DENSITY MEASUREMENT VERIFICATION FOR HOT MIXED ASPHALT CONCRETE PAVEMENT CONSTRUCTION

Final Report

SPR 666

RESEARCH

Oregon Department of Transportation

DENSITY MEASUREMENT VERIFICATION FOR HOT MIXED ASPHALT CONCRETE PAVEMENT CONSTRUCTION

Final Report

PROJECT 666

by

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16. Abstract

Oregon Department of Transportation (ODOT) requires a minimum density for the construction of dense-graded hot mix asphalt concrete (HMAC) pavements to ensure the likelihood that the pavement will not experience distresses that reduce the expected service life of the pavement. Currently, the ODOT Standard Specifications call for density measurements for both quality control and quality assurance testing to be made using nuclear density gauges that are calibrated using reference blocks. Hence, acceptance (i.e., purchase) of the HMAC pavement (or portions thereof) relies on the accuracy of the measurements. However, it has been observed that density measurement results using nuclear gauges have been questionable on a number of projects and that repeatability and reproducibility with the same gauge and between gauges have also been unattainable. Further, these observations have called into question the confidence placed in the use of nuclear gauges for determining HMAC pavement density.

The overall objective of the project was to recommend a system that accurately quantifies density of dense-graded HMAC pavements. This involved critically evaluating how ODOT currently measures HMAC density, investigating and evaluating what other agencies do to measure HMAC density, and conducting testing and analysis of alternate ways of measuring HMAC density (e.g., by measuring the density of cores).

Statistical analyses comparing nuclear gauge measurements to core densities provided convincing evidence that correlation of nuclear gauge measurements to core densities is necessary to ensure accurate results from nuclear gauges. Analyses comparing correlation factors across lifts of pavements constructed under three differing construction scenarios provided strong evidence to suggest correlation factors established for one lift can be used on other lifts under certain constraints. Correlations are recommended for all gauges on each lift and whenever a new mix design is introduced. ODOT should implement use of the CoreLok device for measuring densities of pavement cores and laboratory-prepared specimens as well as further investigate the use of electromagnetic gauges for in-place HMAC density measurement.

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DISCLAIMER

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1.0 INTRODUCTION

The Oregon Department of Transportation (ODOT) Standard Specifications require a minimum density for the construction of dense-graded hot mix asphalt concrete (HMAC) pavements to ensure the likelihood that the pavement will not experience undesirable distresses such as cracking, permanent deformation, and moisture-related damage, all of which reduce the expected service life of the pavement. Currently, the Standard Specifications call for density measurements for both quality control (QC) and quality assurance (QA) testing to be made using nuclear density gauges that are calibrated using reference blocks. Hence, acceptance (i.e., purchase) of the HMAC pavement (or portions thereof) relies on the accuracy of the measurements. However, it has been observed that density measurement results using nuclear gauges have been questionable on a number of projects and that repeatability and reproducibility with the same gauge and between gauges have also been unattainable. Although a number of reasons can be identified as potential causes for these problems, it is unknown at this time as to the exact cause or causes. Further, these observations have called into question the confidence placed in the use of nuclear gauges for determining HMAC pavement density.

The overall objective of the project was to recommend a system that accurately quantifies density of dense-graded HMAC pavements. This involved critically evaluating how ODOT currently measures HMAC density, investigating and evaluating what other agencies do to measure HMAC density, and conducting testing and analysis of alternate ways of measuring HMAC density (e.g., by measuring the density of cores). The findings from the research efforts were used to develop recommendations for: 1) improved HMAC density measurement using nuclear gauges, 2) alternate ways to measure HMAC density, and 3) the optimal system for quantifying dense-graded HMAC density.

1.1 BACKGROUND

As a pavement nears the end of its service life, maintenance costs increase to keep it in a safe and structurally sound condition. Life cycle costs also significantly increase due to a reduction in the time between major rehabilitation treatments and their consequent impact on the road users. Maintenance, rehabilitation, or reconstruction of HMAC pavements requires establishing a work zone to carry out the necessary work. This reduces the mobility of the road users traversing the work zone, often resulting in significant delays and, consequently, loss of potential revenue. Scholz et al (*2002*) showed that delaying the need for major rehabilitation work by as little as two years can significantly reduce the life cycle cost of a pavement structure, particularly on higher volume facilities such as urban interstates.

Perhaps the best way to reduce the likelihood of having to establish a work zone to maintain, rehabilitate, or reconstruct an HMAC pavement before its expected service life is realized is to ensure the pavement is constructed properly at the outset. For properly designed mixtures, compaction is the most significant factor in determining the performance of dense-graded HMAC. Hughes (*1984; 1989*) indicated that inadequate compaction results in a pavement with decreased stiffness, decreased durability (accelerated aging), and increased likelihood of rutting, raveling, and moisture damage. All of these factors increase the likelihood of reduced service life of the pavement by about 10 percent for each one percent increase in air volume above seven percent (*Linden, Mahoney and Jackson 1989*), usually requiring repair or rehabilitation prior to realizing the expected (or designed) life. Density of the finished mat is the universally accepted method for determining the degree of compaction of dense-graded HMAC.

Accurate and reproducible measurement of density is, therefore, essential for indisputably determining whether or not adequate compaction has been achieved. Inaccurate measurement of density leading to a false positive result (i.e., indication of adequate compaction when, in fact, adequate compaction was not attained) could result in having to repair or rehabilitate a pavement (requiring a work zone) before it has reached its expected service life. However, with accurate measurement of density, an inadequately compacted pavement section could be detected and corrected during initial construction (i.e., while the initial work zone is in place), thereby significantly reducing the likelihood of establishing another work zone to repair or rehabilitate the pavement sooner than expected and, consequently, reducing the life cycle cost of the facility. It must be emphasized that inaccurate measurement of density leading to a false negative result (i.e., indication of inadequate compaction when, in fact, adequate compaction was attained) would be equally undesirable. In this case, the contractor could be unjustifiably assessed a penalty or be required to perform unnecessary corrective work. In either scenario, significant cost savings could be realized through implementation of a system that accurately quantifies density of dense-graded HMAC pavements by virtue of avoiding earlier-than-expected repairs or unnecessary corrective work.

1.2 OBJECTIVES

The overall objective of this research was to recommend a system that accurately quantifies the density of dense-graded hot mix asphalt concrete pavement to be used by the state of Oregon for QC and QA purposes. More specifically, the objectives of this research effort were to:

1. Investigate the efficacy of the various methods used by ODOT and other agencies/entities for determining in-place HMAC density.
2. Assess current practices used by ODOT and other agencies/entities for determining in-place HMAC density using nuclear gauges.
3. Conduct field and laboratory testing and analysis to determine the most accurate and reliable state-of-the-practice means for determining in-place HMAC density.
4. Provide recommendations for changes to current practices to improve accuracy and reproducibility of in-place HMAC density measurements using nuclear gauges.
5. Provide recommendations for alternate means for determining in-place HMAC density.

1.3 SCOPE

Chapter 2.0 of this report provides a summary of a literature review that was conducted to investigate research performed by others regarding the efficacy of methods for measuring in-place HMAC density including nuclear gauges, electromagnetic gauges, and measurements on cores. Also, methods of using the gauges to obtain the most accurate density results and factors that affect different types of gauges were investigated. In addition, practices used by other states in utilizing density as part of HMAC acceptance were reviewed.

Based on the findings from the literature review, experiment plans were developed for the field and laboratory investigations as detailed in Chapter 3.0. Findings from the field study are summarized in Chapter 4.0, while Chapter 5.0 summarizes the findings from the laboratory study. Chapter 6.0 provides details of the statistical analyses performed on the various data obtained, including discussions of the results. Finally, conclusions and recommendations, based on the findings from this research effort, are provided in Chapter 7.0.

2.0 LITERATURE REVIEW

A literature review was undertaken to determine the state-of-the-practice regarding hot mix asphalt concrete (HMAC) pavement density measurement in the United States. It covered methods of density measurement that utilize cores, nuclear gauges, and electromagnetic gauges, either solely or as a part of a differences system. In addition, practices in utilizing density as part of hot mix concrete asphalt acceptance by other states were reviewed. This section provides a synopsis of the findings.

2.1 METHODS FOR MEASURING IN-PLACE DENSITY OF HOT MIX ASPHALT PAVEMENTS

In-place density of hot mix asphalt concrete pavements is commonly determined by extracting cores, measuring the bulk specific gravity of the cores in a laboratory, and converting the results to density; or by directly measuring the pavement density through use of nuclear density gauges, or electromagnetic gauges. The following sections provide a brief overview of each method.

2.1.1 Density Measurement on Cores

Cores are extracted from a pavement after the pavement is laid, thus making it a destructive process. Bulk specific gravity measurements are then made on the cores in a laboratory. The methods of measuring bulk specific gravity of cores include: a) saturated surface-dry method, b) paraffin-coated method, c) automatic vacuum sealing method, and d) dimensional analysis. The bulk specific gravity of the core specimen, determined by any of these methods, is then multiplied by the unit density of water to obtain the density of the HMAC core sample. These methods are described briefly in the following paragraphs.

2.1.1.1 Saturated Surface-Dry Specimen Method

The saturated surface-dry method is described in AASHTO T 166 (*2009*) and ASTM D 2726 (*2009*). According to AASHTO T 166, this method should not be used for specimens that contain open or interconnected voids and absorb more than 2.0% water by volume.

Briefly, the test procedure is as follows: 1) determine the dry mass of the specimen, *A*; 2) submerge the specimen in water for a specified period and determine its submerged mass, *C*; and 3) remove the specimen from the water, wipe off the surface moisture and determine its saturated surface-dry mass, *B*. The bulk specific gravity is then determined by dividing the dry mass by the difference between the saturated surface-dry mass and submerged mass as indicated in Equation 2.1.

$$Bulk\ Specific\ Gravity = \frac{A}{B - C} \quad \textbf{(2.1)}$$

2.1.1.2 Paraffin-Coated Specimen Method

The paraffin-coated specimen method is described in AASHTO T 275 (*2009*) and ASTM D 1188 (*2009*). AASHTO T 275 indicates that this method can be used for specimens that contain open or interconnected voids and/or absorb more than 2.0% water by volume because the specimen is coated with paraffin to prevent water from penetrating the surface connected voids (*Cooley Jr. et al. 2002*).

Briefly, the test procedure is as follows: 1) determine the dry mass of the specimen, *A*; 2) coat the entire specimen with melted paraffin and allow it to cool before recording the cooled, coated specimen mass, *D*; 3) submerge the coated specimen in water for a specified period and determine its submerged mass, *E*; and 4) determine the specific gravity of paraffin, *F*. Equation 2.2 is then used to calculate the bulk specific gravity of the specimen.

$$Bulk\ Specific\ Gravity = \frac{A}{D \quad E \quad \left(\frac{D-A}{F}\right)} \qquad \textbf{(2.2)}$$

The *parafilm* method is the same as the paraffin method except that, instead of coating the specimen with paraffin, it is wrapped in parafilm and the mass of the wrapped specimen is recorded as D.

2.1.1.3 Automatic vacuum sealing method

The automatic vacuum sealing method is described in AASHTO T 331, ASTM D 6752, and CoreLok operator's manual (*2003*). It can be used to determine the specific gravity of both fine- and coarse-graded mixtures.

Briefly, the test procedure is as follows: 1) determine the dry mass of the specimen at room temperature, *A*; 2) place it in a plastic bag and evacuate the air from the bag using a vacuum chamber, and then determine the mass of the sealed specimen in air, *B*; and 3) determine the mass of the sealed specimen submerged in water, *E*. Using the apparent specific gravity, *F* of plastic sealing material at 25°C (77°F) provided by manufacturer, Equation 2.3 is then used to calculate the bulk specific gravity of the specimen.

$$Bulk\ Specific\ Gravity = \frac{A}{B - E - \left(\frac{B-A}{F}\right)} \qquad \textbf{(2.3)}$$

2.1.1.4 Dimensional Analysis

In this method, the density of a compacted HMAC specimen is obtained by dividing the mass of the specimen by its volume (*Buchanan 2000)*. The mass is obtained by weighing the specimen, and its volume is calculated from the dimensions (diameter and height) of the specimen.

2.1.2 Density Measurements using Nuclear Devices

An alternative method of measuring density (instead of using cores) is to use a nuclear density gauge. The density values obtained using nuclear density gauges can be compared with those obtained using cores to determine an adjustment factor for the gauge measurements.

Nuclear density gauges can measure density of hot mix asphalt concrete pavements in a span of a few minutes. The methods of density measurements using nuclear density gauges include: 1) backscatter mode, and 2) direct transmission mode. However, for measuring density of bituminous pavements, the backscatter mode is generally used (*Parker and Hossain 1995*). The direct transmission mode is used for measuring the density of materials such as soils and aggregate. The backscatter method of density measurement is described briefly in the following paragraphs.

The procedures for calibrating and operating each nuclear density gauge are provided by the manufacturer of the gauge. ODOT TM 304 (*2008*) also provides a procedure for calibrating nuclear gauges. Methods of measurement of HMAC density are provided in ASTM D 2950 and WAQTC TM 8 (*2008*). Correlation of nuclear gauge density measurements with densities derived from pavement cores are provided in ODOT TM 327 and WAQTC TM 8.

The basic principle employed in measuring density using the backscatter mode is as follows: 1) the gauge contains a radioactive source that emits gamma photons from the surface of the pavement down into the pavement; 2) the materials in the pavement (hot mix asphalt concrete) absorb some of the photons, while the remaining photons are scattered back into a detector located in the gauge (*Choubane et al 1999; Smith 2008*); and 3) the number of gamma photons reaching the detector is used to calculate the density of the pavement (*Smith 2008*). It should be noted that the nuclear gauge is calibrated using blocks of material of known density (typically three blocks of differing density) prior to use in the field.

Nuclear density gauges are set to display a density value after taking measurements that are thirty seconds, one minute, or four minutes in duration. A majority of the states that use nuclear gauges use a duration of one minute (Appendix A). Some of the factors that vary between states that use nuclear gauges include: 1) the number and duration of readings that must be averaged to obtain the density value at a particular location, and 2) the direction and angle of rotation of gauge between readings (Appendix A).

2.1.3 Density Measurements using Electromagnetic Devices

The procedure (calibration and operation) for measuring density using electromagnetic devices is provided by the manufacturer of the gauge. ASTM D 7113 and AASHTO TP 68 (*2004*) also describe procedures for determining density using electromagnetic devices.

During operation, the electromagnetic device sends out an electrical sensing field into the pavement (*Smith and Diefender 2008*). This field is produced by applying an electrical charge to a conductor (*Liao, Sargand and Kim 2006*; *Kvasnak et al. 2007*). The pavement is a dielectric or non-conductor, which impedes the flow of this electrical current, and thus decreases its strength. This decrease in strength can be measured using dielectric constants. The dielectric constant of the pavement material can be measured by an electromagnetic sensing device. The dielectric constants of individual components of the mixture are already known since they are constant values (*Smith and Diefender 2008;, Kvasnak et al. 2007*). When the pavement is compacted, the quantity of each pavement component (e.g., aggregate, binder, etc.) remains the same, but the air void content decreases. It therefore changes the ratio of the volume of air to that of other components, which causes a change in the dielectric constant of the system and, thus, a change in the electric signal (*Liao, Sargand and Kim 2006*). The gauge measures this dielectric constant and change in electric signal. Then it applies a correction for sensor impedance, surface moisture and temperature variation based on data input (which has to be done every time there is a change in site conditions). Finally, it relates this to a proportional density value since the amount and type of each pavement material remains constant except for air (*Liao, Sargand and Kim 2006*). The electromagnetic device can measure density in a few seconds. Significantly, it is not required to have a license to operate such devices.

2.2 SUMMARY OF ODOT QC/QA PROCEDURES FOR MEASURING IN-PLACE DENSITY

ODOT requires that all nuclear gauges used for QC/QA be calibrated annually in accordance with ODOT TM 304 and that operation of the gauges be conducted in accordance with WAQTC TM 8. Further, the 2008 Oregon Standard Specifications (*2008*) indicates that the project engineer may require nuclear gauges to be correlated to pavement core densities. Core correlations may also be requested by the contractor. In either case, ODOT requires that core correlations be conducted in accordance with ODOT TM 327 and WAQTC TM 8. Following calibration and optionally core correlations, routine QC and QA testing is as described in the 2008 Oregon Standard Specifications and the Manual of Field Test Procedures. These procedures are described briefly in the following sections.

2.2.1 Nuclear Gauge Calibration

ODOT TM 304 provides a detailed procedure for calibrating nuclear gauges for use on ODOT projects. The procedure is summarized as follows:

1. The gauge is placed in a temperature-controlled environment for no less than 4 hours to ensure all components are at room temperature (i.e., between 60 and 75°F), and then turned on and allowed to warm up for at least 10 minutes.
2. The gauge is placed on the standard count block (which is placed on the center calibration block and shown in Figure 2.1) and five standard counts are taken in accordance with manufacturer guidelines. Variances between counts are checked against manufacturer guidelines. If the variances are outside of the guidelines, up to two addition counts are taken and the variances between counts are rechecked. If the variances are still outside of the guidelines, the gauge is returned to the manufacturer for repair.

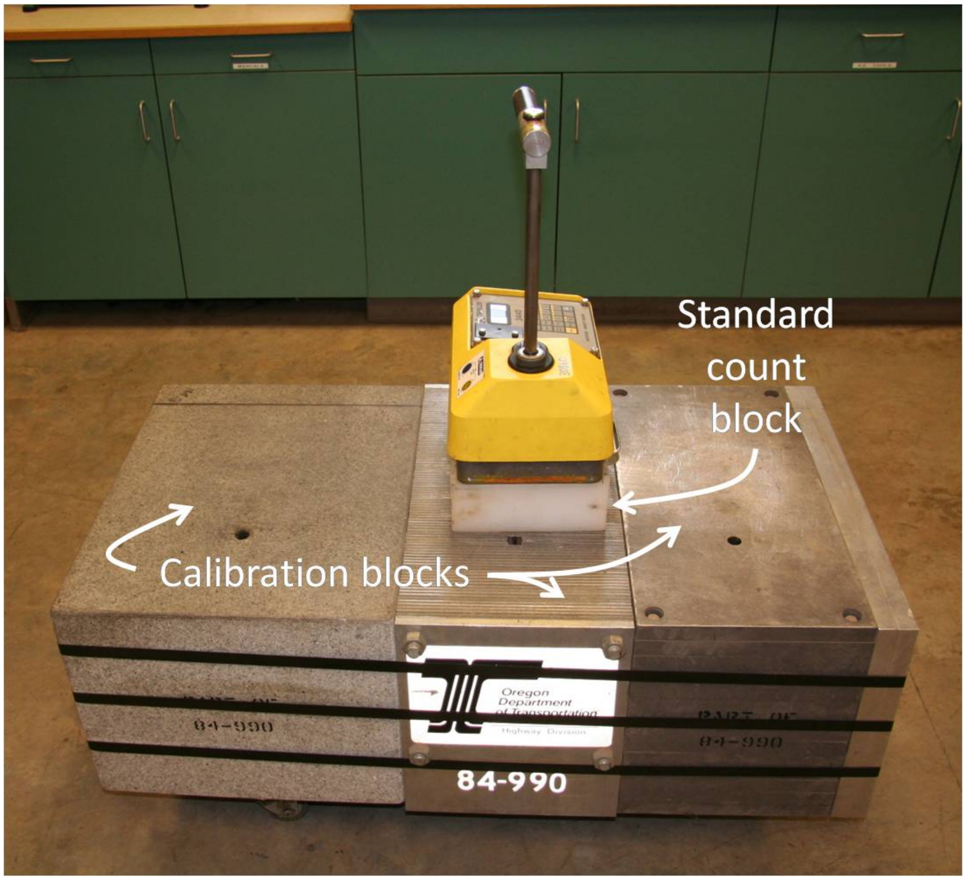


Figure 2.1: Gauge on Standard Block on Calibration Blocks

3. Gauges that show standard counts within the manufacturer's guidelines are then checked to determine if a hot substrate affects the readings. This is accomplished by placing the gauge at room temperature on a hot substrate (aluminum block as shown in Figure 2.2 heated to 185°F) and taking four one-minute readings in succession. These are recorded as the *Initial Test* readings and the average of the four readings is determined. The gauge is then left on the hot substrate for 10 minutes and four additional one-minute readings are taken in succession. These are recorded as the *Final Test* readings and the average of the four readings is determined. If the average of the *Final Test* readings are within 1.0 lb/ft^3 of the average of the *Initial Test* readings, the gauge passes the test; if, not, it fails the test.

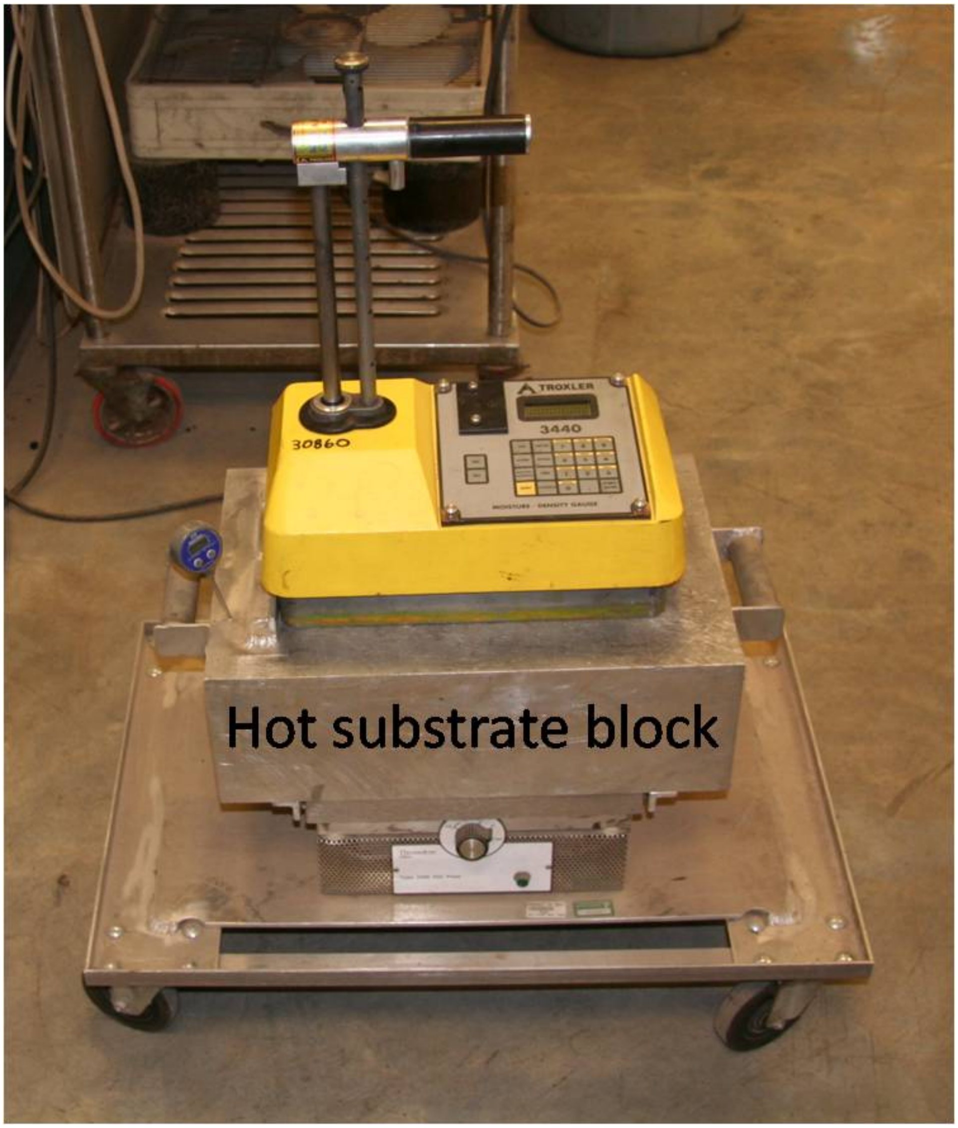


Figure 2.2: Gauge on Hot Substrate Block

4. Density readings of gauges that pass the hot substrate test are then checked against the densities of three blocks of material with known and varying densities (i.e., low, medium, and high density blocks). This is accomplished by taking two one-minute readings on each block and comparing the average of the two one-minute readings to the known densities of the blocks. The gauge is checked in both backscatter and direct transmission modes of operation. The average of the gauge readings must be within 1.0 lb/ft^3 of the density of the low- and medium-density blocks and within 1.5 lb/ft^3 of the density of the high-density block to pass the calibration check. If not, the gauge must be recalibrated.
5. Gauges that pass the check outlined in the previous step are then checked for moisture density determinations. This is accomplished by checking the moisture density readings from the gauges against the density of the low-density block and the density of a high moisture block. One four-minute count is used in each case. The gauge reading on the low-density block must be within ±0.5 lb/ft^3 of 0 lb/ft^3 and that on the high moisture

6. Gauges that pass the above checks are calibrated using the three blocks of material with known and varying densities as shown Figure 2.3. This is accomplished by taking two four-minute readings on each block in the backscatter mode of operation and one four-minute count on each block in the direct transmission mode of operation. The readings are then entered into a computer program to determine the calibration constants for the gauge. Calibration constants are entered manually into the gauge and the gauge is checked for accuracy using the previous two steps.

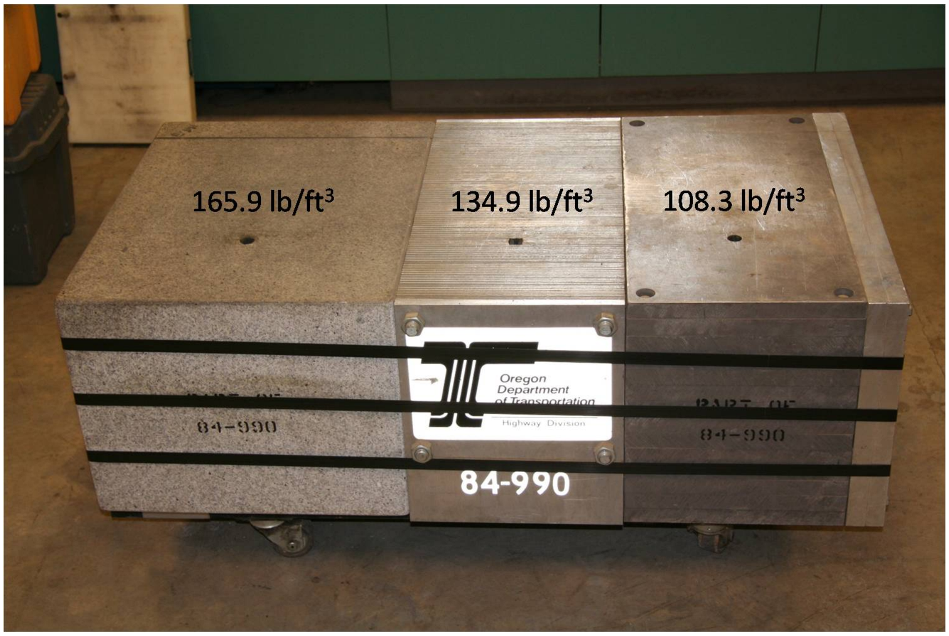


Figure 2.3: Nuclear Gauge Calibration Blocks

In comparing the procedures and criteria in ODOT TM 304 with those in ASTM D 2950, the ODOT method satisfies the ASTM method except with regard to the density criterion of ±1.5 lb/ft^3 on the high-density block; ASTM D 2950 specifies ±1.0 lb/ft^3 on all standards. Table 2.1 summarizes procedures from several other states. Such information was also sought from many other states but was not found. In comparing ODOT's procedures with those summarized in Table 2.1, it can be seen that some agencies require five calibration blocks and additional pre-calibration checks (e.g., Colorado and Virginia), while the procedures from California are not dissimilar to ODOT's procedures. However, none of the states listed utilize a hot substrate check. Note that ODOT's tolerances are more stringent than those of some of the other states.

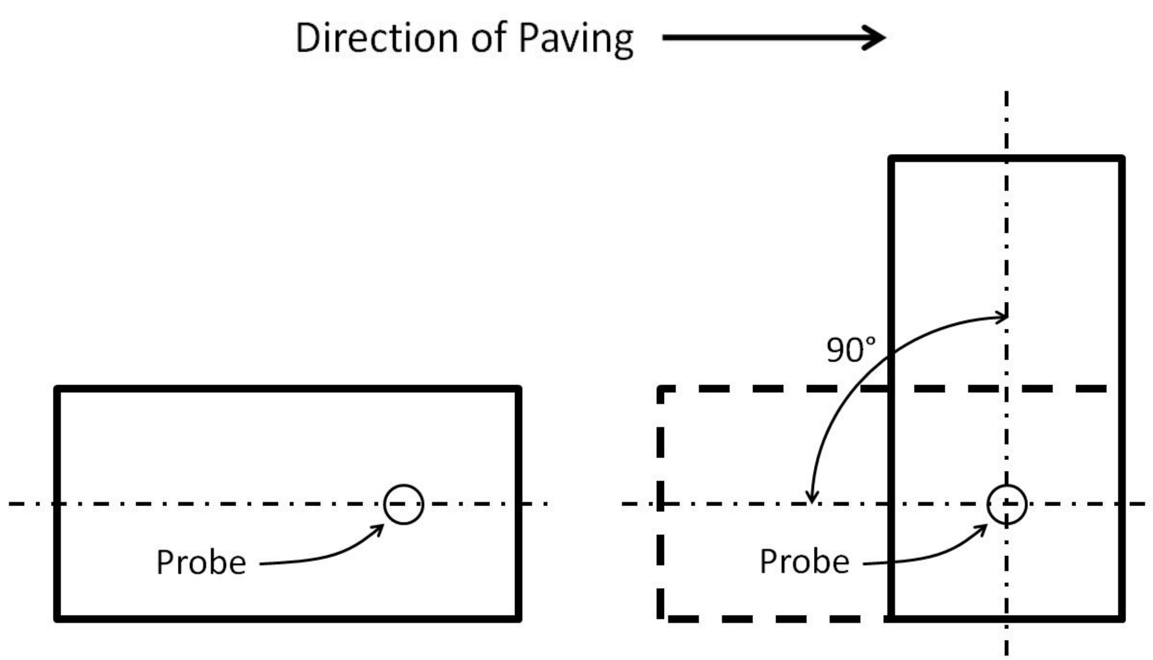
Table 2.1: Summary of Nuclear Gauge Calibration Procedures from Other States

State DOT	Summary of Nuclear Gauge Calibration Method
Alabama	ALDOT-222-82 (*2005*) specifies that, "Before acceptance gauge will be checked on Alabama Department of Transportation calibration standards and gauge accuracy will be required to be within ±1.5% (1.5 lbs) (0.6818 kg) of calibration standards." However, the test method does not provide specifications for the calibration standards or details of the procedures.
California	California Test 111 (*2005*) indicates that, for density calibration, the standard count of the gauge is first determined on the standard count block provided by the manufacturer. Density counts are then made on three metal blocks (magnesium, aluminum, and a combination of the two). The natural logarithms of the ratios of the measured counts to standard count are linearly regressed against the known densities of the metal blocks. If the correlation coefficient for a given mode of calibration (e.g., backscatter mode) is less than 0.999, or the standard error of the linear regression is greater than 1 lb/ft^3, then the gauge is recalibrated in the mode that failed. Gauges are required to be calibrated at once every 15 months.
Colorado	The Colorado procedure (*Colorado Department of Transportation 2009)* requires that the gauge must pass a pre-calibration inspection prior to calibration for proper labeling, source rod damage, sliding block damage, standard count damage and gauge seating, and damage to the sensor. It must also be cleaned. For density calibration, a statistical stability test is conducted first. If the gauge passes, counts are taken on five blocks (magnesium, magnesium/aluminum, aluminum, limestone, and granite). The gauge is then tested for drift. If it passes, calibration constants can be generated, entered into the gauge, and the gauge is checked against the limestone and granite blocks to ensure the reported densities are within ±2 lb/ft^3 of the known densities of the blocks. Gauges are required to be calibrated every two years and checked annually. In addition, the calibrations must be performed in a bay specially designed to reduce external influences during the process.
Florida	FM 1-T 238 (*Florida Department of Transportation 2007*) requires gauges to be calibrated yearly or at any time the operator determines these is a need for recalibration, but does not provide any further details of the procedure.
Nevada	Test Method Nev T 335F (*Nevada Department of Transportation 2002*) requires readings from gauges to be checked daily or every six months, depending on the gauge model, on a magnesium calibration block. Those that require daily validation must be within ±2 lb/ft^3 of the density of the magnesium block; for the other gauges, the validation is by standard count. Details of the calibration procedure are not provided in the test method.
Virginia	Virginia's method (*Virginia Department of Transportation 2001*) uses five density calibration blocks which cover the entire range of densities expected to be encountered in the field, and all of which must have constant and homogenous densities accurate to within ±0.2% (ASTM D 2922). Three of the blocks can be of any material provided that they meet the above criteria, but it is recommended that they consist of magnesium, laminated magnesium and aluminum, or aluminum. One of the blocks must be granite and one must be limestone. The gauge is first checked for stability and drift. If it passes these tests, counts are taken on the five calibration blocks to determine the calibration constants. Calibrated gauges must report densities with ±1.0 lb/ft^3 of the known densities of the blocks.
Washington	WSDOT specifies WAQTC TM 8 (*ODOT 2008*) with the exception that the section regarding calibration of the nuclear gauge has been deleted. Instead, WSDOT performs calibrations according to the manufacturer's operating manual.

2.2.2 Core Correlation

Correlation of nuclear gauges to pavement core densities is necessary when required by contract or requested by either the project engineer or contractor. If required, all nuclear gauges used on a project must be correlated to core densities. In addition, the 2008 Oregon Standard Specifications (*2008*) require new correlations when the aggregate source changes or when the asphalt cement source changes during a project. ODOT requires that core correlations be conducted in accordance with WAQTC TM 8 and ODOT TM 327. The process is described briefly as follows:

1. Ten test locations are randomly selected on the pavement being tested.
2. Density measurements are obtained from the nuclear gauge at each test location. With the gauge positioned parallel to the direction of paving (Figure 2.4a), the footprint of the gauge is marked on the pavement using caulk or a crayon and a one-minute reading is obtained. The gauge is then rotated 90 degrees about its probe (Figure 2.4b), its footprint is marked on the pavement, and a second one-minute reading is obtained. The reported density of the pavement at the test location is the average of the two readings provided that the readings in each direction differ by no more than 2.5 lb/ft^3. The process is repeated for each gauge to be used on the project.



a) First Position b) Second Position

Figure 2.4: Positions for Nuclear Gauge Measurements

3. Following all nuclear gauge measurements, pavement cores are obtained from each test location at a position close to the corner of the overlapping footprints of the nuclear gauge measurements (Figure 2.5). The cores are then tested for bulk specific gravity in

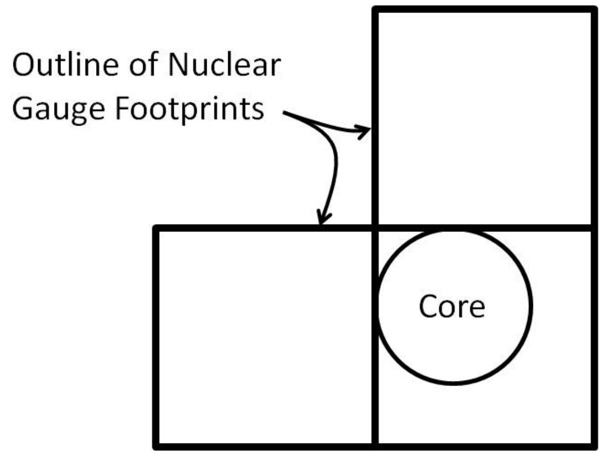


Figure 2.5: Core Location as per WAQTC TM 8

4. For each pair of results for a given test location, the ratio of the core density to nuclear gauge density is calculated to four decimal places and the high and low values are discarded. The correlation factor is determined by averaging the remaining ratios and rounding the result to four decimal places.

On a project where core correlations are performed, all nuclear gauge readings obtained during QC and QA testing are adjusted by multiplying the gauge readings by the correlation factor for the gauge. It should be emphasized that each nuclear gauge correlated to pavement cores has a unique correlation factor that cannot be shared amongst gauges.

2.2.3 QC Testing

For quality control (QC) testing, the 2008 Oregon Standard Specifications requires that the contractor conduct nuclear gauge measurements at five randomly-selected locations per sublot, where one sublot equals 1,000 tons of HMAC. Density measurements are made in accordance with WAQTC TM 8. The reported density of the sublot of pavement is the average of the five measurements which, in turn, are the average of two readings at right angles from each other (one in the direction of paving and one perpendicular to the direction of paving) at each test location.

One of two methods is used to evaluate pavement density based on nuclear gauge measurements: 1) moving average maximum density method, or 2) control strip method. Each method is described briefly in the following paragraphs.

2.2.3.1 Moving Average Maximum Density (MAMD) Method

In this method, the density of each sublot is compared against the moving average maximum density (MAMD), where the MAMD is the average of the current value for the maximum density of the mixture and the four previous values (if available) for the same

JMF. The maximum density of the mixture is the theoretical maximum specific gravity of the mixture, determined in accordance with AASHTO T 209, multiplied by the unit density (or unit weight) of water as described in ODOT TM 305. ODOT requires that the maximum density of the mixture be determined daily, typically from the first sublot of production. For a given mix type and lift of pavement, the 2008 Oregon Standard Specifications require that dense-graded HMAC mixtures be compacted to at least the percentage of MAMD as indicated in Table 2.1.

Table 2.2: Compaction Requirements for Dense-Graded HMAC

Course of Construction	Percentage of MAMD for	
	Level 1, Level 2, and Level 3 HMAC	Level 4 HMAC
First Lift	91.0*	92.0
Single	91.0*	92.0
All Other	92.0	92.0

* If any part of the width of a lift at a station requires 91.0%, then the entire width of that lift at that station shall be 91.0%

2.2.3.2 Control Strip Method

In this method, a strip of pavement is constructed and tested in accordance with ODOT TM 306 to establish optimum rolling procedures and target density, which must conform to the requirements listed in Table 2.1. Once a valid target density has been established in this manner, the HMAC mixture on all subsequent sublots must be compacted to at least 98.0 percent of the target density. A new control strip (and target density) is required when a new JMF is used, when ten days of production have been accepted without construction of a new control strip, or when a new lift of pavement is started.

2.2.4 QA Testing

Quality assurance (QA) testing for compaction is conducted by ODOT personnel at test locations independent of locations where QC testing is conducted and at a minimum frequency of one in every ten sublots of HMAC production. Currently, ODOT does not specify an independent assurance (IA) parameter for HMAC density determined in the field. ODOT does however specify IA parameters for bulk specific gravity and theoretical maximum specific gravity of the mixture obtained during mix design verification testing. Instead, verification of in-place HMAC density in the field is conducted by comparing the QA test results to specification requirements. If the density of the pavement is verified through this process, the contractor’s QC test results are used for acceptance.

2.3 PREVIOUS STUDIES ON DENSITY MEASUREMENT METHODS

This section provides a comparison of the different methods of measurement of density (i.e., by using cores, nuclear gauges, and electromagnetic gauges). It also provides findings regarding calibration of nuclear and electromagnetic gauges, differences of density results obtained through the different methods, and performance and accuracy of the different methods and different gauge models and manufacturers in comparison with each other.

2.3.1 Studies on Density Measurement using Cores

Section 2.1.1 discussed the various methods utilized to measure the density of bituminous paving mixtures using cores. This section provides findings that compare the different test standards for measuring the bulk specific gravity of cores, which can be converted to density by multiplying the bulk specific gravity by the unit density (or unit weight) of water. The accuracy and variability of the various methods, as well as the factors that affect the measurements, are also discussed.

2.3.1.1 General Advantages and Disadvantages

The densities obtained from measurements on cores are considered to be more accurate and have lower variability than nuclear gauge and electromagnetic gauge measurements (*Parker and Hossain 1995*; *Sandars, Rath, and Parker 1994*); thus, they are often used as reference values (*Schmitt et al. 1997*). However, the coring process and laboratory procedure is time consuming (*Parker and Hossain 1995*), and transportation and testing of cores increase the quantity, duration, and cost of work (*Sandars, Rath, and Parker 1994*). Core samples cannot be extracted until the pavement mat has cooled (*Parker and Hossain 1995*; *Sandars, Rath, and Parker 1994; Schmitt et al.1997*). Researchers have indicated that core density values are typically made available a day after the pavement has cooled (*Sandars, Rath, and Parker 1994; Schmitt et al. 1997*). Extraction of cores from the pavement is destructive (*Parker and Hossain 1995*; *Schmitt et al. 1997*) and can possibly result in premature pavement failure (*Schmitt et al. 1997*) due to localized points of weakness along the pavement (*Sandars, Rath, and Parker 1994*). Additionally, the pavement requires patching after the cores have been extracted (*Parker and Hossain 1995*).

2.3.1.2 SSD Method

Although several researchers have indicated that the saturated surface-dry (SSD) method is very reliable, several researchers have identified some disadvantages of the method. These issues are explained in more detail below.

Problems Associated with the SSD Method at High Air Void Content

Cooley Jr. et al. (*2002*) indicated that core samples with high air void contents are likely to have large voids interconnected to the sample surface; thus allowing water to quickly enter the sample during submersion in water, and quickly exit the sample after removal from water. This can lead to overestimation of the density of the core (*Liao, Sargand and Kim 2006*). Cooley Jr. et al. (*2002*) also found that coarse-graded specimens have larger, interconnected internal air voids as compared with fine-graded specimens.

At high air void content, the saturated surface-dry method overestimates density and bulk specific gravity (and underestimates air void content). When air voids approach 8 to 10 percent, the mix becomes permeable and results in an overestimated bulk specific gravity and density and thus an underestimated air void content (*Brown and Greene 2003*). This occurs because water that infiltrates the sample when it is submerged flows out of the core sample through the large interconnected air voids while it is being removed from the water bath (*Cooley Jr. et al. 2001; Brown and Greene 2003*). This results in a false or less-than-actual saturated surface-dry mass indicating a decreased or underestimated sample volume which, in turn, overestimates bulk specific gravity and density and underestimates air void content (*2002*). From the above findings, it can be inferred that the density and bulk specific gravity is overestimated and the air void content is underestimated when one uses the saturated surface-dry method; this is especially true for coarse-graded mixes, which tend to have larger air void content than fine-graded mixes (*Cooley Jr. et al. 2001; Brown and Greene 2003; Williams and Hall 2008)*. Thus, the saturated surface-dry method is not appropriate for coarse mixes due to interconnected air voids and significant surface irregularities.

Willoughby and Mahoney (*2007*) recommended using the CoreLok device, which employs the automatic vacuum sealing method described in AASHTO TP 69 *(2009*) and ASTM D 6752 (*2009*), when the air void content exceeds eight percent.

Variability of SSD Results

According to Spellerberg and Savage (*2004*), "For 9.5, 12.5, and 19.0-mm mixtures containing non-absorptive aggregates, AASHTO T 166 is an excellent method for determining bulk specific gravity. The AASHTO T 166 measurement of bulk specific gravity is a very precise process (for specimens with 3% air voids and 0.5% absorption), indicated by minimal error. The error is so small that it may be impracticable to attempt to find ways to improve AASHTO T 166." For the same mixes, they also found that the within laboratory and between laboratory coefficients of variation for AASHTO T 166 (SSD method) were much better than those obtained using the ASTM D 6752 (automatic vacuum sealing method). Cooley Jr. et al. (*2002*) also found that the results from the CoreLok device (automatic vacuum sealing method) were slightly more variable than those obtained from the AASHTO T 166 method. They concluded that this variability might have been due to the inexperience of the personnel in using the CoreLok device.

Factors Responsible for Variability in SSD Results

Spellerberg and Savage (*2004*) found that "For 12.5 and 19.0 mm mixtures containing non-absorptive aggregates, approximately 90 percent of the variation in AASHTO T 166 bulk density test results for 150 mm diameter Superpave gyratory test specimens can be attributed to the mixing and compaction process." For these mixtures, they concluded "most of the variation in AASHTO T 166 test results can be attributed to an individual laboratory's inability to produce uniform specimens." They also found that, "The added variability resulting from use of different equipment, and mixing and compaction procedures in multiple laboratories does not appear to be very significant." However, the results obtained using AASHTO T 166 consist of additional and unspecified reproducibility errors, which are caused by system level influences such as operators, the coring process, and the specific method utilized (*TransTech Systems 2004*).

Alternate SSD Methods

Gedney et al. (*1987*) recommended that cores with rough surfaces must be paraffin coated. Cooley Jr. et al. (*2002*) indicated that some of the alternatives to alleviate the problems associated with the saturated surface-dry method include using parafilm, paraffin wax, rubber membranes, and masking tape. Other alternatives include using compounds like zinc stearate that are hydrophobic which would prevent water from penetrating into the sample. However, these alternatives were not adopted by Cooley Jr. et al. because they caused increased variability in bulk specific gravity measurements, or damaged the sample such that additional testing could not be performed on the sample.

2.3.1.3 Automatic Vacuum Sealing Method

The CoreLok device utilizes an automatic vacuum sealing procedure, similar to ones described in AASHTO TP 69 and the ASTM D 6752 to measure the bulk specific gravity of core samples. According to Padlo et al. (*2005*), the bulk specific gravity (and density) of core samples did not differ significantly when they were measured in different laboratories and by different personnel in accordance with AASHTO TP 69. They found that when cores were tested by different personnel in three different laboratories, the mean difference observed was 0.06 to 0.29 as a percent of maximum theoretical density, which is well within AASHTO TP 69 standards.

When the automatic vacuum sealing method (AASHTO TP 69 or ASTM D 6752) was compared to the saturated surface-dry method, AASHTO T 166 (10) or ASTM D 2726, studies have indicated that the former method provides more accurate measurements than the latter method.

Automatic Vacuum Sealing Method versus SSD Method

Spellerberg and Savage (*2004*) found that, "For 9.5, 12.5, and 19.0-mm mixtures containing non-absorptive aggregates, the bulk specific gravity values – from specimens with 3 percent air voids and 0.5 percent absorption – obtained using AASHTO T 166 (2.469, 2.495, and 2.497) are significantly higher than those obtained using ASTM D 6752 (2.456, 2.475, and 2.472)." Cooley Jr. et al. (*2002*) found that bulk specific gravity results of coarse-graded mixes (e.g., coarse-graded Superpave mixtures and stone matrix asphalt) measured using the AASHTO T 166 were significantly higher than those of the CoreLok – when the water absorption exceeds 0.4 percent. But, at low levels of water absorption (high density values), the bulk specific gravity measured by the two test methods were similar (i.e., they did not differ significantly). This indicates that, unlike the automatic vacuum sealing (i.e., CoreLok) method, the AASHTO T 166 method overestimates bulk specific gravity at high water absorption levels. Hence, Cooley Jr. et al. recommended that at water absorption above 0.4%, the CoreLok should be used to measure density.

Cooley Jr. et al. (*2002*) also investigated how the number of gyrations in a gyratory compactor influenced the difference in density of fabricated specimens as determined by the SSD and automatic vacuum sealing methods. They found that, among the coarse-graded mixture specimens (i.e., coarse-graded Superpave mixtures and stone matrix asphalt specimens), the largest difference between AASHTO T 166 and CoreLok measurements of bulk specific gravity was observed from the specimens compacted with 15 gyrations, a slightly lower difference was observed from the specimens compacted with 50 gyrations, and the least difference was observed for those compacted with 100 gyrations.

From the studies cited above, comparisons between the two methods indicated that, relative to the automatic vacuum sealing method, the AASHTO T 166 (SSD) method overestimated the bulk specific gravity of mixtures with coarse-graded aggregates, with low density (i.e., high air void content), and with high water absorption. No significant differences existed between the two methods for mixtures with fine-graded aggregates, with high densities (i.e., low air void content), or with low water absorption levels.

Overall, the automatic vacuum sealing method (AASHTO TP 69 or ASTM D 6752) seems like a more viable option for measuring bulk specific gravity when compared to the saturated surface-dry method (AASHTO T 166 or ASTM D 2726). Cooley Jr. et al. (*2002*) suggested that, "the CoreLok vacuum-sealing device could be used to determine the bulk specific gravity of compacted hot mix asphalt samples with greater accuracy than conventional methods such as water displacement, parafilm, and dimensional analysis." Cooley Jr. et al. also cited another source to indicate that "the CoreLok vacuum-sealing device provides a better measure of internal air void content of coarse graded mixes than other conventional methods." Willoughby and Mahoney indicated that the automatic vacuum sealing method provides a better estimate of density than the saturated surface-dry method and the paraffin (and parafilm) method; this is especially significant for samples that have an air void content greater than eight percent (*2002*). Also, Padlo et al. (*2005*) recommended that all cores should be tested for density in accordance with AASHTO TP 69 (i.e., the automatic vacuum sealing method).

Disadvantages of the Automatic Vacuum Sealing Method

Even though the CoreLok device seems like the most viable option for measuring bulk specific gravity and air void content, it still has some shortcomings. Spellerberg and Savage (*2004*) found that "For 9.5, 12.5, and 19.0-mm mixtures containing non-absorptive aggregates, when ASTM D 6752 testing errors occur, they result in densities that are considerably lower than the expected density." Cooley Jr. et al. (*2002*) suggested that even the density values obtained from the CoreLok device can be slightly overestimated due to bridging of the plastic bag over the surface voids of a sample. This overestimation can be greater for laboratory prepared samples, which have texture on all sides, as opposed to field cores. The plastic bags specified in ASTM D6752 are susceptible to leakage due to pin holes *(Spellerberg and Savage 2004*). Cooley Jr. et al. (*2002*) indicated that some labs (of the total of 18 labs) reported that the CoreLok bags used for samples were sometimes punctured resulting in water infiltration or losing of vacuum over time. Specific concerns with the ASTM D 6752 include the durability of the plastic bags (susceptibility to pin holes), possibility of the bag contacting the side of the bath, and air being trapped under the bag while immersed and that it may not be possible to dry back specimens that take on water during immersion (*2004*).

Spellerberg and Savage (2*004*) recommended that if AASHTO T 166 (saturated surface-dry method) is used to determine the bulk specific gravity of specimens during the mix design process, it should also be used in quality control testing. They also recommended that if ASTM D 6752 (automatic vacuum sealing method) is used to determine the bulk specific gravity of specimens during the mix design process; it should also be used in quality control testing.

2.3.1.4 Dimensional Analysis Method

The dimensional analysis method overestimates the internal air void content and the volume of the core sample, and thus it results in an underestimated density value (*CoreLok Operators Guide 2003; Choubane et al. 1999*). This was also indicated by Choubane et al. (*1999*), where they found similar results, based on R^2 values of 0.93 to 0.97, between measurements of densities using Florida's test method FM 1-T 166 (similar to AASHTO T 166 except that immersion of sample was for 2±1 minutes instead of 4±1 minutes), ASTM D 1188 method using parafilm, and the dimensional analysis method. However, from an analysis of variance (ANOVA) at a 95% confidence level, there was indication of significant differences between the values obtained from the three methods. The density values obtained from the dimensional method were always lower, whereas the differences between the Florida and ASTM D 1188 (parafilm) methods were not as significant.

2.3.2 Studies on Density Measurement using Nuclear Gauges

Section 2.1.1 provided an overview of density measurement of HMAC using nuclear gauges. This section compares different standards for measuring density using nuclear gauges. This includes information on variability of gauge density readings, accuracy of various methods to measure density of hot mix asphalt concrete using nuclear gauges, comparison of different nuclear gauges by manufacturer and model, methods for accurate calibration of gauges, and factors that affect nuclear gauge density readings. This section also provides information related to accuracy of gauge density readings when compared to density readings obtained by cores. Information is provided on calibration of the nuclear gauge and differences of the nuclear gauge readings with corresponding core densities to obtain more accurate results.

2.3.2.1 General Advantages

Nuclear gauges use a test procedure that is fast and non-destructive (*Parker and Hossain 1995*; *Sandars, Rath, and Parker 1994; Schmitt et al. 1997*). They can be used to provide results in less than ten minutes (*Sandars, Rath, and Parker 1994*). The principal advantage of using nuclear gauges is that the pavement density can be measured immediately following compaction of the pavement (i.e., while the hot mix asphalt concrete is in a workable state) allowing real-time adjustments to rolling patterns so as to achieve desired density (*Schmitt et al. 1997*). In other words, density can be measured while the mat is still hot, so additional compaction can be applied if necessary (*Parker and Hossain 1995*). In addition, a large number of measurements are possible in a short timeframe, which allows for a more accurate estimate of pavement density (*Schmitt et al.*

1997). However, licensing is required to be able to operate a nuclear gauge (*Sandars, Rath, and Parker 1994*). That is, certified technical training is required for a technician to utilize a nuclear gauge for use in the quality control/quality assurance process.

2.3.2.2 Factors that Influence Measurements

There are a number of significant factors that have considerable influence on nuclear gauge measurements. Details of these factors and the level to which they influence the nuclear gauge measurements are indicated below.

Influence of Lift Thickness

Nuclear gauges are affected by pavement thickness. As the thickness of a pavement decreases, the density results obtained from a nuclear gauge becomes more variable. This is due to the influence of the underlying layers. Esch (*1972*) found that a minor change in compaction (compaction affects thickness) can cause a significant change in density reading. Gedney et al. (*1987*) found that nuclear gauges are sensitive to thin overlays and underlying material, such that the readings obtained are an average of the overlay and the underlying material. They also found that nuclear gauges are sensitive to the top two inches of pavement material, and it gives greatest weight to materials that are closest to the bottom of the gauge.

The subbase material influences density readings more than the base material. While Huot et al. (*1966*) observed that the base course material has a negligible effect on the variability of density measurements, Parikh (*1990*) indicated that the subbase material significantly affects the density reading. Parikh also found that, if thickness is 1.5 to 2 inches, then accuracy of nuclear gauge density measurements is affected by one percent; and if top layer thickness is 1 inch or lesser, then accuracy is affected by one to two percent.

Manufacturers recommend that nuclear gauges should only be used when the pavement thickness is greater than 1 inch (*Sanders et al 1994*). While Sanders et al. (*1994*) found that nuclear gauge density readings are influenced by the mix type, Parker and Hossain (*1995*) observed that density measurement variability is lower in thicker binder mix layers than in thinner ones. They suggested that this can be due to the effect of mat thickness on density determination and due to slower cooling of thicker mats that permits better compaction control. Schmitt et al. (*1996*) found that mat thickness influences variability of nuclear gauge density reading. Choubane et al. (*1999*) found that the thin lift gauge results were highly variable in spite of being corrected for the effect of underlying layers using the previous density data.

Padlo et al. (*2005*) observed that as the mat thickness increases, the error or variability between gauge readings and core measurements decreases. They found that mat thickness and aggregate source caused a significant difference between gauge and core results in the range of 0.3 to 1.2% of maximum theoretical density. They recommended that the thickness of some pavements must be entered into the gauge so that the influence of underlying layers, while determining density, is minimized. However, they also pointed out that entering the exact depth doesn't minimize this effect significantly because different gauges measure density to different depths; thus, they determined that it was necessary to enter a lesser-than-actual depth in order to eliminate the effect of an underlying layer in determining the density of the current layer.

Influence of Aggregates

Huot et al. (*1966*) observed that the aggregate size influenced the nuclear gauge readings such that it caused density variation in the range of ±2%. Esch (*1972*) found that minor changes in gradation, asphalt content, and compaction can cause significant differences in density readings. Mix composition and mix aggregate type also significantly affects nuclear gauge density readings (*Parker and Hossain 1995*; *Sandars, Rath, and Parker 1994; Parikh 1990*). Parker and Hossain (*1995*) suggested that different acceptance limits should be set for different mix types; that is, the acceptance limits should be set using standard deviation of measurements for specific mix types.

Influence of Surface Texture

Huot et al. (*1966*) found that the surface texture has a big influence on nuclear gauge readings. Esch (*1972*) found that the correlations (between gauge and core readings) are affected by surface roughness and insufficient depth of penetration (or influence) of nuclear gauges as compared to cores. Gedney et al. (*1987*) found that the density values obtained from nuclear gauges were significantly lower than those of cores for pavements with rough surface texture. The correlations improved on smoother pavement. A rough surface texture causes the gauge to report a density reading that is lower than the actual density due to the uneven surface and higher surface voids (*Padlo et al. 2005*).

Influence of Gauge Type, Testing Location, and Site Condition

Type of gauge (or gauge model), project conditions, and location are factors that significantly affect gauge readings. Burati and Elzoghbi (*1987*) found that, while measuring joint density, the between-gauge differences were affected by project condition since it significantly varied from project to project. Stroup-Gardiner and Newcomb (*1988*) found that, although little differences existed between nuclear density readings and core measurement, a two-way analysis of variance (ANOVA) indicated that the factors responsible for significantly different results between nuclear gauge readings and core measurements were gauge type, testing location, and site condition.

Choubane et al. (*1999*) indicated that the gauge model and the testing location are factors that significantly influenced the gauge results. They maintained that the variability in gauge readings differed from gauge to gauge and within each gauge from location to location.

Padlo et al. (*2005*) also found in their studies that the type of gauge used to measure pavement density was a cause for significant variation in density determinations. The differences between gauge results were statistically significant. The mean difference in reading between two gauges at the same location was 0.3 to 1.36 as a percent of maximum theoretical density. No two gauges produced statistically similar results (out of the six nuclear gauges used).

Influence of Number and Duration of Measurements

Stroup-Gardiner and Newcomb (*1988*) observed in a paired t-test (with a 99% confidence) that there was no significant difference between the fifteen-second, one-minute and four-minute readings. Parikh (*1990*) found that the count duration did not have significant effect on nuclear density values. He recommended that to be assured of accuracy within ±1 lb/ft^3 of true density, four readings (using a special calibration mode) are required per 200-ton sublot. He also found that laboratory analysis indicated no significant difference in average of four readings taken at one-, two-, or four-minute counts. Schmitt et al. (*1996*) indicated that a total of at least two replicate density readings using one-minute counts are required per site (or testing location) to eliminate erroneous results and to control variability.

Schmitt et al. (*1997*) found that relative densities (i.e., percentage of theoretical maximum density) determined from measurements on adjacent cores obtained at each test site (i.e., where the nuclear gauge measurements were made) varied from 0.0% to 0.5%. Whereas the relative densities obtained from nuclear gauge measurements, based on one-minute counts, varied from about 0.8% to 1.2%. It should be noted that the researchers determined that a fifteen-second count resulted in a variation in relative density of about 2% to 3%, and that a four-minute count resulted in a variation in relative density of about 0.8% to 1.0% (very similar to the one-minute count).

Sebesta et al. (*2003*) recommended taking two one-minute readings (in backscatter mode), with the nuclear gauge rotated 180 degrees after the first reading with the average of the two readings reported as the nuclear density measurement at that location. Padlo et al. (*2005*) also found that one-minute readings provided more accurate results than thirty-second readings. They found that using one-minute readings (instead of thirty-second readings) improved accuracy of gauge results by 0.45% of maximum theoretical density. They recommended taking four one-minute readings at each location to measure pavement density using a nuclear gauge.

Troxler Jr. and Dep (*2006*) also found that counting time (or reading duration) significantly affected gauge results. They suggested that for best precision, two one-minute readings are recommended per location or spot. Schmitt et al. (*2006*) recommended increasing the nuclear gauge density tests from 7 to 15 (per 750-ton lot) to increase the confidence in the estimated pavement density.

Influence of Operating Modes

Nuclear gauges can be operated in different modes to measure the density of asphalt pavements. Some of the modes are standard backscatter mode, backscatter with air gap mode, and thin lift mode. The mode of operation of the gauge can significantly influence the density reading.

Esch (*1972*) found that air gap testing with one surface and one air gap count generally produced standard deviations approximately 20% higher than normal backscatter testing using the average of three one-minute counts. He recommended that the air gap mode should not be used.

Later, Gedney et al. (1987) found that the nuclear gauge was more sensitive to chemical composition and surface roughness in the backscatter mode than in air gap mode. They also found that the backscatter mode was effective in measuring density of pavements up to a minimum thickness of 1.8 inches.

Parikh (*1990*) found that the mode of operation of the gauge influences the density reading, and it can possibly cause variability in results. When comparing normal, special calibration, and surface void modes of operation, the analyses indicated that a difference of less than 2 lb/ft^3 was found between gauge densities and core densities at a 95% confidence level when the gauge was in the special calibration mode. The special calibration mode is used when the gauge readings are significantly different from core results due to asphalt mix composition and mix aggregate type. He indicated that the special calibration mode was the most suitable mode of operation for measuring density of thin layers.

Padlo et al. (*2005*) also found that the mode of operation of the gauge (backscatter or thin lift) significantly affected nuclear gauge readings. They determined that there was a 97 percent probability that the difference between the two modes of operation was greater than 0.1% of maximum theoretical density. On average, the results obtained from the gauge in thin lift mode were 0.33% of maximum theoretical density higher than those obtained from the gauge in backscatter mode; although they conceded that the difference may have been due to differences in the algorithms used to determine density. Even though a statistically significant difference existed between the results obtained using the two modes of operation, there was insufficient evidence to suggest that one mode of operation was better than the other.

Other Factors

Other factors that have been identified as having an effect on nuclear gauge density readings include temperature differentials, use of latex as a modifier, milled pavement surfaces, air gap, and nuclear gauge operator. Huot et al. (*1966*) found that a difference in temperature of almost 100°F can cause a difference in density by 1 lb/ft^3. Parker and Hossain (*1995*) found that using latex as a modifier in surface mixes significantly increased variability of mat density determined by nuclear gauges. They also found that milling of the surfaces of old pavements and application of surface treatments significantly decreased density variability in overlays placed over these treatments. Padlo et al. (*2005*) recommended milling of pavements because it decreased the variability of nuclear gauge density readings.

Troxler Jr. and Dep (*2006*) found in a study investigating use of nuclear and electromagnetic gauges for measuring longitudinal joint density that an air gap under a gauge had a significant effect on the gauge reading. When a gauge was placed right on the joint and there was a 1 mm elevation difference between the adjacent lanes, the density is underestimated by about 2 lb/ft^3.

The operator of the nuclear gauge is also responsible for causing significant variations in density reading (*Choubane et al 1999*; *Sandars, Rath, and Parker 1994)*. When Choubane et al. (*1999*) correlated the manufacturer representative-operated nuclear gauge readings (obtained from Troxler Models 3440 and 3401) with corresponding core results (obtained using the ASTM 1188 paraffin and parafilm method), they found that the correlation was very good (R^2 was greater than 0.89). They also found that among various gauge operators (state, contractor, and manufacturer personnel), the manufacturer's results indicated best correlations.

2.3.2.3 Factors that Do Not Influence Measurements

Previous studies indicate that factors such as gauge direction or use of rubber pads, sand, or coal tar do not have a significant influence on nuclear gauge readings and/or do not cause significant variability in gauge readings.

Padlo et al. (*2005*) determined that the position of the gauge (transverse or longitudinal), while taking measurements, is an insignificant factor that does not affect gauge readings. The mean difference between density obtained in transverse and longitudinal direction was 0.05% of maximum theoretical density. Burati and Elzoghbi (*1987*) found that orienting the gauge in a perpendicular direction to the joint (rather than parallel) gave density values that were closer to core densities obtained from the joints; however, they also concluded that it was not yet appropriate to replace gauges with cores for quality assurance purposes.

Padlo et al. (*2005*) determined that placing rubber pads or material of known density between a gauge and an irregular surface did not improve the results obtained from nuclear gauges. Stroup-Gardiner and Newcomb (*1988*) found that sanding of the pavement or sealing with coal tar did not seem to cause variability in gauge density measurements.

2.3.2.4 Correlation of Measurements with Core Densities

Sanders, Rath, and Parker (*1994*) indicated that density values obtained from nuclear gauges were not as accurate as those obtained from cores. When they averaged 3,524 measurements, they found that a majority of the density values measured from cores were higher, by an average value of 0.9 lb/ft^3 (14.42 kg/m^3), than those measured from nuclear gauges in 69.5% of the cases. They indicated that the type of mix may have influenced the nuclear density gauge measurements.

Schmitt et al. (*1997*), in a study of 14 hot mix asphalt overlay projects in Wisconsin, compared densities determined from cores to those determined by nuclear gauge measurements. They found that the variability of densities determined from cores was less than the variability of densities determined from nuclear gauge measurements in 9 of 14 hot mix asphalt overlay projects (i.e., in 64% of cases). They also found that nearly

74% of the variation between the two measurements was explained by simple regression of core density measurement versus nuclear gauge density measurement. By including core thickness as a step function (thick or thin) and including theoretical maximum specific gravity as a continuous function, they were able to improve the regression model to explain nearly 75% of the variability.

Esch (*1972*) found that an accuracy level of ±1% could be achieved if seven samples were extracted for core testing and nine measurements were made using a nuclear gauge. Prowell and Dudley (*2002*) used the Troxler 4640-B thin lift nuclear gauge to take two readings parallel to the direction of paving and one reading perpendicular to it. They found that the nuclear gauge results correlated better with core densities obtained from AASHTO T 166 than those obtained from the CoreLok device.

2.3.2.5 Recommendations to Improve Accuracy

Sanders et al. found that the calibration procedure and the measurement procedure are factors that significantly affect nuclear gauge density reading (*1994*). Parker and Hossain (*1995*) found that nuclear gauges were inaccurate and varied widely unless the gauges were calibrated for specific conditions including mix composition, layer thickness, and underlying conditions. Brown and Greene (2003) emphasized that if nuclear gauges are to be used for acceptance, it is essential that they be initially correlated to cores and that the accuracy of the gauges be continually verified by core densities to ensure accurate results. With regard to core correlations, Esch (*1972*) suggested that at least seven to ten correlation sets are required to find the average correction factor.

Padlo et al. (*2005*) recommended selecting one location on a paving project so that four one-minute readings could be taken every day to monitor the gauge and ensure its accuracy. Troxler Jr. and Dep (*2006*) found that the problem with factory calibration is that the gauge is calibrated based on the average asphalt mix. In order to make the actual field calibration on a job site more accurate, the gauge must be calibrated for that particular mix by correlating the readings to core density readings. They suggested that these readings must be obtained from random locations in the middle of the pavement to estimate a constant bias between the two methods.

2.3.3 Studies on Density Measurement using Electromagnetic Gauges

Several studies have been conducted on the measurement of density using electromagnetic gauges, particularly the Pavement Quality Indicator (PQI) and the PaveTracker. This section summarizes the findings from many of these studies.

2.3.3.1 Factors that Influence Measurements

Several researchers have reported on the factors that influence electromagnetic gauge measurements. Details of these factors and the degree or extent to which they influence the measurements are provided below.

Influence of Temperature

Earlier models of the Pavement Quality Indicator (namely the Pavement Quality Indicator 100 and the Pavement Quality Indicator Model 300) and the PaveTracker have been shown to be affected by the surface mix temperature (*Liao, Sargand and Kim 2006; Sargand, Kim and Farrington 2005; Andrewski 2003)*. Gauge readings decreased with a decrease in surface mix temperature (*Liao, Sargand and Kim 2006; Sargand, Kim and Farrington 2005*). Liao, Sargand and Kim (*2006*) found that, on average, the gauge reading decreased by 16 kg/m^3 (1 lb/ft^3) with a temperature drop of 50°C (122°F). Likewise, they also found that the gauge reading (measured using a PaveTracker) increased with increasing surface temperature; and this is more profound for mixtures with larger nominal maximum size aggregates.

However, it was found that the latest electromagnetic gauges (Pavement Quality Indicator Model 301 and PaveTracker Model 2701-B) were hardly affected by pavement surface temperature (*Smith and Diefender 2008; Williams and Hall 2008*). Williams and Hall (*2008*) verified this by measuring the density using these two electromagnetic gauges at two temperatures; at a high temperature of 180°F (i.e., just behind the finish roller), and at a low temperature (approximately 100°F) after the mat had cooled considerably. They found through their analyses (t-tests) that the measurements appeared to be unaffected by temperature (i.e., t-test results indicated no significant difference, p-value > 0.05). Thus, it would appear that manufacturers had improved their gauges to account for temperature variation.

Influence of Moisture

Researchers also found that surface moisture and internal moisture affected gauge readings obtained from earlier gauge models (namely the Pavement Quality Indicator Model 300 and the PaveTracker) (*Liao, Sargand and Kim 2006; Sargand, Kim and Farrington 2005; Andrewski 2003)*. An increase in the surface moisture (without internal moisture) caused the gauge to report a lower or decreased value, while an increase in internal moisture (with or without surface moisture) caused the gauge to report a higher or increased value (*Liao, Sargand and Kim 2006; Sargand, Kim and Farrington 2005*).

When compared to cores, it was observed that the density reported by the PaveTracker and derived from cores increased linearly with an increase in surface moisture (*Liao, Sargand and Kim 2006*). However, when subjected to surface and internal moisture (for 24 hours), it was noticed that the gauge and core measurements were nonlinear, and the gauge readings decreased while the core densities increased (*Liao, Sargand and Kim 2006*). Kvasnak et al. (*2007*) also found that gauge density measurement results of wet pavements were more variable than those of dry pavements.

Williams and Hall (*2008*) found that surface and internal moisture also affected the newer electromagnetic gauge models (namely the Pavement Quality Indicator Model 301 and the PaveTracker Model 2701-B). They measured density on two conditions: a 'dry' condition, where there was no visible sign of water; and a 'wet' condition (resembling a saturated surface-dry condition) where water was sprayed on the surface to fill the voids and then a towel was used to blot the surface. It was found that moisture caused a significant change in density. It affected the 1½ inch nominal maximum aggregate (NMAS) mix (which had larger voids) more than the 1/2 inch NMAS mix. The density reported for the 'wet' condition was 1 lb/ft^3 greater than that reported for the 'dry' condition. Thus, it was recommended that all visible signs of water must be removed from the surface. They also found that the PaveTracker Plus™ Model 2701-B was a little more sensitive to surface moisture than the Pavement Quality Indicator Model 301.

Smith and Diefender (*2008*) found that the Pavement Quality Indicator Model 301 could provide valid results when the moisture index was below 10; however, if the moisture index was above 10, the readings were significantly affected. A higher moisture index resulted in a higher reported density and more variation relative to core measurements.

Hausman and Buttlar (*2002)* found that the Pavement Quality Indicator Model 300 seemed to be affected by environmental conditions. It also seemed to be affected by the density gradient in HMAC created by a rolling wheel compactor.

Influence of Mix Type and Aggregate Size

Several researchers have found that electromagnetic gauges are affected by the type of mix (i.e., coarse or fine). Sargand et al. (*2005*) found that the PaveTracker reported more accurate results for measurements made on fine mixes than on coarse mixes. Larsen and Henault (*2006*) observed that, in spite of changing the algorithms of the Pavement Quality Indicator and the PaveTracker to provide improved results, the measured density values were affected by the mix design (i.e., aggregate size and proportion, and particle segregation). Schmitt et al. (*2006*) found that electromagnetic gauges were affected by mixture- and project-specific factors such as aggregate source, design loads, laboratory air voids, asphalt content, aggregate specific gravity, and pavement layer thickness.

The newer gauge models like the PaveTracker Model 2701 were also affected by various factors including traffic level, aggregate type, nominal maximum aggregate size, roller passes, and moisture condition (i.e., wet and dry conditions). The Pavement Quality Indicator Model 301, when used in the single-mode method of data collection, was affected by factors such as roller passes, temperature, and distance across pavement width. In the multi-mode method of data collection, it was affected by factors such as site, pavement width, aggregate type, binder content, roller pass, and distance across pavement width (*Kvasnak et al. 2007*).

Williams and Hall (*2008*) indicated that the gauges were significantly affected by large aggregate size and void size (1½ inch mix). They measured density using the PaveTracker Plus™ Model 2701-B and the Pavement Quality Indicator Model 301 at the same spot (for all test locations). Significant differences between densities were found for the 1½ inch mix, but not for the 1/2 inch mix.

Liao, Sargand, and Kim (*2006*) found better correlations with cores for mixtures with a smaller nominal maximum aggregate size (NMAS) as indicated by a higher coefficient of determination (R^2). The coefficient of determination of the regression line for the mixtures with a NMAS of 9.5 mm was 0.94, indicating that 94% of the variation between gauge readings and core measurements was explained by the regression line. R^2 of the regression line for the mixtures with an NMAS of 19 mm was 0.81, indicating that 81% of the variation between gauge readings and core measurements was explained by the regression line.

Influence of Sand

Williams and Hall (*2008*) found that sprinkling of sand to fill voids and level the pavement surface caused a decrease in density, which was more significant for mixtures with smaller voids (and that the PaveTracker Plus™ Model 2701-B is more sensitive to it). They measured density under two site conditions. The first condition was to brush off all the sand from the surface and then measure the density leaving it susceptible to air voids. The second condition was to sprinkle a small amount of sand on the surface to fill the voids and to level it, excess sand was dusted off. Generally, they found that higher surface voids resulted in decreased density readings. However, the results also indicated that it was better to not level the surface by filling the voids with sand since it tended to prevent solid contact between the gauges and the pavement surface. Sprinkling of sand (to level the surface) caused a decrease in density by approximately 3 lb/ft^3 in 9 of 10 locations. Also, sand had a more significant effect on mixtures with smaller voids and the PaveTracker was more sensitive to it.

Influence of Gauge Position

Williams and Hall (*2008*) determined that the direction of the gauge (i.e., parallel or perpendicular to the direction of paving) resulted in considerable variability in the gauge readings. They found that the measurements taken parallel to the direction of paving were approximately 2.4 lb/ft^3 higher than measurements taken perpendicular to the direction of paving (where the parallel orientation was such that the technician facing the direction of paving could read the gauge display screen directly). They also found that rotating the gauge increased contact with the pavement surface and caused changes in the readings, and that “picking up and placing the gauge” caused further compaction which led to increased density by approximately 3 lb/ft^3.

Influence of the Number of Readings at a Given Location

Researchers have found that the number of electromagnetic gauge readings can significantly influence the reported density. For the Pavement Quality Indicator, Sebesta et al. (*2003*) recommended taking five three-second readings by beginning in the center and then moving clockwise around the center, and moving the instrument at least 2 inches between readings, and that the reported density should be the average of the five readings.

Troxler Jr. and Dep (*2006*) recommended four to eight readings (on places slightly shifted about the measurement locations by about 2 inches) when using the PaveTracker Model 2701 gauge to provide 0.5 to 1.2 lb/ft^3 precision at the 1-sigma level. The authors did not define the meaning of “the 1-sigma level.”

Williams and Hall (*2008*) took one, four, and eight readings at the same location to assess the repeatability and variability of readings. It was found that it was best to average four readings to obtain the density at a particular location. One reading generally showed an overestimated density, and eight readings did not show a significant difference when compared with four readings.

2.3.3.2 Factors that Do Not Influence Measurements

Sebesta et al. (*2003*) confirmed that battery voltage and mineral filler did not influence (or affect the accuracy and variability) the electromagnetic gauge reading. Battery voltage had no effect on the gauge readings using a PaveTracker. Hausman and Buttlar (*2002*) found that the use of mineral filler did not affect the accuracy or variability of density readings from the Pavement Quality Indicator Model 300.

2.3.3.3 Calibration Methods to Improve Accuracy

An electromagnetic gauge can be made to produce more accurate readings by correcting it for errors. Schmitt et al. (*2006*) recommended that electromagnetic gauges must be calibrated daily at each project site (to offset the effect of various factors). They also found that nuclear gauge readings were the most appropriate means to calibrate an electromagnetic gauge. They also recommended that technicians using electromagnetic gauges take at least 30 readings within each lot to ensure acceptable confidence levels.

Rao et al. (*2006*) suggested that an optimal adjustment function must be calculated by correcting the raw electromagnetic readings to match core readings. This should include an additive shift and a slope factor. They suggested that the gauge readings can be corrected (using the slope factor) by multiplying a constant correction factor (or slope term) to the raw gauge readings. Also, the gauge readings can be corrected using the slope and intercept method, wherein the electromagnetic readings are adjusted by multiplying a slope term and adding an intercept term. They recommended that a calibration factor must be determined using the slope function and be based on ten calibration points. Daily calibration for each mix design is recommended when the project involves multiple days of paving. The use of ten test points and a correlation using the slope method is optimal to develop accurate calibration factors. Finally, the study recommends that independent calibrations be established for each day of paving. Also, Smith and Diefender (*2008*) suggested that, if the gauge is calibrated on a test strip before actual field testing and measurement is performed, then it can be used for quality control and quality assurance testing.

However, certain studies suggest that calibration of gauges does not improve differences between results obtained from gauges and cores (*Kvasnak et al. 2007, Prowell and Dudley 2002; Hausman and Buttlar 2002; Hurley et al. 2004*). Prowell and Dudley (*2002*) found that the Pavement Quality Indicator Model 300 was insensitive to pavement changes and also displayed poor differences relative to AASHTO and CoreLok densities. Hausman and Buttlar (*2002*) indicated that the differences between Pavement Quality Indicator Model 300 and AASHTO T166 method was due to influence of density gradient created by rolling wheel compactor. Later, Hurley et al. (*2004*) found that calibrating gauges (Pavement Quality Indicator Model 301, 300, and PaveTracker) for offset and slope did not improve differences between densities obtained from gauges and cores.

Also, statistical evaluations by Kvasnak et al. (*2007*) indicated that the majority of density readings obtained via electromagnetic gauges and cores differed significantly. They found that, in most cases, when readings obtained from the PaveTracker and the Pavement Quality Indicator were compared with core densities, it was observed that the PaveTracker showed the lowest readings and the Pavement Quality Indicator showed highest readings. Variability of the Pavement Quality Indicator readings tended to be more than that of PaveTracker and core readings. When quality indices were compared for the unadjusted data, the Pavement Quality Indicator and core results differed on just 1 out of 14 sites but after correction they differed on 7 sites. When quality indices were compared for the unadjusted data, the PaveTracker and core results differed on 11 out of 14 sites but after correction they differed on just 1 site. The Pavement Quality Indicator showed the most variability, followed by the PaveTracker, and the cores showed the least variability. When a new algorithm was developed for the Pavement Quality Indicator, and results obtained from this new algorithm were compared with the results obtained from the old algorithm, it was observed that the new algorithm yielded better results.

2.3.3.4 Use of Electromagnetic Gauges for QC/QA Purposes

Earlier studies by Romero (*2002*) indicate that the Pavement Quality Indicator Model 300, the Pavement Quality Indicator Model 300+ (i.e., modified algorithm which gives improved results), and the PaveTracker cannot be used for quality assurance purposes, but they can be used for quality control purposes. Andrewski (*2003*) and Allen et al. (*2003*) also found that the Pavement Quality Indicator Model 300 can be used for quality control. Hurley et al. (*2004*) found that the Pavement Quality Indicator Model 301 gave more accurate results than the Pavement Quality Indicator Model 300 and the PaveTracker. Smith and Diefender (*2008*) found that the Pavement Quality Indicator Model 301 can be used for quality control and quality assurance purposes provided that it is calibrated daily on a test strip for each project before QC and/or QA testing is performed.

Romero (*2002*) recommended that the electromagnetic gauges (Pavement Quality Indicator Model 300 and PaveTracker) should be operated by experienced professionals, and that a reference standard should be developed for the Pavement Quality Indicator (like for the PaveTracker). Kvasnak et al. (*2007*) suggested that, to ensure the appropriate implementation of electromagnetic gauges, there is a need for additional work that considers the following elements: 1) utilization of test strips; 2) increase in the testing frequency; and 3) evaluate new electromagnetic gauges that have entered the construction industry (e.g., Pavement Quality Indicator Models 302 and 303).

2.3.4 Studies Comparing Density Measurement Methods

This section provides a review of the findings from studies that compared nuclear and electromagnetic gauges across various parameters. Emphasis is given to advantages of one gauge type over the other, differences between measurements obtained from the two types of gauges, and a comparison of the variability of the results reported by the gauges.

2.3.4.1 Advantages of Nuclear Gauges over Electromagnetic Gauges

Nuclear gauges have been found to be more accurate than electromagnetic gauges. A majority of the literature indicates that densities obtained from nuclear gauges correlate better with cores than densities from electromagnetic gauges. Rogge and Jackson (*1999*) found that the density values obtained from a nuclear gauge correlated better with those of cores than corresponding density differences of electromagnetic gauge (Pavement Quality Indicator) and cores.

When nuclear and electromagnetic gauges were compared to check which gauge provides density values that correlate better with those of cores, it was observed that densities obtained from nuclear gauges correlated better with core densities (*Prowell and Dudley 20002; Hausman and Buttlar 2002*). In spite of changing the algorithm of the Pavement Quality Indicator Model 300 to provide improved density readings, it was found that the nuclear gauge readings always correlated better with cores densities than the corresponding density differences of either the Pavement Quality Indicator or the PaveTracker. Neither the improved Pavement Quality Indicator Model 300 nor the PaveTracker provided better results than the nuclear gauges when being compared with cores for differences purpose (*Romero 2002*). Romero and Kuhnow (*2002*) reported that electromagnetic gauges were never able to match the standards set by the nuclear gauge when they were correlated with core densities.

It was suggested by Sebesta and Scullion (*2003*) that the gauge accuracy and gauge and core density readings differences might improve if a slope function was calibrated to match gauge and core data. However, Hurley et al. (*2004*) found that, even after applying correction for offset and slope, the electromagnetic gauges (Pavement Quality Indicator Model 301, Pavement Quality Indicator Model 300, and PaveTracker) did not correlate as closely with core densities as did a nuclear gauge.

Sargand et al. (*2005*) found that neither the Pavement Quality Indicator Model 300 nor the PaveTracker Model 1-B correlated well with cores or with nuclear gauge readings. Thus, they were not recommended for quality control/quality assurance purposes.

Liao et al. (*2006*) observed that the difference in density measurements between the PaveTracker and cores is greater and more significant than the difference between nuclear and core density measurements; thus, they indicated that nuclear gauges performed better than electromagnetic gauges.

2.3.4.2 Advantages of Electromagnetic Gauges over Nuclear Gauges

Electromagnetic gauges have a few advantages over nuclear gauges in terms of cost and time. Hurley et al. (*2004*) observed that obtaining density measurements using electromagnetic gauges are cheaper compared to using nuclear gauges. Also, electromagnetic gauges measure density faster than nuclear gauges. Electromagnetic gauges provide density readings in a few seconds, while nuclear gauges generally display acceptable density readings in a minute, or in some cases, more than a minute (*Smith and Diefender 2008*). Also, electromagnetic gauges are easier to use and weigh approximately half as much as nuclear gauges. Electromagnetic gauges do not require licensing whereas nuclear gauges do.

2.3.4.3 Comparison of Mean Densities between Nuclear and Electromagnetic Gauges

Rogge and Jackson (*1999*) found on five of six projects that the mean core densities were greater than the mean densities reported by a nuclear gauge and the Pavement Quality Indicator. They found that the Pavement Quality Indicator and nuclear gauge readings were generally within 3% of each other, and that these were generally within about 10% of the mean core densities.

Rao et al. (*2006*) found that the nuclear gauge measurements were higher than the electromagnetic gauge measurements. They also found that the PaveTracker readings were mostly greater than the Pavement Quality Indicator measurements.

Schmitt et al. (*2006*) found that electromagnetic gauge density readings were consistently lower than nuclear gauge density readings. The Pavement Quality Indicator Model 301 read 11.2 to 27.2 lb/ft^3 lower than the nuclear gauge, the Pavement Quality Indicator Model 300 ranged from 4.2 to 26.6 lb/ft^3 lower, and the PaveTracker varied from 1.8 to 17.7 lb/ft^3 lower.

2.3.4.4 Comparison of Variability amongst Gauges

Sebesta and Scullion (*2003*) found from laboratory studies that the standard deviation of readings from an electromagnetic gauge was 0.5 lb/ft^3, whereas the standard deviation was 1 lb/ft^3 for the nuclear gauge. Rao et al. (*2006*) also found that the standard deviation of the values derived from electromagnetic gauge data was lower than that for the nuclear gauge measurements.

When comparing the densities obtained from the Pavement Quality Indicator and a nuclear gauge with core densities in terms of a percentage difference (standard deviation, average difference, and absolute value), Smith and Diefender (*2008*) found that the results from the nuclear gauge contained lower variability than the results from the Pavement Quality Indicator on 7 of 8 projects. They also found that the histogram from the residuals of the regression analysis showed a normal distribution for the nuclear gauge (indicating that a linear regression is a good model) whereas the residual plot for the Pavement Quality Indicator indicated that it might still be influenced by other factors.

2.3.4.5 Lift Thickness Considerations

According to Troxler Jr. and Dep, (*2006*), selection of a gauge is dependent on the top layer thickness. For a lift thickness less than or equal to 1 inch, they indicated that either an electromagnetic gauge or a nuclear gauge set in thin-lift mode is appropriate. For a lift thickness of 1 to 2 inches, they recommended a nuclear gauge set in thin-lift mode.

For layers 2 to 3 inches thick, they indicated that any nuclear gauge in back scatter mode is appropriate.

2.4 SUMMARY

To fulfill the first objective described in Section 1.2, the efficacy of various methods of density measurements were investigated and summarized. This included a description of the principle behind each method of measurement, factors affecting the methods of measurement, factors not affecting the methods of measurement, correlation between the various methods of measurements, and suggestions and recommendations to improve certain methods of measurements or to improve the correlation between methods so that a more accurate density (i.e., closer to the true density) can be obtained. The following sections provide a succinct summary of the findings from the literature review.

2.4.1 Pavement Density Measurements using Cores

The densities obtained from measurements on cores are considered to be more accurate and have lower variability than nuclear gauge and electromagnetic gauge measurements and, therefore, are often used as reference values. However, cores cannot be extracted from the pavement until the mat has cooled, the laboratory procedure is time consuming, and transportation and testing of cores increase the quantity, duration, and cost of work. Researchers have indicated that core density values are typically made available a day after the pavement has cooled. In addition, extraction of cores from the pavement is destructive, requires patching, and can possibly result in premature pavement failure due to localized points of weakness along the pavement.

The density of a core (or laboratory-prepared specimen) is derived from a bulk specific gravity measurement made in a laboratory. The methods of measuring bulk specific gravity of cores include: 1) saturated surface-dry (SSD) method, 2) paraffin-coated method, 3) automatic vacuum sealing method, and 4) dimensional analysis. The bulk specific gravity of the core specimen determined by any of these methods is then multiplied by the unit density of water to obtain the density of the hot mix asphalt core sample.

Many agencies, including the Oregon Department of Transportation, specify the use of AASHTO T 166 (SSD method) for determining the density of pavement cores (and laboratory-compacted specimens). However, AASHTO T 166 A tends to overestimate mixture density at high air void content (i.e., greater than 8%), or when the mixture has interconnected air voids allowing water absorption. For fine and coarse mixes (with water absorption greater than 0.4%), the results obtained from the automatic vacuum sealing method (described in AASHTO T 331 and ASTM D 6752) have been shown to be more accurate than those obtained from the saturated surface-dry method.

2.4.2 Pavement Density Measurement using Nuclear Gauges

Nuclear gauge measurements are fast and non-destructive. They correlate better with cores when compared to electromagnetic gauges. Nuclear gauges are affected by pavement thickness;

a decrease in thickness causes readings to become more variable. The base coarse material has a negligible effect and the subbase material has a significant effect on the gauge readings.

Mix composition, mix aggregate type and size, mix temperature, and surface texture or roughness influence gauge readings. Factors like gauge direction, or use of rubber pads, sand, or coal tar do not cause any significant variability in gauge readings. On the other hand, factors like type of gauge (or gauge model), project conditions, and location significantly affect gauge readings. Many researchers recommend taking two one-minute readings at each test location for best results.

2.4.3 Pavement Density Measurement using Electromagnetic Gauges

Electromagnetic gauges are lighter in weight, measure density the fastest, and are cost-effective. Earlier models like the PQI 300 were affected by surface mix temperature, while later models like the PQI 301 and the PaveTracker Model 2701-B were not. However, several researchers have shown that all electromagnetic gauges are affected by the surface and internal moisture; higher moisture results in more variability in the measurements, and coarse mixes are affected more by moisture than are fine mixes. Also, there is better correlation between gauge densities and core densities at lower moisture.

Mix type has a significant effect on gauge readings; better correlation between gauge and core densities have been found for mixtures with smaller nominal maximum aggregate sizes. Air voids and sprinkling of sand affect the gauge and cause it to report an underestimated density. It is best to calibrate the gauge daily, and then take four to five readings at each location for a more accurate estimate of density. Several studies indicated that electromagnetic gauges can be used for quality control, and one study indicated that the PQI 301 can be used for quality assurance testing.

2.4.4 Comparison of Methods

Studies have shown that nuclear gauges and electromagnetic gauges report densities that lower than densities derived from measurements on pavement cores. Although results from gauges have been shown to be comparable, electromagnetic gauges have been shown to report densities lower than those reported by nuclear gauges. One study indicated that the variability of measurements from electromagnetic gauges was lower than that of measurements from nuclear gauges, while another indicated the opposite to be true.

3.0 EXPERIMENT DESIGN

A major part of this research effort was to conduct field and laboratory studies. Prior to conducting the studies, several research questions were developed to address the specific needs of ODOT. This section presents the research needs, experiment designs for the field and laboratory studies, and a description of the projects investigated.

3.1 RESEARCH NEEDS

At the request of ODOT personnel, several questions were formulated to guide the efforts undertaken in this project. These were developed to address specific issues concerning density measurement of dense-graded hot mix asphalt concrete (HMAC) pavement using cores and nuclear gauges. The specific questions that were formulated are as follows:

1. Is the current calibration procedure for nuclear gauges used by ODOT valid?
2. Is it appropriate to use of the saturated surface-dry (SSD) method for determining the bulk specific gravity of a core even if the water absorption of the core is greater than 2% (as currently allowed by ODOT)?
3. Is there a significant difference between nuclear gauge correlation factors derived from cores obtained from the corner of the overlapping portion of the nuclear gauge measurement footprint (Figure 2.5) and cores obtained from the center of the overlapping portion of the footprint?
4. Is there a significant difference between the bulk specific gravity of HMAC blocks cut from pavements using a lapidary saw blade and cores cut using conventional diamond-tipped barrels?
5. Is it necessary to determine nuclear gauge correlation factors for each lift of HMAC placed in multiple lifts with the same mix design for each lift?
6. For projects incorporating different mix designs for individual lifts (e.g., use of a rich binder base), is there a significant difference between nuclear gauge correlation factors for the different mixtures?
7. On mill-and-inlay-plus-overlay projects, is there a significant difference between the nuclear gauge correlation factors for the inlay material and the overlay material?
8. Can a dedicated location marked on a particular pavement lift be used to spot-check nuclear gauge readings to determine if recalibration of a particular nuclear gauge is necessary?

3.2 EXPERIMENT PLANS

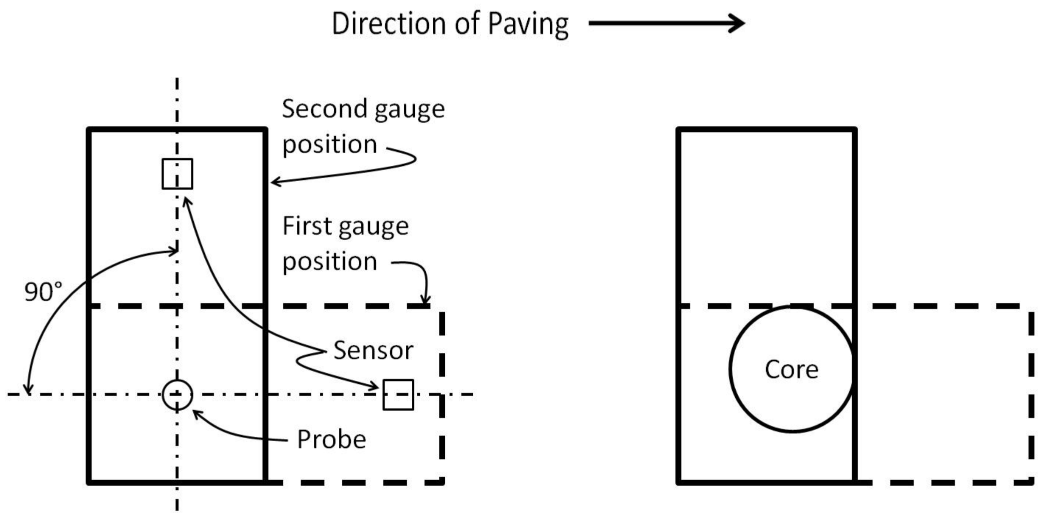
This section describes the experiment plans developed to gather evidence to answer the questions listed in the previous section. It should be noted that experiments were not required for the first and second questions. Evidence for the first question regarding the validity of ODOT's calibration procedure for nuclear gauges was gathered through objective assessment of the procedure. Evidence for the second question, regarding the appropriateness of using the SSD method for measuring the bulk specific gravity of pavement cores with water absorption greater than 2%, was gathered through a thorough review of the literature (Chapter 2.0). Experiments were conducted to gather evidence to answer the remaining questions, as described below.

3.2.1 Core Location under Nuclear Gauge Footprint

Table 3.1 summarizes the experiment design developed to determine if the nuclear gauge correlation factors are affected by core location beneath the gauge (i.e., to gather evidence to answer the third question in Section 3.1). Ten locations in the outside, westbound lane along the Fort Hill – Wallace Bridge project on OR 18 (see Section 3.3.1) were selected randomly according to the procedure described in AASHTO PP 52-05. At five locations, nuclear gauge measurements were made in accordance with WAQTC TM 8, as indicated in Figure 3.1a where the gauge was rotated about the probe, and cores were extracted from the corner of the overlapping footprints as indicated in Figure 3.1b. At the other five locations, nuclear gauge measurements were also made in accordance with WAQTC TM 8 with the exception that the gauge was rotated about its centerline (midway between the probe and sensor) as indicated in Figure 3.2a, and cores were extracted from the center of the overlapping footprints as indicated in Figure 3.2b.

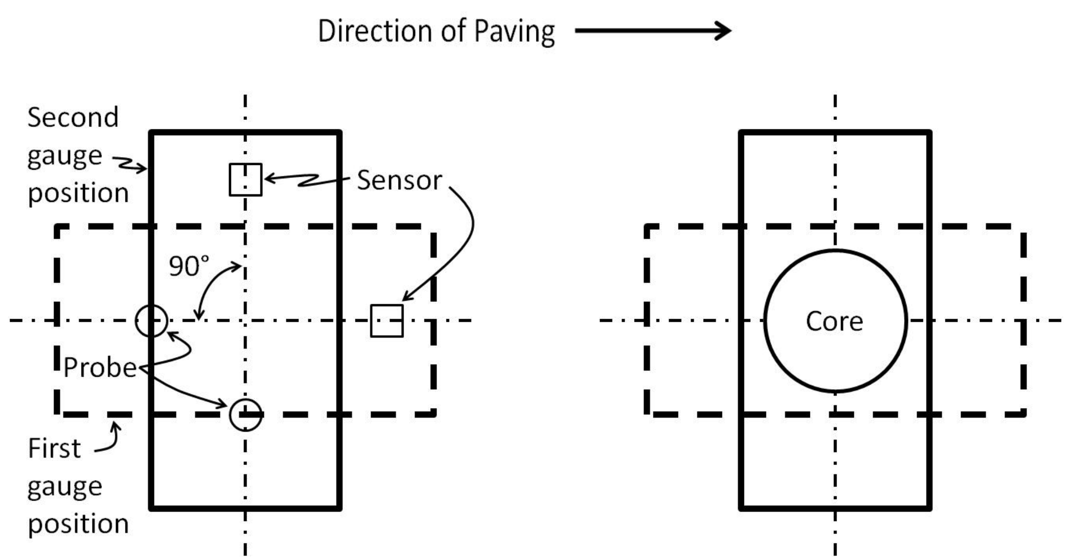
Table 3.1: Experiment Design for Core Location under Gauge Footprint

Nuclear Gauge Footprint Shape	Sample Locations	Nuclear Gauge Measurements		Bulk Specific Gravity			
		No. of Gauges	No. of Readings per Location (for each gauge)	Cores	AASHTO T 166 (Method A)	AASHTO T 166 (Method C)	AASHTO T 331
L-Shaped	5	2	4	5	5	5	5
Cross-Shaped	5	2	4	5	5	5	5



a) Measurement Positions b) Core Location

Figure 3.1: Measurement Positions and Core Location for the 'L-shaped' Footprint



a) Measurement Positions b) Core Location

Figure 3.2: Measurement Positions and Core Location for the 'Cross-shaped' Footprint

Following extraction, the cores were taken to the Oregon State University (OSU) laboratories and tested for bulk specific gravity in accordance with AASHTO T 166 Methods A and C (SSD methods) and AASHTO T 331 (automatic vacuum sealing method). The specific gravities were converted to densities by multiplying by the unit weight of water. This experiment plan allowed comparison of the average density difference (between core densities and gauge measurements) obtained from each core location (see Chapter 6.0)

3.2.2 Core Damage Assessment

Table 3.2 summarizes the experiment plan developed to determine if there was a difference between the bulk specific gravity of blocks cut using a lapidary saw blade and the bulk specific gravity of cores cut using a conventional diamond-tipped core bit (i.e., to gather evidence to answer the fourth question in Section 3.1). Five locations in the northbound, outside lane along the South Medford Interchange project on I-5 (see Section 3.3.2) were selected randomly according to the procedure described in AASHTO PP 52-05. Two blocks approximately 8 inches square (in plan view) were cut from the pavement at each sample location using a hand saw with a conventional asphalt cutting blade having a diamond-impregnated cutting edge. At the OSU laboratories, the perimeter of the blocks were trimmed using a saw with a lapidary blade to provide a very smooth edge, while the top and bottom of the blocks were left uncut.

Table 3.2: Experiment Design for Pavement Material Cutting Method

Sample Locations	Blocks	AASHTO T 166 (Method A)	Cores	AASHTO T 166 (Method A)
5	10	10	10	10

The blocks were tested for bulk specific gravity in accordance with AASHTO T 166 Method A (SSD method). Cores were cut from the center of the blocks using a conventional diamond-tipped core bit and tested for bulk specific gravity in accordance with AASHTO T 166 Method A (SSD method). This experiment plan allowed comparison of the bulk specific gravities of the blocks with the bulk specific gravities of the cores cut from the blocks (see Chapter 6.0).

3.2.3 Correlation Factors for Multi-Lift Pavements with a Single Mix Design

Table 3.3 summarizes the experiment design used to determine if it was necessary to calibrate nuclear gauge measurements to densities derived from cores for each lift of a pavement with multiple lifts having the same mix design (i.e., to gather evidence to answer the fifth question in Section 3.1). Although the principal objective was to evaluate the need for calibrating nuclear gauge measurements to core densities, availability of two electromagnetic gauges allowed inclusion of these gauges in the experiment.

Table 3.3: Experiment Design for Gauge Correlation Factors for Multi-Lift Pavements with a Single Mix Design

Pavement Lift	Sample Locations	Nuclear Gauge Measurements		Electromagnetic Gauge Measurements		Bulk Specific Gravity			
		No. of Gauges	No. of Readings per Location (for each gauge)	No. of Gauges	No. of Readings per Location (for each gauge)	Cores	AASHTO T 166 (Method A)	AASHTO T 166 (Method C)	AASHTO T 331
First (Bottom)	30	3	4	2	5	30	30	30	30
Second (Middle)	20	3	4	2	5	20	20	20	20
Third (Top)	10	3	4	2	5	10	10	10	10

The eastbound, outside lane of the Fort Hill – Wallace Bridge project on OR 18 (see Section 3.3.1) was selected for this work. A total of 30 sample locations were selected randomly in accordance with AASHTO PP 52-05 along the project, ten locations for each lift as illustrated conceptually in Figure 3.3. Following placement of the first lift of HMAC, nuclear gauge measurements were made and cores were taken at 10 of the 30 predetermined locations. Similarly, nuclear gauge measurements were made and cores were taken at ten different locations of the 30 predetermined locations after the second and third lifts were paved. Electromagnetic gauge measurements were also made on the second and third lifts prior to extracting the cores.

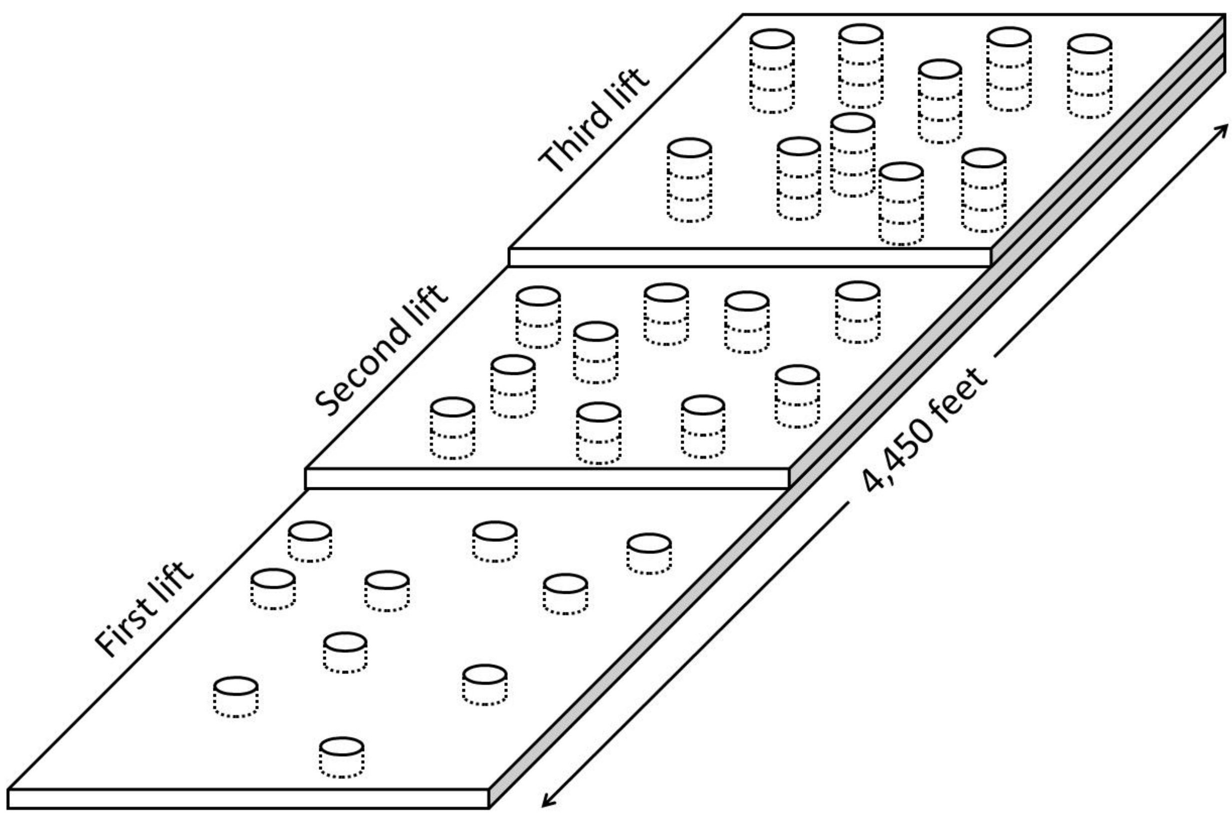


Figure 3.3: Conceptual Layout of Sample Locations in the Eastbound, Outside Lane of OR 18

The cores were tested in the OSU laboratories for bulk specific gravity in accordance with AASHTO T 166 Methods A and C (SSD methods) and AASHTO T 331 (automatic vacuum sealing method). In the case of the cores from the second and third lifts of paving, this involved testing the whole core (AASHTO T 166 Method A and AASHTO T 331), cutting it into individual lifts, and testing the core slices using all three methods.

The experiment design allowed comparison of the densities derived from cores with the densities measured by the gauges. The data were used to determine if core correlations were necessary, as well as to determine if core correlations are required on each lift of paving when all lifts have the same mix design (see Chapter 6.0).

3.2.4 Correlation Factors for Pavement Lifts with Different Mix Designs

Table 3.4 summarizes the experiment design to determine if there is a difference between nuclear gauge correlation factors for individual lifts of a pavement with lifts having different mix designs (i.e., to gather evidence to answer the sixth question in Section 3.1). The South Medford Interchange project on I-5 (see Section 3.3.2) was selected for this work. A total of 20 sample locations were selected randomly in accordance with AASHTO PP 52-05 along the project, ten locations for each lift as illustrated conceptually in Figure 3.4. Following placement of the first lift of HMAC, nuclear gauge measurements were made and cores were taken at 10 of the 20 predetermined locations. Similarly, nuclear gauge measurements were made and cores were taken at 10 different locations of the 20 predetermined locations after the second lift was paved.

Table 3.4: Experiment Design for Gauge Correlation Factors for Multi-Lift Pavements with a Different Mix Designs

		Nuclear Gauge Measurements		Bulk Specific Gravity			
Pavement Lift	**Sample Locations**	**No. of Gauges**	**No. of Readings per Location (for each gauge)**	**Cores**	**AASHTO T 166 (Method A)**	**AASHTO T 166 (Method C)**	**AASHTO T 331**
First[1] (Bottom)	10	3	4	10	10	10	10
Second[2] (Top)	10	4	4	10	10	10	10
[1]Rich binder base course							
[2]Level 4 base course							

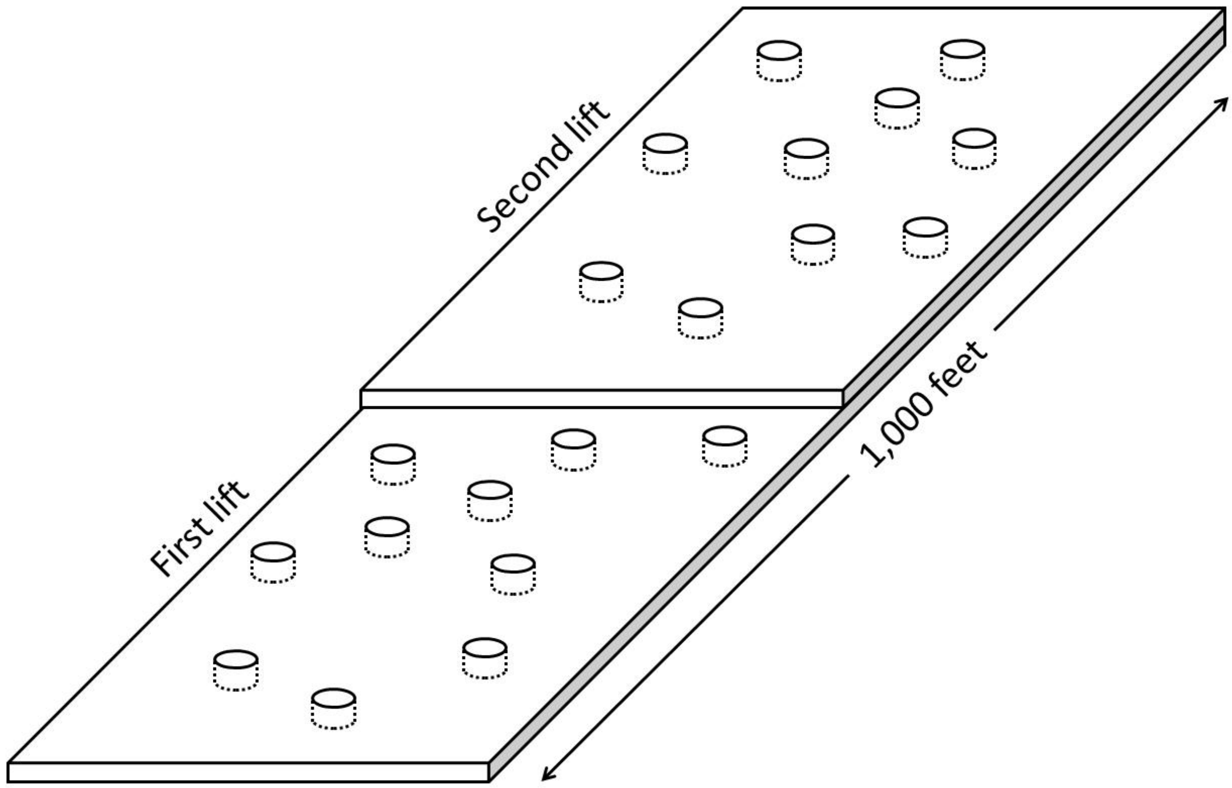


Figure 3.4: Conceptual Layout of Sample Locations along the I-5 Project

The experiment design allowed comparison of the densities derived from cores with the densities measured by the gauges. The data were used to determine if core correlations are necessary as well as to determine if core correlations are required on each lift of paving when the lifts have different mix designs (see Chapter 6.0).

3.2.5 Correlation Factors for Inlays and Overlays with the Same Mix Design

Table 3.5 summarizes the experiment design to determine if the nuclear gauge correlation factors are different for inlays and overlays having the same mix design (i.e., to gather evidence to answer the seventh question in Section 3.1). Although the principal objective was to evaluate the correlation factors for nuclear gauges, availability of two electromagnetic gauges allowed inclusion of these gauges in the experiment.

Table 3.5: Experiment Design for Gauge Correlation Factors for Inlays and Overlays with the Same Mix Design

		Nuclear Gauge Measurements		Electromagnetic Gauge Measurements		Bulk Specific Gravity			
Pavement Lift	**Sample Locations**	**No. of Gauges**	**No. of Readings per Location (for each gauge)**	**No. of Gauges**	**No. of Readings per Location (for each gauge)**	**Cores**	**AASHTO T 166 (Method A)**	**AASHTO T 166 (Method C)**	**AASHTO T 331**
First (Inlay)	20	3	4	2	5	20	20	20	20
Second (Overlay)	10	3	4	2	5	10	10	10	10

The eastbound lane of the North Fork Little Butte Creek to Great Meadow Snow Park project on OR 140 (see Section 3.3.3) was selected for this work. Twenty sample locations were selected randomly in accordance with AASHTO PP 52-05 along the project, ten locations for each lift as illustrated conceptually in Figure 3.5. Following placement of the first (inlay) lift of HMAC, nuclear gauge measurements were made and cores were taken at 10 of the 20 predetermined locations. Similarly, nuclear gauge measurements were made and cores were taken at ten different locations of the 20 predetermined locations after the second (overlay) lift was paved. Electromagnetic gauge measurements were also made on each lift prior to extracting the cores.

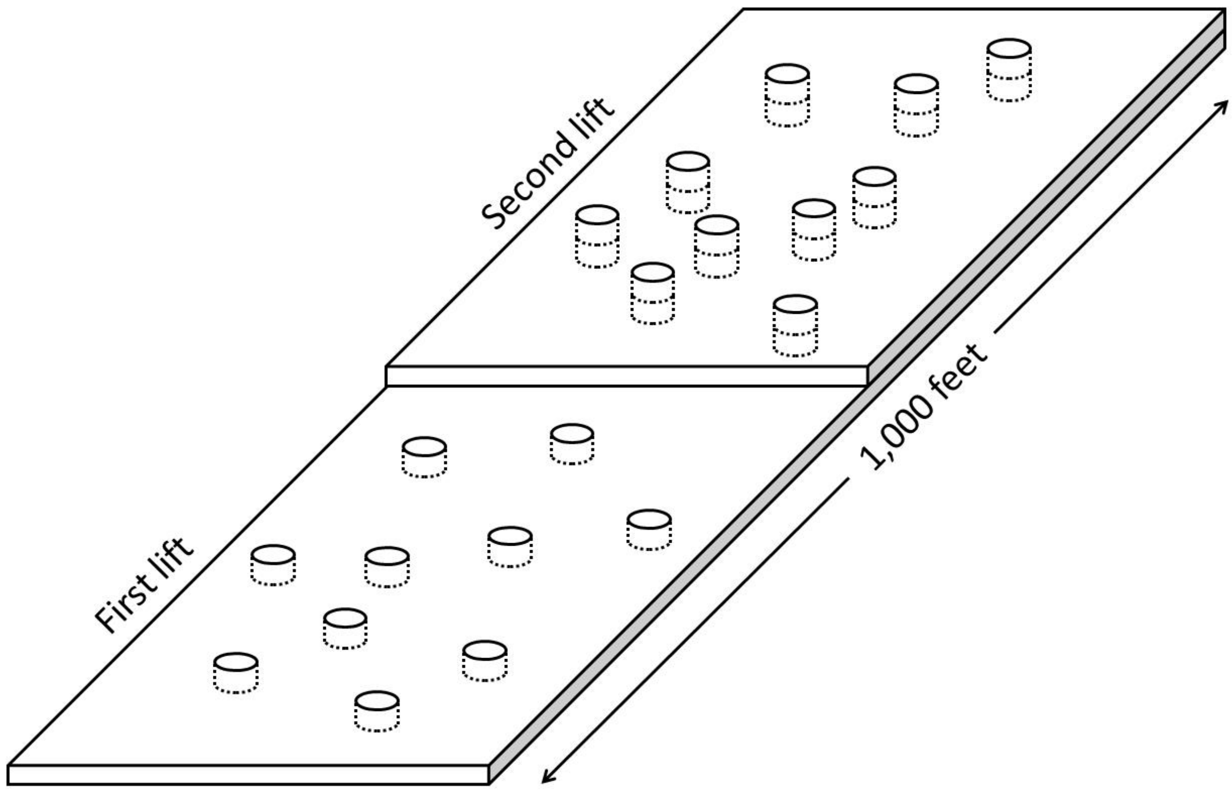


Figure 3.5: Conceptual Layout of Sample Locations along the OR 140 Project

The cores were tested in the OSU laboratories for bulk specific gravity in accordance with AASHTO T 166 Methods A and C (SSD methods) and AASHTO T 331 (automatic vacuum sealing method). In the case of the cores from the second lift of paving, this involved testing the whole core (AASHTO T 166 Method A and AASHTO T 331), cutting it into individual lifts, and testing the core slices using all three methods.

The experiment design allowed comparison of the densities derived from cores with the densities measured by the gauges. The data were used to determine if core correlations are necessary as well as to determine if core correlations are required for inlays and overlays when each have the same mix design (see Chapter 6.0).

3.2.6 Gauge Spot-Check Location

Originally, it was planned to mark an area on one lift of one of the projects so that nuclear gauge measurements could be taken over a period of multiple days. The intent was to gather evidence to determine if a dedicated location on a pavement surface could be used to spot-check a gauge to determine if recalibration was necessary. The plan was to select a location in a gore area on one of the projects for this purpose. This was not possible on the OR 140 project since it was a mill-and-inlay-plus-overlay project with no gore areas, nor was it possible on the I-5 project due to work zone constraints. There were gore areas on the OR 18 project, but the areas were paved in the same manner as the mainline whereby the first lift was covered by the second, and the second was covered by the third. Due to the construction sequence, a location on the first or second lift could not be easily reestablished, nor would it provide the required information. Hence, data were not collected to determine if a location could be used to spot-check nuclear gauges.

3.3 PROJECTS EVALUATED

Three paving projects were selected for the purposes of conducting the field work for this project. Two involved new work sections and the other involved rehabilitation work. All projects incorporated dense-graded HMAC. Brief descriptions of each of the projects are provided in the following sections.

3.3.1 Fort Hill – Wallace Bridge Project on OR 18

Figure 3.6 illustrates the sampling areas on the Fort Hill – Wallace Bridge project. On this widening project, the eastbound lanes were new work (new construction) while the westbound lanes were rehabilitation work (mill and overlay). The base course for the new work section was constructed in three lifts, all with Level 3, 1/2 inch dense-graded HMAC, and all with the same mix design. The plans specified a 3 inch thickness for the first lift and 2 inch thickness for the second and third lifts. Two inches of the existing pavement was removed from the westbound lanes and replaced with a Level 3, 1/2 inch dense-graded HMAC leveling course that varied in depth from approximately 2 to 6 inches. The base course in the eastbound direction and the leveling course in the westbound direction were capped with a wearing course, but all work described herein was conducted on the lifts prior to placement of the wearing course.

The data collected in the field and the laboratory test results from cores obtained from this project were used to gather evidence to answer the third and fifth questions listed in Section 3.1. That is, to determine if the nuclear gauge correlation factors are affected by core location beneath the gauge, and to determine if it is necessary to calibrate nuclear gauge measurements to densities derived from cores for each lift of a pavement with multiple lifts having the same mix design.

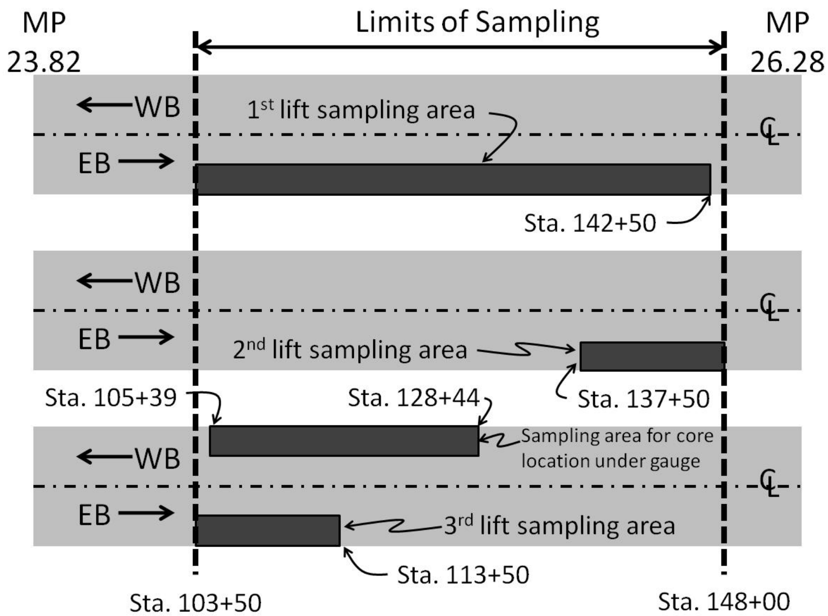


Figure 3.6: Sampling Limits the Fort Hill – Wallace Bridge Project on OR 18

3.3.2 South Medford Interchange Project on Interstate 5 (I-5)

This was a new pavement construction (new work) project wherein the first lift of the base course had a different mix design than the remaining lifts. That is, the design binder content for the rich binder base layer was determined using a target air void content of 3% (rather than 4%) resulting in a content that was 0.8% higher than that of overlying base course layers. The first two lifts were each nominally 3 inches thick.

The blocks (for core damage assessment) were obtained from the first lift (rich bottom base layer) that was paved along the outside shoulder just south of a viaduct as indicated in Figure 3.7. These were obtained to gather evidence for the fourth research question in Section 3.1; that is, to determine if there is a difference between the bulk specific gravities of HMAC blocks cut with a lapidary saw blade and those of cores cut from the blocks using a conventional diamond-tipped core barrel.

The field work for nuclear gauge measurements and core sampling was done on the first two lifts of the base course in the northbound, outside lane approximately between Stations 252+00 and 264+00 as indicated in Figure 3.7. The data collected in the field and the laboratory test results from cores obtained from this project were used to gather evidence to answer the sixth question listed in Section 3.1; that is, to determine if there is a difference between nuclear gauge correlation factors for individual lifts of a pavement with lifts having different mix designs.

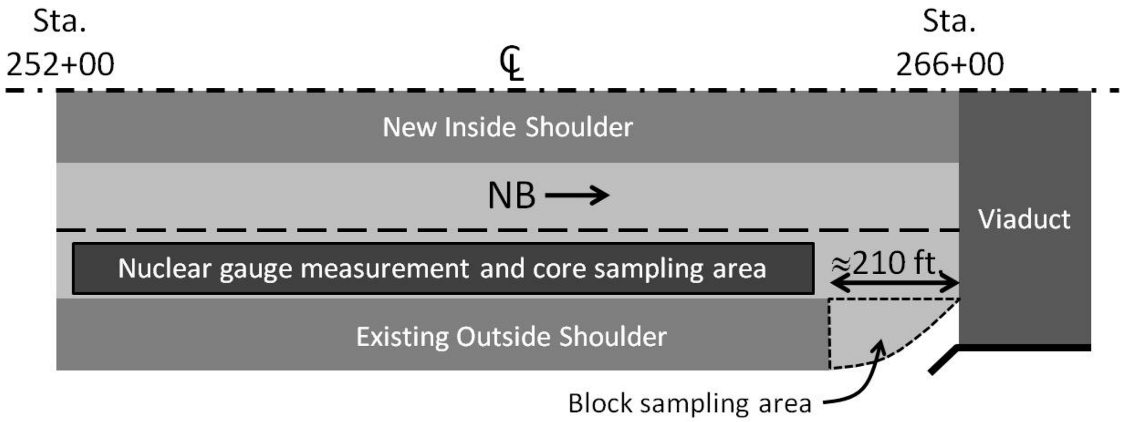


Figure 3.7: Sampling Areas along the South Medford Interchange Project on I-5.

3.3.3 North Fork Little Butte Creek to Great Meadow Snow Park on Oregon Highway 140 (OR 140)

This was a mill-and-inlay-plus-overlay rehabilitation project with the inlay and overlay having the same mix design. Along the portion of the project used for this study (Stations 325+88 to 337+50), 2 inches of the existing pavement was removed and replaced with a Level 3, lime-treated, 1/2 inch dense-graded HMAC base course (inlay). This was capped with a Level 3, lime-treated, 1/2 inch dense-graded HMAC base course (overlay). The plans specified a nominal thickness of 2 inches for both lifts.

The data collected in the field and the laboratory test results from cores obtained from this project were used to gather evidence to answer the seventh question listed in Section 3.1. That is, to determine if the nuclear gauge correlation factors are different for inlays and overlays having the same mix design.

4.0 FIELD STUDY

A small component of the field study involved assessing the nuclear gauge calibration procedure utilized by ODOT, whereas the bulk of the work involved obtaining density measurements using nuclear and electromagnetic gauges at predetermined locations along each of the projects investigated. Following the density measurements, cores were obtained from the locations where gauge measurements were made and subsequently tested as detailed in Chapter 5.0. This section provides details and results of the field study.

4.1 NUCLEAR GAUGE CALIBRATION PROCEDURE ASSESSMENT

The first task undertaken to assess ODOT's nuclear gauge calibration procedure was to critically review the procedure detailed in ODOT TM 304 (see Section 2.2.1 for a summary of the procedure). As noted, the gauge is allowed to stabilize to room temperature, turned on and allowed to warm up for ten minutes, and then it is run though a series of checks for standard count, hot substrate readings, density determinations on blocks of known density, and moisture density determinations on a block with a standard moisture content. Gauges that fail any of these checks require repair and/or recalibration. Calibration involves taking readings in both the backscatter and the direct transmission modes of operation on blocks with known densities. The readings are then entered into a computer program to determine the calibration constants for the gauge. The constants are then entered manually into the gauge and the gauge is then rechecked for accuracy.

The procedure is rigorous and robust, particularly owing to the multistep checks including one that assesses the impact of a hot substrate that simulates operation of the gauge on a hot pavement mat. Assessment of the procedure revealed that it conforms to ASTM D 2950 except with regard to the density criterion on the high-density block, has fewer pre-calibration checks and requires fewer blocks than the procedures from some states, but has more stringent tolerances than that required by some states (see Section 2.2.1).

Having critically reviewed the ODOT TM 304 procedure, a checklist was developed (Appendix B) outlining the required apparatus and procedures identified in ODOT TM 304. This served as an instrument for objectively assessing execution of the procedures by ODOT personnel. With the checklist in hand, OSU researchers observed ODOT quality assurance personnel at the Region 1 (Portland) and Region 2 (Salem) laboratories demonstrate the procedures. In both cases, the procedures were performed by the QA personnel without having to refer ODOT TM 304 indicating complete familiarity with the procedures. In addition, in both cases, all elements of the checklist were satisfied indicating that, in the view of the OSU observers, the procedures were followed in accordance with ODOT TM 304.

Having verified, at least in two region laboratories, that QA personnel were following the procedures contained in ODOT TM 304, efforts were made to validate the procedures through comparisons of ODOT's procedures with those used by other states. Section 2.2.1 summarized the procedures and criteria used by several other states. The principal findings from these comparisons can be summarized as follows:

- ODOT's procedures are not substantially different from those of the other states with the exception that none of the other states, for which procedures were summarized, utilize the hot substrate test.
- A few agencies require a stability check and one requires a drift check prior to calibration, whereas neither is required by ODOT.
- A few agencies require calibration on more blocks than ODOT.
- The tolerances used by ODOT for acceptance of a gauge calibration are more stringent or comparable to those utilized by the other states reviewed.

4.2 FIELD TESTING AND SAMPLING

On each project, the predetermined sample locations (station and offset) were located and marked on the pavement surface as shown in Figure 4.1. A small amount of mineral filler (used in the mixture) was then spread out on each location and leveled (Figure 4.2) so as to minimize the effect of surface irregularities of the pavement on the gauge density readings. Each nuclear gauge was then checked against standard count (Figure 4.3) and density measurements were obtained (Figure 4.4). The nuclear gauge measurements were made in accordance with the WAQTC TM 8, except that the gauge was rotated about its longitudinal and transverse centerlines as indicated by the sequence of measurement illustrated in Figure 4.5.

Figure 4.1: Sample Location Marked on Pavement

Figure 4.2: Sanding the Sample Location

Figure 4.3: Checking Nuclear Gauge Standard Count

Figure 4.4: Density Measurement via Nuclear Gauge

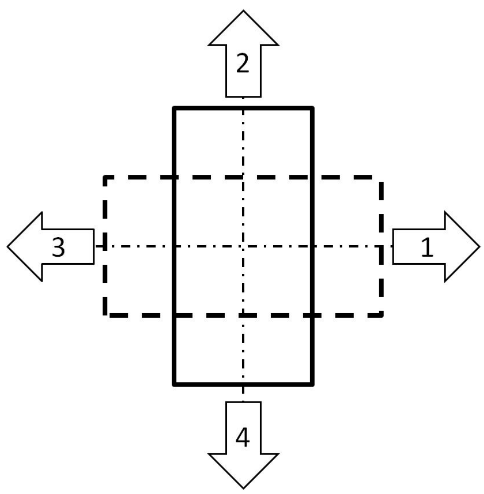


Figure 4.5: Sequence of Nuclear Gauge Density Measurements

On several of the lifts, density measurements were also obtained using electromagnetic gauges (Figure 4.6). In some cases, the electromagnetic gauge measurements were made prior to sanding the location with mineral filler. In all cases, the measurements were made in the center and at four locations around the perimeter of the overlapping footprint as illustrated in Figure 4.7. Finally, a core was extracted from each location using a conventional diamond-tipped core barrel (Figure 4.8).

Figure 4.6: Density Measurement via Electromagnetic Gauge

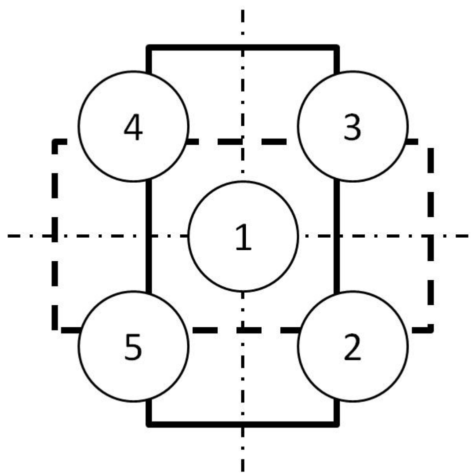


Figure 4.7: Sequence of Electromagnetic Gauge Density Measurements

Figure 4.8: Extracting Pavement Core

Loose HMAC was also obtained from the pavements immediately following the paving operation (i.e., immediately before compaction) so that the theoretical maximum specific (Rice) gravity of the mixture could be measured. The loose HMAC was obtained by randomly sampling the mat using a ‘cookie cutter’ (Figure 4.9) behind the paver in accordance with AASHTO T 168 at different times during the paving operation to account for potential variability in the theoretical maximum specific (Rice) gravity.

On the I-5 project, blocks were cut from the pavement at locations different from the locations where cores were obtained. This involved marking the outline of the blocks and cutting along the marks using a hand saw with an asphalt blade. Figure 4.10 shows an example of the saw cuts in the pavement. As indicated, a narrow block was cut at the end of the two square blocks. This was done so that it could be removed first and to allow room to pry up the adjacent square block from the bottom of the block so as to prevent damage during the removal process.

Figure 4.9: ‘Cookie Cutter’ for Sampling the Loose HMAC

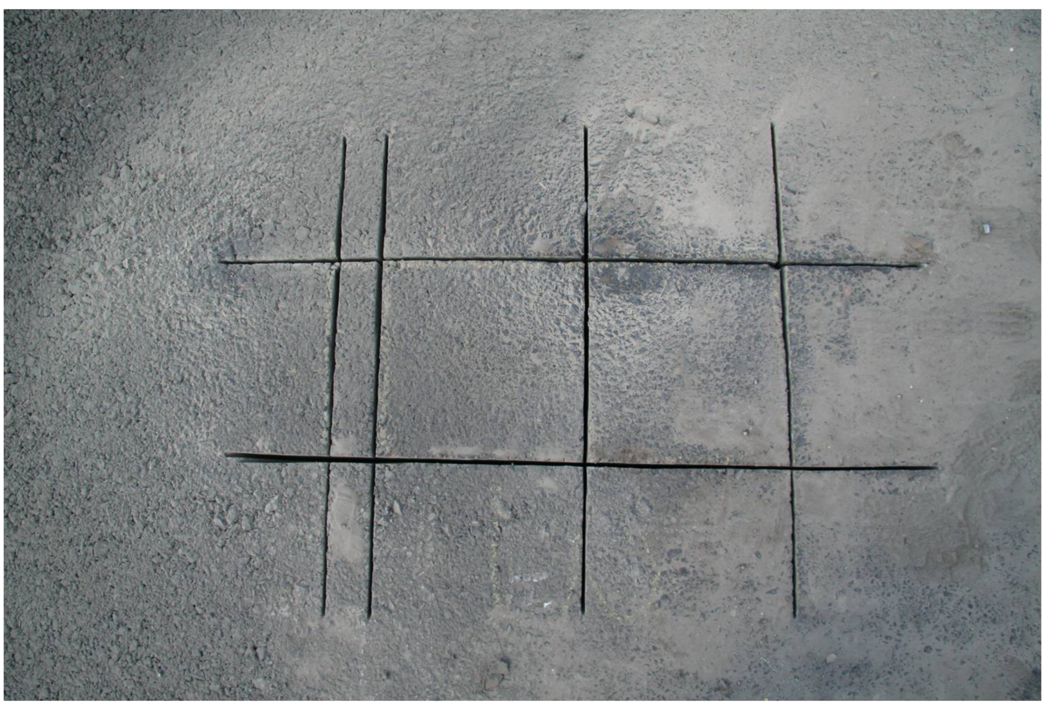


Figure 4.10: Saw Cuts in Pavement to Obtain Pavement Blocks

4.3 FIELD TEST RESULTS

This section presents the results of nuclear gauge measurements and, where appropriate, electromagnetic gauge measurements from each paving lift of each project evaluated during the field study. In addition to the density results, information regarding the gauge operator, gauge identification, and date of last calibration is provided. Further details (e.g., type of mix, date of testing, lift thickness, etc.) are provided in Appendix C.

4.3.1 Core Location under Nuclear Gauge Footprint

Tables 4.1 and 4.2 summarize the gauge data collected to investigate if core correlation factors derived from cores obtained from the 'L-shaped' footprint (indicated in Figure 3.1) are significantly different from those derived from cores obtained from the 'cross-shaped' footprint (indicated in Figure 3.2), respectively. The data were collected by performing the measurements on the leveling course in the westbound lanes of the OR 18 project (see Section 3.3.1). Only two readings were obtained for the 'L-shaped' footprint.

Note that Table 4.1 indicates close agreement between the gauges with regard to the average densities derived from the 'L-shaped' footprints. Table 4.2 also indicates close agreement between the gauges for average densities derived from the 'cross-shaped' footprints.

Table 4.1: Data Obtained from the 'L-shaped' Footprint

Make, Model, and Serial Number	Nuclear Gauges	
	Troxler 3430 # 38806	Troxler 3430 # 38994
Date of Calibration	2/12/2009	1/14/2009
Sample Location	Avg. Density, lb/ft^3	Avg. Density, lb/ft^3
	Two readings	Two readings
12	149.7	151.0
14	147.8	148.6
16	153.7	152.5
18	151.1	152.7
20	153.8	153.7
Average, lb/ft^3	151.2	151.7
Standard Deviation, lb/ft^3	2.6	2.0
Coefficient of Variation	1.7%	1.3%

Table 4.2: Data Obtained from the 'Cross-shaped' Footprint

Make, Model, and Serial Number	Nuclear Gauges			
	Troxler 3430 # 38806		Troxler 3430 # 38994	
Date of Calibration	2/12/2009		1/14/2009	
Sample Location	Avg. Density, lb/ft^3		Avg. Density, lb/ft^3	
	Four readings	Two readings	Four readings	Two readings
11	150.8	150.0	151.9	151.4
13	152.2	151.9	153.4	152.7
15	149.2	149.2	150.4	150.3
17	153.2	153.3	152.5	152.6
19	154.3	154.3	154.7	154.6
Average, lb/ft^3	151.9	151.7	152.6	152.3
Standard Deviation, lb/ft^3	2.0	2.2	1.6	1.6
Coefficient of Variation	1.3%	1.4%	1.1%	1.1%

4.3.2 Core Damage Assessment

The field work to investigate if there is a difference between the bulk specific gravity of blocks cut using a lapidary saw blade and the bulk specific gravity of cores cut using a conventional diamond-tipped core bit only involved sampling. Hence, nuclear gauge measurements were not conducted for this effort.

4.3.3 Multi-Lift Pavements with a Single Mix Design

Tables 4.3 to 4.5 summarize the gauge data collected to investigate density measurements on new construction projects where the base course of the pavement was placed in multiple lifts with each lift having the same mix design (see Section 3.3.1). Table 4.3 includes the data for the first (bottom) lift over the aggregate base, Table 4.4 includes the data for the second (middle) lift, and Table 4.5 includes the data for the third (top) lift of the base course.

The results indicate that, for each nuclear gauge used, the average densities based on two readings and four readings were very similar. In most cases, the coefficient of variation was less than about 2% indicating very low variability in the results. Also, note that the coefficients of variance of the nuclear gauges were higher than those of the electromagnetic gauges in most of the instances. On the bottom and middle lifts (Tables 4.3 and 4.4, respectively), there was at most a 1.7 lb/ft^3 difference in average density between nuclear gauge measurements while, on the top lift (Table 4.5), there was at most a 3 lb/ft^3 difference. Tables 4.4 and 4.5 indicate that the average densities obtained from the electromagnetic gauges were consistently lower than those obtained from the nuclear gauges.

Table 4.3: Data Obtained from the First Lift of the OR 18 Project

Make, Model, and Serial Number	Nuclear Gauges					
	Troxler 3430 # 38804		Troxler 3430 # 38806		Troxler 3440 # 25714	
Date of Calibration	N/A		4/28/2008		3/7/2008	
Sample Location	Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Avg. Density, lb/ft^3	
	Four readings	Two readings	Four readings	Two readings	Four readings	Two readings
1	155.5	155.6	153.7	153.7	155.0	154.5
2	149.2	148.7	149.8	149.5	147.5	147.5
3	147.4	148.8	150.5	150.2	148.0	148.1
4	151.0	150.9	152.7	152.6	150.9	151.1
5	152.6	152.6	152.7	153.4	150.4	150.7
6	156.6	157.1	156.1	156.0	154.3	154.3
7	158.1	157.9	157.7	158.0	156.7	157.0
8	151.7	151.9	152.7	153.1	150.7	151.2
9	156.4	156.5	156.8	156.8	155.2	154.7
10	154.4	154.5	155.7	155.2	153.9	153.5
Average, lb/ft^3	153.3	153.4	153.8	153.8	152.3	152.2
Standard Deviation, lb/ft^3	3.5	3.4	2.7	2.7	3.2	3.1
Coefficient of Variation	2.3%	2.2%	1.7%	1.8%	2.1%	2.0%

Table 4.4: Data Obtained from the Second Lift of the OR 18 Project

Make, Model, and Serial Number	Nuclear Gauges						Electromagnetic Gauges	
	Troxler 3440 # 30860		Troxler 3430 # 38806		Troxler 3440 # 25714		PQI 301	PQI 300
Date of Calibration	2/5/2008		4/28/2008		3/7/2008		N/A	N/A
Sample Location	Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Average Density, lb/ft^3	Average Density, lb/ft^3
	Four readings	Two readings	Four readings	Two readings	Four readings	Two readings		
1	152.3	152.4	152.0	152.0	151.1	150.9	149.54	149.44
2	151.9	151.3	151.1	151.2	149.8	150.1	150.04	149.48
3	149.9	150.5	148.8	148.2	147.1	146.9	147.74	148.06
4	152.1	151.6	150.8	150.8	149.9	150.0	147.02	146.24
5	154.4	154.1	153.2	153.1	152.2	152.3	148.48	147.68
6	151.9	151.8	151.9	151.6	150.7	150.9	148.6	148.42
7	152.1	152.2	152.1	152.3	151.1	151.3	148.44	147.76
8	152.2	151.5	150.8	150.1	151.0	151.7	148.46	148.2
9	153.0	152.8	152.2	151.8	151.1	151.4	148.02	149.58
10	152.7	152.6	152.4	152.8	152.0	152.2	149.5	148.34
Average, lb/ft^3	152.2	152.0	151.5	151.4	150.6	150.7	148.6	148.3
Standard Deviation, lb/ft^3	1.1	1.0	1.2	1.4	1.4	1.6	0.9	1.0
Coefficient of Variation	0.73%	0.65%	0.81%	0.94%	0.96%	1.0%	0.61%	0.69%

Table 4.5: Data Obtained from the Third Lift of the OR 18 Project

Make, Model, and Serial Number	Nuclear Gauges						Electromagnetic Gauges					
	Troxler 3440 # 30860		Troxler 3430 # 38806		Troxler 3440 Plus # 39525		PQI 301 (sand)	PQI 301 (no sand)	PQI 300 (sand)		PQI 300 (no sand)	
Date of Calibration	2/5/2008		4/28/2008		1/24/2008		N/A	N/A	N/A		N/A	
Sample Location	Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Average Density, lb/ft^3	Average Density, lb/ft^3	Average Density, lb/ft^3	Average Moisture Content, percent	Average Density, lb/ft^3	Average Moisture Content, percent
	Four readings	Two readings	Four readings	Two readings	Four readings	Two readings						
1	151.5	151.5	151.6	152.0	155.0	155.0	148.1	N/A*	148.4	6.0	N/A*	N/A*
2	154.3	153.5	154.9	155.3	155.4	155.1	149.9	N/A*	150.5	6.6	N/A*	N/A*
3	152.5	153.3	151.9	152.2	154.7	154.9	147.9	148.1	148.1	6.1	147.0	6.2
4	150.6	150.3	149.8	150.1	152.9	153.1	147.4	147.7	147.8	5.9	147.2	6.1
5	150.0	149.8	148.6	147.6	152.8	152.5	147.7	146.2	147.8	6.3	146.0	6.4
6	151.2	151.6	151.0	151.1	153.1	152.9	149.3	149.1	149.7	6.7	147.4	6.7
7	148.9	148.6	147.8	149.3	152.3	152.3	148.2	148.0	148.2	6.2	147.3	6.5
8	150.3	150.1	150.2	150.1	152.8	152.7	148.3	148.4	148.3	6.4	147.2	6.5
9	145.1	144.9	144.5	145.1	148.4	148.5	145.2	144.6	145.7	5.8	143.9	5.8
10	149.4	149.6	148.9	149.3	152.2	152.2	148.3	147.9	148.7	6.5	146.9	6.7
Average, lb/ft^3	150.4	150.3	149.9	150.2	152.9	152.9	148.0	147.5	148.3	6.2	146.6	6.4
Standard Deviation, lb/ft^3	2.4	2.5	2.8	2.8	2.0	1.9	1.2	1.4	1.3	0.3	1.2	0.3
Coefficient of Variation	1.6%	1.6%	1.8%	1.8%	1.3%	1.3%	0.83%	0.98%	0.85%	4.7%	0.81%	5.0%

*The location was already sanded before the density measurements could be made in the un-sanded condition

4.3.4 Pavement Lifts with Different Mix Designs

Tables 4.6 and 4.7 summarize the gauge data collected to investigate density measurements on new construction projects where the base course of the pavement was placed in multiple lifts with each lift having a different mix design (see Section 3.3.2). Table 4.6 includes the data for the first (bottom) lift (rich binder base layer) over the aggregate base and Table 4.7 includes the data for the second lift of the base course. For each nuclear gauge used, note the similarity of average density based on two readings versus four readings. Also, note the exceptionally low coefficient of variation (less than about 2% in most cases) indicating very low variability in the results. In addition, there was at most a 1.8 lb/ft^3 difference in average density between nuclear gauge measurements.

Table 4.6: Data Obtained from First Lift of the I-5 Project

Gauge Make, Model, and Serial Number	Nuclear Gauges					
	Troxler 3430 # 38996		Troxler 3430 # 38806		CPN MC3 Portaprobe # 7443	
Last date of Calibration	2/26/2009		2/12/2009		7/23/2008	
Sample Location	Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Avg. Density, lb/ft^3	
	Four readings	Two readings	Four readings	Two readings	Four readings	Two readings
1	146.7	146.3	146.4	145.8	146.1	145.8
2	141.6	141.4	141.7	141.8	142.7	143.2
3	144.8	145.0	144.0	144.5	145.4	145.5
4	143.9	143.9	142.5	142.8	144.9	145.0
5	145.9	146.0	144.9	145.1	145.4	145.4
6	144.7	144.9	143.7	143.3	144.4	144.2
7	146.6	146.5	145.3	144.9	146.9	147.0
8	146.3	146.0	144.8	145.1	146.5	146.7
9	146.3	146.5	145.1	145.5	146.6	147.0
10	144.1	143.7	143.8	143.8	144.9	144.8
Average	145.1	145.0	144.2	144.2	145.4	145.4
Standard Deviation	1.6	1.6	1.4	1.3	1.3	1.2
Coefficient of Variation	1.1%	1.1%	0.97%	0.90%	0.87%	0.85%

Table 4.7: Data Obtained from the Second Lift of the I-5 Project

Make, Model, and Serial Number	Nuclear Gauges							
	Troxler 3430 # 38996		Troxler 3430 # 38806		CPN MC3 Portaprobe # 7443		Humboldt 5001C # 1344	
Date of Calibration	2/26/2009		2/12/2009		7/23/2008		4/8/2009	
Sample Location	Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Avg. Density, lb/ft^3	
	Four readings	Two readings	Four readings	Two readings	Four readings	Two readings	Four readings	Two readings
1	144.5	144.4	142.6	142.8	144.1	143.8	N/A*	N/A*
2	146.0	146.0	144.3	144.2	145.5	144.1	145.7	145.9
3	145.8	146.1	143.8	143.7	145.1	145.1	144.7	145.5
4	145.0	144.8	143.2	143.6	144.1	143.7	144.7	144.4
5	142.9	142.7	140.8	140.8	143.0	143.2	142.3	141.8
6	144.0	143.6	141.8	142.1	143.7	143.8	144.3	145.0
7	140.8	141.1	139.7	140.0	141.1	140.4	139.7	139.0
8	143.1	143.2	141.1	141.0	143.6	143.4	142.7	142.3
9	142.8	143.2	140.8	140.7	142.4	141.9	142.1	141.9
10	144.2	144.1	142.8	143.1	143.3	143.8	144.2	144.2
Average, lb/ft^3	143.9	143.9	142.1	142.2	143.6	143.3	143.4	143.3
Standard Deviation, lb/ft^3	1.6	1.5	1.5	1.5	1.3	1.3	1.8	2.2
Coefficient of Variation	1.09%	1.06%	1.04%	1.05%	0.89%	0.91%	1.28%	1.57%

*The location was already sanded before the density measurements could be made in the un-sanded condition

4.3.5 Inlays and Overlays with the Same Mix Design

Tables 4.8 and 4.9 summarize the gauge data collected to investigate density measurements on mill-and-fill-plus-overlay projects with both lifts having the same mix design (see Section 3.3.3). Table 4.8 includes the data for the first (inlay) lift over the aggregate base and Table 4.9 includes the data for the second (overlay) lift of the pavement. For each nuclear gauge used, once again, the average densities based on two readings versus four readings were very similar and the coefficients of variation were very low (less than 3% in all cases). Also, note that the coefficients of variance of the nuclear gauges were always higher than those of the electromagnetic gauges and that the variance of the measurements was higher on the overlay lift. Nevertheless, there was at most a 1.9 lb/ft^3 difference in average density between nuclear gauge measurements. The average densities obtained from the electromagnetic gauges were lower than those obtained from the nuclear gauges except for the density obtained from the PQI 301 on the inlay lift.

Table 4.8: Data Obtained from the First (Inlay) Lift of the OR 140 Project

Make, Model, and Serial Number	Nuclear Gauges						Electromagnetic gauges	
	Troxler 3430 # 38996		Troxler 3430 # 38806		Troxler 3430 # 35601		PQI 301	PQI 300
Date of Calibration	7/31/2008		4/28/2008		8/18/2008		N/A	N/A
Sample Location	Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Average Density, lb/ft^3	Average Density, lb/ft^3
	Four readings	Two readings	Four readings	Two readings	Four readings	Two readings		
1	138.9	139.3	141.0	141.1	140.3	140.5	140.5	138.5
2	141.0	141.2	143.7	143.9	142.7	142.7	141.1	138.6
3	137.4	137.6	139.2	139.2	139.0	138.7	140.3	138.2
4	138.1	138.0	140.7	140.0	140.0	139.9	140.3	139.0
5	138.4	138.8	139.9	140.3	139.4	139.4	140.5	136.4
6	137.4	137.2	139.3	138.7	138.8	139.5	140.1	138.9
7	137.8	137.8	139.1	137.8	139.7	139.5	140.1	138.6
8	134.2	134.0	136.8	136.3	136.0	136.2	139.7	137.3
9	136.5	136.3	138.7	138.5	137.9	138.0	140.1	138.2
10	133.4	133.1	134.1	134.5	134.6	134.5	138.8	134.8
Average, lb/ft^3	137.3	137.3	139.2	139.0	138.8	138.9	140.1	137.9
Standard Deviation, lb/ft^3	2.2	2.4	2.5	2.6	2.3	2.3	0.6	1.3
Coefficient of Variation	1.6%	1.8%	1.8%	1.9%	1.6%	1.6%	0.42%	0.96%

Table 4.9: Data Obtained from the Second (Overlay) Lift of the OR 140 Project

Make, Model, and Serial Number	Nuclear gauges						Electromagnetic gauges	
	Troxler 3430 # 38996		Troxler 3430 # 38806		Troxler 3430 # 35601		PQI 301	PQI 300
Date of Calibration	7/31/2008		4/28/2008		8/18/2008		N/A	N/A
Sample Location	Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Avg. Density, lb/ft^3		Average Density, lb/ft^3	Average Density, lb/ft^3
	Four readings	Two readings	Four readings	Two readings	Four readings	Two readings		
1	140.6	140.9	140.9	140.8	141.2	140.8	139.3	138.8
2	136.6	136.6	137.6	137.6	137.2	136.8	138.2	136.9
3	137.0	137.0	138.1	137.9	135.6	134.3	138.2	136.5
4	138.0	137.9	138.3	137.7	138.3	138.4	138.4	136.8
5	135.5	135.7	135.8	136.5	135.8	136.6	137.3	135.7
6	138.0	137.9	139.3	139.0	139.6	140.0	138.2	136.9
7	142.8	142.9	143.1	142.9	143.5	143.3	139.8	139.4
8	143.0	142.8	144.0	144.7	144.1	143.9	139.8	139.8
9	142.3	142.8	142.7	142.7	143.0	143.5	139.5	138.8
10	144.7	144.1	145.1	144.9	145.7	146.3	140.2	139.7
Average, lb/ft^3	139.8	139.8	140.5	140.5	140.4	140.4	138.9	137.9
Standard Deviation, lb/ft^3	3.2	3.2	3.1	3.2	3.6	3.9	0.9	1.5
Coefficient of Variation	2.3%	2.3%	2.2%	2.2%	2.6%	2.8%	0.68%	1.1%

5.0 LABORATORY STUDY

The laboratory study was undertaken to measure the bulk specific gravity of the cores obtained from the projects evaluated during the field study (see Chapter 4.0), as well as to measure the theoretical maximum specific (Rice) gravity of loose HMAC obtained from the pavements immediately following the paving operation (i.e., immediately before compaction). Bulk specific gravity measurements were performed using the saturated surface-dry (SSD) and automatic vacuum sealing methods. The following sections provide details and results of the laboratory study.

5.1 LABELING OF CORES

The cores extracted from the projects during the field study were labeled, placed in plastic bags, and transported to the asphalt laboratory at Oregon State University (OSU) where they were stored temporarily on shelves. The cores were labeled based on the project highway number, lift number, and location number. For example, a core extracted from the sixth location of the second lift of paving on the OR 18 project was labeled "18-2-6." Further, since it was extracted from the second lift, it was a composite core that comprised of the first and second lifts; thus, the core was cut with a diamond tipped saw blade to separate the lifts. The portion comprising the first lift was then labeled "18-2-6 Lift 1". Similarly, the portion comprising the second lift was labeled "18-2-6 Lift 2."

5.2 DETAILS OF LABORATORY TESTING METHODS

Three test methods were used to measure the bulk specific gravity of the cores and a single test method was used to measure the (Rice) gravity of the loose HMAC. The following sections describe the test methods in further detail.

5.2.1 Density Measurement of Cores

The cores were tested for bulk specific gravity in accordance with the SSD methods as described in AASHTO T 166 Methods A and C, as well as in accordance with the automatic vacuum sealing method described in the CoreLok manufacturer's procedure (*2003*). Cores with more than one lift were tested for bulk specific gravity using the saturated surface-dry and vacuum sealing methods, and then they were cut at the lift interfaces and retested for bulk specific gravity using the same methods.

The cores were tested at OSU and at the Asphalt Pavement Association of Oregon (APAO). The cores were tested at OSU using AASHTO T 166 Method A and the CoreLok method, sent to APAO where the cores were tested using AASHTO T 166 Method A, and then returned to OSU for testing using AASHTO T 166 Method C as shown in the flowchart in Figure 5.1. As indicated, the cores were tested at OSU using AASHTO T 166 Method A and the CoreLok method, sent to APAO where they were tested using AASHTO T 166 Method A, and then returned to OSU. The original plan was to then test the cores using the destructive method specified in AASHTO T 166 Method C. However, reweighing the cores revealed differences in the dry weight of the cores from the dry weights prior to testing at APAO. Due to these differences, the cores were retested using AASHTO T 166 Method A since it merely required one additional weight measurement beyond the weight measurements required for AASHTO T 166 Method C.

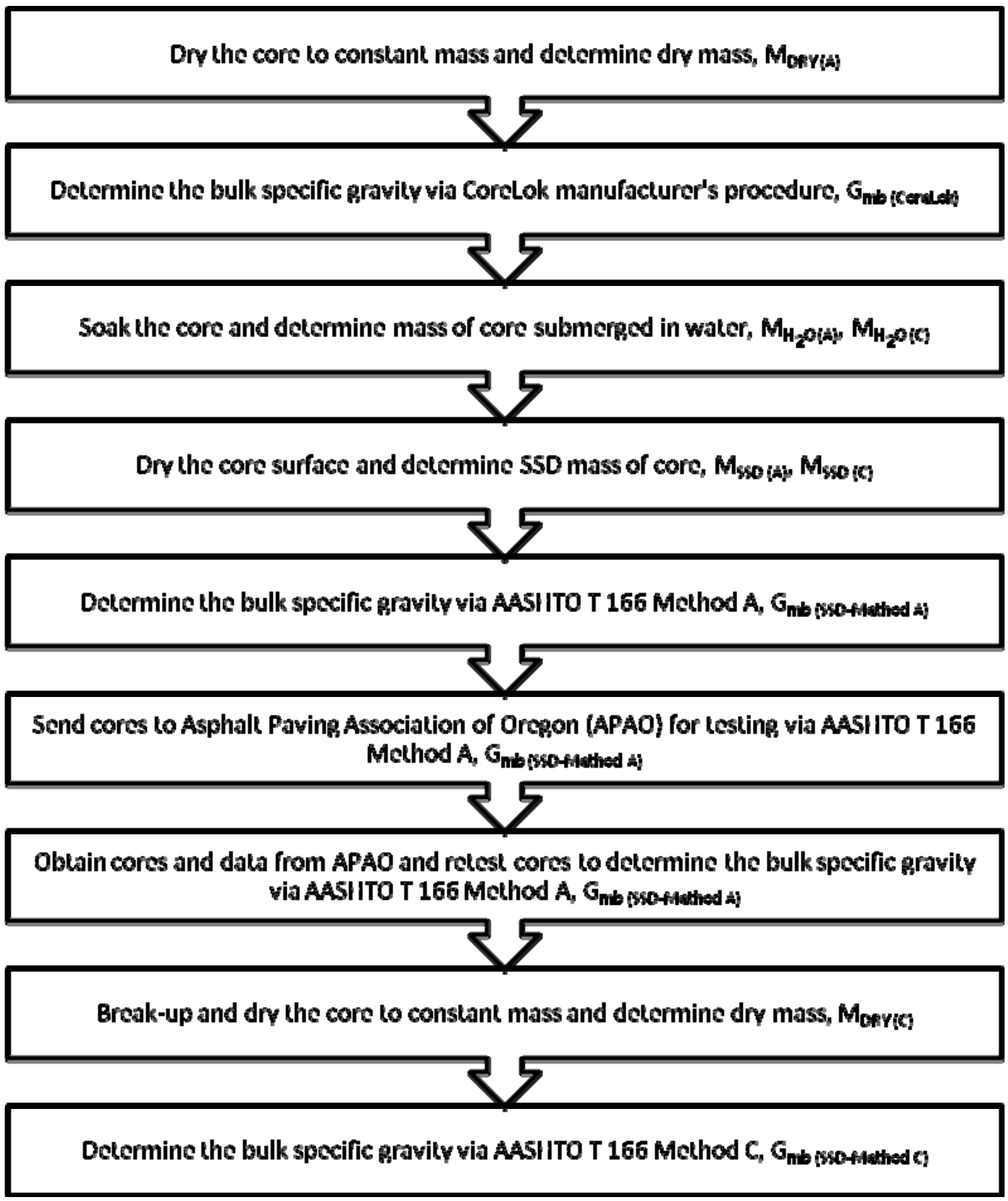


Figure 5.1: Flowchart to Describe the Order in which Laboratory Tests were Performed

During all measurements, the water used in the bulk specific gravity tests was maintained at a temperature of 77±1.8°F (25±1°C) at both laboratories. Hence, the density of each core was calculated by multiplying the bulk specific gravity of the core by the density of water at 77°F (25°C); that is, 62.24 lb/ft^3.

5.2.2 Density Measurement on Loose Mix

Loose mix was sampled in accordance with AASHTO T 168 and tested for theoretical maximum specific gravity in accordance with AASHTO T 209. Quality control (QC) test results for theoretical maximum specific gravity were obtained from the contractor so as to make comparisons of theoretical maximum specific gravity obtained from the plant and from the mat.

5.3 TEST RESULTS

Various data were recorded as a part of the laboratory studies. Detailed tables of the test results as well as condensed summaries of the data are included in Appendix D.

5.3.1 Core Location under Nuclear Gauge Footprint

Table 5.1 summarizes the density of the cores that were extracted from the inner corner of the 'L-shaped' footprint. For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. The cores were obtained from the top lift of the base course material placed in the westbound, outside lane of the Fort Hill – Wallace Bridge project on OR 18 (see Section 3.3.1). Figure 5.2 indicates slight differences in the average densities obtained from the three test methods.

Table 5.1: Density of Cores Extracted from the 'L-shaped' Footprint

Core ID	Sample Location		Thickness of Separated Specimen, in.	Core Density, lb/ft^3, obtained from		
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A*	AASHTO T 166 Method C
18.3.12	106+38	7.4	2	148.1	149.0 (1.2)	147.5
18.3.14	114+21	2.0	2	145.1	146.4 (1.9)	144.8
18.3.16	123+20	4.5	2	151.0	151.4 (0.3)	150.2
18.3.18	126+03	3.3	2	151.3	151.9 (0.2)	151.0
18.3.20	128+44	4.9	2	154.2	154.9 (0.3)	153.5
Average, lb/ft^3			N/A	149.9	150.7	149.4
Standard Deviation, lb/ft^3			N/A	3.4	3.2	3.4
Coefficient of Variation			N/A	2.30%	2.13%	2.25%

*Values in parentheses represent percent absorption by volume.

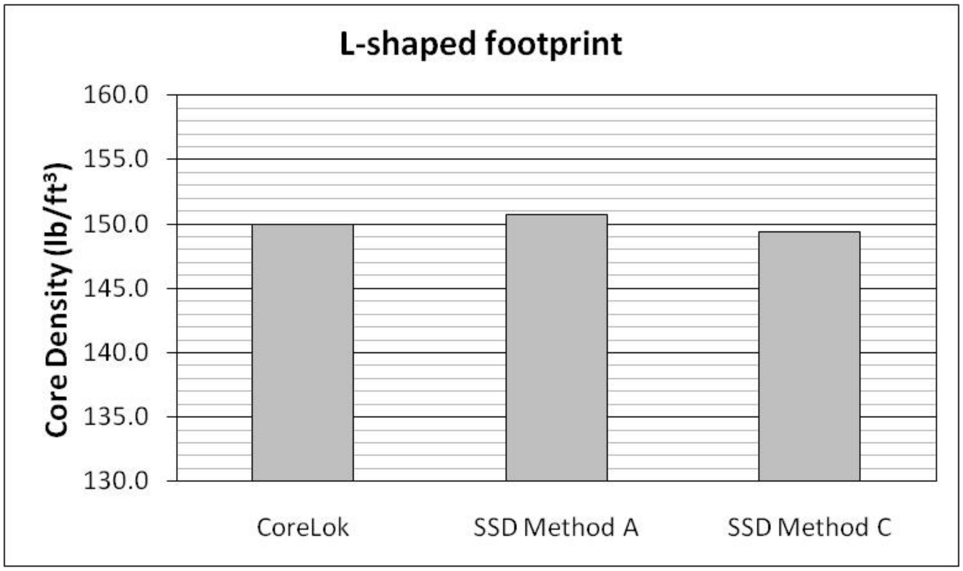


Figure 5.2: Comparison of Core Densities Extracted from the 'L-shaped' Footprint

Table 5.2 summarizes the density of the cores that were extracted from the center of the 'cross-shaped' footprint. For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. The cores were also obtained from the top lift of the base course material placed in the westbound, outside lane of the Fort Hill – Wallace Bridge project on OR 18 (see Section 3.3.1). Figure 5.3 shows the average densities obtained from the three test methods indicated slight differences between the average values.

Table 5.2: Density of Cores Extracted from the 'Cross-shaped' Footprint

Core ID	Sample Location		Nominal Thickness of Intact Specimen, in.	Core Density, lb/ft^3, obtained from		
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A*	AASHTO T 166 Method C
18.3.11	105+39	9.0	2	148.3	148.7 (0.9)	147.3
18.3.13	113+35	8.6	2	149.8	150.2 (0.6)	148.9
18.3.15	118+12	1.7	2	148.4	149.3 (0.5)	148.8
18.3.17	123+94	3.8	2	151.4	151.8 (0.3)	150.5
18.3.19	128+23	5.1	2	154.9	155.2 (0.3)	154.2
Average, lb/ft^3			N/A	150.5	151.1	149.9
Standard Deviation, lb/ft^3			N/A	2.7	2.6	2.6
Coefficient of Variation			N/A	1.8%	1.7%	1.8%

*Values in parentheses represent percent absorption by volume.

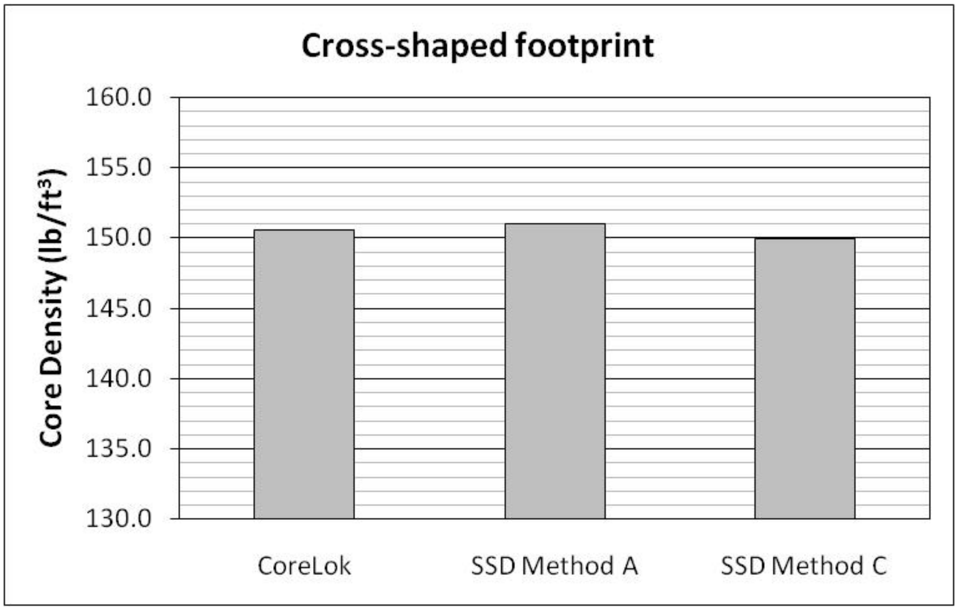


Figure 5.3: Comparison of Core Densities Extracted from the 'Cross-shaped' Footprint

5.3.2 Core Damage Assessment

Table 5.3 summarizes the bulk specific gravities of the blocks and cores extracted from the blocks. The values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. Figure 5.4 displays the results graphically. The blocks were obtained from the bottom lift (rich binder base layer) of the South Medford Interchange project on I-5, trimmed using a saw with a lapidary blade, and then tested. Cores were then extracted from the blocks and tested. All tests were conducted by the same person.

Table 5.3: Summary of Bulk Specific Gravities of Blocks and Cores Extracted from the Blocks

Sample		Bulk Specific Gravity (AASHTO T 166 Method A)	
		Block	Core
1	a	2.318 (0.4)	2.323 (0.3)
	b	2.317 (0.3)	2.318 (0.3)
2	a	2.346 (0.3)	2.339 (0.3)
	b	2.345 (0.3)	2.340 (0.5)
3	a	2.335 (0.3)	2.333 (0.3)
	b	2.331 (0.3)	2.326 (0.3)
4	a	2.303 (0.5)	2.291 (0.4)
	b	2.319 (0.4)	2.310 (0.3)
5	a	2.342 (0.3)	2.344 (0.4)
	b	2.318 (0.4)	2.323 (0.3)

*Values in parentheses represent percent absorption by volume

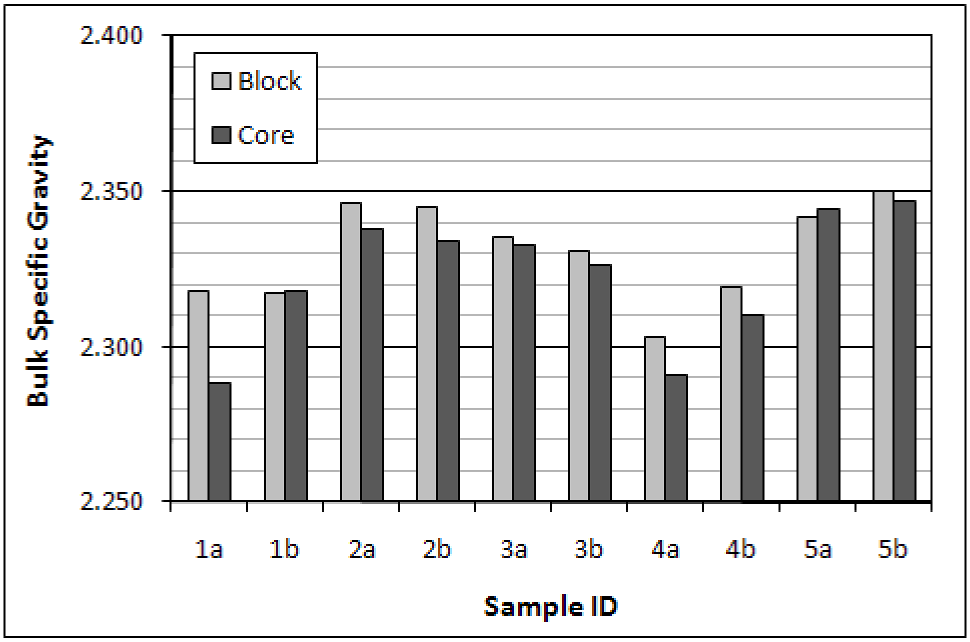


Figure 5.4: Bulk Specific Gravity of Blocks and Cores Extracted from the Blocks

5.3.3 Multi-Lift Pavements with a Single Mix Design

Table 5.4 summarizes the densities of the cores obtained from the first lift of paving on the eastbound, outside lane on the OR 18 project (see Section 3.3.1). For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. Figure 5.5 shows the average values indicating slight differences between the densities obtained from the test methods.

Table 5.5 summarizes the densities of the first-lift core slices obtained after the second lift was paved. For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. Figure 5.6 displays the results graphically. As indicated, small differences existed between the densities obtained from the test methods.

Table 5.6 summarizes the densities of the first-lift cores obtained after the third lift was paved. For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that only one core absorbed more than 2% water. As shown in Figure 5.7, the average densities from all of the test methods were nearly equal.

Table 5.4: Density of First-Lift Cores from OR 18

Core ID	Sample Location		Nominal Thickness of Intact Specimen, in.	Core Density, lb/ft^3, obtained from			
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*	AASHTO T 166 Method A, after APAO testing*	AASHTO T 166 Method C
18-1-1	106+50	8.2	3.35	147.2	155.1 (0.2)	155.0 (0.3)	154.1
18-1-2	116+91	1.6	3.74	147.7	148.0 (0.7)	147.2 (0.9)	146.6
18-1-3	120+53	2.9	2.36	148.3	148.0 (1.1)	147.4 (1.2)	146.7
18-1-4	130+80	6.6	3.54	146.0	150.0 (0.5)	149.6 (0.8)	148.5
18-1-5	142+09	8.2	3.43	150.2	150.3 (0.8)	149.6 (1.1)	148.4
18-1-6	133+38	5.7	3.39	152.7	153.0 (0.2)	152.2 (0.2)	150.9
18-1-7	124+96	4.9	3.62	154.0	155.6 (0.1)	155.5 (0.2)	155.1
18-1-8	123+30	3.0	3.43	148.9	150.0 (0.4)	149.5 (0.4)	148.1
18-1-9	116+56	5.4	3.82	155.1	155.0 (0.1)	154.7 (0.1)	153.5
18-1-10	115+53	4.8	4.25	151.1	154.4 (0.1)	154.2 (0.2)	152.6
Average, lb/ft^3			3.49	150.1	151.9	151.5	150.4
Standard Deviation, lb/ft^3			0.48	3.1	3.0	3.2	3.2
Coefficient of Variation			14%	2.0%	2.0%	2.1%	2.1%

*Values in parentheses represent percent absorption by volume.

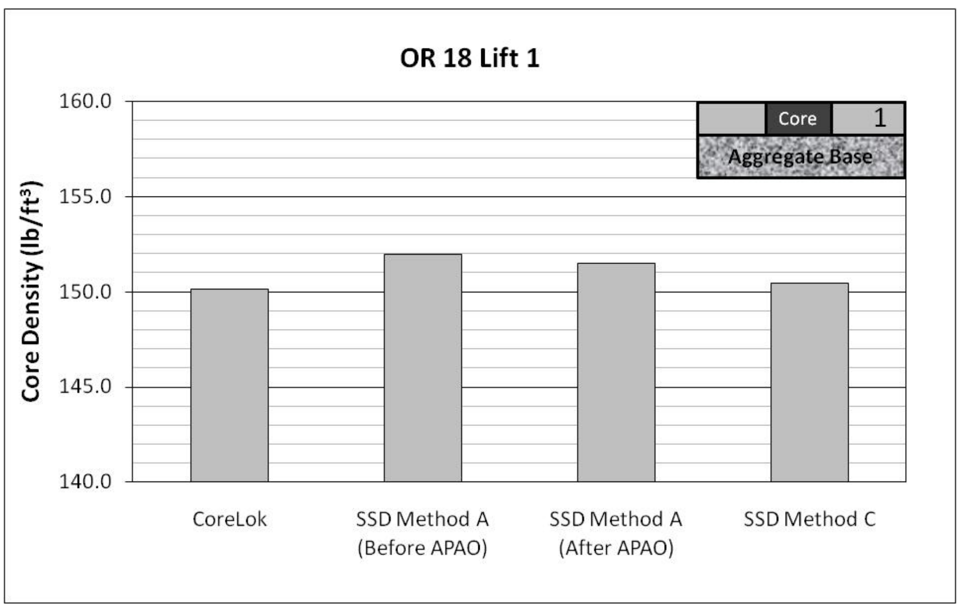


Figure 5.5: Comparison of First-Lift Core Densities from OR 18

Table 5.5: Density of First-Lift Cores Following the Second Lift of Paving on OR 18

Core ID	Sample Location		Thickness of Separated Specimen, in.	Core Density, lb/ft³, obtained from				
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*	AASHTO T 166 Method A, after APAO testing*	AASHTO T 166 Method A, APAO results*	AASHTO T 166 Method C
18-2-1 Lift 1	106+08	5.2	2.17	149.8	149.8 (0.2)	149.3 (0.6)	149.6 (0.5)	148.0
18-2-2 Lift 1	106+53	6.4	2.05	149.0	149.5 (0.3)	148.6 (0.7)	149.1 (0.9)	147.1
18-2-3 Lift 1	107+42	10.8	2.36	151.3	151.3 (0.2)	150.6 (0.2)	151.0 (0.2)	149.9
18-2-4 Lift 1	108+06	15.1	2.52	149.1	149.8 (0.4)	147.3 (0.6)	147.1 (1.0)	146.3
18-2-5 Lift 1	110+06	8.4	2.52	148.4	148.7 (0.6)	147.2 (0.9)	147.4 (0.9)	146.3
18-2-6 Lift 1	111+08	13.6	2.56	150.0	149.9 (0.3)	149.6 (0.3)	149.8 (0.2)	149.3
18-2-7 Lift 1	111+25	3.8	2.24	148.5	148.0 (0.2)	146.2 (0.6)	146.3 (0.6)	145.2
18-2-8 Lift 1	111+94	1.9	2.52	145.1	145.8 (0.5)	144.6 (1.2)	145.0 (1.7)	143.3
18-2-9 Lift 1	112+67	7.4	2.24	152.5	152.6 (0.2)	151.8 (0.2)	152.1 (0.1)	151.2
18-2-10 Lift 1	112+97	4.1	2.28	145.9	150.3 (0.2)	148.4 (0.2)	148.4 (0.3)	147.5
Average, lb/ft³			2.35	149.0	149.6	148.4	148.6	147.4
Standard Deviation, lb/ft³			0.18	2.2	1.8	2.1	2.2	2.3
Coefficient of Variation			7.6%	1.5%	1.2%	1.4%	1.5%	1.6%

*Values in parentheses represent percent absorption by volume.

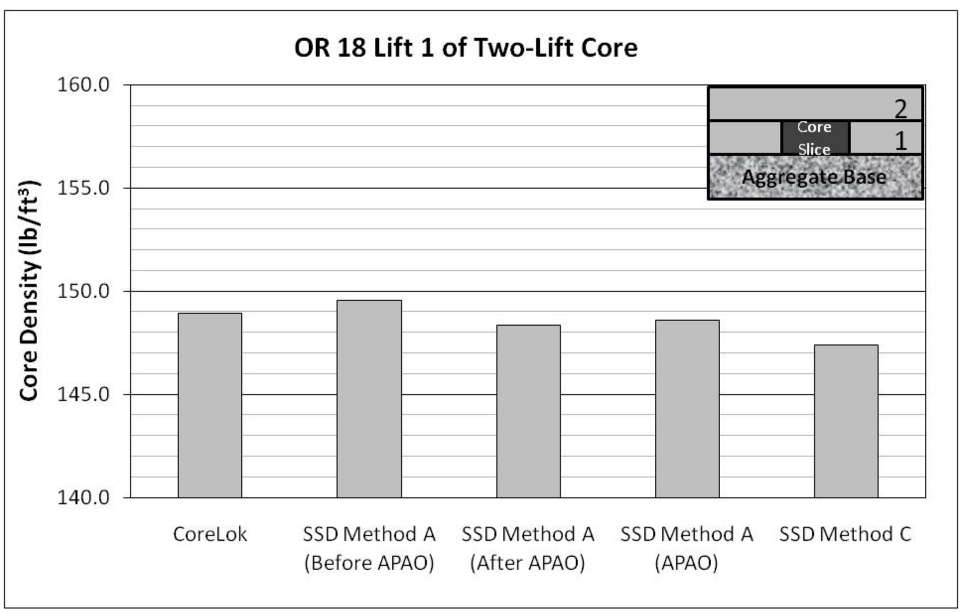


Figure 5.6: Comparison of First-Lift Core Densities of the Two-Lift Cores from OR 18

Table 5.6: Density of First-Lift Cores Following the Third Lift of Paving on OR 18

Core ID	Sample Location		Thickness of Separated Specimen, in.	Core Density, lb/ft^3, obtained from				
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*	AASHTO T 166 Method A, after APAO testing*	AASHTO T 166 Method A, APAO results*	AASHTO T 166 Method C
18-3-1 Lift 1	105+57	3.8	1.81	154.3	154.0 (0.1)	153.9 (0.2)	154.2 (0.1)	153.9
18-3-2 Lift 1	105+84	9.4	2.56	154.9	155.0 (0.1)	154.1 (0.1)	154.0 (0.1)	153.2
18-3-3 Lift 1	106+86	2.2	2.99	153.3	153.1 (0.1)	150.8 (0.4)	150.7 (0.3)	150.0
18-3-4 Lift 1	107+38	10	2.87	152.7	152.9 (0.1)	152.5 (0.2)	152.7 (0.1)	151.6
18-3-5 Lift 1	108+01	5.3	2.95	151.9	151.7 (0.4)	150.7 (0.6)	150.9 (0.5)	150.5
18-3-6 Lift 1	108+51	2.9	1.97	152.0	152.2 (0.2)	152.0 (0.3)	152.5 (0.2)	151.0
18-3-7 Lift 1	109+92	3.4	3.43	149.4	151.0 (0.4)	150.1 (0.9)	150.8 (1.2)	149.3
18-3-8 Lift 1	110+88	11.5	1.89	152.2	152.3 (0.2)	151.7 (0.2)	152.2 (0.2)	150.6
18-3-9 Lift 1	112+82	2.5	2.76	146.6	147.1 (0.6)	144.0 (1.8)	143.6 (3.5)	142.5
18-3-10 Lift 1	113+36	1.5	2.56	141.5	143.1 (1.7)	N/A	N/A	N/A
Average, lb/ft^3			2.58	150.9	151.2	151.1	151.3	150.3
Standard Deviation, lb/ft^3			0.54	4.1	3.6	3.0	3.2	3.3
Coefficient of Variation			21%	2.7%	2.4%	2.0%	2.1%	2.2%

*Values in parentheses represent percent absorption by volume.

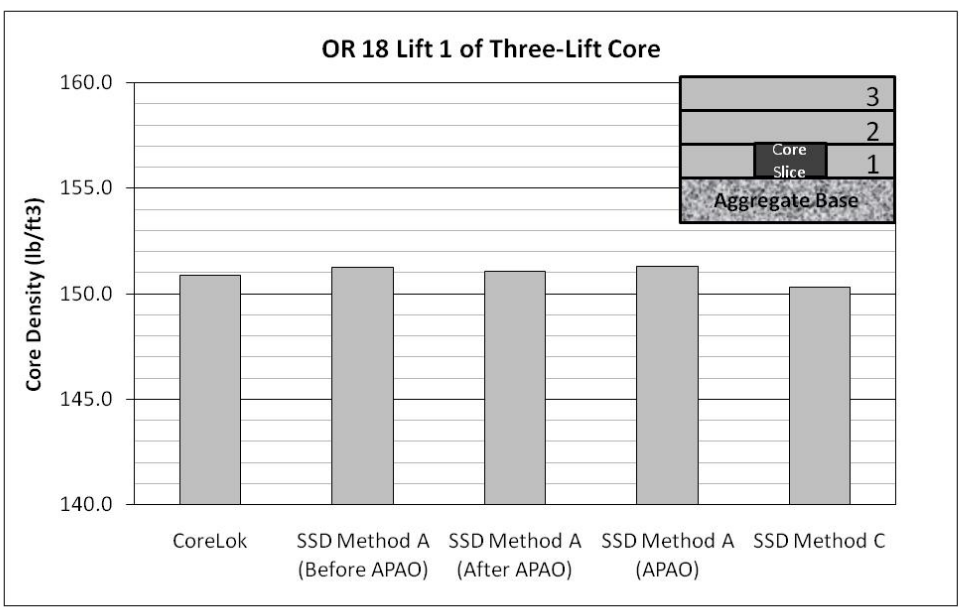


Figure 5.7: Comparison of First-Lift Core Densities of the Three-Lift Cores from OR 18

Table 5.7 summarizes the densities of the second-lift cores obtained after the second lift was paved. For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. Figure 5.8 displays the averages graphically. Only small differences between densities obtained from the various test methods were evident.

Table 5.8 summarizes the densities of the second-lift cores obtained after the third lift was paved. For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. Figure 5.9 displays the results graphically. Note that the differences in densities derived from the various tests methods were greater for those shown in Table 5.7.

Table 5.9 summarizes the densities of the first-lift core slices obtained after the second lift was paved For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that only two cores absorbed more than 2% water. Figure 5.10 displays the averages graphically. As indicated, slight differences in densities obtained from the various test methods existed.

Table 5.7: Density of Second-Lift Cores Following the Second Lift of Paving on OR 18

Core ID	Sample Location		Thickness of Separated Specimen, in.	Core Density, lb/ft^3, obtained from				
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*	AASHTO T 166 Method A, after APAO testing*	AASHTO T 166 Method A, APAO results*	AASHTO T 166 Method C
18-2-1 Lift 2	106+08	5.2	2.24	148.5	148.5 (0.3)	148.8 (0.4)	149.3 (0.5)	148.0
18-2-2 Lift 2	106+53	6.4	2.24	147.1	148.2 (0.6)	147.1 (1.0)	146.6 (1.1)	146.6
18-2-3 Lift 2	107+42	10.8	2.56	147.1	148.3 (0.5)	N/A	N/A	N/A
18-2-4 Lift 2	108+06	15.1	2.44	148.6	145.5 (0.9)	147.7 (0.4)	147.6 (0.5)	147.7
18-2-5 Lift 2	110+06	8.4	2.64	148.5	149.9 (0.3)	149.0 (0.5)	148.8 (0.6)	148.0
18-2-6 Lift 2	111+08	13.6	2.76	148.6	150.4 (0.4)	149.7 (0.3)	150.2 (0.4)	149.0
18-2-7 Lift2	111+25	3.8	2.60	149.0	149.6 (0.4)	148.5 (0.3)	148.6 (0.4)	147.8
18-2-8 Lift 2	111+94	1.9	2.60	149.4	149.9 (0.5)	149.4 (0.4)	149.7 (0.5)	148.7
18-2-9 Lift 2	112+67	7.4	2.36	149.0	149.8 (0.4)	148.7 (0.5)	148.8 (0.5)	147.7
18-2-10 Lift 2	112+97	4.1	2.44	148.0	149.0 (0.2)	147.9 (0.4)	147.9 (0.2)	147.5
Average, lb/ft^3			2.49	148.4	148.9	148.5	148.6	147.9
Standard Deviation, lb/ft^3			0.17	0.8	1.4	0.8	1.1	0.7
Coefficient of Variation			6.87%	0.51%	0.96%	0.56%	0.75%	0.47%

*Values in parentheses represent percent absorption by volume.

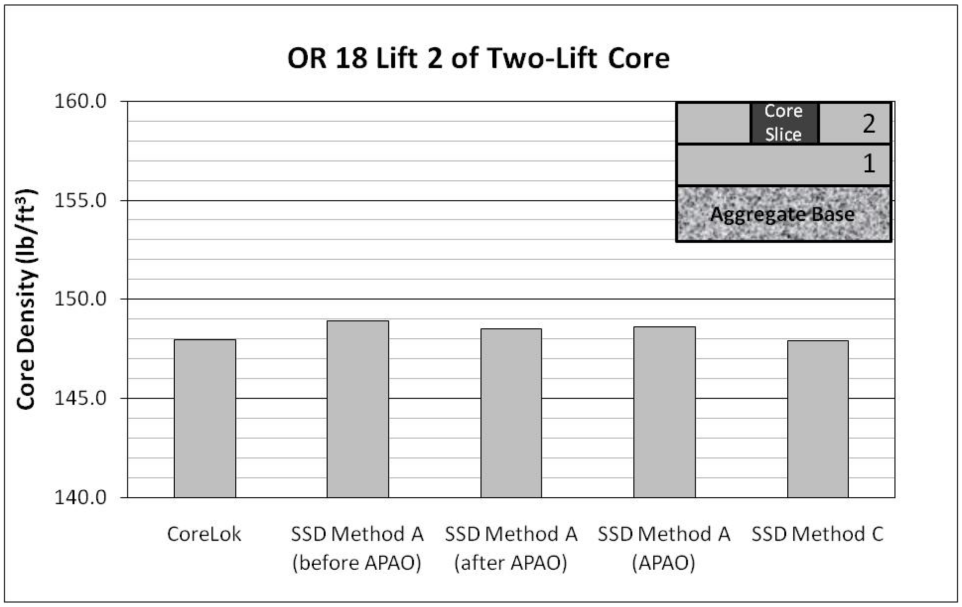


Figure 5.8: Comparison of Second-Lift Core Densities of the Two-Lift Cores from OR 18

Table 5.8: Density of Second-Lift Cores Following the Third Lift of Paving on OR 18

Core ID	Sample Location		Thickness of Separated Specimen, in.	Core Density, lb/ft^3, obtained from				
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*	AASHTO T 166 Method A, after APAO testing*	AASHTO T 166 Method A, APAO results*	AASHTO T 166 Method C
18-3-1 Lift 2	105+57	3.8	1.57	147.9	149.5 (0.3)	149.1 (0.4)	149.5 (0.5)	148.2
18-3-2 Lift 2	105+84	9.4	1.14	147.8	148.8 (---)	147.5 (0.4)	147.5 (1.0)	146.3
18-3-3 Lift 2	106+86	2.2	1.54	151.2	152.2 (0.2)	151.8 (0.3)	151.6 (0.2)	151.2
18-3-4 Lift 2	107+38	10	0.98	147.3	148.3 (0.1)	147.9 (0.4)	148.4 (0.5)	146.3
18-3-5 Lift 2	108+01	5.3	1.02	146.6	148.2 (0.2)	147.3 (0.4)	147.6 (0.5)	146.2
18-3-6 Lift 2	108+51	2.9	1.18	149.0	149.8 (0.3)	149.3 (0.3)	149.9 (0.3)	148.3
18-3-7 Lift 2	109+92	3.4	0.98	142.0	144.3 (0.3)	142.6 (0.7)	143.7 (1.3)	142.0
18-3-8 Lift 2	110+88	11.5	1.06	146.6	148.4 (0.3)	147.9 (0.3)	147.9 (0.4)	146.7
18-3-9 Lift 2	112+82	2.5	1.57	149.3	150.3 (0.3)	149.8 (0.3)	149.8 (0.4)	148.9
18-3-10 Lift 2	113+36	1.5	1.57	146.0	147.3 (0.0)	145.9 (0.5)	145.8 (0.4)	144.5
Average, lb/ft^3			1.26	147.4	148.7	147.9	148.2	146.9
Standard Deviation, lb/ft^3			0.27	2.4	2.1	2.5	2.3	2.5
Coefficient of variation			21.10%	1.65%	1.39%	1.67%	1.52%	1.72%

*Values in parentheses represent percent absorption by volume.

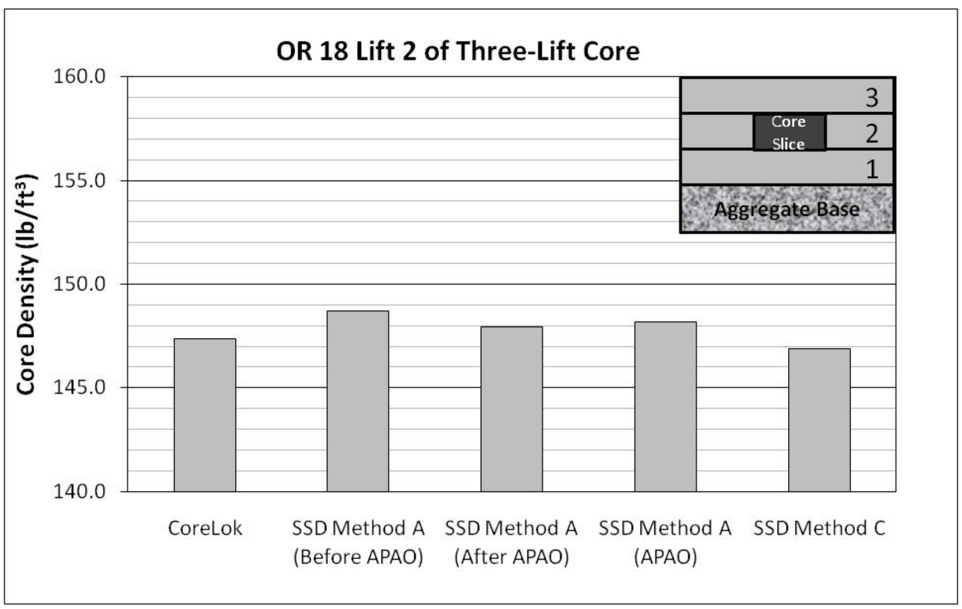


Figure 5.9: Comparison of Second-Lift Core Densities of the Three-Lift Cores from OR 18

Table 5.9: Density of Third-Lift Cores Following the Third Lift of Paving on OR 18

Core ID	Sample Location		Thickness of Separated Specimen, in.	Core Density, lb/ft3, obtained from				
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*	AASHTO T 166 Method A, after APAO testing*	AASHTO T 166 Method A, APAO results*	AASHTO T 166 Method C
18-3-1 Lift 3	105+57	3.8	2.17	149.9	150.1 (0.3)	149.4 (0.6)	149.0 (0.4)	149.0
18-3-2 Lift 3	105+84	9.4	2.20	152.8	153.2 (0.1)	153.0 (0.2)	153.0 (0.1)	152.5
18-3-3 Lift 3	106+86	2.2	2.05	148.2	149.5 (0.6)	148.4 (0.6)	148.5 (0.8)	147.9
18-3-4 Lift 3	107+38	10	2.36	146.2	148.1 (0.7)	147.5 (1.0)	148.0 (1.3)	147.0
18-3-5 Lift 3	108+01	5.3	2.05	146.9	147.7 (0.7)	146.2 (0.7)	146.4 (0.7)	145.7
18-3-6 Lift 3	108+51	2.9	2.32	148.5	149.2 (0.8)	148.9 (1.1)	149.3 (1.1)	148.3
18-3-7 Lift 3	109+92	3.4	2.36	147.6	148.1 (0.6)	147.7 (1.1)	148.0 (1.2)	147.1
18-3-8 Lift 3	110+88	11.5	2.44	147.3	148.2 (0.6)	147.9 (0.7)	148.3 (1.0)	147.4
18-3-9 Lift 3	112+82	2.5	2.48	142.9	144.2 (1.2)	142.7 (2.2)	141.8 (2.4)	142.1
18-3-10 Lift 3	113+36	1.5	2.13	147.3	147.9 (0.5)	147.1 (0.6)	146.9 (1.0)	146.8
Average			2.26	147.7	148.6	147.9	147.9	147.4
Standard Deviation			0.16	2.5	2.3	2.6	2.8	2.6
Coefficient of Variation			7.0%	1.7%	1.5%	1.8%	1.9%	1.8%

*Values in parentheses represent percent absorption by volume.

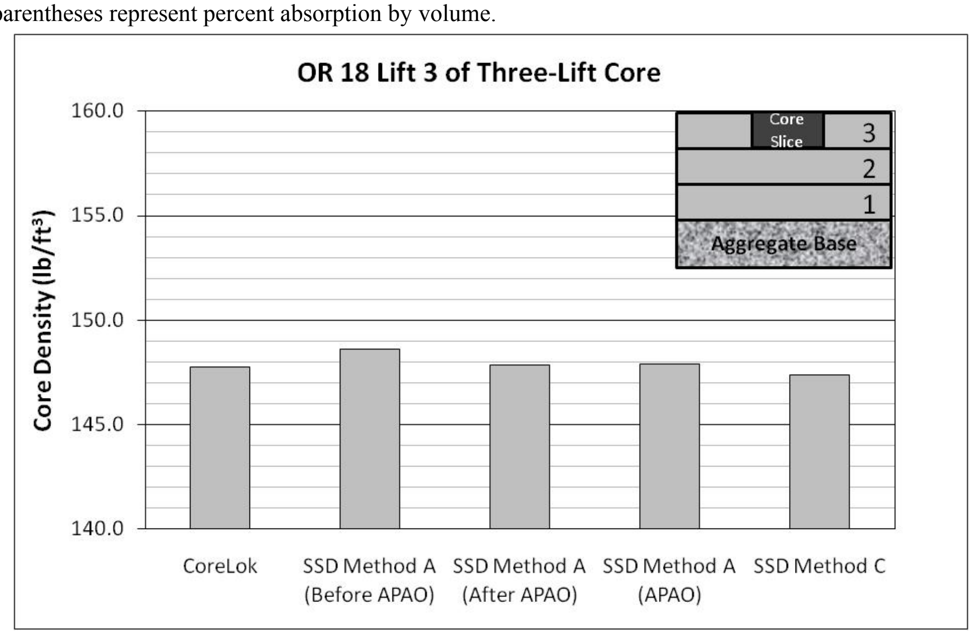


Figure 5.10: Comparison of Third-Lift Core Densities of the Three-Lift Cores from OR 18

Tests were also conducted on the cores before they were cut into the individual lifts. However, only the CoreLok method and AASHTO T 166 Method A were conducted on these cores. Table 5.10 and Figure 5.11 summarize the results from the tests conducted on the two-lift cores (i.e., the whole core obtained following the second lift of paving). For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. Table 5.11 and Figure 5.12 summarize the results from the test conducted on the three-lift cores (i.e., the whole core obtained following the third lift of paving). The results indicate that four of the cores absorbed more than 2% water. In addition, the larger cores (Figure 5.12) indicated a greater difference between densities derived from the two test methods.

Table 5.10: Density of Two-Lift Cores from OR 18

Core ID	Sample Location		Nominal Thickness of Intact Specimen, in.	Core Density, lb/ft^3, obtained from	
	Station	Offset		CoreLok	AASHTO T 166 Method A, before APAO testing*
18-2-1	106+08	5.2	5.12	149.4	149.2 (1.3)
18-2-2	106+53	6.4	5.28	148.2	148.7 (1.6)
18-2-3	107+42	10.8	5.71	148.5	148.3 (1.1)
18-2-4	108+06	15.1	5.71	148.6	148.7 (1.1)
18-2-5	110+06	8.4	5.91	148.9	149.0 (0.8)
18-2-6	111+08	13.6	6.06	149.8	149.8 (0.4)
18-2-7	111+25	3.8	5.75	148.7	148.4 (1.3)
18-2-8	111+94	1.9	5.79	147.0	147.5 (1.9)
18-2-9	112+67	7.4	5.63	148.2	150.7 (0.5)
18-2-10	112+97	4.1	5.39	149.7	149.6 (0.5)
Average, lb/ft^3			5.63	148.7	149.0
Standard Deviation, lb/ft^3			0.3	0.8	0.9
Coefficient of Variation			5.2%	0.56%	0.60%

*Values in parentheses represent percent absorption by volume.

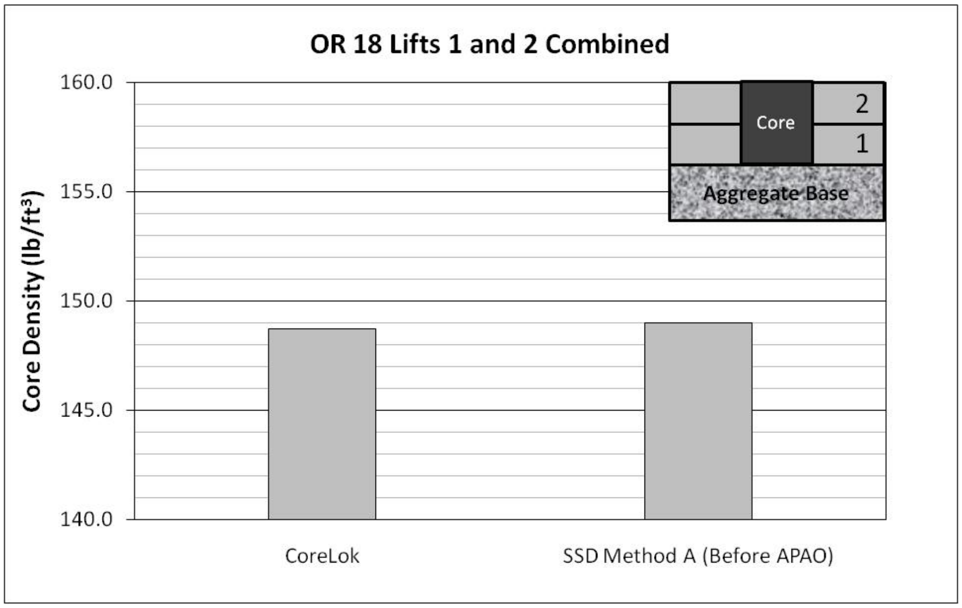


Figure 5.11: Comparison of Two-Lift Core Densities from OR 18

Table 5.11: Density of Three-Lift Cores from OR 18

Core ID	Sample Location		Nominal Thickness of Intact Specimen, in.	Core Density, lb/ft^3, obtained from	
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*
18-3-1	105+57	3.8	6.30	151.1	150.4 (1.0)
18-3-2	105+84	9.4	6.81	155.1	152.6 (1.4)
18-3-3	106+86	2.2	7.36	152.2	151.5 (0.7)
18-3-4	107+38	10	6.81	150.1	149.7 (1.2)
18-3-5	108+01	5.3	6.81	149.5	149.2 (1.6)
18-3-6	108+51	2.9	7.28	150.5	145.7 (8.2)
18-3-7	109+92	3.4	7.44	148.2	147.8 (2.7)
18-3-8	110+88	11.5	7.24	N/A	N/A
18-3-9	112+82	2.5	7.48	145.8	145.7 (3.1)
18-3-10	113+36	1.5	7.20	144.5	145.8 (3.6)
Average, lb/ft^3			7.07	149.7	148.7
Standard Deviation, lb/ft^3			0.38	3.2	2.6
Coefficient of Variation			5.3%	2.2%	1.8%

*Values in parentheses represent percent absorption by volume.

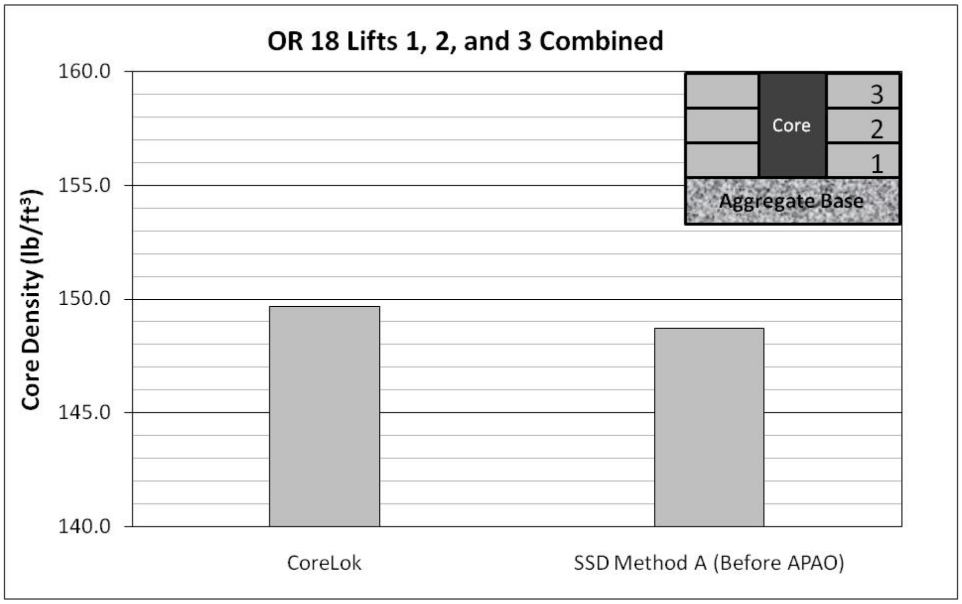


Figure 5.12: Comparison of Three-Lift Core Densities from OR 18

5.3.4 Pavement Lifts with Different Mix Designs

Table 5.12 summarizes the densities of the cores obtained from the first lift of paving on the northbound, outside lane on the I-5 project (see South Medford Interchange Project on Interstate 5 (I-5)Section 3.3.2). For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. Figure 5.13 displays the average values and indicates that the density derived from CoreLok method was lower than the densities derived from the other two test methods.

Table 5.13 summarizes the densities of the cores obtained from the second lift of paving. For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. Figure 5.14 displays the average densities and indicates similar results to those displayed in Figure 5.13.

Table 5.12: Density of First-Lift Cores from the I-5 Project

Core ID	Sample Location		Nominal Thickness of Intact Specimen, in.	Core Density, lb/ft³, obtained from		
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A*	AASHTO T 166 Method C
5.1.1	252+22	4.0	2.76	144.3	146.2 (0.2)	145.6
5.1.2	254+07	6.5	2.95	140.1	142.4 (0.6)	141.9
5.1.3	255+07	9.5	2.56	143.6	144.7 (0.2)	144.1
5.1.4	255+67	5.5	2.68	142.2	143.4 (0.2)	143.3
5.1.5	255+81	8.4	2.24	143.6	145.3 (0.2)	145.5
5.1.6	256+33	9.0	2.76	141.2	143.8 (0.2)	143.6
5.1.7	257+55	9.0	2.83	144.6	145.5 (0.2)	145.0
5.1.8	259+35	2.7	2.95	143.8	145.2 (0.2)	144.3
5.1.9	261+68	5.3	2.56	143.3	145.2 (0.2)	144.8
5.1.10	263+88	7.2	2.48	143.5	144.3 (0.2)	144.0
Average, lb/ft³			2.7	143.0	144.6	144.2
Standard Deviation, lb/ft³			0.2	1.4	1.1	1.1
Coefficient of Variation			8.3%	1.0%	0.79%	0.77%

*Values in parentheses represent percent absorption by volume.

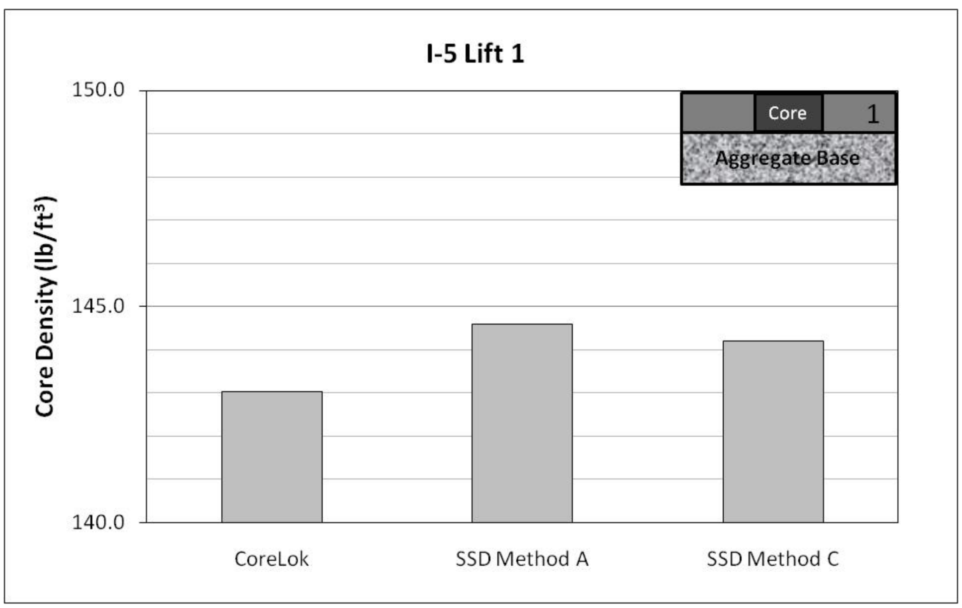


Figure 5.13: Comparison of First-Lift Core Densities from the I-5 Project

Table 5.13: Density of Second-Lift Cores from the I-5 Project

Core ID	Sample Location		Nominal Thickness of Intact Specimen, in.	Core Density, lb/ft^3, obtained from		
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A*	AASHTO T 166 Method C
5.2.1	252+02	9.1	2.48	142.4	143.8 (0.7)	143.1
5.2.2	252+59	3.4	3.15	143.3	144.9 (0.2)	144.7
5.2.3	253+34	2.0	2.95	144.6	145.4 (0.2)	145.1
5.2.4	254+23	4.1	3.15	141.6	143.3 (0.2)	142.9
5.2.5	254+98	3.3	3.23	141.7	142.5 (0.6)	142.1
5.2.6	256+62	2.3	3.23	143.2	144.3 (0.1)	143.8
5.2.7	258+07	11.7	3.31	141.1	142.2 (0.6)	141.9
5.2.8	258+83	6.0	3.23	140.7	142.5 (0.6)	142.0
5.2.9	260+92	10.1	2.91	142.4	143.8 (0.6)	143.3
5.2.10	263+60	9.0	2.95	138.5	144.6 (0.2)	144.4
Average, lb/ft^3			3.1	142.0	143.7	143.3
Standard Deviation, lb/ft^3			0.2	1.7	1.1	1.2
Coefficient of Variation			8.0%	1.2%	0.77%	0.81%

*Values in parentheses represent percent absorption by volume.

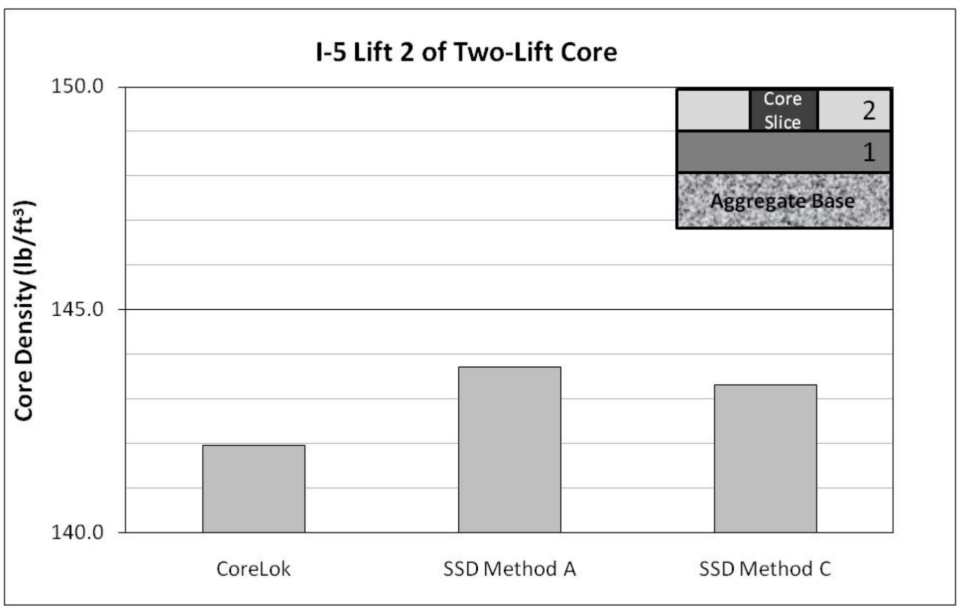


Figure 5.14: Comparison of Second-Lift Core Densities from the I-5 Project

5.3.5 Inlays and Overlays with the Same Mix Design

Table 5.14 summarizes the densities of the cores obtained from the first lift of paving on the eastbound lane on the OR 140 project (see Section 3.3.3). For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that two cores absorbed more than 2% water. APAO did not test the cores obtained from this lift. Examination of the data indicates similar results from the three test methods as also evidenced from Figure 5.15, although the densities derived from AASHTO T 166 Method C and the CoreLok method were lower than those obtained from AASHTO T 166 Method A.

Table 5.15 summarizes the densities of the first-lift core slices obtained after the second lift was paved. For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that none absorbed more than 2% water. Figure 5.16 displays the averages graphically. The averages follow a similar trend to those shown in Figure 5.15.

Table 5.16 summarizes the densities of the cores obtained from the second lift of paving. . For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that several cores absorbed more than 2% water. Figure 5.17 displays the average densities and indicates a similar trend to those shown in Figures 5.15 and 5.16.

Tests were also conducted on the cores before they were cut into the individual lifts. However, only the CoreLok method and AASHTO T 166 Method A were conducted on these cores. Table 5.17 summarizes the results from the tests conducted on the two-lift cores (i.e., the whole core obtained following the second lift of paving). For AASHTO T 166 Method A, the values in parentheses represent the percentage, by volume, of water absorbed by the cores during the tests and indicate that two cores absorbed more than 2% water. Figure 5.18 indicates that the density obtained using the CoreLok method was lower than that obtained using AASHTO T 166 Method A.

Table 5.14: Density of First-Lift Cores from the OR 140 Project

Core ID	Sample Location		Nominal Thickness of Intact Specimen, in.	Core Density, lb/ft^3, obtained from			
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*	AASHTO T 166 Method A, after APAO testing*	AASHTO T 166 Method C
140-1-1	326+93	1.3	2.09	139.9	141.7 (0.7)	141.3 (0.8)	140.2
140-1-2	327+43	11.2	2.13	140.8	142.2 (0.7)	141.5 (0.9)	141.0
140-1-3	327+59	10.2	2.09	138.9	140.4 (1.2)	139.9 (1.3)	138.7
140-1-4	327+75	6.6	2.13	139.8	141.3 (0.8)	140.8 (1.0)	140.4
140-1-5	328+88	3.5	2.36	139.9	141.3 (0.6)	N/A	N/A
140-1-6	329+18	5.1	2.44	139.5	140.6 (0.8)	140.0 (1.2)	138.9
140-1-7	329+78	3.3	2.36	139.5	141.1 (0.8)	140.3 (1.4)	139.3
140-1-8	331+00	12.2	2.28	137.2	139.5 (1.3)	138.0 (2.2)	137.1
140-1-9	332+41	7.8	2.52	138.2	139.8 (1.1)	139.5 (1.6)	138.4
140-1-10	333+24	1.6	2.56	134.5	136.9 (1.8)	136.7 (3.2)	135.7
Average, lb/ft^3			2.30	138.8	140.5	139.8	138.9
Standard Deviation, lb/ft^3			0.18	1.8	1.5	1.5	1.7
Coefficient of variation			7.9%	1.3%	1.1%	1.1%	1.2%

*Values in parentheses represent percent absorption by volume.

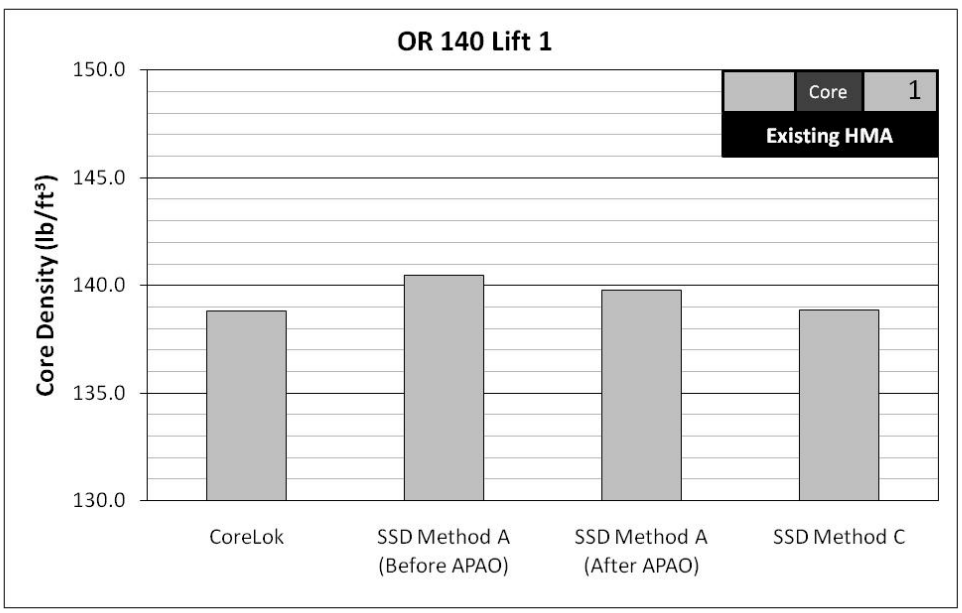


Figure 5.15: Comparison of First-Lift Core Densities from the OR 140 Project

Table 5.15: Density of First-Lift Cores Following the Second Lift of Paving on OR 140

Core ID	Sample Location		Thickness of Separated Specimen, in.	Core Density, lb/ft³, obtained from				
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*	AASHTO T 166 Method A, after APAO testing*	AASHTO T 166 Method A, APAO results*	AASHTO T 166 Method C
140-2-1	326+35	11.6	1.77	142.5	143.1 (0.2)	142.8 (0.3)	143.1 (0.3)	142.1
140-2-2	329+40	6.2	1.69	140.6	141.9 (0.4)	141.0 (0.5)	141.3 (0.4)	139.6
140-2-3	330+65	12.3	1.46	139.0	141.1 (0.4)	140.4 (0.6)	140.8 (0.6)	139.1
140-2-4	331+02	3.6	1.65	140.8	141.8 (0.3)	141.4 (0.5)	141.5 (0.5)	140.3
140-2-5	333+46	2.2	1.97	136.9	139.0 (1.3)	138.5 (1.6)	138.4 (1.7)	
140-2-6	334+02	4.1	1.89	138.5	140.1 (0.6)	139.2 (0.6)	139.9 (0.7)	138.4
140-2-7	334+48	11.2	1.50	138.4	140.3 (0.7)	139.2 (0.8)	139.0 (0.9)	137.6
140-2-8	334+78	10.5	1.97	135.9	139.6 (1.5)	139.1 (1.3)	139.2 (1.5)	137.9
140-2-9	334+83	11.4	1.65	137.3	139.2 (1.0)	138.4 (1.3)	138.0 (1.5)	137.4
140-2-10	334+94	10.1	2.05	140.0	141.2 (0.9)	140.5 (0.9)	140.9 (0.7)	139.6
Average, lb/ft³			1.76	139.0	140.7	140.0	140.2	139.1
Standard Deviation, lb/ft³			0.20	2.0	1.3	1.4	1.6	1.5
Coefficient of Variation			12%	1.5%	0.94%	1.0%	1.1%	1.1%

*Values in parentheses represent percent absorption by volume.

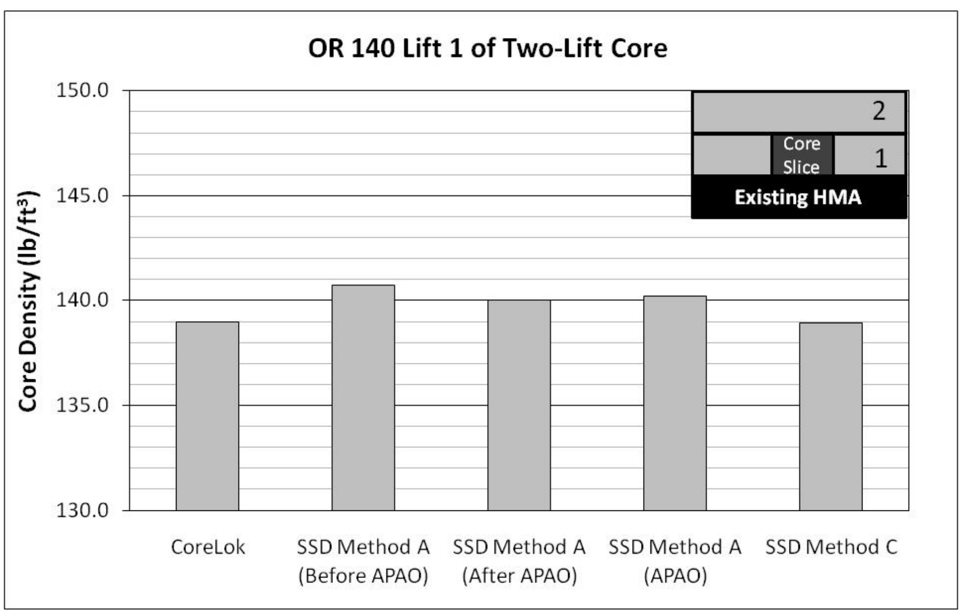


Figure 5.16: Comparison of First-Lift Core Densities of the Two-Lift Cores from OR 140

Table 5.16: Density of Second-Lift Cores Following the Second Lift of Paving on OR 140

Core ID	Sample Location		Thickness of Separated Specimen, in.	Core Density, lb/ft^3, obtained from				
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*	AASHTO T 166 Method A, after APAO testing*	AASHTO T 166 Method A, APAO results*	AASHTO T 166 Method C
140-2-1	326+35	11.6	2.28	139.9	142.3 (0.5)	143.4 (1.1)	141.9 (1.0)	142.2
140-1-2	329+40	6.2	2.28	140.8	139.3 (2.1)	138.0 (2.5)	137.7 (2.6)	137.4
140-1-3	330+65	12.3	2.36	138.9	139.0 (2.5)	138.0 (2.4)	138.0 (2.8)	136.9
140-1-4	331+02	3.6	2.05	139.8	139.7 (1.2)	139.1 (1.5)	139.2 (2.0)	137.9
140-1-5	333+46	2.2	2.56	139.9	138.3 (2.2)	137.3 (2.2)	137.2 (2.4)	137.4
140-1-6	334+02	4.1	2.56	139.5	140.4 (1.1)	139.8 (1.3)	140.3 (1.3)	139.2
140-1-7	334+48	11.2	2.28	139.5	143.8 (0.2)	143.1 (0.3)	143.4 (0.2)	142.6
140-1-8	334+78	10.5	2.56	137.2	144.8 (0.2)	143.5 (0.3)	144.0 (0.4)	142.2
140-1-9	334+83	11.4	2.56	138.2	143.6 (0.2)	142.6 (0.4)	142.7 (0.3)	141.3
140-1-10	334+94	10.1	2.56	134.5	145.7 (0.2)	145.4 (0.3)	145.3 (0.2)	144.9
Average, lb/ft^3			2.41	138.8	141.7	141.0	141.0	140.2
Standard Deviation, lb/ft^3			0.18	1.8	2.7	2.9	2.9	2.8
Coefficient of variation			7.5%	1.3%	1.9%	2.0%	2.0%	2.0%

*Values in parentheses represent percent absorption by volume.

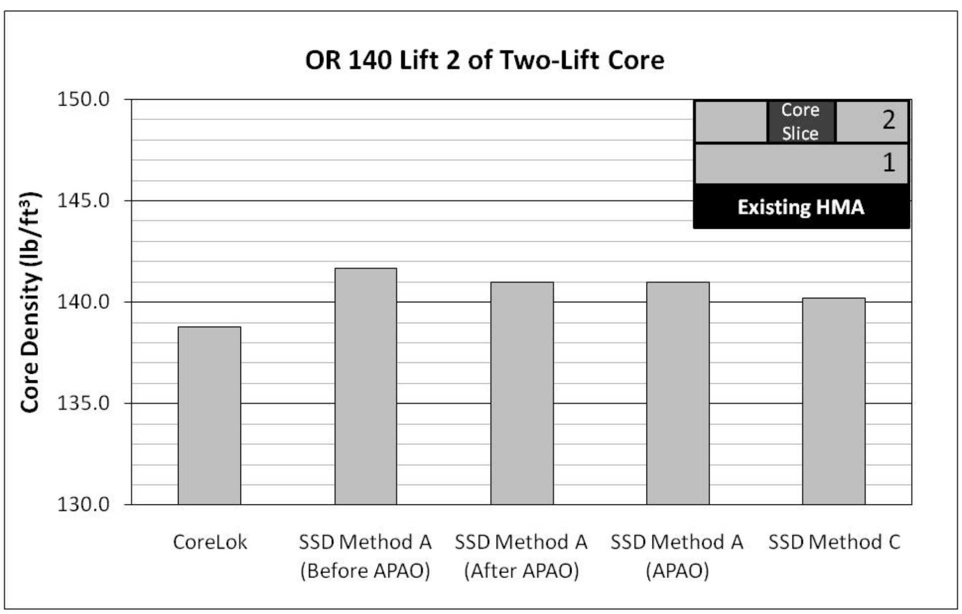


Figure 5.17: Comparison of Second-Lift Core Densities of the Two-Lift Cores from OR 140

Table 5.17: Density of the Two-Lift Cores from OR 140

Core ID	Sample Location		Nominal Thickness of Intact Specimen, in.	Core Density, lb/ft^3, obtained from	
	Station	Offset, ft		CoreLok	AASHTO T 166 Method A, before APAO testing*
140-2-1	326+35	11.6	4.92	142.0	142.4 (1.0)
140-2-2	329+40	6.2	5.04	138.3	139.5 (2.2)
140-2-3	330+65	12.3	4.65	N/A	N/A
140-2-4	331+02	3.6	4.61	139.5	139.8 (1.5)
140-2-5	333+46	2.2	5.12	131.2	138.2 (2.5)
140-2-6	334+02	4.1	5.31	138.6	139.5 (1.3)
140-2-7	334+48	11.2	4.80	142.0	142.6 (0.4)
140-2-8	334+78	10.5	5.00	N/A	N/A
140-2-9	334+83	11.4	5.08	N/A	N/A
140-2-10	334+94	10.1	5.24	143.2	143.6 (0.3)
Average, lb/ft^3			4.98	139.2	140.8
Standard Deviation, lb/ft^3			0.23	4.0	2.0
Coefficient of Variation			4.7%	2.9%	1.4%

*Values in parentheses represent percent absorption by volume.

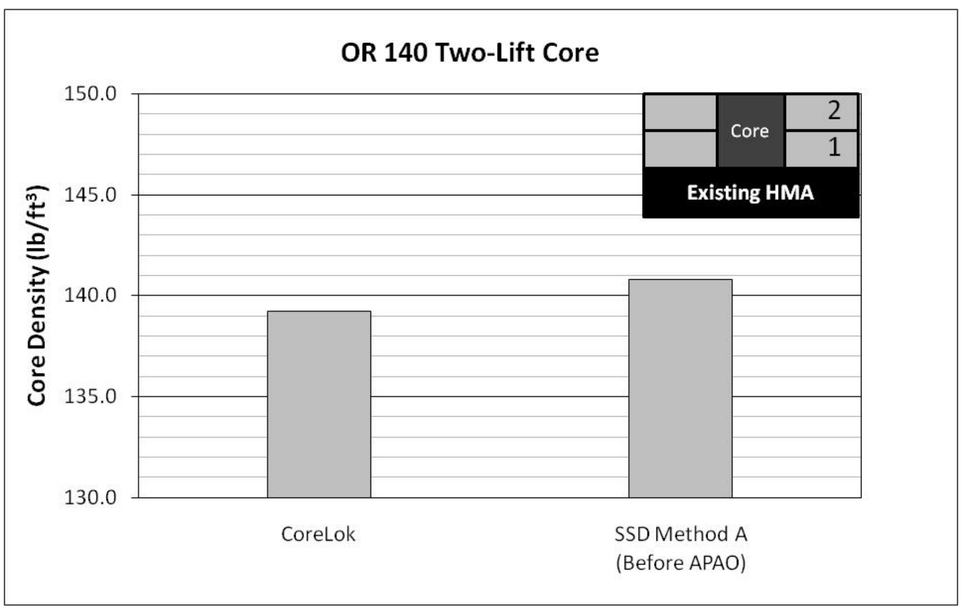


Figure 5.18: Comparison of Two-Lift Core Densities from OR 140

5.3.6 Theoretical Maximum Specific Gravity of Loose-Mix Samples

Loose-mix samples were obtained from each of the projects to determine the maximum theoretical specific (Rice) gravity of the mixtures. QC test results were also obtained from the contractor on the OR 18 and OR 140 projects for the day in which the loose-mix samples were obtained (unfortunately, these were not obtained from the paving contractor on the I-5 project). Table 5.18 summarizes the results and indicates, where applicable, that the differences between the contractors' results and those from OSU were within the multi-laboratory criterion of 0.019 as set forth in AASHTO T 209 in most cases.

Table 5.18: Rice Gravity Data from the OR 18 and OR 140 Projects

Project	Date	Theoretical Maximum Specific (Rice) Gravity		Difference between Results[1]
		Contractor	OSU	
OR 18	18-Aug-08	2.582	2.609	0.027
			2.600	0.018
	22-Aug-08	2.576	2.575	-0.001
			2.588	0.012
			2.592	0.016
	25-Aug-08	2.565	2.577	0.012
			2.569	0.004
I-5	14-Aug 2009	N/A	2.499	N/A
			2.484	N/A
			2.439[2]	N/A
OR 140	20-Aug-08	2.445	2.459	0.014
			2.475	0.030
			2.465	0.020
	11-Sep-08	2.452	2.452	0.000
			2.457	0.005

[1]Shaded cells indicate differences are greater than D2S criterion in AASHTO T 209

[2]Rich binder base

6.0 DATA ANALYSIS

Chapter 3.0 described the questions ODOT desired to have answered through this project, as well as the experiment plans generated to gather the evidence to answer the questions. Chapter 4.0 presented a summary of the nuclear and electromagnetic gauge measurements obtained in the field. Chapter 5.0 presented a summary of the densities derived from laboratory measurements on pavement cores obtained from the locations where the gauge measurements were made. Chapter 5.0 also summarized the results of tests conducted on blocks of HMAC pavement trimmed with a lapidary saw blade and of tests on cores extracted from the blocks. This section presents the results of statistic analyses comparing the densities obtained from the gauge measurements with those obtained from measurements on the cores. It also presents the results of the analyses comparing the bulk specific gravities of blocks and cores cut from the blocks.

6.1 SCOPE OF STATISTICAL ANALYSES

Most of the analyses involved use of paired and two-sample t-tests. Least squares linear regression and analysis of variance were also used to investigate a subset of the data. The rationale for the use of these analysis tools is described below.

6.1.1 Paired t-tests

Paired t-tests were performed to compare the densities obtained from the various methods of measurement to determine if statistically significant differences existed between the methods. More specifically, these comparisons were made to determine if it is necessary to correlate nuclear gauge measurements to densities derived from pavement cores. It should be noted that electromagnetic gauges were available on several occasions during the field work and, where this was the case, the results from these gauges were included in the analyses. Further, it must be emphasized that each of these initial comparisons were performed on the results obtained from a particular lift of pavement, not between lifts. Paired t-tests were also performed to compare the bulk specific gravities of blocks and cores cut from the blocks.

6.1.2 Two-sample t-tests

Two-sample t-tests were performed to compare gauge correlation factors across successive lifts of pavement. More specifically, these comparisons were made to determine if a correlation factor for a nuclear gauge established from one lift of pavement could be used on a different lift of the pavement on the same project. Where possible, the same comparisons were made using the results from the electromagnetic gauges. Comparisons were made for three pavement construction scenarios including:

1. a new work section with a pavement constructed in multiple lifts with each lift having the same mix design;

2. a new work section with the first lift having a different mix design from the second lift; and
3. a section involving rehabilitation work where the existing pavement was milled and replaced (inlayed) and overlaid with both the inlay and the overlay having the same mix design.

Two-sample t-tests were also used to compare correlation factors established using two different core extraction locations within the nuclear gauge footprint. This comparison was performed to determine if the core extraction location (i.e., from the corner of an 'L-shaped' footprint or from the center of a 'cross-shaped' footprint) affected the correlation factor for the nuclear gauge.

6.1.3 Least Squares Linear Regression and ANOVA

Least squares linear regression analyses were used to investigate how water absorption affected bulk specific gravity measurements using the AASHTO T 166 methods. Linear models describing the effect of water absorption on the density of cores were developed; that is, density (obtained from the bulk specific gravity) as a function of water absorption. Analysis of variance of the data used to develop the models was conducted to determine the confidence interval about the intercept (i.e., density at 0% water absorption), which in turn was used to determine if it captured the density derived from the CoreLok method.

6.1.4 Laboratory Test Designations

Since three laboratory methods were used to measure the core densities, and core densities were determined at two laboratories (OSU and APAO), multiple comparisons were made for each gauge utilized. For one method of measurement (i.e., AASHTO T 166 Method A), tests were conducted at the OSU laboratories before and after these tests were conducted at the APAO laboratories. Table 6.1 lists the designations used throughout this section to distinguish between the laboratory tests.

Table 6.1: Designations used for Distinguishing between Laboratory Tests on Pavement Cores

Designation	Test Method	Laboratory
SSD Method A (before APAO testing)	AASHTO T 166 Method A	OSU
SSD Method A (APAO testing)	AASHTO T 166 Method A	APAO
SSD Method A (before APAO testing)	AASHTO T 166 Method A	OSU
SSD Method	AASHTO T 166 Method C	OSU
CoreLok	Manufacturer's Procedure	OSU

6.2 ANALYSIS METHODOLOGIES

As indicated above, the paired t-test was used to compare the various methods of test; the two-sample t-test was used to compare gauge correlation factors across pavement lifts, and linear regression and analysis of variance were used to investigate how water absorption affects the results from the AASHTO T 166 methods. Further details of the methodologies utilized are provided below.

6.2.1 Paired t-tests

A nuclear gauge correlation factor can be used to adjust density values obtained from a particular nuclear gauge on a particular pavement lift to coincide with the average density obtained from pavement cores on the same lift. Paired t-tests were conducted to determine if the differences in average densities between the two methods of measurements (i.e., tests on cores versus nuclear gauge measurements) were equal to zero for a given lift. Any non-zero differences found would provide evidence to suggest the necessity for establishing a nuclear gauge correlation factor on the given lift.

More specifically, for a given set of measurements obtained from cores and nuclear gauges for a particular lift of HMAC pavement, the differences between measurements were determined for each specific location within the lift, and the average and standard deviation of the differences were calculated following the procedure as specified in WAQTC TM 8. The average and standard deviation of the differences were then utilized in the paired t-test to determine if the differences were equal to zero at a specified confidence level[1]. Thus, the hypotheses and test statistic were as follows:

Hypotheses:

- μ_d = difference between the true mean density of the pavement lift when determined by measurements on cores and by nuclear gauge measurements

- Null hypothesis, H_0:

  $\mu_d = 0$ (i.e., no difference exists between determinations of the true mean density)
- Alternate hypothesis, H_a:

  $\mu_d \neq 0$ (i.e., a difference exists between determinations of the true mean density)

Test statistic:

$$t = \frac{\bar{X}_d - 0}{s / \sqrt{n}} = \frac{\bar{X}_d}{s / \sqrt{n}}$$

Where:

t = paired t-statistic

$\bar{X}_d$ = estimate of the difference between the true mean density of the pavement lift when determined by measurements on cores and by nuclear gauge

[1] In WAQTC TM 8, the correlation factor for a particular nuclear gauge is determined from the average difference between core densities and corresponding nuclear gauge readings. In ODOT TM 327, the correlation factor is determined from the average of the ratios of core densities to corresponding nuclear gauge readings. The analyses herein utilized the correlation factors determined using the WAQTC TM 8 methodology. Had the analyses utilized the ODOT TM 327 methodology for determining correlations factors, the average and standard deviation of the ratios would have been used in the paired t-test to determine if the ratios were equal to unity (one) at a specified confidence level. The same outcomes are found from the statistical analyses irrespective of methodology used to determine the correlation factors provided the hypothesis and test statistic account for the differences.

measurements (i.e., mean of differences between core densities and nuclear gauge densities)

s = standard deviation of the differences

n = number of paired observations

The nature of the alternate hypothesis (H_a) implies that a two-tailed rejection region should be used, meaning that the difference could be positive or negative. That is, the two-tailed t-test correctly accounts for the possibility that the mean density determined from nuclear gauge measurements could be less than or greater than the mean density determined from cores. The t-test was conducted using a confidence level of 95% (significance level $\alpha = 0.05$, or 5%). Figure 6.1a illustrates a result that would not allow rejection of the null hypothesis at a 95% confidence level. That is, the 95% confidence interval centered about the mean difference obtained from the test results (i.e., estimate of the true difference) captures the value of zero (i.e., hypothesized true mean difference of the entire population) indicating there is insufficient evidence at this confidence level to suggest a difference in the true mean pavement lift density as determined by the two methods being compared. Conversely, Figure 6.1b illustrates a result that would allow rejection of the null hypothesis (i.e., the value of zero falls outside of the 95% confidence interval).

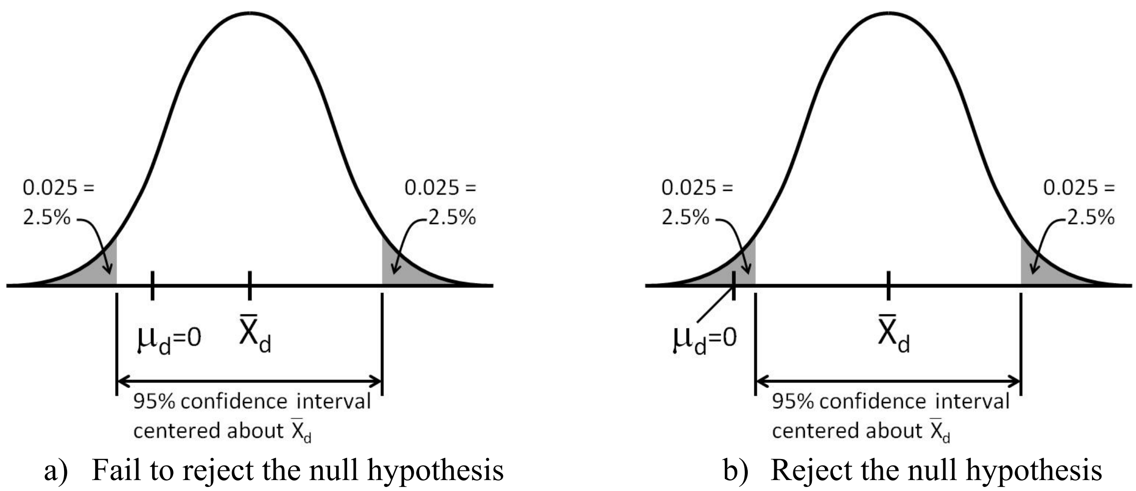
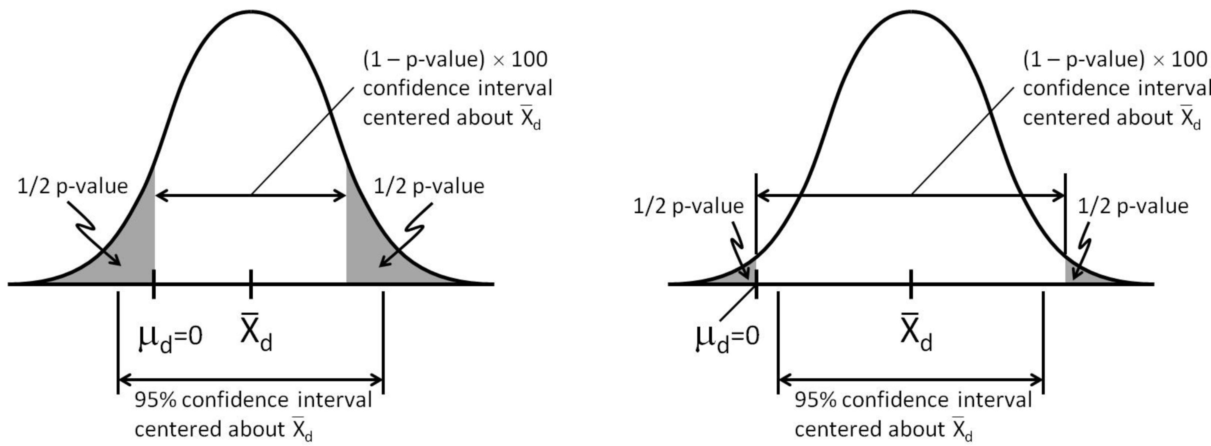


Figure 6.1: Illustration of Interpretation of Paired t-test Results

Another result that can be derived from the t-test is referred to as the p-value, which indicates the smallest level of significance (highest level of confidence) at which the null hypothesis (H_0) can be rejected. Figure 6.2 illustrates that the p-value is the sum of the shaded areas under the curve for a two-tailed test. Figure 6.2a illustrates the p-value corresponding to the scenario shown in Figure 6.1a (where the result indicated that the null hypothesis could not be rejected at the 95% confidence level). In comparing Figure 6.2a to Figure 6.1a, it can be seen that the p-value is greater in Figure 6.2a (i.e., the p-value in Figure 6.2a is greater than the significance level in Figure 6.1a). Conversely, Figure 6.2b illustrates the p-value corresponding to the scenario shown in Figure 6.1b. In this case the p-value in Figure 6.2b is less than the significance level in Figure 6.1b, indicating that the null hypothesis is rejected at the 95% confidence level (5%

significance level). In either case, the p-value can be used to determine whether or not the null hypothesis can be rejected as follows:

- p-value $\leq \alpha \rightarrow$ reject H_0 at significance level α
- p-value $> \alpha \rightarrow$ do not reject H_0 at significance level α



a) Fail to reject the null hypothesis b) Reject the null hypothesis

Figure 6.2: Interpretation of the p-value Obtained from the Paired t-test.

In addition, when the null hypothesis is rejected, the p-value indicates the strength of the evidence against H_0, with a lower value indicating greater strength of evidence. For example, a p-value of 0.01, which is much lower than a 0.05 (i.e., 5%) significance level (95% confidence level), indicates that the evidence is very strong against the null hypothesis. A p-value of 0.001 indicates the evidence is extremely strong against H_0.

Paired t-tests were also conducted to determine if differences between the bulk specific gravities of blocks cut from an HMAC pavement and trimmed using a lapidary saw blade and cores extracted from the blocks using a conventional diamond-tipped core barrel were equal to zero. The basic assumption was that the blocks of HMAC cut using a lapidary saw blade provided a more accurate assessment of the bulk specific gravity of the pavement. Hence, a non-zero difference would provide evidence to suggest that the conventional diamond-tipped core barrel caused damage to the core resulting in a less accurate assessment of the bulk specific gravity. The same methodology as described above was used to conduct the paired t-tests except that the hypotheses and test statistic were as follows:

Hypotheses:

- μ_d = difference between the true mean bulk specific gravity of the pavement when determined by measurements on blocks and cores extracted from the blocks
- Null hypothesis, H_0:

$\mu_d = 0$ (i.e., no difference exists between determinations of the true mean bulk specific gravity)

- Alternate hypothesis, H_a:

$\mu_d \neq 0$ (i.e., a difference exists between determinations of the true mean bulk specific gravity)

Test statistic:

$$t = \frac{\bar{X}_d - 0}{s/\sqrt{n}} = \frac{\bar{X}_d}{s/\sqrt{n}}$$

Where:

t = paired t-statistic

$\bar{X}_d$ = estimate of the difference between the true mean bulk specific gravity of the pavement when determined by measurements on blocks and on cores extracted from the blocks (i.e., mean of differences between block and core bulk specific gravities)

s = standard deviation of the differences

n = number of paired observations

6.2.2 Two-sample t-tests

ODOT personnel were interested in knowing if a correlation factor established from gauge measurements and cores from one lift of pavement could be used on a different lift of the pavement on the same project. To determine if such a practice is reasonable, two-sample t-tests were used to determine if the difference between correlation factors established for individual lifts were equal to zero. Any non-zero differences found would provide evidence to suggest the necessity of establishing a nuclear gauge correlation factor for each lift of pavement on a particular project (i.e., this would indicate that it would not be appropriate to use the correlation factor established for one lift on a different lift of the pavement).

More specifically, the correlation factor for each gauge utilized on each lift of the pavement was calculated as per WAQTC TM 8. This was accomplished by calculating the difference in gauge and core densities for each sample (test) location on a particular pavement lift. The average of the differences was then calculated to establish the correlation factor for a particular gauge and a particular pavement lift. To utilize the two-sample t-test, the standard deviation of the differences was also determined, again for a particular gauge and a particular pavement lift (see footnote in Section 6.2.1). In this manner, the correlation factor (average of differences) and its standard deviation were determined for each pair of measurements listed in Table 6.2.

Table 6.2: Core and Gauge Density Pairings to Determine Correlation Factors

Laboratory Test Designation	Type of Gauge	Number of Gauge Readings to Determine Reported Density	Number of Correlation Factors Determined per Gauge*
SSD Method A (before APAO testing)	Nuclear	2	3
		4	
	Electromagnetic	5	
SSD Method A (after APAO testing)	Nuclear	2	3
		4	
	Electromagnetic	5	
SSD Method A (APAO testing)	Nuclear	2	3
		4	
	Electromagnetic	5	
CoreLok	Nuclear	2	3
		4	
	Electromagnetic	5	

*Including the standard deviation for each correlation factor

In most cases, several gauges were used to measure the pavement density. However, it should be emphasized that two-sample t-tests were conducted only for the cases where the same gauge was used on both lifts being compared.

Since the densities obtained at each location on the various lifts were from the same stretch of pavement, they were considered a part of the same population for statistical purposes. Similarly, since the locations were randomly selected and were at different locations within each successive lift, they were considered two separate samples. Hence, use of a two-sample t-test, rather than a paired t-test, was the appropriate analysis tool to utilize for making comparisons of correlation factors across pavement lifts. With this rationale, the hypotheses and test statistic were as follows:

Hypotheses:

- μ_1 = true mean gauge correlation factor for one lift (i.e., true mean difference between gauge and core densities for a particular gauge, a particular core density measurement method, and a particular lift)
- μ_2 = true mean gauge correlation factor for another lift (i.e., true mean difference between gauge and core densities for the same gauge and core density measurement method, but for a different lift)
- Null hypothesis, H_0:

$\mu_1 - \mu_2 = 0$ (i.e., no difference exists between the true mean correlation factors)

- Alternate hypothesis, H_a:

$\mu_1 - \mu_2 \neq 0$ (i.e., a difference exists between the true mean correlation factors)

Test statistic:

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - 0}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where:

t = two-sample t-statistic

$\bar{X}_1$ = estimate of the true mean correlation factor for one lift (i.e., mean of differences between core and gauge densities)

$\bar{X}_2$ = estimate of the true mean correlation factor for another lift (i.e., mean of differences between core and gauge densities)

s_1 = standard deviation of the differences for one lift (i.e., standard deviation of the differences between core and gauge densities)

s_2 = standard deviation of the differences for another lift (i.e., standard deviation of the differences between core and gauge densities)

n_1 = number of observations of the differences for one lift

n_2 = number of observations of the differences for the other lift

The nature of the alternate hypothesis (H_a) implies that a two-tailed rejection region should be used, meaning that the difference could be positive or negative. That is, the two-tailed t-test correctly accounts for the possibility that the correlation factor on one lift could be less than or greater than the correlation factor on the other lift. The t-test was conducted using a confidence level of 95% (significance level $\alpha = 0.05$, or 5%). Interpretation of the results from the two-sample t-tests is the same as that for paired t-tests, as described in Section 6.2.1. Also, as with paired t-tests, a p-value can be obtained from the two-sample t-test. Interpretation of the p-value is illustrated above in Figure 6.2.

6.2.3 Least Squares Linear Regression and ANOVA

Using the data from the two AASHTO T 166 methods, least squares regression analyses were conducted to develop models of the form $y = \beta1x + \beta0$ where y represented density, x represented water absorption, $\beta1$ represented the slope of the line, and $\beta0$ represented the intercept (density at 0% water absorption) as illustrated in Figure 6.3. Analyses of variance were conducted to determine if the slope, $\beta1$, was equal to zero at a 95% confidence level. This was assessed by comparing the p-value determined from the ANOVA to a 5% (0.05) significance level, where p-values less than 0.05 provided strong evidence to suggest that the slope was not equal to zero; thus, indicating that water absorption had a significant influence on the measured bulk specific gravity (and density).

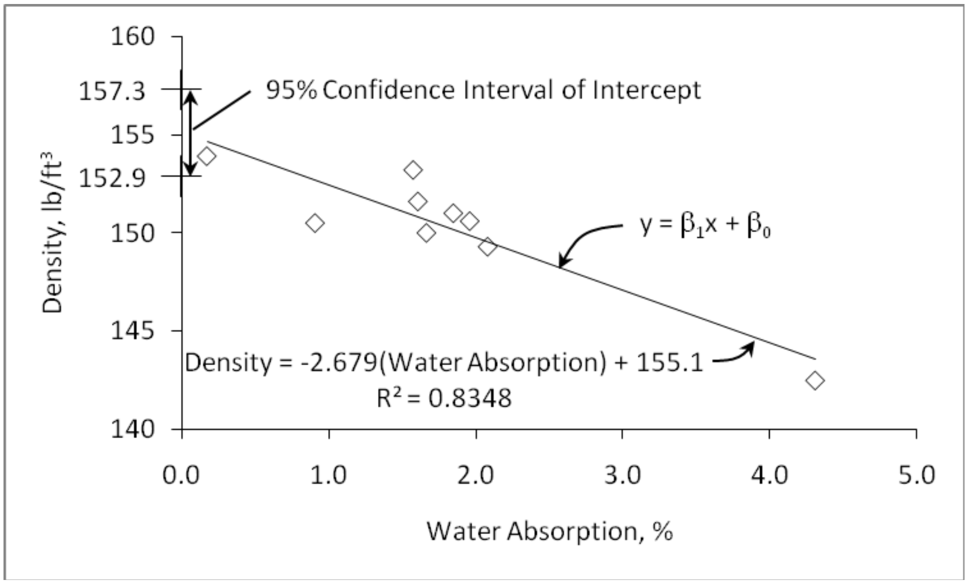


Figure 6.3: Density versus Water Absorption Models for the AASHTO T 166 Methods

The analyses of variance also provided the 95% confidence interval of the intercept for each regression model where the slope was found to be greater than zero. This provided an estimate of the range of densities at 0% water absorption. This interval was then compared against the 95% confidence interval of the density obtained from the CoreLok method to determine if the two intervals overlapped. Overlapping intervals indicated no significant difference at the 95% confidence level between the densities obtained from the different test methods.

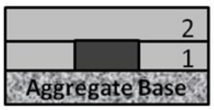
6.3 COMPARISON OF METHODS OF MEASUREMENT ON A GIVEN LIFT

This section presents the results of statistical analyses conducted to determine if it should be recommended to require that nuclear gauge measurements be correlated to densities obtained from measurements on pavement cores. The analyses were conducted as described above in Section 6.2.1 and all inferences indicating “significantly different,” or “not significantly different,” or similar are with respect to a 95% confidence level (i.e., significance level $\alpha = 0.05$, or 5%).

6.3.1 Interpretation of Paired t-test Summary Tables

Table 6.3 displays an example of the table format utilized for presenting the results obtained from the paired t-tests. The upper left cell identifies the lift to which the results apply and includes a small graphical representation for convenience. The methods of density measurement are displayed in the column and row headers. Note that each nuclear gauge is listed twice in the column and row headings since comparisons were made based on average densities derived from two and four readings from the gauges. If electromagnetic gauges were used, these would also be included in the tables. When comparisons were not performed, 'N/A' is displayed indicating 'not applicable' (in the example shown, tests were not conducted at APAO on the cores from this lift of pavement, so comparisons could not be made).

Table 6.3: Example of Table Format Displaying Paired t-test Results

OR 18 Lift 1 of Two-Lift Core 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3440 - #30860 (4 readings)	Troxler 3440 - #30860 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)
CoreLok	0.1976	0.1803	0.4053	0.0056	0.0041	0.0038	0.0159	0.0270
SSD Method A (before APAO)		0.0006	0.0067	0.0000	0.0051	0.0045	0.0246	0.0405
SSD Method A (after APAO)			0.0063	0.0000	0.0012	0.0009	0.0039	0.0068
SSD Method A (APAO)				0.0000	0.0020	0.0017	0.0067	0.0117
SSD Method C					0.0004	0.0003	0.0010	0.0018
Troxler 3440 - #30860 (4 readings)						0.1542	0.0023	0.0057
Troxler 3440 - #30860 (2 readings)							0.0096	0.0183
Troxler 3430 - #38806 (4 readings)								0.1943

All paired t-tests were conducted a significance level α equal to 0.05, or 5%, which is the same as saying a confidence level of 95%. The values listed in the cells of the tables represent the p-values obtained from the paired t-tests, with values less than or equal to 0.05 indicating that the null hypothesis can be rejected at a 5% significance level (95% confidence level). Recalling that, for these comparisons, the null hypothesis is no difference between densities obtained from the two measurement methods being compared, a p-value less than or equal to 0.05 (i.e., rejection of the null hypothesis) provides strong evidence to suggest a true difference between densities determined by the two methods utilized. For convenience, the results of comparisons where the null hypothesis was rejected at the 5% significance level are shaded.

As an example, Table 6.3 indicates there was sufficient evidence to suggest a true difference between the densities derived from AASHTO T 166 Method C and the CoreLok method (i.e., p-values greater than 0.05), but not between the densities derived from AASHTO T 166 Method A (in all cases) and the CoreLok method. Further, since the p-value for the comparison between AASHTO T 166 Method C and the CoreLok method was much less then 0.05, the evidence is very strong. Also, since the vast majority of cells Table 6.3 are shaded, it can be seen at a glance that the null hypothesis was rejected (indicating significant differences) in the vast majority of cases.

6.3.2 OR 18 Project

Recall from Section 3.3.1 that the base course along this project was constructed in three lifts, all having the same mix design. The results presented in this section were derived from density measurements within each of the three lifts, not between lifts. Again, the purpose of the comparisons was to determine if there were significant differences between the various measurement methods.

Table 6.4 presents the results of comparisons of density measurement methods used to determine the density of the first (bottom) lift placed along the OR 18 project. For this set of comparisons, the nuclear gauge was in direct contact with the paving lift from which the cores were obtained.

The results indicate that there was strong evidence to suggest no significant differences between the CoreLok method for determining the density of cores and both AASHTO T 166 methods. However, there was a significant difference between the densities derived from the two AASHTO T 166 methods.

The results also provide strong evidence to suggest significant differences between densities derived from cores using the CoreLok device and densities measured using nuclear gauges. Similarly, there is strong evidence to suggest significant differences between densities obtained from cores using the AASHTO T 166 methods and densities measured using nuclear gauges in all but two of the 18 comparisons.

The results in Table 6.4 also provide information regarding differences between the numbers of nuclear gauge readings (two versus four) used to compute the average density as well as differences between nuclear gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate strong evidence to suggest significant difference between results in four of the six possible comparisons.

Table 6.4: p-values from Comparisons of Measurement Methods on First Lift of the OR 18 Project

OR 18 Lift1 (1, Aggregate Base)	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3430 - #38804 (4 readings)	Troxler 3430 - #38804 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3440 - #25714 (4 readings)	Troxler 3440 - #25714 (2 readings)
CoreLok	0.0532	0.1547	N/A	0.7168	0.0030	0.0014	0.0001	0.0001	0.0285	0.0275
SSD Method A (before APAO)		0.0005	N/A	0.0000	0.0089	0.0038	0.0011	0.0021	0.1863	0.3599
SSD Method A (after APAO)			N/A	0.0000	0.0026	0.0013	0.0006	0.0011	0.0080	0.0391
SSD Method A (APAO)				N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C					0.0002	0.0001	0.0001	0.0001	0.0001	0.0004
Troxler 3430 - #38804 (4 readings)						0.3648	0.2206	0.1965	0.0070	0.0056
Troxler 3430 - #38804 (2 readings)							0.3151	0.3001	0.0014	0.0011
Troxler 3430 - #38806 (4 readings)								0.9345	0.0012	0.0006
Troxler 3430 - #38806 (2 readings)									0.0017	0.0006
Troxler 3440 - #25714 (4 readings)										0.7825
Troxler 3440 - #25714 (2 readings)										

Table 6.5 presents the results of comparisons of density measurement methods used to determine the density of the first (bottom) lift of the composite pavement (comprised of first and second lifts) placed along the OR 18 project. For this set of comparisons, the nuclear gauge was not in direct contact with the lift being evaluated; it was in contact with the second (middle) lift.

The results indicate that there is strong evidence to suggest no significant differences between the CoreLok method and AASHTO T 166 Method A, independent of laboratory. However, there was a significant difference between the densities derived from the CoreLok method and AASHTO T 166 Method C. Also, there were significant differences between the densities obtained from the two AASHTO T 166 methods in all cases.

The results also provide strong evidence to suggest significant differences between densities derived from cores using the CoreLok device and densities measured using nuclear gauges in four of the six possible comparisons. Similarly, there is strong evidence to suggest significant differences between densities obtained from cores using the AASHTO T 166 methods and densities measured using nuclear gauges in 20 of 24 comparisons. However, the results provide strong evidence to suggest no significant differences between the densities derived from any of the tests on cores and the densities measured from either of the PQI electromagnetic gauges.

The results in Table 6.5 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between gauges. For the former case, the results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate strong evidence to suggest significant differences between gauges in all six possible comparisons. The results also indicate that there is strong evidence to suggest significant differences between the densities measured from the nuclear gauges and the densities measured from the electromagnetic gauges, but not between the two electromagnetic gauges.

Table 6.5: p-values from Comparisons of Measurement Methods on First Lift Following the Second Lift of Paving on OR 18

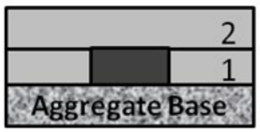
OR 18 Lift 1 of Two-Lift Core 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3440 - #30860 (4 readings)	Troxler 3440 - #30860 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3440 - #25714 (4 readings)	Troxler 3440 - #25714 (2 readings)	PQI 301	PQI 300
CoreLok	0.1976	0.1803	0.4053	0.0056	0.0041	0.0038	0.0159	0.0270	0.1381	0.1219	0.6727	0.3845
SSD Method A (before APAO)		0.0006	0.0067	0.0000	0.0051	0.0045	0.0246	0.0405	0.2585	0.2185	0.1878	0.0609
SSD Method A (after APAO)			0.0063	0.0000	0.0012	0.0009	0.0039	0.0068	0.0429	0.0393	0.7771	0.9345
SSD Method A (APAO)				0.0000	0.0020	0.0017	0.0067	0.0117	0.0679	0.0606	0.9918	0.6491
SSD Method C					0.0004	0.0003	0.0010	0.0018	0.0105	0.0102	0.1794	0.2002
Troxler 3440 - #30860 (4 readings)						0.1542	0.0023	0.0057	0.0000	0.0003	0.0000	0.0000
Troxler 3440 - #30860 (2 readings)							0.0096	0.0183	0.0003	0.0026	0.0000	0.0000
Troxler 3430 - #38806 (4 readings)								0.1943	0.0003	0.0083	0.0000	0.0001
Troxler 3430 - #38806 (2 readings)									0.0030	0.0390	0.0001	0.0002
Troxler 3440 - #25714 (4 readings)										0.0791	0.0016	0.0022
Troxler 3440 - #25714 (2 readings)											0.0016	0.0020
PQI 301												0.3057

Table 6.6 presents the results of comparisons of density measurement methods used to determine the density of the second (middle) lift of the composite pavement (comprised of first and second lifts) placed along the OR 18 project. For this set of comparisons, the nuclear gauge was in direct contact with the paving lift being evaluated.

The results indicate that there is strong evidence to suggest no significant differences between densities obtained from the CoreLok method and the two AASHTO T 166 methods, or between densities derived from AASHTO T 166 Method A conducted at the two laboratories. However, in all three cases, there were significant differences between the densities obtained from the two AASHTO T 166 methods.

The results also provide strong evidence to suggest significant differences between densities derived from cores, independent of test method, and those measured using nuclear gauges. However, the results provide strong evidence to suggest no significant differences between the densities derived from any of the tests on cores and the densities measured from either of the PQI electromagnetic gauges.

The results in Table 6.6 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate strong evidence to suggest significant differences between gauges in all six possible comparisons. The results also indicate that there is strong evidence to suggest significant differences between the densities measured from the nuclear gauges and the densities measured from the electromagnetic gauges, but not between the two electromagnetic gauges.

Table 6.6: p-values from Comparisons of Measurement Methods on Second Lift Following the Second Lift of Paving on OR 18

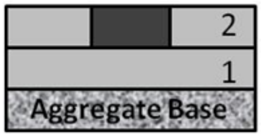
OR 18 Lift 2 of Two-Lift Core 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3440 - #30860 (4 readings)	Troxler 3440 - #30860 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3440 - #25714 (4 readings)	Troxler 3440 - #25714 (2 readings)	PQI 301	PQI 300
CoreLok	0.0611	0.3305	0.2630	0.0598	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2286	0.5012
SSD Method A (before APAO)		0.2585	0.4077	0.0430	0.0001	0.0001	0.0003	0.0013	0.0081	0.0053	0.5002	0.1908
SSD Method A (after APAO)			0.4370	0.0004	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.7442	0.7005
SSD Method A (APAO)				0.0027	0.0000	0.0000	0.0001	0.0002	0.0002	0.0001	0.9181	0.6011
SSD Method C					0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1127	0.3548
Troxler 3440 - #30860 (4 readings)						0.1542	0.0023	0.0057	0.0000	0.0003	0.0000	0.0000
Troxler 3440 - #30860 (2 readings)							0.0096	0.0183	0.0003	0.0026	0.0000	0.0000
Troxler 3430 - #38806 (4 readings)								0.1943	0.0003	0.0083	0.0000	0.0001
Troxler 3430 - #38806 (2 readings)									0.0030	0.0390	0.0001	0.0002
Troxler 3440 - #25714 (4 readings)										0.0791	0.0016	0.0022
Troxler 3440 - #25714 (2 readings)											0.0016	0.0020
PQI 301												0.3057

Table 6.7 presents the results of comparisons of density measurement methods used to determine the density of the composite pavement (comprised of first and second lifts) placed along the OR 18 project. For this set of comparisons, the nuclear gauge was in direct contact with the second lift.

The results indicate that there is strong evidence to suggest no significant differences between densities derived from the CoreLok method and AASHTO T 166 Method A likely owing, in part, to the low water absorption (less than 2%) of the cores during testing using the latter method (see Table 5.10). The cores were not tested using AASHTO T 166 Method C, or at the APAO laboratories.

The results also provide strong evidence to suggest significant differences between densities derived from the cores, independent of test method, and those measured using nuclear gauges. However, the results provide strong evidence to suggest no significant differences between the densities derived from any of the tests on cores and the densities measured using the PQI electromagnetic gauges.

The results in Table 6.7 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate that there is strong evidence to suggest significant differences between gauges in all six possible comparisons. The results also indicate that there is strong evidence to suggest significant differences between the densities measured from the nuclear gauges and the densities measured from the electromagnetic gauges, but not between the two electromagnetic gauges.

Table 6.7: p-values from Comparisons of Measurement Methods on Combined Lifts Following the Second Lift of Paving on OR 18

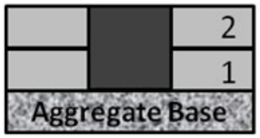
OR 18 Lifts 1 and 2 Combined 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3440 - #30860 (4 readings)	Troxler 3440 - #30860 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3440 - #25714 (4 readings)	Troxler 3440 - #25714 (2 readings)	PQI 301	PQI 300
CoreLok	0.3333	N/A	N/A	N/A	0.0000	0.0000	0.0000	0.0001	0.0036	0.0045	0.6834	0.3500
SSD Method A (before APAO)		N/A	N/A	N/A	0.0000	0.0000	0.0000	0.0002	0.0068	0.0068	0.3205	0.0723
SSD Method A (after APAO)			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO)				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Troxler 3440 - #30860 (4 readings)						0.1542	0.0023	0.0057	0.0000	0.0003	0.0000	0.0000
Troxler 3440 - #30860 (2 readings)							0.0096	0.0183	0.0003	0.0026	0.0000	0.0000
Troxler 3430 - #38806 (4 readings)								0.1943	0.0003	0.0083	0.0000	0.0001
Troxler 3430 - #38806 (2 readings)									0.0030	0.0390	0.0001	0.0002
Troxler 3440 - #25714 (4 readings)										0.0791	0.0016	0.0022
Troxler 3440 - #25714 (2 readings)											0.0016	0.0020
PQI 301												0.3057

Table 6.8 presents the results of comparisons of density measurement methods used to determine the density of the first (bottom) lift of the composite pavement (comprised of first, second, and third lifts) placed along the OR 18 project. For this set of comparisons, the nuclear gauge was not in direct contact with the paving lift being evaluated; it was in contact with the third (top) lift.

The results indicate that there is strong evidence to suggest no significant differences between densities obtained from the CoreLok method and AASHTO T 166 Method A in two of the three possible comparisons. There was also strong evidence to suggest a significant difference between the densities derived from the CoreLok method and AASHTO T 166 Method C. Also, the densities from AASHTO T 166 Method A were significantly different from those of AASHTO T 166 Method C.

The results also provide strong evidence to suggest no significant differences between densities derived from cores using the CoreLok device and densities measured using nuclear gauges. Similarly, there is strong evidence to suggest no significant differences between densities obtained from cores using the AASHTO T 166 methods and densities measured using nuclear gauges in the majority of possible comparisons (i.e., in 18 of 24 cases). However, the results provide strong evidence to suggest significant differences between the densities derived from the tests on cores and the densities using the electromagnetic gauges (with or without sand) in 18 of the 20 possible comparisons.

The results in Table 6.8 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate strong evidence to suggest significant differences between gauges in five of the six possible comparisons. The results also indicate that there is strong evidence to suggest significant differences, in all possible comparisons, between the densities measured from the nuclear gauges and the densities measured from the electromagnetic gauges.

Table 6.8 also provides information regarding the differences between densities measured using the electromagnetic gauges and the influence of sand on the measurements. In all cases, there were significant differences between densities obtained from the two gauges. In addition, the density obtained from the PQI 300 using sand was different from that obtained with the same gauge but without sand. However, there was not a significant difference between densities obtained from the PQI 301 with and without sand.

Table 6.8: p-values from Comparisons of Measurement Methods on First Lift Following the Third Lift of Paving on OR 18

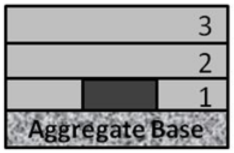
OR 18 Lift 1 of Three-Lift Core 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3440 - #30860 (4 readings)	Troxler 3440 - #30860 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3440 Plus #39525 (4 readings)	Troxler 3440 Plus #39525 (2 readings)	PQI 301 (sand)	PQI 301 (no sand)	PQI 300 (sand)	PQI 300 (no sand)
CoreLok	0.1403	0.0455	0.2139	0.0054	0.5827	0.5662	0.3407	0.4967	0.0697	0.0766	0.0388	0.1129	0.0607	0.0408
SSD Method A (before APAO)		0.0109	0.0803	0.0024	0.3119	0.3147	0.1584	0.2612	0.0756	0.0842	0.0119	0.0413	0.0204	0.0127
SSD Method A (after APAO)			0.1221	0.0010	0.2062	0.2177	0.0617	0.1831	0.0026	0.0043	0.0018	0.0055	0.0032	0.0014
SSD Method A (APAO)				0.0002	0.1671	0.1719	0.0627	0.1492	0.0127	0.0181	0.0019	0.0067	0.0034	0.0020
SSD Method C					0.7659	0.8902	0.6559	0.9763	0.0008	0.0013	0.0184	0.0496	0.0332	0.0102
Troxler 3440 - #30860 (4 readings)						0.7270	0.0386	0.5429	0.0000	0.0000	0.0010	0.0022	0.0023	0.0003
Troxler 3440 - #30860 (2 readings)							0.1514	0.7075	0.0000	0.0000	0.0018	0.0048	0.0041	0.0011
Troxler 3430 - #38806 (4 readings)								0.2169	0.0000	0.0000	0.0102	0.0099	0.0203	0.0018
Troxler 3430 - #38806 (2 readings)									0.0001	0.0001	0.0054	0.0018	0.0101	0.0006
Troxler 3440 Plus - #39525 (4 readings)										0.6339	0.0000	0.0000	0.0000	0.0000
Troxler 3440 Plus - #39525 (2 readings)											0.0000	0.0000	0.0000	0.0000
PQI 301 (sand)												0.2163	0.0018	0.0003
PQI 301 (no sand)													0.0365	0.0010
PQI 300 (sand)														0.0001

Table 6.9 presents the results of comparisons of density measurement methods used to determine the density of the second (middle) lift of the composite pavement (comprised of first, second, and third lifts) placed along the OR 18 project. For this set of comparisons, the nuclear gauge was not in direct contact with the paving lift from which the core slices were obtained; it was in contact with the third (top) lift.

The results indicate that there is strong evidence to suggest significant differences between the densities obtained from the CoreLok method and both AASHTO T 166 methods. There were also significant differences between the densities derived from the AASHTO T 166 methods in four of the five cases.

The results also provide strong evidence to suggest significant differences between densities derived from cores using the CoreLok device and densities measured using nuclear gauges. Similarly, there is strong evidence to suggest significant differences between densities obtained from cores using the AASHTO T 166 methods and densities measured using nuclear gauges in 16 of the 24 comparisons. However, the results provide strong evidence to suggest no significant differences between the densities derived from any of the tests on cores and the densities measured using the electromagnetic gauges.

The results in Table 6.9 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate that there was strong evidence to suggest significant differences between gauges in five of the six possible comparisons. The results also indicate that there is strong evidence to suggest significant differences between the densities measured from the nuclear gauges and the densities measured from the electromagnetic gauges.

Table 6.9 also provides information regarding the differences between densities measured using the electromagnetic gauges and the influence of sand on the measurements. The densities obtained from the PQI 300 were significantly different from those obtained from the PQI 301. Another observation is that the density obtained from the PQI 301 in the sanded condition was not significantly different from that in the un-sanded condition. However, for the PQI 300, the density measurement in the sanded condition differed significantly from that in the un-sanded condition.

Table 6.9: p-values from Comparisons of Measurement Methods on Second Lift Following the Third Lift of Paving on OR 18

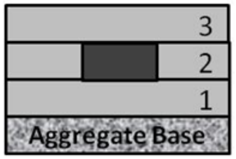
OR 18 Lift 2 of Three-Lift Core 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3440 - #30860 (4 readings)	Troxler 3440 - #30860 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3440 Plus #39525 (4 readings)	Troxler 3440 Plus #39525 (2 readings)	PQI 301 (sand)	PQI 301 (no sand)	PQI 300 (sand)	PQI 300 (no sand)
CoreLok	0.0000	0.0062	0.0053	0.0427	0.0124	0.0109	0.0316	0.0260	0.0002	0.0002	0.4851	0.8302	0.3120	0.5910
SSD Method A (before APAO)		0.0008	0.0118	0.0000	0.0988	0.0956	0.2348	0.1755	0.0007	0.0006	0.4191	0.3161	0.6365	0.0902
SSD Method A (after APAO)			0.0818	0.0000	0.0365	0.0333	0.0868	0.0693	0.0005	0.0004	0.9112	0.7914	0.6771	0.3284
SSD Method A (APAO)				0.0000	0.0469	0.0437	0.1161	0.0892	0.0005	0.0004	0.8801	0.6042	0.8608	0.2076
SSD Method C					0.0075	0.0063	0.0187	0.0156	0.0001	0.0001	0.2595	0.5515	0.1639	0.8871
Troxler 3440 - #30860 (4 readings)						0.7270	0.0386	0.5429	0.0000	0.0000	0.0010	0.0022	0.0023	0.0003
Troxler 3440 - #30860 (2 readings)							0.1514	0.7075	0.0000	0.0000	0.0018	0.0048	0.0041	0.0011
Troxler 3430 - #38806 (4 readings)								0.2169	0.0000	0.0000	0.0102	0.0099	0.0203	0.0018
Troxler 3430 - #38806 (2 readings)									0.0001	0.0001	0.0054	0.0018	0.0101	0.0006
Troxler 3440 Plus - #39525 (4 readings)										0.6339	0.0000	0.0000	0.0000	0.0000
Troxler 3440 Plus - #39525 (2 readings)											0.0000	0.0000	0.0000	0.0000
PQI 301 (sand)												0.2163	0.0018	0.0003
PQI 301 (no sand)													0.0365	0.0010
PQI 300 (sand)														0.0001

Table 6.10 presents the results of comparisons of density measurement methods used to determine the density of the third (top) lift of the composite pavement (comprised of first, second, and third lifts) placed along the OR 18 project. For this set of comparisons, the nuclear gauge was in direct contact with the paving lift from which the core slices were obtained.

The results indicate that there is strong evidence to suggest no significant differences between densities obtained from the CoreLok method and both AASHTO T 166 methods in three of the four possible comparisons. However, there was a significant difference between the densities obtained from the two AASHTO T 166 methods.

The results also provide strong evidence to suggest significant differences between densities derived from cores and those measured using nuclear gauges. However, the results provide strong evidence to suggest no significant differences between the densities derived from the tests on cores and the densities measured using the electromagnetic gauges in 18 of the 20 possible comparisons.

The results in Table 6.10 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate strong evidence to suggest significant differences between gauges in five of the six possible comparisons. The results also indicate that there is strong evidence to suggest significant differences between the densities measured from the nuclear gauges and the densities measured from the electromagnetic gauges.

Table 6.10 also provides information regarding the differences between densities measured using the electromagnetic gauges and the influence of sand on the measurements. The densities obtained from the PQI 300 were significantly different from those obtained from the PQI 301. Another observation is that the density obtained from the PQI 301 in the sanded condition was not significantly different from the density obtained in the un-sanded condition. However, for the PQI 300, the density measurement in the sanded condition differed significantly from that in the un-sanded condition.

Table 6.10: p-values from Comparisons of Measurement Methods on Third Lift Following the Third Lift of Paving on OR 18

OR 18 Lift 3 of Three-Lift Core 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3440 - #30860 (4 readings)	Troxler 3440 - #30860 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3440 Plus #39525 (4 readings)	Troxler 3440 Plus #39525 (2 readings)	PQI 301 (sand)	PQI 301 (no sand)	PQI 300 (sand)	PQI 300 (no sand)
CoreLok	0.0005	0.5046	0.5586	0.0631	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.5777	0.0501	0.2583	0.4411
SSD Method A (before APAO)		0.0009	0.0213	0.0000	0.0000	0.0007	0.0007	0.0002	0.0000	0.0000	0.1906	0.1890	0.4805	0.0012
SSD Method A (after APAO)			0.7445	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.7583	0.0898	0.3693	0.1740
SSD Method A (APAO)				0.0036	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.8390	0.3606	0.4625	0.2365
SSD Method C					0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2193	0.0039	0.0800	0.8107
Troxler 3440 - #30860 (4 readings)						0.7270	0.0386	0.5429	0.0000	0.0000	0.0010	0.0022	0.0023	0.0003
Troxler 3440 - #30860 (2 readings)							0.1514	0.7075	0.0000	0.0000	0.0018	0.0048	0.0041	0.0011
Troxler 3430 - #38806 (4 readings)								0.2169	0.0000	0.0000	0.0102	0.0099	0.0203	0.0018
Troxler 3430 - #38806 (2 readings)									0.0001	0.0001	0.0054	0.0018	0.0101	0.0006
Troxler 3440 Plus - #39525 (4 readings)										0.6339	0.0000	0.0000	0.0000	0.0000
Troxler 3440 Plus - #39525 (2 readings)											0.0000	0.0000	0.0000	0.0000
PQI 301 (sand)												0.2163	0.0018	0.0003
PQI 301 (no sand)													0.0365	0.0010
PQI 300 (sand)														0.0001

Table 6.11 presents the results of comparisons of density measurement methods used to determine the density of the composite pavement (comprised of first, second, and third lifts) placed along the OR 18 project. For this set of comparisons, the nuclear gauge was in direct contact with the paving lift from which the core slices were obtained.

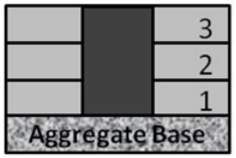
The results indicate that there is strong evidence to suggest no significant differences between densities derived from the CoreLok method and AASHTO T 166 Method A. Tests were not conducted using AASHTO T 166 Method C, or at the APAO laboratories.

The results also provide strong evidence to suggest no significant differences between densities derived from cores using the CoreLok device and densities measured using nuclear gauges in four of the six possible comparisons. Conversely, significant differences existed between densities obtained from cores using AASHTO T 166 Method A and densities measured using nuclear gauges in four of the six possible comparisons. Also, the results provide strong evidence to suggest no significant differences between the densities derived from the tests on cores and the densities measured using the electromagnetic gauges.

The results in Table 6.11 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate strong evidence to suggest no significant difference between gauges in five of the six possible comparisons. The results also indicate that there is strong evidence to suggest significant differences between the densities measured from the nuclear gauges and the densities measured from the electromagnetic gauges.

Table 6.11 also provides information regarding the differences between densities measured using the electromagnetic gauge and the influence of sand on the measurements. The densities obtained from the PQI 300 were significantly different from those obtained from the PQI 301. Another observation is that the density obtained from the PQI 301 in the sanded condition was not significantly different from the density obtained in the un-sanded condition. However, for the PQI 300, the density measurement in the sanded condition differed significantly from that in the un-sanded condition.

Table 6.11: p-values from Comparisons of Measurement Methods on Combined Lifts Following the Third Lift of Paving on OR 18

OR 18 Lifts 1, 2, and 3 Combined 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3440 - #30860 (4 readings)	Troxler 3440 - #30860 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3440 Plus #39525 (4 readings)	Troxler 3440 Plus #39525 (2 readings)	PQI 301 (sand)	PQI 301 (no sand)	PQI 300 (sand)	PQI 300 (no sand)
CoreLok	0.1310	N/A	N/A	N/A	0.2538	0.3337	0.7139	0.4342	0.0011	0.0015	0.0938	0.2040	0.1626	0.0548
SSD Method A (before APAO)		N/A	N/A	N/A	0.0229	0.0411	0.1175	0.0703	0.0001	0.0001	0.4066	0.6011	0.6516	0.1522
SSD Method A (after APAO)			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO)				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Troxler 3440 - #30860 (4 readings)						0.7270	0.0386	0.5429	0.0000	0.0000	0.0010	0.0022	0.0023	0.0003
Troxler 3440 - #30860 (2 readings)							0.1514	0.7075	0.0000	0.0000	0.0018	0.0048	0.0041	0.0011
Troxler 3430 - #38806 (4 readings)								0.2169	0.0000	0.0000	0.0102	0.0099	0.0203	0.0018
Troxler 3430 - #38806 (2 readings)									0.0001	0.0001	0.0054	0.0018	0.0101	0.0006
Troxler 3440 Plus - #39525 (4 readings)										0.6339	0.0000	0.0000	0.0000	0.0000
Troxler 3440 Plus - #39525 (2 readings)											0.0000	0.0000	0.0000	0.0000
PQI 301 (sand)												0.2163	0.0018	0.0003
PQI 301 (no sand)													0.0365	0.0010
PQI 300 (sand)														0.0001

Based on the results summarized in Tables 6.4 to 6.11, the following observations can be made:

- Tables 6.4, 6.6, and 6.10 provide results wherein the cores (or slices of cores) were obtained from the same lift on which the nuclear gauge readings were taken. The methodology used to generate the results in these particular tables follows the methodology provided in WAQTC TM 8 for determining nuclear gauge correlation factors. Hence, in determining whether or not nuclear gauge correlation factors are recommended as a mandatory requirement for dense-graded HMAC paving projects, inferences drawn from these tables carry greater weight than those drawn from the other tables.
- The results of paired t-tests comparing methods of measurement on cores (i.e., CoreLok and AASHTO T 166 methods) can be summarized as follows:
  - Core densities determined using the CoreLok method conducted at the OSU laboratories did not differ significantly from core densities determined using AASHTO T 166 Method A conducted at the OSU laboratories in ten (71%) of 14 comparisons.
  - Core densities determined using the CoreLok method conducted at the OSU laboratories did not differ significantly from core densities determined using AASHTO T 166 Method A conducted at the APAO laboratories in four (80%) of five comparisons.
  - Core densities determined using the CoreLok method conducted at the OSU laboratories differed significantly from core densities determined using AASHTO T 166 Method C conducted at the OSU laboratories in 3 (50%) of 6 comparisons.
  - Significant differences existed between the core densities obtained from the two AASHTO T 166 methods (A and C) in all (100%) of the comparisons for tests conducted at the OSU laboratories.
  - Significant differences did not exist between the densities determined using AASHTO T 166 Method A at the OSU and APAO laboratories in six (60%) of the ten comparisons.
- A majority of the comparisons (152 of 198, or 77%) indicated that the densities from the various tests on cores were significantly different from those of nuclear gauge measurements. A breakdown of the results is as follows:
  - Considering only those comparisons where the nuclear gauge was in direct contact with the lift from which the cores (or core slices) were obtained (i.e., Tables 6.4, 6.6, and 6.10), significant differences existed in 82 (98%) of the 84 comparisons.
  - Considering only those comparisons where the core slices were obtained from the lift immediately below the lift on which the nuclear gauge measurements were made (i.e., Tables 6.5 and 6.9), significant differences existed in 46 (77%) of the 60 comparisons.

  - Considering only those comparisons where the core slices were obtained from the bottom lift of the three-lift pavement (and the nuclear gauge measurements were made on the top lift), Table 6.8 indicates that significant differences existed in only 6 (20%) of the 30 comparisons.
  - Considering only those comparisons where the entire core from a two-lift or three-lift pavement (Tables 6.7 and 6.11), significant differences existed in 18 (75%) of the 24 comparisons.
- A majority of the comparisons (43 of 48, or 90%) indicated that the densities from the various measurements using nuclear gauges were significantly different from each other when the comparisons were based on average densities determined from the same number of readings (i.e., average of two readings each or average of four readings each).
- However, all comparisons on all of the lifts (100%) indicated that the density obtained using the average of two nuclear gauge measurements were not significantly different from the density obtained using the average of four nuclear gauge measurements.
- A majority of the comparisons (74 of 94, or 79%) indicated that the densities from the various tests on cores were not significantly different from those of electromagnetic gauge measurements. The majority of instances where significant differences existed occurred with the comparisons where the core slice was obtained from the bottom lift of the three-lift pavement (and the electromagnetic gauge measurements were made on the top lift) as shown in Table 6.8.
- All 132 comparisons between densities from the various nuclear gauges and electromagnetic gauges indicated significant differences.
- The densities obtained from the two electromagnetic gauges were significantly different from each other in 16 (84%) of 19 comparisons.
- On the third lift (Tables 6.8 to 6.11), where measurements with the electromagnetic gauges were taken in sanded and un-sanded conditions, the PQI 301 density taken in the sanded condition was not significantly different from that taken in the un-sanded condition in all four comparisons. However, for the PQI 300, the density measurements taken in the sanded condition were significantly different from those taken in the un-sanded condition.

6.3.3 I-5 Project

As indicated in Section 3.3.2, the first lift of the base course along this project had a different mix design from the remaining lifts. For research purposes, measurements and samples were taken only from the first and second lift to study the influence of different mix designs on the density measurements. The results presented in this section were derived from density measurements within each of the lifts, not between lifts. Again, the purpose of the comparisons was to determine if there were significant differences between the various measurement methods on pavements with lifts having different mix designs.

Table 6.12 presents the results of comparisons of density measurement methods used to determine the density of the first (bottom) lift placed along the I-5 project (i.e., the rich binder base layer). For this set of comparisons, the nuclear gauge was in direct contact with the paving lift from which the cores were obtained.

The results indicate that there is strong evidence to suggest significant differences between the various methods for determining the density of cores. The results also provide strong evidence to suggest significant differences between densities derived from cores using the CoreLok device and densities measured using nuclear gauges. Similarly, there is strong evidence to suggest significant differences between densities obtained from cores using the AASHTO T 166 methods and densities measured using nuclear gauges in all but three of the twelve possible comparisons.

The results in Table 6.12 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between the densities obtained from various nuclear gauges. The results provide strong evidence to suggest no significant differences between the densities derived from an average of two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate that there is strong evidence to suggest significant differences between gauges in four of the six possible comparisons.

Table 6.12: p-values from Comparisons of Measurement Methods on First Lift of the I-5 Project

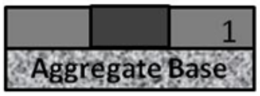
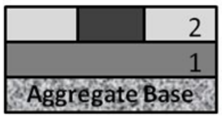
I-5 Lift 1 	SSD Method A	SSD Method C	Troxler 3430 - #38996 (4 readings)	Troxler 3430 - #38996 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	CPN MC3 Portaprobe #7443 (4 readings)	CPN MC3 Portaprobe #7443 (2 readings)
CoreLok	0.0000	0.0005	0.0000	0.0001	0.0010	0.0004	0.0000	0.0000
SSD Method A		0.0025	0.0429	0.1380	0.0062	0.0025	0.0025	0.0060
SSD Method C			0.0041	0.0118	0.9522	0.9015	0.0005	0.0012
Troxler 3430 - #38996 (4 readings)				0.3563	0.0007	0.0011	0.1285	0.1686
Troxler 3430 - #38996 (2 readings)					0.0067	0.0048	0.0953	0.1193
Troxler 3430 - #38806 (4 readings)						0.9544	0.0008	0.0022
Troxler 3430 - #38806 (2 readings)							0.0002	0.0004
CPN MC3 Portaprobe - #7443 (4 readings)								0.5246

Table 6.13 presents the results of comparisons of density measurement methods used to determine the density of the second (top) lift placed along the I-5 project. For this set of comparisons, the nuclear gauge was in direct contact with the paving lift from which the core slices were obtained.

The results indicate that there is strong evidence to suggest significant differences between the various methods for determining the density of cores. The results also provide strong evidence to suggest significant differences between densities derived from cores using the CoreLok device and densities measured using two of the four nuclear gauges. However, there was strong evidence to suggest no significant differences between densities obtained from cores using the SSD methods and densities measured using nuclear gauges in all but four of the 16 possible comparisons.

The results in Table 6.13 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between the densities from various nuclear gauges. The results provide strong evidence to suggest no significant differences between the densities derived from the average of two readings versus four readings for all four nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate that there is strong evidence to suggest significant differences between gauges in eight of the 12 possible comparisons.

Table 6.13: p-values from Comparisons of Measurement Methods on Second Lift of the I-5 Project

I-5 Lift 2  	SSD Method A	SSD Method C	Troxler 3430 - #38996 (4 readings)	Troxler 3430 - #38996 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	CPN MC3 Portaprobe #7443 (4 readings)	CPN MC3 Portaprobe #7443 (2 readings)	Humboldt 5001C - #1344 (4 readings)	Humboldt 5001C - #1344 (2 readings)
CoreLok	0.0062	0.0266	0.0067	0.0047	0.8461	0.7257	0.0073	0.0358	0.0694	0.0981
SSD Method A		0.0000	0.5995	0.4824	0.0002	0.0005	0.7225	0.2506	0.4458	0.4277
SSD Method C			0.1094	0.0678	0.0014	0.0032	0.3869	0.9855	0.9396	0.9176
Troxler 3430 - #38996 (4 readings)				0.6628	0.0000	0.0000	0.1084	0.0358	0.0249	0.0883
Troxler 3430 - #38996 (2 readings)					0.0000	0.0000	0.0872	0.0444	0.0777	0.1259
Troxler 3430 - #38806 (4 readings)						0.1175	0.0000	0.0011	0.0003	0.0049
Troxler 3430 - #38806 (2 readings)							0.0001	0.0024	0.0005	0.0078
CPN MC3 Portaprobe - #7443 (4 readings)								0.1632	0.5604	0.5455
CPN MC3 Portaprobe - #7443 (2 readings)									0.7030	0.9376
Humboldt 5001C - #1344 (4 readings)										0.6475

Based on the results summarized in Tables 6.12 and 6.13, the following observations can be made:

- All comparisons indicated that the densities obtained from the various tests on cores were significantly different from each other.
- Considering the results obtained from the bottom lift (i.e., the rich binder base layer), Table 6.12 indicates that the densities derived from the various tests on cores were significantly different from those determined using the nuclear gauges in 15 of 18 (or 83%) of the comparisons.
- However, a majority (16 of 24, or 67%) of the comparisons on the top lift (Table 6.13) indicated that there were no significant differences between the densities obtained from the tests on cores and those determined using the various nuclear gauges.
- A majority of the comparisons (4 of 6, or 67%) indicated that the densities obtained from the various nuclear gauges were significantly different from each other when the comparisons were based on average densities determined from the same number of readings (i.e., average of two readings each or average of four readings each).

- However, all comparisons on all of the lifts (100%) indicated that the density obtained using the average of two nuclear gauge measurements were not significantly different from the density obtained using the average of four nuclear gauge measurements.

6.3.4 OR 140 Project

As indicated in Section 3.3.3, this project involved rehabilitation work where the pavement was milled and replaced with an inlay followed by placement of an overlay (with both lifts having same mix design). The density measurements and samples were taken from both lifts. The results presented in this section were derived from density measurements within both lifts, not between lifts. Again, the purpose of the comparisons was to determine if there were significant differences between the various measurement methods on pavement layers placed over a milled surface.

Table 6.14 presents the results of comparisons of density measurement methods used to determine the density of the first (bottom, or inlay) lift placed along the OR 140 project. For this set of comparisons, the nuclear gauge was in direct contact with the paving lift from which the cores were obtained.

The results indicate that there is strong evidence to suggest significant differences between the various methods for determining the density of cores. Tests on these cores were not conducted at the APAO laboratories.

The results also provide strong evidence to suggest no significant difference between densities derived from cores using the CoreLok device and densities measured using nuclear gauges in four of the six possible comparisons. Similarly, there was strong evidence to suggest no significant differences between densities obtained from cores using AASHTO T 166 Method C and densities measured using nuclear gauges in four of the six possible comparisons. However, there was strong evidence to suggest significant differences between densities obtained from cores using AASHTO T 166 Method A and densities measured using nuclear gauges in the ten of the twelve possible comparisons. Also, the results provide strong evidence to suggest significant differences between the densities derived from the various tests on cores and the densities measured using the electromagnetic gauges in four of the six possible comparisons.

The results in Table 6.14 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between the densities from the various gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate that there is strong evidence to suggest significant differences between gauges in five of the six possible comparisons. The results also indicate that there is strong evidence to suggest no significant differences between the densities measured using the nuclear gauges and the densities measured using the PQI 300 electromagnetic gauge. Conversely there were significant differences between the densities obtained from the nuclear gauges and the densities obtained from the PQI 301 electromagnetic gauge in a majority of the comparisons. Further, the average density from the PQI 300 electromagnetic gauge was significantly different from that obtained from the PQI 301 electromagnetic gauge.

Table 6.14: p-values from Comparisons of Measurement Methods on the Inlay Lift of the OR 140 Project

OR 140 Lift 1 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3430 - #38996 (4 readings)	Troxler 3430 - #38996 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3430 - #35601 (4 readings)	Troxler 3430 - #35601 (2 readings)	PQI 301	PQI 300
CoreLok	0.0000	0.0002	N/A	0.3501	0.0002	0.0009	0.2057	0.6208	0.9034	0.8226	0.0088	0.0286
SSD Method A (before APAO)		0.0013	N/A	0.0000	0.0000	0.0000	0.0114	0.0113	0.0006	0.0006	0.2841	0.0000
SSD Method A (after APAO)			N/A	0.0000	0.0000	0.0001	0.1938	0.0992	0.0161	0.0186	0.3585	0.0001
SSD Method A (APAO)				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C					0.0003	0.0011	0.4425	0.9839	0.7792	0.8533	0.0096	0.0165
Troxler 3430 - #38996 (4 readings)						0.7640	0.0000	0.0001	0.0000	0.0000	0.0004	0.3231
Troxler 3430 - #38996 (2 readings)							0.0000	0.0000	0.0000	0.0000	0.0010	0.3989
Troxler 3430 - #38806 (4 readings)								0.2140	0.0408	0.0387	0.1871	0.0395
Troxler 3430 - #38806 (2 readings)									0.5311	0.5796	0.1171	0.1154
Troxler 3430 - #35601 (4 readings)										0.7900	0.0408	0.0871
Troxler 3430 - #35601 (2 readings)											0.0443	0.0762
PQI 301												0.0001

Table 6.15 presents the results of comparisons of density measurement methods used to determine the density of the first (bottom, or inlay) lift of the composite pavement comprised of the first and second lift (inlay and overlay lift) placed along the OR 140 project. For this set of comparisons, the nuclear gauge was not in direct contact with the paving lift from which the core slices were obtained, it was in contact with the second (overlay) lift.

The results indicate that there is strong evidence to suggest significant differences between the various methods for determining the density of cores. That is, significant differences existed between densities in eight (80%) of the ten possible comparisons.

The results also provide strong evidence to suggest no significant differences between densities derived from the various tests on cores (i.e., the CoreLok method and the AASHTO T 166 methods) and the densities measured using nuclear gauges. Also, the results provide strong evidence to suggest no significant differences between the densities derived from the CoreLok method and AASHTO T 166 Method C tests on cores and the densities measured using the electromagnetic gauges. However, there were significant differences between the densities derived from AASHTO T 166 Method A and the densities measured using the electromagnetic gauges.

The results in Table 6.15 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between the densities from various gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate that there is strong evidence to suggest no significant difference between gauges in four of the six possible comparisons. The results also indicate that there is strong evidence to suggest no significant differences between the densities obtained from the nuclear gauges and those obtained from the PQI 301 electromagnetic gauge. However, there were significant differences between the densities obtained from the nuclear gauges and those obtained from the PQI 300 electromagnetic gauge in a majority of the comparisons.

Table 6.15: p-values from Comparisons of Measurement Methods on the Inlay Lift Following the Second Lift of Paving on OR 140

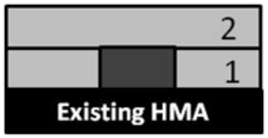
OR 140 Lift 1 of Two-Lift Core 	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3430 - #38996 (4 readings)	Troxler 3430 - #38996 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3430 - #35601 (4 readings)	Troxler 3430 - #35601 (2 readings)	PQI 301	PQI 300
CoreLok	0.0001	0.0037	0.0013	0.8780	0.5120	0.5105	0.2612	0.2883	0.3294	0.3658	0.8973	0.2317
SSD Method A (before APAO)		0.0000	0.0041	0.0000	0.4538	0.4466	0.8327	0.8180	0.8028	0.8048	0.0047	0.0016
SSD Method A (after APAO)			0.1298	0.0000	0.8653	0.8604	0.7059	0.7325	0.7859	0.8134	0.0564	0.0105
SSD Method A (APAO)				0.0000	0.7598	0.7552	0.8242	0.8483	0.8918	0.9118	0.0476	0.0101
SSD Method C					0.4572	0.4545	0.2102	0.2310	0.2848	0.3243	0.9290	0.1718
Troxler 3430 - #38996 (4 readings)						0.9598	0.0007	0.0112	0.0502	0.2213	0.2215	0.0078
Troxler 3430 - #38996 (2 readings)							0.0057	0.0215	0.0810	0.2474	0.2136	0.0065
Troxler 3430 - #38806 (4 readings)								0.8259	0.7742	0.8225	0.0488	0.0010
Troxler 3430 - #38806 (2 readings)									0.8661	0.8736	0.0572	0.0012
Troxler 3430 - #35601 (4 readings)										0.9143	0.1140	0.0063
Troxler 3430 - #35601 (2 readings)											0.1562	0.0145
PQI 301												0.0007

Table 6.16 presents the results of comparisons of density measurement methods used to determine the density of the second (top, or overlay) lift section of the composite pavement comprised of the first and second lift (inlay and overlay lift) placed along the OR 140 project. For this set of comparisons, the nuclear gauge was in direct contact with the paving lift from which the core slices were obtained.

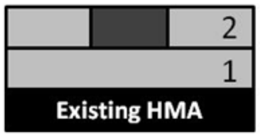
The results indicate that there is strong evidence to suggest no significant differences between the densities derived from the tests using the CoreLok device and the densities derived from the AASHTO T 166 methods. However, the results also indicate that there was strong evidence to suggest significant differences between the densities obtained from the two AASHTO T 166 methods and between laboratories methods.

The results also provide strong evidence to suggest no significant differences between densities derived from the CoreLok device or AASHTO T 166 Method C and the densities measured using nuclear gauges. However, there was strong evidence to suggest significant differences between the densities derived from AASHTO T 166 Method A and the densities measured using the nuclear gauges.

Also, the results provide strong evidence to suggest no significant differences between the densities derived from the CoreLok and the densities measured using the electromagnetic gauges. However, there were significant differences between the densities derived from the AASHTO T 166 methods and the densities measured using the electromagnetic gauges.

The results in Table 6.16 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between the densities obtained from the various gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate that there is strong evidence to suggest no significant difference between gauges in four of the six possible comparisons. The results also indicate that there was strong evidence to suggest no significant differences between the densities measured using the nuclear gauges and the PQI 301 electromagnetic gauge. However, there were significant differences between the densities obtained from the nuclear gauges and the densities obtained from the PQI 300 electromagnetic gauge in a majority of the comparisons. Further, the average densities obtained from the two electromagnetic gauges were significantly different from each other.

Table 6.16: p-values from Comparisons of Measurement Methods on the Overlay Lift Following the Second Lift of Paving on OR 140



OR 140 Lift 2 of Two-Lift Core	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3430 - #38996 (4 readings)	Troxler 3430 - #38996 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3430 - #35601 (4 readings)	Troxler 3430 - #35601 (2 readings)	PQI 301	PQI 300
CoreLok	0.0582	0.1433	0.1538	0.3276	0.5051	0.4973	0.2838	0.2959	0.3449	0.3730	0.9184	0.3827
SSD Method A (before APAO)		0.0132	0.0007	0.0002	0.0000	0.0000	0.0001	0.0001	0.0044	0.0227	0.0007	0.0000
SSD Method A (after APAO)			0.8571	0.0004	0.0012	0.0011	0.0906	0.1111	0.1124	0.2225	0.0081	0.0001
SSD Method A (APAO)				0.0057	0.0001	0.0004	0.0176	0.0360	0.0613	0.1801	0.0091	0.0001
SSD Method C					0.2689	0.2752	0.4388	0.5063	0.6141	0.7241	0.0604	0.0008
Troxler 3430 - #38996 (4 readings)						0.9598	0.0007	0.0112	0.0502	0.2213	0.2215	0.0078
Troxler 3430 - #38996 (2 readings)							0.0057	0.0215	0.0810	0.2474	0.2136	0.0065
Troxler 3430 - #38806 (4 readings)								0.8259	0.7742	0.8225	0.0488	0.0010
Troxler 3430 - #38806 (2 readings)									0.8661	0.8736	0.0572	0.0012
Troxler 3430 - #35601 (4 readings)										0.9143	0.1140	0.0063
Troxler 3430 - #35601 (2 readings)											0.1562	0.0145
PQI 301												0.0007

Table 6.17 presents the results of comparisons of density measurement methods used to determine the density of the composite pavement comprised of the first and second lift (inlay and overlay) placed along the OR 140 project. For this set of comparisons, the nuclear gauge was in direct contact with the paving lift from which the cores were obtained.

The results indicate that there was strong evidence to suggest no significant differences between the densities derived from the tests using the CoreLok device and the densities derived from AASHTO T 166 Method A. Tests were not conducted using AASHTO T 166 Method C, or at the APAO laboratories.

The results also provide strong evidence to suggest no significant differences between densities derived from the various two tests on cores and the densities measured using nuclear gauges in all but one of twelve comparisons. Also, the results provide strong evidence to suggest no significant differences between the densities derived from the CoreLok and the densities measured using the electromagnetic gauges. However, there were significant differences between the densities derived from AASHTO T 166 Method A and the densities measured using the electromagnetic gauges.

The results in Table 6.17 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between the densities obtained from the various nuclear. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for all three nuclear gauges compared. When comparing results between nuclear gauges for a given number of readings (i.e., average of two readings each or average of four readings each), the results indicate that there is strong evidence to suggest no significant difference between gauges in four of the six possible comparisons. The results also indicate that there was strong evidence to suggest no significant differences between the densities measured using the nuclear gauges and the densities measured using the PQI 301 electromagnetic gauge. However, there were significant differences between the densities obtained from the nuclear gauges and the densities obtained from the PQI 300 electromagnetic gauge in a majority of the comparisons.

Table 6.17: p-values from Comparisons of Measurement Methods on Combined Lifts Following the Second Lift of Paving on OR 140

OR 140 Lifts 1 and 2 Combined  	SSD Method A (before APAO)	SSD Method A (after APAO)	SSD Method A (APAO)	SSD Method C	Troxler 3430 - #38996 (4 readings)	Troxler 3430 - #38996 (2 readings)	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3430 - #35601 (4 readings)	Troxler 3430 - #35601 (2 readings)	PQI 301	PQI 300
CoreLok	0.1385	N/A	N/A	N/A	0.8024	0.8506	0.3609	0.4974	0.2854	0.3117	0.7114	0.1990
SSD Method A (before APAO)		N/A	N/A	N/A	0.0520	0.0302	0.1838	0.1107	0.3718	0.4990	0.0017	0.0000
SSD Method A (after APAO)			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO)				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Troxler 3430 - #38996 (4 readings)						0.9598	0.0007	0.0112	0.0502	0.2213	0.2215	0.0078
Troxler 3430 - #38996 (2 readings)							0.0057	0.0215	0.0810	0.2474	0.2136	0.0065
Troxler 3430 - #38806 (4 readings)								0.8259	0.7742	0.8225	0.0488	0.0010
Troxler 3430 - #38806 (2 readings)									0.8661	0.8736	0.0572	0.0012
Troxler 3430 - #35601 (4 readings)										0.9143	0.1140	0.0063
Troxler 3430 - #35601 (2 readings)											0.1562	0.0145
PQI 301												0.0007

Based on the results summarized in Tables 6.14 to 6.17, the following observations can be made:

- Tables 6.14 and 6.16 provide results wherein the cores (or slices of cores) were obtained from the same lift on which the nuclear gauge readings were taken. The methodology used to generate the results in these particular tables followed the methodology provided in WAQTC TM 8 for determining nuclear gauge correlation factors. Hence, these tables carry greater weight than Tables 6.15 and 6.17 in determining whether or not nuclear gauge correlation factors are recommended as a mandatory requirement for dense-graded HMAC paving projects.
- The comparisons on both lifts indicated that the densities derived from the CoreLok device were not significantly different from the densities derived from the AASHTO T 166 Method C in all cases.
- On the top (overlay) lift and for the composite pavement (Tables 6.16 and 6.17, respectively), the densities derived from the CoreLok device were not significantly different from the densities derived from AASHTO T 166 Method A. However, on the bottom (inlay) lift (Tables 6.14 and 6.15), the densities derived from the CoreLok device were significantly different from the densities derived from AASHTO T 166 Method A.
- A majority (44 of 48, or 92%) of the comparisons made on both the lifts indicated that the densities obtained from the tests on cores using the CoreLok device or AASHTO T 166 Method C were not significantly different from the densities measured using nuclear gauges.
- On the bottom (inlay) lift of the composite pavement and on the composite pavement itself (Tables 6.15 and 6.17), the results indicated that there were no significant differences between the densities derived from AASHTO T 166 Method A and the densities measured using the nuclear gauges.
- On the inlay and overlay lifts (Tables 6.14 and 6.16) wherein the gauges were in direct contact with the lift from which the core slices were extracted as per the WAQTC TM 8 procedure, a majority (22 of 30, or 73%) of the comparisons indicated that the densities derived from AASHTO T 166 Method A tests on cores were significantly different from the density measurements from nuclear gauges.
- On the inlay lift (Table 6.14), the comparisons indicated that the densities derived from the CoreLok were significantly different from those of electromagnetic gauge measurements.
- All comparisons made after the overlay lift was paved (Tables 6.15 to 6.17) indicated that the densities derived from the tests on cores using the CoreLok device were not significantly different from those of electromagnetic gauge measurements.
- The majority (18 of 24, or 75%) of the comparisons indicated significant differences between the densities derived from the AASHTO T 166 methods and those measured using the electromagnetic gauges.
- On the inlay lift (Table 6.14), the comparisons indicated that the densities obtained from the various nuclear gauges were significantly different from each other in five of the six possible comparisons when the comparisons were based on average densities determined

from the same number of readings (i.e., average of two readings each or average of four readings each).

- A majority (12 of 18, or 67%) of the comparisons made after the overlay lift was paved (Tables 6.15 to 6.17) indicated that the densities from the various nuclear gauges were not significantly different from each other when the comparisons were based on average densities determined from the same number of readings (i.e., average of two readings each or average of four readings each).
- For a given nuclear gauge used, the density obtained using the average of two nuclear gauge measurements were not significantly different from the density obtained using the average of four nuclear gauge measurements in all cases.
- On the inlay lift (Table 6.14), the comparisons indicated that the densities from the various nuclear gauges were not significantly different from those obtained from the PQI 300 in five of six comparisons, but were significantly different from those obtained from the PQI 301 in four of six comparisons.
- A majority (10 of 12, or 83%) of the comparisons made after the overlay lift was paved (Tables 6.15 to 6.17) indicated that the densities from the various nuclear gauges were not significantly different from those obtained from the PQI 301, but were significantly different from those obtained from the PQI 300 in all cases.
- The average densities obtained from the PQI 301 and the PQI 300 were significantly different from each other in all cases.

6.3.5 OR 18 Project (Core Extraction Location)

Recall from Section 3.2 that a part of the research was to investigate differences between densities obtained from the corner of the 'L-shaped' and 'cross-shaped' footprints. The results presented in this section were derived from density measurements within the 'L-shaped' and 'cross-shaped' footprints, not between the two types of footprints, to determine if there were significant differences between the various measurement methods and devices. Note that section 6.4.2 provides results of comparisons between the footprint core locations.

Table 6.18 presents the results of comparisons of density measurement methods used to determine the densities for the 'L-shaped' footprints along the OR 18 project (only two readings were taken for the 'L-shaped' footprint). The results indicate that there was strong evidence to suggest significant differences between the densities derived from the various tests on cores. The results also provide strong evidence to suggest that the densities derived from the CoreLok and AASHTO T 166 methods on cores were not significantly different from density measurements using nuclear gauges. However, there was a significant difference between the densities derived from AASHTO T 166 Method C and that derived from the average of two readings from the nuclear gauge. A significant difference did not exist between the densities calculated from the average of two readings versus four readings.

Table 6.18: p-values from Comparisons of Measurement Methods for the 'L-shaped' Footprint

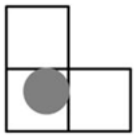
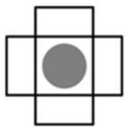
OR 18 'L-shaped' Footprint 	SSD Method A	SSD Method C	Troxler 3430 - #38806 (2 readings)	Troxler 3430 - #38994 (2 readings)
CoreLok	0.0046	0.0043	0.1412	0.0655
SSD Method A		0.0004	0.5347	0.2002
SSD Method C			0.0651	0.0262
Troxler 3430 - #38806 (2 readings)				0.3882

Table 6.19 presents the results of comparisons of density measurement methods used to determine the densities for the 'cross-shaped' footprints along the OR 18 project. The results indicated that there was strong evidence to suggest a significant difference between the densities derived from the CoreLok method and those derived from AASHTO T 166 Method A, but not with those derived from AASHTO T 166 Method C. There was also a significant difference between the densities obtained from the two AASHTO T 166 methods.

The results also provide strong evidence to suggest that the densities measured using nuclear gauges were not significantly different from those derived from the CoreLok method in three of the four comparisons, or different from those obtained from AASHTO T 166 Method A in all comparisons. However, there was significant difference between the densities derived from AASHTO T 166 Method C and those measured using one of the two nuclear gauges.

The results in Table 6.19 also provide information regarding differences between the numbers of readings (two versus four) used to compute the average density as well as differences between the densities from various nuclear gauges. The results provide strong evidence to suggest no significant differences between the average densities derived from two readings versus four readings for either nuclear gauge, or between gauges.

Table 6.19: p-values from Comparisons of Measurement Methods for the 'Cross-shaped' Footprint

OR 18 'Cross-shaped' Footprint 	SSD Method A	SSD Method C	Troxler 3430 - #38806 (4 readings)	Troxler 3430 - #38806 (2 readings)	Troxler 3430 - #38994 (4 readsings)	Troxler 3430 - #38994 (2 readings)
CoreLok	0.0116	0.0907	0.0817	0.0805	0.0526	0.0462
SSD Method A		0.0026	0.236	0.2801	0.1086	0.1063
SSD Method C			0.056	0.0505	0.0337	0.0276
Troxler 3430 - #38806 (4 readings)				0.2826	0.1464	0.2085
Troxler 3430 - #38806 (2 readings)					0.1491	0.1691
Troxler 3430 - #38994 (4 readings)						0.1866

Based on the results summarized in Tables 6.18 and 6.19, a number of observations can be made as follows:

- The comparisons between the densities derived from the various tests on cores indicated that they were significantly different from each other in five of the six comparisons. However, on the 'cross-shaped' footprint, the densities obtained from the CoreLok method were not significantly different from the densities derived from AASHTO T 166 Method C.
- A majority (14 of 18, or 78%) of the comparisons indicated that there were no significant differences between the densities derived from the various tests on cores and the densities measured using the nuclear gauges.
- The comparisons indicated that there were no significant differences between the various nuclear gauge density measurements.
- For the 'cross-shaped' footprint, there were no significant differences between the densities obtained using the average of two measurements versus the average of four measurements. On the 'L-shaped' footprint, only two measurements were taken by a nuclear gauge at every location, so a similar inference cannot be made from these data.

6.3.6 Summary

To determine if it is recommended to establish correlation factors for nuclear gauges, the primary objective was to evaluate the difference between densities derived from measurements on cores and those obtained from nuclear gauge measurements. Sections 6.3.2 through 6.3.5 provided details of 354 such comparisons. The following paragraphs provide a synopsis of the findings.

For the new work section (eastbound lanes) of the OR 18 project, 152 (77%) of the 198 total comparisons indicated significant differences between densities derived from the various tests on cores and those obtained from nuclear gauge measurements. However, 114 of these comparisons involved results from nuclear gauge measurements where the core slices were at least one lift removed from the lift on which the gauge measurements, or involved results from the two- or three-lift (composite) cores. Discounting these results (i.e., considering only those results where the nuclear gauge was in direct contact with the lift from the cores or core slices were obtained and excluding the composite cores), 82 (98%) of remaining 84 comparisons indicated a significant difference between densities derived from the various tests on cores and those obtained from nuclear gauge measurements.

For the new work project on I-5 having two lifts with different mix designs, 15 (83%) of the 18 comparisons on the bottom lift (rich binder base layer) indicated that the densities obtained from various tests on cores were significantly different from the densities obtained from nuclear gauges. However, comparisons on the second lift (with a mix design different from that of the rich binder base layer) indicated significant differences in only eight (33%) of the 24 comparisons. Overall, 23 (55%) of the 42 comparisons indicated significant differences.

For the project on OR 140 involving rehabilitation work (inlay plus overlay), 24 (67%) of the 36 comparisons indicated that the densities derived from the various tests on cores were significantly different from those obtained from nuclear gauge measurements where the gauge was in direct contact with the lift from which the cores (or core slices) were obtained. Overall, only 25 (38%) of the 66 total comparisons indicated significant differences, but 30 of these comparisons were made between gauge measurements and core slices obtained from the lift deeper in the pavement than the lift on which the gauge measurements were made, or using the whole core of the two-lift pavement.

For the comparisons made between core densities and nuclear gauge measurements where the cores were extracted from the corner of the 'L-shaped' footprint or the center of the 'cross-shaped' footprint of the nuclear gauges, only four (22%) of the 18 total comparisons indicated significant differences.

Collectively, 206 (58%) of the 354 comparisons indicated significant differences between the densities derived from tests on cores and those obtained from the nuclear gauges. For the comparisons where the cores (or core slices) were obtained from the lift on which the nuclear gauge measurements were made, 135 (68%) of the 198 comparisons indicated significant differences. A breakdown by core density test method is as follows.

Core Density Test Method	Total Number of Comparisons[1]	Number of Comparisons Indicating a Significant Difference[2]	Percentage of Comparisons Indicating a Significant Difference[2]
CoreLok	50	31	62
AASHTO T 166 Method A	98	75	76
AASHTO T 166 Method C	50	29	58
All methods	198	135	68

[1]Cores or core slices obtained from lift on which the nuclear gauge measurements were made.
[2]Significance determined at a 95% confidence level.

Overall, the results indicated that densities derived from tests on cores, independent of method, differed significantly (at a 95% confidence level) from densities obtained from the nuclear gauges in the majority of comparisons. These findings provide strong evidence in support of requiring correlation of nuclear gauges to pavement cores.

The manner in which the experiments were designed and conducted provided opportunity for evaluating several other aspects of the results. Some of these are summarized as follows:

- With regard to the number of readings used to calculate the average density obtained from the nuclear gauge measurements, no significant differences existed between densities calculated using two versus four readings in all 46 cases.
- However, the densities obtained from the various nuclear gauges were significantly different from each other in 56 (76%) of the 74 cases when the comparisons were based on average densities determined from the same number of readings (i.e., average of two readings each or average of four readings each).
- Significant differences existed between densities measured using nuclear and electromagnetic gauges in 158 (88%) of 180 cases.
- Only 15 (31%) of the 48 densities measured using electromagnetic gauges differed significantly from those derived from measurement on cores when considering only those results where the gauge was in direct contact with the lift from which the cores (or core slices) were obtained. This percentage is much less than half of that found for the nuclear gauges.

6.4 EFFECT OF WATER ABSORPTION ON AASHTO T 166 RESULTS

The comparisons in the previous section showed that the densities derived from the AASHTO T 166 methods were not significantly different from those obtained from the CoreLok method in many cases (particularly for the OR 18 project data). In other cases, the comparisons showed that they were significantly different. Given that the AASHTO T 166 methods utilize the saturated, surface-dry mass in determining the bulk specific gravity of a core under test, the effect of the amount of water absorbed during this process may account for the differences found. Hence, the results were analyzed to determine the effect of water absorption on the density of the cores as described in Section 6.2.3.

Table 6.20 summarizes the results of the analyses conducted using the results from AASHTO T 166 Method A. It shows that there is strong evidence to indicate that the slope, β_1, of the regression line was greater than zero in most cases, meaning that water absorption had a significant influence on the measured bulk specific gravity (and, hence, density). The table lists the estimated confidence intervals for the intercept of the regression lines (i.e., range of densities at 0% water absorption) and provides a comparison with the 95% confidence interval of the densities obtained from the CoreLok method. As indicated, significant differences existed in some cases but not in others. That is, for the results obtained from the OR 18 project, several of the comparisons showed no significant differences between the AASHTO T 166 Method A results and those obtained from the CoreLok method. However, for the results obtained from the

I-5 and OR 140 projects, significant differences existed in all cases. Together, these findings reinforce those of Section 6.3.

Table 6.20: Regression Analyses of the AASHTO T 166 Method A Results

				Regression Model		95% Confidence Intervals				
						Intercept Range		CoreLok		
Project	Lab	Paving Lift(s)	Core Lift	p-value for $\beta_1 = 0$	R^2, %	Lower Value	Upper Value	Lower Value	Upper Value	Significant Difference ?
OR 18	OSU (before APAO tests)	1	1	0.0007	78	153.3	156.8	147.9	152.3	Yes
		1 & 2	1	0.0588	38	N/A	N/A	N/A	N/A	N/A
			2	0.0113	57	149.5	153.0	147.0	149.0	Yes
		1, 2 & 3	1	< 0.0001	90	152.7	155.0	148.0	153.8	No
			2	0.7737	1	N/A	N/A	N/A	N/A	N/A
			3	0.0002	84	151.1	154.4	145.9	149.6	Yes
	OSU after APAO tests)	1	1	0.0013	75	153.0	157.2	147.9	152.3	Yes
		1 & 2	1	0.0020	72	149.6	153.1	147.3	150.6	No
			2	0.0454	46	148.5	151.0	147.0	149.0	No
		1, 2 & 3	1	< 0.0001	93	152.9	154.8	148.0	153.8	No
			2	0.0003	83	152.1	157.4	145.6	149.1	Yes
			3	0.0039	67	149.0	153.5	145.9	149.6	No
	APAO	1 & 2	1	0.0033	68	149.3	152.5	147.3	150.6	No
			2	0.1188	31	N/A	N/A	N/A	N/A	N/A
		1, 2 & 3	1	< 0.0001	91	152.2	154.1	148.0	153.8	No
			2	0.0125	56	148.6	153.0	145.6	149.1	No
			3	0.0013	75	149.7	154.1	145.9	149.6	Yes
I-5	OSU	1	1	0.0166	53	144.9	147.8	142.0	144.0	Yes
		1 & 2	2	0.0227	50	143.8	146.2	140.7	143.2	Yes
OR 140	OSU (before APAO tests)	1	1	< 0.0001	92	143.4	145.4	137.5	140.1	Yes
		1 & 2	1	0.0048	65	141.3	143.7	137.6	140.4	Yes
			2	0.0002	84	143.2	145.8	137.5	140.1	Yes
	OSU (after APAO tests)	1	1	< 0.0001	95	142.2	143.5	137.5	140.1	Yes
		1 & 2	1	0.0067	62	140.7	143.6	137.6	140.4	Yes
			2	0.0002	85	143.0	146.0	137.5	140.1	Yes
	APAO	1 & 2	1	0.0008	78	141.4	143.9	137.6	140.4	Yes
			2	< 0.0001	93	143.4	145.4	137.5	140.1	Yes

Table 6.21 summarizes the results of the analyses conducted using the results from AASHTO T 166 Method C. It indicates that there is strong evidence to suggest that water absorption had a significant influence on the measured bulk specific gravity in most cases. However, the findings do not necessarily support those of Section 6.3, particularly with regard to the results obtained from the OR 140 project. That is, Table 6.21 indicates significant differences in all cases, whereas Section 6.3 indicated no significant differences.

Table 6.21: Regression Analyses of the AASHTO T 166 Method C Results

Project	Paving Lift(s)	Core Lift	Regression Model: p-value for $\beta_1 = 0$	Regression Model: R^2, %	95% Confidence Intervals: Intercept Range Lower Value	Intercept Range Upper Value	CoreLok Lower Value	CoreLok Upper Value	Significant Difference?
OR 18	1	1	0.1093	29	N/A	N/A	N/A	N/A	N/A
	1 & 2	1	0.0079	61	148.9	155.5	147.3	150.6	No
		2	0.8540	1	N/A	N/A	N/A	N/A	N/A
	1, 2 & 3	1	0.0006	83	152.9	157.3	148.0	153.8	No
		2	0.1731	22	N/A	N/A	N/A	N/A	N/A
		3	0.0068	62	149.2	156.5	145.9	149.6	No
OR 140	1	1	< 0.0001	93	142.6	145.1	137.5	140.1	Yes
	1 & 2	1	0.0044	66	140.9	146.7	137.6	140.4	Yes
		2	0.0174	53	141.0	149.1	137.5	140.1	Yes

The comparisons in the previous section also indicated that significant differences existed between the two AASHTO T 166 methods in all cases. Recalling from Section 5.2.1 that, following return of the cores from the APAO laboratories, the cores were tested again using AASHTO T 166 Method A and then tested using Method C. During these tests, the submerged mass and saturated, surface-dry mass determined for Method A were also used for Method C, meaning that the only difference between to the methods was how the core was dried prior to determining the dry mass of the core. In Method A, the core was dried to constant mass in an oven set to 125°F (52°C), whereas for Method C, the cores were heated to 230°F (110°C), broken apart, and dried to constant mass in an oven set to 230°F (110°C).

The dry masses from the two methods were compared statistically using paired t-tests (see Section 6.2.1) to determine if they were significantly different at a 95% confidence level. Table 6.22 lists the p-values obtained from these comparisons. In all cases, the p-values were much less than 0.05 and provided strong evidence to indicate that the dry masses were significantly different. This suggests that the drying procedure in Method A, even though the cores were dried to constant mass, was ineffective in completely drying the cores, likely due to insufficiently high temperature to overcome the surface tension of water trapped in very small voids within the cores.

Table 6.22: Comparison of Dry Masses obtained from AASHTO T 166 Methods A and C

Project	Paving Lift(s)	Core Lift	p-value
OR 18	1	1	< 0.0001
	1 & 2	1	< 0.0001
		2	0.0006
	1, 2 & 3	1	0.0011
		2	< 0.0001
		3	< 0.0001
I-5	1	1	0.0026
	2	2	< 0.0001
OR 140	1	1	< 0.0001
	1 & 2	1	< 0.0001
		2	0.0004

6.5 COMPARISON OF CORRELATION FACTORS BETWEEN LIFTS

This section presents the results of statistical analyses conducted to determine if a correlation factor established for one lift of a paving project can be used on another lift of the same project. The analyses were conducted as described above in Section 6.2.2. Appendix E contains the correlation factors while Appendix F provides details of the hypotheses, test statistics, results, and observations for specific sets of comparisons. In this section, all inferences indicating "significantly different," or "not significantly different," or similar are with respect to a 95% confidence level (i.e., significance level $\alpha = 0.05$, or 5%).

6.5.1 Interpretation of Two-sample t-test Summary Tables

Table 6.23 displays an example of the table format utilized for presenting the results obtained from the two-sample t-tests. In tables with many rows and columns, rows are labeled R1, R2, etc., while columns are labeled C1, C2, and so on, for ease of identifying specific comparisons. Also, at the top of each column and on the left side of each row are graphical representations of the core or core slice location within the pavement. That is, the first three columns (C1, C2, and C3) and the first three rows (R1, R2, and R3) indicate that the core or core slice was obtained from the first lift of the pavement, whereas the last column and row (C4 and R4) indicate that core comprised all three lifts. In all cases, the gauge measurements were made on the uppermost lift. Note that, for ease of interpretation, the results are reflected about the diagonal line.

Table 6.23: Example of Table Format Displaying Two-sample t-test Results

Lifts with the same mix design	C1	C2	C3	C4
R1		10 of 16 (Table E1)	7 of 8 (Table E2)	2 of 4 (Table E8)
R2	10 of 16 (Table E1)		5 of 20 (Table E3)	3 of 8 (Table E17)
R3	7 of 8 (Table E2)	7 of 20 (Table E3)		4 of 8 (Table E24)
R4	2 of 4 (Table E8)	3 of 8 (Table E17)	4 of 8 (Table E24)	

Details of the analyses are provided in Appendix F, whereas the tables in this section summarize the results of the tables contained in Appendix F. Specifically, the tables in this section summarize the number of comparisons between lifts that were *not significantly* different from each other relative to the number of possible comparisons. A single comparison constituted a two-sample t-test between correlation factors from two different lifts for a particular core density test method (e.g., AASHTO T 166 Method A) and a particular gauge. A set of comparisons constituted all possible comparisons of correlation factors from the two lifts of interest for all core density test methods and gauges utilized.

For example, Table F1 in Appendix F provides the results of comparisons between correlation factors from the first and second lifts of pavement where the nuclear gauges were in direct contact with the lift from which the cores (or core slices) were obtained. Three nuclear gauges were used on both lifts, but only two gauges were common to both lifts. Densities from the gauges were calculated using the average of two readings and using the average of four readings. Also, three methods of measurement were used to determine core densities, where one method (AASHTO T 166 Method A) was repeated. Hence, a total of 16 correlation factors (i.e., two gauges × two densities per gauge × four core densities = 16) were determined for each lift allowing 16 comparisons. Of these, ten comparisons indicated that the correlation factors between lifts were not significantly different at a 95% confidence level. Hence, the cells in the representing these findings in the summary table (i.e., R1C2 and R2C1 in Table 6.23) indicate "10 of 16", with reference to the appendix table (i.e., Table F1) from which the summary data was derived.

For ease of interpretation, cells without shading indicate that significant differences were not found between correlation factors in the majority (i.e., greater than 50%) of the comparisons.

Cells shaded with dark gray indicate that significant differences were not found between correlation factors in the minority (i.e., less than 50%) of the comparisons. Cells shaded with light gray indicate that only half (50%) of the comparisons were not significantly different.

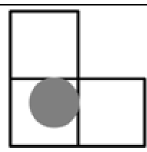
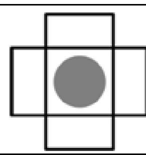
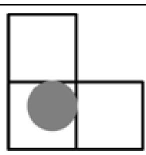
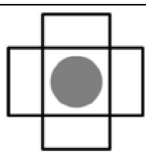
6.5.2 Core Location under Nuclear Gauge Footprint

Section 3.2.1 describes the experiment plan to determine if nuclear gauge correlation factors are affected by the core extraction location beneath the gauge. This section provides a summary of the statistical analyses conducted to determine if the correlation factors established using cores taken from the corner of the ‘L-shaped’ footprint (Figure 3.1b) were significantly different from those established using cores taken from the center of the ‘cross-shaped’ footprint (Figure 3.2b).

Table 6.24 presents a summary of the results detailed in Table F36 in Appendix F. As shown, in all twelve comparisons, all were found to be not significantly different from one another. These findings provide strong evidence to suggest that the correlation factors are not affected by the location of the core provided that it is obtained within the overlapped region of the nuclear gauge measurements.

In addition, as indicated in Table F36 of Appendix F, three core density test methods and two nuclear gauges were used to establish the correlation factors. The results indicated no differences between test methods, or between gauges.

Table 6.24: Summary of Correlation Factor Comparisons for Evaluation of Core Location

Core extraction location		
		12 of 12 (Table E36)
	12 of 12 (Table E36)	

6.5.3 Correlation Factors for Multi-Lift Pavements with a Single Mix Design

Section 3.2.3 described the experiment plan to determine if it is necessary to establish correlation factors on each lift of a multi-lift pavement where each lift has the same mix design. This section summarizes the statistical analyses conducted to compare correlation factors between lifts of a dense-graded HMAC base course constructed in multiple lifts.

Table 6.25 presents a summary of the 374 comparisons detailed in Tables F1 through F28 in Appendix F where nuclear gauge densities were used to establish the correlation factors. The following can be observed from these results:

- Considering a situation where correlation factors were not established on the first lift, but were established on the second lift, the following can be inferred from the results:
  - Where the nuclear gauges were in direct contact with the lifts from which the cores (or cores slices) were obtained (i.e., R1C3), ten (63%) of the 16 comparisons indicated no significant difference between correlation factors. However, note that if the core slices from only the first lift of the two-lift pavement were used to establish the correlation factor for the first lift (i.e., R2C3), it can be seen that 30 (100%) of the 30 possible comparisons indicated no significant difference between correlation factors.
  - If the entire cores from the two-lift pavement were used to establish the correlation factors, it can be seen from the comparisons in R1C4, R2C4, and R3C4 that no significant difference existed between correlation factors in 30 (94%) of the 32 possible comparisons.
- Considering a situation where correlation factors were not established on the first or second lift, but were established on the third lift, the following can be inferred from the results:
  - Where the nuclear gauges were in direct contact with the lifts from which the cores (or cores slices) were obtained (i.e., R1C7 and R3C7), only twelve (43%) of the 28 total comparisons indicated that there were no significant differences between the correlation factors. However, note that for the comparisons between the first and third lifts (i.e., R1C7), seven (88%) of the eight comparisons indicated no significant differences, whereas for the comparisons between the second and third lifts (i.e., R3C7), only five (25%) of the 20 comparisons indicated no significant differences.
  - For the comparisons between the correlation factors for the third lift (i.e., C7) with those in R1 through R6, 57 (59%) of the 96 total comparisons indicated there were no significant differences between the correlation factors.
  - If the entire cores from the three-lift pavement were used to establish the correlation factors, it can be seen from the comparisons between C8 and R1 through R8 that 31 (60%) of the 52 total comparisons indicated no significant differences between correlation factors.

- Considering only those comparisons where the core slices were obtained from the bottom lift of the three-lift pavement (i.e., C5), none (0 of 56, or 0%) of the comparisons indicated that there was a significant difference between the correlation factors.
- Considering only those comparisons where the core slices were obtained from the middle lift of the three-lift pavement (i.e., C6), 60 (83%) of the 72 total comparisons indicated that there was no significant difference between the correlation factors.
- Comparisons that were found to be significantly different only occurred in the comparisons involving the three-lift structure, and the majority of these involved the bottom lift of this structure.

Table 6.25: Summary of Nuclear Gauge Correlation Factor Comparisons between Lifts having the Same Mix Design

Lifts with the same mix design	C1	C2	C3	C4	C5	C6	C7	C8
R1		16 of 16 (Table E4)	10 of 16 (Table E1)	6 of 8 (Table E5)	0 of 8 (Table E6)	8 of 8 (Table E7)	7 of 8 (Table E2)	2 of 4 (Table E8)
R2	16 of 16 (Table E4)		30 of 30 (Table E9)	12 of 12 (Table E10)	0 of 20 (Table E11)	20 of 20 (Table E12)	20 of 20 (Table E13)	5 of 8 (Table E14)
R3	10 of 16 (Table E1)	30 of 30 (Table E9)		12 of 12 (Table E18)	0 of 20 (Table E15)	20 of 20 (Table E16)	5 of 20 (Table E3)	3 of 8 (Table E17)
R4	6 of 8 (Table E5)	12 of 12 (Table E10)	12 of 12 (Table E18)		0 of 8 (Table E26)	8 of 8 (Table E27)	5 of 8 (Table E28)	3 of 8 (Table E25)
R5	0 of 8 (Table E6)	0 of 20 (Table E11)	0 of 20 (Table E15)	0 of 8 (Table E26)		4 of 20 (Table E19)	0 of 20 (Table E20)	4 of 8 (Table E21)
R6	8 of 8 (Table E7)	20 of 20 (Table E12)	20 of 20 (Table E16)	8 of 8 (Table E27)	4 of 20 (Table E19)		20 of 20 (Table E22)	8 of 8 (Table E23)
R7	7 of 8 (Table E2)	20 of 20 (Table E13)	7 of 20 (Table E3)	5 of 8 (Table E28)	0 of 20 (Table E20)	20 of 20 (Table E22)		4 of 8 (Table E24)
R8	2 of 4 (Table E8)	5 of 8 (Table E14)	3 of 8 (Table E17)	3 of 8 (Table E25)	4 of 8 (Table E21)	8 of 8 (Table E23)	4 of 8 (Table E24)	

In addition, as indicated in Tables F3 and F9 through F28 of Appendix F, three core density test methods were used to establish the correlation factors. In many cases, AASHTO T 166 Method A was conducted once at the APAO laboratories and twice at the OSU laboratories. Also, comparisons of the correlation factors between lifts required at least one nuclear gauge common to the lifts under consideration, but many of the comparisons included two gauges. Examination of Tables F1 through F28 indicates consistency amongst core density test methods and between gauges, except in a minority of cases.

Electromagnetic gauges were also used to measure density after the second and third lifts were paved. Table 6.24 presents a summary of the 186 comparisons detailed in Tables F9 through F28 in Appendix F where electromagnetic gauges were used to establish the correlation factors. The following can be observed from these results:

- Considering a situation where correlation factors were not established on the first lift, but were established on the second lift, the following can be inferred from the results:
  - Where the electromagnetic gauges were in direct contact with the lifts from which the cores (or cores slices) were obtained (i.e., R1C3), and the core slices from only the first lift of the two-lift pavement were used to establish the correlation factor for the first lift (i.e., R1C2), it can be seen that ten (100%) of the ten possible comparisons indicated no significant difference between correlation factors.
  - If the entire cores from the two-lift pavement were used to establish the correlation factors, it can be seen from the comparisons in R1C3 and R2C3 that no significant difference existed between correlation factors in eight (100%) of the eight possible comparisons.
- Considering a situation where correlation factors were not established on the first or second lift, but were established on the third lift, the following can be inferred from the results:
  - Where the nuclear gauges were in direct contact with the lifts from which the cores (or cores slices) were obtained (i.e., R2C6), ten (100%) of the ten possible comparisons indicated that there were no significant differences between the correlation factors.
  - For the comparisons between the correlation factors for the third lift (i.e., C6) with those in R1 through R5, 46 (72%) of the 64 total comparisons indicated that were no significant differences between the correlation factors.
  - If the entire cores from the three-lift pavement were used to establish the correlation factors, it can be seen from the comparisons between C7 and R1 through R7 that 35 (97%) of the 36 total comparisons indicated no significant differences between correlation factors.
  - Considering only those comparisons where the core slices were obtained from the bottom lift of the three-lift pavement (i.e., C4), eight (57%) of the 14 total

comparisons indicated that there was no significant difference between the correlation factors.

- Considering only those comparisons where the core slices were obtained from the middle lift of the three-lift pavement (i.e., C5), none (36 of 36, or 100%) of the comparisons indicated that there was no significant difference between the correlation factors.
- As with the nuclear gauges, comparisons that were found to be significantly different only occurred in the comparisons involving the three-lift structure, and the majority of these involved the bottom lift of this structure.

In addition, as indicated in Tables F3 and F9 through F28 of Appendix F, three core density test methods were used to establish the correlation factors. In many cases, AASHTO T 166 Method A was conducted once at the APAO laboratories and twice at the OSU laboratories. Also, in all cases, two electromagnetic gauges were used to generate the correlation factors. Examination of Tables E3 and E9 through E28 indicates consistency amongst core density test methods and between gauges, except in a minority of cases.

Table 6.26: Summary of Electromagnetic Gauge Correlation Factor Comparisons between Lifts having the Same Mix Design

Lifts with the same mix design	C1	C2	C3	C4	C5	C6	C7
R1		10 of 10 (Table E9)	4 of 4 (Table E10)	4 of 10 (Table E11)	10 of 10 (Table E12)	9 of 10 (Table E13)	4 of 4 (Table E14)
R2	10 of 10 (Table E9)		4 of 4 (Table E18)	1 of 10 (Table E15)	10 of 10 (Table E16)	10 of 10 (Table E3)	3 of 4 (Table E17)
R3	4 of 4 (Table E10)	4 of 4 (Table E18)		3 of 4 (Table E26)	4 of 4 (Table E27)	3 of 4 (Table E28)	4 of 4 (Table E25)
R4	4 of 10 (Table E11)	1 of 10 (Table E15)	3 of 4 (Table E26)		12 of 20 (Table E19)	4 of 20 (Table E20)	8 of 8 (Table E21)
R5	10 of 10 (Table E12)	10 of 10 (Table E16)	4 of 4 (Table E27)	12 of 20 (Table E19)		20 of 20 (Table E22)	8 of 8 (Table E23)
R6	9 of 10 (Table E13)	10 of 10 (Table E3)	3 of 4 (Table E28)	4 of 20 (Table E20)	20 of 20 (Table E22)		8 of 8 (Table E24)
R7	4 of 4 (Table E14)	3 of 4 (Table E17)	4 of 4 (Table E25)	8 of 8 (Table E21)	8 of 8 (Table E23)	8 of 8 (Table E24)	

6.5.4 Correlation Factors for Pavement Lifts with Different Mix Designs

Section 3.2.4 described the experiment plan to determine if it is necessary to establish correlation factors on each lift of a pavement where each lift has a different mix design. This section summarizes the statistical analyses conducted to compare correlation factors between the first two lifts of a dense-graded HMAC base course constructed with two different mix designs.

Table 6.27 presents a summary the 18 comparisons detailed in Table E29 in Appendix E where nuclear gauges were used to establish the correlation factors. It can be seen from these results that ten (56%) of the 18 comparisons indicated no significant differences between correlation factors.

In addition, as indicated in Table F29 of Appendix F, three core density test methods and three nuclear gauges were used to establish the correlation factors. For the correlation factors calculated using the densities derived from AASHTO T 166 Methods A and C, differences of results existed amongst the gauges. However, for the correlation factors calculated using the densities derived from the CoreLok tests, the results were consistent amongst the gauges.

Table 6.27: Summary of Nuclear Gauge Correlation Factor Comparisons between Lifts having Different Mix Designs

Lifts with different mix designs		
		10 of 18 (Table E29)
	10 of 18 (Table E29)	

6.5.5 Correlation Factors for Inlays and Overlays with the Same Mix Design

Section 3.2.5 described the experiment plan to determine if it is necessary to establish correlation factors for inlays and overlays where both lifts have the same mix design. This section summarizes the statistical analyses conducted to compare correlation factors between the lifts constructed using dense-graded HMAC.

Table 6.28 presents a summary the 114 comparisons detailed in Tables F30 through F35 in Appendix F where nuclear gauges were used to establish the correlation factors. It can be observed from these data that 108 (95%) of the 114 comparisons indicated no significant difference between correlation factors. Examination of Tables F30 through F35 indicates that significant differences only occurred when AASHTO T 166 Method A was used to determine the correlation factors.

Table 6.28: Summary of Nuclear Gauge Correlation Factor Comparisons of Inlays and Overlays

Inlay versus overlay with the same mix design	C1	C2	C3	C4
R1		24 of 24 (Table E30)	20 of 24 (Table E31)	10 of 12 (Table E32)
R2	24 of 24 (Table E30)		30 of 30 (Table E33)	12 of 12 (Table E34)
R3	20 of 24 (Table E31)	30 of 30 (Table E33)		12 of 12 (Table E35)
R4	10 of 12 (Table E32)	12 of 12 (Table E34)	12 of 12 (Table E35)	

Table 6.29 presents a summary the 38 comparisons detailed in Tables F30 through F35 in Appendix F where electromagnetic gauges were used to establish the correlation factors. It can be observed from these data that 29 (76%) of the 38 comparisons indicated no significant difference between correlation factors. Examination of Tables F30 through F35 indicates that significant differences only occurred when the AASHTO T 166 methods, particularly Method A, were used to determine the correlation factors.

Table 6.29: Summary of Electromagnetic Gauge Correlation Factor Comparisons of Inlays and Overlays

Inlay versus overlay with the same mix design	C1	C2	C3	C4
R1		6 of 8 (Table E30)	2 of 8 (Table E31)	3 of 4 (Table E32)
R2	6 of 8 (Table E30)		10 of 10 (Table E33)	4 of 4 (Table E34)
R3	2 of 8 (Table E31)	10 of 10 (Table E33)		4 of 4 (Table E35)
R4	3 of 4 (Table E32)	4 of 4 (Table E34)	4 of 4 (Table E35)	

6.5.6 Summary

Comparisons of nuclear gauge correlation factors established from cores obtained from the corner of the 'L-shaped' footprint and those obtained from the center of the 'cross-shaped' footprint indicated no significant differences. These findings provide strong evidence to suggest that the correlation factors are not affected by the location of the core provided that it is obtained within the overlapped region of the nuclear gauge measurements.

To determine if a nuclear gauge correlation factor established for one lift of an HMAC pavement can be used on a different lift of the same project, the primary objective was the evaluation of the differences between correlation factors across lifts. Sections 6.4.3 through 6.4.5 provided details of 506 such comparisons. The following paragraphs provide a synopsis of the findings.

When considering all possible combinations, a majority (352 of 506, or 70%) of the comparisons indicated that the correlation factors established for one lift were not significantly different from those established for another lift. Included in these comparisons are correlation factors developed from core slices that were obtained from the bottom or middle lift of a three-lift pavement and where the nuclear gauge measurements were made on the top lift of the pavement.

Also included in these comparisons are correlation factors derived from cores comprised of either two or three lifts (i.e., entire core of a two-lift or three-lift pavement). Discounting these results due to the potential impracticality and error associated with testing large core samples on a routine basis reduces the majority to 67%; that is, 257 of 386 of the comparisons where the correlation factors were not found to be significantly different.

From a practical standpoint of establishing correlation factors, the most logical approach would be to utilize cores obtained from the lift on which the nuclear gauge measurements are made (as is the case specified in WAQTC TM 8). Considering only those results for which this applies, the majority is further reduced to 60%; that is, 52 of 86 of the comparisons where the correlation factors were not found to be significantly different.

These findings suggest that, at best, about three of every ten correlation factors established for one lift would not be representative of the correlation factor of another lift on the same paving project. However, assuming that WAQTC TM 8 will continue to be used for establishing correlation factors, the findings suggest that about four in every ten correlation factors established for one lift would not be representative of the correlation factor of another lift on the same paving project.

Electromagnetic gauges were used on two of the projects allowing similar comparisons of correlation factors across lifts. Sections 6.4.3 and 6.4.5 provided details of 196 such comparisons. When considering all possible combinations, 172 (77%) of the 196 comparisons indicated that the correlation factors established for one lift were not significantly different from those established for another lift. Considering only those comparisons involving correlation factors derived from cores obtained from the lifts on which the electromagnetic gauge measurements were made, 12 (67%) of the 18 comparisons indicated no significant differences between correlation factors. Hence, for both scenarios, correlation factors for electromagnetic gauges indicated fewer differences across lifts (on a percentage basis) than did correlation factors for nuclear gauges.

6.6 CORE DAMAGE ASSESSMENT

This section presents the results of the statistical analysis that was conducted to determine if cores are damaged by a conventional diamond-tipped core barrel. The analysis was conducted as described above in Paired t-tests (Section 6.2.1).

Table 6.30 displays the data that was presented in Table 5.3, but also includes the differences between the bulk specific gravities of the blocks and the cores as well as the p-values. Note that there was typically no difference or only a 0.1% difference in water absorption between a given block and the core extracted from the block; however, in one case there was a 0.2% difference. Since the p-value was much greater than 0.05, there was insufficient evidence to reject the null hypothesis (i.e., equal specific gravities between blocks and cores extracted from the blocks) at the 95% confidence level. That is, there was insufficient evidence to suggest that a conventional diamond-tipped core barrel caused damage to the core leading to inaccurate results.

Table 6.30: Summary of Comparison between Blocks and Cores Extracted from the Blocks

Sample		Bulk Specific Gravity (AASHTO T 166 Method A)*		
		Block	Core	Difference
1	a	2.318 (0.4)	2.323 (0.3)	-0.005
	b	2.317 (0.3)	2.318 (0.3)	-0.001
2	a	2.346 (0.3)	2.339 (0.3)	0.008
	b	2.345 (0.3)	2.340 (0.5)	0.005
3	a	2.335 (0.3)	2.333 (0.3)	0.002
	b	2.331 (0.3)	2.326 (0.3)	0.005
4	a	2.303 (0.5)	2.291 (0.4)	0.010
	b	2.319 (0.4)	2.310 (0.3)	0.010
5	a	2.342 (0.3)	2.344 (0.4)	-0.002
	b	2.350 (0.2)	2.347 (0.3)	0.003
Paired t-test p-value		0.0627		

*Values in parentheses represent percent absorption by volume.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The overall objective of this research was to recommend a system that accurately quantifies the density of dense-graded hot mix asphalt concrete (HMAC) to be used for quality control and quality assurance purposes. With this in mind, the specific objectives were to: 1) investigate the effectiveness of the various methods for determining in-place HMAC density; 2) assess current practices used by ODOT and other agencies; 3) conduct field and laboratory testing using state-of-the-practice methods to determine the best method or combination of methods; 4) provide recommendations for changes to current practices utilized by ODOT, and 5) recommend alternate means for determining in-place HMAC density.

Chapter 2.0 provides the findings from a review of literature that was conducted to satisfy the first enumerated objective. Methods of determining in-place HMAC pavement density include measurements on cores to determine bulk specific gravity (which is multiplied by the unit density of water to provide core density) and measurements using nuclear gauges and electromagnetic gauges.

Several methods exist for measuring the bulk specific gravity of cores (and laboratory-prepared specimens) including AASHTO T 166 (similar to ASTM D 2726), AASHTO T 275 (similar to ASTM D 1188), and AASHTO T 331 (similar to ASTM D 6752). AASHTO T 166 is commonly used by many states (Appendix A), whereas only a few states use AASHTO T 275 or ASTM D 6752. Some states have developed their own procedure. It can also be seen from Appendix A that many states only use cores for assessing in-place HMAC density. It is noted, however, that the listing in Appendix A is not exhaustive since it was difficult to find this information in many cases.

ASTM D 2950 provides procedures for calibrating and operating nuclear gauges for the purposes of measuring in-place HMAC density. Some states, such as Oregon, utilize WAQTC TM 8, while many have developed their own procedures. For electromagnetic gauges, AASHTO TP 68 and ASTM D 7113 provide procedures for measuring in-place density.

Numerous studies have been conducted to evaluate in-place density measurement methods. Chapter 2.0 provides a synopsis of several of these studies.

To fulfill the second enumerated objective, the current practices utilized by ODOT and other agencies to measure in-place density were investigated. Appendix A provides a comparison of the methods of density measurement, number of samples per location, and acceptance criteria. From this comparison, it can be concluded that the methods and criteria employed by ODOT are not dissimilar to those employed by many other states.

ODOT’s method of nuclear gauge calibration was also investigated. This involved a critical review of ODOT TM 304 with comparison to procedures from other states (Section 2.2.1) as well as verification and validation of the procedure (Sections 2.2.1 and 4.1). It can be concluded from this evaluation that ODOT's procedure is rigorous and robust, but includes a check of the gauge on a hot substrate that was not found in procedures from the states from which detailed information could be found. However, since this is simply a pre-calibration check of the gauge, there appears to be no reason to deem it invalid. A few states include additional pre-calibration checks that are not employed by ODOT; namely a stability check and a drift check.

Chapter 3.0 provides details of the experiment plans developed to fulfill the third enumerated objective. Chapter 4.0 summarizes the data collected during the field study, while Chapter 5.0 summarizes the data obtained during the laboratory study. The results were analyzed using paired t-tests to determine if correlating nuclear gauge measurements to cores is necessary (or advised), and two-sample t-tests to determine if correlation factors established for one lift of a pavement could be used on a different lift of the pavement on the same project. Chapter 6.0 provides descriptions of the analyses as well as the results, including discussions of the results. Based on these findings, conclusions and recommendations have been developed to fulfill the fourth and fifth enumerated objectives as well as the overall objective of the study.

7.1 CONCLUSIONS

The findings from this research project are limited by various factors and are bounded in their scope and application. The findings only apply to dense-graded hot mix asphalt concrete pavements. Data were obtained from only one project for each of the three construction scenarios investigated. These scenarios were a new pavement construction project with multiple lifts having the same mix design, a new pavement construction project with the first two lifts having different mix designs, and a rehabilitation project (mill and inlay followed by an overlay) with the inlay and overlay lifts having the same mix design. Hence, the following conclusions are limited in scope to these construction scenarios.

The findings are also based on data obtained from specific nuclear gauges, electromagnetic gauges, and core density test methods. The conclusions are, therefore, also limited in scope to only the gauges and test methods utilized in the study, and may not apply to gauges from other manufacturers, or to other test methods (namely AASHTO T 275 or ASTM D 1188).

With these constraints in mind and based on the findings presented herein, the following conclusions appear to be warranted:

1. Nuclear gauge measurements need to be adjusted to core densities to ensure accurate results from the nuclear gauges.
2. It is sufficient to take two one-minute nuclear gauge density readings, rather than four one-minute readings, for the purposes of determining the average density of the pavement at a given location.
3. No changes need to be made to the calibration procedure used by ODOT for nuclear gauges (i.e., ODOT TM 304). However, some agencies employ pre-calibration checks that are not implemented by ODOT.
4. Water absorption was found to have a significant influence on the bulk specific gravity (and density) derived from AASHTO T 166 Methods A and C in most, but not all, of the

comparisons investigated. Comparisons between the two methods, which were found to be significantly different in all cases, provided strong evidence to suggest that the differences were associated with the dry mass of the test specimen and that the drying procedure specified in Method A is ineffective in completely drying the test specimens.

5. Review of several studies indicated that the CoreLok method provides a more accurate measure of density than the AASHTO T 166 methods at air void contents greater than 8% and/or water absorption levels greater than 0.4%. Thus, under these conditions, the CoreLok method should be used instead of the AASHTO T 166 methods.
6. Cores extracted for the purpose of obtaining a correlation factor to adjust nuclear gauge density values need to be extracted from the overlapping portion of the gauge footprint, but the evidence presented herein suggests that the location of the core can be anywhere within the overlapping portion of the gauge footprints.
7. While taking two readings at a given location using a nuclear gauge, there was no significant difference in results when the gauge was rotated about its probe (Figure 3.1) relative to when the gauge was rotated about its longitudinal axis (Figure 3.2). Thus, the evidence presented herein suggests that either method can be used.
8. A statistical comparison of bulk specific gravities determined from blocks of HMAC pavement cut with a lapidary saw blade to provide very smooth cut faces and from cores extracted from the blocks using a conventional diamond-tipped core barrel indicated no significant difference between results at a 95% confidence level. This provides strong evidence to suggest that a conventional diamond-tipped core barrel does not cause sufficient damage to render the results inaccurate.
9. The evidence presented herein suggests that nuclear gauge correlation factors established for the first lift of paving can be used on the next two overlying lifts given the following constraints:

   a. The lifts are comprised of the same mix design, and

   b. The lifts are limited to a thickness of between 2 and 3 inches, and

   c. In establishing the correlation factor, the nuclear gauge is in direct contact with the lift from which the core or core slice is obtained.

   The evidence also suggests that the correlation factors are interchangeable between lifts under the same constraints. That is, a correlation factor established for the second lift can be used for the first lift or the third lift, and a correlation factor established for the third lift can be used for the two underlying lifts.

   There is also strong evidence to suggest that correlation factors established where the core slice is only one lift removed from the top lift (i.e., nuclear gauge measurement made on the top lift of pavement but core slice obtained from the lift immediately beneath the top lift) can be used for either of the top two lifts of pavement. However, there is strong evidence to suggest that a correlation factor determined in this way cannot be used on any lifts underlying these two lifts.

For situations where two mix designs are used for two adjacent lifts, there is much weaker evidence to suggest that the correlation factor developed for one lift can be used for the other lift. That is, based on the evidence presented herein, there is slightly better than a 50% chance that the correlation factor developed for one lift can be used for another lift with a different mix design.

10. The evidence presented herein suggests that, for new construction projects where at least two of the lifts have the different mix designs, there is slightly better than a 50% chance that the correlation factor developed for one lift can be used for another lift with a different mix design.
11. For mill-and-inlay-plus-overlay rehabilitation projects where the inlay and overlay have the same mix design, the evidence presented herein suggests that the nuclear gauge correlation factor established for the inlay lift can be used for the overlay lift, and vice versa.
12. Comparisons made using paired t-tests between densities obtained from nuclear gauges and electromagnetic gauges indicated significant differences in 88% (i.e., 158) of the 180 comparisons. However, a much lower proportion of differences existed between electromagnetic gauges and cores (32%) than between nuclear gauges and cores (58%).
13. A higher proportion of all possible comparisons of correlation factors across lifts were not significantly different when electromagnetic gauges were used (77%) than when nuclear gauges were used (70%). When considering only those comparisons involving correlation factors derived from cores obtained from the lifts on which the gauge measurements were made, 67% of the comparisons indicated no significant differences between correlation factors for electromagnetic gauges as compared with 60% for nuclear gauges. Correlation factors established between electromagnetic gauge readings and densities derived from measurements on cores using the CoreLok device were particularly strong in this regard in that less than 10% of all possible comparisons across lifts indicated significant differences between correlation factors (Appendix E).
14. The preceding two conclusions provide strong evidence that the electromagnetic gauges not only did a better job than the nuclear gauges in reporting densities representative of cores densities, but also resulted in a higher proportion of instances where the correlation factors established for one lift could be used on another lift of the pavement on the same project.
15. Sanding the location where electromagnetic gauge readings were made significantly affected the reported densities from one of the two gauges utilized in this research effort.

7.2 RECOMMENDATIONS

Based on the various findings from the literature review, the results presented herein, and conclusions listed above, the following recommendations appear to be warranted:

1. Although it was concluded that the nuclear gauge calibration procedure utilized by ODOT (i.e., ODOT TM 304) need not be modified, ODOT should consider adding pre-calibration checks as follows:

- Verification that the standard block has the same identification number as the gauge.
- Verification that the standard block is not cracked, split, delaminated, or otherwise damaged.
- Verification that the gauge seats properly on the standard block.
- Inspection of the source rod and sliding blocks for existence of micro-cracking in the welds and excessive rod or sliding block wear.
- Implementation of a statistical stability test to ensure that the ratio of the standard deviation of density standard counts to the square root of the average of density standard counts is within acceptable tolerances. The stability test should be conducted on the laminated magnesium and aluminum block.

2. All nuclear gauges used for quality control or quality assurance purposes on ODOT paving projects incorporating dense-graded HMAC should be correlated to core densities. The correlation factor utilized to adjust the gauge densities should be calculated in accordance with the procedure described in ODOT TM 327 or WAQTC TM 8, except that the following changes are recommended to these procedures:
   - Densities from at least ten cores should be used to obtain the adjustment factor on every lift.
   - A high or low value of the ratio calculated in accordance with ODOT TM 327, or the highest average difference value calculated as described in WAQTC TM 8 if the standard deviation is greater than 2.5 lb/ft^3, should not be discarded when calculating the correlation factor unless it is deemed to be a true outlier as determined by the following tests:

     $D > Q_3 + 1.5(Q_3 - Q_1)$, or
     $D < Q_1 - 1.5(Q_3 - Q_1)$

     Where:
     D = density value in question
     Q_1 = lower quartile of the ordered data set of density values from lowest density to highest density
     Q_3 = upper quartile of the ordered data set of density values from lowest density to highest density

     Note that Microsoft Excel provides the quartile function that returns the quartiles as follows:
     - Q_3 = quartile(*Data Set*, 3)
     - Q_1 = quartile(*Data Set*, 1)

3. It was concluded that, under certain constraints, there was strong evidence to suggest correlation factors established for one lift can be used on a different lift of a pavement on a particular project. However, it must be emphasized that only one project for each

4. However, it is further recommended that ODOT collect nuclear gauge correlation factor information from a variety of projects over at least one construction season so that further statistical analyses can be undertaken to verify or refute the findings from this study. If verified for a wide range of construction projects, ODOT could then potentially dispense with the requirement of establishing nuclear gauge correlations factors for each lift of each project, thus potentially cutting project costs.

5. Although the study established that differences existed between methods for measuring density on cores, between core and nuclear gauge density measurements, and between measurements derived from different gauges, it did not explicitly identify why these differences existed (except, perhaps, for the differences between AASHTO T 166 Methods A and C). Hence, further work should be conducted to identify the specific causes for the differences so that these can be mitigated.

6. ODOT should purchase at least one CoreLok device for the central laboratory, but preferably also one for each region laboratory, and implement the methodology for determining the bulk specific gravity of pavement cores and laboratory-prepared specimens. Initial implementation of the methodology should shadow routine use of the current AASHTO T 166 / T 275 procedures.

7. In contrast to the findings from the literature review, the electromagnetic gauges showed significant promise for accurately measuring in-place pavement density. However, use of the gauges for this study did not involve an exhaustive investigation. Consequently, a more extensive study using electromagnetic gauges with the latest technological refinements is recommended.

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APPENDIX A
SUMMARY OF STATE PRACTICES REGARDING IN-PLACE HMAC DENSITY MEASUREMENT

State	Method of Density Measurement	Number of Samples/Location	Acceptance Criteria	Notes
Alabama	Nuclear gage density measurement for every 1000ft stretch Nuclear and Cores (ALDOT 210).	Minimum Sample Size= 4 in. dia. Two samples further split into 2 more (so total 4 samples per location). Nuclear gage density measurement for every 1000ft stretch	The density indicated by both nuclear gages must be within 1.5 % of the bulk density determined by the core in accordance with AASHTO T 166. Nuclear gage density measurement for every 1000ft stretch.	http://fhwapap04.fhwa.dot.gov/nhswp/servlet/updateIPAddressServlet
Alaska	Cores (AASHTO T 166).	One minimum 6-inch diameter core is required per sublot (500 tones)	The target value for density is 94% of the maximum specific gravity (MSG), as determined by WAQTC FOP for AASHTO T 209. Acceptance testing for density will be determined by WAQTC FOP for AASHTO T 166/T 275 except that a minimum 6-inch diameter core is required.	
Arizona	Nuclear Gauge and Cores	Not Found	Not Found.	
Arkansas	Cores [AASHTO T 166 (field) or AHTD 461 (field) & T 209 (theoretical)].	One sample per sublot of 750 metric tonnes. Sampling shall be performed according to AASHTO T 168 and AHTD 465.	Maximum Theoretical density will be as per AASHTO T 209. Also, theoretical density limits are 92.0%* to 96.0%.	
California	Not Found	Not Found	Not Found	
Colorado	Not Found	Not Found	Not Found	
Connecticut	Cores (Theoretical densities will be determined by AASHTO Method T 209).	Total 5 samples. One sample per sublot. Minimum 275 tons/day. 10 sublots = 1 lot = 1 day's length of work in meters.	In-Place Density is 90 to 98% of Theoretical Density. Theoretical densities will be determined by AASHTO Method T209	
Delaware	Nuke gages and Cores [AASHTO T 209 and nuclear density gauge (ASTM D 2950)].	4" (100 mm) diameter, diamond-bit drilled roadway cores as per AASHTO T 230. Number of readings and samples Not Found.	The mean pavement compaction shall be at least 98% of the control strip (90m) target density.	The mean density of the control strip, as determined by cored samples taken in accordance with AASHTO T 230 Method B must be more than 95% of the density of laboratory compacted specimens for surface mixtures.
Dist of Col	Not Found	Not Found	Not Found	
Federal Lands Highways	Nuclear and Core Readings.	4 nuke readings / control strip (1000 feet long lane).	Measure density of 1 core per 500 tons. The lower specification limit is 90 percent of the maximum specific gravity (density) determined according to AASHTO T 209.	

State	Method of Density Measurement	Number of Samples/Location	Acceptance Criteria	Notes
Florida	Nuclear Gauge & cores (AASHTO T 166 Method A or B).	4 cores within each location. Nuke readings and location size unknown.	Sample Depth 12 in. and approx. 5 gallon in size.	
Georgia	Cores.	6 in (150 mm) cores. 5 samples per lot (1 lot = 500 tons)	For a lot to receive a pay factor of 1.00 for compaction acceptance, the air void range cannot exceed 4 percent. If the air void range exceeds these tolerances, apply a Pay Factor of 95%.	A lot consists of the tons of asphaltic concrete produced and placed each production day. If this production is less than 500 tons (500 Mg), or its square yard (meter) equivalent, production may be incorporated into the next working day).
Hawaii	Cores.	Sample size is = 12in X 12in or 4 inch diameter cores. No./location not found.	Not Found	
Idaho	Not Found	Not Found.	Not Found	
Illinois	Not Found	Not Found	Not Found	
Indiana	Cores (AASHTO T 166 and T 209).	2 random samples per sublot (size of sublot is unknown). [In accordance with ITM 802, 572]. Core size is 6 in. (150 mm dia).	BSG – AASHTO T 166, MSG – AASHTO T 209. The target value for density of dense graded mixtures of each sublot shall be 92.0%. Density of any random core location(s) in these areas will be assigned a value of 92.0 %MSG.	The density for the mixture will be expressed as the percentage of maximum specific gravity (%MSG) obtained by dividing the average bulk specific gravity by the maximum specific gravity for the sublot, times 100.
Iowa	Not Found	Not Found	Not Found	
Kansas	Nuclear and Cores.	2 nuclear tests and 1 core per sublot (200 tons).	Nuke reading must be within 3 pcf.	
Kentucky	Cores	4 cores per sublot (1000 tons).	1 sample per sublot of 1000 tons (4000 tons = 1 lot).	
Louisiana	Not Found	Not Found	Not Found	
Maine	Nuclear and Core Measurements	Not Found. Lot size=1000 lane-meters.	Nuclear tests every 12 in. of mat and must not vary more than 2% (daily basis). For cores limit is not less than 95% of Theoretical Maximum Density.	
Maryland	Nuclear (MSMT 417) and Cores (MSMT 418, MSMT 452)	2 cores per sublot of 200 tons. 2 nuclear tests per sublot - Each test has 2 one minute readings rotated by 180^0. 5 sublots = 1 lot.	In place density = 92 to 97 % of maximum density. For acceptance 3 cores and 3 nuclear tests are tested every 6000 tons and diff in sp gr must be within 0.03. Nuclear tests diff must be within 3 pcf.	MSMT 730 table 3

State	Method of Density Measurement	Number of Samples/Location	Acceptance Criteria	Notes
Massachusetts	Nuclear (ASTM D2950) and Cores.	Not Found	Not Found	http://epg.modot.mo.gov/index.php?title=106.7.41_TM-41%2C_Density_Testing_of_Bituminous_Mixtures_with_Nuclear_Gauges
Michigan	Nuclear and Core Measurements.	Not Found	Not Found	
Minnesota	Cores (AASHTO T 166) or nuclear & core measurements.	3 split samples (3cores/lot). 2 nuclear measurements per control strip of 330 m^2.	Contractor and State Core difference in bulk sp gr must be within 0.03. Cores shall not be taken within 1 foot of longitudinal joint or 20 feet of transverse joint. Sample limit is = not less than 1 sample per 1000 metric tons.	
Mississippi	Nuclear (MT 16 Method C) and Core Measurements (AASHTO T 166 Method C).	Avg of 2 nuclear readings per lot. Each is a 4 minute count. 1 core per lot. 1 lot is approximately 300 to 400 tons.	Diff in nuke readings must not exceed 3pcf. For multiple lifts, bottom one must be 92% of Max Density and subsequent ones must be 93% of Max Density. Difference between gauge and core must not exceed 6pcf. Correction factor is obtained every 5000 tons.	
Missouri	Cores.	One core/7500 sq. yards.	The final, in-place density of the mixture shall be 94.0 ± 2.0 percent of the theoretical maximum specific gravity. Core dia is 3 to 4 inches.	
Montana	Nuclear and Core Measurements.	Four 1 minute tests at 90^0 (for comparison with cores) but generally 2 readings rotated 180^0. Take 7 to 10 CORE samples per 100m for comparison with nuclear readings. 1 lot = 5 tests/3000 tons.	When 2 nuclear readings are taken at 180^0, the limit in difference between both is 3pcf. Correction factor between core and gauge should be less than 5pcf.	

State	Method of Density Measurement	Number of Samples/Location	Acceptance Criteria	Notes
Nebraska	Average of four nuclear gauge readings is the final reading and a core is taken for testing between these 4 readings [NDR T 587 (ASTM D 2950, AASHTO T 166, AASHTO T 209 and NDR 572)].	5 cores (1 each for the first five locations where average of 4 nuclear readings is taken).	When comparing core and nuclear density reading, the correction factor must be compared with another core reading for every 15th reading. The differences is acceptable if the difference is within 2 lbs/cu. ft.	http://www.nebraskatransportation.org/mat-n-tests/NDR%20Standard%20Test%20Methods/ndrt587.pdf
Nevada	Not Found	Not Found	Not Found	Not Found
New Hampshire	Cores or nuclear (AASHTO T 166 or ASTM D 2950).	One core per sublot. 5 cores (1 each for the first five nuclear readings taken every 100 feet). 1 core per 500 metric tons or minimum 2 per day. One sublot Size is 700 metric tons (test method is AASHTO T 209 or NHDOT B-8).	Maximum Theoretical Specific Gravity is 1 per day of operation as per AASHTO T-209	http://www.nh.gov/dot/bureaus/highwaydesign/specifications/documents/Division400.pdf
New Jersey	Cores (NJDOT B-5)	5 samples per 3500 metric tons of HMA or 1 sample per 700 metric tons. (Sample - AASHTO T 168, NJDOT B-2 and ASTM D 3665)	Not Found.	http://www.state.nj.us/transportation/eng/specs/2007/spec900.shtm#s90201, http://www.state.nj.us/transportation/eng/specs/2007/njdotb2.shtm
New Mexico	Cores (AASHTO T 166, T 209).	3 samples per location.	1 core per 1500 ton	http://nmshtd.state.nm.us/upload/images/Contracts_Unit/2007_Specs_for_Highway_and_Bridge_Construction.pdf
New York	Nuclear readings and Cores [AASHTO and ASTM and NY specifications (MP 96-01 and 01 M, 02 and 02 M, 04 and 04 M)].	4 cores per sublot. 1 sublot is 1250 metric tons.	Not Found	

State	Method of Density Measurement	Number of Samples/Location	Acceptance Criteria	Notes
North Carolina	Nuclear readings and Cores [AASHTO T 166 (or ASTM D 6752) and T 209].	1 sample per 750 metric tons. 1 sample per test section. 3 samples per lot (2000 linear feet). 5 samples per control strip. Five gauge readings.	Not Found.	http://www.ncdot.org/doh/preconstruct/ps/specifications/metric/web6a.pdf , http://www.ncdot.org/doh/operations/dp_chief_eng/constructionunit/paveconst/Asphalt_Mgmt/qms_manual/2007/default.html , http://www.ncdot.org/doh/operations/dp_chief_eng/constructionunit/paveconst/Asphalt_Mgmt/qms_manual/2007/sect10.html#b8
North Dakota	Cores (AASHTO T 166).	One sample per 250 tons (One sample = Two 1 – liter samples) or Two cores per sublot (1 sublot = 2000 feet)	Not Found	
Ohio	Cores.	2 samples per location or 4 cores per sublot (1 lot = 3000 tons and 1 sublot = 750 tons).	Split sample as per AASHTO T 248 (quartering size) for acceptance. Diff in BSG must not be more than 0.015.	
Oklahoma	Cores.	AASHTO T 2, 40 (sampling methods)	Density must be within 95 to 97% of Maximum Theoretical Sp. Gr.	
Oregon	Nuclear and Core Measurements.	2 one-minute wet-density nuke readings rotated 90^0 (if in backscatter) and 1 core per test location.	Diff between 2 nuke readings must not be greater than 3pcf. There should at least be a minimum of 5 nuke readings in a data set for purpose of core differences and std dev of diff must be within 2.5 pcf (40 kg/m^3).	
Pennsylvania	Nuclear gages (AASHTO T 238-86) and Cores.	3 cores/ 250 tons. Nuke details not found.	No cores must be taken within 2 feet of unsupported edge of pavement or 1 foot of obstruction or longitudinal joint edge.	
Puerto Rico	Nuclear and Core Measurements (AASHTO T 166 is followed).	3 core random specimens per lot (300 tons). 4 in dia cores of 2kgs. 10 random nuclear readings / lot (1 minute readings).	Mix density must be within 92 to 97% of lab density.	
Rhode Island	Cores (AASHTO T 166).	2 cores per lane mile and at least 10 cores per project.	Minimum acceptable density shall be 95-percent of the density of laboratory Marshall specimens	

State	Method of Density Measurement	Number of Samples/Location	Acceptance Criteria	Notes
South Carolina	Cores and Nuclear readings.	5 cores of 6 in dia / lot. [1 lot = a day's production of asphalt mixture]. 10 nuke readings / lot.	In-place density shall be between 98% and 102% of the target density established in accordance with SC-T-65. The average nuclear gauge density for a lot, should be at least 100% (98 to 102%) of the target density obtained by SC-T-65. Individual nuclear density tests should not be less than 98% of the target. The average roadway core density for a day's production shall be a least 96% of the average daily field laboratory density as determined by the Marshall method of test. Individual roadway core densities shall not be less than 95% of the field lab Marshall density.	The nuclear density gauge shall be of the Troxler Model 3400 series, 4600 series or equivalent.
South Dakota	Not Found	Not Found	Not Found	
Tennessee	Cores (AASHTO T 168).	1 random core sample per sublot (4 sublots=1 lot=1 day's production)	Not Found	
Texas	Nuclear Density Gauge with 4 readings and Cores.	Minimum 3 samples per location. Sample size is = 1 gal clean friction top bucket with minimum diameter of 4 ± 0.25 in. (100 ± 6 mm).	Mix design must have Optimum Density of 96%	Nuclear Gauge calibration as per manufacturers' recommendations. Establish a average differences using a minimum of seven core densities and seven nuclear densities.

State	Method of Density Measurement	Number of Samples/Location	Acceptance Criteria	Notes
Utah	Only Cores.	4 samples/lot (1 lot = 1 day's production in tons)	Sample is 4" dia. Target in-place density is 92.5% of Max sp.gr. if design thickness is $\leq$ 2in. and 93.5% if > 2in.	Cores should not be less than 1 ft from edge of pavement. Also see table 4 and sec. 3.5 of UTAH-02741 for formulas and differences.
Vermont	Only Cores (AASHTO and ASTM).	3 samples per lot (day's production)	Not Found.	http://www.aot.state.vt.us/conadmin/Documents/2006%20Spec%20Book%20for%20Construction/2006Division100.pdf
Virginia	Cores and thin-lift nuclear gauge (AASHTO and ASTM, VTM-22, VTM-76, VTM-81).	2 cores/site (4in. dia) , 2 random nuclear readings per sublot of size 1000 linear feet. During comparison, 1 core reading is compared with avg of 4 nuke readings taken around it.	For compacted course, 98 to 102% of target density is only accepted. Avg of 10 nuclear readings is control strip density (control strip is = lot)	http://www.virginiadot.org/business/resources/bu-mat-AsphFldAppA.pdf . http://www.virginiadot.org/business/resources/const/2007SpecBook.pdf
Washington	Nuclear and Core Measurements.	Nuclear density readings every 5 feet for up to 50 feet. Each density reading = avg of 2 readings in backscatter or thin lift at 90^0 from each other (difference between the 2 must not be more than 1 pcf). Cores Not found.	2 nuclear readings – direct transmission – 90^0 from each other. Diff must not be more than 3pcf.	
West Virginia	Nuclear and Core Readings. Nuke gage in backscatter and wet density reading.	Avg 5 nuke readings for calibration block. Range is within 1.5pcf. Also 1 site per sublot (5 sublots in a lot) and 1 nuke test per site.	Nuke gage std count must be within $\pm$2% of manufacturers' guidelines.	USES ALUMINIUM PLATE.
Wisconsin	Nuclear and Cores (AASHTO T 166, T 209).	Number of core samples varies from 1 to 4 based on production in tons from 50 to 4200. Also, 5 nuclear densities per lot &/or 3 cores per lot (1 lot = 750 tons).	Not Found	http://roadwaystandards.dot.wi.gov/standards/stndspec/sect460.pdf
Wyoming	Nuclear density	Not Found.	Not Found	

APPENDIX B
CHECKLIST FOR NUCLEAR GAUGE CALIBRATION PROCEDURE ASSESSMENT

Checklist for Nuclear Gauge Calibration Procedure Assessment

Apparatus

1. Nuclear Gauge.
2. Copy of Owner's radioactive materials license.
3. Copy of most current leak test results
4. Carrying/transport case.
5. Gauge manufacturer's Instruction Manual describing the operating procedures.
6. Reference standard block.
7. Logbook for recording daily counts obtained on the reference block.
8. Calibration tables.
9. Calibration blocks of approximate densities 1,735 kg/m^3 (108.3 lb/ft^3), 2,161 kg/m^3 (134.9 lb/ft^3), and 2,657 $kg/\ m^3$ (165.9 lb/ft^3).
10. High Moisture Calibration Block which will produce moisture reading of 839 kg/m^3 (52.4 lb/ft^3).
11. Surface Temperature measuring device (range -10°C to 150°C or 0°C to 300°F) readable to 2°C (5°F).
12. Hot Plate device consisting of an aluminum block that fits on an electric hot plate mounted on a dolly. The electric hot plate requires a 120 volt, 60 hertz power source. ODOT uses an aluminum block 41 cm (16 in) x 46 cm (18 in) x 16 cm (6.3 in).

Gauge Preparation

1. Was gauge placed in a temperature controlled area (16°C to 24°C or 60°F to 75°F)?
2. After turning gauge on, was it allowed to warm up for a minimum of 10 minutes?
3. Was the standard count block placed in the center of the middle calibration block?
4. While in this position, were five standard counts performed in accordance with manufacturer's guidelines?
5. Were they recorded on gauge calibration check sheet?

6. Was the variance between counts, within manufacturer's guidelines?

7. If not, were an additional of maximum two standard counts performed?

8. If not yet in compliance then was gauge returned/replaced?

9. Were the readings, one minute readings?

Gauge Hot Substrate Test

1. Was the aluminum block heated to 85°C±2°C or 185°F±4°F (measured with surface temperature)?

2. With the gauge at room temperature (16°C to 24°C or 60°F to 75°F) and the block at 85°C or 185°F was the gauge placed on the block and a one minute count started in backscatter mode?

3. Was the first wet density recorded in the "Initial Test" column of the Hot Substrate Test portion of the Nuclear Density Gauge Calibration Check Sheet?

4. Were a total of four 1 minute counts of wet density recorded immediately?

5. Was the gauge left on the block for 10 minutes?

6. After 10 minutes were four 1 minute count taken and recorded in the "Final Test" column of the Hot Substrate Test portion of the Nuclear Density Gauge Calibration Check Sheet?

7. After that was the gauge removed from the block to cool?

8. During the tests did the gauge display fog or become unreadable due to moisture? (If yes, then the gauge fails this test so return or replace gauge)

9. Was the average of the initial test column and final test column within 16 kg/m^3 or 1 lb/ft^3? (if yes then gauge passed the test)

10. If not within limits then was the gauge returned?

Annual Check of Accuracy for Gauges with Internal Computers

1. Was the calibration block located in accordance with manufacturer's recommendations and was it ensured that there is no other unshielded nuclear gauge within 15 meters (50 feet) during annual check of accuracy or calibration?

2. Were the block values used in accordance with mode of testing?

3. With the gauge at room temperature (16°C to 24°C or 60°F to 75°F) was the gauge located on the low density block such that the edge of the gauge closes to

the probe was 2.5 cm (1 in) from the edge of the transmission hole and was the gauge in the center of the block?

4. Was it ensured that the gauge does not cover the transmission hole during back scatter reading?

5. Were 2 one minute counts performed and wet density recorded in back scatter mode?

6. Was this process repeated on the medium and high density block?

7. Was it ensured that the source rod was located in the 50 mm (2 in) direct transmission position and seated in the transmission hole of the low density block and were two 1 minute counts performed to record wet density?

8. Were the counting and recording procedures for all depth increments repeated to the maximum depth on the low, medium and high density blocks?

9. Was this average of each individual depth's results and block density difference, within 16 kg/m^3 (1 lb/ft^3), on low and medium density blocks and 24 kg/m^3 (1.5 lb/ft^3) on High Density Block?

10. Was this gauge placed on the low density block (to not be influenced by the transmission hole) and was a four minute count performed to record the moisture density?

11. Was its value within ±16 kg/m^3 (1 lb/ft^3) of 839 kg/m^3 (52.4 lb/ft^3)?

APPENDIX C
FIELD STUDY DATA

Table C-1: Troxler 3430 # 38804 Nuclear Gauge data on OR 18 project dated 08-18-2008

Date	8/18/2008												
Project	OR 18 Fort Hill Road to Wallace Bridge												
Limits	art at Culvert (Sta.74+20) 300-400 ft from start of paving TO Sta. 142+!												
Gauge Make, Model, and Sr. No.	Troxler 3430 # 38804												
Gauge Operator	Ray												
Date of Last Calibration													
Type of Mix	B Mix?												
Lift	1st Base Lift												
Thickness	NOM 3 in.												
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**	**Variance**		
	Density	3108	3110	3117	3132	3094	3116.75	0.729927					
	Moisture	742	744	739	737	737	740.5	0.472654					
	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**					**Average of 2 readings**	**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Rice Locations	4116	4											
	Sta. 140+00	6.9											
10 Locations	300.3	8.2		89	156.3	154.8	155.6	155.1	155.45	155.55	18-1-1	2.4974	2.4990
	1341	1.6		114	148.5	148.8	149.7	149.6	149.15	148.65	18-1-2	2.3962	2.3882
	1703	2.9		99	147.9	149.7	148.6	143.3	147.375	148.8	18-1-3	2.3677	2.3906
	2730	6.6		129	151.1	150.6	151	151.4	151.025	150.85	18-1-4	2.4264	2.4235
	3859	8.2		126	152.3	152.8	153.2	152.1	152.6	152.55	18-1-5	2.4517	2.4509
	2988	5.7		104	156.5	157.7	155	157	156.55	157.1	18-1-6	2.5151	2.5240
	2146	4.9		100	158.9	156.9	158.1	158.3	158.05	157.9	18-1-7	2.5392	2.5368
	1980	3		93	151.5	152.3	151.4	151.7	151.725	151.9	18-1-8	2.4376	2.4404
	1306	5.4		102	157.4	155.6	156.2	156.4	156.4	156.5	18-1-9	2.5127	2.5143
	1203	4.8		101	155.4	153.5	154.8	153.7	154.35	154.45	18-1-10	2.4798	2.4814

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the inside edge of the 1st panel. The temperature for the first 3 values was measured on the sand coated loaction instead of the pavement.

Table C-2: Troxler 3430 # 38806 Nuclear Gauge data on OR 18 project dated 08-18-2008

Date	8/18/2008												
Project	OR 18 Fort Hill Road to Wallace Bridge												
Limits	Start at Culvert 300-400 ft from start of paving TO Sta. 142+50												
Gauge Make, Model, and Sr. No.	Troxler 3430 # 38806												
Gauge Operator	Dean Chess												
Date of Last Calibration	4/28/2008												
Type of Mix	B Mix?												
Lift	1st Base Lift												
Thickness	NOM 3 in.												
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**			
	Density	2943	2961	2942	2940	2969	2946.5	-0.76362					
	Moisture	719	720	721	716	721	719	-0.27816					
	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**						**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Rice Locations	4116	4											
	7741	6.9											
10 Locations	300.3	8.2		84.5	153.0	154.3	153.6	154.0	153.7	153.65	18-1-1	2.4697	2.4685
	1341	1.6		104.5	149.9	149.1	150.6	149.5	149.8	149.5	18-1-2	2.4063	2.4019
	1703	2.9		96.0	149.2	151.1	150.7	151.0	150.5	150.15	18-1-3	2.4179	2.4123
	2730	6.6		128.0	151.8	153.3	152.8	153.0	152.7	152.55	18-1-4	2.4537	2.4509
	3859	8.2		123.5	152.1	154.6	152.3	151.6	152.7	153.35	18-1-5	2.4525	2.4637
	2988	5.7		104.0	155.3	156.7	156.5	155.9	156.1	156	18-1-6	2.5079	2.5063
	2146	4.9		100.0	157.5	158.4	156.6	158.1	157.7	157.95	18-1-7	2.5328	2.5376
	1980	3		93.0	152.5	153.6	151.6	152.9	152.7	153.05	18-1-8	2.4525	2.4589
	1306	5.4		102.0	156.4	157.1	157.0	156.5	156.8	156.75	18-1-9	2.5183	2.5183
	1203	4.8		101.0	154.8	155.6	156.6	155.9	155.7	155.2	18-1-10	2.5019	2.4934

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the inside edge of the 1st panel. The temperature for the first 3 values was measured on the sand coated loaction instead of the pavement.
Also, Dean copied Surface Temp. values for locations 6 to 10 from Ray.

Table C-3: Troxler 3440 # 25714 Nuclear Gauge data on OR 18 project dated 08-18-2008

Date	8/18/2008												
Project	OR 18 Fort Hill Road to Wallace Bridge												
Limits	Start at Culvert 300-400 ft from start of paving TO Sta. 142+50												
Gauge Make, Model, and Sr. No.	Troxler 3440 # 25714												
Gauge Operator	Paul Sloan												
Date of Last Calibration	3/7/2008												
Type of Mix	B Mix?												
Lift	1st Base Lift												
Thickness	NOM 3 in.												
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**			
	Density	2574	2570	2593	2565	2571	2575.5	0.2					
	Moisture	667	672	678	682	676	674.75	-0.2					
	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**						**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Rice Locations	4116	4											
	7740.6	6.9											
10 Locations	300.3	8.2		84	154.2	154.8	155.1	155.7	154.95	154.5	18-1-1	2.4894	2.4822
	1341	1.6		104	147.1	147.8	148.4	146.6	147.475	147.45	18-1-2	2.3693	2.3689
	1703	2.9		96	147	149.1	148.1	147.9	148.025	148.05	18-1-3	2.3782	2.3786
	2730	6.6		126.5	151.4	150.7	150.9	150.7	150.925	151.05	18-1-4	2.4247	2.4268
	3859	8.2		122	151	150.3	148.8	151.5	150.4	150.65	18-1-5	2.4163	2.4203
	2988	5.7		104.5	154.5	154.1	154.3	154.2	154.275	154.3	18-1-6	2.4786	2.4790
	2146	4.9		97	157	156.9	155.1	157.8	156.7	156.95	18-1-7	2.5175	2.5215
	1980	3		92	150.5	151.8	150.5	150	150.7	151.15	18-1-8	2.4211	2.4284
	1306	5.4		98	155.2	154.1	155.7	155.8	155.2	154.65	18-1-9	2.4934	2.4846
	1203	4.8		99	153.9	153	153.6	154.9	153.85	153.45	18-1-10	2.4717	2.4653

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the inside edge of the 1st panel. The temperature for the first 3 values was measured on the sand coated loaction instead of the pavement.

Table C-4: Troxler 3430 # 38806 Nuclear Gauge data on OR 18 project dated 08-22-2008

Date	8/22/2008												
Project	OR 18 Fort Hill Road to Wallace Bridge												
Limits	Start at Sta. 137+50 and end before Sta. 148+00 (1000ft)												
Gauge Make, Model, and Sr. No.	Troxler 3430 # 38806												
Gauge Operator	Dean Chess												
Date of Last Calibration	4/28/2008												
Type of Mix	C Mix? (Level 3, 1/2 inch)												
Lift	2nd Base Lift												
Thickness	NOM 2 in.												
	Std Count	1	2	3	4	5	Avg. of 1-4	Variance	6	7	Variance		
	Density	2942	2940	2969	2972	2961	2955.75	-0.17762					
	Moisture	721	716	721	725	723	720.75	-0.31217					
	Testing Location		No.	Surface temp (F)	Gauge Readings						Core ID	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	Offset (ft)			0	90	180	270	Average				
Rice Locations													
10 Locations	258	5.2		129	152.4	151.6	151	153.1	152.025	152	18-2-1	2.4424	2.4420
	303	6.4		131.5	151.6	150.8	150.8	151.2	151.1	151.2	18-2-2	2.4276	2.4292
	392	10.8		136.5	147.5	148.9	149.1	149.6	148.775	148.2	18-2-3	2.3902	2.3810
	456	15.1		134.5	150.5	151.1	151	150.4	150.75	150.8	18-2-4	2.4219	2.4227
	656	8.4		145.5	153.6	152.5	152.7	153.9	153.175	153.05	18-2-5	2.4609	2.4589
	758	13.6		145	151.7	151.4	152.5	151.9	151.875	151.55	18-2-6	2.4400	2.4348
	775	3.8		139	151.6	152.9	152.3	151.6	152.1	152.25	18-2-7	2.4436	2.4460
	844	1.9		140	150.2	150	151.7	151.1	150.75	150.1	18-2-8	2.4219	2.4115
	917	7.4		140	151.3	152.2	152.6	152.6	152.175	151.75	18-2-9	2.4448	2.4380
	947	4.1		141	151.9	153.6	153	151.1	152.4	152.75	18-2-10	2.4484	2.4541

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

Table C-5: Troxler 3440 # 30860 Nuclear Gauge data on OR 18 project dated 08-22-2008

Note: These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

Date	8/22/2008												
Project	OR 18 Fort Hill Road to Wallace Bridge												
Limits	Start at Sta. 137+50 and end before Sta. 148+00 (1000ft)												
Gauge Make, Model, and Sr. No.	Troxler 3440 # 30860												
Gauge Operator	Josh Huber												
Date of Last Calibration	2/5/2008												
Type of Mix	C Mix? (Level 3, 1/2 inch)												
Lift	2nd Base Lift												
Thickness	NOM 2 in.												
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**			
	Density	2589	2603	2588	2624	2601	2601	0					
	Moisture	599	583	589	596	594	591.75	-0.38023					
	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**						**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Rice Locations													
10 Locations	258	5.2		129.5	152.0	152.7	152.3	152.2	152.3	152.35	18-2-1	2.4468	2.4476
	303	6.4		132.5	151.3	151.2	152.4	152.6	151.9	151.25	18-2-2	2.4400	2.4300
	392	10.8		136.0	150.3	150.6	150.5	148.2	149.9	150.45	18-2-3	2.4083	2.4171
	456	15.1		135.0	150.9	152.2	151.7	153.4	152.1	151.55	18-2-4	2.4428	2.4348
	656	8.4		137.0	154.1	154.0	153.9	155.4	154.4	154.05	18-2-5	2.4798	2.4750
	758	13.6		140.0	152.3	151.3	152.7	151.2	151.9	151.8	18-2-6	2.4400	2.4388
	775	3.8		138.0	152.8	151.6	152.0	152.1	152.1	152.2	18-2-7	2.4440	2.4452
	844	1.9		137.0	151.5	151.4	152.4	153.3	152.2	151.45	18-2-8	2.4444	2.4332
	917	7.4		134.0	153.2	152.3	153.1	153.5	153.0	152.75	18-2-9	2.4585	2.4541
	947	4.1		138.0	152.8	152.4	152.6	152.8	152.7	152.6	18-2-10	2.4525	2.4517

Table C-6: Troxler 3440 # 25714 Nuclear Gauge data on OR 18 project dated 08-22-2008

Date	8/22/2008
Project	OR 18 Fort Hill Road to Wallace Bridge
Limits	Start at Sta. 137+50 and end before Sta. 148+00 (1000ft)
Gauge Make, Model, and Sr. No.	Troxler 3440 # 25714
Gauge Operator	Paul Sloan
Date of Last Calibration	3/7/2008
Type of Mix	C Mix? (Level 3, 1/2 inch)
Lift	2nd Base Lift
Thickness	NOM 2 in.

Note: **These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.**

	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**
	Density	2571	2588	2600	2607	2595	2591.5	-0.1		
	Moisture	676	684	676	678	678	678.5	0.1		

	Testing Location		No.	Surface temp (F)	Gauge Readings						Core ID	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	Offset (ft)			0	90	180	270	Average				
Rice Locations													
10 Locations	258	5.2		139	151.1	150.7	151.3	151.3	151.1	150.9	18-2-1	2.4276	2.4243
	303	6.4		140	150.8	149.3	150	149	149.775	150.05	18-2-2	2.4063	2.4107
	392	10.8		140	147.7	146	147.3	147.3	147.075	146.85	18-2-3	2.3629	2.3593
	456	15.1		141	149.9	150	148.8	151	149.925	149.95	18-2-4	2.4087	2.4091
	656	8.4		143	151.7	152.8	152.8	151.3	152.15	152.25	18-2-5	2.4444	2.4460
	758	13.6		144	151.4	150.3	151.3	149.6	150.65	150.85	18-2-6	2.4203	2.4235
	775	3.8		139	150.4	152.2	150.4	151.4	151.1	151.3	18-2-7	2.4276	2.4308
	844	1.9		142	150.9	152.4	149.8	150.8	150.975	151.65	18-2-8	2.4255	2.4364
	917	7.4		140	152.2	150.6	149.6	151.8	151.05	151.4	18-2-9	2.4268	2.4324
	947	4.1		141	151.9	152.5	151	152.4	151.95	152.2	18-2-10	2.4412	2.4452

Table C-7: PQI 301 Electromagnetic Gauge data on OR 18 project dated 08-22-2008

Date	8/22/2008	
Project	OR 18 Fort Hill Road to Wallace Bridge	
Limits	Start at Sta. 137+50 and end before Sta. 148+00 (1000ft)	
Gauge Make, Model, and Sr. No.	PQI 301	
Gauge Operator		
Date of Last Calibration		
Type of Mix	C Mix? (Level 3, 1/2 inch)	
Lift	2nd Base Lift	
Thickness	NOM 2 in.	

<u>Note</u>:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

	Testing Location		Gauge Readings												Core ID	BSG
	Distance (ft)	Offset (ft)	1		2		3		4		5		Average			
			Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture		
Rice Locations																
10 Locations	258	5.2	149.4	9.4	149.6	9.8	149.7	9.9	149.2	9.8	149.8	10.2	149.54	9.82	18-2-1	2.4025
	303	6.4	150.2	10.0	149.7	10.1	150.1	10.3	149.9	10.5	150.3	10.1	150.04	10.20	18-2-2	2.4105
	392	10.8	148.2	9.4	148.4	9.8	147.1	9.4	147.1	9.5	147.9	9.1	147.74	9.44	18-2-3	2.3736
	456	15.1	147.3	8.7	146.5	8.4	147.7	8.8	146.8	8.8	146.8	8.9	147.02	8.72	18-2-4	2.3620
	656	8.4	147.4	8.8	148.8	9.4	149.2	9.4	149.0	9.7	148.0	8.8	148.48	9.22	18-2-5	2.3855
	758	13.6	148.5	9.4	149.1	9.7	149.3	9.8	148.7	9.5	147.4	9.2	148.60	9.52	18-2-6	2.3874
	775	3.8	148.8	9.4	147.5	8.9	149.4	9.6	148.1	9.5	148.4	9.4	148.44	9.36	18-2-7	2.3848
	844	1.9	148.6	9.3	148.8	9.3	148.7	9.4	148.4	9.3	147.8	9.1	148.46	9.28	18-2-8	2.3851
	917	7.4	150.1	10.3	149.7	10.1	140.1	10.0	150.3	9.9	149.9	10.3	148.02	10.12	18-2-9	2.3781
	947	4.1	149.8	9.9	150.1	9.8	148.8	9.6	149.4	9.6	149.4	9.7	149.50	9.72	18-2-10	2.4019

Table C-8: PQI 300 Electromagnetic Gauge data on OR 18 project dated 08-22-2008

Date	8/22/2008
Project	OR 18 Fort Hill Road to Wallace Bridge
Limits	Start at Sta. 137+50 and end before Sta. 148+00 (1000ft)
Gauge Make, Model, and Sr. No.	PQI 300
Gauge Operator	
Date of Last Calibration	
Type of Mix	C Mix? (Level 3, 1/2 inch)
Lift	2nd Base Lift
Thickness	NOM 2 in.

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

	Testing Location		Gauge Readings												Core ID	BSG
	Distance (ft)	Offset (ft)	1		2		3		4		5		Average			
			Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture		
Rice Locations																
10 Locations	258	5.2	149.5	7.1	149.8	7.3	149.5	7.5	148.9	7.3	149.5	7.4	149.44	7.32	18-2-1	2.4009
	303	6.4	150.2	7.6	148.1	7.2	150.0	7.7	149.7	7.8	149.4	7.3	149.48	7.52	18-2-2	2.4015
	392	10.8	148.6	7.0	148.4	6.8	148.2	7.2	147.1	7.1	148.0	6.9	148.06	7.00	18-2-3	2.3787
	456	15.1	145.8	6.2	145.3	6.1	147.2	6.2	146.4	6.5	146.5	6.6	146.24	6.32	18-2-4	2.3495
	656	8.4	146.1	6.2	148.0	6.7	148.7	6.8	148.4	6.9	147.2	6.5	147.68	6.62	18-2-5	2.3726
	758	13.6	148.4	6.9	148.0	7.1	148.5	7.3	148.9	7.2	148.3	7.0	148.42	7.10	18-2-6	2.3845
	775	3.8	148.6	7.2	147.4	6.9	146.9	7.0	147.5	7.2	148.4	7.3	147.76	7.12	18-2-7	2.3739
	844	1.9	148.4	7.0	148.8	6.8	148.3	7.0	147.7	6.9	147.8	6.7	148.20	6.88	18-2-8	2.3810
	917	7.4	149.3	7.7	149.0	7.3	150.5	7.4	149.9	7.5	149.2	7.3	149.58	7.44	18-2-9	2.4031
	947	4.1	149.6	7.4	148.4	7.0	147.5	7.2	148.4	7.1	147.8	7.0	148.34	7.14	18-2-10	2.3832

Table C-9: Troxler 3440 # 30860 Nuclear Gauge data on OR 18 project dated 08-25-2008

Date	8/25/2008												
Project	OR 18 Fort Hill Road to Wallace Bridge												
Limits	Start at Sta. 103+50 and end near Sta. 113+50 (1000ft)												
Gauge Make, Model, and Sr. No.	Troxler 3440 # 30860												
Gauge Operator	Josh Huber												
Date of Last Calibration	2/5/2008												
Type of Mix	C Mix? (Level 3, 1/2 inch Dense)												
Lift	3rd Base Lift												
Thickness	NOM 2 in.												
	Std Count	1	2	3	4	5	Avg. of 1-4	Variance	6	7	Variance		
	Density						#DIV/0!	#DIV/0!					
	Moisture						#DIV/0!	#DIV/0!					
	Testing Location		No.	Surface temp (F)	Gauge Readings						Core ID	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	Offset (ft)			0	90	180	270	Average				
Block Locations	Sta. 68+65	2'10"											
	Sta. 68+69	20'0"											
	Sta. 68+72	9'2"											
	Sta. 68+80	15'6"											
	Sta. 68+91	4'9"											
10 Locations	207	3.8		120.0	151.5	151.4	152.6	150.6	151.5	151.5	18-3-1	2.4344	2.4332
	234	9.4		117.0	153.8	153.2	155.8	154.2	154.3	153.5	18-3-2	2.4782	2.4661
	336	2.2		108.0	153.4	153.2	150.9	152.4	152.5	153.3	18-3-3	2.4496	2.4629
	388	10		110.0	150.0	150.6	151.3	150.4	150.6	150.3	18-3-4	2.4191	2.4147
	451	5.3		110.0	149.5	150.0	149.6	150.8	150.0	149.8	18-3-5	2.4095	2.4059
	501	2.9		111.0	152.6	150.6	150.7	150.8	151.2	151.6	18-3-6	2.4288	2.4356
	642	3.4		113.0	149.1	148.0	149.3	149.0	148.9	148.6	18-3-7	2.3914	2.3866
	748	11.5		116.0	150.6	149.6	151.0	149.8	150.3	150.1	18-3-8	2.4139	2.4115
	932	2.5		114.0	145.3	144.5	145.2	145.4	145.1	144.9	18-3-9	2.3312	2.3279
	986	1.5		112.0	149.3	149.9	149.0	149.3	149.4	149.6	18-3-10	2.3998	2.4035

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

Table C-10: Troxler 3440 Plus # 39525 Nuclear Gauge data on OR 18 project dated 08-25-2008

Note: These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

Date	8/25/2008												
Project	OR 18 Fort Hill Road to Wallace Bridge												
Limits	Start at Sta. 103+50 and end near Sta. 113+50 (1000ft)												
Gauge Make, Model, and Sr. No.	Troxler 3440 Plus# 39525												
Gauge Operator	Terry Vann												
Date of Last Calibration	1/24/2008 (Gauge check on ODOT blocks was 07/31/2008)												
Type of Mix	C Mix? (Level 3, 1/2 inch Dense)												
Lift	3rd Base Lift												
Thickness	NOM 2 in.												
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**			
	Density	2816	2798	2803	2798	2829	2803.75	-0.90058					
	Moisture	759	755	756	751	756	755.25	-0.0993					
	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**						**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Block Locations	36	4.2											
	353	9.6											
	451	13.6											
	706	13.1											
	760	6.4											
10 Locations	207	3.8		108.0	154.5	155.5	154.8	155.0	155.0	155.0	18-3-1	2.4894	2.4902
	234	9.4		110.0	155.1	155.0	155.7	155.8	155.4	155.1	18-3-2	2.4966	2.4910
	336	2.2		112.0	154.2	155.5	154.6	154.3	154.7	154.9	18-3-3	2.4846	2.4878
	388	10		107.0	153.1	153.0	152.9	152.5	152.9	153.1	18-3-4	2.4561	2.4589
	451	5.3		111.0	152.8	152.2	153.0	153.1	152.8	152.5	18-3-5	2.4545	2.4500
	501	2.9		110.0	151.4	154.4	152.7	153.8	153.1	152.9	18-3-6	2.4593	2.4565
	642	3.4		108.0	152.2	152.3	152.5	152.0	152.3	152.3	18-3-7	2.4460	2.4460
	748	11.5		110.0	153.0	152.3	153.2	152.6	152.8	152.7	18-3-8	2.4545	2.4525
	932	2.5		107.0	148.1	148.9	148.5	147.9	148.4	148.5	18-3-9	2.3834	2.3858
	986	1.5		110.0	152.4	152.0	152.2	152.0	152.2	152.2	18-3-10	2.4444	2.4452

Table C-11: Troxler 3430 # 38806 Nuclear Gauge data on OR 18 project dated 08-25-2008

Date	8/25/2008												
Project	OR 18 Fort Hill Road to Wallace Bridge												
Limits	Start at Sta. 103+50 and end near Sta. 113+50 (1000ft)												
Gauge Make, Model, and Sr. No.	Troxler 3430 # 38806												
Gauge Operator	Dean Chess												
Date of Last Calibration	4/28/2008												
Type of Mix	C Mix? (Level 3, 1/2 inch Dense)												
Lift	3rd Base Lift												
Thickness	NOM 2 in.												
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**			
	Density	2940	2969	2972	2961	2954	2960.5	0.219558					
	Moisture	716	721	725	723	726	721.25	-0.65858					
	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**						**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Block Locations	36	4.2											
	353	9.6											
	451	13.6											
	706	13.1											
	760	6.4											
10 Locations	207	3.8		100.0	151.6	152.3	151.8	150.7	151.6	152.0	18-3-1	2.4356	2.4412
	234	9.4		110.0	155.4	155.1	154.4	154.5	154.9	155.3	18-3-2	2.4878	2.4942
	336	2.2		112.0	151.7	152.7	151.6	151.5	151.9	152.2	18-3-3	2.4400	2.4452
	388	10		110.0	150.2	149.9	149.3	149.9	149.8	150.1	18-3-4	2.4071	2.4107
	451	5.3		108.0	147.9	147.2	149.7	149.6	148.6	147.6	18-3-5	2.3874	2.3705
	501	2.9		108.0	151.4	150.8	150.4	151.4	151.0	151.1	18-3-6	2.4259	2.4276
	642	3.4		108.0	149.3	149.2	150.6	142.2	147.8	149.3	18-3-7	2.3749	2.3978
	748	11.5		109.5	149.9	150.3	149.8	150.7	150.2	150.1	18-3-8	2.4127	2.4115
	932	2.5		104.0	144.9	145.2	144.1	143.9	144.5	145.1	18-3-9	2.3219	2.3304
	986	1.5		103.0	148.8	149.7	149.0	148.2	148.9	149.3	18-3-10	2.3926	2.3978

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

Table C-12: PQI 301 Electromagnetic Gauge data (used on sanded surface) on OR 18 project dated 08-25-2008

Date	8/25/2008
Project	OR 18 Fort Hill Road to Wallace Bridge
Limits	Start at Sta. 103+50 and end near Sta. 113+50 (1000ft)
Gauge Make, Model, and Sr. No.	PQI 301 (used on sanded surface)
Gauge Operator	
Date of Last Calibration	
Type of Mix	C Mix? (Level 3, 1/2 inch Dense)
Lift	3rd Base Lift
Thickness	NOM 2 in.

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

	Testing Location		Gauge Readings												Core ID	Bulk Specific Gravity
	Distance (ft)	Offset (ft)	1		2		3		4		5		Average			
			Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture		
Rice Locations																
10 Locations	207	3.8	148.4	8.1	148.2	8.4	148.0	7.8	148.5	8.1	147.6	8.0	148.14	8.08	18-3-1	2.3800
	234	9.4	150.0	9.1	149.2	8.5	150.5	9.3	149.6	8.4	150.0	8.7	149.86	8.80	18-3-2	2.4076
	336	2.2	147.6	7.9	148.2	8.5	148.0	8.1	148.4	8.4	147.4	8.1	147.92	8.20	18-3-3	2.3765
	388	10	147.3	8.1	147.4	8.2	147.1	8.2	147.7	7.9	147.6	8.0	147.42	8.08	18-3-4	2.3684
	451	5.3	147.9	8.6	147.3	8.5	147.6	8.8	147.8	8.3	147.9	8.7	147.70	8.58	18-3-5	2.3729
	501	2.9	149.6	9.1	148.6	9.4	149.0	8.6	149.3	8.9	149.9	9.9	149.28	9.18	18-3-6	2.3983
	642	3.4	148.1	8.6	148.5	8.6	147.4	8.3	148.1	8.2	148.7	9.0	148.16	8.54	18-3-7	2.3803
	748	11.5	148.4	8.6	147.7	8.7	148.7	9.1	148.2	8.6	148.5	8.6	148.30	8.72	18-3-8	2.3826
	932	2.5	144.9	7.5	145.5	7.7	145.3	8.1	145.1	7.8	145.3	7.8	145.22	7.78	18-3-9	2.3331
	986	1.5	148.6	9.1	147.2	8.5	148.6	8.7	149.4	9.6	147.5	8.6	148.26	8.90	18-3-10	2.3819

Table C-13: PQI 301 Electromagnetic Gauge data (no sand) on OR 18 project dated 08-25-2008

Date	8/25/2008
Project	OR 18 Fort Hill Road to Wallace Bridge
Limits	Start at Sta. 103+50 and end near Sta. 113+50 (1000ft)
Gauge Make, Model, and Sr. No.	PQI 301 (used on sanded surface)
Gauge Operator	
Date of Last Calibration	
Type of Mix	C Mix? (Level 3, 1/2 inch Dense)
Lift	3rd Base Lift
Thickness	NOM 2 in.

Note: **These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.**

	Testing Location		Gauge Readings													
	Distance (ft)	Offset (ft)	1		2		3		4		5		Average		Core ID	**BSG**
			Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture		
Rice Locations																
10 Locations	207	3.8											0.00	0.00	18-3-1	0.0000
	234	9.4											0.00	0.00	18-3-2	0.0000
	336	2.2	148.0	8.2	148.2	8.6	148.7	8.9	147.9	8.7	147.9	8.7	148.14	8.62	18-3-3	2.3800
	388	10	147.1	8.1	148.0	8.3	147.7	8.4	147.4	8.1	148.5	8.5	147.74	8.28	18-3-4	2.3736
	451	5.3	144.5	7.7	147.7	9.0	147.4	8.8	144.6	7.3	146.9	8.8	146.22	8.32	18-3-5	2.3492
	501	2.9	149.2	9.1	149.4	9.9	148.7	9.0	149.5	9.2	148.8	9.2	149.12	9.28	18-3-6	2.3957
	642	3.4	148.6	9.3	148.4	9.2	147.3	8.9	147.8	8.5	147.8	8.8	147.98	8.94	18-3-7	2.3774
	748	11.5	148.5	8.9	148.9	9.1	148.7	9.2	147.7	8.8	148.2	9.2	148.40	9.04	18-3-8	2.3842
	932	2.5	145.2	7.7	144.2	7.8	145.1	8.4	143.5	7.6	144.8	7.8	144.56	7.86	18-3-9	2.3225
	986	1.5	148.8	9.5	147.4	8.9	148.2	9.0	147.3	8.8	147.6	9.1	147.86	9.06	18-3-10	2.3755

Table C-14: PQI 300 Electromagnetic Gauge data (used on sanded surface) on OR 18 project dated 08-25-2008

Date	8/25/2008
Project	OR 18 Fort Hill Road to Wallace Bridge
Limits	Start at Sta. 103+50 and end near Sta. 113+50 (1000ft)
Gauge Make, Model, and Sr. No.	PQI 300 (used on sanded surface)
Gauge Operator	
Date of Last Calibration	
Type of Mix	C Mix? (Level 3, 1/2 inch Dense)
Lift	3rd Base Lift
Thickness	NOM 2 in.

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

	Testing Location		Gauge Readings												Core ID	**BSG**
	Distance (ft)	Offset (ft)	1		2		3		4		5		Average			
			Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture		
Rice Locations																
10 Locations	207	3.8	148.4	6.4	148.6	6.1	148.1	5.9	148.1	5.9	148.7	5.9	148.38	6.04	18-3-1	2.3839
	234	9.4	149.2	6.7	151.6	6.7	151.0	6.7	150.1	6.1	150.6	6.7	150.50	6.58	18-3-2	2.4179
	336	2.2	148.4	5.9	147.4	6.1	148.3	6.3	149.2	6.4	147.3	5.8	148.12	6.10	18-3-3	2.3797
	388	10	148.5	6.2	148.4	6.0	146.8	5.9	146.6	5.4	148.9	6.0	147.84	5.90	18-3-4	2.3752
	451	5.3	147.8	6.3	147.5	6.3	146.8	6.1	148.3	6.3	148.4	6.7	147.76	6.34	18-3-5	2.3739
	501	2.9	150.6	6.6	149.3	7.0	148.9	6.3	149.9	6.5	149.7	6.9	149.68	6.66	18-3-6	2.4047
	642	3.4	148.5	6.5	147.1	6.1	147.6	5.9	149.3	6.1	148.5	6.2	148.20	6.16	18-3-7	2.3810
	748	11.5	148.9	6.3	148.1	6.3	148.3	6.4	148.2	6.3	148.1	6.5	148.32	6.36	18-3-8	2.3829
	932	2.5	145.8	5.5	145.9	5.8	145.4	5.8	145.6	5.8	145.7	6.0	145.68	5.78	18-3-9	2.3405
	986	1.5	149.0	6.6	147.7	6.2	149.3	6.6	149.3	6.7	148.3	6.3	148.72	6.48	18-3-10	2.3893

Table C-15: PQI 300 Electromagnetic Gauge data (no sand) on OR 18 project dated 08-25-2008

Date	8/25/2008
Project	OR 18 Fort Hill Road to Wallace Bridge
Limits	Start at Sta. 103+50 and end near Sta. 113+50 (1000ft)
Gauge Make, Model, and Sr. No.	PQI 300
Gauge Operator	
Date of Last Calibration	
Type of Mix	C Mix? (Level 3, 1/2 inch Dense)
Lift	3rd Base Lift
Thickness	NOM 2 in.

Note:
These test results are obtained from the lane which is 2nd from the Jersey Barrier (the lane is also called the 1st panel). The offset is measured from the outside edge of the 1st panel.

	Testing Location		Gauge Readings												Core ID	**BSG**
	Distance (ft)	Offset (ft)	1		2		3		4		5		Average			
			Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture		
Rice Locations																
10 Locations	207	3.8											0.00	0.00	18-3-1	0.0000
	234	9.4											0.00	0.00	18-3-2	0.0000
	336	2.2	147.3	5.9	147.0	6.3	148.2	6.5	146.6	6.1	145.8	6.1	146.98	6.18	18-3-3	2.3614
	388	10	147.5	6.3	147.9	6.3	147.3	6.0	145.1	5.7	148.0	6.1	147.16	6.08	18-3-4	2.3643
	451	5.3	145.1	6.4	146.9	6.7	145.5	6.2	146.7	6.0	146.0	6.6	146.04	6.38	18-3-5	2.3463
	501	2.9	148.4	7.0	146.0	6.9	147.2	6.5	148.7	6.6	146.6	6.5	147.38	6.70	18-3-6	2.3678
	642	3.4	148.0	6.8	145.6	6.4	147.5	6.8	147.9	6.3	147.3	6.4	147.26	6.54	18-3-7	2.3659
	748	11.5	147.8	6.4	147.3	6.5	147.6	6.6	146.6	6.7	146.6	6.4	147.18	6.52	18-3-8	2.3646
	932	2.5	143.7	5.5	143.5	5.8	144.7	6.2	143.0	5.8	144.4	5.9	143.86	5.84	18-3-9	2.3112
	986	1.5	147.3	6.8	146.7	6.7	147.0	6.8	146.3	6.7	147.2	6.7	146.90	6.74	18-3-10	2.3601

Table C-16: Troxler 3430 # 38996 Nuclear Gauge data on OR 140 project dated 08-20-2008

Date	8/20/2008
Project	OR 140
Limits	Start at MP 22 (Marker) (Apprx. 327+50) and End after 1000 ft.
Gauge Make, Model, and Sr. No.	Troxler 3430 # 38996
Gauge Operator	John Groth
Date of Last Calibration	7/31/2008
Type of Mix	C Mix
Lift	Inlay
Thickness	NOM 2 in.

Note:
The paving was done in the morning, and the readings were taken in the afternoon from 15:15 to 17:00. The offset is measured from the center line.

Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**	**Variance**
Density	2822	2818	2780	2793	2804	2820	0.567376			
Moisture	731	734	739	733	728	734.25	0.851209			

	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**					**Average of 2 readings**	**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Rice Locations	Sta. 287+49	4.4											
	Sta. 292+50	9.3											
	Sta. 296+24	2.3											
10 Locations	105	1.3		123.5	140.1	138.5	139.0	137.9	138.9	139.3	140-1-1	2.2312	2.2380
	155	11.2		124.0	141.4	141.0	140.5	141.0	141.0	141.2	140-1-2	2.2649	2.2685
	171	10.2		114.0	136.3	138.8	137.3	137.3	137.4	137.6	140-1-3	2.2079	2.2099
	187	6.6		112.0	137.9	138.1	137.9	138.6	138.1	138.0	140-1-4	2.2191	2.2171
	300	3.5		111.0	139.2	138.3	138.0	137.9	138.4	138.8	140-1-5	2.2227	2.2291
	330	5.1		115.0	137.4	137.0	137.5	137.5	137.4	137.2	140-1-6	2.2067	2.2042
	390	3.3		109.5	137.5	138.1	137.6	138.0	137.8	137.8	140-1-7	2.2139	2.2139
	512	12.2		107.5	134.3	133.6	134.4	134.4	134.2	134.0	140-1-8	2.1556	2.1520
	653	7.8		110.5	135.3	137.3	136.5	136.7	136.5	136.3	140-1-9	2.1922	2.1898
	736	1.6		120.0	132.5	133.7	133.2	134.1	133.4	133.1	140-1-10	2.1428	2.1384

Table C-17: Troxler 3430 # 38806 Nuclear Gauge data on OR 140 project dated 08-20-2008

Date	8/20/2008												
Project	OR 140												
Limits	Start at MP 22 (Marker) (Apprx. 327+50) and End after 1000 ft.												
Gauge Make, Model, and Sr. No.	Troxler 3430 # 38806												
Gauge Operator	Dean Chess												
Date of Last Calibration	4/28/2008												
Type of Mix	C Mix												
Lift	Inlay												
Thickness	NOM 2 in.												
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**			
	Density	2961	2942	2940	2969	2972	2953	-0.64341					
	Moisture	720	721	716	721	725	719.5	-0.76442					
	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**					**Average of 2**	**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Rice Locations	Sta. 287+49	4.4											
	Sta. 292+50	9.3											
	Sta. 296+24	2.3											
10 Locations	105	1.3		109.0	141.1	141.1	140.8	141.1	141.0	141.1	140-1-1	2.2657	2.2669
	155	11.2		109.5	144.6	143.2	143.8	143.2	143.7	143.9	140-1-2	2.3087	2.3119
	171	10.2		107.0	139.8	138.6	139.2	139.0	139.2	139.2	140-1-3	2.2356	2.2364
	187	6.6		104.5	140.2	139.7	141.0	141.7	140.7	140.0	140-1-4	2.2597	2.2484
	300	3.5		121.0	140.0	140.6	139.5	139.5	139.9	140.3	140-1-5	2.2476	2.2540
	330	5.1		121.0	138.8	138.5	139.3	140.6	139.3	138.7	140-1-6	2.2380	2.2275
	390	3.3		119.0	135.1	140.5	139.4	141.4	139.1	137.8	140-1-7	2.2348	2.2139
	512	12.2		117.5	135.7	136.9	138.2	136.3	136.8	136.3	140-1-8	2.1974	2.1898
	653	7.8		116.5	139.0	138.0	139.5	138.4	138.7	138.5	140-1-9	2.2287	2.2251
	736	1.6		115.5	134.4	134.5	133.5	134.1	134.1	134.5	140-1-10	2.1548	2.1601

Note: **The paving was done in the morning, and the readings were taken in the afternoon from 15:15 to 17:00. The offset is measured from the center line. At the seventh location (140-1-7), a second shot was taken at 0^0C, and a value of 140.8 was obtained.**

Table C-18: Troxler 3440 # 35601 Nuclear Gauge data on OR 140 project dated 08-20-2008

Date	8/20/2008												
Project	OR 140												
Limits	Start at MP 22 (Marker) (Apprx. 327+50) and End after 1000 ft.												
Gauge Make, Model, and Sr. No.	Troxler 3440 # 35601												
Gauge Operator	Dean Chess												
Date of Last Calibration	8/18/2008												
Type of Mix	C Mix												
Lift	Inlay												
Thickness	NOM 2 in.												
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**			
	Density	2593	2597	2573	2589	2578	2588.0	0.4					
	Moisture	724	729	716	723	727	723	-0.6					
	Testing Location		No.	Surface temp (F)	Gauge Readings						Core ID	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings**
	Distance (ft)	Offset (ft)			0	90	180	270	Average				
Rice Locations	Sta. 287+49	4.4											
	Sta. 292+50	9.3											
	Sta. 296+24	2.3											
10 Locations	105	1.3		103.5	140.6	140.4	141	139.2	140.3	140.5	140-1-1	2.2540	2.2573
	155	11.2		106	142.3	143.1	142.3	143	142.675	142.7	140-1-2	2.2922	2.2926
	171	10.2		105.5	139.2	138.1	139.3	139.5	139.025	138.7	140-1-3	2.2336	2.2275
	187	6.6		104.5	140.5	139.2	139.6	140.8	140.025	139.9	140-1-4	2.2496	2.2468
	300	3.5		126.5	139.4	139.3	139.2	139.5	139.35	139.4	140-1-5	2.2388	2.2388
	330	5.1		125	139.3	139.7	137.6	138.7	138.825	139.5	140-1-6	2.2303	2.2412
	390	3.3		118	140.2	138.7	140.3	139.6	139.7	139.5	140-1-7	2.2444	2.2404
	512	12.2		111	136.5	135.8	136.5	135.3	136.025	136.2	140-1-8	2.1854	2.1874
	653	7.8		115	137.9	138	138.1	137.5	137.875	138.0	140-1-9	2.2151	2.2163
	736	1.6		110	135	134	134.7	134.5	134.55	134.5	140-1-10	2.1617	2.1609

Note:
The paving was done in the morning, and the readings were taken in the afternoon from 15:15 to 17:00. The offset is measured from the center line.

Table C-19: PQI 301 Electromagnetic Gauge data on OR 140 project dated 08-20-2008

Date	8/20/2008
Project	OR 140
Limits	Start at MP 22 (Marker) (Apprx. 327+50) and End after 1000 ft.
Gauge Make, Model, and Sr. No.	PQI 301
Gauge Operator	Larry ILG
Date of Last Calibration	
Type of Mix	C Mix? (Level 3, 1/2 inch Dense)
Lift	Inlay
Thickness	NOM 2 in.

Note: **The paving was done in the morning, and the readings were taken in the afternoon from 15:15 to 17:00. The offset is measured from the center line. For the Rice Locations, the offset was measured from the outside edge of the milled surface.**

	Testing Location		Gauge Readings															
	Distance (ft)	**Offset (ft)**	**Center**		**45**		**135**		**225**		**315**		**Average**		**Core ID**	**Sp. Gr.**
			Density	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**		
Rice Locations	Sta. 287+49	4.4														
	Sta. 292+50	9.3														
	Sta. 296+24	2.3														
10 Locations	105	1.3	140.3		140.5		140.6		140.8		140.1		140.46	0.00	140-1-1	2.2566
	155	11.2	141.6		140.3		141.0		141.4		141.0		141.06	0.00	140-1-2	2.2663
	171	10.2	140.4		140.6		139.8		139.9		140.6		140.26	0.00	140-1-3	2.2534
	187	6.6	140.6		140.1		139.8		140.6		140.5		140.32	0.00	140-1-4	2.2544
	300	3.5	140.7		140.5		140.2		140.5		140.5		140.48	0.00	140-1-5	2.2569
	330	5.1	140.6		140.3		140.4		139.4		139.9		140.12	0.00	140-1-6	2.2512
	390	3.3	140.7		139.8		139.9		140.0		140.1		140.10	0.00	140-1-7	2.2508
	512	12.2	140.3		139.9		139.1		139.1		139.9		139.66	0.00	140-1-8	2.2438
	653	7.8	139.8		140.2		139.8		139.9		140.6		140.06	0.00	140-1-9	2.2502
	736	1.6	138.5		138.3		139.5		139.1		138.6		138.80	0.00	140-1-10	2.2299

Table C-20: PQI 300 Electromagnetic Gauge data on OR 140 project dated 08-20-2008

Date	8/20/2008
Project	OR 140
Limits	Start at MP 22 (Marker) (Apprx. 327+50) and End after 1000 ft.
Gauge Make, Model, and Sr. No.	PQI 300
Gauge Operator	Larry ILG
Date of Last Calibration	
Type of Mix	C Mix? (Level 3, 1/2 inch Dense)
Lift	Inlay
Thickness	NOM 2 in.

<u>Note</u>:
The paving was done in the morning, and the readings were taken in the afternoon from 15:15 to 17:00. The offset is measured from the center line. For the Rice Locations, the offset was measured from the outside edge of the milled surface.

	Testing Location		**Gauge Readings**													
	Distance (ft)	**Offset (ft)**	**1**		**2**		**3**		**4**		**5**		**Average**		**Core ID**	**BSG**
			Density	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**		
			Center		**to 45 deg**		**to 135 deg**		**to 225 deg**		**to 315 deg**					
Rice Locations	Sta. 287+49	4.4														
	Sta. 292+50	9.3														
	Sta. 296+24	2.3														
10 Locations	105	1.3	138.9		138.3		138.3		138.3		138.8		138.52	0.00	140-1-1	2.2254
	155	11.2	139.1		138.7		139.2		138.2		137.8		138.60	0.00	140-1-2	2.2267
	171	10.2	139.0		138.3		137.4		137.6		138.6		138.18	0.00	140-1-3	2.2200
	187	6.6	139.3		139.0		138.2		138.9		139.7		139.02	0.00	140-1-4	2.2335
	300	3.5	138.1		134.8		137.4		134.6		137.1		136.40	0.00	140-1-5	2.1914
	330	5.1	138.5		139.0		139.4		138.4		139.1		138.88	0.00	140-1-6	2.2312
	390	3.3	139.2		138.5		138.3		138.3		138.5		138.56	0.00	140-1-7	2.2261
	512	12.2	138.9		136.1		137.0		136.6		138.1		137.34	0.00	140-1-8	2.2065
	653	7.8	138.3		138.4		137.8		138.1		138.3		138.18	0.00	140-1-9	2.2200
	736	1.6	136.0		133.5		134.0		136.8		133.8		134.82	0.00	140-1-10	2.1660

Table C-21: Troxler 3430 # 38996 Nuclear Gauge data on OR 140 project dated 09-11-2008

Date	9/11/2008												
Project	OR 140												
Limits	Start at 325+87.5 and End after 1000 ft.												
Gauge Make, Model, and Sr. No.	Troxler 3430 # 38996												
Gauge Operator	Ray Cunningham												
Date of Last Calibration	7/31/2008												
Type of Mix													
Lift													
Thickness													
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**	**Variance**		
	Density	2868	2860	2848	2857	2838	2864	0.907821					
	Moisture	734	734	737	736	730	735.25	0.714043					
	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**						**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Rice Locations													
10 Locations				102.5	142.1	139.7	140.8	139.7	140.6	140.9	140-1-1	2.2585	2.2637
				137.5	135.8	137.3	136.8	136.4	136.6	136.6	140-1-2	2.1942	2.1938
				137.5	137.1	136.9	137.2	136.7	137.0	137.0	140-1-3	2.2006	2.2010
				138.5	138.6	137.1	138.0	138.2	138.0	137.9	140-1-4	2.2167	2.2147
				140.5	135.3	136.1	136.1	134.6	135.5	135.7	140-1-5	2.1773	2.1801
				142.0	137.5	138.2	137.6	138.8	138.0	137.9	140-1-6	2.2175	2.2147
				141.0	142.5	143.2	142.8	142.7	142.8	142.9	140-1-7	2.2942	2.2950
				142.0	142.7	142.8	143.4	142.9	143.0	142.8	140-1-8	2.2966	2.2934
				144.5	142.7	142.9	141.9	141.7	142.3	142.8	140-1-9	2.2862	2.2942
				146.0	144.5	143.7	144.7	145.9	144.7	144.1	140-1-10	2.3247	2.3151

Note:
The paving was done in the morning, and the readings were taken in the afternoon from 15:15 to 17:00. The offset is measured from the center line.

Table C-22: Troxler 3430 # 38806 Nuclear Gauge data on OR 140 project dated 09-11-2008

Date	9/11/2008												
Project	OR 140												
Limits	Start at 325+87.5 and End after 1000 ft.												
Gauge Make, Model, and Sr. No.	Troxler 3430 # 38806												
Gauge Operator	Dean Chess												
Date of Last Calibration													
Type of Mix													
Lift													
Thickness													
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**			
	Density	2970	2956	2936	2937	2956	2949.75	-0.21188					
	Moisture	726	729	661	715	721	707.75	-1.87213					
	Testing Location		**No.**	**Surface temp (F)**	**Gauge Readings**						**Core ID**	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	**Offset (ft)**			**0**	**90**	**180**	**270**	**Average**				
Rice Locations	Sta. 287+49	4.4											
	Sta. 292+50	9.3											
	Sta. 296+24	2.3											
10 Locations	47	11.6		114.5	141.4	140.2	141.7	140.4	140.9	140.8	140-1-1	2.2641	2.2621
	352	6.2		143.5	137.6	137.5	138.0	137.1	137.6	137.6	140-1-2	2.2099	2.2099
	477	12.3		143.0	138.1	137.7	137.3	139.2	138.1	137.9	140-1-3	2.2183	2.2155
	514	3.6		145.5	138.0	137.3	138.5	139.5	138.3	137.7	140-1-4	2.2223	2.2115
	758	2.2		145.0	136.8	136.1	135.0	135.2	135.8	136.5	140-1-5	2.1813	2.1922
	814	4.1		148.5	137.5	140.5	139.5	139.6	139.3	139.0	140-1-6	2.2376	2.2332
	860	11.2		147.0	142.8	142.9	142.9	143.9	143.1	142.9	140-1-7	2.2994	2.2950
	890	10.5		148.5	145.0	144.4	143.4	143.3	144.0	144.7	140-1-8	2.3139	2.3247
	895	11.4		148.0	142.1	143.3	142.5	142.8	142.7	142.7	140-1-9	2.2922	2.2926
	906	10.1		148.5	144.0	145.8	145.8	144.6	145.1	144.9	140-1-10	2.3304	2.3279

Table C-23: Troxler 3430 # 35601 Nuclear Gauge data on OR 140 project dated 09-11-2008

Date	9/11/2008												
Project	OR 140												
Limits	Start at 325+87.5 and End after 1000 ft.												
Gauge Make, Model, and Sr. No.	Troxler 3430 # 35601												
Gauge Operator	Dean Chess												
Date of Last Calibration	8/18/2008												
Type of Mix													
Lift													
Thickness													
	Std Count	**1**	**2**	**3**	**4**	**5**	**Avg. of 1-4**	**Variance**	**6**	**7**			
	Density	2654	2566	2641	2578	2591	2609.8	0.7					
	Moisture	727	719	732	727	721	726.25	0.7					
	Testing Location		No.	Surface temp (F)	Gauge Readings						Core ID	**Bulk Specific Gravity (4 readings)**	**Bulk Specific Gravity (2 Readings)**
	Distance (ft)	Offset (ft)			0	90	180	270	Average				
Rice Locations													
10 Locations				114	141	140.6	142.3	141	141.225	140.8	140-1-1	2.2689	2.2621
				136	137.2	136.4	138.1	137.1	137.2	136.8	140-1-2	2.2042	2.1978
				135	133.7	134.8	137	136.9	135.6	134.3	140-1-3	2.1785	2.1568
				135	138.6	138.2	137.5	138.9	138.3	138.4	140-1-4	2.2219	2.2235
				136	136.3	136.9	135.2	134.9	135.825	136.6	140-1-5	2.1821	2.1946
				136	140.8	139.2	139.3	139.2	139.625	140.0	140-1-6	2.2432	2.2492
				139	143.6	142.9	143	144.5	143.5	143.3	140-1-7	2.3055	2.3014
				140	144.1	143.6	143.3	145.3	144.075	143.9	140-1-8	2.3147	2.3111
				138	143.8	143.2	143.1	141.7	142.95	143.5	140-1-9	2.2966	2.3055
				137	146.6	146	144.7	145.4	145.675	146.3	140-1-10	2.3404	2.3504

Table C-24: PQI 301 Electromagnetic Gauge data on OR 140 project dated 09-11-2008

Date	9/11/2008
Project	OR 140
Limits	Start at 325+87.5 and End after 1000 ft.
Gauge Make, Model, and Sr. No.	PQI 301
Gauge Operator	Todd Scholz
Date of Last Calibration	
Type of Mix	
Lift	
Thickness	

<u>Note</u>:
The paving was done in the morning, and the readings were taken in the afternoon from 15:15 to 17:00. The offset is measured from the center line. For the Rice Locations, the offset was measured from the outside edge of the milled surface.

	Testing Location		Gauge Readings												Core ID	Sp. Gr.
	Distance (ft)	Offset (ft)	Center		45		135		225		315		Average			
			Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture	Density	Moisture		
Rice Locations																
10 Locations			140.4		139.5		139.1		138.6		139.1		139.34		140-1-1	2.2386
			138.2		137.9		138.1		138.5		138.2		138.18		140-1-2	2.2200
			138.9		138.2		138.0		138.1		137.8		138.20		140-1-3	2.2203
			139.2		137.6		138.1		138.5		138.5		138.38		140-1-4	2.2232
			138.3		137.3		136.7		137.3		137.0		137.44		140-1-5	2.2081
			138.9		137.9		137.4		138.8		138.1		138.62		140-1-6	2.2271
			140.5		139.9		140.1		138.9		139.6		139.88		140-1-7	2.2473
			140.4		140.3		140.1		139.0		139.0		139.54		140-1-8	2.2418
			140.1		139.2		139.3		139.2		139.5		139.68		140-1-9	2.2441
			141.3		140.3		139.6		140.3		139.6		140.22		140-1-10	2.2528

Table C-25: PQI 300 Electromagnetic Gauge data on OR 140 project dated 09-11-2008

Date	9/11/2008
Project	OR 140
Limits	Start at 325+87.5 and End after 1000 ft.
Gauge Make, Model, and Sr. No.	PQI 300
Gauge Operator	Todd Scholz
Date of Last Calibration	
Type of Mix	
Lift	
Thickness	

Note:
The paving was done in the morning, and the readings were taken in the afternoon from 15:15 to 17:00. The offset is measured from the center line. For the Rice Locations, the offset was measured from the outside edge of the milled surface.

	Testing Location		Gauge Readings													
	Distance (ft)	**Offset (ft)**	**1**		**2**		**3**		**4**		**5**		**Average**		**Core ID**	**BSG**
			Density	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**	**Density**	**Moisture**		
Rice Locations			**Center**		**to 45 deg**		**to 135 deg**		**to 225 deg**		**to 315 deg**					
10 Locations	47	11.6	140.4		139.5		137.2		138.2		138.5		138.76	0.00	140-1-1	2.2293
	352	6.2	136.7		137.1		137.1		137.2		136.2		136.86	0.00	140-1-2	2.1988
	477	12.3	137.6		136.9		135.8		136.3		136.1		136.54	0.00	140-1-3	2.1936
	514	3.6	138.1		136.4		136.1		136.8		136.8		136.84	0.00	140-1-4	2.1985
	758	2.2	137.0		135.4		134.7		135.7		135.6		135.68	0.00	140-1-5	2.1798
	814	4.1	137.8		136.3		135.3		137.9		137.3		136.92	0.00	140-1-6	2.1997
	860	11.2	140.2		138.5		139.7		139.2		139.3		139.38	0.00	140-1-7	2.2393
	890	10.5	140.5		140.3		140.5		138.5		139.0		139.76	0.00	140-1-8	2.2454
	895	11.4	139.5		138.8		139.4		137.9		138.5		138.82	0.00	140-1-9	2.2303
	906	10.1	140.8		139.8		140.1		139.4		138.5		139.72	0.00	140-1-10	2.2447

APPENDIX D
LABORATORY STUDY DATA

Table D-1: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-1 core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		9/28/2008			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness	NOM 3in.			
Date Extracted		8/18/2008			Mix Type	B			
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-1-1	300.3	8.2	85	64	2660.4	1595.1	2662.6	0.2	2.4922
18-1-2	1341	1.6	95	87	3523.5	2052.7	3534.2	0.7	2.3783
18-1-3	1703	2.9	60	52	2169.1	1267.1	2179.3	1.1	2.3779
18-1-4	2730	6.6	90	75	3047.2	1789.1	3053.4	0.5	2.4102
18-1-5	3859	8.2	87	75	3072.8	1810.3	3082.7	0.8	2.4150
18-1-6	2988	5.7	86	75	3053.8	1813.7	3055.8	0.2	2.4586
18-1-7	2146	4.9	92	76	3236.6	1942.9	3237.7	0.1	2.4997
18-1-8	1980	3	87	71	2910.0	1707.1	2914.4	0.4	2.4103
18-1-9	1306	5.4	97	86	3607.8	2160.1	3609.0	0.1	2.4900
18-1-10	1203	4.8	108	90	3855.8	2304.1	3858.0	0.1	2.4814

Table D-2: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 18-1 core set

Oregon State University												
CoreLok Bulk Specific gravity Data Collection Table												
CoreLok Operator's Guide Method												
Date		9/17/2008			Tested by	Suraj Darra						
Project		OR 18			Lift Thickness	NOM 3 in.						
Date Extracted		8/18/2008			Mix Type	B						
Core ID	Sample Location		Bag Wt. A (grams)	Dry Sample Weight before Sealing B	Sealed Sample Weight in Water C	Dry Sample Weight after Water Submersion D	Ratio B/A E (grams)	Bag Volume Correction from table	Total Volume (A+D)-C G	Volume of Bag A/F H	Volume of Sample G-H I	Bulk Sp.Gr. B/I J
	Station	Offset										
18-1-1	300.3	8.2	47.3	2660.2	1520.6	2660.2	56.24	0.77	1186.90	61.73	1125.17	2.3643
18-1-2	1341	1.6	47.6	3523.4	2022	3523.4	74.02	0.74	1549.00	64.61	1484.39	2.3736
18-1-3	1703	2.9	47.3	2169	1245.8	2169.0	45.86	0.78	970.50	60.37	910.13	2.3832
18-1-4	2730	6.6	47.6	3047.1	1732.3	3047.1	64.01	0.75	1362.40	63.19	1299.21	2.3453
18-1-5	3859	8.2	47.6	3072.7	1783.5	3072.6	64.55	0.75	1336.70	63.26	1273.44	2.4129
18-1-6	2988	5.7	47.9	3053.6	1793.7	3053.6	63.75	0.75	1307.80	63.55	1244.25	2.4542
18-1-7	2146	4.9	47.9	3236.5	1912.2	3236.4	67.57	0.75	1372.10	64.09	1308.01	2.4744
18-1-8	1980	3	47.9	2909.7	1678.1	2909.8	60.75	0.76	1279.60	63.13	1216.47	2.3919
18-1-9	1306	5.4	47.8	3607.6	2142.2	3607.6	75.47	0.73	1513.20	65.09	1448.11	2.4913
18-1-10	1203	4.8	48	3855.6	2249.4	3855.7	80.33	0.73	1654.30	66.09	1588.21	2.4276

Table D-3: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-2 Non-separated core set

Oregon State University

Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens

AASHTO T 166-05

Date	10/15/2008	Tested by	Suraj Darra			
Project	OR 18	Lift Thickness	NOM 2 in.			
Date Extracted	8/22/2008	Mix Type				

Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-2-1	258	5.2	130	113	4680.0	2754.0	4705.7	1.3	2.3979
18-2-2	303	6.4	134	109	4787.1	2815.5	4819.5	1.6	2.3888
18-2-3	392	10.8	145	125	5327.1	3114.9	5350.7	1.1	2.3826
18-2-4	456	15.1	145	126	5147.8	3016.7	5171.0	1.1	2.3895
18-2-5	656	8.4	150	136	5579.7	3267.2	5598.7	0.8	2.3932
18-2-6	758	13.6	154	135	5758.2	3375.1	5767.1	0.4	2.4073
18-2-7	775	3.8	146	125	5165.7	3028.4	5194.7	1.3	2.3846
18-2-8	844	1.9	147	130	5185.0	3038.7	5226.8	1.9	2.3696
18-2-9	917	7.4	143	120	5086.7	2995.7	5096.5	0.5	2.4213
18-2-10	947	4.1	137	122	4981.1	2918.5	4991.3	0.5	2.4031

Table D-4: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 18-2 Non-separated core set

Oregon State University												
CoreLok Bulk Specific gravity Data Collection Table												
CoreLok Operator's Guide Method												
Date		10/15/2008			Tested by	Suraj Darra						
Project		OR 18			Lift Thickness							
Date Extracted		8/22/2008			Mix Type							
Core ID	Sample Location		Bag Wt. A (grams)	Dry Sample Weight before Sealing B (grams)	Sealed Sample Weight in Water C (grams)	Dry Sample Weight after Water Submersion D (grams)	Ratio B/A E (grams)	Bag Volume Correction from table F	Total Volume (A+D)-C G	Volume of Bag A/F H	Volume of Sample G-H I	Bulk Sp.Gr. B/I J
	Station	Offset										
18-2-1	258	5.2	47.1	4680.1	2710	4680	99.3652	0.6947	2017.1000	67.8036	1949.2964	2.40092
18-2-2	303	6.4	47.8	4787.1	2755.8	4787.1	100.1485	0.6934	2079.1000	68.9403	2010.1597	2.38145
18-2-3	392	10.8	47	5327.3	3071.9	5327.1	113.3468	0.6714	2302.2000	69.9984	2232.2016	2.38657
18-2-4	456	15.1	47.7	5162.2	2975.5	5159.9	108.2222	0.6800	2232.1000	70.1521	2161.9479	2.38775
18-2-5	656	8.4	47.1	5579.3	3223	5579.7	118.4565	0.6630	2403.8000	71.0448	2332.7552	2.39172
18-2-6	758	13.6	46.9	5757.8	3341.8	5758.2	122.7676	0.6558	2463.3000	71.5151	2391.7849	2.40732
18-2-7	775	3.8	47	5164.9	2981.8	5165.7	109.8915	0.6772	2230.9000	69.4055	2161.4945	2.3895
18-2-8	844	1.9	46.9	5183.1	2968.6	5185	110.5139	0.6761	2263.3000	69.3636	2193.9364	2.36247
18-2-9	917	7.4	47.1	5086.5	2929	5086.7	107.9936	0.6803	2204.8000	69.2311	2135.5689	2.3818
18-2-10	947	4.1	47.3	4981.2	2889	4981.1	105.3108	0.6848	2139.4000	69.0729	2070.3271	2.406

Table D-5: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-2 lift 1 separated core set

Oregon State University

Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens

AASHTO T 166-05

Date		10/30/2008			**Tested by**	Suraj Darra			
Project		OR 18			**Lift Thickness**	NOM 2 in.			
Date Extracted		8/22/2008			**Mix Type**				

Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-2-1	258	5.2		55	2362	1382.6	2364.1	0.2140	2.4065
18-2-2	303	6.4		52	2203.7	1288.8	2206.2	0.2725	2.4021
18-2-3	392	10.8		60	2474.5	1458.5	2476.3	0.1769	2.4312
18-2-4	456	15.1		64	2635.8	1545.0	2640	0.3836	2.4071
18-2-5	656	8.4		64	2602.2	1520.0	2609.3	0.6518	2.3889
18-2-6	758	13.6		65	2583.3	1513.6	2586.3	0.2797	2.4082
18-2-7	775	3.8		57	2454.4	1424.6	2456.9	0.2422	2.3776
18-2-8	844	1.9		64	2523.6	1451.0	2528.6	0.4640	2.3419
18-2-9	917	7.4		57	2435	1443.1	2436.5	0.1510	2.4512
18-2-10	947	4.1		58	2342.4	1374.3	2344.5	0.2165	2.4143

Table D-6: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 18-2 Lift 1 Separated core set

Oregon State University													
CoreLok Bulk Specific gravity Data Collection Table													
CoreLok Operator's Guide Method													
Date		10/30/2008			Tested by	Suraj Darra							
Project		OR 18			Lift Thickness	NOM 2 in.							
Date Extracted		8/22/2008			Mix Type								
Core ID	Sample Location		Bag Wt. A (grams)	Dry Sample Weight before Sealing B (grams)	Sealed Sample Weight in Water C (grams)	Dry Sample Weight after Water Submersion D (grams)	Ratio B/A E (grams)	Bag Volume Correction from table F	Total Volume (A+D)-C G	Volume of Bag A/F H	Volume of Sample G-H I	Bulk Sp.Gr. B/I J
	Station	Offset										
18-2-1	258	5.2	47.6	2362	1366.2	2361.1	49.6218	0.7772	1042.5000	61.2433	981.25669	2.40712
18-2-2	303	6.4	47.4	2203.7	1269.2	2202.6	46.4916	0.7824	980.8000	60.581	920.21904	2.39476
18-2-3	392	10.8	47.3	2474.5	1442.1	2474.2	52.3150	0.7728	1079.4000	61.2094	1018.1906	2.43029
18-2-4	456	15.1	47.4	2635.8	1520.8	2635.3	55.6076	0.7673	1161.9000	61.7757	1100.1243	2.39591
18-2-5	656	8.4	47.4	2602.2	1495.5	2601.5	54.8987	0.7685	1153.4000	61.6812	1091.7188	2.38358
18-2-6	758	13.6	47.4	2583.3	1496.7	2583	54.5000	0.7691	1133.7000	61.6281	1072.0719	2.40963
18-2-7	775	3.8	47.4	2454.4	1410.8	2453.7	51.7806	0.7736	1090.3000	61.2685	1029.0315	2.38516
18-2-8	844	1.9	47.6	2523.6	1425.6	2522.4	53.0168	0.7716	1144.4000	61.6906	1082.7094	2.33082
18-2-9	917	7.4	47.6	2435	1427.4	2434.9	51.1555	0.7747	1055.1000	61.4446	993.65543	2.45055
18-2-10	947	4.1	47.6	2342.4	1329.4	2342.4	49.2101	0.7779	1060.6000	61.1895	999.4105	2.34378

Table D-7: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-2 lift 2 separated core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		10/30/2008			**Tested by**	Suraj Darra			
Project		OR 18			**Lift Thickness**	NOM 2 in.			
Date Extracted		8/22/2008			**Mix Type**				
Core ID	**Sample Location**		**Nominal Thickness of Intact Specimen (mm)**	**Thickness of Separated Specimen (mm)**	**Mass of Specimen in Air A (grams)**	**Mass of Specimen in Water C (grams)**	**Mass of Saturated Surface-Dry Specimen in Air B (grams)**	**Percent of Water Absorbed by Volume**	**Bulk Specific Gravity of Specimen G**
	Station	**Offset**							
18-2-1	258	5.2		57	2152.2	1252.7	2154.7	0.3	2.3860
18-2-2	303	6.4		57	2424.6	1412.5	2431.0	0.6	2.3806
18-2-3	392	10.8		65	2348.1	1367.9	2353.1	0.5	2.3834
18-2-4	456	15.1		62	2686.6	1547.9	2697.4	0.9	2.3372
18-2-5	656	8.4		67	2817.3	1650.4	2820.4	0.3	2.4079
18-2-6	758	13.6		70	3001.8	1764.8	3006.9	0.4	2.4167
18-2-7	775	3.8		66	2555.7	1496.7	2560.3	0.4	2.4029
18-2-8	844	1.9		66	2500.3	1467.2	2505.3	0.5	2.4085
18-2-9	917	7.4		60	2482.7	1455.7	2487.0	0.4	2.4073
18-2-10	947	4.1		62	2466.8	1438.3	2469.0	0.2	2.3933

Table D-8: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 18-2 Lift 2 Separated core set

Oregon State University

CoreLok Bulk Specific gravity Data Collection Table

CoreLok Operator's Guide Method

Date		**Tested by**	Suraj Darra
Project	OR 18	**Lift Thickness**	
Date Extracted		**Mix Type**	

Core ID	Sample Location		Bag Wt. A (grams)	Dry Sample Weight before Sealing B (grams)	Sealed Sample Weight in Water C (grams)	Dry Sample Weight after Water Submersion D (grams)	Ratio B/A E (grams)	Bag Volume Correction from table F	Total Volume (A+D)-C G	Volume of Bag A/F H	Volume of Sample G-H I	Bulk Sp.Gr. B/I J
	Station	Offset										
18-2-1			47.3	2152.2	1236.7	2151.9	45.5011	0.7841	962.5000	60.3264	902.17362	2.38557
18-2-2			47.2	2424.6	1383.9	2423.3	51.3686	0.7743	1086.6000	60.9561	1025.6439	2.36398
18-2-3			47.2	2348.1	1341.2	2348	49.7479	0.7770	1054.0000	60.745	993.25499	2.36405
18-2-4			47.1	2686.6	1514.6	2685.7	57.0403	0.7649	1218.2000	61.5756	1156.6244	2.32279
18-2-5			47.2	2817.3	1621.4	2817.4	59.6886	0.7605	1243.2000	62.063	1181.137	2.38524
18-2-6			47.3	3001.8	1729	3001.9	63.4630	0.7543	1320.2000	62.7112	1257.4888	2.38714
18-2-7			47.6	2555.7	1473.8	2555.8	53.6912	0.7705	1129.6000	61.7803	1067.8197	2.39338
18-2-8			47.5	2500.3	1445.1	2500.4	52.6379	0.7722	1102.8000	61.5109	1041.2891	2.40116
18-2-9			47.8	2482.7	1431	2482.4	51.9393	0.7734	1099.2000	61.8066	1037.3934	2.39321
18-2-10			47.6	2466.8	1415.5	2466.9	51.8235	0.7736	1099.0000	61.5327	1037.4673	2.37771

Table D-9: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-3 Non-separated core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		9/28/2008			**Tested by**	Suraj Darra			
Project		OR 18			**Lift Thickness**				
Date Extracted		8/25/2008			**Mix Type**				
Core ID	**Sample Location**		**Nominal Thickness of Intact Specimen (mm)**	**Thickness of Separated Specimen (mm)**	**Mass of Specimen in Air A (grams)**	**Mass of Specimen in Water C (grams)**	**Mass of Saturated Surface-Dry Specimen in Air B (grams)**	**Percent of Water Absorbed by Volume**	**Bulk Specific Gravity of Specimen G**
	Station	**Offset**							
18-3-1	207	3.8	160	140	6025.3	3556.8	6050.0	1.0	2.4167
18-3-2	234	9.4	173	150	6535.4	3906.7	6572.4	1.4	2.4517
18-3-3	336	2.2	187	162	7213.0	4270.0	7234.1	0.7	2.4335
18-3-4	388	10	173	157	6623.1	3903.5	6657.2	1.2	2.4052
18-3-5	451	5.3	173	154	6382.5	3761.6	6424.3	1.6	2.3970
18-3-6	501	2.9	185	140	6680.1	4062.6	6915.3	8.2	2.3417
18-3-7	642	3.4	189	174	7105.9	4194.1	7186.6	2.7	2.3746
18-3-8	748	11.5	184	143					
18-3-9	932	2.5	190	169	6968.5	4082.5	7060.3	3.1	2.3402
18-3-10	986	1.5	183	160	6410.5	3772.4	6509.2	3.6	2.3423

Table D-10: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 18-3 Non-Separated core set

Oregon State University			
CoreLok Bulk Specific gravity Data Collection Table			
CoreLok Operator's Guide Method			
Date	9/17/2008	**Tested by**	Suraj Darra
Project	OR 18	**Lift Thickness**	
Date Extracted	8/18/2008	**Mix Type**	

Core ID	**Sample Location**		**Bag Wt. A (grams)**	**Dry Sample Weight before Sealing B (grams)**	**Sealed Sample Weight in Water C (grams)**	**Dry Sample Weight after Water Submersion D (grams)**	**Ratio B/A E (grams)**	**Bag Volume Correction from table F**	**Total Volume (A+D)-C G**	**Volume of Bag A/F H**	**Volume of Sample G-H I**	**Bulk Sp.Gr. B/I J**
	Station	**Offset**										
18-3-1	207	3.8	47.4	6025.3	3517.9	6025.3	127.1160	0.6486	2554.8000	73.0819	2481.7181	2.42787
18-3-2	234	9.4	47.4	6535.4	3885.8	6535.4	137.8776	0.6307	2697.0000	75.1518	2621.8482	2.49267
18-3-3	336	2.2	47.7	7223.6	4239.7	7224.6	151.4382	0.6082	3032.6000	78.4265	2954.1735	2.44522
18-3-4	388	10	47.7	6623.2	3848.6	6623.1	138.8512	0.6291	2822.2000	75.8217	2746.3783	2.41161
18-3-5	451	5.3	47.7	6382.6	3698.7	6382.5	133.8071	0.6375	2731.5000	74.8259	2656.6741	2.40248
18-3-6	501	2.9	47.7	6880.2	4006.2	6880.1	144.2390	0.6202	2921.6000	76.9152	2844.6848	2.41862
18-3-7	642	3.4	47.5	7106	4092	7105.9	149.6000	0.6113	3061.4000	77.7078	2983.6922	2.38161
18-3-8	748	11.5										
18-3-9	932	2.5	47.2	6968.6	3964	6968.5	147.6398	0.6145	3051.7000	76.8082	2974.8918	2.34247
18-3-10	986	1.5	47.5	6410.7	3621.3	6410.5	134.9621	0.6356	2836.7000	74.7369	2761.9631	2.32107

Table D-11: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-3 Lift 1 Separated core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		9/28/2008			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness				
Date Extracted					Mix Type				
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-3-1	207	3.8		46	1849.1	1102.8	1850.0	0.1	2.4747
18-3-2	234	9.4		65	2654.1	1588.6	2654.6	0.0	2.4898
18-3-3	336	2.2		76	3180.3	1889.0	3181.9	0.1	2.4598
18-3-4	388	10		73	3045.6	1807.0	3046.4	0.1	2.4573
18-3-5	451	5.3		75	3013.1	1781.8	3017.7	0.4	2.4380
18-3-6	501	2.9		50	2018.6	1195.0	2020.3	0.2	2.4459
18-3-7	642	3.4		87	3545.6	2090.5	3551.9	0.4	2.4262
18-3-8	748	11.5		48	1937.4	1147.2	1938.9	0.2	2.4471
18-3-9	932	2.5		70	2747.9	1591.8	2754.8	0.6	2.3628
18-3-10	986	1.5		65	2503.4	1432.5	2521.7	1.7	2.2984

Table D-12: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 18-3 Lift 1 Separated core set

Oregon State University												
CoreLok Bulk Specific gravity Data Collection Table												
CoreLok Operator's Guide Method												
Date		9/17/2008			**Tested by**	Suraj Darra						
Project		OR 18			**Lift Thickness**							
Date Extracted		8/18/2008			**Mix Type**							
Core ID	**Sample Location**		**Bag Wt. A (grams)**	**Dry Sample Weight before Sealing B (grams)**	**Sealed Sample Weight in Water C (grams)**	**Dry Sample Weight after Water Submersion D (grams)**	**Ratio B/A E (grams)**	**Bag Volume Correction from table F**	**Total Volume (A+D)-C G**	**Volume of Bag A/F H**	**Volume of Sample G-H I**	**Bulk Sp.Gr. B/I J**
	Station	**Offset**										
18-3-1	207	3.8	47.7	1849.1	1091	1849	38.7652	0.7952	805.7000	59.9812	745.71884	2.47962
18-3-2	234	9.4	47.4	2654.1	1572.8	2653.7	55.9937	0.7667	1128.3000	61.8274	1066.4726	2.48867
18-3-3	336	2.2	47.5	3180.3	1873.4	3180.3	66.9537	0.7485	1354.4000	63.4639	1290.9361	2.46356
18-3-4	388	10	48.9	3045.6	1787.9	3044.8	62.2822	0.7562	1305.8000	64.6644	1241.1356	2.45388
18-3-5	451	5.3	47.8	3013.1	1762	3012.5	63.0356	0.7550	1298.3000	63.3145	1234.9855	2.43979
18-3-6	501	2.9	47.7	2018.6	1179.4	2018.5	42.3187	0.7894	886.8000	60.4294	826.37061	2.44273
18-3-7	642	3.4	47.4	3545.6	2050.8	3544.6	74.8017	0.7354	1541.2000	64.4522	1476.7478	2.40095
18-3-8	748	11.5	47.6	1937.4	1132.8	1937.4	40.7017	0.7920	852.2000	60.0983	792.10166	2.4459
18-3-9	932	2.5	47.3	2747.9	1565.9	2747	58.0951	0.7632	1228.4000	61.979	1166.421	2.35584
18-3-10	986	1.5	47.5	2503.4	1387.4	2502.2	52.7032	0.7721	1162.3000	61.5195	1100.7805	2.2742

Table D-13: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-3 Lift 2 Separated core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		9/28/2008			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness				
Date Extracted		8/25/2008			Mix Type				
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-3-1	207	3.8		40	1539.8	900.9	1542.0	0.3	2.4018
18-3-2	234	9.4		29	1099.5	638.6	1098.4	-0.2	2.3913
18-3-3	336	2.2		39	1607.5	951.2	1608.6	0.2	2.4452
18-3-4	388	10		25	1012.6	588.3	1013.2	0.1	2.3831
18-3-5	451	5.3		26	1073.4	623.3	1074.2	0.2	2.3806
18-3-6	501	2.9		30	1303.5	763.4	1305.0	0.3	2.4068
18-3-7	642	3.4		25	967.9	551.5	969.0	0.3	2.3183
18-3-8	748	11.5		27	1221.8	710.9	1223.3	0.3	2.3845
18-3-9	932	2.5		40	1606.7	943.2	1608.7	0.3	2.4143
18-3-10	986	1.5		40	1525.3	881.3	1525.6	0.0	2.3674

Table D-14: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 18-3 Lift 2 Separated core set

Oregon State University												
CoreLok Bulk Specific gravity Data Collection Table												
CoreLok Operator's Guide Method												
Date		9/17/2008			Tested by	Suraj Darra						
Project		OR 18			Lift Thickness							
Date Extracted		8/18/2008			Mix Type							
Core ID	Sample Location: Station	Sample Location: Offset	Bag Wt. A (grams)	Dry Sample Weight before Sealing B (grams)	Sealed Sample Weight in Water C (grams)	Dry Sample Weight after Water Submersion D (grams)	Ratio B/A E (grams)	Bag Volume Correction from table F	Total Volume (A+D)-C G	Volume of Bag A/F H	Volume of Sample G-H I	Bulk Sp.Gr. B/I J
18-3-1			27.1	1539.8	884.1	1539.7	56.8192	0.7799	682.7000	34.7462	647.95375	2.3764
18-3-2			26	1099.5	628.1	1098.2	42.2885	0.7882	496.1000	32.988	463.11197	2.37416
18-3-3			26.5	1607.5	938.2	1607.6	60.6604	0.7778	695.9000	34.0719	661.82807	2.42888
18-3-4			27	1012.6	576.9	1011.9	37.5037	0.7909	462.0000	34.1395	427.86051	2.36666
18-3-5			27	1073.4	609.9	1072.7	39.7556	0.7896	489.8000	34.1946	455.6054	2.35599
18-3-6			26.3	1303.5	751.4	1303.1	49.5627	0.7840	578.0000	33.5439	544.45611	2.39413
18-3-7			26.7	967.9	535.8	967.1	36.2509	0.7916	458.0000	33.7299	424.27008	2.28133
18-3-8			27.3	1221.8	695.2	1221.4	44.7546	0.7868	553.5000	34.6989	518.80112	2.35505
18-3-9			26.6	1606.7	928.8	1606.4	60.4023	0.7779	704.2000	34.1941	670.00592	2.39804
18-3-10			26.6	1525.3	866.9	1524.5	57.3421	0.7796	684.2000	34.1181	650.08188	2.34632

Table D-15: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-3 Lift 3 Separated core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		9/28/2008			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness				
Date Extracted		8/25/2008			Mix Type				
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-3-1	207	3.8		55	2289.1	1343.0	2292.4	0.3	2.4111
18-3-2	234	9.4		56	2445.8	1452.7	2446.4	0.1	2.4613
18-3-3	336	2.2		52	2079.4	1218.8	2084.4	0.6	2.4023
18-3-4	388	10		60	2238.1	1303.7	2244.4	0.7	2.3792
18-3-5	451	5.3		52	1976.8	1150.0	1983.0	0.7	2.3731
18-3-6	501	2.9		59	2295.8	1345.0	2303.0	0.8	2.3965
18-3-7	642	3.4		60	2274.5	1324.7	2280.6	0.6	2.3794
18-3-8	748	11.5		62	2359.3	1374.1	2365.0	0.6	2.3810
18-3-9	932	2.5		63	2322.9	1332.7	2335.3	1.2	2.3169
18-3-10	986	1.5		54	2081.4	1209.7	2085.4	0.5	2.3768

Table D-16: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 18-3 Lift 3 Separated core set

Oregon State University												
CoreLok Bulk Specific gravity Data Collection Table												
CoreLok Operator's Guide Method												
Date		9/17/2008			**Tested by**	Suraj Darra						
Project		OR 18			**Lift Thickness**							
Date Extracted		8/18/2008			**Mix Type**							
Core ID	**Sample Location**		**Bag Wt. A (grams)**	**Dry Sample Weight before Sealing B (grams)**	**Sealed Sample Weight in Water C (grams)**	**Dry Sample Weight after Water Submersion D (grams)**	**Ratio B/A E (grams)**	**Bag Volume Correction from table F**	**Total Volume (A+D)-C G**	**Volume of Bag A/F H**	**Volume of Sample G-H I**	**Bulk Sp.Gr. B/I J**
	Station	**Offset**										
18-3-1			47.6	2289.1	1324.8	2289	48.0903	0.7798	1011.8000	61.0436	950.75636	2.40766
18-3-2			47.6	2445.8	1435.4	2445.3	51.3824	0.7743	1057.5000	61.4745	996.02554	2.45556
18-3-3			47.5	2079.4	1192.9	2079.3	43.7768	0.7869	933.9000	60.3611	873.53888	2.38043
18-3-4			47.6	2238.1	1271.3	2237.7	47.0189	0.7815	1014.0000	60.9047	953.09528	2.34824
18-3-5			47.9	1976.8	1126	1976.4	41.2693	0.7911	898.3000	60.5491	837.75086	2.35965
18-3-6			47.5	2295.8	1320.2	2295.6	48.3326	0.7794	1022.9000	60.9468	961.95317	2.3866
18-3-7			47.8	2274.5	1301.5	2273.9	47.5837	0.7806	1020.2000	61.2341	958.96592	2.37183
18-3-8			47.8	2359.3	1347.4	2358.3	49.3577	0.7777	1058.7000	61.466	997.23404	2.36584
18-3-9			47.5	2322.9	1296.9	2322.2	48.9032	0.7784	1072.8000	61.021	1011.779	2.29586
18-3-10			47.3	2081.4	1188.2	2080.8	44.0042	0.7866	939.9000	60.1358	879.76419	2.36586

Table D-17: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-1 Separated core set after APAO testing

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		2/27/2009			**Tested by**	Suraj Darra			
Project		OR 18			**Lift Thickness**	NOM 3in.			
Date Extracted		8/18/2008			**Mix Type**	B			
18-1-lift 1									
Core ID	**Sample Location**		**Nominal Thickness of Intact Specimen (mm)**	**Thickness of Separated Specimen (mm)**	**Mass of Specimen in Air A (grams)**	**Mass of Specimen in Water C (grams)**	**Mass of Saturated Surface-Dry Specimen in Air B (grams)**	**Percent of Water Absorbed by Volume**	**Bulk Specific Gravity of Specimen G**
	Station	**Offset**							
18-1-1	300.3	8.2	85	64	2661	1595.7	2664.2	0.3	2.4904
18-1-2	1341	1.6	95	87	3523.6	2047.5	3537.5	0.9	2.3648
18-1-3	1703	2.9	60	52	2167.9	1263.8	2178.9	1.2	2.3690
18-1-4	2730	6.6	90	75	3045.5	1788.1	3055.5	0.8	2.4030
18-1-5	3859	8.2	87	75	3071.5	1807.7	3085.9	1.1	2.4030
18-1-6	2988	5.7	86	75	3055.1	1808.9	3058.0	0.2	2.4458
18-1-7	2146	4.9	92	76	3237.4	1943.8	3239.5	0.2	2.4986
18-1-8	1980	3	87	71	2909.3	1702.7	2914.2	0.4	2.4014
18-1-9	1306	5.4	97	86	3609.2	2158.9	3611.2	0.1	2.4852
18-1-10	1203	4.8	108	90	3857.7	2303.5	3860.7	0.2	2.4773

Table D-18: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-2 Lift 1 Separated core set after APAO testing

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		2/27/2009			**Tested by**	Suraj Darra			
Project		OR 18			**Lift Thickness**	NOM 3in.			
Date Extracted		8/18/2008			**Mix Type**	B			
18-2-lift 1									
Core ID	**Sample Location**		**Nominal Thickness of Intact Specimen (mm)**	**Thickness of Separated Specimen (mm)**	**Mass of Specimen in Air A (grams)**	**Mass of Specimen in Water C (grams)**	**Mass of Saturated Surface-Dry Specimen in Air B (grams)**	**Percent of Water Absorbed by Volume**	**Bulk Specific Gravity of Specimen G**
	Station	**Offset**							
18-2-1					2356.9	1380.0	2362.5	0.6	2.3989
18-2-2					2194.9	1281.7	2201.3	0.7	2.3868
18-2-3					2471.9	1452.7	2474.0	0.2	2.4203
18-2-4					2632.6	1526.3	2638.7	0.5	2.3666
18-2-5					2596.8	1508.7	2606.4	0.9	2.3657
18-2-6					2581.9	1510.8	2584.7	0.3	2.4042
18-2-7					2441.6	1408.5	2448.2	0.6	2.3484
18-2-8					2509.3	1442.1	2522.0	1.2	2.3236
18-2-9					2434.3	1438.4	2436.2	0.2	2.4397
18-2-10					2341.4	1361.8	2343.9	0.3	2.3841

Table D-19: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-2 Lift 2 Separated core set after APAO testing

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		2/27/2009			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness	NOM 3in.			
Date Extracted		8/18/2008			Mix Type	B			
18-2-lift 2									
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-2-1					2149.9	1254.4	2153.9	0.4	2.3901
18-2-2					2420.6	1407.2	2431.1	1.0	2.3641
18-2-3									
18-2-4					2345.4	1361.3	2349.8	0.4	2.3727
18-2-5					2816.7	1646.2	2822.5	0.5	2.3945
18-2-6					3002	1757.4	3005.3	0.3	2.4056
18-2-7					2554.9	1486.7	2557.8	0.3	2.3853
18-2-8					2501.1	1462.8	2505.1	0.4	2.3996
18-2-9					2481.5	1448.0	2486.7	0.5	2.3890
18-2-10					2466	1432.1	2470.0	0.4	2.3760

Table D-20: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-3 Lift 1 Separated core set after APAO testing

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		2/27/2009			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness	NOM 3in.			
Date Extracted		8/18/2008			Mix Type	B			
18-3-lift 1									
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-3-1					1849.4	1102.7	1850.7	0.2	2.4725
18-3-2					2652.9	1583.0	2654.3	0.1	2.4763
18-3-3					3182	1874.2	3187.6	0.4	2.4227
18-3-4					3043.5	1803.5	3045.9	0.2	2.4497
18-3-5					3005.9	1772.0	3013.7	0.6	2.4208
18-3-6					2018.9	1194.6	2021.3	0.3	2.4421
18-3-7					3540.8	2085.9	3554.5	0.9	2.4110
18-3-8					1938	1144.5	1939.6	0.2	2.4374
18-3-9					2737	1576.0	2758.8	1.8	2.3140
18-3-10									

Table D-21: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-3 Lift 2 Separated core set after APAO testing

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		2/27/2009			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness	NOM 3in.			
Date Extracted					Mix Type	B			
18-3-lift 2									
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-3-1					1537.7	898.5	1540.4	0.4	2.3955
18-3-2					1091	632.4	1092.7	0.4	2.3702
18-3-3					1607.3	950.2	1609.0	0.3	2.4397
18-3-4					1007.9	585.5	1009.6	0.4	2.3766
18-3-5					1067.7	618.6	1069.7	0.4	2.3669
18-3-6					1299	759.2	1300.6	0.3	2.3993
18-3-7					960.1	543.9	962.9	0.7	2.2914
18-3-8					1220.3	708.1	1221.8	0.3	2.3755
18-3-9					1604.2	939.5	1606.0	0.3	2.4069
18-3-10					1511.9	870.2	1515.3	0.5	2.3437

Table D-22: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 18-3 Lift 3 Separated core set after APAO testing

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		2/27/2009			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness	NOM 3in.			
Date Extracted					Mix Type	B			
18-3-lift 3									
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
18-3-1					2288.2	1340.7	2294.1	0.6	2.4000
18-3-2					2444.4	1451.4	2446.0	0.2	2.4577
18-3-3					2075.2	1210.2	2080.5	0.6	2.3845
18-3-4					2235.6	1301.7	2244.8	1.0	2.3705
18-3-5					1973.4	1139.2	1979.2	0.7	2.3493
18-3-6					2293.5	1345.4	2304.3	1.1	2.3918
18-3-7					2270.8	1324.1	2281.1	1.1	2.3728
18-3-8					2358	1372.8	2365.4	0.7	2.3756
18-3-9					2316.4	1328.3	2338.9	2.2	2.2921
18-3-10					2078.2	1204.1	2083.3	0.6	2.3637

Table D-23: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 140-1 Separated core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		9/28/2008			**Tested by**	Suraj Darra			
Project		OR 18			**Lift Thickness**	NOM 2 in.			
Date Extracted		8/20/2008			**Mix Type**	C Mix? (Level 3, 1/2 inch Dense)			
Core ID	**Sample Location**		**Nominal Thickness of Intact Specimen (mm)**	**Thickness of Separated Specimen (mm)**	**Mass of Specimen in Air A (grams)**	**Mass of Specimen in Water C (grams)**	**Mass of Saturated Surface-Dry Specimen in Air B (grams)**	**Percent of Water Absorbed by Volume**	**Bulk Specific Gravity of Specimen G**
	Station	**Offset**							
140-1-1	105	1.3	53	32	1208.6	681.6	1212.5	0.7	2.2765
140-1-2	155	11.2	54	42	1594.4	901.3	1599.3	0.7	2.2842
140-1-3	171	10.2	53	37	1425.4	800.9	1432.7	1.2	2.2561
140-1-4	187	6.6	54	35	1359.8	765.5	1364.5	0.8	2.2701
140-1-5	300	3.5	60	42	1548.2	870.4	1552.5	0.6	2.2698
140-1-6	330	5.1	62	45	1797.9	1008.8	1804.5	0.8	2.2595
140-1-7	390	3.3	60	45	1751.5	985.0	1757.5	0.8	2.2673
140-1-8	512	12.2	58	37	1367.0	765.0	1374.8	1.3	2.2417
140-1-9	653	7.8	64	47	1815.3	1016.1	1824.5	1.1	2.2455
140-1-10	736	1.6	65	50	1824.1	1009.6	1839.0	1.8	2.1993

Table D-24: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 140-1 Separated core set

Oregon State University												
CoreLok Bulk Specific gravity Data Collection Table												
CoreLok Operator's Guide Method												
Date		9/17/2008			Tested by	Suraj Darra						
Project		OR 18			Lift Thickness							
Date Extracted		8/18/2008			Mix Type							
Core ID	Sample Location		Bag Wt. A (grams)	Dry Sample Weight before Sealing B (grams)	Sealed Sample Weight in Water C (grams)	Dry Sample Weight after Water Submersion D (grams)	Ratio B/A E (grams)	Bag Volume Correction from table F	Total Volume (A+D)-C G	Volume of Bag A/F H	Volume of Sample G-H I	Bulk Sp.Gr. B/I J
	Station	Offset										
140-1-1	105	1.3	26.7	1208.7	663.5	1208.6	45.27	0.79	571.80	33.95	537.85	2.2473
140-1-2	155	11.2	26.5	1594.7	881.9	1594.5	60.18	0.78	739.10	34.06	705.04	2.2619
140-1-3	171	10.2	26.8	1425.9	779.2	1425.5	53.21	0.78	673.10	34.27	638.83	2.2321
140-1-4	187	6.6	27	1360	746.7	1359.8	50.37	0.78	640.10	34.46	605.64	2.2455
140-1-5	300	3.5	26.5	1549.1	851.6	1548.4	58.46	0.78	723.30	34.02	689.28	2.2474
140-1-6	330	5.1	26.9	1798.4	987.6	1798.1	66.86	0.77	837.40	34.74	802.66	2.2406
140-1-7	390	3.3	27.1	1751.9	962.1	1751.6	64.65	0.78	816.60	34.94	781.66	2.2413
140-1-8	512	12.2	26.5	1368	739.2	1367.3	51.62	0.78	654.60	33.85	620.75	2.2038
140-1-9	653	7.8	26.6	1816	989.9	1815.4	68.27	0.77	852.10	34.39	817.71	2.2208
140-1-10	736	1.6	27.3	1825.6	971.5	1824.4	66.87	0.77	880.20	35.26	844.94	2.1606

Table D-25: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 140-2 Non-Separated core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		9/28/2008			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness	NOM 2 in.			
Date Extracted		9/11/2008			Mix Type				
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
140-2-1	47	11.6	125	100	3882.2	2201.5	3898.7	1.0	2.2874
140-2-2	352	6.2	128	100	3953.9	2229.0	3992.7	2.2	2.2418
140-2-3	477	12.3	118	95					
140-2-4	514	3.6	117	95	3751.3	2106.9	3776.6	1.5	2.2467
140-2-5	758	2.2	130	110	4173.0	2341.4	4220.1	2.5	2.2212
140-2-6	814	4.1	135	112	4271.1	2391.2	4296.8	1.3	2.2413
140-2-7	860	11.2	122	95	3875.0	2190.2	3881.6	0.4	2.2910
140-2-8	890	10.5	127	114					
140-2-9	895	11.4	129	106					
140-2-10	906	10.1	133	116	4421.8	2510.7	4427.0	0.3	2.3075

Table D-26: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 140-2 Non-Separated core set

Oregon State University												
CoreLok Bulk Specific gravity Data Collection Table												
CoreLok Operator's Guide Method												
Date					Tested by	Suraj Darra						
Project		OR 18			Lift Thickness							
Date Extracted					Mix Type							
Core ID	Sample Location		Bag Wt. A (grams)	Dry Sample Weight before Sealing B (grams)	Sealed Sample Weight in Water C (grams)	Dry Sample Weight after Water Submersion D (grams)	Ratio B/A E (grams)	Bag Volume Correction from table F	Total Volume (A+D)-C G	Volume of Bag A/F H	Volume of Sample G-H I	Bulk Sp.Gr. B/I J
	Station	Offset										
140-2-1	47	11.6	47.2	3882.4	2162.4	3882.2	82.2542	0.7231	1767.0000	65.2783	1701.7217	2.28145
140-2-2	352	6.2	47.8	3967.4	2163.1	3967.3	83.0000	0.7218	1852.0000	66.2215	1785.7785	2.22166
140-2-3	477	12.3		5327.3								
140-2-4	514	3.6	47.5	3751.7	2059.2	3751.3	78.9832	0.7285	1739.6000	65.2035	1674.3965	2.24063
140-2-5	758	2.2	47.6	4173.8	2173.6	4173	87.6849	0.7140	2047.0000	66.6626	1980.3374	2.10762
140-2-6	814	4.1	47.4	4271.4	2333.9	4271.1	90.1139	0.7100	1984.6000	66.7595	1917.8405	2.22719
140-2-7	860	11.2	47.4	3875	2158	3875	81.7511	0.7239	1764.4000	65.4793	1698.9207	2.28086
140-2-8	890	10.5										
140-2-9	895	11.4										
140-2-10	906	10.1	47.6	4421.6	2479.3	4421.5	92.8908	0.7054	1989.8000	67.4793	1922.3207	2.30014

Table D-27: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 140-2 Lift 1 Separated core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		10/15/2008			**Tested by**	Suraj Darra			
Project		OR 18			**Lift Thickness**	NOM 2 in.			
Date Extracted		9/11/2008			**Mix Type**				
Core ID (Lift 1)	**Sample Location**		**Nominal Thickness of Intact Specimen (mm)**	**Thickness of Separated Specimen (mm)**	**Mass of Specimen in Air A (grams)**	**Mass of Specimen in Water C (grams)**	**Mass of Saturated Surface-Dry Specimen in Air B (grams)**	**Percent of Water Absorbed by Volume**	**Bulk Specific Gravity of Specimen G**
	Station	**Offset**							
140-2-1	47	11.6		45	1648	932.8	1649.7	0.2	2.2988
140-2-2	352	6.2		43	1637.7	922.3	1640.7	0.4	2.2796
140-2-3	477	12.3		37	1430.6	802.2	1433.2	0.4	2.2672
140-2-4	514	3.6		42	1604.6	902.4	1606.9	0.3	2.2776
140-2-5	758	2.2		50	1925.3	1074.5	1936.9	1.3	2.2325
140-2-6	814	4.1		48	1826.4	1019.7	1831.0	0.6	2.2512
140-2-7	860	11.2		38	1339.7	749.4	1343.6	0.7	2.2546
140-2-8	890	10.5		50	1831.2	1027.2	1843.8	1.5	2.2425
140-2-9	895	11.4		42	1587.4	884.7	1594.7	1.0	2.2358
140-2-10	906	10.1		52	1888.1	1063.9	1895.9	0.9	2.2694

Table D-28: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 140-2 Lift 1 Separated core set

Oregon State University

CoreLok Bulk Specific gravity Data Collection Table

CoreLok Operator's Guide Method

Date	9/17/2008	**Tested by**	Suraj Darra
Project	OR 18	**Lift Thickness**	
Date Extracted	8/18/2008	**Mix Type**	

Core ID (Lift 1)	Sample Location		Bag Wt. A (grams)	Dry Sample Weight before Sealing B (grams)	Sealed Sample Weight in Water C (grams)	Dry Sample Weight after Water Submersion D (grams)	Ratio B/A E (grams)	Bag Volume Correction from table F	Total Volume (A+D)-C G	Volume of Bag A/F H	Volume of Sample G-H I	Bulk Sp.Gr. B/I J
	Station	Offset										
140-2-1	47	11.6	26.9	1648	920	1647.5	61.26	0.78	754.40	34.60	719.80	2.2895
140-2-2	352	6.2	26.8	1637.7	904.6	1637.4	61.11	0.78	759.60	34.47	725.13	2.2585
140-2-3	477	12.3	26.5	1430.6	782.2	1430.4	53.98	0.78	674.70	33.91	640.79	2.2325
140-2-4	514	3.6	27	1604.6	887.3	1604.1	59.43	0.78	743.80	34.68	709.12	2.2628
140-2-5	758	2.2	27	1925.3	1040.9	1924.5	71.31	0.77	910.60	34.99	875.61	2.1988
140-2-6	814	4.1	26.7	1826.4	997.1	1825.7	68.40	0.77	855.30	34.52	820.78	2.2252
140-2-7	860	11.2	26.8	1339.7	729.5	1339.4	49.99	0.78	636.70	34.19	602.51	2.2235
140-2-8	890	10.5	27	1831.2	984.5	1831	67.82	0.77	873.50	34.90	838.60	2.1836
140-2-9	895	11.4	26.6	1587.4	859.2	1586.6	59.68	0.78	754.00	34.18	719.82	2.2053
140-2-10	906	10.1	26.6	1888.1	1041	1888	70.98	0.77	873.60	34.46	839.14	2.2500

Table D-29: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 140-2 Lift 2 Separated core set

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		9/28/2008			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness	NOM 2 in.			
Date Extracted		9/11/2008			Mix Type				
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
140-2-1	47	11.6		58	2082.5	1176.5	2087.4	0.5	2.2862
140-2-2	352	6.2		58	2171	1220.9	2191.0	2.1	2.2379
140-2-3	477	12.3		60	2063.8	1162.8	2086.8	2.5	2.2335
140-2-4	514	3.6		52	2001.3	1120.4	2012.0	1.2	2.2446
140-2-5	758	2.2		65	2104.4	1178.0	2125.0	2.2	2.2222
140-2-6	814	4.1		65	2303.7	1293.5	2314.7	1.1	2.2559
140-2-7	860	11.2		58	2375.9	1349.7	2378.3	0.2	2.3098
140-2-8	890	10.5		65	2422.8	1383.6	2425.3	0.2	2.3258
140-2-9	895	11.4		65	2396.4	1360.0	2398.5	0.2	2.3076
140-2-10	906	10.1		65	2376.9	1363.0	2378.7	0.2	2.3402

Table D-30: Bulk Specific Gravity of Specimens by Corelok Method (Corelok manual procedure) on the 140-2 Lift 2 Separated core set

Oregon State University													
CoreLok Bulk Specific gravity Data Collection Table													
CoreLok Operator's Guide Method													
Date		9/17/2008			Tested by	Suraj Darra							
Project		OR 18			Lift Thickness								
Date Extracted		8/18/2008			Mix Type								
Core ID	Sample Location		Bag Wt. A (grams)	Dry Sample Weight before Sealing B (grams)	Sealed Sample Weight in Water C (grams)	Dry Sample Weight after Water Submersion D (grams)	Ratio B/A E (grams)	Bag Volume Correction from table F	Total Volume (A+D)-C G	Volume of Bag A/F H	Volume of Sample G-H I	Bulk Sp.Gr. B/I J
	Station	Offset										
140-1-1			26.7	1208.7	663.5	1208.6	45.2697	0.7865	571.8000	33.9488	537.85115	2.24728
140-1-2			26.5	1594.7	881.9	1594.5	60.1774	0.7780	739.1000	34.06	705.04004	2.26186
140-1-3			26.8	1425.9	779.2	1425.5	53.2052	0.7820	673.1000	34.2717	638.82828	2.23206
140-1-4			27	1360	746.7	1359.8	50.3704	0.7836	640.1000	34.4568	605.64322	2.24555
140-1-5			26.5	1549.1	851.6	1548.4	58.4566	0.7790	723.3000	34.0174	689.28262	2.24741
140-1-6			26.9	1798.4	987.6	1798.1	66.8550	0.7743	837.4000	34.7428	802.65715	2.24056
140-1-7			27.1	1751.9	962.1	1751.6	64.6458	0.7755	816.6000	34.9447	781.65528	2.24127
140-1-8			26.5	1368	739.2	1367.3	51.6226	0.7829	654.6000	33.8493	620.75069	2.20378
140-1-9			26.6	1816	989.9	1815.4	68.2707	0.7735	852.1000	34.391	817.70903	2.22084
140-1-10			27.3	1825.6	971.5	1824.4	66.8718	0.7743	880.2000	35.2599	844.9401	2.16063

Table D-31: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 140-1 Separated core set after APAO testing

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		2/27/2009			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness	NOM 3in.			
Date Extracted					Mix Type	B			
140-1-lift 1									
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
140-1-1					1206.7	679.4	1211.1	0.8	2.2695
140-1-2					1590.9	897.4	1597.2	0.9	2.2734
140-1-3					1421.2	797.3	1429.7	1.3	2.2473
140-1-4					1355.6	762.3	1361.4	1.0	2.2627
140-1-5									
140-1-6					1793.5	1005.9	1803.3	1.2	2.2492
140-1-7					1745.9	982.0	1756.5	1.4	2.2542
140-1-8					1359.8	759.9	1373.0	2.2	2.2179
140-1-9					1810.6	1015.2	1823.2	1.6	2.2408
140-1-10					1811.8	1013.5	1838.3	3.2	2.1967

Table D-32: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 140-2 Lift 1 Separated core set after APAO testing

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		2/27/2009			Tested by	Suraj Darra			
Project		OR 18			Lift Thickness	NOM 3in.			
Date Extracted					Mix Type	B			
140-2-lift 1									
Core ID	Sample Location		Nominal Thickness of Intact Specimen (mm)	Thickness of Separated Specimen (mm)	Mass of Specimen in Air A (grams)	Mass of Specimen in Water C (grams)	Mass of Saturated Surface-Dry Specimen in Air B (grams)	Percent of Water Absorbed by Volume	Bulk Specific Gravity of Specimen G
	Station	Offset							
140-2-1					1645.8	931.0	1648.1	0.3	2.2951
140-2-2					1635.1	916.5	1638.4	0.5	2.2650
140-2-3					1429.4	799.3	1432.9	0.6	2.2560
140-2-4					1600.3	899.4	1604.0	0.5	2.2712
140-2-5					1920.4	1071.4	1934.5	1.6	2.2250
140-2-6					1821.3	1011.3	1825.8	0.6	2.2361
140-2-7					1336.9	743.8	1341.4	0.8	2.2371
140-2-8					1833.8	1023.7	1844.4	1.3	2.2344
140-2-9					1586.3	882.2	1595.8	1.3	2.2230
140-2-10					1886.3	1057.9	1893.6	0.9	2.2571

Table D-33: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method (AASHTO T 166 Method A) on the 140-2 Lift 2 Separated core set after APAO testing

Oregon State University									
Bulk Specific gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens									
AASHTO T 166-05									
Date		2/27/2009			**Tested by**	Suraj Darra			
Project		OR 18			**Lift Thickness**	NOM 3in.			
Date Extracted					**Mix Type**	B			
140-2-lift 2									
Core ID	**Sample Location**		**Nominal Thickness of Intact Specimen (mm)**	**Thickness of Separated Specimen (mm)**	**Mass of Specimen in Air A (grams)**	**Mass of Specimen in Water C (grams)**	**Mass of Saturated Surface-Dry Specimen in Air B (grams)**	**Percent of Water Absorbed by Volume**	**Bulk Specific Gravity of Specimen G**
	Station	**Offset**							
140-2-1					2078.8	1185.9	2088.4	1.1	2.3034
140-2-2					2168.2	1214.6	2192.2	2.5	2.2179
140-2-3					2062.1	1154.6	2084.7	2.4	2.2171
140-2-4					1999.3	1118.0	2012.6	1.5	2.2349
140-2-5					2101.4	1170.0	2122.8	2.2	2.2055
140-2-6					2298.7	1288.0	2311.5	1.3	2.2459
140-2-7					2375.1	1344.5	2377.7	0.3	2.2988
140-2-8					2423.2	1375.2	2426.5	0.3	2.3050
140-2-9					2395.7	1353.7	2399.4	0.4	2.2910
140-2-10					2376.4	1361.7	2379.0	0.3	2.3360

Table D-34: Bulk Specific Gravity data (by AASHTO T 166 Method A – SSD tests) as obtained from APAO

Gmb DATA (AASHTO T 166)					
Specimen Number	Dry Mass	Weight in Water	SSD Mass	Immersed Volume	Gmb
18-2-1 Lift 1	2358.8	1382.5	2363.8	981.3	2.404
18-2-1 Lift 2	2150.5	1258.0	2154.6	896.6	2.399
18-2-2 Lift 1	2198.0	1288.8	2206.1	917.3	2.396
18-2-2 Lift 2	2420.4	1403.9	2431.8	1027.9	2.355
18-2-3 Lift 1	2473.4	1455.4	2475.1	1019.7	2.426
18-2-3 Lift 2		1547.4	2698.6	1151.2	
18-2-4 Lift 1	2632.0	1529.8	2643.0	1113.2	2.364
18-2-4 Lift 2	2346.4	1361.6	2350.9	989.3	2.372
18-2-5 Lift 1	2598.5	1511.0	2607.9	1096.9	2.369
18-2-5 Lift 2	2816.8	1645.6	2823.5	1177.9	2.391
18-2-6 Lift 1	2582.8	1512.3	2585.3	1073.0	2.407
18-2-6 Lift 2	3002.8	1763.7	3007.5	1243.8	2.414
18-2-7 Lift 1	2445.9	1411.3	2452.2	1040.9	2.350
18-2-7 Lift 2	2555.7	1489.5	2559.9	1070.4	2.388
18-2-8 Lift 1	2511.8	1451.0	2529.6	1078.6	2.329
18-2-8 Lift 2	2501.1	1466.1	2506.1	1040.0	2.405
18-2-9 Lift 1	2434.8	1439.6	2435.8	996.2	2.444
18-2-9 Lift 2	2482.0	1448.6	2486.9	1038.3	2.390
18-2-10 Lift 1	2341.9	1362.4	2344.5	982.1	2.385
18-2-10 Lift 2	2466.5	1431.2	2468.8	1037.6	2.377
18-3-1 Lift 1	1849.6	1103.8	1850.2	746.4	2.478
18-3-1 Lift 2	1538.2	901.1	1541.5	640.4	2.402
18-3-1 Lift 3	2288.4	1337.0	2292.7	955.7	2.394
18-3-2 Lift 1	2653.3	1581.9	2654.2	1072.3	2.474
18-3-2 Lift 2	1092.3	635.9	1096.7	460.8	2.370
18-3-2 Lift 3	2444.7	1451.3	2446.0	994.7	2.458
18-3-3 Lift 1	3180.8	1870.9	3184.9	1314.0	2.421
18-3-3 Lift 2	1607.5	949.0	1608.8	659.8	2.436
18-3-3 Lift 3	2076.4	1213.6	2083.7	870.1	2.386
18-3-4 Lift 1	3043.8	1805.2	3045.4	1240.2	2.454
18-3-4 Lift 2	1009.1	587.9	1011.2	423.3	2.384
18-3-4 Lift 3	2235.3	1307.6	2247.6	940.0	2.378
18-3-5 Lift 1	3008.8	1774.8	3015.6	1240.8	2.425
18-3-5 Lift 2	1069.0	620.3	1071.2	450.9	2.371
18-3-5 Lift 3	1974.7	1140.9	1980.6	839.7	2.352
18-3-6 Lift 1	2019.0	1196.8	2021.0	824.2	2.450
18-3-6 Lift 2	1300.3	761.7	1301.7	540.0	2.408
18-3-6 Lift 3	2294.2	1347.9	2304.5	956.6	2.398
18-3-7 Lift 1	3539.6	2096.6	3557.7	1461.1	2.423
18-3-7 Lift 2	961.3	550.5	966.9	416.4	2.309
18-3-7 Lift 3	2271.1	1327.9	2283.0	955.1	2.378
18-3-8 Lift 1	1937.9	1146.8	1939.1	792.3	2.446
18-3-8 Lift 2	1220.8	708.8	1222.7	513.9	2.376
18-3-8 Lift 3	2358.6	1378.2	2368.3	990.1	2.382

Table D-34 (cont.): Bulk Specific Gravity data (by AASHTO T 166 Method A – SSD tests) as obtained from APAO

Gmb DATA (AASHTO T 166)			
Specimen Number	Dry Mass	Weight in Water	SSD Mass
18-3-9 Lift 1	2733.5	1589.9	2774.9
18-3-9 Lift 2	1604.6	940.8	1607.4
18-3-9 Lift 3	2316.5	1324.6	2341.2
18-3-10 Lift 1		1425.7	2531.7
18-3-10 Lift 2	1515.1	870.5	1517.5
18-3-10 Lift 3	2079.2	1207.3	2088.4
140-2-1 Lift 1	1646.8	932.7	1648.9
140-2-1 Lift 2	2080.1	1176.8	2089.1
140-2-2 Lift 1	1636.1	918.6	1639.1
140-2-2 Lift 2	2168.7	1214.5	2194.6
140-2-3 Lift 1	1429.6	801.5	1433.5
140-2-3 Lift 2	2063.3	1158.2	2089.0
140-2-4 Lift 1	1601.8	900.7	1605.3
140-2-4 Lift 2	1997.7	1122.4	2015.7
140-2-5 Lift 1	1923.4	1073.3	1938.4
140-2-5 Lift 2	2102.5	1172.3	2125.6
140-2-6 Lift 1	1824.0	1018.2	1829.6
140-2-6 Lift 2	2302.1	1294.5	2315.7
140-2-7 Lift 1	1337.9	744.0	1343.1
140-2-7 Lift 2	2375.5	1346.1	2377.3
140-2-8 Lift 1	1833.8	1026.3	1846.0
140-2-8 Lift 2	2422.8	1379.6	2426.7
140-2-9 Lift 1	1587.1	882.2	1597.6

Table D-35: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method C (AASHTO T 166 Method C) on the 18-1 core set

18-1	lift 1	FLAGGED due to improper breaking (possible loss of material)							
Core ID	Mass of Core (grams)	Mass of Pan P (grams)	Initial Mass of Pan and Separated Specimen (grams)	Final Mass of Pan and Separated Specimen M (grams)	Percentage difference (not>0.05%)	Dry Mass of Specimen 'A' (=M-P) (grams)	Mass of Specimen in Water 'C' (grams)	Mass of Saturated Surface-Dry Specimen in Air 'B' (grams)	Bulk Specific Gravity of Specimen G1
18-1-1	2659.9	25.8	2672.4	2672	0.01	2646.2	1595.7	2664.2	2.4766
18-1-2	3522.8	26.3	3537.3	3537	0.01	3510.7	2047.5	3537.5	2.3562
18-1-3	2166.8	25.5	2182	2181.7	0.01	2156.2	1263.8	2178.9	2.3562
18-1-4	3044.4	30.1	3054.5	3053.9	0.02	3023.8	1788.1	3055.5	2.3858
18-1-5	3071.4	26	3074.2	3073.7	0.02	3047.7	1807.7	3085.9	2.3844
18-1-6	3054.5	26.5	3055.2	3055.1	0.00	3028.6	1808.9	3058.0	2.4246
18-1-7	3236.7	30.3	3259.3	3259	0.01	3228.7	1943.8	3239.5	2.4919
18-1-8	2907.6	26.7	2910.3	2909.7	0.02	2883	1702.7	2914.2	2.3797
18-1-9	3608.6	45.7	3626.8	3626.4	0.01	3580.7	2158.9	3611.2	2.4655
18-1-10	3856.9	46.3	3864.2	3863.4	0.02	3817.1	2303.5	3860.7	2.4513

Table D-36: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method C (AASHTO T 166 Method C) on the 18-2 Lift 1 core set

18-2	lift 1								
Core ID	**Mass of Core (grams)**	**Mass of Pan P (grams)**	**Initial Mass of Pan and Separated Specimen (grams)**	**Final Mass of Pan and Separated Specimen M (grams)**	**Percentage difference (not>0.05%)**	**Dry Mass of Specimen 'A' (=M-P) (grams)**	**Mass of Specimen in Water 'C' (grams)**	**Mass of Saturated Surface-Dry Specimen in Air 'B' (grams)**	**Bulk Specific Gravity of Specimen G1**
18-2-1	2354.7	26.9	2364	2363.8	0.01	2336.9	1380.0	2362.5	2.3785
18-2-2	2191.7	26.5	2200.6	2200.1	0.02	2173.6	1281.7	2201.3	2.3636
18-2-3	2470.8	38.3	2498.1	2497.7	0.02	2459.4	1452.7	2474.0	2.4081
18-2-4	2629.8	26.3	2641.2	2640.2	0.04	2613.9	1526.3	2638.7	2.3498
18-2-5	2595.6	34.2	2614.5	2614.1	0.02	2579.9	1508.7	2606.4	2.3503
18-2-6	2581.3	26	2602.4	2602	0.02	2576	1510.8	2584.7	2.3987
18-2-7	2439	25.9	2451.5	2451	0.02	2425.1	1408.5	2448.2	2.3325
18-2-8	2504.4	28.1	2516	2515.1	0.04	2487	1442.1	2522.0	2.3030
18-2-9	2433.8	27	2451.5	2451	0.02	2424	1438.4	2436.2	2.4293
18-2-10	2340.4	27.2	2355.7	2355.1	0.03	2327.9	1361.8	2343.9	2.3703

Table D-37: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method C (AASHTO T 166 Method C) on the 18-2 Lift 2 core set

18-2	lift 2								
Core ID	Mass of Core (grams)	Mass of Pan P (grams)	Initial Mass of Pan and Separated Specimen (grams)	Final Mass of Pan and Separated Specimen M (grams)	Percentage difference (not>0.05%)	Dry Mass of Specimen 'A' (=M-P) (grams)	Mass of Specimen in Water 'C' (grams)	Mass of Saturated Surface-Dry Specimen in Air 'B' (grams)	Bulk Specific Gravity of Specimen G1
18-2-1	2148.3	36.3	2176.7	2175.9	0.04	2139.6	1254.4	2153.9	2.3787
18-2-2	2417.9	34	2446	2445.5	0.02	2411.5	1407.2	2431.1	2.3552
18-2-3					#DIV/0!	0			
18-2-4	2343.9	43.6	2390.7	2390	0.03	2346.4	1361.3	2349.8	2.3737
18-2-5	2815.6	30.1	2827.7	2827.2	0.02	2797.1	1646.2	2822.5	2.3779
18-2-6	3000.9	33.9	3021.7	3021.1	0.02	2987.2	1757.4	3005.3	2.3938
18-2-7	2553.6	37.7	2581.7	2581.5	0.01	2543.8	1486.7	2557.8	2.3749
18-2-8	2500	34.2	2524.3	2524	0.01	2489.8	1462.8	2505.1	2.3888
18-2-9	2480.6	29.6	2494.2	2494	0.01	2464.4	1448.0	2486.7	2.3726
18-2-10	2465	52.9	2512.7	2512.4	0.01	2459.5	1432.1	2470.0	2.3697

Table D-38: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method C (AASHTO T 166 Method C) on the 18-3 Lift 1 core set

18-3	lift 1								
Core ID	Mass of Core (grams)	Mass of Pan P (grams)	Initial Mass of Pan and Separated Specimen (grams)	Final Mass of Pan and Separated Specimen M (grams)	Percentage difference (not>0.05%)	Dry Mass of Specimen 'A' (=M-P) (grams)	Mass of Specimen in Water 'C' (grams)	Mass of Saturated Surface-Dry Specimen in Air 'B' (grams)	Bulk Specific Gravity of Specimen G1
18-3-1	1848.8	26	1876.2	1875.4	0.04	1849.4	1102.7	1850.7	2.4725
18-3-2	2651.9	26.8	2664.6	2664.2	0.02	2637.4	1583.0	2654.3	2.4619
18-3-3	3182	25.8	3192	3191.5	0.02	3165.7	1874.2	3187.6	2.4103
18-3-4	3042.1	26.9	3053.6	3052.8	0.03	3025.9	1803.5	3045.9	2.4355
18-3-5	3003.3	26	3028.9	3028.4	0.02	3002.4	1772.0	3013.7	2.4180
18-3-6	2017.6	26.1	2032.6	2032.1	0.02	2006	1194.6	2021.3	2.4265
18-3-7	3537.1	27.1	3551.4	3551	0.01	3523.9	2085.9	3554.5	2.3995
18-3-8	1937.1	26.9	1951.4	1950.9	0.03	1924	1144.5	1939.6	2.4198
18-3-9	2728.8	26.3	2735	2734.1	0.03	2707.8	1576.0	2758.8	2.2893
18-3-10					#DIV/0!	0			

Table D-39: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method C (AASHTO T 166 Method C) on the 18-3 Lift 2 core set

18-3	lift 2								
Core ID	Mass of Core (grams)	Mass of Pan P (grams)	Initial Mass of Pan and Separated Specimen (grams)	Final Mass of Pan and Separated Specimen M (grams)	Percentage difference (not>0.05%)	Dry Mass of Specimen 'A' (=M-P) (grams)	Mass of Specimen in Water 'C' (grams)	Mass of Saturated Surface-Dry Specimen in Air 'B' (grams)	Bulk Specific Gravity of Specimen G1
18-3-1	1536.5	31.2	1560.6	1560.1	0.03	1528.9	898.5	1540.4	2.3818
18-3-2	1089.5	27.8	1110.1	1109.7	0.04	1081.9	632.4	1092.7	2.3504
18-3-3	1607	27.8	1628.5	1628	0.03	1600.2	950.2	1609.0	2.4290
18-3-4	1006.6	29.5	1027	1026.7	0.03	997.2	585.5	1009.6	2.3513
18-3-5	1066.5	28.1	1087.9	1087.6	0.03	1059.5	618.6	1069.7	2.3487
18-3-6	1297.6	27.3	1318.1	1317.7	0.03	1290.4	759.2	1300.6	2.3835
18-3-7	958.6	29	985.1	984.7	0.04	955.7	543.9	962.9	2.2809
18-3-8	1219.1	27.6	1239.2	1238.8	0.03	1211.2	708.1	1221.8	2.3578
18-3-9	1602.3	28.3	1623.3	1623	0.02	1594.7	939.5	1606.0	2.3926
18-3-10	1509	28.8	1526.8	1526.2	0.04	1497.4	870.2	1515.3	2.3212

Table D-40: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method C (AASHTO T 166 Method C) on the 18-3 Lift 3 core set

18-3	lift 3								
Core ID	**Mass of Core (grams)**	**Mass of Pan P (grams)**	**Initial Mass of Pan and Separated Specimen (grams)**	**Final Mass of Pan and Separated Specimen M (grams)**	**Percentage difference (not>0.05%)**	**Dry Mass of Specimen 'A' (=M-P) (grams)**	**Mass of Specimen in Water 'C' (grams)**	**Mass of Saturated Surface-Dry Specimen in Air 'B' (grams)**	**Bulk Specific Gravity of Specimen G1**
18-3-1	2288.3	47.4	2329.7	2329.2	0.02	2281.8	1340.7	2294.1	2.3933
18-3-2	2444.2	33.1	2470.7	2470.3	0.02	2437.2	1451.4	2446.0	2.4504
18-3-3	2074.2	35	2103.3	2102.9	0.02	2067.9	1210.2	2080.5	2.3761
18-3-4	2234.2	40.7	2268.1	2267.8	0.01	2227.1	1301.7	2244.8	2.3615
18-3-5	1972.6	37.2	2003.9	2003.3	0.03	1966.1	1139.2	1979.2	2.3406
18-3-6	2292.1	35.9	2320.2	2320	0.01	2284.1	1345.4	2304.3	2.3820
18-3-7	2268.9	38.1	2300.5	2300	0.02	2261.9	1324.1	2281.1	2.3635
18-3-8	2357.1	43.5	2394.5	2394.1	0.02	2350.6	1372.8	2365.4	2.3681
18-3-9	2313.3	32.2	2339.8	2339.4	0.02	2307.2	1328.3	2338.9	2.2830
18-3-10	2076.6	30.2	2104	2103.6	0.02	2073.4	1204.1	2083.3	2.3583

Table D-41: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method C (AASHTO T 166 Method C) on the 140-1 Lift 1 core set

140-1	lift 1	FLAGGED due to improper breaking (possible loss of material)							
Core ID	**Mass of Core (grams)**	**Mass of Pan P (grams)**	**Initial Mass of Pan and Separated Specimen (grams)**	**Final Mass of Pan and Separated Specimen M (grams)**	**Percentage difference (not>0.05%)**	**Dry Mass of Specimen 'A' (=M-P) (grams)**	**Mass of Specimen in Water 'C' (grams)**	**Mass of Saturated Surface-Dry Specimen in Air 'B' (grams)**	**Bulk Specific Gravity of Specimen G1**
140-1-1	1206.1	27.2	1225.8	1225.2	0.05	1198	679.4	1211.1	2.2532
140-1-2	1590.4	26	1611.2	1611	0.01	1585	897.4	1597.2	2.2649
140-1-3	1420.4	26.1	1436	1435.5	0.03	1409.4	797.3	1429.7	2.2287
140-1-4	1354.8	26.1	1377.8	1377.7	0.01	1351.6	762.3	1361.4	2.2561
140-1-5	1543.8	27.4	1559.2	1559.1	0.01	1531.7			
140-1-6	1792.3	31.4	1811.2	1810.7	0.03	1779.3	1005.9	1803.3	2.2314
140-1-7	1744.7	27.5	1761.1	1760.7	0.02	1733.2	982.0	1756.5	2.2378
140-1-8	1358.7	27.3	1378.8	1378.2	0.04	1350.9	759.9	1373.0	2.2034
140-1-9	1809.9	26.6	1823.9	1823.1	0.04	1796.5	1015.2	1823.2	2.2234
140-1-10	1809.5	26.6	1826.2	1825.5	0.04	1798.9	1013.5	1838.3	2.1810

Table D-42: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method C (AASHTO T 166 Method C) on the 140-2 Lift 1 core set

140-2	lift 1	FLAGGED due to improper breaking (possible loss of material)							
Core ID	Mass of Core (grams)	Mass of Pan P (grams)	Initial Mass of Pan and Separated Specimen (grams)	Final Mass of Pan and Separated Specimen M (grams)	Percentage difference (not>0.05%)	Dry Mass of Specimen 'A' (=M-P) (grams)	Mass of Specimen in Water 'C' (grams)	Mass of Saturated Surface-Dry Specimen in Air 'B' (grams)	Bulk Specific Gravity of Specimen G1
140-2-1	1644.4	26.3	1664.9	1664	0.05	1637.7	931.0	1648.1	2.2838
140-2-2	1633.2	27.9	1647.7	1647.1	0.04	1619.2	916.5	1638.4	2.2430
140-2-3	1427.9	26.2	1443.3	1442.6	0.05	1416.4	799.3	1432.9	2.2355
140-2-4	1598.6	26.1	1615.5	1614.9	0.04	1588.8	899.4	1604.0	2.2549
140-2-5	1918.9	25.9	1931.4	1931.3	0.01	1905.4	1071.4	1934.5	
140-2-6	1819.1	26.1	1837.1	1836.8	0.02	1810.7	1011.3	1825.8	2.2231
140-2-7	1335.8	25.7	1347	1346.5	0.04	1320.8	743.8	1341.4	2.2102
140-2-8	1829.7	33	1851	1850.8	0.01	1817.8	1023.7	1844.4	2.2149
140-2-9	1583.4	26.4	1602.3	1602	0.02	1575.6	882.2	1595.8	2.2080
140-2-10	1884.7	25.6	1899.9	1899.4	0.03	1873.8	1057.9	1893.6	2.2422

Table D-43: Bulk Specific Gravity of Specimens by Saturated Surface Dry Method C (AASHTO T 166 Method C) on the 140-2 Lift 2 core set

140-2	lift 2	FLAGGED due to improper breaking (possible loss of material)							
Core ID	Mass of Core (grams)	Mass of Pan P (grams)	Initial Mass of Pan and Separated Specimen (grams)	Final Mass of Pan and Separated Specimen M (grams)	Percentage difference (not>0.05%)	Dry Mass of Specimen 'A' (=M-P) (grams)	Mass of Specimen in Water 'C' (grams)	Mass of Saturated Surface-Dry Specimen in Air 'B' (grams)	Bulk Specific Gravity of Specimen G1
140-2-1	2077.2	26	2088.3	2087.7	0.03	2061.7	1185.9	2088.4	2.2844
140-2-2	2163.8	25.6	2184.2	2184	0.01	2158.4	1214.6	2192.2	2.2079
140-2-3	2057.8	26	2071.6	2071.2	0.02	2045.2	1154.6	2084.7	2.1989
140-2-4	1995.4	26.3	2008.2	2007.9	0.01	1981.6	1118.0	2012.6	2.2151
140-2-5	2098.3	26.8	2130.9	2130.3	0.03	2103.5	1170.0	2122.8	2.2077
140-2-6	2296.5	26.3	2316.4	2316.1	0.01	2289.8	1288.0	2311.5	2.2372
140-2-7	2373.8	26	2393	2392.7	0.01	2366.7	1344.5	2377.7	2.2907
140-2-8	2422.1	25.7	2428.9	2428.2	0.03	2402.5	1375.2	2426.5	2.2853
140-2-9	2394.6	26.1	2401.1	2400.8	0.01	2374.7	1353.7	2399.4	2.2709
140-2-10	2375.9	25.7	2394.7	2394.2	0.02	2368.5	1361.7	2379.0	2.3282

Table D-44: Rice Gravity Data for OR 18 and OR 140 for all lifts

Project	Date	Station	Sample	Dry Mass (g)	Pyc + Water + Sample (g)	Gmm	Average Gmm at one station	Overall OSU Gmm Results	ODOT (Contractor) Gmm Results
OR 18	18-Aug	142	a	2117.5	7502.8	2.6042	2.6092	2.6047	2.582
OR18	18-Aug	142	b	2014	7436.7	2.5964			
OR 18	18-Aug	142	c	2241.4	7584	2.6191			
OR 18	18-Aug	142	d	2075.9	7481.1	2.6171			
OR 18	18-Aug	41+16	a	2082.2	7478.7	2.5966	2.6002		
OR 18	18-Aug	41+16	b	2130.3	7508.2	2.5963			
OR 18	18-Aug	41+16	c	2131.7	7512.8	2.6082			
OR 18	18-Aug	41+16	d	2037.2	7452	2.5998			
OR 18	22-Aug	129+00	a	2121.1	7495	2.5726	2.5748	2.5850	2.576
OR 18	22-Aug	129+00	b	2024.5	7436.9	2.5757			
OR 18	22-Aug	129+00	c	2009.8	7426.3	2.5704			
OR 18	22-Aug	129+00	d	2163.9	7523.7	2.5804			
OR 18	22-Aug	124+00	a	2030.7	7443.7	2.5856	2.5879		
OR 18	22-Aug	124+00	b	2021	7440.6	2.5950			
OR 18	22-Aug	124+00	c	2170.1	7528.4	2.5831			
OR 18	22-Aug	126+75	a	2185.5	7540.5	2.5913	2.5923		
OR 18	22-Aug	126+75	b	2068.1	7472.4	2.6043			
OR 18	22-Aug	126+75	c	2149.9	7515.4	2.5812			
OR 18	25-Aug	120+95	a	2131.7	7500.9	2.5708	2.5770	2.5730	2.565
OR 18	25-Aug	120+95	b	2077.3	7467.4	2.5700			
OR 18	25-Aug	120+95	c	2192.1	7538.1	2.5717			
OR 18	25-Aug	120+95	d	2052.9	7460.4	2.5957			
OR 18	25-Aug	135+80	a	2142.8	7507.8	2.5712	2.5690		
OR 18	25-Aug	135+80	b	2128.9	7498	2.5671			
OR 18	25-Aug	135+80	c	2217.8	7552.8	2.5687			
OR 140	20-Aug	287+49	a	2137.9	7467.9	2.4619	2.4589	2.4663	2.445
OR 140	20-Aug	287+49	b	2053.3	7417.1	2.4602			
OR 140	20-Aug	287+49	c	2135.1	7463.7	2.4547			
OR 140	20-Aug	296+24	a	2090.2	7445.4	2.4789	2.4754		
OR 140	20-Aug	296+24	b	2102.5	7451.6	2.4756			
OR 140	20-Aug	296+24	c	2028.9	7406.5	2.4719			
OR 140	20-Aug	292+50	a	2019.1	7393.3	2.4498	2.4645		
OR 140	20-Aug	292+50	b	2121.6	7462	2.4727			
OR 140	20-Aug	292+50	c	2120.5	7460.7	2.4709			
OR 140	11-Sep	209+30	a	2087.4	7434.8	2.4529	2.4523	2.4547	2.452
OR 140	11-Sep	209+30	b	2194	7495.3	2.4457			
OR 140	11-Sep	209+30	c	2133.4	7464	2.4584			
OR 140	11-Sep	211+00.36754	a	2085	7435.1	2.4579	2.4571		
OR 140	11-Sep	211+00.36754	b	2124.6	7457.7	2.4553			
OR 140	11-Sep	211+00.36754	c	2157.1	7478	2.4582			

APPENDIX E: CORRELATION FACTORS

Table E-1: Correlation Factors for the First Lift of the Single-Lift Pavement on the OR 18 Project

Location/ CoreID	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	CoreLok - Troxler 3440 #25714 (4)	CoreLok - Troxler 3440 #25714 (2)	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #25714 (4)	SSD Method A (before APAO) - Troxler 3440 #25714 (2)
18.1.1	-6.573	-6.498	-7.798	-7.348	1.388	1.463	0.163	0.613
18.1.2	-2.040	-1.765	0.260	0.285	-1.748	-1.473	0.552	0.577
18.1.3	-2.171	-1.821	0.304	0.279	-2.501	-2.151	-0.026	-0.051
18.1.4	-6.751	-6.576	-4.951	-5.076	-2.715	-2.540	-0.915	-1.040
18.1.5	-2.470	-3.170	-0.220	-0.470	-2.343	-3.043	-0.093	-0.343
18.1.6	-3.353	-3.253	-1.528	-1.553	-3.078	-2.978	-1.253	-1.278
18.1.7	-3.646	-3.946	-2.696	-2.946	-2.069	-2.369	-1.119	-1.369
18.1.8	-3.777	-4.177	-1.827	-2.277	-2.631	-3.031	-0.681	-1.131
18.1.9	-1.694	-1.694	-0.144	0.406	-1.771	-1.771	-0.221	0.329
18.1.10	-4.629	-4.104	-2.754	-2.354	-1.285	-0.760	0.590	0.990
Average	-3.710	-3.700	-2.135	-2.105	-1.875	-1.865	-0.300	-0.270
Standard Deviation	1.801	1.774	2.592	2.534	1.265	1.384	0.663	0.886
Coefficient of Variation	-0.485	-0.479	-1.214	-1.204	-0.674	-0.742	-2.211	-3.278

Table E-1: Correlation Factors for the First Lift of the Single-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method A (after APAO) - Troxler 3430 #38806 (4)	SSD Method A (after APAO)- Troxler 3430 #38806 (2)	SSD Method A (after APAO) - Troxler 3440 #25714 (4)	SSD Method A (after APAO) - Troxler 3440 #25714 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)	SSD Method C - Troxler 3440 #25714 (4)	SSD Method C - Troxler 3440 #25714 (2)
18.1.1	1.278	1.353	0.053	0.503	0.416	0.491	-0.809	-0.359
18.1.2	-2.588	-2.313	-0.288	-0.263	-3.127	-2.852	-0.827	-0.802
18.1.3	-3.052	-2.702	-0.577	-0.602	-3.847	-3.497	-1.372	-1.397
18.1.4	-3.165	-2.990	-1.365	-1.490	-4.231	-4.056	-2.431	-2.556
18.1.5	-3.088	-3.788	-0.838	-1.088	-4.247	-4.947	-1.997	-2.247
18.1.6	-3.871	-3.771	-2.046	-2.071	-5.191	-5.091	-3.366	-3.391
18.1.7	-2.139	-2.439	-1.189	-1.439	-2.557	-2.857	-1.607	-1.857
18.1.8	-3.187	-3.587	-1.237	-1.687	-4.538	-4.938	-2.588	-3.038
18.1.9	-2.074	-2.074	-0.524	0.026	-3.295	-3.295	-1.745	-1.195
18.1.10	-1.536	-1.011	0.339	0.739	-3.159	-2.634	-1.284	-0.884
Average	-2.342	-2.332	-0.767	-0.737	-3.378	-3.368	-1.803	-1.773
Standard Deviation	1.442	1.554	0.716	0.966	1.546	1.646	0.812	1.015
Coefficient of Variation	-0.616	-0.666	-0.934	-1.311	-0.458	-0.489	-0.450	-0.573

Table E-2: Correlation Factors for the First Lift of the Two-Lift Pavement on the OR 18 Project

Location/ CoreID	CoreLok - Troxler 3440 #30860 (4)	CoreLok - Troxler 3440 #30860 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	CoreLok - Troxler 3440 #25714 (4)	CoreLok - Troxler 3440 #25714 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)
18.2.1	-2.481	-2.531	-2.206	-2.181	-1.281	-1.081	-2.518	-2.568
18.2.2	-2.825	-2.200	-2.050	-2.150	-0.725	-1.000	-2.367	-1.742
18.2.3	1.361	0.811	2.486	3.061	4.186	4.411	1.419	0.869
18.2.4	-2.928	-2.428	-1.628	-1.678	-0.803	-0.828	-2.231	-1.731
18.2.5	-5.996	-5.696	-4.821	-4.696	-3.796	-3.896	-5.667	-5.367
18.2.6	-1.899	-1.824	-1.899	-1.574	-0.674	-0.874	-1.987	-1.912
18.2.7	-3.673	-3.748	-3.648	-3.798	-2.648	-2.848	-4.143	-4.218
18.2.8	-7.080	-6.380	-5.680	-5.030	-5.905	-6.580	-6.392	-5.692
18.2.9	-0.503	-0.228	0.347	0.772	1.472	1.122	-0.464	-0.189
18.2.10	-6.773	-6.723	-6.523	-6.873	-6.073	-6.323	-2.381	-2.331
Average	-3.280	-3.095	-2.562	-2.415	-1.625	-1.790	-2.673	-2.488
Standard Deviation	2.714	2.534	2.735	2.893	3.158	3.314	2.296	2.097
Coefficient of Variation	-0.828	-0.819	-1.068	-1.198	-1.943	-1.852	-0.859	-0.843

Table E-2: Correlation Factors for the First Lift of the Two-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #25714 (4)	SSD Method A (before APAO) - Troxler 3440 #25714 (2)	SSD Method A (after APAO) - Troxler 3440 #30860 (4)	SSD Method A (after APAO) - Troxler 3440 #30860 (2)	SSD Method A (after APAO) - Troxler 3430 #38806 (4)	SSD Method A (after APAO) - Troxler 3430 #38806 (2)
18.2.1	-2.243	-2.218	-1.318	-1.118	-2.994	-3.044	-2.719	-2.694
18.2.2	-1.592	-1.692	-0.267	-0.542	-3.321	-2.696	-2.546	-2.646
18.2.3	2.544	3.119	4.244	4.469	0.742	0.192	1.867	2.442
18.2.4	-0.931	-0.981	-0.106	-0.131	-4.753	-4.253	-3.453	-3.503
18.2.5	-4.492	-4.367	-3.467	-3.567	-7.110	-6.810	-5.935	-5.810
18.2.6	-1.987	-1.662	-0.762	-0.962	-2.236	-2.161	-2.236	-1.911
18.2.7	-4.118	-4.268	-3.118	-3.318	-5.962	-6.037	-5.937	-6.087
18.2.8	-4.992	-4.342	-5.217	-5.892	-7.527	-6.827	-6.127	-5.477
18.2.9	0.386	0.811	1.511	1.161	-1.180	-0.905	-0.330	0.095
18.2.10	-2.131	-2.481	-1.681	-1.931	-4.265	-4.215	-4.015	-4.365
Average	-1.956	-1.808	-1.018	-1.183	-3.861	-3.676	-3.143	-2.996
Standard Deviation	2.294	2.392	2.669	2.828	2.613	2.409	2.576	2.714
Coefficient of Variation	-1.173	-1.323	-2.622	-2.391	-0.677	-0.656	-0.820	-0.906

Table E-2: Correlation Factors for the First Lift of the Two-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method A (after APAO) - Troxler 3440 #25714 (4)	SSD Method A (after APAO) - Troxler 3440 #25714 (2)	SSD Method A (APAO) - Troxler 3440 #30860 (4)	SSD Method A (APAO) - Troxler 3440 #30860 (2)	SSD Method A (APAO) - Troxler 3430 #38806 (4)	SSD Method A (APAO) - Troxler 3430 #38806 (2)	SSD Method A (APAO) - Troxler 3440 #25714 (4)	SSD Method A (APAO) - Troxler 3440 #25714 (2)
18.2.1	-1.794	-1.594	-2.675	-2.725	-2.400	-2.375	-1.475	-1.275
18.2.2	-1.221	-1.496	-2.748	-2.123	-1.973	-2.073	-0.648	-0.923
18.2.3	3.567	3.792	1.094	0.544	2.219	2.794	3.919	4.144
18.2.4	-2.628	-2.653	-4.915	-4.415	-3.615	-3.665	-2.790	-2.815
18.2.5	-4.910	-5.010	-6.903	-6.603	-5.728	-5.603	-4.703	-4.803
18.2.6	-1.011	-1.211	-2.063	-1.988	-2.063	-1.738	-0.838	-1.038
18.2.7	-4.937	-5.137	-5.861	-5.936	-5.836	-5.986	-4.836	-5.036
18.2.8	-6.352	-7.027	-7.193	-6.493	-5.793	-5.143	-6.018	-6.693
18.2.9	0.795	0.445	-0.910	-0.635	-0.060	0.365	1.065	0.715
18.2.10	-3.565	-3.815	-4.208	-4.158	-3.958	-4.308	-3.508	-3.758
Average	-2.206	-2.371	-3.638	-3.453	-2.921	-2.773	-1.983	-2.148
Standard Deviation	2.961	3.111	2.671	2.475	2.639	2.782	3.023	3.169
Coefficient of Variation	-1.342	-1.312	-0.734	-0.717	-0.904	-1.003	-1.525	-1.475

Table E-2: Correlation Factors for the First Lift of the Two-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method C - Troxler 3440 #30860 (4)	SSD Method C - Troxler 3440 #30860 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)	SSD Method C - Troxler 3440 #25714 (4)	SSD Method C - Troxler 3440 #25714 (2)
18.2.1	-4.261	-4.311	-3.986	-3.961	-3.061	-2.861
18.2.2	-4.762	-4.137	-3.987	-4.087	-2.662	-2.937
18.2.3	-0.019	-0.569	1.106	1.681	2.806	3.031
18.2.4	-5.799	-5.299	-4.499	-4.549	-3.674	-3.699
18.2.5	-8.069	-7.769	-6.894	-6.769	-5.869	-5.969
18.2.6	-2.578	-2.503	-2.578	-2.253	-1.353	-1.553
18.2.7	-6.950	-7.025	-6.925	-7.075	-5.925	-6.125
18.2.8	-8.812	-8.112	-7.412	-6.762	-7.637	-8.312
18.2.9	-1.823	-1.548	-0.973	-0.548	0.152	-0.198
18.2.10	-5.121	-5.071	-4.871	-5.221	-4.421	-4.671
Average	-4.819	-4.634	-4.102	-3.954	-3.164	-3.329
Standard Deviation	2.778	2.565	2.723	2.863	3.108	3.255
Coefficient of Variation	-0.576	-0.553	-0.664	-0.724	-0.982	-0.978

Table E-3: Correlation Factors for the Second Lift of the Two-Lift Pavement on the OR 18 Project

Location/ CoreID	CoreLok - Troxler 3440 #30860 (4)	CoreLok - Troxler 3440 #30860 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	CoreLok - Troxler 3440 #25714 (4)	CoreLok - Troxler 3440 #25714 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)
18.2.1	-3.822	-3.872	-3.547	-3.522	-2.622	-2.422	-3.793	-3.843
18.2.2	-4.741	-4.116	-3.966	-4.066	-2.641	-2.916	-3.709	-3.084
18.2.3	-5.329	-5.879	-4.204	-3.629	-2.504	-2.279	-1.559	-2.109
18.2.4	-4.912	-4.412	-3.612	-3.662	-2.787	-2.812	-6.583	-6.083
18.2.5	-5.892	-5.592	-4.717	-4.592	-3.692	-3.792	-4.479	-4.179
18.2.6	-3.299	-3.224	-3.299	-2.974	-2.074	-2.274	-1.459	-1.384
18.2.7	-3.161	-3.236	-3.136	-3.286	-2.136	-2.336	-2.570	-2.645
18.2.8	-2.702	-2.002	-1.302	-0.652	-1.527	-2.202	-2.243	-1.543
18.2.9	-4.072	-3.797	-3.222	-2.797	-2.097	-2.447	-3.192	-2.917
18.2.10	-4.661	-4.611	-4.411	-4.761	-3.961	-4.211	-3.689	-3.639
Average	-4.259	-4.074	-3.542	-3.394	-2.604	-2.769	-3.328	-3.143
Standard Deviation	1.023	1.145	0.949	1.153	0.744	0.697	1.521	1.394
Coefficient of Variation	-0.240	-0.281	-0.268	-0.340	-0.286	-0.252	-0.457	-0.444

Table E-3: Correlation Factors for the Second Lift of the Two-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #25714 (4)	SSD Method A (before APAO) - Troxler 3440 #25714 (2)	SSD Method A (after APAO) - Troxler 3440 #30860 (4)	SSD Method A (after APAO) - Troxler 3440 #30860 (2)	SSD Method A (after APAO) - Troxler 3430 #38806 (4)	SSD Method A (after APAO) - Troxler 3430 #38806 (2)
18.2.1	-3.518	-3.493	-2.593	-2.393	-3.540	-3.590	-3.265	-3.240
18.2.2	-2.934	-3.034	-1.609	-1.884	-4.734	-4.109	-3.959	-4.059
18.2.3	-0.434	0.141	1.266	1.491				
18.2.4	-5.283	-5.333	-4.458	-4.483	-4.374	-3.874	-3.074	-3.124
18.2.5	-3.304	-3.179	-2.279	-2.379	-5.314	-5.014	-4.139	-4.014
18.2.6	-1.459	-1.134	-0.234	-0.434	-2.148	-2.073	-2.148	-1.823
18.2.7	-2.545	-2.695	-1.545	-1.745	-3.664	-3.739	-3.639	-3.789
18.2.8	-0.843	-0.193	-1.068	-1.743	-2.799	-2.099	-1.399	-0.749
18.2.9	-2.342	-1.917	-1.217	-1.567	-4.331	-4.056	-3.481	-3.056
18.2.10	-3.439	-3.789	-2.989	-3.239	-4.771	-4.721	-4.521	-4.871
Average	-2.610	-2.463	-1.673	-1.838	-3.964	-3.697	-3.291	-3.191
Standard Deviation	1.434	1.698	1.564	1.589	1.018	1.020	0.985	1.248
Coefficient of Variation	-0.549	-0.690	-0.935	-0.864	-0.257	-0.276	-0.299	-0.391

Table E-3: Correlation Factors for the Second Lift of the Two-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method A (after APAO) - Troxler 3440 #25714 (4)	SSD Method A (after APAO) - Troxler 3440 #25714 (2)	SSD Method A (APAO) - Troxler 3440 #30860 (4)	SSD Method A (APAO) - Troxler 3440 #30860 (2)	SSD Method A (APAO) - Troxler 3430 #38806 (4)	SSD Method A (APAO) - Troxler 3430 #38806 (2)	SSD Method A (APAO) - Troxler 3440 #25714 (4)	SSD Method A (APAO) - Troxler 3440 #25714 (2)
18.2.1	-2.340	-2.140	-2.986	-3.036	-2.711	-2.686	-1.786	-1.586
18.2.2	-2.634	-2.909	-5.300	-4.675	-4.525	-4.625	-3.200	-3.475
18.2.3								
18.2.4	-2.249	-2.274	-4.417	-3.917	-3.117	-3.167	-2.292	-2.317
18.2.5	-3.114	-3.214	-5.534	-5.234	-4.359	-4.234	-3.334	-3.434
18.2.6	-0.923	-1.123	-1.628	-1.553	-1.628	-1.303	-0.403	-0.603
18.2.7	-2.639	-2.839	-3.496	-3.571	-3.471	-3.621	-2.471	-2.671
18.2.8	-1.624	-2.299	-2.463	-1.763	-1.063	-0.413	-1.288	-1.963
18.2.9	-2.356	-2.706	-4.271	-3.996	-3.421	-2.996	-2.296	-2.646
18.2.10	-4.071	-4.321	-4.706	-4.656	-4.456	-4.806	-4.006	-4.256
Average	-2.439	-2.647	-3.867	-3.600	-3.194	-3.094	-2.342	-2.550
Standard Deviation	0.881	0.871	1.318	1.279	1.229	1.476	1.101	1.101
Coefficient of Variation	-0.361	-0.329	-0.341	-0.355	-0.385	-0.477	-0.470	-0.432

Table E-3: Correlation Factors for the Second Lift of the Two-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method C - Troxler 3440 #30860 (4)	SSD Method C - Troxler 3440 #30860 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)	SSD Method C - Troxler 3440 #25714 (4)	SSD Method C - Troxler 3440 #25714 (2)
18.2.1	-4.253	-4.303	-3.978	-3.953	-3.053	-2.853
18.2.2	-5.287	-4.662	-4.512	-4.612	-3.187	-3.462
18.2.3						
18.2.4	-4.311	-3.811	-3.011	-3.061	-2.186	-2.211
18.2.5	-6.351	-6.051	-5.176	-5.051	-4.151	-4.251
18.2.6	-2.886	-2.811	-2.886	-2.561	-1.661	-1.861
18.2.7	-4.309	-4.384	-4.284	-4.434	-3.284	-3.484
18.2.8	-3.474	-2.774	-2.074	-1.424	-2.299	-2.974
18.2.9	-5.356	-5.081	-4.506	-4.081	-3.381	-3.731
18.2.10	-5.161	-5.111	-4.911	-5.261	-4.461	-4.711
Average	-4.598	-4.332	-3.926	-3.826	-3.073	-3.282
Standard Deviation	1.056	1.075	1.042	1.254	0.910	0.915
Coefficient of Variation	-0.230	-0.248	-0.265	-0.328	-0.296	-0.279

Table E-4: Correlation Factors for the First and Second Lifts (Composite Cores) of the Two-Lift Pavement on the OR 18 Project

Location/ CoreID	CoreLok - Troxler 3440 #30860 (4)	CoreLok - Troxler 3440 #30860 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	CoreLok - Troxler 3440 #25714 (4)	CoreLok - Troxler 3440 #25714 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)
18.2.1	-2.867	-2.917	-2.592	-2.567	-1.667	-1.467	-3.054	-3.104
18.2.2	-3.653	-3.028	-2.878	-2.978	-1.553	-1.828	-3.198	-2.573
18.2.3	-1.360	-1.910	-0.235	0.340	1.465	1.690	-1.605	-2.155
18.2.4	-3.436	-2.936	-2.136	-2.186	-1.311	-1.336	-3.325	-2.825
18.2.5	-5.489	-5.189	-4.314	-4.189	-3.289	-3.389	-5.398	-5.098
18.2.6	-2.043	-1.968	-2.043	-1.718	-0.818	-1.018	-2.046	-1.971
18.2.7	-3.402	-3.477	-3.377	-3.527	-2.377	-2.577	-3.709	-3.784
18.2.8	-5.110	-4.410	-3.710	-3.060	-3.935	-4.610	-4.664	-3.964
18.2.9	-4.782	-4.507	-3.932	-3.507	-2.807	-3.157	-2.322	-2.047
18.2.10	-2.901	-2.851	-2.651	-3.001	-2.201	-2.451	-3.082	-3.032
Average	-3.504	-3.319	-2.787	-2.639	-1.849	-2.014	-3.240	-3.055
Standard Deviation	1.320	1.082	1.174	1.261	1.498	1.698	1.151	0.990
Coefficient of Variation	-0.377	-0.326	-0.421	-0.478	-0.810	-0.843	-0.355	-0.324

Table E-4: Correlation Factors for the First and Second Lifts (Composite Cores) of the Two-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #25714 (4)	SSD Method A (before APAO) - Troxler 3440 #25714 (2)
18.2.1	-2.779	-2.754	-1.854	-1.654
18.2.2	-2.423	-2.523	-1.098	-1.373
18.2.3	-0.480	0.095	1.220	1.445
18.2.4	-2.025	-2.075	-1.200	-1.225
18.2.5	-4.223	-4.098	-3.198	-3.298
18.2.6	-2.046	-1.721	-0.821	-1.021
18.2.7	-3.684	-3.834	-2.684	-2.884
18.2.8	-3.264	-2.614	-3.489	-4.164
18.2.9	-1.472	-1.047	-0.347	-0.697
18.2.10	-2.832	-3.182	-2.382	-2.632
Average	-2.523	-2.375	-1.585	-1.750
Standard Deviation	1.091	1.263	1.434	1.583
Coefficient of Variation	-0.432	-0.532	-0.905	-0.905

Table E-5: Correlation Factors for the First Lift of the Three-Lift Pavement on the OR 18 Project

Location/ CoreID	CoreLok - Troxler 3440 #30860 (4)	CoreLok - Troxler 3440 #30860 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)
18.3.1	2.807	2.882	2.732	2.382	2.501	2.576	2.426	2.076
18.3.2	0.645	1.395	0.045	-0.355	0.714	1.464	0.114	-0.286
18.3.3	0.857	0.032	1.457	1.132	0.624	-0.201	1.224	0.899
18.3.4	2.155	2.430	2.905	2.680	2.368	2.643	3.118	2.893
18.3.5	1.877	2.102	3.252	4.302	1.765	1.990	3.140	4.190
18.3.6	0.860	0.435	1.035	0.935	1.058	0.633	1.233	1.133
18.3.7	0.585	0.885	1.610	0.185	2.155	2.455	3.180	1.755
18.3.8	1.983	2.133	2.058	2.133	2.060	2.210	2.135	2.210
18.3.9	1.527	1.727	2.102	1.577	1.959	2.159	2.534	2.009
18.3.10	-7.829	-8.054	-7.379	-7.704	-6.324	-6.549	-5.874	-6.199
Average	0.547	0.597	0.982	0.727	0.888	0.938	1.323	1.068
Standard Deviation	3.034	3.169	3.086	3.245	2.621	2.785	2.720	2.817
Coefficient of Variation	5.549	5.310	3.144	4.465	2.952	2.970	2.056	2.638

Table E-5: Correlation Factors for the First Lift of the Three-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method A (after APAO) - Troxler 3440 #30860 (4)	SSD Method A (after APAO) - Troxler 3440 #30860 (2)	SSD Method A (after APAO) - Troxler 3430 #38806 (4)	SSD Method A (after APAO) - Troxler 3430 #38806 (2)	SSD Method A (APAO) - Troxler 3440 #30860 (4)	SSD Method A (APAO) - Troxler 3440 #30860 (2)	SSD Method A (APAO) - Troxler 3430 #38806 (4)	SSD Method A (APAO) - Troxler 3430 #38806 (2)
18.3.1	2.361	2.436	2.286	1.936	2.706	2.781	2.631	2.281
18.3.2	-0.123	0.627	-0.723	-1.123	-0.268	0.482	-0.868	-1.268
18.3.3	-1.685	-2.510	-1.085	-1.410	-1.792	-2.617	-1.192	-1.517
18.3.4	1.894	2.169	2.644	2.419	2.162	2.437	2.912	2.687
18.3.5	0.695	0.920	2.070	3.120	0.957	1.182	2.332	3.382
18.3.6	0.823	0.398	0.998	0.898	1.313	0.888	1.488	1.388
18.3.7	1.211	1.511	2.236	0.811	1.958	2.258	2.983	1.558
18.3.8	1.456	1.606	1.531	1.606	1.989	2.139	2.064	2.139
18.3.9	-1.077	-0.877	-0.502	-1.027	-1.512	-1.312	-0.937	-1.462
18.3.10								
Average	0.617	0.698	1.051	0.803	0.835	0.915	1.268	1.021
Standard Deviation	1.346	1.565	1.452	1.653	1.648	1.830	1.760	1.919
Coefficient of Variation	2.181	2.242	1.382	2.058	1.974	2.000	1.388	1.880

Table E-5: Correlation Factors for the First Lift of the Three-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method C - Troxler 3440 #30860 (4)	SSD Method C - Troxler 3440 #30860 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)
18.3.1	2.361	2.436	2.286	1.936
18.3.2	-1.023	-0.273	-1.623	-2.023
18.3.3	-2.457	-3.282	-1.857	-2.182
18.3.4	1.012	1.287	1.762	1.537
18.3.5	0.520	0.745	1.895	2.945
18.3.6	-0.149	-0.574	0.026	-0.074
18.3.7	0.495	0.795	1.520	0.095
18.3.8	0.360	0.510	0.435	0.510
18.3.9	-2.613	-2.413	-2.038	-2.563
18.3.10				
Average	-0.166	-0.086	0.267	0.020
Standard Deviation	1.618	1.802	1.733	1.952
Coefficient of Variation	-9.736	-21.054	6.484	97.705

Table E-5: Correlation Factors for the Second Lift of the Three-Lift Pavement on the OR 18 Project

Location/ CoreID	CoreLok - Troxler 3440 #30860 (4)	CoreLok - Troxler 3440 #30860 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)
18.3.1	-3.618	-3.543	-3.693	-4.043	-2.036	-1.961	-2.111	-2.461
18.3.2	-6.483	-5.733	-7.083	-7.483	-5.418	-4.668	-6.018	-6.418
18.3.3	-1.302	-2.127	-0.702	-1.027	-0.283	-1.108	0.317	-0.008
18.3.4	-3.274	-2.999	-2.524	-2.749	-2.248	-1.973	-1.498	-1.723
18.3.5	-3.338	-3.113	-1.963	-0.913	-1.808	-1.583	-0.433	0.617
18.3.6	-2.164	-2.589	-1.989	-2.089	-1.378	-1.803	-1.203	-1.303
18.3.7	-6.860	-6.560	-5.835	-7.260	-4.558	-4.258	-3.533	-4.958
18.3.8	-3.672	-3.522	-3.597	-3.522	-1.841	-1.691	-1.766	-1.691
18.3.9	4.154	4.354	4.729	4.204	5.164	5.364	5.739	5.214
18.3.10	-3.340	-3.565	-2.890	-3.215	-2.030	-2.255	-1.580	-1.905
Average	-2.990	-2.940	-2.555	-2.810	-1.644	-1.594	-1.209	-1.464
Standard Deviation	3.035	2.906	3.178	3.339	2.823	2.707	3.002	3.147
Coefficient of Variation	-1.015	-0.989	-1.244	-1.188	-1.718	-1.699	-2.484	-2.150

Table E-5: Correlation Factors for the Second Lift of the Three-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method A (after APAO) - Troxler 3440 #30860 (4)	SSD Method A (after APAO) - Troxler 3440 #30860 (2)	SSD Method A (after APAO) - Troxler 3430 #38806 (4)	SSD Method A (after APAO) - Troxler 3430 #38806 (2)	SSD Method A (APAO) - Troxler 3440 #30860 (4)	SSD Method A (APAO) - Troxler 3440 #30860 (2)	SSD Method A (APAO) - Troxler 3430 #38806 (4)	SSD Method A (APAO) - Troxler 3430 #38806 (2)
18.3.1	-2.426	-2.351	-2.501	-2.851	-2.025	-1.950	-2.100	-2.450
18.3.2	-6.729	-5.979	-7.329	-7.729	-6.741	-5.991	-7.341	-7.741
18.3.3	-0.626	-1.451	-0.026	-0.351	-0.858	-1.683	-0.258	-0.583
18.3.4	-2.658	-2.383	-1.908	-2.133	-2.195	-1.920	-1.445	-1.670
18.3.5	-2.660	-2.435	-1.285	-0.235	-2.404	-2.179	-1.029	0.021
18.3.6	-1.840	-2.265	-1.665	-1.765	-1.301	-1.726	-1.126	-1.226
18.3.7	-6.233	-5.933	-5.208	-6.633	-5.138	-4.838	-4.113	-5.538
18.3.8	-2.398	-2.248	-2.323	-2.248	-2.368	-2.218	-2.293	-2.218
18.3.9	4.706	4.906	5.281	4.756	4.712	4.912	5.287	4.762
18.3.10	-3.505	-3.730	-3.055	-3.380	-3.609	-3.834	-3.159	-3.484
Average	-2.437	-2.387	-2.002	-2.257	-2.193	-2.143	-1.758	-2.013
Standard Deviation	3.140	3.007	3.295	3.462	3.013	2.890	3.197	3.341
Coefficient of Variation	-1.288	-1.260	-1.646	-1.534	-1.374	-1.349	-1.819	-1.660

Table E-5: Correlation Factors for the Second Lift of the Three-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method C - Troxler 3440 #30860 (4)	SSD Method C - Troxler 3440 #30860 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)
18.3.1	-3.280	-3.205	-3.355	-3.705
18.3.2	-7.960	-7.210	-8.560	-8.960
18.3.3	-1.296	-2.121	-0.696	-1.021
18.3.4	-4.228	-3.953	-3.478	-3.703
18.3.5	-3.792	-3.567	-2.417	-1.367
18.3.6	-2.829	-3.254	-2.654	-2.754
18.3.7	-6.886	-6.586	-5.861	-7.286
18.3.8	-3.501	-3.351	-3.426	-3.351
18.3.9	3.818	4.018	4.393	3.868
18.3.10	-4.904	-5.129	-4.454	-4.779
Average	-3.486	-3.436	-3.051	-3.306
Standard Deviation	3.212	3.068	3.369	3.513
Coefficient of Variation	-0.921	-0.893	-1.104	-1.063

Table E-5: Correlation Factors for the Third Lift of the Three-Lift Pavement on the OR 18 Project

Location/ CoreID	CoreLok - Troxler 3440 #30860 (4)	CoreLok - Troxler 3440 #30860 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)
18.3.1	-1.672	-1.597	-1.747	-2.097	-1.458	-1.383	-1.533	-1.883
18.3.2	-1.416	-0.666	-2.016	-2.416	-1.058	-0.308	-1.658	-2.058
18.3.3	-4.317	-5.142	-3.717	-4.042	-2.958	-3.783	-2.358	-2.683
18.3.4	-4.420	-4.145	-3.670	-3.895	-2.494	-2.219	-1.744	-1.969
18.3.5	-3.110	-2.885	-1.735	-0.685	-2.273	-2.048	-0.898	0.152
18.3.6	-2.633	-3.058	-2.458	-2.558	-2.020	-2.445	-1.845	-1.945
18.3.7	-1.228	-0.928	-0.203	-1.628	-0.754	-0.454	0.271	-1.154
18.3.8	-3.000	-2.850	-2.925	-2.850	-2.059	-1.909	-1.984	-1.909
18.3.9	-2.206	-2.006	-1.631	-2.156	-0.898	-0.698	-0.323	-0.848
18.3.10	-2.124	-2.349	-1.674	-1.999	-1.440	-1.665	-0.990	-1.315
Average	-2.613	-2.563	-2.178	-2.433	-1.741	-1.691	-1.306	-1.561
Standard Deviation	1.116	1.380	1.059	1.000	0.733	1.050	0.813	0.797
Coefficient of Variation	-0.427	-0.539	-0.486	-0.411	-0.421	-0.621	-0.622	-0.510

Table E-5: Correlation Factors for the Third Lift of the Three-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method A (after APAO) - Troxler 3440 #30860 (4)	SSD Method A (after APAO) - Troxler 3440 #30860 (2)	SSD Method A (after APAO) - Troxler 3430 #38806 (4)	SSD Method A (after APAO) - Troxler 3430 #38806 (2)	SSD Method A (APAO) - Troxler 3440 #30860 (4)	SSD Method A (APAO) - Troxler 3440 #30860 (2)	SSD Method A (APAO) - Troxler 3430 #38806 (4)	SSD Method A (APAO) - Troxler 3430 #38806 (2)
18.3.1	-2.146	-2.071	-2.221	-2.571	-2.522	-2.447	-2.597	-2.947
18.3.2	-1.285	-0.535	-1.885	-2.285	-1.264	-0.514	-1.864	-2.264
18.3.3	-4.066	-4.891	-3.466	-3.791	-3.970	-4.795	-3.370	-3.695
18.3.4	-3.036	-2.761	-2.286	-2.511	-2.568	-2.293	-1.818	-2.043
18.3.5	-3.755	-3.530	-2.380	-1.330	-3.587	-3.362	-2.212	-1.162
18.3.6	-2.309	-2.734	-2.134	-2.234	-1.923	-2.348	-1.748	-1.848
18.3.7	-1.165	-0.865	-0.140	-1.565	-0.843	-0.543	0.182	-1.243
18.3.8	-2.394	-2.244	-2.319	-2.244	-1.994	-1.844	-1.919	-1.844
18.3.9	-2.439	-2.239	-1.864	-2.389	-3.255	-3.055	-2.680	-3.205
18.3.10	-2.256	-2.481	-1.806	-2.131	-2.489	-2.714	-2.039	-2.364
Average	-2.485	-2.435	-2.050	-2.305	-2.442	-2.392	-2.007	-2.262
Standard Deviation	0.932	1.234	0.820	0.655	0.986	1.270	0.920	0.821
Coefficient of Variation	-0.375	-0.507	-0.400	-0.284	-0.404	-0.531	-0.459	-0.363

Table E-5: Correlation Factors for the Third Lift of the Three-Lift Pavement on the OR 18 Project (Continued)

Location/ CoreID	SSD Method C - Troxler 3440 #30860 (4)	SSD Method C - Troxler 3440 #30860 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)
18.3.1	-2.564	-2.489	-2.639	-2.989
18.3.2	-1.735	-0.985	-2.335	-2.735
18.3.3	-4.588	-5.413	-3.988	-4.313
18.3.4	-3.597	-3.322	-2.847	-3.072
18.3.5	-4.296	-4.071	-2.921	-1.871
18.3.6	-2.919	-3.344	-2.744	-2.844
18.3.7	-1.744	-1.444	-0.719	-2.144
18.3.8	-2.858	-2.708	-2.783	-2.708
18.3.9	-3.006	-2.806	-2.431	-2.956
18.3.10	-2.596	-2.821	-2.146	-2.471
Average	-2.990	-2.940	-2.555	-2.810
Standard Deviation	0.950	1.250	0.815	0.653
Coefficient of Variation	-0.318	-0.425	-0.319	-0.232

Table E-6: Correlation Factors for the First, Second, and Third Lifts (Composite Cores) of the Two-Lift Pavement on the OR 18 Project

Location/ CoreID	CoreLok - Troxler 3440 # 30860 (4)	CoreLok - Troxler 3440 # 30860 (2)	CoreLok - Troxler 3430 # 38806 (4)	CoreLok - Troxler 3430 # 38806 (2)	SSD Method A (before APAO) - Troxler 3440 # 30860 (4)	SSD Method A (before APAO) - Troxler 3440 # 30860 (2)	SSD Method A (before APAO) - Troxler 3430 # 38806 (4)	SSD Method A (before APAO)- Troxler 3430 # 38806 (2)
18.3.1	-0.414	-0.339	-0.489	-0.839	-1.110	-1.035	-1.185	-1.535
18.3.2	0.894	1.644	0.294	-0.106	-1.658	-0.908	-2.258	-2.658
18.3.3	-0.285	-1.110	0.315	-0.010	-1.017	-1.842	-0.417	-0.742
18.3.4	-0.476	-0.201	0.274	0.049	-0.878	-0.603	-0.128	-0.353
18.3.5	-0.445	-0.220	0.930	1.980	-0.786	-0.561	0.589	1.639
18.3.6	-0.640	-1.065	-0.465	-0.565	-5.429	-5.854	-5.254	-5.354
18.3.7	-0.618	-0.318	0.407	-1.018	-1.057	-0.757	-0.032	-1.457
18.3.8								
18.3.9	0.695	0.895	1.270	0.745	0.551	0.751	1.126	0.601
18.3.10	-4.912	-5.137	-4.462	-4.787	-3.588	-3.813	-3.138	-3.463
Average	-0.689	-0.650	-0.214	-0.506	-1.663	-1.625	-1.188	-1.480
Standard Deviation	1.681	1.896	1.690	1.843	1.777	2.005	2.033	2.128
Coefficient of Variation	-2.440	-2.916	-7.898	-3.644	-1.068	-1.234	-1.710	-1.437

Table E-7: Correlation Factors for the First Lift of the Single-Lift Pavement on the I-5 Project

Core ID	SSD Method A - Troxler 3430 #38996 (4)	SSD Method A - Troxler 3430 #38996 (2)	SSD Method A - Troxler 3430 #38806 (4)	SSD Method A - Troxler 3430 #38806 (2)	SSD Method A - CPN MP3 Portaprobe-7443(4)	SSD Method A - CPN MP3 Portaprobe-7443(2)
5.1.1	-0.495	-0.070	-0.195	0.480	0.113	0.455
5.1.2	0.779	1.029	0.679	0.629	-0.314	-0.812
5.1.3	-0.097	-0.247	0.728	0.253	-0.667	-0.791
5.1.4	-0.492	-0.517	0.933	0.583	-1.520	-1.582
5.1.5	-0.524	-0.624	0.451	0.226	-0.107	-0.076
5.1.6	-0.815	-1.015	0.160	0.585	-0.555	-0.321
5.1.7	-1.158	-0.983	0.142	0.617	-1.475	-1.491
5.1.8	-0.997	-0.747	0.478	0.203	-1.206	-1.455
5.1.9	-1.077	-1.327	0.073	-0.277	-1.442	-1.784
5.1.10	0.297	0.697	0.522	0.597	-0.572	-0.432
Average	-0.458	-0.380	0.397	0.390	-0.774	-0.829
Standard Deviation	0.626	0.755	0.346	0.291	0.599	0.741
Coefficient of Variation	-1.368	-1.986	0.872	0.746	-0.773	-0.894

Table E-7: Correlation Factors for the First Lift of the Single-Lift Pavement on the I-5 Project (Continued)

Core ID	CoreLok - Troxler 3430 #38996 (4)	CoreLok - Troxler 3430 #38996 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	CoreLock - CPN MP3 Portaprobe-7443(4)	CoreLock - CPN MP3 Portaprobe-7443(2)
5.1.1	-2.407	-1.982	-2.107	-1.432	-1.799	-1.456
5.1.2	-1.481	-1.231	-1.581	-1.631	-2.574	-3.072
5.1.3	-1.148	-1.298	-0.323	-0.798	-1.718	-1.843
5.1.4	-1.679	-1.704	-0.254	-0.604	-2.707	-2.769
5.1.5	-2.266	-2.366	-1.291	-1.516	-1.848	-1.817
5.1.6	-3.434	-3.634	-2.459	-2.034	-3.174	-2.940
5.1.7	-1.984	-1.809	-0.684	-0.209	-2.301	-2.316
5.1.8	-2.485	-2.235	-1.010	-1.285	-2.694	-2.943
5.1.9	-2.922	-3.172	-1.772	-2.122	-3.287	-3.629
5.1.10	-0.548	-0.148	-0.323	-0.248	-1.416	-1.276
Average	-2.035	-1.958	-1.180	-1.188	-2.352	-2.406
Standard Deviation	0.855	0.992	0.790	0.691	0.640	0.782
Coefficient of Variation	-0.420	-0.507	-0.670	-0.582	-0.272	-0.325

Table E-7: Correlation Factors for the First Lift of the Single-Lift Pavement on the I-5 Project (Continued)

Core ID	SSD Method C - Troxler 3430 #38996 (4)	SSD Method C - Troxler 3430 #38996 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)	SSD Method C - CPN MP3 Portaprobe-7443(4)	SSD Method C - CPN MP3 Portaprobe-7443(2)
5.1.1	-1.154	-0.729	-0.854	-0.179	-0.546	-0.204
5.1.2	0.335	0.585	0.235	0.185	-0.758	-1.256
5.1.3	-0.709	-0.859	0.116	-0.359	-1.279	-1.404
5.1.4	-0.591	-0.616	0.834	0.484	-1.620	-1.682
5.1.5	-0.339	-0.439	0.636	0.411	0.078	0.109
5.1.6	-1.088	-1.288	-0.113	0.312	-0.828	-0.595
5.1.7	-1.635	-1.460	-0.335	0.140	-1.952	-1.967
5.1.8	-1.903	-1.653	-0.428	-0.703	-2.112	-2.361
5.1.9	-1.439	-1.689	-0.289	-0.639	-1.804	-2.147
5.1.10	-0.039	0.361	0.186	0.261	-0.908	-0.768
Average	-0.856	-0.779	-0.001	-0.009	-1.173	-1.227
Standard Deviation	0.717	0.791	0.508	0.433	0.701	0.841
Coefficient of Variation	-0.838	-1.015	-358.329	-48.518	-0.597	-0.685

Table E-8: Correlation Factors for the Second Lift of the Two-Lift Pavement on the I-5 Project

Core ID	SSD Method A - Troxler 3430 #38996 (4)	SSD Method A - Troxler 3430 #38996 (2)	SSD Method A - Troxler 3430 #38806 (4)	SSD Method A - Troxler 3430 #38806 (2)	SSD Method A - CPN MP3 Portaprobe-7443(4)	SSD Method A - CPN MP3 Portaprobe-7443(2)	SSD Method A - Humbold5001C -1344(4)	SSD Method A - Humbold5001C -1344(2)
5.2.1	-0.662	-0.612	1.238	1.038	-0.353	-0.057		143.788
5.2.2	-1.024	-1.074	0.676	0.776	-0.569	0.863	142.585	142.582
5.2.3	-0.393	-0.718	1.632	1.682	0.245	0.261	143.056	143.045
5.2.4	-1.699	-1.524	0.051	-0.274	-0.865	-0.413	140.952	140.956
5.2.5	-0.377	-0.202	1.723	1.748	-0.460	-0.693	140.212	140.220
5.2.6	0.270	0.670	2.495	2.170	0.534	0.425	141.952	141.942
5.2.7	1.421	1.121	2.471	2.221	1.049	1.781	139.927	139.939
5.2.8	-0.573	-0.673	1.427	1.477	-1.119	-0.963	140.184	140.191
5.2.9	1.057	0.607	3.032	3.157	1.378	1.922	141.523	141.528
5.2.10	0.427	0.477	1.752	1.477	1.307	0.732	142.260	142.261
Average	-0.155	-0.193	1.650	1.547	0.115	0.386	141.406	141.407
Standard Deviation	0.952	0.869	0.884	0.923	0.918	0.971	1.144	1.137
Coefficient of Variation	-6.127	-4.505	0.536	0.597	7.992	2.519	0.008	0.008

Table E-8: Correlation Factors for the Second Lift of the Two-Lift Pavement on the I-5 Project (Continued)

Core ID	CoreLok - Troxler 3430 #38996 (4)	CoreLock - Troxler 3430 #38996 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLock - Troxler 3430 #38806 (2)	CoreLok - CPN MP3 Portaprobe-7443(4)	CoreLok - CPN MP3 Portaprobe-7443(2)	CoreLok - Humbold5001C -1344(4)	CoreLok - Humbold5001C -1344(2)
5.2.1	-2.060	-2.010	-0.160	-0.360	-1.751	-1.456		142.390
5.2.2	-2.614	-2.664	-0.914	-0.814	-2.158	-0.727	140.996	140.992
5.2.3	-1.155	-1.480	0.870	0.920	-0.517	-0.501	142.295	142.283
5.2.4	-3.342	-3.167	-1.592	-1.917	-2.508	-2.057	139.309	139.313
5.2.5	-1.167	-0.992	0.933	0.958	-1.250	-1.484	139.421	139.430
5.2.6	-0.798	-0.398	1.427	1.102	-0.534	-0.643	140.883	140.873
5.2.7	0.387	0.087	1.437	1.187	0.015	0.747	138.893	138.905
5.2.8	-2.376	-2.476	-0.376	-0.326	-2.922	-2.766	138.381	138.388
5.2.9	-0.335	-0.785	1.640	1.765	-0.014	0.531	140.132	140.136
5.2.10	-5.673	-5.623	-4.348	-4.623	-4.793	-5.369	136.160	136.161
Average	-1.913	-1.951	-0.108	-0.211	-1.643	-1.372	139.608	139.609
Standard Deviation	1.7342	1.6607	1.8483	1.9151	1.5143	1.7707	1.7705	1.7655
Coefficient of Variation	-0.906	-0.851	-17.054	-9.082	-0.922	-1.290	0.013	0.013

Table E-8: Correlation Factors for the Second Lift of the Two-Lift Pavement on the I-5 Project (Continued)

Core ID	SSD Method C - Troxler 3430 #38996 (4)	SSD MethodC-Troxler 3430 #38996 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)	SSD Method C - CPN MP3 Portaprobe-7443(4)	SSD Method C - CPN MP3 Portaprobe-7443(2)	SSD Method C - Humbold5001C -1344(4)	SSD Method C - Humbold5001C -1344(2)
5.2.1	-1.385	-1.335	0.515	0.315	-1.076	-0.781		
5.2.2	-1.233	-1.283	0.467	0.567	-0.777	0.654	142.377	142.373
5.2.3	-0.662	-0.987	1.363	1.413	-0.024	-0.008	142.788	142.776
5.2.4	-2.089	-1.914	-0.339	-0.664	-1.255	-0.803	140.562	140.566
5.2.5	-0.722	-0.547	1.378	1.403	-0.805	-1.039	139.866	139.875
5.2.6	-0.170	0.230	2.055	1.730	0.094	-0.015	141.511	141.501
5.2.7	1.111	0.811	2.161	1.911	0.739	1.470	139.616	139.628
5.2.8	-1.028	-1.128	0.972	1.022	-1.574	-1.418	139.729	139.736
5.2.9	0.525	0.075	2.500	2.625	0.846	1.391	140.992	140.996
5.2.10	0.270	0.320	1.595	1.320	1.150	0.575	142.103	142.104
Average	-0.538	-0.576	1.267	1.164	-0.268	0.002	141.060	141.062
Standard Deviation	0.974	0.891	0.878	0.919	0.962	1.011	1.201	1.194
Coefficient of Variation	-1.808	-1.546	0.693	0.789	-3.587	407.015	0.009	0.008

Table E-9: Correlation Factors for the First Lift of the Single-Lift Pavement on the OR 140 Project

Location/ CoreID	CoreLok - Troxler 3430 #38996 (4)	CoreLok - Troxler 3430 #38996 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	CoreLok - Troxler 3440 #35601 (4)	CoreLok - Troxler 3440 #35601 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)
140.1.1	0.995	0.570	-1.155	-1.230	-0.430	-0.630	2.815	2.390
140.1.2	-0.197	-0.422	-2.922	-3.122	-1.897	-1.922	1.196	0.971
140.1.3	1.498	1.373	-0.227	-0.277	-0.102	0.273	2.994	2.869
140.1.4	1.638	1.763	-0.887	-0.187	-0.262	-0.087	3.167	3.292
140.1.5	1.529	1.129	-0.021	-0.421	0.529	0.529	2.920	2.520
140.1.6	2.102	2.252	0.152	0.802	0.627	-0.048	3.283	3.433
140.1.7	1.697	1.697	0.397	1.697	-0.203	0.047	3.318	3.318
140.1.8	2.988	3.213	0.388	0.863	1.138	1.013	5.350	5.575
140.1.9	1.775	1.925	-0.500	-0.275	0.350	0.275	3.313	3.463
140.1.10	1.102	1.377	0.352	0.027	-0.073	-0.023	3.509	3.784
Average	1.513	1.488	-0.442	-0.212	-0.032	-0.057	3.186	3.161
Standard Deviation	0.817	0.973	1.025	1.310	0.816	0.784	1.002	1.169
Coefficient of Variation	0.540	0.654	-2.318	-6.173	-25.333	-13.699	0.314	0.370

Table E-9: Correlation Factors for the First Lift of the Single-Lift Pavement on the OR 140 Project (Continued)

Location/ CoreID	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #25714 (4)	SSD Method A (before APAO) - Troxler 3440 #25714 (2)	SSD Method A (after APAO) - Troxler 3440 #30860 (4)	SSD Method A (after APAO) - Troxler 3440 #30860 (2)	SSD Method A (after APAO) - Troxler 3430 #38806 (4)	SSD Method A (after APAO) - Troxler 3430 #38806 (2)
140.1.1	0.665	0.590	1.390	1.190	2.379	1.954	0.229	0.154
140.1.2	-1.529	-1.729	-0.504	-0.529	0.519	0.294	-2.206	-2.406
140.1.3	1.269	1.219	1.394	1.769	2.448	2.323	0.723	0.673
140.1.4	0.642	1.342	1.267	1.442	2.707	2.832	0.182	0.882
140.1.5	1.370	0.970	1.920	1.920				
140.1.6	1.333	1.983	1.808	1.133	2.639	2.789	0.689	1.339
140.1.7	2.018	3.318	1.418	1.668	2.503	2.503	1.203	2.503
140.1.8	2.750	3.225	3.500	3.375	3.868	4.093	1.268	1.743
140.1.9	1.038	1.263	1.888	1.813	3.020	3.170	0.745	0.970
140.1.10	2.759	2.434	2.334	2.384	3.345	3.620	2.595	2.270
Average	1.231	1.461	1.641	1.616	2.603	2.620	0.603	0.903
Standard Deviation	1.230	1.455	1.001	0.994	0.919	1.090	1.276	1.453
Coefficient of Variation	0.999	0.996	0.610	0.615	0.353	0.416	2.115	1.609

Table E-9: Correlation Factors for the First Lift of the Single-Lift Pavement on the OR 140 Project (Continued)

Location/ CoreID	SSD Method A (after APAO) - Troxler 3440 #25714 (4)	SSD Method A (after APAO) - Troxler 3440 #25714 (2)	SSD Method C - Troxler 3440 #30860 (4)	SSD Method C - Troxler 3440 #30860 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)	SSD Method C - Troxler 3440 #25714 (4)	SSD Method C - Troxler 3440 #25714 (2)
140.1.1	0.954	0.754	1.361	0.936	-0.789	-0.864	-0.064	-0.264
140.1.2	-1.181	-1.206	-0.006	-0.231	-2.731	-2.931	-1.706	-1.731
140.1.3	0.848	1.223	1.286	1.161	-0.439	-0.489	-0.314	0.061
140.1.4	0.807	0.982	2.292	2.417	-0.233	0.467	0.392	0.567
140.1.5								
140.1.6	1.164	0.489	1.531	1.681	-0.419	0.231	0.056	-0.619
140.1.7	0.603	0.853	1.483	1.483	0.183	1.483	-0.417	-0.167
140.1.8	2.018	1.893	2.964	3.189	0.364	0.839	1.114	0.989
140.1.9	1.595	1.520	1.934	2.084	-0.341	-0.116	0.509	0.434
140.1.10	2.170	2.220	2.371	2.646	1.621	1.296	1.196	1.246
Average	0.998	0.970	1.691	1.707	-0.309	-0.009	0.085	0.057
Standard Deviation	0.985	0.988	0.846	1.026	1.148	1.343	0.881	0.901
Coefficient of Variation	0.987	1.018	0.500	0.601	-3.713	-144.351	10.347	15.704

Table E-10: Correlation Factors for the First Lift of the Two-Lift Pavement on the OR 140 Project

Location/ CoreID	CoreLok - Troxler 3430 #38996 (4)	CoreLok - Troxler 3430 #38996 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	CoreLok - Troxler 3440 #35601 (4)	CoreLok - Troxler 3440 #35601 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)
140.2.1	1.925	1.600	1.575	1.700	1.275	1.700	2.501	2.176
140.2.2	3.993	4.018	3.018	3.018	3.368	3.768	5.310	5.335
140.2.3	1.979	1.954	0.879	1.054	3.354	4.704	4.135	4.110
140.2.4	2.863	2.988	2.513	3.188	2.538	2.438	3.786	3.911
140.2.5	1.328	1.153	1.078	0.403	1.028	0.253	3.425	3.250
140.2.6	0.472	0.647	-0.778	-0.503	-1.128	-1.503	2.090	2.265
140.2.7	-4.407	-4.457	-4.732	-4.457	-5.107	-4.857	-2.472	-2.522
140.2.8	-7.041	-6.841	-8.116	-8.791	-8.166	-7.941	-3.379	-3.179
140.2.9	-5.045	-5.545	-5.420	-5.445	-5.695	-6.245	-3.145	-3.645
140.2.10	-4.658	-4.058	-5.008	-4.858	-5.633	-6.258	-3.456	-2.856
Average	-0.859	-0.854	-1.499	-1.469	-1.416	-1.394	0.880	0.885
Standard Deviation	3.979	3.941	3.954	4.116	4.344	4.629	3.553	3.515
Coefficient of Variation	-4.633	-4.615	-2.638	-2.802	-3.067	-3.321	4.039	3.973

Table E-10: Correlation Factors for the First Lift of the Two-Lift Pavement on the OR 140 Project (Continued)

Location/ CoreID	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #25714 (4)	SSD Method A (before APAO) - Troxler 3440 #25714 (2)	SSD Method A (after APAO) - Troxler 3440 #30860 (4)	SSD Method A (after APAO) - Troxler 3440 #30860 (2)	SSD Method A (after APAO) - Troxler 3430 #38806 (4)	SSD Method A (after APAO) - Troxler 3430 #38806 (2)
140.2.1	2.151	2.276	1.851	2.276	2.271	1.946	1.921	2.046
140.2.2	4.335	4.335	4.685	5.085	4.398	4.423	3.423	3.423
140.2.3	3.035	3.210	5.510	6.860	3.438	3.413	2.338	2.513
140.2.4	3.436	4.111	3.461	3.361	3.386	3.511	3.036	3.711
140.2.5	3.175	2.500	3.125	2.350	2.959	2.784	2.709	2.034
140.2.6	0.840	1.115	0.490	0.115	1.150	1.325	-0.100	0.175
140.2.7	-2.797	-2.522	-3.172	-2.922	-3.562	-3.612	-3.887	-3.612
140.2.8	-4.454	-5.129	-4.504	-4.279	-3.879	-3.679	-4.954	-5.629
140.2.9	-3.520	-3.545	-3.795	-4.345	-3.943	-4.443	-4.318	-4.343
140.2.10	-3.806	-3.656	-4.431	-5.056	-4.215	-3.615	-4.565	-4.415
Average	0.240	0.270	0.322	0.345	0.200	0.205	-0.440	-0.410
Standard Deviation	3.483	3.599	3.959	4.282	3.629	3.587	3.569	3.675
Coefficient of Variation	14.537	13.348	12.292	12.427	18.122	17.477	-8.116	-8.969

Table E-10: Correlation Factors for the First Lift of the Two-Lift Pavement on the OR 140 Project (Continued)

Location/ CoreID	SSD Method A (after APAO) - Troxler 3440 #25714 (4)	SSD Method A (after APAO) - Troxler 3440 #25714 (2)	SSD Method A (APAO) - Troxler 3440 #30860 (4)	SSD Method A (APAO) - Troxler 3440 #30860 (2)	SSD Method A (APAO) - Troxler 3430 #38806 (4)	SSD Method A (APAO) - Troxler 3430 #38806 (2)	SSD Method A (APAO) - Troxler 3440 #25714 (4)	SSD Method A (APAO) - Troxler 3440 #25714 (2)
140.2.1	1.621	2.046	2.515	2.190	2.165	2.290	1.865	2.290
140.2.2	3.773	4.173	4.772	4.797	3.797	3.797	4.147	4.547
140.2.3	4.813	6.163	3.812	3.787	2.712	2.887	5.187	6.537
140.2.4	3.061	2.961	3.497	3.622	3.147	3.822	3.172	3.072
140.2.5	2.659	1.884	2.835	2.660	2.585	1.910	2.535	1.760
140.2.6	-0.450	-0.825	1.891	2.066	0.641	0.916	0.291	-0.084
140.2.7	-4.262	-4.012	-3.818	-3.868	-4.143	-3.868	-4.518	-4.268
140.2.8	-5.004	-4.779	-3.719	-3.519	-4.794	-5.469	-4.844	-4.619
140.2.9	-4.593	-5.143	-4.252	-4.752	-4.627	-4.652	-4.902	-5.452
140.2.10	-5.190	-5.815	-3.789	-3.189	-4.139	-3.989	-4.764	-5.389
Average	-0.357	-0.335	0.374	0.379	-0.266	-0.236	-0.183	-0.161
Standard Deviation	4.036	4.355	3.755	3.731	3.673	3.785	4.142	4.463
Coefficient of Variation	-11.298	-13.008	10.033	9.836	-13.823	-16.057	-22.606	-27.765

Table E-10: Correlation Factors for the First Lift of the Two-Lift Pavement on the OR 140 Project (Continued)

Location/ CoreID	SSD Method C - Troxler 3440 #30860 (4)	SSD Method C - Troxler 3440 #30860 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)	SSD Method C - Troxler 3440 #25714 (4)	SSD Method C - Troxler 3440 #25714 (2)
140.2.1	1.568	1.243	1.218	1.343	0.918	1.343
140.2.2	3.027	3.052	2.052	2.052	2.402	2.802
140.2.3	2.161	2.136	1.061	1.236	3.536	4.886
140.2.4	2.370	2.495	2.020	2.695	2.045	1.945
140.2.5						
140.2.6	0.340	0.515	-0.910	-0.635	-1.260	-1.635
140.2.7	-5.239	-5.289	-5.564	-5.289	-5.939	-5.689
140.2.8	-5.092	-4.892	-6.167	-6.842	-6.217	-5.992
140.2.9	-4.877	-5.377	-5.252	-5.277	-5.527	-6.077
140.2.10	-5.146	-4.546	-5.496	-5.346	-6.121	-6.746
Average	-1.210	-1.185	-1.893	-1.785	-1.796	-1.685
Standard Deviation	3.750	3.721	3.644	3.836	4.150	4.543
Coefficient of Variation	-3.100	-3.141	-1.925	-2.150	-2.311	-2.697

Table E-11: Correlation Factors for the Second Lift of the Two-Lift Pavement on the OR 140 Project

Location/ CoreID	CoreLok - Troxler 3430 #38996 (4)	CoreLok - Troxler 3430 #38996 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	CoreLok - Troxler 3440 #35601 (4)	CoreLok - Troxler 3440 #35601 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)
140.2.1	-0.705	-1.030	-1.055	-0.930	-1.355	-0.930	1.718	1.393
140.2.2	4.203	4.228	3.228	3.228	3.578	3.978	2.713	2.738
140.2.3	1.948	1.923	0.848	1.023	3.323	4.673	2.041	2.016
140.2.4	1.788	1.913	1.438	2.113	1.463	1.363	1.730	1.855
140.2.5	4.354	4.179	4.104	3.429	4.054	3.279	2.783	2.608
140.2.6	1.427	1.602	0.177	0.452	-0.173	-0.548	2.381	2.556
140.2.7	-3.303	-3.353	-3.628	-3.353	-4.003	-3.753	0.964	0.914
140.2.8	-5.787	-5.587	-6.862	-7.537	-6.912	-6.687	1.809	2.009
140.2.9	-4.075	-4.575	-4.450	-4.475	-4.725	-5.275	1.322	0.822
140.2.10	-10.223	-9.623	-10.573	-10.423	-11.198	-11.823	0.952	1.552
Average	-1.037	-1.032	-1.677	-1.647	-1.595	-1.572	1.841	1.846
Standard Deviation	4.725	4.615	4.653	4.694	5.059	5.303	0.653	0.678
Coefficient of Variation	-4.555	-4.471	-2.775	-2.850	-3.173	-3.373	0.355	0.367

Table E-11: Correlation Factors for the Second Lift of the Two-Lift Pavement on the OR 140 Project (Continued)

Location/ CoreID	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #25714 (4)	SSD Method A (before APAO) - Troxler 3440 #25714 (2)	SSD Method A (after APAO) - Troxler 3440 #30860 (4)	SSD Method A (after APAO) - Troxler 3440 #30860 (2)	SSD Method A (after APAO) - Troxler 3430 #38806 (4)	SSD Method A (after APAO) - Troxler 3430 #38806 (2)
140.2.1	1.368	1.493	1.068	1.493	2.787	2.462	2.437	2.562
140.2.2	1.738	1.738	2.088	2.488	1.466	1.491	0.491	0.491
140.2.3	0.941	1.116	3.416	4.766	1.016	0.991	-0.084	0.091
140.2.4	1.380	2.055	1.405	1.305	1.122	1.247	0.772	1.447
140.2.5	2.533	1.858	2.483	1.708	1.745	1.570	1.495	0.820
140.2.6	1.131	1.406	0.781	0.406	1.761	1.936	0.511	0.786
140.2.7	0.639	0.914	0.264	0.514	0.276	0.226	-0.049	0.226
140.2.8	0.734	0.059	0.684	0.909	0.510	0.710	-0.565	-1.240
140.2.9	0.947	0.922	0.672	0.122	0.292	-0.208	-0.083	-0.108
140.2.10	0.602	0.752	-0.023	-0.648	0.692	1.292	0.342	0.492
Average	1.201	1.231	1.284	1.306	1.167	1.172	0.527	0.557
Standard Deviation	0.592	0.600	1.076	1.505	0.792	0.787	0.879	0.997
Coefficient of Variation	0.493	0.487	0.838	1.152	0.679	0.672	1.668	1.790

Table E-11: Correlation Factors for the Second Lift of the Two-Lift Pavement on the OR 140 Project (Continued)

Location/ CoreID	SSD Method A (after APAO) - Troxler 3440 #25714 (4)	SSD Method A (after APAO) - Troxler 3440 #25714 (2)	SSD Method A (APAO) - Troxler 3440 #30860 (4)	SSD Method A (APAO) - Troxler 3440 #30860 (2)	SSD Method A (APAO) - Troxler 3430 #38806 (4)	SSD Method A (APAO) - Troxler 3430 #38806 (2)	SSD Method A (APAO) - Troxler 3440 #25714 (4)	SSD Method A (APAO) - Troxler 3440 #25714 (2)
140.2.1	2.137	2.562	1.332	1.007	0.982	1.107	0.682	1.107
140.2.2	0.841	1.241	1.162	1.187	0.187	0.187	0.537	0.937
140.2.3	2.391	3.741	1.011	0.986	-0.089	0.086	2.386	3.736
140.2.4	0.797	0.697	1.194	1.319	0.844	1.519	0.869	0.769
140.2.5	1.445	0.670	1.714	1.539	1.464	0.789	1.414	0.639
140.2.6	0.161	-0.214	2.264	2.439	1.014	1.289	0.664	0.289
140.2.7	-0.424	-0.174	0.601	0.551	0.276	0.551	-0.099	0.151
140.2.8	-0.615	-0.390	1.073	1.273	-0.002	-0.677	-0.052	0.173
140.2.9	-0.358	-0.908	0.354	-0.146	-0.021	-0.046	-0.296	-0.846
140.2.10	-0.283	-0.908	0.630	1.230	0.280	0.430	-0.345	-0.970
Average	0.609	0.632	1.134	1.139	0.494	0.524	0.576	0.599
Standard Deviation	1.095	1.525	0.560	0.662	0.539	0.672	0.853	1.303
Coefficient of Variation	1.797	2.413	0.494	0.582	1.091	1.284	1.480	2.176

Table E-11: Correlation Factors for the Second Lift of the Two-Lift Pavement on the OR 140 Project (Continued)

Location/ CoreID	SSD Method C - Troxler 3440 #30860 (4)	SSD Method C - Troxler 3440 #30860 (2)	SSD Method C - Troxler 3430 #38806 (4)	SSD Method C - Troxler 3430 #38806 (2)	SSD Method C - Troxler 3440 #25714 (4)	SSD Method C - Troxler 3440 #25714 (2)
140.2.1	1.608	1.283	1.258	1.383	0.958	1.383
140.2.2	0.842	0.867	-0.133	-0.133	0.217	0.617
140.2.3	-0.115	-0.140	-1.215	-1.040	1.260	2.610
140.2.4	-0.109	0.016	-0.459	0.216	-0.434	-0.534
140.2.5	1.882	1.707	1.632	0.957	1.582	0.807
140.2.6	1.220	1.395	-0.030	0.245	-0.380	-0.755
140.2.7	-0.230	-0.280	-0.555	-0.280	-0.930	-0.680
140.2.8	-0.715	-0.515	-1.790	-2.465	-1.840	-1.615
140.2.9	-0.958	-1.458	-1.333	-1.358	-1.608	-2.158
140.2.10	0.209	0.809	-0.141	0.009	-0.766	-1.391
Average	0.363	0.368	-0.277	-0.247	-0.194	-0.172
Standard Deviation	0.975	1.003	1.080	1.127	1.175	1.490
Coefficient of Variation	2.684	2.722	-3.904	-4.568	-6.055	-8.681

Table E-12: Correlation Factors for the First and Second Lifts (Composite Cores) of the Two-Lift Pavement on the OR 140 Project

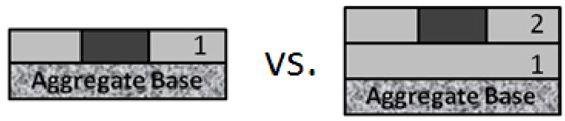
Location/ CoreID	CoreLok - Troxler 3430 #38996 (4)	CoreLok - Troxler 3430 # 38996 (2)	CoreLok - Troxler 3430 #38806 (4)	CoreLok - Troxler 3430 #38806 (2)	CoreLok - Troxler 3440 #35601 (4)	CoreLok - Troxler 3440 #35601 (2)	SSD Method A (before APAO) - Troxler 3440 #30860 (4)	SSD Method A (before APAO) - Troxler 3440 #30860 (2)
140.2.1	1.423	1.098	1.073	1.198	0.773	1.198	1.794	1.469
140.2.2	1.701	1.726	0.726	0.726	1.076	1.476	2.956	2.981
140.2.3								
140.2.4	1.482	1.607	1.132	1.807	1.157	1.057	1.859	1.984
140.2.5	-4.347	-4.522	-4.597	-5.272	-4.647	-5.422	2.724	2.549
140.2.6	0.595	0.770	-0.655	-0.380	-1.005	-1.380	1.476	1.651
140.2.7	-0.839	-0.889	-1.164	-0.889	-1.539	-1.289	-0.208	-0.258
140.2.8								
140.2.9								
140.2.10	-1.540	-0.940	-1.890	-1.740	-2.515	-3.140	-1.083	-0.483
Average	-0.218	-0.164	-0.768	-0.650	-0.957	-1.071	1.360	1.413
Standard Deviation	2.202	2.209	2.054	2.381	2.159	2.566	1.488	1.324
Coefficient of Variation	-10.115	-13.458	-2.676	-3.664	-2.256	-2.395	1.094	0.937

Table E-12: Correlation Factors for the First and Second Lifts (Composite Cores) of the Two-Lift Pavement on the OR 140 Project (Continued)

Location/ CoreID	SSD Method A (before APAO) - Troxler 3430 #38806 (4)	SSD Method A (before APAO)- Troxler 3430 #38806 (2)	SSD Method A (before APAO) - Troxler 3440 #25714 (4)	SSD Method A (before APAO) - Troxler 3440 #25714 (2)
140.2.1	1.444	1.569	1.144	1.569
140.2.2	1.981	1.981	2.331	2.731
140.2.3				
140.2.4	1.509	2.184	1.534	1.434
140.2.5	2.474	1.799	2.424	1.649
140.2.6	0.226	0.501	-0.124	-0.499
140.2.7	-0.533	-0.258	-0.908	-0.658
140.2.8				
140.2.9				
140.2.10	-1.433	-1.283	-2.058	-2.683
Average	0.810	0.927	0.620	0.506
Standard Deviation	1.426	1.312	1.701	1.861
Coefficient of Variation	1.762	1.415	2.742	3.678

APPENDIX F
TWO-SAMPLE T-TEST RESULTS

Table F-1: p-values from Correlation Factor Comparisons; 18-1 vs. 18-2, Lift 2 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300	PQI 300	PQI 301	PQI 301
CoreLok - gauge (avg of 4 readings)	N/A	0.7962	0.5941	N/A	N/A	N/A	N/A
CoreLok - gauge (avg of 2 readings)	N/A	0.6527	0.4424				
SSD Method A (before APAO) - gauge (avg of 4 readings)	N/A	0.2398	0.0250	N/A	N/A	N/A	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	N/A	0.3997	0.0139				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	0.1162	0.0003	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	0.2048	0.0003				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	0.3829	0.0050	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	0.5075	0.0035				

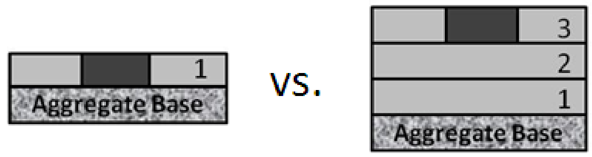
Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from the first set of first lift (μ_{1a}) and true mean correlation factor from the first set of second lift (μ_{2a})
- H_0: $\mu_{1a} - \mu_{2a} = 0$
- H_a: $\mu_{1a} - \mu_{2a} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1a} - \bar{X}_{2a}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The p-values in the above table suggest that the different nuclear gauges provided differing results when the correlation factors (between the densities from the SSD methods and the densities from the nuclear gauges) were compared between the two lifts. In other words, all the correlation factors (between the densities from the control gauge and the densities from other methods of measurement) did not differ significantly between the two lifts at 90% level of confidence. Whereas the correlation factors (between the SSD results and the other nuclear gauge used) differed significantly between the two lifts even at 97% level of confidence. Another observation is that the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 56%; and this result remained consistent irrespective of the nuclear gauge used. Overall, at 95% level of confidence, a majority of the p-values (10 of 16) from the table indicated that there was no significant difference between the correlation factors compared between the two lifts.

Table F-2: p-values from Correlation Factor Comparisons; 18-1 vs. 18-3, Lift 3 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300	PQI 300	PQI 301	PQI 301
CoreLok - gauge (avg of 4 readings)	N/A	0.0323	N/A	N/A	N/A	N/A	N/A
CoreLok - gauge (avg of 2 readings)	N/A	0.0646	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	N/A	0.2470	N/A	N/A	N/A	N/A	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	N/A	0.5548	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	0.5848	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	0.9606	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	0.1542	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	0.3397	N/A				

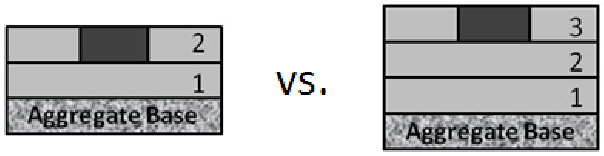
Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from the first set of first lift (μ1a) and true mean correlation factor from the third lift (μ3)
- H_0: $\mu_{1a} - \mu_3 = 0$
- H_a: $\mu_{1a} - \mu_3 \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1a} - \bar{X}_3}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The p-values in the above table suggest that the correlation factors (between the densities from the SSD method the densities from the nuclear gauge) did not differ significantly between the two lifts at 76% level of confidence. Another observation is that the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauge) did not differ significantly between the two lifts only at 97% level of confidence. Overall, at 95% level of confidence, a majority of the p-values (7 of 8) from the table indicated that there was no significant difference between the correlation factors compared between the two lifts.

Table F-3: p-values from Correlation Factor Comparisons; 18-2, Lift 2 vs. 18-3, Lift 3 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0029	0.0071	N/A	0.7448	N/A	0.6352	N/A
CoreLok - gauge (avg of 2 readings)	0.0158	0.0617	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0108	0.0222	N/A	0.0827	N/A	0.3796	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0170	0.1530	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.0042	0.0081	N/A	0.3519	N/A	0.9958	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.0274	0.0656	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.0156	0.0281	N/A	0.3674	N/A	0.9406	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	0.0546	0.1415	N/A				
SSD Method C - gauge (avg of 4 readings)	0.0028	0.0051	N/A	0.4723	N/A	0.8541	N/A
SSD Method C - gauge (avg of 2 readings)	0.0192	0.0380	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

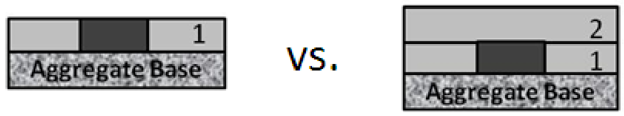
- True mean correlation factor from first set of second lift (μ_{2a}) and true mean correlation factor from third lift (μ_3)
- H_0: $\mu_{2a} - \mu_3 = 0$
- H_a: $\mu_{2a} - \mu_3 \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{2a} - \bar{X}_3}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the cores and the densities from the nuclear gauges) were significantly different between the two lifts at 94% level of confidence in 17 of 20 comparisons. However, when the average of two nuclear gauge readings were used to calculate the correlation factors (between the densities from the control gauge and the densities from the other methods of measurements on the cores) instead of four, it was observed that there was no significant difference between the correlation factors of the two lifts at 95% level of confidence.

For the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at a level of confidence as low as 65% (in 9 of 10 comparisons). For the same correlation factors compared between the two lifts, it must be noted that, although both the electromagnetic gauges provided similar results, the PQI 301 provided stronger evidence than the PQI 300 of not being significantly different between the two lifts; i.e., the level of confidence was as low as 63%.

Table F-4: p-values from Correlation Factor Comparisons; 18-1 vs. 18-2, Lift 1 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	N/A	0.2822	0.6973	N/A	N/A	N/A	N/A
CoreLok - gauge (avg of 2 readings)	N/A	0.2465	0.8136				
SSD Method A (before APAO) - gauge (avg of 4 readings)	N/A	0.9237	0.4282	N/A	N/A	N/A	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	N/A	0.9486	0.3514				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	0.4022	0.1661	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	0.5108	0.1418				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	0.4739	0.2091	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	0.5811	0.1773				

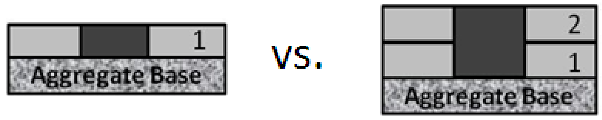
Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from first set of first lift (μ_{1a}) and true mean correlation factor from second set of first lift (μ_{1b})
- H_0: $\mu_{1a} - \mu_{1b} = 0$
- H_a: $\mu_{1a} - \mu_{1b} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1a} - \bar{X}_{1b}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The p-values in the above table provide evidence to indicate that the correlation factors (between the densities from the various tests on cores and the densities from the two nuclear gauges) did not differ significantly at a level of confidence as low as 86%. This is true for all of the 16 comparisons made. Another observation is that both the nuclear gauges provided similar results when the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) were compared between the two lifts.

Table F-5: p-values from Correlation Factor Comparisons; 18-1 vs. 18-2, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	N/A	0.1911	0.7661	N/A	N/A	N/A	N/A
CoreLok - gauge (avg of 2 readings)	N/A	0.1406	0.9259				
SSD Method A (before APAO) - gauge (avg of 4 readings)	N/A	0.2359	0.0236	N/A	N/A	N/A	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	N/A	0.4005	0.0217				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

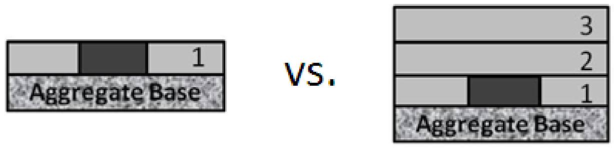
Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from first set of first lift (μ_{1a}) and true mean correlation factor from combination of first and second lifts (μ_{12})
- H_0: $\mu_{1a} - \mu_{12} = 0$
- H_a: $\mu_{1a} - \mu_{12} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1a} - \bar{X}_{12}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The p-values from the above table suggest that the different nuclear gauges provided differing results when the correlation factors (between the densities from the SSD methods and the densities from the nuclear gauges) were compared between the two lifts. In other words, all the correlation factors (between the densities from the control gauge and the densities from other methods of measurement) do not differ significantly between the two lifts at 86% level of confidence, whereas the correlation factors (between the SSD results and the other nuclear gauge used) differed significantly between the two lifts even at 97% level of confidence. Another observation is that the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 86%; and this result remained consistent irrespective of the nuclear gauge used. Overall, at 95% level of confidence, a majority of the p-values (6 of 8) from the table indicated that there was no significant difference between the correlation factors compared between the two lifts.

Table F-6: p-values from Correlation Factor Comparisons; 18-1 vs. 18-3, Lift 1 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	N/A	0.0006	N/A	N/A	N/A	N/A	N/A
CoreLok - gauge (avg of 2 readings)	N/A	0.0020	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	N/A	0.0052	N/A	N/A	N/A	N/A	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	N/A	0.0085	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	0.0001	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	0.0005	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	0.0002	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	0.0007	N/A				

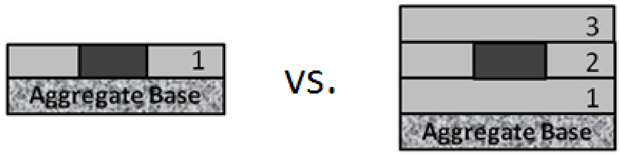
Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from first set of first lift (μ_{1a}) and true mean correlation factor from third set of first lift (μ_{1c})
- H_0: $\mu_{1a} - \mu_{1c} = 0$
- H_a: $\mu_{1a} - \mu_{1c} \neq 0$

Test statistic: $t = \frac{\bar{X}_{1a} - \bar{X}_{1c}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauge) differed significantly between the two lifts, even at 99% level of confidence. This was true for all of the eight comparisons made.

Table F-7: p-values from Correlation Factor Comparisons; 18-1 vs. 18-3, Lift 2 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	N/A	0.3303	N/A	N/A	N/A	N/A	N/A
CoreLok - gauge (avg of 2 readings)	N/A	0.4659	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	N/A	0.5296	N/A	N/A	N/A	N/A	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	N/A	0.7181	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	0.7699	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	0.9511	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	0.7849	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	0.9606	N/A				

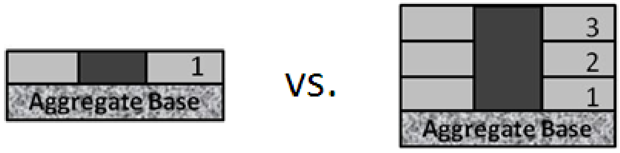
Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from first set of first lift (μ_{1a}) and true mean correlation factor from first set of second lift (μ_{2a})
- H_0: $\mu_{1a} - \mu_{2a} = 0$
- H_a: $\mu_{1a} - \mu_{2a} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1a} - \bar{X}_{2a}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The p-values in the above table suggest that the correlation factors (between the densities from the SSD method the densities from the nuclear gauge) did not differ significantly between the two lifts at 67% level of confidence. This was true for all of the eight comparisons made.

Table F-8: p-values from Correlation Factor Comparisons; 18-1 vs. 18-3, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	N/A	0.0004	N/A	N/A	N/A	N/A	N/A
CoreLok - gauge (avg of 2 readings)	N/A	0.0013	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	N/A	0.3835	N/A	N/A	N/A	N/A	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	N/A	0.6426	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

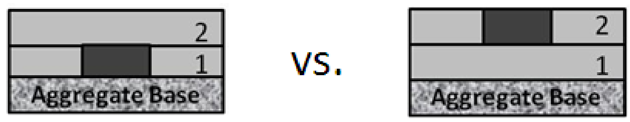
Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from first set of first lift (μ_{1a}) and true mean correlation factor from combination of first, second, and third lifts (μ_{123})
- H_0: $\mu_{1a} - \mu_{123} = 0$
- H_a: $\mu_{1a} - \mu_{123} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1a} - \bar{X}_{123}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The p-values in the above table suggest that the CoreLok and the SSD tests on cores provide differing results when the correlation factors (between the densities from the tests on cores and the densities from the nuclear gauge) were compared between the two lifts. In other words, all the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauge) differed significantly between the two lifts even at 99% level of confidence, whereas the correlation factors (between the densities from the SSD test and the densities from the nuclear gauge) did not differ significantly between the two lifts at a level of confidence as low as 62%.

Table F-9: p-values from Correlation Factor Comparisons; 18-2, Lift 1 vs. 18-2, Lift 2 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.3075	0.3074	0.3622	0.2646	N/A	0.3230	N/A
CoreLok - gauge (avg of 2 readings)	0.2863	0.3400	0.3824				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.4620	0.4541	0.5119	0.3683	N/A	0.4348	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.4218	0.4894	0.5314				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.9100	0.8687	0.8167	0.8670	N/A	0.9451	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.9799	0.8405	0.7927				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.8194	0.7731	0.7326	0.9984	N/A	0.9461	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	0.8751	0.7612	0.7135				
SSD Method C - gauge (avg of 4 readings)	0.8194	0.8531	0.9312	0.5912	N/A	0.6892	N/A
SSD Method C - gauge (avg of 2 readings)	0.7386	0.8998	0.9654				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from second set of first lift (μ_{1b}) and true mean correlation factor from first set of second lift (μ_{2a})
- H_0: $\mu_{1b} - \mu_{2a} = 0$
- H_a: $\mu_{1b} - \mu_{2a} \neq 0$

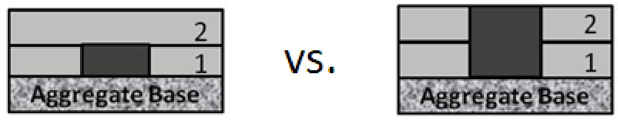
Test statistic: $t = \dfrac{\bar{X}_{1b} - \bar{X}_{2a}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 58%. This was true for all of the 30 comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts even at a level of confidence as low as 64%. This was true for all of the ten comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F-10: p-values from Correlation Factor Comparisons; 18-2, Lift 1 vs. 18-2, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.8176	0.8153	0.8421	0.7828	N/A	0.8080	N/A
CoreLok - gauge (avg of 2 readings)	0.8009	0.8256	0.8509				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.4938	0.4926	0.5611	0.4046	N/A	0.4787	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.4532	0.5156	0.5867				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from second set of first lift (μ_{1b}) and true mean correlation factor from combination of first and second lifts (μ_{12})
- H_0: $\mu_{1b} - \mu_{12} = 0$
- H_a: $\mu_{1b} - \mu_{12} \neq 0$

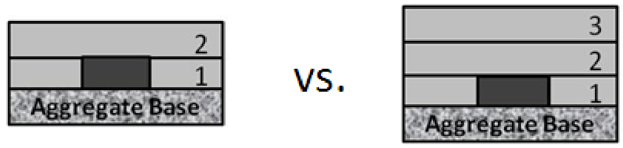
Test statistic: $t = \dfrac{\bar{X}_{1b} - \bar{X}_{12}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 55%. This was true for all of the twelve comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts even at a level of confidence as low as 60%. This was true for all four comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F-11: p-values from Correlation Factor Comparisons; 18-2, Lift 1 vs. 18-3, Lift 1 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0082	0.0141	N/A	0.1768	N/A	0.1019	N/A
CoreLok - gauge (avg of 2 readings)	0.0100	0.0347	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0046	0.0093	N/A	0.1736	N/A	0.0848	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0061	0.0242	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.0002	0.0005	N/A	0.0065	N/A	0.0044	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.0002	0.0021	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.0005	0.0009	N/A	0.0086	N/A	0.0056	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	0.0005	0.0033	N/A				
SSD Method C - gauge (avg of 4 readings)	0.0004	0.0007	N/A	0.0104	N/A	0.0068	N/A
SSD Method C - gauge (avg of 2 readings)	0.0004	0.0028	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from second set of first lift (μ_{1b}) and true mean correlation factor from third set of first lift (μ_{1c})
- H_0: $\mu_{1b} - \mu_{1c} = 0$
- H_a: $\mu_{1b} - \mu_{1c} \neq 0$

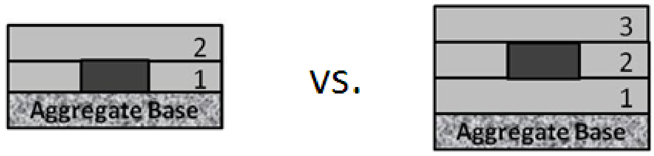
Test statistic: $t = \dfrac{\bar{X}_{1b} - \bar{X}_{1c}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) differed significantly between the two lifts even at 97% level of confidence. This was true for all of the 20 comparisons made.

For the electromagnetic gauges, the p-values in the above table suggest that the CoreLok and the SSD tests on cores provided differing results when the correlation factors (between the densities from the tests on cores and the densities from the electromagnetic gauge) were compared between the two lifts. In other words, all of the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauge) did not differ significantly between the two lifts even at 92% level of confidence, whereas the correlation factors (between the densities from the SSD test and the densities from the nuclear gauge) differed significantly between the two lifts even at a level of confidence as high as 98%.

Overall, the results were similar irrespective of the gauge used.

Table F-12: p-values from Correlation Factor Comparisons; 18-2, Lift 1 vs. 18-3, Lift 2 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.8243	0.9955	N/A	0.1766	N/A	0.4169	N/A
CoreLok - gauge (avg of 2 readings)	0.9002	0.7807	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.3828	0.5397	N/A	0.4029	N/A	0.7891	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.4197	0.7860	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.2849	0.3996	N/A	0.6869	N/A	0.9299	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.3043	0.6019	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.2712	0.3867	N/A	0.6866	N/A	0.9120	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	0.2904	0.5869	N/A				
SSD Method C - gauge (avg of 4 readings)	0.3338	0.4528	N/A	0.6467	N/A	0.9896	N/A
SSD Method C - gauge (avg of 2 readings)	0.3557	0.6562	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from second set of first lift (μ_{1b}) and true mean correlation factor from second set of second lift (μ_{2b})
- H_0: $\mu_{1b} - \mu_{2b} = 0$
- H_a: $\mu_{1b} - \mu_{2b} \neq 0$

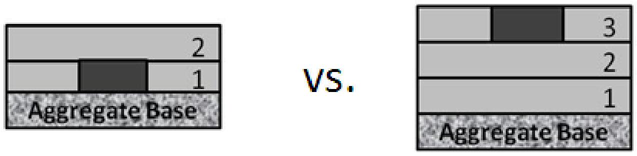
Test statistic: $t = \dfrac{\bar{X}_{1b} - \bar{X}_{2b}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 73%. This was true for all of the 20 comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts even at a level of confidence as low as 87%. This was true for all of the 10 comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F-13: p-values from Correlation Factor Comparisons; 18-2, Lift 1 vs. 18-3, Lift 3 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.4860	0.6859	N/A	0.1673	N/A	0.5123	N/A
CoreLok - gauge (avg of 2 readings)	0.5691	0.9857	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.2475	0.4164	N/A	0.0264	N/A	0.1524	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.3019	0.7627	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.1445	0.2279	N/A	0.5162	N/A	0.9481	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.1703	0.4523	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.2099	0.3230	N/A	0.3981	N/A	0.8965	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	0.2483	0.5887	N/A				
SSD Method C - gauge (avg of 4 readings)	0.0743	0.1143	N/A	0.9557	N/A	0.5961	N/A
SSD Method C - gauge (avg of 2 readings)	0.0830	0.2463	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from second set of first lift (μ_{1b}) and true mean correlation factor from third lift (μ_3)
- H_0: $\mu_{1b} - \mu_3 = 0$
- H_a: $\mu_{1b} - \mu_3 \neq 0$

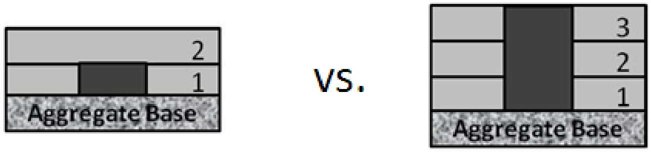
Test statistic: $t = \dfrac{\bar{X}_{1b} - \bar{X}_3}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts at a 93% level of confidence. This was true for all of the 20 comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts even at a level of confidence as low as 85%. This was true for 9 of 10 comparisons made. The correlation factors between the densities from the SSD Method A and the densities from the PQI 300 differed significantly between the two lifts even at 97% level of confidence.

Overall, the results were similar irrespective of the gauge used.

Table F-14: p-values from Correlation Factor Comparisons; 18-2, Lift 1 vs. 18-3, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0246	0.0404	N/A	0.5203	N/A	0.2955	N/A
CoreLok - gauge (avg of 2 readings)	0.0306	0.1089	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.3029	0.4533	N/A	0.3981	N/A	0.8037	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.3732	0.7572	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from second set of first lift (μ_{1b}) and true mean correlation factor from combination of first, second, and third lifts (μ_{123})
- H_0: $\mu_{1b} - \mu_{123} = 0$
- H_a: $\mu_{1b} - \mu_{123} \neq 0$

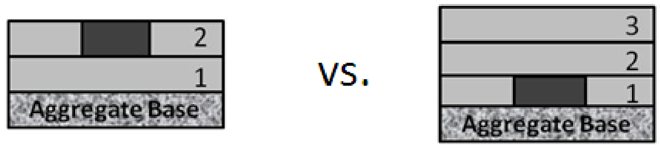
Test statistic: $t = \dfrac{\bar{X}_{1b} - \bar{X}_{123}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The CoreLok and the SSD tests on cores provided differing results when the correlation factors (between the densities from the tests on cores and the densities from the nuclear gauges) were compared between the two lifts. In other words, all the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) differed significantly between the two lifts at 89% level of confidence, whereas the correlation factors (between the densities from the SSD tests and the densities from the nuclear gauges) did not differ significantly between the two lifts at a level of confidence as low as 70%.

For the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts even at a level of confidence as low as 71%. This was true for all four comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F-15: p-values from Correlation Factor Comparisons; 18-2, Lift 2 vs. 18-3, Lift 1 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0006	0.0011	N/A	0.0442	N/A	0.0187	N/A
CoreLok - gauge (avg of 2 readings)	0.0010	0.0029	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0003	0.0008	N/A	0.0588	N/A	0.0232	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0006	0.0032	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.0000	0.0000	N/A	0.0049	N/A	0.0010	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.0000	0.0000	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.0000	0.0000	N/A	0.0071	N/A	0.0018	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	0.0000	0.0001	N/A				
SSD Method C - gauge (avg of 4 readings)	0.0000	0.0000	N/A	0.0154	N/A	0.0033	N/A
SSD Method C - gauge (avg of 2 readings)	0.0000	0.0001	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

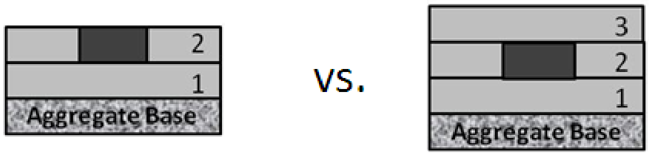
- True mean correlation factor from first set of second lift (μ_{2a}) and true mean correlation factor from third set of first lift (μ_{1c})
- H_0: $\mu_{1c} - \mu_{2a} = 0$
- H_a: $\mu_{1c} - \mu_{2a} \neq 0$

Test statistic: $t = \dfrac{\overline{X}_{1c} - \overline{X}_{2a}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) differed significantly between the two lifts even at a level of confidence as high as 99%. This was true for all of the 20 comparisons made.

For the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) differed significantly between the two lifts at a level of confidence of 92%. This was true for all of the ten comparisons made.

Table F-16: p-values from Correlation Factor Comparisons; 18-2, Lift 2 vs. 18-3, Lift 2 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.2360	0.3677	N/A	0.5625	N/A	0.9637	N/A
CoreLok - gauge (avg of 2 readings)	0.2736	0.6110	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.1141	0.2058	N/A	0.8344	N/A	0.6971	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.1251	0.3886	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.1735	0.2633	N/A	0.5855	N/A	0.9666	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.2205	0.4411	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.1354	0.2127	N/A	0.6833	N/A	0.8574	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	0.1727	0.3706	N/A				
SSD Method C - gauge (avg of 4 readings)	0.3226	0.4513	N/A	0.3684	N/A	0.7327	N/A
SSD Method C - gauge (avg of 2 readings)	0.4042	0.6692	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from first set of second lift (μ_{2a}) and true mean correlation factor from second set of second lift (μ_{2b})
- H_0: $\mu_{2a} - \mu_{2b} = 0$
- H_a: $\mu_{2a} - \mu_{2b} \neq 0$

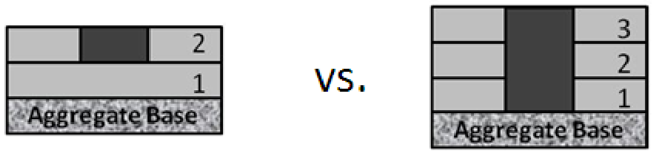
Test statistic: $t = \frac{\bar{X}_{2a} - \bar{X}_{2b}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence of 89%. This was true for all of the 20 comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts even at a level of confidence as low as 68%. This was true for all of the ten comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F-17: p-values from Correlation Factor Comparisons; 18-2, Lift 2 vs. 18-3, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0000	0.0001	N/A	0.1019	N/A	0.0309	N/A
CoreLok - gauge (avg of 2 readings)	0.0002	0.0007	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0419	0.0935	N/A	0.8249	N/A	0.6714	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0700	0.2790	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from first set of second lift (μ_{2a}) and true mean correlation factor from combination of first, second, and third lifts (μ_{123})
- H_0: $\mu_{2a} - \mu_{123} = 0$
- H_a: $\mu_{2a} - \mu_{123} \neq 0$

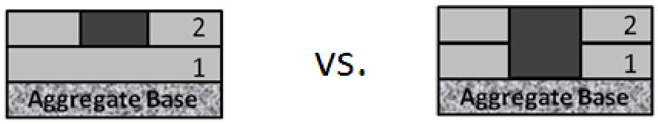
Test statistic: $t = \dfrac{\bar{X}_{2a} - \bar{X}_{123}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The CoreLok and the SSD tests on cores provided differing results when the correlation factors (between the densities from the tests on cores and the densities from the nuclear gauges) were compared between the two lifts. In other words, all the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) differed significantly between the two lifts at 99% level of confidence, whereas the correlation factors (between the densities from the SSD tests and the densities from the nuclear gauges) did not differ significantly between the two lifts at a 96% level of confidence.

For the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at a 94% level of confidence. This was true for all four comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F18: p-values from Correlation Factor Comparisons; 18-2, Lift 2 vs. 18-2, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.1701	0.1312	0.1708	0.2580	N/A	0.2108	N/A
CoreLok - gauge (avg of 2 readings)	0.1472	0.1793	0.2099				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.8866	0.8800	0.8980	0.8703	N/A	0.8851	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.8736	0.8977	0.9035				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from first set of second lift (μ_{2a}) and true mean correlation factor from combination of first and second lifts (μ_{12})
- H_0: $\mu_{2a} - \mu_{12} = 0$
- H_a: $\mu_{2a} - \mu_{12} \neq 0$

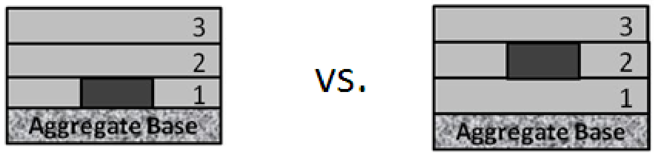
Test statistic: $t = \dfrac{\overline{X}_{2a} - \overline{X}_{12}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 55%. This was true for all of the twelve comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts even at a level of confidence as low as 48%. This was true for all four comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F19: p-values from Correlation Factor Comparisons; 18-3, Lift 1 vs. 18-3, Lift 2 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0179	0.0212	N/A	0.0298	0.1477	0.0296	0.1482
CoreLok - gauge (avg of 2 readings)	0.0181	0.0273	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0523	0.0636	N/A	0.0697	0.2545	0.0682	0.2578
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0541	0.0742	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.0155	0.0201	N/A	0.0143	0.2959	0.0151	0.2960
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.0135	0.0275	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.0161	0.0224	N/A	0.0137	0.0903	0.0140	0.0870
SSD Method A (APAO) - gauge (avg of 2 readings)	0.0146	0.0288	N/A				
SSD Method C - gauge (avg of 4 readings)	0.0125	0.0168	N/A	0.0133	0.0933	0.0136	0.0915
SSD Method C - gauge (avg of 2 readings)	0.0109	0.0225	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

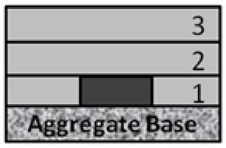
- True mean correlation factor from third set of first lift (μ_{1c}) and true mean correlation factor from second set of second lift (μ_{2b})
- H_0: $\mu_{1c} - \mu_{2b} = 0$
- H_a: $\mu_{1c} - \mu_{2b} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1c} - \bar{X}_{2b}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

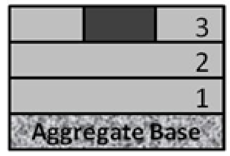
For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) differed significantly between the two lifts at a 92% level of confidence. This was true for all of the 20 comparisons made.

For the electromagnetic gauges, the p-values in the above table suggest that the presence or absence of sand on the surface of the locations provided differing results when the correlation factors are compared between the two lifts. In sanded condition, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges when the locations were sanded) differed significantly between the two lifts at 97% level of confidence. This was true for all of the ten comparisons made. In un-sanded condition, the p-values suggest that the correlation factors did not differ significantly at 92% level of confidence. This was true for all of the 10 comparisons made.

Table F-20: p-values from Correlation Factor Comparisons; 18-3, Lift 1 vs. 18-3, Lift 3 (OR 18)



vs.



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0099	0.0107	N/A	0.0317	0.0547	0.0304	0.0564
CoreLok - gauge (avg of 2 readings)	0.0133	0.0138	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0116	0.0142	N/A	0.0094	0.0170	0.0088	0.0183
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0168	0.0169	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.0000	0.0000	N/A	0.0009	0.2795	0.0010	0.2797
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.0001	0.0003	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.0001	0.0001	N/A	0.0013	0.0014	0.0014	0.0010
SSD Method A (APAO) - gauge (avg of 2 readings)	0.0002	0.0007	N/A				
SSD Method C - gauge (avg of 4 readings)	0.0002	0.0009	N/A	0.0043	0.0081	0.0046	0.0091
SSD Method C - gauge (avg of 2 readings)	0.0008	0.0022	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

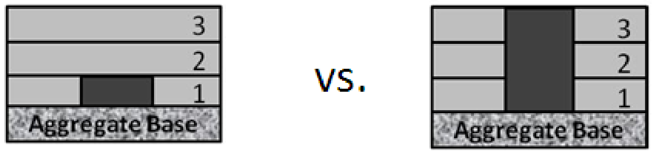
- True mean correlation factor from third set of first lift (μ_{1c}) and true mean correlation factor from third lift (μ_3)
- H_0: $\mu_{1c} - \mu_3 = 0$
- H_a: $\mu_{1c} - \mu_3 \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1c} - \bar{X}_3}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) differed significantly between the two lifts even at 98% level of confidence. This was true for all of the 20 comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) differed significantly between the two lifts at a level of confidence of 94%. This was true for 18 of the 20 comparisons made.

Table F-21: p-values from Correlation Factor Comparisons; 18-3, Lift 1 vs. 18-3, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.2952	0.3175	N/A	0.4326	0.4888	0.4404	0.5090
CoreLok - gauge (avg of 2 readings)	0.3197	0.3306	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0252	0.0374	N/A	0.0760	0.1205	0.0753	0.1443
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0360	0.0416	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

True mean correlation factor from third set of first lift (μ_{1c}) and true mean correlation factor from combination of first, second, and third lifts (μ_{123})

H_0: $\mu_{1c} - \mu_{123} = 0$

H_a: $\mu_{1c} - \mu_{123} \neq 0$

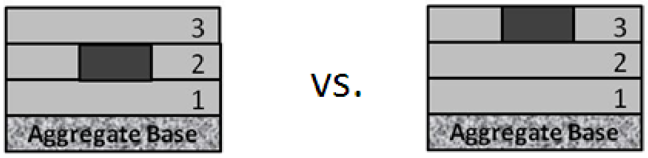
Test statistic: $t = \dfrac{\bar{X}_{1c} - \bar{X}_{123}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The CoreLok and the SSD tests on cores provided differing results when the correlation factors (between the densities from the tests on cores and the densities from the nuclear gauges) were compared between the two lifts. In other words, all the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 71%, whereas the correlation factors (between the densities from the SSD test and the densities from the nuclear gauges) differed significantly between the two lifts at a 95% level of confidence.

For the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at a 93% level of confidence. This was true for all eight comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F-22: p-values from Correlation Factor Comparisons; 18-3, Lift 2 vs. 18-3, Lift 3 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.7191	0.7286	N/A	0.7137	0.7439	0.7190	0.7404
CoreLok - gauge (avg of 2 readings)	0.7169	0.7389	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.9177	0.9228	N/A	0.3126	0.1363	0.3197	0.1337
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.9171	0.9261	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.9638	0.9651	N/A	0.9639	0.5373	0.9643	0.5299
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.9634	0.9664	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	0.8085	0.8175	N/A	0.8102	0.4368	0.8118	0.4269
SSD Method A (APAO) - gauge (avg of 2 readings)	0.8072	0.8236	N/A				
SSD Method C - gauge (avg of 4 readings)	0.6495	0.6609	N/A	0.6498	0.8442	0.6531	0.8408
SSD Method C - gauge (avg of 2 readings)	0.6448	0.6708	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from second set of second lift (μ_{2b}) and true mean correlation factor from third lift (μ_3)
- H_0: $\mu_{2b} - \mu_3 = 0$
- H_a: $\mu_{2b} - \mu_3 \neq 0$

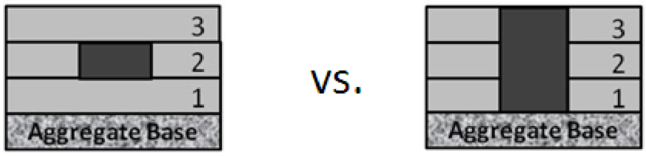
Test statistic: $t = \dfrac{\bar{X}_{2b} - \bar{X}_3}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 36%. This was true for all of the 20 comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts even at a level of confidence as low as 87%. This was true for all of the 20 comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F-23: p-values from Correlation Factor Comparisons; 18-3, Lift 2 vs. 18-3, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0606	0.0654	N/A	0.0838	0.3295	0.0832	0.3141
CoreLok - gauge (avg of 2 readings)	0.0609	0.0847	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.9857	0.9867	N/A	0.9943	0.6577	0.9848	0.6936
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.9779	0.9896	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from second set of second lift (μ_{2b}) and true mean correlation factor from combination of first, second, and third lifts (μ_{123})
- H_0: $\mu_{2b} - \mu_{123} = 0$
- H_a: $\mu_{2b} - \mu_{123} \neq 0$

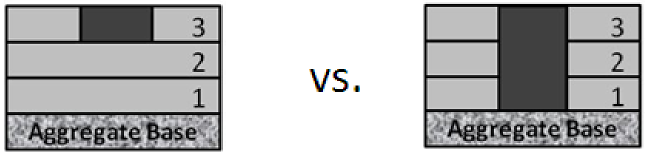
Test statistic: $t = \dfrac{\bar{X}_{2b} - \bar{X}_{123}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) differed significantly between the two lifts at 91% level of confidence. However, the correlation factors (between the densities from the SSD and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 3%.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at 92% level of confidence. This was true for all eight comparisons made.

Overall, at 95% level of confidence, all the comparisons made in the above table indicate that there was no significant difference between the correlation factors of the two lifts.

Table F-24: p-values from Correlation Factor Comparisons; 18-3, Lift 3 vs. 18-3, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0086	0.0069	N/A	0.0638	0.0835	0.0622	0.0792
CoreLok - gauge (avg of 2 readings)	0.0215	0.0105	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.9051	0.8741	N/A	0.3128	0.2419	0.2981	0.2725
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.9277	0.9164	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from third lift (μ_3) and true mean correlation factor from combination of first, second, and third lifts (μ_{123})
- H_0: $\mu_3 - \mu_{123} = 0$
- H_a: $\mu_3 - \mu_{123} \neq 0$

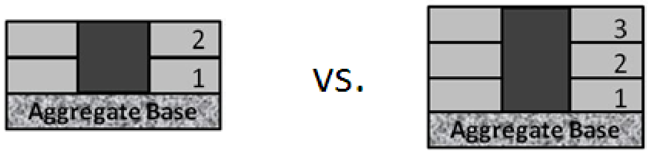
Test statistic: $t = \dfrac{\bar{X}_3 - \bar{X}_{123}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The CoreLok and the SSD tests on cores provided differing results when the correlation factors (between the densities from the tests on cores and the densities from the nuclear gauges) were compared between the two lifts. In other words, all the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) differed significantly between the two lifts at 97% level of confidence, whereas the correlation factors (between the densities from the SSD tests and the densities from the nuclear gauges) did not differ significantly between the two lifts even at a level of confidence as low as 13%.

For the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at 94% level of confidence. This was true for all eight comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F-25: p-values from Correlation Factor Comparisons; 18-2, uncut vs. 18-3, uncut (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0008	0.0012	N/A	0.3260	N/A	0.1338	N/A
CoreLok - gauge (avg of 2 readings)	0.0014	0.0085	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0330	0.0880	N/A	0.7514	N/A	0.7316	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0611	0.2743	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from combination of first and second lift (μ_{12}) and true mean correlation factor from combination of first, second, and third lifts (μ_{123})
- H_0: $\mu_{12} - \mu_{123} = 0$
- H_a: $\mu_{12} - \mu_{123} \neq 0$

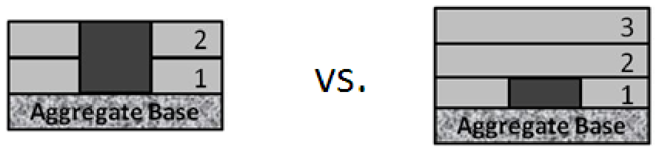
Test statistic: $t = \dfrac{\bar{X}_{12} - \bar{X}_{123}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The CoreLok and the SSD tests on cores provided differing results when the correlation factors (between the densities from the tests on cores and the densities from the nuclear gauges) were compared between the two lifts. In other words, all the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) differed significantly between the two lifts even at 99% level of confidence, whereas the correlation factors (between the densities from the SSD test and the densities from the nuclear gauges) did not differ significantly between the two lifts at 97% level of confidence.

For the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at 87% level of confidence. This was true for all four comparisons made.

Overall, the results were similar irrespective of the gauge used.

Table F-26: p-values from Correlation Factor Comparisons; 18-2, uncut vs. 18-3, Lift 1 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.0021	0.0038	N/A	0.1152	N/A	0.0504	N/A
CoreLok - gauge (avg of 2 readings)	0.0035	0.0102	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0006	0.0014	N/A	0.0638	N/A	0.0252	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0013	0.0039	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

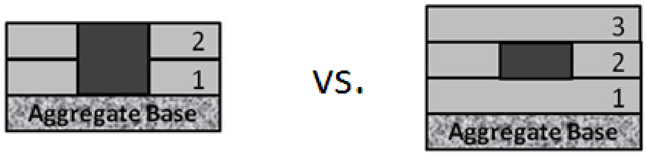
- True mean correlation factor from combination of first and second lifts (μ_{12}) and true mean correlation factor from third set of first lift (μ_{1c})
- H_0: $\mu_{1c} - \mu_{12} = 0$
- H_a: $\mu_{1c} - \mu_{12} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1c} - \bar{X}_{12}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) differed significantly between the two lifts even at 98% level of confidence. This was true for all eight comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) differed significantly between the two lifts at a level of confidence of 88%. However, at 95% level of confidence three out of four comparisons indicated that there was no significant difference.

Table F-27: p-values from Correlation Factor Comparisons; 18-2, uncut vs. 18-3, Lift 2 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.6316	0.8322	N/A	0.1897	N/A	0.4241	N/A
CoreLok - gauge (avg of 2 readings)	0.7057	0.8827	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.1238	0.2190	N/A	0.7534	N/A	0.7600	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.1362	0.4120	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

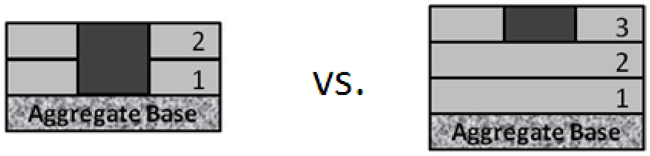
- True mean correlation factor from combination of first and second lifts (μ_{12}) and true mean correlation factor from second set of second lift (μ_{2b})
- H_0: $\mu_{2b} - \mu_{12} = 0$
- H_a: $\mu_{2b} - \mu_{12} \neq 0$

Test statistic: $t = \frac{\bar{X}_{2b} - \bar{X}_{12}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts at 88% level of confidence.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts even at 82% level of confidence. This was true for all eight comparisons made.

Table F-28: p-values from Correlation Factor Comparisons; 18-2, uncut vs. 18-3, Lift 3 (OR 18)



Average difference compared	(Troxler 3430 # 30860)	(Troxler 3430 # 38806)	(Troxler 3440 # 25714)	PQI 300 (sand)	PQI 300 (no sand)	PQI 301 (sand)	PQI 301 (no sand)
CoreLok - gauge (avg of 4 readings)	0.1202	0.2386	N/A	0.1367	N/A	0.4840	N/A
CoreLok - gauge (avg of 2 readings)	0.1893	0.6892	N/A				
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0027	0.0111	N/A	0.0456	N/A	0.2843	N/A
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0079	0.1018	N/A				
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A				
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A				

Hypotheses for the two-sample t-test at 95% level of confidence:

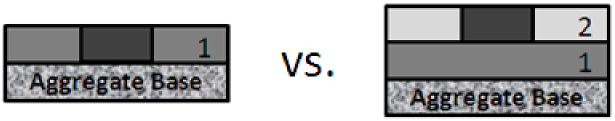
- True mean correlation factor from third lift (μ_3) and true mean correlation factor from first and second lifts (μ_{12})
- H_0: $\mu_3 - \mu_{12} = 0$
- H_a: $\mu_3 - \mu_{12} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_3 - \bar{X}_{12}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The CoreLok and the SSD tests on cores provided differing results when the correlation factors (between the densities from the tests on cores and the densities from the nuclear gauges) were compared between the two lifts. In other words, all the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) did not differ significantly between the two lifts even at 88% level of confidence, whereas the correlation factors (between the densities from the SSD test and the densities from the nuclear gauges) differed significantly between the two lifts at 89% level of confidence.

For the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at 96% level of confidence. This was true for all four comparisons made.

Table F-29: p-values from Correlation Factor Comparisons; 5-1 vs. 5-2 (I-5)



Average difference compared	(Troxler 3440 # 38996)	(Troxler 3430 # 38806)	(CPN Portaprobe # 7443)
CoreLok - nucelar gauge (avg of 4 readings)	0.8442	0.1090	0.1896
CoreLok - nuclear gauge (avg of 2 readings)	0.9911	0.1466	0.1084
SSD Method A - nuclear gauge (avg of 4 readings)	0.4119	0.0006	0.0194
SSD Method A - nuclear gauge (avg of 2 readings)	0.6126	0.0014	0.0056
SSD Method C - nuclear gauge (avg of 4 readings)	0.4165	0.0009	0.0272
SSD Method C - nuclear gauge (avg of 2 readings)	0.5965	0.0018	0.0084

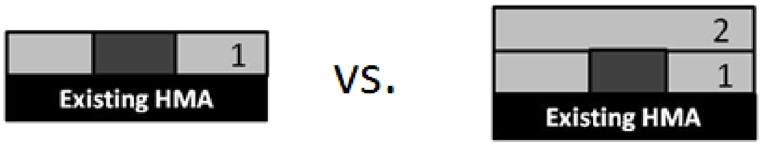
Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from first set of first lift (μ_{1a}) and true mean correlation factor from combination of first and second lifts (μ_{12})
- H_0: $\mu_{1a} - \mu_{12} = 0$
- H_a: $\mu_{1a} - \mu_{12} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{1a} - \bar{X}_{12}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The p-values in the above table suggest that the different nuclear gauges provided differing results when the correlation factors (between the densities from the SSD methods and the densities from the nuclear gauges) were compared between the two lifts. In other words, all the correlation factors (between the densities from the Troxler 3430 # 38996 and the densities from other methods of measurement) did not differ significantly between the two lifts even at 59% level of confidence, whereas the correlation factors (between the SSD results and the other nuclear gauge used) differed significantly between the two lifts even at 97% level of confidence. Another observation is that the correlation factors (between the densities from the CoreLok and the densities from the nuclear gauges) did not differ significantly between the two lifts even at 89% level of confidence; and this result remained consistent irrespective of the nuclear gauge used. Overall, at 95% level of confidence, a majority of the p-values (10 of 18) from the table indicated that there was no significant difference between the correlation factors compared between the two lifts.

Table F-30: p-values from Correlation Factor Comparisons; 140-1 vs. 140-2, Lift 1 (OR 140)



Average difference compared	(Troxler 3440 # 38996)	(Troxler 3430 # 38806)	(Troxler 3440 # 35601)	PQI 300 (sand)	PQI 301 (sand)
CoreLok - gauge (avg of 4 readings)	0.0954	0.4320	0.3462	0.9130	0.0947
CoreLok - gauge (avg of 2 readings)	0.0978	0.3776	0.3901		
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0752	0.4136	0.3307	0.8163	0.0190
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0780	0.3510	0.3818		
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.0699	0.4049	0.3278	0.6271	0.0337
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.0680	0.3176	0.3785		
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A		
SSD Method C - gauge (avg of 4 readings)	0.0505	0.2433	0.2172	0.8327	0.0772
SSD Method C - gauge (avg of 2 readings)	0.0505	0.2196	0.2896		

Hypotheses for the two-sample t-test at 95% level of confidence:

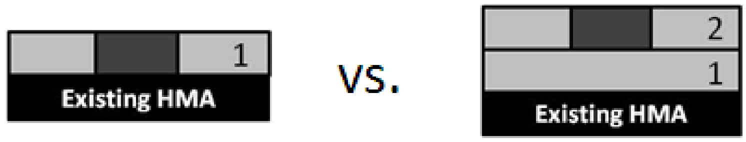
- True mean correlation factor from first set of inlay (μ_{Ia}) and true mean correlation factor from second set of inlay (μ_{Ib})
- H_O: $\mu_{Ia} - \mu_{Ib} = 0$
- H_a: $\mu_{Ia} - \mu_{Ib} \neq 0$

Test statistic: $t = \frac{\bar{X}_{Ia} - \bar{X}_{Ib}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts at 93% level of confidence.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at 95% level of confidence. This was observed in four of the six comparisons made.

Table F-31: p-values from Correlation Factor Comparisons; 140-1 vs. 140-2, Lift 2 (OR 140)



Average difference compared	(Troxler 3440 # 38996)	(Troxler 3430 # 38806)	(Troxler 3440 # 35601)	PQI 300 (sand)	PQI 301 (sand)
CoreLok - gauge (avg of 4 readings)	0.1250	0.4318	0.3589	0.9404	0.1844
CoreLok - gauge (avg of 2 readings)	0.1226	0.3729	0.3938		
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0023	0.9454	0.4516	0.0359	0.0011
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0065	0.6522	0.5932		
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.0019	0.8799	0.4297	0.0263	0.0039
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.0038	0.5489	0.5788		
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A		
SSD Method C - gauge (avg of 4 readings)	0.0055	0.9500	0.5635	0.0207	0.0029
SSD Method C - gauge (avg of 2 readings)	0.0107	0.6839	0.6877		

Hypotheses for the two-sample t-test at 95% level of confidence:

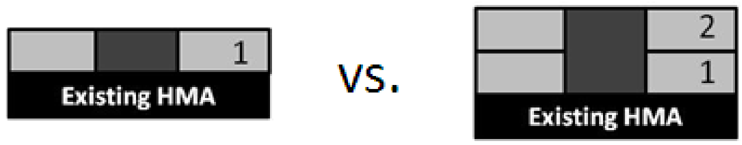
- True mean correlation factor from first set of inlay (μ_{Ia}) and true mean correlation factor from overlay (μ_O)
- H_O: $\mu_{Ia} - \mu_O = 0$
- H_a: $\mu_{Ia} - \mu_O \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{Ia} - \bar{X}_O}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts at 95% level of confidence. This was observed in 20 of the 24 comparisons.

However, for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) differed significantly between the two lifts at 95% level of confidence. This was observed in six of the eight comparisons made.

Table F-32: p-values from Correlation Factor Comparisons; 140-1 vs. 140-2, uncut (OR 140)



Average difference compared	(Troxler 3440 # 38996)	(Troxler 3430 # 38806)	(Troxler 3440 # 35601)	PQI 300 (sand)	PQI 301 (sand)
CoreLok - gauge (avg of 4 readings)	0.0865	0.6706	0.3147	0.6341	0.1912
CoreLok - gauge (avg of 2 readings)	0.1022	0.6318	0.3458		
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.0083	0.5240	0.1389	0.2930	0.0042
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.0116	0.4510	0.1300		
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A		
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A		
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A		

Hypotheses for the two-sample t-test at 95% level of confidence:

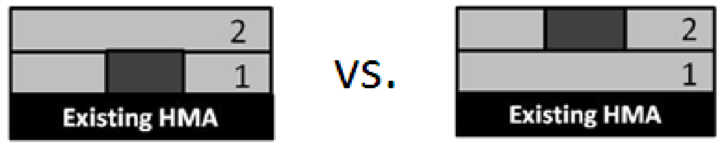
- True mean correlation factor from first set of inlay (μ_{Ia}) and true mean correlation factor from both lifts i.e., inlay and overlay (μ_{IO})
- H_O: $\mu_{Ia} - \mu_{IO} = 0$
- H_a: $\mu_{Ia} - \mu_{IO} \neq 0$

Test statistic: $t = \dfrac{\overline{X}_{Ia} - \overline{X}_{IO}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts at 95% level of confidence. This was observed in ten of the twelve comparisons.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at 95% level of confidence. This was observed in three of the four comparisons made.

Table F-33: p-values from Correlation Factor Comparisons; 140-2, Lift 1 vs. 140-2, Lift 2 (OR 140)



Average difference compared	(Troxler 3440 # 38996)	(Troxler 3430 # 38806)	(Troxler 3440 # 35601)	PQI 300 (sand)	PQI 301 (sand)
CoreLok - gauge (avg of 4 readings)	0.9283	0.9275	0.9336	0.8889	0.8695
CoreLok - gauge (avg of 2 readings)	0.9270	0.9291	0.9371		
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.4203	0.4105	0.4751	0.2075	0.2105
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.4161	0.4250	0.5164		
SSD Method A (after APAO) - gauge (avg of 4 readings)	0.4300	0.4249	0.4812	0.2448	0.2528
SSD Method A (after APAO) - gauge (avg of 2 readings)	0.4249	0.4403	0.5211		
SSD Method A (APAO) - gauge (avg of 4 readings)	0.5422	0.5333	0.5830	0.3814	0.3863
SSD Method A (APAO) - gauge (avg of 2 readings)	0.5411	0.5468	0.6162		
SSD Method C - gauge (avg of 4 readings)	0.2529	0.2313	0.2920	0.1423	0.1440
SSD Method C - gauge (avg of 2 readings)	0.2558	0.2757	0.3636		

Hypotheses for the two-sample t-test at 95% level of confidence

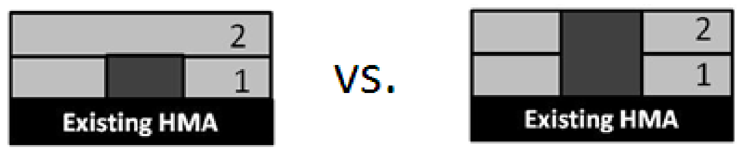
- True mean correlation factor from second set of inlay (μ_{Ib}) and true mean correlation factor from both lifts i.e., inlay and overlay (μ_O):
- H_O: $\mu_{Ib} - \mu_O = 0$
- H_a: $\mu_{Ib} - \mu_O \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{Ib} - \bar{X}_O}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at 77% level of confidence. This was observed in all 30 comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at 87% level of confidence. This was observed in all ten comparisons made.

Table F-34: p-values from Correlation Factor Comparisons; 140-2, Lift 1 vs. 140-2, uncut (OR 140)



Average difference compared	(Troxler 3440 # 38996)	(Troxler 3430 # 38806)	(Troxler 3440 # 35601)	PQI 300 (sand)	PQI 301 (sand)
CoreLok - gauge (avg of 4 readings)	0.7059	0.6620	0.8009	0.7384	0.7818
CoreLok - gauge (avg of 2 readings)	0.6826	0.6442	0.8701		
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.7424	0.6499	0.8548	0.6737	0.7678
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.6721	0.6058	0.9271		
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A		
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A		
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A		

Hypotheses for the two-sample t-test at 95% level of confidence:

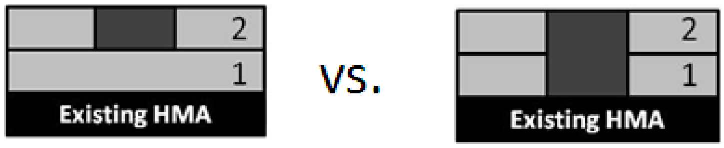
- True mean correlation factor from second set of inlay (μ_{Ib}) and true mean correlation factor from both lifts i.e., inlay and overlay (μ_{IO})
- H_O: $\mu_{Ib} - \mu_{IO} = 0$
- H_a: $\mu_{Ib} - \mu_{IO} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_{Ib} - \bar{X}_{IO}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at 40% level of confidence. This was observed in all twelve comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at 33% level of confidence. This was observed in all four comparisons made.

Table F-35: p-values from Correlation Factor Comparisons; 140-2, Lift 2 vs. 140-2, uncut (OR 140)



Average difference compared	(Troxler 3440 # 38996)	(Troxler 3430 # 38806)	(Troxler 3440 # 35601)	PQI 300 (sand)	PQI 301 (sand)
CoreLok - gauge (avg of 4 readings)	0.6771	0.6370	0.7595	0.6698	0.6995
CoreLok - gauge (avg of 2 readings)	0.6528	0.6146	0.8211		
SSD Method A (before APAO) - gauge (avg of 4 readings)	0.4457	0.5132	0.3382	0.1896	0.3194
SSD Method A (before APAO) - gauge (avg of 2 readings)	0.3881	0.5834	0.3425		
SSD Method A (after APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method A (after APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A		
SSD Method A (APAO) - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method A (APAO) - gauge (avg of 2 readings)	N/A	N/A	N/A		
SSD Method C - gauge (avg of 4 readings)	N/A	N/A	N/A	N/A	N/A
SSD Method C - gauge (avg of 2 readings)	N/A	N/A	N/A		

Hypotheses for the two-sample t-test at 95% level of confidence:

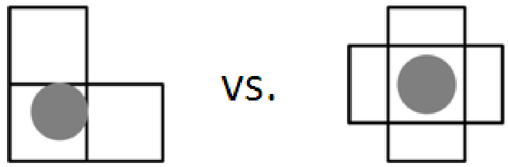
- True mean correlation factor from overlay (μ_O) and true mean correlation factor from both lifts i.e., inlay and overlay (μ_{IO})
- H_O: $\mu_O - \mu_{IO} = 0$
- H_a: $\mu_O - \mu_{IO} \neq 0$

Test statistic: $t = \dfrac{\bar{X}_O - \bar{X}_{IO}}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

For the nuclear gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at 67% level of confidence. This was observed in all twelve comparisons made.

Even for the electromagnetic gauges, the p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the electromagnetic gauges) did not differ significantly between the two lifts at 82% level of confidence. This was observed in all four comparisons made.

Table F-36: p-values from Correlation Factor Comparisons; 'L-shaped' vs. 'Cross-shaped' Footprint



Average difference compared	(Troxler 3430 # 38994)	(Troxler 3430 # 38806)
CoreLok - nucelar gauge (avg of 4 readings)	0.7924	0.9019
CoreLok - nuclear gauge (avg of 2 readings)	0.9716	0.9116
SSD Method A - nuclear gauge (avg of 4 readings)	0.5691	0.6629
SSD Method A - nuclear gauge (avg of 2 readings)	0.7169	0.8220
SSD Method C - nuclear gauge (avg of 4 readings)	0.7492	0.8576
SSD Method C - nuclear gauge (avg of 2 readings)	0.9128	0.9825

Hypotheses for the two-sample t-test at 95% level of confidence:

- True mean correlation factor from 'L-shaped' footprint (μ_L) and true mean correlation factor from 'cross-shaped' footprint (μ_C)
- H_0: $\mu_L - \mu_C = 0$
- H_a: $\mu_L - \mu_C \neq 0$

Test statistic: $t = \dfrac{\bar{X}_L - \bar{X}_C}{s_p / \sqrt{n}}$; where s_p = two-sample standard deviation

The p-values in the above table suggest that the correlation factors (between the densities from the various tests on cores and the densities from the nuclear gauges) did not differ significantly between the two lifts even at 44% level of confidence. This was observed in all twelve comparisons made.