proposed corrections will be explained in Chapter 6 along with the Statistical Analysis.

In addition to the individual test values, the average is given to show the values used to generate the statistical analysis provided in Chapter 6. Lastly a bar graph is given for each district to show the overall trend of G_{sb} results compared to uG_{sb}.

District 1 Coarse Aggregates

District 1 results for the AASHTO T 85 test procedure had bulk specific gravities that ranged from 2.609 to 2.681 and absorption values that varied between 0.108 and 0.580 percent. The apparent specific gravities ranged between 2.680 and 2.725. Figure 5.1 shows the G_{sb} values determined using both the AASHTO T 85 and CoreLok test procedures.

Table 5.9 ITD District 1 Test Data using the AASHTO T 85 Test Procedure

Test Number	Aggregate	UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*
1	Kt-213c	1E-1	2.624	2.653	2.701	1.080
2	Kt-213c	1E-2	2.609	2.636	2.680	1.019
3	Kt-213c	1E-3	2.624	2.652	2.699	1.060
4	Kt-222c - 3/8 in.	1H-1	2.630	2.655	2.698	0.959
5	Kt-222c - 3/8 in.	1H-2	2.648	2.671	2.710	0.859
6	Kt-222c - 3/8 in.	1H-3	2.643	2.666	2.706	0.890
7	Kt-222c - 3/4 in.	1F-1	2.681	2.697	2.724	0.580
8	Kt-222c - 3/4 in.	1F-2	2.676	2.694	2.725	0.669
9	Kt-222c - 3/4 in.	1F-3	2.676	2.693	2.723	0.649

Table 5.10 ITD District 1 Test Data using the CoreLok Test Procedure

Test Number	Aggregate	UI Lab ID	*uG_{sb}*	*uG_{sb} SSD*	*uG_{sa}*	*uAbs*
1	Kt-213c	1E-1	2.634	2.655	2.689	0.774
2	Kt-213c	1E-2	2.648	2.667	2.700	0.733
3	Kt-213c	1E-3	2.652	2.671	2.703	0.712
4	Kt-222c - 3/8 in.	1H-1	2.664	2.682	2.714	0.702
5	Kt-222c - 3/8 in.	1H-2	2.658	2.681	2.722	0.879
6	Kt-222c - 3/8 in.	1H-3	2.664	2.685	2.719	0.751
7	Kt-222c - 3/4 in.	1F-1	2.691	2.701	2.717	0.366
8	Kt-222c - 3/4 in.	1F-2	2.691	2.702	2.721	0.404
9	Kt-222c - 3/4 in.	1F-3	2.699	2.710	2.729	0.414

Table 5.11 ITD District 1 Average Values

UI Lab ID	*G_{sb}*	*G_{sb} SSD*	*G_{sa}*	*Abs*	*uG_{sb}*	*uG_{sb} SSD*	*uG_{sa}*	*uAbs*
1E	2.619	2.647	2.693	1.053	2.645	2.664	2.698	0.740
1H	2.640	2.664	2.705	0.903	2.662	2.683	2.718	0.777
1F	2.678	2.695	2.724	0.632	2.694	2.704	2.723	0.395

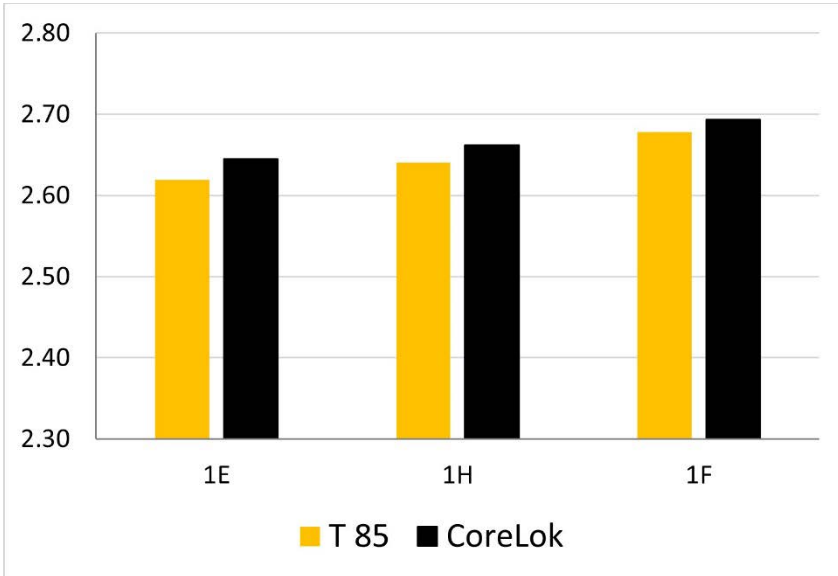

Figure 5.1 Bulk (Dry) Specific Gravity Averages for ITD District 1

District 2 Coarse Aggregates

District 2 results for the AASHTO T 85 test procedure bulk specific gravities ranged from 2.800 to 2.853 and absorptions varied between 1.162 and 1.799 percent. The apparent specific gravities were slightly higher, ranging between 2.942 and 2.952. Figure 5.2 shows the G_{sb} values determined using both the AASHTO T 85 and CoreLok test procedures.

Table 5.12 ITD District 2 Test Data using the AASHTO T 85 Test Procedure

Test Number	Aggregate	UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*
10	WCW-23c	2C-1	2.800	2.848	2.942	1.724
11	WCW-23c	2C-2	2.805	2.854	2.949	1.733
12	WCW-23c	2C-3	2.802	2.853	2.951	1.799
13	NP-82c	2D-1	2.853	2.887	2.952	1.182
14	NP-82c	2D-2	2.852	2.885	2.949	1.162
15	NP-82c	2D-3	2.841	2.876	2.945	1.241

Table 5.13 ITD District 2 Test Data using the CoreLok Test Procedure

Test Number	Aggregate	UI Lab ID	uG_{sb}	uG_{sb} SSD	uG_{sa}	*uAbs*
10	WCW-23c	2C-1	2.865	2.894	2.949	1.000
11	WCW-23c	2C-2	2.865	2.893	2.949	0.993
12	WCW-23c	2C-3	2.869	2.897	2.953	0.995
13	NP-82c	2D-1	2.883	2.895	2.919	0.430
14	NP-82c	2D-2	2.871	2.888	2.920	0.584
15	NP-82c	2D-3	2.871	2.888	2.919	0.572

Table 5.14 ITD District 2 Average Values

UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*	uG_{sb}	uG_{sb} SSD	uG_{sa}	*uAbs*
2C	2.803	2.852	2.947	1.752	2.866	2.895	2.950	0.996
2D	2.849	2.883	2.949	1.195	2.875	2.890	2.919	0.529

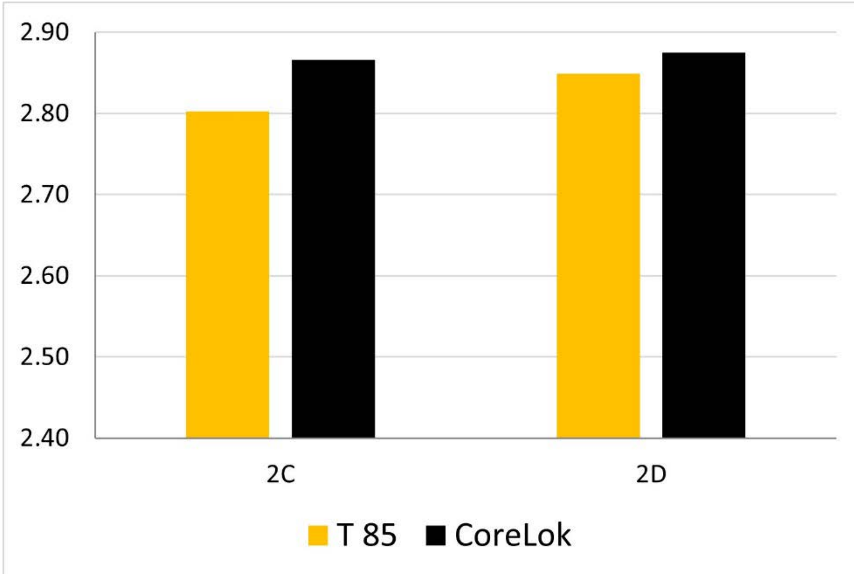

Figure 5.2 Bulk (Dry) Specific Gravity Averages for ITD District 2

District 3 Coarse Aggregates

District 3 results for the AASHTO T 85test method bulk (dry) specific gravity ranged from 2.412 to 2.519 and absorption varied between 2.491 and 2.671 percent. The apparent specific gravity values were slightly higher, ranging from 2.574 and 2.671. Figure 5.3 shows the G_{sb} values determined using both the AASHTO T 85 and CoreLok test procedures.

Table 5.15 ITD District 3 Test Data using the AASHTO T 85 Test Procedure

Test Number	Aggregate	UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*
16	OW-94 Pile B	3G-1	2.414	2.479	2.581	2.671
17	OW-94 Pile B	3G-2	2.412	2.475	2.574	2.611
18	OW-94 Pile B	3G-3	2.419	2.479	2.574	2.491

Table 5.16 ITD District 3 Test Data using the CoreLok Test Procedure

Test Number	Aggregate	UI Lab ID	uG_{sb}	uG_{sb} SSD	uG_{sa}	*uAbs*
16	OW-94 Pile B	3G-1	2.495	2.544	2.623	1.964
17	OW-94 Pile B	3G-2	2.499	2.543	2.614	1.757
18	OW-94 Pile B	3G-3	2.501	2.548	2.626	1.903

Table 5.17 ITD District 3 Average Values

UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	Abs	uG_{sb}	uG_{sb} SSD	uG_{sa}	uAbs
3G	2.415	2.478	2.576	2.591	2.498	2.545	2.621	1.875

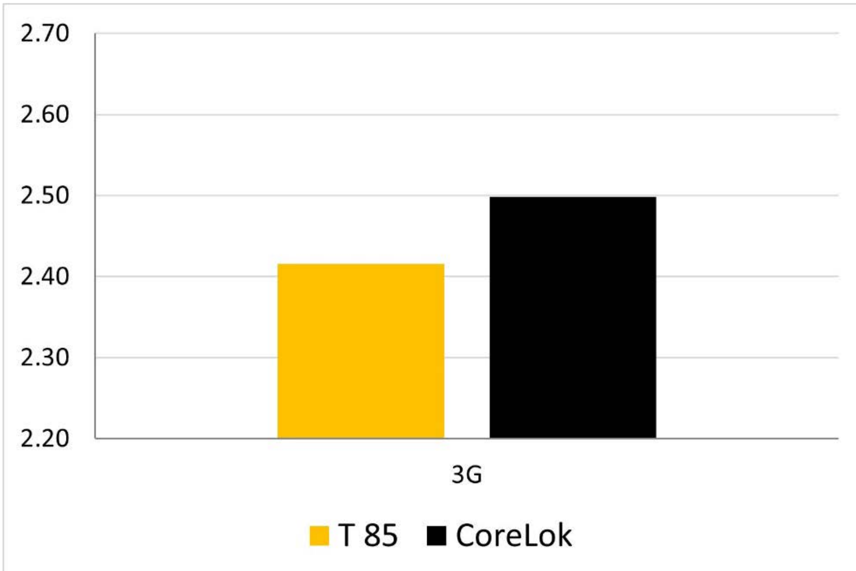

Figure 5.3 Bulk (Dry) Specific Gravity Average for ITD District 3

District 5 Coarse Aggregates

District 5 results for the AASHTO T 85 test method bulk specific gravities ranged from 2.581 to 2.599 and absorptions varied between 0.610 and 0.881 percent. The apparent specific gravities ranged between 2.631 and 2.650. Figure 5.4 shows the G_{sb} values determined using both the AASHTO T 85 and CoreLok test procedures.

Table 5.18 ITD District 5 Test Data using the AASHTO T 85 Test Procedure

Test Number	Aggregate	UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*
19	BG-111c Pile A	5I-1	2.599	2.615	2.642	0.631
20	BG-111c Pile A	5I-2	2.590	2.606	2.631	0.610
21	BG-111c Pile A	5I-3	2.594	2.614	2.645	0.740
22	BG-111c Pile B	5J-1	2.581	2.604	2.641	0.881
23	BG-111c Pile B	5J-2	2.599	2.618	2.650	0.751
24	BG-111c Pile B	5J-3	2.593	2.614	2.650	0.830

Table 5.19 ITD District 5 Test Data using the CoreLok Test Procedure

Test Number	Aggregate	UI Lab ID	uG_{sb}	uG_{sb} SSD	uG_{sa}	*uAbs*
19	BG-111c Pile A	5I-1	2.602	2.622	2.655	0.769
20	BG-111c Pile A	5I-2	2.609	2.628	2.658	0.705
21	BG-111c Pile A	5I-3	2.617	2.635	2.666	0.698
22	BG-111c Pile B	5J-1	2.636	2.648	2.667	0.454
23	BG-111c Pile B	5J-2	2.629	2.642	2.664	0.502
24	BG-111c Pile B	5J-3	2.630	2.644	2.667	0.526

Table 5.20 ITD District 5 Average Values

UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*	uG_{sb}	uG_{sb} SSD	uG_{sa}	*uAbs*
5I	2.594	2.611	2.640	0.660	2.609	2.628	2.660	0.724
5J	2.591	2.612	2.647	0.821	2.632	2.645	2.666	0.494

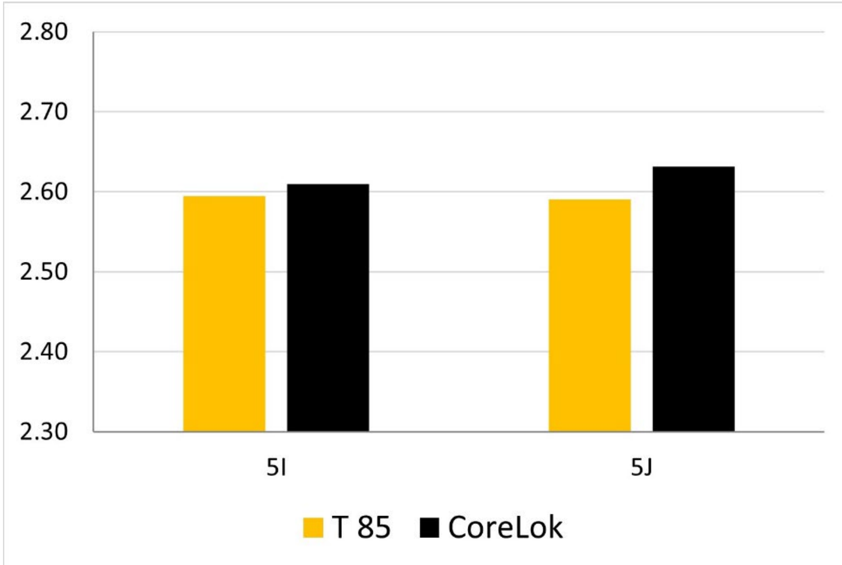

Figure 5.4 Bulk (Dry) Specific Gravity Averages for ITD District 5

District 6 Coarse Aggregates

District 6 results for the AASHTO T 85 test procedure bulk (dry) specific gravities ranged from 2.435 to 2.652 and the absorptions varied between 0.501 and 2.395 percent. The absorption range for District 6 is larger than the ranges for the other districts. The apparent specific gravities ranged between 2.584 and 2.702. Figure 5.5 shows the G_{sb} values determined using both the AASHTO T 85 and CoreLok test procedures.

Table 5.21 ITD District 6 Test Data using the AASHTO T 85 Test Procedure

Test Number	Aggregate	UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*
25	Fr-104c	6A-1	2.440	2.496	2.584	2.290
26	Fr-104c	6A-2	2.455	2.509	2.595	2.201
27	Fr-104c	6A-3	2.451	2.506	2.595	2.272
28	Fr-104c	6A-4	2.459	2.511	2.594	2.122
29	Fr-104c	6A-5	2.468	2.527	2.622	2.382
30	Fr-104c	6A-6	2.447	2.504	2.594	2.311
31	Fr-104c	6A-7	2.435	2.493	2.586	2.395
32	Fr-104c	6A-8	2.440	2.497	2.588	2.342
33	BN-59s	6B-1	2.652	2.668	2.694	0.590

Test Number	Aggregate	UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	*Abs*
34	BN-59s	6B-2	2.629	2.644	2.670	0.583
35	BN-59s	6B-3	2.625	2.639	2.662	0.530
36	BN-59s	6B-4	2.617	2.634	2.662	0.641
37	BN-59s	6B-5	2.617	2.635	2.664	0.663
38	BN-59s	6B-6	2.608	2.624	2.652	0.630
39	BN-59s	6B-7	2.632	2.645	2.667	0.501
40	BN-59s	6B-8	2.615	2.635	2.668	0.765
41	LE-91s - 3/8 in.	6K-1	2.612	2.645	2.702	1.281
42	LE-91s - 3/8 in.	6K-2	2.598	2.632	2.689	1.313
43	LE-91s - 3/8 in.	6K-3	2.604	2.640	2.701	1.383
44	LE-91s - 3/4 in.	6L-1	2.597	2.627	2.677	1.139
45	LE-91s - 3/4 in.	6L-2	2.621	2.644	2.683	0.879
46	LE-91s - 3/4 in.	6L-3	2.621	2.648	2.694	1.031
47	Le-160c	6M-1	2.611	2.641	2.691	1.142
48	Le-160c	6M-2	2.555	2.609	2.700	2.094
49	Le-160c	6M-3	2.615	2.647	2.700	1.204
50	BN-156c Pile A	6N-1	2.609	2.628	2.659	0.713
51	BN-156c Pile A	6N-2	2.581	2.604	2.641	0.881
52	BN-156c Pile A	6N-3	2.603	2.621	2.651	0.700
53	BN-156c Pile B	6O-1	2.606	2.622	2.647	0.590
54	BN-156c Pile B	6O-2	2.613	2.628	2.652	0.561
55	BN-156c Pile B	6O-3	2.601	2.616	2.642	0.600

Table 5.22 ITD District 6 Test Data using the CoreLok Test Procedure

Test Number	Aggregate	UI Lab ID	uG_{sb}	uG_{sb} SSD	uG_{sa}	*uAbs*
25	Fr-104c	6A-1	2.550	2.580	2.629	1.166
26	Fr-104c	6A-2	2.560	2.585	2.626	0.980
27	Fr-104c	6A-3	2.540	2.571	2.620	1.194
28	Fr-104c	6A-4	2.549	2.577	2.622	1.095
29	BN-59s	6B-1	2.660	2.666	2.675	0.212
30	BN-59s	6B-2	2.655	2.663	2.676	0.296
31	BN-59s	6B-3	2.652	2.660	2.673	0.297
32	BN-59s	6B-4	2.650	2.656	2.665	0.216
33	LE-91s - 3/8 in.	6K-1	2.667	2.680	2.702	0.489
34	LE-91s - 3/8 in.	6K-2	2.655	2.669	2.692	0.522
35	LE-91s - 3/8 in.	6K-3	2.656	2.673	2.703	0.657
36	LE-91s - 3/4 in.	6L-1	2.647	2.665	2.695	0.669
37	LE-91s - 3/4 in.	6L-2	2.644	2.662	2.692	0.677
38	LE-91s - 3/4 in.	6L-3	2.646	2.663	2.691	0.625
39	Le-160c	6M-1	2.656	2.670	2.693	0.506
40	Le-160c	6M-2	2.661	2.672	2.690	0.410
41	Le-160c	6M-3	2.666	2.678	2.697	0.435
42	BN-156c Pile A	6N-1	2.639	2.655	2.682	0.612
43	BN-156c Pile A	6N-2	2.636	2.656	2.690	0.761
44	BN-156c Pile A	6N-3	2.639	2.656	2.684	0.625
45	BN-156c Pile B	6O-1	2.644	2.654	2.672	0.395
46	BN-156c Pile B	6O-2	2.637	2.649	2.669	0.460
47	BN-156c Pile B	6O-3	2.637	2.650	2.670	0.468

Table 5.23 ITD District 6 Average Values

UI Lab ID	G_{sb}	G_{sb} SSD	G_{sa}	Abs	uG_{sb}	uG_{sb} SSD	uG_{sa}	uAbs
6A	2.449	2.505	2.595	2.289	2.550	2.578	2.624	1.109
6B	2.624	2.640	2.667	0.613	2.654	2.661	2.672	0.255
6K	2.604	2.639	2.698	1.326	2.659	2.674	2.699	0.556
6L	2.613	2.640	2.684	1.017	2.646	2.663	2.693	0.657
6M	2.594	2.632	2.697	1.480	2.661	2.673	2.693	0.450
6N	2.598	2.618	2.650	0.764	2.638	2.656	2.685	0.666
6O	2.607	2.622	2.647	0.584	2.639	2.651	2.670	0.441

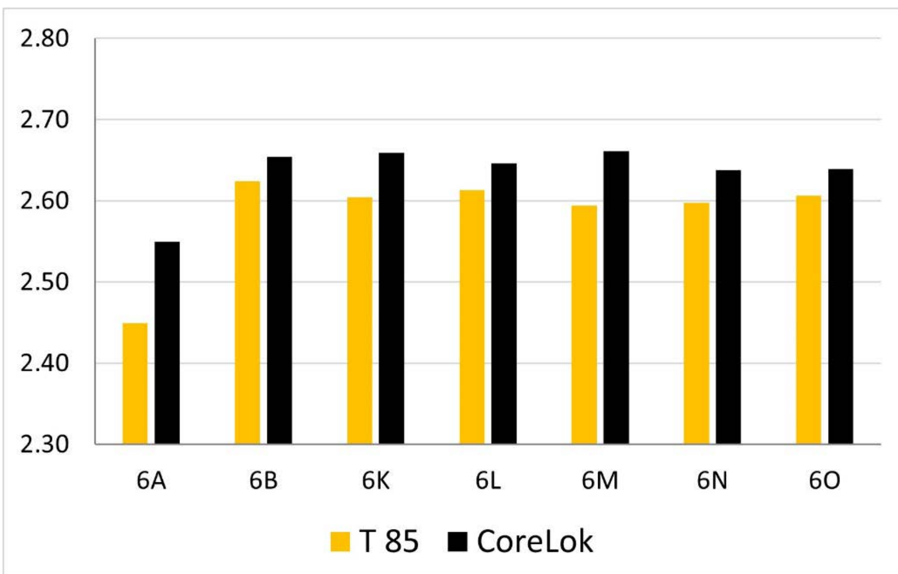

Figure 5.5 Bulk (Dry) Specific Gravity Averages for ITD District 6

Summary for All Districts

The bulk (dry) specific gravities of the aggregates tested with the AASHTO T 85 test procedure ranged from 2.412 to 2.853. The corresponding values from the CoreLok ranged from 2.495 to 2.853. The CoreLok test procedure consistently reported higher G_{sb} values than the AASHTO T 85 test procedure. Figure 5.6 shows the G_{sb} values determined using both the AASHTO T 85 and CoreLok test procedures.

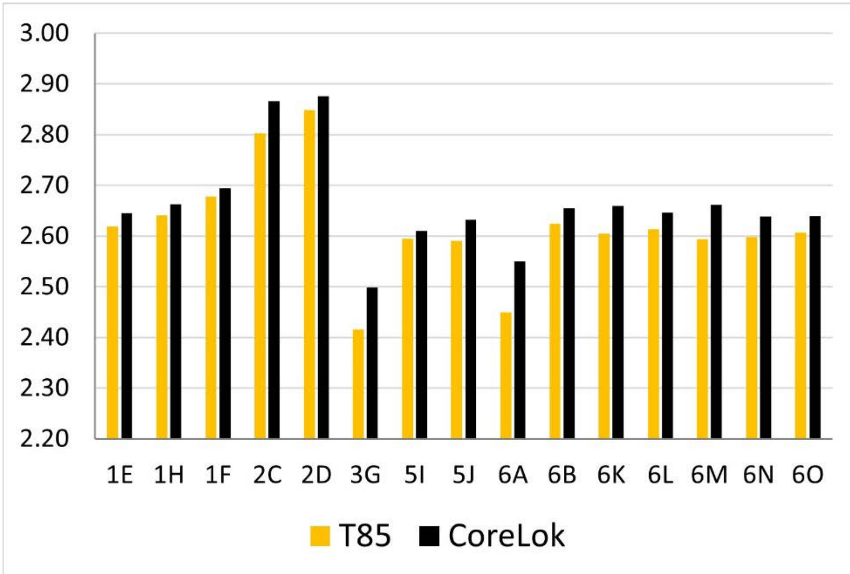

Figure 5.6 Bulk (Dry) Specific Gravity Averages of All Tested Coarse Aggregates

Unlike the bulk specific gravity, the apparent specific gravity results had a much closer range between the two test procedures. The AASHTO T 85 test procedure G_{sa} results ranged from 2.574 to 2.952. The CoreLok test procedure yielded results that ranged from 2.614 to 2.953. The results for the apparent specific gravities are presented in Figure 5.7.

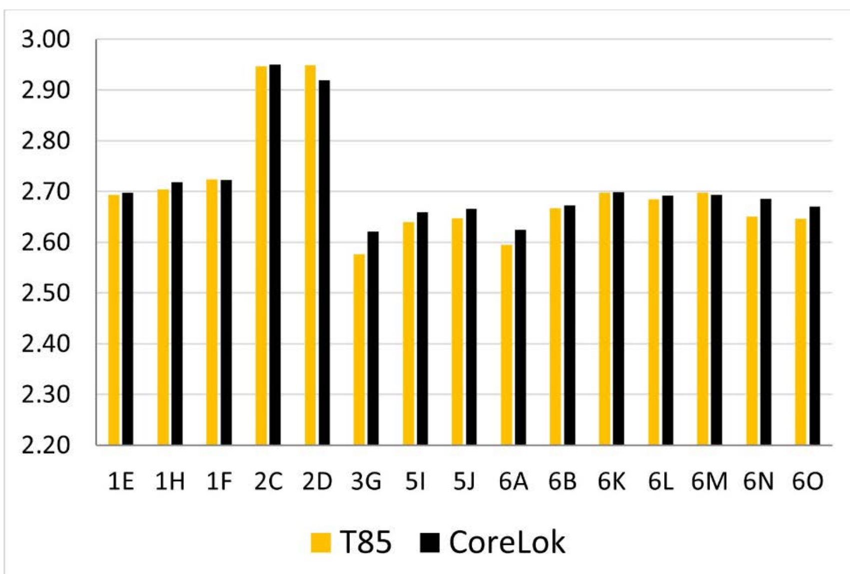

Figure 5.7 Apparent Specific Gravity Averages of All Aggregates Tested

Aggregate Blends

Blended aggregates were tested using the CoreLok test procedure to determine if the CoreLok device is capable of accurately measuring the specific gravity of a blend of aggregates (i.e., a combination of coarse and fine aggregates). Samples were prepared in accordance with methods described in Chapter 4. Two replicates from each blend were prepared so that the values could be averaged to develop representative specific gravities for the blend.

Given that there is no AASHTO test procedure for specific gravities of an aggregate blend, the AASHTO specific gravity for a blend was calculated using Equation 5.1.

$$G = \left(\frac{p_1 + p_2 + \cdots p_n}{\frac{p_1}{G_1} + \frac{p_2}{G_2} + \cdots \frac{p_n}{G_n}} \right) \tag{5.1}$$

where $p_1, p_2, \ldots p_n$ are the percentages by weight of aggregates 1, 2, through *n,* and $G_1, G_2, \ldots G_n$ are the corresponding specific gravities of aggregates 1, 2, through *n.*

The application of this equation may be illustrated using an example blend consisting of 25 percent fine aggregate with a specific gravity of 2.300 and 75 percent coarse aggregate with a specific gravity of 2.500. For such a blend, the combined specific gravity is calculated using Equation 5.2.

$$G = \left(\frac{25\% + 75\%}{\frac{25\%}{2.300} + \frac{75\%}{2.500}} \right) = 2.446 \tag{5.2}$$

The calculated values of the specific gravity of the prepared blends using Equation 5.1 are given Table 5.24. The specific gravities of the aggregate blends, determined using the CoreLok test procedure, are given in Table 5.25.

In Tables 5.24 and 5.25, the identification code uses the following order:

Sample ID for coarse aggregate – Blend (B) – Percent Fine Aggregate – Sample #

For samples that use an aggregate from more than one source, the source for the coarse aggregate is given first in the aggregate description.

Table 5.24 Theoretical Specific Gravities of Blended Aggregates using AASHTO Methods

UI Lab ID	Aggregate	G_{sb}	G_{sa}	*Abs*
6N-B-25-1	BN-156 25 percent #1	2.600	2.628	2.190
6N-B-50-1	BN-156 50% #1	2.601	2.639	1.730
6N-B-75-1	BN-156 75% #1	2.603	2.650	1.271
3G-B-25-1	OW-94 25% #1	2.421	2.513	2.663
3G-B-50-1	OW-94 50% #1	2.427	2.550	2.749
3G-B-75-1	OW-94 75% #1	2.433	2.587	2.836
6A-B-25-1	Fr-104c 25% #1	2.438	2.530	2.752
6A-B-50-1	Fr-104c 50% #1	2.444	2.564	2.909
6A-B-75-1	Fr-104c 75% #1	2.442	2.595	3.066
5I-B-50-1	BG-111c 50% #1	2.601	2.631	1.640
2C-B-50-1	WCW-23 50% #1	2.778	2.908	2.782
2C-B-90-1	WCW-23 90% #1	2.759	2.955	2.651
6M-B-75-1	LE-160 75% #1	2.549	2.637	1.840
6M-B-25-1	LE-160 25% #1	2.579	2.634	2.412
6N-B-75-1	OW-94f(25%)/BN-156c(75%) #1	2.556	2.620	2.718
2D-B-75-1	BG-111cf(25%)/NP-82(75%) #1	2.784	2.821	2.372
2D-B-50-1	BG-111cf(50%)/NP-82(50%) #1	2.722	2.762	1.795

The difference in the uG_{sa} value for Tests 70 and 71 in Table 5.25 is 0.094, which exceeds the AASHTO standard of 0.025 variation "within lab testing" for the same sample (Tran et al., 2015). This value comes from a nationwide round-robin experiment performed by AASHTO and is the standard deviation multiplied by two; this is the allowable tolerance for the same technician to test the same sample.

The values vary much due in part to the non-exact gradation of the coarse and fine material. All samples were prepared as explained in Chapter 3 to obtain equal samples but due to the random variation in the splitting procedure one sample may contain more aggregates passing Sieve No. 100 but retained on Sieve No. 200.

Table 5.25 Test Results for Blended Aggregates using the CoreLok Method

Test Number	District	Identification	Aggregate	***uG_{sb}***	***uG_{sa}***	***uAbs***
48	2	2C-B-50-1	WCW-23 50%	2.891	2.933	0.492
49	2	2C-B-50-2	WCW-23 50%	2.884	2.939	0.647
50	2	2C-B-90-1	WCW-23 90%	2.879	2.904	0.300
51	2	2C-B-90-2	WCW-23 90%	2.909	2.909	0.000
52	2	2D-B-75-1	BG-111cf(25%)/NP-82c(75%)	2.812	2.842	0.373
53	2	2D-B-75-2	BG-111cf(25%)/NP-82c(75%)	2.811	2.839	0.344
54	2	2D-B-50-1	BG-111cf(50%)/NP-82c(50%)	2.748	2.776	0.375
55	2	2D-B-50-2	BG-111cf(50%)/NP-82c(50%)	2.750	2.773	0.297
56	3	3G-B-25-1	OW-94 25%	2.517	2.635	1.779
57	3	3G-B-25-2	OW-94 25%	2.511	2.635	1.871
58	3	3G-B-50-1	OW-94 50%	2.524	2.645	1.811
59	3	3G-B-50-2	OW-94 50%	2.524	2.644	1.804
60	3	3G-B-75-1	OW-94 75%	2.544	2.615	1.063
61	3	3G-B-75-2	OW-94 75%	2.544	2.639	1.414
62	5	5I-B-50-1	BG-111c 50%	2.635	2.662	0.380
63	5	5I-B-50-2	BG-111c 50%	2.63	2.665	0.500
64	6	6N-B-25-1	BN-156c 25%	2.638	2.67	0.450
65	6	6N-B-25-2	BN-156c 25%	2.64	2.678	0.545
66	6	6N-B-50-1	BN-156c 50%	2.637	2.654	0.243
67	6	6N-B-50-2	BN-156c 50%	2.644	2.668	0.340
68	6	6N-B-75-1	BN-156c 75%	2.645	2.666	0.295
69	6	6N-B-75-2	BN-156c 75%	2.638	2.657	0.264
70	6	6A-B-25-1	Fr-104c 25%	2.535	2.616	1.218
71	6	6A-B-25-2	Fr-104c 25%	2.504	2.522	0.281
72	6	6A-B-50-1	Fr-104c 50%	2.545	2.619	1.100

Test Number	District	Identification	Aggregate	uG_{sb}	uG_{sa}	*uAbs*
73	6	6A-B-50-2	Fr-104c 50%	2.541	2.615	1.124
74	6	6A-B-75-1	Fr-104c 75%	2.532	2.623	1.370
75	6	6A-B-75-2	Fr-104c 75%	2.529	2.625	1.449
76	6	6M-B-75-1	Le-160c 75%	2.648	2.703	0.766
77	6	6M-B-75-2	Le-160c 75%	2.651	2.691	0.554
78	6	6M-B-25-1	Le-160c 25%	2.648	2.678	0.424
79	6	6M-B-25-2	Le-160c 25%	2.645	2.68	0.490
80	6	6N-B-75-1	OW-94f(25%)/BN-156c(75%)	2.594	2.61	0.235
81	6	6N-B-75-2	OW-94f(25%)/BN-156c(75%)	2.603	2.611	0.123

Similar to the coarse aggregate data, Table 5.26 presents the average values for the blended aggregates along with a comparative bar graph in Figure 5.8. The averages are used for the statistical analysis presented and discussed in Chapter 6.

Table 5.26 Average Test Results for Blended Aggregates using the CoreLok Method

Sample ID	uG_{sb}	uG_{sa}	***uAbs***
2C-B-50-1	2.888	2.936	0.570
2C-B-90-1	2.894	2.907	0.150
2D-B-75-1	2.812	2.840	0.359
2D-B-50-1	2.749	2.774	0.336
3G-B-25-1	2.514	2.635	1.825
3G-B-50-1	2.524	2.645	1.808
3G-B-75-1	2.544	2.627	1.239
5I-B-50-1	2.633	2.663	0.440
6N-B-25-1	2.639	2.674	0.498
6N-B-50-1	2.640	2.661	0.292
6N-B-75-1	2.642	2.661	0.279
6A-B-25-1	2.519	2.569	0.750
6A-B-50-1	2.543	2.617	1.112
6A-B-75-1	2.530	2.624	1.409
6M-B-75-1	2.650	2.697	0.660
6M-B-25-1	2.647	2.679	0.457
6N-B-75-1	2.598	2.611	0.179

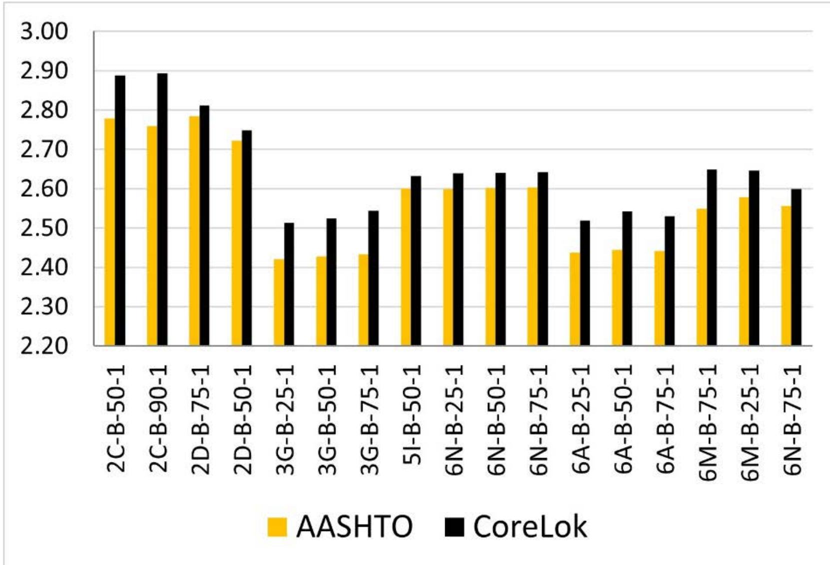

Figure 5.8 Comparison of Average Bulk (Dry) Specific Gravity for Blended Aggregate

Summary

Analyzing the test results from the coarse, blended and RAP aggregates provide insight into the characteristics of the test aggregates and how the specific gravity values compare to each other. It is also worth noting how the same results compared against each other when using the AASHTO T 85 or the CoreLok test procedures Below are observations from the results discussed in this chapter.

- Both test procedures reported similar apparent specific gravity values.
- The CoreLok test procedure systematically reported higher bulk specific gravities than the AASHTO T 85 test procedure.
- Absorptions on the high end of the spectrum (>1.5 percent) from the AASHTO T 85 are reported at a significantly lower value using the CoreLok test procedure.
    - For *Abs* greater than 1.5 percent, the average AASHTO T 85 values were 0.884 percent greater than the CoreLok results.
    - For *Abs* values less than 1.5 percent, the average AASHTO T 85 values were 0.364 percent greater than the CoreLok results.
- For *Abs* values less than 0.5 percent, both methods reported similar results.
- The bulk specific gravities from the 15 aggregates ranged from 2.4 to 2.9 with a majority falling between 2.5 and 2.7
- ITD District 2 coarse aggregates had the highest average G_{sb} values.
- ITD District 3 coarse aggregates had the lowest average G_{sb} values.
- The absorption values for the 15 aggregates ranged from 0.5 to 2.4 percent.

6. Statistical Analysis

Introduction

The statistical analysis presented in this chapter used averaged values from the 102 coarse aggregate tests performed in this study. Additionally, the averaged values for the 33 blended aggregate tests were used in their individual statistical analyses. Each sample has data gathered from the AASHTO T 85, or equivalent AASHTO test procedure, and the CoreLok test procedure. These data points and the subscript identifiers are listed in Table 6.1. A "*u*" or "*c*" prefix will be added to the CoreLok terms to denote if the term represents the uncorrected or corrected value.

Table 6.1 Notation of Values used in the Statistical Analyses

Material	Test Method	Bulk Specific Gravity	Apparent Specific Gravity	Effective Specific Gravity	Absorption
Aggregate	AASHTO	G_{sb}	G_{sa}	N/A	*Abs*
Aggregate	CoreLok	uG_{sb}	uG_{sa}	N/A	*uAbs*

The SSD bulk specific gravity results are not included in these analyses because G_{sb} *SSD* is not an independent variable as it is a function of G_{sb} and *Abs*, as indicated by Equation (1.5).

For the coarse and blended aggregates, the analyses were performed in a similar manner. To start, correlations were established to show similarities between variables. Regression trends were then established to modify the uG_{sb} values, and the trends were tested to see if the models provided good fits for the data.

Prior to beginning the statistical analysis portion of this report, the researchers decided in conjunction with ITD to use an alpha value (α) of 0.05 for all statistical tests. With $\alpha = 0.05$, the confidence interval is 95 percent, or in other words there is a 95 percent chance that the two sample populations being compared are statistically similar to each other.

Coarse Aggregates

The G_{sb} test results for coarse aggregate ranged from 2.400 to 2.900, and the G_{sa} values ranged between 2.500 and 3.000. The CoreLok test procedure yielded values that fell within the same ranges allowing for ease of comparison between the two tests. Figure 6.1 provides a scatterplot of the bulk (dry) specific gravity values gathered from the testing procedures. In Figure 6.1, the G_{sb} (CL) values represent data from the CoreLok tests and the G_{sb} (T) values represent results from the AASHTO T 85 test procedure. The solid red line in the figure represents the one-to-one line of equality.

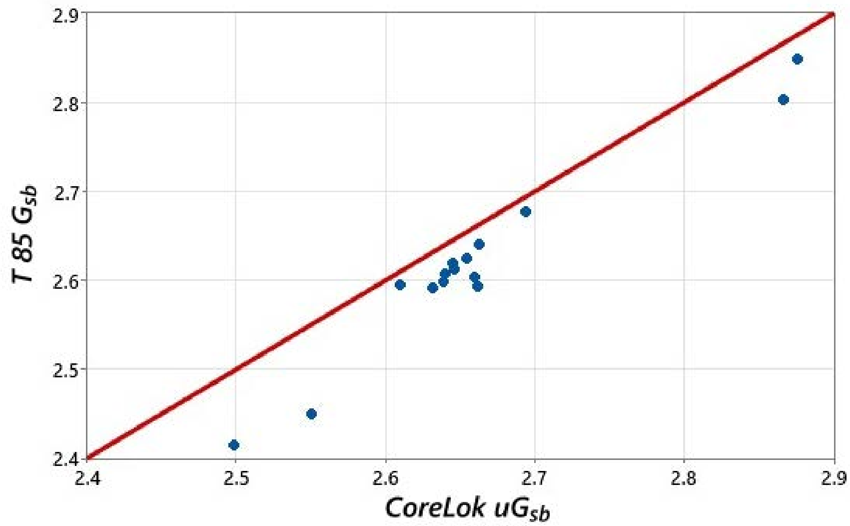

Figure 6.1 Plot of Bulk (Dry) Specific Gravities for Coarse Aggregates without correction

As can be seen in Figure 6.1, the CoreLok test procedure overestimated bulk specific gravities for all aggregates tested. To correct for this the uG_{sb} values need to be modified to meet the equality line shown in red.

Prior to making any corrections, the data must be fully examined to see if any correlations exist between the data collected from testing. In addition to this, the base statistics need to be examined to ensure that the populations are approximately the same. The descriptive statistics (i.e., minimum, maximum, mean, median, standard deviation, and quartile ranges) for all values used in the coarse analysis are summarized in Table 6.2.

Table 6.2 Descriptive Statistics for 15 Coarse Aggregates

Variable	Minimum	Maximum	Mean	Median	Standard Deviation	Quartile 1	Quartile 3
G_{sb}	2.415	2.849	2.619	2.607	0.108	2.594	2.640
G_{sa}	2.577	2.949	2.701	2.685	0.108	2.647	2.705
Abs	0.584	2.591	1.179	1.017	0.617	0.660	1.480
uG_{sb}	2.498	2.875	2.662	2.646	0.097	2.632	2.662
uG_{sa}	2.621	2.950	2.713	2.693	0.095	2.666	2.718
$uAbs$	0.255	1.875	0.711	0.657	0.393	0.450	0.777

The data shown in Table 6.2 have the same number of values for each variable, ensuring that each variable belongs to a matching set of data points. The standard deviations are approximately similar, except for the absorption values, *Abs* and *uAbs*. The specific gravities also all fall within the 2.400 to 3.000 range.

Table 6.3 shows the correlation matrix between all values for the coarse aggregate. The values displayed on the matrix are the Pearson correlation coefficient (r) and the p-value between the two samples. The r value explains how much of the relationship between the two variables can be predicted with a perfectly linear trend. For example, an $r = 1$ would mean that every data point is exactly the same for the two variables being compared. The p-value is a statistical output from a hypothesis test comparing the means of the two variables. A p-value less than the selected alpha value ($\alpha = 0.05$) means that with the supplied data the sample means cannot be proven not to be equal. In other words, a p-value less than 0.05 means that for all data collected, the means are approximately similar.

The correlations that are statistically similar according to the p-values are bolded in Table 6.3. These similarities correspond to the strongest linear trends according to the r value. The correlations are summarized below:

- uG_{sa} *and* G_{sa} have the strongest correlation ($r = 0.992$), with 99.2 percent of the data being explained by a one-to-one relationship.
- Other notable correlations are: (uG_{sb} and G_{sb}), (uG_{sb} and G_{sa}), and (G_{sb} and uG_{sa}).
- Absorptions have negative trends with all variables except for the (*uAbs* and *Abs*) correlation.

Table 6.3 Correlation Matrix for Coarse Aggregate Variables

Variable	Statistical Measurement	G_{sb}	G_{sa}	Abs	uG_{sa}	*uAbs*
G_{sa}	Pearson r	**0.9292**				
	p-Value	**0.000**				
Abs	Pearson r	-0.405	-0.039			
	p-Value	0.134	0.889			
uG_{sa}	Pearson r	**0.905**	**0.992**	0.007		
	p-Value	**0.000**	**0.000**	0.981		
uAbs	Pearson r	-0.496	-0.209	**0.829**	-0.127	
	p-Value	0.060	0.455	**0.000**	0.651	
uG_{sb}	Pearson r	**0.975**	**0.979**	-0.217	**0.963**	-0.389
	p-Value	**0.000**	**0.000**	0.437	**0.000**	0.152

Apparent Specific Gravity

As shown in the literature review portion of this document, several researchers (Cross et al., 2005; Sholar et al., 2005) found that the G_{sa} values determined by the CoreLok and AASHTO T 85 test procedures produced results that were statistically similar and did not require regression models to correct the values. The data shown in Table 6.3 confirms these findings for the aggregates tested in this study. The linear trend between the G_{sa} and uG_{sa} has the strongest correlation ($r = 0.992$) and the sample means are statistically similar.

Figure 6.2 shows a scatterplot of the apparent specific gravities for 15 coarse aggregates tested in this study. The data is centered around the line of equality and has a clear positive linear trend. These results clearly show that the G_{sa} values measured using both test procedures can be treated as equal in future calculations. In other words, we can assume that cG_{sa} is equal to uG_{sa}, which is also the same as the G_{sb} value determined using the AASHTO T 85 test procedure.

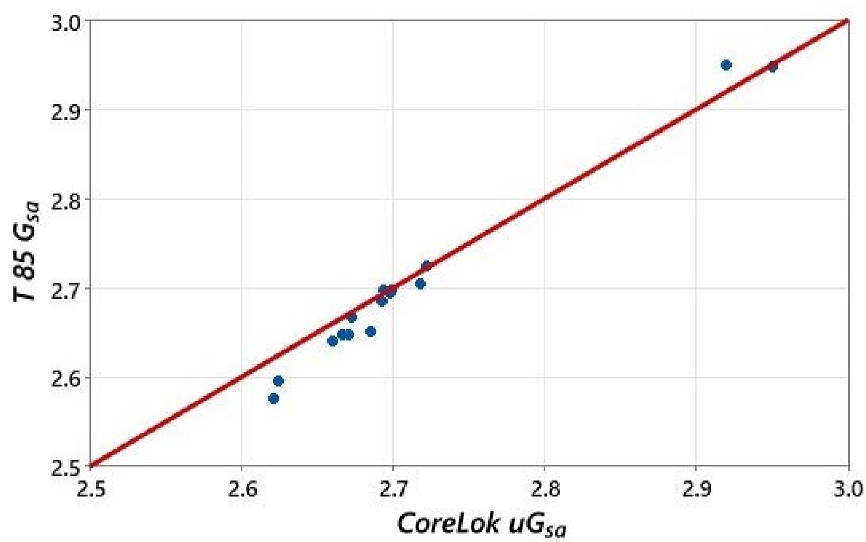

Figure 6.2 Plot of Apparent Specific Gravities for Coarse Aggregates

Bulk Specific Gravity

The bulk (dry) specific gravity determined by the AASHTO T 85 and CoreLok test procedures does not have as strong of a trend compared to the G_{sa} values for the same tests. As seen in Figure 6.3 the uG_{sb} values require modification so that the populations display a stronger linear correlation with the G_{sb} determined by the AASHTO T 85 test procedure. A regression model will be investigated to implement such a modification.

The first regression model considered was a linear regression, meaning the regression equation follow the standard form of a line: $y = B + Mx$. The G_{sb} value was selected as the response variable for the predictor variable, uG_{sb}. This linear regression model is presented in Figure 6.3.

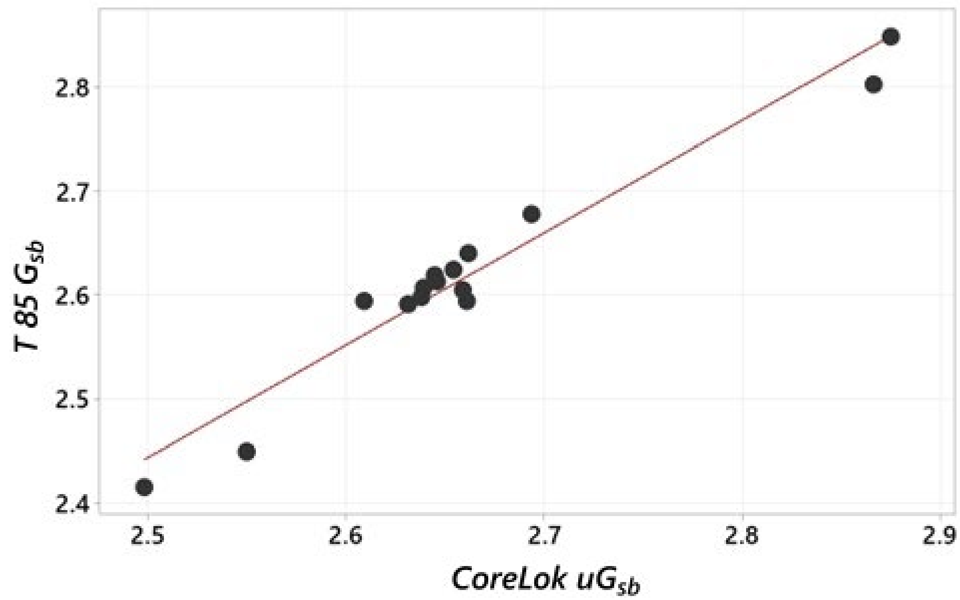

Figure 6.3 Linear Regression Model for Bulk (Dry) Specific Gravity

The linear regression equation and several descriptive statistics are summarized below.

$$cG_{sb} = -0.2610 + 1.082 \times uG_{sb} \tag{6.1}$$

- R^2 = 0.9504
- Standard deviation of residuals = 0.025

The R^2 value stated above is a measurement of how strongly the model predicts the *y*-value as it is a function of the deviation of all data points from the predicted model. The standard deviation of the residual is the standard deviation of this distance.

Examining the residual plots of this model provides further insight into the individual data interaction with the model. Residuals are values that are representative of the absolute differences between each datapoint and the fitted equation. Figure 6.4 shows the residual normal probability plot for the linear regression model. This plot is a representation of how the data is distributed along a typical bell-curve. If the data follows the solid red line exactly, then it has a perfect bell curve distribution.

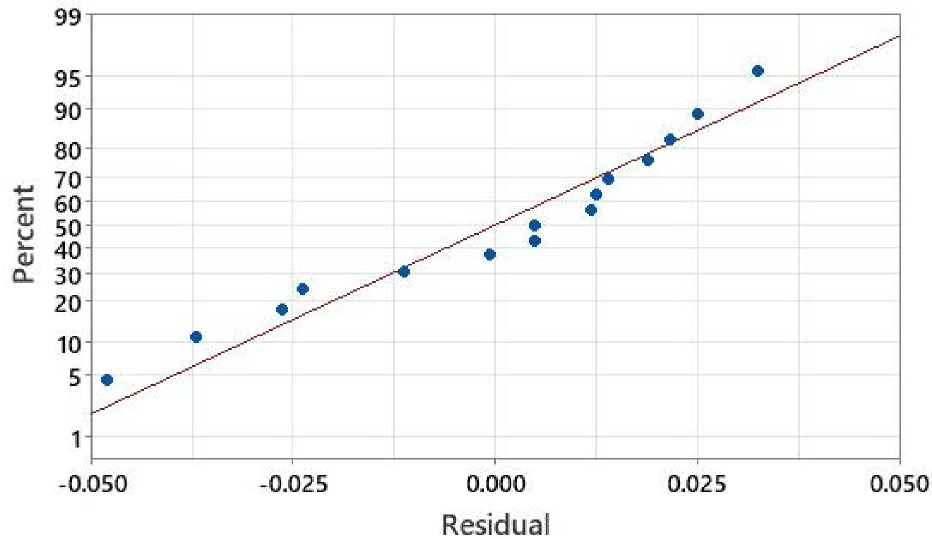

Figure 6.4 Normal Probability Plot for Linear Regression Residuals

Figure 6.4 shows a wave pattern around the normal distribution line. This indicates that residuals at the lower and upper ends of the spectrum fall above a bell distribution. This implies the need to consider a quadratic, regression fit with a squared term.

Figure 6.5 shows a quadratic regression model with a uG_{sb}^2 term included to center the residuals around a bell curve distribution more evenly.

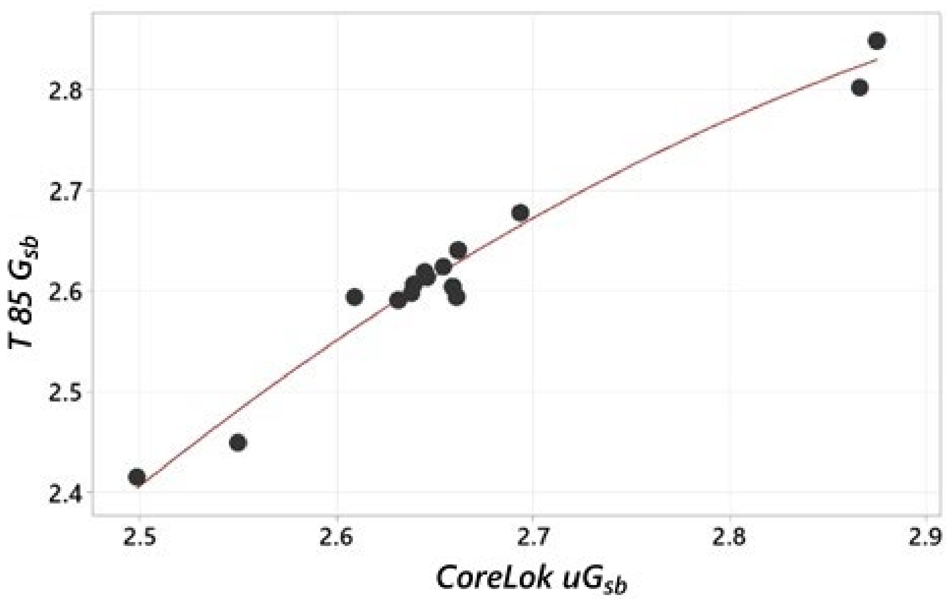

Figure 6.5 Quadratic Regression Model for Bulk (Dry) Specific Gravity

Figure 6.5 shows a regression model with a better fit through most of the G_{sb} data points. Descriptive statistics for the model are given below.

$$cG_{sb} = -8.657 + 7.299 \times uG_{sb} - 1.147 \times uG_{sb}^{\ 2} \tag{6.2}$$

- R^2 = 0.9696
- Standard deviation of residuals = 0.020

The quadratic model offers a higher R^2 term and lower standard deviation of the residuals, compared to the linear model. This model provides a better fit for the data. The normal probability plot for this model is given in Figure 6.6

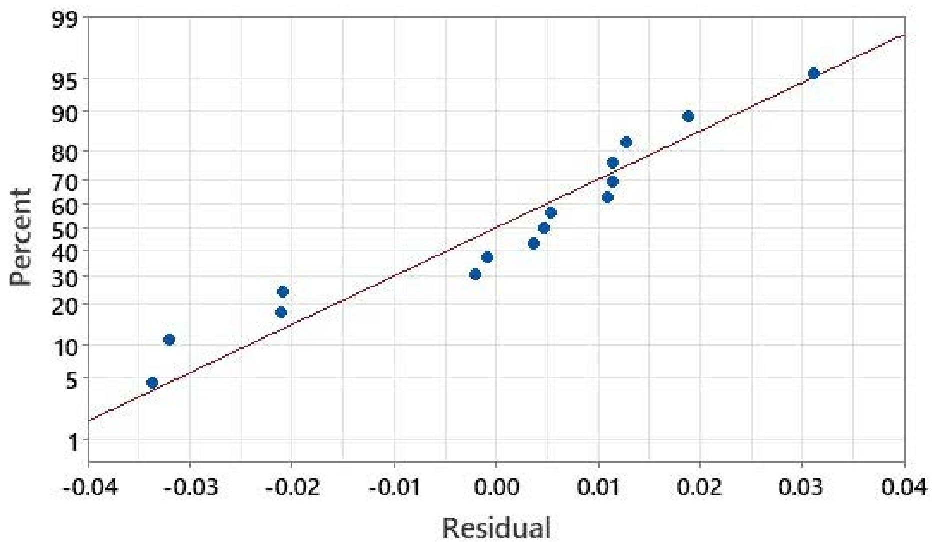

Figure 6.6 Normal Probability Plot for Quadratic Regression Residuals

While not completely fixing the issues of distribution discussed above, the new model provided residuals that are more evenly distributed above and below the curve, thus creating a more reliable model.

Figure 6.7 shows the quadratic regression model with the 95 percent confidence interval plotted with dashed lines. All points shown in Figure 6.7 fall within the confidence interval. It can be concluded that this model reliably predicts all values produced by the CoreLok test procedure.

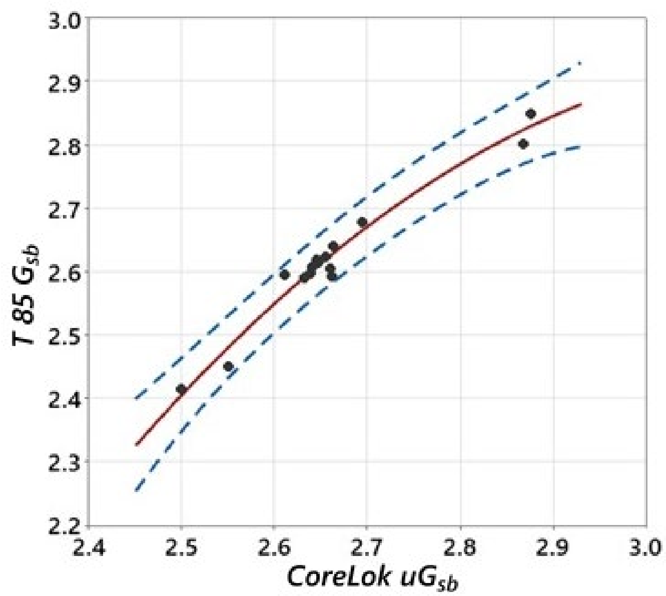

Figure 6.7 Quadratic Regression Model with 95 percent Confidence Limits

Table 6.4 presents the coefficient table for the quadratic model. While examining the coefficients for this model, it should be noted that the uG_{sb} and uG_{sb}^2 terms have high variance inflation factor (VIF) numbers. The VIF is a measurement of multicollinearity within the model. It is expected that these terms are collinear and trend together as they both measure the same quantity.

Table 6.4 Coefficient Table for Quadratic Regression Model for Coarse Aggregates

Term	Coefficient	95 percent Confidence Interval	T-Value	p-Value	VIF
Constant	-8.66	(-15.32, -1.99)	-2.83	0.015	
uG_{sb}	7.29	(2.37, 12.22)	3.23	0.007	1635.69
uG_{sb}^2	-1.147	(-2.056, -0.238)	-2.75	0.018	1635.69

VIF measurements can be decreased by centering the data around the overall mean of the data. To achieve this, the value of the overall mean will be calculated and subtracted from individual data values, leaving a positive or negative values. This transformation provides a new variable, $\Delta(uG_{sb})$ given by:

$$\Delta(uG_{sb}) = uG_{sb} - \text{mean}(uG_{sb}) \tag{6.3}$$

Where "mean(uG_{sb})" is the overall mean of all the uG_{sb} values in the data set. For values centered around the mean of the data, the quadratic regression model produced the following:

$$cG_{sb} = 2.62869 + 1.1847 \times \Delta(uG_{sb}) - 1.147 \times \Delta(uG_{sb})^2 \tag{6.4}$$

- R^2 = 0.9696
- Standard deviation of residuals = 0.020

The VIF measurements for the uG_{sb} and uG_{sb}^2 terms were both reduced to 1.47 after centering the data, implying that model is good. While this indicates a more statistically accurate model, the practicality of the model is reduced slightly. The mean for this analysis was available because all data points were available for the analysis, whereas if this equation is used by laboratory technicians the mean will constantly change with increased sample testing. In response, the coefficients in the model would also change to reflect the changing value of the mean.

As the R^2 values for both quadratic models are the same, the recommended equation for coarse aggregates is the non-centered model from Equation 6.2. A plot of the corrected cG_{sb} values derived from CoreLok testing compared to the G_{sb} results from AASHTO T 85 testing is presented in Figure 6.8.

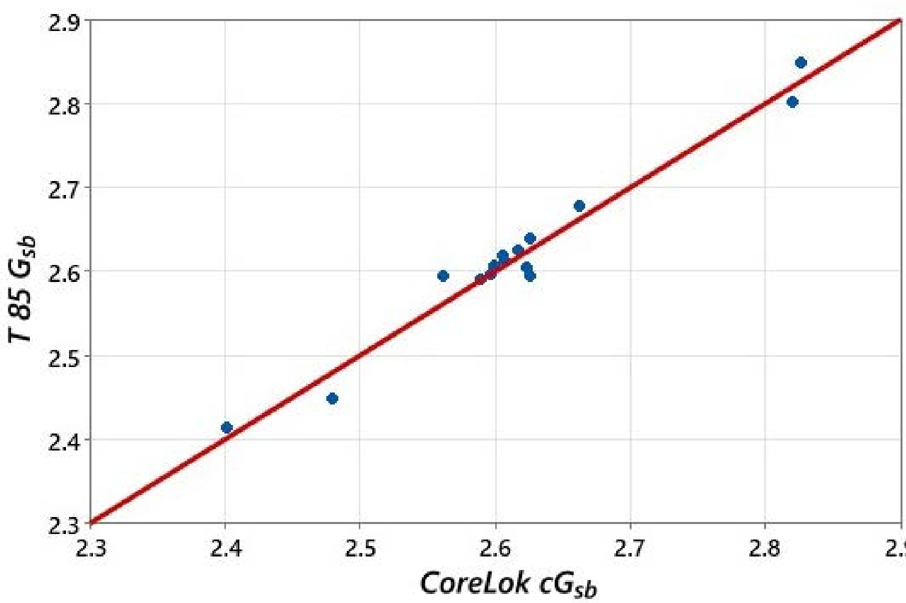

Figure 6.8 Plot of Bulk (Dry) Specific Gravities for Coarse Aggregates (with correction)

The correlation between the AASHTO T 85 test procedure G_{sb} and the corrected cG_{sb} from CoreLok test procedure is now 0.985, which is an improvement from the original correlation of 0.975.

Figure 6.9 shows a plot of the residuals for the modified cG_{sb} values. The variation of cG_{sb} from the AASHTO T 85 G_{sb} is about ± 0.03. The mean of these residuals is calculated to be 6.67E-06. There is no observed trend in the fit of these residuals. This shows that the model is a good fit for the data points.

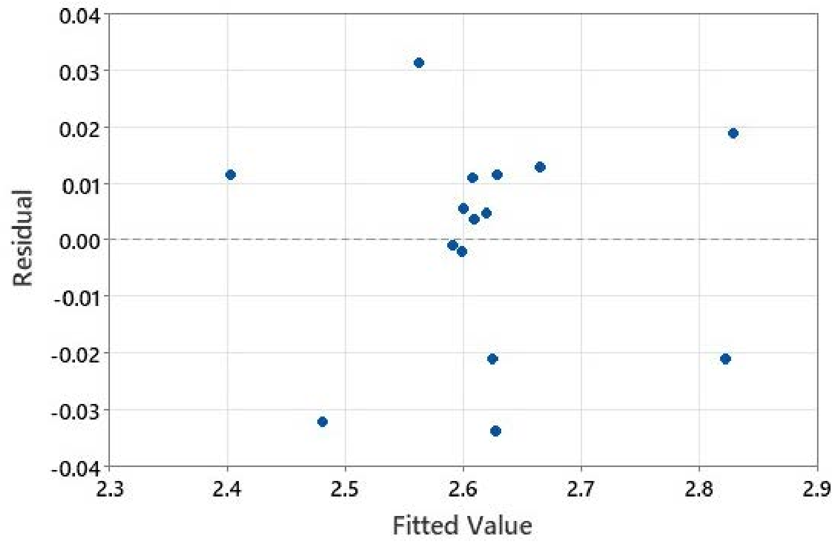

Figure 6.9 Residuals of Fitted Values for the Quadratic Trend for Coarse Aggregates

Absorption

The absorptions determined by the CoreLok test procedure are significantly lower than the absorptions reported from AASHTO T 85 test procedure. As presented in Table 6.1, the maximum *uAbs* value is 1.875 percent from CoreLok testing, whereas the maximum *Abs* value from AASHTO T 85 tests is 2.591. This has been speculated to be caused by the lack of direct G_{sb} *SSD* determination by the CoreLok test procedure (Sholar et al., 2005). Figure 6.10 shows the magnitude of these differences using a scatterplot of the absorption values from the AASHTO T 85 and CoreLok tests.

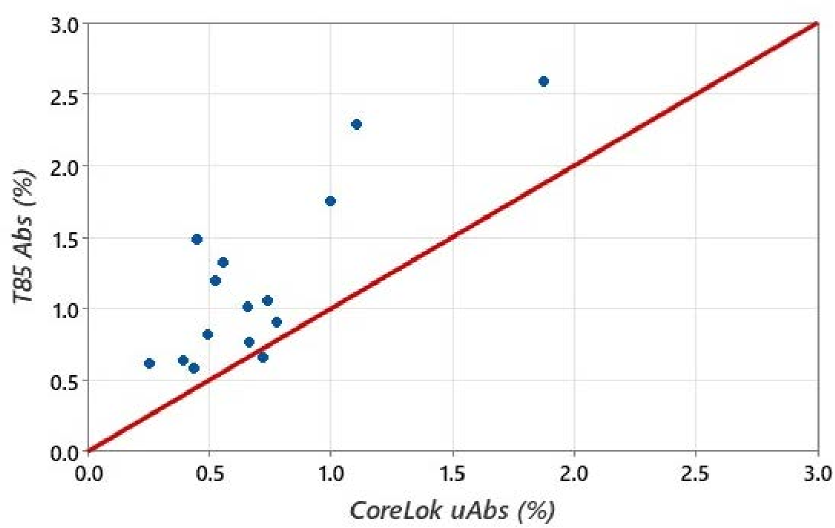

Figure 6.10 Plot of Absorptions for Coarse Aggregates (without correction)

As absorption (*Abs*) is a function of G_{sa} and G_{sb}, a corrected absorption from CoreLok testing is obtained using Equation 6.5.

$$cAbs\ (\%) = \left(\frac{1}{cG_{sb}} - \frac{1}{uG_{sa}}\right) \times 100 \tag{6.5}$$

This equation uses the corrected cG_{sb} value calculated using Equation 6.4 and the uG_{sa} value determined directly from the CoreLok test. Based on earlier discussions, the corrected cG_{sa} is the same value as uG_{sa} determined from the CoreLok test.

Figure 6.11 shows a plot of the corrected *cAbs* values against the *Abs* values from AASHTO T 85 test procedure. The calculated Pearson correlation coefficient for the absorption relationships is $r = 0.830$.

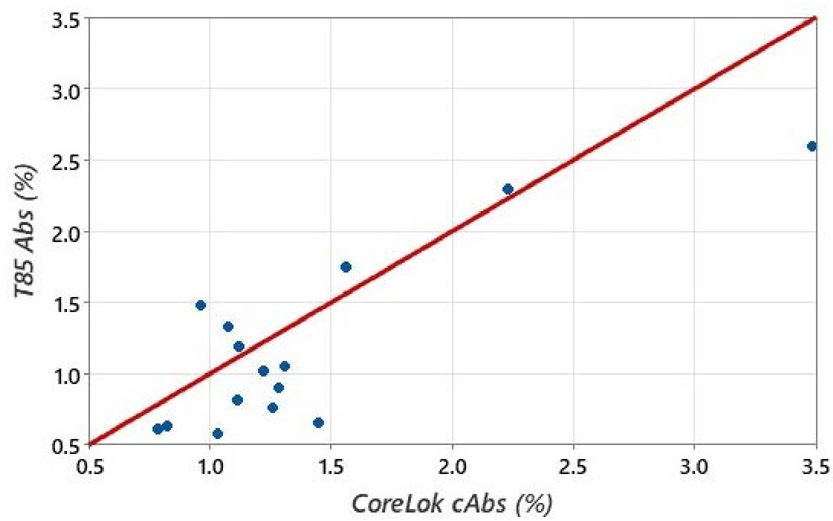

Figure 6.11 Plot of Absorptions for Coarse Aggregates (with correction)

Discussion

There is a strong correlation of the apparent specific gravities from testing of coarse aggregate when using the AASHTO T 85 and CoreLok test procedures. Hence there is no need to adjust the uG_{sa} value from the CoreLok test procedure as it is essentially the same as the AASHTO T 85 test procedure result. However, the bulk (dry) specific gravity, uG_{sb}, must be correlated to the AASHTO T 85 data to develop a suitable modification. After considering several models, the non-centered quadratic model was selected to correct the uG_{sb} values from CoreLok testing. Once the correct cG_{sb} is determined, the corrected absorption, *cAbs*, may be determined using the volumetric relationship equation.

Blended Aggregates

The analysis for blended aggregates was handled in a similar manner to the analysis for coarse aggregates. Some correlations differed slightly, but the overall trends and the test procedures remained the same.

To begin, the descriptive statistics and correlation relationships are needed to start an assessment of the data. Tables 6.5 and 6.6 show the descriptive statistics and correlation matrix for the blended aggregates.

Table 6.5 Descriptive Statistics for 17 Blended Aggregates

Variable	Minimum	Maximum	Mean	Median	Standard Deviation	Quartile 1	Quartile 3
G_{sb}	2.4211	2.7841	2.5728	2.579	0.1284	2.4398	2.6628
G_{sa}	2.5133	2.9555	2.6604	2.6314	0.1275	2.5758	2.7062
Abs (percent)	1.271	3.066	2.375	2.651	0.532	1.818	2.767
uG_{sb}	2.514	2.894	2.645	2.639	0.1232	2.5368	2.6993
uG_{sa}	2.569	2.936	2.695	2.662	0.106	2.625	2.736
uAbs	0.150	1.825	0.727	0.498	0.548	0.314	1.175
Percent Fines (P_F)	25.00	90.00	55.29	50.00	21.47	25.00	75.00

The maximum and minimum values for each variable follow the same trends as shown for the coarse aggregates. The maximum value of *uAbs* is much lower than maximum value of *Abs* and the range of minimum/maximum values fall between 2.400 and 3.000. The variable, percent fines (P_F), is included in the analysis to help differentiate samples with varying quantities of fine aggregate in the blends.

Table 6.6 provides insight into the correlations between the variables used in this portion of the analysis. The key findings from this Table 6.6 are summarized below.

- The uG_{sa} and G_{sa} has a strong correlation (r = 0.964), with 96.4 percent of the data being explained with a one-to-one relationship.
- Other notable correlations are: (uG_{sb} and G_{sb}), (uG_{sb} and G_{sa}), (uG_{sb} and uG_{sa}).
- Absorptions have negative trends with all variables except for the (*uAbs* and *Abs*) correlation.

Table 6.6 Correlation Matrix of 17 Blended Aggregates

Variable	Statistical Measurement	G_{sb}	G_{sa}	***Abs***	***u**G_{sa}*	***uAbs***
G_{sa}	Pearson *r*	**0.920**				
	p-Value	**0.000**				
Abs	Pearson *r*	-0.362	-0.084			
	p-Value	0.154	0.75			
uG_{sa}	Pearson *r*	**0.882**	**0.964**	-0.045		
	p-Value	**0.000**	**0.000**	0.864		
uAbs	Pearson *r*	**-0.751**	-0.583	0.539	-0.417	
	p-Value	**0.001**	0.014	0.026	0.095	
uG_{sb}	Pearson *r*	**0.962**	**0.983**	-0.195	**0.963**	-0.646
	p-Value	**0.000**	**0.000**	0.452	**0.000**	0.005

Apparent Specific Gravity

A scatterplot showing the trend of the apparent specific gravities can be seen in Figure 6.12. There is a clear positive trend with some deviation from the equality line at the lower end of the spectrum (2.500 to 2.700). The correlation *r* value for the G_{sa} and uG_{sa} relationship is 0.964, with a p-value of nearly zero. This provides evidence that the two sample populations can be treated as the same without the need for a regression model.

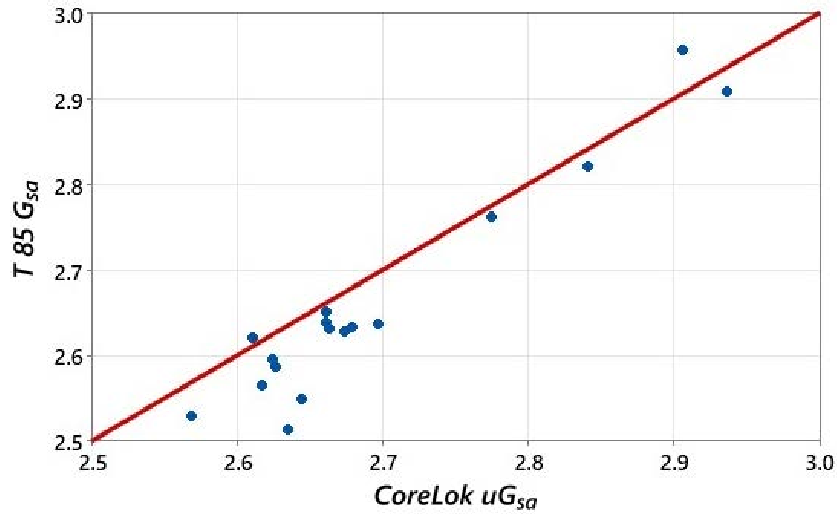

Figure 6.12 Plot of Apparent Specific Gravities for Blended Aggregates (without correction)

Bulk (Dry) Specific Gravity

The bulk specific gravities for blended aggregates ranged from 2.400 to 2.900. Figure 6.13 shows a plot of bulk specific gravities determined using the AASHTO T 85 and the CoreLok test procedures.

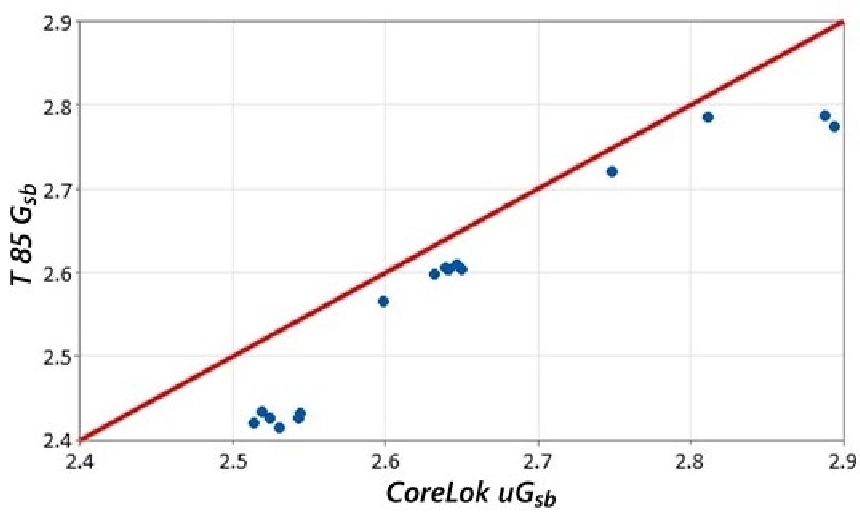

Figure 6.13 Plot of Bulk (Dry) Specific Gravities for Blended Aggregates (without correction)

The groupings of values in Figure 6.13 are indicative of the same type of aggregate used for the blends. For instance, the group with uG_{sb} values between 2.500 and 2.600 consists of blends containing 25 percent to 75 percent fine aggregate mixed using aggregates 6A and 3G. Figure 6.13 shows a clear trend that the CoreLok overestimates the bulk (dry) specific gravity when compared to the AASHTO T 85 test procedure data. To reliably predict G_{sb}, a regression model is required to develop a correction.

The regression procedure for blended aggregate followed the same process as explained for the coarse aggregate section. All regression models for the blended aggregates include the percent fine aggregate (P_F) term. This helps explain some of the variability produced by the different amounts of fine aggregate in each blended aggregate sample. As the fine aggregate particles contribute an increase in surface area compared to the additional weight, their presence will influence the G_{sb} of the blended aggregate. To account for this, the P_F term was retained in all models even if it did not lead to an improvement of the R^2 value.

A linear model was identified to that accounted for most of the data points in the model (R^2 = 0.9281). As the residuals for this model were not well balanced in the normal probability plot, a squared term was added to the regression equation. After adding the squared term, the R^2 value increased to 0.9720 and the distribution of the residuals on the normal distribution plot improved considerably. The equation for this quadratic function is given below, followed by the coefficient table information in Table 6.7.

Linear Model:

$$cG_{sb} = -0.109 + 1.0208 \times uG_{sb} + 0.000320 \times P_F \quad (6.6)$$

The R^2 for this model is 0.9281.

Table 6.7 Coefficient Table for Multivariable Regression for G_{sb}

Term	Coefficient	95 percent Confidence Interval	T-Value	P-Value	VIF
Constant	-0.109	(-0.544, 0.325)	-0.540	0.598	
uG_{sb}	1.021	(0.851, 1.191)	12.890	0.000	1.130
P_F	-0.0003	(-0.0012, 0.00065)	-0.700	0.493	1.130

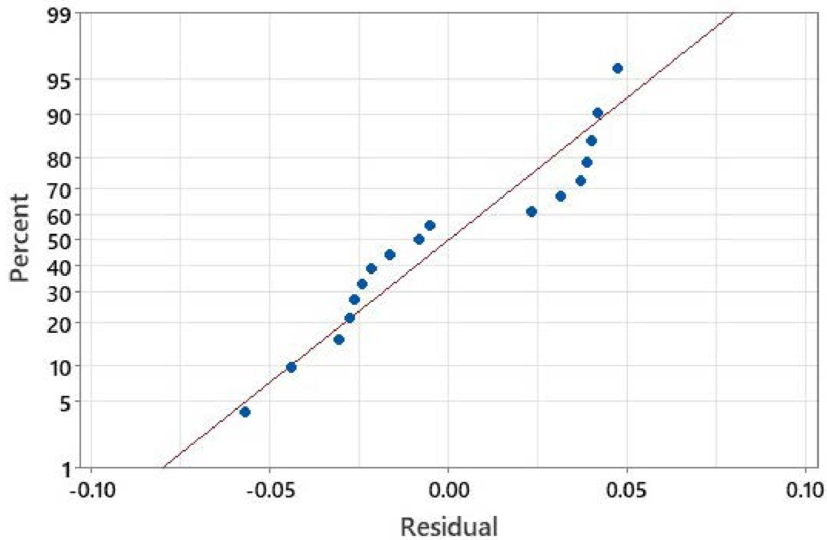

Figure 6.14 Normal Probability Plot of G_{sb} Multivariable Regression of Blended Aggregates

Quadratic model:

$$cG_{sb} = -14.08 + 11.40 \times uG_{sb} - 1.925 \times uG_{sb}{}^{2} - 0.000260 \times P_F \tag{6.7}$$

The R^2 for this model is 0.972.

Table 6.8 Coefficient Table for Quadratic Regression of G_{sb}

Term	Coefficient	95 percent Confidence Interval	T-Value	P-Value	VIF
Constant	-14.08	(-20.77, -7.39)	-4.540	0.001	
uG_{sb}	11.4	(6.430, 16.370)	4.906	0.000	2263.720
$uG_{sb}{}^2$	-1.925	(-2.846, -1.003)	-4.510	0.001	2265.120
P_F	-0.00026	(-0.000897, 0.000377)	-0.880	0.393	1.130

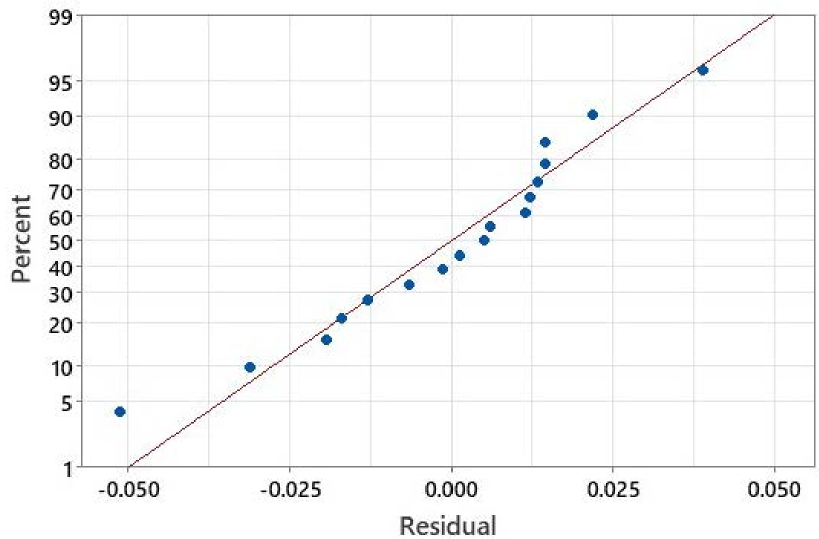

Figure 6.15 Normal Probability Plot of Quadratic G_{sb} Regression for Blended Aggregates

The quadratic regression model has a high VIF value similar to the quadratic model for the coarse aggregate. If the data were centered to negate this effect, the issue of a changing mean value would limit the application of this this model. So, the uncentered quadratic model is used as the adjustment for the uG_{sb}.

Figure 6.16 shows the correlation between the corrected cG_{sb} values from the CoreLok test procedure and the G_{sb} values from the AASHTO T 85 test procedure.

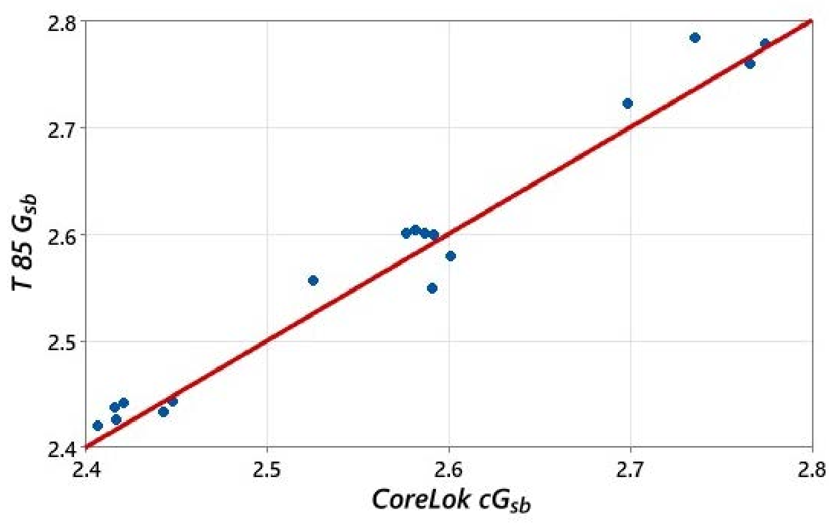

Figure 6.16 Plot of Bulk (Dry) Specific Gravities for Blended Aggregates (with correction)

The correlation between the G_{sb} and cG_{sb} has a Pearson Correlation Coefficient of r = 0.986. This is a considerable improvement from the originally correlation of r = 0.962 for the uncorrected data.

A plot of the residuals for the corrected cG_{sb} values can be seen in Figure 6.17. The residuals ranged from about -0.050 to +0.040. The mean of these residuals is 4.06E-04. There is no observed trend in the fit of these residuals. This shows that the model provides a good fit for the data points.

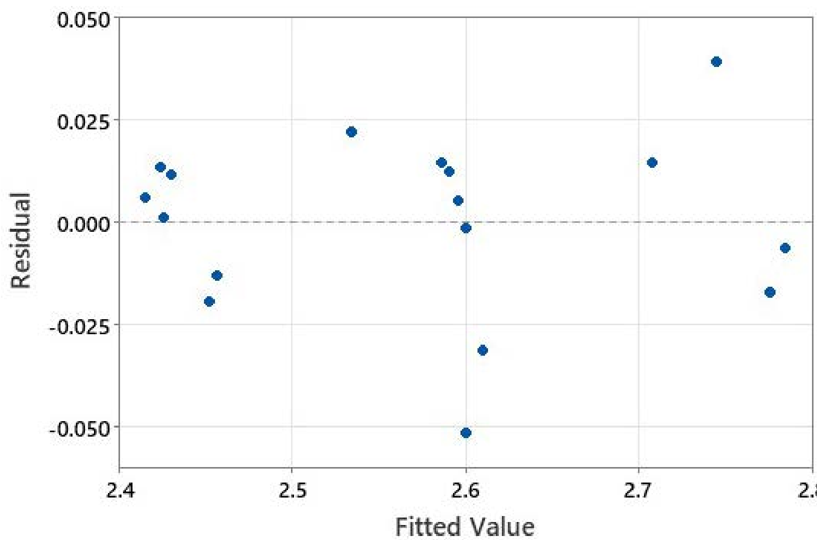

Figure 6.17 Residuals of Fitted Values for Quadratic G_{sb} Trend for Blended Aggregates

Absorption

As absorption (*Abs*) is a function of G_{sa} and G_{sb}, the corrected absorption, *cAbs*, from CoreLok testing may be calculated using Equation 6.5. Figure 6.18 shows a plot of the corrected absorption values against the *Abs* values.

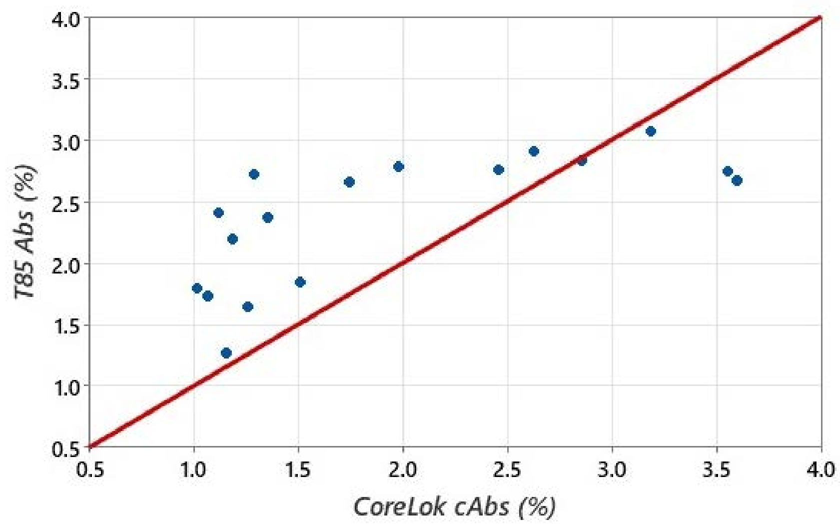

Figure 6.18 Plot of Absorptions for Blended Aggregates (with correction)

Discussion

After adjusting the values produced by the CoreLok either through regression or volumetric equation the new values showed significant improvement in terms of correlation and linear trends. All transformed data is included in the Appendix.

Coarse, Blended, and Fine Aggregate

After developing models for determining cG_{sb} of coarse and selected blended aggregates, this study also investigated a "Comprehensive" model that could be applied to all mixtures consisting of coarse and fine aggregates. To develop such a model, the data on fine aggregate from a previous study (RP252) by Sharma et al. (2020) was added to the data collected by this study. This portion of the analysis covers 57 average values that represent a total of 349 individual samples. The statistical analysis used to develop a correlation model followed the same process, as described earlier, for the development of the models for the coarse and blended aggregates.

In a similar manner to the statistical analyses completed in the previous sections, this analysis begins with an examination of the data and correlation as presented in Tables 6.9 and 6.10. All specific gravities tested range from 2.400 to 3.000. The CoreLok test procedure overestimates the bulk specific gravities and underestimates the apparent specific gravities. Through the volumetric relationship this also means that the CoreLok underestimated the absorption of the aggregates.

Table 6.9 Descriptive Statistics for Variables used in the Comprehensive Analysis

Variable	Minimum	Maximum	Mean	Median	Standard Deviation	Quartile 1	Quartile 3
G_{sb}	2.401	2.849	2.595	2.601	0.110	2.553	2.634
G_{sa}	2.513	2.978	2.690	2.659	0.116	2.628	2.711
Abs	0.500	3.223	1.686	1.480	0.843	0.899	2.624
uG_{sb}	2.498	2.894	2.659	2.645	0.105	2.615	2.685
uG_{sa}	2.563	2.970	2.702	2.670	0.104	2.638	2.720
*u*Abs)	0.000	1.875	0.609	0.498	0.461	0.258	0.874
P_F	0	100	61.430	75.000	42.220	6.250	100.000

Table 6.10 Correlation Matrix for Variables used in the Comprehensive Analysis

Variable	Statistical Measurement	G_{sb}	G_{sa}	G_{sa}	uG_{sa}	*uAbs*
G_{sa}	Pearson R	**0.889**				
	p-Value	**0.000**				
Abs	Pearson R	-0.335	0.014			
	p-Value	0.011	0.917			
uG_{sa}	Pearson R	**0.856**	**0.972**	0.101		
	p-Value	**0.000**	**0.000**	0.454		
uG_{sa}	Pearson R	**-0.476**	-0.170	**0.657**	-0.026	
	p-Value	**0.000**	0.205	**0.000**	0.847	
uG_{sb}	Pearson R	**0.952**	**0.970**	-0.100	**0.954**	-0.325
	p-Value	**0.000**	**0.000**	0.461	**0.000**	0.014

Table 6.10 shows insight into the correlations between the variables used in this portion of the analysis. The key findings from this table are presented below.

- The uG_{sa} and G_{sa} has a strong correlation (r = 0.972), with 97.2 percent of the data being explained with a one-to-one relationship.

- Other notable correlations are: (uG_{sb} and G_{sb}), (uG_{sb} and G_{sa}), (uG_{sa} and uG_{sa}).
- Absorptions have a negative or very minor correlation trend with all variables except for (*uAbs* and *Abs*)

Apparent Specific Gravity

The correlation *r* value for the G_{sa}, uG_{sa} relationship is 0.972 (Figure 6.19) and a p-value which is close to zero. This provides strong evidence that the two sample populations can be treated as equal without the need for a regression model.

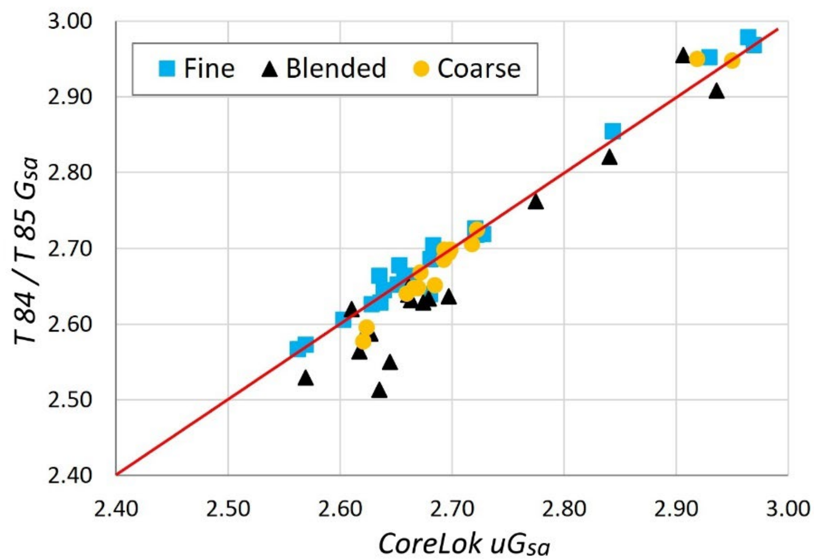

Figure 6.19 Comparison of Apparent Specific Gravities for All Aggregates (without correction)

Bulk (Dry) Specific Gravity

The bulk (dry) specific gravities cover a range of 2.300 to 2.900 with the CoreLok overestimating the uG_{sb} values, as shown in Figure 6.20. A regression is needed to adjust these values so that they fall closer to the one-to-one line.

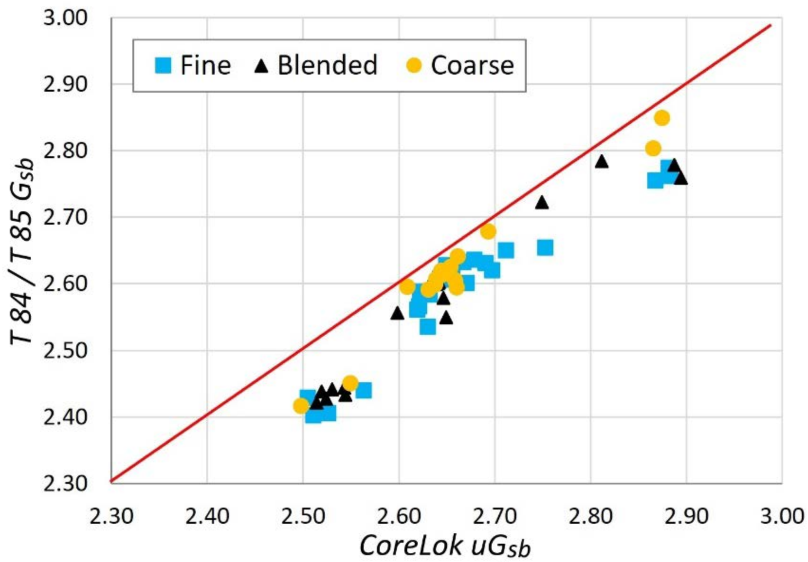

Figure 6.20 Bulk (Dry) Specific Gravities for All Aggregates (without correction)

As shown in the previous analyses, a model with a singular uG_{sb} value has residuals that deviate away from a normal distribution and the correct model requires a squared term to account for this shift. These same conclusions are observed during the statistical analysis of the comprehensive data set. The following section summarizes the statistical analysis of the full data set. A proposed linear model is presented in Equation 6.8, and Table 6.11 summarizes the linear model coefficients. Figure 6.21 shows the normal probability plot for the linear model presented in Equation 6.8. Equation 6.9 presents a nonlinear model for the data, and Table 6.12 summarizes the nonlinear model coefficients. Also, Figure 6.22 shows the normal probability plot for the nonlinear model presented in Equation 6.9.

Linear Model:

$$cG_{sb} = -0.036 + 0.9948 \times uG_{sb} + 0.000240 \times P_F \qquad (6.8)$$

Table 6.11 Coefficients Table for Multivariable Regression Model for Comprehensive Analysis

Term	Coefficient	95 percent Confidence Interval	T-Value	P-Value	VIF
Constant	-0.036	(-0.266, 0.194)	-0.310	0.756	
uG_{sb}	0.9948	(0.9077, 1.0820)	22.890	0.000	1.02
P_F	-0.000240	(-0.000450, -0.000030)	-2.290	0.026	1.02

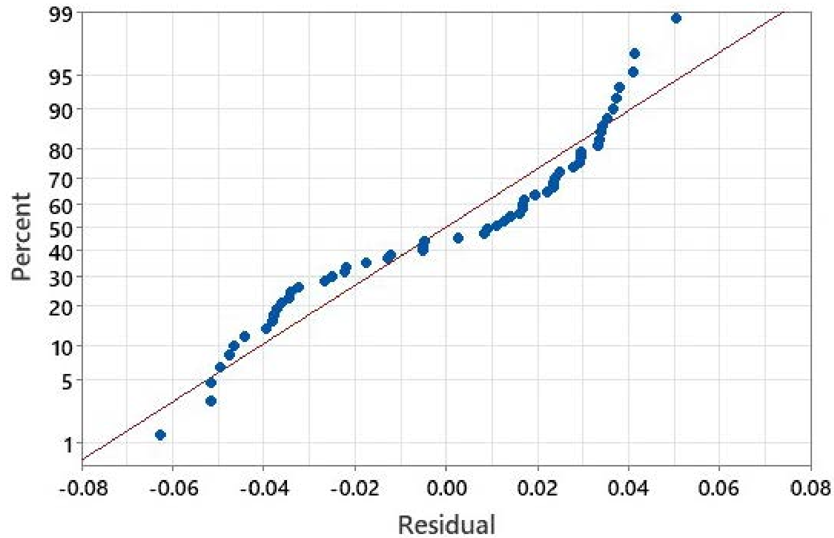

Figure 6.21 Normal Probability Plot of Quadratic Regression for All Aggregates

Nonlinear Model:

$$cG_{sb} = -12.94 + 10.58 \times uG_{sb} - 1.776 \times uG_{sb}{}^{2} - 0.000219 \times P_F \quad (6.9)$$

The R^2 for this model is 0.9607.

Table 6.12 Coefficients Table for Quadratic Regression Model for the Comprehensive Analysis

Term	Coefficient	95 percent Confidence Interval	T-Value	P-Value	VIF
Constant	-12.94	(-16.050, -9.820)	-8.340	0.000	
uG_{sb}	10.58	(8.270, 12.890)	9.190	0.000	1636.56
$uG_{sb}{}^{2}$	-1.776	(-2.204, -1.348)	-8.330	0.000	1636.95
P_F	-0.00022	(-0.000357, -0.000080)	-3.160	0.003	1.02

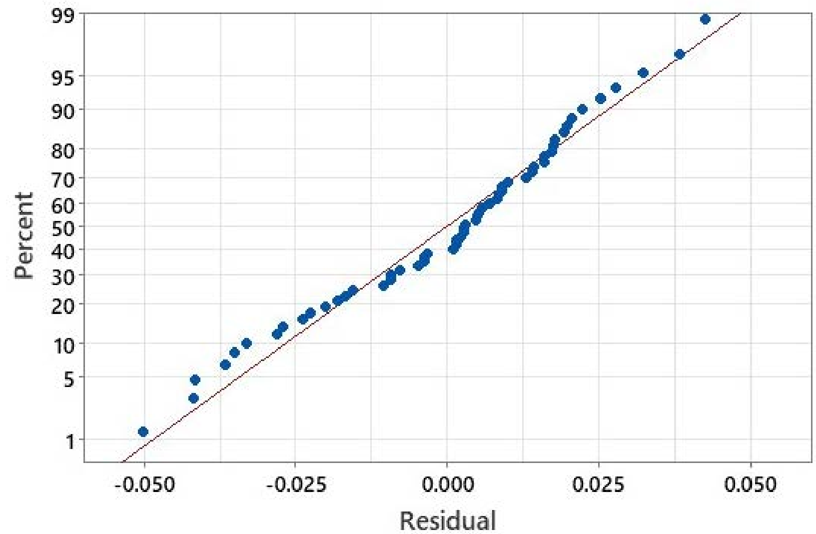

Figure 6.22 Normal Probability Plot of Quadratic Regression for the Comprehensive Analysis

The correlation of cG_{sb} with G_{sb} values (Figure 6.23) now provides a fit with a Pearson r of 0.980 and a p-value of < 0.0001. This provides evidence that the two populations are statistically similar to each other on the basis of the nonlinear model.

A plot of the residuals for the modified G_{sb} values can be seen in Figure 6.24. The mean of these residuals is calculated to be 1.79×10^{-7}. There is no observed trend in the fit of these residuals. This shows that the model provides a good fit for the data points.

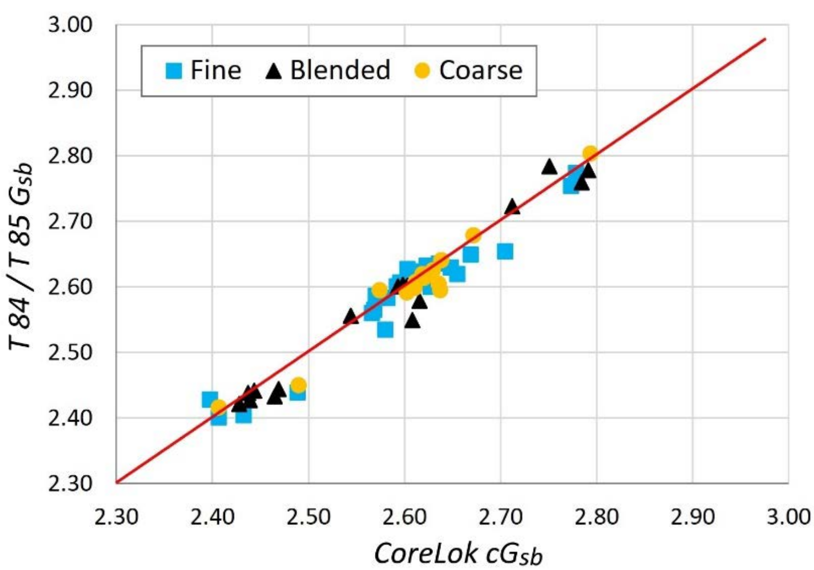

Figure 6.23 Bulk (Dry) Specific Gravities for All Aggregates (with correction)

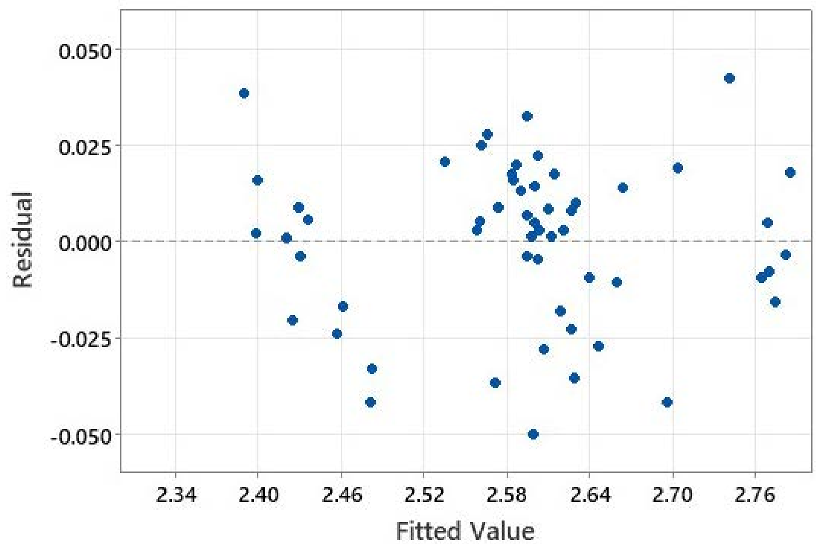

Figure 6.24 Residuals of Fitted Values for Quadratic G_{sb} Trend on All Aggregates

Absorption

The comprehensive analysis used the volumetric relationship to calculate the *cAbs* values. Figure 6.25 shows a plot of the corrected absorption values against the *Abs* values. After adjusting the absorption values produced by the CoreLok, the correlation *r* values improved from 0.657 to 0.789.

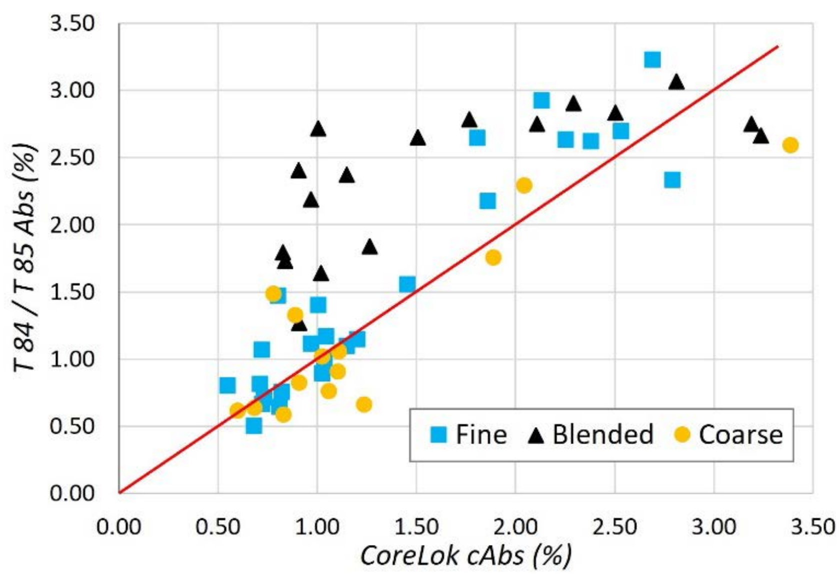

Figure 6.25 Absorptions for All Aggregates (with correction)

Discussion

The quadratic model, provided in the comprehensive analysis, has the high VIF terms that were seen in the coarse and blended aggregates. The same conclusion is held for this model where centering the data is unrealistic for a real-world application.

All correlations improved for the corrected values showing that this model provides a good estimate of the values produced by AASHTO test procedures. All values can be seen in the Appendix.

Summary

Based on the statistical analyses presented in this chapter, the CoreLok test procedure overestimated the bulk specific gravities and consequentially underestimated the absorptions in comparison to the AASHTO T 85 test procedure results. The apparent specific gravities showed strong correlation for all analyses and allowed for a singular regression on the bulk specific gravity. Once the cG_{sb} equation was developed, it was used in a volumetric relationship with the uG_{sa} (same as cG_{sa}) to determine the absorption, *cAbs*. After adjustments, the *cAbs* term and the cG_{sb} terms showed good correlations with the corresponding AASHTO test procedure results. Recommendations, based on the statistical analyses are given in Chapter 7.

7. Summary, Conclusions, and Recommendations

Summary

The AASHTO T 85 test procedure was used to standardize a procedure method that could determine the specific gravities of coarse aggregates. The AASHTO T 85 test procedure requires approximately 24-hours to complete, and the determination of the aggregate SSD condition is subjective and highly dependent on the operator's expertise. The CoreLok test procedure has been suggested as an alternative to the AASHTO T 85 procedure. The CoreLok test procedure utilizes a vacuum device and volumeter to determine the aggregates' specific gravities. As there is no subjectivity inherent in the CoreLok procedure, most sources of operator error are eliminated. In addition, due to the low variability and fast turnaround time, the CoreLok test procedure is a viable alternative to the current test procedure based on AASHTO T 85.

The literature review of several studies showed that the specific gravity results produced by the CoreLok test procedure are not statistically similar to the AASHTO T 85 test procedure results. However, trends do exist between the bulk (dry) specific gravities of the two procedures, indicating the existence of a relationship. The primary objective of this research was to examine the correlation between the specific gravity calculated using AASHTO T 85 versus the values calculated using the CoreLok test procedure. After correlations were established, regression models were constructed so that the CoreLok specific gravity values match the results from the AASHTO T 85 test procedure.

This study also investigated measurements on aggregate blends, consisting of various combinations of coarse and fine aggregates, to see if the CoreLok test procedure could be used to predict specific gravities measured following AASHTO T- 84 and T 85 test procedures on fine and coarse aggregates., respectively.

To examine these relationships, test materials from across the state of Idaho were collected from different aggregate sources identified by ITD. In total, 15 coarse aggregates were tested using the AASHTO T 85 and CoreLok test methods. Additionally, 17 aggregate blends were tested using the CoreLok test procedure only. Data from a previous project (Sharma et al., 2020) on the testing of 25 fine aggregate specific gravities was also used in this research for the blended aggregates.

At the start of the project, a round-robin testing experiment was conducted to assess the quality of the tests performed by the UI researchers. This was considered a useful experiment as some judgement is required to recognize the SSD condition in the AASHTO T 85 test procedure. A total of eight laboratories participated in the round-robin testing of two aggregates samples according to the AASHTO T 85 test procedure. Additionally, three laboratories participated in a smaller round-robin testing of the same aggregates using the CoreLok test method.

The samples tested by the researchers fell within two standard deviations of all laboratories that participated in the round-robin testing. This confirmed that the testing performed by the researchers was comparable to the results obtained by the other participants.

After testing, the specific gravities and absorptions of the aggregates were analyzed using the statistical software (Minitab, version 19). Correlation tests showed that the apparent specific gravities of the coarse and blended aggregates were statistically similar to those produced by the AASHTO T 85 test procedure. Regression analyses were then performed on the bulk specific gravities of the aggregate to develop an equation to correct the CoreLok bulk specific gravities to match the AASHTO T 85 values more closely. The regression analyses produced three equations which may be used to correct the bulk specific gravities obtained with the CoreLok test procedure.

Conclusions

The statistical analyses present in Chapter 6 used average data points from the series of specific gravity tests that were conducted on aggregates samples from across Idaho. The statistical analyses resulted in three regression models for predicting AASHTO T 85 values base on CoreLok specific gravity values. The results of this statistical analysis are summarized below.

Coarse Aggregates

- The Pearson correlation coefficient (r) showed strong similarity between the CoreLok G_{sa} (uG_{sa}) and AASHTO T 85 G_{sa} (r = 0.992). The p-value of this correlation was close to zero, showing that the samples are statistically similar to each other.
- The regression equation (Equation 7.1) provided an R^2 of 0.9696.

$$cG_{sb} = -8.657 + 7.299 \times uG_{sb} - 1.147 \times {uG_{sb}}^2 \tag{7.1}$$

- Comparing the corrected G_{sb} from the CoreLok (cG_{sb}) and the AASHTO T 85 G_{sb} showed a correlation of r = 0.985 with a p-value close to zero.

Aggregate Blends

- The Pearson correlation coefficient (r) showed a strong similarity between the uG_{sa} and G_{sa} (r = 0.964). The p-value of this correlation is close to zero, showing that the samples are statistically similar to each other.
- The regression equation (Equation 7.2) provided an R^2 of 0.972.

$$cG_{sb} = -14.08 + 11.40 \times uG_{sb} - 1.925 \times {uG_{sb}}^2 - 0.000260 \times P_F \tag{7.2}$$

- A comparison of the corrected cG_{sb} from the CoreLok and the AASHTO T 85 G_{sb} showed a correlation of r = 0.987 with a p-value of nearly zero.

Coarse, Blended, and Fine Aggregates (Comprehensive Model)

- The Pearson correlation coefficient (r) showed strong similarity between the uG_{sa} and G_{sa} ($r = 0.972$). The p-value for this correlation was close to zero, showing that the samples are statistically similar to each other.
- The quadratic regression equation (Equation 7.3), with an R^2 of 0.9607, provided the best fit.

$$cG_{sb} = -12.94 + 10.58 \times uG_{sb} - 1.776 \times {uG_{sb}}^2 - 0.000219 \times P_F \qquad (7.3)$$

- A comparison of the corrected cG_{sb} from the CoreLok and the AASHTO T 85 G_{sb} showed a correlation of $r = 0.980$ with a p-value of nearly zero.

Absorption

- Corrected absorptions (*cAbs*) from the CoreLok tests may be calculated using the following volumetric equation with cG_{sa} assumed to be the same as the uG_{sa} from the CoreLok test.

$$cAbs\ (\%) = \left(\frac{1}{cG_{sb}} - \frac{1}{cG_{sa}}\right) \times 100 \qquad (7.4)$$

Recommendations

The following recommendations are made based on the results of this study.

1. If testing for the apparent specific gravity, the CoreLok values do not need to be adjusted as it produces replicable results compared to the AASHTO T 85 test procedure.
2. The CoreLok test procedure can replace the AASHTO T 85 test for coarse aggregate by using the following proposed coarse aggregate correction:

$$cG_{sb} = -8.657 + 7.299 \times uG_{sb} - 1.147 \times {uG_{sb}}^2 \qquad (7.7)$$

3. For mixtures consisting of coarse and fine aggregates tested using the CoreLok procedure, the following equation is proposed for correcting the CoreLok bulk specific gravity:

$$cG_{sb} = -12.94 \times uG_{sb} + 10.58 \times uG_{sb} - 1.776 \times {uG_{sb}}^2 - 0.000219 \times P_F \qquad (7.8)$$

4. Absorptions may be calculated using the volumetric equation:

$$cAbs\ (\%) = \left(\frac{1}{cG_{sb}} - \frac{1}{cG_{sa}}\right) \times 100 \qquad (7.9)$$

5. Other state DOTs should perform similar studies of local aggregates to develop trends that are specific to the aggregates found in their region.

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Appendix A. Reclaimed Asphalt Pavement (RAP)

Introduction

The use of Reclaimed Asphalt Pavement (RAP) materials in Hot Mix Asphalt (HMA) design requires knowledge about the bulk (dry) specific gravity (G_{sb}) of the RAP aggregate. However, this parameter is difficult to determine in practice. The adopted value is usually estimated based on empirical data or approximations.

A small-scale study was conducted to see if a more precise procedure could be developed for estimating the G_{sb} value of RAP aggregate. The proposed plan was to:

1. Select a virgin aggregate blend of coarse and fine aggregates used for typical HMA.
2. Determine the G_{sb} and *Abs* values of the aggregate.
3. Prepare five HMA samples with different binder contents.
4. Age the HMA samples for 72 hours to approximately simulate typical RAP.
5. Determine the maximum specific gravity of the mix (G_{mm}) using the Rice (AASHTO T 209) and CoreLok test procedures.
6. Use available procedures to estimate the G_{sb} of the RAP aggregate.
7. Using the mineral extraction equipment available in the ITD HQ laboratory to determine the exact binder content of the five samples with values assigned in Step 3.
8. Determine the G_{sb} and *Abs* values of the five “cleaned” RAP samples for comparison with values determined in Step 2.

Steps 1 to 6 were completed successfully. Unfortunately, equipment problems prevented completion of Step 7, which subsequently prevented completion of the final step.

Binder Definitions

The prepared HMA material consists of binder and aggregate. The contribution of the binder component is defined below.

Percent Binder P_b

The total percentage of asphalt binder in the asphalt mixture, expressed as a percentage of the total mix mass.

Percent Binder Effective P_{be}

The portion of the asphalt binder that coats the aggregate in the asphalt mixture but is not absorbed into the aggregate, expressed as a percentage of the total mix mass.

Percent Binder Absorbed P_{ba}

The portion of the asphalt binder that is absorbed into the aggregate, expressed as a percentage of the total aggregate mass. The sum of the absorbed binder and effective binder are approximately equal to the total binder content (P_b) of the mix.

Volumetric Properties of HMA

With reference to Figure A.1, the following definitions (adapted from Asphalt Institute, 2015) are applicable to a loose HMA sample prepared in the laboratory:

Theoretical Maximum Specific Gravity G_{mm}

The theoretical maximum specific gravity (G_{mm}) for loose asphalt mixtures is determined by AASHTO T 209 (Rice Test) using the ratio of the oven-dry mass of a unit volume of asphalt mixture (including the volumes of the aggregate and binder only) to the mass of the same volume of water. Considering the quantities shown in Figure A.1,

$$G_{mm} = \frac{M_s + M_b}{V_{mm}} \tag{A.1}$$

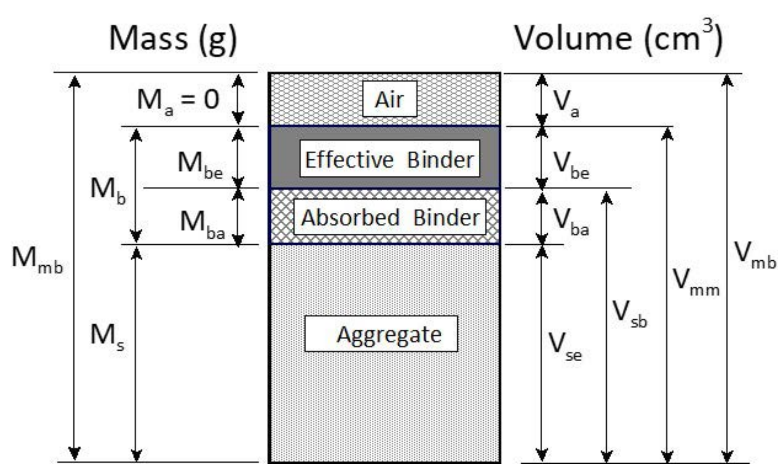

Figure A.1 Phase Diagram for HMA Volumetrics (after Asphalt Institute, 2015)

Bulk (Dry) Specific Gravity G_{mb}

As determined for compacted asphalt mixtures by AASHTO T 166, this is the ratio of the oven-dry mass of a unit volume of asphalt mixture (including the volumes of aggregate, binder, and air) to the mass of the same volume of water. Considering the quantities shown in Figure A.1,

$$G_{mb} = \frac{M_s + M_b}{V_{mb}} \tag{A.2}$$

Effective Specific Gravity G_{se}

This is calculated for aggregate as the ratio of the oven-dry mass of a unit volume of aggregate (including both the impermeable void volumes and the water permeable voids not filled with absorbed asphalt) to the mass of the same volume of water. Considering the quantities shown in Figure A.1,

$$G_{se} = \frac{M_s}{V_{se} + V_a} \tag{A.3}$$

The volume of the water permeable voids not filled with absorbed asphalt in a HMA sample is difficult to determine directly. Instead of using in Equation (A.3), a simpler, alternative equation using the known binder content and theoretical maximum specific gravity of the mix, as determined from an AASHTO T 209 test, is used to calculate the effective specific gravity using Equation (A.4).

$$G_{se} = \frac{(100 - P_b)}{\left(\frac{100}{G_{mm}} - \frac{P_b}{G_b}\right)} \tag{A.4}$$

Where G_b is the specific gravity of the binder.

In practice, an HMA design with RAP requires information regarding the bulk (dry) specific gravity (G_{sb}) of the aggregate. This parameter is usually approximated using empirical equations, as presented in Table A.1.

Indiana, Michigan, and Minnesota DOTs recommend the use of the expressions shown in Table A.1 to determine the bulk (dry) specific gravity of the RAP aggregate using the effective specific gravity calculated using Equation (A.4). It should be noted that these are empirical corrections and are not based on theoretical considerations.

Table A.1 DOT Procedures for determining G_{sb} for RAP Materials

Agency	G_{sb} of RAP	Notes	Source
Indiana DOT	$G_{sb} = 0.0795 + 0.9397 \times G_{se}$	N/A	Indiana Department of Transportation Division of Materials and Tests (2017)
Michigan DOT	$G_{sb} = 1.097 \times G_{se} - 0.32$	N/A	Michigan DOT (2020)
Minnesota DOT	$G_{sb} = 0.9246 \times G_{se}$	N/A	Minnesota DOT (2007)
Idaho Transportation Department	See Equation (A.5)	where the Aggregate Absorption (*Abs*) is estimated from records and experience and $P_{ba} = 0.667 \times Abs$	Idaho Transportation Department of (2019)

The Idaho Department of Transportation (ITD) test procedure IT146-19: *Determination of Reclaimed Asphalt Pavement (RAP) Aggregate Bulk (dry) specific gravity (G_{sb})* outlines a method to determine the G_{sb} of aggregate from RAP materials. Approximately one percent asphalt binder is added to the sample to achieve full coating, and then tested to determine the maximum specific gravity (G_{mm}) and percent binder (P_b) of the prepared RAP sample. The percent absorption of the aggregate (*Abs*) is assumed based on historical records and engineer's experience. ITD assumes that two thirds of the surface voids are filled with binder, i.e., $P_{ba} = 0.667 \times Abs$. With effective specific gravity calculated using Equation (A.4), the bulk (dry) specific gravity of the RAP aggregate can be determined using Equation (A.5).

$$G_{sb} = \frac{G_{se}}{\frac{P_{ba} \times G_{se}}{100 \times G_b}} \tag{A.5}$$

where:

G_{sb} = Calculated G_{sb} of the RAP aggregate

G_{se} = Theoretical effective specific gravity of the RAP, as determined using Equation (A.4)

P_{ba} = Percent absorbed binder in the RAP

G_b = Specific gravity of the binder

RAP Materials

Samples prepared for RAP testing included coarse aggregate only, and blends of coarse and fine aggregates. The washing, drying, and splitting procedures for both coarse and fine aggregates followed the procedures outlined in Chapter 4. For aggregate blend samples, the individual sieve sizes were separated into piles to be used during the gradation assembly. An artificial gradation was created by combining the coarse and fine materials, as shown in Table A.2. The same gradation was used for all prepared samples.

After the aggregate samples were prepared, they were heated up in an oven prior to mixing with the selected binder. The mixing process follows the AASHTO R 30 Procedure: *Standard Practice for Mixture Conditioning of Hot Mix Asphalt*. For this study, three percent binder was used for the coarse mixes and five percent binder was used for the blended samples. The binder content is based on the weight of binder to the total weight of the aggregate sample. More binder was added to the blended samples because of the increased surface area of the fine particles. The binder selected for the sample mixes was PG 64-28 which is a common binder used in the state of Idaho.

Table A.2 Prepared Gradation of RAP Aggregate

Sieve Size	Percent Passing
¾ - inch	100
½ - inch	92
⅜ - inch	81
No. 4	58
No. 8	38
No. 30	17
No. 50	12
No. 100	9
No. 200	6.7

In addition to the samples prepared to simulate RAP material, duplicate gradations were created for each sample so that the virgin aggregate could be tested using the CoreLok procedure.

After adding the binder, the samples were placed in a temperature-controlled oven set to 85 ± 5°C (185 ± 10°F) for 120 ± 0.5 hours to simulate long-term aging of asphalt mixtures. This procedure is modified from AASHTO R 30. The materials were then removed from the oven, cooled down, and stored for testing.

RAP Testing

The AASHTO T 84/T 85 RAP specific gravities were calculated using the AASHTO equivalent values for the virgin RAP aggregates. In addition, the Theoretical Maximum Specific Gravity (G_{mm}) of the RAP material was calculated using AASHTO T 209 *Theoretical Maximum Specific Gravity (G_{mm}) and Density of Asphalt Mixtures.*

Results from RAP Sample Testing

Table A.3 presents the AASHTO T 85 specific gravities and absorptions calculated using Equations (5.1) and (5.2) based on the use of 58 percent fine aggregate and 42 percent coarse aggregate in the blended mixture. These data are based on AASHTO T 84 and T 85 tests that were previously performed on fine and coarse aggregates.

Table A.3 Calculated AASHTO Values for Virgin Aggregates used to Prepare RAP Samples

Identification	Aggregate	G_{sb}	G_{sa}	*Abs*
3G	OW-94 (Coarse only)	2.415	2.576	2.591
6N	BN-156c (Coarse only)	2.598	2.650	0.764
3G-MD	OW-94 Gradation	2.429	2.605	2.783
6M-MD	Le-160c Gradation	2.594	2.700	1.516
6A-MD	Fr-104c Gradation	2.416	2.598	2.888

The prepared virgin aggregate gradations were also tested using the CoreLok test procedure to determine the usual specific gravity and absorption values. The specific gravities and absorptions data for the virgin aggregate mixes are presented in Table A.4, and Table A.5 includes the results from testing the HMA RAP samples. All samples tested were within a range of 0.025, as recommended by the AASHTO specification. Table A.6 presents the average values of the uncorrected apparent specific gravity for the data presented in Table A.5.

The nomenclature for sample identification in Tables A.3 and A.4 is detailed below.

Virgin aggregate samples:

Sample ID for coarse aggregate – Mix Design (MD) – Sample #

RAP samples (coarse aggregate or aggregate blends mixed with asphalt):

Sample ID for coarsest aggregate – Binder (B) – Percent Binder – Sample #

Table A.4 CoreLok Test Results for Virgin Aggregates used to prepare RAP Samples

Test Number	Identification	Aggregate	uG_{sb}	uG_{sa}	*uAbs*
82	3G-MD-1	OW-94 Gradation	2.570	2.647	1.135
83	6M-MD-1	Le-160c Gradation	2.671	2.700	0.398
84	6A-MD-1	Fr-104c Gradation	2.546	2.609	0.944

Table A.5 CoreLok Test Results for RAP Samples

Test Number	Identification	Aggregate	uG_{sa}
85	3G-R-3-1	OW-94 RAP 3%	2.354
86	3G-R-3-2	OW-94 RAP 3%	2.362
87	6N-R-3-1	BN-156c RAP 3%	2.529
88	6N-R-3-2	BN-156c RAP 3%	2.533
89	3G-R-5-1	OW-94 RAP 5%	2.372
90	3G-R-5-2	OW-94 RAP 5%	2.365
91	6M-R-5-1	Le-160c RAP 5%	2.454
92	6M-R-5-2	Le-160c RAP 5%	2.448
93	6A-R-5-1	Fr-104c RAP 5%	2.334
94	6A-R-5-2	Fr-104c RAP 5%	2.337

Table A.6 Average uG_{sa} Values for the RAP Samples from CoreLok Testing

Identification	Percent Binder	uG_{sa}
3G-R-3	3%	2.358
6N-R-3	3%	2.531
3G-R-5	5%	2.368
6M-R-5	5%	2.451
6A-R-5	5%	2.336

The specific gravity of the asphalt binder is assumed to be 1.040. If included in the bulk volume, this lowers the overall bulk specific gravity.

In addition to testing RAP samples with the CoreLok device, they were tested also according to AASHTO T 209 to determine G_{mm} values. As explained in Chapter 4, this procedure is similar to the determination of uG_{sa} in a CoreLok test. Table A.7 presents the average G_{mm} per AASHTO T 209 and uG_{sa} data from CoreLok testing and Figure A.2 offers a visual comparison. In all cases, the G_{mm} values were slightly greater than the uG_{sa} values, with the difference ranging between 0.002 and 0.034. In view of the relatively small difference, this study assumed that the uG_{sa} was a good substitute for the G_{mm} value determined by the AASHTO T 209 test procedure.

Table A.7 Average G_{mm} and uG_{sa} Values for RAP Samples

Identification	AASHTO T 209 G_{mm}	CoreLok uG_{sa} (uG_{mm})
3G-R-3	2.383	2.358
6N-R-3	2.548	2.531
3G-R-5	2.371	2.368
6M-R-5	2.457	2.451
6A-R-5	2.370	2.336

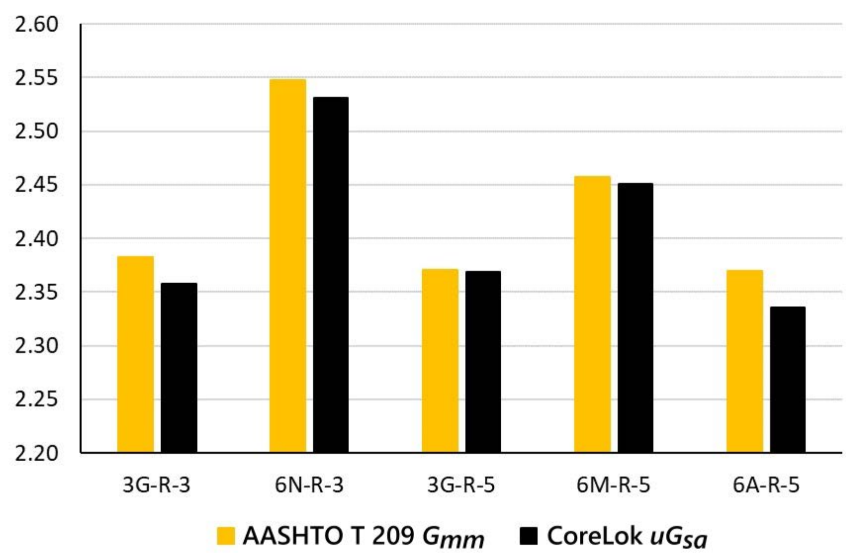

Figure A.2 Comparison of G_{mm} and uG_{sa} values of RAP Samples

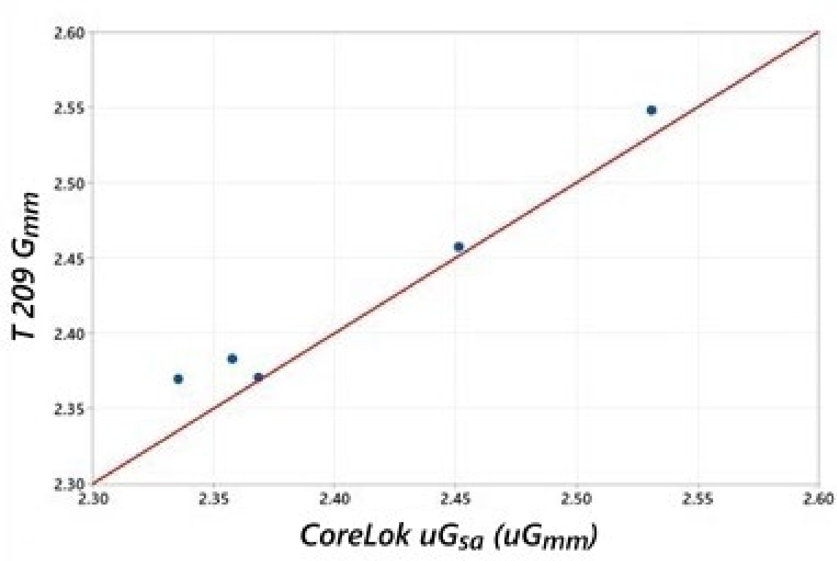

Figure A.3 Comparison of G_{mm} and uG_{sa} for Five RAP Samples (without correction)

Figure A.3 shows a comparison of G_{mm} and uG_{sa} values determined from the testing of five RAP materials. The correlation between uG_{sa} and G_{mm} has a Pearson r value of 0.987 and a p-value of 0.002. As the p-value is less than the predetermined alpha level of 0.05, this provides good evidence that the two populations are not statistically different from each other.

Calculation of Bulk (Dry) Specific Gravity

If the CoreLok values of uG_{sa} are assumed to be equivalent to the G_{mm} values, the effective specific gravity of the RAP, G_{se}, may be calculated using Equation (A.6).

$$G_{se} = \frac{(100 - P_b)}{\left(\frac{100}{uG_{sa}} - \frac{P_b}{G_b}\right)} \qquad \text{(A.6)}$$

where P_b is the percent binder content and G_b is the specific gravity of the binder. If the absorption of the virgin aggregate is known (or estimated), the IT-146 test procedure assumes that the absorbed binder content will be equal to 0.667 × *Abs*. With P_{ba} calculated, the bulk (dry) specific gravity of the RAP, G_{sb}, may be calculated using Equation (A.7).

$$G_{sb} = \frac{G_{se}}{1 + \left(\frac{0.667 \times Abs}{100} \times \frac{G_{se}}{G_b}\right)} \qquad \text{(A.7)}$$

The Indiana DOT (IN G_{sb}), Michigan DOT (MI G_{sb}), and Minnesota DOT (MN G_{sb}) bulk specific gravities were computed using the equations given in Table A.1. The ITD values of G_{sb} were calculated using Equation (A.7).

Table A.8 Calculated G_{sb} and T 85 G_{sb} Values of RAP Aggregate

Identification	*Abs*	G_{se}	P_{ba} (percent)	ITD G_{sb}	IN G_{sb}	MI G_{sb}	MN G_{sb}	AASHTO T 85 – G_{sb}
3G-R-3	2.591	2.454	1.728	2.358	2.386	2.372	2.269	2.415
6N-R-3	0.764	2.648	0.510	2.615	2.568	2.585	2.449	2.598
3G-R-5	2.783	2.539	1.837	2.430	2.465	2.465	2.347	2.424
6M-R-5	1.516	2.639	0.886	2.581	2.560	2.576	2.440	2.605
6A-R-5	2.888	2.500	1.890	2.391	2.429	2.422	2.311	2.426

Table A.8 presents the calculated values of G_{se} and RAP G_{sb} for the five gradations used to create the RAP samples. The absorption values given in Table A.3 were used for these calculations.

Figure A.4 compares the RAP G_{sb} values presented in Table A.8. The ITD test procedure produced results within 98 to 101 percent of the AASHTO T 84/85 G_{sb} of the aggregate used to prepare the RAP material. Based on the limited testing conducted on RAP materials and the inability to test the "cleaned" RAP aggregates after extraction and recovery (proposed in Step 8), there is no need for ITD to change their method of calculating the G_{sb} of the RAP aggregate. In addition, the results showed that the Indiana DOT results appear to be the closest overall to the actual G_{sb} of the virgin aggregate used to prepare the RAP material.

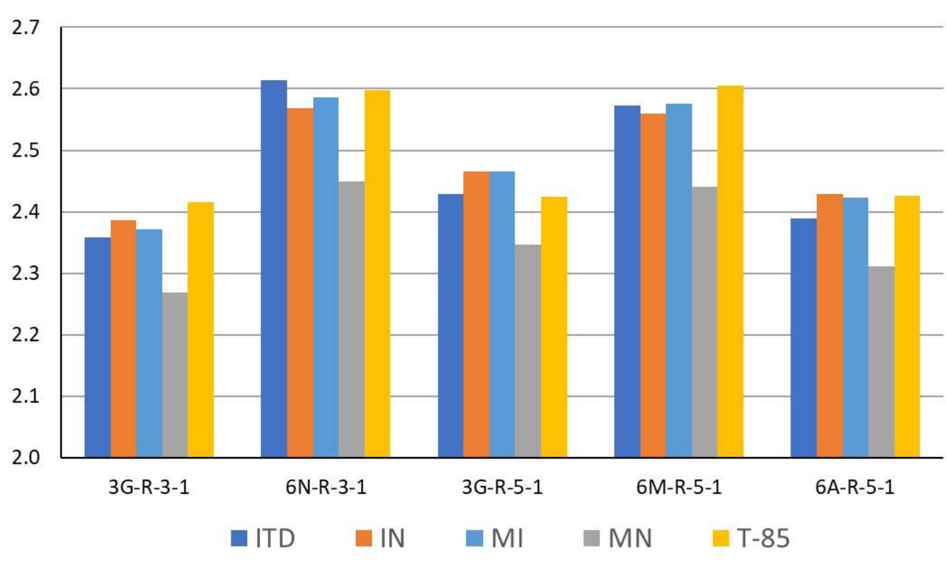

Figure A.4 Comparison of Bulk Specific Gravities of RAP Aggregate

- The RAP testing revealed that that the CoreLok uG_{sa} of the RAP material was statistically equivalent to the G_{mm} determined using the Rice test per AASHTO T 209.
- The current ITD test procedure (IT-146) may be used to successfully calculate the G_{sb} of the RAP aggregate.

Conclusions

- The G_{mm} value correlated with the uG_{sa} value from the CoreLok test with a Pearson correlation coefficient of r = 0.987 and a p-value of 0.002. This strongly suggests that the two values are statistically equivalent, i.e., $G_{mm} = uG_{sa}$
- For known values of G_{mm} and P_b for RAP materials, and the absorption (*Abs*) of the aggregate, the bulk (dry) specific gravity may be calculated using Equations (A.8) and (A.9).

$$G_{se} = \frac{(100 - P_b)}{\left(\frac{100}{G_{mm}} - \frac{P_b}{G_b}\right)} \tag{A.8}$$

$$G_{sb} = \frac{G_{se}}{1 + \left(\frac{0.667 \times Abs}{100} \times \frac{G_{se}}{G_b}\right)} \tag{A.9}$$

Appendix B. UI Lab Testing Data

Table B.1 CoreLok Specific Gravity Data for Coarse Aggregates

Test #	Date Tested	Sample ID	Calibration Volumeter (g)	Dry Sample Wt. (g)	Sample + Volumeter + Water (g)	Bag Wt. (g)	Rubber Sheet Wt. (g)	Dry Sample Wt. (g)	Wt. of Bag in Water (g)	uG_{sa}	uG_{sb}	*uAbs*
1	06/15/21	1E-1	5727.37	1001.7	6352.3	72.7	203.2	2001.5	1302.4	2.689	2.658	0.430
2	06/15/21	1E-2	5727.37	1001.6	6350.7	72.9	203.3	2001.5	1305.5	2.700	2.648	0.733
3	06/15/21	1E-3	5727.37	1001.5	6351.3	73.1	203.3	2001.3	1306.2	2.703	2.652	0.712
4	06/28/21	1H-1	5726.57	1001.6	6352.1	73.2	203.2	2001.4	1309.2	2.714	2.664	0.702
5	06/28/21	1H-2	5726.57	1001.6	6351.4	73.2	203.1	2001.0	1310.9	2.722	2.658	0.879
6	06/28/21	1H-3	5726.57	1001.5	6352.2	73.5	203.1	2001.1	1310.2	2.719	2.664	0.751
7	06/16/21	1F-1	5727.37	1001.7	6356.8	73.2	203.0	2001.4	1310.0	2.717	2.691	0.366
8	06/16/21	1F-2	5727.37	1001.4	6356.7	73.5	203.2	2001.4	1311.0	2.721	2.691	0.404
9	06/16/21	1F-3	5727.37	1001.4	6357.7	73.3	203.0	2000.9	1312.8	2.729	2.699	0.414
10	06/08/21	2C-1	5727.10	1001.6	6379.1	73.2	202.6	2001.8	1368.1	2.949	2.865	1.000
11	06/08/21	2C-2	5727.10	1001.1	6378.8	73.6	203.7	2001.4	1367.9	2.949	2.865	0.993
12	06/08/21	2C-3	5727.10	1001.4	6379.4	73.3	203.2	2001.8	1369.0	2.953	2.869	0.995
13	06/10/21	2D-1	5727.10	1001.0	6380.8	72.9	202.9	2000.5	1360.2	2.919	2.883	0.430
14	06/10/21	2D-2	5727.10	1001.4	6379.7	72.9	202.7	2001.7	1361.3	2.920	2.871	0.584
15	06/10/21	2D-3	5727.10	1001.7	6380.0	73.2	202.6	2001.2	1360.7	2.919	2.871	0.572
16	06/25/21	3G-1	5726.57	1001.3	6326.5	73.4	203.2	2001.5	1283.7	2.623	2.495	1.964

Test #	Date Tested	Sample ID	Calibration Volumeter (g)	Dry Sample Wt. (g)	Sample + Volumeter + Water (g)	Bag Wt. (g)	Rubber Sheet Wt. (g)	Dry Sample Wt. (g)	Wt. of Bag in Water (g)	*uG_{sa}*	*uG_{sb}*	*uAbs*
17	06/25/21	3G-2	5726.57	1001.4	6327.3	73.2	202.9	2001.7	1281.0	2.614	2.499	1.757
18	06/25/21	3G-3	5726.57	1001.7	6327.7	73.6	203.4	2001.6	1284.5	2.626	2.501	1.903
19	07/01/21	5I-1	5726.57	1000.1	6342.3	72.4	203.0	1999.9	1291.9	2.655	2.602	0.769
20	07/01/21	5I-2	5726.57	1000.1	6343.4	73.1	203.5	1999.3	1292.4	2.658	2.609	0.705
21	07/01/21	5I-3	5726.57	1000.7	6344.9	73.2	203.0	1999.5	1294.5	2.666	2.617	0.698
22	07/05/21	5J-1	5726.57	1000.0	6347.2	73.2	203.6	1999.7	1295.3	2.667	2.636	0.454
23	07/05/21	5J-2	5726.57	999.8	6346.1	72.7	203.2	1999.5	1294.2	2.664	2.629	0.502
24	07/05/21	5J-3	5726.57	1000.8	6346.9	73.2	203.5	1999.5	1295.0	2.667	2.630	0.526
25	06/01/21	6A-1	5726.00	1000.6	6334.3	72.5	203.8	2000.6	1284.9	2.629	2.550	1.166
26	06/01/21	6A-2	5726.00	1000.6	6335.7	72.4	203.4	2001.1	1284.3	2.626	2.560	0.980
27	06/02/21	6A-3	5726.00	1000.6	6332.7	72.1	203.8	2000.1	1282.1	2.620	2.540	1.194
28	06/02/21	6A-4	5726.00	1000.2	6333.8	72.9	203.7	1998.8	1281.8	2.622	2.549	1.095
29	06/01/21	6B-1	5726.00	1000.6	6350.5	72.1	203.9	2000.3	1298.1	2.675	2.660	0.212
30	06/01/21	6B-2	5726.00	1000.3	6349.5	71.6	203.6	2000.9	1298.6	2.676	2.655	0.296
31	06/03/21	6B-3	5726.00	1000.1	6349.0	72.4	203.4	2000.7	1297.5	2.673	2.652	0.297
32	06/03/21	6B-4	5726.00	1000.4	6348.9	72.7	203.8	2000.5	1295.3	2.665	2.650	0.216
33	07/06/21	6K-1	5725.97	1000.5	6351.4	72.7	203.3	2000.4	1305.4	2.702	2.667	0.489

Test #	Date Tested	Sample ID	Calibration Volumeter (g)	Dry Sample Wt. (g)	Sample + Volumeter + Water (g)	Bag Wt. (g)	Rubber Sheet Wt. (g)	Dry Sample Wt. (g)	Wt. of Bag in Water (g)	uG_{sa}	uG_{sb}	*uAbs*
34	07/06/21	6K-2	5725.97	1000.4	6349.6	72.9	203.2	2000.8	1302.8	2.692	2.655	0.522
35	07/06/21	6K-3	5725.97	1000.3	6349.6	73.3	202.8	2000.1	1305.1	2.703	2.656	0.657
36	07/06/21	6L-1	5725.97	1000.3	6348.4	72.8	203.3	2000.4	1303.4	2.695	2.647	0.669
37	07/06/21	6L-2	5725.97	1000.5	6348.1	73.6	202.5	2000.3	1302.3	2.692	2.644	0.677
38	07/06/21	6L-3	5725.97	1000.6	6348.5	73.4	203.2	2000.4	1302.1	2.691	2.646	0.625
39	07/11/21	6M-1	5727.23	1000.6	6351.2	73.6	203.1	2000.5	1302.6	2.693	2.656	0.506
40	07/11/21	6M-2	5727.23	1000.3	6351.6	72.6	203.6	2000.5	1302.2	2.690	2.661	0.410
41	07/11/21	6M-3	5727.23	1000.5	6352.5	73.4	203.4	2000.8	1304.2	2.697	2.666	0.435
42	07/11/21	6N-1	5727.23	1000.2	6348.4	73.1	204.5	2000.6	1300.2	2.682	2.639	0.612
43	07/11/21	6N-2	5727.23	1000.7	6348.3	72.7	205.2	2000.5	1302.6	2.690	2.636	0.761
44	07/11/21	6N-3	5727.23	1000.4	6348.6	72.9	204.3	2000.3	1300.4	2.684	2.639	0.625
45	07/11/21	6M-1	5727.23	1000.6	6349.4	72.8	203.6	2000.8	1297.2	2.672	2.644	0.395
46	07/11/21	6M-2	5727.23	1000.7	6348.4	72.2	203.6	2000.0	1296.0	2.669	2.637	0.460
47	07/11/21	6M-3	5727.23	1000.4	6348.3	73.7	204.8	2000.2	1296.7	2.670	2.637	0.468

Table B.2 AASHTO T 85 Specific Gravity Data for Coarse Aggregates

Test #	Date Tested	Sample ID	Dry Wt. (g)	Submerged Wt. (g)	SSD Wt. (g)	G_{sb}	G_{sa}	*Abs*
1	06/16/21	1E-1	1000.4	1011.2	630.0	2.624	2.701	1.080
2	06/16/21	1E-2	1000.8	1011.0	627.4	2.609	2.680	1.019
3	06/16/21	1E-3	1000.2	1010.8	629.6	2.624	2.699	1.060
4	06/29/21	1H-1	1000.7	1010.3	629.8	2.630	2.698	0.959
5	06/29/21	1H-2	1000.8	1009.4	631.5	2.648	2.710	0.859
6	06/29/21	1H-3	1000.2	1009.1	630.6	2.643	2.706	0.890
7	06/16/21	1F-1	1000.7	1006.5	633.3	2.681	2.724	0.580
8	06/16/21	1F-2	1001.7	1008.4	634.1	2.676	2.725	0.669
9	06/16/21	1F-3	1001.9	1008.4	634.0	2.676	2.723	0.649
10	06/09/21	2C-1	997.9	1015.1	658.7	2.800	2.942	1.724
11	06/09/21	2C-2	998.4	1015.7	659.8	2.805	2.949	1.733
12	06/09/21	2C-3	995.1	1013.0	657.9	2.802	2.951	1.799
13	06/10/21	2D-1	998.2	1010.0	660.1	2.853	2.952	1.182
14	06/10/21	2D-2	998.7	1010.3	660.1	2.852	2.949	1.162
15	06/10/21	2D-3	999.2	1011.6	659.9	2.841	2.945	1.241
16	06/29/21	3G-1	999.6	1026.3	612.3	2.414	2.581	2.671
17	06/29/21	3G-2	999.8	1025.9	611.4	2.412	2.574	2.611

Test #	Date Tested	Sample ID	Dry Wt. (g)	Submerged Wt. (g)	SSD Wt. (g)	G_{sb}	G_{sa}	*Abs*
18	06/29/21	3G-3	999.6	1024.5	611.3	2.419	2.574	2.491
19	07/02/21	5I-1	998.9	1005.2	620.8	2.599	2.642	0.631
20	07/02/21	5I-2	1000.2	1006.3	620.1	2.590	2.631	0.610
21	07/02/21	5I-3	999.4	1006.8	621.6	2.594	2.645	0.740
22	07/02/21	5J-1	998.5	1007.3	620.4	2.581	2.641	0.881
23	07/02/21	5J-2	998.7	1006.2	621.9	2.599	2.650	0.751
24	07/02/21	5J-3	999.7	1008.0	622.4	2.593	2.650	0.830
25	06/02/21	6A-1	1008.7	1031.8	618.4	2.440	2.584	2.290
26	06/02/21	6A-2	1003.9	1026.0	617.1	2.455	2.595	2.201
27	06/02/21	6A-3	999.2	1021.9	614.2	2.451	2.595	2.272
28	06/02/21	6A-4	1013.3	1034.8	622.7	2.459	2.594	2.122
29	06/04/21	6A-5	1003.2	1027.1	620.6	2.468	2.622	2.382
30	06/04/21	6A-6	999.6	1022.7	614.2	2.447	2.594	2.311
31	06/04/21	6A-7	1002.0	1026.0	614.5	2.435	2.586	2.395
32	06/04/21	6A-8	999.2	1022.6	613.1	2.440	2.588	2.342
33	06/02/21	6B-1	999.5	1005.4	628.5	2.652	2.694	0.590
34	06/02/21	6B-2	994.5	1000.3	622.0	2.629	2.670	0.583
35	06/02/21	6B-3	999.3	1004.6	623.9	2.625	2.662	0.530
36	06/02/21	6B-4	999.0	1005.4	623.7	2.617	2.662	0.641

Test #	Date Tested	Sample ID	Dry Wt. (g)	Submerged Wt. (g)	SSD Wt. (g)	G_{sb}	G_{sa}	*Abs*
37	06/04/21	6B-5	995.9	1002.5	622.0	2.617	2.664	0.663
38	06/04/21	6B-6	1000.7	1007.0	623.3	2.608	2.652	0.630
39	06/04/21	6B-7	998.7	1003.7	624.3	2.632	2.667	0.501
40	06/04/21	6B-8	993.8	1001.4	621.3	2.615	2.668	0.765
41	07/06/21	6K-1	999.3	1012.1	629.5	2.612	2.702	1.281
42	07/06/21	6K-2	1005.3	1018.5	631.5	2.598	2.689	1.313
43	07/06/21	6K-3	997.7	1011.5	628.3	2.604	2.701	1.383
44	07/06/21	6L-1	1000.8	1012.2	626.9	2.597	2.677	1.139
45	07/06/21	6L-2	1000.7	1009.5	627.7	2.621	2.683	0.879
46	07/06/21	6L-3	998.9	1009.2	628.1	2.621	2.694	1.031
47	07/12/21	6M-1	998.0	1009.4	627.2	2.611	2.691	1.142
48	07/12/21	6M-2	993.3	1014.1	625.4	2.555	2.700	2.094
49	07/12/21	6M-3	996.4	1008.4	627.4	2.615	2.700	1.204
50	07/12/21	6N-1	995.5	1002.6	621.1	2.609	2.659	0.713
51	07/12/21	6N-2	999.4	1008.2	621.0	2.581	2.641	0.881
52	07/12/21	6N-3	1000.7	1007.7	623.2	2.603	2.651	0.700
53	07/12/21	6M-1	1000.8	1006.7	622.7	2.606	2.647	0.590
54	07/12/21	6M-2	998.9	1004.5	622.2	2.613	2.652	0.561
55	07/12/21	6M-3	999.2	1005.2	621.0	2.601	2.642	0.600

Table B.3 CoreLok Specific Gravity Data for Aggregate Blends

Test #	Date Tested	Sample ID	Calibration Volumeter (g)	Dry Sample Wt. (g)	Sample + Volumeter + Water (g)	Bag Wt. (g)	Rubber Sheet Wt. (g)	Dry Sample Wt. (g)	Wt. of Bag in Water (g)	uG_{sa}	uG_{sb}	*uAbs*	Percent Fines
48	10/26/21	2C-B-50-1	5728.53	1000.2	6382.8	73.4	202.5	2000.5	1363.4	2.933	2.891	0.492	50.0
49	10/26/21	2C-B-50-2	5728.53	1000.2	6381.9	73.4	202.9	2000.4	1364.8	2.939	2.884	0.647	50.0
50	10/26/21	2C-B-90-1	5728.53	1000.4	6385.5	73.7	203.2	2000.3	1356.6	2.904	2.879	0.300	90.0
51	10/26/21	2C-B-90-2	5728.53	1000.2	6385.3	73.8	203.1	2000.2	1357.7	2.909	2.909	0.000	90.0
52	02/08/22	2D-B-75-1	5728.63	1000.8	6373.6	73.4	202.2	2000.7	1341.6	2.842	2.812	0.373	75.0
53	02/08/22	2D-B-75-2	5728.63	1000.7	6373.4	73.2	203.5	2000.3	1340.9	2.839	2.811	0.344	75.0
54	02/08/22	2D-B-50-1	5728.63	1000.7	6365.2	73.0	203.0	1999.9	1324.7	2.776	2.748	0.375	50.0
55	02/08/22	2D-B-50-2	5728.63	1000.7	6365.4	72.9	202.7	2000.3	1323.9	2.773	2.750	0.297	50.0
56	09/14/21	3G-B-25-1	5727.83	1000.2	6330.6	73.8	203.2	2000.2	1286.1	2.635	2.517	1.779	25.0
57	09/14/21	3G-B-25-2	5727.83	1000.5	6330.0	73.5	202.6	2000.3	1286.2	2.635	2.511	1.871	25.0
58	09/14/21	3G-B-50-1	5727.83	1000.6	6332.0	74.2	203.5	2000.6	1289.3	2.645	2.524	1.811	50.0
59	09/14/21	3G-B-50-2	5727.83	1000.4	6331.9	73.9	203.6	2000.3	1289.0	2.644	2.524	1.804	50.0
60	09/14/21	3G-B-75-1	5727.83	1000.3	6334.9	74.4	203.0	2000.2	1280.2	2.615	2.544	1.063	75.0
61	09/14/21	3G-B-75-2	5727.83	1000.3	6335.0	74.6	203.7	2000.5	1287.7	2.639	2.544	1.414	75.0
62	10/26/21	5I-B-50-1	5728.53	1000.1	6349.2	73.4	203.3	2000.2	1294.0	2.662	2.635	0.380	50.0

Test #	Date Tested	Sample ID	Calibration Volumeter (g)	Dry Sample Wt. (g)	Sample + Volumeter + Water (g)	Bag Wt. (g)	Rubber Sheet Wt. (g)	Dry Sample Wt. (g)	Wt. of Bag in Water (g)	*uG_{sa}*	*uG_{sb}*	*uAbs*	Percent Fines
63	10/26/21	5I-B-50-2	5728.53	1000.1	6348.3	73.2	203.3	2000.0	1294.6	2.665	2.630	0.500	50.000
64	09/14/21	6N-B-25-1	5727.83	1000.3	6349.0	73.6	203.4	2000.1	1296.1	2.670	2.638	0.450	25.0
65	09/14/21	6N-B-25-2	5727.83	1000.4	6349.3	73.9	203.2	2000.2	1298.5	2.678	2.640	0.545	25.0
66	09/14/21	6N-B-50-1	5727.83	1000.4	6349.9	73.3	203.7	2000.2	1291.8	2.654	2.637	0.243	50.0
67	09/14/21	6N-B-50-2	5727.83	1000.3	6349.8	73.9	202.4	2000.1	1295.2	2.668	2.644	0.340	50.0
68	09/14/21	6N-B-75-1	5727.83	1000.5	6354.1	73.4	203.4	2000.5	1295.2	2.666	2.645	0.295	75.0
69	09/14/21	6N-B-75-2	5727.83	1000.3	6354.0	73.7	202.6	2000.4	1292.4	2.657	2.638	0.264	75.0
70	09/22/21	6A-B-25-1	5727.73	1000.3	6333.4	73.7	202.8	2000.1	1280.4	2.616	2.535	1.218	25.0
71	09/22/21	6A-B-25-2	5727.73	1000.2	6333.5	73.7	202.8	2000.3	1252.0	2.522	2.504	0.281	25.0
72	09/22/21	6A-B-50-1	5727.73	1000.2	6335.0	74.0	202.6	2000.2	1281.3	2.619	2.545	1.100	50.0
73	09/22/21	6A-B-50-2	5727.73	1000.2	6334.3	73.8	203.0	2000.3	1280.5	2.615	2.541	1.124	50.0
74	09/22/21	6A-B-75-1	5727.73	1000.2	6332.9	73.9	203.0	2000.2	1282.6	2.623	2.532	1.370	75.0
75	09/22/21	6A-B-75-2	5727.73	1000.5	6332.6	73.2	202.9	2000.9	1283.7	2.625	2.529	1.449	75.0
76	10/26/21	6M-B-75-1	5728.53	1000.3	6351.0	73.8	202.7	2000.3	1305.1	2.703	2.648	0.766	75.0
77	10/26/21	6M-B-75-2	5728.53	1000.2	6351.5	73.9	203.0	2000.5	1302.1	2.691	2.651	0.554	75.0
78	10/26/21	6M-B-25-1	5728.53	1000.2	6351.0	73.8	203.4	2000.2	1298.4	2.678	2.648	0.424	25.0

Test #	Date Tested	Sample ID	Calibration Volumeter (g)	Dry Sample Wt. (g)	Sample + Volumeter + Water (g)	Bag Wt. (g)	Rubber Sheet Wt. (g)	Dry Sample Wt. (g)	Wt. of Bag in Water (g)	*uG_{sa}*	*uG_{sb}*	*uAbs*	Percent Fines
79	10/26/21	6M-B-25-2	5728.53	1000.2	6350.7	73.2	202.7	2000.3	1299.0	2.680	2.645	0.490	25.0
80	02/08/22	6N-B-75-1	5728.63	1000.5	6343.5	73.5	202.7	1999.4	1278.4	2.610	2.594	0.235	75.0
81	02/08/22	6N-B-75-2	5728.63	1000.4	6344.7	73.3	203.5	2000.6	1279.6	2.611	2.603	0.123	75.0

Table B.4 Fine and Coarse Aggregate Data used to calculate Specific Gravities and Absorption for Blended Aggregate

Sample ID	Fine G_{sb} (Avg)	Fine G_{sa} (Avg)	Fine *Abs* (Avg)	Coarse G_{sb} (Avg)	Coarse G_{sa} (Avg)	Coarse *Abs* (Avg)	Percent Fines	Calc. G_{sb}	Calc. G_{sa}	Calc. *Abs*
6N-B-25-1	2.605	2.661	0.811	2.598	2.650	0.764	25.0	2.600	2.628	2.190
6N-B-50-1	2.605	2.661	0.811	2.598	2.650	0.764	50.0	2.601	2.639	1.730
6N-B-75-1	2.605	2.661	0.811	2.598	2.650	0.764	75.0	2.603	2.650	1.271
3G-B-25-1	2.439	2.626	2.922	2.415	2.576	2.591	25.0	2.421	2.513	2.663
3G-B-50-1	2.439	2.626	2.922	2.415	2.576	2.591	50.0	2.427	2.550	2.749
3G-B-75-1	2.439	2.626	2.922	2.415	2.576	2.591	75.0	2.433	2.587	2.836
6A-B-25-1	2.405	2.606	3.223	2.449	2.595	2.289	25.0	2.438	2.530	2.752
6A-B-50-1	2.405	2.606	3.223	2.449	2.595	2.289	50.0	2.444	2.564	2.909
6A-B-75-1	2.405	2.606	3.223	2.449	2.595	2.289	75.0	2.442	2.595	3.066
5I-B-50-1	2.607	2.652	0.641	2.594	2.640	0.660	50.0	2.601	2.631	1.640
2C-B-50-1	2.754	2.968	2.618	2.803	2.947	1.752	50.0	2.778	2.908	2.782
2C-B-90-1	2.754	2.968	2.618	2.803	2.947	1.752	90.0	2.759	2.955	2.651
6M-B-75-1	2.535	2.639	1.555	2.594	2.697	1.480	75.0	2.549	2.637	1.840
6M-B-25-1	2.535	2.639	1.555	2.594	2.697	1.480	25.0	2.579	2.634	2.412
6N-B-75-1	2.439	2.626	2.922	2.598	2.650	0.764	75.0	2.556	2.620	2.718
2D-B-75-1	2.607	2.652	0.641	2.849	2.949	1.195	75.0	2.784	2.821	2.372
2D-B-50-1	2.607	2.652	0.641	2.849	2.949	1.195	50.0	2.722	2.762	1.795

Table B.5 CoreLok Specific Gravity Values for RAP Materials

Test #	Date Tested	Sample ID	Calibration Volumeter (g)	Dry Sample Wt. (g)	Sample + Volumeter + Water (g)	Bag Wt. (g)	Rubber Sheet Wt. (g)	Dry Sample Wt. (g)	Wt. of Bag in Water (g)	uG_{sa}	uG_{sb}	uAbs	P_b (%)
82	02/22/22	3G-MD-1	5727.83	1000.3	6338.9	73.5	202.8	2000.4	1289.8	2.647	2.570	1.135	0.0
83	02/22/22	6M-MD-1	5727.83	1000.3	6353.6	73.5	202.0	2000.5	1304.3	2.700	2.671	0.398	0.0
84	02/22/22	6A-MD-1	5727.83	1000.1	6335.2	73.8	203.0	2000.5	1278.8	2.609	2.546	0.944	0.0
85	01/04/22	3G-R-3-1	5728.37	1000.25	6304.95	73.6	203.2	2000.4	1195.6	2.354	2.361	-0.131	3.0
86	01/05/22	63-R-3-2	5728.37	1000.7	6305.3	73.9	202.1	2000.3	1198.2	2.362	2.361	0.011	3.0
87	01/11/22	6N-R-3-1	5728.37	1000.0	6335.3	73.8	203.0	2000.2	1254.4	2.529	2.544	-0.226	3.0
88	01/11/22	6N-R-3-2	5728.37	999.9	6334.2	73.6	203.5	2000.6	1256.0	2.533	2.537	-0.067	3.0
89	02/22/22	3G-R-5-1	5725.40	1000.3	6286.1	72.9	202.8	2000.2	1201.9	2.372	2.275	1.784	5.0
90	02/22/22	3G-R-5-2	5725.40	1000.2	6287.3	73.1	203.5	2000.0	1199.7	2.365	2.282	1.546	5.0
91	02/22/22	6M-R-5-1	5727.83	1000.5	6303.2	73.7	202.4	2000.1	1230.1	2.454	2.353	1.754	5.0
92	02/22/22	6M-R-5-2	5727.83	1000.3	6307.5	73.5	202.3	2000.2	1228.1	2.448	2.378	1.202	5.0
93	02/22/22	6A-R-5-1	5727.83	1000.2	6269.7	73.2	202.2	2000.3	1188.2	2.334	2.182	2.986	5.0
94	02/22/22	6A-R-5-2	5727.83	1000.3	6278.9	74.0	202.3	2000.0	1189.1	2.337	2.227	2.120	5.0

Appendix C. Particle Size Distribution Curves for Coarse Aggregates

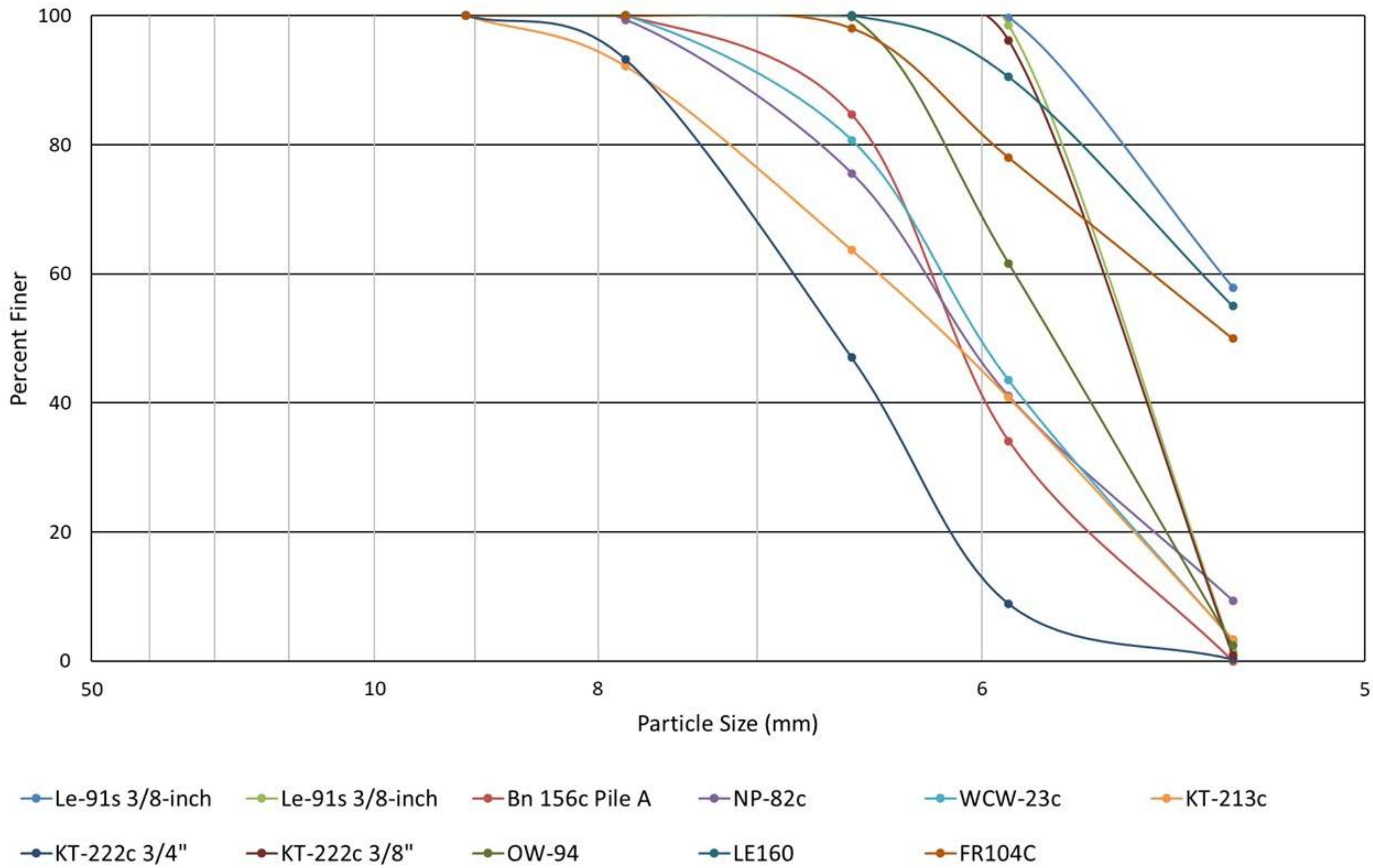

Figure C.1 Particle Size Distribution of Coarse Aggregates