IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

Evaluation, Comparison, and Correlation between the Idaho IT-144 and AASHTO T-84 Methods for Determining the Specific Gravity and Absorption Properties of Fine Aggregate

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16. Abstract

The objective of this study was to develop a correlation between lab tests performed using the CoreLok (Idaho -IT-144) method and results from the AASHTO T-84 procedure for fine aggregates in Idaho. These tests are used to determine critical aggregate parameters such as (a) absorption, (b) *Gsa*, (c) *Gsb*, and (d) Gsb_{SSD}. The AASHTO T-84 procedure takes up to three days to complete, and also requires considerable expertise to recognize the SSD condition. In contrast, the CoreLok method can be completed within 30 minutes, and provides consistent, repeatable results which are not influenced to the level of T-84 by operator experience. Unfortunately, the CoreLok results for Idaho aggregates do not always agree with values from a T-84 test. To investigate the differences, 116 T-84 and 101 CoreLok tests were performed on 25 fine aggregates commonly used by ITD. The carefully conducted tests revealed that the *Gsa* values determined from both tests were very similar at a 95 percent level of significance, while the absorption and *Gsb* values showed significant differences. This study used uncorrected values of absorption and *Gsb* from the CoreLok method to develop correlations between the absorption and *Gsb* values determined using a more intricate AASHTO T-84 procedure. As the CoreLok *Gsa* values were found to be reliable, only correlations for predicting absorption *and Gsb* were considered by this study. A multi-variable, linear correlation was found to predicts the *Gsb* value based on the uncorrected *Gsb* and the *Gsa* value from CoreLok tests.

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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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List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
Abs	Absorption
cAbs	Corrected Absorption from a Corelok test
cGsa	Apparent Specific Gravity from a Corelok test
cGsb	Dry Bulk Specific Gravity from a CoreLok test
DOT	Department of Transportation
FHWA	Federal Highway Agency
ITD	Idaho Transportation Department
Gsa	Apparent Specific Gravity
Gsb	Dry Bulk Specific Gravity
Gsb_{SSD}	SSD Bulk Specific Gravity
HMA	Hot Mix Asphalt
uAbs	Uncorrected Absorption from a CoreLok test
uGsb	Uncorrected Dry Bulk Specific Gravity from a CoreLok test
VMA	Voids in Mineral Aggregate

Executive Summary

Introduction

The design of a Hot Mixed Asphalt (HMA) pavement mix requires information about the Bulk Specific Gravity (*Gsb*) and Absorption characteristics of the fine aggregates. This data is often determined using the standard AASHTO T-84 test for fine aggregates, which usually takes 2-3 days to complete. As the test is strongly dependent on the expertise of the operator, it has encountered ongoing criticism due to the subjective nature of the test. To overcome some of the operator-dependent errors associated with the AASHTO T-84 procedures, a method, known as the CoreLok method was developed about twenty years ago. This method is quick, reliable, portable, and provides consistent, repeatable results for fine aggregates. The Idaho Transportation Department (ITD) has its own standard procedure for the CoreLok test, IT-144 (2008), which is based on the original ASTM standard D7370. As the CoreLok test may be completed on an aggregate sample within 30 minutes, it has become a popular replacement for the AASHTO T-84 test. Unfortunately, the values of the bulk specific gravity, *Gsb*, and the absorption, *Abs,* determined using the CoreLok test are not in good agreement with the results from the AASHTO T-84 test performed on fine aggregate.

Project Objectives and Tasks

The main objective of this study was to develop models which would correlate the IT-144 test (CoreLok) results with AASHTO T-84 test results for Idaho fine aggregates. Additionally, the research evaluated both testing methods to determine if the procedures could be modified to improve the reliability of the test results.

To achieve the above objectives, a total of 25 typical aggregate samples collected from all six ITD districts were tested using AASHTO T-84 and Idaho IT-144 test methods. A Round-Robin experiment was carried out involving ITD (Boise), ALLWEST and STRATA to confirm that the results were comparable between the participants. In the end, a total of 116 “AASHTO T-84” tests and 101 “Idaho IT-144” tests were completed by UI, ALLWEST, and the ITD (Boise) lab for the data analysis. The data from CoreLok testing included: uncorrected absorption, *uAbs* , corrected absorption, *cAbs* , uncorrected *uGsb*, corrected c*Gsb*, and (4) c*Gsa*. The data from T-84 testing included: Absorption, T-Abs, Bulk Specific Gravity,T-*Gsb*, and Apparent Specific Gravity, T-*Gsa*.

The values of aggregate properties like Specific Gravities (SGs) and Absorption obtained from the test methods were analyzed using statistical software (Minitab, version 18). Simple regression analyses and multiple regression analyses were performed to develop linear and nonlinear prediction models. AASHTO T-84 results were used as the dependent variables and the CoreLok test results as the predictor variables. This analysis resulted in two good models which may be used by ITD to predict T-84 results based on data obtained from the CoreLok test.

Key Findings

The data collected from UI, ALLWEST, and the ITD (Boise) Lab were used to develop the regression models. The main conclusions are:

1. The paired T-tests indicated a statistically significant difference in the mean values of the absorption (*Abs*) and bulk specific gravity (*Gsb*) results based on the AASHTO T-84 and the CoreLok test methods. Values of the apparent specific gravity, *Gsa*, were found to be the “same” at the 95 percent significance level.

2. In most of the cases, the CoreLok test overestimated the values of *Gsb*, and underestimated the absorption values compared to the AASHTO T-84 results. The *Gsa* results from both tests were very similar.

3. The use of uncorrected values of *uAbs* and *uGsb* from the CoreLok testing are preferred over the AggSpec calculated values, *cAbs* and *cGsb*, for model development.

4. Two good regression models, with high R^2 values, have been identified by this study for calculating the bulk specific gravity, *cGsb*, and absorption, *cAbs,* from the CoreLok test. Both equations rely on the *cGsa* value determined from the CoreLok test.

    - Absorption (c*Abs*) may be determined using the uncorrected CoreLok value, *uAbs*, as shown below. With *cAbs* known, c*Gsb* may be calculated using the equation shown below.

      Linear Regression:

      $$cAbs = 0.6265 + 1.9759 \times (uAbs)$$

      $R^2_{pred} = 0.7998$; $R^2 = 0.8291$; $R^2_{adj} = 0.8216$

      $$cGsb = \frac{cGsa}{1 + \frac{cAbs}{100\%} cGsa}$$

- If the *cGsb* value is determined using the multiple linear regression equation, the absorption may be calculated using the given theoretical equation.

  Multiple Linear Regression:

$$cGsb = -5.5937 + 15.9435[uGsb] - 10.5729[cGsa]$$
$$-4.5893[uGsb]^2 + 3.7309(uGsb \times cGsa)$$

$R^2_{pred} = 0.9454$; $R^2 = 0.9668$; $R^2_{adj} = 0.9602$

$$cAbs = \left[\frac{1}{cGsb} - \frac{1}{cGsa}\right] \times 100\%$$

Recommendations

Based on the results of this study,

1. It is recommended that the current Idaho IT-144 (CoreLok) test procedure continue to be used, except that the Idaho Correlation Procedure from this report be used for calculating fine aggregate specific gravities and absorption values. The Idaho IT-144 method, compared to the AASHTO T-84 method, is a much faster test to perform, more repeatable, and not as affected by operator experience or the lack thereof.

$$cGsb = -5.5937 + 15.9435[uGsb] - 10.5729[cGsa]$$
$$-4.5893[uGsb]^2 + 3.7309(uGsb \times cGsa)$$

2. The value of the measured, uncorrected parameter, *uGsb*, must be modified to predict the bulk specific gravity. This study recommends that the *cGsb* value be corrected using the following equation:

$$cAbs = \left[\frac{1}{cGsb} - \frac{1}{cGsa}\right] \times 100\%$$

3. With the c*Gsa* and the corrected value *cGsb* determined, the absorption may be calculated using the equation:

4. Based on the successful outcome of this study, ITD should consider further research to produce similar prediction models which may be used for coarse aggregates, and combined fine and coarse aggregates, tested using the faster CoreLok device.

5. Other state DOTs should consider performing similar studies on fine aggregates with a view to developing better prediction models based on the more reliable CoreLok tests.

Chapter 1
Introduction

Overview and Problem Statement

The design of a Hot Mixed Asphalt (HMA) pavement mix requires information about the Bulk Specific Gravity (*Gsb*) and Absorption characteristics of the fine aggregates. This data is often determined using the standard AASHTO T-84 test for fine aggregates, which usually takes 2-3 days to complete. As the test is strongly dependent on the expertise of the operator, it has encountered ongoing criticism due to the subjective nature of the test.(1) This concerns the reliable determination of a condition known as, “Saturated Surface Dry” (SSD), which contributes to variability, especially between different laboratories.

The use of erroneous *Gsb* values and absorption for aggregates used in HMA design results in mix volumetric errors, especially in the calculation of the voids in mineral aggregate (VMA) and asphalt content. This may result in bad design of the mix and may cause early distresses in the pavement.

To overcome some of the operator-dependent errors associated with the AASHTO T-84 procedures, a method was developed some 20 years ago. Known as the CoreLok method, this method is quick, reliable, portable, and provides consistent, repeatable results for fine aggregates. The standardized procedures for the test have been published as ASTM D7370. The Idaho Transportation Department (ITD) has its own standard procedure for the CoreLok test, IT-144 (2008), which is based on the original ASTM standard. In that a CoreLok test may be completed on an aggregate sample within 30 minutes, it has become a popular replacement for the older AASHTO T-84 test.

Results however, from the CoreLok Bulk Specific Gravity test are adversely affected by aggregate absorption in the two-minute time frame allowed in the test method. There was a need then to develop correlations for aggregates used in Idaho.

Objectives of the Study

For this study, aggregate samples were collected from Contractor and State sources currently in use on Idaho projects and tested using the Idaho IT-144 and AASHTO T-84 test procedures. After verifying the quality of the results, correlations were proposed to estimate the AASHTO T-84 results using the readily obtained CoreLok values. Additionally, the study examined nuances of AASHTO T-84 test procedures, and present recommendations that minimize operator dependent results.

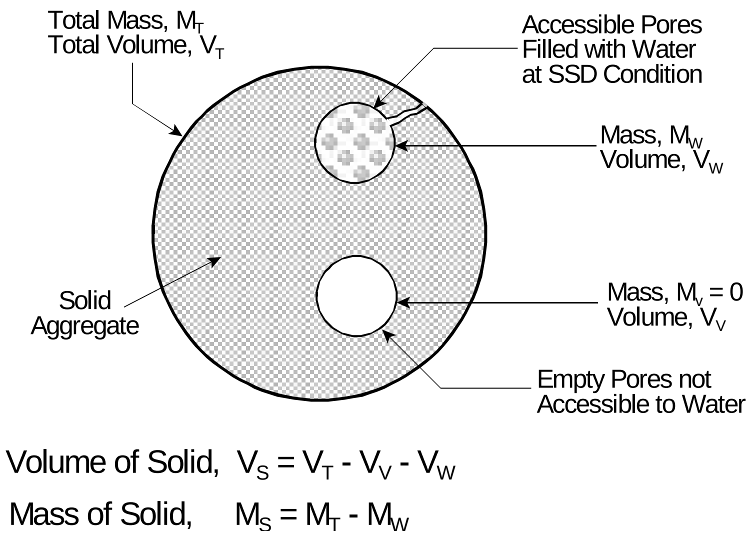


Figure 1 Definition of mass and volumes for an aggregate particle at SSD condition

Definitions of Specific Gravity

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 shows the masses and volumes for a unit aggregate particle that may be determined from IT-144 and AASHTO T-84 tests. By considering the volume of water permeable or impermeable voids in the aggregate, three different specific gravities are defined in practice.[2]

Apparent Specific Gravity

Apparent Specific Gravity (*Gsa*) is defined as the ratio of total mass (M_T) to volume of solids (V_S) of an aggregate particle. The volume that is considered here is the volume of the aggregates, excluding impermeable and water permeable voids. This value is the highest of all the specific gravities because it only considers the volume of solids.

Bulk Dry Specific Gravity

Bulk Dry Specific Gravity (*Gsb*) is defined as the ratio of the mass of solids (M_s) to total volume (V_s) of the aggregate particle. This value is smaller than the apparent specific gravity, *Gsa*, because the mass of the water in the water permeable voids is excluded, while using the same volume.

Bulk Saturated Surface Dry Specific Gravity

Bulk Saturated Surface Dry Specific Gravity (Gsb_{SSD}) is defined as the ratio of the total mass (M_T) of an aggregate particle to the total volume (V_T). The total mass of the aggregate includes mass of the solid and mass of water in the accessible pores at SSD condition.

Definition of Absorption

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.

If the masses and volumes are measured in grams and cubic centimeters, respectively, the following equations may be used to calculate the specific gravities.

(a) Bulk Dry Specific Gravity,

$$Gsb = \frac{M_T - M_W}{V_T}$$

(b) Bulk SSD Specific Gravity,

$$Gsb_{SSD} = \frac{M_T}{V_T}$$

(c) Apparent Specific Gravity,

$$Gsa = \frac{M_T}{V_s}$$

(d) Absorption,

$$Gsa = \frac{M_T}{V_s}$$

Additional relationships between these four variables may be derived, as shown in the equations presented below.

(e) Bulk SSD Specific Gravity,

$$Gsb_{SSD} = \left(1 + \frac{Abs}{100\%}\right) \times Gsb$$

(f) Apparent Specific Gravity,

$$Gsa = \frac{Gsb}{\left(1 - \frac{Abs}{100\%} \times Gsb\right)}$$

Figure 2. Equations for Calculating Specific Gravities and Absorption

The two methods for determining the Specific Gravity and Absorption properties of fine aggregates used in this analysis are: (1) Idaho test method IT-144, "Specific Gravity and Absorption of Fine Aggregate using Automatic Vacuum Sealing (CoreLok) Method", and (2) AASHTO's standard method of test T-84, "Specific Gravity and Absorption of Fine Aggregate." 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 2 presents a summary of the information gathered from a comprehensive literature review of research and findings concerning T-84 and CoreLok testing. At least five state DOTs have evaluated these tests and adopted guidelines for their use.

Chapter 3 concerns the samples of fine aggregates selected for testing, their descriptions, and sources. For this study, 25 samples from six ITD Districts were tested for the development of useful correlations. The chapter also discusses the various procedures used to prepare samples for testing.

Chapter 4 discusses the testing procedures followed to determine the specific gravities and absorption properties. Specifically, there is a discussion of the Idaho IT-144 and AASHTO T-84 test methods. Additionally, with a view to minimizing variability, helpful information for completing these tests are presented along with appropriate recommendations.

Chapter 5 discusses the aggregate test results. The chapter discusses the Round Robin experiment, results from the five ITD districts, and presents a summary of the results used for the statistical data analysis.

Chapter 6 presents detailed information about the analytical methods used to develop practical correlations between the IT-144 and AASHTO T-84 results. Several regression models are presented in this chapter to estimate AASHTO T-84 values using the IT-144 values.

Chapter 7 provides a summary of the research performed, along with conclusions and recommendations for future research. The best regression model to correlate two test methods, IT-144 and AASHTO T-84, are presented with their R^2 values.

The complete calculations and results from testing 25 fine aggregate samples are presented in the Appendix.

Chapter 2
Literature Review

Introduction

This chapter discusses the significance of the specific gravity and absorption parameters, as used for HMA mix design and volumetrics. This is followed by a discussion of the AASHTO T-84 and Idaho IT-144 test methods followed by a summary of the relevant literature reviewed for the project. Much of the literature on this topic concerned the assessment of the CoreLok method's ability to generate results that are comparable with the AASHTO T-84 method.

Bulk specific gravity (*Gsb*) is one of the most important parameters in the design of Hot Mix Asphalt (HMA) pavement mixtures, as the value is used in the calculation of Voids in Mineral Aggregate (VMA).(3) Once calculated, its value is used in the calculation of effective binder content.

HMA mix designs also rely heavily on accurate aggregate absorption values.(4) Aggregate absorption depends primarily on the aggregate type and gradation, and typically varies from 0 to 5 percent. Miscalculation may affect the HMA design, such that an artificially low calculation will produce dry mixes leading to reduced durability of pavement. Conversely, higher than actual absorption values require more asphalt in the HMA mixture often producing a pavement that is prone to rutting and other distresses.

There are traditional and new mechanical methods to measure the specific gravities and absorption of the aggregates. For this study, specific gravity and aggregate absorption are determined using two tests, IT-144 and AASHTO T-84.

Typical equations used to calculate Air Voids (V_a), VMA, Voids Filled with Asphalt (VFA) and Volume of Effective Binder (V_{be}) are presented in Figure 3: (5)

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times\ 100$$

$$VMA = \left(100 - \frac{G_{mb} \times\ P_s}{G_{sb}}\right)$$

$$VFA = \left(\frac{VMA - V_a}{VMA}\right)$$

$$V_{be}\ = VMA - V_a$$

Figure 3. Equations for calculating volumes

where,

G_{mb} = Bulk Specific Gravity of the compacted sample

G_{mm} = Maximum Specific Gravity of asphalt mixture

P_s = Percentage of aggregate in the total mixture

G_{sb} = Aggregate Bulk Specific Gravity

Standard Test Method (AASHTO T-84)

The Idaho Transportation Department (ITD) has in the past used the American Association of State Highway and Transportation Officials (AASHTO) standard test method T-84 for fine aggregates. AASHTO T-84 is a standard method for determining Specific Gravity and Absorption of fine aggregates that pass the #4 sieve (4.75mm mesh). The critical part of the test is the determination of the Saturated Surface Dry (SSD) condition.

The cone test is used to determine if the aggregate has reached the SSD condition. This is basically a small-scale slump test indicating that the apparent cohesion between the aggregate particles is reduced allowing the cone to collapse. The cone test works well for aggregates which are natural sands and rounded clean aggregates. With the growing trend of using manufactured aggregates, the cones may not slump readily and may cause problem with the determination of correct specific gravities and absorption values. For the aggregates that do not slump readily there are four criteria that can be used, as mentioned in Note 2 in AASHTO T-84.[2]

After the SSD condition is reached, the volume-displacement portion of the test starts by using the wetted aggregate in a pycnometer. This is followed by drying the aggregate and determining its mass. The whole process may take approximately 24 to 36 hours to complete.[2] The test method is discussed in greater detail in Chapter 3.

CoreLok Method (Idaho IT-144)

The CoreLok test method follows the ASTM D7370 standard and ITD has its own version Idaho IT-144. The IT-144 procedures use a CoreLok device from Instrotek. IT-144 is an Idaho standard method of test for Specific Gravity and Absorption of fine aggregates using the automatic vacuum sealing (CoreLok) method.[6] The IT-144 method addresses many of the drawbacks of the AASHTO T-84 method. For a typical test, the aggregate sample is oven dried and then divided into two 500g and one 1000 g samples for two different parts of the test. In the first part of the test, the 1000 g aggregate is sealed in a bag in a vacuum chamber and opened under water to rapidly saturate the sample. The dry and submerged weight of the aggregate is used to calculate *Gsa*. The second part of the test uses a metal pycnometer (volumeter) and the remaining two 500 g samples. Bulk Dry Specific Gravity (*Gsb*) is calculated using the weight of volumeter filled with water, dry aggregate (500 g), and average weight of volumeter with aggregate and water only. These results are used to calculate the Gsb_{SSD} and Absorption.[6]

There are some aspects that could introduce errors in the test procedure. In the volumeter test, it is assumed that the oven dried aggregates absorb negligible amount of water during the two minutes of testing. Whereas, the amount of water absorbed depends upon two properties of aggregates, rate of absorption and absorptive capacity. Therefore, it is practical to assume that there is significant amount of water ingress into the water permeable voids of the aggregates during the two minutes of testing. Also, the test result for the vacuum chamber test could be affected by the duration and magnitude of vacuum applied to the plastic bag, and gradation of the aggregates.(2) More discussion about the test is given in Chapter 3.

Attempts have been made to minimize possible errors. The objectives of the study by Richardson and Lusher in 2006 for Missouri DOT (MoDOT) was to create a better calibration model for the CoreLok device to more reliably predict T-84/85 specific gravity values based on the CoreLok results. (2) It was believed that the increased confidence in using CoreLok method would be useful in quality control and quality assurance to determine the specific gravities and absorption of the aggregates.

The researchers accomplished this through multiple regression analysis on information from previously tested samples supplied by MoDOT that had been tested with both methods. In total, results from 233 unique samples were analyzed. The data were modified to remove certain non-natural sands (manufactured sands) which brought the total to 200 individual tests. Twenty random selections were removed from that dataset to use for independent model validation and the remaining 180 samples were used to create the correlation.

In the AggSpec software developed by Instrotek in 2002, corrections were made considering the variation in *Gsa* and *Gsb* values calculated using the two different test methods. Corrections were applied to the *Gsb* value obtained using CoreLok based on the laboratory work in which the actual water absorbed by the fine aggregates during the two minutes was taken into account. Later, Instrotek also corrected the Excel spreadsheet prepared by MoDOT. Corrections were made on both *Gsa* and *Gsb* values obtained from CoreLok test for fine and coarse aggregates. The correction was a simple linear correlation for the CoreLok-*Gsa* values to predict the T-84 *Gsa*. Correction of CoreLok-*Gsb* still posed a problem however, with the three discontinuous predictive models developed using T-84-*Abs* as a dependent variable and CoreLok-*Abs* as a predictor variable. The correction method was doubly problematic in that absorption is the most imprecise measurement of the properties *Gsa*, *Gsb*, and *Abs*, as documented in the single operator precision statement in T84/85 and ASTM C 128. These problems became the genesis of the MoDOT study.

The researchers did a secondary analysis to discover other factors that might be used as predictor variables in a calibration model. They considered Los Angeles Abrasion and Micro-Deval tests because these are a good quantitative indication of aggregate mineralogy.(2)

LA Abrasion and Micro-Deval were also shown to be statistically significant as predictor variables, though only in a preliminary sense. The correlation between *Gsa*/CoreLok-*Gsa* was found to be stronger than the *Gsb*/CoreLok-*Gsb*. The correlation between *Abs*/CoreLok-*Abs* was significant but was lower than the correlations between *Gsa*/CoreLok-*Gsa* and *Gsb*/CoreLok-*Gsb*.

The purpose of the Florida study was to evaluate the suitability of the CoreLok device to replace or supplement existing Florida DOT procedures. (1) The researchers evaluated this objective based on the G_{mm}, *Gsb*, and G_{mb} for asphalt mixes, coarse aggregate, and fine aggregate. Seven fine aggregates were tested and a total of 28 tests were performed (7 aggregate types × 2 methods × 2 samples). The researchers found that the CoreLok device produces *Gsb* results equivalent to Florida DOT procedures for low absorptive aggregates (similar to the granites in this study). However, they recommended not to use the CoreLok for determining *Gsb*, *Gsa*, or percent absorption because it generally does not produce results consistent with Florida DOT procedures.(1)

The objective of the Oklahoma DOT study was to determine if the AggPlus/CoreLok or SSDetect system would produce statistically similar results to standard AASHTO T-84/85 procedures and evaluate each method's ease of use. (7) SSDetect measures the SSD condition of the fine aggregate using an infrared light source tuned to water. To accurately measure the SSD condition, the amount of infrared reflectance is measured. The researchers tested 15 different samples of fine aggregate (in addition to coarse aggregate and blended samples) comprised of limestone, sandstone, granite and rhyolite, and natural sands and gravels. They performed a total of 180 tests (3 methods × 2 operators × 2 replicates × 15 sources).

After performing the tests, the researchers concluded that the CoreLok *Gsb* and *Gsa* were statistically similar to AASHTO T-84/85 but the CoreLok percent-absorption was statistically different from AASHTO. They also determined that the CoreLok produced a lower average standard deviation for *Gsb*, *Gsa*, and percent-absorption than the other methods. They also concluded that the procedure was easy to perform and took the least time. The researchers recommended a round-robin testing program within the state to verify the results for fine aggregates.

Prowell and Baker evaluated the SSDetect and CoreLok methods for determining the dry bulk specific gravity (*Gsb*) of fine aggregates. (3) Each method was evaluated against the standard method described in AASHTO T-84. The evaluation was based on a round robin study with twelve labs and six materials, four crushed and two uncrushed (natural) fine aggregate sources. The new test procedures, SSDetect and CoreLok were checked for bias and precision.

Here, bias is defined as the difference between the measured value and the true value of the measured property. Precision is defined as the measure of variability of the test procedure and the repeatability by a single operator or between two different laboratories.

Until this day, there is no fine aggregate sample whose actual specific gravity is known precisely. Comparisons were made between the values obtained from two test methods with the AASHTO T-84, because it is the accepted method at present. Analysis of Variance (ANOVA) was used to observe the interaction between the response and factors using the statistical software, Minitab. *Gsb*, *Gsa*, and Absorption were used as the response variables separately with material types and method of testing used as the factors.

Material types, test methods, and the interaction between them were all found to be significant for *Gsb*, *Gsa*, and *Abs*. For each material, separate one-way ANOVA were carried out. Tukey's family error rate comparison was used to compare the confidence interval at five percent significance level for the mean *Gsb*, *Gsa*, and Absorption for each test method. The statistical difference between the test methods AASHTO T-84 and CoreLok for *Gsb*, *Gsa*, and Absorption are given in Tables 1 and 2. Table 1 provides acceptable precision estimates for the pooled standard deviation for tests run by a single operator within a testing lab, and for comparing tests performed at multiple labs. Table 2 provides acceptable precision estimates for the difference between tests run by a single operator within a testing lab, and for comparing tests performed at multiple labs.

Table 1 Precision estimates for pooled standard deviation (1s) within a lab (Single Operator) and between multiple labs (Multi-labs)

Method	Single Operator CoreLok	Single Operator T-84	Multi-labs CoreLok	Multi-labs T-84
Gsb	0.0440	0.0157	0.0519	0.0230
Gsa	0.0230	0.0093	0.0238	0.0151
Absorption (%)	0.3618	0.2170	0.5709	0.4380

Table 2 Precision estimates for acceptable difference between two results (D2S) within a lab (Single Operator) and between multiple labs (Multi-labs)

Method	Single Operator CoreLok	Single Operator T-84	Multi-labs CoreLok	Multi-labs T-84
Gsb	0.1245	0.0443	0.1468	0.0651
Gsa	0.0651	0.0264	0.0672	0.0428
Absorption (%)	1.0233	0.6137	1.6148	1.2389

ASTM 691 software was used to calculate the precision of test methods from the round robin results. The precision has two components: repeatability and reproducibility. Repeatability is the standard deviation of the test results within a laboratory whereas reproducibility is the standard deviation of the test results between two laboratories.

Prowell and Baker found that statistical differences exist between the automated methods (Corelok and SSDetect) and AASHTO T-84.[(3)] The SSDetect method showed lower variability compared to AASHTO T-84, as shown in Table 1. Prowell and Baker concluded that the precision of the CoreLok method was not as good as AASHTO T-84 and that the precision of the CoreLok method could improve with the familiarity of technicians with the procedure.[(3)]

The purpose of the West Virginia study was to evaluate different methods for measuring aggregate specific gravity for slag and limestone, and statistically compare the results with AASHTO methods. [(8)] The researchers used 9 alternative methods to the standard AASHTO procedures ranging from modified

AASHTO procedures to the CoreLok method. The study did not make any attempt to verify if another state's methods could find results similar to the standard AASHTO methods. Only two aggregate sources were tested – limestone and slag. A total of 30 samples were prepared and tested using 10 methods. Each sample being tested three times. The researchers found that there were statistically significant differences between the CoreLok method and the established AASHTO T-84 method results. They recommended that further research be done on other aggregate types and the department should continue to use the AASHTO T-84 test method.

The standard methods of testing AASHTO T-84 and T-85 are not typically used in practice for quality control because of the time it takes to run those tests. The vacuum-sealing method (CoreLok method) eliminates the sample soaking time and the time to reach the SSD state in T-84. Hall[10] in his study measured the specific gravity and absorption of the aggregates using both traditional and vacuum methods. Six coarse and four fine aggregate were selected with different types of mineralogy. Tests were performed on five replicates of each aggregate sample.

Hall states that values of *Gsa*, *Gsb*, and Absorption are used in the calculation of volumetric properties of hot-mix asphalt and are also important in obtaining the field density and proper compaction. [9] It is of high priority to the material engineer to accurately and consistently measure the specific gravity and absorption while designing any civil engineering structures. The objective of the study was to evaluate the CoreLok method for its suitability in determining the specific gravities and absorption of different types of aggregates.

For the study aggregates of different types like limestone, sandstone, granite, gravel, and natural sand were selected. All the aggregates were crushed and sampled from in-service stockpiles at the material production facilities. The AASHTO T-84/85 and CoreLok test methods were used, and a single operator performed all the tests to minimize variability. To attain a more realistic measure of variability, a random testing sequence was adopted for the study.[9]

When all the values for aggregates were obtained for different tests, the values were averaged. The mean values for the fine aggregates are tabulated in Table 3. Two statistical tests, the F-test and t-test, were used to see whether the test methods are statistically significant with respect to the results. A significance level of five percent ($\alpha = 0.05$) was used for the analyses.

Table 3 Mean specific gravity and absorption results for individual aggregates based on 5 replicates

Aggregate	AASHTO, *Abs*	CoreLok, *Abs*	AASHTO, *Gsa*	CoreLok, *Gsa*	AASHTO, *Gsb*	CoreLok, *Gsb*
GRSC	1.30	0.66	2.650	2.646	2.601	2.562
SSSC	2.37	2.10	2.669	2.658	2.510	2.518
DFLL	0.14	3.28	2.638	2.622	2.629	2.415
SAND	0.41	0.51	2.651	2.639	2.623	2.604

It should be noted that AASHTO T-84 and T-85 require expressing a specific gravity value to two decimal places; the values in Table 3 are shown with three decimal places for subsequent use in hot-mix asphalt applications.

Almost half of the results for *Gsa*, *Gsb*, and Absorption were observed to be significantly different at the 95 percent confidence level. The results showed that for Absorption values of less than one percent, CoreLok overestimated the absorption values and for 1.0 to 2.5 percent, CoreLok underestimated the absorption capacity. CoreLok underestimated the *Gsa* for fine aggregates, and the mineralogy did not play any significant role. A determining factor could not be identified for the *Gsb* as the results were not consistent with mineralogy or the higher or lower absorption values. The findings and the analyses of variability of the test results agreed with those reported by Prowell and Baker.(3)

Hall in his study concludes that the CoreLok method could be a likely alternative to the traditional method to measure the specific gravities and absorption of the aggregates.(9) Also, based on the test results carried out by Hall, before the CoreLok method can be considered as a replacement for the AASHTO procedure, the CoreLok results have to be consistent and comparable to the AASHTO methods.

It is important to accurately determine the bulk specific gravity of the aggregate for the accurate calculation of the realistic volumetric properties of the compacted HMA mixtures. A team of Khandal, Mallick and Huner(10) performed a study to develop an equipment to determine the SSD condition of the fine aggregates with high precision and accuracy. The SSD condition is usually reproducible for the well graded natural fine aggregates whereas, for the crushed fine aggregates, the results are inconsistent.

Various studies have been done in the past to improve reproducibility of the bulk specific gravity results. Some of those are: a glass jar method(13) (14), Martin's wet and dry bulb temperature method(15), Saxer's absorption time curve procedure(16), and Hughes and Bahranian's saturated air drying method.(17) The proposed modifications to those methods either didn't provide a significant improvement in the result or were too elaborative to be used in the field or were not practical for an average laboratory.

To determine the SSD condition, Khandal and Lee, developed a colorimetric method which involved soaking of sample in water with a specific dye.(18) The color of dye changed when dried and that stage was assumed to be SSD condition. This method had some drawbacks as the color was not distinct for dark aggregates, there was no mechanism to ensure that if some aggregates will dry up faster, and the color change relied on the subjective judgement of the operator, which could introduce errors in the process.

Dana and Peters, for Arizona Department of Transportation, tried a different approach to directly determine the SSD condition by using simple thermodynamic principles.(19) Hot air was blown into a small rotating drum where the sample was placed. The temperature of the incoming and the outgoing hot air was monitored using thermocouples mounted at the inlet and outlet of the rotating drum. A steady value of the thermal gradient was observed when the aggregate was drying, but once the sample reached SSD condition, the thermal gradient suddenly dropped. The sample was then taken out of the drum for further testing. The first prototype of the equipment generated good results, but further development of the equipment did not materialize, and it was also recommended to perform testing on a wide range of fine aggregates.

Krugler et al. also proposed procedures for the determination of the SSD condition for the fine aggregates. [20] They proposed four methods. The sample is assumed to be in SSD condition if it fulfils at least two of the procedures mentioned below.

1. An oven dried sample is used as a reference while drying the fine aggregate sample. When the drying sample has the same color as the oven dried sample (for comparison), then SSD condition is supposedly reached.
2. A sample is assumed to be in SSD condition if it no longer adheres to the bottom of the pan and flows freely when placed over a tilted pan.
3. A sample is assumed to be in SSD condition if it no longer adheres to the bottom of the trowel and flows freely as individual particles.
4. A sample is assumed to be in SSD condition if no more than one sample particle adheres to the packaging tape which is attached to the small block of tape (Supreme Super-standard gummed paper tape, 2-in. medium duty).

The equipment developed by Dana and Peters at Arizona DOT was adopted for the study performed by Khandal, Mallick and Huner.[19, 10] The average bulk specific gravity value for cone test and the drum test method were not significantly different for the natural sands. The absorption values for the crushed aggregates were lower for the cone method than the drum test method because the crushed aggregates are over dried before the cone slump. The resulting bulk specific gravity value is thus higher for the cone method than the drum method.

The second prototype of the drum equipment was developed to overcome the problems that were encountered in the first prototype and to improve the result. The equipment needed to shut automatically once the sample reached the SSD condition. This helps to ensure the repeatability and reproducibility of the test method. It was recommended to develop the third prototype as soon as possible. The recommendation was to develop the mechanism to record the mass fluctuation in the drum when the sample dries because that way the sample will not have to be removed from the drum for weighing after it reaches the SSD condition. This would help to ensure the repeatability and reproducibility of the test method.

After reviewing over 15 articles, the general consensus is that the CoreLok method is a viable alternative to the AASHTO T-84 test method to measure the specific gravities and absorption of fine aggregates. Nevertheless, Hall stated that to accept CoreLok method as a replacement for AASHTO T-84 method, the CoreLok results must be consistent and comparable to the AASHTO T-84 test method.[9] Prowell and Baker also concluded that the CoreLok was not as good as AASHTO T-84 based on the precision and they believed that the precision of the technician may improve with the familiarity.[3] The study by West Virginia Division of Highways recommended further research on other aggregate types (other than those considered for the study) and for the meantime, the department should continue using the AASHTO T-84 method.[8]

Some new methods, such as, SSDetect, CoreLok, and many other modifications in the standard test procedure have been proposed but more research is needed before these can be adopted over the current T-84 standard. More specifically, many of the correlations proposed in the literature are aggregate specific and should not be used for other materials without calibration.

Chapter 3
Samples

Introduction

There are many aggregate sources available to ITD throughout Idaho. To focus on a limited number of samples, the Chief Materials Engineer in each ITD District (see Figure 4) was contacted and asked to provide details of their most popular fine aggregate sources. This survey was sent out in early February 2016 and finalized in late March 2016. From the results of the survey, representative aggregates were selected, and the ITD Districts were asked to send sack samples of 70-80 kg per aggregate source. A total of 22 aggregate samples were delivered by five ITD Districts to the University of Idaho lab in Moscow, ID, by the end of May 2016.

An additional three samples, one from District 3 and two from District 4, were added to the study in late 2018. These samples were selected to cover apparent gaps in the generated results from the testing of the initial 22 samples of fine aggregates.

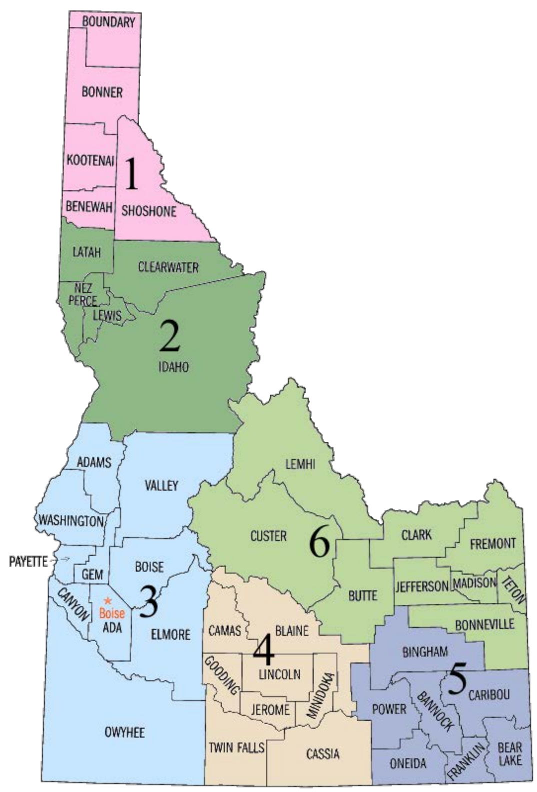


Figure 4 Idaho Transportation Department Districts

Material Selection

The sources of the 25 aggregate samples, and their mineralogy, are shown in Table 4. The Idaho Transportation Department aggregate identifier (ITD-ID), such as "Kt-213c", is also included in the Table. Once the samples were received and logged, each sample was given a unique identifier to introduce some anonymity. With this identifier, one can clearly recognize the district number and label assigned according to the testing sequence.

For example, the ITD-ID sample "Kt-213c" from ITD District 1 was labeled as "1D". Here the first number represents the district, and the second alphabetic label "D" indicates that this is sample "D", which implies that it was the fourth sample tested. With this labeling, one can quickly note that "A' must have been the first sample tested, and the 25th sample tested must be labeled "Y".

This identifier is further expanded for the testing phase, by adding numbers, and a unique identifier regarding the lab that performed the test. For example, a test labeled "UI-1D-02" indicates the second sample from aggregate "1D', as tested by the University of Idaho, i.e. "UI". The other identifiers for the labs involved in the project are: ITD – Idaho Transportation Lab, Boise; AW – ALLWEST, Meridian; and ST – STRATA, Boise.

Table 4 Aggregate - ID, Source Location, and Mineralogy

District	UI - ID	ITD - ID	Aggregate Source Location	Mineralogy
1	1D	Kt-213c	Rathdrum	Quartzite, Argillite/Siltite, Calcareous Siltstone/Siltite, and Granodiorite
1	1N	Kt-222c	Stateline	Quartz
1	1P	Kt-215c	Hayden	Quartz
2	2C	WCW-23c	Summit Stone Motley-Motley	Basalt
2	2Q	Id-256c	Lamb Pit Camas Gravel	Basalt
2	2T	WCW-18c	Poe Jorstad	Basalt
2	2V	NP-82c	Atlas Concrete Pit	Basalt, Rhyolite, Quartzite, and Andesite
3	3A	Pit Ad136	Central Paving – Apple Pit	Andesite, Granodiorite, Rhyolite/Dacite, Basalt, and Quartzite
3	3E	Ad-182c	C&A Paving	
3	3H	Ad-161C	Knife River Amyx Pit	
3	3J	Cn-140c	Idaho Materials and Construction Look Lane Pit	Granodiorite, Rhyolite/Dacite, Andesite, Basalt, and Quartzite
3	3W	Ow-94	Owyhee Co.	Diorite Rhyolite/Andesite

Table 4 Aggregate - ID, Source Location, and Mineralogy (continued)

District	UI - ID	ITD - ID	Aggregate Source Location	Mineralogy
4	4X	Cs-184c	Kloepfer Pit Cassia Co.	Rhyolite/Andesite
4	4Y	Cs-192	Cassia Co.	Rhyolite/Andesite
5	5O	Bg-111-c	Mickelsen Const., Blackfoot	Quartzite, Sandstone, Basalt, Rhyolite, Obsidian, and Opal
5	5R	Bk-100-c	JB Parson Co. Pocatello	Alluvial
5	5S	Bg-107-c	Gale Lim Const., Blackfoot	Alluvial
5	5U	Bl-93-s	Myron Earley, Ovid	Quartzite
6	6B	Fr-104-c	Teton Pit – Teton	Basalt, Rhyolite, Andesite, Obsidian, Granite, Quartzite, Chert
6	6F	Le-96-s	Leadore Pit – Leadore	Quartzite, Limestone, Andesite, Schist, Gneiss
6	6G	Cu-75-s	ITD Pit – SH-75 Clayton	Quartzite, Rhyolite, granite, Argillite, Siltite, Siltstone, Dacite, Andesite, Gneiss
6	6I	Bn-59-s	ITD Poplar Pit - Ririe	Quartzite, Limestone, Granodiorite, Diorite
6	6K	Bn-156-c	HK Willow Creek Pit	Quartzite, Rhyolite, Basalt, Granodiorite, Sandstones, Chert
6	6L	Le-160-c	Dahle Pit – US-93 Salmon River	Quartzite, Rhyolite, granite, Argillite, Siltite, Siltstone, Dacite, Andesite Gneiss
6	6M	Cl-56-s	ITD Ripper Pit - Dubois	Quartzite, Limestone, Basalt

Sample Preparation

For this study, plans called for testing each aggregate multiple times using the IT-144 and AASHTO T-84 procedures. For such a testing sequence, it is important that individual test samples be prepared carefully such that they are almost identical. For this project, a rigorous protocol was developed and followed closely to ensure that each prepared test sample was representative of the original aggregate. The sample preparation for each aggregate sample involved the following sequence:

1. Drying the entire sample;
2. Splitting the dried sample into roughly 15 kg portions;

3. Removing material greater than #4 (i.e. 4.75mm);
4. Washing the minus #4 material to remove fines, i.e. material passing the #200 sieve (0.075mm);
5. Drying the washed material;
6. Splitting all the dried, minus #4, washed material into approximately 4 kg samples. This size was selected as it allows splitting into sub-samples suitable for conducting one AASHTO T-84 test, and one IT-144 test from the 4 kg sample.

These preparation procedures are discussed in greater detail in the next section.

Reducing Samples of Aggregate to Testing Size

The delivered aggregate samples were oven dried first and split according to AASHTO T-248, to create uniform samples for testing. According to the standard, the splitter should have at least 12 equal width chutes for fine aggregates and the minimum width of the chutes should be at least 50 percent larger than the largest particle in the sample. A splitter with 16 equal width chutes was used and had two catch pans to collect the split samples.

Sieving to Remove Plus 4.75 mm Materials

Next, the split samples were sieved according to the standard AASHTO T-27. A large tray shaker was used to remove particle sizes greater than the #4 sieve (4.75mm).

Washing

The minus #4 samples were washed to remove fines (minus #200 material) following the AASHTO T-11 standard. The sample was agitated such that the fines were suspended in water and the runoff was drained through a No. 200 sieve. The No. 200 (75 µm) sieve was regularly inspected for cracks or holes. A nesting sieve, No. 16 (1.18 mm), with a larger opening, was used above the No. 200 (75 µm) sieve to protect the sieve underneath and also to prevent clogging. The sieve was washed using a rinsing bottle to remove the fines sticking to the No. 200 sieve.

Drying

The washed sample was oven dried at 230 ± 9°F (110 ± 5°C) following the AASHTO T-255 standard.

Preparing Samples for Testing

The dried, clean, minus #4 material was then reduced to testing size using the sample splitter. The aggregate sample was split into about four kg fractions and packed into plastic bags. The four kg amount is ideal for performing an AASHTO T-84 and IT-144 test. Some of the four kg samples were delivered to ITD-Boise, for testing by the ITD (Boise) lab, and by outside commercial labs, ALLWEST, Meridian, and STRATA, Boise.

Grain Size Distribution

There was some concern expressed that the multiple four kg bag samples prepared from one aggregate may have been split unevenly. Although there are no guarantees that the material in each bagged sample is identical, several pairs of bagged samples were selected from the 10 bagged samples prepared from aggregate 2E, and their grain size distribution checked for similarity.

The samples were sieved through sieve numbers 4, 10, 20, 40, 60, 100 and 200, and the difference in the grain size distribution between samples was negligible. Results clearly showed that the prepared aggregate samples were uniform with a nearly identical grain size distribution. This confirmed that the splitting process worked well for aggregate 2E. If it worked well for this sample, it was assumed that the aggregate splitting process probably created uniform samples for all other aggregates as well.

Summary

The procedures discussed above were performed on all batches of aggregates to minimize sample variabilities and to ensure that the samples were similar to the best extent possible. The bagged, 4 kg samples were used for all AASHTO T-84 and IT-144 tests performed for this study by UI, ALLWEST, STRATA and the ITD (Boise) lab. The results of the aggregate testing are included in Chapter 5 and later analyzed in Chapter 6.

Chapter 4
Methodology

Introduction

This chapter discusses the procedures followed for testing the fine aggregate. To determine the Specific Gravities (SGs) and Absorption, ITD relies on AASHTO T-84 and IT-144 standards. AASHTO T-84 is the standard test which is used nationally by most state DOTs with or without modifications. This test method has been in use for many years. However, as the AASHTO T-84 test method takes more time, the new automated CoreLok method has started to become more popular. The CoreLok test method follows the ASTM D7370 standard and ITD has its own version, Idaho IT-144, which was published in 2008. These two test methods are discussed in detail below.

IT-144 Method

The Idaho Transportation Department (ITD) follows the standard IT-144, "Specific Gravity and Absorption of Fine Aggregate using Automatic Vacuum Sealing (CoreLok) Method" for testing performed using the CoreLok device from Instrotek. This method is faster and has fewer apparent variabilities than the AASHTO T-84. For example, there is no need to soak samples and the only sample preparation necessary is oven drying the test sample. Other than the sample preparation, it takes only 30 minutes for testing. There are two parts to the test: (1) Using a metal pycnometer to determine weights, and (2) using the CoreLok vacuum chamber to effectively seal the dried sample using a vacuum, and then measuring the weight while the cut bag is submerged in water.

Procedures

The temperature of water used in this test procedure must be maintained at 25 ± 1°C (77 ± 2°F). Before starting the test, the pycnometer should be left in the water bath for conditioning such that it comes to the same equilibrium temperature. The pycnometer is then dried thoroughly using a towel.

Pycnometer Testing

This part of the test consists of a calibration followed by the actual test. For the calibration, the pycnometer is clamped over a plain surface and the level indicator is used to ensure that the clamped device is level. The pycnometer is filled with water to within 10 mm of the rim and isopropyl alcohol is sprayed on the surface if there are any air bubbles. The lid is placed on the pycnometer and locked. Using a syringe, water is injected into the pycnometer from the top center hole of the pycnometer until water comes out of a 3mm hole on the surface of the lid. This is an indication that the pycnometer is full. The application should be gentle and slow to ensure that no water bubbles are formed during the process. Water is wiped using a paper towel and the full pycnometer is weighed to the nearest 0.1 g. This process is repeated three times. The readings should have a range within 0.5 g and averaged calibrated weight is used in calculations. This calibration procedure effectively determines the volume of the pycnometer.

The testing involves the use of a pycnometer which must be completed in less than two minutes. Water is added to halfway and 500 g of fine aggregate is slowly and evenly poured into the pycnometer. A metal spatula is used to stir the aggregate thoroughly, with the aggregate being gently pushed from the circumference towards the center of the pycnometer. The pycnometer is filled to within 10 mm of the rim with water and isopropyl alcohol is sprayed on the top to remove any air bubbles. The lid is gently placed on the pycnometer and locked. Using a syringe, water is slowly injected into the pycnometer. Any excess water is wiped from the pycnometer with a paper towel and the full pycnometer is weighed to the nearest 0.1 g.

The pycnometer is cleaned, and the test is performed again with a fresh 500 g sample. The recorded mass in the two trials should be within one gram. If the difference is greater than one gram, a third test is performed, and the masses are averaged for calculations.

CoreLok Testing

This part of the test involves the use of the CoreLok vacuum device. The CoreLok vacuum chamber is run in program 2 mode and the other settings are shown in Table 5. The immersed weighing basket is tared in the water bath where the temperature of water is maintained at a constant 25 ± 1°C. A small plastic bag, of size 10 × 14 inch, was used for all tests. All bags were carefully examined for holes, stress points, or folds before use.

Table 5 Factory setting for CoreLok device

Control	Program #2	Description
Power Switch	On	Operation begins when lid is closed.
Vacuum Control	99%	Vacuum within chamber is 99% of absolute vacuum.
Dwell	300	Ensures that a vacuum of 99% is achieved.
Seal	1	Time setting of seal bar.

The mass of the plastic bag is measured and recorded to the nearest 0.1 g. Next, 1-kg of dried aggregate sample is poured into the plastic bag which is placed in the vacuum chamber and evenly spread. The bag should not be pressed from outside at any time. The open end of the plastic bag is placed over the seal bar and the chamber door is closed. The chamber door opens after drawing vacuum and the bag is sealed. It takes five to six minutes to create the vacuum and seal the plastic bag in the CoreLok machine.

The sample is gently removed and submerged in the water bath within five seconds of opening of the vacuum chamber. A small cut, approximately 50 mm (2 inches), is made on the top of the plastic bag. The bag is cut while submerged at least 50 mm below the water surface and at no time is the plastic bag brought outside the water bath. The immersed bag is held for 45 seconds to freely allow water into the plastic bag. During this process, the bag should not be shaken or squeezed because it may cause the loss of fines. Once the bag is filled with water, another cut, approximately 50 mm long, is made on the other side of the plastic bag. The top of the plastic bag is squeezed to remove the air bubbles by running fingers across the top.

The plastic bag is placed on the immersed weighing basket and water is allowed to enter. The weighing basket should not at any time touch the base of the walls of the water bath. The submerged mass is measured at the end of 15 minutes, recorded to 0.1 g. If the mass fluctuates by more than one gram at the end of 16 minutes, the mass is recorded at the end of 20 minutes. The six masses measured for the test are defined in Table 6.

Table 6 Data collected from CoreLok test

Item	Variable
Average calibration mass of pycnometer filled with water:	$W_{calibration}$
Mass of dry aggregate for the pycnometer:	W_{agg2}
Mass of pycnometer with aggregate W_{agg2} and water:	W_{pycn}
Mass of plastic bag:	W_{bag}
Mass of aggregate placed in the plastic bag:	W_{agg1}
Mass of submerged aggregate in water:	$W_{submerged}$

AggSpec Calculations

The data recorded are entered into the software, AggSpec, provided by the manufacturer, Instrotek. The software provides a report with Bulk Dry Specific Gravity (*Gsb*), Bulk SSD Specific Gravity (*Gsb-SSD*), Apparent Specific Gravity (*Gsa*), and Absorption (*Abs*) values. The software calculations are described below.

Calculations

1. Determine the **Apparent** Specific Gravity (SG) from the data collected from the CoreLok test. Volume of the plastic bag is obtained by dividing the weight of the bag by its density, 0.903 g/cm^3. Here, the volume of the aggregate sample is given by:

$$Volume = \left(W_{bag} + W_{agg\,1} - W_{submerged}\right) - \frac{W_{bag}}{0.903}$$

$$\text{Apparent, } cGsa = \frac{W_{agg\,1}}{Volume}$$

Figure 5 Equations used to calculate the apparent specific gravity, *cGsa*, from the CoreLok test

2. Determine the **Bulk** SG from the pycnometer test. Here, the aggregate volume is given by

$$Volume = W_{calibration} - \left(W_{pycn} - W_{agg\,2}\right)$$

$$\text{Pycnometer Bulk SG, } uGsb = \frac{W_{agg\,2}}{Volume}$$

Figure 6. Equations used to determine the uncorrected bulk specific gravity

3. Using the computed *cGsa* and *uGsb*, determine the volume of the SSD water (in cm^3) for 1 gram of aggregate. The same value of volume will give the mass of the water in grams. Using these values, estimate the uncorrected absorption, *uAbs* , which is the same as the gravimetric water content.

$$Vol_{SSD} = \left(\frac{1}{uGsb} - \frac{1}{cGsa}\right) = Mass_{SSD}$$

$$uAbs = \left(\frac{Mass_{SSD}}{1.0}\right) \times 100\%$$

Figure 7 Equation used to calculate the uncorrected absorption

4. Instrotek proposes that if the above calculated value of *uAbs* is less than −0.1, add 0.3 to the value, i.e. *uAbs* = *uAbs* + 0.3.

5. Next, the corrected absorption value is calculated using Instrotek's regression equation

$$cAbs = 1.97675 \times uAbs + 0.28003$$

Figure 8 Equation for calculating the corrected absorption

6. If the calculated value of *cAbs* is less than 0.2, make one of the following adjustments:

   (a) If *cAbs* < 0, set *cAbs* = 0

   (b) If *cAbs* > 0 and *cAbs* < 0.1, add 0.2 to *cAbs* , i.e. *cAbs* = *cAbs* + 0.2

   (c) If *cAbs* ≥ 0.1 and *cAbs* < 0.2, add 0.1 to *cAbs* , i.e. *cAbs* = *cAbs* + 0.1

7. Calculate the moist mass of aggregate using the above absorption value, *cAbs.* Using the "average" of the aggregate weight in the bag and pycnometer, W_{avg}, and the absorption value, *cAbs*, calculate the moist mass, W_{wet}. The volume is calculated using the Apparent SG, *cGsa*, determined from the CoreLok data.

$$W_{avg} = \frac{1}{2}(W_{agg\,1} + W_{agg\,2})$$

$$W_{wet} = \frac{cAbs}{100} \times W_{avg} + W_{avg}$$

$$Volume = \frac{cAbs}{100} \times W_{avg} + \frac{W_{avg}}{cGsa}$$

Figure 9 Equations for determining the volume of the aggregate sample

8. Finally, the bulk specific gravities are calculated using the equation in Figure 10, as shown below.

$$cGsb_{SSD} = \frac{W_{wet}}{Volume}$$

$$cGsb = \frac{W_{avg}}{Volume}$$

Figure 10 Equations for calculating the SSD, and dry, bulk specific gravities

In conclusion, the calculations performed by the AggSpec Software may be summarized as:

1. Measure *cGsa* from the bag sample, and *uGsb* from the volumeter;
2. Calculate the uncorrected absorption, *uAbs* , using the above values, *cGsa* and *uGsb*;
3. Calculate a "corrected" absorption, *cAbs* , using the regressions and adjustments proposed by Instrotek;
4. Using the *cGsa* and *cAbs* values, calculate the corrected bulk SG, *cGsb*.

AASHTO T-84 Method

AASHTO T-84 is the standard test method for the determination of specific gravity and absorption of aggregates. The test involves getting the aggregate to a condition known as SSD, and then using it find the apparent SG and Absorption.

At first, a pycnometer is calibrated using water at 23ºC. The weight of the empty and water-filled pycnometer is measured in grams. This is the calibration part of the testing and determines the volume of the pycnometer.

For the test, approximately one kg of oven-dried, fine aggregate (passing 4.75mm sieve) is required for the test. The sample is allowed to cool, and then six percent moisture by weight of aggregate is added.

The sample is mixed thoroughly, and the pan is covered with aluminum foil and left to soak for the recommended 15 to 19 hours as shown in Figure 11.

After completion of the soaking period, the sample is spread on a dry non-absorbent mat and a gentle stream of cool air (using a fan) is used to dry the sample. The sample is stirred during the process for homogenous drying. The first cone test is performed after about five minutes of drying. At this stage, the first cone test is run to make sure that the sample has not dried beyond the SSD condition.

The drying process is continued by pouring the aggregate from one pan into the other, as shown in Figure 12. Next the drying material is tamped into a cone, as shown in Figure 13. After placing the compacted material into the cone, the cone is carefully removed, and the resulting shape of the cone section is reviewed for SSD conditions. This cone test will have to be repeated at frequent intervals as the sample gets drier before reaching the critical SSD condition.

Figure 11 Setup of the test and SSD condition

Figure 12 Drying of sample using pans

Figure 13 Tamping aggregate into cone

Cone Test for Determination of SSD Condition

The SSD condition is determined by filling a standard cone with moist aggregate, which is then lightly tamped. The SSD condition is presumed, if upon removal of the cone, parts of the compacted aggregate cone start to slump. Essentially, the procedure calls for checking for the SSD condition several times as the aggregate sample is dried from its original soaked condition. This procedure is described in greater detail below.

The empty cone is placed firmly on a clear plastic board and moist aggregate is added to the cone until it overflows the cone. Using a metal tamper with a mass of 340 ± 15 g, the aggregate is tamped 25 times. The tamper is allowed to fall freely through a height of 5 mm.

The over flowed aggregate is cleaned from the base of the cone using a brush. Holding the top of the metal cone, the cone is lifted vertically, and the state of the compacted cone is examined. There are three states possible, as shown in Figure 14.

1. If the compacted cone maintains its shape, the aggregate is still too wet. This is shown in Figure 14(a).
2. If a small portion at the top of the cone slumps leaving a flat aggregate surface equivalent to a dime on the top of the cone, this corresponds to the SSD condition. This is shown in Figure 14(b).
3. If a considerable portion of the compacted cone material falls apart, the sample is drier than the SSD condition. This is shown in Figure 14(c).

So, with the above possibilities in mind, the test is repeated several times as the aggregate is dried from the soaked condition to the critical SSD condition.

Using the quartering method of splitting (Figure 15) to ensure the homogeneity of samples, a representative 500 ± 10 g of the aggregate at the SSD condition is selected and added to the pycnometer which is partially filled with water. For testing performed at the University of Idaho, 500 ml flasks were used as pycnometers. Others have used 1,000 ml flasks for this part of the test.

Water is added to the pycnometer to fill it to 90 percent of its capacity as shown in Figure 16. The temperature of the water is checked to make sure that it is at the same temperature as used for the calibration.

The pycnometer is agitated manually to eliminate the air bubbles and left still after agitation for about 20 minutes. The pycnometer is again agitated to see if there are more air bubbles. If foam (i.e. air bubbles) is present on the top of the water surface, a few drops of isopropyl alcohol are added. Finally, more water is added to bring the water level to the fill-mark in the pycnometer.

(a)

(b)

(c)

Figure 14 Various stages of the cone, (a) Stage 1 – aggregate is too wet, (b) Stage 2 – SSD condition, (c) Stage 3 – Drier than SSD condition

Figure 15 Quartering of SSD aggregate sample

Figure 16 Pouring of SSD samples for de-airing

The pycnometer is left to sit in a water bath at controlled temperature for 16 hours to ensure that all air has been removed from the water. To complete the test, the aggregate in the pycnometer is poured into a drying pan and then dried in the oven for 24 hours. The final weight of the dried aggregates is used for the calculations.

Shortcomings of the AASHTO T-84 Test

The shortcomings of the AASHTO T-84 test are listed below.[1]

- Determination of SSD condition of the fine aggregates may not be consistent using the cone and tamper method because the slump in the cone test is not only dependent on the moisture present on the sample but also on the angularity and the texture of the aggregate.
- The test requires an initial soaking period of 15-19 hours followed by overnight drying of the sample.

AASHTO T-84 Calculations

The measurements consist of the mass of the pycnometer with and without the SSD samples, and the mass of the aggregate at the SSD and dry conditions which is illustrated in Figure 17.

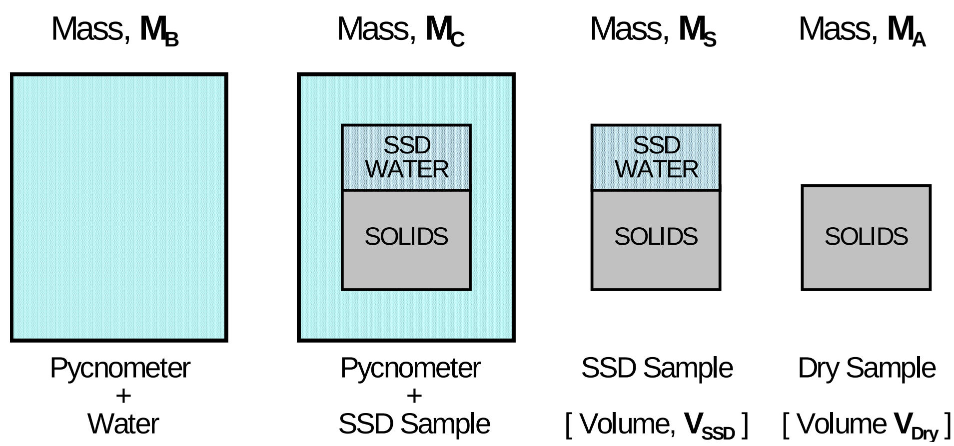


Figure 17 Data collected for T-84 testing consists of the mass (in grams) for four conditions

For measurements made in grams, the volume of the SSD and dry samples may be calculated using the following expressions:

(a) Volume of SSD sample: $V_{SSD} = M_B + M_S - M_C$

(b) Volume of the dry sample: $V_{Dry} = M_B + M_A - M_C$

Once the volumes are determined, the required specific gravities and the absorption may be calculated using the equations shown in Figure 18.

(a) Bulk Specific Gravity, Dry:

$$Gsb = \frac{M_A}{V_{SSD}}$$

(b) Bulk Specific Gravity, SSD:

$$Gsb_{SSD} = \frac{M_S}{V_{SSD}}$$

(c) Apparent Specific Gravity:

$$Gsa = \frac{M_A}{V_{Dry}}$$

(d) Absorption (%):

$$Abs = \frac{M_S - M_A}{M_A} \times 100\%$$

Figure 18 Equations used to determine specific gravities and absorption according to AASHTO T-84

Variabilities in the Test Procedures

AASHTO T-84 is a more sensitive test to run than the IT-144. There are many variabilities that should be considered while performing the test. Also, AASHTO T-84 is a more operator dependent test which introduces more variabilities and potential errors. IT-144 has lesser variabilities than AASHTO T-84 because it does not rely on subjective judgement to identify the SSD condition of the aggregate.

The factors likely to affect AASHTO T-84 testing are noted as follows:

- Agitation and de-airing wait time (20 minutes or 16 hours)
- Sample weight equilibrium after drying in oven
- Tamper drop height
- Water temperature - maintained at constant 23 ± 1.7°C
- Flask Size (500 mL or 1000 mL)

Tests were run to investigate the effects of these factors, which are discussed next.

Agitation and De-airing Wait Time (20 minutes or 16 hours)

The AASHTO T-84 standard recommends a vigorous agitation of aggregate in the pycnometer for 20 minutes, followed by drying to a constant mass. A test was performed to check on the deairing process. The sample was agitated for the first 20 minutes and the weight was measured. The sample was then left in a water bath, maintained at 23ºC, for two hours and the sample was agitated vigorously before measuring the weight. This process was repeated after 16 hours. The changes in the weight of the pycnometer are shown in the Table 7.

Table 7 Change in weight after deairing

	Flask A (g)	Flask B (g)
Sample + Water to mark + Pycn. (20 mins)	1015.4	1021.1
After water added to mark in 2 hours	1016.1	1022.2
After water added to mark in 16 hours	1016.8	1023.3
After water added to mark in 24 hours	1016.8	1023.3

In the test, 0.7 g of water was added to Flask A flask after two hours, and then another 0.7 g was added after 16 hours. For Flask B, 1.1 g was added after two and 16 hours, respectively. It should be noted that no additional water was required to fill the pycnometers after 24 hours (i.e. after another 8 hours). As a result of this investigation, a de-airing time of 16 hours was adopted for all the AASHTO T-84 testing.

Table 8 Test for Agitation and De-airing Time

De-airing Time	Gsb	Gsb-SSD	Gsa	Absorption (%)	Remarks
20 minutes	2.748	2.819	2.956	2.56%	None
2 hours	2.756	2.826	2.965	2.56%	0.5 g of water added
16 hours	2.762	2.833	2.972	2.56%	0.3 g of water added

Using the same data, no change was observed in the absorption value, but significant difference was observed in the calculated specific gravity values, as shown in Table 8.

Sample Weight Equilibrium after Drying in Oven

The aggregate from the pycnometer is oven-dried and then allowed to cool off before its weight is measured for absorption and specific gravity determination. The AASHTO T-84 standard recommends a cool off time of 1.0 ± 0.5 hours. To check the variation, a test was performed to see the effect of cooling time and the results are noted in Table 9.

Table 9 Variation of Sample Weight (in grams) with Cooling

Time (min)	Weight of Pan 4 (Evaporating Dish)	Weight of Pan 7 (Evaporating Dish)
0	784.2	780.6
5	784.4	780.7
10	784.4	780.8
15	784.5	780.8
20	784.6	780.9
25	784.7	780.9
30	784.7	780.9

It was noted that the weight came to equilibrium after 30 minutes of cooling. Therefore, a cooling time of 30 minutes was adopted for all AASHTO T-84 testing.

Tamper Drop Height

The tamper fall height and speed of the tamping are important parameters in the cone test to determine the SSD condition. As per the AASHTO T-84 standard, the free-falling height under the action of gravity must be 5 mm (0.2 in.) above the top surface of the fine aggregate in the cone.(11) Also, the number of blows should be 25. No additional fine aggregates should be added during the tamping process. Fall heights greater than 5 mm will increase the compaction energy imparted to the aggregate in the cone. With a higher compaction, the resulting cone may not slump even when the aggregate is at the SSD condition.

Tests were performed to check if the drop height was a consistent 5 mm. The test setup was as shown in Figure 19. To investigate this, a video of the tamping process was recorded and reviewed for inconsistencies. The slow-motion video clearly depicted that the drop height was very close to 5 mm and the rate of tamping was consistent, with 25 blows being completed within 20 seconds.

Water Temperature - Maintained at Constant 23 ± 1.7°C

The AASHTO T-84 standard states that the temperature of water should be maintained at 23 ± 1.7°C during the testing. This temperature should be maintained during the calibration of pycnometer, and also during the de-airing process. For all testing, a constant temperature of 23 ± 1.7°C was maintained consistently throughout testing process.

Figure 19 Test for tamper drop height

Flask Size (500 mL or 1000 mL)

The AASHTO T-84 standard states that the size of the pycnometer should be at least 50 percent greater than the space required for 500 g of sample. Typically, a 500 ml pycnometer is used for the test. It is possible that a larger pycnometer may de-air the sample faster. To evaluate this possibility, a 1000 mL pycnometer was used for the test. The results showed that the size of the pycnometer did not have any effect on the de-airing time.

The IT-144 standards were strictly followed for the CoreLok testing whereas in AASHTO T-84, a modification was made in the de-airing time. The standard allows 20 minutes of vigorous shaking to de-air, whereas, a 16 hour wait time for de-airing was practiced ensuring adequate de-airing. The standard does not specify the wait time before taking the weight of hot samples from the oven. A wait time of 30 minutes was used in all the tests because the weight of the dry aggregate sample was stable after 30 minutes. The main focus in AASHTO T-84 testing was to minimize variabilities, and to perform the test according to a consistent procedure.

Chapter 5
Aggregate Test Results

Introduction

In this chapter, all results from testing the 25 aggregate samples according to the AASHTO T-84 and Idaho IT-144 are presented, along with an assessment of the quality of the test results. All of these tests were completed according to the procedures discussed in Chapter 4. Recalling the concerns mentioned regarding the subjectivity of recognizing the “Saturated Surface Dry” (SSD) condition, the testing plan followed a special sequence of events to ensure a high level of quality assurance. The sequence required: (1) Initial testing at UI, (2) Training and evaluation at the ITD (Boise) lab, (3) A “round-robin” testing experiment involving ITD (Boise), and material testing consultants: ALLWEST (Meridian) and STRATA (Boise), and (4) final testing for 22 aggregates. As mentioned earlier, 3 additional aggregates were added to the original list.

Initial familiarity with the equipment and testing procedures was achieved by performing tests on samples at the UI lab in Moscow, ID. These initial tests closely followed the published standards, AASHTO T-84 and Idaho IT-144. After erratic results at first, increased familiarity with the procedures and equipment led to more consistent results. At the end of this initial phase of preliminary testing, the only remaining concern was whether the cone and tamping process (AASHTO T-84) was being performed correctly, i.e. was the SSD condition achieved consistently. To eliminate these concerns, aggregate samples were transported to the ITD (Boise) lab for testing by the Boise and UI personnel.

Tests Performed in Boise

The Boise tests were conducted over a 2-day period, December 21-22, 2016. At this training session, Bob Englemann (lab manager) demonstrated the part of the AASHTO T-84 procedure concerning the drying process and attaining the SSD condition precisely. Following the demonstration, three other aggregates were tested by Sandarva Sharma (UI) and Travis Enzminger (ITD lab technician). The intent here was to perform the SSD portion of the test under supervision. While in Boise, six aggregates were also tested using the IT-144 procedure and the CoreLok device available in the Boise lab. The results of the tests performed in Boise by Travis Enzminger (TE) and Sandarva Sharma (SMS) are given in Tables 10 and 11. These tables show results of lab tests performed by Travis Enzminger (TE) in columns 2 to 5, followed by results determined by Sandarva Sharma (SMS) in columns 6 to 9 to the right.

A D2S range of 0.007 to 0.016, and 0.004 to 0.025 was observed between the tests performed by SMS and TE for *Gsb* using test methods AASHTO T-84 and IT-144 respectively. In reviewing and comparing the results from the AASHTO T-84 testing, it was agreed that the tests performed by Sandarva Sharma were comparable to the ITD results. The same conclusion was reached for the IT-144 tests performed using the metal pycnometer (volumeter) and the CoreLok vacuum chamber. Overall, this training session was a success as many important features, not mentioned in the standards, were adopted for future tests to be performed at the University of Idaho.

Table 10 AASHTO T-84 test results for the tests performed in ITD-Boise lab in December 2016

Sample ID	(TE) *Abs*	(TE) *Gsa*	(TE) Gsb_{SSD}	(TE) *Gsb*	(SMS) Abs	(SMS) *Gsa*	(SMS) Gsb_{SSD}	(SMS) *Gsb*
Bg111c	0.60%	2.646	2.619	2.603	0.60%	2.657	2.633	2.618
Np82c	1.60%	2.799	2.722	2.679	1.50%	2.808	2.735	2.695
Cn140c	0.60%	2.639	2.612	2.596	0.80%	2.643	2.610	2.589

Table 11 IT-144 test results for the tests performed in ITD-Boise lab in December 2016

Sample ID	(TE) *cAbs*	(TE) *cGsa*	(TE) $cGsb_{SSD}$	(TE) *cGsb*	(SMS) cAbs	(SMS) *cGsa*	(SMS) $cGsb_{SSD}$	(SMS) *cGsb*
Np82c (1)	1.60	2.822	2.745	2.703	1.40	2.806	2.736	2.697
Np82c (2)	1.70	2.802	2.772	2.677	1.60	2.813	2.736	2.693
Bg111c (1)	0.60	2.667	2.642	2.628	0.50	2.655	2.632	2.619
Bg111c (2)	0.60	2.668	2.642	2.627	0.50	2.652	2.632	2.620
Cn149c Virgin	1.70	2.681	2.610	2.567	1.80	2.662	2.587	2.542
Cn140c	1.10	2.649	2.601	2.571	1.00	2.646	2.602	2.575

Round Robin Testing

Once the initial training and testing was completed, it was agreed that four aggregate samples would be tested in the UI and ITD (Boise) labs for quality assurance in a “round-robin” experiment. The four samples selected were considered to be representative of the original 22 aggregates collected from the ITD Districts. Parameters such as rock type, absorption, and particle shapes were considered in selecting these representative samples. The four samples selected for this experiment were:

1. Aggregate Sample 3A (Ad-136) from District 3;
2. Aggregate Sample 6B (Fr-104-c) from District 6;
3. Aggregate Sample 2C (WCW-23-c) from District 2;
4. Aggregate Sample 1D (Kt-213-c) from District 1;

These four samples were prepared according to the procedures discussed in Chapter 3 and shipped to the Boise lab. Each shipped aggregate sample package consisted of five 4 kg bags. The intent here was to use the material in one 4 kg bag to conduct one AASHTO T-84 and one Idaho IT-144 test. The UI lab completed tests on all four samples in March 2017. However, due to time constraints, the ITD (Boise) lab was able to complete tests on only two samples, Samples 6B and 2C, by April 2017.

As only two out of four samples had been tested, it was agreed in late May 2017, that additional tests would be conducted by two local material testing labs, ALLWEST (Meridian) and STRATA (Boise). To get this underway, one more sample was added to the experiment as the ITD (Boise) lab had used up Samples 6B and 2C in completing their testing. The fifth sample selected for the round-robin experiment was Sample 3E from District 3. So, at the end Samples 3A, 6B, 2C, 1D, and 3E were added to the round-robin experiment by the end of July 2017.

ALLWEST (Meridian) completed tests on Samples 3E, 1D, and 3A in early December, but STRATA (Boise) was able to only provide results for Sample 3E. STRATA (Boise) did test one or two additional samples, but due to personnel changes, the results of these tests could not be verified, and were thus excluded from the study. A summary of test results for all five aggregates is presented in Tables 12 to 16 for each selected sample. In these tables, the data in columns 2 to 5 is from AASHTO T-84 testing, and is designated with a "**T-**" prefix. The results from the IT-144 testing are labeled with a "**c**" prefix.

Table 12 Round Robin Test results for Sample 3A

Sample Designation	T-*Gsb*	T-Gsb_{SSD}	T-*Gsa*	T-*Abs* (%)	*cGsb*	$cGsb_{SSD}$	*cGsa*	*cAbs* (%)
UI-3A-01	2.578	2.608	2.657	1.16%	2.589	2.616	2.662	1.07%
UI-3A-02	2.564	2.596	2.648	1.24%	2.586	2.616	2.665	1.14%
UI-3A-03	2.586	2.616	2.666	1.16%	2.589	2.616	2.661	1.05%
UI-3A-04	2.581	2.610	2.658	1.12%	2.587	2.615	2.662	1.09%
Average	**2.577**	**2.607**	**2.657**	**1.17%**	**2.588**	**2.616**	**2.663**	**1.08%**
Std. Dev.	**0.00817**	**0.00726**	**0.00638**	**0.04%**	**0.00130**	**0.00043**	**0.00150**	**0.03%**
COV	**0.32%**	**0.28%**	**0.24%**	**3.73%**	**0.05%**	**0.02%**	**0.06%**	**3.10%**
Range	**0.022**	**0.020**	**0.018**	**0.12%**	**0.003**	**0.001**	**0.004**	**0.09%**
AW-3A-01	2.591	2.615	2.653	0.90%	2.581	2.609	2.657	1.10%
UI-3A-05	2.597	2.623	2.666	1.00%	-	-	-	-

Table 12 above shows the test result of sample 3A. The Coefficient of Variation (COV) for *Gsb* and *Gsa* were all observed to be less than one percent, and the COV for absorption was observed to be around three percent. This showed that the variation in the test results was small and the tests were repeatable. A new set of tests were performed afterwards, and the results were compared with that of ALLWEST. The values were almost identical and satisfied the D2S limit of 0.015 for *Gsb*. The low D2S value for ALLWEST and UI IT-144 test results showed that both labs were performing the test in a similar, consistent manner.

Table 13 Round Robin test results for Sample 6B

Sample Designation	T-*Gsb*	T-*Gsb*$_{SSD}$	T-*Gsa*	T-*Abs* (%)	*cGsb*	*cGsb*$_{SSD}$	*cGsa*	*cAbs* (%)
UI-6B-01	2.381	2.473	2.599	3.40%	2.441	2.504	2.603	2.55%
UI-6B-02	2.391	2.472	2.601	3.38%	2.436	2.502	2.607	2.68%
UI-6B-03	2.393	2.473	2.599	3.31%	2.441	2.502	2.598	2.47%
UI-6B-04	2.387	2.468	2.597	3.39%	2.440	2.503	2.605	2.59%
Average	**2.388**	**2.471**	**2.599**	**3.37%**	**2.440**	**2.503**	**2.603**	**2.57%**
Std. Dev.	**0.00458**	**0.00206**	**0.00141**	**0.04%**	**0.00206**	**0.00083**	**0.00334**	**0.08%**
COV	**0.19%**	**0.08%**	**0.05%**	**1.05%**	**0.08%**	**0.03%**	**0.13%**	**2.94%**
Range	**0.012**	**0.005**	**0.004**	**0.09%**	**0.005**	**0.002**	**0.009**	**0.21%**
ITD-6B-01	2.429	2.503	2.623	3.03%	2.440	2.501	2.598	2.50%
ITD-6B-02	2.437	2.512	2.635	3.08%	2.457	2.509	2.593	2.10%
ITD-6B-03	2.424	2.497	2.613	2.98%	2.446	2.502	2.592	2.30%
ITD-6B-04	2.422	2.494	2.610	3.00%	2.462	2.514	2.598	2.10%
Average	**2.428**	**2.502**	**2.620**	**3.02%**	**2.451**	**2.507**	**2.595**	**2.25%**
Std. Dev.	**0.00579**	**0.00687**	**0.00978**	**0.04%**	**0.00870**	**0.00532**	**0.00277**	**0.17%**
COV	**0.24%**	**0.27%**	**0.37%**	**1.25%**	**0.35%**	**0.21%**	**0.11%**	**7.37%**
Range	**0.015**	**0.018**	**0.025**	**0.10%**	**0.022**	**0.013**	**0.006**	**0.40%**

Table 13 shows the test results for sample 6B performed at the UI and ITD-Boise lab. The COV for *Gsb* and *Gsa* for UI were all observed to be less than one percent and that for absorption was observed to be one and three percent for AASHTO T-84 and IT-144 test methods, respectively. Similar was the case with ITD-Boise lab, except COV was around seven percent for IT-144 which could still be considered a good result. The D2S limit for UI results for T-84 and IT-144 satisfied the 0.015 limit for *Gsb* whereas, that for ITD-Boise results for IT-144 was slightly higher than the 0.015 limit. The results also showed that the two labs were very good in producing similar results.

Table 14 Round Robin test results for Sample 2C

Sample Designation	T-*Gsb*	T-Gsb_{SSD}	T-*Gsa*	T-*Abs* (%)	*cGsb*	$cGsb_{SSD}$	*cGsa*	*cAbs* (%)
UI-2C-01	2.733	2.813	2.972	2.95%	2.753	2.827	2.972	2.67%
UI-2C-02	2.712	2.794	2.954	3.02%	2.758	2.829	2.969	2.57%
UI-2C-03	2.729	2.807	2.961	2.86%	2.753	2.826	2.969	2.65%
UI-2C-04	2.743	2.817	2.964	2.72%	2.756	2.830	2.975	2.67%
UI-2C-05	2.745	2.819	2.964	2.69%	2.753	2.824	2.963	2.58%
UI-2C-06	2.738	2.814	2.963	2.77%	-	-	-	-
UI-2C-07	2.767	2.838	2.977	2.54%	-	-	-	-
UI-2C-08	2.762	2.833	2.972	2.56%	-	-	-	-
Average	**2.741**	**2.817**	**2.966**	**2.76%**	**2.755**	**2.827**	**2.970**	**2.63%**
Std. Dev.	**0.01656**	**0.01301**	**0.00688**	**0.16%**	**0.00206**	**0.00214**	**0.00398**	**0.04%**
COV	**0.60%**	**0.46%**	**0.23%**	**5.84%**	**0.07%**	**0.08%**	**0.13%**	**1.67%**
Range	**0.055**	**0.044**	**0.023**	**0.48%**	**0.005**	**0.006**	**0.012**	**0.10%**
ITD-2C-01	2.785	2.845	2.962	2.20%	2.75	2.819	2.995	2.50%
ITD-2C-02	2.794	2.855	2.974	2.20%	2.749	2.817	2.949	2.50%
ITD-2C-03	2.772	2.836	2.96	2.30%	2.769	2.826	2.936	2.10%
ITD-2C-04	2.772	2.844	2.987	2.60%	2.748	2.816	2.946	2.40%
Average	**2.781**	**2.845**	**2.971**	**2.33%**	**2.754**	**2.82**	**2.957**	**2.38%**
Std. Dev.	**0.00931**	**0.00675**	**0.01080**	**0.16%**	**0.00869**	**0.00391**	**0.02274**	**0.16%**
COV	**0.33%**	**0.24%**	**0.36%**	**7.04%**	**0.32%**	**0.14%**	**0.77%**	**6.89%**
Range	**0.022**	**0.019**	**0.027**	**0.40%**	**0.021**	**0.010**	**0.059**	**0.40%**

Table 14 shows the test results of sample 2C, performed at the UI and ITD-Boise lab. The COV for *Gsb* and *Gsa* for UI were all observed to be less than one percent and that for absorption was observed to be about six and two percent for T-84 and IT-144 test methods respectively. Similar was the case with ITD-Boise lab, except COV for AASHTO T-84 and IT-144 were around seven percent. The D2S limit for UI results for IT-144 satisfied the 0.015 limit for *Gsb* whereas, that for AASHTO T-84 of UI and AASHTO T-84 and IT-144 of ITD-Boise results were slightly higher than 0.015. The AASHTO T-84 tests for samples UI-2C-07 and UI-2C-08 were carried out with 16 hours of de-airing and the results obtained were almost identical.

Table 15 Round Robin test results for Sample 1D

Sample Designation	T-*Gsb*	T-Gsb_{SSD}	T-*Gsa*	T-*Abs* (%)	*cGsb*	$cGsb_{SSD}$	*cGsa*	*cAbs* (%)
UI-1D-01	2.622	2.660	2.725	1.44%	2.655	2.681	2.724	0.95%
UI-1D-02	2.606	2.644	2.709	1.45%	2.653	2.680	2.726	1.02%
UI-1D-03	2.595	2.637	2.709	1.62%	2.660	2.683	2.722	0.86%
UI-1D-04	2.606	2.640	2.697	1.29%	2.656	2.681	2.725	0.95%
UI-1D-05	2.655	2.683	2.731	1.04%	2.643	2.674	2.726	1.15%
UI-1D-06	2.629	2.665	2.728	1.38%	2.656	2.682	2.727	0.98%
Average	**2.619**	**2.655**	**2.717**	**1.37%**	**2.654**	**2.680**	**2.725**	**0.99%**
Std. Dev.	**0.01966**	**0.01622**	**0.01230**	**0.18%**	**0.00527**	**0.00291**	**0.00163**	**0.09%**
COV	**0.75%**	**0.61%**	**0.45%**	**12.96%**	**0.20%**	**0.11%**	**0.06%**	**8.94%**
Range	**0.060**	**0.046**	**0.034**	**0.58%**	**0.017**	**0.009**	**0.005**	**0.29%**

Table 15 shows the test results of sample 2C, performed at the UI lab. The COV for *Gsb* and *Gsa* for UI were all observed to be less than one percent and that for absorption was observed to be about 13 and nine percent for AASHTO T-84 and IT-144 test methods respectively. Omitting the results of UI-1D-01, UI-1D-05, and UI-1D-06 improves the D2S limit of *Gsb* from 0.060 to 0.011 which is within the assumed acceptable limit of 0.015.

Table 16 Round Robin test results for Sample 3E

Sample Designation	T-*Gsb*	T-*Gsb*$_{SSD}$	T-*Gsa*	T-*Abs* (%)	*cGsb*	*cGsb*$_{SSD}$	*cGsa*	*cAbs* (%)
UI-3E-01	2.536	2.565	2.611	1.13%	2.578	2.601	2.638	0.88%
UI-3E-02	2.571	2.595	2.635	0.95%	2.591	2.608	2.637	0.67%
UI-3E-03	2.571	2.598	2.641	1.03%	2.584	2.605	2.639	0.80%
Average	**2.559**	**2.586**	**2.629**	**1.00%**	**2.584**	**2.605**	**2.638**	**0.80%**
Std. Dev.	**0.01650**	**0.01490**	**0.01296**	**0.07%**	**0.00531**	**0.00287**	**0.00082**	**0.09%**
COV	**0.64%**	**0.58%**	**0.49%**	**7.36%**	**0.21%**	**0.11%**	**0.03%**	**10.82%**
Range	**0.035**	**0.033**	**0.030**	**0.18%**	**0.013**	**0.007**	**0.002**	**0.21%**
AW-3E-01	2.561	2.585	2.624	0.94%	2.585	2.603	2.632	0.70%
AW-3E-02	2.564	2.589	2.629	0.95%	-	-	-	-
Average	**2.563**	**2.587**	**2.627**	**0.95%**	**-**	-	-	-
Std. Dev.	**0.00150**	**0.00200**	**0.00250**	**0.00%**	**-**	**-**	**-**	**-**
COV	**0.06%**	**0.08%**	**0.10%**	**0.53%**	**-**	**-**	**-**	**-**
Range	**0.003**	**0.004**	**0.005**	**0.01%**	**-**	**-**	**-**	**-**
ST-3E-01	-	-	-	-	2.589	2.608	2.640	0.75%

Table 16 shows the test results of sample 2C, performed at the UI, ALLWEST, and STRATA lab. The COV of *Gsb* and *Gsa* were below one percent for UI test results for AASHTO T-84 and IT-144 test methods whereas, that of absorption were around seven and 11 percent for AASHTO T-84 and IT-144 test methods, respectively. The COV were observed to be lower than one percent for specific gravities and absorption for the test results by ALLWEST. The average values of the test results for UI, ALLWEST and STRATA were comparable and had very less differences for both AASHTO T-84 and IT-144 methods.

Assessment of Round-Robin Experiment

The results in Tables 12 to 16 for different fine aggregates show that the results from the labs that participated in the “round-robin” experiment are comparable and the results within the labs were very close. The D2S values for the Round Robin experiment ranged from 0.006 to 0.04 for AASHTO T-84 test method and from 0.001 to 0.011 for IT-144 test method. The results were shared with ITD-Boise and it was agreed that UI continue to follow the same procedures for testing all aggregates. The results for all aggregate samples tested by UI are presented in Tables 17 to 31. A summary of all data is presented in Table 30 in Chapter 6.

AASHTO T-84 and IT-144 Results

In this section, results are presented for the tested aggregates according to their source districts. Tests were performed on 25 aggregates from six ITD districts in Idaho. A total of 114 AASHTO T-84 tests and 101 IT-144 tests have been run for the data analysis. The tests performed at the University of Idaho (UI), ALLWEST (AW), ITD-Boise (ITD), and STRATA (ST) for the six ITD Districts are discussed in this section. Table 17 summarizes the number of tests completed by UI, ALLWEST, ITD (Boise), and STRATA on the 25 aggregates and Table 18 provides a summary of the total number of test performed by each lab.

Overall, of the 117 AASHTO T-84 tests completed by UI, ITD (Boise), ALLWEST, and STRATA, 37 (32 percent) were not used to determine the final averages used for the regression analysis. The subjectivity concerning the ability to correctly recognize the SSD condition is probably to blame for such a large number of omitted test results. In contrast, of the 101 tests conducted using the Idaho IT-144 (CoreLok) procedure, only 9 (9 percent) were excluded from the final analysis. The exclusion of fewer CoreLok results is a strong indication of their reliability and repeatability of the procedure as it is not controlled by operator subjectivity.

A summary of the results for each ITD District are presented in separate tables, one for AASHTO T-84 results, and another for the IT-144 results. These are followed by the average specific gravities and the absorption values, as used for the statistical analysis.

In these tables, the sample identifier code, such as UI-1N-01, refers to aggregate number 1N (i.e. District 1, aggregate N, as shown in Table 4 earlier) and the final two numbers report the sample number. The prefix consisting of UI, AW, ST, or ITD refers to the organization which performed the test, so for the result labeled as “UI-1N-01”, it implies that the test was performed by the University of Idaho (UI) on the first 4 kg sample taken from aggregate 1N. Abbreviations used for the other contributing organizations are: AW for ALLWEST, ST for STRATA, and ITD for the ITD (Boise) lab.

As these results will be used for the regression analyses discussed in Chapter 6, it is important that the quality of the data be examined carefully. This involves checking the intra-lab results for variability, and possibly repeating tests if the variability is excessive. For this project, the intra-lab variability (d2s) was assessed by calculating the range of the Bulk Specific Gravity (*Gsb*) results. A d2s limit of 0.015 was adopted for this study, which is about 0.6 percent of the average *Gsb* value of all 25 aggregates. If this calculated d2s value was less than 0.015, the variability was deemed acceptable. If the d2s exceeded 0.015, additional testing was performed, and the outliers omitted from the data set for that particular aggregate. In some instances, a slightly higher d2s was deemed acceptable, if a large number of tests were performed. The acceptable results were averaged for further evaluation.

To further assess the quality of the averaged test data, the averages were compared with results from tests performed by ALLWEST, and others, if available. This inter-lab comparison is reported as the difference between the average of the multiple tests performed by UI with the consultant’s single test.

Table 17 Tests run by UI, ITD-Boise, ALLWEST (AW) and STRATA

UI - ID	ITD - ID	T84 UI	T84 ITD	T84 AW	T84 STRATA	IT-144 UI	IT-144 ITD	IT-144 AW	IT-144 STRATA
1D	Kt-213c	7	1	2	2*	8	-	2	1*
1N	Kt-222c	3	-	2	-	3	-	1	-
1P	Kt-215c	2	-	1	-	3	-	1	
2C	WCW-23c	8	4	-	-	5	(4)	-	-
2Q	Id-256c	2	-	1	-	2	-	2	-
2T	WCW-18c	2	1	2	-	3	1	1	-
2V	NP-82c	4	1	1	-	3	-	2	-
3A	Ad-136	5	-	1	-	4	-	1	-
3E	Ad-182c	3	-	2	-	3	-	1	-
3H	Ad-161C	3	-	1	-	2	-	1	-
3J	Cn-140c	2	-	1	-	2	-	2	-
3W	Ow-94	-	2	-	-	-	2	-	-
4X	Cs-184c	-	2	-	-	-	2	-	-
4Y	Cs-192	-	2	-	-	-	2	-	-
5O	Bg-111-c	2	-	1	-	2	-	1	-
5R	Bk-100-c	2	-	1	-	3	-	1	-
5S	Bg-107-c	3	-	1	-	3	-	1	-
5U	Bl-93-s	3	-	1	-	3	-	1	-
6B	Fr-104-c	5	4	-	-	4	4*	-	-
6F	Le-96-s	4	-	2	-	3	-	1	-
6G	Cu-75-s	3	-	1	-	2	1	2	-
6I	Bn-59-s	2	-	1	-	3	-	1	-
6K	Bn-156-c	2	-	1	-	2	-	1	-
6L	Le-160-c	3	-	1	-	3	-	2	-
6M	Cl-56-s	2	-	2	-	2	-	1	-

**Data for these tests was incomplete*

Table 18 Total tests run by UI, ITD-Boise, ALLWEST and STRATA

Testing Method	UI-Lab	ITD-Boise	ALL WEST	STRATA
AASHTO T-84	72	17	26	2
IT-144 (CoreLok)	68	7	26	1

This careful examination of the data resulted in the exclusion of some data which was considered to be outside the acceptable range. In the summary tables presented for each District, the right column indicates if the test data was used for the final regression analysis.

Data from the T-84 and CoreLok testing is presented next for each district. The T-84 test generates four results: (a) bulk specific gravity for the dry condition (*Gsb*), (b) bulk specific gravity at the SSD condition (*Gsb*-SSD), (c) apparent specific gravity (*Gsa*), and (d) absorption in percent. The CoreLok method produces the same four results as the T-84 test, but along the way also calculates two "uncorrected" values. These six values are: (a) "uncorrected" absorption (*uAbs*), (b) "uncorrected" bulk specific gravity (*uGsb*), (c) apparent specific gravity (*Gsa*), (d) corrected absorption (*cAbs*), (e) corrected bulk specific gravity (c*Gsb*), and (f) bulk specific gravity at the SSD condition (*Gsb*-SSD). The *Gsb*-SSD is really computed using the *Gsa*, c*Gsb*, and *cAbs* using the equation given in Chapter 4.

Results from ITD District 1

The AASHTO T-84 for the three aggregates supplied by ITD District 1 are summarized in Table 19. For T-84 testing, the greatest variability was noted for aggregate Kt-213c, with only 5 results used out of a total of 12 tests. Overall, a total of 20 tests were performed, with 12 results used to determine the averages.

Results from the CoreLok tests (according to Idaho IT-144) for the three aggregates supplied by ITD District 1 are summarized in Table 20. The variability for all tests was small, and all 18 results were used for the averages.

The averaged values for both test methods, based on the approved test results, are presented in Table 21 for the three aggregates from District 1. The same averages from the T-84 and CoreLok tests are also presented in Figure 20. The absorptions ranged from 0.5 to 1.5 percent, and the Bulk specific gravities all fell into a narrow range, 2.6 to 2.7.

Table 19 AASHTO T-84 test method results for ITD District 1 aggregates

#	Date	UI - ID	Aggregate ID	Gsb	Gsb-SSD	Gsa	Absorption (%)	Test Result Used
1.	n/a	AW-1D-01	Kt-213c	2.610	2.652	2.724	1.600	yes
2.	n/a	AW-1D-02	Kt-213c	2.635	2.664	2.714	1.110	no
3.	n/a	ITD-1D	Kt-213c	2.610	2.646	2.706	1.358	yes
4.	n/a	ST-1D-01	Kt-213c	2.610	2.654	2.731	1.700	no
5.	n/a	ST-1D-02	Kt-213c	2.609	2.653	2.729	1.700	no
6.	02/23/17	UI-1D-01	Kt-213c	2.622	2.660	2.725	1.438	no
7.	02/23/17	UI-1D-02	Kt-213c	2.606	2.644	2.709	1.453	yes
8.	02/24/17	UI-1D-03	Kt-213c	2.595	2.637	2.709	1.624	yes
9.	02/24/17	UI-1D-04	Kt-213c	2.606	2.640	2.697	1.291	yes
10.	08/30/17	UI-1D-05	Kt-213c	2.655	2.683	2.731	1.042	no
11.	02/14/18	UI-1D-06	Kt-213c	2.629	2.665	2.728	1.378	no
12.	08/10/18	UI-1D-07	Kt-213c	2.645	2.675	2.726	1.124	no
13.	n/a	AW-1N-01	Kt-222c	2.635	2.668	2.725	1.260	no
14.	n/a	AW-1N-02	Kt-222c	2.649	2.674	2.717	0.960	yes
15.	11/30/17	UI-1N-01	Kt-222c	2.653	2.679	2.723	0.965	yes
16.	01/09/18	UI-1N-02	Kt-222c	2.656	2.684	2.732	1.049	yes
17.	02/14/18	UI-1N-03	Kt-222c	2.653	2.682	2.732	1.087	yes
18.	n/a	AW-1P	Kt-215c	2.634	2.663	2.712	1.090	yes
19.	11/28/17	UI-1P-01	Kt-215c	2.634	2.664	2.717	1.155	yes
20.	01/05/18	UI-1P-02	Kt-215c	2.638	2.670	2.724	1.197	yes

Table 20 IT-144 test method results for ITD District 1 aggregates

#	Date Tested	Sample ID	Aggregate ID	*uAbs*	*cAbs*	*Gsa*	*Gsb*-SSD	*uGsb*	*cGsb*	Test Result Used
1.	09/05/17	AW-1D-01	Kt-213c	0.562	1.390	2.719	2.656	2.678	2.620	yes
2.	11/09/17	AW-1D-02	Kt-213c	0.187	0.650	2.722	2.692	2.709	2.675	yes
3.	03/08/17	UI-1D-01	Kt-213c	0.341	0.954	2.724	2.681	2.699	2.655	yes
4.	03/08/17	UI-1D-02	Kt-213c	0.372	1.016	2.726	2.680	2.699	2.653	yes
5.	03/08/17	UI-1D-03	Kt-213c	0.296	0.864	2.722	2.683	2.700	2.660	yes
6.	03/08/17	UI-1D-04	Kt-213c	0.341	0.954	2.725	2.681	2.700	2.656	yes
7.	08/31/17	UI-1D-05	Kt-213c	0.440	1.151	2.726	2.674	2.694	2.643	yes
8.	09/05/17	UI-1D-06	Kt-213c	0.354	0.980	2.727	2.682	2.701	2.656	yes
9.	02/14/18	UI-1D-07	Kt-213c	0.445	1.160	2.730	2.677	2.698	2.647	yes
10.	08/10/18	UI-1D-08	Kt-213c	0.767	1.797	2.759	2.676	2.702	2.629	no
11.	01/05/18	AW-1N-01	Kt-222c	0.122	0.521	2.715	2.691	2.706	2.677	yes
12.	11/30/17	UI-1N-01	Kt-222c	0.117	0.512	2.722	2.699	2.714	2.685	yes
13.	01/09/18	UI-1N-02	Kt-222c	0.123	0.523	2.726	2.702	2.717	2.688	yes
14.	02/14/18	UI-1N-03	Kt-222c	0.149	0.574	2.722	2.696	2.711	2.681	yes
15.	01/05/18	AW-1P-01	Kt-215c	0.782	1.826	2.743	2.663	2.685	2.612	yes
16.	11/28/17	UI-1P-01	Kt-215c	0.610	1.487	2.717	2.651	2.673	2.612	yes
17.	01/05/18	UI-1P-02	Kt-215c	0.389	1.050	2.707	2.660	2.679	2.632	yes
18.	02/16/18	UI-1P-03	Kt-215c	0.581	1.428	2.722	2.657	2.680	2.620	yes

Table 21 Test averages based on Tables 20 and 21 for ITD District 1 aggregates

#	UI-ID	ITD ID	*uAbs*	*cAbs*	T-84 Abs	CoreLok *cGsa*	T-84 *Gsa*	*uGsb*	*cGsb*	T-84 *Gsb*
1	1D	Kt-213c	0.371	1.013	1.465	2.725	2.709	2.698	2.652	2.606
2	1N	Kt-222c	0.127	0.532	1.015	2.721	2.726	2.712	2.683	2.653
3	1P	Kt-215c	0.591	1.448	1.147	2.722	2.718	2.679	2.619	2.635

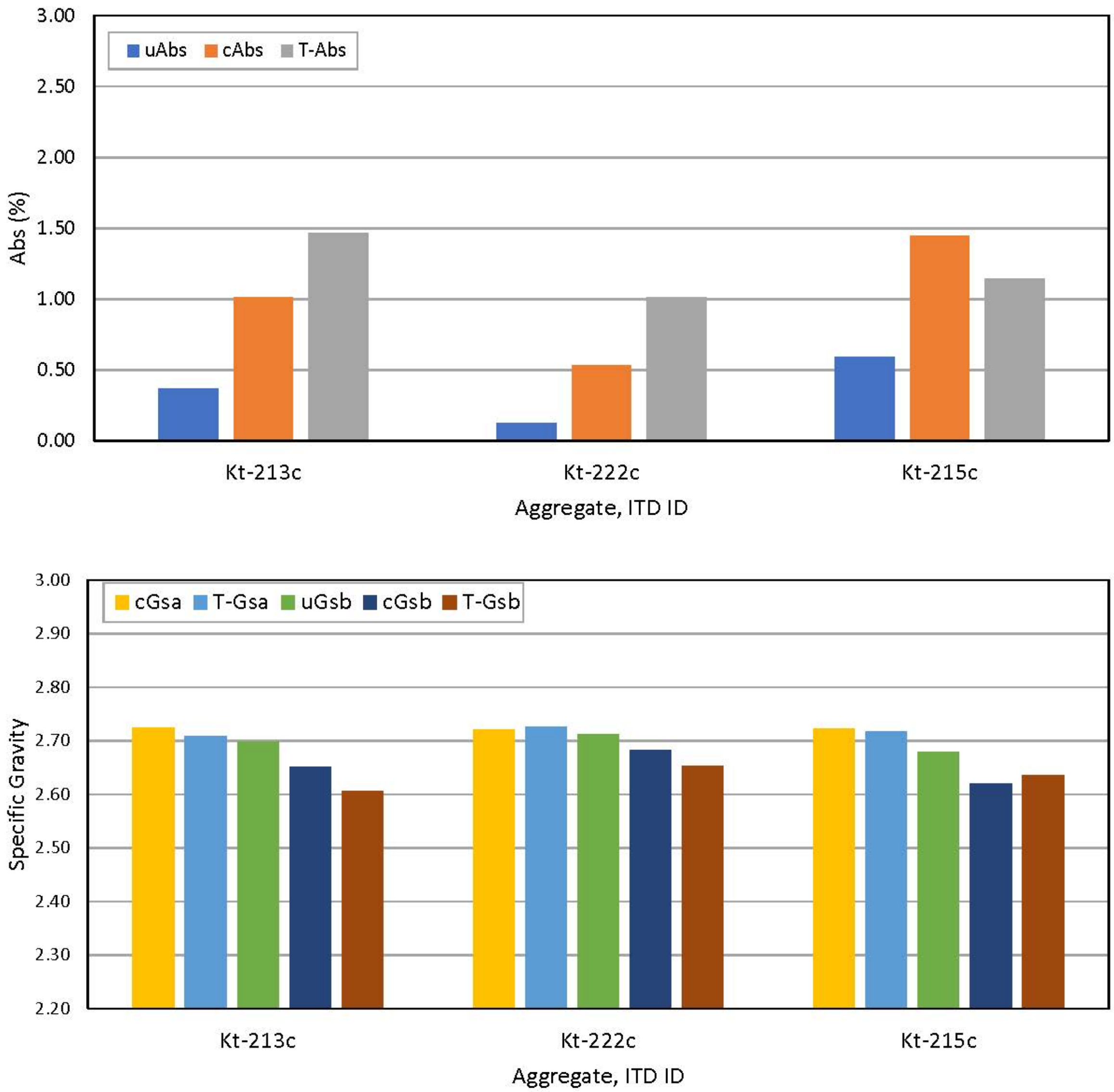


Figure 20 Visual representation of the averaged data for the 3 aggregates from District 1

Results from ITD District 2

The AASHTO T-84 for the four aggregates supplied by ITD District 2 are summarized in Table 22. For T-84 testing, the greatest variability was noted for aggregate, with only 2 results deemed to be acceptable out of a total of 12 tests. Overall, a total of 28 tests were performed, with 13 results used to determine the averages. The average test values are presented in Table 24.

Table 22 AASHTO T-84 test method results for ITD District 2 aggregates

#	Date	UI - ID	Aggregate ID	*Gsb*	*Gsb*-SSD	*Gsa*	Absorption (%)	Test Result Used
1.	n/a	ITD-2C-01	WCW-23c	2.785	2.845	2.962	2.200	no
2.	n/a	ITD-2C-02	WCW-23c	2.794	2.855	2.974	2.200	no
3.	n/a	ITD-2C-03	WCW-23c	2.772	2.836	2.960	2.300	no
4.	n/a	ITD-2C-04	WCW-23c	2.772	2.844	2.987	2.600	no
5.	02/22/17	UI-2C-01	WCW-23c	2.733	2.813	2.972	2.947	no
6.	02/22/17	UI-2C-02	WCW-23c	2.712	2.794	2.954	3.021	no
7.	02/22/17	UI-2C-03	WCW-23c	2.729	2.807	2.961	2.862	no
8.	02/22/17	UI-2C-04	WCW-23c	2.743	2.817	2.964	2.720	no
9.	04/12/17	UI-2C-05	WCW-23c	2.745	2.819	2.964	2.691	no
10.	04/12/17	UI-2C-06	WCW-23c	2.738	2.814	2.963	2.770	no
11.	09/12/17	UI-2C-07	WCW-23c	2.767	2.838	2.977	2.543	yes
12.	09/14/17	UI-2C-08	WCW-23c	2.762	2.833	2.972	2.558	yes
13.	n/a	AW-2Q	Id-256c	2.644	2.717	2.852	2.760	yes
14.	11/28/17	UI-2Q-01	Id-256c	2.657	2.724	2.848	2.526	yes
15.	01/05/18	UI-2Q-02	Id-256c	2.661	2.731	2.862	2.645	yes
16.	n/a	AW-2T-01	WCW-18c	2.735	2.815	2.974	2.940	no
17.	n/a	AW-2T-02	WCW-18c	2.765	2.833	2.966	2.460	yes
18.	n/a	ITD-2T	WCW-18c	2.760	2.828	2.963	2.484	yes
19.	12/26/17	UI-2T-01	WCW-18c	2.768	2.846	3.001	2.805	yes
20.	01/09/18	UI-2T-02	WCW-18c	2.774	2.847	2.991	2.618	yes
21.	08/10/18	UI-2T-03	WCW-18c	2.771	2.839	2.974	2.456	no
22.	08/10/18	UI-2T-04	WCW-18c	2.757	2.830	2.974	2.651	no
23.	n/a	AW-2V	NP-82c	2.770	2.830	2.949	2.200	yes
24.	n/a	ITD-2V	NP-82c	2.770	2.823	2.925	1.922	yes
25.	01/01/18	UI-2V-01	NP-82c	2.771	2.838	2.972	2.445	yes
26.	01/17/18	UI-2V-02	NP-82c	2.769	2.837	2.970	2.449	yes
27.	08/10/18	UI-2V-03	NP-82c	2.779	2.835	2.944	2.014	no
28.	08/10/18	UI-2V-04	NP-82c	2.782	2.838	2.948	2.028	no

Table 23 IT-144 test method results for ITD District 2 aggregates

#	Date Tested	Sample ID	Aggregate ID	*uAbs*	*cAbs*	*Gsa*	*Gsb*-SSD	*uGsb*	*cGsb*	Test Result Used
1.	03/07/17	UI-2C-01	WCW-23c	1.210	2.671	2.972	2.827	2.869	2.753	yes
2.	03/07/17	UI-2C-02	WCW-23c	1.158	2.570	2.969	2.829	2.870	2.758	yes
3.	03/07/17	UI-2C-03	WCW-23c	1.197	2.646	2.969	2.826	2.867	2.753	yes
4.	03/07/17	UI-2C-04	WCW-23c	1.211	2.675	2.975	2.830	2.872	2.756	yes
5.	04/12/17	UI-2C-05	WCW-23c	1.162	2.577	2.963	2.824	2.864	2.753	yes
6.	08/10/18	AW-2Q-02	Id-256c	1.620	3.484	2.833	2.668	2.709	2.578	yes
7.	01/04/18	AW-2Q-01	Id-256c	1.501	3.247	2.837	2.682	2.721	2.597	no
8.	11/28/17	UI-2Q-01	Id-256c	0.765	1.792	2.849	2.760	2.789	2.711	yes
9.	01/05/18	UI-2Q-02	Id-256c	0.795	1.852	2.856	2.763	2.793	2.712	yes
10.	02/26/18	AW-2T-01	WCW-18c	0.581	1.428	2.945	2.866	2.895	2.825	yes
11.	n/a	ITD-2T-01	WCW-18c	1.048	2.352	2.961	2.833	2.871	2.768	yes
12.	12/26/17	UI-2T-01	WCW-18c	0.775	1.812	2.950	2.851	2.884	2.801	yes
13.	01/09/18	UI-2T-02	WCW-18c	0.844	1.948	2.964	2.857	2.892	2.802	yes
14.	08/10/18	UI-2T-03	WCW-18c	1.461	3.168	3.004	2.830	2.877	2.743	no
15.	02/26/18	AW-2V-01	NP-82c	0.609	1.485	2.923	2.843	2.872	2.801	yes
16.	07/07/18	AW-2V-02	NP-82c	0.728	1.720	2.926	2.834	2.865	2.786	no
17.	01/02/18	UI-2V-01	NP-82c	0.296	0.865	2.914	2.867	2.889	2.843	yes
18.	01/18/18	UI-2V-02	NP-82c	0.281	0.835	2.919	2.873	2.895	2.849	yes
19.	08/10/18	UI-2V-03	NP-82c	0.909	2.076	2.968	2.854	2.890	2.796	no

Table 24 Test averages based on Tables 22 and 23 for ITD District 2 aggregates

#	UI-ID	ITD ID	*uAbs*	*cAbs*	T-84 Abs	CoreLok *cGsa*	T-84 *Gsa*	*uGsb*	*cGsb*	T-84 *Gsb*
1	2C	WCW-23c	1.187	2.628	2.551	2.970	2.975	2.868	2.755	2.765
2	2Q	Id-256c	1.060	2.376	2.644	2.846	2.854	2.763	2.667	2.654
3	2T	WCW-18c	0.812	1.885	2.592	2.955	2.980	2.886	2.799	2.767
4	2V	NP-82c	0.395	1.062	2.254	2.919	2.954	2.885	2.831	2.770

Results from the CoreLok tests (according to Idaho IT-144) for the four aggregates supplied by ITD District 2 are summarized in Table 23. The variability for all tests was small, and 15 out of a total of 19 results were used for the averages.

The averaged values for both test methods, based on the approved test results, are presented in Table 24 for the four aggregates from District 2. The same averages from the T-84 and CoreLok tests are also presented in Figure 21. The absorptions generally ranged from 2.0 to 2.5 but were smaller for sample NP-82c. The specific gravities fell within a range of 2.65 to 2.95.

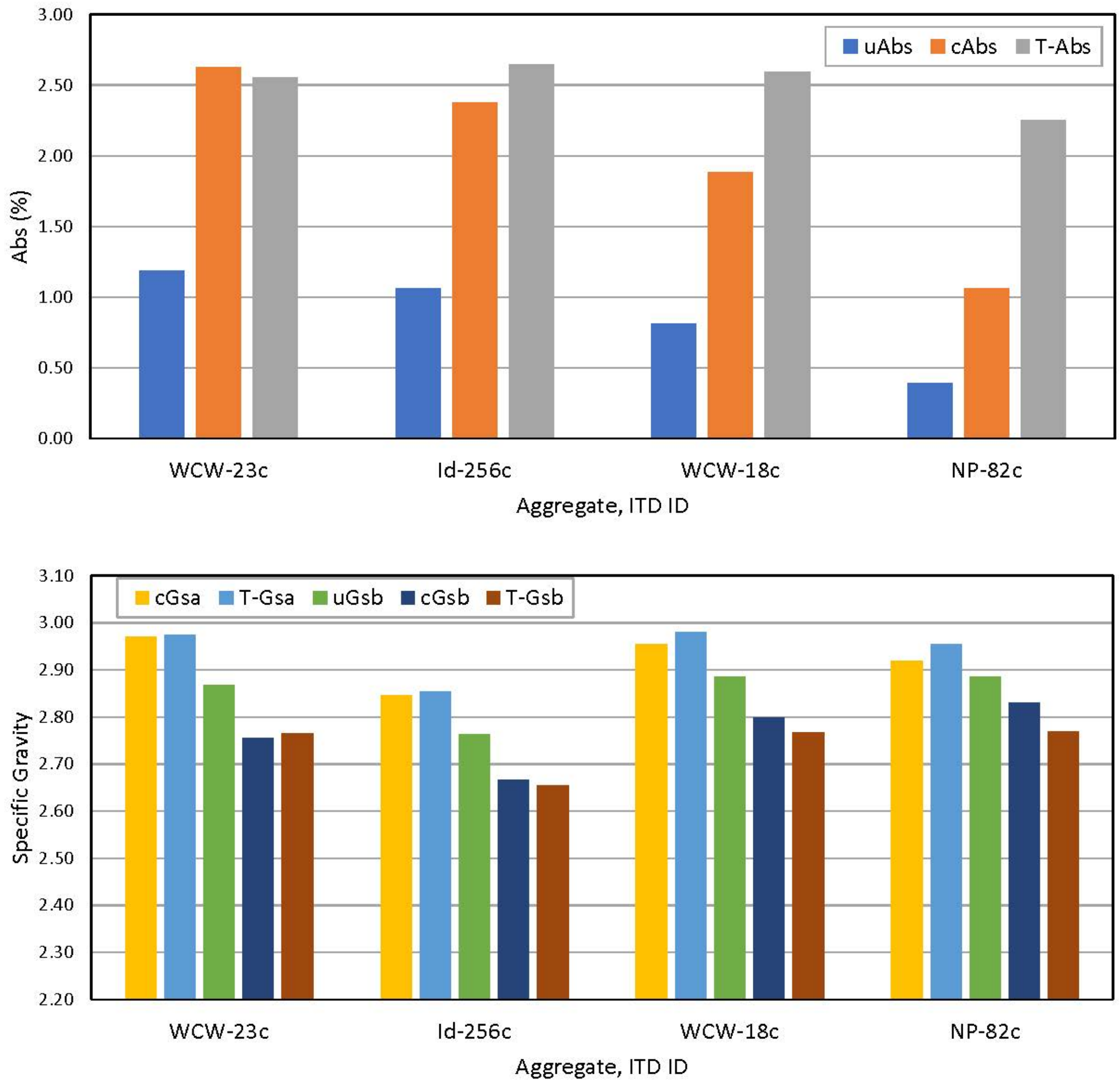


Figure 21 Visual representation of the averaged data for the 4 aggregates from District 2

Results from ITD District 3

The AASHTO T-84 for the five aggregates supplied by ITD District 3 are summarized in Table 25. For T-84 testing, all variabilities were reasonable and at least 3 tests were found acceptable for each aggregate. Sample Ow-94 was added to the collection in late 2018, with only one test being performed at the ITD (Boise) lab. Overall, a total of 19 tests were performed, with 15 results used to determine the averages.

Table 25 AASHTO T-84 test method results for ITD District 3 aggregates

#	Date	UI - ID	Aggregate ID	*Gsb*	*Gsb*-SSD	*Gsa*	Absorption (%)	Test Result Used
1.	n/a	AW-3A-01	Ad-136	2.591	2.615	2.653	0.900	yes
2.	02/21/17	UI-3A-01	Ad-136	2.578	2.608	2.657	1.164	no
3.	02/21/17	UI-3A-02	Ad-136	2.564	2.596	2.648	1.243	no
4.	02/21/17	UI-3A-03	Ad-136	2.586	2.616	2.666	1.157	yes
5.	02/21/17	UI-3A-04	Ad-136	2.581	2.610	2.658	1.120	yes
6.	08/25/17	UI-3A-05	Ad-136	2.597	2.623	2.666	0.998	yes
7.	n/a	AW-3E-01	Ad-182c	2.561	2.585	2.624	0.940	yes
8.	n/a	AW-3E-02	Ad-182c	2.564	2.589	2.629	0.950	yes
9.	07/21/17	UI-3E-01	Ad-182c	2.536	2.565	2.611	1.134	no
10.	08/21/17	UI-3E-02	Ad-182c	2.571	2.595	2.635	0.953	yes
11.	08/24/17	UI-3E-03	Ad-182c	2.571	2.598	2.641	1.025	yes
12.	n/a	AW-3H	Ad-161C	2.568	2.596	2.641	1.080	yes
13.	11/02/17	UI-3H-01	Ad-161C	2.564	2.592	2.637	1.085	yes
14.	01/02/18	UI-3H-02	Ad-161C	2.649	2.680	2.735	1.187	no
15.	04/11/18	UI-3H-03	Ad-161C	2.566	2.594	2.640	1.097	yes
16.	n/a	AW-3J	Cn-140c	2.559	2.592	2.647	1.300	yes
17.	11/07/17	UI-3J-01	Cn-140c	2.569	2.595	2.638	1.025	yes
18.	01/04/18	UI-3J-02	Cn-140c	2.568	2.598	2.648	1.174	yes
19.	n/a	ITD-3W	Ow-94	2.439	2.510	2.626	2.922	yes

Results from the CoreLok tests (according to Idaho IT-144) for the five aggregates supplied by ITD District 3 are summarized in Table 26. The variability for all tests was small, with only one test omitted from the averages.

The averaged values for both test methods, based on the approved test results, are presented in Table 27 for the four aggregates from District 3. The same averages from the T-84 and CoreLok tests are also presented in Figure 22. The absorptions ranged from 0.6 to 1.0 percent for four of the aggregates, with one aggregate (Ow-94) peaking in the 2.2 to 2.9 range. Similarly, the specific gravities were in the 2.5 to 2.7 range, with sample Ow-94 showing considerably lower *Gsa* values.

Table 26 IT-144 test method results for ITD District 3 aggregates

#	Date Tested	Sample ID	Aggregate ID	*uAbs*	*cAbs*	*Gsa*	*Gsb*-SSD	*uGsb*	*cGsb*	Test Result Used
1.	09/27/17	AW-3A-01	Ad-136	0.419	1.110	2.657	2.609	2.627	2.581	yes
2.	03/09/17	UI-3A-01	Ad-136	0.398	1.067	2.662	2.616	2.634	2.589	yes
3.	03/09/17	UI-3A-02	Ad-136	0.435	1.139	2.665	2.616	2.634	2.586	yes
4.	03/09/17	UI-3A-03	Ad-136	0.387	1.045	2.661	2.616	2.634	2.589	yes
5.	03/09/17	UI-3A-04	Ad-136	0.409	1.088	2.662	2.615	2.634	2.587	yes
6.	08/10/17	AW-3E-01	Ad-182c	0.210	0.700	2.632	2.603	2.618	2.585	yes
7.	07/20/17	UI-3E-01	Ad-182c	0.305	0.882	2.638	2.601	2.617	2.578	yes
8.	08/30/17	UI-3E-02	Ad-182c	0.195	0.666	2.637	2.608	2.623	2.591	yes
9.	09/05/17	UI-3E-03	Ad-182c	0.264	0.802	2.639	2.605	2.621	2.584	yes
10.	11/09/17	AW-3H-01	Ad-161C	0.168	0.610	2.639	2.613	2.627	2.597	yes
11.	11/02/17	UI-3H-01	Ad-161C	0.193	0.661	2.632	2.604	2.618	2.587	yes
12.	01/02/18	UI-3H-02	Ad-161C	0.194	0.663	2.636	2.608	2.623	2.591	yes
13.	01/04/18	AW-3J-01	Cn-140c	0.367	1.010	2.632	2.590	2.607	2.564	yes
14.	07/06/18	AW-3J-02	Cn-140c	0.269	0.811	2.644	2.609	2.625	2.588	no
15.	11/07/17	UI-3J-01	Cn-140c	0.186	0.648	2.643	2.615	2.630	2.599	yes
16.	01/04/18	UI-3J-02	Cn-140c	0.224	0.723	2.639	2.609	2.624	2.590	yes
17.	n/a	ITD-3W-01	Ow-94	1.013	2.283	2.629	2.537	2.561	2.481	yes
18.	n/a	ITD-3W-02	Ow-94	0.912	2.084	2.628	2.543	2.566	2.492	yes

Table 27 Test averages based on Tables 25 and 26 for ITD District 3 aggregates

#	UI-ID	ITD ID	*uAbs*	*cAbs*	T-84 Abs	CoreLok *cGsa*	T-84 *Gsa*	*uGsb*	*cGsb*	T-84 *Gsb*
1	3A	Ad-136	0.410	1.090	1.044	2.661	2.661	2.633	2.586	2.589
2	3E	Ad-182c	0.244	0.763	0.967	2.637	2.632	2.620	2.585	2.567
3	3H	Ad-161C	0.185	0.645	1.087	2.636	2.639	2.623	2.592	2.566
4	3J	Cn-140c	0.259	0.794	1.166	2.638	2.644	2.620	2.584	2.565
5	3W	Ow-94	0.963	2.183	2.922	2.629	2.626	2.564	2.486	2.439

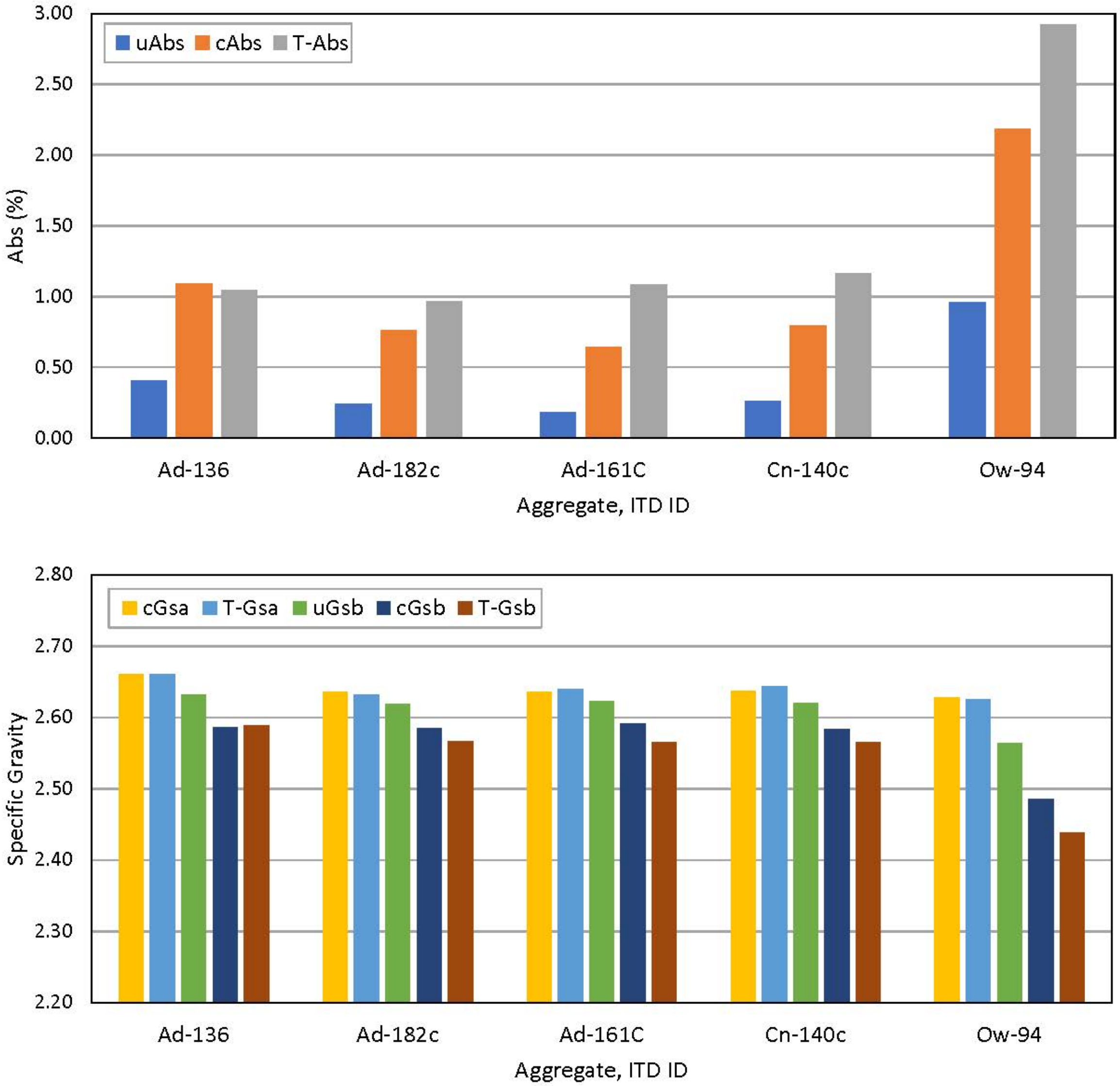


Figure 22 Visual representation of the averaged data for the 5 aggregates from District 3

Results from ITD District 4

The AASHTO T-84 for the two selected aggregates supplied by ITD District 4 are summarized in Table 28. These aggregates were tested in late 2018 at the ITD (Boise) lab, with only one test performed on each sample.

Table 28 AASHTO T-84 test method results for ITD District 4 aggregates

#	Date	UI - ID	Aggregate ID	*Gsb*	*Gsb*-SSD	*Gsa*	Absorption (%)	Test Result Used
1.	n/a	ITD-4X	Cs-184	2.428	2.484	2.573	2.329	yes
2.	n/a	ITD-4Y	Cs - 192	2.401	2.465	2.566	2.693	yes

Results from the CoreLok tests (according to Idaho IT-144) for the two aggregates supplied by ITD District 4 are summarized in Table 29.

Table 29 IT-144 test method results for ITD District 4 aggregates

#	Date Tested	Sample ID	Aggregate ID	*uAbs*	*cAbs*	*Gsa*	*Gsb*-SSD	*uGsb*	*cGsb*	Test Result Used
1.	n/a	ITD-4X-01	Cs-184	1.021	2.299	2.574	2.486	2.508	2.431	yes
2.	n/a	ITD-4X-02	Cs-184	0.975	2.208	2.565	2.482	2.503	2.428	yes
3.	n/a	ITD-4Y-02	Cs-192	0.806	1.874	2.563	2.492	2.511	2.446	yes

The averaged values for both test methods, based on the approved test results, are presented in Table 30 for the two aggregates from District 4. The same averages from the T-84 and CoreLok tests are also presented in Figure 23. The absorptions ranged from 2.0 to 2.5 percent, and the specific gravities all fell in a narrow range of 2.4 to 2.6.

Table 30 Test averages based on Tables 28 and 29 for ITD District 4 aggregates

#	UI-ID	ITD ID	*uAbs*	*cAbs*	T-84 Abs	CoreLok *cGsa*	T-84 *Gsa*	*uGsb*	*cGsb*	T-84 *Gsb*
1	4X	Cs-184c	0.998	2.253	2.329	2.570	2.573	2.506	2.429	2.428
2	4Y	Cs-192	0.806	1.874	2.693	2.563	2.566	2.511	2.446	2.401

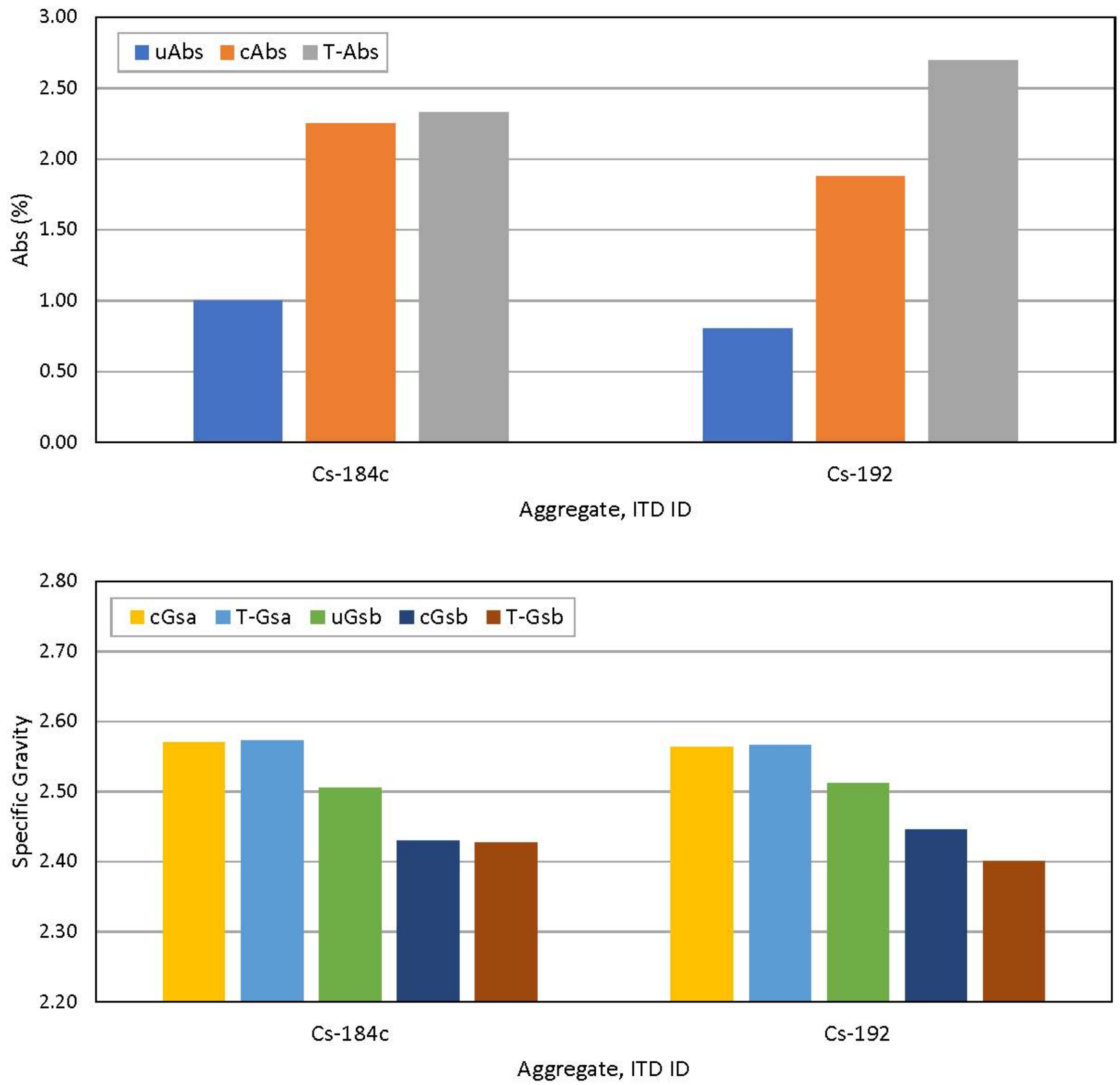


Figure 23 Visual representation of the averaged data for the 3 aggregates from District 4

Results from ITD District 5

The AASHTO T-84 for the four aggregates supplied by ITD District 5 are summarized in Table 31. Most of the T-84 results were reasonable. Overall, a total of 14 tests were performed, with 13 results used for the averages.

Table 31 AASHTO T-84 test method results for ITD District 5 aggregates

#	Date	UI - ID	Aggregate ID	*Gsb*	*Gsb*-SSD	*Gsa*	Absorption (%)	Test Result Used
1.	n/a	AW-5O	Bg-111-c	2.601	2.618	2.645	0.640	yes
2.	11/30/17	UI-5O-01	Bg-111-c	2.604	2.620	2.647	0.619	yes
3.	01/11/18	UI-5O-02	Bg-111-c	2.616	2.634	2.663	0.663	yes
4.	n/a	AW-5R	Bk-100-c	2.629	2.646	2.673	0.620	yes
5.	12/26/17	UI-5R-01	Bk-100-c	2.630	2.653	2.694	0.903	yes
6.	01/09/18	UI-5R-02	Bk-100-c	2.631	2.654	2.693	0.878	yes
7.	n/a	AW-5S	Bg-107-c	2.591	2.613	2.648	0.830	yes
8.	12/27/17	UI-5S-01	Bg-107-c	2.698	2.718	2.752	0.728	no
9.	01/11/18	UI-5S-02	Bg-107-c	2.607	2.624	2.653	0.666	yes
10.	02/16/18	UI-5S-03	Bg-107-c	2.611	2.628	2.656	0.649	yes
11.	n/a	AW-5U	BI-93-s	2.606	2.624	2.654	0.700	yes
12.	12/27/17	UI-5U-01	BI-93-s	2.623	2.640	2.667	0.620	yes
13.	01/17/18	UI-5U-02	BI-93-s	2.611	2.629	2.658	0.681	yes
14.	02/16/18	UI-5U-03	BI-93-s	2.620	2.637	2.665	0.646	yes

Table 32 IT-144 test method results for ITD District 5 aggregates

#	Date Tested	Sample ID	Aggregate ID	*uAbs*	*cAbs*	*Gsa*	*Gsb*-SSD	*uGsb*	*cGsb*	Test Result Used
1.	01/05/18	AW-5O-01	Bg-111-c	0.137	0.550	2.648	2.624	2.639	2.610	yes
2.	11/30/17	UI-5O-01	Bg-111-c	0.137	0.551	2.652	2.628	2.642	2.613	yes
3.	01/18/18	UI-5O-02	Bg-111-c	0.079	0.435	2.655	2.636	2.650	2.625	yes
4.	02/26/18	AW-5R-01	Bk-100-c	-0.251	0.380	2.682	2.665	2.700	2.655	yes
5.	12/26/17	UI-5R-01	Bk-100-c	0.135	0.547	2.686	2.662	2.677	2.647	yes
6.	01/09/18	UI-5R-02	Bk-100-c	-0.221	0.437	2.695	2.676	2.711	2.664	yes
7.	04/12/18	UI-5R-03	Bk-100-c	0.134	0.545	2.686	2.661	2.676	2.647	yes
8.	02/26/18	AW-5S-01	Bg-107-c	-0.201	0.480	2.648	2.628	2.662	2.615	yes
9.	12/27/17	UI-5S-01	Bg-107-c	0.163	0.602	2.654	2.628	2.643	2.612	yes
10.	01/18/18	UI-5S-02	Bg-107-c	0.091	0.459	2.658	2.638	2.651	2.625	yes
11.	02/16/18	UI-5S-03	Bg-107-c	0.162	0.600	2.654	2.628	2.643	2.612	yes
12.	02/26/18	AW-5U-01	BI-93-s	-0.181	0.490	2.650	2.629	2.664	2.616	yes
13.	12/27/17	UI-5U-01	BI-93-s	0.154	0.584	2.664	2.639	2.653	2.623	yes
14.	01/18/18	UI-5U-02	BI-93-s	0.154	0.584	2.661	2.636	2.650	2.621	yes
15.	02/16/18	UI-5U-03	BI-93-s	0.133	0.543	2.663	2.640	2.654	2.625	yes

Results from the CoreLok tests (according to Idaho IT-144) for the four aggregates supplied by ITD District 5 are summarized in Table 32. The variability for all tests was small, and all 15 results were used for the averages.

The averaged values for both test methods, based on the approved test results, are presented in Table 33 for the four aggregates from District 5. The same averages from the T-84 and CoreLok tests are also presented in Figure 24. The absorptions ranged from 0.5 to 0.8 percent, and the specific gravities all fell into a narrow range, 2.6 to 2.7.

Table 33 Test averages based on Tables 31 and 32 for ITD District 5 aggregates

#	UI-ID	ITD ID	*uAbs*	*cAbs*	T-84 Abs	CoreLok *cGsa*	T-84 *Gsa*	*uGsb*	*cGsb*	T-84 *Gsb*
1	5O	Bg-111-c	0.118	0.512	0.641	2.652	2.651	2.643	2.616	2.607
2	5R	Bk-100-c	-0.051	0.477	0.800	2.687	2.686	2.691	2.653	2.630
3	5S	Bg-107-c	0.054	0.535	0.715	2.654	2.652	2.650	2.616	2.603
4	5U	BI-93-s	0.065	0.550	0.662	2.660	2.661	2.655	2.621	2.615

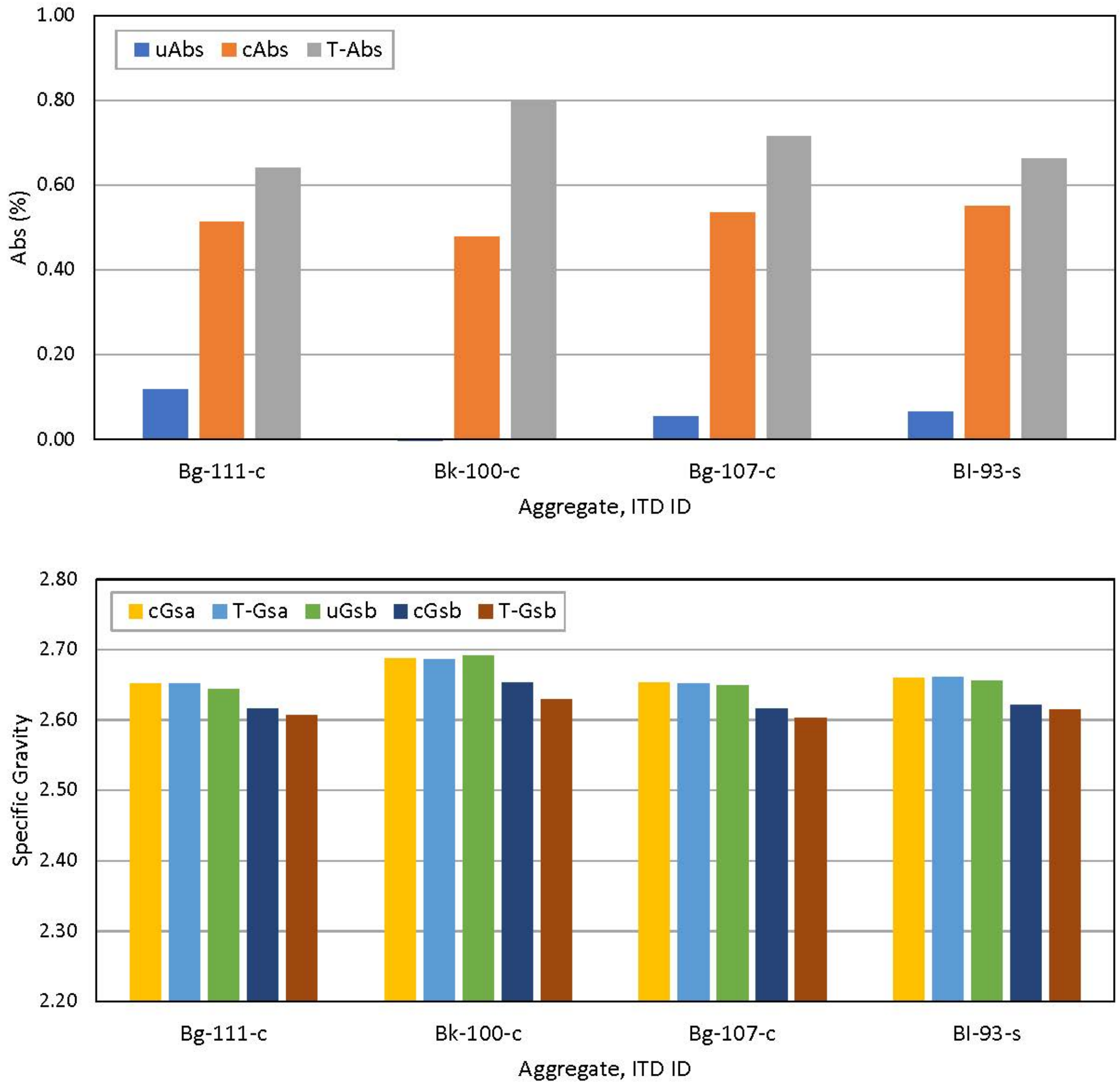


Figure 24 Visual representation of the averaged data for the 3 aggregates from District 5

Results from ITD District 6

The AASHTO T-84 for the seven aggregates supplied by ITD District 6 are summarized in Table 34. For T-84 testing, the greatest rejection rate was noted for Fr-104-c, with only 4 results used out of a total of 9 tests. Overall, a total of 36 tests were performed, with 24 results used to determine the averages.

Table 34 AASHTO T-84 test method results for ITD District 6 aggregates

#	Date	UI - ID	Aggregate ID	*Gsb*	*Gsb*-SSD	*Gsa*	Absorption (%)	Test Result Used
1.	n/a	ITD-6B-01	Fr-104-c	2.429	2.503	2.623	3.000	no
2.	n/a	ITD-6B-02	Fr-104-c	2.437	2.512	2.635	3.100	no
3.	n/a	ITD-6B-03	Fr-104-c	2.424	2.497	2.613	3.000	no
4.	n/a	ITD-6B-04	Fr-104-c	2.422	2.494	2.610	3.000	no
5.	02/28/17	UI-6B-01	Fr-104-c	2.381	2.461	2.590	3.401	no
6.	02/28/17	UI-6B-02	Fr-104-c	2.391	2.472	2.601	3.384	yes
7.	03/01/17	UI-6B-03	Fr-104-c	2.393	2.473	2.599	3.314	yes
8.	03/01/17	UI-6B-04	Fr-104-c	2.387	2.468	2.597	3.389	yes
9.	09/08/17	UI-6B-05	Fr-104-c	2.402	2.479	2.602	3.199	yes
10.	n/a	AW-6F-01	Le-96-s	2.618	2.643	2.685	0.950	yes
11.	n/a	AW-6F-02	Le-96-s	2.616	2.638	2.676	0.860	no
12.	11/02/17	UI-6F-01	Le-96-s	2.650	2.667	2.696	0.642	yes
13.	01/02/18	UI-6F-02	Le-96-s	2.640	2.658	2.689	0.690	yes
14.	02/13/18	UI-6F-03	Le-96-s	2.641	2.658	2.687	0.647	yes
15.	08/10/18	UI-6F-04	Le-96-s	2.629	2.648	2.681	0.746	no
16.	n/a	AW-6G	Cu-75s	2.604	2.638	2.695	1.300	yes
17.	10/31/17	UI-6G-01	Cu-75s	2.590	2.631	2.700	1.571	yes
18.	10/31/17	UI-6G-02	Cu-75s	2.607	2.647	2.716	1.542	yes
19.	01/04/18	UI-6G-03	Cu-75s	2.588	2.630	2.702	1.633	yes
20.	n/a	AW-6I	Bn-59-s	2.622	2.636	2.658	0.520	yes
21.	10/31/17	UI-6I-01	Bn-59-s	2.626	2.638	2.659	0.469	yes
22.	01/02/18	UI-6I-02	Bn-59-s	2.624	2.637	2.660	0.512	yes
23.	n/a	AW-6K	Bn-156-c	2.594	2.618	2.657	0.920	yes
24.	11/07/17	UI-6K-01	Bn-156-c	2.609	2.627	2.656	0.685	yes
25.	01/05/18	UI-6K-02	Bn-156-c	2.612	2.634	2.670	0.827	yes
26.	n/a	AW-6L	Le-160-c	2.585	2.626	2.695	1.580	yes
27.	11/09/17	UI-6L-01	Le-160-c	2.600	2.638	2.704	1.488	yes
28.	01/15/18	UI-6L-02	Le-160-c	2.355	2.393	2.447	1.593	no
29.	02/13/18	UI-6L-03	Le-160-c	2.600	2.640	2.709	1.558	yes
30.	n/a	AW-6M-01	Cl-56-s	2.585	2.615	2.664	1.140	yes
31.	n/a	AW-6M-02	Cl-56-s	2.612	2.628	2.656	0.630	no
32.	11/09/17	UI-6M-01	Cl-56-s	2.603	2.625	2.662	0.852	yes
33.	01/04/18	UI-6M-02	Cl-56-s	2.604	2.629	2.671	0.962	yes

Results from the CoreLok tests (according to Idaho IT-144) for the seven aggregates supplied by ITD District 6 are summarized in Table 35. The variability for all tests was small, and 26 out of a total of 28 results were used for the averages.

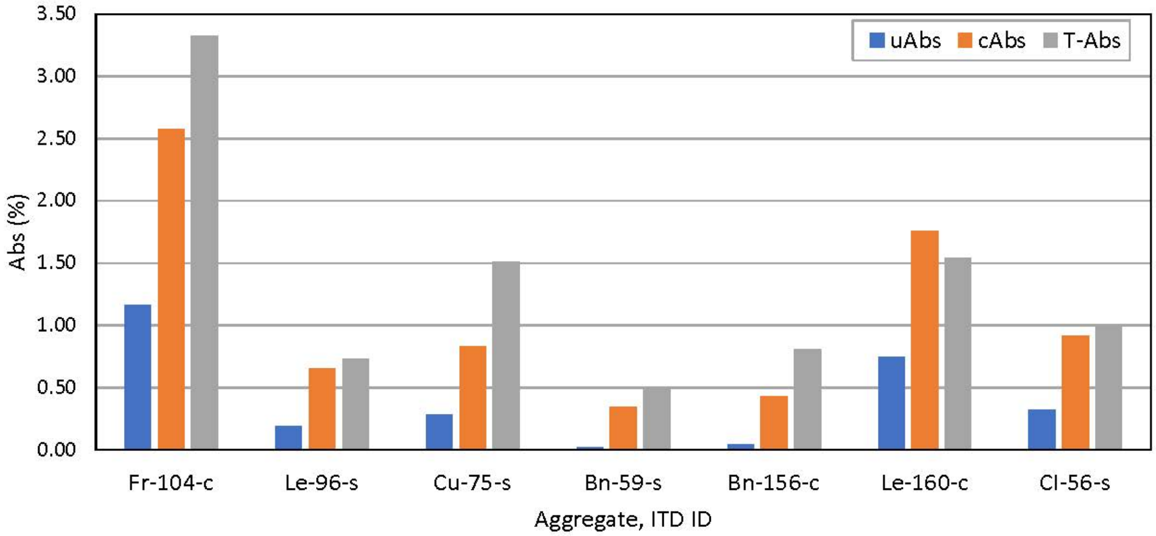
Table 35 IT-144 test method results for ITD District 6 aggregates

#	Date Tested	Sample ID	Aggregate ID	*uAbs*	*cAbs*	*Gsa*	*Gsb*-SSD	*uGsb*	*cGsb*	Test Result Used
1.	03/06/17	UI-6B-01	Fr-104-c	1.148	2.550	2.603	2.504	2.528	2.441	yes
2.	03/06/17	UI-6B-02	Fr-104-c	1.214	2.680	2.607	2.502	2.527	2.436	yes
3.	03/06/17	UI-6B-03	Fr-104-c	1.107	2.468	2.598	2.502	2.525	2.441	yes
4.	03/06/17	UI-6B-04	Fr-104-c	1.171	2.594	2.605	2.503	2.528	2.440	yes
5.	11/09/17	AW-6F-01	Le-96-s	0.078	0.440	2.681	2.661	2.675	2.650	yes
6.	11/02/17	UI-6F-01	Le-96-s	0.214	0.703	2.678	2.647	2.663	2.629	yes
7.	01/02/18	UI-6F-02	Le-96-s	0.217	0.709	2.686	2.654	2.670	2.636	yes
8.	02/13/17	UI-6F-03	Le-96-s	0.242	0.758	2.680	2.647	2.663	2.627	yes
9.	11/09/17	AW-6G-01	Cu-75-s	0.078	0.435	2.688	2.669	2.682	2.657	yes
10.	07/07/18	AW-6G-02	Cu-75s	-0.253	0.374	2.649	2.633	2.667	2.623	no
11.	n/a	ITD-6G-01	Cu-75s	0.335	0.942	2.690	2.648	2.666	2.623	yes
12.	10/31/17	UI-6G-01	Cu-75-s	0.346	0.964	2.697	2.654	2.672	2.629	yes
13.	01/04/18	UI-6G-02	Cu-75-s	0.364	0.999	2.695	2.651	2.669	2.624	yes
14.	11/09/17	AW-6I-01	Bn-59-s	-0.074	0.230	2.646	2.636	2.651	2.630	yes
15.	10/31/17	UI-6I-01	Bn-59-s	0.024	0.327	2.664	2.650	2.662	2.641	yes
16.	01/02/18	UI-6I-02	Bn-59-s	0.103	0.483	2.664	2.643	2.657	2.630	yes
17.	04/12/18	UI-6I-03	Bn-59-s	0.032	0.343	2.657	2.642	2.655	2.633	yes
18.	01/04/18	AW-6K-01	Bn-156-c	-0.092	0.300	2.659	2.646	2.665	2.638	yes
19.	11/07/17	UI-6K-01	Bn-156-c	0.067	0.413	2.655	2.637	2.650	2.626	yes
20.	01/05/18	UI-6K-02	Bn-156-c	0.155	0.586	2.660	2.634	2.649	2.619	yes
21.	01/05/18	AW-6L-01	Le-160-c	1.042	2.340	2.681	2.582	2.608	2.523	yes
22.	07/07/18	AW-6L-02	Le-160-c	0.569	1.410	2.677	2.617	2.637	2.580	no
23.	11/09/17	UI-6L-01	Le-160-c	0.475	1.219	2.675	2.622	2.641	2.590	yes
24.	01/18/18	UI-6L-02	Le-160-c	0.705	1.673	2.681	2.609	2.632	2.566	yes
25.	02/13/17	UI-6L-03	Le-160-c	0.762	1.786	2.690	2.612	2.636	2.566	yes
26.	01/04/18	AW-6M-01	CI-56-s	0.417	1.110	2.666	2.619	2.637	2.590	yes
27.	11/09/17	UI-6M-01	CI-56-s	0.245	0.764	2.654	2.621	2.637	2.602	yes
28.	01/04/18	UI-6M-02	CI-56-s	0.304	0.881	2.669	2.631	2.648	2.608	yes

The averaged values for both test methods, based on the approved test results, are presented in Table 36 for the seven aggregates from District 6. The same averages from the T-84 and CoreLok tests are also presented in Figure 25. The absorptions generally ranged from 0.5 to 1.5 percent, while sample Fr-104-c showed absorptions in the 2.5 to 3.4 range. The specific gravities mostly fell into a narrow range of 2.6 to 2.7, while sample Fr-104-c displayed values in the 2.4 to 2.6 range.

Table 36 Test averages based on Tables 34 and 35 for ITD District 6 aggregates

#	UI-ID	ITD ID	*uAbs*	*cAbs*	T-84 Abs	CoreLok *cGsa*	T-84 *Gsa*	*uGsb*	c*Gsb*	T-84 *Gsb*
1	6B	Fr-104-c	1.160	2.573	3.322	2.603	2.600	2.527	2.440	2.393
2	6F	Le-96-s	0.188	0.653	0.732	2.681	2.689	2.668	2.636	2.637
3	6G	Cu-75-s	0.281	0.835	1.511	2.692	2.703	2.672	2.633	2.597
4	6I	Bn-59-s	0.021	0.346	0.500	2.658	2.659	2.656	2.634	2.624
5	6K	Bn-156-c	0.043	0.433	0.811	2.658	2.661	2.655	2.628	2.605
6	6L	Le-160-c	0.746	1.755	1.542	2.682	2.703	2.629	2.561	2.595
7	6M	Cl-56-s	0.322	0.918	0.985	2.663	2.665	2.641	2.600	2.597



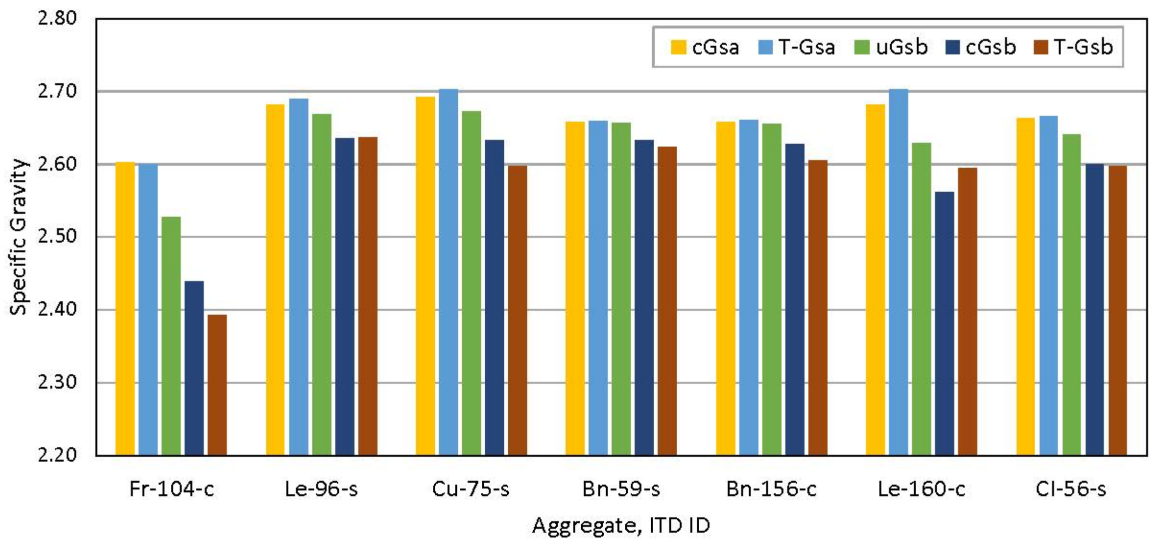


Figure 25 Visual representation of the averaged data for the 7 aggregates from District 6

Summary of Results

The T-84 and CoreLok methods are used to determine values of (a) Absorption, (b) Apparent specific gravity, and (c) the dry bulk specific gravity of fine aggregates. Figure 17 presents a comparison of these average values for the 25 aggregates tested for this study. Looking further at the averaged results, the following observations should be noted.

Absorption

- Overall, the absorptions ranged from 0.4 to 3.4 percent.
- Eight aggregates had absorptions in the 2.0 to 3.4 percent range.
- The other 17 aggregates had absorptions in 0.4 to 1.5 percent range.
- Sample Fr-104-c (shown as 6B) from District 6 had the highest absorption, 3.4 percent.
- For 22 out of the 25 aggregates, the T-84 absorptions were higher than the CoreLok values.

Apparent Specific Gravity (*Gsa*)

- The *Gsa* values ranged from about 2.6 to nearly 3.0.
- 21 aggregates had *Gsa* values in a narrow band ranging from 2.58 to 2.70.
- All Four aggregates from District 2 had higher *Gsa* values, with a range of 2.83 to 2.98.
- The CoreLok and T-84 values of *Gsa* were similar.

Bulk Specific Gravity (*Gsb*)

- The bulk modulus had a range of 2.40 to 2.82.
- Four aggregates had *Gsb* values in a low range of 2.4 to 2.5 range.
- 17 aggregates had *Gsb* values very close to 2.60.
- Three samples from district 2 had higher *Gsb* values in the range of 2.76 to 2.82.
- Out of the 25 results, 21 aggregates had reported *Gsb* values which were greater than the T-84 values.

The average T-84 and CoreLok values will be used for the statistical analysis, which is discussed in Chapter 6.

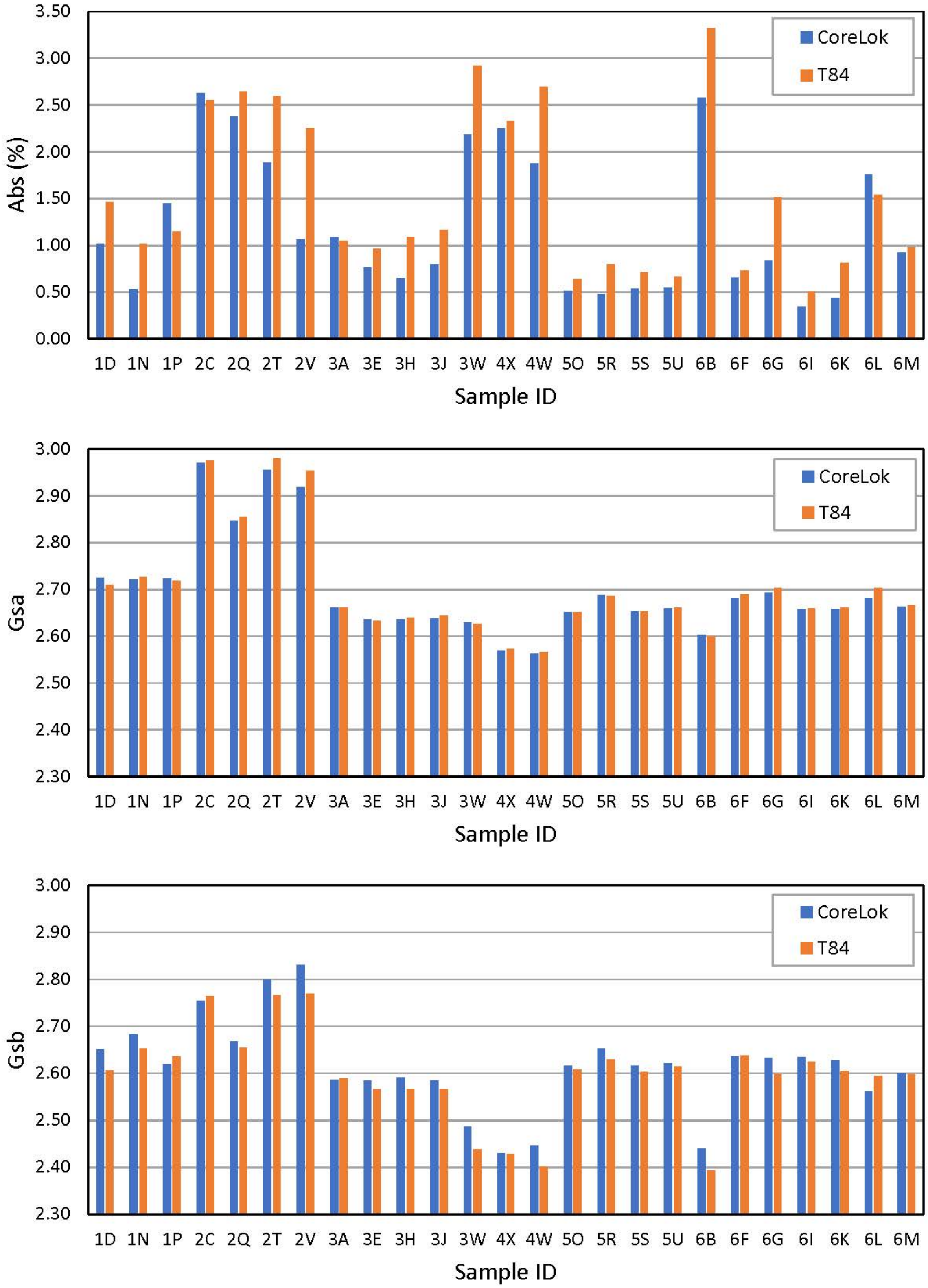


Figure 26 Comparison of average values determined using the CoreLok and T-84 methods

Chapter 6
Statistical Analysis

Introduction

The data from the CoreLok and T-84 tests performed on 25 fine aggregates were used for the statistical analysis. The objective of this study was to develop a reliable correlation for predicting T-84 values using results from CoreLok testing. The T-84 tests takes several days to complete, and the results depend heavily on the technician's ability to recognize the "Saturated Surface Dry" condition, as explained in Chapter 4. In contrast, the CoreLok method is direct and can provide results within 30 minutes. Unfortunately, the Absorption and *Gsb* results from the CoreLok method are not in agreement with the T-84 results. Hence the need to develop a correlation which may be used to predict results that are close to the T-84 values.

Previous research, such as the MoDOT study in 2006, did perform a similar statistical analysis using T-84 and Corelok results from a database of over 200 test results. (2) In reality, the CoreLok method uses the lab data to calculate two numbers (1) Apparent SG (*cGsa*), and (2) the bulk SG (*uGsb*). These two values can then be used to calculate an uncorrected value of the absorption, *uAbs* . Next, a corrected absorption value (*cAbs*) is determined through a regression equation and a series of corrections, as mentioned in Chapter 4. This corrected value of absorption is then used to compute the corrected value of the bulk SG (c*Gsb*) and the SSD bulk SG (Gsb_{SSD}).

As this study has access to the uncorrected CoreLok values, appropriate correlations were evaluated without being limited by any corrections implemented within the AggSpec software. So, for this study, the uncorrected (raw) values from the CoreLok testing were used in developing correlations for use by ITD.

Statistical Analysis

Based on testing 25 aggregates, the following results are available from each test method.

AASHTO T-84 Method: (1) Apparent SG (T-*Gsa*), (2) Bulk SG (T-*Gsb*), and (3) Absorption (T-*Abs*).

Idaho IT-144 (CoreLok) Method: (1) Apparent SG (*cGsa*), (2) Uncorrected Bulk SG (*uGsb*), (3) Uncorrected absorption (*uAbs*), (4) Corrected Bulk SG (*cGsb*), and (5) Corrected absorption (*cAbs*). It should be noted that the *cGsb* and *cAbs* values are calculated by Instrotek's AggSpec software.

In the above list, the *Gsa*, *Gsb*, and *Abs* are inter-related through theoretical equations presented in Chapter 1, Figure 2, and so only two of these three values are independent variables. Similarly, the Bulk SSD specific gravity (Gsb_{SSD}) value is not included as a potential variable in the above list as it is not unique. It can be derived using *Gsb* and Abs, as shown in Figure 2(e) in Chapter 1. The data used for the statistical analysis is presented in Table 37.

Table 37 Average values from T-84 and CoreLok Testing of 25 Aggregates

#	UI-ID	ITD ID	*uAbs*	*cAbs*	T-84 Abs	CoreLok *cGsa*	T-84 *Gsa*	*uGsb*	*cGsb*	T-84 *Gsb*
1	1D	Kt-213c	0.371	1.013	1.465	2.725	2.709	2.698	2.652	2.606
2	1N	Kt-222c	0.127	0.532	1.015	2.721	2.726	2.712	2.683	2.653
3	1P	Kt-215c	0.591	1.448	1.147	2.722	2.718	2.679	2.619	2.635
4	2C	WCW-23c	1.187	2.628	2.551	2.970	2.975	2.868	2.755	2.765
5	2Q	Id-256c	1.060	2.376	2.644	2.846	2.854	2.763	2.667	2.654
6	2T	WCW-18c	0.812	1.885	2.592	2.955	2.980	2.886	2.799	2.767
7	2V	NP-82c	0.395	1.062	2.254	2.919	2.954	2.885	2.831	2.770
8	3A	Ad-136	0.410	1.090	1.044	2.661	2.661	2.633	2.586	2.589
9	3E	Ad-182c	0.244	0.763	0.967	2.637	2.632	2.620	2.585	2.567
10	3H	Ad-161C	0.185	0.645	1.087	2.636	2.639	2.623	2.592	2.566
11	3J	Cn-140c	0.259	0.794	1.166	2.638	2.644	2.620	2.584	2.565
12	3W	Ow-94	0.963	2.183	2.922	2.629	2.626	2.564	2.486	2.439
13	4X	Cs-184c	0.998	2.253	2.329	2.570	2.573	2.506	2.429	2.428
14	4Y	Cs-192	0.806	1.874	2.693	2.563	2.566	2.511	2.446	2.401
15	5O	Bg-111-c	0.118	0.512	0.641	2.652	2.651	2.643	2.616	2.607
16	5R	Bk-100-c	-0.051	0.477	0.800	2.687	2.686	2.691	2.653	2.630
17	5S	Bg-107-c	0.054	0.535	0.715	2.654	2.652	2.650	2.616	2.603
18	5U	Bl-93-s	0.065	0.550	0.662	2.660	2.661	2.655	2.621	2.615
19	6B	Fr-104-c	1.160	2.573	3.322	2.603	2.600	2.527	2.440	2.393
20	6F	Le-96-s	0.188	0.653	0.732	2.681	2.689	2.668	2.636	2.637
21	6G	Cu-75-s	0.281	0.835	1.511	2.692	2.703	2.672	2.633	2.597
22	6I	Bn-59-s	0.021	0.346	0.500	2.658	2.659	2.656	2.634	2.624
23	6K	Bn-156-c	0.043	0.433	0.811	2.658	2.661	2.655	2.628	2.605
24	6L	Le-160-c	0.746	1.755	1.542	2.682	2.703	2.629	2.561	2.595
25	6M	Cl-56-s	0.322	0.918	0.985	2.663	2.665	2.641	2.600	2.597

Correlation Matrix

Before starting with regression analysis, it is prudent to evaluate any potential relationships between the selected five parameters from the CoreLok method and the three parameters from the T-84 testing. This relationship may be evaluated by generating a correlation matrix. Table 38 presents the correlation matrix using the data from Table 37.

Table 38 Correlation Matrix

Variable	Statistic	T-Abs	T-*Gsa*	T-*Gsb*	*uAbs*	*cAbs*	*uGsb*	*cGsb*
T-*Gsa*	Pearson	0.297						
	p-value	0.149						
T-*Gsb*	Pearson	-0.258	0.845					
	p-value	0.213	0.000					
uAbs	Pearson	**0.911**	0.268	-0.240				
	p-value	**0.000**	0.196	0.247				
cAbs	Pearson	**0.912**	0.267	-0.241	0.997			
	p-value	**0.000**	0.197	0.245	0.000			
uGsb	Pearson	0.053	**0.962**	**0.944**	0.003	0.004		
	p-value	0.801	**0.000**	**0.000**	0.989	0.984		
cGsb	Pearson	-0.172	0.866	**0.974**	-0.244	-0.246	0.968	
	p-value	0.410	0.000	**0.000**	0.239	0.237	0.000	
cGsa	Pearson	0.290	**0.997**	**0.846**	0.270	0.270	0.964	0.866
	p-value	0.159	**0.000**	**0.000**	0.192	0.191	0.000	0.000

The correlations between the selected variable are assessed using the Pearson coefficient, which ranges between -1 and +1, and the magnitude of the number is a reflection of the strength of the relationship. The p-values are used to assess the level of significance, with $\alpha = 0.05$ being a popular acceptable value. So, any p-value smaller than 0.05 indicates significance. The strong correlation values in Table 38 are shown in “bold”, and leads to the following observations:

1. The best correlation, based on the highest value of the Pearson coefficient, occurs between *cGsa* and T-*Gsa*.
2. The correlation between *cGsb* and T-*Gsb* is also good.
3. Other good correlations for the specific gravities are: *uGsb* and T-*Gsa*, and *uGsb* and T-*Gsb*.
4. For absorption, good correlations exist for *cAbs* and T-*Abs*, and *uAbs* and T-*Abs*.

For these potential linear correlations, the p-values indicate a high level of significance for the selected pairs of variables. Again, it should be noted that all of these parameters are inter-related and there are only two unique parameters for each of the two test methods.

Paired T-test

Before developing complex relationships, the relationship between the computed pairs of values: *cGsa* and T-*Gsa*, *cGsb* and T-*Gsb*, and *cAbs* and T-*Abs* need investigation. In other words, if the reported CoreLok values agree closely with the T-84 test results, there is no need for any correlations. The paired T-test is used to investigate the difference between the CoreLok and T-84 test results. For the paired T-test, the differences between T-*Abs* and *cAbs*, T-*Gsa* and *cGsa*, and T-*Gsb* and *cGsb* were investigated and the results are summarized in Tables 39 to 41.

Table 39 Paired T-test Results for T-*Abs* and c*Abs*

Sample	N	Mean	StDev	T-value	p-value	(Lower, Upper)
T-*Abs*	25	1.5200	0.859			
cAbs	25	1.2050	0.751			
Difference		0.3150	0.3559			
T-test mean difference				4.43	0.000	
95% CI for mean difference						(0.1681, 0.4619)

Table 40 Paired T-test Results for T-*Gsa* and c*Gsa*

Sample	N	Mean	StDev	T-value	p-value	(Lower, Upper)
T-*Gsa*	25	2.7035	0.1148			
cGsa	25	2.6993	0.1088			
Difference		0.00426	0.01033			
T-test mean difference				2.06	0.050	
95% CI for mean difference						(-0.0000, 0.0085)

Table 41 Paired T-test Results for T-*Gsb* and c*Gsb*

Sample	N	Mean	StDev	T-value	p-value	(Lower, Upper)
T-*Gsb*	25	2.5964	0.0990			
c*Gsb*	25	2.6140	0.0975			
Difference		-0.01763	0.02263			
T-test mean difference				-3.90	0.001	
95% CI for mean difference						(-0.0270, -0.0083)

Results from the paired T-test confirm that the absorption and bulk SG results from the CoreLok and T-84 testing are different at 95 percent significance level. Interestingly, the T-test confirms that the apparent SG values from the CoreLok and T-84 testing are very similar at the 95 percent significance level. In other words, the apparent SG (*Gsa*) determined using the CoreLok or T-84 test methods is not influenced by the testing method, i.e. the CoreLok *cGsa* values may be used without any corrections.

Figures 27 to 29 show the histograms of differences between the three selected parameters. In each figure, the range for the 95 percent confidence interval is shown, along with a symbol H_0 which is located at a value of zero on the *x*-axis. For data, which is essentially the same, the difference will be close to zero (or a very small number) and the 95 percent confidence interval will span zero. The histograms in Figures 27 and 29 show that the CoreLok and T-84 values are different, while Figure 28 shows that the Corelok *cGsa* values are very similar to the T-84 values.

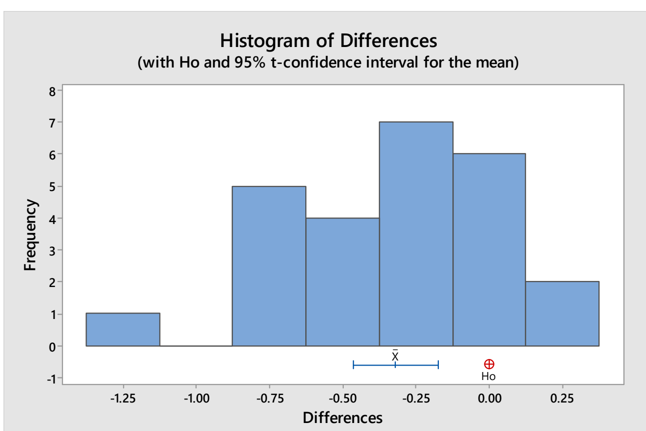


Figure 27 Histogram of differences between T-*Abs* and *cAbs*

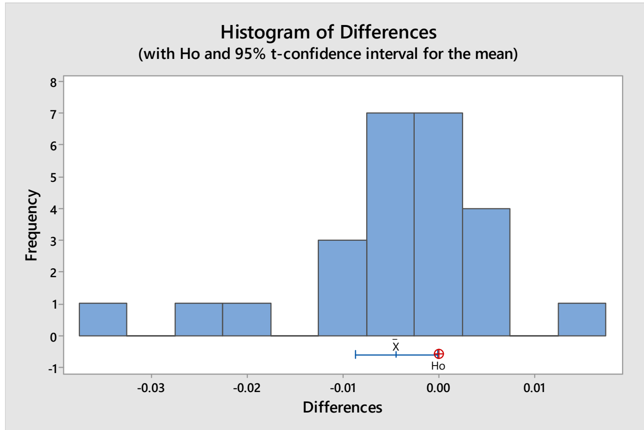


Figure 28 Histogram of differences between T-*Gsa* and *cGsa*

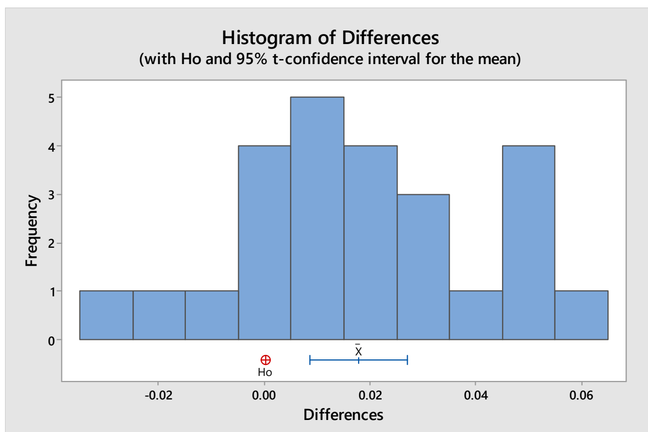


Figure 29 Histogram of differences between T-*Gsb* and c*Gsb*

With confirmation that there are significant differences between the T-*Abs* and *cAbs*, and T-*Gsb* and *cGsb* values based on the AggSpec equations, and information from the correlation matrix, a detailed regression analyses were performed.

Regression Analysis

Regression analysis will use a combination of the CoreLok parameters *cGsa*, *uAbs* and *uGsb* to predict the T-84 parameters. If we presume that the CoreLok test will determine a reliable value of the apparent SG (*Gsa*), correlations will only have to be developed to predict either T-*Abs* or T-*Gsb*. As the three parameters are related, the *Gsb* or *Abs* value can be calculated using the predicted value of either *Abs* and *Gsa* or *Gsb* and *Gsa* using the equations discussed in Chapter 1. Simple linear regression and multiple regression will be considered in a stepwise approach to selecting the best equation. The multiple regression analysis will consider two predictor variables.

Simple Linear Regression

The first series of linear regressions was performed using the “AggSpec corrected” CoreLok data to predict the T-84 variables. Figure 30 show the correlation between (1) *cGsa* and T84-*Gsa*, and (2) *cGsb* and T84-Gsb. As discussed earlier, the *Gsa* values from CoreLok and T84 testing have an excellent relationship with an R^2_{pred} = 0.993 (R^2 = 0.994). In this study, the R^2_{pred} is the preferred parameter for assessing the quality of the regression model. This parameter was also used by the MoDOT study.(2)

Most of the data sits on the line of equality, and it is only the T84-*Gsa* values greater than 2.90 which exhibit some deviation, suggesting that the CoreLok values tend to slightly underestimate the apparent SG, *Gsa*. The relationship between T84-*Gsb* and *cGsb* is not as good. As a majority of the data sits below the line of equality, the CoreLok data overestimates the T84 values in comparison. The regression generated an R^2_{pred} = 0.934, which is high, but the predictions are not very good.

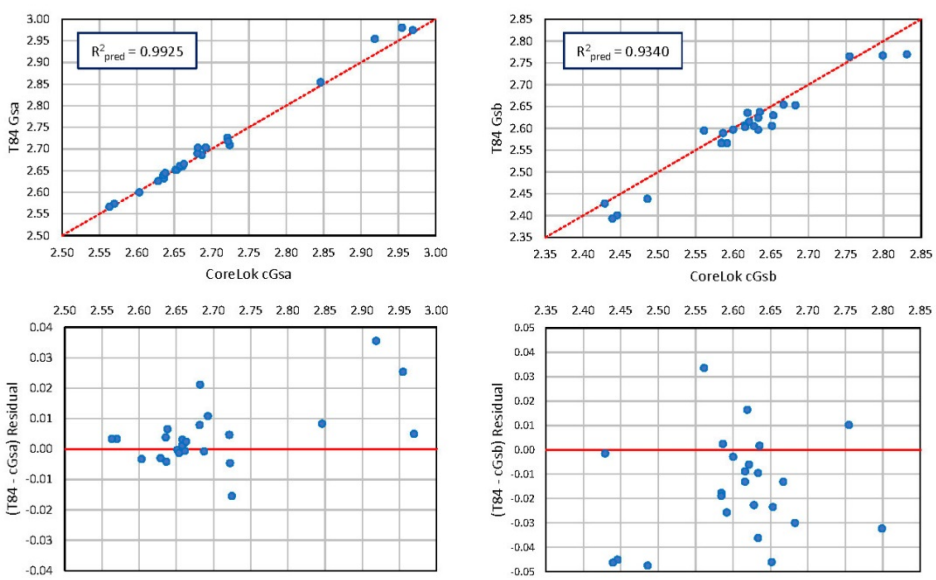


Figure 30 Regressions performed on the *Gsa* and *Gsb* data

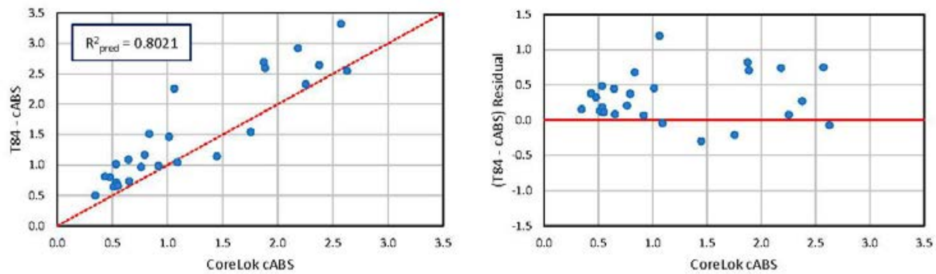


Figure 31 Regression performed on the *Abs* data

Figure 31 shows the potential relationship between the absorption values from the CoreLok and T84 tests. The quality of the correlation is lower than the other two parameters, with an R^2_{pred} = 0.802. In this case, the T84-Abs results are greater than those predicted by the CoreLok test. This is agreement with the results of the paired T-test.

Next, a series of models were examined which will provide better correlations with possibly higher R^2_{pred} values and better predictions. Rather than use CoreLok values which have been corrected by the AggSpec software, this study will use the uncorrected value of either *uAbs* or *uGsb* to predict the T84 results. Figure 32 presents three regression models and the various R^2 values determined to assess the quality of the fit.

(a) Linear Model 1:

$$Abs = 0.2702 + 1.0401 \times [cAbs]$$

R^2_{pred} = 0.8021; R^2 = 0.8313 R^2_{adj} = 0.8240

(b) Linear Model 2:

$$cAbs = 0.6265 + 1.9759 \times (uAbs)$$

R^2_{pred} = 0.7998; R^2 = 0.8291; R^2_{adj} = 0.8216

(c) Quadratic Model:

$$cAbs = 0.6414 + 1.8692 \times [uAbs] - 0.0943 \times [uAbs]^2$$

R^2_{pred} = 0.7691; R^2 = 0.8292; R^2_{adj} = 0.8137

Figure 32 Equations for potential regression models for predicting absorption

From the equations in Figure 32, the linear models for predicting *Abs* do a much better job than the quadratic function, based on the reported R^2 values. The model using the uncorrected values is favored here as it does not depend on the AggSpec software corrections and adjustments. It is a direct predictor of the required *Abs* value.

Figure 33 shows the regression fit for predicting the *Abs* value using the uncorrected CoreLok *uAbs* results. The testing data is well dispersed around the fitted line and appears to more dispersed for values of *uAbs* greater than 0.5 percent. The prediction capability of this linear model can also be assessed by comparing the predicted *Abs* values with the values determined from the T84 tests. This comparison is shown in Figure 34. The predicted *Abs* values correlate well for predicted *Abs* values less than 1.5 percent but display a greater dispersion at higher absorption values.

The predicted *Abs* value may be used with the *Gsa* value to calculate *Gsb*, which is then termed the predicted Gsb. The figures on the right-hand side of Figure 34 show a comparison of the "predicted" *Gsb* and the results from testing according to the T84 method. Most of the predicted specific gravity values are within ± 0.02 of the model's fitted line, but one outlier point is predicted to be 0.06 less than the actual T84 value.

The R^2 for the quadratic model is slightly better than the R^2 for the linear model, but both the R^2_{pred} and R^2_{adj} values are lower than the values for the linear model. The quadratic model fit is displayed in Figure 35, and the predicted values and residual in Figure 36. Observations for this quadratic fit are the same as the ones made for the linear fit, and this really does not offer anything better. If a single parameter model is desirable, the linear model performs well.

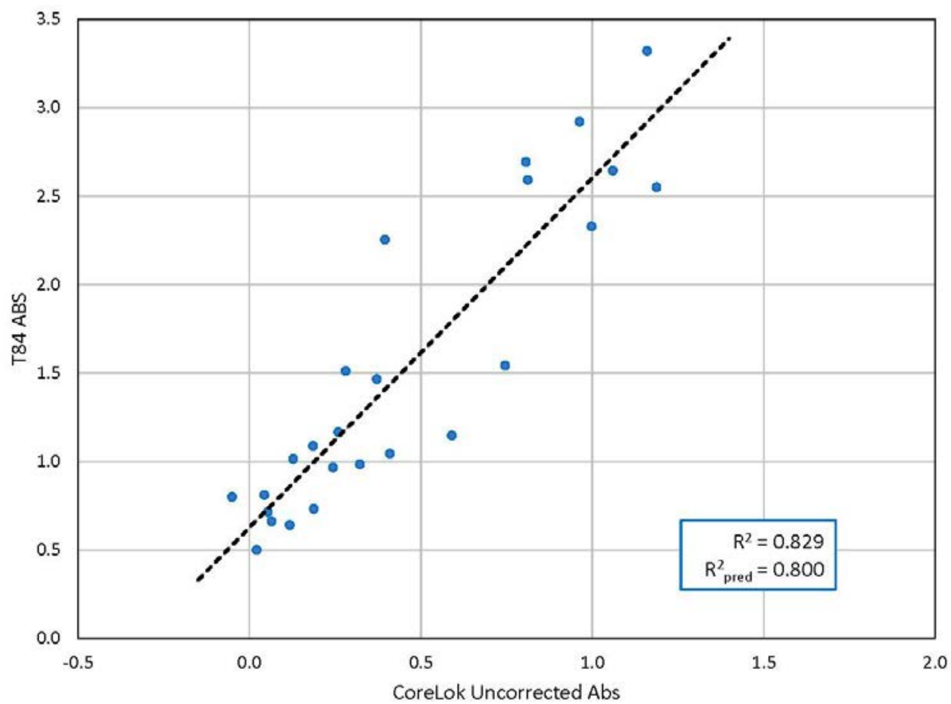


Figure 33 Linear regression fit for predicting absorption with *uAbs*

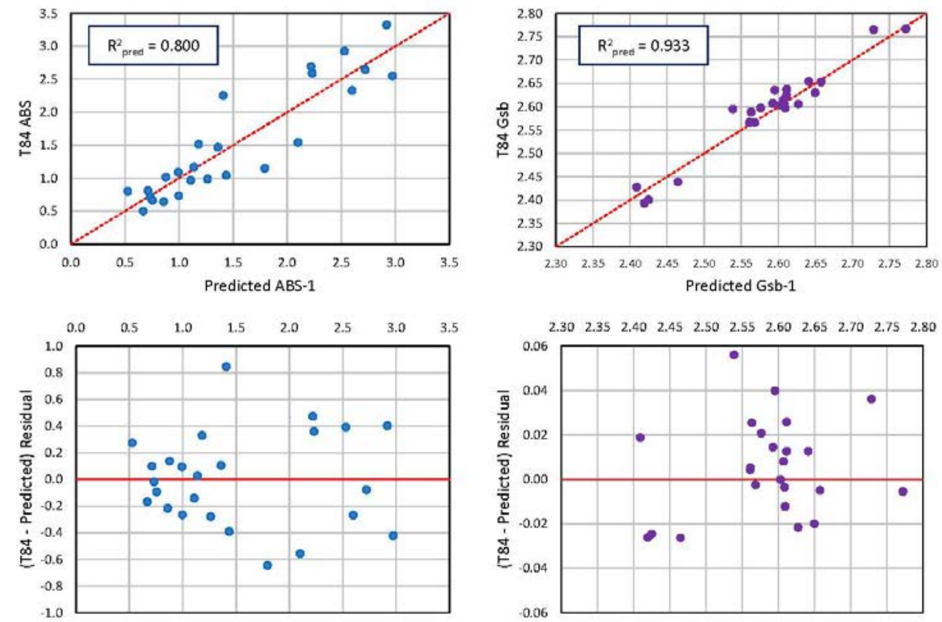


Figure 34 Comparison of predicted *Abs* values with T84 results

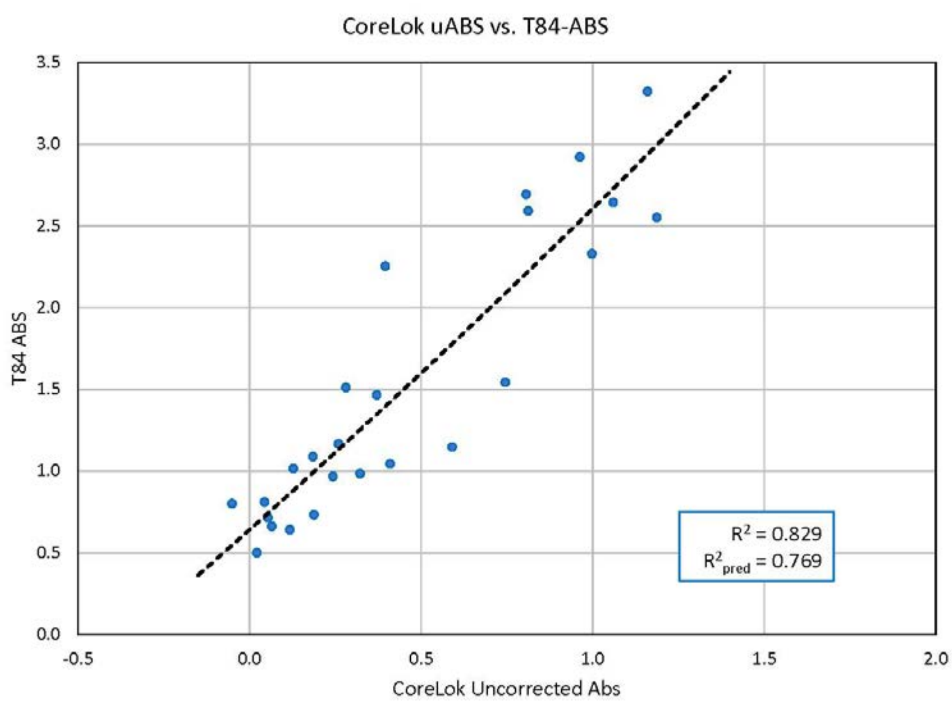


Figure 35 Quadratic regression fit for predicting absorption using *uAbs*

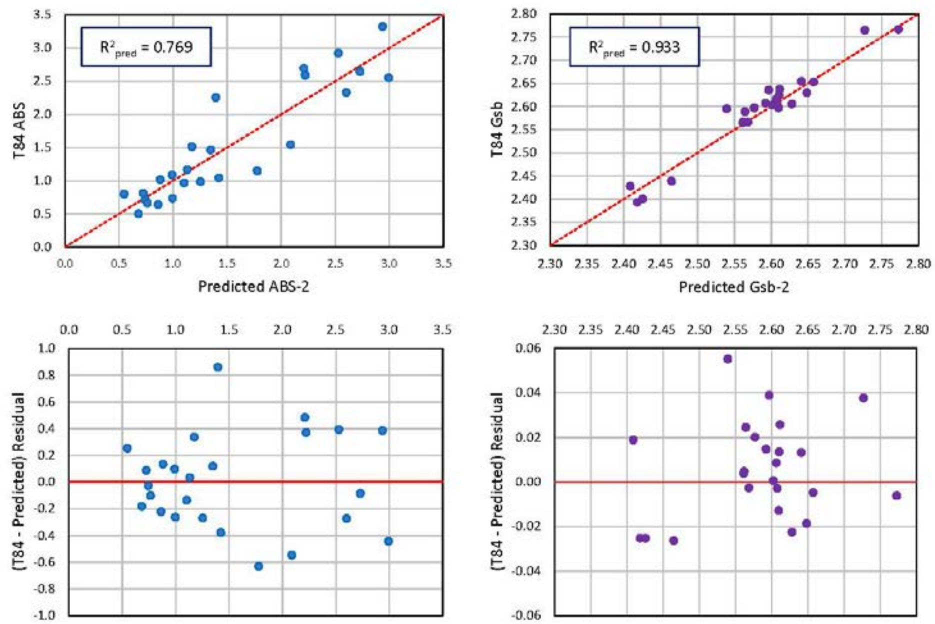


Figure 36 Comparison of predicted *Abs* values with T84 results

The CoreLok data may also be used to predict the bulk specific gravity, *Gsb*. For this prediction the *cGsb* and *uGsb* parameters are used as the predictor values. The statistical analysis revealed the models shown in Figure 37. As the use of the uncorrected *uGsb* is preferred, the quadratic model offers the best fit, as indicated by the R^2 numbers.

(a) Linear Model 1:

$$Gsb = 0.0110 + 0.9890 \times [cGsb]$$

R^2_{pred} = 0.9340; R^2 = 0.9486; R^2_{adj} = 0.9464

(b) Linear Model 2:

$$cGsb = 0.1062 + 0.9339 \times (uGsb)$$

R^2_{pred} = 0.8647; R^2 = 0.8913; R^2_{adj} = 0.8865

(c) Quadratic Model:

$$cGsb = -12.8766 + 10.5495 \times [uGsb] - 1.7777 \times [uGsb]^2$$

R^2_{pred} = 0.9340; R^2 = 0.9506; R^2_{adj} = 0.9461

Figure 37 Equations for potential regression models for predicting *Gsb*

Figure 37 shows the equations for the regression fit for predicting the *Gsb* value using the uncorrected CoreLok *uGsb* results. The testing data is well dispersed around the fitted line and appears to be more dispersed for values of *uGsb* less than about 2.60. The prediction capability of this linear model can also be assessed by comparing the predicted *Gsb* values with the values determined from the T84 tests. This comparison is shown in Figure 38. The predicted *Gsb* values correlate well with the T-84 *Gsb* values greater than 2.60 but display a greater dispersion at lower *uGsb* values.

The predicted *Abs* value may be used with the *cGsa* value to calculate *Gsb*, which is then termed the predicted *Gsb*. The figures on the right-hand side of Figure 39 show a comparison of the "predicted" *Abs* and the results from testing according to the T84 method. Most of the predicted absorption values agree with the T84 data, but only for absorption values less than 2.0 percent.

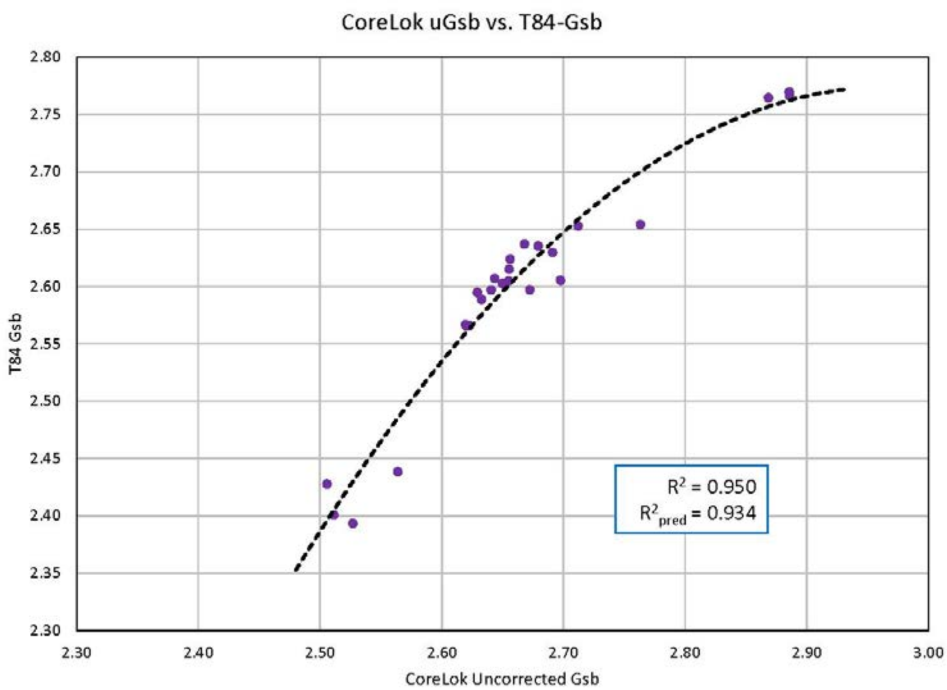


Figure 38 Nonlinear regression fit for predicting *Gsb* using *uGsb* from CoreLok testing

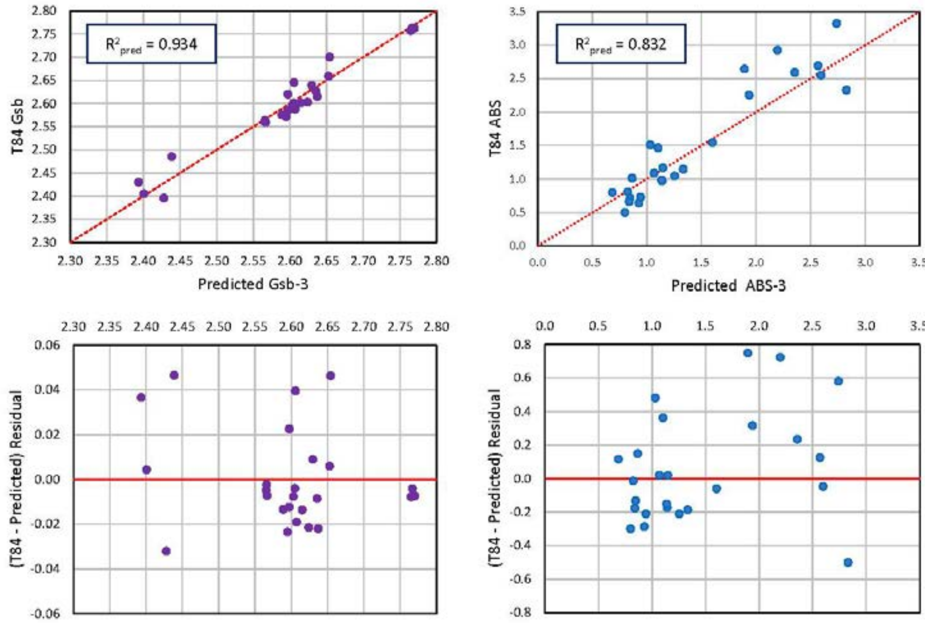


Figure 39 Comparison of predicted *Gsb and Abs* values with T84 results

Further data analyses were also performed to investigate the use of two CoreLok parameters, *uAbs* and *cGsa*, to predict the T84 *Gsb* values. The statistical analysis revealed the models shown in Figure 40. For this case, both the linear and nonlinear models have good R^2 values.

(a) Linear Model:

$$cGsb = 0.0328 + 1.7749 \times [uGsb] - 0.8035 \times (cGsa)$$

R^2_{pred} = 0.9251; R^2 = 0.9470; R^2_{adj} = 0.9422

(b) Nonlinear Model:

$$cGsb = -5.5937 + 15.9435[uGsb] - 10.5729[cGsa]$$
$$-4.5893[uGsb]^2 + 3.7309(uGsb \times cGsa)$$

R^2_{pred} = 0.9454; R^2 = 0.9668; R^2_{adj} = 0.9602

Figure 40 Equations for potential regression models for predicting c*Gsb* using *uGsb* and *cGsa*

The prediction capability of the linear model was assessed by comparing the predicted *Gsb* values with the values determined from the T84 tests. This comparison is shown in Figure 41. The predicted *Gsb* values correlate well for predicted *Gsb* values greater than 2.55 but display a greater dispersion at lower values of *Gsb* less than 2.50.

The predicted *Gsb* value may be used with the *cGsa* value to calculate *Abs*, which is then termed the predicted Abs. The figures on the right-hand side of Figure 41 show a comparison of the “predicted” *Abs* and the results from testing according to the T84 method. Most of the predicted absorption values are within ± 0.4 percent for absorption less than 1.5 percent. At higher absorptions, greater dispersion should be noted with variations of up to ± 0.6 percent from the predicted T84 value.

The prediction capability of the nonlinear model may also be assessed by comparing the predicted *Gsb* values with the values determined from the T84 tests. This comparison is shown in Figure 42. The predicted *Gsb* values correlate well for predicted *Gsb* values greater than 2.55 but display a greater dispersion at lower values of *Gsb* less than 2.50. The difference between the predicted and measured values is about ± 0.03.

The predicted *Gsb* value was used *cGsa* value to calculate Abs, which is then termed the predicted Abs. The figures on the right-hand side of Figure 42 show a comparison of the “predicted” *Abs* and the results from testing according to the T84 method. The predicted absorption values are within ± 0.4 percent. The nonlinear predictions are better with the nonlinear model.

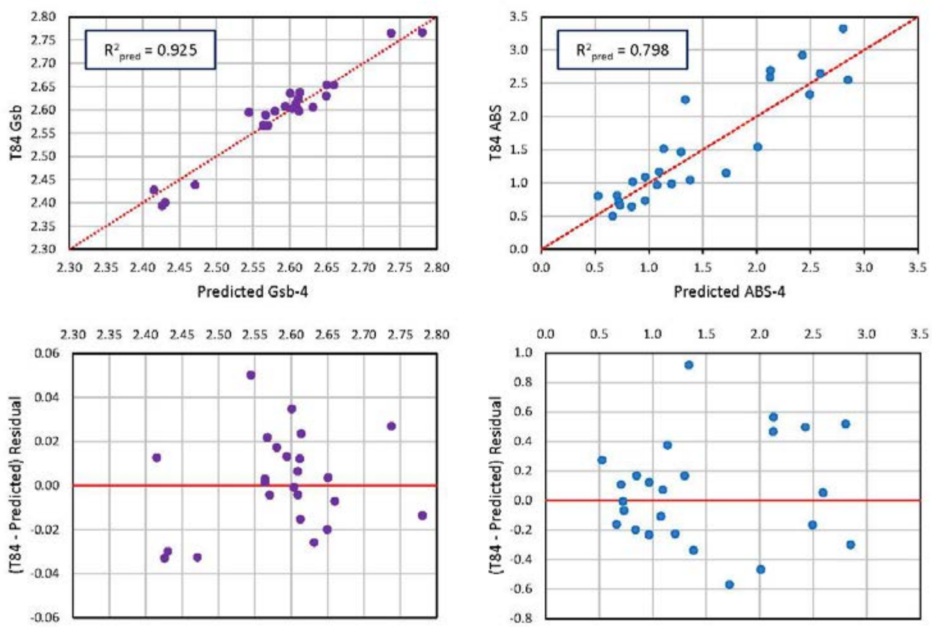


Figure 41 Comparison of predicted *Gsb and Abs* values with T84 results for the linear model

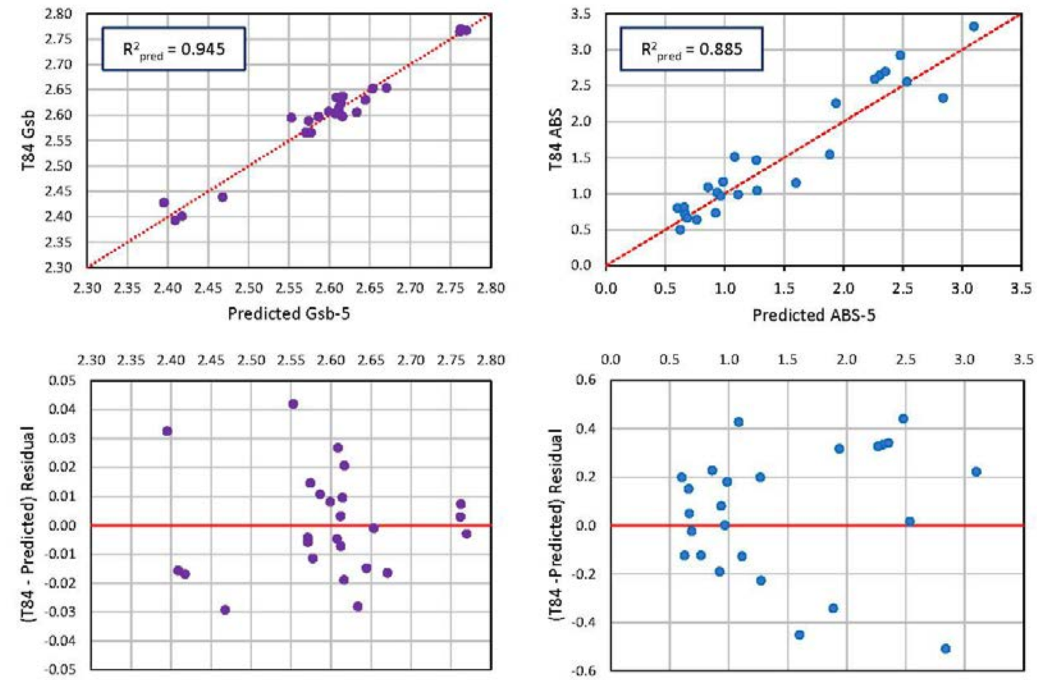


Figure 42 Comparison of predicted *Gsb and Abs* values with T84 results for the nonlinear model

Summary

Five different regression models have been considered for either predicting the absorption, *Abs*, or the bulk SG, *Gsb*, using uncorrected values from the CoreLok method. Of all the models considered, the nonlinear model which uses *uAbs* and *cGsa* from the CoreLok test to predict *Gsb* offers the best model for predicting *Gsb* values. The regression fit had values of R^2_{pred} = 0.9454 and R^2 = 0.9668, which are indicative of the high quality of the fit. Once the *Gsb* values are calculated using this model, the corresponding absorption for the fine aggregate may be calculated theoretically.

Chapter 7
Summary, Conclusions, and Recommendations

Summary

The AASHTO T-84 method is a traditional test method which takes almost 3 days to complete and it also introduces operator-dependent errors in the results. Whereas, the IT-144 test method is gaining popularity because of its efficiency, 30-minute testing time, and less variabilities in the test procedures. Many DOTs including ITD want to use the simpler and easier CoreLok test method as a practical method for daily testing.

This study was conducted to develop models which correlate the CoreLok (Idaho IT-144) test results with AASHTO T-84 test results. For this purpose, the typical aggregate samples collected from the popular quarry sites used by ITD were tested using AASHTO T-84 and CoreLok test methods. A total of 101 CoreLok and 116 AASHTO T-84 tests were run on the selected 25 aggregate samples. The approved test results were averaged for each aggregate and used for the statistical analysis. Models were developed to predict the AASHTO T-84 values of absorption and bulk specific gravity using the values determined from the CoreLok testing.

Additional tests were performed to check the effect of variabilities on the test methods. A round robin experiment was performed involving ITD (Boise), and commercial material testing labs, ALLWEST (Meridian) and STRATA (Boise) to confirm that the results were comparable between the participants.

The values of aggregate properties like Specific Gravities (SGs) and Absorption obtained from the test methods were analyzed using statistical software (Minitab, version 18). Simple regression analyses and multiple regression analyses were performed to develop linear and nonlinear prediction models. AASHTO T-84 results were used as the dependent variables and the CoreLok test results as the predictor variables. This analysis resulted in two good models which may be used by ITD to predict T-84 results based on data obtained from the CoreLok test.

Based on the successful outcome of this study, ITD should consider further research to produce similar prediction models which may be used for coarse aggregates, and combined fine and coarse aggregates, tested using the faster CoreLok device. Additionally, other state DOTs should consider performing similar studies on fine aggregates with a view to developing better prediction models based on the more reliable CoreLok tests.

Conclusions

The data collected from UI, ALLWEST, and the ITD (Boise) Lab were used to develop the regression models. The main conclusions are:

1. The paired T-tests indicated a statistically significant difference in the mean values of the absorption (*Abs*) and bulk specific gravity (*Gsb*) results based on the AASHTO T-84 and the CoreLok test methods. Values of the apparent specific gravity, *Gsa*, were found to be the "same" at the 95 percent significance level.

2. In most of the cases, the CoreLok test overestimated the values of *Gsb*, and underestimated the absorption values compared to the AASHTO T-84 results. The *Gsa* results from both tests were very similar.

3. The use of uncorrected values of *uAbs* and *uGsb* from the CoreLok testing are preferred over the AggSpec calculated values, *cAbs* and *cGsb*, for model development.

4. Two good regression models have been identified by this study. These are shown in Figure 43, below. If the absorption (c*Abs*) is predicted using the uncorrected CoreLok value, *uAbs*, the c*Gsb* may be calculated using the equation shown in Figure 43(a). Conversely, if the *cGsb* value is predicted, the absorption may be calculated using the theoretical equation shown in Figure 43(b). These calculations use the *cGsa* value determined from the CoreLok test.

(a) Linear Regression:

$$cAbs = 0.6265 + 1.9759 \times (uAbs)$$

$R^2_{pred} = 0.7998$; $R^2 = 0.8291$; $R^2_{adj} = 0.8216$

$$cGsb = \frac{cGsa}{1 + \frac{cAbs}{100\%} cGsa}$$

(b) Multiple Linear Regression:

$$cGsb = -5.5937 + 15.9435[uGsb] - 10.5729[cGsa]$$
$$-4.5893[uGsb]^2 + 3.7309(uGsb \times cGsa)$$

$R^2_{pred} = 0.9454$; $R^2 = 0.9668$; $R^2_{adj} = 0.9602$

$$cAbs = \left[\frac{1}{cGsb} - \frac{1}{cGsa}\right] \times 100\%$$

Figure 43 Regression models for predicting absorption (*cAbs*) and bulk specific gravity (*cGsb*)

5. The CoreLok method, corrected by the Multiple Linear Regression Model presented in Figure 43, may be used to predict highly reliable values of Bulk Specific Gravity (*cGsb*) and subsequently combined with the corresponding CoreLok (*cGsa)* value to calculate absorption.

Recommendations

Based on the results of this study,

1. It is recommended that the current Idaho IT-144 (CoreLok) test procedure continue to be used, except that the Idaho Correlation Procedure from this report be used for calculating fine aggregate specific gravities and absorption values. The Idaho IT-144 method, compared to the AASHTO T-84 method, is a much faster test to perform, more repeatable, and not as affected by operator experience or the lack thereof.

2. The value of the measured, uncorrected parameter, *uGsb*, must be modified to predict the bulk specific gravity. This study recommends that the *cGsb* value be corrected using the following equation:

$$
\begin{aligned}
cGsb = {} & -5.5937 + 15.9435[uGsb] - 10.5729[cGsa] \\
& -4.5893[uGsb]^2 + 3.7309(uGsb \times cGsa)
\end{aligned}
$$

Figure 44 Recommended equation for calculating the bulk specific gravity, *cGsb*, from CoreLok test

3. With the c*Gsa* and the corrected value *cGsb* determined, the absorption may be calculated using the equation:

$$cAbs = \left[\frac{1}{cGsb} - \frac{1}{cGsa}\right] \times 100\%$$

Figure 45 Recommended equation for calculating the absorption, *cAbs*, based on CoreLok testing

4. Based on the successful outcome of this study, ITD should consider further research to produce similar prediction models which may be used for coarse aggregates, and combined fine and coarse aggregates, tested using the faster CoreLok device.

5. Other state DOTs should consider performing similar studies on fine aggregates with a view to developing better prediction models based on the more reliable CoreLok tests.

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Appendix A
Lab Testing Data

Table A1 Lab data for CoreLok tests completed according to Idaho IT-144

#	Date Tested	Sample ID	Agg. ID	Volumetric Wt (Avg) (g)	Dry Sample Wt (Avg) (g)	Sample + Volum. + Water (g)	Bag Wt (g)	Dry Sample Wt (g)	Wt of Bag in Water (g)	uAbs	cAbs	Gsa	uGsb	cGsb	Test Used
1.	09/05/17	AW-1D-01	Kt-213c	4130.3	500.0	4443.6	29.0	1000.0	629.1	0.562	1.390	2.719	2.678	2.620	Y
2.	11/09/17	AW-1D-02	Kt-213c	4129.7	500.0	4445.1	28.6	1000.0	629.6	0.187	0.650	2.722	2.709	2.675	Y
3.	03/08/17	UI-1D-01	Kt-213c	4221.0	522.4	4549.8	22.9	1050.6	662.5	0.341	0.954	2.724	2.699	2.655	Y
4.	03/08/17	UI-1D-02	Kt-213c	4221.0	550.4	4567.4	23.1	1066.3	672.7	0.372	1.016	2.726	2.699	2.653	Y
5.	03/08/17	UI-1D-03	Kt-213c	4221.0	526.1	4552.3	23.1	1092.2	688.5	0.296	0.864	2.722	2.700	2.660	Y
6.	03/08/17	UI-1D-04	Kt-213c	4221.0	529.0	4554.0	22.7	1064.4	671.4	0.341	0.954	2.725	2.700	2.656	Y
7.	08/31/17	UI-1D-05	Kt-213c	4221.2	500.0	4535.6	22.8	1054.4	665.2	0.440	1.151	2.726	2.694	2.643	Y
8.	09/05/17	UI-1D-06	Kt-213c	4221.2	500.0	4536.1	22.7	1000.0	630.9	0.354	0.980	2.727	2.701	2.656	Y
9.	02/14/18	UI-1D-07	Kt-213c	4220.8	500.0	4535.5	28.4	1000.0	630.7	0.445	1.160	2.730	2.698	2.647	Y
10.	08/10/18	UI-1D-08	Kt-213c	4221.3	504.7	4539.2	28.1	1003.4	636.7	0.767	1.797	2.759	2.702	2.629	N
11.	01/05/18	AW-1N-01	Kt-222c	4131.2	500.0	4446.4	29.0	1000.0	628.5	0.122	0.521	2.715	2.706	2.677	Y
12.	11/30/17	UI-1N-01	Kt-222c	4220.1	500.0	4535.9	23.0	1000.0	630.2	0.117	0.512	2.722	2.714	2.685	Y
13.	01/09/18	UI-1N-02	Kt-222c	4220.4	500.0	4536.4	22.6	1000.0	630.8	0.123	0.523	2.726	2.717	2.688	Y
14.	02/14/18	UI-1N-03	Kt-222c	4220.8	500.0	4536.4	27.8	1000.0	629.7	0.149	0.574	2.722	2.711	2.681	Y
15.	01/05/18	AW-1P-01	Kt-215c	4131.2	500.0	4445.0	28.1	1000.0	632.4	0.782	1.826	2.743	2.685	2.612	Y
16.	11/28/17	UI-1P-01	Kt-215c	4220.6	500.0	4533.6	23.3	1000.0	629.5	0.610	1.487	2.717	2.673	2.612	Y
17.	01/05/18	UI-1P-02	Kt-215c	4220.6	500.0	4533.9	23.2	1000.0	628.1	0.389	1.050	2.707	2.679	2.632	Y

Table A1 Lab data for CoreLok tests completed according to Idaho IT-144 (continued)

#	Date Tested	Sample ID	Agg. ID	Volumetric Wt (Avg) (g)	Dry Sample Wt (Avg) (g)	Sample + Volum. + Water (g)	Bag Wt (g)	Dry Sample Wt (g)	Wt of Bag in Water (g)	uAbs	cAbs	Gsa	uGsb	cGsb	Test Used
18.	02/16/18	UI-1P-03	Kt-215c	4220.7	500.0	4534.1	28.0	1000.0	629.6	0.581	1.428	2.722	2.680	2.620	Y
19.	03/07/17	UI-2C-01	WCW-23c	4220.8	558.3	4584.4	22.8	1197.5	792.1	1.210	2.671	2.972	2.869	2.753	Y
20.	03/07/17	UI-2C-02	WCW-23c	4220.8	630.0	4631.2	22.9	1164.7	769.9	1.158	2.570	2.969	2.870	2.758	Y
21.	03/07/17	UI-2C-03	WCW-23c	4220.8	674.0	4659.7	22.9	1078.0	712.5	1.197	2.646	2.969	2.867	2.753	Y
22.	03/07/17	UI-2C-04	WCW-23c	4220.8	532.6	4567.9	22.7	1197.2	792.4	1.211	2.675	2.975	2.872	2.756	Y
23.	04/12/17	UI-2C-05	WCW-23c	4221.0	542.9	4574.4	22.9	1138.4	751.7	1.162	2.577	2.963	2.864	2.753	Y
24.	08/10/18	AW-2Q-02	Id-256c	4131.2	500	4446.6	28.9	1000.0	643.9	1.620	3.484	2.833	2.709	2.578	Y
25.	01/04/18	AW-2Q-01	Id-256c	4131.5	500.1	4447.8	28.7	1000.0	644.4	1.501	3.247	2.837	2.721	2.597	N
26.	11/28/17	UI-2Q-01	Id-256c	4220.6	500.0	4541.3	22.8	1000.0	646.6	0.765	1.792	2.849	2.789	2.711	Y
27.	01/05/18	UI-2Q-02	Id-256c	4220.6	500.0	4541.5	22.8	1000.0	647.4	0.795	1.852	2.856	2.793	2.712	Y
28.	02/26/18	AW-2T-01	WCW-18c	4130.4	500.0	4457.7	28.0	1000.0	657.4	0.581	1.428	2.945	2.895	2.825	Y
29.	n/a	ITD-2T-01	WCW-18c	4119.1	500.2	4445.1	27.2	1000.0	659.3	1.048	2.352	2.961	2.871	2.768	Y
30.	12/26/17	UI-2T-01	WCW-18c	4220.5	500.0	4547.1	22.8	1000.0	658.6	0.775	1.812	2.950	2.884	2.801	Y
31.	01/09/18	UI-2T-02	WCW-18c	4220.4	500.0	4547.5	22.7	1000.0	660.2	0.844	1.948	2.964	2.892	2.802	Y
32.	08/10/18	UI-2T-03	WCW-18c	4220.6	507.3	4551.6	27.9	1042.0	692.1	1.461	3.168	3.004	2.877	2.743	N
33.	02/26/18	AW-2V-01	NP-82c	4130.4	500.0	4456.3	28.8	1000.0	654.8	0.609	1.485	2.923	2.872	2.801	Y
34.	07/07/18	AW-2V-02	NP-82c	4131.7	500.0	4457.2	28.7	1000.0	655.2	0.728	1.720	2.926	2.865	2.786	N

Table A1 Lab data for CoreLok tests completed according to Idaho IT-144 (continued)

#	Date Tested	Sample ID	Agg. ID	Volumetric Wt (Avg) (g)	Dry Sample Wt (Avg) (g)	Sample + Volum. + Water (g)	Bag Wt (g)	Dry Sample Wt (g)	Wt of Bag in Water (g)	uAbs	cAbs	Gsa	uGsb	cGsb	Test Used
35.	01/02/18	UI-2V-01	NP-82c	4220.2	500.0	4547.2	22.9	1000.0	654.4	0.296	0.865	2.914	2.889	2.843	Y
36.	01/18/18	UI-2V-02	NP-82c	4220.0	500.0	4547.3	28.0	1000.0	654.4	0.281	0.835	2.919	2.895	2.849	Y
37.	08/10/18	UI-2V-03	NP-82c	4220.9	501.4	4548.8	28.4	1001.2	660.8	0.909	2.076	2.968	2.890	2.796	N
38.	09/27/17	AW-3A-01	Ad-136	4130.7	500.0	4440.4	28.8	1000.0	620.5	0.419	1.110	2.657	2.627	2.581	Y
39.	03/09/17	UI-3A-01	Ad-136	4221.1	560.5	4568.8	23.0	1224.7	762.2	0.398	1.067	2.662	2.634	2.589	Y
40.	03/09/17	UI-3A-02	Ad-136	4221.1	521.5	4544.6	22.9	1221.9	760.9	0.435	1.139	2.665	2.634	2.586	Y
41.	03/09/17	UI-3A-03	Ad-136	4221.1	533.6	4552.1	23.1	1050.3	653.1	0.387	1.045	2.661	2.634	2.589	Y
42.	03/09/17	UI-3A-04	Ad-136	4221.1	537.5	4554.5	22.7	1024.3	637.1	0.409	1.088	2.662	2.634	2.587	Y
43.	08/10/17	AW-3E-01	Ad-182c	4130.6	500.0	4439.6	28.9	1000.0	617.0	0.210	0.700	2.632	2.618	2.585	Y
44.	07/20/17	UI-3E-01	Ad-182c	4221.3	525.6	4546.1	22.6	1078.3	667.1	0.305	0.882	2.638	2.617	2.578	Y
45.	08/30/17	UI-3E-02	Ad-182c	4221.0	501.2	4531.1	22.9	1127.8	697.6	0.195	0.666	2.637	2.623	2.591	Y
46.	09/05/17	UI-3E-03	Ad-182c	4221.2	500.0	4530.4	22.7	1000.0	618.6	0.264	0.802	2.639	2.621	2.584	Y
47.	11/09/17	AW-3H-01	Ad-161C	4129.7	500.0	4439.4	28.7	1000.0	618.0	0.168	0.610	2.639	2.627	2.597	Y
48.	11/02/17	UI-3H-01	Ad-161C	4221.1	500.0	4530.1	22.6	1000.0	617.6	0.193	0.661	2.632	2.618	2.587	Y
49.	01/02/18	UI-3H-02	Ad-161C	4220.2	500.0	4529.6	22.7	1000.0	618.2	0.194	0.663	2.636	2.623	2.591	Y
50.	01/04/18	AW-3J-01	Cn-140c	4131.2	500.0	4439.4	28.6	1000.0	617.0	0.367	1.010	2.632	2.607	2.564	Y
51.	07/06/18	AW-3J-02	Cn-140c	4131.7	500.1	4441.3	28.5	1000.0	618.7	0.269	0.811	2.644	2.625	2.588	N

Table A1 Lab data for CoreLok tests completed according to Idaho IT-144 (continued)

#	Date Tested	Sample ID	Agg. ID	Volumetric Wt (Avg) (g)	Dry Sample Wt (Avg) (g)	Sample + Volum. + Water (g)	Bag Wt (g)	Dry Sample Wt (g)	Wt of Bag in Water (g)	uAbs	cAbs	Gsa	uGsb	cGsb	Test Used
52.	11/07/17	UI-3J-01	Cn-140c	4220.7	500.0	4530.6	22.9	1000.0	619.2	0.186	0.648	2.643	2.630	2.599	Y
53.	01/04/18	UI-3J-02	Cn-140c	4220.3	500.0	4529.7	22.7	1000.0	618.7	0.224	0.723	2.639	2.624	2.590	Y
54.	01/05/18	AW-5O-01	Bg-111-c	4131.2	500.0	4441.7	29.5	1000.0	619.2	0.137	0.550	2.648	2.639	2.610	Y
55.	11/30/17	UI-5O-01	Bg-111-c	4220.1	500.0	4530.9	23.0	1000.0	620.4	0.137	0.551	2.652	2.642	2.613	Y
56.	01/18/18	UI-5O-02	Bg-111-c	4220.0	500.0	4531.3	27.8	1000.0	620.4	0.079	0.435	2.655	2.650	2.625	Y
57.	02/26/18	AW-5R-01	Bk-100-c	4130.4	500.0	4445.2	28.8	1000.0	624.0	-0.251	0.380	2.682	2.700	2.655	Y
58.	12/26/17	UI-5R-01	Bk-100-c	4220.5	500.0	4533.7	22.8	1000.0	625.3	0.135	0.547	2.686	2.677	2.647	Y
59.	01/09/18	UI-5R-02	Bk-100-c	4220.4	500.0	4536.0	23.2	1000.0	626.5	-0.221	0.437	2.695	2.711	2.664	Y
60.	04/12/18	UI-5R-03	Bk-100-c	4221.1	500.0	4534.2	28.3	1000.0	624.6	0.134	0.545	2.686	2.676	2.647	Y
61.	02/26/18	AW-5S-01	Bg-107-c	4130.4	500.0	4442.6	28.8	1000.0	619.3	-0.201	0.480	2.648	2.662	2.615	Y
62.	12/27/17	UI-5S-01	Bg-107-c	4220.6	500.0	4531.4	22.6	1000.0	620.8	0.163	0.602	2.654	2.643	2.612	Y
63.	01/18/18	UI-5S-02	Bg-107-c	4220.0	500.0	4531.4	28.0	1000.0	620.7	0.091	0.459	2.658	2.651	2.625	Y
64.	02/16/18	UI-5S-03	Bg-107-c	4220.7	500.0	4531.5	28.1	1000.0	620.2	0.162	0.600	2.654	2.643	2.612	Y
65.	02/26/18	AW-5U-01	Bl-93-s	4130.5	500.0	4442.8	28.8	1000.0	619.7	-0.181	0.490	2.650	2.664	2.616	Y
66.	12/27/17	UI-5U-01	Bl-93-s	4220.6	500.0	4532.1	22.7	1000.0	622.2	0.154	0.584	2.664	2.653	2.623	Y
67.	01/18/18	UI-5U-02	Bl-93-s	4220.9	500.0	4532.2	28.3	1000.0	621.2	0.154	0.584	2.661	2.650	2.621	Y
68.	02/16/18	UI-5U-03	Bl-93-s	4220.7	500.0	4532.3	28.2	1000.0	621.5	0.133	0.543	2.663	2.654	2.625	Y

Table A1 Lab data for CoreLok tests completed according to Idaho IT-144 (continued)

#	Date Tested	Sample ID	Agg. ID	Volumetric Wt (Avg) (g)	Dry Sample Wt (Avg) (g)	Sample + Volum. + Water (g)	Bag Wt (g)	Dry Sample Wt (g)	Wt of Bag in Water (g)	uAbs	cAbs	Gsa	uGsb	cGsb	Test Used
69.	03/06/17	UI-6B-01	Fr-104-c	4220.9	600.3	4583.7	22.7	1468.0	901.7	1.148	2.550	2.603	2.528	2.441	Y
70.	03/06/17	UI-6B-02	Fr-104-c	4220.9	537.1	4545.4	22.9	1257.3	772.5	1.214	2.680	2.607	2.527	2.436	Y
71.	03/06/17	UI-6B-03	Fr-104-c	4220.9	591.7	4578.3	23.0	1245.3	763.5	1.107	2.468	2.598	2.525	2.441	Y
72.	03/06/17	UI-6B-04	Fr-104-c	4220.9	613.0	4591.4	23.3	1113.6	683.6	1.171	2.594	2.605	2.528	2.440	Y
73.	11/09/17	AW-6F-01	Le-96-s	4129.7	500.0	4442.8	28.7	1000.0	623.9	0.078	0.440	2.681	2.675	2.650	Y
74.	11/02/17	UI-6F-01	Le-96-s	4221.1	500.0	4533.3	22.7	1000.0	624.2	0.214	0.703	2.678	2.663	2.629	Y
75.	01/02/18	UI-6F-02	Le-96-s	4220.2	500.0	4533.0	23.0	1000.0	625.2	0.217	0.709	2.686	2.670	2.636	Y
76.	02/13/17	UI-6F-03	Le-96-s	4221.1	500.0	4533.4	28.1	1000.0	623.9	0.242	0.758	2.680	2.663	2.627	Y
77.	11/09/17	AW-6G-01	Cu-75-s	4129.7	500.0	4443.3	28.7	1000.0	624.9	0.078	0.435	2.688	2.682	2.657	Y
78.	07/07/18	AW-6G-02	Cu-75-s	4131.7	500.0	4444.2	28.6	1000.0	619.4	-0.253	0.374	2.649	2.667	2.623	N
79.	n/a	ITD-6G-01	Cu-75-s	4119.1	500.1	4431.6	27.0	1000.6	625.7	0.335	0.942	2.690	2.666	2.623	Y
80.	10/31/17	UI-6G-01	Cu-75-s	4220.5	500.0	4533.4	22.9	1000.0	626.8	0.346	0.964	2.697	2.672	2.629	Y
81.	01/04/18	UI-6G-02	Cu-75-s	4220.3	500.0	4532.9	22.7	1000.0	626.5	0.364	0.999	2.695	2.669	2.624	Y
82.	11/09/17	AW-6I-01	Bn-59-s	4129.7	500.0	4441.1	28.5	1000.0	619.0	-0.074	0.230	2.646	2.651	2.630	Y
83.	10/31/17	UI-6I-01	Bn-59-s	4220.5	500.0	4532.7	22.7	1000.0	622.2	0.024	0.327	2.664	2.662	2.641	Y
84.	01/02/18	UI-6I-02	Bn-59-s	4220.2	500.0	4532.0	22.6	1000.0	622.2	0.103	0.483	2.664	2.657	2.630	Y
85.	04/12/18	UI-6I-03	Bn-59-s	4221.1	500.0	4532.7	28.1	1000.0	620.6	0.032	0.343	2.657	2.655	2.633	Y

Table A1 Lab data for CoreLok tests completed according to Idaho IT-144 (continued)

#	Date Tested	Sample ID	Agg. ID	Volumetric Wt (Avg) (g)	Dry Sample Wt (Avg) (g)	Sample + Volum. + Water (g)	Bag Wt (g)	Dry Sample Wt (g)	Wt of Bag in Water (g)	uAbs	cAbs	Gsa	uGsb	cGsb	Test Used
86.	01/04/18	AW-6K-01	Bn-156-c	4131.2	500.0	4443.6	28.7	1000.0	620.8	-0.092	0.300	2.659	2.665	2.638	Y
87.	11/07/17	UI-6K-01	Bn-156-c	4220.7	500.0	4532.0	23.0	1000.0	620.9	0.067	0.413	2.655	2.650	2.626	Y
88.	01/05/18	UI-6K-02	Bn-156-c	4220.6	500.0	4531.8	22.8	1000.0	621.6	0.155	0.586	2.660	2.649	2.619	Y
89.	01/05/18	AW-6L-01	Le-160-c	4131.2	500.0	4439.5	29.0	1000.0	623.9	1.042	2.340	2.681	2.608	2.523	Y
90.	07/07/18	AW-6L-02	Le-160-c	4131.7	500.0	4442.1	28.8	1000.0	623.4	0.569	1.410	2.677	2.637	2.580	N
91.	11/09/17	UI-6L-01	Le-160-c	4221.0	500.0	4531.7	22.8	1000.0	623.7	0.475	1.219	2.675	2.641	2.590	Y
92.	01/18/18	UI-6L-02	Le-160-c	4220.9	500.0	4530.9	22.8	1000.0	624.6	0.705	1.673	2.681	2.632	2.566	Y
93.	02/13/17	UI-6L-03	Le-160-c	4221.1	500.0	4531.4	28.1	1000.0	625.2	0.762	1.786	2.690	2.636	2.566	Y
94.	01/04/18	AW-6M-01	CI-56-s	4131.2	500.0	4441.6	28.6	1000.0	621.9	0.417	1.110	2.666	2.637	2.590	Y
95.	11/09/17	UI-6M-01	CI-56-s	4221.0	500.0	4531.4	22.8	1000.0	620.8	0.245	0.764	2.654	2.637	2.602	Y
96.	01/04/18	UI-6M-02	CI-56-s	4220.3	500.0	4531.4	22.7	1000.0	622.9	0.304	0.881	2.669	2.648	2.608	Y
97.	n/a	ITD-3W-01	Ow-94	4119.2	500.2	4424.1	25.0	1000.0	617.0	1.013	2.283	2.629	2.561	2.481	Y
98.	n/a	ITD-3W-02	Ow-94	4119.2	500.2	4424.5	25.4	1000.4	617.0	0.912	2.084	2.628	2.566	2.492	Y
99.	n/a	ITD-4X-01	Cs-184	4119.7	500.1	4420.4	27.1	1000.1	608.7	1.021	2.299	2.574	2.508	2.431	Y
100.	n/a	ITD-4X-02	Cs-184	4119.7	500.0	4419.9	27.1	1000.0	607.3	0.975	2.208	2.565	2.503	2.428	Y
101.	n/a	ITD-4Y-02	Cs-192	4118.9	500.0	4419.8	29.8	999.9	606.6	0.806	1.874	2.563	2.511	2.446	Y

Table A2 Lab data for tests completed according to AASHTO T-84

#	Date	UI - ID	Agg. ID	Pycn Only	Pycn + Water	Pycn + SSD Sample	SSD Sample	Pycn + Water + Sample	Pan Only	Dry Agg. + Pan	Dry Agg.	Gsb	Gsa	Abs (%)	Test Used
1.	n/a	AW-1D-01	Kt-213c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.610	2.724	1.600	Y
2.	n/a	AW-1D-02	Kt-213c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.635	2.714	1.110	N
3.	n/a	ITD-1D	Kt-213c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.610	2.706	1.358	Y
4.	n/a	ST-1D-01	Kt-213c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.610	2.731	1.700	N
5.	n/a	ST-1D-02	Kt-213c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.609	2.729	1.700	N
6.	02/23/17	UI-1D-01	Kt-213c	190.5	689.5	691.4	500.9	1002.1	243.4	737.2	493.8	2.622	2.725	1.438	N
7.	02/23/17	UI-1D-02	Kt-213c	186.0	685.0	716.7	530.7	1015.0	243.0	766.1	523.1	2.606	2.709	1.453	Y
8.	02/24/17	UI-1D-03	Kt-213c	186.0	685.0	705.3	519.3	1007.4	238.8	749.8	511.0	2.595	2.709	1.624	Y
9.	02/24/17	UI-1D-04	Kt-213c	190.5	689.5	700.5	510.0	1006.3	246.8	750.3	503.5	2.606	2.697	1.291	Y
10.	08/30/17	UI-1D-05	Kt-213c	190.4	688.6	694.5	504.1	1004.8	784.5	1283.4	498.9	2.655	2.731	1.042	N
11.	02/14/18	UI-1D-06	Kt-213c	181.7	680.4	726.2	544.5	1020.6	251.6	788.7	537.1	2.629	2.728	1.378	N
12.	08/10/18	UI-1D-07	Kt-213c	n/a	1272.1	503.9	503.9	1587.6	n/a	n/a	498.3	2.645	2.726	1.124	N
13.	n/a	AW-1N-01	Kt-222c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.635	2.725	1.260	N
14.	n/a	AW-1N-02	Kt-222c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.649	2.717	0.960	Y
15.	11/30/17	UI-1N-01	Kt-222c	190.4	689.5	713.3	522.9	1017.2	758.4	1276.3	517.9	2.653	2.723	0.965	Y
16.	01/09/18	UI-1N-02	Kt-222c	208.2	706.8	718.9	510.7	1027.2	243.3	748.7	505.4	2.656	2.732	1.049	Y
17.	02/14/18	UI-1N-03	Kt-222c	208.2	706.8	756.9	548.7	1050.9	243.2	786.0	542.8	2.653	2.732	1.087	Y

Table A2 Lab data for tests completed according to AASHTO T-84 (continued)

#	Date	UI - ID	Agg. ID	Pycn Only	Pycn + Water	Pycn + SSD Sample	SSD Sample	Pycn + Water + Sample	Pan Only	Dry Agg. + Pan	Dry Agg.	Gsb	Gsa	Abs (%)	Test Used
18.	n/a	AW-1P	Kt-215c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.634	2.712	1.090	Y
19.	11/28/17	UI-1P-01	Kt-215c	186.0	685.0	694.1	508.1	1002.4	780.5	1282.8	502.3	2.634	2.717	1.155	Y
20.	01/05/18	UI-1P-02	Kt-215c	208.2	706.8	724.0	515.8	1029.4	120.3	630.0	509.7	2.638	2.724	1.197	Y
21.	n/a	ITD-2C-01	WCW-23c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.785	2.962	2.200	N
22.	n/a	ITD-2C-02	WCW-23c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.794	2.974	2.200	N
23.	n/a	ITD-2C-03	WCW-23c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.772	2.960	2.300	N
24.	n/a	ITD-2C-04	WCW-23c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.772	2.987	2.600	N
25.	02/22/17	UI-2C-01	WCW-23c	190.5	689.5	718.0	527.5	1029.5	251.5	763.9	512.4	2.733	2.972	2.947	N
26.	02/22/17	UI-2C-02	WCW-23c	182.0	681.0	731.0	549.0	1033.5	86.1	619.0	532.9	2.712	2.954	3.021	N
27.	02/22/17	UI-2C-03	WCW-23c	186.0	685.0	718.0	532.0	1027.5	120.0	637.2	517.2	2.729	2.961	2.862	N
28.	02/22/17	UI-2C-04	WCW-23c	190.5	689.5	723.0	532.5	1033.0	90.0	608.4	518.4	2.743	2.964	2.720	N
29.	04/12/17	UI-2C-05	WCW-23c	190.5	689.5	694.2	503.7	1014.5	251.5	742.0	490.5	2.745	2.964	2.691	N
30.	04/12/17	UI-2C-06	WCW-23c	186.0	685.0	716.5	530.5	1027.0	243.3	759.5	516.2	2.738	2.963	2.770	N
31.	09/12/17	UI-2C-07	WCW-23c	190.4	688.6	690.4	500.0	1012.4	780.9	1268.5	487.6	2.767	2.977	2.543	Y
32.	09/14/17	UI-2C-08	WCW-23c	190.4	688.6	695.5	505.1	1015.4	780.8	1273.3	492.5	2.762	2.972	2.558	Y
33.	n/a	AW-2Q	Id-256c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.644	2.852	2.760	Y
34.	11/28/17	UI-2Q-01	Id-256c	190.4	689.5	714.0	523.6	1020.9	758.4	1269.1	510.7	2.657	2.848	2.526	Y

Table A2 Lab data for tests completed according to AASHTO T-84 (continued)

#	Date	UI - ID	Agg. ID	Pycn Only	Pycn + Water	Pycn + SSD Sample	SSD Sample	Pycn + Water + Sample	Pan Only	Dry Agg. + Pan	Dry Agg.	Gsb	Gsa	Abs (%)	Test Used
35.	01/05/18	UI-2Q-02	Id-256c	181.7	680.4	709.4	527.7	1014.9	89.4	603.5	514.1	2.661	2.862	2.645	Y
36.	n/a	AW-2T-01	WCW-18c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.735	2.974	2.940	N
37.	n/a	AW-2T-02	WCW-18c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.765	2.966	2.460	Y
38.	n/a	ITD-2T	WCW-18c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.760	2.963	2.484	Y
39.	12/26/17	UI-2T-01	WCW-18c	190.4	688.6	769.5	579.1	1064.2	73.1	636.4	563.3	2.768	3.001	2.805	Y
40.	01/09/18	UI-2T-02	WCW-18c	190.4	688.6	746.9	556.5	1049.6	244.8	787.1	542.3	2.774	2.991	2.618	Y
41.	08/10/18	UI-2T-03	WCW-18c	n/a	706.8	500.6	500.6	1031.1	n/a	n/a	488.6	2.771	2.974	2.456	N
42.	08/10/18	UI-2T-04	WCW-18c	n/a	677.8	526.7	526.7	1018.4	n/a	n/a	513.1	2.757	2.974	2.651	N
43.	n/a	AW-2V	NP-82c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.770	2.949	2.200	Y
44.	n/a	ITD-2V	NP-82c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.770	2.925	1.922	Y
45.	01/01/18	UI-2V-01	NP-82c	190.4	688.6	722.6	532.2	1033.3	243.3	762.8	519.5	2.771	2.972	2.445	Y
46.	01/17/18	UI-2V-02	NP-82c	181.7	680.4	696.3	514.6	1013.6	243.3	745.6	502.3	2.769	2.970	2.449	Y
47.	08/10/18	UI-2V-03	NP-82c	n/a	684.4	537.0	537.0	1032.0	n/a	n/a	526.4	2.779	2.944	2.014	N
48.	08/10/18	UI-2V-04	NP-82c	n/a	680.5	513.2	513.2	1012.9	n/a	n/a	503.0	2.782	2.948	2.028	N
49.	n/a	AW-3A-01	Ad-136	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.591	2.653	0.900	Y
50.	02/21/17	UI-3A-01	Ad-136	186.0	685.0	707.5	521.5	1006.5	238.5	754.0	515.5	2.578	2.657	1.164	N
51.	02/21/17	UI-3A-02	Ad-136	190.5	689.5	720.0	529.5	1015.0	246.5	769.5	523.0	2.564	2.648	1.243	N

Table A2 Lab data for tests completed according to AASHTO T-84 (continued)

#	Date	UI - ID	Agg. ID	Pycn Only	Pycn + Water	Pycn + SSD Sample	SSD Sample	Pycn + Water + Sample	Pan Only	Dry Agg. + Pan	Dry Agg.	Gsb	Gsa	Abs (%)	Test Used
52.	02/21/17	UI-3A-03	Ad-136	182.0	681.0	706.5	524.5	1005.0	243.0	761.5	518.5	2.586	2.666	1.157	Y
53.	02/21/17	UI-3A-04	Ad-136	201.0	700.0	742.5	541.5	1034.0	243.5	779.0	535.5	2.581	2.658	1.120	Y
54.	08/25/17	UI-3A-05	Ad-136	185.9	684.3	722.1	536.2	1016.1	784.5	1315.4	530.9	2.597	2.666	0.998	Y
55.	n/a	AW-3E-01	Ad-182c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.561	2.624	0.940	Y
56.	n/a	AW-3E-02	Ad-182c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.564	2.629	0.950	Y
57.	07/21/17	UI-3E-01	Ad-182c	190.4	688.6	707.5	517.1	1004.1	780.9	1292.2	511.3	2.536	2.611	1.134	N
58.	08/21/17	UI-3E-02	Ad-182c	190.4	688.6	719.8	529.4	1014.0	784.5	1308.9	524.4	2.571	2.635	0.953	Y
59.	08/24/17	UI-3E-03	Ad-182c	190.4	688.6	732.3	541.9	1021.9	780.8	1317.2	536.4	2.571	2.641	1.025	Y
60.	n/a	AW-3H	Ad-161C	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.568	2.641	1.080	Y
61.	11/02/17	UI-3H-01	Ad-161C	190.4	689.5	693.7	503.3	998.6	120.2	618.1	497.9	2.564	2.637	1.085	Y
62.	01/02/18	UI-3H-02	Ad-161C	201.0	700.0	746.7	545.7	1042.1	243.2	782.5	539.3	2.649	2.735	1.187	N
63.	04/11/18	UI-3H-03	Ad-161C	181.7	680.4	707.0	525.3	1003.2	238.7	758.3	519.6	2.566	2.640	1.097	Y
64.	n/a	AW-3J	Cn-140c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.559	2.647	1.300	Y
65.	11/07/17	UI-3J-01	Cn-140c	190.4	689.5	693.1	502.7	998.5	89.3	586.9	497.6	2.569	2.638	1.025	Y
66.	01/04/18	UI-3J-02	Cn-140c	208.2	706.8	716.7	508.5	1019.6	243.2	745.8	502.6	2.568	2.648	1.174	Y
67.	n/a	AW-5O	Bg-111-c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.601	2.645	0.640	Y
68.	11/30/17	UI-5O-01	Bg-111-c	186.0	685.0	738.3	552.3	1026.5	780.5	1329.4	548.9	2.604	2.647	0.619	Y

Table A2 Lab data for tests completed according to AASHTO T-84 (continued)

#	Date	UI - ID	Agg. ID	Pycn Only	Pycn + Water	Pycn + SSD Sample	SSD Sample	Pycn + Water + Sample	Pan Only	Dry Agg. + Pan	Dry Agg.	Gsb	Gsa	Abs (%)	Test Used
69.	01/11/18	UI-5O-02	Bg-111-c	190.4	688.6	691.6	501.2	999.5	91.4	589.3	497.9	2.616	2.663	0.663	Y
70.	n/a	AW-5R	Bk-100-c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.629	2.673	0.620	Y
71.	12/26/17	UI-5R-01	Bk-100-c	186.0	685.0	688.8	502.8	998.3	73.0	571.3	498.3	2.630	2.694	0.903	Y
72.	01/09/18	UI-5R-02	Bk-100-c	181.7	680.4	687.5	505.8	995.6	243.2	744.6	501.4	2.631	2.693	0.878	Y
73.	n/a	AW-5S	Bg-107-c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.591	2.648	0.830	Y
74.	12/27/17	UI-5S-01	Bg-107-c	201.0	700.0	713.0	512.0	1023.6	780.9	1289.2	508.3	2.698	2.752	0.728	N
75.	01/11/18	UI-5S-02	Bg-107-c	182.0	681.0	696.1	514.1	999.2	89.3	600.0	510.7	2.607	2.653	0.666	Y
76.	02/16/18	UI-5S-03	Bg-107-c	208.2	706.8	720.3	512.1	1024.0	243.2	752.0	508.8	2.611	2.656	0.649	Y
77.	n/a	AW-5U	BI-93-s	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.606	2.654	0.700	Y
78.	12/27/17	UI-5U-01	BI-93-s	190.4	688.6	709.6	519.2	1011.1	784.7	1300.7	516.0	2.623	2.667	0.620	Y
79.	01/17/18	UI-5U-02	BI-93-s	208.2	706.8	725.8	517.6	1027.5	243.1	757.2	514.1	2.611	2.658	0.681	Y
80.	02/16/18	UI-5U-03	BI-93-s	181.7	680.4	695.7	514.0	999.5	239.6	750.3	510.7	2.620	2.665	0.646	Y
81.	n/a	ITD-6B-01		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.429	2.623	3.000	N
82.	n/a	ITD-6B-02	Fr-104-c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.437	2.635	3.100	N
83.	n/a	ITD-6B-03	Fr-104-c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.424	2.613	3.000	N
84.	n/a	ITD-6B-04	Fr-104-c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.422	2.610	3.000	N
85.	02/28/17	UI-6B-01	Fr-104-c	190.6	689.6	698.4	507.8	991.1	251.5	742.6	491.1	2.381	2.590	3.401	N

Table A2 Lab data for tests completed according to AASHTO T-84 (continued)

#	Date	UI - ID	Agg. ID	Pycn Only	Pycn + Water	Pycn + SSD Sample	SSD Sample	Pycn + Water + Sample	Pan Only	Dry Agg. + Pan	Dry Agg.	Gsb	Gsa	Abs (%)	Test Used
86.	02/28/17	UI-6B-02	Fr-104-c	186.1	685.1	705.4	519.3	994.3	90.1	592.4	502.3	2.391	2.601	3.384	Y
87.	03/01/17	UI-6B-03	Fr-104-c	186.1	685.1	713.0	526.9	998.9	243.4	753.4	510.0	2.393	2.599	3.314	Y
88.	03/01/17	UI-6B-04	Fr-104-c	190.6	689.6	706.1	515.5	996.2	243.3	741.9	498.6	2.387	2.597	3.389	Y
89.	09/08/17	UI-6B-05	Fr-104-c	190.4	688.6	690.4	500.0	986.9	780.9	1265.4	484.5	2.402	2.602	3.199	Y
90.	n/a	AW-6F-01	Le-96-s	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.618	2.685	0.950	Y
91.	n/a	AW-6F-02	Le-96-s	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.616	2.676	0.860	N
92.	11/02/17	UI-6F-01	Le-96-s	274.7	1271.6	776.6	501.9	1585.3	780.5	1279.2	498.7	2.650	2.696	0.642	Y
93.	01/02/18	UI-6F-02	Le-96-s	190.4	688.6	715.6	525.2	1016.2	244.9	766.5	521.6	2.640	2.689	0.690	Y
94.	02/13/18	UI-6F-03	Le-96-s	208.2	706.8	736.9	528.7	1036.6	243.3	768.6	525.3	2.641	2.687	0.647	Y
95.	08/10/18	UI-6F-04	Le-96-s	n/a	1260.8	527.0	527.0	1588.8	n/a	n/a	523.1	2.629	2.681	0.746	N
96.	n/a	AW-6G	Cu-75s	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.604	2.695	1.300	Y
97.	10/31/17	UI-6G-01	Cu-75s	190.4	689.5	714.0	523.6	1014.1	244.7	760.2	515.5	2.590	2.700	1.571	Y
98.	10/31/17	UI-6G-02	Cu-75s	274.7	1271.6	841.1	566.4	1624.0	239.5	797.3	557.8	2.607	2.716	1.542	Y
99.	01/04/18	UI-6G-03	Cu-75s	182.0	681.0	723.5	541.5	1016.6	780.9	1313.7	532.8	2.588	2.702	1.633	Y
100.	n/a	AW-6I	Bn-59-s	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.622	2.658	0.520	Y
101.	10/31/17	UI-6I-01	Bn-59-s	186.0	685.0	700.5	514.5	1004.5	251.5	763.6	512.1	2.626	2.659	0.469	Y
102.	01/02/18	UI-6I-02	Bn-59-s	182.0	681.0	692.3	510.3	997.8	780.8	1288.5	507.7	2.624	2.660	0.512	Y

Table A2 Lab data for tests completed according to AASHTO T-84 (continued)

#	Date	UI - ID	Agg. ID	Pycn Only	Pycn + Water	Pycn + SSD Sample	SSD Sample	Pycn + Water + Sample	Pan Only	Dry Agg. + Pan	Dry Agg.	Gsb	Gsa	Abs (%)	Test Used
103.	n/a	AW-6K	Bn-156-c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.594	2.657	0.920	Y
104.	11/07/17	UI-6K-01	Bn-156-c	186.0	685.0	700.3	514.3	1003.5	784.3	1295.1	510.8	2.609	2.656	0.685	Y
105.	01/05/18	UI-6K-02	Bn-156-c	190.4	688.6	726.9	536.5	1021.4	91.5	623.6	532.1	2.612	2.670	0.827	Y
106.	n/a	AW-6L	Le-160-c	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.585	2.695	1.580	Y
107.	11/09/17	UI-6L-01	Le-160-c	190.4	689.5	711.4	504.7	1002.9	91.5	588.8	497.3	2.600	2.704	1.488	Y
108.	01/15/18	UI-6L-02	Le-160-c	201.0	700.0	711.1	510.1	996.9	89.3	591.4	502.1	2.355	2.447	1.593	N
109.	02/13/18	UI-6L-03	Le-160-c	181.7	680.4	683.6	501.9	992.2	239.6	733.8	494.2	2.600	2.709	1.558	Y
110.	n/a	AW-6M-01	Cl-56-s	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.585	2.664	1.140	Y
111.	n/a	AW-6M-02	Cl-56-s	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.612	2.656	0.630	N
112.	11/09/17	UI-6M-01	Cl-56-s	186.0	685.0	690.7	521.0	1007.5	244.7	761.3	516.6	2.603	2.662	0.852	Y
113.	01/04/18	UI-6M-02	Cl-56-s	190.4	688.6	715.1	524.7	1013.7	244.8	764.5	519.7	2.604	2.671	0.962	Y
114.	n/a	ITD-3W	Ow-94	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.439	2.626	2.922	Y
115.	n/a	ITD-4X	Cs-184	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.428	2.573	2.329	Y
116.	n/a	ITD-4Y	Cs - 192	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.401	2.566	2.693	Y