BITUMINOUS MATERIALS Report

Superpave Gyratory Compactor Internal Angle of Gyration Study

Washington State
Department of Transportation

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16. ABSTRACT

This study on the angle of gyration for Superpave compactors was done to determine if there is a difference in the bulk specific gravity (Gmb) – and ultimately the volumetric properties – when calibrating the compactor's angle of gyration internally and externally. WSDOT currently has Troxler, Pine, Pine-Brovold, and Interlaken compactors across the state, so a representative sample (two to four compactors per region) was tested in this study. Triplicate samples of hot-mix asphalt (HMA) were used for each compactor.

It was found that 41 percent of the compactors tested were not in specification when using the internal angle to calibrate the compactor. Adjustments were made to those compactors and the bulk specific gravity results were compared. The results of the bulk specific gravity affect the volumetric properties of HMA (Va, VMA, and VFA) and therefore can have an affect on the design and acceptance of HMA. When calibrating the compactors via external angle (current AASHTO standard), the average air voids (target of 4.0) were 3.81 with a standard deviation of 0.54. When calibrating via internal angle, the average air voids were 3.98 with a standard deviation of 0.50.

Based on the results of this study, WSDOT is working to: (1) evaluate additional gyratory compactors (both WSDOT- and Contractor-owned), (2) make changes to current verification/calibration procedures, and (3) implement the use of the internal angle of calibration for 2008.

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Abstract

This study on the angle of gyration for Superpave compactors was done to determine if there is a difference in the bulk specific gravity (Gmb) – and ultimately the volumetric properties – when calibrating the compactor's angle of gyration internally and externally. WSDOT currently has Troxler, Pine, Pine-Brovold, and Interlaken compactors across the state, so a representative sample (two to four compactors per region) was tested in this study. Triplicate samples of hot-mix asphalt (HMA) were used for each compactor.

It was found that 41 percent of the compactors tested were not in specification when using the internal angle to calibrate the compactor. Adjustments were made to those compactors and the bulk specific gravity results were compared. The results of the bulk specific gravity affect the volumetric properties of HMA (Va, VMA, and VFA) and therefore can have an affect on the design and acceptance of HMA. When calibrating the compactors via external angle (current AASHTO standard), the average air voids (target of 4.0) were 3.81 with a standard deviation of 0.54. When calibrating via internal angle, the average air voids were 3.98 with a standard deviation of 0.50.

Based on the results of this study, WSDOT is working to: (1) evaluate additional gyratory compactors (both WSDOT- and Contractor-owned), (2) make changes to current verification/calibration procedures, and (3) implement the use of the internal angle of calibration for 2008.

Objective of Study

To measure and compare, both internal and external angles of gyration of Superpave gyratory compactors and the impacts these measurements have on bulk specific gravity (Gmb) and air voids (Va) of hot mix asphalt.

Introduction

The Washington State Department of Transportation (WSDOT) first purchased a SGC in 1995. The initial purchase was a first generation Troxler model 4140 gyratory compactor. Since that time WSDOT has purchased several different brands and models of SGC which have been used throughout the state. Currently, there are three types of SGC in use, the Troxler model 4140, Pine-Brovold model AFGB1A, and Interlaken model GYR-001 (below).

Troxler 4140

Pine-Brovold AFGB1A

Interlaken GYR-001

Due to the variety of gyratory compactors in use throughout the state, there is concern of possible variability in the angle of gyration between the different brands of compactors. Because WSDOT uses volumetric properties on many projects as part of the statistical evaluation of materials for acceptance, accurate compacted density determination is essential.

Prior to this study, the WSDOT State Materials Laboratory had the internal angle of gyration calibrated on four Troxler 4140 SGC's with the RAM™. This internal angle calibration was done as an experiment to see if the external angle calibration currently used by WSDOT would differ from that determined by the RAM™. It was also an opportunity to get familiar with the RAM™ prior to purchasing an angle measure device that does not require the use of hot mix. All four of the compactors were calibrated by internal angle using the RAM™ per AASHTO PP-48. With the internal angles set to 1.16±0.02° the external angles were determined to be outside the 1.25±0.02° tolerance on three of the four compactors. One SGC was found to have a loose ram head which kept it from achieving external angle specification. The ram head was disassembled; fittings were lubricated, and reassembled. The compactor was then able to be set to the correct external angle of gyration.

During cost and product comparisons prior to purchasing a mix-less internal angle measuring device Test Quip Inc. offered to upgrade the DAV™ currently owned by WSDOT to the mix-less DAV II™ for much less than the cost of purchasing a new device. The DAV II™ incorporates the Hot Mix Simulator (HMS) which eliminates the need for HMA in the internal angle determination.

A significant difference between the RAM™ and the DAV™ is temperature of operation. The RAM™ is temperature sensitive and must use room temperature molds or be allowed to cool between measures when using a heated mold. The DAV II™ use molds heated to compacting temperature with no cool down period needed. Research performed by the Florida DOT [1] comparing hot and cold mold internal angle measurements show there is an effect on the measurement. Results show lower (smaller) internal angle with heated molds and the Pine Brovold compactor demonstrated the greatest difference. A similar study was performed by the University of Arkansas [1] and the differences in internal angle were similar to Florida DOT results with the exception that the Pine Brovold compactor did not have as large a difference between hot and cold molds. The University of Arkansas study also identified other factors that influence angle measurement such as gyratory component lubrication and cleanliness of mechanical bearings.

Background

Studies conducted at the Asphalt Institute during the Strategic Highway Research Program investigated the effect of angle of gyration, speed of gyration, and vertical pressure on bulk specific gravity of hot mix asphalt compacted in Superpave gyratory compactors. These studies determined that the bulk specific gravity, or otherwise referred to as Gravity Mix Bulk (Gmb), of compacted Hot Mix Asphalt (HMA) was most influenced by the angle of gyration.[2] A change of 0.1° in angle of gyration can cause a change of 0.014 in the Gmb of the mixture, which can equate to a difference in air voids of up to 0.6%.[3] A study done by Troxler Electronic Laboratories Inc. contains the following statement; *"Greater than allowable precision differences in bulk specific gravities between specimens compacted in different SGC's have been reported in the field. The precision stated in AASHTO T166-00 of 0.02 equates to a difference in calculated air voids of approximately 0.8 percent. This could be the difference between passing and failing"*.[4] The Gmb and theoretical maximum specific gravity or otherwise referred to as Gravity Mix Mass (Gmm) are the two major physical tests conducted in order to determine the volumetric properties of HMA.

Historically the angle of gyration has been measured relative to the rigid frame of the compactor and the external wall of the mold (Figure 1 "α"). This method assumes that both end plates remain parallel. The specification governing the SGC [5] offers no tolerances explaining the degree to which end plates must remain parallel to each other. *"Compliance issues within the equipment affect parallel-ness."* [4] Each SGC model applies the external angle to the mold differently, and offers verification and calibration tools that are unique to each model. Pine Instruments report 2000-02 states *"Given that (in its present form) the SGC specification does not address the issue of end plate deflection, it would appear that two SGCs could conform to the specification yet provide different compaction results."* [3]

In order to measure the internal angle of gyration the Angle Validation Kit (AVK), or what became the Dynamic Angle Validator (DAV™), was developed. The DAV™ was designed to operate inside a standard mold (Figure 2 "δ_T & δ_B") during compaction accompanied by a sample of hot-mix asphalt. Linear Variable Differential Transformers (LVDT) were used to measure movement between the mold wall and the end platen (angle of gyration).

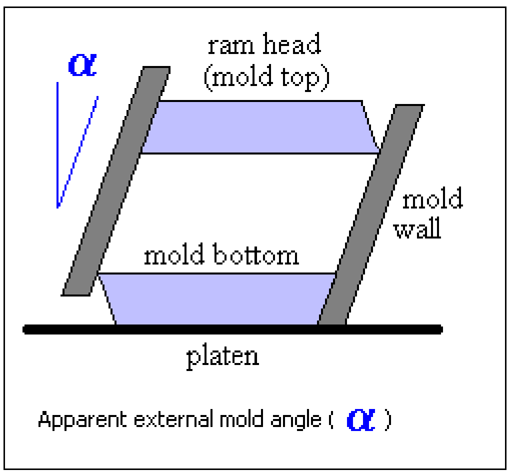


Figure 1

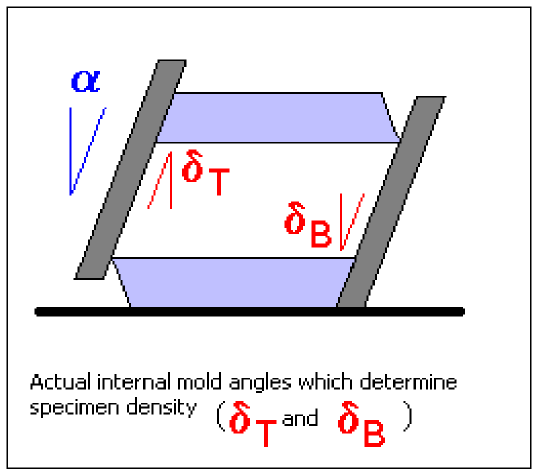


Figure 2

In 2002 the WSDOT State Materials Laboratory purchased a DAV™ and began evaluating its ability to measure the internal angle of gyration. Although the DAV™ was a big step toward measurement of internal angle of gyration, the calibration procedure for this device proved to be cumbersome and very time consuming. Use of HMA along with the DAV™ introduced procedural difficulties i.e. heating and mixing samples, determining the correct amount of HMA needed to achieve the proper height of sample. Another challenge with using HMA was the need to extrapolate the internal angle because some SGC molds could not accommodate full size samples of HMA. WSDOT observed that the internal angles measured were often out of specification while the external angles measured were in specification.

Because of the difficultly of use, and questionable accuracy associated with the use of HMA in conjunction with the DAV™, testing equipment manufacturers began the developing mix-less devices for measuring internal angles of SGCs. A couple of these new devices the Pine Instrument's "RAM™" (Photo 1) and Test Quip's "DAV-II™"

(Photo 2), are equipped with rings or cones that can change the eccentricity to simulate different mix stiffness without the use of HMA specimens.

Photo 1 (RAM™)

Photo 2 (DAV II™)

The DAV II™ comes with three cones of different eccentricity, 18°, 21°, and 24° (Photo 3). The 18° cone is used when the anticipated HMA samples are expected to be tender conversely the 24° cone is used if the HMA samples are expected to be stiff. All of the internal angle measurements performed in this study were taken with the 21° cone (22 mm of eccentricity) to provide a conservative eccentricity. This was to establish the dynamic internal angle of gyration (Photo 4) in relation to the physical characteristics of the HMA used. Research done by Michael Anderson of the Asphalt Institute has indicated that using a cone of higher eccentricity would likely increase SGC frame deflection and potentially give higher differences in Bulk Specific Gravity of compacted mix among specimens from different gyratory compactors [6].

Photo 3

DAV II HMS™ with 18°, 21°, and 24° cones of eccentricity

Photo 4

DAV II with 21° Cone

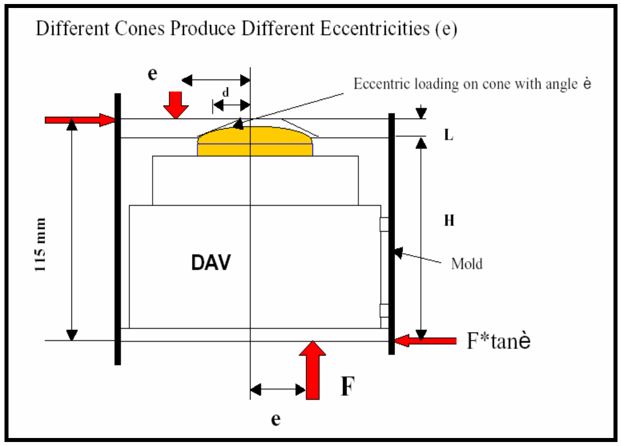


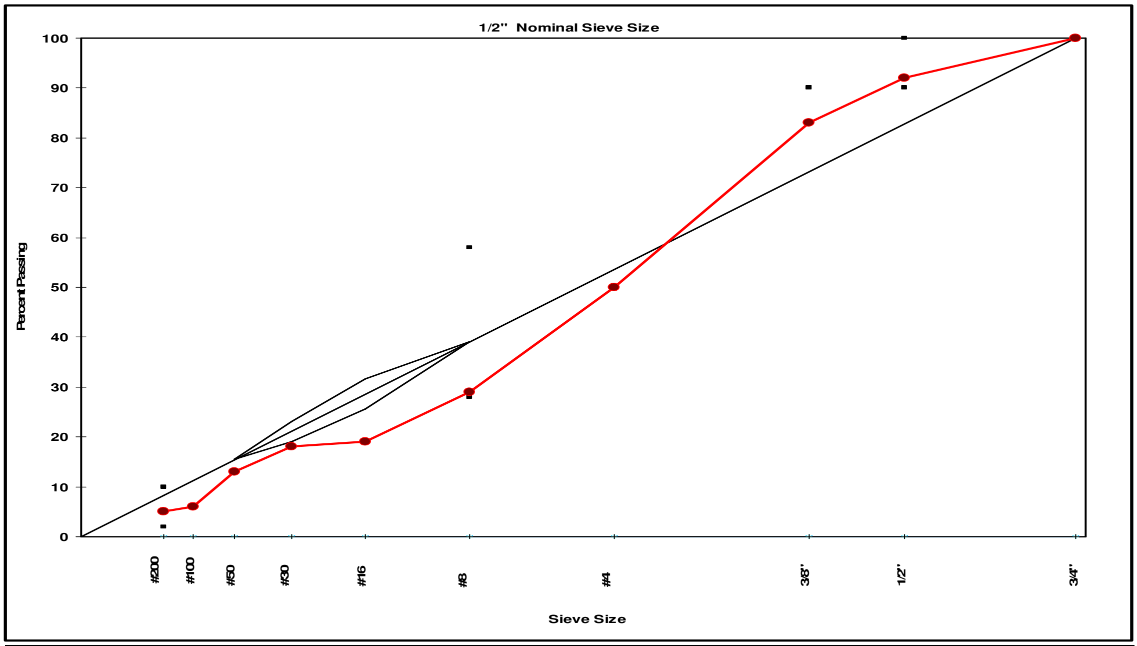
Figure 3
Test Quip, Inc. ™

Sample Preparation

All of the HMA samples used in this study were prepared at the WSDOT State Materials Laboratory in accordance with:

- AASHTO R-30 — Practice for Short and Long Term Aging of Hot Mix Asphalt (HMA)
- WAQTC T-27/11 — FOP for AASHTO for Sieve Analysis of Fine and Coarse Aggregates
- WSDOT T-724 — Method for Preparation of Aggregate for ACP Job Mix Design
- WSDOT T-726 — Mixing Procedure for Asphalt Concrete
- WSDOT T-732 — Standard Operating Procedure for Superpave Volumetric Design for Hot Mix Asphalt (HMA)

For the purpose of this study a ½ inch HMA 100 gyration (N_{design}) was selected. This design required an asphalt content of 5.9% using PG64-22 binder and a gradation as shown in Figure 1. The mixing temperature was 310°F and the compaction temperature was 289°F as outlined on Figure 2. Each sample was prepared at the same target gradation and weighed approximately 4740 grams to provide a final sample height of approximately 115 mm after 100 gyrations of compaction. In order to determine air voids (Va) of the HMA samples compacted in this study, an average Gmm of 2.467 was determined from samples prepared as described above.



Sieve Size:	#200	#100	#50	#30	#16	#8	#4	⅜"	½"	¾"
Passing:	5.0	6	13	18	19	29	50	83	92	100

Figure 1. Gradation on HMA Mix (½" Superpave).

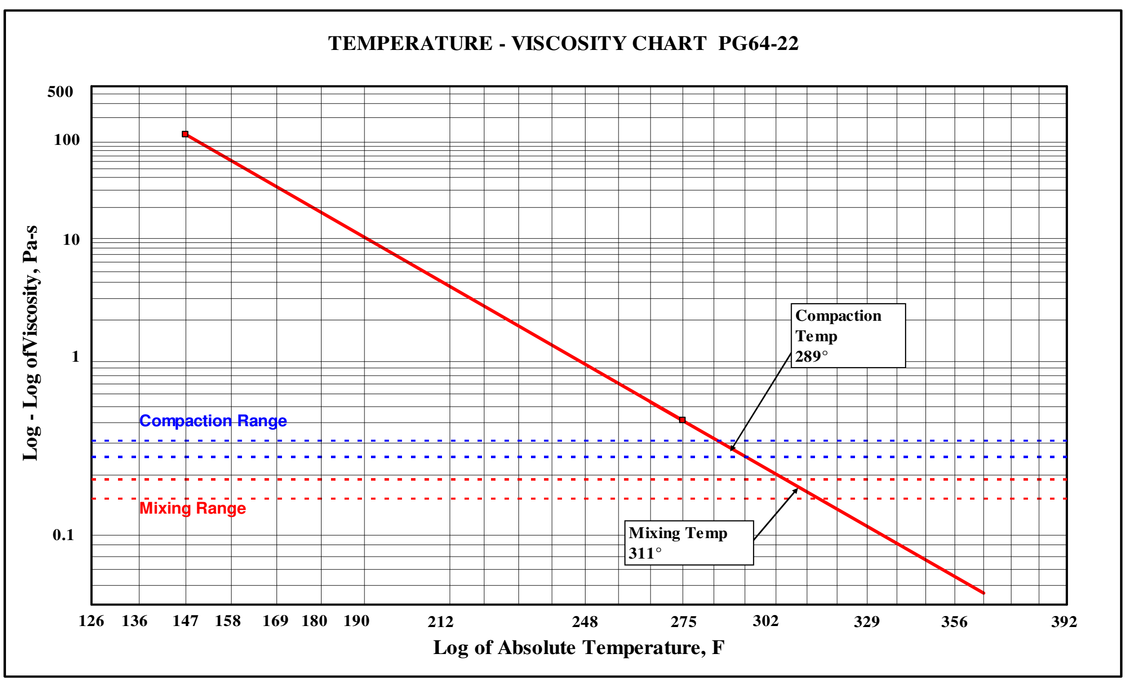


Figure 2. Temperature-Viscosity Graph for the Performance-Grade Binder (PG 64-22).

Work Plan

Based on the various locations and number of gyratory compactors employed by WSDOT it was decided to initiate this "Phase One" study to evaluate two to four compactors in each of the six regions throughout the state. This first phase provides an evaluation of compactors used in each region's central laboratory and others used in field applications. Depending on the findings of "Phase One" additional testing and data collection may be employed to evaluate all compactors used within WSDOT by internal angle of gyration. Prior to measuring the angle of gyration on any SGC used in this study the sample molds were calibrated to ensure specification compliance.

The first step of phase one was to calibrate each compactor used in this study by external angle measure to the standard of 1.25 ± 0.02°. After external calibration three replicate samples of the ½ inch HMA were heated to a temperature of 289°F and compacted to 100 gyrations.

The second step was to measure the internal angle using the DAV II™. If the measured internal angle of gyration was outside the standard tolerance it was adjusted to 1.16 ± 0.02° and three replicate samples of the ½ inch HMA were heated to a temperature of 289°F and compacted to 100 gyrations. If the measured internal angle of gyration was within the standard of 1.16±0.02° no additional HMA samples were compacted on that SGC.

When a compactor requires adjustment to achieve the internal angle after being calibrated by external means the potential for variation in Gmb exists so compacting samples for comparison purposes is essential.

All of the angle measurements, calibrations, and sample testing for this study were performed by one technician using the SGC and testing equipment located at the regional laboratory or field testing trailer. Within 15-24 hours of compaction the Gmb testing was performed in accordance with AASHTO T166 "Bulk Specific Gravity of Dense Graded Hot Mix Asphalt."

Once the angle calibrations and sample compactions were completed each SGC used in this study was returned to its original state, the SGC was recalibrated to the specified external gyration angle of 1.25±0.02°.

Data Collection

Table 1 identifies the location, make, model, and serial number of the seventeen compactors used in this study.

Table 1. Superpave Gyratory Compactors Used in Internal Angle Study				
Location	**Designation**	**Make**	**Model**	**Serial #**
Olympic Region Lab	OR1	Pine-Brovold	AFGB1A	5128
Olympic Region, Aberdeen	OR2	Pine-Brovold	AFGB1A	5127
State Materials Lab	ML1	Troxler	4140	463
State Materials Lab	ML2	Troxler	4140	738
State Materials Lab	ML3	Troxler	4140	111
Southwest Region Lab	SW1	Pine	BGC-1	59919
Southwest Region Lab	SW2	Pine-Brovold	AFGB1A	5136
Southwest Region Lab	SW3	Pine-Brovold	AFGB1A	5364
Eastern Region Lab	ER1	Interlaken	GYR-001	CDG
Eastern Region Lab	ER2	Pine-Brovold	AFGB1A	5143
South Central Region Lab	SC1	Troxler	4140	132767
South Central Region Lab	SC2	Pine-Brovold	AFGB1A	5109
North Central Region Lab	NC1	Pine-Brovold	AFGB1A	5121
Northwest Region Lab	NW1	Pine-Brovold	AFGB1A	5116
Northwest Region, Issaquah	NW2	Pine-Brovold	AFGB1A	5118
Northwest Region, Auburn	NW3	Pine-Brovold	AFGB1A	5088
Northwest Region, Everett	NW4	Pine-Brovold	AFGB1A	5117

Table 2 shows the initial external, initial internal, and adjusted internal angle of gyration for each compactor listed in Table 1. It should be noted that, upon initial inspection, all of the external angle measurements were within the specification of 1.25 ± 0.02º.

Table 2. Angle Measurements			
Designation	**Initial External Angle**	**Initial Internal Angle**	**Adjusted Internal Angle**
OR1	1.24	1.12	1.15
OR2	1.25	1.20	1.16
ML1	1.25	1.14	
ML2	1.26	1.15	
ML3	1.27	1.18	
SW1	1.24	1.17	
SW2	1.24	1.18	
SW3	1.24	1.18	
ER1	1.25	1.17	
ER2	1.24	1.20	1.16
SC1	1.25	1.16	
SC2	1.26	1.19	1.16
NC1	1.25	1.19	1.16
NW1	1.24	1.18	1.17
NW2	1.23	1.17	
NW3	1.25	1.19	1.16
NW4	1.24	1.18	
Average	1.25	1.18	1.16

As shown in Table 2, 7 out of 17 (41%) of the compactors used in this study required adjustment to achieve the standard internal angle of 1.16 ± 0.02° after being calibrated by external means. All of the compactors that required internal angle adjustment were Pine-Brovold AFGB1A models.

Table 3 and Table 4 provide a summary of the Gmb data collected for both initial external and adjusted internal angle calibrated compactors.

Table 3. Gmb Data Summary (<u>Initial</u> External Angle)

	Sample					
	1	2	3	Avg	Std Dev	Range
OR1	2.364	2.383	2.382	2.376	0.011	0.019
OR2	2.384	2.380	2.399	2.388	0.010	0.019
ML1	2.357	2.349	2.358	2.355	0.005	0.009
ML2	2.379	2.364	2.383	2.375	0.010	0.019
ML3	2.370	2.351	2.398	2.373	0.024	**<u>0.047</u>**
SW1	2.339	2.362	2.355	2.352	0.012	**<u>0.023</u>**
SW2	2.361	2.367	2.359	2.362	0.004	0.008
SW3	2.379	2.372	2.388	2.380	0.008	0.016
ER1	2.384	2.367	2.370	2.374	0.009	0.017
ER2	2.371	2.362	2.368	2.367	0.005	0.009
SC1	2.360	2.357	2.366	2.361	0.005	0.009
SC2	2.385	2.396	2.382	2.388	0.007	0.014
NC1	2.389	2.369	2.371	2.376	0.011	0.020
NW1	2.375	2.384	2.380	2.380	0.005	0.009
NW2	2.370	2.377	2.372	2.373	0.004	0.007
NW3	2.378	2.377	2.370	2.375	0.004	0.008
NW4	2.399	2.383	2.384	2.389	0.009	0.016
Population Average				2.373		
Population Std Dev				0.013		

<u>Bold, Underlined Numbers</u> = Data would be outside the precision statement of AASHTO T166.

Table 3 shows two sets of data outside the single operator duplicate sample limit for AASHTO T166 Section 13.1 which states, “Duplicate specific gravity results by the same operator should not be considered suspect unless they differ more than 0.02.” These were included for general analysis as part of this study since the study data set required a replicate of three samples. Upon further statistical analysis per ASTM C670 and ASTM E177 we find that the population data are within the acceptable range.

Table 4. Gmb Data Summary (<u>Adjusted</u> Internal Angle)						
	Sample					
	1	2	3	Avg	Std Dev	Range
OR1	2.371	2.376	2.375	2.374	0.003	0.005
OR2	2.352	2.365	2.388	2.368	0.018	**<u>0.036</u>**
ML1	2.357	2.349	2.358	2.355	0.005	0.009
ML2	2.379	2.364	2.383	2.375	0.010	0.019
ML3	2.370	2.351	2.398	2.373	0.024	**<u>0.047</u>**
SW1	2.339	2.362	2.355	2.352	0.012	**<u>0.023</u>**
SW2	2.361	2.367	2.359	2.362	0.004	0.008
SW3	2.379	2.372	2.388	2.380	0.008	0.016
ER1	2.384	2.367	2.370	2.374	0.009	0.017
ER2	2.359	2.353	2.355	2.356	0.003	0.006
SC1	2.360	2.357	2.366	2.361	0.005	0.009
SC2	2.377	2.378	2.374	2.376	0.002	0.004
NC1	2.363	2.369	2.360	2.364	0.005	0.009
NW1	2.376	2.374	2.362	2.371	0.008	0.014
NW2	2.370	2.377	2.372	2.373	0.004	0.007
NW3	2.372	2.367	2.374	2.371	0.004	0.007
NW4	2.399	2.383	2.384	2.389	0.009	0.016
	Population Average			2.369		
	Population Std Dev			0.012		

<u>Bold, Underlined Numbers</u> = Data would be outside the precision statement of AASHTO T166.

Shaded Numbers = Data from compactors requiring adjustment to achieve internal angle.

The adjusted internal angle data in Table 4 shows one additional data set that was outside the precision statement for AASHTO T166 of 0.02 for single operator duplicate sample. Again, these were included for general analysis as part of this study since the study data set required a replicate of three samples. Upon further statistical analysis per ASTM C670 and ASTM E177 we find that all data sets are within the acceptable range. It can be seen that the standard deviation of the population in Table 4 of 0.012 is smaller than the standard deviation of 0.013 for the external angle population in Table 3. The average Gmb also dropped from 2.373 in Table 3 to 2.369 in Table 4, which relates to a change in air voids (Va) of 0.2% (from 3.8% to 4.0%) as shown in Appendix A.

Figure 3 provides a comparison of the average Gmb data from both the initial external angle setting and the adjusted internal angle setting for each compactor.

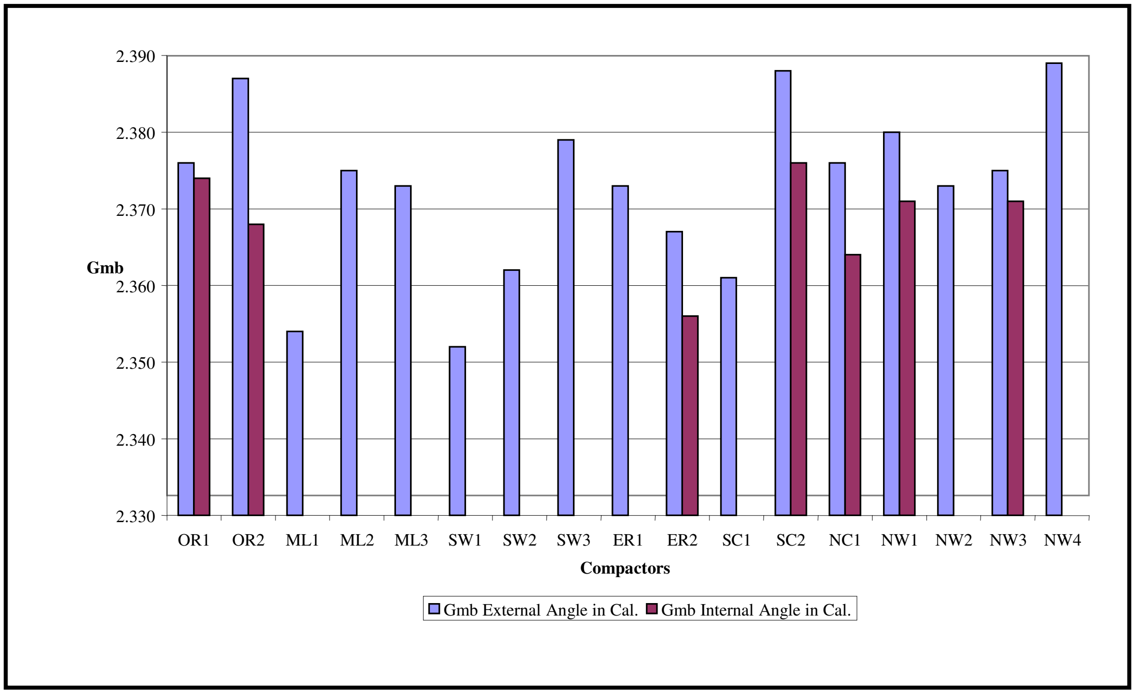


Figure 3. Comparison of Average Gmb from External Angle Setting and Adjusted Internal Angle Setting.

As seen in Tables 3 and 4 and Figure 3, there is a pattern of lower average Gmb values after adjusting the internal angle to the standard of 1.16±0.02°. The Gmb data collected from each compactor listed in Table 3 and Table 4 was also used to determine Air Voids (Va) and corresponding Relative Density from the initial external angle setting to the adjusted internal angle setting for each compactor. Tables 5 and 6 show comparisons of the Relative Density data.

Table 5. Relative Density Comparison - External Angle						
	Sample				Std	
Designation	**1**	**2**	**3**	**Avg.**	**Dev**	**Range**
OR1	95.83	96.60	96.57	96.33	0.44	0.77
OR2	96.62	96.46	97.24	96.77	0.41	0.78
ML1	95.52	95.20	95.57	95.43	0.20	0.37
ML2	96.42	95.82	96.59	96.28	0.40	0.77
ML3	96.05	95.29	97.20	96.18	0.96	**<u>1.91</u>**
SW1	94.81	95.75	95.45	95.34	0.48	0.94
SW2	95.71	95.96	95.60	95.76	0.18	0.36
SW3	96.42	96.14	96.79	96.45	0.33	0.65
ER1	96.62	95.95	96.05	96.21	0.36	0.67
ER2	96.10	95.75	96.01	95.95	0.18	0.35
SC1	95.65	95.55	95.91	95.70	0.19	0.36
SC2	96.67	97.12	96.55	96.78	0.30	0.57
NC1	96.84	96.02	96.11	96.32	0.45	0.82
NW1	96.28	96.62	96.48	96.46	0.17	0.34
NW2	96.08	96.37	96.14	96.20	0.15	0.29
NW3	96.40	96.35	96.05	96.27	0.19	0.35
NW4	97.26	96.58	96.63	96.82	0.38	0.68
Total Population Std Dev		0.54				
Total Pop Avg Rel Dens		96.19				

Table 6. Relative Density Comparison - Adjusted Angle						
	Sample				Std	
Designation	**1**	**2**	**3**	**Avg.**	**Dev**	**Range**
OR1	96.09	96.32	96.26	96.22	0.12	0.23
OR2	95.34	95.87	96.78	96.00	0.73	1.44
ML1	95.52	95.20	95.57	95.43	0.20	0.37
ML2	96.42	95.82	96.59	96.28	0.40	0.77
ML3	96.05	95.29	97.20	96.18	0.96	**<u>1.91</u>**
SW1	94.81	95.75	95.45	95.34	0.48	0.94
SW2	95.71	95.96	95.60	95.76	0.18	0.36
SW3	96.42	96.14	96.79	96.45	0.33	0.65
ER1	96.62	95.95	96.05	96.21	0.36	0.67
ER2	95.62	95.39	95.44	95.48	0.12	0.23
SC1	95.65	95.55	95.91	95.70	0.19	0.36
SC2	96.34	96.38	96.23	96.32	0.08	0.15
NC1	95.79	96.04	95.66	95.83	0.19	0.38
NW1	96.30	96.24	95.74	96.09	0.31	0.56
NW2	96.08	96.37	96.14	96.20	0.15	0.29
NW3	96.14	95.93	96.23	96.10	0.15	0.30
NW4	97.26	96.58	96.63	96.82	0.38	0.68
Total Population Std Dev		0.50				
Total Pop Avg Rel Dens		96.02				

Bold, Underlined Numbers = Data would be outside the multilaboratory precision statement of AASHTO T312.

Shaded Numbers = Data from compactors requiring adjustment to achieve internal angle.

According to AASHTO T312 the Precision and Bias for a HMA 12.5-mm (1/2 in) nominal maximum aggregate is:

Precision Estimates	1S Limit - Relative Density %	d2S Limit - Relative Density %
Single Operator Precision		
12.5-mm nominal max. agg.	0.3	0.9
Multilaboratory Precision		
12.5-mm nominal max. agg	0.6	1.7

In deciding which precision statement to use for analyzing the data from Tables 5 and 6 neither the single operator nor multilaboratory statements from AASHTO T312 accurately fit. The Multilaboratory Precision definition is, "The results of two properly conducted tests on the same material, by different operators, using different equipment." The Single Operator Precision definition is, "The results of two properly conducted tests on the same material, by the same operator, using the same equipment. The Multilaboratory Precision d2s limit was chosen as a best fit for this study because the same material was being tested on multiple sets of equipment in different labs even though the same operator performed the testing. The ½ inch (12.5- mm nominal max. agg.) category was chosen to be comparable with the HMA used in this study.

The Relative Density data in Tables 5 and 6 shows that one set of results is outside the acceptable range of two results at the d2s level for AASHTO T312 multilaboratory precision. It is of interest to recognize that the precision estimates for AASHTO T312 were determined using external angle measurements. According to ASTM E178 the Relative Density data used in Tables 5 and 6 contain no outliers when evaluating the entire population.

For a more detailed look at the volumetric calculations see Appendix A.

Summary

Ultimately, we are given the choice of two methods to calibrate the angle of gyration of Superpave gyratory compactors (SGC). Either externally using different manufacturers' methods or internally using one of the new internal angle validation devices. As seen in the data generated from this study, when a difference is observed between external and internal angle of compaction (i.e. adjustment is necessary to achieve internal angle when initially calibrated externally) the Gmb results are consistently lower. The lower Gmb value will produce higher air voids (Va) when calculated with a constant Gmm value. It will also increase the voids in mineral aggregate (VMA) and decrease the voids filled with asphalt (VFA). Consequently, this change in test data could affect the acceptance of HMA produced for volumetrically accepted WSDOT projects.

Many of the SGC used in this study were within specification for both external and internal angle of compaction but 41% required adjustment to achieve the internal angle when calibrated externally. This percentage of a portion of the WSDOT owned SGCs is substantial enough to raise concern about the potential for variation of volumetric results among multiple laboratories. Studies performed around the country have identified variation among different gyratory compactors. Given this information, one way to eliminate some of the variation in volumetric test results would be to calibrate all of the gyratory compactors with one device using one method. As stated earlier, external angle adjustment methods vary from manufacturer to manufacturer. The only method of calibration that uses the same methodology and equipment is an internal angle measurement system.

Calibration frequencies for SGC vary from manufacturer to manufacturer. Troxler recommends a minimum of six months; Pine-Brovold and Interlaken have no set frequency for calibration. WSDOT procedure for calibration of SGC is done following Verification Procedure No. 58 (VP-58) which requires calibrating gyratory compactors every six months at the State Materials Lab and once per year on region gyratory compactors with a verification of the calibration after any movement to a new location. In Howard Mosley's research with the DAV™ he recommends that the internal angle be set and verified once or twice a year and a correlation established between the internal and external angles of gyration [7]. This would allow technicians to monitor the internal angle by measuring the external angle and apply the correction factor for a specific SGC. AASHTO T312-04 only requires that the same method be used for calibration, either external or internal and that external calibration and internal calibration are not to be considered equivalent.

Recommendations

1. Develop an implementation plan to use internal angle calibration on all WSDOT gyratory compactors for all new construction projects in 2008.
2. Draft changes to current verification procedure.
3. Measure internal and external angle on remaining WSDOT gyratory compactors.
4. Discuss results with WAPA and WSDOT HMA expert task groups.
5. Work with interested WAPA members and private testing laboratories to familiarize them with the internal angle device and evaluate their gyratory compactors.
6. Submit request for purchase of additional internal angle calibration devices.
7. Provide training and support to Region staff members.

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Appendix A

Volumetric Data From Internal Angle Study									
	External Calibration					Internal Calibration			
	Gmb	VMA	Va	VFA		Gmb	VMA	Va	VFA
OR1	2.364	15.3	4.2	73		2.371	15.0	3.9	74
OR1	2.383	14.6	3.4	77		2.376	14.8	3.7	75
OR1	2.382	14.6	3.4	76		2.375	14.9	3.7	75
AVG	2.376	14.8	3.7	75		2.374	14.9	3.8	75
OR2	2.384	14.6	3.4	77		2.352	15.7	4.7	70
OR2	2.380	14.7	3.5	76		2.365	15.2	4.1	73
OR2	2.399	14.0	2.8	80		2.388	14.4	3.2	78
AVG	2.388	14.4	3.2	78		2.368	15.1	4.0	74
ML1	2.357	15.5	4.5	71		2.357	15.5	4.5	71
ML1	2.349	15.8	4.8	70		2.349	15.8	4.8	70
ML1	2.358	15.5	4.4	71		2.358	15.5	4.4	71
AVG	2.355	15.6	4.6	71		2.355	15.6	4.6	71
ML2	2.379	14.7	3.6	76		2.379	14.7	3.6	76
ML2	2.364	15.3	4.2	73		2.364	15.3	4.2	73
ML2	2.383	14.6	3.4	77		2.383	14.6	3.4	77
AVG	2.375	14.9	3.7	75		2.375	14.9	3.7	75
ML3	2.370	15.1	3.9	74		2.370	15.1	3.9	74
ML3	2.351	15.7	4.7	70		2.351	15.7	4.7	70
ML3	2.373	14.9	3.8	75		2.373	14.9	3.8	75
AVG	2.365	15.2	4.1	73		2.365	15.2	4.1	73
SW1	2.339	16.2	5.2	68		2.339	16.2	5.2	68
SW1	2.362	15.3	4.3	72		2.362	15.3	4.3	72
SW1	2.355	15.6	4.6	71		2.355	15.6	4.6	71
AVG	2.352	15.7	4.7	70		2.352	15.7	4.7	70
SW2	2.361	15.4	4.3	72		2.361	15.4	4.3	72
SW2	2.367	15.1	4.0	73		2.367	15.1	4.0	73
SW2	2.359	15.5	4.4	72		2.359	15.5	4.4	72
AVG	2.362	15.3	4.2	72		2.362	15.3	4.2	72
SW3	2.379	14.7	3.6	76		2.379	14.7	3.6	76
SW3	2.372	15.0	3.9	74		2.372	15.0	3.9	74
SW3	2.388	14.4	3.2	78		2.388	14.4	3.2	78
AVG	2.380	14.7	3.6	76		2.380	14.7	3.6	76
ER1	2.384	14.6	3.4	77		2.384	14.6	3.4	77
ER1	2.367	15.1	4.1	73		2.367	15.1	4.1	73
ER1	2.370	15.1	4.0	74		2.370	15.1	4.0	74
AVG	2.374	14.9	3.8	75		2.374	14.9	3.8	75
ER2	2.371	15.0	3.9	74		2.359	15.4	4.4	72
ER2	2.362	15.3	4.2	72		2.353	15.6	4.6	71
ER2	2.368	15.1	4.0	74		2.355	15.6	4.6	71
AVG	2.367	15.1	4.0	73		2.356	15.5	4.5	71
SC1	2.360	15.4	4.3	72		2.360	15.4	4.3	72
SC1	2.357	15.5	4.4	71		2.357	15.5	4.4	71
SC1	2.366	15.2	4.1	73		2.366	15.2	4.1	73

AVG	2.361	15.4	4.3	72		2.361	15.4	4.3	72
SC2	2.385	14.5	3.3	77		2.377	14.8	3.7	75
SC2	2.396	14.1	2.9	80		2.378	14.8	3.6	75
SC2	2.382	14.6	3.4	76		2.374	14.9	3.8	75
AVG	2.388	14.4	3.2	78		2.376	14.8	3.7	75
NC1	2.389	14.4	3.2	78		2.363	15.3	4.2	72
NC1	2.369	15.1	4.0	74		2.369	15.1	4.0	74
NC1	2.371	15.0	3.9	74		2.360	15.4	4.3	72
AVG	2.376	14.8	3.7	75		2.364	15.3	4.2	73
NW1	2.375	14.9	3.7	75		2.376	14.8	3.7	75
NW1	2.384	14.6	3.4	77		2.374	14.9	3.8	75
NW1	2.380	14.7	3.5	76		2.362	15.3	4.3	72
AVG	2.380	14.7	3.5	76		2.371	15.0	3.9	74
NW2	2.370	15.0	3.9	74		2.370	15.0	3.9	74
NW2	2.377	14.8	3.6	75		2.377	14.8	3.6	75
NW2	2.382	15.0	3.9	74		2.382	15.0	3.9	74
AVG	2.376	14.9	3.8	74		2.376	14.9	3.8	74
NW3	2.378	14.7	3.6	76		2.372	15.0	3.9	74
NW3	2.377	14.8	3.7	75		2.367	15.2	4.1	73
NW3	2.370	15.1	3.9	74		2.374	14.9	3.8	75
AVG	2.375	14.9	3.7	75		2.371	15.0	3.9	74
NW4	2.399	14.0	2.7	80		2.399	14.0	2.7	80
NW4	2.383	14.6	3.4	77		2.383	14.6	3.4	77
NW4	2.384	14.5	3.4	77		2.384	14.5	3.4	77
AVG	2.389	14.4	3.2	78		2.389	14.4	3.2	78
AVERAGE	2.373	15.0	3.8	75		2.369	15.1	4.0	74
St.Dev	0.013	0.46	0.5	2.7		0.012	0.42	0.5	2.4
	Gmb	**VMA**	**Va**	**VFA**		**Gmb**	**VMA**	**Va**	**VFA**

Shaded Numbers = Data from compactors not requiring adjustment to achieve internal angle.